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A NEW INSTRUMENT FOR UNATTENDED CATV MEASUREMENTS FOR YEARLY PROOF OF PERFORMANCE AND ROUTINE MAINTENANCE

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ABSTRACT

This paper presents a new instrument, the Kay 9021, and discusses the methods and equipment required for automatic, unattended CATV measurements. The authors discuss the types of parameters that may be measured, and the data-logging equipment that is required. Methods of reducing interference to the subscriber are analyzed. Included is a description of a new high-level sweep system receiver and its application to unattended measurements. Also discussed is a useful piece of auxiliary equipment not commercially available but which may be constructed by the system operator. Results of actual system tests are presented and analyzed.

Time history measurements are required by the Federal Communications Commission for yearly proof of performance. Time study measurements are often helpful in locating and predicting system failures as well as a method of status monitoring. Such measurements, when manually performed, can be rather expensive, prone to errors and can tie up valuable manpower and equipment for days at a time.

This paper describes methods of unattended system measurements using the Kay 9021 "Digital Recording Receiver." Also described is a "home-brew" item which even a small system operator could construct that makes possible automatic time annotation.

TYPES OF UNATTENDED MEASUREMENTS

Almost any system parameter may be studied over periods of time. These parameters may be studied at the head end, at the trunk amplifiers, at the subscriber terminals, etc., depending on which part of the CATV system is to be isolated for fault analysis.

Some of the more important parameters to be analyzed are: (1) System frequency response, (2) Carrier levels by wide-band spectrum analysis, (3) Spurious signals, such as co-channel by narrow-band spectrum analysis, and (4) Any other parameter that may be suspect such as a specific voltage, frequency, etc.

This paper deals with the first two categories of unattended measurement. The need for measurement of specific voltages and currents is usually indicative of a special problem and is not required by the FCC nor is it useful in the isolation of routine problems.

EQUIPMENT REQUIREMENTS FOR UNATTENDED MEASUREMENTS

Since it would be desirable to do the measurements without continuous services of a technician or engineer, some means must be provided for automatic data logging. Automatic data logging takes several forms. Analog data recorders are relatively inexpensive and useful. There are several strip-chart recorders or modifications of the basic strip chart recorder such as an X-Y recorder, drum recorder, or circular chart recorder. Or, some applications would require a digital logging device such as a strip printer or teletype machine. Generally, digital printers are useful only when the data analyzed is in a digital format such as frequency. But, converting analog data to digital numbers is often self defeating since it is much easier to see general trends from a histogram than scanning columns of figures.

The authors have found the strip chart recorder the most useful and cost effective. There are two modes of operating the strip chart recorder. One is to use a chart driven by a clock motor. But, this allows the measurement of only one parameter on a continuous basis. The second mode is to drive the chart at a rapid rate, such as a few centimeters per second but allowing the unit to run for only a few seconds during the accurately known time period, when the actual measurements take place. The beginning and ending of the chart motion is thus synchronized with the independent variable of another instrument such as a spectrum analyzer. There will be a series of plots inter-connected on a continuous strip of paper each one separated from the other by a fixed period of time. This intermittent operation allows a huge number of data points to be generated and studied on one piece of paper.

The 9021 Digital Recording Receiver has such a strip chart recorder. Recorders with timers and specialized instruments using recorders as an integral part of the system are also sometimes available to the CATV system operator.

SPECIAL CONSIDERATIONS FOR TEST EQUIPMENT USED IN UNATTENDED OPERATION

Reliability is one of the most important characteristics of any test equipment used for recorded measurements. The measuring equipment is often required to operate for long periods of time without adjustment or maintenance. The reli-[illegible] must be established for the environment in which the tests [illegible] take place. Extremes of temperature and humidity are the usual stresses which cause problems.

All electronic instruments have some measure of temperature instability. It is necessary to have some idea of the magnitude of this temperature dependence especially if the instrument is used in the uncontrolled environment of field equipment. Sometimes the error introduced by temperature is of little consequence to the actual measured amount. However, if the error is great, then the temperature compensation factor must be known if the equipment is to be successfully used in the CATV environment.

If the equipment is located in a place that has no electrical power, battery operation must be used. Sometimes an automobile battery is the most cost-effective battery to use. But, be sure that the battery has sufficient ampere hour capacity to operate the equipment for the desired time. Also note that the ampere hour capacity of most batteries decreases with lowered temperature. Check the specifications of the energy storage system you intend to use.

If equipment that operates only on 117V AC is employed it will be necessary to supply either power from the mains or to use an inverter. However, unless the equipment to be operated from an inverter is of unusually low power consumption, the battery size for a continuous 24 hour operation would be prohibitive. For example, if a spectrum analyzer requiring 100 watts is operated for 24 hours from an inverter of 50 percent efficiency, the required ampere hour rating for a 12-volt battery would be 400 ampere hours. This would require at least six automotive batteries and that is ordinarily impractical. However, to reduce the battery requirements it is possible to power the equipment only during the actual operating period, which is only a tiny fraction of the total time. A battery operated timer may be used to drive a large relay to apply power to the inverter for only ten minutes out of every hour. This allows sufficient time for the equipment to warm up and stabilize and still reduce the battery load by a factor of more than six. The factor is actually more than six since battery systems tend to last longer if a rest period is allowed between discharges. Therefore, the system may operate a full 24 hours from only one fully-charged automotive battery.

The 9021 employs such a design philosophy. Despite the capability of such a system to operate from batteries it is obviously preferable to use a location which has available AC power. However for the yearly proof of performance tests, the locations of the test points are set by law and usually do not have such power-equipped enclosures.

A weatherproof and theft proof enclosure must often be used. A variety of military surplus equipment cases are available for this purpose. The equipment, placed inside such boxes, is sealed against the weather, locked against vandals and may be chained to a utility pole. If power is available, the box may be insulated and heated with a small electrical heater. The degree of sophistication is limited only by the system operator.

ACTUAL TEST RESULTS

Several parameters were measured on the Telecommunications Inc. system in Dover, N.J. by using the Kay 9021 Digital Recording Receiver. This system has nearly 400 miles of cable and serves several towns.

Two basic parameters were measured: frequency response and carrier level.

The test systems were set up and debugged using the cable system office. The facility offered the convenience of a heated location where plenty of bench space and power were available to evaluate the test systems. Communication was available to the head end, which proved to be an absolute necessity during the early phases of the test system development.

The high level sweep system transmitter used was the Kay 9059B. The receiver used was the Kay model 9021. This receiver was specifically designed in 1975 for the CATV industry using state of the art techniques and the design philosophy presented in this paper.

The high level (15 dB above the carriers) sweeping signal covers the entire spectrum of interest in 2.56 milliseconds. Since this produces a slight but visible interference to a television receiver, the repetition rate is usually limited to one every six seconds or longer. The sweep can be detected anywhere along the system with a wide-band amplifier and detector. Because the sweep is short and the repetition time so long, some method of storing the sweep is required. This was done with a storage oscilloscope in the older Kay 9020 receiver.

Please refer to Fig. 1 which presents a block diagram of the 9021 to assist in following the details of the circuit. The RF input is applied to a 0 to 29 dB calibrated attenuator. This attenuator is marked with the carrier amplitudes in DBMV. Because the carriers are usually known or could be easily determined, this level is the most useful for reference. The RF is amplified by a wideband RF amplifier and then envelope detected. The detected amplitude is converted to 256 eight-bit binary words and then stored in a 2000 bit digital MOS memory. A 50 MHz narrowband amplifier/detector provides a signal for triggering the storage cycle. The entire storage is accomplished in 2.56 milliseconds allowing 10 microseconds for each eight-bit word. The data remains in the memory until updated by the next sweep. A print command is entered manually by the operator or automatically by the internal timer and either will cause a printout without loss of stored data.

FIG. 1a KAY MODEL 9021 SWEEP RECEIVER

The print cycle operates at a much slower rate to match the relatively slow speed of the chart recorder. The 256 words are read out of the memory in about four seconds and applied to a D/A converter which converts the digital data to analog form. This analog data is amplified and printed on the chart recorder.

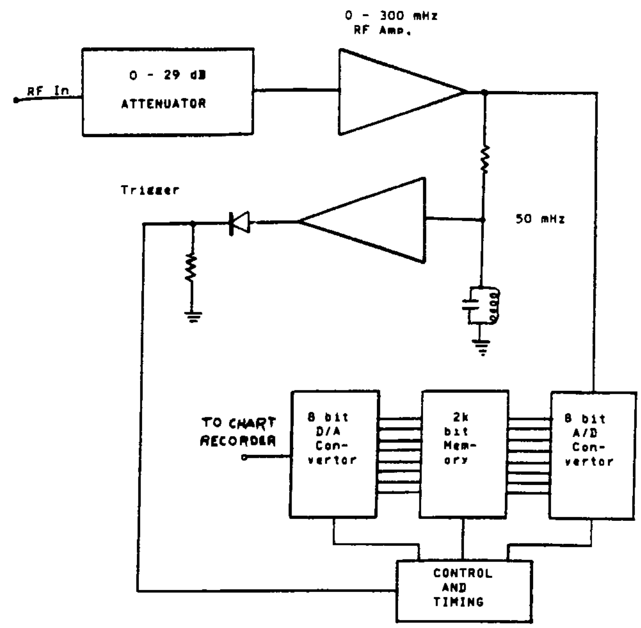


FIG. 1b SWEEP RECEIVER BLOCK DIAGRAM

To reduce the interference to the subscriber to an absolute minimum it was decided to sweep the system only once during each measurement time period. At either once or twice an hour it was obviously necessary to synchronize the sweeper and the receiver so that the receiver would be "on" and "listening" when the sweeper was triggered. This was accomplished with a battery operated crystal controlled clock. Two CMOS chips, a crystal, and a handful of resistors and capacitors were used to construct an accurate battery operated timer. The schematic of the timer may be found in Fig. 3. Battery operation is essential to avoid errors due to power outages. The timer will run for months on four standard D cells.

When synchronizing the clocks, a very handy reference is the time of day service provided by one of the system channels. Should the transmitter and receiver clocks become unsynchronized, it is a simple matter to reset the system. The sweeper at the head end is timed to sweep 10 seconds after the exact hour and exact half hour. The timer may be overriden at any time for routine maintenance chores without upsetting the timed measurements.

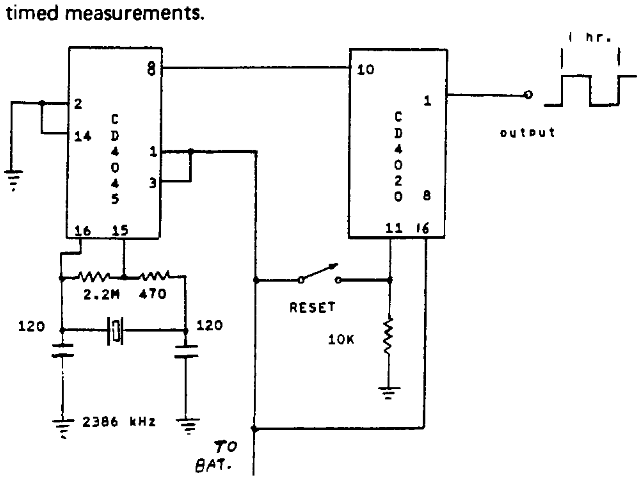


FIG. 3 BATTERY OPERATED TIMER SCHEMATIC

Tests on the Dover system were run on two different trunks: one 12 amplifiers deep and the other 27 amplifiers deep. The tests were run for 24 and 60 hours respectively. Fortunately both locations were heated structures since outside temperatures were near zero several nights.

Fig. 4 shows six successive frequency response traces taken at a test point after a 12 amplifier cascade. The frequency response is measured from 50 MHz at the low end to 300 MHz at the upper end. Since the frequency response of this system had been set up in the past using only the carriers normally handled on this system and a field strength meter, there were two areas with dips in the response. The sharp peak at the 270 MHz end of spectrum is due to the cumulative effect of mistuning the high end peaking coils to improve the high end performance when channel R was added to the existing system.

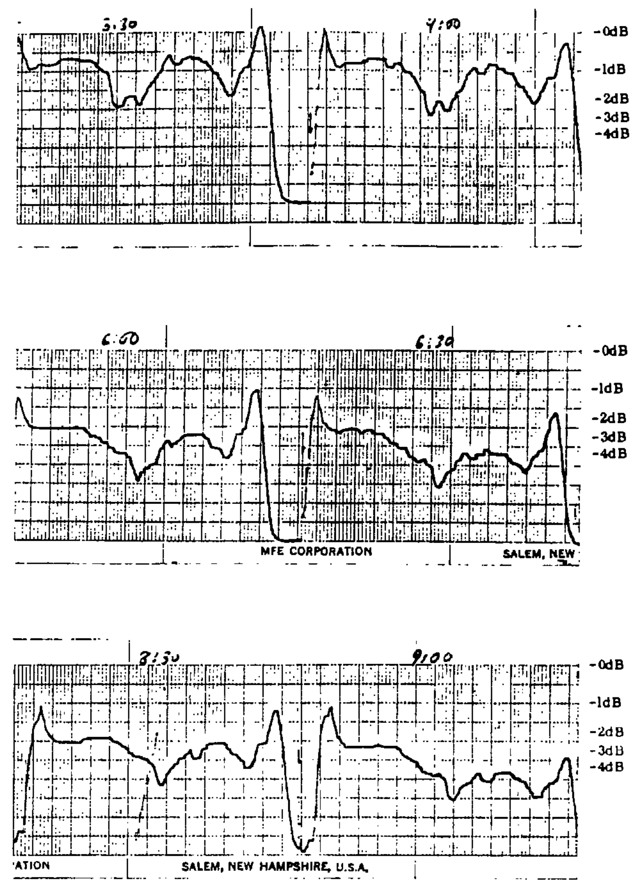


FIG. 4 FREQUENCY RESPONSE TRACES AFTER TWELFTH AMPLIFIER

Notice that for the five and one half hour period from 3:30 pm to 9:00 pm the high end dropped by 3 dB and the low end by 1 dB. The temperature dropped by about 12° Farenheit. For a cascade of only 12 amplifiers this was considered a faulty system. Subsequent investigation did show an incorrect pilot carrier level at the head end. This unit was repaired and the system rebalanced. Fig. 5 shows the sweep response of the repaired system. The system now had a more correct tilt and the dips were not quite as bad. Notice the traces during the five and one half hour from 2:50 pm to 8:20 pm. The high end had gone down by 1.5 dB and the low end had remained relatively unchanged.

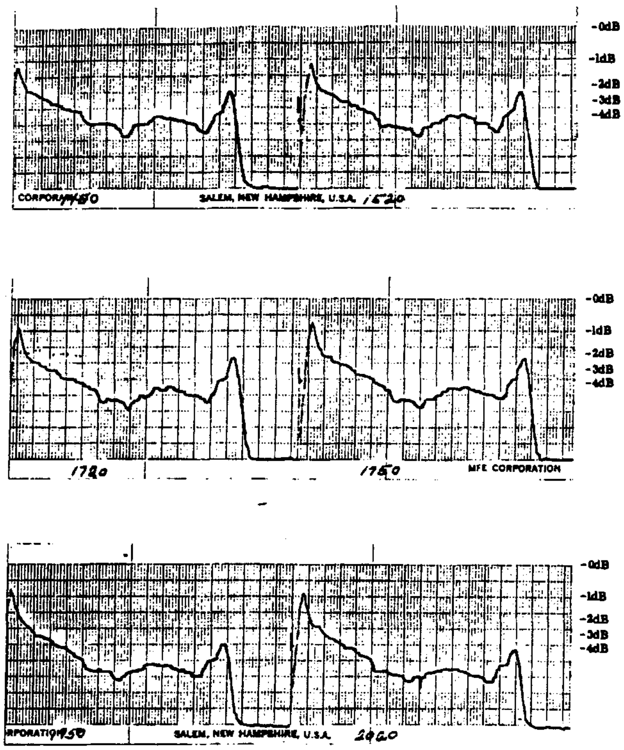


FIG. 5 FREQUENCY RESPONSE TRACES OF REPAIRED SYSTEM

During the time that these measurements were made there were no customer complaints and none of the routine measurements made by the installers and technicians indicated any trouble despite the existence of a bona fide malfunction.

Typical test results of the wideband spectrum analysis are shown in Fig. 7. No serious problems were encountered in these traces. These strip chart recordings are documented by an online time code generator. This time code generator indicates the time of day by injecting three RF signals into the CATV system. The time is then coded as a binary number, the amplitude of the three signals indicating zeros or ones. Fig. 6 shows an expanded spectrum analyzer trace of the time code signal showing the binary number 101. Since only three RF signals are used, the unit will repeat after eight hours. Therefore, additional information will be required for completely unambiguous annotation. The addition of this device to the system allows the technician to place the equipment in the field without requiring an exact knowledge of the precise time the equipment was started (see Table 1). Furthermore, the annotation allows the data to be reconstructed should the strip become damaged or if any of the measurements are missing due to equipment malfunction or loss of power.

TIME	TIME CODE
0000	000
0100	001
0200	010
0300	011
....	...
0700	111
0800	000
....	...
1500	111
1600	000
....	...
2300	111

TABLE 1

The time code generator is not at present a commercially available device and was constructed for these tests. The unit consists of three oscillators operating at 110, 115 and 120 MHz. The level of these oscillators is controlled by a crystal controlled clock; the higher level indicates a binary "one" and the ten dB lower level indicates a binary "zero."

Fig. 7 shows three spectrum analyzer traces taken at one hour intervals. The time code of the trace at the bottom of the display is the binary number 101 which in this case, corresponds to 1:00 pm. The middle trace is 2:00 pm and the top is 3:00 pm. The vertical scale is five dB per major division.

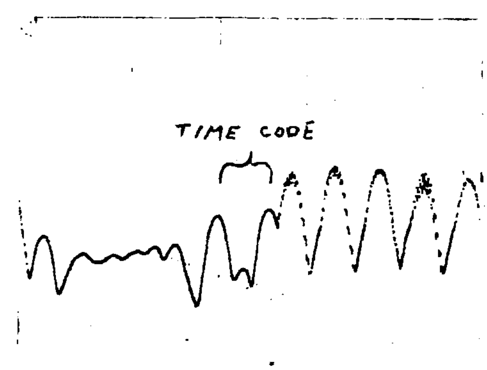


FIG. 6 EXPANDED SPECTRUM ANALYZER TRACE SHOWING TIME CODE GENERATOR

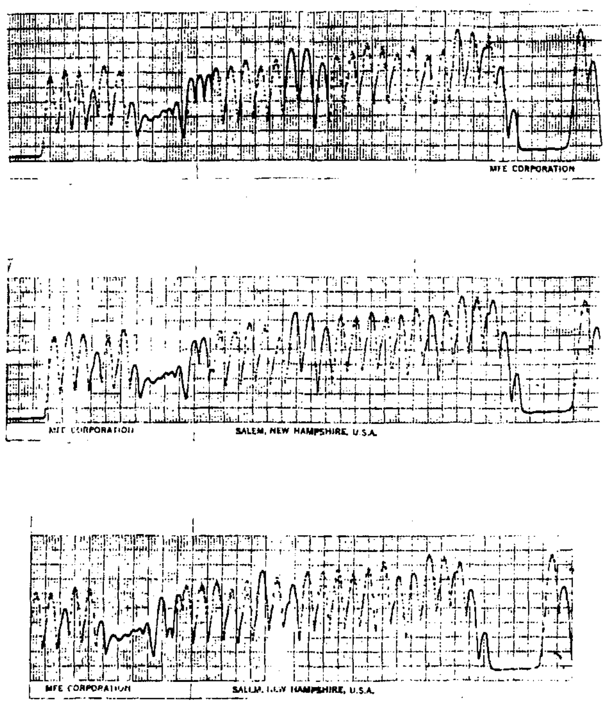


FIG. 7 TYPICAL TEST RESULTS OF WIDEBAND SPECTRUM ANALYSIS

Several differences between the results of sweep testing and the results found with wideband spectrum analysis are apparent. The five dB per division scale of the spectrum analyzer trace makes it difficult to resolve one dB variations. The trace could be expanded to two dB per division but the speed required tends to tax the speed capability of the chart recorder. Furthermore, the apparent signal amplitude depends on the nature of the modulation at the time of the measurement. Compare channel G amplitude at 1:00 pm and the amplitude at 2:00 pm. Note the change in apparent amplitude level although there is actually no change in carrier level.

For the two reasons mentioned first, the difficulty in measuring small differences in carrier level because of the compressed scale and the second, the errors introduced by the effects of modulation, it was determined that the sweep method was actually superior to the spectrum analyzer technique in locating small deviations in frequency response and temperature induced variations.

Although the conclusion here is that the high level sweep check is superior to the measurement of carrier levels for the determination of system response, it is still debatable whether the high level sweep measurements may be used in lieu of carrier level measurements. The FCC regulations do specify that the visual signal level cannot vary more than 12 dB during a 24 hour period. If one measures the relative gain of the system as a function of frequency then it is necessary to know the level of the visual signals at the head end for that time period to certify the signal level at the test point. This can be accomplished by using a recording spectrum analyzer but this may be unnecessary. Usually the signal levels at the head end are very stable and reliable and thus able to provide the desired reference. Perhaps a one-time measurement should be made at the head end with a recording spectrum analyzer. And, this will document the fact that the signal variation due to the head end is negligible.

Consider the money saving aspects of unattended measurements for yearly proof or performance measurements.

Usually to monitor three test points over a 24 hour period would require the services of four technicians; three for a full eight hour shift. This would involve climbing three poles and installing drop cables. (These cables may be tied up about 8 feet for each access.) One technician is required to make the rounds using a field strength meter to record manually the carrier levels. This would be required to continue for the full 24 hours. During the last round of measurements the drops must also be removed again requiring two technicians.

Using a figure of $14.00 per hour this amounts to a cost of $272.00 for the entire job. The $14.00 per hour reflects the cost of salaries, fringe benefits and overhead (such as gasoline, oil, equipment expense, etc.).

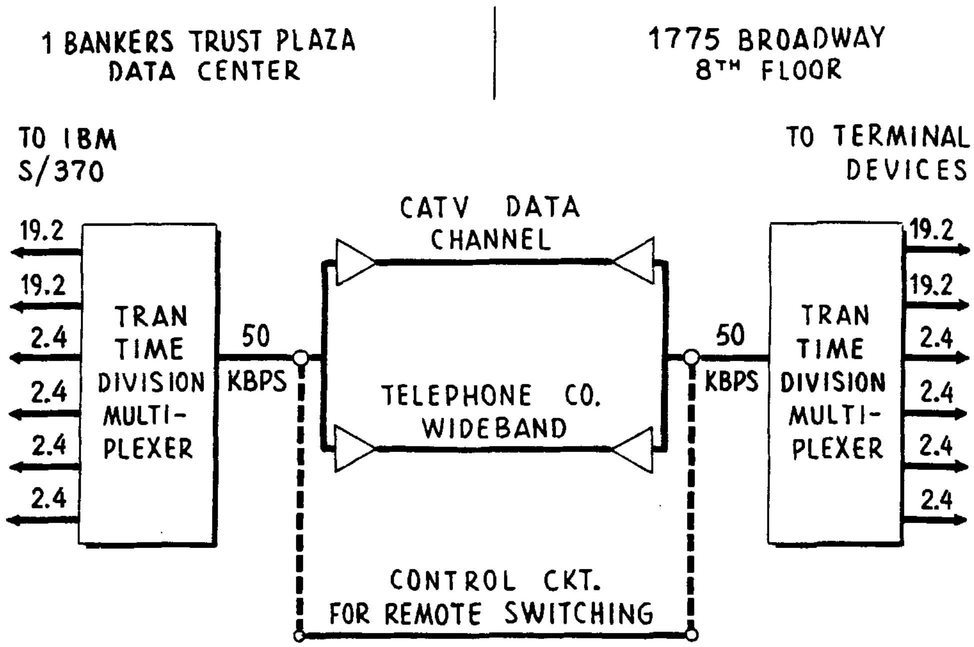
But, using automatic battery operated equipment only two technicians are required to set up the measurements and to remove the equipment 24 hours later. Assuming this requires four manhours each, this cost is $112.00, a saving of $160.00 per each 24 hour measurement. Particularly in large systems, where it may be necessary to repeat the operation in several towns, the total cost saved will be substantial and well worth the cost of the equipment required. This equipment is also valuable for attended operation usage where the written records of system faults and corrections and the easy portability from the small size and self contained battery operation make it easy to troubleshoot any system problems.

To summarize the conclusions of this paper, two basic types of unattended RF measurements applicable to CATV systems have been discussed. The equipment required for such measurements has been outlined and the description of the units has been presented. An actual system malfunction was discovered, repaired, and verified using the high level sweep system and the Kay 9021 Digital Recording Receiver.

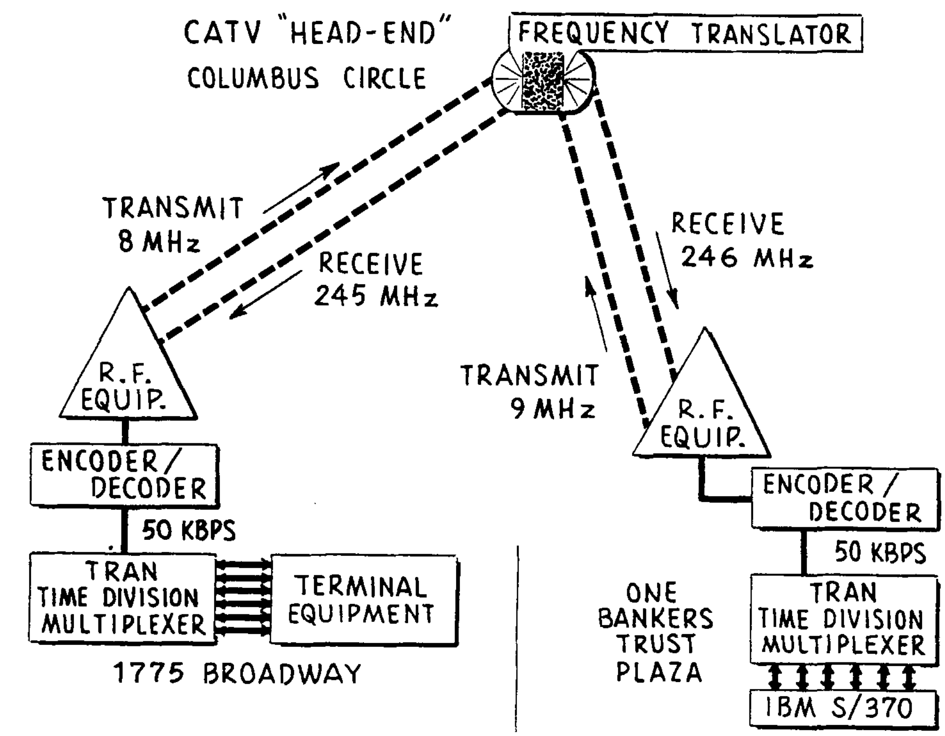
The use of unattended measurements should be helpful in diagnosing system faults and as a money and time saving device for the yearly and proof of performance measurements.

" Our thanks to Bob Geissler of Vitek Electronics for the use of their Spectrum Recorder Timer, model SRT-1, in the preparation of this paper "

BANKERS TRUST COMPANY
EXISTING TELECOMMUNICATIONS CONFIGURATION



THE CABLE TELEVISION DATA NETWORK



AMPLIFIER LINEARIZATION BY COMPLEMENTARY PRE OR POST DISTORTION*

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ABSTRACT

A technique of amplifier linearization through the use of complementary pre or post distortion correction circuits is investigated. Using the Volterra series representation distortion cancellation constraints imposed on the correction circuit are derived. A simple distortion correction circuit consisting of a diode, a resistor and a capacitor (inductor) is then devised to meet the above constraints for cancellation of the amplifier's third order distortion products.

A theoretical analysis of distortion generated in both a single stage transistor amplifier and a complementary distortion correction circuit (C.D.C.C.) is carried out to verify the realizability of this linearization technique.

* Patent Pending

INTRODUCTION

The design and manufacture of transistors and semiconductor diodes has advanced significantly since their introduction many years ago. This has resulted in the availability of semiconductor components with higher gain - bandwidth products, low noise, high power and better linearity.

Despite the advanced state of the art in the overall performance of semiconductor diodes and transistors the remaining distortion and noise are still the primary obstacles to the construction of large CATV systems. However, there are several design techniques used quite often in multistage amplifiers which help further minimize nonlinear distortion. [1] Feedback, push-pull and cascode amplifier design are the ones most common today. Others, such as feedforward and distortion compensation techniques are now being implemented.

Cascode amplifiers connected in push-pull usually suppress second order distortion far below the level considered objectionable. Also, as evidenced from theory [2]-[4] and supported by experimental observations, some partial cancellation of second order distortion along the CATV trunk always exists. The third order distortion, however, is only slightly improved in a push-pull amplifier. A significant reduction in the magnitude of the third order distortion is obtained if a cascode amplifier is used. Despite this improvement, a cascode connection is not as efficient for suppression of the third order products as push-pull is for the second order products. Also, if the amplifiers are exactly alike, crossmodulation and triple beat products $f_1-f_2+f_3$ will generally increase by 6 dB any time the number of amplifiers is doubled [2]-[4]. (In practice, cancellation of these products has also been observed and can be accounted for by the nonuniform magnitude and phase of the aforementioned distortion products in the amplifiers.) In conclusion, we can say that it is either crossmodulation or a build-up of triple beat products of the type $f_1-f_2+f_3$ which affects the performance of a vast majority of new CATV systems.

Some five years ago, a research program was undertaken by Delta-Benco-Cascade to develop a technique for a substantial reduction of crossmodulation distortion in CATV amplifiers. Out of a number of promising ideas a complementary distortion correction technique was singled out and pursued further. The scope of the research program was later extended to include a reduction of voltage additive triple beat products. This technique provides a circuit which may be connected across the signal path on either the input or the output side of an amplifier and which is designed to distort the signal in a manner complementary to the crossmodulation or triple beat distortion contributed by the amplifier itself.

MATHEMATICAL REPRESENTATION OF A CASCADE

Let us restrict our attention to the complementary post distortion correction circuit shown in Fig. 1.

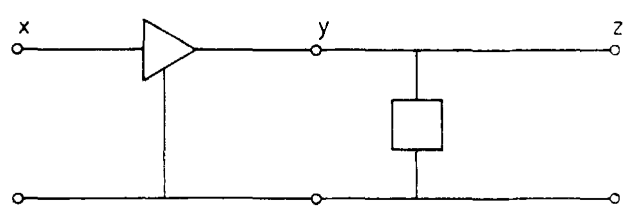

Fig. 1 · Amplifier With A Post Distortion Correction Circuit

At low frequencies, where reactive effects can be neglected the transfer characteristic of a nonlinear device, such as an amplifier, can be expressed by a power series. At high frequencies capacitive and inductive parasitics and components affect the overall performance of an amplifier. The device has a memory and can not, in general, be represented by a power series. A different analysis such as one employing the Volterra series approach, must be used. The Volterra series can account for frequency dependence and give the phase as well as the magnitude of distortion products.

For small enough signal levels and small transistor nonlinearities a third order product, such as crossmodulation or a triple beat, can be predicted accurately using a third order Volterra series. Assuming that the conditions for existence of the Volterra series are satisfied we can represent the output of a time invariant nonlinear system with memory (such as the amplifier in Fig. 1) by a third order Volterra series

$$y(t)=\sum_{n=1}^{3}\int_{-\infty}^{\infty}d\tau_1\cdots\int_{-\infty}^{\infty}d\tau_n b_n(\tau_1,\ldots,\tau_n)\prod_{r=1}^{n}x(t-\tau_r) \tag{1}$$

$$b_n(\tau_1,\ldots,\tau_n)=0 \text{ for } \tau_n<0$$

where $b_1(\tau)$ is the impulse response of the amplifier. The terms in (1) are, in fact, n^{th} order convolution integrals. Each kernel b_n is assumed to be a symmetrical function of its arguments. Since the output corresponding to sinusoidal signals is of interest all computations can be carried out in the frequency domain by means of Volterra transfer functions $B_n(s_1,\ldots s_n)$ defined as follows:

$$B_n(s_1,\ldots,s_n)=\int_{-\infty}^{\infty}d\tau,\ldots\int_{-\infty}^{\infty}d\tau_n b_n(\tau_1\ldots\tau_n).$$
$$.\exp[-j(\omega_1\tau_1+\ldots+\omega_n\tau_n)] \tag{2}$$

If B_n is known and the input consists of a linear superposition of sinusoidal signals the output can be expressed in terms of the transform B_n of the kernel b_n as will be shown later.

Similarly the output z of the post distortion correction circuit is expressed as the Volterra series of the input signal y

$$z(t)=\sum_{n=1}^{3}\int_{-\infty}^{\infty}d\tau_1,\ldots\int_{-\infty}^{\infty}d\tau_n c_n(\tau_1,\ldots,\tau_n)\prod_{r=1}^{n}y(t-\tau_r) \tag{3}$$

The Volterra transfer functions C_n are related to c_n according to equation (2). Both C_n and c_n are symmetric functions of their arguments. The overall first, second and third order Volterra transfer functions are given, respectively, by [5].

$$H_1(s)=B_1(s)C_1(s) \tag{4}$$
$$H_2(s_1,s_2)=B_2(s_1,s_2)C_1(s_1+s_2)+B_1(s_1)B_1(s_2).C_2(s_1,s_2) \tag{5}$$
$$H_3(s_1,s_2,s_3)=C_1(s_1+s_2+s_3)B_3(s_1,s_2,s_3)+2C_2(s_1,s_2+s_3).$$
$$B_1(s_1)B_2(s_2,s_3)+C_3(s_1,s_2,s_3)B_1(s_1)B_1(s_2)B_1(s_3) \tag{6}$$

The fundamental, second and third order components at the output of the cascade can be expressed as follows

$$z_1=x_o^{(1)}|H_1(s)|\cos(\omega_1 t-\eta_1) \tag{7}$$
$$z_{12}=k_1x_o^{(1)}x_o^{(2)}|H_2(s_1,s_2)|\cos[(\pm\omega_1\pm\omega_2)t-\eta_2] \tag{8}$$
$$z_{123}=k_2x_o^{(1)}x_o^{(2)}x_o^{(3)}|H_3(s_1,s_2,s_3)|.$$
$$\cos[(\pm\omega_1\pm\omega_2\pm\omega_3)t-\eta_3] \tag{9}$$
$$s_1=\pm j\omega_1 \qquad s_2=\pm j\omega_2 \qquad s_3=\pm j\omega_3$$

with

$$x=x_o^{(1)}\cos\omega_1 t+x_o^{(2)}\cos\omega_2 t+x_o^{(3)}\cos\omega_3 t \tag{10}$$

k_1, k_2, are constants characterizing a specific type of second or third order distortion, respectively. $\eta_k(\omega)$ is the relative phase of the k^{th} order Volterra transfer function H_k at the fundamental, product frequency.

DISTORTION CANCELLATION CONSTRAINTS

By neglecting the second order interaction term in (6) and assuming the shunt impedance presented by the post distortion correction circuit is large compared to the output impedance of the amplifier we can simplify (6) to

$$H_3(s_1,s_2,s_3)=B_3(s_1,s_2,s_3)+C_3(s_1,s_2,s_3).$$
$$G.\exp[-j(\rho_1+\rho_2+\rho_3)\psi-j(\pm\omega_1\pm\omega_2\pm\omega_3)t_o] \tag{11}$$

where $G=|B_1(s_1).B_1(s_2).B_1(s_3)|$ (12)

$$\rho_1=\pm1 \text{ for } \pm\omega_1$$
$$\rho_2=\pm1 \text{ for } \pm\omega_2 \tag{13}$$
$$\rho_3=\pm1 \text{ for } \pm\omega_3$$

ψ is the zero frequency phase intercept of the amplifier. A constant group delay (linear phase vs frequency dependence) in the amplifier is assumed. In order to minimize a specific third order product at frequency $s=s_1+s_2+s_3$ we require

$$|H_3(s_1,s_2,s_3)|=0 \tag{14}$$

Using the substitutions

$$\left[\frac{B_3(s_1,s_2,s_3)}{C_3(s_1,s_2,s_3).G}\right]=K \tag{15}$$
$$-\gamma_3+\beta_3-(\rho_1+\rho_2+\rho_3)\psi-(\pm\omega_1\pm\omega_2\pm\omega_3)t_o=\kappa$$

we can express the magnitude of (11) as

$$|H_3(s_1,s_2,s_3)|=|C_3(s_1,s_2,s_3).G|.\left[(K+\cos\kappa)^2+(\sin\kappa)^2\right]^{1/2} \tag{16}$$

So the constraints imposed on the magnitude and phase of the third order product generated by the post distortion correction circuit are found to be

$$|B_3(s_1,s_2,s_3)|=G|C_3(s_1,s_2,s_3)| \tag{17}$$
$$-\gamma_3+\beta_3-(\rho_1+\rho_2+\rho_3)\psi-(\pm\omega_1\pm\omega_2\pm\omega_3)t_o=(2n+1)\pi \tag{18}$$

for some $n=\pm1,\pm2$ ....

For a specific type of distortion these constraints can be reduced as follows

a) vector crossmodulation distortion

The signal at the input of the amplifier is expressed as a sum of two sinusoidal signals, one of them modulated by a sine wave with a modulation frequency f_m and modulation factor m $(x_o^{(1)}=x_o^{(2)}=x_o^{(3)}=x_o)$

$$x=\tfrac{1}{2}x_o^{(1)}(1+m\cos\omega_m t)\cos\omega_1 t+x_o^{(3)}\cos\omega_3 t \tag{19}$$

It then follows (6)

$$s_1=j\omega_1 \qquad s_2=-j\omega_1 \qquad s_3=j\omega_3 \tag{20}$$

and $|B_3(j\omega_1,-j\omega_1,j\omega_3)|=G|C_3(j\omega_1,-j\omega_1,j\omega_3)|$ (21)

$$-\gamma_3+\beta_3-\psi-\omega_3t_o=(2n+1)\pi \tag{22}$$

$\gamma_3(\omega)$, $\beta_3(\omega)$ are the relative phases of the third order Volterra transfer functions B_3,C_3, respectively, at the product frequency $\omega=\omega_1-\omega_1+\omega_3$. (Fig. 2)

b) triple beat distortion

The input signal is now given by (10). We now have

$$s_1=j\omega_1 \qquad s_2=-j\omega_2 \qquad s_3=j\omega_3 \tag{23}$$

The constraints are simplified to

$$B_3(j\omega_1,-j\omega_2,j\omega_3)=G|C_3(j\omega_1,-j\omega_2,j\omega_3)| \quad (24)$$

$$-\gamma_3+\beta_3-\psi-(\omega_1-\omega_2+\omega_3)t_o=(2n+1)\pi \quad (25)$$

where γ_3, β_3 refer now to the product frequency $\omega=\omega_1-\omega_2+\omega_3$. (Fig. 2 with $-\omega_1$ replaced by $-\omega_2$). Note that for $\omega_1=\omega_2$ these constraints are identical to (21),(22).

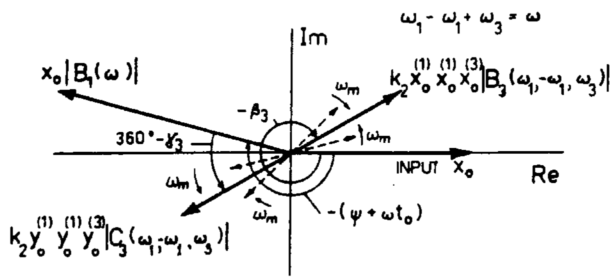

Fig. 2: Cancellation Of Vector Crossmodulation

MINIMIZATION OF AMPLITUDE CROSSMODULATION

As this high frequency distortion analysis enables one to bring into focus the phase characteristic of nonlinearities, the concept of transfer of modulation from one carrier onto another one (crossmodulation) is changed as well. Using the low frequency model (power series), only the amplitude of the originally unmodulated carrier was seen to be affected. The high frequency analysis by means of the Volterra series reveals that both the amplitude and the phase of the unmodulated carrier become modulated.[6] Let the input to the amplifier be given by (19). The total output from the amplifier at frequency ω_3 is then determined from

$$y_{\omega_3}=x_o^{(3)}|B_1(j\omega_3)|(1+m_A\cos\nu_A\cos\omega_m t).$$
$$.\cos(\omega_3 t-\beta_1+m_A\sin\nu_A\cos\omega_m t) \quad (26)$$

where

$$m_A=\frac{3m}{4}\,\frac{(x_o^{(1)})^2|B_3(j\omega_1,-j\omega_1,j\omega_3)|}{|B_1(j\omega_1)|} \quad (27)$$

is the magnitude of the vector crossmodulation (Fig. 3) and

$$\nu_A=-\beta_3+\beta_1 \quad (28)$$

where $\beta_1(\omega)$ is the linear phase delay through the amplifier at frequency ω_3 and $\beta_3(\omega)$ is the relative phase of the third order Volterra transfer function of the amplifier at product frequency $\omega=\omega_1-\omega_1+\omega_3$.

According to the NCTA Engineering Standards crossmodulation is defined as the ratio of the peak-to-peak variation of the amplitude of the test signal ω_3, due to crossmodulation, to the amplitude of the test signal with the interference signals removed. Applying this definition to equation (26) we deduce that the NCTA crossmodulation ratio is identical to twice the amplitude crossmodulation ratio

$$\text{NCTA XM} = 2M_{xm}^{(A)}=2m_A\cos\nu_A \quad (29)$$

the corresponding phase crossmodulation ratio is expressed as

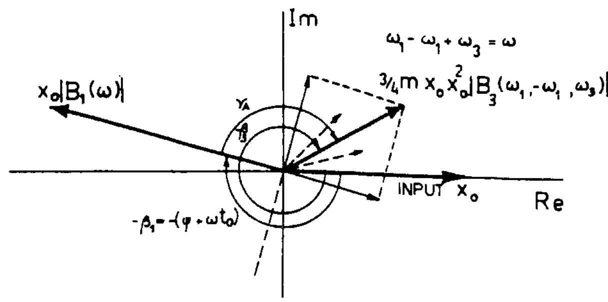

Fig. 3: Vector Representation of Crossmodulation

$$M_{xm}^{(p)}=m_A\sin\nu_A \quad (30)$$

The ratio of the amplitude to phase crossmodulation is determined solely by the phase relationship between the Volterra transfer functions of the amplifier. In practical amplifiers ν_A is determined by the transistor characteristics and by the feedback and other circuitry used. Since the amplifier design is governed by many other criterii one can hardly exercise full control of ν_A when designing an amplifier. Amplitude crossmodulation is thus likely to be inevitable in any amplifier design and is more easily minimized by the use of C.D.C.C.

Let us consider the aforementioned cascade made up of an amplifier and a post distortion correction circuit. The signal at frequency ω_3 at the output of a cascade is found to be

$$z_{\omega_3}=x_o^{(3)}|H_1(j\omega_3)|(1+m_c\cos\nu_c\cos\omega_m t).$$
$$\cos(\omega_3 t-\eta_1+m_c\sin\nu_c\cos\omega_m t) \quad (31)$$

$$m_c=\frac{3m}{4}\,\frac{(x_o^{(1)})^2|H_3(j\omega_1,-j\omega_1,j\omega_3)|}{|H_1(j\omega_3)|} \quad (32)$$

In order to minimize amplitude crossmodulation we must have

$$\nu_c=-\eta_3+\eta_1=\frac{\pi}{2}+n\pi \quad (33)$$

after substitution for η_1 from

$$\eta_1=\psi+\omega_3 t_o \quad (34)$$

and for η_3 from (11) we arrive at

$$\nu_c=\tan^{-1}\left[\frac{K\sin(\psi+\omega_3 t_o-\beta_3)-\sin\gamma_3}{K\cos(\psi+\omega_3 t_o-\beta_3)+\cos\gamma_3}\right]+r\pi \quad r=0,\pm1,\ldots \quad (35)$$

It can be shown that ν_c will attain a value of $\frac{\pi}{2}+n\pi$ provided that the denominator

$$K\cos(\psi+\omega_3 t_o-\beta_3)+\cos\gamma_3=0 \quad (36)$$

For a given amplifier many combinations of K and γ_3 will satisfy this condition. As an example let us assume that K=1. The relative phase of the vector crossmodulation generated by the correction circuit must be 180° out of phase with the vector crossmodulation generated in an amplifier, ie:

$$\gamma_3-\beta_3+\psi+\omega_3 t_o=\pi+2n\pi \quad (37)$$

This condition is basically the same as that given by (22). It is obvious that if the vector crossmodulation at the output of a cascade vanishes so does the amplitude crossmodulation (Fig. 2).

The other example we are going to mention is the situation where $\gamma_3=0$. It then turns out from (36) that the projection of the vector crossmodulation generated in an amplifier must be equal to the magnitude of the vector crossmodulation generated in a post distortion correction circuit (Fig. 4).

$$|B_3(j\omega_1,-j\omega_1,j\omega_3)|\cos(\psi+\omega_3 t_o-\beta_3)= -|C_3(j\omega_1,-j\omega_1,j\omega_3).G| \quad (38)$$

Note here that signals producing the crossmodulation distortion in a post distortion correction circuit are first amplified before being fed to the correction circuit.

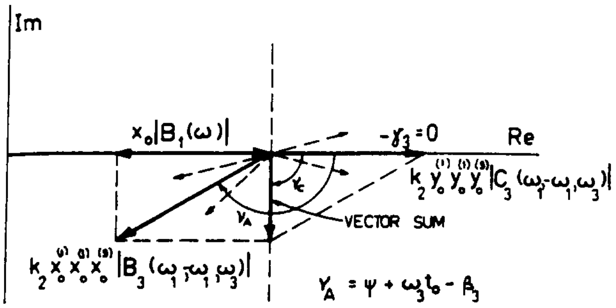

Fig. 4: Minimization of Amplitude Crossmodulation

COMPLEMENTARY DISTORTION CORRECTION CIRCUIT

The following complementary distortion correction circuit (Fig. 5) was devised to cancel amplitude crossmodulation and triple beat distortion generated in the nonlinear amplifier. It is made up of a semiconductor diode in series with an external resistor R_S' plus the biasing circuitry (not shown). The magnitude of this series external resistance must be sufficiently high so as not to appreciably affect the gain of the amplifier. From the aspect of operating point adjustment it has been found advantageous to use a Schottky or hot carrier diode with a very low junction capacitance. Usually, a reactive element in either series or parallel to the diode is needed when elimination of triple beat distortion is desired.

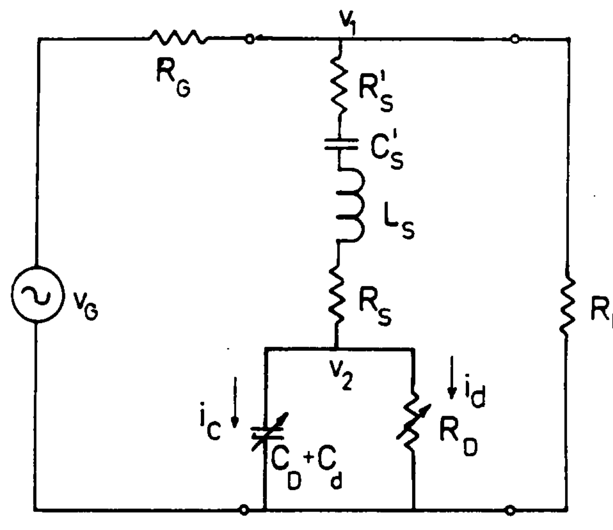

Fig. 5: Equivalent Circuit of C.D.C.C.

For purposes of analysis, the diode is represented by its small signal equivalent circuit consisting of the nonlinear junction conductance, nonlinear junction capacitance, series bulk resistance and series lead inductance. An extensive analysis of nonlinear distortion produced in a Schottky diode in series with an external impedance has been carried out and published in the literature [7]. We shall briefy summarize some results of that report. The nonlinear currents i_d and i_c are each first expressed as a Taylor series in v_2, the junction voltage. This is accomplished by the expansion of

$$I_D+i_d = I_o[\exp(a(V_D+v_d))-1] \quad (39)$$

$$i_c = \frac{dq(v_2)}{dt} \quad (40)$$

about the DC bias. The output voltage $v_1=z$ is then expressed as a Volterra series expansion of the generator voltage v_G (equal to $2\gamma_1$ when $R_L=R_G$, $R_S' >> R_G$) given by

$$v_1=C_1(s)*v_G+C_2(s_1,s_2)*v_G^2+C_3(s_1,s_2,s_3)*v_G^3 \quad (41)$$

where * denotes an operator. By applying Kirchoff's Law, representing the impedances by their transforms and collecting all the terms of each degree we can successively find the Volterra transfer functions $C_1(s), C_2(s_1,s_2), C_3(s_1,s_2,s_3)$. [7]

A time sharing computer was used to compute the sum and difference intermodulation distortion and triple beat distortion. The computed and measured values of second order sum beat distortion at 266.5 MHz (Channel 13 video + Channel 2 video) are shown in Fig. 6. The magnitude of this distortion product in dB was measured using a Dix Hills Electronics SX-16 Frequency Source and R-12 Distortion Analyzer. The output level of each carrier was set at 34 dBmV. Figure 7 summarizes the computed and measured values of single channel amplitude crossmodulation. The computed and measured values of triple beat distortion at 55.25 MHz (Channel 12 video - Channel 13 video + Channel 3 video) at two different output levels are shown in Fig. 8. As can be seen there is a significant difference between the measured and computed values at an output level of 34 dBmV and at low bias. This is probably due to the higher order terms (7th, 9th) and a package capacitance which were neglected in our analysis. However, when using the C.D.C.C. to cancel the third order distortion of the amplifier, the direct current values of more than .1mA are selected. Specifically, when the DC current reaches lmA, the fifth and higher order contributions are negligible for signal levels below 50 dBmV. The following values were used for calculations: $R_S'=1000\Omega$, C_D varying from 1.8pF to 3pF at lmA, $a=37.35$, $R_G=R_L=75\Omega$.

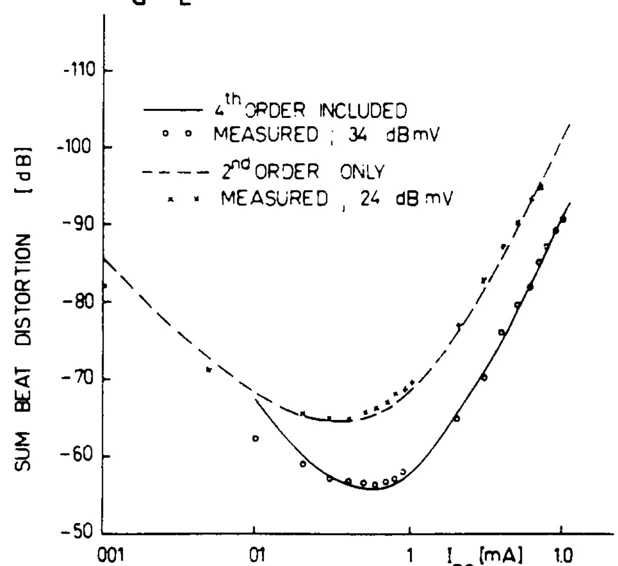

Fig. 6 Sum Beat Distortion at 266.5 MHz vs I_{DC}

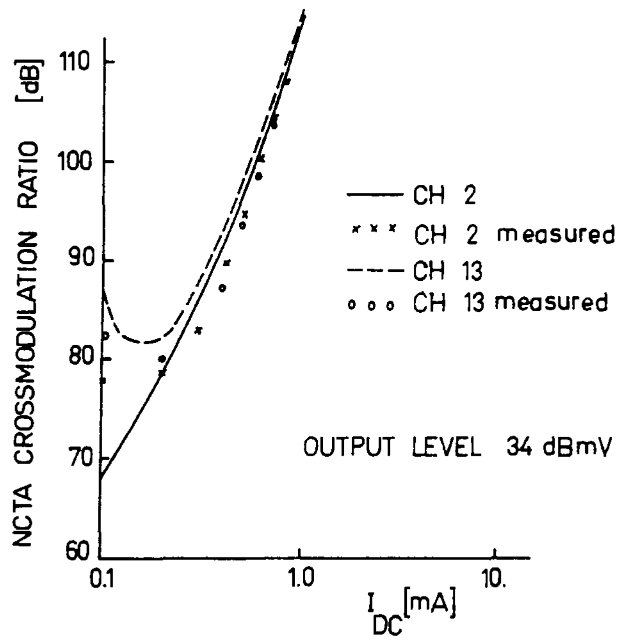

Fig. 7: Single Channel NCTA XM Ratio vs I_{DC}

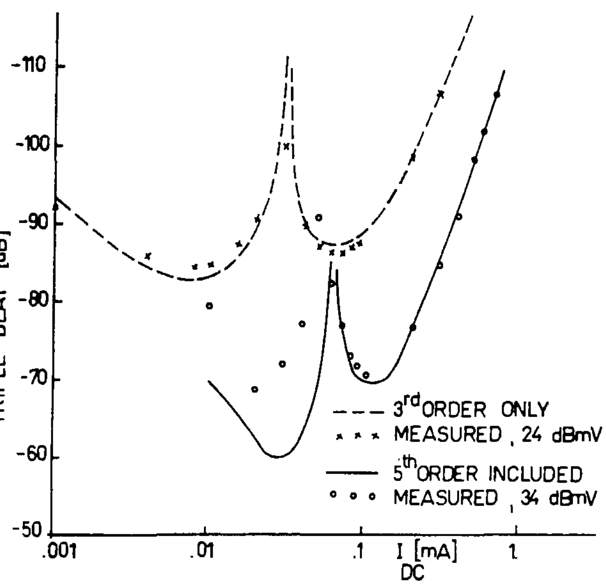

Fig. 8: Triple Beat Distortion at 55.25 MHz vs I_{DC}

As mentioned above, at higher bias currents, when the generated third order product is practically in phase with the fundamental signal, the fullfilment of the phase constraints (22), (38) is accomplished by means of an external reactive impedance. Calculated as well as measured results indicate that the magnitude of the triple beat or vector crossmodulation is only slightly changed when a 5-10pF capacitor is connected in series with the diode and a 1000Ω resistor. Such a capacitor, however, produces a sufficient change in the phase of the third order product generated in the C.D.C.C. so as to cancel a specific third order product generated in most broadband amplifiers. Sometimes, the capacitor must be replaced by an inductor in order to eliminate a specific third order product produced in a nonlinear amplifier. Cancellation of amplitude crossmodulation can be obtained with or without an external reactive element (see Section on Amplitude Crossmodulation).

DISTORTION PRODUCED IN A NONLINEAR AMPLIFIER

Let us consider a nonlinear amplifier as shown in Fig. 9. Derivation of closed form expressions for the second and third order Volterra transfer functions is an extremely difficult if not impossible task. If, however, the intrinsic parameters of a transistor are known these Volterra transfer functions can be evaluated with the help of a computer. As the phase of third order distortion products was of utmost importance to us we decided to computer-analyze distortion generated in a wideband amplifier.

A low distortion amplifier, incorporating both emitter and collector feedback, was built using a 500mW transistor having a gain bandwidth product of 5 GHz (Fig. 9). A thorough knowledge of the distortion processes in this amplifier provides insight into methods for reducing the amplifier distortion by means of adjusting the bias and the component values, and in particular, by the use of C.D.C.C. The latter method requires that both magnitude and phase of the distortion products be known so that the cancellation conditions (17), (18) can be applied. Just as in the case of the C.D.C.C., such magnitude and phase information were obtained by a Volterra series analysis of the transistor amplifier.

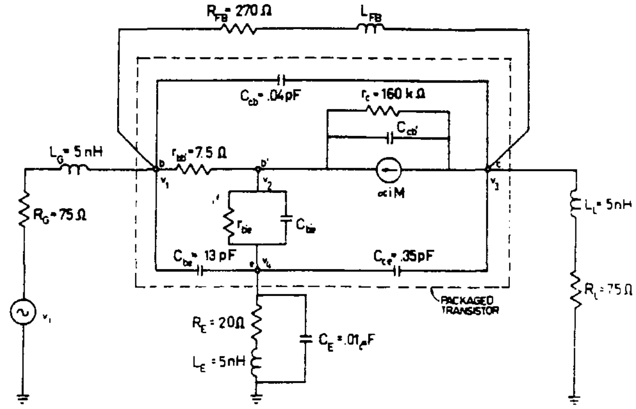

Fig 9: Nonlinear T Model of Transistor Amplifier

The transistor model and the method of circuit analysis follow the case of Narayanan [5]. Fig. 9 shows the nonlinear T-model of the transistor with the addition of the collector-base feedback elements and a fourth node for the emitter feedback components. The nonlinearities included in the model are: base emitter nonlinear resistance and capacitance, avalanche and gain nonlinearity and collector-base nonlinear capacitance. The last nonlinearity was found to contribute negligibly to overall amplifier distortion and will henceforth be ignored.

A request for assistance in transistor modelling to several major manufacturers of CATV devices was met only by Philips who have been very co-operative in this matter. Using instruments such as Tektronix Curve Tracer 576, Boonton Capacitive Bridge 250A, Rohde & Schwarz network analyzer ZWA, we have obtained the basic model parameters for two Philips' transistors built around the same chip. The remaining parameters such as $r_{bb'}$, r_c were supplied by Philips, Eindhoven. For actual calculation, the device with a 500mW power dissipation (stripline package) was selected. The nonlinear parameters on the other hand, had to be measured individually, as they vary from transistor to transistor, particularly in the case of the gain and avalanche nonlinearities. Accurate measurements of the transistor's nonlinear characteristics yield data which can be fitted to the theoretical expressions applicable to each nonlinearity. The nonlinear resistance $r_{b'e}$ can be obtained from the base emitter I-V characteristic.

$$I = I_o \left[e^{\frac{qV_{BE}}{nkT}} - 1 \right] \tag{42}$$

with I_o=.36mA, n=1.35 as fitted values. The nonlinear capacitance, $C_{b'e}$ consists of two components: a depletion capacitance, C_d, measured with the base emitter junction reverse biased

$$C_d = \frac{C_1}{\left(1 - \frac{V_{BE}}{V_o}\right)^{1/3}} \tag{43}$$

and a diffusion capacitance C_D obtained from forward bias measurements.

$$C_D = C_2 \cdot I_E(V_{BE}) \tag{44}$$

Both components are expressed here as functions of V_{BE}. Fitting of measured values gave C_1= 4.3pF, V_o= .8V, C_2= 650pF/A. Differentiation of the above expressions yields the higher order terms required for the second and third order Volterra series. Measurements of low frequency gain vs collector current were fitted by a simple polynomial which was then manipulated to give values for the nonlinear parameter α and its derivatives. The avalanche nonlinearity was determined by measuring I_C vs V_{CE}, then taking the ratio of the curved I_C characteristic to the straight line I_C characteristic which would have been obtained in the absence of avalanche multiplication, and fitting it to the equation

$$M = \frac{1}{\left[1 - \frac{V_{CB}}{V_{CBO}}\right]^n} \tag{45}$$

with resulting values of V_{CBO}= 26V, n= 4. Derivatives of this last equation combined with the previously determined nonlinear parameters and their derivatives, plus the linear transistor parameters, complete the nonlinear T-model of Fig. 9.

A complete program was written to analyze this T-model, in a manner similar to the analysis of the C.D.C.C. mentioned above. The calculations yield the voltages of each of the circuit nodes as a Volterra series of the input voltage v_i. With v_i consisting of either 2 or 3 input signals, 2nd and 3rd order distortion, respectively (Intermodulation, Crossmodulation, Triple Beat) can be calculated. All transistor parameters can be varied in value as desired and each of the nonlinear elements can be turned 'on' or 'off' to determine the contribution of each individual nonlinearity to the overall amplifier distortion. Equally important are the calculated values for the phases of the distortion products - required information for the design of the C.D.C.C. according to the constraints given by (17), (18).

The theoretical distortion levels are obtained by calculating the appropriate 2nd or 3rd order distortion product at the desired frequency and comparing it to the linear output which the amplifier would produce at the same frequency. For example, a triple beat is calculated as the ratio, in dB, of the 3rd order term of the Volterra series of the output voltage at product frequency f_1-f_2+f_3 to the linear (Ist order term) output at frequency f=f_1-f_2+f_3. Fig. 10 shows representative calculated and measured values of triple beat distortion at Ch 2, 13 vs collector current I_C. The calculated results show a definite minimum in distortion at about 50mA bias. This minimum, or 'troughing' may be explained by careful consideration of the individual distortion contributions of the various nonlinear transistor parameters as shown in Fig. 11. The phase of each distortion component, approximately

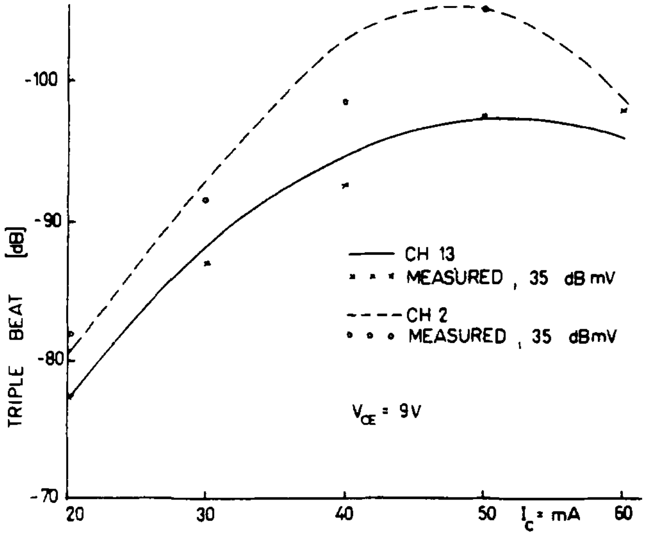

Fig. 10 Triple Beat Distortion of Amplifier

constant over the range of bias current, shows that the $r_{b'e}$ and gain components, similar in magnitude, are nearly in phase, while the avalanche component is about opposite in phase to the latter two. It is thus to be expected that, at some values of collector current, there will be a considerable degree of distortion cancellation. The depth of this minimum and its exact location depend on many factors. Where the dominant components cancel to a large degree, the residual distortion is determined by those factors which were previously neglected, the capacitive nonlinearities and higher order distortion components (5th, 7th order, etc.) due to the higher order terms in the Volterra series. The depth and location of the minimum are as well both sensitive to the exact values of magnitude and phase of the distortion components, which in turn depend on the accuracy with which the nonlinearities of this particular transistor could be determined. Considerable variation in, or even the complete absence of the distortion minimum could be expected due to variations from transistor to transistor. The experimental results of Fig. 10 indicate a distortion minimum occuring at a collector current of about 60mA, somewhat higher than the theoretical value. Agreement in magnitude between theory and experiments is close enough that theoretical values for the phase of the distortion products can be used in the equations for the C.D.C.C. Only near the distortion minimum do phase values vary greatly, undergoing a nominal 180° change.

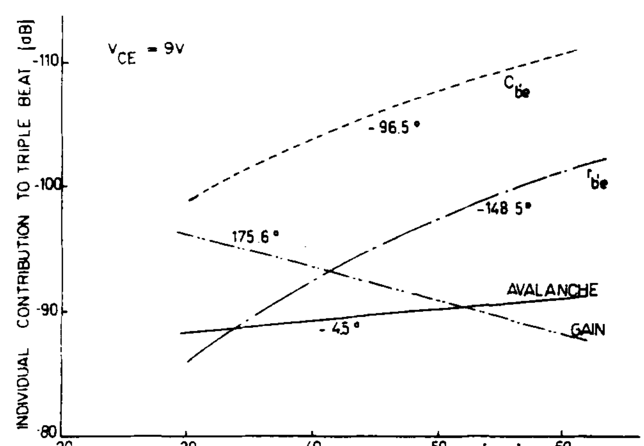

Fig. 11 Contributions of Individual Transistor Nonlinearities to Triple Beat Distortion

Theoretical values for the phase and amplitude crossmodulation can be obtained from the triple beat calculations according to (29), (30) for $-\omega_2+\omega_1$. Fig. 12 compares the measured and computed values of amplitude crossmodulation.

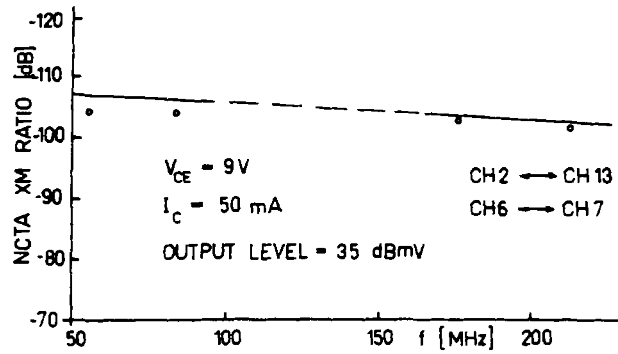

Fig. 12: Single Channel NCTA XM Ratio vs Frequency

DISTORTION CANCELLATION RESULTS

a) Narrowband Distortion Cancellation

In order to obtain perfect cancellation of a particular triple beat or vector crossmodulation distortion generated by the nonlinear amplifier, one must voltage add another product of the same frequency, magnitude and opposite phase. This additional product is produced by a complementary post distortion correction circuit. The same three signals which give rise to a triple beat or vector crossmodulation in the amplifier are, after passing through the amplifier, fed to the C.D.C.C. This circuit will then produce, due to the second and third order terms of the diode's nonlinear V-I characteristic, a distortion product at the same frequency. The magnitude of this product produced in the correction circuit is controlled by an external resistance R_S' in series with the diode and by adjustments of the DC bias. The relative phase of this distortion product is controlled by either a capacitor or inductor in series with the diode or in parallel to it. Other arrangements for controlling the magnitude and relative phase of this product have also been tried and found effective.

Let us turn our attention back to the amplifier shown in Fig. 9 with the C.D.C.C. of Fig. 5 connected at the output. Assume first that the diode is biased at $I_{DC} \approx$ lmA. The situation could now be represented as shown in Fig. 4 where $-\omega_1$ is replaced by $-\omega_2$ if the triple beat distortion is considered. If the resistance $R_S' \to \infty$ the magnitude $k_2 y_o^{(1)} y_o^{(2)} y_o^{(3)} | C_3(j\omega_1, -j\omega_2, j\omega_3)$ approaches zero and the third order distortion product generated in the amplifier is not affected. If the resistance R_S' is reduced the overall triple beat or vector crossmodulation of this cascade will start to decrease. The minimum value is attained when the vector representing the triple beat or crossmodulation distortion of this cascade is normal to the vector representing the amplifier fundamental output signal at the product frequency. This improvement in the triple beat or vector crossmodulation is given by $-20 \log | \sin\nu_A |$.

Table I Triple Beat of Amplifier

V_{CE}=9V., I_C=40mA 35 dBmV	Ch 2 (2,3,12,13)	Ch 6 (5,6,7,8)	Ch 7 (5,6,7,8)	Ch 13 (2,3,12,13)
Amplifier Without C.D.C.C. (dB)	-98.5	-97.5	-94.5	-91.5
Improvement With C.D.C.C. (dB)	>20	19	6	4.5 dB
R_S' (Ω)	700 Ω	680 Ω	640 Ω	610 Ω

Table I summarizes the measured values of the triple beat improvement. The improvement in vector crossmodulation could not be measured using the Dix Hills distortion set-up as it yields only amplitude crossmodulation. However, some confirmation was obtained at higher output levels when a spectrum analyzer could be used. Table I also gives the value of the series resistance R_S' measured when the minimum was obtained. Fig. 4 indicates that this null is quite broad and so practically the same results could be obtained with a value R_S' set somewhere midway between 700 ohms and 610 ohms. Fig. 13 gives the magnitude of the triple beat product produced in the diode circuit for a given value of R_S'. Comparison of calculated values of R_S' with those needed for this partial cancellation shows good agreement.

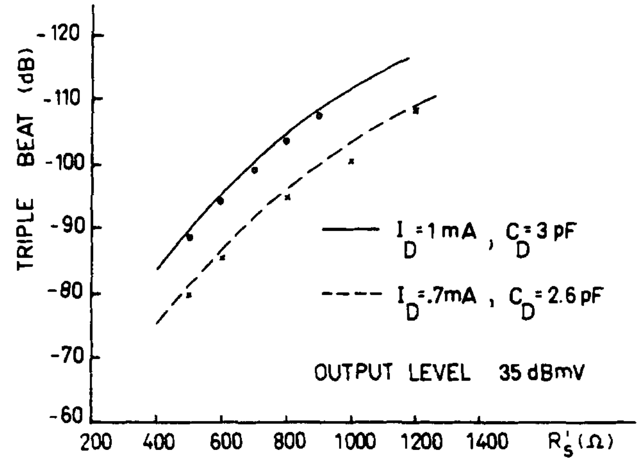

Fig. 13: Triple Beat Distortion vs R_S'

The capacitor C_S' = 1500pF is now replaced with a variable 2-18pF capacitor. The triple beat or vector crossmodulation generated by the correction circuit must now attain a relative phase of $180-|\nu_A|$ (see Fig. 4) with respect to the horizontal axis in order to achieve a complete cancellation. Calculations have indicated that C_S' of 10pF results in $-\gamma_3$=-330°. This was verified experimentally when a value of C_S' from 7-10pF was needed to arrive at perfect cancellation of triple beat and vector crossmodulation distortion on Ch 2 and Ch 6. Since the magnitude of the third order distortion product produced in the correction circuit starts decreasing slightly for C_S' below 10pF the value of the resistor R_S' has to be lowered by about 10%. A slight further decrease in R_S' (compared to partial cancellation as mentioned above) was necessary since now the opposing vectors have equal magnitudes. Cancellation of distortion products on Ch 7 and Ch 13 was obtained with values of C_S' around 5pF.

As indicated by the computed results complete cancellation for one particular frequency can also be obtained with C_S' = 1500pF and an inductor of 200nH in parallel with the diode. In practice, much higher values of inductance had to be used to compensate for the intrinsic diode capacitance. Note again that inclusion of any reactive element in the C.D.C.C. makes this circuit effective in a narrow band of frequencies only.

When a value of R_S' much below 1000 ohms is needed the amplifier gain is slightly affected. This can be avoided by changing the bias current, connecting two diodes in series etc. However, DC bias of lmA for the diode was generally used when amplifiers built with Philips, TRW, or MSC stud devices were linearized and so it was used here as well. In practice, ¼ dB change in amplifier gain can be tolerated.

b) Broadband Distortion Cancellation

Broadband cancellation of the amplifier triple beat and vector crossmodulation products through the use of a simple C.D.C.C. (Fig. 5) is possible provided that the magnitude of these products is approximately constant and $|\nu_A| \approx 180^\circ$ or 0° over the frequency range of interest. Amplifiers incorporating transistors with a high gain bandwidth product f_T often come close to meeting these two conditions. In such a situation, the parameters of the C.D.C.C. are adjusted for a complete cancellation of the triple beat and vector crossmodulation distortion at the high frequency end (amplifier triple beat usually increases with frequency) with only a partial cancellation of these products at the low frequency end.

We have verified both theoretically and experimentally [1] that the level of distortion noise due to a large number of triple beat products generated in a typical CATV trunk amplifier is much higher in a channel near the 300 MHz end. Using the simple C.D.C.C. of Fig. 5 we can reduce the level of this distortion noise by 6–8 dB at the high frequency channel while the level of distortion noise at the low frequency channel is improved by 1–2 dB. The fact that a complete elimination of this composite triple beat can not be realized may be accounted for by the higher order terms of the nonlinear transfer characteristics and as well by the dependence of the Volterra transfer functions on the input frequencies.

The amplifier second order distortion is not affected because the level of the second order distortion produced in the C.D.C.C. is much lower (see Fig. 6 at DC bias of 1mA). If, however, the second order distortion of the amplifier were degraded by the C.D.C.C. one could employ two diodes in a push-pull arrangement to suppress the second order distortion from the C.D.C.C.

In a more general case, the magnitude of the triple beat and vector crossmodulation distortion generated in the amplifier increases with frequency and the relative phase $|\nu_A|$ varies monotonically over the frequency range of interest. Such was the case with our model amplifier of Fig. 9. It was found that a broadband cancellation of the triple beat and vector crossmodulation products was possible provided that a parallel resonant circuit was incorporated in the design of the C.D.C.C.

c) Amplitude Crossmodulation Minimization

The vector representation of amplitude crossmodulation minimization is shown in Fig. 4. In order to eliminate amplitude crossmodulation produced in a nonlinear amplifier the post distortion correction circuit must produce amplitude crossmodulation of the same magnitude. The magnitudes of the corresponding vector crossmodulations may however differ. Amplitude crossmodulation of a cascade comprised of a nonlinear amplifier and a post distortion correction circuit (Fig. 4) vanishes as soon as the vector sum of

$k_2 y_o^{(1)} y_o^{(2)} y_o^{(3)} C_3(j\omega_1, -j\omega_1, j\omega_3)$ and

$k_2 x_o^{(1)} x_o^{(2)} x_o^{(3)} B_3(j\omega_1, -j\omega_1, j\omega_3)$ is normal to the

vector $x_o^{(3)} B_1(\omega_3)$. The magnitude of the overall vector crossmodulation reaches a minimum when amplitude crossmodulation vanishes (all amplitude crossmodulation converted into phase crossmodulation).

The experimental investigation has confirmed that amplitude crossmodulation can be made to vanish at any product frequency by properly adjusting the DC bias and the resistor R_S in series with the diode. Table II summarizes the measured values of the NCTA crossmodulation ratio of the amplifier shown in Fig. 9. The measurement was done with eleven amplitude modulated carriers whose peak levels at the modulation crest were equal to the peak level of the test (unmodulated) carrier. Reductions of the NCTA crossmodulation ratio of more than 30 dB at an output level of 35 dBmV could be observed on the distortion analyzer. Actual improvements were much higher but the distortion analyzer can only measure the distortion product magnitude down to about -120 dB. When the amplifier output level was increased to 45 dBmV, improvements of 50 dB could be observed (NCTA crossmodulation ratio reduced from -70 dB down to less than -120 dB).

Table II gives the measured values of the NCTA crossmodulation ratio before the C.D.C.C. was connected at the output and the values of the resistor R_S' needed to cause the NCTA crossmodulation ratio of this cascade to vanish. If we relate these values of R_S' to the NCTA crossmodulation ratio according to Fig. 7 (note that the values given in Fig. 7 must be degraded by approximately 20 log 11 to sum up contributions from all amplitude modulated carriers) we find good agreement between the measured values of the NCTA crossmodulation ratio of the amplifier and the C.D.C.C. All the above tests were done with the diode in the C.D.C.C. biased at ImA and C_S' = 1500pF). Similar results could be achieved at a different DC bias (ie: I_{DC}=.7mA).

Table II. 12 Channel NCTA XM Ratio of Amplifier

V_{CE}=9V, I_C = 50mA 35 dBmV	Ch 2	Ch 6	Ch 7	Ch 13
Amplifier Without C.D.C.C (dB)	-83	-82.5	-81.5	-82
R_S' (Ω)	770	790	800	820
Measured Improvement (dB)	16	16	22	18
Calculated Improvement (db)	16.1	20.6	31	24.5
Measured Improvement With C_S' = 7pF (dB)	20.5	22.5	21.5	23.5

It should be understood that narrow band amplitude crossmodulation cancellation is also possible at much lower values of diode bias current even though the relative phase $-\gamma_3$ of the vector representing the crossmodulation generated in the C.D.C.C. is not equal to zero (see equation (36)). Minimization could also be achieved if we used other values of series or parallel capacitance (inductance). As mentioned above amplitude crossmodulation vanishes if the vector crossmodulation is cancelled (Fig. 2). Note also that minimization of amplitude crossmodulation is accompanied by a partial cancellation of the triple beat distortion at the same product frequency (see Fig. 4 with $-\omega_1$ replaced by $-\omega_2$).

Theoretical as well as experimental investigations indicate that amplitude crossmodulation in wideband amplifiers varies with frequency. Under such conditions a complete elimination of amplitude crossmodulation over the frequency band of interest by means of a simple C.D.C.C. is not possible. The amount of broadband improvement (partial reduction) is related to the actual difference in measured amplitude crossmodulation at different product frequencies. With capacitor C_S' set to 1500pF, a minimum broadband improvement (Ch 2 through Ch 13) of 16 dB could be obtained with our model amplifier of Fig. 9. Expected as well as measured improvements in the NCTA crossmodulation ratio on four tested carriers at one particular value of the linearizing resistor R_S' = 790 ohms are given in Table II.

A broadband improvement of more than 20 dB in 12 channel NCTA crossmodulation ratio was attained with C_S' set to 7pF (see Fig. 14). If desired, even better results can be achieved if a resonant circuit is incorporated in the C.D.C.C.

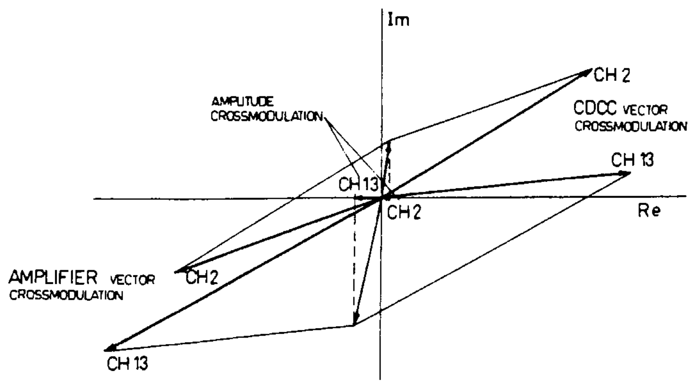

Fig. 14 Broadband Minimization of NCTA XM Ratio

ACKNOWLEDGEMENT

The authors wish to thank J. Greenan for her excellent job in preparing the paper and J. Prochazka for drawing the figures.

REFERENCES

[1] A. Prochazka, Improving CATV system performance through amplifier design, CCTA Convention,18th, Technical Records, Vancouver 1975

[2] A. Prochazka, Cascading of distortion in CATV trunk line, IEEE Trans. Broadcasting, Vol BC-20, pp 25-32, June 1974

[3] A. Prochazka, P. Lancaster, Limitations in distribution of TV signals over cable transmission systems, Technical Report, Delta-Benco-Cascade Ltd., December 1974

[4] R.J. Seacombe, A. Prochazka, P. Lancaster, Some further notes on "Cascadeability", Cable Television Engineering, Vol 10, No. 7, December 1975

[5] S. Narayanan, Transistor distortion analysis using Volterra series representation, BSTJ, Vol XLVI, pp 991-1024, May-June 1967

[6] R.G. Meyer, M.J. Shensa, R. Eschenbach, Crossmodulation and intermodulation in amplifiers at high frequencies, IEEE J. Solid State Circuits, Vol SC-7, pp 16-23, February 1972

[7] A. Prochazka, R. Neumann, High frequency distortion analysis of a semiconductor diode for CATV applications, IEEE Trans. Consumer Electronics, Vol CE-21, No. 2, May 1975

BODE'S VARIABLE EQUALIZER

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The Bode Equalizer, an adjustable equalizer circuit long used in the telephone industry at voice carrier frequencies, is finding its way into the CATV industry at VHF frequencies. This type of circuit provides superior cable tracking accuracy and ease of adjustment, compared to circuits used in the past. The design of these equalizers can be accomplished by a straightforward bench procedure, or by computer aided design techniques. The theory, design, and application of the Bode Equalizer are discussed in this paper, and a sample CAD program used in its design is presented.

BODE'S VARIABLE EQUALIZER

Introduction

The CATV industry has borrowed terminology as well as technology from a number of other fields. One obvious source is the telephone industry, especially carrier telephony. This paper discusses one recent acquisition.

In the April, 1938, Bell System Technical Journal, H. W. Bode described a type of variable equalizer circuit, which has come to be known as the Bode equalizer. The name Bode is familiar to engineers through his many other contributions to electrical engineering. The original application was for telephone carrier systems, with top frequencies of a few Megahertz or so. A number of articles have appeared in print on the subject over the years, usually related to the same frequency range. The technique is readily adaptable to the VHF range for CATV purposes, and this has been done in recent years.

Equalization

In any cable-repeater amplifier system, equalization of the cable attenuation is a fundamental requirement. For the frequencies and transmission lines of interest in CATV, the decibel attenuation is very nearly proportioned to the square root of the frequency. In order to maintain uniform signal levels over a long cascade of cable spans and repeater amplifiers, unity gain must be preserved. The repeater amplifier must complement the cable loss, i.e., the amplifier must have high gain at high frequencies and low gain at low frequencies. This can be done by arranging the active devices themselves to have the desired gain-versus-frequency characteristic. But the more common pattern nowadays is to use a more or less flat broadband amplifier with a separate passive equalizer. This equalizer is usually a bridged-T circuit, and may have any number of adjustments available to achieve system flatness.

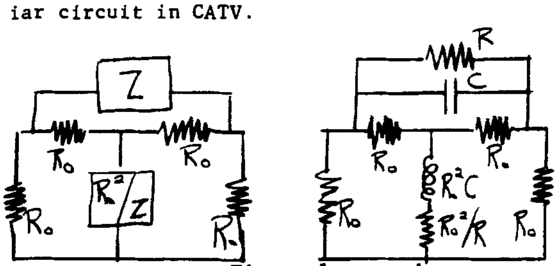
The major concern of this article is the need for variable equalization. The need arises because as the cable temperature changes, its attenuation changes, in a fashion also proportional to frequency. The normal rule of thumb is that attenuation changes by .2% per ^{o}C (.11% per ^{o}F.), at any frequency. A 22 dB span of cable at 20^{o} C will be a 23 dB span at 43^{o}C and a 21 dB span at -3^{o}C. To preserve unity gain, the corresponding amplifier must change its gain by +1 dB -1 dB at the top frequency, and by lesser amounts at lower frequencies, with the same frequency characteristic. This needs to be done automatically, simply, and reliably.

The usual passive equalizer is designed with minimum loss at the top frequency, and a variety of controls for the loss at lower frequencies. It does not lend itself well to the thermal compensation problem described above. A variety of "handles" is desirable for setting-up a system, but a simple and reliable control system for automatic operation of a number of controls is difficult to conceive, to say the least.

What is needed then is a separate network to perform the gain adjustment function. It should have a single control point, and be capable of precise gain-versus-frequency control. The Bode equalizer fills this need.

Bridged-T Networks

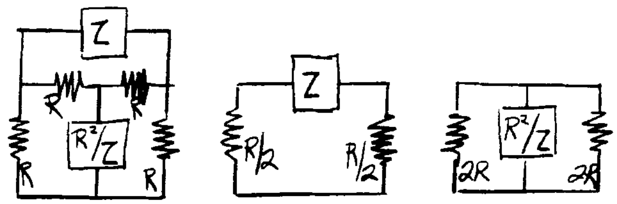
First a brief review of some pertinent network theory. The bridged-T network is a familiar circuit in CATV.



a Figure 1 b
Bridged-T Networks

Frequently used for equalizers and attenuators, it has the property of showing a purely resistive input impedance of Ro ohms if the series network and the shunt network are duals of each other, and the network is properly terminated. Referring to Figure 1a, this means that the product of the series network impedance and the shunt network impedance must equal Ro^2, and the network must be terminated with Ro. Another way of saying this is if the series network impedance is Zo, then the shunt network impedance must be Ro^2/Zo. For the usual case of Ro = 75Ω, this might be as simple as a 68Ω resistor for Zo, and an 82Ω resistor for Ro^2/Zo, in which case you would have a 5.6 dB flat pad. Figure 1b, shows a simple kind of equalizer circuit. The parallel RC network in the series leg and the series RL network in the shunt leg are duals.

It is sometimes stated that the series network controls the response of the entire bridged-T network. This is true, and can be carried even further; the series network of a bridged-T network in an Ro ohm system can be lifted out and placed in series in an Ro/2 system to yield exactly the same insertion loss characteristic. Moreover, the shunt network can be likewise taken out and placed in shunt in a 2 Ro ohm system, also with the same insertion loss.



a b c
Figure 2
Three Networks with the same Insertion Loss

Of course the new networks will not be matched; they will not have the Ro input impedance of the bridged-T circuit. But the notion is very useful for analysis and discussion, and, with due caution, for bench testing.

Another point to mention is that if the bridged-T network is not terminated in its characteristic impedance will not in general even be resistive, let alone equal to Ro.

The Bode Equalizer

The curves of Figure 3 represent a sweep system display of an equalized length of cable at three different temperatures. The coordinates are chosen to correspond to a conventional scope display. The idea here is that the cable has been perfectly equalized by a passive network at a nominal temperature. For low temperatures, the loss decreases in a manner proportional to frequency and for high temperatures the loss increases in a similar fashion.

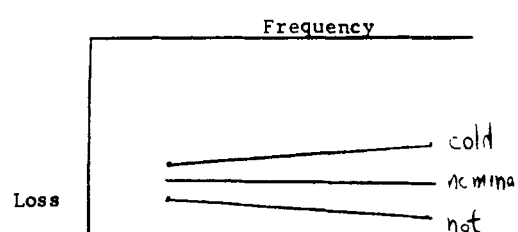


Figure 3
Loss of Equalized Length of Cable at Various Temperatures

We now look for a network capable of keeping the transmission flat across the band by some simple control. Figure 4 shows what kind of characteristics this network must have, considering only series attenuator networks, as discussed earlier. For low temperatures, a series RL network of 4a with attenuate the high frequencies more than the low, in effect simulating cable, because of the increasing reactance of the inductor with frequency. At midrange, the resistor of 4b causes flat loss. For high temperatures, the parallel RC of 4c will have less attenuation at high frequencies, due to the decreasing reactance of the capacitor, and will act like a cable equalizer.

The Bode equalizer is a circuit which will vary smoothly and controllably between the three states of Figure 4. It is itself a bridged-T circuit, with a variable termination.

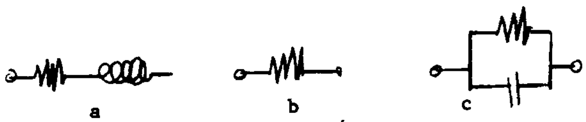


Figure 4
Desired Variable Equalizer Characteristics

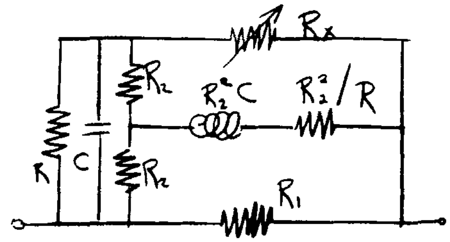


Figure 5
Bode Equalizer - Series Version

Referring to Figure 5, the parallel RC and the series RL are made to be duals of each other with respect to R_2, such that the product of their impedances is equal to R_2^2. This is similar to the network of Figure 1b. Now when this bridged-T circuit is properly terminated, i.e., when $R_x = R2$, the input impedance is equal to R2, and this is simply in parallel with R_1, and we have the condition of Figure 4b. When R_x is shorted, the parallel RC is placed across R1, yielding essentially the condition of Figure 4c. And when $R_x = \infty$, the general effect is to connect the series RL network in series in the line.

The critical point is the ability of the network to vary smoothly, predictably, and symmetrically through the three states described on Figure 4, when only the terminating resistance R_x is varied. It is the reflection coefficient of R_x with respect to R2 or $\rho = \frac{Rx - R2}{Rx + R2}$, which determines what fraction of the total range of the equalizer is brought into play. Figure 6 indicates the behavior of a Bode equalizer for various terminations.

Appendix II presents a proof that the above statements of the previous paragraph are true. The proof indicates how R_1 and R2 are to be chosen, but if one accepts on faith the symmetry property, it is not difficult to see how to pick R_1 and R_2.

Design Procedure

The starting point is the desired flat loss of the network, called on Figure 6.

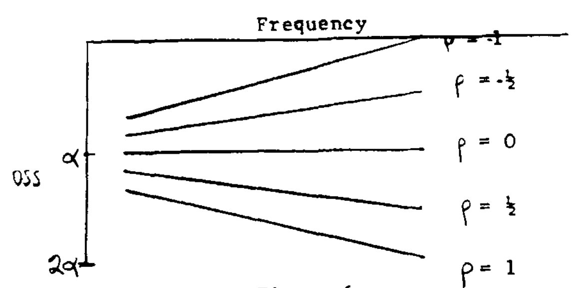


Figure 6
Loss of a Bode Equalizer

This will usually be somewhat more than half the total range of control desired. Going back to Figure 5, the equalizer will be flat when $R_x = R_2$. The input impedance to the R_2 bridged-T network will be R_2 ohms, and this will be in parallel with R_1. This establishes that R_2 in parallel with R_1 is the resistance that determines the flat loss of the Bode equalizer. Also from Figure 5 notice that for $R_x = \infty$, at very high frequencies, the series inductor takes everything out of the picture except R_1. Now back to Figure 6, and the realization that for that situation, the symmetry condition requires that R_1 be associated with 2α, twice the flat loss. In other words, if this circuit is to be symmetrical about a flat loss of α dB, then its two extremes have to be 0 dB and 2α dB.

To sum it up; pick R_1 to yield twice the desired flat loss, and pick R_2 such that $R_2 \| R_1$ yields the desired flat loss.

The more difficult part lies ahead; how to choose the reactances to yield the desired equalization. But the theory of the Bode equalizer simplifies this task enormously. With Rx set to zero, you design an equalizer by your favorite method; "tweaking" at the bench, calculating breakpoints, or computer programs. Once the equalizer is designed on a Bode basis, one can be confident that varying Rx will produce the desired symmetrical behavior. Appendix I is an example of a CAD program used to design a Bode equalizer. Of course, if we are dealing with broadband VHF, the accuracy of the final result will depend on how well the stray impedances are dealt with. And that is a significant qualification.

The equalizer based on a parallel RC described above is about as simple as possible. The need for wider bandwidth, increased precision, or wider range may require a more complex network to start with, e.g., two parallel RC's in series, or a series LC.

The Bode equalizer is by no means limited to the specific usage described above. Any variable gain versus frequency characteristic which is symmetrical about a flat loss can be accomplished this way. Figure 7 shows some of the possibilities. Figure 7a shows what is usually called a slope control, normally used to interpolate between fixed values of main equalizer for set-up purposes. Another conceivable version is shown in 7b, which is an adjustable bow or sag.

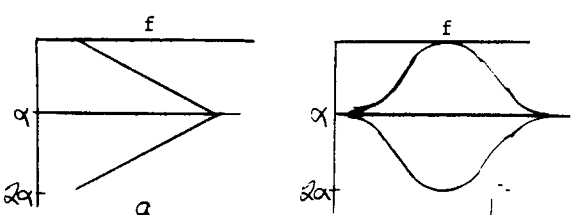


Figure 7
Other Bode Type Equalizers

To be useful in CATV, the Bode equalizer must be used in an impedance matched version. This is accomplished by providing the 75 Ω dual in the shunt position of a 75 Ω T. The dual of a bridged-T network is itself a bridged-T network. The dual of the terminating resistor must also be provided. Figure 8 shows a full dual version of the circuit of Figure 5.

In a fully matched Bode equalizer the terminating resistor must also be provided dually. There are a variety of ways of doing this. Dual potentiometers are available, but are not suitable for automatic control. PIN diodes and thermistors are candidates for R_x. The PIN diodes may be controlled by an AGC loop, or perhaps by a thermistor. One thing to keep in mind is that to achieve to full range of the Bode equalizer. R_x must vary very widely, from a short to an open circuit.

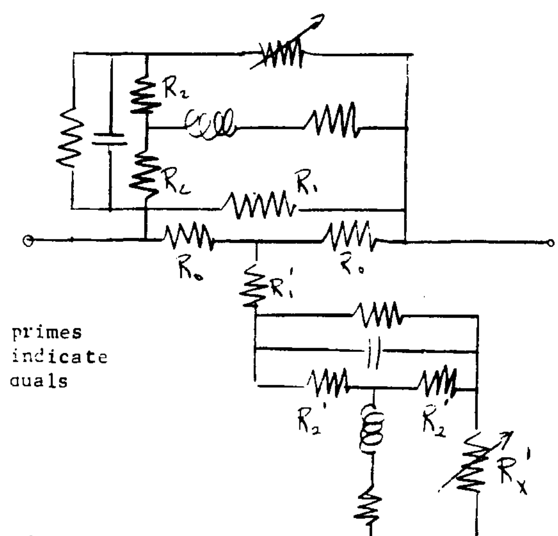


Figure 8
Full Dual Bode Equalizer

Bibliography

H. W. Bode; Variable Equalizers; Bell System Technical Journal, April, 1938.

S. S. Hakim; Bode's Variable Equalizer; Electronic Technology, June, 1961.

W. Haas; Theory and Design of an Adjustable Equalizer; Electrical Communication, February, 1965.

W. A. Brading; Exact Design Method for Adjustable Equalizers; Electrical Communication, March, 1972.

Appendix I

This is a CAD program used for designing a Bode equalizer. It is written for COMPACT, a network analysis and optimization program, which is available on UCS timesharing and elsewhere. This equalizer uses two parallel RC networks in series. They are assigned in lines 100-120. In line 190 the terminating resistance is set to 10 ohms. Line 250 puts 4.5 dB of cable in series with the equalizer, and lines 290 and 320 instruct the program to look at 5 to 115 MHz, and make the total loss 5.7 dB.

```
00100 PRC AA SE  -75  -100
00110 PRC BB SE  -33  -240
00120 CAS AA BB
00130 RES BB PA  204
00140 RES CC SE  110
00150 INV DD AA  110
00160 RES EE SE  110
00170 CAX BB EE
00180 PAR AA BB
00190 SBR AA AA   10
00200 RES BB SE   75
00210 INV CC AA   75
00220 RES DD SE   75
00230 CAX BB DD
00240 PAR AA BB
00250 CAB BB SE  4.5   .05   .0007
00260 CAS AA BB
00270 PRI AA S1   75
00280 END
00290 5 115 10
00300 END
00310 0.1
00320 0 0 10 -5.7
00330 END
```

CABLE AND SATELLITES--NEW OPPORTUNITIES FOR SERVICE

Frank W. Norwood

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Washington, D.C.

A review of the similarities and differences between existing commercial satellite configurations and the NASA experimental communications satellites ATS-6 and CTS. CATV system operators are urged to consider experimentation on the latter, particularly in the area of continuing education--a movement gaining increased momentum in this country.

At the 1969 NCTA convention there was a major Engineering and Management session on "CATV via Satellite." Fred Ford and Irving Kahn were on that panel and I was too. The argument was made that it was both desirable and inevitable that CATV systems would soon be linked together by satellite. Now, with the added ingredient of pay television providing the catalyst, that prediction is coming true.

My contribution to the 1969 panel was to call attention to the fact that education's interest in the new technologies are complementary to your own and that linking cable and satellites must surely open up new opportunities for us to cooperate to our mutual advantage.

I believe that now even more strongly than I did in 1969. Let me cite one significant example--the technology of communication satellites.

Domestic communications satellite services currently available are more marked by their similarities than their differences. The common configuration, 5-watt transponders at 4 GHz, makes compelling sense for communications systems whose primary mission is long-haul traffic between and among major population centers. The constraints such a configuration puts upon ground requirements are as familiar to you as they are to me: "small" earth stations require 30-foot antennas and cost upwards of $70,000. In major urban areas, problems of frequency coordination require earth station siting at locations far from the user's premises and add the costly burden of microwave "tails" to the system requirements.

This is not to be critical of the domsat carriers or the satellite designers. Current systems are appropriately sized for the work they were designed to do. Earth station installations at $100,000 apiece are not prohibitively expensive if 99.99% reliability is required and if only a limited number of ground terminals is needed. Those of us in education, health and other public service fields, however, find such costs well beyond our reach. In addition, schools, universities, hospitals and the like--especially those which most need the help that communications can bring--are not neatly clustered in the nation's major metropolitan areas.

Our constituents--and there are many of them--are scattered all across the 50 states. I trust you're beginning to sense that there is an interesting parallel here between our constituency and yours. Cable television head-ends are also widely dispersed, and there are many of them. A satellite communications system when configured to meet the needs of education and health would resemble pretty closely the kind of system which would be required if satellite interconnection of all cable systems should become a reality.

One of our prime criteria is low earth station cost. Not only is that important in terms of bringing the benefits of satellite communications to small institutions at a price they can afford, but because earth station costs have an enormous impact on "the bottom line." There are more than 22,000 school districts in the United States. If a satellite system were to serve one school in each district, a $1,000 reduction in the cost of earth terminals would save $22,000,000. For satellite systems requiring more than a few thousand terminals, it is the cost of the ground stations, not the cost of the satellite, which drives the system.

For that reason, we in education have been keenly interested in the possibilities which new communications satellite technology has opened up. The National Aeronautics and Space Administration's ATS-6 delivered color television signals of more-than-acceptable quality into earth stations with antennas only ten feet in diameter and stations of the same size could be used to transmit television programming back to the satellite. (Such two-way "intensive terminals" were permissible only in Alaska: their use was precluded from the Lower 48 not by the limitations of the technology but by insurmountable problems of frequency coordination).

What makes such a startlingly different television service available via ATS-6 are the satellite's greater power, the ability of its 30-foot space-deployed antenna to concentrate all of the available energy into a relatively small footprint, and the fact that ATS-6 transmitted not at 4 GHz but at 2.5.

What satellite experts call the 2.5 GHz band, instructional television users refer to as 2500 MHz. Terrestrially, the band is assigned to the Instructional Television Fixed Service but the sharing criteria are such that interference problems are no where near so horrendous as at 4 GHz. In the ATS-6 experiments, two satellite receive points were in cities with ITFS installations. In Huntsville, Alabama, the space and terrestrial services were able to operate without difficulty. In Las Vegas, Nevada, one ATS terminal was located at the city schools' headquarters where the schools' ITFS transmitter is also located. When the terrestrial system was operating, reception of space signals was impossible. However, the satellite receiver at the University of Nevada-Las Vegas, a few miles away, could receive the satellite signal without interference.

At the 1971 World Administrative Radio Conference, the United States was successful in securing reservation of the 2.5 GHz band for satellite broadcasting for education and community development. While that allocation precludes the use of the band for relaying commercial entertainment to CATV systems, a first step in cooperation between our two communities was taken in the Satellite Technology Demonstration project of the Federation of Rocky Mountain States. STD school and community programming transmitted on ATS-6 went directly to 56 rural schools and to public television stations in the Rocky Mountain area, but in Osburn, Idaho, and Elko, Nevada, the ATS-6 terminals were located at the head end of the local cable systems. They are the true pioneers of satellite cable interconnection.

ATS-6's 15-watt transponders are three times more powerful than those of WESTAR and SATCOM. The Communications Technology Satellite, launched in January, carries two television transponders, one at 20-watts and one at 200. CTS, a joint venture of NASA and Canada's Department of Communication, will soon be providing television into small terminals, similar to those used for ATS-6. The coverage area of CTS, however, will be far larger than those of the earlier satellite. Each of its two independently-steerable beams can cover an entire U.S. time zone.

During the first year of its operation, a variety of experiments in education and health care will fill CTS's schedule. SECA--the Southern Educational Communications Association --plans to explore the use of CTS for regional TV networking. SECA is the largest of public television's regional associations and its Southern Educational Network extends from Virginia to Texas.

The SECA experiment is not to be confused with the plans of the Corporation for Public Broadcasting and the Public Broadcasting Service to interconnect PBS stations on an operational basis via WESTAR transponders leased from Western Union. Nationally, public broadcasting like pay cable, must look to existing systems with established technology as a basis of any operational enterprise. Like all CTS users, SECA is engaging in an experiment and the results of that experiment may be of considerable use in developing the next generation of communications satellite systems.

The Joint Council on Educational Telecommunications works closely with NASA on both ATS-6 and CTS experiments and if any of the U.S. or Canadian CTS experiments proposed for the first year involve cable television, I am not aware of it. Albert Whalen and others are better qualified to speak to the technological considerations, but it appears to me that cable television should be as interested in gaining first hand experience with satellites at the 12 GHz band as we in education are.

The opportunities to explore what high power satellites can do for cable and education (separately or together) are too attractive to resist. The CTS schedule is only firm for its first year of operation and, while the satellite has a design life of two years, the launch last January was so nearly perfect that there is enough fuel on board to maintain station-keeping for an additional two years. Further, ATS-6 becomes available for its third year of operation after the conclusion of India's Satellite Instructional Television Experiment.

While members of the cable community are free to propose their own CTS or ATS-6 experiments to NASA without any assistance from us, I continue to be as enthusiastic as I was in 1969 for finding areas of common interest where we might work together and gain mutual benefits from our explorations in programming as well as in technology. Let me sketch out some areas in which I think cable and education might try out cable satellite interconnection, whether by CTS, ATS-6, WESTAR or SATCOM.

At the same time that pay cable has been drawing the increased attention of the cable industry an equally exciting development has been afoot in post-secondary education. I'm sure that most of you have read about the British Open University which is now providing tens of thousands of British citizens with a "second chance" to pursue a University degree. While the Open University of the United Kingdom is internationally known, it is a manifestation of the trend that is going on all around the world. Here in the United States there are such projects as the University of Mid-America which like the British OU makes television a principal ingredient (but not the only one) in its college-level course offerings. Other projects, here and abroad, may or may not use television but all are directed at bringing opportunities in post-secondary education to a large, eager, and previously under-served clientele: those who are past 25 and whose work and/or family responsibilities preclude them from returning to the campus to enroll in conventional college programs.

The University of Mid-America was spawned by the University of Nebraska, and its growth has taken it beyond the border of the Cornhusker State and now involves established state universities in Kansas, Iowa and Missouri as well. Another important trend is to be found in the development of college courses around such outstanding public television series as AMERICA, CLASSIC THEATRE, and THE ASCENT OF MAN. The University of California-San Diego and Miami-Dade Community College district have been leaders in seizing the opportunity which such outstanding television fare provides. Working closely with print publishers, they have developed work books, teacher guides, additional reading materials, and the like to assemble a complete "package" which enables any cooperating college or university to offer a course, on- or off-campus. The success of that approach may be measured by the fact that more than 300 colleges enrolled 23,000 students in the course based upon THE ASCENT OF MAN during its first run on PBS in the spring of 1975. During the second run, in the fall, an estimated 30,000 students were enrolled.

These programs have, of course, been on open circuit television just as their predecessors on NBC's old CONTINENTAL CLASSROOM and New York University's perennial SUNRISE SEMESTER. In the past, such educational programs had to measure their success by counting the total of viewers--and at 6 AM those numbers were never large. The number of students enrolled for credit--and paying fees--has never been more than a small percentage of the total number of viewers--some casual, but some quite as avid as those who enroll as college students.

On the college campus, interested students and citizens of the community who want to "audit" a popular course need not take nor pay for credit but in most institutions they are expected to register as "auditors" and pay at a somewhat reduced rate. Broadcast television has always "let the auditors in free" because there was no way of tapping that source of potential revenue.

University deans and business managers in public as well as private institutions are quite comfortable with the idea of charging money for the educational product their institutions offer. That pay cable could provide the necessary technology is a fact of which most of them are simply unaware.

To explore this opportunity would clearly require the participation of cable television operators, pay channel entrepreneurs, institutions of higher education, and satellite interconnection. To mount an experiment in higher education by pay cable and do it well is likely to require more than local resources. A conventional cable system and a local college are almost certainly doomed to the kind of Great Talking Face lectures which were all too characteristic of instructional television in the days before SESAME STREET and Jacob Bronowski. In this area, as in entertainment, substantial critical mass will have to be achieved before such a development has any chance of success.

On the other hand, the price of getting started is not so immense as to be beyond our combined grasp. The British Parliament charted and funded the Open University and made a long term commitment to the development of a new national institute of higher learning which would eventually give undergraduate and graduate degrees in a wide variety of disciplines. To explore what cable, higher education, and satellites might do in combination on this side of the Atlantic requires no such resources or commitment. Software now exists at the University of Mid-America, as well as the public television programs which have provided the basis for college courses. We are not talking about television programs alone; each series has its set of ancillary materials--text, course outlines, and the like.

Finally, across the country there are hundreds of colleges and universities which have already had successful experience with these materials or others like them and which have demonstrated their willingness to offer academic credit.

At a different academic level there are also several already-developed and tested television series keyed to the General Educational Development tests. The prestigious American Council on Education (one of the founding members of the JCET) administers these GED tests and in almost every state and Canadian province, local education authorities are prepared to grant a high school diploma on the basis of successful completion of these GED exams. Whether on pay or open channels the combination of these television materials and nationally accepted tests offers yet another opportunity to mount a program which could both meet a pressing national need and provide its own economic support.

In 1969, I ended my remarks by saying that "our interests are rapidly converging--in fact, they have already converged. . . . Toward establishing our broader dialogue, let me close by offering you whatever help the Joint Council on Educational Telecommunications can provide."

CABLE TELEVISION - ITS ROLE IN DATA TRANSMISSION
A CASE STUDY AT BANKERS TRUST COMPANY

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INTRODUCTION

Commercial Data Transmission in dense metropolitan areas is a CATV "natural", both because the system capacity is there, and because coaxial cable is inherently one of the cleanest mediums for the transmission of computer data. Virtually any building in the CATV franchise area can easily be entered and cabled internally, thus making the system accessible to most business offices.

COMMERCIAL DATA TRANSMISSION REQUIREMENTS

Just ten years ago, low-speed teletype circuits comprised the majority of remote data processing line networks. Technological advances in equipment design have necessitated increased data throughput requirements, often to megabit per second transmission. Two years ago 2400 bps was the maximum through-put on private leased line circuits. It is now possible to transmit 4800 bps on dial-up lines and 9600 bps on private-unconditioned leased lines; a four-fold increase in just two years!
The data transmission environment in New York City is almost totally analog in nature, interconnected by telephone circuits. With the enormous growth of electronic data processing and on-line remote terminal usage over the past few years, the telephone network is having difficulty keeping pace with the ever-increasing network demands.

One group of typical data users are the banks. One bank might have as many as thirty branches in the Manhattan area that must communicate extensively with the central data file. Typically these networks are used to update savings, demand-deposit and installment loan accounts. They are generally polled networks, where the central computer interrogates the terminal at each branch office requesting a response back to the computer. Systems of this type often use medium speed transmission (1.2 - 4.8 kbps).

Another requirement is transmission between the data center and an operations center some miles apart. These systems currently utilize wideband synchronous data transmission with rates from 19.2 - 230.4 kbps. Remote job entry (RJE) sites would fit into this category. Many of these signals are carried in multiplexed form where several lower rate channels are combined into a single high data stream. The same type of service is often required by businesses for control of finances, inventories, shipments, etc. The financial community employs extensive data communications between branch offices and central computer.

Facsimile is another area of broadening interest. With the advent of high speed facsimile machines, letter size documents can be sent in just a few seconds; however, transmission bandwidths as high as 250 khz are required. Many firms have found facsimile transmission desirable over conventional forms of record transmission (TELEX, TWX) due to the convenience of obtaining standard forms rather than handling unwieldy lists of received data and obviating the cost of message preparation and transcription.

GENERAL OVERVIEW

As a Telecommunications analyst with Bankers Trust Company, I have been involved in a joint venture with Manhattan Cable Television for the past year employing their cable system for synchronous transmission at data rates of 50 to 230.4 kbps. Subsequently, I will describe in greater detail our network design and the results of our studies.

The CATV plant in NYC has enormous over-capacity for its basic purpose of distributing entertainment TV to 65,000 subscribers (a business that is only now showing a bottom line trend toward a profit) and Time, Inc. (parent company of Manhattan Cable) has been evaluating supplemental potential revenue-generating uses for the system.

Manhattan Cable Television is franchised to operate in New York City south of 79th Street on the West side and 86th Street on the East side. This area includes some 350,000 dwelling units and encompasses the entire midtown Manhattan business district and the concentrated Wall Street financial community. This represents one of the world's highest concentrations of business and financial offices. In seeking sources of revenue outside of domestic television service, carriage of commercial data became a prime candidate. A good deal of effort has been expended by Manahattan and other interested parties in surveying this market potential. The conclusions have been very encouraging to the point of initiating technical studies, tests, system design and equipment development.

CABLE TELEVISION AS A TRANSMISSION MEDIUM

INTRODUCTION

There are literally thousands of miles of wideband local distribution circuits in the U. S. potentially available to be used for business communications. The network is installed, under constant maintenance and ready for usage. This broadband plant is CATV. While most people think of it as a means of getting the Knicks and Rangers without "ghosts"; to engineers the CATV system is a rudimentary, frequency division multiplex transmission system with potential far exceeding the transmission requirements of 20 channels of entertainment television.

Cable television employs "coaxial cable" as its highway for transmitting signals. Coaxial cable consist of an outer conductor concentric to an inner conductor, separated from each other by insulating material. The outer conductor is called the "shield" and is covered by a plastic insulation.

We can easily consider the half-inch diameter coaxial cable as the equivalent of 30,000 full duplex telephone pairs. This provides a great savings in space, cost and has capability of providing far more transmission than we normally consider as the capability of 30,000 paper insulated copper telephone pairs; copper pairs can carry video signals only short distances.

Although much developmental work is in progress, commercial data transmission on CATV is still in its infancy. Cable is in use as an industrial communications link within some dozen mid-USA industrial complexes. These include plants of General Motors, American Motors, Dow Chemical, and Kellogg Cereals. In these plants, Interactive Systems Inc., of Ann Arbor, Michigan, has installed their Video Data System. This technique employs a bi-directional CATV type system, in-house, to carry multi-channel closed circuit TV, digital data, and voice communications. The present installation handles data rates to 48,000 baud. I repeat again that this particular application is used for in-house services and is <u>not</u> on the general transmission system. At the present time, Bankers Trust Company, New York, has the only operational data network on a general entertainment network.

CABLE OPERATOR'S PERSPECTIVE

The cable systems and equipment designs which evolved over the past two decades concentrated on the wideband carriage of analog TV signals, little else was needed but the ability to carry as many TV signals as possible. In recent years, designs considered bi-directional service for a host of hoped for, "blue sky" interactive consumer services. Amplifiers were improved, cables shielding and installation practices made more consistent.

All of these actions and changes in design make the cable a far more useful conduit for business information than it was a few short years ago.

An important factor to be considered is the degree of the CATV operator's involvement in the sophisticated realm of EDP. Reviewing the applications previously discussed, it can be seen that many phases of data communications are involved. Such terms as Time Division Multiplex, store and forward, etc; are encountered and we find that the modes of transmission are far from uniform. In this regard it was the desire of Manhattan CATV that direct involvement in the details of user's data transmission systems, data formats, etc., be avoided. Standard established interfaces would be used (RS-232 for speed up to 9.6 kbps, 301/303 current interface-19.2 kbps and above).

The use of Time Division Multiplexing has been explored and suggested by some. This would mean that a basic system must be set up in the data channel of interest (this would have to be in some RF channel, or, for the sake of discussion, some television channel). Each terminal in the system would then be assigned a specific time slot and could transmit or receive its data, bit by bit, each time the assigned time slot occurred. There are two major disadvantages of this approach. First the timing of a "tree" type system, such as a CATV system, becomes quite complex. Secondly, the TDM "modem" becomes a rather sophisticated device especially when the timing system must include operation at RF frequencies. It is estimated that a terminal will cost in the order of $2000 in reasonable quantities after development. The TDM approach was seriously considered but was not accepted due to these limitations.

With all these factors in mind it becomes plain that the parameters for successful CATV data transmission are:

1. Provision of point-to-point (not switched) service.
2. Sold and utilized strictly on a bandwidth requirement basis, independent of user's data format.
3. Easy to operate, dependable, and easily maintainable by CATV technicians i.e. FDM analog.

THE OPERATION OF THE CATV DATA NETWORK

The Cable Television network employs Frequency Division Multiplexing (FDM) for the transmission of signals whether they be television, FM radio or data. In this method each signal occupies a different portion of the frequency spectrum. For example television channel 2 operates at a portion of the spectrum surrounding 54-60 Megahertz (MHz - million cycles per second) while channel 13 broadcasts at 210-216 MHz. In so far as television and FM radio broadcast is concerned, we are transmitting <u>to</u> the home consumer in a uni-directional mode.

While using the CATV system for data transmission we must have the capability of full-duplex operation; i.e., transmitting and receiving simultaneously. Previously, this was accomplished by using one coaxial cable for transmitting, and another cable for receiving: each cable is used uni-directionally. The most recent circuit installed at Bankers Trust employed coaxial cable operation in a bi-directional mode.

To study the operation of the data network operation the starting point would be the Data Terminal Equipment (channel equipment). The data stream is encoded using four level Amplitude Modulation. The encoded data is then frequency translated on the "upstream" cable (transmit cable). A sub-low radio frequency (R.F.) in the 5.75-11.75 MHz band is used as the transmit carrier frequency. This upstream signal is sent to the Cable Television "head-end" located at Columbus Circle; here the signal is heterodyned (shifted in frequency) to the 246-252 MHz region. This signal is now impressed on the "downstream" (receive) cable, and down shifted in frequency in the RF section at the other terminal end. The receive signal is next decoded and sent to the data channel equipment.

Hopefully, Figure 1 will clarify the description in the above paragraph.

THE ADVANTAGES OF CATV AS A DATA TRANSMISSION MEDIUM SERVICEABILITY

Inherent in the CATV scheme lies the fact that all signals, whether they be television, radio or data are transmitted on the same coaxial cable. While this might appear as a shortcoming, it in fact adds to the reliability and serviceability of the system.

Manhattan Cable's primary trunk line now runs down 9th Ave., and they are presently installing a redundant cable down Broadway. Monitoring equipment located in the head-end will automatically switch between these two trunk cables in the event of signal degradation; providing complete redundancy on signal paths.

REPAIRABILITY

The restoral time in the event of service outages on the CATV system is generally better than that on the equivalent Telephone Co. circuit. Since all signals on the CATV system are transmitted on just a single coaxial cable, disasters such as a cut cable can be repaired with only one connection. In Telephone cables, on the other hand, as many as two-thousand twisted wire pairs need to be spliced when damage occurs. The inherent ability of a CATV technician to pinpoint network problems quickly and without the customer's intervention, is a marked advantage for the system. The performance of the cable system is inherently better, but the burden falls on the cable operator to maintain it this way.

3. COST

The excellence of the medium allows less terminal equipment complexity for services such as high speed data transmission. Bankers Trust Co. has realized savings of 25-50% over the cost of equivalent Telephone Company wideband channels.

4. FLEXIBILITY

Once again, since all transmissions are sent on one cable; once a building is wired, all new requirements can be accommodated with a minimum of additional cabling.

5. INCREASED THROUGHPUT

There are apparently many misconceptions on the viability of using FDM for data communications, a carry-over from the days of low-speed teletype transmission. The CATV hardware employs a highly effective coding technique and a unique filtering method resulting in a high-performance data highway.

The high signal-to-noise ratio on the CATV network, makes it an inherently clean medium for the transmission of computer data. Tests at Bankers Trust indicate that bit error rates are two orders of magnitude better than can be expected on conventional analog data lines.

A CASE STUDY - BANKERS TRUST CO., NEW YORK

BACKGROUND

Back in 1971, Bankers Trust was plagued by excessive downtime on private voice-grade data lines: they were not providing the highly reliable, error-free performance required for on-line banking applications.

Specifically two 2400 bps conditioned voice grade lines to 1775 Broadway from Wall Street servicing IBM 2848 CRT controllers for BankAmericard credit card authorization were frequently out of service. Participating BankAmericard merchants in the tri-state area of New York, New Jersey and Connecticut were calling the Authorization Center while their customers were waiting. While the lines were down, the cards could not be properly verified: long waits and irate customers ensued.

At the same time the bank was employing a New York Telephone 50 kbps "Wideband Data Line" interfacing to a IBM System/360 Model 20 when operating in a remote job entry mode to the Data Center S/360-65. Experience proved that the 50 kbps line was consistently solid while only 19.2 kbps of the total bandwidth was used for the RJE operation.

A time division multiplexed network was proposed, utilizing the existing 50 kbps wideband line, permitting the multiplexing of both the RJE and authorization applications on the same wideband link. (I might add that the Multiplexing of a wideband Common Carrier line by a user was a pioneering first by Bankers Trust). The network was configured to accommodate not only the two existing CRT controllers and the Model 20 but also another Model 20 and one more CRT system.

It should be noted that the same TDM network is still in use today linked by a 50 kbps CATV channel, backed up by the Telco wideband line, providing reliable service to our users.

MULTIPLEXING WIDEBAND SERVICE

Until recently, almost all TDM networks available to the EDP community were configured to operate over voice-grade private lines with aggregate bit rates of 2400-9600 bps. Such multiplexers have found wide spread use in applications involving low-speed teletypewriter terminals. More and more applications are now appearing where low-speed communications facilities are not able to satisfy user needs. Applications involving RJE line printers designed to run at 300 lines per minute will not operate at desired speeds if the communications channel's throughput is less than 4800 bps.

One of the more important design criteria faced by designers of on-line teleprocessing systems is to make a clear distinction between the volume of traffic to be carried on the data communications links and the response time required by the operators of the various terminal equipment. Much too often, teleprocessing systems have been designed using the historical precedent of teletypewriter networks, which concentrates on the total volume of information to be transmitted over a relatively long period of time. The fact that a single message often takes several minutes to be transmitted; and messages must line up in a queue is of secondary importance. In on-line teleprocessing systems, response time considerations demand a whole new approach to the engineering of communications circuits. Facilities with data rate capabilities significantly higher than teletypewriter speeds are becoming mandatory requisites of these systems. These facilities are attainable by efficiently multiplexing wideband service, readily provided by existing common carriers - and now offered by CATV, at least within the confines of the Manhattan Cable franchise area.

NOTE: Wideband channels are data lines which operate over more than a single voice-grade channel bandwidth within the common carrier facilities. For example, a Type 8801 channel with an aggregate data rate of 50 kbps has the analog equivalent bandwidth of twelve voice-grade channels.

A PILOT VENTURE WITH CATV

In 1973, Time, Inc. (parent company of Manhattan CATV) was conducting interviews with Telecommunications Managers as part of a survey to assess the commercial potential of the transmittal of data over CATV facilities.

With the ambitious forward planning in progress at Bankers Trust concerning on-line branching and point-of-sale terminals in retail locations; Stevens H. Harrison -V.P., Telecommunications viewed CATV as a possible significant alternative to Telephone Company circuits for a widely deployed intracity point-of-sale network: provided CATV's projected performance, pricing and marketing claims proved true.

The talks that ensued led to a joint pilot venture wherein Bankers Trust would parallel their existing 50 kbps Telephone Co. wideband links between 1775 Broadway and the Wall Street Data Center with a Manhattan CATV data channel. The Bank would offer 'live' data and their existing multiplex channel equipment, while CATV would develop the necessary interface devices and arrange to pull cable to both sites.

In April, 1974 the CATV 'modem' equipment had been designed and built. It had been 'cooking' in the E-COM laboratories (consultants to CATV) with success for months. Now was the time for the real test.

Two 50 kpbs CATV channels were to parallel existing telephone wideband channels, to be driven by Computer Transmission Corporation (TRAN) multiplex equipment. To be quite honest, the CATV Data Interface was somewhat clumsy looking -- it housed the data encoder/decoder; the R. F. Transmitter/ receiver, and the front panel had large 'bat-handled' manual switches permitting the multiplexer to run on either CATV or Telco.

The CATV channel interface equipment was installed on Saturday April 6, 1974. It was an instant success. Our first and only failure during a test period of four months (to August) occurred just four days after installation - a line amplifier lost power near City Hall. The trouble was reported at 9:45 A.M.; cleared at 11:00 A.M. - time to repair just a little over one hour. For our twelve hour day, six-day a week operation we had an uptime factor of 99.9%!

Using a test device capable of transmitting and detecting a pseudo-random data bit pattern we observed one bit error in 100 million bits transmitted (10^{-8}). We did have periods where zero errors were detected in a 36 hour period.

'MOVING' A DATA CENTER

During the Summer of 1974, Bankers Trust moved its downtown operations center from the 16 Wall Street location to it's just completed building, 1 Bankers Trust Plaza. A multi-million dollar Data Center was established at the Plaza site paralleling the existing location. All applications had to be fully tested with the new equipment before the final "switch" was thrown.

Two high-speed (230.4 kbps) CATV channels and two Telephone Co. wideband links mutually backing up each other were established between the existing and the new data center. By use of a TRAN custom designed switching array, applications could run from the old site during the day and be switched to the new system at night for testing.

The CATV channels were private, point-to-point cables driven by INTERTRAN line drivers. The channel equipment used was TRAN Multiplexers providing synchronous channels of 19.2, 9.6,4.8 and 2.4 kbps.

It is difficult to relate in a paragraph or two the intense involvement of all parties concerned in making this move go. The bottom line -- the data center was established at the new location one month ahead of schedule! These CATV links are still in use today supporting applications located at 16 Wall Street. There has not been a single outage on these CATV facilities in over a full year of operation!

FURTHER SYSTEM REFINEMENTS

Now that the move to the new Data Center was complete it was time to reterminate the data links from 1775 Broadway (which at the time were going to the now non-existent 16 Wall Street

Data Center) to the Bankers Trust Plaza Operations Center.

A CATV data channel paralleled by a Telephone Co. Wideband link was established to the new data center. The CATV channel equipment was now beginning to look like a commercial offering; it was rack-mounted, with a plexiglass cover.

One of the shortcomings with the original network was the manual switching required between CATV and Telco, in the event of a facility outage (we did not normally staff our 1775 Broadway location). For this new link we requested a remote switching arrangement which would permit the switching of the multiplex channel equipment to either CATV or Telco from either terminal location. Figure 2 depicts the existing network configuration between our Data Center and our 1775 Broadway operations center.

This equipment was installed in November, 1974 and as of this writing (late - April, 1975 we have had two CATV outages, total downtime was six hours, for a 99.6% performance record. I might add at this point, that with the remote switching capability, downtime to our users in this period was measured in minutes.

The latest CATV data 'modem' housing the data encoder/decoder, and the necessary RF equipment fits in a standard 19" rack, and measures just 5" high. Quite a change from the original 'basement special .

CONCLUSIONS

While the specific data transmission services discussed in this paper are presently offered only in the confines of lower Manhattan, it is encouraging to note that these services can be profitably offered in much smaller urban (and even suburban) communities. The decision to employ Frequency Division Multiplexing with its low up-front costs makes it feasible for a small cable company to install one or two circuits profitably since no expensive computer system is required.

INTERCONNECTION - THE SPECIALIZED COMMON CARRIERS

Within the last few years (as a result of the landmark Carterfone case - 1969) there has been a birth of a new telecommunications industry - the Specialized Common Carriers (SCC's). These carriers, regulated by the FCC, offer private line voice/data service, primarily between large urban areas. While the marketing impetus for these vendors has primarily been for voice applications, it is interesting to note that a cable system can quite easily interface to these analog circuits.

SCC's provide interstate microwave radio channels between central city locations. It is now necessary to connect the microwave radios located in some tall building (say the Empire State) with the customer's location, say Wall Street. This portion of the circuit, while only a small fraction of the overall circuit mileage, comprises the Telecommunications manager's nightmare, the infamous "local loop"; it is this section of the circuit that tends to cause a majority of the recorded outages. Presently the Bell System usually provides these local loops for the SCC's probably at an economic loss, because of the amount of maintenance required. There are presently many requests for increased tariffs for these loops by Bell System operating companies across the coutry.

While it would probably be uneconomic for a CATV company to provide a single loop between microwave hub and customer, it would seem quite possible and plausible for a Cable System to provide loops for multi-channel customers or those with broadband requirements. An example of this could be local interconnection of a television broadcast studio for nationwide transmission.

The future of Cable Television in this area depends not on the ability of the system to handle this requirement, but on the future demand of the SCC's for local distribution facilities independent of the Telephone Company.

POINT-OF SALE APPLICATIONS

The introduction of point-of-sale terminals at merchant locations and the growth of branch bank automation within the last few years present an interesting application for the cable system.

These networks typically operate in a polled environment wherein the central-site computer sequentially interrogates the terminals/branches eliciting responses. The FDM approach employed suits these requirements ideally, since these locations can be assigned to a single data channel. The terminal devices would be equipped with the necessary control circuits to raise a "Request-to-send" when a transmission is desired.

Typical credit-card verification systems employ leased voice-grade circuits configured in a multi-drop configuration, using polled operation through audio tones. These terminals with their built-in modems could economically operate via "voice-grade" cable links.

The fact that Manhattan Cable's data service is sold on a "no mileage" basis and with minimal additional charges for multi-drops make it a viable alternate to the telephone network for POS applications.

SUMMARY

In recent years, there has been considerable speculation concerning the viability of CATV systems, designed to transmit television programming, in the transmission of computer data.

The CATV network, it turns out, because of the innate cleanness of the medium, the ample bandwidth and low incremental costs, its reliability and ease of repair is ideal for this purpose.

The joint Bankers Trust-Manhattan Cable pilot effort is the country's first successful, large-scale application of this technology and the implications are significant. It has now been proven feasible to communicate between intracity locations at data transmission speeds that have not been economically practical in the past.

It is also safe to say that the growth of data communication requirements will provide a real need for a more reliable local distribution system complementing the Specialized Common Carrier's interstate network.

The next few years will tell.

BIBLIOGRAPHY

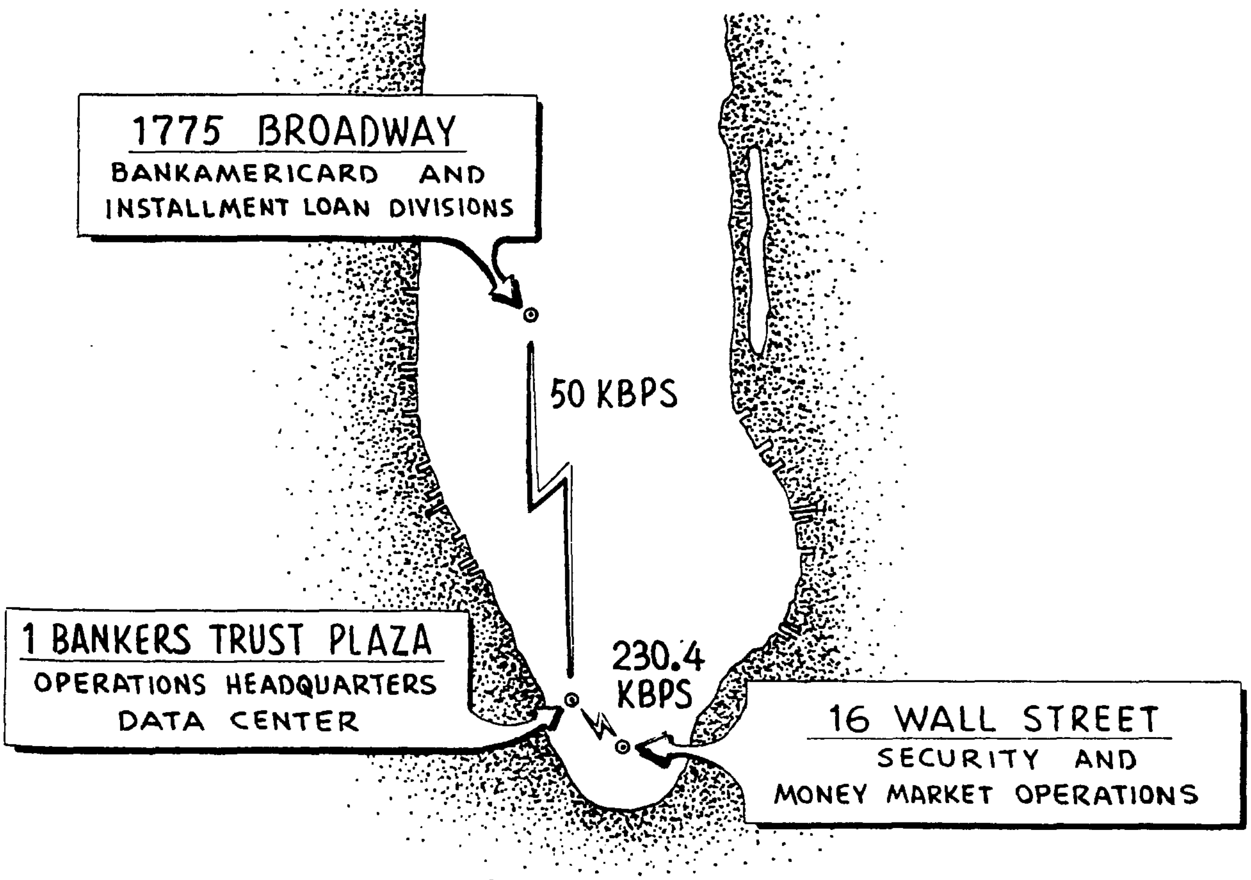
Dickinson, Robert V.C. "Commercial Data Communications Over a Cable Television System": a paper presented to the National Cable Television Association, June, 1973.

Dickinson, Robert V.C. "Manhattan's Data-by-Cable: A Business Reality": a paper presented to the National Cable Television Association, April, 1975.

Martin, James. Systems Analysis for Data Transmission. Englewood Cliffs, N.J.: 1972.

Stern, Joseph L. "Business Data on CATV Possible with Wideband Analog Cable Systems." Communications News, January, 1975, pp. 30-31.

BANKERS TRUST COMPANY TELECOMMUNICATIONS NETWORK



COMMUNICATION SATELLITE AND CABLE TV

ROMAN ZAPUTOWITZ and BERNARD MIROWSKI

WESTERN UNION

Of approximately 3000 cable TV systems, approximately 2/3 have 1000 or fewer subscribers. Many of these have looked forward to taking advantage of distributed cost of high quality programming by using the wide area broadcast capability of communication satellites in conjunction with low cost receive only stations and redistribution networks. Regulatory requirements, state of art hardware, spectrum availability, and in-place and planned space segments seem to forestall this hope. This paper explores the more significant system and economic considerations affecting the use of the space segment as it relates to satellite video and the associated redistribution networks.

Satellite communication systems became a reality in the last few years, when synchronous satellite technology became perfected. The most known and currently operational are ATS-6, INTELSAT's, ANIK, SATCOM and Western Union's WESTAR I and II; others are soon to follow.

In general all these geostationary satellites are capable of handling voice and data telephony, digital data and, primarily of interest to this audience, video and program material.

The quality of transmission is superior to that achieved by terrestrial systems. The overall reliability is at 99.95% (i.e., 43.2 seconds non-availability) and in practice achieves 100% on a short term (24 hour) basis.

In view of the above, communication satellites suddenly became not only the most desired means for point-to-point transmission of intelligence but also for simultaneous wide area Television and Broadcast program distribution.

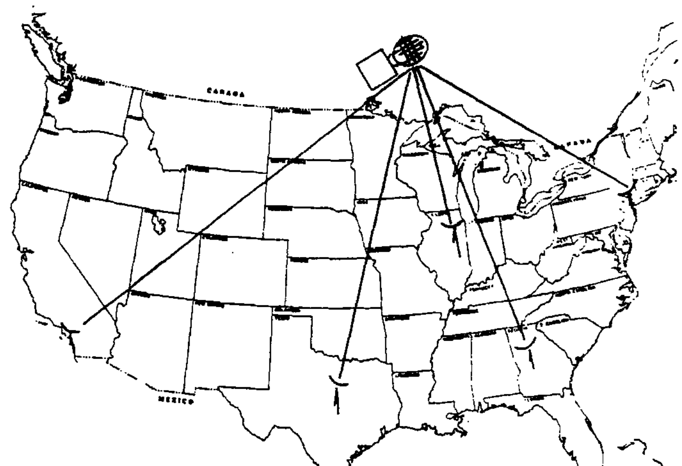


FIGURE 1
U.S. COVERAGE FROM
GEOSTATIONARY ORBIT

This feature suggests that a number of suitable ground stations can be built for local rebroadcast purposes and, using satellite characteristic performance parameters, can be sized for a maximized economy in an envisioned application.

Presently the transmission is at 4/6 GHz (C-Band) and the trend is to shift to 12/14 GHz (Ku-Band) for the next, advanced technology, generation of communication satellites of 1980's.

This paper presents the technical background and establishes the rationale for this trend.

As a starting point one must be intimately familiar with parameters such as effective isotropically radiated power (EIRP), transmission frequency, location in orbit, polarization of the beam and useful bandwidth per transponder.

An overview of this type information is shown in Table I.

TABLE I

ITEM	INTELSAT IV	ANIK	SATCOM	ATS-6	WESTAR I & II
Launch Data	1969	1972	1975	1974	1974
No. of X-ponders	12	12	24	3	12
TWT Output W	5	5	4	10	5
X-ponder BW, MHz	36	34	34	30	36
Uplink Freq. GHz nom.	6	6	6	6	6
Downlink Freq. GHz	4	4	4	4	4
Avg. EIRP dBw	36	36	32	28	34
Design Life, yrs	7	10	8	6	10

As if was mentioned in the outset, the EIRP is one of the most important parameters for ground system planning and design. With this information the effective received power can be calculated and the balance of the receiving system designed. Typically this information is provided in a form of a footprint map.

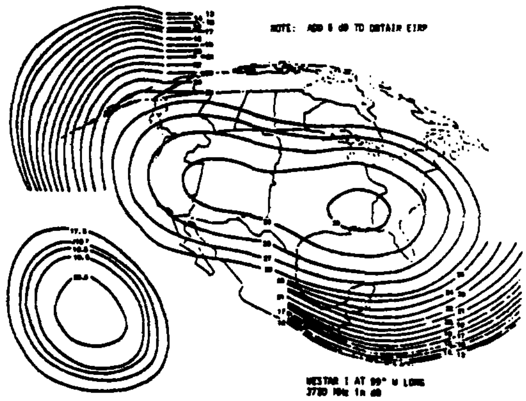
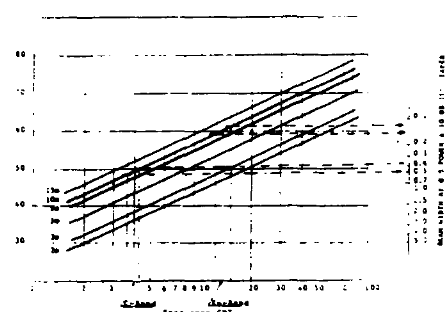


FIGURE 2
ANTENNA GAIN CONTOUR COVERAGE

Using the EIRP and frequency data the received signal power can be calculated. At the WESTAR receive frequency from the synchronous altitude, or 22,300 miles, the free space attenuation is in the order of 200 dB which relates to a ratio of 10^{20}. The handling of such a weak signal requires very careful consideration of the receiving antenna size and the quality of the receiving electronics, specifically that of the preamplifier.

The receiving antenna, if it is relatively large, can provide substantial gain to the signal strength prior to any kind of electronic amplification as depicted with curves in Figure 3.

FIGURE 3
THEORETICAL ANTENNA GAIN
55% EFFICIENCY



Another effect of operating frequency and antenna diameter is pointing beamwidth. This phenomenon is important for reception of the desired satellite from a group that is operating on the same frequency.

The gain obtainable from an antenna is a function of the operating frequency and diameter. The gain increases with an increase of the operating frequency and antenna diameter. At the same time the beam becomes progressively finer, thus improving discrimination between slosely spaced satellites operating on the same frequency but with different programs.

For maximized utilization of a transmit/receive spectrum that is the same for all satellites, it becomes necessary to place angular beam limits on both the satellite and ground station antennas which ultimately tends to drive the cost of the ground segment upward.

In addition to the two properties mentioned (gain and pointing beamwidth), reception of interferring ground based/generated signals is reduced with an increase of antenna diameter. This fact is of paramount importance in frequency coordination tradeoffs and is the reason for a general reluctance on the part of FCC to agree on antenna diameters less than 10 meters operating in the present 4-6 GHz band (C-Band).

The antenna for reception and transmission discussed above is a parabolic dish. Other antenna types are also available. One type that offers some advantages is a horn, shown in Figure 4.

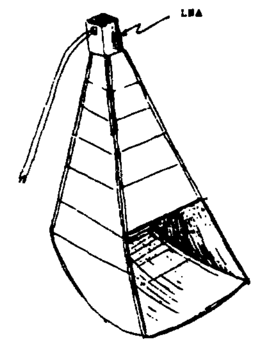


FIGURE 4
INVERTED HORN ANTENNA

The gain of a horn antenna is slightly higher than for a parabolic type of comparable inlet/acquisition area. This advantage can be as high as 6 dB. An improvement in terms of pointing accuracy, i.e. beam size and sidelobe reduction is also achieved. However, this antenna may not be practical for large aperture requirements. This type of an antenna is normally used upside down, as shown in the figure, or on roof-top installations.

Another factor in system design considerations is the noise level picked up by the antenna and contributed by the input stages of the receiving electronics, specifically preamplifiers. The noise levels are additive and determine the total system noise figure.

High gain antennas have an almost negligible amount of noise, i.e., about 0.6 dB. Input amplifiers, however, can be big offenders depending upon the type and quality used. The quality of a preamplifier is usually governed by the total permissible cost of the system in which it is used and the required gain-temperature ratio, and thus is subject to a cost tradeoff between antenna size and preamplifier noise figure.

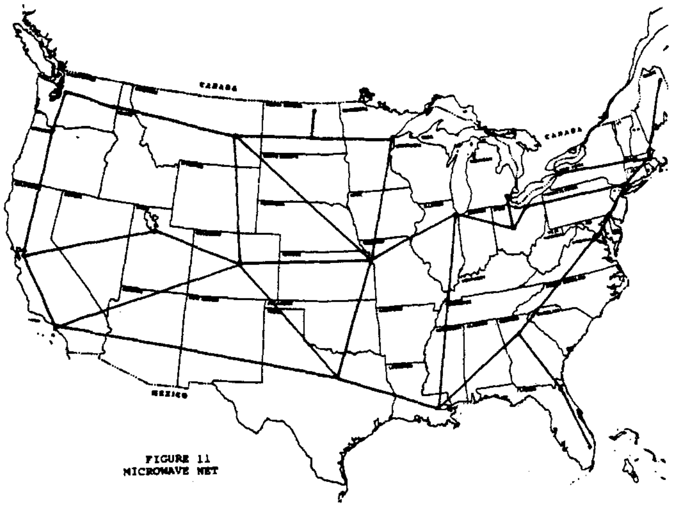


FIGURE 11
MICROWAVE NET

The reliability of such a system is good but is achieved only at a great expense in equipment redundancies, around-the-clock manning of T/R stations and other similar expedients. Due to these facts, operating costs are high.

This largely antiquated approach, dating back to the onset of transcontinental telephone networks, will gradually be replaced by the dedicated common carrier and privately owned, ground stations. Ground stations will serve an immediate area around its location with short microwave links as shown in Figure 12.

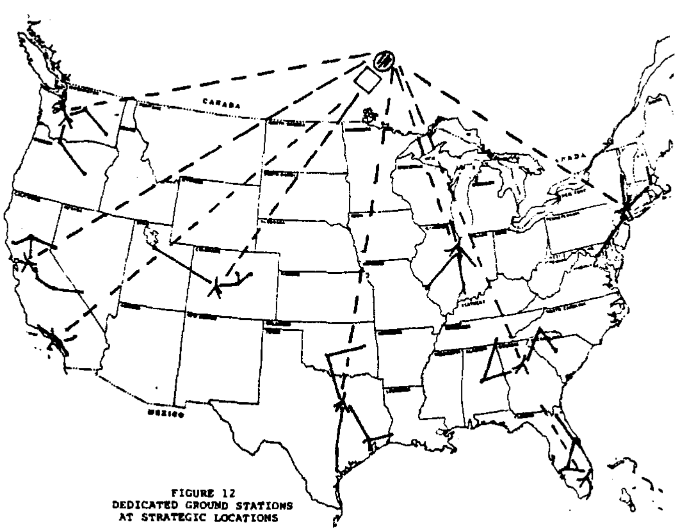


FIGURE 12
DEDICATED GROUND STATIONS
AT STRATEGIC LOCATIONS

Program material will be simultaneously available to the whole area of a country. A choice of program will be possible by dedicated multiple transponder assignments in the satellite and reception by frequency agile receivers in the ground station.

Transmit/Receive mobile ground stations in the 12/14 GHz freqency band will require no more than a collapsible installation on top of a van-truck with all the necessary electronics and support gear inside.

Both C-Band and Ku-Band space segments will be available in the 1980 decade. Some prognosticators predict the Ku-Band space segment will predominate in commercial transmission facilities in the late 1980's and the 1990's. However, the commitment to Ku-Band in terms of capital is not clear at this point in time. The demand for spectrum and orbital slots will be the pacing factor in this transition. Technology breakthroughs such as in fibre optics with significant cost reduction impact in terrestrial communication, could affect the transition to Ku-Band, but most likely to a minor degree in this century.

With reference to receive station costs in C-Band, for quantities exceeding 10, estimates tend to indicate a $60,000-$70,000 installed cost for non-redundant, one video channel, receive only station with an FCC compliant 8 meter antenna.

A C-Band receive only radio program station (10' antenna) for 2 channels of 8 KHz radio can probably be installed in quantities of 100 or more at costs of less than $10,000 per station, but with some risk of interference from ground and adjacent satellite transmissions.

C-Band transponder lease costs have moved downward from $3.5 million/year to under one million per year with unprotected service. Modulation equipment for transmitting two video channels in one transponder is becoming a reality.

With reference to Ku-Band, studies performed in the early 1970's indicate potential for video receive only stations that will cost under $1000 for quantities in the thousands.

Today, the cost requirement for receive only stations by the 2000 cable TV enterprises with 1000 or less subscribers each, may not be tolerable in the C-Band domain. However, with the acceptance of reduction of S/N from 55 dB to approximately 49 dB, with technology advances in front end electronics, favorable rulings by the FCC, and some implied risk with smaller antenna size, costs can come down to acceptable levels within a time frame well preceding development of adequate capacity and low cost hardware for the Ku-Band.

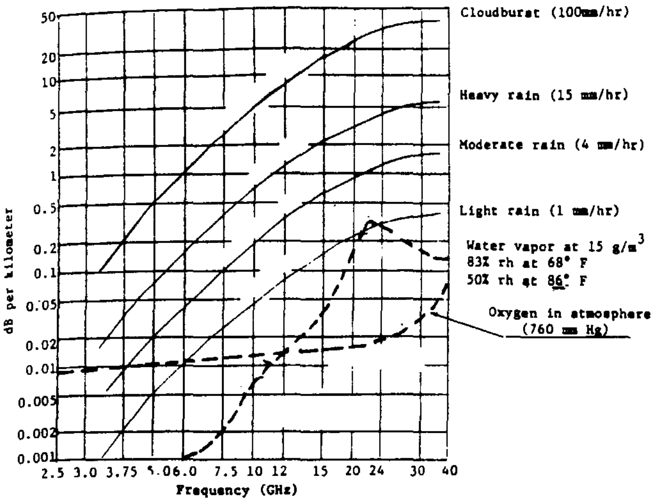


FIGURE 8
ESTIMATED ATMOSPHERIC ABSORPTION

Considering the ATS-6 frequency as 2.5 GHz, present day communication satellites at 5 GHz, as a median, and nominally 13 GHz for the future, one can see rather disturbing effects. Up to about 6 GHz the attenuation effects due to moisture and rain are negligible. In the Ku-Band planned for future communication satellites, this effect becomes an appreciable factor in overall system performance. This causes signal strength fluctuations as atmospheric conditions change.

The mechanism of this effect lies in the fact that the radio energy is absorbed and scattered by the raindrops. It becomes more pronounced as the wavelength approaches the size of the raindrops.

From this illustration, it appears that 15 GHz is the upper limit in selection of communications frequency over a long distance, such as it is found in deep space communications from synchronous satellites. However, advanced system designs for specialized applications beyond the oxygen molecular resonance frequency (approximately 23 GHz) are currently being planned. These systems will probably be out of cost range for commercial users in this century.

Summarizing technical and regulatory considerations, one can see that the general trend in satellite communications is toward the upper end of RF spectrum, i.e. 12/14 GHz, Ku-Band, and not toward S-Band. The summary of impact of reduced size antennas at C-Band and at Ku-Band is characterized in Figures 9 and 10.

C-BAND SMALL ANTENNA CONSIDERATIONS

- DECREASED DIRECTIVITY
- MORE SUSCEPTIBLE TO EXTERNAL NOISE
- LENGTHENED SUN OUTAGE TIME
- FCC COORDINATION DIFFICULT
- LIMITED UPLINK POWER
- UNINTENTIONAL INTERFERENCE WITH ADJACENT SATELLITES

HOWEVER

- WITH RISK TO USER - LOW COST RECEIVE ONLY STATIONS FEASIBLE
- TRANSMIT PORTABILITY REALIZABLE

Fig. 9

KU-BAND SMALL ANTENNA CONSIDERATIONS

- RECEIVE STATION CAN BE LOCATED AT USER SITE (ELIMINATED TERRESTRIAL FEED COSTS)
- MORE EXPENSIVE LOW NOISE AMPLIFIER
- SMALLER INTERFERRENCE DUE TO EXTERNAL NOISE SOURCES
- FCC COORDINATION FOR EQUIVALENT ANTENNA PERFORMANCE PARAMETERS IS LESS DIFFICULT THAN THAT IN C-BAND
- FCC DOES NOT CURRENTLY HAVE DOWNLINK POWER DENSITY LIMIT
- A 3 METER ANTENNA AT KU-BAND IS EQUIVALENT IN PERFORMANCE TO A 10 METER UNIT AT C-BAND
- PORTABILITY OF A KU-BAND ANTENNA AND ITS COST PERMIT BUILDING OF MOBILE GROUND STATIONS FOR SPOT COVERAGES

Fig. 10

The move to Ku-Band will result in significant cost reduction of antenna installation, support structure, an improved mobility (transportable, on the spot transmit/receive ground stations), elimination of terrestrial microwave feed systems, cheaper de-icing equipment or a possibility of housing in a bubble enclosure (radome), just to name a few.

Disadvantages can also be found: an increased cost of low noise preamplifiers, more susceptibility to antenna reflector inaccuracies, more critical system frequency stabilization and alignment and increased RF path attenuation (about 216 vs. 196 dB). However, in general, the advantages appear to outweigh the disadvantages. Also, the impact will diminish in view of the rapidly improving equipment design technology especially in the area of front end receive systems. Thus one can expect a significant system cost decrease by the start of the next decade, i.e. in the early 1980's.

An additional advantage in the use of Ku-Band is the lack of radiated power limitation toward the earth. This will partially counteract increased path attenuation and will minimize terrestrial antenna size increase.

System Economics

The subject of space communications would not be complete without a brief discussion of the system economics. A typical microwave net serving TV and Program distribution (Figure 11) constitutes a maze of point-to-point repeaters with individual drop-off points as required.

Typical preamplifier and antenna performance is shown in Figure 5 by type and as a function of operating frequency.

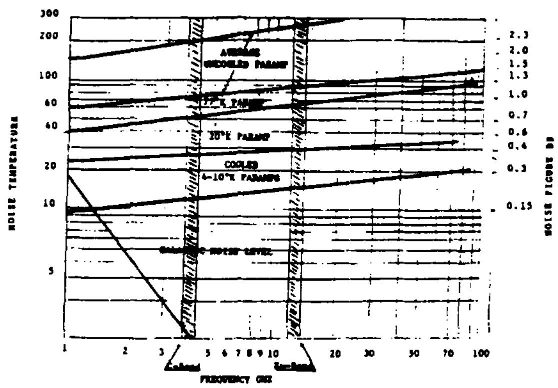


FIGURE 5
ANTENNA NOISE TEMPERATURE

The performance of both antenna and preamplifier is most conveniently characterized by the Gain/Temperature figure of merit.

The cost tradeoffs of antenna performance vs. preamplifier performance are shown in Figures 6 and 7.

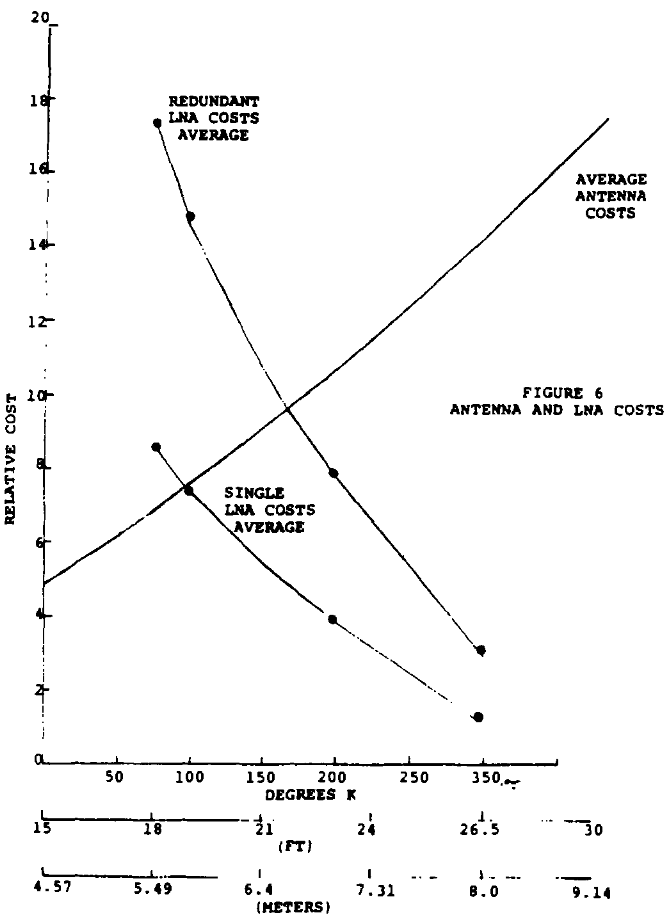


FIGURE 6
ANTENNA AND LNA COSTS

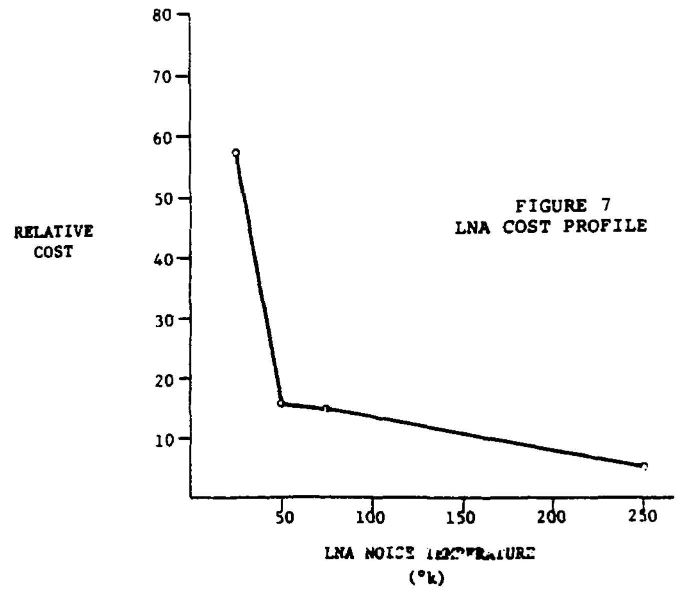


FIGURE 7
LNA COST PROFILE

It is evident from these figures, there is a crossover point which lies at the theoretical optimal point for a given system. These graphs were prepared for the 4-6 GHz band. Similar curves can be drawn for the future 12/14 GHz frequencies.

In general as frequency decreases the cost of antenna system with a given performance as a parameter will increase although not as drastically. The cost of preamplifiers, on the other hand, will drop significantly with frequency decrease but will rise sharply for frequency increase. From these considerations, another set of tradeoffs can be obtained and a conclusion drawn that ground stations for 2 GHz (i.e. S-Band) operations are less expensive than those of 5 GHz (i.e. C-Band). The opposite can also be said of ground stations for 12 GHz (i.e. Ku-Band). However, actual costs must be calculated through an exact system analysis. At times such an analysis can lead to very unexpected and at the first glance not obvious results, and it must be remembered that the performance of the satellite in a given frequency spectrum can move costs up or down by setting the required gain/noise parameter for the ground segment. This in turn specifies carrier to system noise ratio which further results in the signal to noise ratio in the video. There is room for compromise in that the EIA 55 dB S/N versus 45 dB can hardly be discerned in mass-produced home TV receivers.

The selection of satellite operating frequency was approached from the point of view of equipment costs. But another factor that enters into overall consideration is the increased attenuation of transmitted signal with an increase in transmission frequency. This effect is illustrated in Figure 8.

COMMUNICATIONS APPLICATIONS OF FIBER OPTICS

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Low loss optical fibers are the basis of a new communications technology which is just emerging. Field trials of data links incorporating optical fibers are underway. For maximum efficiency and economy a communication system must be specifically designed to take advantage of the properties of optical fibers.

Data transmission over optical fibers is a rapidly developing new technology. Over the past few years a wide variety of components has been developed for application to fiber optics communication systems. These components were first assembled into laboratory demonstration communication systems links. Now field demonstration links are being deployed to evaluate the potential of this new technology under actual operating conditions.

In the United States ATT and GTE have both announced field trials for PCM telephone communication links. The Navy is placing an optical fiber link aboard an A-7 aircraft in the aloft program. There is an optical fiber telephone communications link aboard the USS Little Rock, and a CCTV system aboard the USS Kitty Hawk.

These demonstration systems by no means define the limits of interest in this technology. The Army and the Air Force both have programs to develop fiber optics communications for their particular needs. Several companies have made studies of the feasibility of applying fiber optics to CATV systems.

Optical fibers first attracted attention as a transmission medium because of their low loss and wide bandwidth. It was realized that their small size, low weight, and dielectric properties were also advantages. They are immune to RFI/EMI and EMP. Further advantages are the absence of grounding, cross talk, and short circuit problems. Probably their greatest disadvantage is that they represent a new technology. New components and systems must be developed in order to exploit the advantages. The personnel that will deploy and maintain the new systems must receive new training. An additional disadvantage at present is their high cost. However, estimates have been made that project drastic price reductions in large volume production.

Low loss and wide bandwidth do not directly translate into system parameters. For instance, electronics allow trade-offs between bandwidth, loss, and repeater spacing. A comparison between this new technology and present technology can only be made if systems designed for the same application are compared. If optical fibers are used in PCM telephone links, greater repeater spacing can be achieved and more channels transmitted through the same underground ducts than with coaxial cable or twisted pair.

If optical fiber data links are used aboard aircraft, size and weight reductions are achieved. The weight penalty costs for high performance aircraft is in excess of $1000 per pound over the life cycle of the aircraft. In part, the gain is achieved by reduction of the size and weight of the cable, and in part by the elimination of protective devices installed on coaxial and twisted pair transmission lines to reduce EMP and EMC problems.

Optical fiber technology will find widespread application outside of the telephone industry and DoD. The advantages that accrue to these users by employing optical fibers are sufficient to justify the large investment necessary to bring this new technology to fruition. Once the initial development is completed, component pricing is expected to follow the traditional trends of the semiconductor industry. It is at that time that the technology will be open to exploitation by such cost conscious industries as CATV.

When optical fibers are first considered for an application such as CATV, the initial approach is usually a simple retrofit. Often such projects are far from a complete success. The architecture of present systems is strongly influenced by the properties of coaxial cable and twisted pair transmission at VHF. These properties are significantly different from optical fiber transmission of optical energy.

One of the most significant differences is that $h\nu$ is six orders of magnitude larger in the optical region than in the VHF region of the spectrum. This does not indicate that the dynamic range is 60 dB lower for optical systems compared with VHF systems, the minimum detectable signal of a VHF system is usually determined by cross talk, EMC, and noise sources such as cars and lighting.

System dynamic range is also determined by the available source power. LED and laser optical sources have power outputs of the order of a few milliwatts. In contrast, the output power of VHF CATV repeaters can be a few tens of milliwatts. The dynamic range for an optical system with a bandwidth of 3.5 MHz, an avalanche photodiode detector, and a laser diode source is 80 dB.

The bandwidth of optical fibers is a strong function of their construction. Single mode optical fibers have bandwidths on the order of ten GHz/km, graded index fibers one GHz/km, and step index fibers 30 MHz/km. Since the dynamic range of optical systems is restricted, they are seldom designed to have significant signal energy above the upper 3 dB frequency of the transmission channel. This precaution reduces equalization to a minimum. The losses of all three fiber types are essentially identical. Ten dB/km fibers are readily available today and two dB/km fibers have been demonstrated in the laboratory. There is excess loss when a fiber is incorporated into a cable, but this loss is held below one dB/km in good quality cables.

The two most promising sources for the transmitter are the light emitting diode and the laser diode. Both can be tuned to the windows in the fibers by materials selection. In each case the source selected has an influence on system architecture through its particular physical properties. The candidates for the receiver optical detector are the PIN and the avalanche photodiode. The latter contributes internal gain and hence greater receiver sensitivity at the expense of greater receiver circuit complexity.

A video signal can be transmitted over the optical fiber by AM, FM, pulse code and pulse position modulation techniques. Amplitude modulation can be implemented with the least complex receiver and transmitter electronics. However, the large dynamic range necessary for faithful picture reproduction leaves little margin for coupling and transmission losses. If only one AM video signal is transmitted over the fiber, no advantage can be taken of the large bandwidth of the fiber compared with the relatively narrow bandwidth of a video signal.

In contrast to AM, pulse code modulation requires a small signal margin at the receiver at the expense of a bandwidth in the neighborhood of 100 MHz for a single video channel. With the proper selection of components a high quality video signal could be transmitted over six miles of fiber without a repeater. Pulse code modulation requires even greater bandwidth, but greatly reduces the complexity of the electronics. Frequency modulation allows a trade-off between bandwidth and dynamic range with relatively simple electronics.

If greatest economy is to be achieved, the application of fiber optics to trunk and end distribution will require the use of different modulation formats for each application. For the trunk transmission the number of repeaters is minimized if pulse code modulation is used. The short paths in the distribution net can be adequately implemented using AM or FM with a minimum of circuit complexity at the receivers.

For most economical use of the fibers, the architecture of the distribution net will also be different from present systems. While taps on an optical system are possible in most systems, optical scramblers used in association with parallel distribution are more economical. Color multiplexing can be used to increase capacity over a single fiber.

COMPUTER-AIDED ANALYSIS OF COAXIAL CABLE ATTENUATION AS A FUNCTION OF FREQUENCY AND TEMPERATURE

Jacob Shekel and Eric Winston

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ABSTRACT

A thorough understanding of cable attenuation as a function of frequency and temperature is of prime importance to the user, as well as the manufacturer, of the cable. This paper describes measurements of attenuation conducted in an automated, computer-controlled test facility, suggests different ways to present the data, and describes the analysis of the data by computer-aided mathematical techniques.

The analysis exposes the differences in the temperature behavior of different cables, and shows how to design an optimum equalization scheme (with fixed and thermal equalizers) for any particular type of cable. The results also indicate that the widely accepted analysis of approximating the frequency response by $\sqrt{f}$ and f terms, is not always the correct way to separate the dielectric losses from the conductor losses.

1.0 INTRODUCTION

Anyone who attempts to design a CATV system must have a thorough knowledge of the properties of coaxial cable. Most of the equipment that makes up the trunk and distribution lines is there only to compensate for the attenuation of the cable. It is therefore important to know, in full detail, how cable attenuation depends on various parameters, such as frequency and temperature.

Even if we restrict the analysis to variation with frequency and temperature, we are faced with a quite complex function of 2 variables. We have to consider 3 aspects of the problem:

1. How to get enough measured data to represent the function;

2. How to digest and present the data in a form that will lend itself to analysis and interpretation;

3. How to use the data in the design of a system.

In this paper we shall report on work done related to these aspects of studying the attenuation of coaxial cables.

2.0 DESCRIPTION OF MEASUREMENT PROCEDURE

The attenuation of the cables was measured by an automated sweep test facility, controlled by a NOVA 1200 minicomputer. A suitable sweep generator, modified for digital control of frequency, was used as the primary signal source. The local oscillator of the receiver was another sweep generator at a fixed frequency difference, which allowed using a very narrow band IF amplifier for noise reduction and increased dynamic range. The final measurement of signal level was done by means of a Pacific Measurements Model 1036 (a logarithmic RF power meter, $\pm$0.02 dB accuracy). The results of the measurements were tabulated, stored in the minicomputer for further processing, or punched out on paper tape. The tape was used to transfer the data to a teletype terminal for analysis by various programs on GE Time-Sharing Mark III service.

Cables were furnished on reels (with the exception of one inch O.D."Spirafil", received as a coil of 6 ft. diameter). After initial mechanical testing, and measurements of impedance, return loss, and attenuation at 70^{o}F, each reel was placed in a large environmental-control van(which is normally used for system evaluation). The van temperature was successively stabilized at -40, -20, 0, 35, 70, 100, 120 and 140^{o}F, and the attenuation of the cable measured at each of these temperatures. Before each measurement, the cable would dwell at the nominal temperature (within $\pm 5^{o}$F) for not less than 4 hours; total cycle for the measurements was 96 hours.

3.0 PRESENTATION OF DATA

Cable attenuation data are of particular reportorial interest, since there are so many methods of presentation, depending on the specific technical interest to be served. Cable manufacturers may concentrate on dielectric material control; equipment suppliers may want to know how closely their various thermatic equalizers compensate a given cable; the system operator or designer focusses on changes in attenuation along the cable plant, and the consequent effects on subscriber set signal levels, signal distortion etc.

The problem is, basically, how best to present a function of 2 variables on a two-dimensional sheet of paper. This is usually done by a set of curves, with one variable plotted along the horizontal axis, and the other variable as a parameter defining the different curves in the set. We therefore have the choice of presenting dB vs. frequency for different temperatures, or dB vs. temperature for different frequencies.

4.0 ATTENUATION VERSUS FREQUENCY

This method of presentation, which is directly related to the frequency response of the cable system and its components, is the traditional method. Fig. 1 shows the measurements on 3 different types of cable, plotted for 3 temperatures. The horizontal axis is conventionally drawn proportional to $\sqrt{f}$, resulting in less curvature of the plots (theoretically, a cable with no dielectric losses would be represented by a straight line in this presentation). For comparison, the measurements on each cable were normalized to a loss of 20 dB at 300 MHz and 70°F.

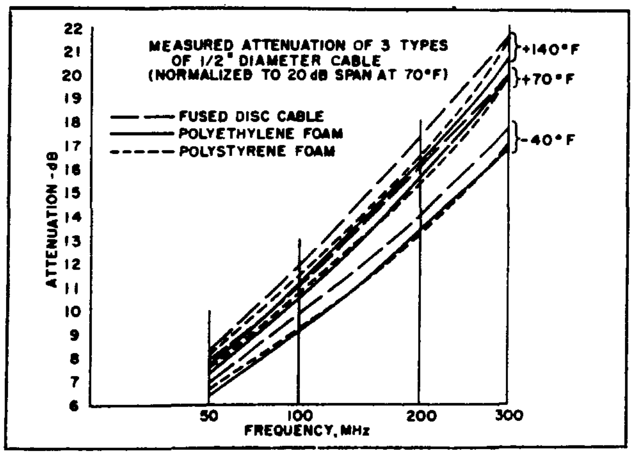


Fig. 1

Even from this simple presentation, it is obvious that the cables do not behave in a similar manner when temperature or frequency is changed. But the different curves are all jumbled together, and it is not easy to find the difference (similarity) between different cables.

A presentation as in Figs. 2-4, where the attenuation at any temperature is plotted relative to the attenuation at 70°F, makes it much easier to study the effects of temperature. The resulting curves indicate the thermal compensation needed such as thermal equalizers, ALC, ASC. Fig 2 shows the attenuation of three different 1/2"polystyrene dielectric cables, for which the attenuation of a span (20 dB) at 300 MHz will increase by 1.4 dB at +140°F, and decrease by 2.8 dB at -40°F. Fig.3 shows the same data for four cables with gas injected polyethylene foam dielectric; note the comparative similarity in low temperature performance, but the disparity at high temperatures. Still more striking are the data in Fig.4, showing fused-disc and "Spirafil" cables; the latter shows 3.5 dB increase at -40°F, compared with 2.5 dB for polyethylene foam. Clearly a thermal device optimized for one of these cables will be inadequate for the other.

This type of presentation could readily be utilized as a generic cable specification for system design, pre-assigning attenuation limits for given temperature extremes.

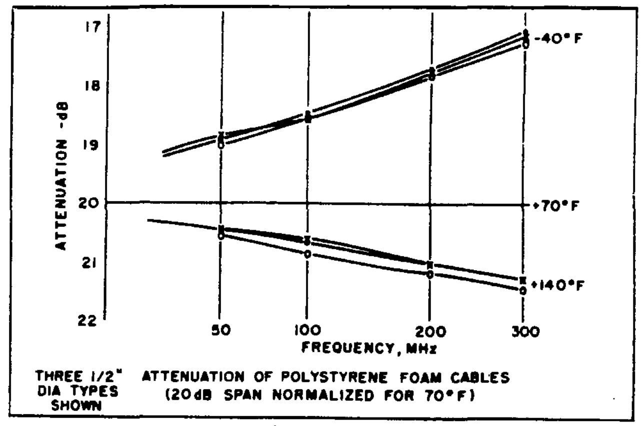


Fig. 2

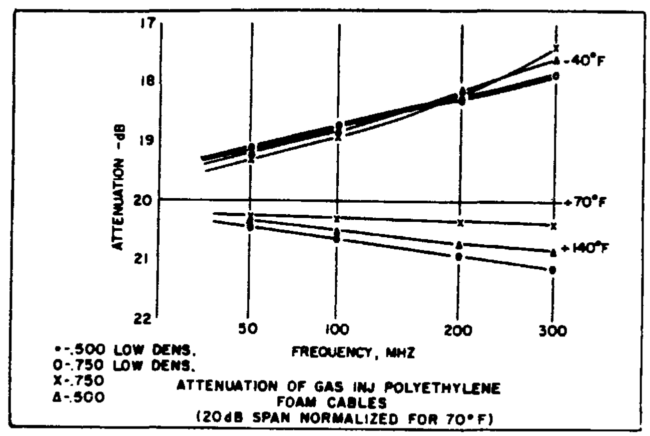


Fig. 3

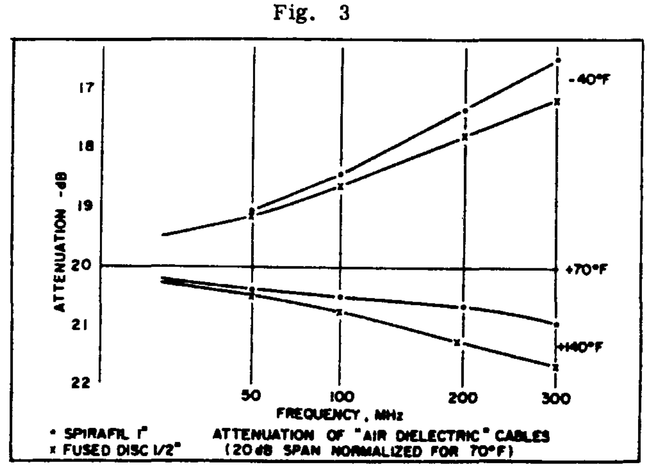
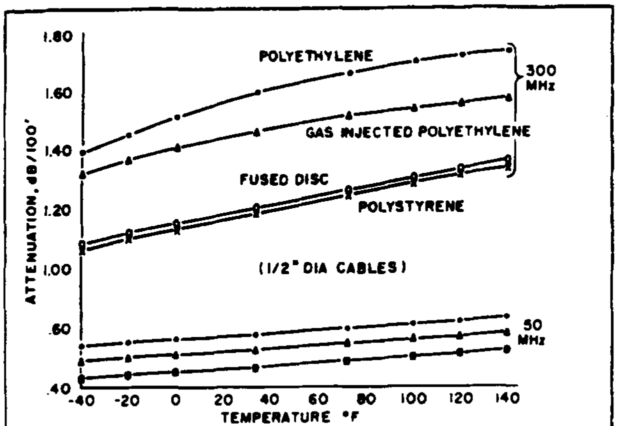


Fig. 4

5.0 ATTENUATION VERSUS TEMPERATURE

There is an accepted rule of thumb in CATV system design, that the attenuation of cable changes by 1% (more precisely, 1.1%) for every 10^{o}F. This implies that the plot of attenuation vs. temperature, at any frequency, would be a straight line.

Fig. 5 presents the attenuation of four types of cable, at 50 and 300 MHz, plotted against temperature. Some of the lines are nearly straight, although the slope of the 50 MHz line is different from that of the 300 MHz line, and both are different from the .0011/°F coefficient.



ATTENUATION AS A FUNCTION OF TEMPERATURE

Fig. 5

Some lines, however, are noticeably curved. A careful examination of the "nearly straight" lines will show that they have different slopes at the two ends of the temperature scale.

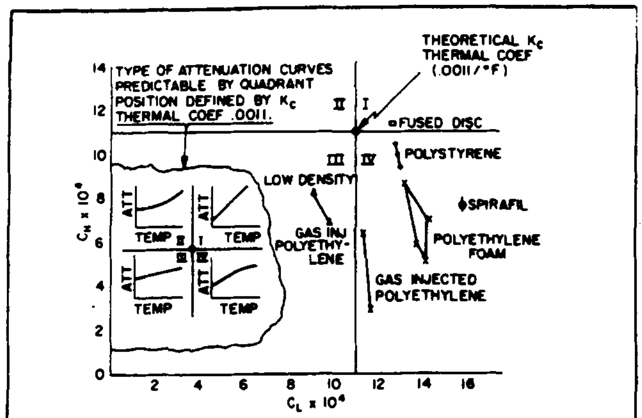
For purposes of system design, the temperature range may conveniently be divided into two zones, arbitrarily defined as "high" (70 to 140^{o}F) and "low" (-40 to 70^{o}F). Two temperature coefficients assigned to these zones, may be defined as follows:

$$C_H = \frac{A_{140} - A_{70}}{70 \times A_{70}} \qquad C_L = \frac{A_{70} - A_{-40}}{110 \times A_{70}}$$

These represent attenuation change per degree F and are comparable to the theoretical value of .0011 derived for conductor loss (see Appendix A).

C_H and C_L values were calculated for all cables studied, and each cable was plotted as a point in C_H-C_L coordinates in Fig. 6, using the values computed for 300 MHz. A cable with no dielectric loss would appear as a point at the intersection of the two lines at .0011 on each axis. It is evident that departure from this value must be due to the effect of the cable dielectric.

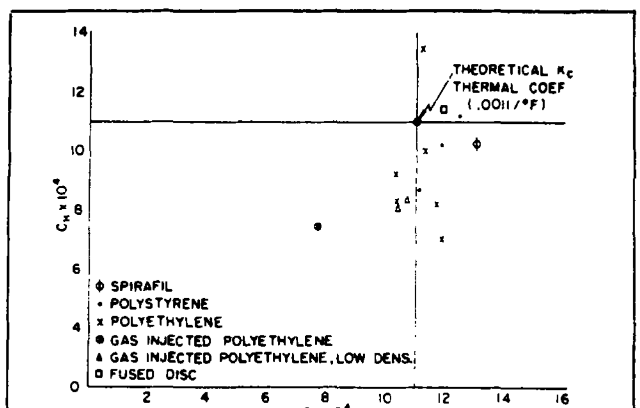
Fig. 6 is separated into 4 quadrants relative to the .0011 point. Each quadrant defines the type of attenuation vs. temperature relationship to be expected. Note the preponderance of points in the lower right quadrant, as anticipated by the curves generally having greater slope in the low-temperature part of the A-T curves of Fig. 5. The points representing the polystyrene dielectric and the fused-disc cables are quite close to the theoretical value; the low-density gas-injected foam dielectric cable is in the quadrant showing the least A vs T slope.



C_H, C_L FOR VARIOUS CABLE TYPES - 300 MHz

Fig. 6

Fig. 7 shows the same configurations for 50 MHz attenuation. The points are clustered much closer to the theoretical .0011 value, indicating the reduced effect of dielectric losses at the lower frequency.



C_H, C_L FOR VARIOUS CABLE TYPES-50 MHz

Fig. 7

The C_H-C_L groupings, indicated by the connecting lines in Fig. 6, provide a means to examine and compare a large number of cable attenuation characteristics and may help in defining specifications for A vs T limits for a given type of dielectric.

6.0 A 3-DIMENSIONAL APPROACH

The data obtained from the measurements would be best represented as a surface in 3 dimensions. Even though such a surface is not easy to represent on a 2-dimensional sheet of paper, the table in Fig. 8 can suggest a representation of such a surface. If the columns and rows are considered as the horizontal and vertical axis (representing temperature and frequency), each entry (dB attenuation) is the elevation of the corresponding point above the horizontal base plane. The attenuation $A(f_i, t_k)$ at the frequency f_i and temperature t_k is a function of 2 variables, defined over a discrete set of points.

TABLE I

TEMP / FREQ	-40	-20	0	35	70	100	120	140
50 MHZ	7.32	7.60	7.82	8.24	8.60	8.93	9.05	9.12
60 MHZ	7.99	8.31	8.56	9.03	9.51	9.70	9.93	9.90
70 MHZ	8.70	9.04	9.33	9.85	10.39	10.68	10.83	10.90
80 MHZ	9.29	9.69	9.99	10.55	11.14	11.47	11.61	11.67
90 MHZ	9.92	10.33	10.66	11.30	11.93	12.27	12.41	12.47
100 MHZ	10.43	10.88	11.22	11.90	12.58	12.94	13.10	13.16
110 MHZ	10.98	11.47	11.84	12.53	13.25	13.66	13.84	13.89
120 MHZ	11.52	12.04	12.44	13.19	13.96	14.39	14.55	14.58
130 MHZ	11.99	12.55	12.96	13.76	14.57	15.01	15.18	15.23
140 MHZ	12.49	13.06	13.52	14.37	15.21	15.67	15.85	15.87
150 MHZ	10.96	13.56	14.02	14.89	15.82	16.27	16.44	16.48
160 MHZ	13.44	14.07	14.54	15.45	16.39	16.88	17.09	17.14
170 MHZ	13.84	14.50	15.00	15.95	16.90	17.45	17.65	17.67
180 MHZ	14.25	14.94	15.48	16.51	17.48	18.04	18.21	18.22
190 MHZ	14.79	15.52	16.05	17.09	18.15	18.69	18.89	18.91
200 MHZ	15.11	15.85	16.43	17.52	18.58	19.18	19.35	19.35
210 MHZ	15.55	16.32	16.91	18.04	19.17	19.74	19.93	19.95
220 MHZ	15.98	16.77	17.36	18.49	19.66	20.26	20.49	20.51
230 MHZ	16.28	17.11	17.71	18.89	20.08	20.72	20.93	20.95
240 MHZ	16.78	17.62	18.26	19.50	20.70	21.37	21.58	21.57
250 MHZ	17.15	18.01	18.69	19.94	21.22	21.86	22.07	22.08
260 MHZ	17.57	18.47	19.14	20.43	21.71	22.44	22.63	22.62
270 MHZ	17.96	18.86	19.55	20.89	22.23	22.91	23.10	23.14
280 MHZ	18.26	19.20	19.90	21.29	22.63	23.33	23.52	23.53
290 MHZ	18.66	19.58	20.31	21.69	23.11	23.81	23.99	24.01
300 MHZ	19.04	20.03	20.79	22.20	23.66	24.38	24.59	24.57
310 MHZ	19.39	20.39	21.13	22.59	24.07	24.85	25.02	25.04
320 MHZ	19.80	20.84	21.62	23.13	24.62	25.38	25.59	25.54

Fig. 8

We may assume a continuous function $\bar{A}(f,t)$ tc represent this continuous surface, of which we know only a discrete set of points. The function $\bar{A}$ can be defined in an arbitrary manner, but it would be of any use only if it fits the measurements at the discrete set of frequency-temperature pairs. The error for each measured point is:

$$E(f_i, t_k) = A(f_i, t_k) - \bar{A}(f_i, t_k)$$

and the parameters of the function $\bar{A}$ are varied to minimize the expression

$$\Sigma_i \Sigma_k \left[E(f_i, t_k) \right]^2$$

resulting in a "least squares" fit. The function $\bar{A}$ may be defined with 5 or 6 variable parameters, and the summation may involve about 200 measured points; the surface fitting therefore will also help to smooth out the errors contributed by any one measurement.

The choice of $\bar{A}$ is, in principle, arbitrary. We shall see that different functions can be made to fit the same set of measured data equally well; the particular form of matching function A should therefore be selected according to the purpose for which the approximation will be used.

7.0 DESIGN OF OPTIMUM EQUALIZATION

To a system designer, the variation of attenuation with frequency and temperature is an effect to be compensated by equalization. From this point of view, the cable attenuation can be represented by a function of the form:

$$\bar{A}(f,t) = P_1(f) + P_2(f)\, Q(t-70)$$

This represents the attenuation as a combination of 3 functions:

- $P_1(f)$ the attenuation of the cable at 70°F, to be compensated by a fixed equalizer;
- $P_2(f)$ the frequency response of a temperature-dependent equalizer;
- $Q(t-70)$ the amount of thermal equalization necessary at t°F.

The formula assumes that the thermal equalizers, and the ASC network in the amplifiers, are "Bode" equalizers, whose frequency response is independent of temperature (except for a constant multiplier).

Assuming that, to a first approximation, attenuation varies linearly with temperature and with the square-root of frequency, we specify the functions as

$$P_1(f) = a_1\sqrt{f} + b_1 f$$

$$P_2(f) = a_2\sqrt{f} + b_2 f$$

$$Q(t) = (t-70)\left[1 + c\,(t-70)\right]$$

We have thus defined $\bar{A}(f,t)$ with 5 arbitrary parameters : a_1, b_1, a_2, b_2 and c.
Note that the values obtained for these parameters by curve fitting do not represent any intrinsic properties of the cable; they are only guides in the design of equalizers for the cable.

Table II (in Fig.9) shows the result of fitting the function to measured attenuation of 3 cables (all measurements normalized to an attenuation of 20 dB at 300 MHz and 70°F).

The first part of the table shows the values of the 5 parameters for each cable, and the largest deviation from the measured value (the point of worst fit). These parameters are then used to compute the optimum equalizers for each cable.

The fixed equalization is based on the function $P_1(f)$, and shows the value of equalizer attenuation at 3 frequencies (relative to 0 dB at 300 MHz). The numbers in parenthesis are the values of attenuation normalized to the attenuation at 50 MHz, and indicate the frequency response of the equalizer. The numbers show that the differ-

TABLE II

SURFACE-FITTING FOR OPTIMUM EQUALIZATION

	Cable A	Cable B	Cable C
Dielectric type:	Polyethylene foam	Styrene foam	Polyethylene discs
Fitting function:			
a_1	.976	1.09	1.05
b_1	.0108	.00399	.00576
a_2	.000707	.00104	.000891
b_2	.0000184	.0000135	.000036
c	-.00555	-.00137	-.0000721
Maximum deviation dB/20 dB span	.2	.2	.2
Fixed Equalization, dB/20 dB span			
50 MHz	12.6 (1.000)	12.2 (1.000)	12.3 (1.000)
100 MHz	9.2 (0.733)	8.7 (0.721)	8.9 (0.724)
200 MHz	4.2 (0.329)	3.8 (0.318)	3.9 (0.321)
ALC control at 67.25 MHz, dB/20 dB span			
$-40^{o}F$	-1.25	-1.20	-1.08
$+140^{o}F$	+0.30	+0.60	+0.68
Fig. 9 Thermal Equalization, dB/20 dB span/$100^{o}F$			
50 MHz	.53 (1.000)	1.21 (1.000)	1.80 (1.000)
100 MHz	.39 (0.748)	.89 (0.735)	1.36 (0.757)
200 MHz	.18 (0.345)	.40 (0.332)	.64 (0.355)

ent cables need equalizers with different frequency responses. The change of attenuation at 67.25 MHz (ALC pilot frequency) indicates that different cables place different requirements on the ALC system.

In particular,cable A varies much less in the high temperature region than in the temperatures below $70^{o}F$ (compare the C_L-C_H groupings described in an earlier section).

Thermal equalization (whether by thermal equalizers or by automatic slope control) is specified in the last part of the table. The equalization is given per span and $100^{o}F$ change,but it can be used as a guide to the frequency of placing equalizers of a similar frequency response. The normalized frequency response is shown by the numbers in parenthesis. The table indicates that the different cables need equalizers of different frequency responses; also that for each cable, the frequency response of the optimum thermal equalizer is different from the response of the optimum fixed equalizer for that cable. It also indicates that thermal equalizers,or ASC stations, should be placed more frequently in systems built with cable C than in those with cable A.

8.0 CONDUCTOR AND DIELECTRIC LOSSES

For cable manufacturers, it is very important to separate the losses into conductor and dielectric losses. How can this be done?

Since the approximating formula used above has $\sqrt{f}$ and f terms, it is very tempting to assume that they represent the conductor and dielectric contributions to the total attenuation. If we follow this assumption, then the ratio a_2/a_1 would be the temperature coefficient of the conductor losses. For the 3 cables in Table II, the ratio is .000731 and .000954 and .000825 respectively. The values for cables A and C are too far from the theoretical value of .00109 (see Appendix A); and why should this value change so much between the 3 cables that differ in their dielectric only, but have the same conductor structure?

There is a subtle point involved in the fitting of a continuous function to a discrete set of measured points. It is true that the attenuation contributed by the conductors would follow a $\sqrt{f}$ function; but the converse is not true -- the $\sqrt{f}$ portion of an approximating function does not necessarily represent the conductor losses. Appendix B shows an example where the attenuation of a cable at one temperature is approximated by different functions, all of the form of a $\sqrt{f}$ term paired with another function. The coefficient of the $\sqrt{f}$ term in the approximation depends on the "other function" used, and the "goodness of fit" cannot be any guide in selecting the "correct" value of k_c.

One way to separate conductor from dielectric losses would be to compute the former from the cable dimensions and from the properties of the conducting materials (Appendix A). It is likely that the properties of drawn aluminum tubes and copper-clad aluminum wire are known in more detail and are easier controlled than those of the various dielectrics used in cables. On the other hand, we must realize that low-loss cables, as used in CATV, are designed for minimal dielectric losses (in addition to the inevitable conductor loss). If, for example, the dielectric loss is 5% of the total, an error of 1% in computing the conductor loss will result in a 20% error in the loss ascribed to the dielectric.

In a cable with a homogenous, low-loss dielectric, the dielectric losses are proportional to the frequency. We can try to fit the measured attenuation to the function

$$\bar{A}(f,t) = k_c\left[1+\alpha_c(t-70)\right]\sqrt{f}+k_d\left[1+\alpha_d(t-70)\right]f$$

which assumes linear temperature dependence of both components. Indeed, when this approximation is applied to cable B of Fig. 9, the deviation of any measured point is less than 0.2 dB, and the coefficients for best match are

$$k_c = 1.09 \qquad \alpha_c = 0.00102$$

$$k_d = 0.00395 \qquad \alpha_d = 0.00363$$

and the temperature coefficient of k_c is very close to the theoretical value. The same function applied to cable C, with a fit just as good, yields

$$k_c = 1.05 \qquad \alpha_c = 0.000847$$

$$k_d = 0.00576 \qquad \alpha_d = 0.00627$$

which seems very curious when the two cables are examined; cable C has much less dielectric than cable B, but its k_d contribution is much higher. The low value of α_c is another indication that the $\sqrt{f}$ term, in this approximation, does not represent conductor losses.

Could it be that we used an improper "other function" for cable C? Indeed, the derivation in Appendix C shows that if we assume the attenuation as a result of reflections from the supporting discs, rather than from dissipated energy within the dielectric, the loss ascribed to the dielectric should be proportional to f^2 (with added f^4, f^6... terms if needed for extra refinement). When the f term in $\bar{A}(f,t)$ above is replaced by an f^2 term, the fit (which is just as close as in the other examples) gives the following parameters:

$$k_c = 1.10 \qquad \alpha_c = 0.00110$$

$$k_d = 0.0000101 \qquad \alpha_d = 0.00610$$

The value of α_c is further assurance that we have selected the correct "other function" for the dielectric loss, and the k_c and k_d have a physical meaning.

In summary, the fact that an assumed function provides a good fit to the measurements is not sufficient proof, by itself, that the various components of the function correspond to particular physical parameters in the cable. If the form of the function can be justified by a theoretical analysis then the values of the parameters can be derived by curve fitting. If there is no a-priori justification for the selected functional form, one can use the derived value of known parameters as an indication that the function has physical meaning (or, at least, to reject a function as incorrect). We suggest that the temperature coefficient of the f term can be used as a guide to the possible correctness of the assumed function.

As an example, the measured attenuation of a spiral dielectric 1" cable was analyzed, with the following results:

sum of $\sqrt{f}$ and f terms	sum of $\sqrt{f}$ and f^2 terms
$k_c = 0.972$ $\alpha_c = 0.000703$	$k_c = 1.06$ $\alpha_e = 0.00101$
$k_d = 0.0105$ $\alpha_d = 0.00433$	$k_d = 0.000018$ $\alpha_d = 0.00433$

The value of α_c indicates that the second decomposition is likely to be the correct one, so that dielectric losses in this cable are proportional to f^2 (indicating that the loss mechanism is reflective rather than absorbtive).

CONCLUSION

A meticulous study of cable attenuation is of extreme importance to the designers of CATV equipment and systems. We have described a measurement procedure that provides detailed attenuation vs frequency and temperature data, and presents it in a form that is easily transferred to a computer for analysis. The analysis results in logical definition and computation of various parameters useful in the design of cable systems. It shows that some cables can be clustered in closely related groups with similar properties; and that a system properly designed for a cable in one group may not operate properly if a cable of a different group is used in the same design.

The computer-aided analysis method can also be used to probe into the mechanism responsible for the dielectric loss, and indicate some of the causes behind the grouping of cable types.

Since the study was conducted on a limited number of samples, we strongly caution against interpreting the results as inherently representative of any type of cable or dielectric. In fact, cable manufacturers agree that incoming dielectric materials, particularly polyethylene, may be subject to certain variations -- not yet fully understood -- which influence the dielectric constant and power factor, with a resulting variation in attenuation. Furthermore, there is no certainty that the results, as presented here, are valid for an extended life period of a cable.

ACKNOWLEDGEMENT

The study of cable attenuation was made possible, in part, by the contribution of sample reels from various cable manufacturers. This report is not intended to imply relative merit of one type of cable over another. The inclusion of any particular type was guided only by the desire to present the widest possible variety of data, and should not be interpreted in any other way.

APPENDIX A [1]

CONDUCTOR LOSSES IN COAXIAL CABLE

The RF resistance of a cylindrical copper conductor of diameter d mils at a frequency of f MHz and a temperature of 20°C (68°F) is [2]

$$R = 0.996\sqrt{f}/d \quad \text{ohms}/100'$$

Let d mils denote the diameter of the center conductor of a coaxial cable, and D mils the inner diameter of the outer conductor. It may be assumed that the RF current in the copper-clad inner conductor is confined to the copper skin. The conductivity of the aluminum outer conductor is 61% of that of copper [3], and the total RF resistance of the coaxial cable at f MHz is then

$$R=(0.996/d+1.276/D)\sqrt{f} \quad \text{ohms}/100'$$

The contribution of the conductor resistance to the cable attenuation at f MHz is [4]

$$A_c = 4.343\ R/Z_o$$

which for 75-ohm cable, reduces to

$$A_c=(5.771/d+7.389/D)\sqrt{f} \quad \text{dB}/100' = k_c\sqrt{f}$$

$$k_c = 5.771/d+7.389/D \quad \text{dB}/100'/\sqrt{\text{MHz}} \ .$$

The temperature coefficient of the resistivity of copper and aluminum is the same [5], 0.00393/°C, or .00218/°F. The resistivity of the coaxial cable conductors at any temperature t°F is therefore

$$\rho_t = \rho_{68}\left[1+0.00218\ (t-68)\right]$$

Because of skin-effect, the RF resistance is proportional to the square root of the resistivity [6], therefore

$$R_t=R_{68}\sqrt{1+0.00218\ (t-68)}$$

$$\doteq R_{68}\left[1+0.00109\ (t-68)\right]$$

The k_c coefficient, which is proportional to the RF resistance, will have the same temperature coefficient, namely 0.00109/°F.

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(1) The material in this Appendix is abstracted from "Calculations relating to aluminum shielded cables", by K.A. Simons, Jerrold Electronics Corporation Memorandum, Oct. 22, 1975.

(2) Reference Data for Radio Engineers, 5th Edition, ITT, 1972 printing; page 6-7.

(3) Texas Instruments Bulletin 516-WP26-1070.

(4) Reference 2, page 22-13.

(5) Reference 2, page 4-21.

(6) Reference 2, page 6-5.

APPENDIX B

CAN k_c BE DETERMINED BY CURVE FITTING ?

The first two columns in TABLE A show the measured attenuation vs frequency of a reel of cable at 70°F, the other columns indicate the result of trying to match the measurements to a curve of the form

$$k_c\ \sqrt{f} + k_d\ G(f)$$

The various columns pertain to different functions assumed for the dielectric loss G(f). Each column shows the assumed function, the resultant values for k_c and k_d that gave the best least-squares match, and how close each measured point is to the approximating smooth curve.

It is evident that very different values of k_c can be obtained, depending on the "other function" G(f) used in the approximation. The "goodness of fit" cannot be any guide in selecting the "right" approximation. The fit shown by the column from the right, with a k_c =0.398, is just as good as the second column which assumes dielectric loss proportional to f and giving k_c=0.893. In fact, even the value k_c=2.464 could not be rejected just on the basis of "poor fit".

This shows that the coefficient of a $\sqrt{f}$ term in an approximation that fits the measurements can not be interpreted, on the basis of good fit alone, as representing the conductor losses (or for that matter, any intrinsic property) of the coaxial cable.

TABLE A

MATCH MEASURED CABLE LOSS TO

$$K_C * F^{.5} + K_D * G(F)$$

	$G(F)=$	1	F	$F^{1.5}$	F^{2}	LN(F)	F*LN(F)	$[LN(F)]^2$	$F^{.5}$*LN(F)
	$K_C =$	1.498	0.893	1.045	1.096	1.686	2.464	0.398	0.976
	$K_D =$	-4.15	0.215E-01	0.739E-03	0.331E-04	-1.29	-0.639	0.151	0.293E-02
MHZ	MEASURED	ERROR IN APPROXIMATION BY MATCH							
100	10.99	0.16	-0.08	-0.20	-0.30	0.08	-0.11	0.04	-0.12
110	11.70	0.14	-0.02	-0.11	-0.20	0.09	-0.03	0.06	-0.05
120	12.37	0.11	0.01	-0.05	-0.11	0.09	0.02	0.07	-0.00
130	12.95	0.02	-0.02	-0.06	-0.11	0.01	-0.01	0.01	-0.03
140	13.56	-0.02	-0.01	-0.03	-0.06	-0.01	0.00	-0.00	-0.01
150	14.16	-0.04	0.01	0.00	-0.01	-0.02	0.02	-0.01	0.01
160	14.73	-0.07	0.00	0.02	0.02	-0.04	0.01	-0.03	0.01
170	15.30	-0.08	0.01	0.04	0.05	-0.05	0.02	-0.03	0.02
180	15.84	-0.11	-0.00	0.04	0.06	-0.07	0.00	-0.05	0.01
190	16.46	-0.04	0.08	0.12	0.16	-0.00	0.08	0.02	0.03
200	16.91	-0.13	-0.01	0.04	0.08	-0.09	-0.01	-0.07	0.01
210	17.48	-0.08	0.04	0.09	0.14	-0.05	0.03	-0.02	0.05
220	17.96	-0.11	-0.00	0.05	0.10	-0.08	-0.01	-0.06	0.01
230	18.44	-0.13	-0.04	0.02	0.07	-0.10	-0.04	-0.09	-0.02
240	19.06	0.00	0.08	0.12	0.17	0.02	0.07	0.04	0.09
250	19.51	-0.03	0.03	0.07	0.11	-0.02	0.02	-0.00	0.04
260	20.01	0.00	0.03	0.06	0.10	0.01	0.03	0.01	0.04
270	20.46	-0.01	-0.00	0.01	0.04	-0.01	-0.01	-0.01	-0.00
280	20.94	0.02	-0.01	-0.01	0.00	0.01	-0.01	0.00	-0.01
290	21.42	0.06	-0.01	-0.02	-0.03	0.03	-0.01	0.02	-0.01
300	21.93	0.13	0.03	-0.01	-0.03	0.10	0.03	0.08	0.02
310	22.31	0.08	-0.06	-0.12	-0.17	0.04	-0.06	0.01	-0.08
320	22.78	0.13	-0.06	-0.14	-0.22	0.07	-0.05	0.03	-0.08

APPENDIX C

DIELECTRIC LOSS IN FUSED DISC CABLE

In the following analysis, it is assumed that:

1. The thickness of the discs is very small compared to a wavelength, so the effect of a disc on the cable is that of a lumped capacitive loading.
2. The spacing between discs is small compared to half a wavelength, so that the periodic discontinuity will not result in a spike in the structural return loss.

At 300 MHz, the free-space wavelength is one meter, so that both assumptions are valid for a cable that has discs spaced about 1" apart.

Let each disc be represented by a capacity C, loading the cable by an admittance $j\omega C$. The reflection from a single discontinuity is

$$r = \frac{-j\omega C}{2Y_0 + j\omega C}$$

and if the loading is small compared to the characteristic admittance Y_0,

$$r = -j\omega C/2Y_0 = -jkf$$

where $\underline{f}$ is the frequency, and $k = \pi C/Y_0$

The ratio of the power transmitted beyond the discontinuity to the incident power is

$$1 - r^2 = 1 - k^2 f^2$$

If the span of cable (100', or 20 dB, or whichever length is analyzed) contains $\underline{n}$ discs, the reflections from the discs will result in an output power of

$$(1-k^2f^2)^n = 1 - nk^2f^2 + \frac{n(n-1)}{2}k^4f^4 - \ldots$$

We can take the f^2 term for a first approximation, and higher terms (all in even powers of the frequency f) if further refinement is necessary.

The loss, expressed in dB, due to reflections from the discs, is

$$A_d = -10 \log(1-nk^2f^2) = -43.43 \ln(1-nk^2f^2)$$

$$\cong 43.43\, nk^2f^2$$

The last approximation is valid because $nk^2f^2 \ll 1$. (In the example in the body of the paper, the coefficient of f^2 for the fused-disc cable is about 10^{-5}).

DESIRED SPECIFICATIONS OF PAY CABLE TRAPS

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ABSTRACT

A list of desired specifications is developed, with a discussion of each, for a trap on channel A (121.25 MHz). The specifications are intended to describe a filter whose performance will be predictable over a wide range of environments and with many different TV receivers. Also discussed are the differences to be expected in operating parameters of filters for channels higher and lower than channel A.

Considerations discussed are: the critical portions of the signal to be trapped, the parameters needed to effect scrambling action in the receiver, specifications geared to insure time stability, and specifications intended to cause poor to indiscernible audio in most receivers.

NOTCH FREQUENCY: Desired visual carrier ±2 KHz
TEMPERATURE: -40°F to 140°F
DEPTH OF NOTCH: 45 dB at room temperature
INSERTION LOSS: Adjacent visual carrier 2 dB; all others 0.75 dB
RETURN LOSS: All channels outside 3 dB points 16 dB
FREQUENCY STABILITY: ±75 KHz
3 dB BANDWIDTH: 10 MHz
3 dB NOTCH WIDTH: 32 KHz minimum; 100 KHz maximum
POWER PROTECTION: Withstand 250 VAC from center conductor to sheath
SHOCK: Withstand 20-foot fall to concrete
MECHANICAL CONFIGURATION: Not removable with common hand tools
WARRANTY: One year

INTRODUCTION

The rapid growth of pay cable has resulted in a heavy demand for a device previously unknown to the cable industry: an inexpensive (relative to other filters in use in the industry), highly stable, weatherproof filter (or trap) designed to render a pay signal unwatchable, available in large quantities to accommodate any given channel line-up found in the industry. Such a device is difficult to specify, and consequently not all filters are purchased under the same specifications. It is to the benefit of the operators and manufacturers if both describe the unit by the same manner of specification, with changes in absolute values to accommodate special circumstances found in different CATV systems. The desired specifications are listed here with the appropriate discussion of each one.

NOTCH FREQUENCY: Desired Visual Carrier ±2 KHz

The notch frequency should be specified as the assigned visual carrier frequency of the pay channel with a tolerance of ±2 KHz to allow for slight variances between equipment. This specification is intended to insure that the center and deepest portion of the notch lies in the area of its maximum effect. Other parameters will deal with the shape of the notch.

TEMPERATURE: -40°F to 140°F

The temperature range commonly specified for most CATV equipment lies from -40°F to 140°F, and these units should be compatible with other equipment operating in the industry. Certainly southern coastal areas might wish to relax these somewhat for their particular needs, but filters with good stability and temperature compensation generally have little difficulty meeting the -40°F to 140°F temperature range.

DEPTH OF NOTCH: 45 dB at Room Temperature

The depth of the notch can be specified to satisfy one of two desires: either to effect scrambling action in the receiver or to reduce the visual carrier and consequently the carrier to noise value of the signal displayed on the receiver to that which is generally accepted to be unwatchable. Most late-model color receivers will not reliably synchronize when the video carrier approaches an absolute level of -35 dBmV.

The maximum drop levels found in most systems rarely exceed 10 dBmV such that a notch depth of 45 dB is adequate to effect scrambling action in most receivers. If the notch, however, does not retain that value through the channel of interest but rather only very near the visual carrier, as is the case in a pay cable trap, there are appreciable energy components within the desired channel (particularly within the areas of the color subcarrier and sound carrier).

In addition, most receivers develop AGC voltage by reference to the horizontal sync information, which is located within 15,750 Hz of the visual carrier. With the gain of the receiver circuitry at a relatively high value, these added energy components may aid scrambling effect by the generation of intermodulation products in the receiver IF circuitry and detectors. Also aiding this effect are any adjacent channels that lie in the bandpass of the tuner and IF response of the receiver.

These added effects may be used as a basis to modify the 45 dB specifications at room temperature to include a tolerance for the temperature extremes of 5 dB to allow a 40 dB specification at the two temperature extremes of -40 and +140 provided that the filter returns to 45 dB at room temperature. The depth of notch specification, then, should read 45 dB at room temperature, 40 dB at the temperature extremes.

If the goal is to simply provide a snowy picture that may be considered unwatchable, then the value of the notch does not necessarily have to be so high since a 40 dB trap in conjunction with a converter with a 13 dB noise figure and 10 dBmV input leaves a carrier to noise ratio of 16.1 dB, excluding the effects of the noise contribution of the TV tuner and the system itself as being negligible. A poor picture has been defined as one whose carrier to noise ratio is 30 dB or less. A barely viewable picture has been defined as one having a 27 dB carrier to noise ratio such that any value below 24 dB could be considered unwatchable. For the protection of the premium channel, however, specifications written for a scrambling effect would be advisable.

While a 45 dB notch may render a video signal viewed on a television set unwatchable, it most likely will not have a discernible effect on the audio portion of that signal since a filter designed not to suppress the visual carrier on the adjacent channel by more than 2 dB will not suppress the aural carrier by more than approximately 10 dB. In cable systems where the aural carrier is operated 15 to 17 dB below the visual carrier, the audio will still be quite discernible.

Virtually every television set used in the U.S. today makes use of the 4.5 MHz difference between the aural and visual carriers with the use of an intercarrier sound technique whereby after IF detection there follows a 4.5 MHz sound detector to recover the aural information. The level of the 4.5 MHz carrier is directly dependent upon a level of the visual carrier, so it is possible to place a value on the visual carrier at which or below which the value of the 4.5 carrier produces a garbled audio component. This absolute value has been established to be on the order of -45 to -50 dBmV, which means that a 55 or 60 dB trap is necessary if the maximum subscriber levels are 10 dBmV.

The reduction of the visual carrier is, however, not absolutely certain to produce garbled audio since the pay aural carrier can beat with any adjacent carrier or even with high level luminance components if the trap is very sharp in the IF detection process and produce a 4.5 MHz component that the FM detector in the receiver will receive. Since the gain of the receiver circuitry is relatively high, many more distortion products will be presented to the FM detector and, depending on the alignment and fine tuning range of the receiver, it may be possible to fine tune to receive discernible pay channel audio even when the pay visual carrier has been attenuated 90 dB or more. The only sure way to reduce the audio to an indiscernible level in every receiver is to reduce the aural carrier level before IF detection. This may present a problem to upper adjacent visual carriers, particularly for operation above the low VHF channels.

It is very important that the depth of the notch specification be considered in conjunction with the other frequency and bandwidth specifications since it is entirely possible that a 60 dB notch can be placed in a channel in such a frequency position as to be barely noticeable. A 45 dB trap is not effective unless it attenuates the information within ±15.75 KHz of the pay visual carrier by 45 dB.

INSERTION LOSS: Adjacent Visual Carrier 2 dB; All Others 0.75 dB

Insertion loss for all channels other than the adjacent channel to the trapped channel should be 0.75 dB maximum. This should include any peak to valley or other variations in the response. The adjacent channel carrier should not be attenuated by any value more than 3 dB for the average home receiver to be unaffected, and the figure of 2 dB provides adequate margin for variance between receivers.

While the trapped pay TV channel is not offered to the subscriber and by yet-unqualified opinions doesn't have to be tested to meet the FCC standards, the adjacent channel does have to meet them, and a value of 2 dB at the visual carrier is intended to provide a reasonable variance in that channel. Since the filter response will return to about its insertion loss value above the visual carrier and will also drop another dB approximately to the lower channel limit, the recommended FCC limits of ±2 dB may be met if the 2 dB insertion loss specification is observed for the adjacent channel.

Also, tests have shown (see photos 1A-4A) that the trained eye can begin to determine differences in the transient response (where the picture contains sharp transitions) but cannot determine variances in the color saturations or hues at this level of adjacent channel attenuation.

Photographs 1-4 show the variance in test waveforms through a demodulator that may be considered equal in quality to those of the average home receivers. Since the AGC voltage is developed from the 15,750 Hz components lying within 15.750 KHz of the visual carrier, the difference in the amplitude of the upper and lower 15.75 KHz sidebands is very slight and can be neglected. However, there is a discernible difference in attenuation between the components of appreciable energy content at the lower end of the lower vestigial sideband and those of the same corresponding frequencies away from the carrier in the upper sideband, resulting in a reconstituted signal having variances in this response relative to equal amplitudes of components not passing through a trap having non-linear attenuation throughout the adjacent channel. Since the gain is corrected using reconstituted lower frequency components, which are attenuated by the value of the slope of the incoming RF response, the corresponding value of the slope of the higher frequency components will be greater.

Photos 1-4 show the effects of a reconstituted signal for values of carrier attenuation given in Table 1. Also shown in Table 1 are the values of attenuation at the lower limits of the vestigial sideband.

TABLE 1

Photo	Attenuation, dB at Visual Carrier	1 MHz Below Visual Reference
1	Reference	Reference
2	1.4	2.1
3	2.3	3.0
4	2.6	4.5

Photos 1A-4A show responses through the same demodulator with 2T, 12.5T and window test signals. Since most of the energy of the 2T pulse lies in the low-frequency areas of the video signal, its amplitude is affected less than that of the 12.5T pulse. The 12.5T pulse shows a relative chroma level increase in photos 2A, 3A and 4A with relative chroma delay in photo 4A. The 2T pulse reveals that the transient response as well as the amplitude is affected, as may be predicted by the change in phase relationships for those frequencies reconstituted from components above and below the visual carrier since the components on the lower edge of the vestigial sideband are on the lagging edge of the filter and are affected more by any phase difference. The low to high frequency phase variance is apparent by the observation of the 12.5T pulse. These phase relationships, amplitude, variances and transient response differences will be determined largely by the alignment of the subscriber's receiver, but the effects of the trap will be additive in any case. The fact that the trained eye may begin to see the effects on using an average representative receiver with a filter whose upper adjacent is attenuated beyond the values given in Table 1 is used as a basis for the specification.

RETURN LOSS: 16 dB

Since taps commonly used in CATV systems have return loss specifications of 15 dB or better, the trap used in conjunction with these should have at least an equal return loss except, of course, within the effects of the notch. All channels other than those within the 3 dB points of the trap should exhibit a return loss of 16 dB or better. Of course, systems with taps that have better or worse return losses may wish to alter these numbers slightly.

Tests at United Cable have shown that a feeder line with traps on roughly 50 percent of the tap spigots exhibiting return loss of 11 dB does not result in a measurable difference in the response of that feeder line, nor does it result in discernible impairment of the adjacent color picture or any other channel when viewed by trained observers. The tap values on the tested feeder line ran from the high 20s to 8 dB, and the minimum isolation specification of the taps was 26 dB.

FREQUENCY STABILITY: ±75 KHz

The frequency stability of the notch is important to insure that the critical components remain at the attenuation value that has been chosen. To insure that a notch retains its position in the frequency spectrum a specification of ±75 KHz across the temperature extremes has been shown to be a valid specification. Measurement of frequency for any attenuation value chosen should not vary more than ±75 KHz over the -40°F to 140°F extremes.

3 dB BANDWIDTH: 10 MHz

The 3 dB bandwidth has long been a standard measurement of filter performance and indicates that value at which the frequency response is 3 dB below its incident value. It is referenced as a basis in a great deal of filter design information and should serve a similar purpose in the description of its use in a trapping effort. Spectrum lying above and below the 3 dB points of the filter will be considered available for program use for any purpose. Spectrum lying with the 3 dB points should be considered incapable of carrying useful information to cable subscribers not choosing to subscribe to pay cable.

Notch filters, for most practical purposes, will be symmetrical about their deepest point. There are special conditions where, to favor lower adjacent sound carriers, skewing techniques have been incorporated; but the majority of these filters have been in the low-band channels. Filters in use in the mid-band channels utilize designs that do not generally lend themselves well to this technique. Since the upper adjacent video carrier lies at 6 MHz above the carrier to be trapped and its lower sideband cannot be attenuated more than 3 dB, and the appreciable energy components of this lower sideband extend 1 MHz below it, then we may establish the 3 dB point of the filter to be 5 MHz above and below the carrier to be trapped (assuming a symmetrical filter). To include those situations where the filter may not be symmetrical about its deepest point, the specification for 3 dB bandwidth should be 10 MHz with no indication of its variance of the visual carrier.

3 dB NOTCH WIDTH: 32 KHz Minimum; 100 KHz Maximum

A 3 dB notch width can be used also to describe the performance of the filter in that the points 3 dB less than the maximum attenuation figure must remain a given width in order for the synchronization components contained in the video signal to be attenuated to the value that has been previously determined to effect scrambling action in the receiver. Since sync components lie as far as 15.75 KHz above and below the visual carrier, the 3 dB notch width should be greater than 31.5 KHz and is limited on the high end by the shape factor of the filter. However, in order for appreciable energy to lie in the color burst and aural components to help in the scrambling effect, experience has shown that this value should be limited to 100 KHz. The 3 dB notch width should be specified at greater than 32 KHz but less than 100 KHz and may be specified at 50 KHz nominal if desired to effect maximum scrambling action and allow a slight tolerance for temperature drift. This specification, coupled with the frequency stability specification, is designed to insure that the notch retains its most effective shape at its most effective portion in the frequency spectrum throughout the temperature range.

POWER PROTECTION: Withstand 250 VAC from Center Conductor to Ground

In order to resist intentional damage by subscribers who introduce common house voltages from center conductor to ground in an effort to destroy the trapping effect of the filter, the unit should be designed such that there is no degradation in the trapping action with 250 VAC introduced from center conductor to ground in its normal operating environment. A normal operating environment is, of course, between the subscriber and the tap.

SHOCK: Withstand 20-foot Fall to Concrete

The nature of the pay cable trap, be it a band stop filter, a trap, or a band reject filter, is such that its operating conditions are somewhat opposite to that of most other equipment found in the industry. It has to operate with very high circuit Qs and very high stability yet over very narrow bandwidth, where the other equipment in the industry operates over a very broad bandwidth. Slight physical displacement introduced by shock may have catastrophic effects on the action of the filter. For this reason the unit must be able to withstand a 20-foot fall to concrete to insure that it will retain its electrical performance during and after installation. It also gives a relatively good idea that the unit will perform well with long-term environmental impacts and gives a good idea that the mechanical exercise caused by temperature extremes over the years will not adversely affect the unit.

MECHANICAL CONFIGURATION

If a unit can be installed with common hand tools, it may quite naturally be removed with common hand tools. Since the pay channel represents an annual worth of approximately $100 to the trapped subscriber, the propensity for him to steal the service is dramatically increased over that of the theft of the normal cable service. Where economically feasible, the filter should lock to the tap mechanically and not be removable except with special tools not normally available. Other alternatives to that, of course, include the use of a locking "F" connector or other arrangement on the subscriber's drop to mechanically lock the drop to the filter rather than the filter to the tap. The disadvantage of this method is the availability of type F connectors at hobby shops and the likelihood a potential pay subscriber may connect himself at a point on the tap side of the filter. In apartment boxes and some underground installations there is the reliable padlock for security. Regardless of the type of mechanical security, he may connect himself to a neighboring pay drop. The inclusion of the mechanical locking specification is to indicate to the manufacturer the desireability of that feature.

WARRANTY: One Year

Cable television equipment operates in environments and over bandwidths surpassed only by a few industries. The inherent nature of this narrow band device suddenly developed for pay cable use dictates the concern for its long-term stability. Component changes, mechanical exercise through temperature extremes, water absorption, potting compound aging effects and countless other factors can affect the long-term stability of the unit. The unit should be warranted to exhibit these outlined specifications for a period of one year.

DISCUSSION

These specifications were drawn for units operating on Channel A and represent reasonable specifications for that spectral area. Filters that are intended to operate at higher frequencies into the high VHF or super band must have relaxations in the 3 dB bandwidth since that parameter may be expressed as a percentage of center frequency and used as a rough estimate of performance for channels above the lower mid-band. For channels in the low VHF area the 3 dB value may be expected to reduce by approximately the same percentage value.

There are many other conditions that come into play in the actual design, and the use of the percentage estimations yields only crude approximations. Certainly with the vacating of upper adjacent and lower adjacent channels units may be used on channels in the high VHF and super band. However, the sacrifice of those two channels involves the sacrifice of an important resource of the system--that of valuable spectrum space that can never be used for distribution of information to all subscribers except when the filters are removed. Units operating in the low VHF band have a spectral opening given them by the FCC in the 4 MHz space between channels 4 and 5. Units on channel 5 have that 4 MHz with which to recover their 3 dB bandwidth without adversely affecting the aural carrier of channel 4. Also, some designs incorporate 3 dB bandwidth sufficiently narrow to be used in the lower four channels without adversely affecting lower adjacent sound or color subcarriers, while keeping the required stability. The spectral area below channel 2, of course, contains no useful information to the subscriber, and units operating in that area have no lower adjacent problems.

The program of trapping non-pay subscribers must be carried through with the highest integrity possible for many reasons. The filter protects a service with an annual worth of $100 or more, and its performance has an effect on the number of pay subscribers since inadequate performance may let a poor signal reach the home. A poor signal relative to the other cable signals offered at a cost of a few cents per signal per month may in the eyes of a subscriber become a signal good enough not to be worth $8-10 more per month to be made better. Also, subscribers paying for the premium channel often fail to see the dollar difference between their good signal and their neighbor's free snowy signal. These undesirable events may be avoided by 100 percent incoming inspection and rigid testing for these specifications presented on a sample lot of units from each production run. Continued observation of filter performance may be carried out by observing the trapped channel on every service call to a non-pay subscriber.

General trends that may be noticed during the testing of filters may be the slight dependency for the scramble effect on the average picture level, depths of modulation and picture information. A test pattern such as the cross hatch and dot pattern where rapid transitions are apparent will effect the scrambling action more so than dark movie scenes since dark scenes have more visual carrier available to the receiver, and any scrambling action introduced by the rapid transitions is not apparent. Also, for systems using converters, a receiver that does not synchronize with the fine tuning at its normal range may synchronize if the fine tuning is adjusted to one extreme partly because of the frequency response of the television receiver and partly because of the response of the converter.

CONCLUSIONS

Perhaps by the establishment of a set of desired specifications with the flexibility to adapt them to every particular situation to be encountered in the CATV industry the industry's needs may be more closely conveyed to the manufacturer, and the manufacturer's response may be more closely correlated with the predetermined CATV operator's need.

REFERENCES

Bostick, Glynn, "Trap Selection--Some Notes on Basics." Unpublished article, Microwave Filter Company, October, 1975.

Ennes, Harold. E. TELEVISION BROADCASTING: SYSTEMS MAINTENANCE. Howard W. Sams & Company, Inc.: Indianapolis, Indiana, 1972.

"Pay TV Traps--Just How Bad is the Language Leakage Problem?" CATJ, Vol. 2, No. 11, November, 1975, p. 12.

Pillow, Jerry. Personal interview, November, 1975.

Rhodes, Charles W., "The 12.5T Modulated Sine-Squared Pulse for NTSC," IEEE TRANSACTIONS ON BROADCASTING, Vol. BC 18, No. 1, March, 1972.

Schmid, Hans, "The Measurement of Linear Chroma Distortion in NTSC TV Facilities," IEEE TRANSACTIONS ON BROADCASTING, VOL. BC 18, No. 3, September, 1972.

Wilbanks, Jim. Personal interview, February, 1976.

Wilson, Roger, "Pay TV Filters," COMMUNICATIONS ENGINEERING DIGEST, Vol. 1, No. 2, November, 1975, p. 21.

FCC TECHNICAL STANDARDS

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The Federal Communications Commission received the final report of the Cable Technical Advisory Committee (CTAC) nearly eleven months ago. Some actions to modify cable technical standards are now under way, partly as a result of the CTAC report. Other possible actions are being considered and further researched by the Commission staff. This paper is to report the current status of FCC's re-examination of cable technical standards on the basis of CTAC recommendations and other sources of advice and information.

The purpose of this paper is two-fold. First, I'd like to report to you the current status of FCC staff's re-examination of technical standards for cable television. This re-examination is based in large part on the detailed recommendations and background materials provided to the Commission almost eleven months ago by the Cable Technical Advisory Committee (CTAC) (Ref. 1). Second, I hope to stimulate informal comments from you concerning the specifics of our re-examination.

I want to point out here that these remarks are my own. My comments are meant to be informal and in some cases exploratory, and should not be taken as the opinions of any or all of the Commissioners.

WHY FCC STANDARDS?

Before discussing individual standards we should review the reasons why FCC writes technical standards for cable television. I see four basic functions for technical standards:

- Standards may promote compatibility of equipment and procedures, within a given cable system and among cable systems and other systems with which they interact (broadcasts, video tape recorders, cameras, receivers);
- standards may discourage interference among cable systems and other activities and systems (safety of persons and property, electromagnetic interference both to and from other electronic and electrical systems);
- standards may encourage high quality of service (pictures, sound, reliable data transmission), particularly in those instances where normal market forces may be inadequate; and
- standards may promote or preserve future flexibility, by permitting or encouraging innovation or by preventing short term cost savings from jeopardizing long term savings, flexibility for new services, or long term service quality.

DESIRED CHARACTERISTICS OF STANDARDS

As a framework for discussing possible new or revised standards, let us consider some of the characteristics FCC standards should have in order to perform effectively and at reasonable cost the four functions given above. Then we'll look at our present technical standards and suggest how they might be modified or supplemented to perform those functions.

I would suggest the following as six of the important characteristics that FCC's cable technical standards should have:

A. Must define a "cable television system," its major component subsystems, and its interfaces with other systems (broadcast, recorders, subscriber terminal equipment), in a manner corresponding to the physical reality of cable system architecture. For purposes of technical regulation ownership, signal carriage rules, and political subdivisions within the area served are less relevant.

B. Should include or recognize others' definitions of the most important technical terms, whether the quantity defined is itself subject to regulation or not. Technical definitions are themselves standards, which can help or hinder communication in the technical community and thereby affect the compatibility and/or the quality of cable television systems.

C. Should include mandatory standards and measurements where and only where they are necessary to achieve the four functions given at the beginning of this paper. Unnecessary standards may either stifle innovation or unreasonably increase system costs without commensurate gains in quality of service provided.

D. Should require the least possible complexity, cost, and time, commensurate with performing the desired functions. This criterion is not merely to save a bit of money in making mandatory measurements or filling out bureaucratic forms. Rather, it is hoped that most cable operators will go far beyond the rather minimal measurement requirements specified by the FCC, further improving the quality and reliability of their systems. This is less likely to happen if measurement requirements are unnecessarily complex and costly.

E. Should be sufficiently flexible to permit innovation in cable television and related technologies, and to recognize different circumstances in different types of cable television systems.

F. Must include clear guidelines for reference by cable operators, the public, and FCC inspectors for determining whether the technical standards have actually been met.

PRESENT RULES AND POSSIBLE CHANGES

How do the present rules compare with these criteria, and what changes and additions are actively being considered or proposed by FCC staff? We will consider each in turn, keying the comments to the lettered criteria in the previous section.

A. System and interface definitions. Cable television systems are now defined in the Rules on the basis of communities served. Although a single set of cables may be under common ownership and management, it is considered to comprise two or more separate systems if it serves two or more separate communities. Although this is convenient for dealing with signal carriage rules and franchising arrangements, it is inappropriate for technical standards and measurements.

Action: Staff has proposed to the Commission that for technical regulation only a cable system should be considered to be an electrically and mechanically continuous set of closed or shielded transmission paths used for cable television purposes as described elsewhere in the Rules. This would imply relief from the present requirement for three annual sets of FCC measurements in each community served; on the other hand, separate sets of measurements would be required on each electrically or mechanically separate set of cables, even though they might serve the same community under the same franchise.

In addition, the staff is preparing a proposal, largely following the recommendations of Panel 1 of CTAC, to define in the Rules the major subsystems of cable television systems. Major subsystems include the signal reception unit(s) used for broadcast reception, signal source and control unit(s), and distribution unit(s). Once definitions for these subsystems and for the interfaces between the cable system its signal sources and its subscribers are defined, then standards and measurement requirements can be applied to the appropriate subsystems. A frequency measurement, for example, may need only be made at the signal source unit, whereas signal to noise ratio should be measured at the end of each distribution unit.

B. Definition of technical terms. The Commission received from CTAC's Panel 1 (Ref. 1) many sound and thoughtful recommendations concerning technical definitions. Perhaps the most significant departure from past practice is the recommendation that both thermal noise and signal power be measured relative to the power produced in a 75 ohm load at room temperature over a bandwidth of 3.33 MHz instead of the conventional 4 MHz. At a temperature of 290K (17°C) this noise power works out to be 1/75 pW ($1/75 \times 10^{-12}$ watts). Noise and signal power referenced to this level would be given in "dBc" (for "decibels cable"). The awkward unit "dBmV" would no longer be necessary and signal to noise ratios could be obtained by simple subtraction, once signal and noise were measured relative to 1/75 pW. Present meters calibrated in dBmV would be correctable by simply adding a constant (59.1 dB) to the signal level reading obtained in dBmV from the meter.

Action: The technical staff of the Cable Bureau is now considering the proposed definition of dBc for inclusion in a Rulemaking proceeding, along with other definitions proposed by CTAC Panel 1 and other sources.

C. Choice of mandatory standards and measurements. The present technical standards have, by and large, stood the time-test of the last four years rather well. With the exception of distortion standards originally adopted, they seem to have generally been judged useful standards of system quality and not too onerous to meet and measure. Their existence has clearly caused a number of system operators to obtain test gear and make measurements that had not been made routinely before, and in many cases this process has led to demonstrably higher quality of service. There are striking instances of improved system reliability as a result of measurement programs which began (not ended!) with the required FCC tests.

But today's needs do require some additions and modifications, as was recognized in 1972 when the present standards were adopted. We now examine a few examples in some detail. This is not a complete list of action items. It is a selection chosen to illustrate our general approach and in some cases to prompt informal comments from you. Look at six examples:

(a) frequency channeling plans
(b) cable compatible receivers
(c) signal level
(d) synchronizing pulse amplitude and waveform
(e) time base stability of video tape recorders
(f) distortion measurements

(a) frequency channeling plans

Need: The prime need here is for a frequency plan to be imposed at the interface between the cable system and the subscriber's terminal equipment (TV receiver), as that terminal equipment now exists or may be manufactured in the future. Agreement on such a plan would encourage manufacturers to market receivers which can receive without the use of converters all or any subset of the 20 or more channels expected to be carried on many future cable systems.

One such plan, of course, would be simply to continue use of the VHF and UHF broadcast channels for cable. However, to date the suggestion of delivery of cable signals on UHF frequencies, although technically feasible, has received very little enthusiasm in the cable industry. As UHF tuners continue to improve and as we on this side of the Atlantic learn more about UHF signal delivery on European cable systems, that attitude may well change. CTAC Panel 5 recommended adoption of a plan based on the 12 VHF channel assignments plus a particular choice of midband and superband channels. The recommended choice would put all carriers (except channels 5 and 6) at 6 MHz intervals, which would lend itself to operation of a phase-stable carrier system with its attendant reduction of the effects of intermodulation distortion products.

Action: We are considering whether and how a harmonically related carrier plan or a phase-stable carrier plan based on 6 MHz difference frequencies (except channels 5 and 6) might conceivably be implemented in the future. If it seems likely that phase-stable carrier techniques will become common in the future, then the plan recommended by Panel 5 of CTAC would be an appropriate choice.

(b) cable compatible receivers

Need: Cable-compatible receivers (able to receive more than twelve channels from cable or a full complement of over the air signals without a set-top converter) are needed to promote compatibility among the various subsystems of our overall television delivery system. Such receivers could not only eliminate the inconvenient and expensive set-top converter in many cases, but also would allow fuller use of the frequency spectrum within the cable. Present receivers not only cannot receive directly mid-band and superband channels, but their poor shielding against ambient electromagnetic fields prohibits the use on cable of channels carrying strong over-the-air signals.

Action: In cooperation with receiver manufacturers and the cable industry, we hope to define a marketable cable compatible receiver. Criteria include input impedance (75 ohms), input connector(s), shielding, adjacent channel performance, and lower limits on signal level at which the receiver overloads.

(c) signal level

Need: Some modern receivers overload at input levels of 1 mV (across 75 ohms). But FCC rules require the cable operator to deliver a minimum of 1 mV of signal.

Action: The FCC rules now allow for waivers in specific cases. But in cases like this one, where a problem will occur all over the country whereever such receivers are sold, the rules should specifically provide that the cable operator may deliver a signal which does not meet the normal FCC specifications, when the subscriber's terminal equipment requires such a signal. Such a provision would not, however, solve the operator's problem of having to modify his output signal to match the characteristics of an out-of-the-ordinary receiver. FCC has no jurisdiction over such input characteristics of receivers, so it cannot now simply require manufacturers to accommodate 1 mV signals. If, however, an FCC definition of a "cable compatible receiver" included such a specification, it should at least discourage manufacture of receivers unable to handle a 1 mV signal.

(d) synchronizing pulse amplitude and waveform

Need: If the ratio of peak carrier amplitude to black level in a signal delivered to the receiver is too low, the picture will not be properly synchronized. This is not a common problem in the cable industry, but it has been reported in the case of some cable systems and some receivers. Modern (digital circuit) receivers may be less tolerant than many older receivers.

Action: It may be appropriate to propose synchronizing pulse amplitude and waveform standards patterned after FCC's broadcast standards, but probably with somewhat relaxed tolerances.

(e) time base stability of video tape recorders

Need: Compatibility between low cost video tape recorders and television receivers is desirable. Compatibility may be attained either by (1) use of a time base corrector (expensive) by the cable operator, or (2) a shortened time constant in the horizontal synchronization circuits of the receiver. CTAC recommended the first procedure. It is true that technology improvement is reducing the cost of time base correctors. But it is not clear that it is desirable at this time to impose costs for such items on cable operators. There is presumably at least some market pressure to encourage such expenditures without mandatory standards. To the extent program material recorded on inexpensive tape recorders is of interest to the public, it is clearly to the cable system operators' benefit if the picture doesn't have its top sheared away. Again, definition of a cable compatible receiver may offer a useful alternative. Appropriately short time constants could be specified as part of the definition.

Action: None at present.

(f) distortion measurements

Need: In principle, measurements of harmonic distortion, cross modulation (cross-picture interference) and other forms of signal distortion are as important as signal level and signal-to-noise measurements as indicators of signal quality. Thus the question of whether distortion standards should be imposed arises.

Action: Adoption of definitions of these quantities would surely improve communications about them within the technical community. But three factors make immediate adoption of mandatory standards and measurement requirements questionable: (1) Once a system has been built and balanced, signal level and signal-to-noise ratio are simpler and reportedly more useful diagnostic measurements to indicate system performance. (2) Measurement of distortion product levels requires much more expensive equipment (e.g., a spectrum analyser) than is normally available to many cable system operators. (3) There is at least some market pressure at work in this instance. Distortion problems are most severe when the system carries more than twelve channels. This is most likely to occur in the larger markets, and in those markets the subscriber usually has one or more good over-the-air signal with which to compare the cable signal. Thus, the large-market subscriber not only is likely to be more critical of signal quality but has at least some alternative to the cable for television entertainment. Thus, the operator is rather likely to be motivated to reduce distortion as much as possible without the existence of mandatory standards and measurements.

D. Minimum complexity, cost, and time. The present technical rules do not seem inordinately complex and costly as they stand. However, we have already initiated some proposals to reduce some unnecessary costs and confusion.

We have already mentioned the proposal to define cable systems for technical purposes in terms of their physical layout rather than in terms of the communities served, thus eliminating unnecessary duplicate measurement requirements.

We have proposed elimination of the requirement to keep on file records of the expected signal level at each subscriber location. The operator may well want this information for his own purposes, but there seems no need for the Commission to require it.

There has been some confusion about whether annual field measurement of subscriber isolation is required, in view of the usual stability of subscriber taps. We have proposed that this measurement requirement be clarified, and that manufacturer's specifications or laboratory measurements on the taps should constitute an acceptable measurement procedure.

E. Flexibility. A certain degree of flexibility is necessary in standards, to prevent stifling of innovation and to recognize that different circumstances might apply in different types of cable systems. The present standards do have such flexibility built in, and future standards will maintain this characteristic. Flexibility is incorporated in at least three ways: (1) the standards are in general set rather on the low side, depending on market forces to encourage higher performance when circumstances permit; (2) the standards are performance standards, not design standards; they are applied to the signal as delivered to the subscriber and do not impose restrictions on techniques the operator should use to obtain the results needed for compatibility and quality; and (3) the rules allow for specific waivers in cases where waivers are in the public interest.

F. Measurements. Last, but certainly not least, FCC technical rules need to specify, for cable operators, the public, and FCC field inspectors how to tell when the standards are being met. These measurement procedures should recognize different cost constraints and different test equipment available from one cable system to another. Until now the approach has been to include a set of optional measurement procedures in the Rules themselves, with a clear statement that other measurement procedures are acceptable to FCC if they meet standards of good engineering practice. (An exception is the measurement of signal leakage or radiation, where a mandatory procedure is specified.) This approach has the advantage of displaying at least one acceptable procedure in a readily accessible place. But it does leave a great deal of ambiguity to be resolved between the cable operator and the inspector in case the cable operator chooses to use a measurement procedure not specified in the Rules.

We are planning, therefore, to publish a collection of measurement procedures, any of which is acceptable for indicating that the relevant standard is met. It is expected that the collection will include both sophisticated measurements using expensive equipment as well as other procedures which require less sophisticated equipment but are still accurate and dependable enough for the purpose at hand. The publication could be in a notebook form which could easily be updated as other measurements became accepted. Of course, the old rule would apply as well -- measurement procedures not included in the publication would be acceptable if they corresponded to good engineering practice. But the publication would contain a wider range of prima facia acceptable procedures than would be practical to include in the Rules themselves. Calibration procedures for test instruments would also be included.

Reference: Cable Technical Advisory Committee Report to the Federal Communications Commission, FCC Report No. FCC-CTB-75-01, May 1975.

MULTIPOINT DISTRIBUTION OF SATELLITE RECEPTION

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The size of satellite receive ground station antennas must be limited in metropolitan areas - both to avoid interference and to maximize the total nationwide satellite information handling capacity. In these metropolitan areas, then, local loops must be used to distribute the satellite signal to CATV systems and other users. MDS systems provide one method for such local loops. The MDS system in concept is similar to the satellite, and many of the economic advantages accrue to both. MDS provides distribution of the signal to any number of reception points, in an economic manner, and with high quality.

Introduction

A common problem of all long distance communications requirements is the final connection at each end to the final user. Thus, in establishing a telephone circuit between two distant points, a microwave or cable circuit is set up between two central offices, and the circuit in question becomes one of the many carried by the microwave or cable. Beyond each control office, local wire pairs are then used to provide the final connection to the end user.

In the case of satellite transmission of television signals, a similar situation exists. Ground stations must be established for both the transmit and receive functions to and from the satellite. Local loop connections are then established to serve the final user (except in those few cases where a ground station can be constructed at the physical site of the final user).

Satellite Reception in Metropolitan Areas

Generally speaking, in a metropolitan area, only a limited number of earth terminals can be established. The two major factors limiting the number of earth stations are signal interference; and the availability of suitable, economically feasible real estate for the receiving antenna.

Satellite transmission today is authorized in the 3.7-4.2 GHz band for satellite to earth transmission, and in the band 5.925-6.425 GHz for earth to satellite transmission. It should be noted that each of these bands of frequency is also used for terrestrial point-to-point microwave. Therefore, not only must there be some interference protection between signals from different satellites, but also there must be protection for interference between satellite and terrestrial systems.

Since Metropolitan areas are natural centers of communication needs, it follows that there are many terrestrial microwave paths into and out of each such area. Indeed, in many metropolitan areas, it is almost impossible to add another terrestrial link in either of these two frequency bands. Thus, additional demands are made on satellite ground stations which must not interfere with terrestrial reception (in the case of a satellite transmit station) and must not be interfered with by terrestrial transmissions (in the case of satellite receive stations). Consequently, finding a location for a satellite station in a metropolitan area becomes quite difficult, and results in a limit on the number of such satellite stations that may be located in that metropolitan area.

The ABC Petition

The American Broadcasting Company has petitioned the Federal Communication Commission to establish definitive licensing and allocation policies and guidelines so the satellite capacity in these two frequency bands will be utilized in accordance with appropriate principles of spectrum efficiency and management. ABC makes the point that satellite capacity in these two bands may be depleted within the next five years,due,at least in part, to the possibility that assignments may not be consistent with appropriate technical and operational criteria. In particular, proposals to utilize smaller size satellite receiving antennas can cause this result.

FCC Rules

The Federal Communications Commission has stated that they will not authorize earth station terminals of less than 9 meters in diameter, unless the applicant can demonstrate that satellite orbital separation need not be greater, and that no other constraints would be placed on the operations of domestic satellites.

If a substandard antenna is used, then terrestrial stations, other earth stations, and space stations can be established without regard to the substandard antenna, and, of course, no protection against interference is provided to the substandard antenna.

The FCC rules also indicate that earth station antennas should be able to be directed to any point on the geostationary arc visible at the earth station location at which the elevation angle equals or exceeds 5°, and that they be capable of being used at all frequencies in the band.

In locating an earth station, interference studies must be conducted to any terrestrial stations within 100 kilometers, and it must be assumed that the terrestrial station uses an antenna specified by the FCC for non-congested locations.

Since earth stations do not have priority over terrestrial stations, and indeed, may even be subject to interference from future terrestrial stations if the earth station uses substandard components, the difficulty of locating earth stations becomes obvious.

Satellite Capacity

If there is an 80° longitudinal arc available for satellites in stationery orbit to serve the continental United States, and if a 4° spacing between satellites is assumed, then approximately 20 domestic satellites can be accommodated.

Studies conducted of message traffic demands (voice and data) show that as early as 1980 these services alone could completely occupy 20 satellites - and if the number of satellites has to be decreased because technical standards for earth stations are relaxed, the problem will become that much more difficult.

The inevitable conclusion must be that only a few earth stations can be accommodated in the metropolitan areas. Distribution of television signals from these earth stations to the final points of use can then be accomplished by appropriate terrestrial facilities.

Local Loops

Depending on the particular circumstances, these local loop facilities can take the form of CARS band system(s), either owned by the using CATV system, or co-operatively owned if several CATV systems are to be served by the earth station; regional point-to-point microwave common carriers; or MDS stations.

Point-to-point microwave systems use relatively expensive equipment for both transmitting and receiving. MDS stations, on the other hand, use expensive transmitting equipment, but employ very inexpensive receiving stations. This results in inherent cost advantages when a number of receiving points are to be served from one transmitting station.

MDS

Thus the MDS station can act as the local counterpart of the satellite service. Nationwide distribution by satellite involves one transmitting station - the satellite - which is very expensive, and many receiving earth stations. The MDS stations, in a restricted area, likewise employ one transmitter, and many receiving stations. The same types of cost advantages result.

MDS, or Multipoint Distribution Service, stations were first authorized by the FCC in 1970. They provide a common carrier service operating at present in the 2.150-2.162 GHZ frequency range. The FCC presently has authorized two channels, each 6 MHz wide, for the top 50 markets in the United States, and one 6 MHz plus one 4 MHz channel anywhere else that a station can be accommodated without mutual interference. Additional channels are being set forth in a Proposed Rule Making expected to be issued by the FCC in the near future.

The 6 MHz MDS channel, for television purposes, contains a vestigal sideband visual carrier, plus an FM aural carrier. These are arranged according to standard television practice. Most MDS receivers are simply frequency convertors, and their output is a normal television signal on any standard or mid-band channel. The receiver output, therefore, can be fed directly into a CATV system head-end.

MDS stations operate with 10 to 100 watt transmitters, with radiated powers of up to 400 to 4,000 watts (56-66 DBM). Most transmitting stations are located at high elevations, since line-of-sight transmission is required at these frequencies.

The coverage area of an MDS station depends on the availability of line-of-sight, and on the gain and noise figure of the receiving installation. The nominal service area is 25 miles, but satisfactory reception has been obtained out to 35 or more miles.

In a metropolitan area where a number of CATV systems are located, either in town, in the suburbs, or both, broadcast quality reception of the satellite signal can be obtained with an MDS station. And that reception can be obtained at any number of reception points, and at any location (provided that line-of-sight can be obtained).

Conclusion

Thus the optimum satellite reception system in a metropolitan area can consist of a large size earth station antenna, reducing the possibility of interference, and maximizing the total domestic satellite information handling capability, coupled with an MDS station to provide unlimited, low cost, local distribution of the satellite signal.

PRACTICAL ROUTINE MAINTENANCE

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The topic, Practical Routine Maintenance, has been broken down into four basic catagories for discussion. The catagories have been placed in what I feel is their order of priority.

1. Equipment Selection
2. Personnel Training
3. Scheduling of Preventative Maintenance, Testing and Procedure
4. Record Keeping

This order of priority should not lead one to believe that, for example, Record Keeping is less important than Equipment Selection. Record Keeping, in normal system planning, is simply approached after Equipment Selection.

Equipment Selection

The major criteria for equipment selection is "cost versus performance". While this is extremely important in system planning, in far too many cases it over shadows two other very important considerations:

1. Dependability
2. Maintainability

Since the "performance" side of the equation in "cost versus performance" is generally derived from either Manufacturers Published Specifications or short term evaluations, the indicated savings of a good "cost versus performance" ratio can easily be offset by loss of subscriber revenue due to a low "mean time between failure" and increased maintenance cost.

This problem can be approached by enhancing the "performance evaluation" to include (1) a long time user inquiry as to failure ratios, major component involved in most common failures, average repair time, manufacturer repair turn-around time and cost; (2) service technicians practical evaluation of maintainability; (3) manufacturers statement as to units in service and warantee repair volume.

Consideration must also be given to future system up grading or improvements. Does the housing size and mechanical lay out of modules provide for future add on with out major changes? How many major changes has a manufacturer introduced during the normal life of a system? Have new generations of equipment totally obsoleted past generations?

Personnel Training

The most frequently missed step in the proper training of Service Personnel relates back to the previously discussed area, "Equipment Selection". In many situations the equipment is selected, ordered and delivered without the Service Technicians involvement. The selection process itself is a very valuable training tool.

Manufacturers provide service for the training of maintenance personnel. These services are available through seminars conducted in central locations throughout the country on a scheduled basis. The key to being apprised of seminars and other training services offered is to assure your place on the "mailing list".

Industry periodicals also provide a source for training. Many articles of a practical nature pertaining to system maintenance, testing techniques and trouble shooting tips are published. A great deal of these articles are written by System Service Technicians.

In the small systems (ie: one technician) training and information may be more difficult to obtain but it is not impossible. Most equipment manufacturers maintain toll free telephone numbers and are more than willing to answer questions whenever possible.

There are many technicians who have questions but do not ask them because they are afraid that the question will appear "dumb" or that the answer will be too obvious to others. Just remember that the only "dumb question is the one which is not asked!

In larger systems (ie: Chief Technicians and two or more service technicians) formal training programs can and should be set up. Such programs can be of your own invention tailored to serve the needs of the particular system or can be of fixed formats such as provided by correspondence schools.

In either the small or the large system "hands on experience" is the best teacher. A great deal of care must be taken to properly plan times and tasks for this type of training as it can be the most costly in terms of subscriber revenue. Over estimating your own or others capabilities can be disastrous!

Scheduling Of Preventative Maintenance Testing And Procedures

Before discussing the scheduling of "Preventative Maintenance" let us first define it. "Intended or serving to ward off harm, disease, etc; a precautionary measure" is the dictionary definition. of the word "Preventative". Maintenance is "The act of maintaining" which is "to keep unimpaired and in proper condition".

From these dictionary definitions we can define "Preventative Maintenance" as those steps which we will take to insure unimpaired service to the system subscriber. The key word is unimpaired, which should indicate not only uninterrupted but also a high quality service. While it is true that customer tolerance to interruptions is very low and their reaction immediate, the corrective action is generally high priority and as long as the frequency of interruptions is low and the reasons valid, customer understanding and retention will be high. On the other hand, a gradual degrading of quality over a long period of time is as insidious as cancer. By the time the complaint is received, in as many as 50% of the cases, the customer has already decided to disconnect and has spread the word to friends and neighbors.

Any well planned Preventative Maintenance Schedule begins by listing the potential problems which could occur by priority and then evaluating the steps which can be taken to prevent their occurance. The following is such a list:

1. Service Interruption
    a) Power Failure
    b) Electronic Failure
    c) Discontinuity
    d) Cable Failure
    e) Drop System Failure

The evaluation of steps to be taken to prevent such interruptions would yield the following:

a) Headend stand-by power is a <u>must</u> as a power outage here would affect 100% of the subscribers. This can be accomplished by a gasoline generator or a battery/inverter configurations.

   Stand-by power at key line power supplies where large percentages of subscribers could be affected by a power outage. Long transportation runs should take first priority.

   Stand-by shelf generators should also be considered for smaller distribution areas.

   Remember in your evaluation that a power primary or secondary outage effecting the line power supply does not affect all subscriber houses.

b) This area requires that adequate system spares are on hand in good condition when needed. The most common problem here is that units are not returned or repaired on a regular basis thus depleting spares stock.

   In many cases, repairs are accomplished at the system level. Care should be taken that <u>only</u> manufacture recommended parts are used for repairs.

c) Two types of discontinuities are possible: 1) Those which come from poor installation practices resulting in "pull outs" due to thermal changes. These problems can be greatly reduced by proper training and follow-up inspection after all splicing. Key points for inspection should be center siezure tightness, connector tightness and weather proofing application. 2) Those which are caused by uncontrollable circumstances such as car/pole incidents, high wind or heavy loading conditions. For this type of outage it is imperative to have on hand the necessary equipment to effect the repairs to re-instate service. You should also have on hand a list of construction contractors who could, on short notice, react to emergencies beyond the scope of the system technical personnel.

d) Cable failure is uncommon as a normal failure, however, rodent damage, vandalism and other forms of breakage do occur. The best preventative action is to inspect the physical plant on a regular basis both from a mechanical viewpoint and the radiation of signals. The latter method is the preferred as it will point up small cracks in the sheath of the cable prior to a breakage occurring.

e) The best prevention of this type of failure is accomplished during the system planning stages. If your system will be subjected to high wind loading or heavy ice loading care must be taken in proper selection of drop cable and associated hardware. Remember, the drop system is as important as the cable system itself and can be the weakest link if not properly planned. Messangered drop cables are available for long drops and for use under the adverse conditions stated above.

2. System Performance
    a) Head End Equipment
    b) System Electronics
    c) System Interfaces
    d) System Passives
    e) Converter or In Home Devices

The above comprises the basic building blocks of the system which require periodic maintenance. In the following evaluation it is important to keep one thing in mind. The final determination of systam quality is made at the subscriber level. While system numbers (ie: beat ratios, noise, cross-modulation,etc.) are important tools to the technician for evaluating his system performance, the viewed picture is the final product which must be delivered and maintained!

a) The Maintenance routine must begin with a physical inspection of the tower installation. It is not necessary to climb the tower for each inspection, although periodic close inspection should be made of connectors, weather proofing and mounting hardware. The normal inspection can be made from the ground with a good pair of binoculars (the power of which is determined by the tower height). The inspection should begin with the most obvious faults, broken antenna elements, unsecured electronic or passive devices, unsecured down leads, loose or broken wench lines and general condition of tower structure and associated guy wires. A few moments should be taken during the close inspection to boldly mark the antenna mounting interfaces with paint to enable the technician to determine proper position during ground inspections (CATV antenna configurations are generally of a relatively narrow beam width and a few degrees of movement can cause signal degradation.) Search antenna rotation should also be checked during all inspections to insure operation when needed.

After completion of the inspection of the tower installation, an inclosure inspection should be performed to evaluate general condition, noting any required repairs. This must include environmental control devices such as heaters and air-conditioners.

If stand-by powering devices are installed, check them for proper operation. In the case of a gasoline driven generator, start it and allow it to run during the balance of the maintenance routine at the head end.

To start the electrical evaluation, all input and output levels are to be checked, comparing them against the levels recorded at the initial system set up. Adjustments should be made to the output levels of all devices as needed to return them to the initial levels. Remember, devices which require frequent or excessive adjustment are probably leaning toward failure. Do not wait until it fails, take action to correct the deficiency at once!

The next step in the Head End evaluation is to inspect the picture quality. In many cases this is performed in a rather loose fashion, not being critical. Since this evaluation is essentially what the subscriber is doing on a daily basis, it should recieve adequate time and consideration. All impairments must be recorded when viewed and investigated as to cause and cure. Electrical properties such as multipath ghosting, co-channel, off air beats and head end generated beats, noise levels, AGC/AFC control windows and frequency stability must also be tested on a less frequent basis.

b, c & d) These areas can be checked by two simple tests 1.) Picture quality as viewed by the subscriber at pre-selected key system location and additional random locations. The quality evaluation should be augmented with recorded levels at the pre-selected key locations. 2.) System radiation testing as covered in the NCTA publication "Signal Leakage and Interference Control". Locations for this test should be random throughout the system to include trunk, feeder and drop locations and should be changed for each test period.

On a less frequent basis, the major system parameters should be tested in detail. As a minimum, frequency vs. gain (both narrow and wide band), signal to noise ratios, carrier to cross-modulation and low frequency components (60 and 120 cycle) must be checked and recorded. For more complex systems, group delay, differencial gain and phase, echo and ingress testing may be added to the list.

e) The subscriber drop system is basically a physical inspection for worn drop cable, loose connectors, staples entering the shield and mounting hardware such as ground blocks and clamps. This inspection can be quickly made during the testing of b, c & d above.

In scheduling test periods remember that the first year of operation is the most critical. The first impression of the subscriber is the most lasting. It is for this reason that I suggest more frequent testing during this period.

For the sake of simplicity, I shall refer to testing and inspections, other than major parameter measurements, as "mini tests" and those which involve large amounts of equipment and time as "maxi tests". The following might be the basis for a 5 year plan of scheduled maintenance:

Year	Mini	Maxi
1	52	4
2	26	3
3	13	2
4	13	2
5	13	2

At the close of each year, an evaluation of the program effectivness should be made and the schedule adjusted accordingly.

There are many test methods for maxi testing, using various cost reletive equipment packages which are industry accepted as yielding valid results. The methods for your particular system should be selected according to cost, technician competence and availability (you may choose to rent test equipment on an as needed basis, thus rental availability is very important.) Once methods are selected they must not be varied test period to test period. Variations in methods of testing may yield variations in results which are not comparable to previous tests performed.

Record Keeping

Through this paper various areas of inspection and testing have been referred to, with the intent to "satisfy the subscriber" with a full time quality product. All of these steps are in vain if five years from now you are unable to establish their effectivness.

The most important record, other than that of payment, is the "Service Call Record". If it is properly thought out and filled out, the SCR will tell you the cost of service calls and the weak points of the system causing this cost. The SCR should include:

1. Date and time initiated
2. Basic complaint
3. Customer name and account number
4. Date and time given to technician
5. Technicians report of failure
    a) Fine Tuning
    b) Set Problem
    c) Drop Failure
    d) Distribution System Failure
    e) Trunk Failure
    f) Power Interruption
    g) Head End Failure
    h) Other
6. Corrective action taken
7. Date and time completed
8. Customer signature

At the end of each week a consolidation should be made showing:

1. Total number of SCR's
2. Total of each type of failure and percentage of total SCR's
3. Total time expended
4. Disconnects due to service problems

This report can be a valuable tool to management. For example if 50% of the service calls involve fine tuning of TV sets, he may choose to send out information bulletins to the subscriber base for training purposes, thereby reducing service cost in this area and applying it to the preventative maintenance area.

Records of both mini and maxi test results and dates should be consolidated on a running spread sheet for direct comparison purposes. This record will show up degredation trends at a glance.

Remember, also, that test equipment requires maintenance and calibration. Records of this must also be kept.

When laying out your record keeping program, first establish your objectives and then devise your forms to provide the desired information in an easy to read format. Cumbersome, long and complicated forms very seldom get filled out completely or properly. Use basic catagories and "check blocks" where ever practical.

Summary

The topic of Practical Routine Maintenance is a very broad one and can be very "dry", but is very important to the success or failure of a CATV system. In the practical world a satisfied customer is a paying customer, thus I have invented a new formula, for those who like equations,

$$PM + PA = SS$$

"Preventative Maintenance plus Positive Action equals Satisfied Subscribers" which is the entire point of this paper.

REGULATORY ASPECTS OF EARTH STATION LICENSING

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The Domestic Satellite plus means for local distribution or collection of signals provides a new parameter for the expansion of national communication services. A number of regulatory practices, which may not be a true reflection of Commission policy, seem to be obstacles for the broad development of these new services. Limitation on the authorization of earth station signal reception and on inter-connection of facilities for the use of such received signals is considered one such obstacle. This problem is considered here in detail and a solution which may be consistent with present Commission policy and authorized communications service is proposed.

The promise and the potential of the communications satellite is its "anywhere to everywhere" characteristic. Satellite communications makes this kind of service possible for tremendous geographic areas without introducing the traditional parameter of distance. It permits new efficiencies through multiple re-use of the same portion of the frequency spectrum for any earth station terminal and simultaneous reception of the same signal at any number of receiver locations. Transmissions require only three principal parts - an input terminal - a single relay point - and an output terminal. Such simplicity of transmission inherently incorporates two highly desirable ingredients that are essential to the flowering of full social and commercial use of communications. These are

1. Quality
2. Economy.

True the single relay point is expensive, sophisticated and inaccessible. Although it incorporates a multitude of the recent wonders of our space age technology, although it required tradition breaking, bullet biting conceptualization, implementation and risk taking by a large number of dedicated individuals and entities, it is simple in its basic concept and amazingly reliable in its operation. Space stations are being engineered for an active life of seven to ten years. They operate in what has always been considered a hostile and isolated environment. Apparently, its working environment is less hostile than the knob twiddling, power interrupted, weather scourged, cascade degradated, topography limited and access demanding communications facilities that we have traditionally associated with land lines and terrestrial microwave.

Once this anywhere to everywhere link is established there remains the problem of terminal point transmission to or from the point of use or origination. Broadband cable is an obvious, economic and totally compatible means of local delivery of signal to or from either dedicated or all inter-connected terminals within a community. Other speakers on this panel have or will detail and recommend other ways of local distribution - either in place of cable or in cooperative conjunction with cable. But whether the satellite terminal is co-located with the point of use - be that a school, a community center, an industrial plant or even a private home; or whether the local distribution is by cable, broadcast, MDS, or by private or CARS or common carrier microwave, or even by a telephone company local loop - the long line function can be, is and will be admirably served by satellite networking.

As wonderful and efficient as satellite networking is in principle and operation, there seems to be a serious flaw in the establishment of the "anywhere to everywhere" concept. That flaw is not technical, or physical or even economic - it is in the multiple roadblocks spawned by natural regulatory precedent, caution, politics, protectivism, routine priorities and workload. I am sorry to say that I believe many of these obstacles, which are natural and possibly even desirable under a bureaucratic system of control, are greatly encouraged or magnified by powerful, experienced and established forces which rightly or wrongly believe that their own special interests would not be served by the proliferation of the satellite concept except for their own use.

This paper might occupy its brief slot of time or space by naming a number of examples of regulatory obstacles - including the question of small earth terminals and including the increasingly serious problem of finding suitable locations for up-link transmission without danger of interference to those terrestrial services which "equally share" the 6 GHz earth-to-satellite band. I prefer, however, to concentrate these remarks on one area of concern. I hope that with sufficient industry and public support the logic and reasonableness of the solution can successfully tilt this windmill of regulatory practice.

Let us consider the case of authorized signal carriage for a licensed satellite receive-only earth terminal. Government policy, affirmed by the Federal Communications Commission, allows Domestic Satellite Communications to operate under the "open sky" concept. This means that anyone who can demonstrate satisfactory legal, financial, technical and other qualifications can apply for a satellite facilities license - even including a space station. Domestic service is not intended to be a facility for the exclusive use of a major common carrier or, as ABC recently proposed in its Petition for Rule Making, for the exclusive use of the broadcast industry. This policy is a positive and healthy recognition of the "anywhere to everywhere" concept and encourages the national proliferation of satellite facilities. Nevertheless, satellite licensing was assigned to the Common Carrier Bureau and is largely controlled by established common carrier rules and precedents drawn from an extension of common carrier terrestrial microwave and international carrier traffic control.

Receive only earth station applicants have been urged - in fact required - to submit engineering coordination data showing that the station complies with rules governing interference over the entire 4 GHz satellite-to-earth frequency band. They are required to provide such coordination for all of the possible domestic satellite orbital stations from 70°W to 150°W longitude in the Equatorial Plane. Notwithstanding this general nature of the application, Form 403, entitled "Application for Radio Station License or Modification Thereof Under Parts 21, 23 or 25" must be filed and approved for any change (Part 25 of the Rules relates to Satellite Communications). Modifications covered by this form include change in frequency, power, control points, points of communication and a catch-all called "other particulars".

The Bureau also asks for proof of a station's authority to use received signals and the license authorization stresses that "these facilities shall be used for the reception of only such programming material that the permittee has been authorized to receive and use, by the owner". Such a warning is certainly appropriate as a reminder. It is obvious that property rights and authorization for use by the owner of the baseband signal must be observed. But protection and relief in such instances is probably not a matter of Common Carrier Bureau responsibility certainly not before-the-fact. After-the-fact the Bureau's concern should be only when court ordered penalties are directed.

The Bureau goes further, it seems to assert de facto control over the type and content of the signal, possibly in conflict with rights guaranteed under the First Amendment. An earth station authorization for a cable system operator contains the restriction that it be "solely for the purpose of providing <u>program reception</u> services" for his own cable system or "on a non-profit basis to other cable television systems operated by affiliated companies under common corporate control with the grantee". (emphasis added) He must file this information with the Bureau, including "identification of the terrestrial facilities utilized to interconnect".

Further control is exerted over the space relay station carrier regarding the type of signal the space station may carry and where it may be received. Section 214 of the Communications Act, which relates to "Extension of Lines" has been interpreted to require a "certificate of necessity" for the construction and/or operation of such line extensions by a common carrier. I suggest that it is extremely doubtful that a satellite space relay licensee authorized to place a usable signal over a specified geometric area, is "extending its lines" each time a receiver is constructed within the area served.

Each of these practices and requirements in effect give the Common Carrier Bureau a powerful control over message content and use of a satellite earth terminal, which I believe is far in excess of any technical or traffic control regulation and user qualifications intended by the Communications Act. Enforcement is made effective, if not by outright denial of authorization, then by the process of delay. This is regulation by procedure rather than by policy or rule. It is regulation by staff rather than Commission. I am not suggesting that this is a nefarious scheme on the part of the Bureau. Lacking positive direction to the contrary, by the Congress or the Commission, it is a cautious treatment of a new communications parameter from the point of view of the familiar and the traditional. It follows the logical reasoning that "we must think this thing through" being subverted by the practical problem of not having time in which to do the thinking. I suggest however that there is a logical solution to this problem which could be adopted as standard practice by the Bureau. It would relieve the decision making of what is good and what is bad. It is a solution that is totally consistent with and supportive of the Commission's existing rules -- its policy and practice.

In the case of cable television the Commission has already defined as being in the public interest and authorized by Report and Order and by Part 76 of the Rules, the communications services permitted and required of a cable system. These rules relate to the reception, carriage and distribution of communication signals within a properly franchised area for an operator to whom a certificate of compliance has been issued. In fact the Commission and individual Commissioners spent many many years, engaged in many public hearings, studied many staff reports and debated many policy issues before making the decisions which now form the rules for cable service. It does not seem to me to be the duty nor does it come under the authority of the Common Carrier Bureau to independently repeat these deliberations or to rethink, reapprove - or worse, set aside, frustrate or even unduly delay implementation of the rulings or policy decisions that the Commission has already issued. Now let's consider, what are the communications services authorized for a cable television system operator.

It _is_ the business of a cable operator to receive communications signals from whatever source and, in accord with the Commission's rules, deliver them to points of use within his authorized area of service. Note, I stress communications signals - and not "programming material" specified in the Common Carrier Bureau Earth Station Authorization. What kind of communications signals did the Commission have in mind for a cable system? Television programming including pay cable is certainly part of the service. What else? I could not have given better examples myself than the illustrations given in Footnote 10 of the Cable Television Report and Order. *

It _is_ the business of a cable operator to "lease channels" on his cable system to others who may have a dedicated use for the signals carried on that leased channel. Not only _may_ a cable operator lease channels on his cable system, he _must_ provide leased channel service. Furthermore, when this type of use exceeds his capacity to offer service he must provide additional capacity.

It _is_ the business of a cable operator to interconnect with other cable operators, regardless of whether they are "operated by affiliated companies under common corporate control" or non-affiliated cable television systems. The Commission does not specify or limit the means by which this interconnection may take place. It could be a direct hand-off through the subscriber cable; it could be an express cable which runs between the head-ends of two contiguous cable systems; it could be a CARS band delivery, by point to point or LDS; it could be by hand off to a common carrier using land line or microwave, including MDS, for delivery to the interconnected system.

I maintain that this is the legitimate business of a cable television system and that authorization and regulation of the Cable Television Service by the Commission constitutes the necessary precedent for automatic approval by the Common Carrier Bureau for earth station reception of any cable service related signal. The same reasoning applies to any other private user/operator of a satellite earth terminal. If that earth station licensee is authorized to provide communication services in accord with an established part of the Commission's Rules, he should be authorized to receive those signals at his earth station. A broadcaster, an MDS operator or a private microwave licensee as well as a cable operator could be confident that signals used in his business or authorized service can be received by his own earth station and interconnected by any appropriate means without regard to or limitation on any prior handling of that signal.

Therefore I recommend to the Common Carrier Bureau that satellite earth station operation by private owners be authorized, under the license, for reception of any or all signals from space stations licensed in the U.S. Domestic Satellite Service, provided·

(1) the signals are transmitted within the coordinated frequency band and orbital arc of the licensed satellite earth station;

(2) The satellite earth station is within the authorized service area of the space relay station;

(3) The satellite earth station operator acknowledges that he must be contractually and legally eligible to receive the signals;

(4) The signals are received at the satellite earth station

a) for the private use of the station operator, or

b) are used by the station licensee in connection with communications services that he has been authorized to provide under existing Commission Rules.

We, as cable operators and satellite earth station applicants are not innocent of responsibility for the arbitrary limitations on signal reception that have developed. We have had as our objective the immediate use of an earth station for access to a specific program channel. Therefore we have not been too concerned by a limitation of authorization. In fact we've been advised that any attempt to extend the authorization beyond these limitations - including shared use or interconnection with others - would surely cause delays that would materially affect the primary and immediate use of the station. The time has now come to determine if such limitations of the use of an earth station is truly a reflection of Commission policy, or an unnecessary expedient whose purpose, intentional or otherwise, is to limit communication service opportunities of the developing technologies for the interest and benefit of the American public.

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Footnote 10 36 FCC2d 143 (1972)

* "Facsimile reproduction of newspapers, magazines, documents, etc.; electronic mail delivery; merchandising; business concern links to branch offices, primary customers or suppliers; access to computers; e.g. man to computer communications in the nature of inquiry and response (credit checks, airlines reservations, branch banking, etc.); information retrieval (library and other reference material, etc.) and computer to computer communications; the furtherance of various governmental programs on a Federal, State and municipal level, e.g. employment services and manpower utilization, special communications systems to reach particular neighborhoods or ethnic groups within a community, and for municipal surveillance of public areas for protection against crime, fire detection, control of air pollution and traffic; - - - - - - - - "

SHF - NEW QUALITY FOR CABLE TV

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ABSTRACT

The quality of the signal received by cable television systems would be improved if there was a more direct link between broadcast studios and cable systems. Such direct links have regulatory and legal obstacles. Television broadcasting using frequency modulation at SHF (12.2-12.5 GHz) would provide a very high quality signal feed to cable television systems and others while overcoming the legal and technical problems associated with direct signal delivery schemes previously considered.

INTRODUCTION

Cable television will not become a meaningfull factor in society until it successfully penetrates our major cities. While those in our industry who are concerned with the legal and economic problems affecting big city prospects for cable television try and overcome these problems, we who are concerned with engineering aspects of the industry must simultaneously overcome the engineering problems. Transmission quality is one of the major parameters to be considered in the overall engineering of cable television systems for major cities. At our present stage of development of cable television technology we have achieved a high degree of capability in our distribution systems. Amplifiers, cables, signal processing and system design have all advanced significantly in the last few years. The present state of the "distribution art" in cable television is now advanced to the point where we can profitably direct our attention to improvements in other aspects of the whole television system. This paper proposes some improvements in the link between the broadcaster and the cable system.

THE STUDIO-CABLE LINK

Television program production has achieved a very high degree of picture quality. Cameras, film chains, video tape recorders and all the transmission equipment used to interconnect studios, network centres and transmitters have all achieved excellent performance standards. We may now concern ourselves with some improvements in the link between studio and cable system, particularly the television broadcast transmitter and the signal path from transmitter to cable system.

The high power broadcast transmitter has a very difficult job to do. It must take a complex baseband signal and impress it on a very high power carrier for transmission. The visual carrier transmitter is required to operate linearly at power levels of up to 55 KW peak power. By contrast, the peak power per channel typically used in cable television equipment does not exceed 0.0001 watt (-40dBw). Broadcast transmitter powers are almost 90 dB greater than cable system levels. Our experience in a number of situations has been that we can provide a noticeably better picture to our subscribers if we have a direct feed from a broadcast studio instead of an "off-air" pickup from a high power transmitter. The "off-air" pickup is further degraded by the probability of some multi-path distortion in even good quality "off-air" reception.

We have, over the years, had several cable system head-ends co-located with local broadcaster's transmitters. In such situations we have preferred to obtain a "direct feed" from the local broadcaster, bypassing his transmitter. We have also tried "direct feeds" from the output of the transmitter, obtaining our signal from a small probe in the output transmission line, thus avoiding any possible problems in propagation from transmitting antenna to a receiving antenna. Even in such cases we preferred the quality obtained from a good quality, low level modulator fed directly from the broadcaster's video line.

The broadcaster has good quality transmission in his STL (Studio Transmitter Link). This STL is usually a high quality FM microwave system. Alternately, it may be a high quality video cable link. We are convinced that our picture quality in big city cable systems would benefit considerably if we could extend the broadcaster's STL right through to our cable system, creating a direct link from broadcaster to cable systems.

LEGAL CONSIDERATIONS

Our existing direct links with broadcaster's are strictly informal. Broadcasters' program *rights cover broadcast only. They do not have the right to provide programs on a closed circuit basis. Our efforts to extend our use of direct broadcaster-cable links have been blocked by these legal considerations. Negotiations to obtain such direct connection rights for all of the programs in a broadcaster's schedules have been very slow and frustrating.*

A SOLUTION - SHF BROADCASTING

We believe that the problem could be overcome by the use of SHF (Super High Frequency) television broadcasting. ITU Region II encompasses the Western Hemisphere. The band 12.2 - 12.5 GHz is allocated in Region II to "Fixed", "Mobile Except Aeronautical Mobile" and "Broadcasting". The band 11.7 - 12.2 GHz is also allocated to "Broadcasting" and other services but these other services include "Broadcasting-Satellite" and this band would have to be shared with satellite broadcasting services. The use of frequency modulation technique coupled with omni-directional broadcasting of this signal would, in effect, extend current STL techniques right out to the cable system head-end. We propose that broadcasters would apply to operate high power SHF transmitters in parallel with their present VHF or UHF transmitters. An SHF transmitter would be a conventional FM microwave transmitter, as presently used for high quality STL service, driving a power amplifier to provide several thousand watts of power into an omni-directional transmitting antenna. The amount of RF power required can be estimated by comparison with conventional STL type microwave systems. A 1 watt transmitter feeding a 6 foot diameter antenna has an ERP of approximately +45 dBw. Achieving the same ERP with an omni-directional antenna of about 15 dB gain requires a transmitter power of about +30 dBw (1,000 watts). RF power for frequency modulated carriers is easily achieved at SHF frequencies at relatively low cost with klystron amplifiers. Klystron amplifiers in the 1,000 to 10,000 watt range are available and many are being used as satellite up-links and in special purpose military systems.

Antennas with circular polarization would be desirable to help reduce the effects of multi-path propagation. This is probably not essential because receive antennas of modest diameters achieve considerable directivity. A 6' diameter receiving antenna has a half-power beam width of about one degree at 12 GHz.

SHF broadcasts would be available to anyone within line of sight range. Because of the relatively high cost of the FM receivers required it is likely that only cable systems and larger MATV systems would avail themselves of the service. Any future developments in satellite broadcasting would use frequency bands and transmission techniques similar to this proposed terrestrial service and any improvements in the performance and costs of receiving systems for satellite television broadcasting would immediately benefit this terrestrial service as well. Cable systems have nothing to fear from such developments. I believe that cable service, where available, will always be more attractive a proposition than direct reception of either terrestrial or satellite broadcast services. Transmission at these frequencies is strictly line of sight. Anyone not having a clear and direct line of sight to the terrestrial or satellite transmitter will be dependant on some kind of cable service as an intermediary.

DEVELOPMENTS ABROAD

There is considerable experimentation with terrestrial SHF broadcasting in Europe and Japan. Propagation characteristics have been thoroughly investigated and considerable work has been done in developing the equipment and antennas required. Even the UHF band is becoming saturated in some of these areas and SHF is looked upon as a natural means of expanding television broadcast services. Both FM and VSB-AM techniques are being explored. Figure 1 shows two types of antennas being used in experiments in the Netherlands. The bibliography appended to this paper lists some of the papers and reports describing these experiments.

PROSPECTS IN NORTH AMERICA

In centres where cable television is firmly established, broadcasters are increasingly dependant on cable television systems as part of the link between studio and viewer. In the Toronto region where there are now almost one million cable homes we estimate that 90% of all viewing of UHF stations and about 50% of all viewing of VHF stations is by cable. Broadcasters in such situations must be just as concerned about the quality of their links to cable systems as they are concerned about the quality of their more direct links to viewers. We believe that broadcasters in such a situation can be persuaded to provide more direct and higher quality links to cable systems. Early discussions of the subject proposed point-to-point microwave services but ran into the legal problems previously discussed and the technical and logistics problems of providing direct point-to-point microwave service to a very large number of cable systems in a metropolitan area. We hope that an omni-directional microwave service - SHF broadcasting - can overcome both the legal and technical problems of providing these direct studio to cable links.

Initial experiments await the confirmation of spectrum allocation at the forthcoming World Administrative Radio Conference (WARC). We have made representations to the Canadian government asking them to confirm the present ITU allocations with a view to early implementation of the terrestrial SHF broadcast services we have proposed, as well as satellite broadcast services.

BIBLIOGRAPHY

G. F. Koch and H. Thielen

BIBLIOGRAPHY

G. F. Koch and H. Thielen -
Transmitting Antenna with Cosecant-Shaped Vertical Pattern for 12 GHz Television System, IEEE Transactions on Communications, Vol. COM-22, No. 9, September 1974 pp 1391 - 1393

K. Sakowski -
Planning Parameters for Terrestrial Broadcasting in Band VI, NTZ Journal, Vol. 26, No. 5, 1973, pp 228 - 233

J. W. A. van der Scheer -
Distribution and Broadcast of TV Signals in the 12 GHz Band, International TV Symposium, Montreux, 1974

T. Saito et al -
Omni-Directional Biconical Horn Antenna Using Metcal-Plate Lens for SHF TV Broadcasting, 1973 G-AP International Conference, Boulder, Colorado, pp 379 - 382

T. Saito et al -
NHK Kinuta SHF Experimental Station, NHK Laboratories Note #150, January, 1972

T. Saito et al -
NHK Kinuta SHF Experimental Station, NHK Laboratories Note #182, October 1974

Forschungsinstitut Der Deutschen Bundespost Beim Fernmeldetechnischen Zentralamt (Darmstad) various internal and published reports

SOLVING INGRESS PROBLEMS OF FOREIGN SIGNALS

Walter O. Gerber

Guam Cable TV System

The entrance of foreign signals into a CATV System can cause serious problems. There are off-the-air carriers throughout the spectrum used in CATV. The unwanted signal on your system can disrupt service and cause a flood of customer complaints. The following is an inexpensive, field proven method to locate the exact point where ingress of foreign signals can occur.

The entrance of foreign signals into a CATV System can cause severe problems whether you have 30 channels with dual pilot carriers, or less than 12 channels with no pilot carriers. The most common problem exists in the 73 MHz region which the FCC has allocated for aircraft beacons. Ingress of signals at this frequency can disrupt your pilot carrier causing erratic or no automatic gain control. The citizens' band operates at 27 MHz, and the second harmonic falls at television channel 2; the third harmonic is in television channel 6. It is possible for a citizens' band carrier to enter your system and disrupt both channels. The military is allocated the area from 7 MHz to 29 MHz, where two-way return with data is carried on your system. Entrance of even a low level of foreign signal in this area can make the return signals unusable. From 108 to 162 MHz is a combination of allocations for both civilian and military use. Ingress of outside signals in this region could ruin one or more of your mid-band channels. Above channel 13, 230 MHz to 400 MHz, is radar and other communications which can cause trouble in the low channels of your super-band. In short, the entrance of foreign signals into your system can cause sleepless nights and angry customers. Also, if outside signals are getting in, CATV signals are getting out and you are most likely in violation of FCC radiation limits.

Until recently there has been no tried and true method to locate the point of ingress. A device has been recently placed on the market that is said to perform the task. However, the price is $1,000. Having a serious ingress problem on my hands and not having a grand to plunk down on a new gadget, I developed a simple and inexpensive method which proved satisfactory in the field. Basically, all you do is apply a strong signal into your system so it will radiate out, a signal you can easily detect. Find the point where it radiates out and that's where the foreign signals are getting in. Use a dipole antenna connected to a signal level meter with an audio detector circuit. Drive along the system and listen for the radiated signal. Although this method was field tested on an overhead system, it can be used on an underground system. The transmitters in your area may make it difficult or impossible to hear the signals radiating from your system. The secret to the success of this whole idea was to modulate the system signal with a 1 kc tone. It is easily distinguised from any off-the-air signal.

Apply the 1 kc tone modulated signal to your system so its level is 40 db above normal system levels. A higher level of signal can cause limiting in the amplifiers.

My particular problem was the signal of several military transmitters getting into the low-sub system from 7 MHz to 29 MHz making channels T-7 and T-8 unwatchable. The presence of the high powered transmitter near the system made it impossible to hear the radiated system signal. I used an R. F. signal generator with an output capability of 50 DBMV that had a built in 1 kc tone. I applied the tone modulated signal to the system by connecting the R.F. generator to the input of the low-sub post amplifier. A standard head end may require the use of an amplifier after the R.F. generator to obtain the necessary signal level. With all other carriers removed and the R.F. generator tuned to 25 MHz we began the search. With the dipole antenna connected to the signal level meter we drove along the system. I used a Jerrold 727 meter which has a built-in speaker. We found meters which required the use of an external earphone effective; however, the Jerrold 727 proved easiest to use. Driving along the system, we first heard the tone 4 poles away from a bad splice. The tone grew considerably louder as we approached the splice. As we passed the splice, the tone reached its maximum volume and began to decrease in volume as we moved away. After replacing the splice we could detect no trace of the tone. Continuing the search we found three other locations where the tone was heard. When all locations were repaired, all the foreign signals were removed from the systems making channels T-7 and T-8 usuable.

To use this method to test a return line ingress problem on a two-way system, connect the signal generator to the input of the return amplifier farthest out from the head-end. The output of the generator plus the gain of the return amplifiers will provide enough signal to radiate out and be detected by the antenna and meter.

I stress the use of an R.F. signal generator, however, another signal source may be used. Success depends on using a 1 kc tone. Have the tone-modulated signal operating at an R.F. level as high as possible. If limiting occurs, lower the R.F. level of the test carrier until the gain of your system amplifiers restores and begin the search. WHERE YOU HEAR THE TONE, CATV SIGNALS ARE GETTING OUT AND FOREIGN SIGNALS CAN GET IN.

SPACE TELECOMMUNICATIONS - THE FUTURE IS NOW

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Abstract

The present communication satellites used for international and domestic traffic employ low-powered transponders. This characteristics is compatible with the mission of interconnecting a few earth stations in a high density traffic mode. From the total system viewpoint when there are a small number of earth stations, it is economical to spend more on the earth station and minimize the cost of the satellite segment.

However, if the number of earth stations is large, it is far more economical to reduce the size and cost of the earth terminal and increase the power (and cost) of the spacecraft. The total systems cost is lowered by the reduced cost of the total ground segment.

Communications experiments with the Applications Technology Satellite-VI and the Communications Technology Satellite, both high-powered spacecraft, broadcasted to low-cost earth stations. These experiments demonstrated that low-cost, good performance earth stations are a reality.

INTRODUCTION

Space Telecommunications has advanced dramatically in the past decade. Television via satellite is viewed daily on news broadcasts. A good case in point is the recent coverage of the Winter Olympics. The concept of large earth stations being required to receive high quality television signals however, is erroneous. The state-of-the-art has advanced and the technology proven that the total system can be planned and implemented according to the demands and needs of the user.

U.S. DOMESTIC COMMUNICATION SATELLITE SYSTEMS

The United States Domestic Communications Satellite Systems incorporates the ultimate in space technology. Design life-times of seven to ten years are the norm. Twelve to twenty-four transponder channels are available. Antennas cover the lower forty-eight states with spot beams available to Alaska, Puerto Rico and Hawaii. However, all transponders are low-powered, i.e., normally 5 watts per channel. With the associated antenna gain, effective isotropic radiated power (EIRP) ranges from 22 dBw to 33 dBw. These powers fall within the allowable power flux density limitations and are compatible with the mission of interconnecting a few earth stations that operate in in a high density traffic mode.

The receive earth-stations operating in the 4 GHz band are large, sensitive and expensive terminals. Figure-of-merit ranges from 30 dB/^{o}K to 41 dB/^{o}K with antenna sizes from 10 meters to 30 meters. These terminals are capable of multi-channel telephony and high quality video performance. A receive-only capability earth station costs will start about $65,000 for a ten-meter antenna with a transistorized front-end.

The synchronous orbital slots that are available are rapidly diminishing. Protection from interference requires spacing and the orbital arc that enjoys good look angles for the earth stations is limited.

The spectrum at 6/4 GHz shared with terrestrial services provides 12 thirty-six MHz channels.

THE APPLICATIONS TECHNOLOGY SATELLITE VI

The Applications Technology Satellite (ATS-6) is a multi-purpose experimental satellite. The spacecraft, launched in May 1974, contained many scientific and technological experiments onboard as well as a complex communications payload. The main feature of the satellite, a nine-meter parabolic antenna, provided a remarkable departure from the conventional spacecraft. The effective isotropic radiated power (EIRP) at S-band frequencies was 52 dBw (180,000 watts). The Health/Education Telecommunications (HET) Experiment conducted by the Department of Health, Educztion and Welfare deployed 119 small earth terminals in isolated regions of Appalachia, the Rocky Mountain area and the states of Alaska and Washington.

It was the high power of ATS-6 for HET experiment that reduced the size (and cost) as well as the complexity of the earth terminal. Operating in the 2500 to 2690 MHz band, the terminal consisted of a 3 meter antenna, an outdoor preamplifier unit mounted on the antenna, and an indoor unit which demodulated and processed the signals to provide, as outputs, the video and associated aural signals at baseband. The figure-of-merit of the earth station is 7.2 dB/^{o}K. The earth terminal is procured for the HET experiment cost less than $4,000 each (FOB) in 1973. The current estimate in quantities of 100 or more is approximately $5,000 each. The earth station weighs about 320 kilograms (700 pounds) and can be installed in one day by two men.

The receiver is capable of receiving either of two TV channels provided by ATS-6. Also four aural channels are available with each video channel.

Data collected during the nine months of the HET experiment, with the earth stations operated by non-technical users, indicated a median peak-to-peak video signal-to-weighted RMS noise ratio of 51.1 dB.

In considering the cost of the entire system, it would be unfair to weight the total cost by the cost of ATS-6, since the spacecraft was developmental and included a multi-discipline payload (over 25 experiments). The multi-discipline payload not only added directly to the cost but also added weight which created the high launch costs. The cost of a spacecraft operating with the same EIRP, frequencies and number of channels is estimated to provide a more fair comparison. The simplified satellite consists of an earth-coverage horn, a 6 GHz receiver and a two-channel S-band transponder with a shaped-beam antenna. The spacecraft provides a 50 dBw EIRP and it is assumed to be launched on a 3914 vehicle. The estimated total system cost (1976 dollars) are:

Spacecraft	*$15.0 M*
Up-link Station	*.30M*
120 video receive terminals @ $5K ea	*.60M*
	$15.9M

There are limiting issues to be addressed if such a system were planned to be operational. Orbital occupancy in this case would be determined only by the choice of 6 GHz as the up-link frequency. The S-band down-link is restricted in power flux density, but the use of energy dispersed signals will allow this ERIP. Terminals will most likely be only located in rural isolated regions. The metropolitan areas, having Instructional Television Fixed Service (ITFS) and Multi-point Distribution Service (MDS) would present a serious coordination problem for small earth terminals.

THE COMMUNICATIONS TECHNOLOGY SATELLITE (CTS)

The Communications Technology Satellite (CTS) is another experimental satellite. A joint venture between the Department of Communication, Canada, and the National Aeronautics and Space Administration, CTS was launched in January 1976 and also provides a high ERIP. A 200-watt travelling wave tube amplifier (TWTA) over 50% efficient, operating in the 12 GHz band provides 59 dBw on beam center. The antenna coverage is larger than ATS-6 (2.6 degrees compated to 1.0 degrees). The earth-station, as presently configured, consists of a 1.8 meter antenna, an outdoor translator and an indoor unit for demodulation. Since CTS (like ATS-6) has no north-south station-keeping, motorized vernier adjustments of the antenna is provided for operation. The earth-stations as procured for CTS experiments, cost $10,800 each in quantities of two. The earth station weighs approximately 110 kilograms. These earth stations are capable of receiving one TV channel and four associated aural channels.

As of this writing, the spacecraft is undergoing in-orbit tests by NASA. Early video performance test indicate received carrier levels ±0.5 dB of pre-launched calculated values. These calculations predict a clear weather peak-to-peak video-to-weighted RMS noise of 54 dB.

As in the case of ATS-6, for total system costs, a spacecraft, sized to provide the same EIRP, frequency and channels such as the Japanese BSE, is used for total system cost comparison.

Uplink costs for CTS, capable of providing the wideband TV signals are still comparable to domestic up-links. The total system cost is summarized below:

Spacecraft	*$15.0 M*
Up-link	*.3 M*
120 video receive terminal @$10K ea	*1.2 M*
	$16.5 M

Since CTS operates in the 12/14 GHz frequency bands, coordination of orbital slots with future systems would be required. The Satellite Business System satellites planned for 1979-1980 use this same band. At the present time coordination with terrestrial facilities are minimal and there is no power flux density limitation above 10 GHz.

COMPARISON OF TOTAL SYSTEM COST

In comparing the three-systems' total cost of the ground segment and the space segment, assume each satellite would be launched on the same type of vehicle (e.g. Delta 3914). The initial cost consists of the satellite and an up-link transmitter and a receiver. In order to properly weight the cost of the satellite, the spacecraft cost is divided by the number of usable transponders yielding a unit, dollars/channel. Then the cost of additional earth stations is added to provide the curve shown in Figure 1.

Two curves are indicated for the C-Band system. Curve #1 reflects the more sensitive earth station (G/T 41 dB/°K); curve #2 the less sensitive earth station (G/T 27 dB/°K). The Ku band and S-Band systems use the previously mentioned prices with no learning curves applied.

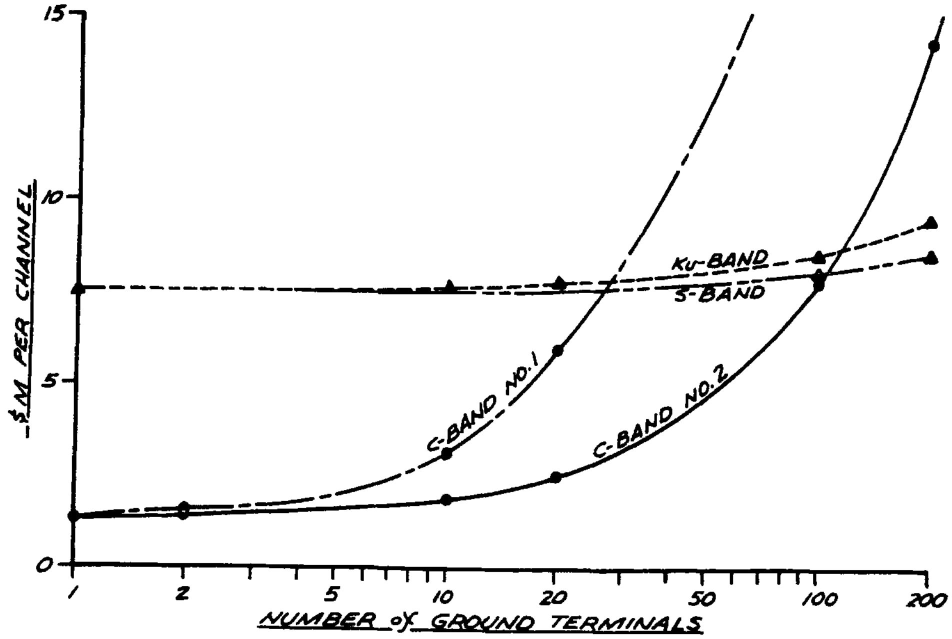

FIGURE 1

CONCLUSIONS

The technology exists to provide high quality communications to relatively low earth stations. The total system requirements (present and future, allowing for growth) must be determined and the system can be sized economically. The major decisions are not to be made by the technologists but by the user community. If the market is available the interprenuers of the commercial satellite systems can and will provide the capacity.

TECHNICAL EYE OPENER

ALPHA NUMERICS AND NON-STANDARD BASEBAND FORMATS IN CABLE

SPONSOR -- SOCIETY OF CABLE TELEVISION ENGINEERS

The use of alpha numerics on cable is already wide-spread and data transmission is close behind.

The purpose of this session is to shed some light on the hardware considerations in the application of non-standard baseband formats, such as alpha-numeric display, data, and other test signals, when imposed upon the composite parts that make up the total CATV system. The effect on the quality of the signals delivered, the behavior of receivers, modulator requirements, and the impact on other signal carriage by the system will be treated in some detail. In particular, time will be devoted to show how non-standard video formats must be processed and shaped to provide compatible visual and aural signals for the home TV set. A discussion of commercial data applications and the use of FM modulators on cable for high quality point-to-point transmission will also be included.

The background of the panel and those making presentations is from broadcast, cable operations and manufacturing -- to explore most of the facets of this timely subject.

A description of an application of wideband FM on cable in terrestial land line will provide a bridge with the Wednesday morning session on practical earth station considerations.

PANELISTS

James Dalke
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Robert Dickinson - President
E-COM
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Robert McAll - Northeast Manager
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Hicksville, New York

Donald Lolli
Catel
Mountain View, California

MODERATOR

Steve Dourdoufis - Vice President
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PRACTICAL CONSIDERATIONS FOR TERRESTIAL RECEPTION AND DISTRIBUTION

SPONSOR -- SOCIETY OF CABLE TELEVISION ENGINEERS

The presentations and panel discussion outlined for this session will focus on the every-day considerations in the purchase, design, installation and operation of satellite fed earth stations. The participants on the panel will take the audience from initial planning through final installation, operation, and maintenance of the associated hardware. A discussion of design considerations relative to placement and positioning of satellites; a discussion of the interference considerations and licensing requirements; a discussion of site acquisition and costs; a discussion of the set-up and environmental considerations; a discussion of immediate and long-term uses; and a discussion of the operation, maintenance, and reliability of equipment and path, will collectively ensue from the inputs made by various panelists representing all of these various facets of the subject matter. A question and answer period closes the program. Technical papers will be available from several of the panelists.

PANELISTS

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THICK FILM TECHNOLOGY FOR PAY TV SECURITY; THE T.E.S.T. SYSTEM

by

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Abstract

The TEST System for pay-TV security consists of adding a modulated rf signal to the pay-TV channel transmission. The frequency of the rf signal falls within the band of frequencies of the pay-TV channel. The TV receiver set is unable to reconstitute coherent picture or sound, while this added signal is present in the transmission. Regular reception is restored for subscribers by removing the interfering rf signal at the TV receiver set. Thick film technology facilitates the realization of stringent requirements of stability for the components of the System.

Introduction

The need for practical systems offering security for pay TV has become increasingly apparent. Both active and passive systems have been developed and are marketed at present which claim to prevent non-subscribers from watching pay TV premium channels. Some of the accepted systems include trapping at the pole, converters, switchable taps, and various encoding-decoding systems. In general, it has been true that the cost of these systems was directly proportional to the degree of security they offered. It seems fair to say, however, that there is no fully secure system, and that the ultimate solution to pay TV security lies in catching and prosecuting those who illegitimately watch pay TV programs. Still, it remains necessary to secure pay TV transmissions to some extent in order to make pay TV a realistic business proposition.

The proprietary TEST System offers a novel solution to the problem of pay TV security. Its theoretical foundation is clear and concise, its implementation is ideally suited to high technology mass production, resulting in low cost to the user. It will become apparent from the discussion below, that the System is universally applicable, i.e. it will function not only in CATV, but in MDS and over the air systems as well.

Following an analysis of the theoretical basis of the TEST System, the basic components will be described in detail. Engineering considerations of general interest to user and a review of the merits of the System will be presented in the concluding section of the paper.

Theory

It is well known that a TV receiver will detect as video information the presence of a single frequency sinosoidal signal, located between the visual and aural carriers of a TV channel. When such a signal is not part of the regular picture material, it will be observed as interference, or disturbance of the intended picture.[1]

The degree of disturbance by this (scrambling) signal primarily depends on the combination of the following factors:

1. Level of the scrambling signal relative to the visual and aural carriers.
2. Frequency of the scrambling signal, i.e. the position of this signal in the frequency domain relative to the visual and aural carriers.
3. Modulation of the scrambling signal.

Relative level:

It turns out that the threshhold of interference by the scrambling signal is a strong function of the signal's frequency and modulation. Considering a pure sinosoidal rf scrambling signal, however, experiments indicate that the threshhold of interference is at the -45dB level with respect to the visual carrier, when the scrambling signal is anywhere between the visual and aural carriers. The threshhold of interference is as low as -60dB at certain frequencies within the TV channel band. The degree of interference by the scrambling signal becomes more severe with increasing level, and the picture is greatly impaired at the 0dB level.

Relative frequency:

In general, for a given relative level of the scrambling signal, the picture quality becomes more objectionable as the scrambling signal is moved closer in frequency to the visual carrier. The sound quality is degraded in a similar fashion when the scrambling signal is moved close in frequency to the aural carrier. There is, however, no simple mathematical relationship between the frequency of the scrambling signal and the level of interference observed.[2] In addition to these effects, there are certain other phenomena which are noticeable as the frequency of the scrambling signal is varied. There are frequencies which are more effective in disrupting picture and sound reception than others; e.g. if the scrambling signal is harmonically related to the line scanning frequency (15.734Hz) and/or the carrier frequencies. TV reception is of much poorer quality than if some other frequencies are chosen.

Modulation.

Modulation of the scrambling signal increases the level of interference with TV reception. AM modulation is generally more effective than FM, and modulating frequencies below 100Hz result in greater scrambling of the picture material than if some other frequencies were used.

It can be seen from the preceding brief analysis that a proper choice of scrambling signal, i.e. one of a certain level, a selected frequency, and one which is AM modulated, will make enjoyable TV reception impossible. It must be remembered, however, that the scrambled picture and the degree of annoyance caused by it is perceived in the mind of the observer, therefore it is difficult to objectively determine and define just what is "enjoyable".

Although the idea of purposefully injecting a scrambling signal is new, the phenomenon of single frequency interference has been dealt with before.[3] Specifically, in CATV engineering one is sometimes faced with the problem of interference created by the presence of several TV channels, and non-linear devices on the cable. In these situations the source of interference is outside the channel of interest (where the disturbance is noted) as, for example in the case of adjacent channel interference. A sharply tuned notch filter is frequently used by engineers to attenuate the single frequency causing the interference, i.e. the adjacent carriers.

The novel modification of this procedure incorporated in the TEST System is that it is also possible to remove an in channel single frequency interference, such as a scrambling signal, by means of a sharply tuned notch filter. If the notch filter, or Descrambler, attenuates the scrambling signal to at least the -45dB level, TV reception may become acceptable in most cases. Figures 1a. and 1b. depict schematically the frequency spectrum of a TV channel with the scrambling signal present, and with the scrambling signal removed.

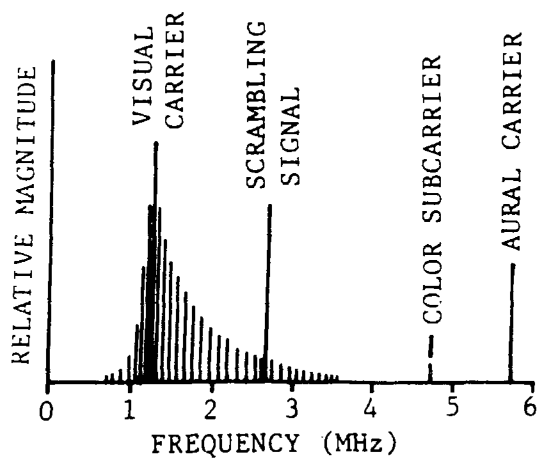


Figure 1a.

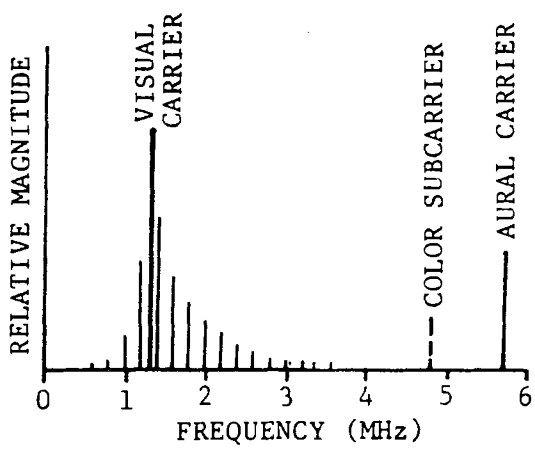


Figure 1b.

In practice, it is not possible to remove a single frequency. A notch filter removes a band of frequencies about the undesired signal.[4] This means, of course, that regular picture material is removed from the transmission along with the interfering signal. There are, thus, stringent design considerations for the Descrambler, even though in theory it is merely an in channel notch filter.

The principle of the TEST System is the inserting of a scrambling signal into a particular TV channel, e.g. between the visual and aural carriers, and thereby obliterating the received picture and sound. The reception may be restored, or descrambled, for a subscriber by removing the scrambling signal at the TV set. Figure 2. is a block diagram of a typical CATV facility equipped with the TEST System.

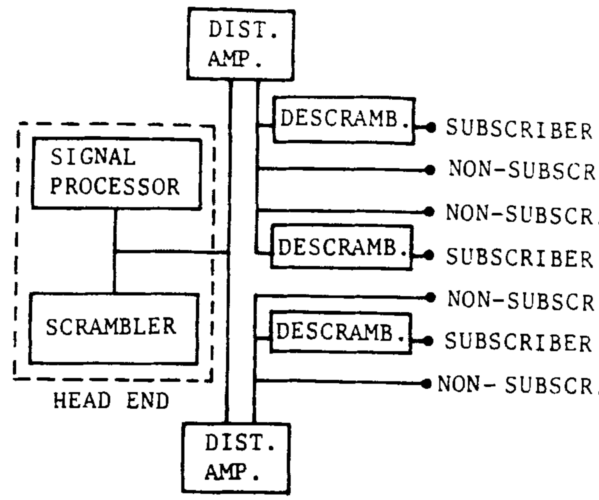


Figure 2. The Scrambler Unit

The scrambling signal is generated by the Scrambler which is located typically at the head-end of a CATV facility, as indicated in Figure 2. The function of the Scrambler is best understood through a practical example.

If it is desired to scramble Ch4 for purposes of payTV security, the following choice of parameters for the scrambling signal will render reception unenjoyable without the use of the TEST Descrambler unit.

Scrambling signal frequency:	69.507 MHz ± 1KHz
Frequency difference between scrambling signal and visual carrier:	2.257 MHz ± 1KHz
Level of scrambling signal relative the visual carrier:	0 dB
Modulation of scrambling signal:	15 Hz AM 1 KHz AM
% modulation of scrambling signal:	80%

Table 1.

It can be noted from Table 1. that the scrambling signal is very nearly midway between the Ch 4 visual and the aural carriers. The frequency spectrum is shown in Figure 4.

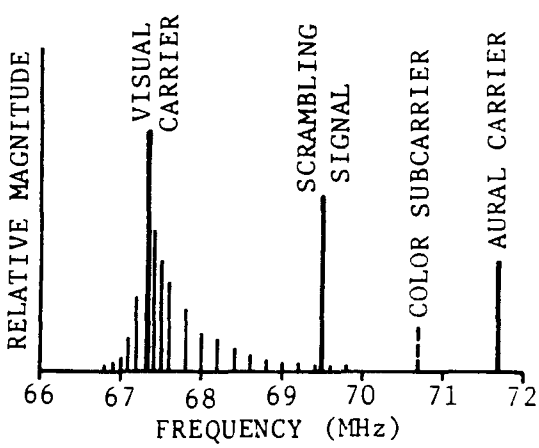


Figure 4.

Systematic investigations indicate that this choice of parameters is just one of several which will function well in the TEST System. In this instance, the scrambling signal has the following effect on TV reception.

1. The 2.242 MHz signal is detected and amplified along with regular video information by the TV set. Because of the 1 KHz AM modulation the interference appears as a set of horizontal bars across the receiver screen. The 15 Hz AM modulation interferes with the A.G.C. and vertical synchronizing pulses, and causes the picture to roll and jump.
2. The beat and harmonics generated by the video detector become part of the 4.5 MHz sound information. The 1KHz AM modulation, passing through the limiters, is detected and amplified by the audio circuits such that the 1 KHz tone from the speakers overrides regular sound material. Additionally, the 15 Hz AM modulation is audible as a "chirping" sound.

This frequency of 2.257 MHz interleaves the scrambling signal between harmonics of the scanning frequency, which arrangement facilitates the eventual descrambling process. This frequency of 2.257 MHz also positions the scrambling signal away from the chroma information, so that colors are not disturbed when the scrambling signal is removed.

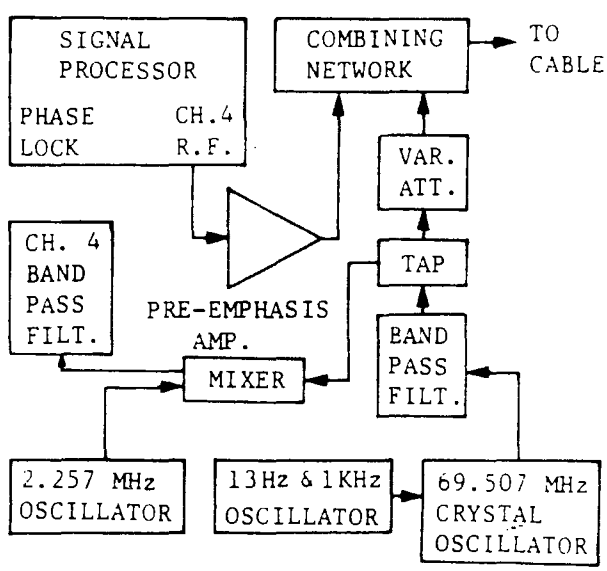


Figure 5

Figure 5. is a block diagram of the Scrambler unit and of the connections to other parts of a typical CATV head-end installation. The 69.507 MHz signal is generated by the crystal controlled rf oscillator. The crystal is maintained in an oven for added stability. A series of band pass filters reduce the harmonic content to -70 dB with respect to the fundamental. Another highly stable crystal oscillator, operating at 2.257 MHz, is used to produce a reference for the visual carrier. This 2.257 MHz signal is then mixed with the 69.507 MHz scrambling signal, and it is to this frequency, i.e. to 69.507 MHz-2.257 MHz, or to 67.250MHz, that the visual carrier of Ch 4 is phase locked. Consequently, the 2.257 MHz frequency difference is insured to remain constant for the system.

The pre-emphasizing amplifier processes the rf band containing Ch 4 in such a way as to counter balance the degradation anticipated from the descrambling process. It amplifies the band symmetrically about the 69.507 MHz point. Figure 6. shows the frequency response of the pre-emphasizing amplifier, providing approximately 12dB gain at 69.507 MHz.

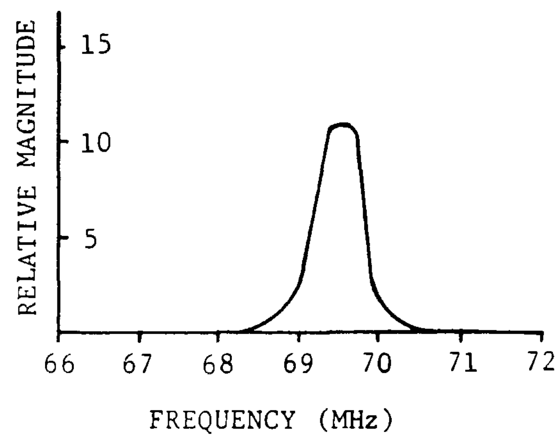


Figure 6.

The pre-emphasized Ch 4 band is then combined with the 69.507 MHz scrambling signal and is coupled into the cable system via an impedence matching device. The frequency spectrum of the transmitted rf band is pictured in Figure 7.

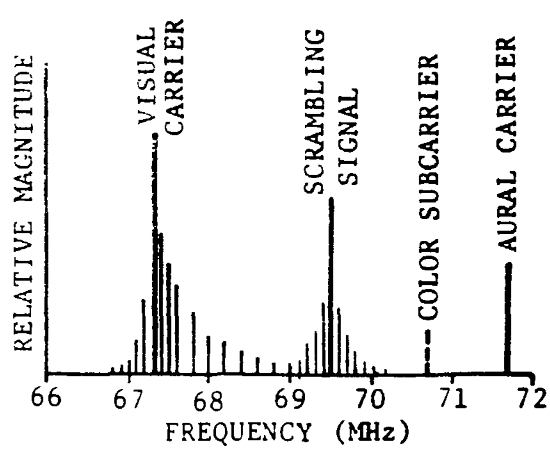


Figure 7

The Descrambler

The descrambling process consists of removing the scrambling signal from the Ch 4 rf band. This is accomplished by connecting a Descrambler unit in the subscriber's drop line. The Descrambler unit, as described below, is designed to be located indoors, mounted on the baseboard close to the TV receiver set.

As mentioned before, the Descrambler is a sharply tuned LC notch filter whose frequency spectrum is symmetric about the scrambling signal. It is a completely passive device requiring no power for its operation. The ultimate attenuation of the Descrambler is in excess of 60 dB at 69.507 MHz, the notch being sufficiently wide to remove the AM sidebands of the scrambling signal, but being sufficiently narrow to prevent serious degradation of the video information. Outside the notch, the Descrambler offers a nearly perfect 75 Ohm impedence match, and transmission is attenuated less than 1 dB. A bandwidth of 1.25 MHz at the 3 dB level is typical. Figure 8a. shows the frequency response of the Descrambler, while Figure 8b. shows the frequency response of the pre-emphasizing amplifier superimposed on Figure 8a. It can be seen that the ultimate bandwidth of the Descrambler as employed in the TEST System is less than 0.5 MHz at the 3 dB point.

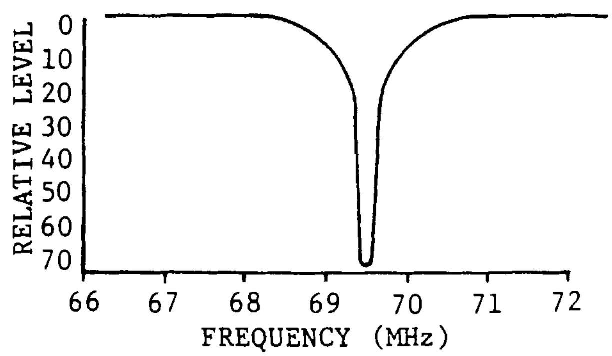


Figure 8a.

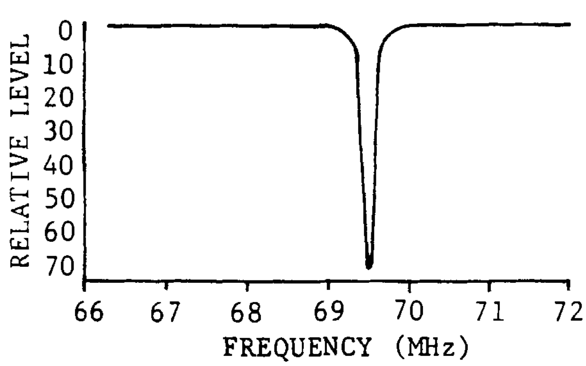


Figure 8b.

Stability is the primary consideration in the design of the Descrambler. Short and long term changes in the environment must be considered. In particular, changes in temperature will cause thermal expansion of the components and hysteresis effects become noticeable. In order to minimize such environmental impact, the Descrambler components are made out of some of the most stable materials available, i.e. from glass and ceramics. In order to take advantage of the great thermal and mechanical stability of these substances, a certain means of depositing conductors on glasses and ceramics has to be employed. The so-called thick film technology is ideally suited for the purpose.

The thick film process, as it applies to the Descrambler, consists of screening a conductive thick film paste onto a ceramic or glass substrate. The screened on silver pattern is dried and subsequently fired at temperatures up to 1500°F., so that it is permanently fused to the substrate. Special kilns provide the proper temperature profile for this process.

Except for inductors, all parts of the Descrambler, that is all conductors and capacitors are screened onto an NPO type ceramic substrate. This particular kind of ceramic has very nearly zero temperature coefficient for its dielectric constant, as well as very nearly zero hysteresis. Along with glass, its thermal expansion coefficient is of the order of one part in a million. In other words, capacitors made from NPO dielectrics have both short and long term thermal stability. The actual capacitors in the Descrambler are of parallel plate design, thus both sides of the NPO substrate are utilized.

The inductors are supported by low loss electronic glass substrates. The silver thick film paste is printed on the cylindrical glass by a special technique. The pattern is fired onto the glass in a manner already described, except, of course, a different temperature profile is required.

In order to facilitate the high Q required, the conductivity of the fired film is increased by a silver electroplating process.

In the event that the notch of the Descrambler is off the desired frequency because of variations in the manufacturing process, the unit can be fine tuned by the laser trimming process. In this procedure, various portions of the conducting surfaces are burnt off from the substrate by a guided laser beam.

The stability of the Descrambler is further enhanced by the rigid, thick walled die cast aluminum enclosure. It is, of course, in the subscriber's interest to prevent the Descrambler from being damaged, nevertheless the sturdy enclosure is necessary to minimize unintentional damage. A unique feature of the Descrambler is the Deactivator device which makes the unit virtually theft proof. The design of this feature incorporates a spring loaded trigger mechanism which is released when the unit is tampered with. This might happen, for example, when someone unauthorized attempts to remove the Descrambler from the base board. Since a special tool is required to turn the uniquely shaped screw that holds the unit to the board, force would have to be applied to pry the unit off the wall. This forceful removal releases the Deactivator, which, shattering the glass and ceramic substrates, renders the Descrambler totally inoperative.

* * *

It should be apparent from the preceding discussion that the sole modification of the TV channel is the addition of what amounts to another carrier signal. This third carrier, the scrambling signal, doesn't, however, interact with the rest of the rf information in the channel, because the scrambling signal is combined with the regular transmission through a linear network. The actual "scrambling" is accomplished by the receiver, which is unable to reconstitute a coherent TV picture while the scrambling signal is present. The scrambling signal, located as it is in the TV channel, is readily processed by the line amplifiers of a cable system. For the same reason, the scrambling signal is compatible with AML, and MDS as well. Any small increase in distortion, if it occurs, can be eliminated by slightly reducing the overall level of the channel band.

It is reasonable to conclude then, that the TEST System does provide a degree of security adequate for most pay-TV operations. Its salient features are:

1. Low cost. Initial capital outlay is low, since one Scrambler unit readily handles an entire cable system. Only paying customers are supplied with the Descrambler.

2. Simplicity, and inherent reliability of operation. Easy to service and maintain.

3. Flexibility. Centrally controlled scrambling, turning scrambling on or off at will, provides great advantage from a promotional as well as from an engineering viewpoint.

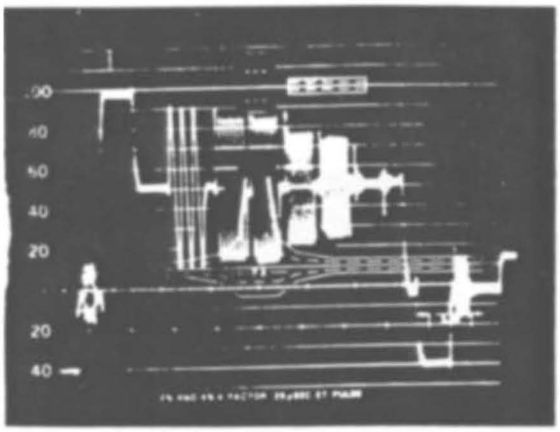
REFERENCES:

1. Wm. I. Orr,
"Radio Handbook"
(Indianapolis: Howard W. Sams & Co., Inc. 1972)

2. Members of the Technical Staff Bell Telephone Laboratories,
"Transmission Systems for Communications"
(Bell Telephone Laboratories, Inc., 1971)

3. Wm. A. Rheinfelder,
"CATV System Engineering"
(Blue Ridge Summit, Pa., Tab Books, 1966)

4. Donald G. Fink, Editor,
"Electronic Engineer's Handbook"
(New York: McGraw-Hill Book Co., Inc., 1975)



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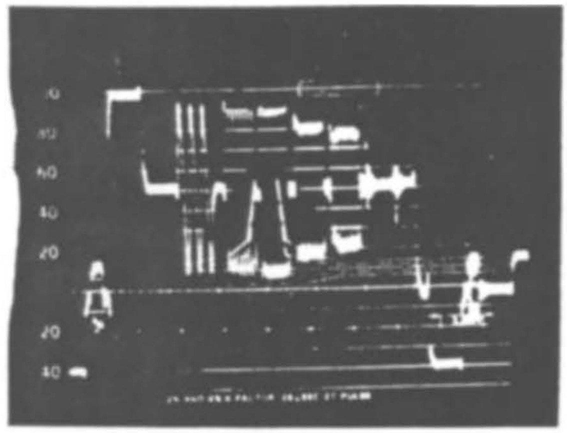

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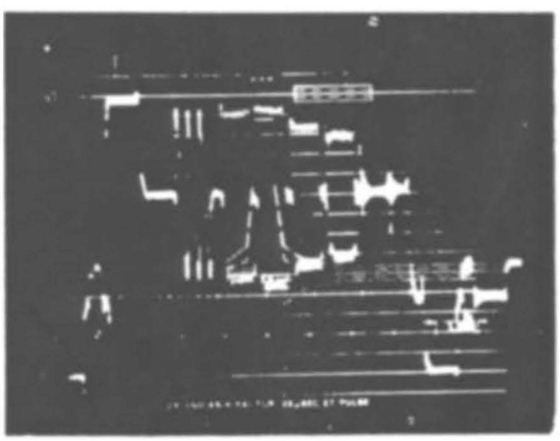

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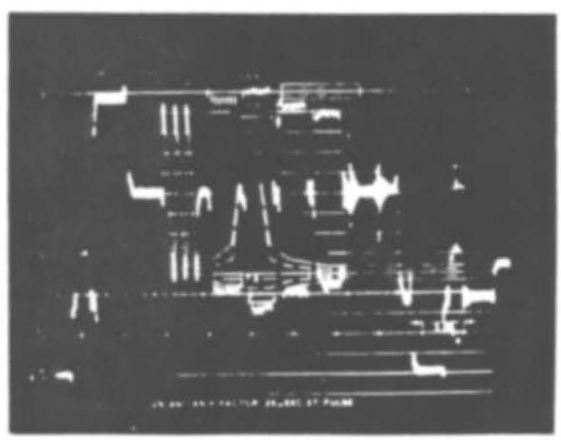

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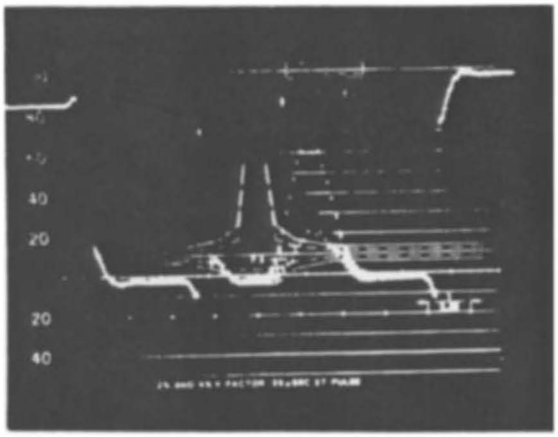

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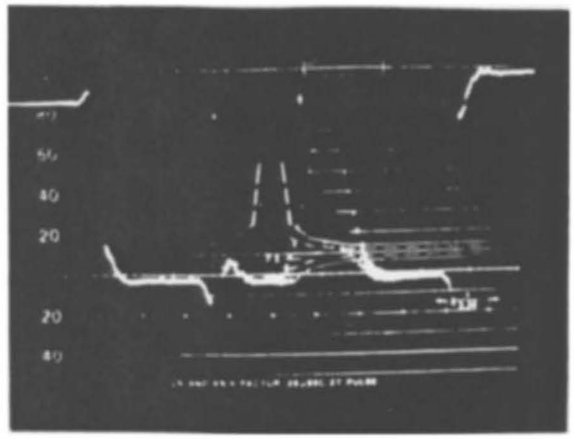

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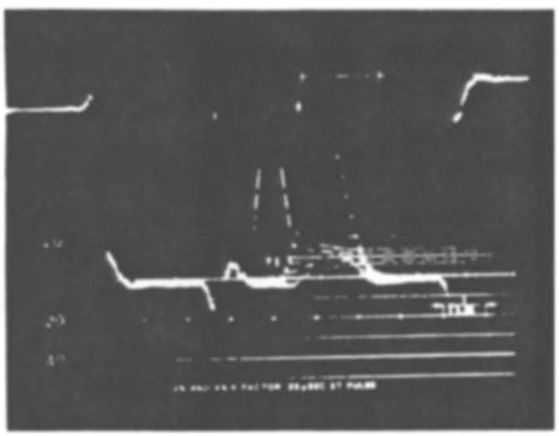

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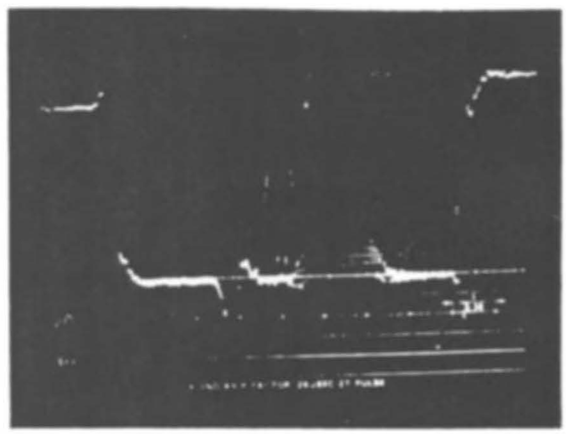

4A

THE MARRIAGE OF CABLE AND SATELLITES (REVISITED)

John P. Witherspoon
Public Service Satellite Consortium
San Diego, California

There is great potential in the long-predicted marriage of satellites and cable. The public service community and the cable industry have many mutual interests in such a liaison.

The satellite does not provide an alternative way to provide conventional terrestrial services. Rather, it makes feasible the development of services which are not otherwise possible; e.g., clinical support services for health care in remote areas, interactive education services to widely distributed student populations, a more diversified system of television and radio networking.

Satellites of relatively high power, coupled with small, inexpensive ground terminals, make these and other developments possible.

Five years ago it was fashionable to observe that a satellite and cable television could transform the marketplace for wideband communications from an economy of scarcity to one of abundance. At about that time, a lot of people set out to get rich quick in cable. Not many of them have done it.

Nevertheless, in spite of all the intervening difficulties, when one looks again at the opportunities predicted for the cable industry five years ago, most of the important options remain. We can still make the satellite-cable marriage work. But time and technology are moving on, and the relationship can become obsolete before the honeymoon is properly begun.

Before I overwork that analogy, let me bring you up-to-date on the Public Service Satellite Consortium. The PSSC was incorporated about a year ago, in March, 1975. For the first six months, our Interim Board coped with the arduous tasks of securing initial funding and recruiting key personnel. I came on board as President of the Consortium on October first, and our first Permanent Board was elected by the membership in December.

That membership now numbers about 50 non-profit organizations. Our constituency is as diverse as the concept of public service itself, ranging from CPB, PBS, and NPR in the public broadcasting fraternity, to the American College of Physicians and the Academy of Orthopaedic Surgeons in the professional community, with other key fronts represented by the American Library Association, the State of Alaska, and various distinguished institutions of learning.

We are assisting our members with several major functions, beginning with aids to help them formulate precise, realistic statements of their requirements as they exist today and as they can be projected into the future. Additionally, the Consortium provides coordination services and technical support to its members for appropriate experiments. Under the terms of our founding grant, the Consortium will become responsible for the transmission facilities in Denver and nearby Morrison, Colorado, which were major elements of the health and education telecommunications experiments on ATS-6. The excellent technical staff which served as Operations Manager of these experiments is now the engineering arm of the Consortium.

Once we understand the composite communications requirements of our members, the staff will prepare and analyze alternatives in terms of technology, financing, and organization to help individual members implement working plans to satisfy their requirements. Finally, the Consortium will maintain an active policy and administrative structure in order to coordinate the joint activities of our members.

The Consortium will perform a brokerage function in behalf of our members by integrating their traffic requirements and by assisting in negotiations with suppliers. Pools of interest will be aggregated on a national basis; so that the more users there are, the lower the cost of service will be for each member.

The Consortium is by no means limited to the sole use of communications satellites as a distribution mechanism. Even if the cost of satellite distribution continues to decline, it probably will be more economical to use a mixture of satellite and terrestrial facilities to reach all but the most isolated users.

As you know, public broadcasting is planning to implement a nationwide network of satellite earth stations and has already expressed interest in developing the non-broadcast uses of such a system. The stations are scheduled to be operational by the summer of 1978. We are working with public broadcasting to develop the full public service implications of these stations. There is a clear role for cable in that process.

In fact, our institution and yours have many common interests. As cable moves toward specialized service in urban markets, we mutually have an opportunity and obligation to think further about the nature and variety of services rendered, and to redefine the concept of a network.

With that brief introduction to the Consortium, let me concentrate on a conviction that we are riding some favorable trends, and we think you are, too. The communication satellite has opened up new opportunities, and the FCC is encouraging competition in the marketing of "new and innovative" communication services. This climate of competition has had a very positive impact on the domestic satellite industry. However, it is not clear whether present FCC policy will prevail indefinitely. This policy is intended to result in a greater diversity of service and more attractive prices to the consumer. The PSSC, of course, would welcome such a development. What AT&T calls the "experiment" in competion, however, may not last long enough to result in such an outcome. Thus, the PSSC feels a need to move quickly while opportunities are available. You have a stake in moving quickly too.

Unquestionably, the communication satellite is one of the most significant outgrowths of the $50-billion commitment to place a man on the moon. As yet, however, the full impact of this technological breakthrough has not been realized. Satellite technology has been used historically to supplement terrestrial trunks between major population centers. A good example of this approach is the Westar system of Western Union, which consists of five earth stations that are integrated into the Bell system and other microwave facilities owned by Western Union. The RCA system also uses low-powered satellite transponders to serve a small number of relatively large, expensive ground stations.

The principal utility of a satellite, however, is not to provide an alternate means of moving conventional terrestrial services. Rather, it makes feasible the development of services which are not otherwise possible. NASA's experimental satellite programs have conclusively demonstrated the feasibility of transferring the burden of performance in a satellite communication network from the earth stations to the satellite itself. The resultant decrease in both the cost and complexity of the earth stations could put satellite communication into the budgetary grasp of the small, independent user.

I believe that the future lies with low-cost satellite earth stations which tie in with comprehensive local distribution facilities. It is imperative to reduce the end-to-end cost of distributing wideband signals and interactive narrowband signals to small users. For systems using substantial numbers of earth stations, the small earth station coupled with a more powerful satellite, seems to be the way to go. It should be of great interest, therefore, that the 3400 individual cable television systems in the United States probably represent the largest short-term potential domestic market for satellite earth stations.

Perhaps someone is listening to the stirrings of people like ourselves who require inexpensive earth stations that can be located at the point of use. While nothing is definite, the newest satellite carrier in the U.S., known as Satellite Business Systems, has announced a system designed to serve a large number of stations. This satellite system is scheduled to become operational in 1980. SBS is an independent subsidiary of IBM, The Aetna Life Insurance Company, and Comsat General. We all know that these people do not pursue their business affairs in a casual manner. They play to win. Personally, I view the advent of SBS into the communications business with great interest.

SBS has stated that they plan to serve business and government markets using a flexible digital format. It is not clear that SBS is interested in video traffic, but modern digital coding techniques would permit video networking. The important message to the PSSC and the cable industry is that SBS plans to deploy a large number of stations at the point of use. Local origination will be possible, and presumably the stations will be relatively inexpensive.

Of perhaps greater interest to the cable industry is a preliminary announcement to the effect that SBS will make extensive use of fiber optics in their ground facilities. This new distribution medium is capable of providing gigahertz bandwidths with remarkably low attenuation. It is possible that in the next ten years these glass fibers will start to replace copper wires and coaxial cables as the principal means of routing electronic information locally. Many experts believe that these glass fibers will have a greater impact than satellites on the structure of the domestic communications industry. While SBS is making no such claims, it is likely that the cable industry as presently constituted would face serious competition in developing the Wired Nation.

Cablecasters, then, no longer have the luxury of time. There are new markets ripe for development. If the cable industry ignores them or cannot move strongly enough, others such as IBM and AT&T will reap the harvest.

What are the most promising markets for cable and satellites? The first on the list, of course, is networking. The satellite is ideally suited for interconnecting a few originating points with many receiving points. The cost of nationwide broadcasting and cablecasting will drop markely if this market can be aggregated.

The satellite is also well suited for interconnecting many transmit points to few receiving points. IBM has stated that it will be cheaper and much more convenient to store office materials in a central computer than in a file cabinet. Patient histories, billing information, and library functions could be accomodated more easily using a combination of satellites and cables.

If equal access to adequate health, educational, and other social services is to be made available throughout the U.S., and if service-delivery arrangements are to become more flexible, the heavy reliance on face-to-face delivery must be modified. It seems inevitable that communications will play an important role in whatever organizational arrangements evolve to cope with these expanding service arrangements. The cost reductions made possible by the marriage of cables and satellites should accelerate this organizational development. The organizational implications of increased use of telecommunications in such fields as education, however, imply a long transition between the present experimental period and the onset of operational service.

It is likely that the first serious education markets for satellite/cable service will be in the areas variously characterized as continuing education, post-graduate professional education, informal adult education, or nontraditional study. Consider continuing professional education. There are approximately 2 million professionals (doctors, lawyers, nurses, vets, engineers, etc.) in the U.S. today. An increasing number face a need for continuing education as a requirement for recertification. If one-fifth of this population took an extension course each year at an average cost of $250 per person, $100-million of revenue would be generated annually.

One of the successful programs in continuing education is administered by the American College of Physicians. Approximately 20,000 internists belong to this professional society. Two years ago, the College of Physicians administered an exam that was taken by 18,000 doctors, each paying a respectable fee for the test. Dr. Edward Rosenow, the Executive Vice President of the College of Physicians, and also a member of the PSSC Board of Directors, says the exam will be administered again this September. Already over 33,000 doctors have signed up. The College of Physicians has joined the PSSC to expand this and other programs through the creative use of telecommunications.

There is, then, a growing requirement for non-entertainment, non-broadcast services, and the people who want them are not all asking for a free ride. There are substantial markets in the public service sector.

In order to develop these markets, a flexible and economical interconnection system is needed, and we believe that such a system is likely to be satellite-based in a configuration that uses a large number of small, relatively inexpensive earth stations.

The interest of the Public Service Satellite Consortium is to see that needed services are rendered well and economically. You are in a business which can provide such services. We should have a lot to talk about.

TRANSMISSION OF HIGH-SPEED PCM SIGNALS ON CATV SYSTEMS

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INTRODUCTION

This paper describes experimental work conducted at GTE Lenkurt, San Carlos, California, and at GTE Sylvania CATV Equipment and Installation Operation, El Paso, Texas, to examine the feasibility of transmitting high-speed, pulse code modulation signals simultaneously with normal video transmission over CATV systems.

BACKGROUND

Pulse code modulation (PCM) involves the transformation of continuously variable, analog signals into a series of digitally-coded pulses and then reversing this process to recover the original waveform.

The basic PCM system now in service for telephone communications, and used for this experimental study, provides 24, two-way voice channels on two cable pairs, one for each direction of transmission. These channels are processed into a bipolar 1.544 Mb/s digital line format in three successive operations, as shown in Figure 1: sampling; quantizing and encoding.[1] First, a time varying voltage, such as speech (or a sine wave as shown), is converted into discrete samples at a rate which is at least twice the highest frequency to be transmitted. This is defined as pulse amplitude modulation (PAM). Each channel, which has an upper frequency limit of 3400 Hz, is then sampled at 8 KHz to satisfy the sampling rate requirement.

Next, the voltage amplitude of each sample is assigned to the nearest value of a set of discrete voltages. This process is known as quantizing and is equivalent, in mathematics, to rounding off to the nearest whole number or integer. The final step is to code each discrete amplitude value into a binary digital word, similar to coding the letters of the alphabet for telegraphy. Each amplitude sample is coded into an 8-bit digital word and transmitted sequentially (time multiplexed) as a single bit-stream. At the receiver the reverse process takes place, as also shown in Figure 1.

One sampling period for all 24 channels consists of 192 bits (one 8-bit word for each of 24 channels) plus one bit for framing, giving a total of 193 bits. At the 8000 Hz sampling rate, this equals the line rate of 1.544 Mb/s (8000 samples/second x 193 bits). The resultant binary pulses are then in fixed, predetermined time positions, and only the presence or absence of a pulse determines the information content of the signal. This type of 24-channel system is designated as T1 carrier.

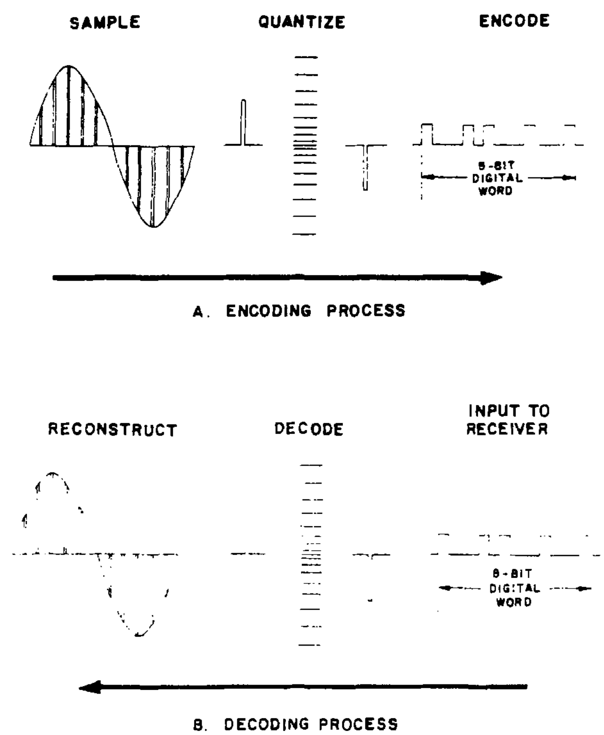

Figure 1

PCM Operations

APPLICATION OF PCM TO CATV

While substantial bandwidth is available in most CATV systems, it is seldom fully utilized. Expanding plant usage by leasing channel space or sharing facilities where PCM is transmitted along with video and other services could provide increased revenue for the cable operator. Potentially, PCM could be employed in the following situations:

a. Leased Channels for Data Transmission for Industrial Users

Although initially designed for voice transmission, PCM systems are particularly well suited for carrying data due to their digital format. The fact that digital transmission systems can carry data at a lower cost, and with much better performance than analog systems, has long been recognized by the communications industry. Transmission of low-speed data (2.4, 4.8 and 9.6 Kb/s) can be accomplished by using existing data modems with tonal outputs and applying them directly into a voice channel of T1 equipment. The data modem output is sampled by the PCM terminal equipment the same as with a voice signal.

Special data modems, which provide a T1 line signal format directly, allow data speeds from 50 to 500 Kb/s. If it is desirable to mix voice and data on the same system, special data modems are available as listed in Table I.[2]

Table I

Available Modems and Channel Arrangements

Wideband Data Modem	Channel Arrangements
GTE Lenkurt 9003A Western Electric T1WB-1	8 Channel - 50 Kb/s
	4 Channel - 50 Kb/s 1 Channel - 250 Kb/s
	2 Channel - 250 Kb/s
GTE Lenkurt 9003A Western Electric T1WB-2	2 Channel - 250 Kb/s
Western Electric T1WB-3	1 Channel - 50 Kb/s 21 Channel - Voice
	2 Channel - 50 Kb/s 18 Channel - Voice
	4 Channel - 50 Kb/s 12 Channel - Voice

New equipment designs provide wideband data modems which promise still more efficient use of the T1, 1.544 Mb/s digital line format.

The wideband channels available on CATV systems are ideal for transmitting high-speed data up to 500 Kb/s, using the standard PCM, T1 line signal format. Leasing of high-speed data channels to industrial users would appear to be a viable market for the CATV industry.

b. Digitally Encoded Video

For applications where security of transmission is important, especially when channels are leased for private signal carriage, digitized video can be useful.[3] Signals, in this format, are relatively immune to repeater - introduced distortion and can be transmitted over long distances with little degradation. These signals, however, require relatively high data rates on the order of 20 to 30 megabits per second for quality picture reproduction. With efficient encoding, such a signal would have a 20 to 30 MHz bandwidth at baseband, thus using the spectrum space of several 6 MHz channels on the CATV system.

c. Voice Communication

In certain geographic areas, particularly outside the United States, it may be attractive to use long-haul CATV trunk systems for transmission of voice communication (primarily T1 telephone signals) along with video programming to interconnect small, relatively isolated areas. A combined system, with its inherent cost savings, could be economically viable, while separate systems could not, perhaps, be justified.

TRANSMISSION TESTS AND RESULTS

a. Lenkurt Tests

For these tests, two, 24-channel PCM signals (1.544 Mb/s each) were combined in a Lenkurt Model 9120A PCM Multiplexer. The output of the 9120A, a 3.156 Mb/s modified duobinary[4] signal,* was fed into a CATV modulator/demodulator pair arranged in a back-to-back configuration.

An oscilloscope, with an eye pattern** (intersymbol interference) display of the signal, and a bit error rate test set were connected to the output of the demodulator. The modulator/demodulator employed amplitude modulation with envelope detection, and vestigial-sideband filtering of the type normally used for video transmission.

The eye pattern of the signal exhibited a high degree of distortion with an unacceptable error rate. The quadrature component, inherent in single-sideband filtering with envelope detection, distorted the signal beyond acceptable limits.

When envelope detection is used, the output is determined by the resultant of the in-phase and quadrature components. In double-sideband transmission, the quadrature component is reduced to zero. However, in single-sideband or vestigial-sideband operation, the presence of the quadrature component

*Modified duobinary is a correlative, level-coded signal which provides spectral shaping into a bandwidth which extends to only one-half the signaling rate.

**An eye pattern is a graphical display used to determine the effects of degradations introduced on digital pulses as they travel over a transmission medium. This pattern is obtained by observing a random pulse train on an oscilloscope, synchronized externally by the clock pulses which drive the random data.

leads to an envelope shape which differs from the modulating signal. One method of reducing the amount of distortion caused by the quadrature component is to reduce the depth (percent) of modulation. This was tried during the laboratory tests. The eye pattern of the resulting detected signal was somewhat improved, but the bit error rate was still unacceptable for back-to-back tests.

When synchronous detection is used, only the in-phase component of the signal contributes to the recovered baseband; thus, requiring that synchronous detection be used for this application to avoid quadrature distortion. It was also concluded that the AGC in the demodulator must be disabled for optimum performance.

b. Sylvania Tests

Transmission tests of PCM were conducted during May 1975 on the Sylvania CATV test system in El Paso, Texas. The majority of the tests employed FM transmission; some minor testing was also conducted using AM.

The PCM signal was a 48-channel, multiplexed T1 telephone waveform (3.156 megabit). Investigations were made into carrier-to-noise ratio requirements, channel interaction, and a brief check on the impact of system group delay on PCM error rate.

For these tests, two T1 signals were combined in a Lenkurt Model 9120A multiplexer whose output signal is compatible with modulators used for radio transmission. The spectrum of the 3.156 Mb/s signal extended to approximately 1.5 MHz (Figure 2). This was well within the bandwidth requirements of modulation/demodulation equipment manufactured for CATV applications.

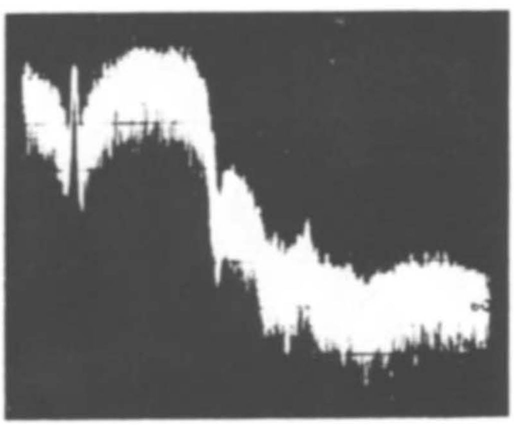

Figure 2

3.156 Mb/s Baseband Output Spectrum From Multiplexer
(+40dBmV full scale; 10dB/cm vertical;
50 KHz/cm horizontal)
Marker at Left Side of Screen
Shows Zero Frequency

The CATV test system, shown in Figure 3, consisted of 20 trunk amplifier stations in cascade, with a 50 to 300 MHz bandwidth, spaced 23dB at 300 MHz. All stations were controlled by two, CW pilot signals which provided for the automatic compensation of gain and slope to adjust for changes in cable attenuation with temperature. The first 10 spans of the cascade were straight 23dB cable sections; the remaining ones had directional couplers (either 3 or 7dB) cut into the line to simulate splits in the trunk, with the cable length adjusted accordingly. The system frequency response (peak-to-valley) was 1.6dB over the 50 to 300 MHz band. This arrangement was the equivalent of over 10 miles of point-to-point system length and provided a convenient facility for tests of this nature.

Figure 3

Sylvania CATV Test System

The equipment setup used for these tests is shown in Figure 4. A Bowmar Model 271A Error Rate Test generated the two 1.544 Mb/s, T1 signals for the input to the transmit side of the multiplexer. One of the recovered, 24-channel, T1 lines from the receiver side of the 9120A was then fed into the test set's receiver input to give a direct readout of error rate on that T1 line. While in normal system application, two multiplexers would be used, one at each end of the system, it was possible to "loop back" the multiplexer output to its own input since the CATV test facility was contained within a relatively small area. With this setup, 48-channel T1 signals could be transmitted concurrently with video for the system tests.

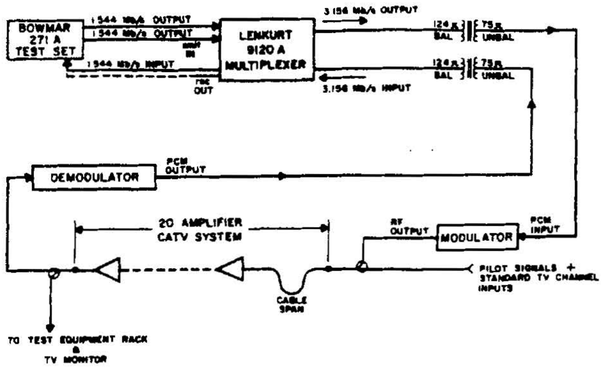

Figure 4

Test Equipment Arrangement for PCM Transmission Tests

FM Tests

The FM modulator/demodulator combination was a Model VFMS-2000 manufactured by the CATEL division of United Scientific Corporation, and operated at a center frequency of 75 MHz.

The modulator had to be run at 90% deviation (approximately 1.5 MHz) in order to obtain sufficient output from the demodulator to drive the multiplexer. The deviation rate was maintained at this level for all subsequent tests. Figure 5 shows the modulator output spectrum at 75 MHz using the 3.156 Mb/s modulation at this deviation.

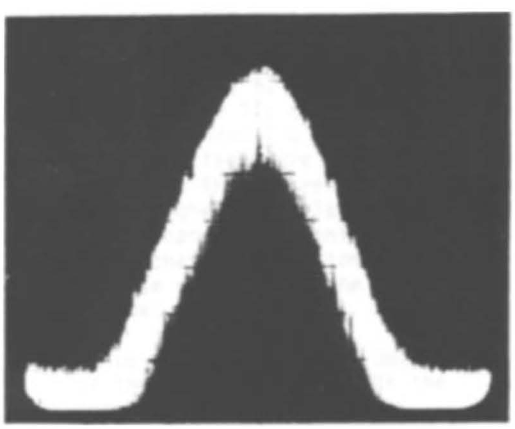

Figure 5

Modulator Output Spectrum at 90% Deviation
3.156 Mb/s Modulation; 75 MHz Center Frequency
(+34dBmV full scale; 10dB/cm vertical;
2 MHz/cm horizontal)

The demodulator output spectrum is shown in Figure 6. This compares well with the input spectrum from the multiplexer (Figure 2), except for the addition of system noise. A qualitative check on the sensitivity of the demodulator to input level variations showed that there was no significant impact on error rate as long as the input level to the demodulator was maintained within the limits shown on the manufacturer's specification sheet (+9.5 to +40dBmV). If the input level went below the specified minimum, the error rate went beyond one in 10^6 immediately because of a reduction in the baseband signal level which could not be tolerated by the multiplexer. Because of this, the input level to the demodulator was set at +20dBmV for all tests.

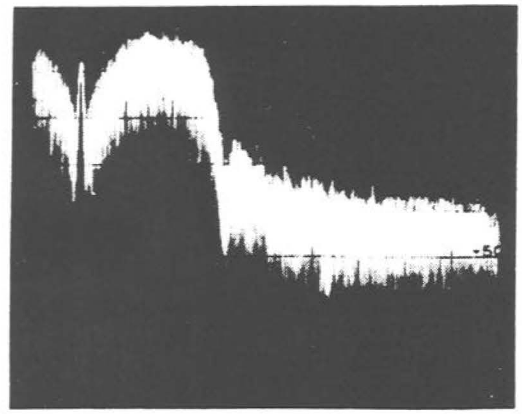

Figure 6

3.156 Mb/s Baseband Output Spectrum from Demodulator
(+40dBmV full scale; 10dB/cm vertical;
500 KHz/cm horizontal)
Marker at Left Side of Screen
Shows Zero Frequency

With the PCM link operating over the CATV system at video level (+30dBmV at 75 MHz) in the absence of any other signals, a plot was made of error rate vs signal-to-noise ratio at the 75 MHz carrier frequency. Carrier level was measured at zero deviation on the modulator. Excess noise was introduced into the system by adding attenuation to the input of the amplifier cascade. This technique reduced the pilot level and the signal level by the same amount; this, in turn, increased the station gain in order to hold the output level constant. With the increased gain, noise was added to the system output without sacrificing signal level into the demodulator. Noise levels were measured on a Hewlett-Packard spectrum analyzer having a 100 KHz bandwidth, and extrapolated to a 4 MHz bandwidth* using their published correction factors.[5]

The curve produced (Figure 7) shows that, if an RF carrier-to-noise ratio of at least 25dB is maintained at the output of the CATV system over the operating temperature range, error rates better than one in 10^8 can be expected.

*All carrier-to-noise measurements in this paper are based on a 4 MHz bandwidth unless otherwise noted.

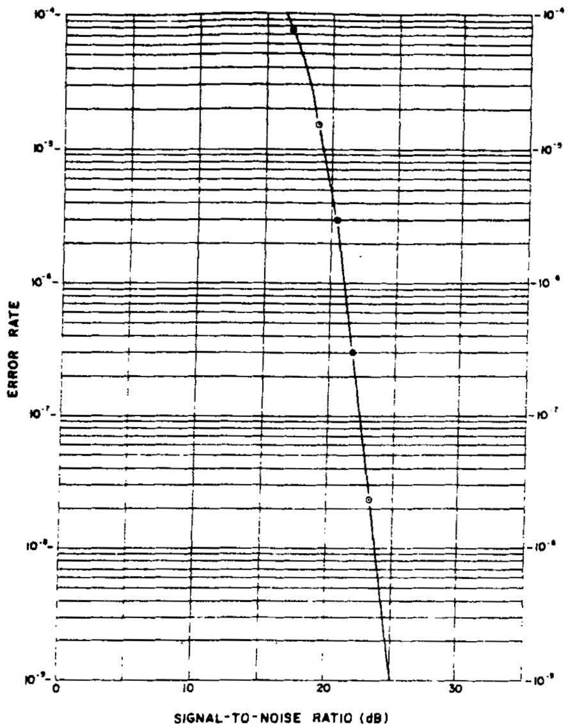

Figure 7

Error Rate vs Signal-to-Noise Ratio for FM Transmission

The effects of video channels operating simultaneously with the T1 were observed in the next test. The PCM was operated at the same level as the adjacent channel TV signals. Live, off-the-air video was run on channels 2, 6, and 11; channels 4 and 5 were reserved for the T1; channels 3, and 7 through W (except for the channel J pilot and channel A which were inoperative) were run using 100 percent synchronous, 15.75 KHz square-wave modulation. Levels for the higher channels were set in accordance with the standard Sylvania block tilt.* This represented 31-channel operation in addition to the T1. Under these conditions, the following observations were made:

(a) There was no observable degradation on any of the video channels with the T1 operating. .

(b) The composite beat at the CATV system output, measured on Channel 10, was -63dB with the T1 signal "on" or "off".

(c) Visual triple beat margin on the live video was the same with or without the T1.

(d) The error rate on the T1 signal was 2.88 x 10^{-9} , which was not as good as expected since the composite carrier-to-noise ratio on the PCM channel was 46.3dB. This was traced to the demodulator's sensitivity to Channel 6. In fact, with the PCM off, the video output of the demodulator showed detection of Channel 6 sync pulses.

*Channels 2-E at +30dBmV; F-13 at +32dBmV; J-W at +34dBmV.

Considering that, in the future, 96-channel multiplexing equipment with increased bandwidth may be available, it would be preferrable to run the PCM at levels lower than the video to minimize its contribution to composite beat build-up in the CATV system. It was desirable, therefore, to run the PCM channel 10dB below the level of the adjacent channel video. Since demodulator sensitivity to the adjacent channel precluded doing this, all remaining tests were performed with Channel 6 disabled.

A long-term error rate test with the PCM operating 10dB down from video (+20dBmV) produced an error rate of 2.3×10^{-11}. This was a 15-hour, 35 minute run with the PCM operaging simultaneously with 30 modulated TV channels. Composite carrier-to-noise ratio on the PCM channel was 36.3dB.

Finally, the PCM was transmitted over the system after sub-VHF diplex filters were added to each trunk station. These filters are used to establish bi-directional system operation and added about 40 nanoseconds of differential group delay at the 75 MHz carrier frequency; this differential delay is specified over the 3.58 MHz video-chroma carrier separation normally used for television transmission. With the added delay produced by these filters, a two-hour test yielded an error rate of 3.598×10^{-10}, using the same operating conditions as in the 30-channel test described previously.

AM Tests

A few tests were also run with a AM video modulator/demodulator pair designed for normal television transmission operated on Channel 2. Figure 8 shows the modulator output spectrum, where some slight clipping of the lower sideband by the vestigial filter is noticeable.

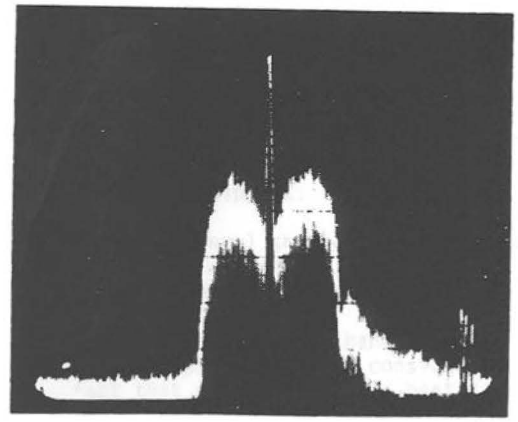

Figure 8

AM Modulator Output Spectrum
3.156 Mb/s Input; 55.25 MHz Carrier Frequency
(+34dBmV full scale; 10dB/cm vertical; 1 MHz/cm horizontal)

In order to get satisfactory PCM transmission, certain operating conditions had to be maintained on the modulator and demodulator;

(a) The percentage of modulation had to be reduced to 50 percent, presumably, to minimize the effects of quadrature distortion in the video detector from the clipping of the lower sideband.

(b) The IF and AGC levels in the demodulator had to be very carefully set to obtain the proper detected output level. The AGC system in this particular equipment used sync-tip reference. Since the PCM is transmitted without sync pulses, some limited AGC action will be obtained by detection of the composite signal making the setup of the AGC very critical.

There were also slow, long-term, level shifts due to AGC drift which precluded making any extensive measurements. However, the following could be determined:

(a) With the T1 signal operating at video level along with 33 modulated TV channels and 140 nanoseconds differential group delay, an error rate of 5.39×10^{-9} was obtained for a 25-minute test. This was with a 48dB carrier-to-noise ratio.

(b) When the carrier-to-noise ratio was reduced to 35dB, the error rate degraded to beyond one in 10^{4} ; at a 40dB carrier-to-noise ratio, a 5.8×10^{-7} error rate was recorded.

These AM tests, although brief, indicated problems similar to those pointed out by the GTE Lenkurt work, and since this was the only AM equipment available, no further testing was conducted.

EQUIPMENT REQUIREMENTS

These experimental tests point to certain performance requirements for the modulation/demodulation equipment and CATV transmission system if PCM and video signals are to be transmitted simultaneously without degradation.

a. Modulation/Demodulation

Tests conducted thus far indicate that coaxial cable and cable amplifiers do not constitute a major impairment to the transmission of high-speed PCM signals over CATV systems. The CATV modulator/demodulator are the most critical points in the system. Such equipment should be specified as follows:

(1) The modulator should be designed for color TV transmission. This should include pre-equalization circuits to correct for phase distortion inherent in the shaping circuits of the modulator, and optimized circuits to provide the minimum linear differential phase characteristics (equivalent to minimum differential delay) necessary for high quality color TV signals.

(2) Synchronous detection should be employed in the AM demodulator in order to achieve high performance levels with respect to differential delay and gain and quadrature distortion. The keyed AGC circuit in the demodulator must also be disabled.

b. CATV Transmission System

In general, if the CATV transmission system has been designed for video-quality transmissions, no problems will be encountered in transmitting PCM with an acceptable error rate. The curve of Figure 7 shows that signal-to-noise ratios of 30dB or more on the PCM channel will give excellent digital signal recovery. Discrete and composite beat distortion products should be maintained at comparable levels to avoid unsatisfactory error rates. These reduced signal-to-noise ratio requirements allow the PCM signals to be run on the system at levels 10 to 15dB below the video, thus minimizing contributions of the PCM channel(s) to distortion ~~products affecting the video signals.~~[6] Systems designed exclusively for PCM transmission can take advantage of the lower carrier-to-distortion ratio requirements to increase amplifier spacing and reduce the size of the cascade.

SUMMARY

Overall, the experimental tests show, especially for the FM transmission system, that 3.156 Mb/s PCM can be transmitted over CATV systems without degradation to either the PCM or the video. Certain guidelines, however, should be followed:

(1) Sensitivity of the PCM demodulator to adjacent channel signals must be considered. If it is unacceptably high, extra preselection must be specified, or, preferably, a guard band maintained between the PCM channel(s) and the video.

(2) Sufficient signal level and carrier-to-noise ratio must be maintained at the input to the demodulator as the system levels vary with temperature. A 30dB carrier-to-noise ratio would provide a good basis for system design and guarantee sufficient signal-to-noise at baseband for proper operation of the PCM decoding equipment.

(3) The PCM channel should be run 10dB below video to minimize its contribution to composite beat build-up in the CATV system.

(4) Selection of the PCM channel carrier frequency should take into consideration the fact that composite triple-beat distortion is worst at the standard TV channel video carrier frequencies. If PCM is operated "off channel", triple beat distortion will have a lesser effect on the PCM error rate.

REFERENCES

1. L. D. Crawforth, "Second Generation Toll-Quality PCM Carrier Terminal", Automatic Electric Technical Journal, April 1972.

2. GTE Lenkurt Demodulator, April 1968.

3. R. B. Chadwick and P. M. McManamon, "Advantages of Digital Transmission in CATV Trunks", 22nd Annual NCTA Convention Official Transcript, Technical Volume, June, 1973.

4. Adam Lender, "Correlative Level Coding for Binary-Data Transmission". IEEE Spectrum, February, 1966.

5. "Spectrum Analysis - CATV Proof of Performance", Hewlett-Packard Co., Application Note #150-6. April, 1974.

6. K. Y. Chang, "Transmission Properties of Analog Coaxial-Cable Lines", Conference Record IEEE International Symposium - Subscriber Loops and Services, Ottawa, Canada, May 1974.

TWO-WAY IS ALIVE AND WELL

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ABSTRACT

This paper deals with certain technical, operational, and economic considerations and features relating to interactive, bidirectional CATV systems developed and installed by TOCOM, Inc. at several locations. Extensive operational field experience has provided TOCOM with a fully-operational two-way system design and production home terminal units that are generating additional, paid services in these systems. Inherent features of the TOCOM system provide faster, more accurate system maintenance techniques and an array of interactive functions, including effective "per-program" pay-TV mechanisms. The services described represent a new market for CATV systems with the TOCOM capability.

Contrary to the impression one might gain from the lack of publicity, discussion, and articles in the CATV industry trade journals, "Two-Way" is alive and well across the country. The term "Two-Way", as used herein, does not denote bidirectional "capability" only, which is theoretically present in many operating systems today, but refers to fully-operational, bidirectional systems utilizing interactive response terminals in the customer's home.

These systems are not "experimental" systems, utilizing limited numbers of esoteric hand-crafted terminal units. These are fully operational, bidirectional, 31-channel CATV systems utilizing production terminal units in the subscriber's home to provide additional, paid services. These systems are not subsidized by the manufacturer, but are systems that were purchased for cash by seasoned businessmen during a period when the CATV industry was in one of the worst recessions in its history.

The reader will probably be surprised to learn that the developer and supplier of these operating two-way systems is not one of the industry giants or a major MSO, but is TOCOM, Inc., a small, Dallas-based firm formerly known as CAS Manufacturing Company.

TOCOM has sold and installed the headend, central data system, and initial section of cable plant at five locations, to date. Each system is also a fully-compliant, licensed CATV system. Follow-on installation contracts with TOCOM provide for continuing plant construction; system owners may also contract with TOCOM to provide system management, operation, and maintenance personnel and services under a management contract. Home terminal units are also supplied on a continuing basis, as the systems require them.

The author of this paper is the manager of one such operational two-way system, located in The Woodlands, Texas. The Woodlands is a new town development located about 30 miles north of Houston, and will comprise about 50,000 homes when completed.

Woodlands CATV, Inc. is actually the third of five such systems to come on line in the past two years. Two new systems are currently scheduled to become operational during 1976. This paper will deal principally with the Woodlands system, but is representative of the other systems, as well. The intent of this paper is to provide the reader with an insight into some of the daily operation aspects of two-way systems, rather than merely reiterate all the "pie in the sky" features that may some day be available to the users of future two-way systems.

The past difficulties associated with the creation of a demand for cable TV service in the urban and suburban marketplaces should be a familiar subject for those readers responsible for sales and marketing in those marketplaces. Pay-TV represents an additional piggy-back service that is currently responsible for increasing average revenue-per-subscriber and basic penetration percentages in many systems. Pay-TV is only the first step in the right direction, however. The end objective of those system operators desirous of maximizing return on investment is the addition of as many more piggy-back services as possible, providing revenues increase faster than costs.

Two-way services represent an additional incremental increase in potential revenue per drop that does not detract from existing services, but adds another attraction to the existing package offered by the cable system. A two-way command and control capability is also obviously not unrelated to the problem of hard security for pay-TV.

The current major commodity in the TOCOM II systems is security, an area of opportunity not currently addressed by any other CATV system. Conventional commercial security systems offering central-station monitoring 24 hours a day are generally too expensive for typical residential application. The "residential" security systems are typically too expensive (if they work reliably), or unreliable (if they are affordable). Despite this problem, there is an increasing demand among urban and suburban residents for household security systems; a demand that closely parallels the increasing crime rate. It is this demand that has provided TOCOM the opening wedge in supplying two-way service that the subscriber is ready and willing to pay a monthly premium to obtain.

Household emergencies requiring outside assistance generally fall into three categories: fire, police, and medical. In each case, the speed of response is extremely critical in determining the effectiveness of the response. The typical time lag, from the moment the need for assistance is recognized by the individual to the time the appropriate response agency has sufficient information to react effectively, is three to five minutes....or more. If automatic detection and reporting systems are not utilized, the delay frequently means total loss, with little or no chance for recovery.

To demonstrate to the reader's satisfaction that the 3-5 minutes is not an excessive estimate, visualize the specific, time-consuming steps that would follow discovery of a fire in the reader's home: the first indication would generally be detection of smoke, by sight or smell; assuming the reader was not asleep at the beginning of this excercise, detection might be after the fire is well-started. Second, the reader would try to locate the source and make an on-the-spot determination as to whether it can be handled without assistance. If the decision is negative, the next step is to find the phone, locate the number of the fire department, dial the number, wait for someone to answer, identify the problem to the answerer, provide name, address, and telephone number, and then wait while the information is relayed to the fire department dispatcher, who selects and dispatches the nearest available unit.

Alternatively, visualize a fire detection system that detects the fire immediately, whether the reader is home and awake or not. The alarm is sounded locally and, at the same time, is printed out at the fire department dispatcher location, together with the reader's name, address, telephone number, and other data which might be pertinent to the responding unit....all within 30 seconds from the time the alarm first sounded.

Without further belaboring the point, it should be obvious that elimination of the requirement for personal action and possible communication delays associated with the telephone system drastically reduces the total time required for an agency to arrive on the scene of an emergency. Operating experience in the various TOCOM systems has demonstrated both demand and acceptance by the subscriber, and a willingness to pay an additional premium for these services.

The balance of this paper will deal principally with a functional description of the TOCOM II system and how various operational aspects of the system impact on daily operations.

The TOCOM II system essentially consists of a Central Data System, bidirectional cable plant, and home terminal units. Each of these major elements are described in more detail below:

a) Central Data System: The CDS comprises a Hardwire Control and Display Console, a minicomputer with bulk memory, a data transmitter, one or more data receivers, several modems, teleprinters, and other peripheral devices.

b) Cable Plant: The cable plant utilizes dual trunk cable with unidirectional amplifiers providing a 5-300 MHZ response, and bidirectional distribution cable and line extenders which exhibit a 5-30 MHZ response.

c) Home Terminal Unit: The home terminal unit is a flush-mounted device, with all control functions located in a remote-control "palm unit", which is connected by a 25-ft cord to the terminal unit. The home terminal incorporates a preamplifier, a 31-channel converter with AFC, a digital transceiver, and a control logic board.

Each home terminal incorporates unique identification logic which allows the unit to respond to only one "address" in a block of 1024. The transmitter portion of the integral digital transceiver utilizes one of 60 possible frequencies, thereby providing a potential of 60,000 unique addresses for the system. The limitation is arbitrary, rather than inherent.

The home terminal is modular in construction, which greatly facilitates field maintenance. Functional problems are readily associated with specific modules, which can be easily replaced in a matter of minutes by the field technician or installer. Experienced MTR (mean time to repair) in the Woodlands System, for service calls resulting from malfunction of the home terminal unit, is approximately 15 minutes.

The hardwire controller generates sequential interrogations for all terminal units during a six-second cycle, which is transmitted to all units on a common interrogation frequency. Responses are received by one or more receivers in the CDS as time-division multiplexed signals within each frequency "group". The detected signals are fed to the hardwire control console logic for decoding and display of the returned data. The hardwire controller normally operates under computer control in the "ON-LINE" mode, but is also capable of operating in a free-standing (OFF-LINE) mode without computer assistance.

When operating in the ON-LINE mode, the computer recognizes only those addresses which have been entered by the operator into memory. If an "active" address fails to respond to interrogation, the computer pauses and reinterrogates that address up to 50 times. Each response, if any, is parity checked for valid data; less than 47 out of 50 valid data responses initiates a MONITOR alarm, as does a totally missing response, or a response that appears in an "inactive" address time slot.

Return data words containing MONITOR, FIRE, POLICE, or MEDICAL alarms cause the computer to initiate an output alarm message to a teleprinter in the appropriate location (i.e.:fire station, police station, etc.) which identifies the unit address code, the type of alarm, time of day and date, followed by a block of demographic subscriber data which includes name, street address, telephone number, geographic location, and other selected data pertinent to the specific nature of the alarm.

Each home terminal unit may be addressed with any one of 16 different commands during interrogation, and can select its response from any one of 16 different local inputs. This command/control/response capability affords ample reserve functions for future services. Currently, the basic system utilizes only two command words and one response word in normal operations. The normal response word contains status of the three alarm circuits, on/off status of the TV set, channel selected, subscriber response data, pay-TV authorization, and data validation information.

The full data block from a single terminal unit may be selected manually for display on the operator console, or the computer can summarize specific data blocks for all units in the system, without individual identification.

Two separate techniques may be alternatively employed for pay-TV operations:
a)<u>Positive Control</u>: In this system, all terminal units will display only a "preview" channel when any premium channel is initially selected. Actuation of the pay-TV key on the home terminal palm unit initiates a "request" for that channel to the CDS. If previously authorized, the computer will return a tuning command to the home terminal which causes the converter to tune the appropriate channel for display. Subscriber identification and viewing time is logged by the computer for each requested block of premium viewing time.
b)<u>Passive Control</u>: In this system, actuation of the subscriber's pay-TV key enables the tuning of a premium channel. The combination of pay-TV authorization, TV power "ON", and the selection of a premium channel during premium viewing time is required to initiate the identification and logging process for that subscriber.

With the basic functional description provided above, let us now move on to the method of implementation of these various services in the Woodlands CATV system:

Construction of new cable plant in the Woodlands CATV system is accomplished at a pace dictated by the development of new real estate, currently about two miles of plant per month. All utilities in the Woodlands are underground, and are installed concurrently in advance of release of each parcel to the builders. TOCOM Construction Company, a division of TOCOM, Inc., provides turnkey construction of the CATV, gas, and electrical plant, plus physical installation of the telephone plant at the Woodlands. Major blocks of CATV plant construction at other sites are also supported by TOCOM Construction Company.

Housing construction typically begins within 30 days after completion of plant installation, with total buildout of each parcel currently averaging about 15 months from activation of the plant.

Each residential dwelling unit in The Woodlands is required, by covenant, to be prewired for a minimum service capability. The "minimum package" required for each unit consists of a smoke detector, two tv outlets, two manual medical alarm stations, and two manual police alarm stations. The cost of this prewire package is borne by the builder, and is included in the price of the house. The builder and/or buyer have a further option of adding additional outlets, smoke detectors, heat detectors, alarm stations, and sophisticated intrusion detection systems which are interfaced to the police alarm circuit.

It is interesting to note that over 65% of the homebuyers are currently specifying optional intrusion detection systems.

House drops are installed by the prewire crew on a turnkey basis. Responsibility for repair and maintenance of the prewired system and the house drop is assumed by system operations and maintenance personnel after functional acceptance tests of the installation.

As each new home is occupied, the resident has the option of not subscribing, subscribing to TV service only, or subscribing to the full-service package. All service charges are flat-rate monthly charges that are independent of the number of outlets, or number or type of alarm devices in the home. If the subscriber desires the full-service package, he is required to "purchase" a home terminal unit. Some builders purchase the home terminal units in advance and supply them with the house.

This mechanism, of course, eliminates the major capitalization requirement that has historically been the downfall of proposed two-way systems, and represents a major key to economic viability in this type system.

The basic statistics of the Woodlands CATV system penetration, in the environment described above, may be somewhat surprising:

a) 97.4% of all occupied homes behind the plant are subscribers to some level of service.

b) 93.5% of the system subscribers subscribe to the full-service package.

Higher penetration percentages have the net effect of reducing plant maintenance costs, when computed on a "per-subscriber" basis. With the exception of the additional staffing required to cover operation and maintenance of the Central Data System complex and the home terminal units, plant maintenance requirements, in the aggregate, are no greater than that required in any properly-maintained, fully compliant system.

Downstream electronics, which consist of TOCOM "Blue Chip" series amplifiers, are completely conventional in operation and maintenance. Upstream electronics require periodic adjustment of squelch thresholds until the home terminal population on each feeder leg stabilize; thereafter, the maintenance interval required is the same as for the downstream electronics.

Maintenance of the home terminal units requires principally digital logic skills. Competent RF maintenance technicians can be cross-trained readily to handle repairs of the RF circuitry and components of the home terminal unit, as well as field replacement and calibration of functional modules within the unit. Although the theoretical MTBF (mean time between failures) has not been officially calculated for current production terminal units, the actual, experienced MTBF of the units installed in the Woodlands CATV system is currently (at this writing) in excess of 10,000 hours...and improving.

The two-way nature of the operating system provides a maintenance bonus: performance of any portion of the system can be observed by analysis of the data returns from that section of plant. The console operator can select a single terminal unit for examination, in the OFF-LINE MANUAL mode of operation, which results in continuous interrogation of that unit. The RF signal, when examined with a spectrum analyzer, provides an indication of the performance of the section of cable plant through which that signal passes. Level measurements from several adjacent locations quickly provide an indication of any degredation that may have occured since the last examination of that section, well before problems become evident in the subscriber's pictures.

In the event of failure of an amplifier or power supply, or physical damage to the cable plant, an immediate alarm message generation for units downstream of the affected point permit immediate pinpointing of trouble spots. No more 5:15 PM service calls to correct a 10 AM problem!

In normal operation, the home terminals, central data system, and cable plant have sufficient dynamic range to accommodate cumulative pertubations of interrogation and return signal levels. It is immediately apparent to an experienced operator at the CDS when a section of the system displays a trend away from normal operational levels.

On a personal level, the system personnel are more closely involved with the quality of their workmanship than the author has ever observed in conventional systems. Although the complexity of the system, in overall terms, is at least an order of magnitude greater than a conventional one-way system, the incidence of service calls does not appear to be significantly higher than in a one-way system of equivalent size.

At the initial briefing of fire, police, and medical personnel last year on the operational capabilities of the system, there was some quiet skepticism evident about the effectiveness of the system. These agencies have all completely accepted the system, to the point where standard operating procedures for all three services are specifically written around the operation and capability of the system.

Subscriber response to the services offered can only be described as overwhelmingly affirmative. In the words of one subscriber, "....the system is worth its weight in gold!". The subscriber, Mrs. Terry Merritt, made this statement to the Fire Chief after having a fire extinguished in an attic-mounted gas furnace....less than five minutes after the alarm sounded in the Merritt residence. The family was unable to even locate the fire until less than a minute before the Fire Department arrived on the scene, and the fire was extinguished without any damage to the roof, attic, or ceiling of the house.

Although a year of operation at the Woodlands is perhaps not statistically valid, there has not yet been a burglary loss involving a home with an intrusion detection system, or a major loss due to smoke or fire damage. Numerous incidents have been recorded at the Woodlands and in other systems of major losses that have been averted and lives saved that would not have been possible without the TOCOM II system.

The effectiveness of the protection afforded by the Woodlands CATV system has been recognized by some insurance companies, who are now offering substantial discounts on homeowner insurance premiums to full-service subscribers of the system. The total amount of the discount on an average policy reduces the mortgage payments by more than the monthly service charge for the additional service.

In summary, it is evident that a system service that requires a substantial outlay of cash for a home terminal unit, plus an additional monthly service charge for the service must have something to offer to achieve a net penetration of 91% of all homes behind the plant.

Readers interested in learning more about TOCOM II systems or in seeing a two-way system in actual operation are invited to contact the author at The Woodlands system or just drop in anytime they are in the Houston area. For those readers in other parts of the country, contact TOCOM, Inc. in Dallas, Texas for the location of the system nearest you.

WAVEFORM TESTING

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Abstract

Existing subjective and frequency domain testing procedures are shown to have major weaknesses in ensuring the delivery of acceptable television pictures to cable subscribers. Recommended, instead, are waveform test techniques using VIT signals as generated by the networks. Applications of measurement procedures and performance objectives are discussed for echoes, noise and chrominance/ luminance gain and delay.

Waveform testing of television signals introduces a valuable concept to the performance testing and maintenance of R. F. distribution systems; including cable, satellite and fiber optics. Waveform techniques, as presently used by broadcast engineers to meet performance objectives for their video facilities, can also be used by cable engineers to meet performance objectives as to the picture quality of the television signals delivered to the subscribers. This is in contrast to present procedures that are primarily designed to provide information on quality and performance of cable equipment and distribution system.

Monitoring picture quality to ascertain that the delivered signals meet minimum acceptable level of impairment to the TV picture also ensures that the distribution system performs satisfactorily: the converse is not true. Knowing that the distribution system meets minimum standards does not ensure the delivery of satisfactory pictures. Maintenance procedures, based on distribution system characteristics, have resulted in many complaints by broadcasters, of excessive degradation of their local channels when carried by a cable system. This is especially true of local UHF signals where interference is often introduced at the head end by the mixing of harmonics of the local oscillator from the converter with other UHF. Distribution system testing has little value in resolving these complaints.

Waveform test procedures have had little application in the past to the cable industry as it was expensive to introduce these test signals at the head end. In addition, they provided no information as to the quality of incoming television signals. Equipment was necessary to demodulate each channel, insert these diagnostic signals and then remodulate them; all of which added degradation to the desired TV signal.

Today, waveform test procedures are applicable to the cable industry as these diagnostic signals are already injected into the four major network transmissions; ABC, CBS, NBC, and PBS. This eliminates the need for a cable operator to own expensive equipment to introduce these signals. Most important, in a report published in 1975 by the Network Transmission Committee 1/ there are recommended test procedures to meet picture impairment performance objectives. Granted these objectives for network transmission are more stringent than required for viewer reception, the signals still provide an excellent reference of quality and the measurement procedures are valuable and easy to use. There need only be reduced, reasonable standards for subscriber reception.

This paper compares linear waveform distortion analysis with presently used methods of subjective testing and frequency domain measurements. It also endeavors to show that waveform analysis merits consideration by the cable industry to improve subscriber penetration in existing systems and as an aid to gaining entry into urban markets. Before going into waveform analysis, this paper discusses the procedures we are using now, including subjective and frequency domain testing, and points out their present weaknesses.

Subjective testing can be defined as evaluation by observation of the television picture and is a valuable technique in the hands of qualified viewers in detecting visible degradation of the picture. In some respects, it is superior to measurements of impairments as it deals directly with the end result rather than causative factors that correlate with picture quality. All distortions are simultaneously visible and are diagnosed by the eye/brain complex for their acceptability. Other advantages include high sensitivity to some observable factors, the use of the TV set as test device and the lack of need to disrupt the system. Subjective testing has many advantages.

Subjective testing also has many limitations; one is the dependence for results on the viewer's competence or motivation. The viewer may be a cable technician without knowledge of the type or magnitude of the distortion observed or may be more concerned with concealing defects. A major weakness of subjective testing lies in the field of maintenance; some factors such as hum modulation can be difficult to see depending on the TV picture content, brightness, contrast and ambient light. Other distortions cannot be detected or measured until they are definitely visible; therefore they cannot be corrected until they reach this relatively high level. An example is an amplifier in the early part of a system which may be introducing an excessible amount of distortion, using up most of the system tolerance. Still the picture at that location may not appear degraded. Therefore the cable industry and the FCC requires that these procedures be supplemented with other techniques that include frequency domain measurements.

Frequency domain techniques involve introducing equal amplitude sine wave signals at various frequencies into equipment, cable or a system; and then measuring the amplitude or phase response variations that result. These techniques are valuable for maintenance of equipment, cable or detecting gross distortions in the cable distribution system since amplitude variations can affect other noise and overload factors. An important plus is that cable technicians generally have the test equipment and the know how to make frequency domain measurements whether using a standard sweep generator or a simultaneous sweep technique. The latter permits analysis of a cable system response during daytime hours while creating a minimum amount of distortion to the television picture.

Unfortunately frequency domain testing provides little information concerning the quality of the TV pictures delivered for the following reasons:

-(1) Faithful reproduction of the television signal, or minimum distortion of the waveform, requires that delay be considered as well as amplitude. The cable industry techniques do not include delay versus frequency measurements.

-(2) As pointed out by Osborne 2/ even "full knowledge of the amplitude/frequency and delay/frequency characteristics does not give a direct indication of the consequent deterioration of picture quality, save in certain extreme cases, and involves a great deal of unnecessary effort."

-(3) This same viewpoint is emphasized by Thiele 3/ "the deviation in frequency response (in dB) to produce a given subjective impairment in transient response, i.e. a minimum error in waveform shape, -----will be different at different frequencies. In a particular case the same picture impairment was produced by a deviation of 0.4dB at 5Mc/s as by a deviation of 0.5dB at 100Kc/s." Although these measurements were made using Australian TV standards, the fact remains that there could be a differential of more than 20dB in amplitude/frequency response, to produce equivalent impairment.

-(4) MacDiarmid 4/ discusses frequency domain in terms of picture impairment tolerances. He states "What is perhaps the most important objection to the use of sine-waves arises in considering the question of tolerances" and then "where the amount of distortion to be tolerated is modest, the only economical method is to specify and measure the waveform response and to abandon sine-wave ideas."

These are but a few examples from the published literature that encourage the use of waveform analysis for television signal measurement, and which show that existing methods do not ensure acceptable pictures to the viewers. I will now discuss waveform analysis and then its application to the cable industry.

Waveform analysis techniques involve measurement of the wave shape or the amplitude versus time response of a test signal of a specified waveform to determine the amount of distortion introduced. The test signals are selected to provide maximum information as to the desired parameters, in a manner that is easily evaluated, permits rapid testing and is accurate. These signals conform to the television picture which are of waveforms with similar energy distribution.

Waveform analysis signals as used by broadcast engineers fall into two categories: the first, Vertical Interval Reference (VIR) and the second, Vertical Interval Test (VIT) Signals. Because these signals are helpful to the broadcast engineer in adjusting electronic equipment, cameras, lighting, ect., they are incorporated into the programs in specified horizontal lines during the vertical blanking interval.

The VIR signals are valuable to broadcasters in referencing the program content to reduce undesired variations in color. They assist television producers and operators in adjusting various signal parameters so that different programs will have similar amplitude and phase characteristics. The VIR's are not applicable to cable systems as they reference program content factors that deal with video rather than transmission factors that also include R.F. Therefore this paper will not deal with these signals but for those desiring more information see the article by C. Bailey Neal on their history, in Communications/Engineering Digest 5/ or the EIA Television System Bulletins Nos. 1 and 3. 6, 7/

This article has covered some weaknesses of subjective and frequency domain testing. Now it will touch on my recommendation to the cable industry for the use of VIT waveform signals. This includes not only their advantages but also applications, measurement procedures and performance objectives.

The VIT signals are diagnostic tools used by the broadcast industry and intended to measure the characteristics of a transmission facility and to reduce picture impairments that occur on local or intercity transmission facilities. They are also used by remote control and test functions. Although these signals are designed to cope with video distortions, many of these same distortions can be introduced at RF by a broadcast transmitter, a microwave link, propagation, a cable headend or distribution system. A major feature of VIT signals is that they are very sensitive and can measure relatively small picture impairments. They can, therefore be used to pinpoint errors occuring in the various links of the transmission path and to allocate maximum acceptable levels of distortion for each link. The use of performance objectives for each link is not only helpful in determining responsibility for excessive total degradations but is also desirable for trouble shooting purposes.

These VIT signals are generally available to the cable engineer since they are transmitted by the four major networks and AT&T in accordance with the Network Transmission Committee (NTC) Report No. 7. 8/ These are: the Composite Test Signal (see figure 1a) which is inserted on line 17, field 1, and the Combination Test Signal (see figure 1b) which is inserted on line 17, field 2. This NTC report is especially valuable in that it defines transmission parameters, test signals, measuring methods and performance objectives for major network facilities. It is published by the Public Broadcasting Service.

A major advantage to the use of these signals is that the information they provide about linear distortions can be directly converted to impairments to the television signal and that these in turn can be correlated with subjective evaluation of picture quality. For CTAC Panel 2, the chairman Archer Taylor compiled some Bell Telephone Laboratory studies that provide this type of correlation. 9/

This paper will discuss the merits of those VIT signals pertinent to RF transmission systems that are important for the delivery of improved TV on locally broadcast channels. This includes factors such as echoes for which the broadcasters have no performance objectives, but it excludes many factors over which the cable operator has little control, such as luminance or chrominance non-linearity. However, first it is worthwhile touching on some of the history of VIT signals.

The history of waveform techniques dates back at least to 1935 when Puckle dealt with signal transients and later wrote a text suggesting the use of various waveforms for an oscilloscope time base. 10/ This analysis was expanded to television by Bedford and Fredenhall in 1939. 11/ In 1954, N.W. Lewis did a detailed study on Waveform Responses of Television Links based on sine squared bar and pulses plus a square wave. 12/ A few years later I.F. MacDiarmid did a two part tutorial analysis of waveform distortion: its derivation, choice of waveforms and examples of various types of distortion. 13/

In the early 60s, there were increasing applications of these techniques: Osborne 14/ did a paper on assessing picture quality by means of the K-rating and suggested the use of Wheeler's 15/ proposal that pairs of echoes of adjustable amplitude and polarity could be used to correct for amplitude/frequency and delay/frequency distortions.

In 1963, AT&T 16/ published a valuable tutorial manual (as revised by the Network

Transmission Committee) dealing with an analysis of television signals. Siocos 17/ published a paper in 1966 evaluating CBS network transmissions with slight variations of VIT signals. Also about this time Peter Wolf 18/ proposed the addition of a special 20T pulse for measuring short-time distortions with and without a graticule: Everett 19/ derived means for correcting waveform errors; and Rhodes 20/ and Schmid 21/ contributed excellent analytical papers dealing with the modulated 12.5 sine-Squared Pulse.

The IEEE 22/ published a Video Signal Trial-Use Standard in 1974 that precisely defined the various terms, discussed measurement and included, in the appendices, a detailed description, derivation and measurement of the Sin^2 Pulse, Sin^2 Step, T Step and the Mod 12.5T Pulse.

A major step forward in terms of applications came in June of 1975 with NTC Report #7 23/ which introduced non-regulatory standards or "Performance Objectives" for network transmissions of video links. This report also defines the transmission parameters, test signals and measuring methods to be used. It also replaced the IEEE use of the sin^2 T pulse with the sin^2 2T pulse as the latter introduces less irrelevant distortions. Furthermore, these NTC recommended test signals are the ones presently transmitted by the four major networks, ABC, CBS, NBC and PBS.

This is an abridged history of the many important papers and texts that have dealt with waveform testing. Now I return to the present to discuss the advantages of VIT signals for cable systems.

There are some important advantages that are worth summarizing:

-1) Most important; tests can be made of parameters that greatly affect the picture reception, but which have not been feasible using present test procudures. This includes measurement of echoes, color saturation, color delay and impulse noise.

-2) Tests can be made without disrupting subscriber service, at any system location and on those channels for which the cable operator has responsibility for quality.

-3) There is no need to purchase equipment to interject these signals; for reception the only test equipment needed is a demodulator with several input modules plus a waveform monitor. This could total about $4000.

-4) There are major savings in labor which will soon exceed the above equipment cost. These savings will result from reduced system maintenance and especially from the minimization of conflicts with subscribers and TV service companies.

-5) The performance objectives for network transmission are more stringent than needed for subscriber reception. For these less sensitive objectives, the measurements are well within the capability of a system technician.

The advantages of using VIT signals for cable systems apply to many factors. However, this paper is being limited to just a few of these that are extremely difficult or costly to measure in any other way; noticably affect subscriber reception and for which the cable engineer has some control. In the future additional parameters will also be useful.

-1) Echoes; whether leading, due to direct pickup or lagging, for many other reasons. The cable industry often specifies the Paul Mertz 24/ curve without knowing how to measure compliance. Often, Time Domain Reflectometers or other techniques are used that merely measure the reflective characteristics of a component.

For the echo test,the 2T sin^2 pulse or the T bar from the Composite Test Signal can be used. (see figures 2,3) This 2T pulse is an excellent test signal as its energy spectrum is similar to the waveform of the television signal; approaching zero at the video cutoff frequency.

These signals are also used by broadcasters to measure transients, high frequency amplitude and phase delay; e.g. waveform distortions from 125 ns to 1us. For the cable industry it may be wise to ignore short time echoes of less than 500 ns as the broadcast signal or the test demodulator can also introduce transients. Measurements are made of the amplitude and delay of the undesired pulses. Where difficulty exists in identifying echoes down 30 dB or more, because of noise levels at the end of a system, the use of photographs are helpful since the pulse is constant and the noise random.

The echoes of most concern are from 0.5 to 2 u seconds which can be correlated with its displacement on a TV set. For example, the video part of a TV line is 53 u sec; for a 20" wide screen this would be a displacement of 0.38 inches for 1 us.

Alternate methods of measuring echoes are through the examination of the first few microseconds of the T bar which has a rise time of 125 ns. or the horizontal sync pulse with a rise time of 250 ns. between 10 and 90%.

It is far easier during antenna surveys to observe waveform echoes than to attempt to minimize echoes by observing the television picture. For example, it can be very difficult in an urban area to pinpoint an antenna location with minimum echoes by subjective testing. The picture content varies, background light changes and the eye/brain cannot remember slight variations of quality while taking in changes of color and noise. Using VIT signals, a far better job can be done in much reduced time in measuring and locating the source of echoes.

-2) Chrominance/Luminance Gain and Delay Inequalities produce noticable effects on the quality of a color picture.

Chrominance/Luminance gain refers to the amplitude ratio of frequencies, between the low frequencies near the video carrier and the high frequencies near the color sub carriers. Improper ratios result in degraded color saturation of the TV picture.

Chrominance/Luminance delay refers to the additional time involved in the path of the color energy with respect to the low frequency energy near the video carrier. Additional time results in delayed chrominance which can show on the TV screen as funny picture effect; for example, the red color of the lips of a persons face can be displaced from the monochrome detail of the lips. In spite of their importance, these factors are rarely measured by cable engineers. This is due to the excessive cost of equipment and time, using other techniques.

The key to delivering satisfactory color is the ability to measure and correct chrominance inequalities. Color saturation inequalities are easily correctible by slight amplitude/frequency response alignment of a headend channel processor or preferably by correcting the source of distortion which could be antenna site location, a narrow band antenna array, incorrectly aligned trap etc.

For these tests a modulated 12.5T Chrominance Pulse Test Signal is used (see figure 4) which is also part of the Composite Test Signal. Relative Chrominance Level (RCL) - where there is no delay - is equal to the sum in percent of the peak and base displacements of the pulse or RCL = ± 2a percent.

Relative Chrominance Time (RCT), where there is no gain distortion, is equal to ten times the total base displacements in nanoseconds or RCT = ± 10 b nanoseconds (figure 4) where b is the total base displacement.

Where both gain and delay distortions exist, the equations are more complicated and it is easier to use one of the nomographs as developed by Charles Rhodes of Tektronix 25/ (see figure 5). This nomograph not only gives the delay in nanoseconds but also converts the gain to decibels.

Reasonable performance objectives for a viewer for Chrominance Gain would be ± 2dB* and for Chrominance Delay would be ± 477 nanoseconds, 26/ based on a study by A. Lessman of Bell Laboratories. The ± 2dB compares with the broadcast network gain performance objective of ± 0.5 dB and the ± 477 ns. compares with the network objective of ± 75 ns. These are standards that can be measured and met by the cable industry. The ± 477 ns. may seem too permissive, however it involves shaped delay which is less objectionable than the broadcasters flat delay. 27/

Some sources of degraded RCL and RCT in cable systems are the filters for two-way in amplifiers and traps, bandpass filters and signal processors at the head end.

-3) Random Impulse and Periodic Noise are also parameters of importance to the quality of a TV picture. and unfortunately are not generally measured in a cable system. Most procedures measure the random noise as introduced by head end and distribution equipment. This ignores Impulse noise caused by automobiles, industrial plants, cosmic sources, power lines and video tape or film program sources. Likewise Periodic noise can be introduced in the broadcast transmission and also at a cable head end from defective equipment or interfering signals.

A very simple method for measuring the summation of these noises or for identifying them independently is by the use of the 18 us. flat part of the line bar. For low frequency periodic noise, use can be made of the television

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* The basis for ± 2 dB is past experiments showing noticeably degraded pictures on some TV sets resulting from a chrominance level reduced by 3 dB.

signal itself, observing it at a verticle sync rate.

This procedure is helpful in locating a cable antenna site or isolating noise sources as measurements are made during the actual signal transmission. This technique provides a means of comparing the total Signal-to-Noise with that introduced by the system.

There are other distortion measurements that can be made just as easily using VIT signals. However, time permits discussing only these few. Some others, such as differential gain and phase, are not presently serious sources of picture impairment although they become more important with the use of cable ancillary services such as satellites or terrestrial microwave. Another VIT signal, the multiburst, could supplement present amplitude/frequency response techniques in providing information as to total variations. In short this paper has just begun to scratch the surface in describing ways that tests using the VIT signals can contribute to the efficient operation of a cable system with a reduction in cost and time over current measuring procedures.

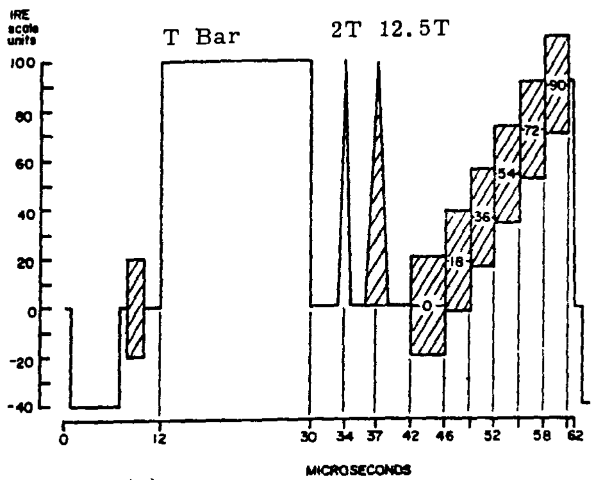
The measurement techniques discussed in this paper should help ensure that the quality of subscriber service is raised to its full potential. High quality subscriber service is necessary to open up urban markets and reduce broadcaster complaints. In addition high quality subscriber service will improve relations with subscribers, and therefore franchise officials. These points are elaborated in a previous paper. 27/

While the desireability of measuring picture impairment has often been acknowledged, the difficulties of measuring these parameters with traditional techniques has been a deterrent. As this paper demonstrates the test procedures using the VIT signals are not difficult, nor are they new or untried, having been used by broadcasters for years. The VIT signals are generally available for those channels over which the cable operator has some control. Finally the amounts of impairment measured can be compared with the television network performance objectives or be correlated with the Bell Telephone Lab picture quality ratings.

The parameters are important and there is no longer any reason not to measure them. For the future; there will be a need to use waveform analysis not only for measuring other parameters affecting picture quality, but also for isolating sources of problems, automating test procedures and correlating analog and digital TV reception.

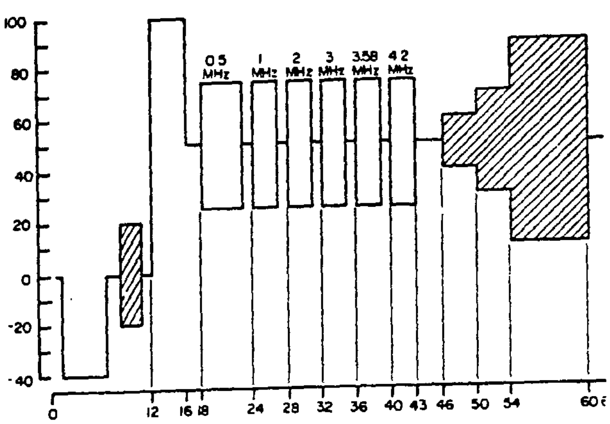
FIGURE 1

The Composite Test Signal



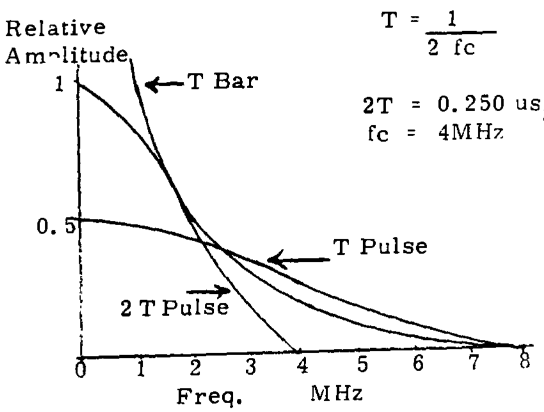
(a)

The Combination Test Signal



(b)

FIGURE 2

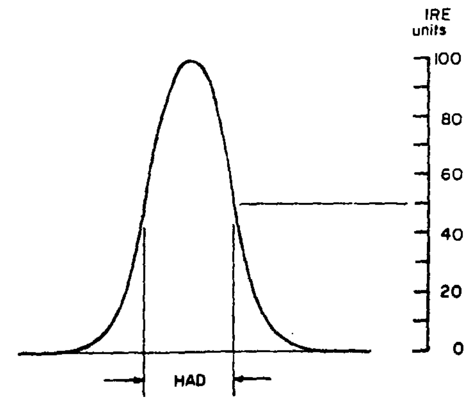


$T = \dfrac{1}{2\ fc}$

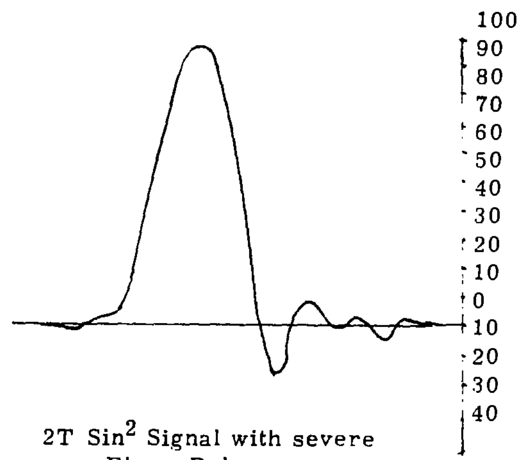
$2T = 0.250$ us, where $fc = 4$MHz

FIGURE 3

2T Pulse Test Signal



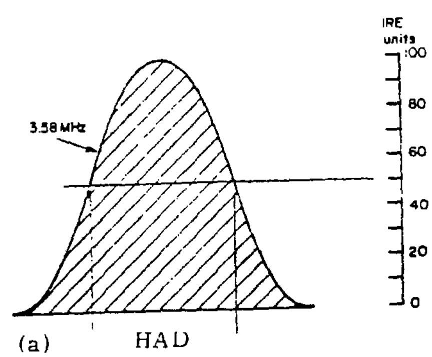
2t HALF-AMPLITUDE DURATION = 250ns



2T Sin^2 Signal with severe Phase Delay

FIGURE 4

Chrominance Pulse Test Signal



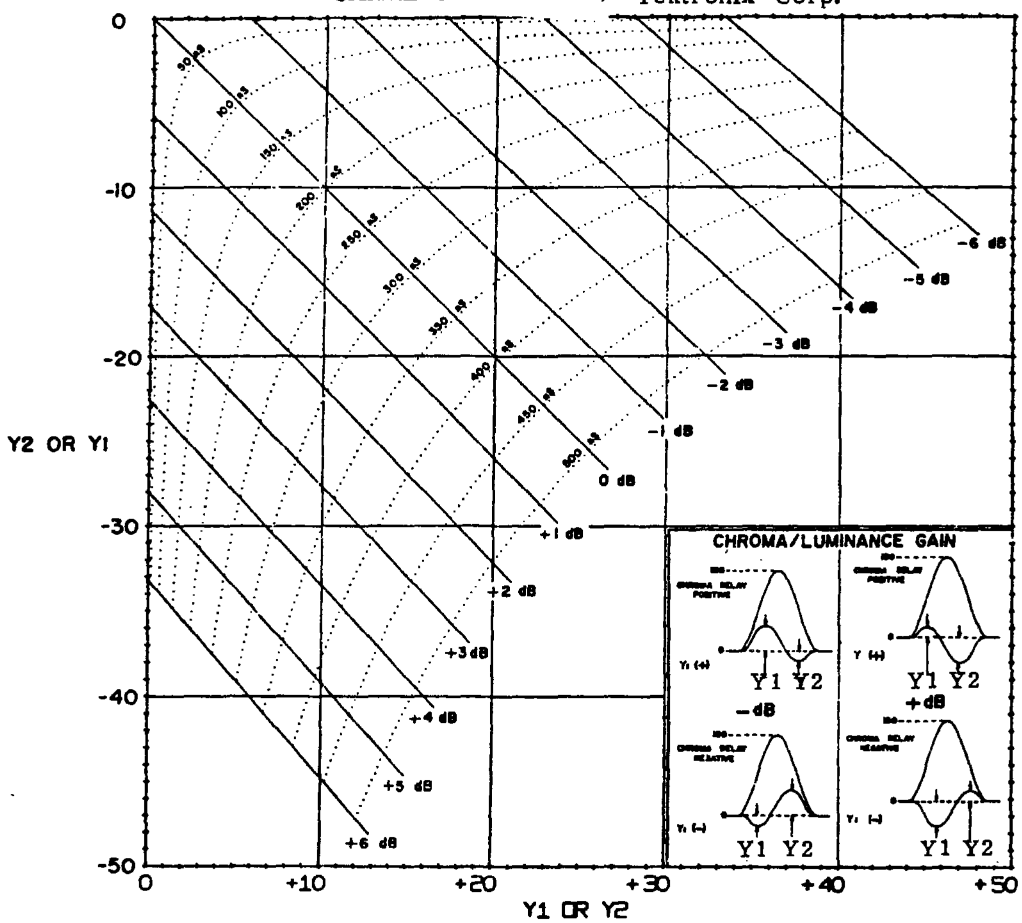
(a)

12.5T HAD = 1570 nanoseconds

FIGURE 4 (b)

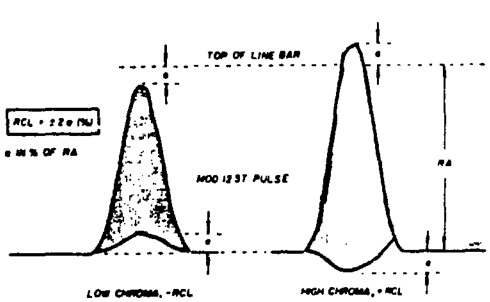
Nomograph 12.5T Modulated Sine-Squared Pulse for NTSC

CHARLES W. RHODES, Tektronix Corp.

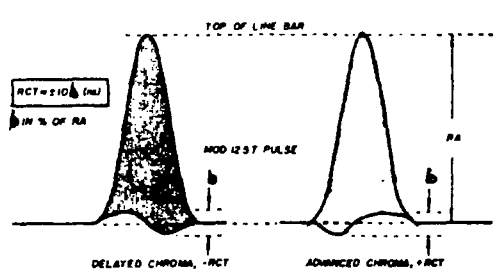


The Measurement of Linear Chroma Distortion in NTSC TV Facilities

HANS SCHMID



Relative chroma level.



Relative chroma time.

References

(1) "NTC Report No. 7" Video Facility Testing Prepared by the Network Transmission Committee of the Video Transmission Engineering Advisory Committee (Joint Committee of Television Network Broadcasters and the Bell System). Published by the Public Broadcasting Service, June 1975

(2) B.W. Osborne, "Picture Quality Assessment and Waveform Distortion Correction on Wired Television Systems," 1962 Jour. Brit. Inst. Rad-Engrs. 399-404

(3) A.N. Thiele, "Methods of Waveform Testing, Pulse and Bar - "K" Factor" Australian Bdcst. Commission Laboratory Report No. 26 Alderson Bldg., 508 Pacific Highway St. Leonards, N.S.W., Australia

(4) I.F. MacDiarmid, "Waveform Distortion in Television Links, Part I - Introduction to Waveform Distortion" Post Office Elect. Engrs. Jour., 1959, pp. 108-114

(5) C. Bailey Neal, "A Brief History of the VIR: Vertical Interval Reference Signal" Communications/Engineering Digest, Jan 1976, pp. 20-25

(6) "EIA Television Systems Bulletin No. 1," EIA Recommended Practice for Use of a Vertical Interval Reference (VIR) Signal. July 1972, Price $1.60 Electronic Industries Asso., Eng. Dept. 2001 Eye St., N.W., Wash. D.C. 20006

(7) "EIA Television Systems Bulletin No. 3" A history of the Vertical Interval Reference (VIR) Signal March 1975, Price $7.50

(8) NTC Report No. 7

(9) Archer S. Taylor, Chairman CTAC Panel 2 Final Report "Subjective Evaluation of Picture Quality" 12-13-14, Table 1

(10, a) O.S. Puckle, "The Transient Aspect of Wide-Band Amplifiers," 1935, Wireless Eng., p. 251

(10, b) O.S. Puckle, "Time Bases" John Wiley & Sons, Inc.

(11) A.V. Bedford and G.L. Fredenhall, "Analysis, Synthesis and Evaluation of the Transient Response of Television Apparatus" Inst. of Rad. Eng., 1942, p. 440

(12) N.W. Lewis, "Waveform Responses of Television Links" Proc. Inst. Elect. Eng., 1954, pp. 258-270

(13) I.F. MacDiarmid, "Waveform Distortion in TV Links" Post Office Elect. Eng. J., Parts I, II and III, 1959

(14) B. W. Osborne, See reference 2.

(15) H.A. Wheeler, "The Interpretation of Amplitude and Phase Distortion in Terms of Paired Echoes," Proc. IRE, June 1939, pp. 359-385

(16) "Television Signal Analysis" A.T. & T. Long Lines Dept, New York, N.Y.

(17) C.A. Siocos, Television Transmission Testing, "Vertical Interval Test and Reference Signals (VITS) in the CBC Television Network" 1965, Jour. Soc. Mat. Pict. Telev. Engrs., pp. 81-84

(18) P. Wolf, "Modification of the Pulse-and-Bar Test Signal with Special Reference to Application in Color Television" Jan, 1966, vol 75 Jour. Soc. Mot. Pict. Telev. Engrs. pp. 15-19

(19) F.C. Everett, "Recognition and Correction of Waveform Errors in TV Transmission" IEEE Trans. on Bdcst., Vol. BC-18, No. 1, Mar. 1972.

(20) C.W. Rhodes, Tektronix Corp. "The 12.5T Modulated Sine-Squared Pulse for NTSC," IEEE Trans. on Bdcst., Vol BC-18, No. 1, Mar. 1972

(21) H. Schmid, Am. Bdcst. Co. "The Measurement of Linear Chroma Distortion in NTSC TV Facilities" IEEE Trans. on Bdcst. Vol. BC-18, No. 3 Sept. 1972, pp. 77-80

(22) IEEE Std 511-1974 "IEEE Trial-Use Standard on Video Signal Transmission Measurement of Linear Waveform Distortion" IEEE, 345 East 47 St., New York, N.Y. 10017

(23) NTC Report No. 7

(24) P. Mertz, "Influence of Echoes on Television Transmission," Jour Soc. Mot. Pict. Telev. Engrs., 60, pp. 572-596, 1953

(25) C.W. Rhodes, Same as Reference 20

(26) A.M. Lessman, "The Effects of Delay Difference of the NTSC Color Television Signal" 1971, Bell Tel. Labs

(27) Vic Nicholson, "The Case for Picture Quality Standards," CTIC, Communications/Engr. Digest, Vol 1, No. 1 October 1975

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