June 26, 1967

The Monday Afternoon Technical Session of the 16th Annual Convention, National Community Television Association, held in the Adams Room of the Palmer House, Chicago, Illinois, convened at two-fifteen o'clock, Archer Taylor, Malarkey, Taylor & Associates, Engineering Management Consultant, Washington, D. C., Chairman presiding.

CHAIRMAN TAYLOR: I would like to formally welcome you to the first technical session of the 16th Annual Convention of the National Community Television Association.

We have a very interesting group of technical papers to present this afternoon and in the other sessions in the convention; and I think, in spite of the absence of the slide projector for the moment, we will proceed.

The first speaker, fortunately, can do without the slide projector, so we can have his paper first. It is with great pleasure that I introduce Mr. Carmine D'Elio of the Vikoa Corporation.

Mr. D'Elio received his B.E.E. degree in 1960 from the City College of New York, his M.S.E.E. degree in 1963 from Drexel Institute of Technology. He is currently enrolled in a doctoral program at the Newark College of Engineering. Presently he is a section head for advanced engineering at Vikoa, and formerly was a transistor application engineer for R.C.A.

Mr. D'Elio's paper is on "Noise Figure—Its Meaning and Measurement." Mr. D'Elio. (Applause)

MR. CARMINE D'ELIO (Vikoa, Inc.): Thank you, Mr. Taylor and gentlemen.

This discussion is tutorial in nature, nothing new will be advanced. The aim hopefully, is to present information on noise figure and signal to noise ratio in general, and show how the information is used for determining the effects of noise on cable systems.

NOISE FIGURE AND THE SYSTEM SIGNAL TO NOISE RATIO

By

Carmine D'Elio - Vikoa, Inc.

Introduction:-

Everyone is well aware of the fact, that noise in an amplifier or system, serves to degrade the information of the desired signal. In a cable system it sets the limit on the minimum signal that can be transmitted along the cable and still provide a good quality picture. In order to describe the quality of the picture in a more concise manner, we establish a relationship between the signal and the noise, namely the signal to noise ratio. Since noise fluctuates randomly over a period of time, it would be meaningless to try to relate an instantaneous signal voltage to instantaneous noise voltage. Instead, we deal with averages over a long period of time and use the mean squared signal voltage and mean squared noise voltage. The ratio of these two voltages is then referred to, as the signal to noise ratio. Since the signal and the noise are measured at the same point in a system and therefore appear across the same load, the ratio of mean squared voltages is also the ratio of powers and thus represents the signal to noise power ratio. Using this relation, the quality of a T.V. picture can now be described with a number and the performance of a system, with respect to noise, can be rated by the signal to noise ratio.

Noise Figure

The higher the signal to noise ratio the better the quality of the picture. The signal to noise ratio continuously decreases as the signal passes through the system because additional noise is introduced by the components of the system. This additional noise added by the system can be determined by comparing the output signal to noise ratio and the input signal to noise ratio. This measure of noisiness is called the noise figure of the system and is defined by equation (1) commonly referred to as the "degradation" or "deterioration" ratio.

$$(1)\quad F = \frac{(S/N)i}{(S/N)o} \quad \text{where} \quad \begin{array}{l}(S/N)i = \text{input signal to noise ratio} \\ (S/N)o = \text{output signal to noise ratio}\end{array}$$

and F = the noise figure (or noise factor). The noise figure in terms of db is 10 $\log_{10}F$. An ideal system would be, where the (S/N)o = (S/N)i and F = 1. This would indicate that no noise was added by the system. As the amount of noise added by the system increases, F increases. The definition is the same for one amplifier or for a cascade of amplifiers. The noise figure of a black box can be determined, by simply measuring the input and output signal to noise ratio.

In an actual system design the problem is changed somewhat. The designer must be able to compute what the operating levels should be for a given amplifier and cascade, in order to achieve a given signal to noise ratio at the end of the cascade. The system noise figure is used just to enable the designer to determine what this output signal to noise ratio will be.

Overall Noise Figure

From equation (1), it can be readily seen that, if the output signal to noise ratio and the overall system noise figure are known, the required input signal to noise ratio can be calculated. In order to determine the noise figure of an entire system, it is important to know what the relative contribution of each part of the system is, to the overall noise output. If the noise figure of each amplifier is known, the overall noise figure of the cascaded amplifiers can be determined from equation (2)

$$(2)\quad F = F_1 + \frac{F_2 - 1}{G1} + \frac{F_3 - 1}{G2\ G3} + \frac{F_u - 1}{G1G2G3} \ldots\ldots\ldots \frac{F_n - 1}{G1G2G3 \ldots\ldots G_n - 1}$$

where the F's represent the noise factor of each individual network and the G's represent gains or losses whichever the case may be. Appendix I gives a detailed explanation and derivation of this equation starting with the definition of noise figure. To use equation (2) in its present form, to calculate the overall noise figure, of a cascade of more than two or three amplifiers, is quite unwieldy. The equation can be simplified, for calculating the noise figure of a cable system. In this case, the noise figures of all the amplifiers are equal, for all practical purposes. The gains are also the same and the cable losses between amplifiers are equal to the gains of the amplifiers, making the total system gain unity. Under these conditions equation (2) reduces to $F = N F_1$ or in terms of db

$$(3)\quad N.F. = (NF)_1 + 10 \log_{10} N$$

where N.F. is the overall noise figure in db, $(NF)_1$ is the noise figure of one amplifier and N is the number of amplifiers cascaded.

Appendix II shows how equation (3) is derived from equation (2), using the premise of a unity gain system.

Input Signal to Noise Ratio

By the use of equation (3) the overall noise figure can be quickly calculated for any number of amplifiers, provided, the noise figure of each amplifier is the same and the amplifiers have been equally spaced and the gain is unity for the cascade. Once the overall noise figure has been computed the required input signal to noise ratio can be determined for any desired output signal to noise ratio, with equation (1). Since signal to noise and noise figure are generally given in terms of db, equation (1) can be expressed in terms of db for a direct calculation of the input signal to noise ratio. Equation (1) in terms of db is:

$$(4)\quad (S/N)i = (S/N)o + N.F.$$

where all the terms of the equation are expressed in db. As an example; if the desired (S/N)o is 44 db and ten amplifiers with a noise figure of 10 db are to be cascaded, the input signal to noise ratio would be calculated by first using eq. (3) to calculate the overall noise figure, in this example, N.F. = 10 + 10 $\log_{10}$ 10 = 20 db then from equation (4) the input signal to noise ratio is found to be, (S/N)i = 44 + 20 = 64 db.

Noise Voltage

The input signal to noise can be divided into two factors, the signal voltage and the noise voltage. If either of the two is known, the other can be calculated. The objective of the system designer, is to determine the minimum input signal level required to give the desired output signal to noise ratio. This can be accomplished by computing the noise voltage present at the beginning of the system.

The mean squared noise voltage for a resistor due to temperature is defined by equation (5)

$$(5)\quad \overline{E_n^2} = 4RKTB$$

R = resistor generating thermal noise
K = Boltzman's constant = 1.38 x 10^{-23} joules/°K
T = Absolute temperature in °Kelvin
B = Equivalent noise bandwidth

Noise levels for a T.V. channel are specified for a 4 MHZ bandwidth in C.A.T.V. The characteristic impedance of the cable used is 75 ohms and all components are matched to this impedance. The thermal noise resistance is therefore 75 ohms. The mean squared voltage can be calculated for any given temperature condition.

A more useful number to calculate is the R.M.S. noise voltage, because it can be compared to the R.M.S. signal voltage which can be measured directly. The R.M.S. noise voltage is found by just taking the square root of the mean squared noise voltage ($\sqrt{\overline{E_n^2}}$). Using equation (5), the noise voltage computed for a 75 ohms resistor with a 4 MHZ bandwidth and normal room temperature (298°K) is -59 dbmv. This is the level of noise that will be present at the beginning of a cable system.

Input Signal Level

With the signal to noise ratio in db and the noise voltage in dbmv the signal level in dbmv can be determined. The signal level in dbmv is equal to the signal to noise ratio in db plus the noise voltage in dbmv. So that for a signal to noise ratio of 64 db and a noise voltage of -59 dbmv ($S_i = (S/N)_i + N_i = 64 - 59 = 5$ dbmv). This indicates that a minimum signal level of 5 dbmv must be available at the beginning of the system in order to have a signal to noise ratio of 64 db.

Measurement of Noise Figure

There are many methods that can be used, for measuring the noise figure of an amplifier. The simpliest way, is to use an automatic noise figure meter. This instrument is commercially sold and permits a direct reading of the noise figure from a meter. Most other techniques become somewhat more involved and require a calibrated noise source. A Field Strength meter could be used also, but it must first be calibrated properly, to read the R.M.S. noise voltage. The F.S.M.'s used in the C.A.T.V. industry have peak detectors and are calibrated to read the R.M.S. voltage of a sinusoidal wave form. The relation between the peak noise voltage and its R.M.S. value is different than it is for a sine wave. The F.S.M.'s therefore can only give correct readings for a sine wave and will always be in error when the wave shape is other than sine wave.

C.A.T.V. Systems

Most of the preceding discussion has dealt with noise figure and signal to noise in a general way. There are some important features about a C.A.T.V. system and its relation to noise figure that should be stressed.

As we all know cable does not attenuate signals equally across the T.V. frequency range. The higher the frequency the higher the loss. Amplifiers are designed to compensate for this effect, in order to maintain a unity gain system. This compensation, is usually implemented by having a fixed amount of tilt in front of the amplifier and a variable tilt control in the middle stages of the amplifier. The number of db of loss introduced in front of the amplifier, increases the noise figure by the same number of db. The variable tilt may or may not degrade the noise figure, depending upon the design. The automatic noise figure meter will, under any setting of the amplifier's control, give the correct noise figure.

Most amplifiers employ 17 db of cable tilt equalization in the front of the amplifier. This means the noise figure at channel 2 is increased by 8.5 db over the noise figure measured without tilt. At first glance this situation would appear to be intolerable for proper system performance, but because the cable loss is less at channel 2 than 13 the input level is higher. This situation helps minimize the effect of the tilt and permits output signal to noise ratios to be comparable for channel 2 and 13.

Calculations, using hypothetical but typical numbers, will help clarify the preceding statements. Assume that the following numbers are specifications for a typical amplifier.

N.F. @ Chan 13 = 10 db	amplifier set for 22 db gain
N.F. @ Chan 2 = 15 db	and 22 db tilt.

There are ten amplifiers to be cascaded, with 22 db of cable spacing between amplifiers. The output levels are set for 5 db block tilt, channel 13 will be at 35 dbmv output and channel 2 will be at 30 dbmv. The input levels to the amplifier will then be 19 dbmv at channel 2 and 13 dbmv at channel 13.

If this is the situation, we can then compute the output signal to noise for channel 2 and 13 with equations (3) and (4). The overall noise figure for the ten amplifier is as follows;

@ Chan. 13	N.F. = 10 + 10 log 10 = 20 db
@ Chan. 2	N.F. = 15 + 10 log 10 = 25 db

The input signal to noise is found to be;

@ Chan. 13	(S/N)i = 13 + 59 = 72 db
@ Chan. 2	(S/N)i = 19 + 59 = 78 db

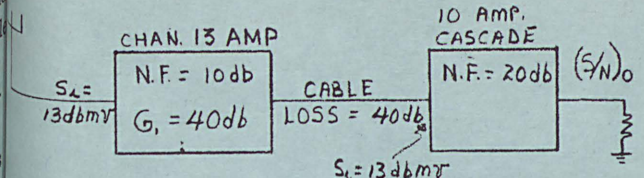
The output signal to noise is;

@ Chan 13	(S/N)o = 72-20 = 52 db
@ Chan 2	(S/N)o = 78-25 = 53 db

These calculations show that, although the tilt compensator does increase the noise figure, the systems performance is not degraded, below channel 13.

Effect of Headend Equipment on S/N

A complete analysis of a cable system must necessarily start at the antenna. The previous discussion assumed, that the input signal to noise ratio was established at the first amplifier. This was done just to facilitate the sample calculation. In reality, the signal to noise ratio is established at the antenna. Any loss between the antenna and the headend amplifiers, is a direct reduction in the signal to noise ratio. The noise figure of the headend amplifiers have very little influence, on the signal to noise ratio at the end of the cascade, provided the noise figure, is not much worse than the noise figure of the trunk amplifier. This can demonstrated, by including the headend amplifier noise figure in the calculation of the overall noise figure. Fig. 1 below depicts the situation for one channel, namely channel 13.



The figure shows the ten amplifier cascade as a single amplifier with a 20 db noise figure.

Assume the channel 13 head end amplifier has the following specs. N.F. = 10 db, Gain = 40 db, and the cable loss following the channel amplifier is 40 db. For this calculation equation (2) must be used.

(2) $$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1\,G_2}$$

$$F = 10 + \frac{10^4 - 1}{10^4} + \frac{100 - 1}{10^4\,1/10^4}$$

$$F = 10 + 1 + 99 = 110$$

$$N.F. = 10 \log. 110 = 20.4 \text{ db}$$

- F_1 = Noise factor of chan amp. = 10
- F_2 = Noise factor of cable = 10^4
- F_3 = Noise factor of cascade = 100
- G_1 = Gain of chan. amp. = 10^4
- A_2 = Loss of cable = $1/10^4$

The result shows that the channel amp. had very little effect on the overall noise figure. If there were more than ten amplifiers in the cascade the effect would have been even less. Equation (2) shows another interesting fact, that is, if the gain of the channel amplifier is substantially greater than the loss of the cable following it, the effect of the noise figure of the cascade on the overall noise figure can be reduced. For instance, if the input signal level were only 3 dbmv, the gain of the channel amplifier still 40 db, the cable would have to be shortened to 30 db loss to maintain a signal level of 13 dbmv into the first amplifier. Using equation (2) the overall noise figure would calculate to be 13.2 db. At first glance it appears as though the system performance has been improved for a smaller signal. A calculation of the output signal to noise for both cases shows this not to be true.

1st case (S/N)i = 72 db N.F. = 20.4 db (S/N)o = 51.6 db
2nd case (S/N)i = 62 db N.F. = 13.2 db (S/N)o = 48.8 db

The output (S/N) has been reduced in part by 3 db. This type of calculation is quite useful in determining whether or not a preamp. is practical to use, when a signal level at the antenna is marginal. Quite often the improvement obtained with the use of a preamp. is not worth the money, or effort to install it at the antenna.

These examples have indicated that the only way the output signal to noise ratio of a system can be improved is by decreasing the noise figure of the individual amplifiers or increasing the input signal levels.

APPENDIX I

Noise Figure is Defined as;

(1) $$F = \frac{S_i/N_i}{S_o/N_o}$$

Where S_i = Input signal, N_i = Input noise, S_o = Output signal

But

$$S_o = GS_i$$

(2) $$F = \frac{S_i/N_1}{GS_i/N_o} = \frac{N_o}{GN_i}$$

- N_o = Output noise
- G = Gain (or loss)
- N_n = Noise generated in network itself

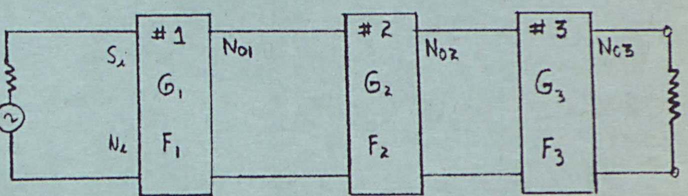
The noise output is comprised of two parts GN_i and N_n the noise generated in the network.

(3) $$N_o = GN_i + N_n$$

Subst. eq. (3) into eq. (2)

(4) $$F = \frac{N_i + N_n}{G\,N_i}$$

Equations (2) and (4) are sometimes used as the definition of noise figure. Using equation (2), (3), and (4) the overall noise figure of cascaded networks can be determined. Consider a cascade of three networks as shown in Fig. 2.



The noise out of the first stage is

$$N_{o1} = G_1\,N_i + N_{n1}$$

The second stage noise output is

$$N_{o2} = G_2\,N_{o1} + N_{n2} = G_2\,(G_1\,N_i + N_{n1})$$

the noise out of the third stage is

$$N_{o3} = G_3 N_{o2} + N_{n_3} = G_3 \left[G_2 (G_1 N_i + N_{n_1}) + N_{n_2} \right] + N_{n_3}$$

From equation (2) $F = \frac{N_o}{GN_i}$ in this case the N_o is equal to N_{o3} and the gain G is the total gain of the three stages therefore

(5) $$F = \frac{N_{o_3}}{G_1, G_2, G_3 N_i}$$ Subst for N_{o_3} in equation (5)

$$F = \frac{G_3 \left[G_2 (G_1 N_i + N_{n_1}) + N_{n_2} \right] + N_{n_3}}{G_1 G_2 G_3 N_i}$$

$$F = \frac{G_3 G_2 G_1 N_i + G_3 G_2 N_{n_1} + G_3 N_{n_2} + N_{n_3}}{G_1 G_2 G_3 N_i}$$

(6) $$F = 1 + \frac{N_{n_1}}{G_1 N_i} + \frac{N_{n_2}}{G_1, G_2 N_i} + \frac{N_{n_3}}{G_1, G_2, G_3 N_i}$$

but from eq. (4)

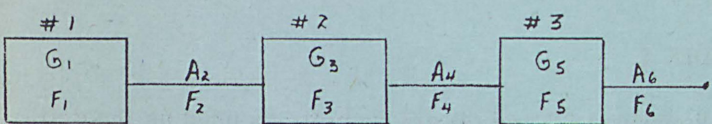
$$F = 1 + \frac{N_n}{GN_i} \text{ or } \frac{N_n}{GN_i} = F - 1$$ subst into eq. 6

(7) $$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1, G_2}$$

These results can be easily extended to more cascaded networks.

APPENDIX II

To simplify the equation of the noise figure for cascaded networks, it will facilitate matters by using only three amplifiers to demonstrate the technique to be used. Fig. 3 below shows a block diagram of the layout for the three amplifiers.



$G_1 = G_3 = G_5$ Represent the gains of the amplifiers

$A_2 = A_4 = A_6$ Represent the loss of the cable between amplifiers

$G = \frac{1}{A}$ The gain in db equals the loss of the cable in db

$F_1 = F_3 = F_3$ Noise factor of the amplifiers

$F_2 = F_4 = F_6$ Noise factor of the cable

$F_2 = \frac{1}{A_2} = G$ *Noise figure of cable in db equal the loss of the cable in db.

(1) $$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 A_2} + \frac{F_4 - 1}{G_1 A_2 G_3} + \frac{F_5 - 1}{G_1 A_2 G_3 A_4} + \frac{F_6 - 1}{G_1 A_2 G_3 A_4 G_5}$$

$$\text{N.F.} = 10 \text{ Log}_{10} F.$$

Since all of the gains are equal and all of the losses are equal to $\frac{1}{G}$ it follows.

$$\text{N.F.} = 10 \text{ Log}_{10} \; F_1 + \frac{F_2 - 1}{G_1} + \frac{F_1 - 1}{1} + \frac{F_2 - 1}{G_1} + \frac{F_1 - 1}{1} + \frac{F_2}{G_1}$$

Combining terms

$$\text{N.F.} = 10 \log_{10} \left[3F_1 - 2 + 3 \frac{(F_2 - 1)}{G_1} \right]$$

since $F_2 = G_1$, $\frac{F_2 - 1}{G_1} = 1 \frac{-1}{G_1}$, approximately equal to 1

$$\text{N.F.} = 10 \log_{10} (3F_1 + 1)$$

since $3F_1 \gg 1$

$$\text{N.F.} = 10 \log_{10} 3F_1$$

For "n" amplifiers the overall noise figure would be

$$\text{N.F.} = 10 \log_{10} nF_1$$ which is equal to

$$\text{N.F.} = 10 \log_{10} F_1 + 10 \log_{10} n$$

* The fact that the noise figure of the cable, equals the loss of the cable in db, can be easily shown.

We know that as the noise voltage passes through a cable it is attenuated. We also know that the cable acts as a resistance and introduces noise, depending upon its temperature. Therefore the total noise-out is equal to the noise input times the loss of the cable plus the noise introduced by the cable. In mathematics this reads.

$N_o = AN_i + N_n$ but $AN_i + N_n = N_i$ therefore $N_n =$

$(1 - A)\ N_i$ using eq. (4) from appendix I $F = 1 + \frac{N_n}{AN_i} =$

$$1 + \frac{(1 - A)\ N_i}{A\ N_i} \quad F = \frac{A + 1 - A}{A} = \frac{1}{A}$$

CHAIRMAN TAYLOR: Thank you very much. (Applause) Does anyone have any questions from the floor? If not, I have some announcements to make. (Convention announcements were made.)

CHAIRMAN TAYLOR (Continuing): In order to expedite the proceeding, I will take the presentations a little out of order to accommodate the mechanical problems we have with the slide projector.

Our next speaker will be Mr. Alan Ross of the Nelson-Ross Electronics Company. Alan Ross was educated at the City College of New York and Brooklyn Polytechnic Institute. He received his initial field experience with the Sperry Gyroscope Company. He then joined Polaroid Electronics Corporation where he specialized in spectrum analysis and R. F. instrumentation. He rose through the ranks to the position of chief engineer.

About four years ago, Mr. Ross organized Nelson-Ross Electronics, a firm which pioneered the concept of plug-in spectrum analyzers. He will discuss the application of such a spectrum analyzer to CATV systems.

It is with great pleasure that I present Mr. Alan Ross. (Applause)

MR. ALAN ROSS (Nelson-Ross Electronics, Inc.): I would like to preface this by saying that we have gone to a great deal of trouble to publish a paper which is almost vervatim of what I am going to say, with a lot of photographs of the CRT screen. Thanks to the printer, I couldn't get them here on time. I will give the paper, without referring to the photographs off the screen, but we do have some two-thousand copies printed which are probably being delivered to my office right now. Anybody who wants one has merely to ask me, and I will see that it is sent in the mail so that all of you can eventually see what I am talking about.

CATV AND THE SPECTRUM ANALYZER

By

Alan Ross, Nelson-Ross Electronics

In the past, newly developing electronic services have started with time-based instrumentation, measuring waveforms — and subsequently have adopted spectrum analysis techniques as systems became more complex. CATV — a young, rapidly developing giant among these services — has, by its very nature, been forced into spectrum analysis at its onset.

The best known and most widely used test instrument for CATV applications is the Field Strength Meter (FSM), which is really a nanually scanned spectrum analyzer. Starting with the FSM, the Spectrum Analyzer (SA) and its operating principles are evolved. A commercially available SA will be described, its advantages and limitations explored, and applications detailed.

The common FSM is a heterodyne receiver capable of tuning the frequency band of interest, usually 54 to 216 MHz, with a meter for indicating the input RF voltage. The block diagram for a typical CATV FSM is shown in Figure 1.

The RF stage provides RF preselection and amplification. The IF amplifier may have a center frequency of 25 MHz and will usually have a 3 db bandwidth of 600 KHz. The local oscillator and RF amplifier are ganged together for tuning. The detector usually provides a peak detecting function and output is indicated on a meter on the instrument. Image rejection is provided by the RF stage. Range selection is provided by input attenuators or IF gain controls or a combination of both. Range selection is necessary since the indicating meter will usefully cover a range of only 20 db at a time. Some FSM's have expanded range on the indicating dial, but this restricts the meter's use when a wide dynamic range is not desired.

A FSM could be converted into a spectrum analyzer by providing an automatic mechanical drive for the tuning mechanism, and displaying the detector output on an oscilloscope whose horizontal drive was sychronized to the tuning. This would provide a CRT display of signal strength against frequency. Such mechanical displays are impractical for high speed repetitive use and some electrical equivalent is desirable.

Varactor diodes could be used to provide electronic tuning in a FSM, but it is very difficult to build an RF stage that can be electrically tuned and that will track with an electronically swept local oscillator. Elimination of the RF stage reduces stage sensitivity and makes the receiver succeptible to spurious image responses. Thus a FSM without an RF preselector stage may have its local oscillator at 75 MHz when tuned to a 50 MHz signal (IF 25 MHz). It will be equally sensitive to a 100 MHz signal. It will be impossible to distinguish whether the noted response is from a 50 or 100 MHz signal at the input.

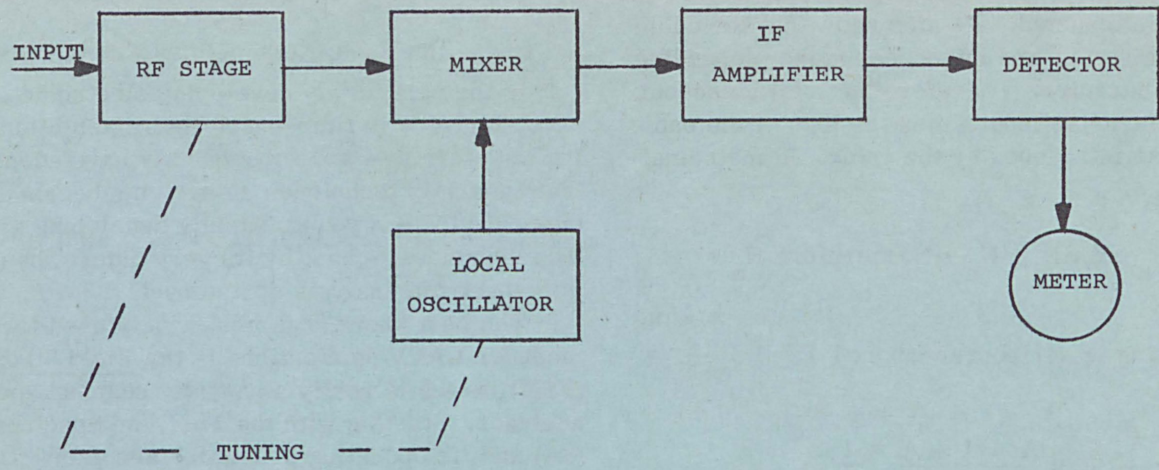


FIGURE 1

The image rejection problem can be overcome by using a very high IF frequency. If a 500 MHz IF is used with a local oscillator sweeping from 500 to 800 MHz, the receiver responses will be 0 - 300 MHz and 1000 - 1800 MHz. Since the 1000 to 1800 MHz sensitivity is not likely to be a problem in CATV applications we have a useful receiver — with a few additional complications. IF amplifiers for 500 MHz cannot be built with the narrow bandwidths needed for CATV work. Narrower bandwidths are obtained by additional conversions to lower IF's using fixed frequency local oscillators. Thus we may go progressively to IF's of 65 and 10.7 MHz and achieve bandwidths of 5 KHz and lower. This resultant instrument is an electronically swept spectrum analyzer.

While there are several available spectrum analyzers that could be used in the CATV industry, the only instrument specifically designed for such applications is the Nelson-Ross Mark I CATV Analyzer. This analyzer features complete frequency coverage in one scan, 60 db display dynamic range, 75 ohm input impedance (type F connector), video (600 kc) display capability, logarithmic, linear and square law vertical scales and ± 2 db overall flatness. The block diagram of this analyzer is given in Figure 2.

The sweep generator controls sweep width and center frequency, thus controlling center frequency and dispersion (tuning range). It also controls the sweep repetition rate. Receiver bandwidth is controlled in the 10.7 MHz IF amplifier. This amplifier normally has a 600 KHz bandwidth, but it can be restricted to 5 KHz by switching in a crystal filter. Logarithmic response is also provided at this stage by means of a front panel control. Square law and linear response can also be selected. The video amplifier provides the required drive for the vertical deflection system of the associated oscilloscope. A variable IF gain control is provided along with a step attenuator between the 65 MHz and 10.7 MHz IF stages.

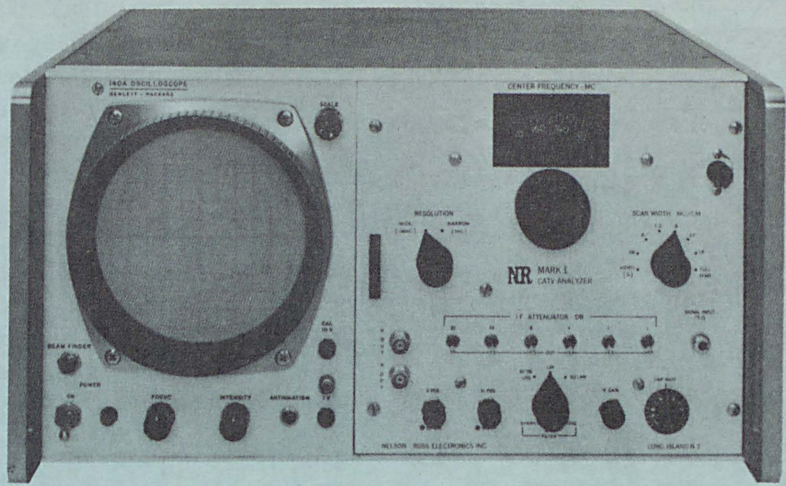
Some general characteristics of the spectrum analyzer should be considered before discussion of specific applications. A thorough understanding of advantages and limitations of the SA will help in understanding its principal applications and the application of the instrument to new uses.

SA Advantages

The SA gives a sweep frequency display. It shows everything that is going on in a given frequency band in a single oscilloscope display. In maximum dispersion, it displays the whole spectrum from zero to 300 MHz. In its narrowest dispersion mode it displays a 600 KHz segment of spectrum across the full width of the oscilloscope. It can also be operated in a "zero" dispersion mode. In this mode it acts as a regular receiver, displaying the demodulated video on the oscilloscope, subject to the bandwidth limitations of the IF and video amplifiers (600 KHz maximum bandwidth) and the horizontal sweep provided by the sweep rate control.

The SA has a wide dynamic range in a single display. Signals that differ in amplitude by as much as 60 db can be readily observed in the log mode, subject to distortion considerations to be discussed later.

The SA has resolving power comparable to the ordinary FSM when operated in the "wide" mode, and has very much greater resolving power (narrow bandwidth) when operated in the narrow (5 KHz) position. Narrow bandwidth operation permits separation of carriers, beats, etc., that are very close together; just how close depends on their relative levels. If they are about the same level, they would be just separated if they were 5 KHz apart. If they are of different levels, they will have to be more widely separated since one carrier will tend to disappear into the



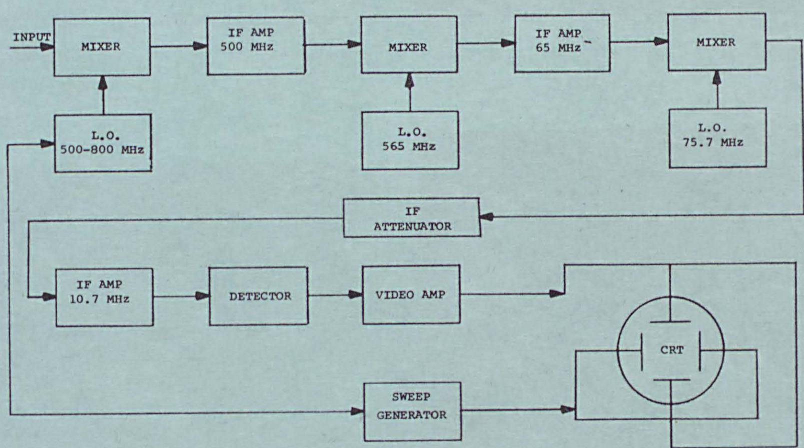


FIGURE 2

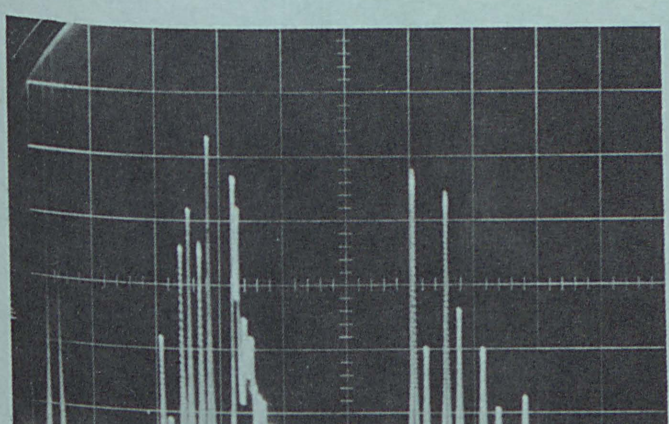


FIGURE 3: 300 megacycle scan of output of allband antenna in the New York City area. The large signal at left is zero frequency. Channels 2, 4 and 5 can be seen between 2nd & 3rd graticule lines. The FM band is immediately to the right. Channels 7, 9, 11 and 13 are visible between the 6th & 8th graticule lines. Note poor response to channels 2 & 13. (linear display)

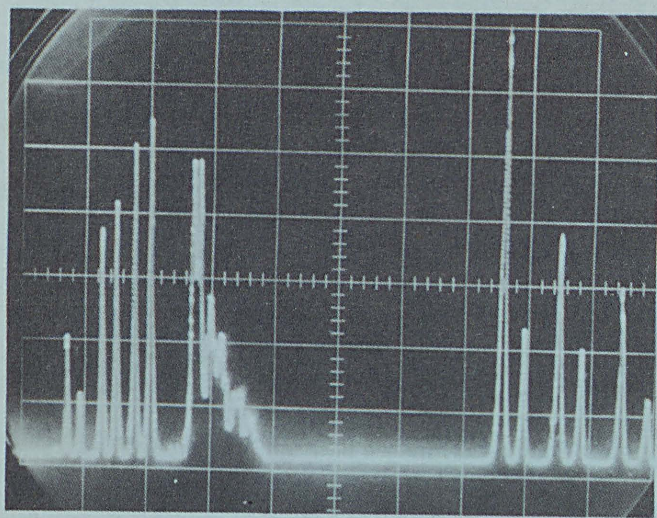


Figure 4: Same signal as in fig. 1 with analyzer dispersion reduced to 180 megacycles eliminating unnecessary upper & lower portions of the display. Note increased resolution. (linear display)

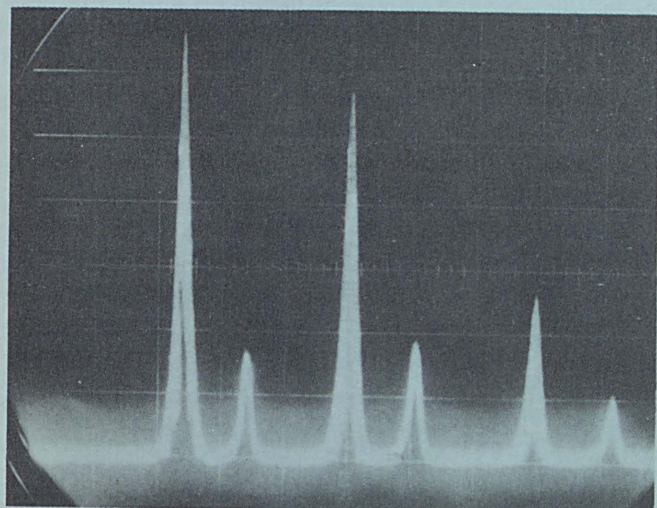


Figure 5: 6 megacycle/cm scan of channels 7, 9 and 11. Relative levels between carriers can be measured using I.F. step attenuator, will yield 7 picture: 0 db, 7 sound:-10 db, 9 picture: -1 db, 9 sound: -9 db, 11 picture: -7 db, 11 sound-14 db. Levels may be calibrated to dbmv (see text) (linear display).

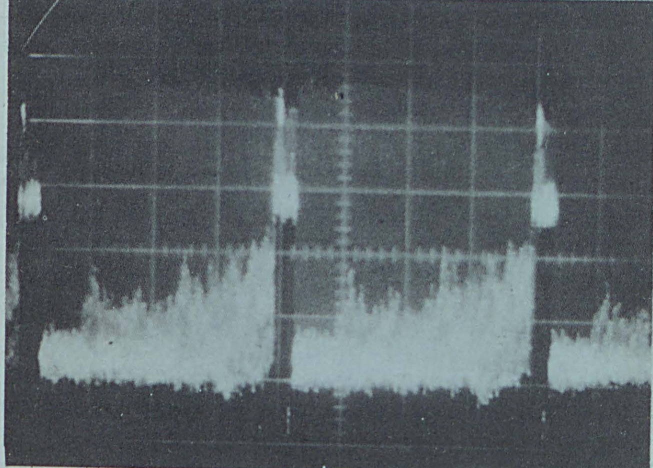


Figure 6: Video display (0 mc/cm dispersion) showing two frames of video. This setting provides V output signals suitable for inspecting sync pulses, etc. (linear display)

"skirt" of the other. Resolving power is still much greater than that of the ordinary FSM.

The SA has optional log, linear or square law response. In log mode, the vertical deflection is proprotional to the log of signal amplitude, thus giving a display that is linear in decibels. In linear mode display is proportional to amplitude of signal input. In square law mode, display is proportional to signal power (square of amplitude) thus accentuating differences between signals.

The SA oscilloscope display can be photographed (Polariod is preferred) for permanent reference and record, or recordings can be made on X-Y recorders using auziliary output jacks which are provided.

SA Limitations

The SA has high noise figure and low sensitivity. Having no RF stage and a high frequency IF the noise figure is set by the mixer loss and the noise figure of the 500 MHz first IF amplifier.

The SA is subject to overload problems. The mixer generates distortion products — harmonics, intermodulation, and cross modulation products, comparatively easily. It will overload at far lower levels than the more familiar FSM's.

The SA is difficult to calibrate for absolute readings. Gain depends very critically on sweep speed, particularly at narrow band width and wide dispersion. The SA does however make an excellent "transfer standard" permitting easy comparison of a standard reference and an unknown signal for both frequency and amplitude.

Applications of the Spectrum Analyzer

1. Swept Field Strength Meter for System Checking

Checking and setting CATV systems requires tuning the FSM back and forth and remembering or writing dow levels for the various channels of interest. This procedure can be simplified by use of the SA. The SA will display all the channels in an all band, low band, or sub

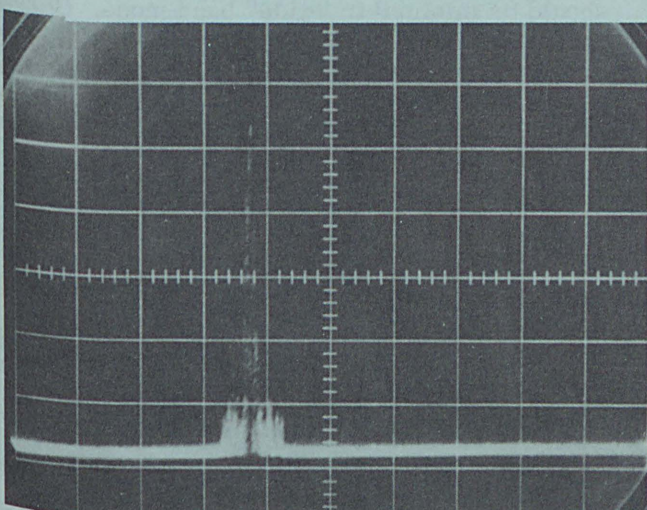


Figure 7: High resolution, low dispersion display - 5 kc resolution coupled with 60 kc/cm dispersion permits identification of FM multiplex transmission. Note grouping of low level modulation around multiplex sidebands (linear display).

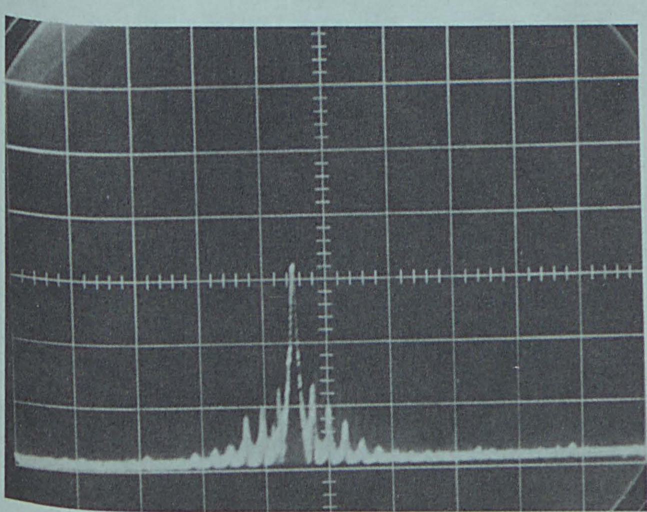


Figure 8: High resolution Log display shows 15.75 kc sidebands around picture carrier. The first sideband, while 20 db below the carrier is still clearly visible. (Log display)

low/low system simultaneously. Use "Wide" bandwidth for this application and set dispersion and tuning to display the band required. Calibrate the SA with any available reference generator. In the log mode, the analyzer will have a 10 db/cm vertical calibration. The SA used should be checked for flatness across the band to be sure that it meets the manufacturers specification of plus or minus two db. This can be done by feeding a good quality sweep generator into the SA. With the SA at a low sweep speed, note the envelope displayed. In log mode, the maximum peak to valley difference should be 0.4 cm (4 db). Greater sensitivity to level differences can be achieved in the linear mode. Adjust IF gain for suitable vertical deflection and check against reference source.

The SA displays all the carriers, picture and sound, at the same time, and the effects of adjustments of amplifier gain and tilt controls are readily observed. In the "wide" mode (600 KHz) the SA is not senstitive to changes in sweep speed and shop calibration at the start of the day can be relied on through the day. The oscilloscope power supplies are quite well regulated against line voltage variations. While the wide bandwidth mode does not give maximum sensitivity, it guarantees immunity against changes in sensitivity and resolving power caused by changes in sweep speed. Check to see whether displayed amplitude changes with sweep speed. Use slowest speed which gives readable display (flicker level tolerable) and which does not reduce displayed amplitudes. The narrow bandwidth position reduces sensitivity drastically — in wide dispersion for all band display, 180 MHz sweep, and with 15 sweep per second sweep rate, the sensitivity is reduced by about 17 db and the apparant resolving power reduced almost 50 times, i.e. effective resolving power becomes almost 250 KHz. The wide band display for setting or checking systems does not need the narrow bandwidth.

2. Precision Field Strength Meter

RF levels can be very accurately measured and set by using the SA as a "transfer standard". Select a hybrid splitter for balanced outputs (a high speed RF switch is handy for this). When sensitivity is not a problem an adder can be made from two 20 db attenuators and a tee. Use the splitter, to mix the signal from the reference generator with the signal being measured. The reference signal can be "walked" up against the signal being measured, by adjusting frequency until it stands right beside the other signal. Use wide bandwidth and narrow dispersions. Adjust the reference generator until signals have equal amplitude. Amplitude comparisons can be made more sensitive by changing to linear or square law mode. Signal amplitude can be read from level of reference generator. Frequency can be determined by tuning the reference generator until it lies right over the signal being checked. Beat effects will be small since the SA is presumably being operated with signal inputs at levels that cause minimum distortions. Signals can be compared in this way to small fractions of a decibel.

Be careful to watch for sweep speed effects. This should be minimal in "wide" band mode. Check for these by seeing whether sweep speed has any effect on amplitude of reference and test signals. Signals with wide band modulation, i.e. wide compared to SA bandwidth, are subject to sweep speed effects. Effect can be minimized or eliminated by using narrow dispersion, slow sweep speeds, and wide bandwidths.

3. Reception Interference

The great resolving power of the SA in its "narrow" band mode makes the instrument very useful for tracking down interfering carriers. Dispersion can be narrowed down to a width of one or two channels. The picture, sound and color carriers on the desired channel are easily identified. Interfering carriers, provided they have reasonable separation from desired carriers are easily identified. These may turn out to be spurious

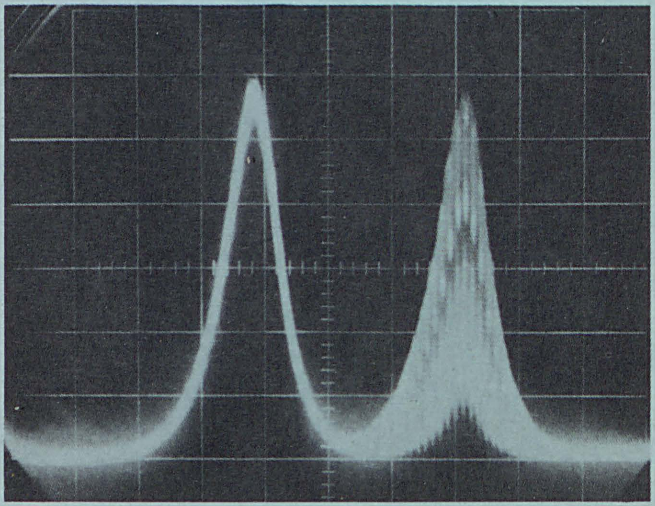


Figure 9: The spectrum analyzer as a transfer standard. The cw signal on the left was inserted via a power divider to calibrate the peak signal level of the video carrier on the right. When the two signals have been made equal the level may be read off the signal generator (linear display).

radiations from nearby transmitters, or may be spurious carriers generated somewhere in the CATV system.

A preselector of some kind is useful for this application. The preselector limits the input signals to the particular band of interest. This prevents generation of undesired distortion products within the SA which may be undistinguishable from the interference being studied. Simple passive band pass filters may be used for this purpose. Better results are obtained by use of an external receiver like a Channel Commander or a TV demodulator. The SA is connected to the IF of the receiver being used as the preselector. The SA scans the IF output of the preselector. The preselector is then tuned to the channel being examined. For applications requiring continuous tuning of the spectrum not provided by a TV demodulator tuner, a FSM may be used with adaptation to permit plugging the SA into the FSM IF. The SA then scans the 600 KHz IF of the FSM. This restricts examination to a 600 KHz "window" at a time, but it does permit continuous tuning within the main tuning range of the FSM.

Narrow dispersions and slow sweep rates should be used to preserve SA sensitivity and resolving power. Co-channel carriers are very difficult to resolve. They are separated by only 10 or 20 KHz from the main picture carrier, and unless they are of exceptionally high amplitude they get lost in the "skirt" of the main carrier. Interfering carriers spaced more than 100 KHz from desired carriers can usually be observed. They can then be tracked back through the system and their sources usually identified. A case history will illustrate:

A CATV system complained of intermittent color "drop out" on channel 2. Extensive equipment substitutions failed to turn up the problem. The SA was connected to the head end Channel Commander output. It was noted that a spurious carrier appeared quite close to the color carrier intermittently, causing color "drop out". This was traced back through the Channel Commander with the SA. It was identified as a nearby police transmitter on a frequency quite close to the IF color frequency. This Channel Commander had poor RF preselection on channel 2. The police transmitter "bulled"

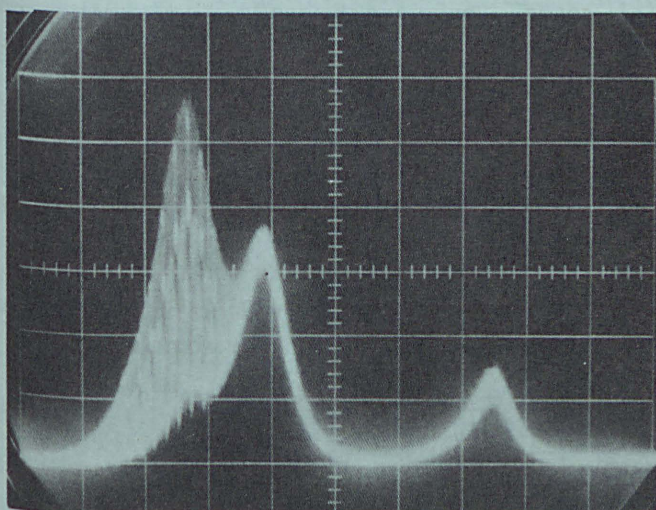


Figure 10: Interfering carrier as seen on the spectrum analyzer. A high level cw signal is interfering with the video portion of the channel under analysis. This signal will be clearly visible on the picture as a "herringbone" type of interference pattern (linear display).

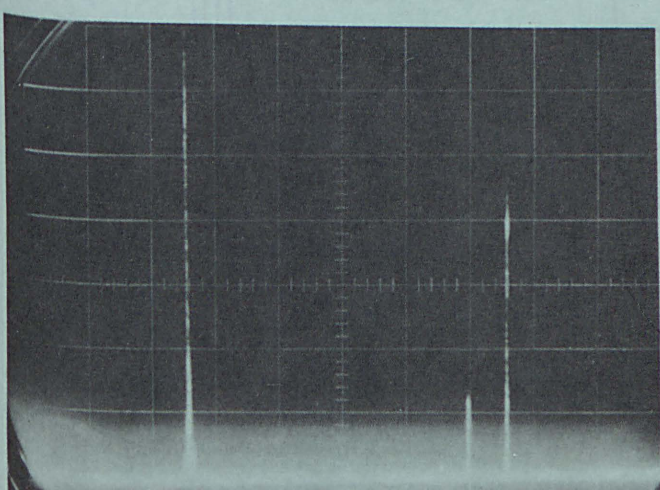


Figure 11: Interference located by means of high resolution examination of an individual channel. An interfering signal can be clearly seen between the sound carrier and color subcarrier (linear display).

right through the tuner into the IF where it interfered with the color carrier. Once the problem was identified it was easy to fix by adding a high pass filter in front of the Channel Commander to improve its RF selectivity. The continuous scanning of the SA permitted the technician to spot the intermittent offending interference. It would have been almost impossible to find in any other way.

Preselectors and preamplifiers considerably improve the performance of the SA by restricting its input to the portion of the spectrum of immediate interest. This prevents harmonic distortion products and intermodulation products from showing up in the spectrum being studied. The problem is common to all SA's that use "wide open front ends".

The SA can be checked for internally generated distortion products. In order to check whether a particular product noted on the screen is valid, or is internally generated, use an external step attenuator. Reduce input signal level by 10 db. If the displayed level changes by more than 1 cm (10 db) the input signal level is too high and should be reduced. All or part of the observed signal was being generated internally. It should also be noted that external preselectors in the form of tuners (Channel Commander, demodulators, FSM's) are also subject to overload distortion and should be checked in the same way. By careful choice and adjustment of preselectors it is possible to distinguish beats and other spurious carriers over a 60 db dynamic range. Such measurements have been made with the SA in connection with checking for spurious beats in tests of amplifier output handling capability.

Since narrow bandwidths are commonly used in this application, it is worthwhile at this point to discuss effect of bandwidth and sweep speed on sensitivity and resolving power.

Very narrow bandwidth IF's take some time to respond completely to changing frequencies. The effect of too fast a sweep for a given IF bandwidth is to reduce displayed amplitude and to increase effective bandwidth (reduce resolving power). Figure 12 can be used to calculate this effect.

In the Nelson-Ross CATV Spectrum Analyzer, the wide position is so wide that effects are negligible at normal sweep speeds. The narrow bandwidth position is subject to these effects. It is recommended that the narrow position be used only at lower sweep rates and narrower dispersions which will reduce effect on sensitivity and resolving power. Use of a long persistence phosphor (P-7) in the oscilloscope, facilitates use of slower sweep speeds. In extreme cases it may be desirable to use storage type oscilloscope (HP 141A) and modify the SA for lower sweep speeds.

4. <u>Checking Amplifier Overload and Distortion</u>

The SA can be used to check amplifier overloads and distortion by displaying the broad spectrum of beats and distortion products caused by serious amplifier overloads. These are generally easy to distinguish from the normal modulation sidebands observed in a working CATV system. Care should be taken, as noted previously, to control the SA input level to prevent internal generation of distortion products. With careful use of preamplifiers preselectors, distortion beats on what should be blank carriers can be observed to a -60 db level. Harmonic beats can also be displayed if care is taken with use of preselectors.

Cross modulation products are very difficult to display. The SA is a frequency domain instrument. The

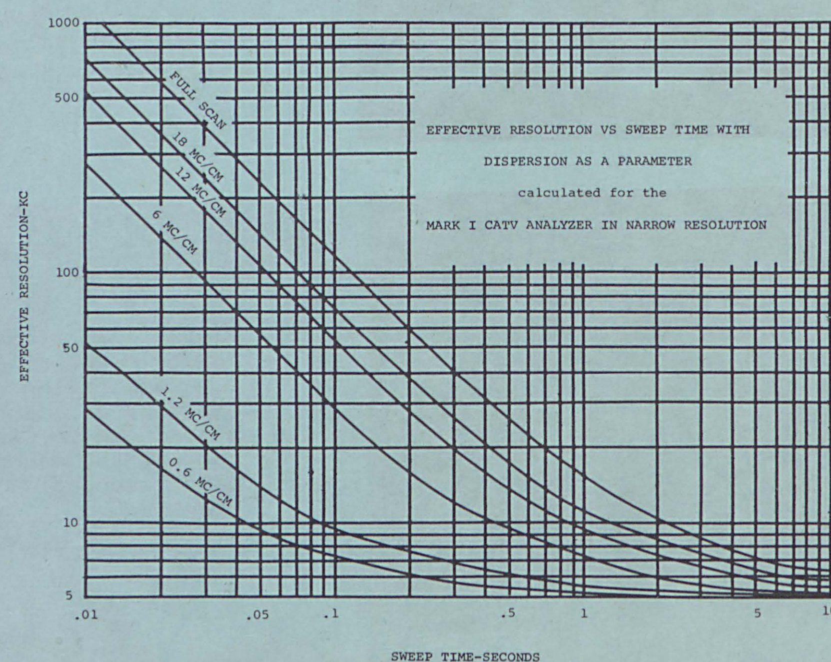
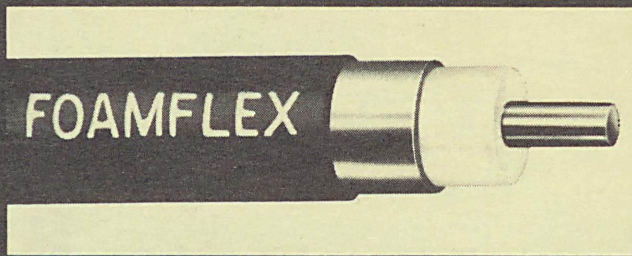


FIGURE 12



The other name on this cable is Phelps Dodge.

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PHELPS DODGE COPPER, ALUMINUM AND ALLOY PRODUCTS frequency domain manifestation of cross modulation is the appearance of AM modulation sidebands on a carrier that should be free of modulation sidebands. Sideband levels are normally 6 db down from main carrier, plus the depth of modulation. Thus a carrier with -40 db cross modulation will have a spectrum in which sidebands are 40 + 6 = 46 db down from main carrier. Present cross modulation testing techniques call for sensitivities in the range of -40 to -90 db. This means that sidebands in frequency domain will be 46 to 96 db down. This exceeds the dynamic capability of the spectrum analyzer. The situation is further complicated by the fact that present cross modulation testing techniques call for use of 15.750 KHz from main carrier. This sideband soon is lost in the "skirt" of the main carrier. Modulation frequencies of more than 100 KHz would be more readily observed but would still suffer from the 60 db dynamic range limitation of the SA. Cross modulation up to about -50 db with modulating frequencies of 1 MHz or so could be checked with the SA.

Harmonic distortion products in a sublow/low system could be observed to a -55 to -60 db level by careful use of preselectors to prevent generation of distortion products within the SA itself.

5. Checking Modulation Spectra

Spectra of various modulations are not generally of interest in CATV systems except possibly as an aid to identification of spurious carriers. Use of narrow bandwidth, narrow dispersion modes will display modulation spectra and permit identification of modulation type (FM or AM) and some information on modulation bandwidth.

6. Checking Spurious Outputs

The wide display range and continuous scanning of the SA permits easy checking of amplifiers and other system components for spurious outputs. Be sure to check for possible internal generation of spurious responses, and use preselectors if necessary. The 60 db dynamic range of the SA permits easy recognition of low level spurious outputs in presence of stronger main signals. Undesired local oscillator radiation is also easily checked and measured with the SA.

7. Signal Reconnaisance and Field Strength Recording

The wide scanning nature of the SA makes it suitable for signal reconnaisance work. A broad band antenna and preamplifier would be desirable. All carriers in the band of interest would be displayed. Signal strengths could be recorded by using a data camera capable of sequential frame data photography. The camera would be set to photograph the SA screen every minute or at other desired intervals.

A standard reference level signal can be mixed in with the test signals to provide continuous calibration. The log mode permits recording a wide dynamic range of signal levels, and the continuous scan display would permit recording of differential fades between channels, and between sound and picture carriers. Intermittent interfering carriers would also be recorded, depending on their relationship to the interval of the data recording camera. Signals from several narrow band antennas and preamplifiers could be combined for simultaneous display on the SA.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Alan Ross of Nelson-Ross Electronics for reviewing this article as well as supplying the photographs.

Thank you. (Applause) I would like to acknowledge the work of Mr. Switzer for preparing the rough text for this paper. Thank you again very much. (Applause)

CHAIRMAN TAYLOR: Thank you very much, Mr. Alan Ross. I wonder if we have any questions of Mr. Ross on the spectrum analyzer and its applications?

QUESTION: You spoke of using a pre-selector such as a Channel Commander. You are now using a dispersion of about six megacycles, I presume. What scan rate and what resolution can go or, rather, what scan rate and what resolution can you get at a six megacycle dispersion?

MR. ROSS: At six megacycles you probably wouldn't want to use the wide resolution. You could use the 600 kc, which is roughly ten per cent of the display. I don't know if anybody can see this, but I have a picture of those exact conditions on the front of my paper here, the 600 kc dispersion condition, and that is the picture and sound carrier. That was from Channel 4 and off my home antenna.

I also have pictures further on where you can sweep six megacycles, and I am guessing from experience at five or six sweeps per second, and you can literally see everything that goes on, including the modulation spectrum around the picture carrier. I have that here also. You can see the color carrier, and you can see any spuri ous signals or interference that may occur in between.

I have seen, for example, an operating CATV systen where there has been an ignition noise which is very easily and very quickly identified, because it forms a random pattern of spikes between the picture and sound carrier on a setup like this, and I was able to trace it down to find out it wasn't coming in the antenna but coming in because of a bad connector some place.

CHAIRMAN TAYLOR: Are there any more question I still have not figured out how to use the spectrum analyzer when I can't get delivery on the scope. (Laughter) Are there any other questions? Putting my fingers on the terminals doesn't help much. (Laughter)