OPTIMIZATION OF SUBSCRIBER SIGNAL QUALITY THROUGH LOCAL DISTRIBUTION MICROWAVE

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ABSTRACT

Although the era of high definition television (HDTV) may not yet be quite upon us, there can be little doubt that new CATV system designs and upgrades must increasingly strive to provide improved signal quality to subscribers to enhance the competitive stance of the CATV system. This paper addresses some of the quality criteria that will most likely be required of future CATV systems. As in the past, local distribution service (LDS) microwave can play an important role in achieving this improved system performance. One obvious technique is to reduce the length of trunk amplifier cascades by increasing the number of receiving hubs. However, the improved quality imposes more stringent requirements on the microwave link. It is shown that recent improvements in microwave systems and technology can accommodate these requirements. Specific examples are provided that illustrate how microwave system elements can be configured to meet the needs of CATV systems that will carry the HDTV signals.

INTRODUCTION

One of the primary motivations for the development of LDS microwave in the late 1960s was the potential for improvement in cable system signal quality. The idea was to reduce the length of trunk amplifier cascades, thereby improving carrier-to-noise ratio (C/N) delivered to the farthest subscriber. It was also felt that maintainability would improve if shorter trunk cascades were utilized. This, in fact, has proven to be the case in numerous instances. Bilodeau has provided the example of Suburban Cable in Essex County, New Jersey.[1] That reduction of trunk amplifier cascade lengths tends to improve quality, maintainability, and reduce outages is a fact that has more recently been recognized to potentially apply to other transmission technologies.[2] A key requirement is that each hub site, and the connection to it, be low in cost and simply implemented. The outdoor-mountable, cable-powered Hughes AML® microwave receiver shown in Figure 1 has widely fulfilled this requirement for the cable industry.

Figure 1 Typical CATV system AML hub.

While AML microwave has been utilized since 1971, the quality requirements imposed on the microwave link have become increasingly stringent over the years. Initially, the receiver microwave AGC threshold was set for 45 dB C/N, but already in 1972, this was increased to 48 dB. In 1976, the factory-set threshold was raised to 50 dB, and by 1981, it was again raised to 53 dB. The threshold could, of course, be adjusted in the field to any desired value, limited only by the link margin and distortion considerations, but the above-cited progression of C/N ratio settings is indicative of the increasingly tighter standards imposed by the CATV industry. To accommodate these requirements and still maintain link margins, especially over longer paths, it was necessary to provide 11 dB increased transmitter output capability with a klystron amplifier dedicated to each channel and then to provide a further 3-dB increase through improved upconverter linearity. At the same time, the receiver noise figure was reduced from 13 dB to 10 dB, and then through the introduction of low noise amplifiers (LNAs) to 7 dB and 5 dB.[3] Most recently, the increase of channel loading up to 80 channels necessitated improvement in second-and third-order distortion characteristics.[4] This steady evolution of the AML microwave in response to tighter CATV system needs has also witnessed the introduction of new classes of equipment, such as the active repeater and the microwave feed forward amplifier.[5,6] These past developments have set the stage for further improvements required to meet the future needs of CATV systems approaching the era of high definition television.

SYSTEM REQUIREMENTS

Overall minimum CATV system performance recommendations can presently be found in NCTA Recommended Practices for measurements on cable television systems. Similar information is contained in the Canadian

Technical Standards BP-23. These are minimum standards, and in many cases, cable systems are even today designed to meet tighter requirements. In anticipation of the advent of advanced television systems (ATV), including HDTV, there exist presently ongoing investigations to more fully characterize actual cable systems. At the same time, the various proposed ATV systems are under evaluation with regard to their robustness in the face of nonideal transmission media. The investigation being conducted in support of the HDTV subcommittee of the NCTA Engineering Committee will contribute to a wider study by the Advanced Television Systems Committee, which will formulate recommendations dealing with delivery standards for HDTV.[7]

Although a general consensus exists to the effect that some improvements in the cable plant will be required to accommodate ATV, there are as yet no agreed-upon numbers to provide firm guidance to the CATV system design. The problem is compounded by the fact that different ATV systems will undoubtedly exhibit a varying degree of susceptibility to transmission system impairments. However, it has been tentatively suggested that a 6-dB improvement of C/N (to 49 dB at the farthest subscriber) might be a logical design objective.[8] C/N is, of course, only one of several system performance parameters that are under investigation. Other parameters that are also of potential concern to elements of a CATV system and the LDS microwave are reflections, phase noise, frequency response, envelope delay, and distortion, including quadrature intermodulation.

A scenario that nearly meets the 49-dB C/N objective has been proposed by Switzer.[9] In his Table 3, he allocates 56 dB to the supertrunk, the role which can be played by AML microwave. Although this can represent a challenge when utilizing the lower cost block conversion type transmitters, this C/N requirement can be met in a large number of existing AML systems and is also furthered by recent AML improvements. Other CATV system parameters, although not yet allocated to the subsystems, including supertrunk, can also be improved with new AML developments, which are described in the following section.

If the signal being carried is reasonably robust, there is no intrinsic reason why existing CATV systems cannot provide a satisfactory transportation medium. This was most recently demonstrated at the 1987 HDTV Colloquium in Ottawa, Canada, where side-by-side HDTV display of signals directly received via satellite and satellite signals carried over Ottawa's Skyline Cable, including AML, were essentially indistinguishable. The signal in question was, however, MUSE in FM format, so that close to 30-MHz bandwidth was required. On the other hand, carriage of spectrum-conservative VSBAM television signals over AML microwave need not be associated with any significant degradation in picture quality. Indeed, baseband signal-to-noise ratio in excess of 63 dB has been demonstrated.[10] Other baseband performance criteria were generally in conformance with the rigid short-haul requirements of RS250B. However, cable systems do not normally employ the test equipment type quality VSBAM modulators (and demodulators) used in this demonstration. Nor are the baseband parameters routinely measured in AML production, since, in fact, VSBAM modulators and demodulators are not generally a part of the microwave link equipment. It is nevertheless clear that greater care will be required both in the operation and design of standard AML systems utilized by the cable industry if these systems are to meet the higher standards associated with carrying ATV signals.

AML PERFORMANCE PARAMETERS

1. Carrier to Noise Ratio - The principal source of thermal noise in AML microwave systems is usually noise generated within the receiver. In this case, the microwave AGC circuit maintains a constant C/N once the input exceeds the microwave AGC threshold. Adjustment of the threshold therefore controls C/N, provided sufficient signal is available to reach and exceed the threshold. The receiver parameter that determines the equivalent input noise level at threshold is the noise figure. For instance, an 8-dB noise figure receiver has an equivalent input noise power per 4 MHz bandwidth of -100 dBm. If the AGC threshold is set to -47 dBm input, the C/N will be 53 dB. The recently introduced 550-MHz receiver, which incorporates a single-stage LNA inside the AGC loop, is factory set in just such a manner and provides an 80-channel composite triple beat (C/CTB) of 80 dB. If, instead of a single-stage LNA, a 2-stage LNA is inserted into the AGC loop, the receiver noise figure is improved to under 6 dB. The AGC threshold could then be set for -49 dBm, while still providing the same 53 dB C/N. However, because of the increased LNA gain, the 80-channel C/CTB would be degraded to 70 dB. If then one wished to improve C/N to 56 dB by resetting the AGC threshold to -46 dBm, the resultant 80-channel C/CTB would be further degraded to 64 dB. Although this still allows margin to the 53 dB C/CTB (CW measurement) NCTA CATV system performance objective, it does eat into the overall budget, particularly if the calculation assumes voltage addition of third-order distortion products. Further improvement in receiver linearity was therefore desirable if 80-channel operation at 56 dB C/N was contemplated.

Figure 2 is a photograph of the new compact outdoor receiver (COR), which provides this improvement. Table I summarizes its key performance parameters. The phase-lock receiver block diagram is essentially the same as in the 550-MHz receiver introducted in 1987.[4] That is, it incorporates both an LNA and separate microwave and VHF AGCs. The main change is that the temperature control housing is not used, thus making possible a substantial reduction in weight and power consumption. The new compact housing is designed for optimal thermal transfer under maximum ambient temperature conditions. This permits use of a high-power solid-state source to drive a high-level mixer with improved distortion performance in the dual-stage LNA version of the receiver. The distortion performance thus achieved allows setting the C/N to 56 dB, even with 80-channel loading.

The two COR configurations described by Table I are not the only possible cases. For instance, the dual-stage LNA could be housed within the receiver, but outside the AGC loop as in a tower mounted LNA application. In that case, the receiver noise figure is less than 5 dB, but the receiver is now vulnerable to a signal overload condition. The 3-IM output intercept point of the LNA is specified as a minimum of 24 dBm. From this, and a nominal LNA gain of 15 dB, one can calculate that 80-channel C/CTB would fall below 69 dB for input signals in excess of -44 dBm. Thus, for heavy channel

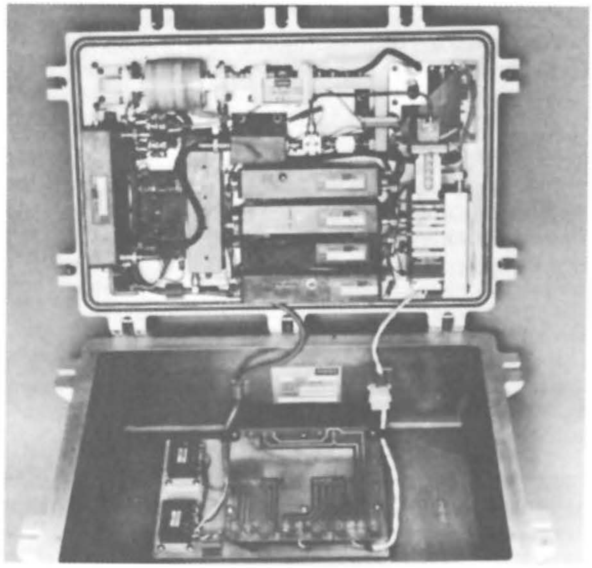


Figure 2 Compact outdoor receiver.

TABLE I

COMPACT OUTDOOR RECEIVER (COR) PERFORMANCE

	WITH SINGLE-STAGE LNA IN AGC	WITH DUAL-STAGE LNA IN AGC
NOISE FIGURE, dB	8	6
C/CTB (dB) FOR C/N = 56 dB		
80 CHANNELS	74	69
40 CHANNELS	80	75
C/CSB (dB) FOR C/N = 56 dB		
80 CHANNELS	63	67
40 CHANNELS	66	70
OUTPUT FREQUENCY ERROR	0 Hz (PHASE LOCKED TO AML TRANSMITTER)	
FREQUENCY RESPONSE, dB		
54-550 MHz OUTPUT	±1.5	±1.5
AGC		
MICROWAVE THRESH-OLD (56 dB C/N)	-44 dBm	-46 dBm
VHF RANGE, dB	12	12
NOMINAL OUTPUT, dBmV	+20	+25
COMBINED MICROWAVE AND VHF FLATNESS, dB	±1	±1
WEIGHT (lbs)	45	45
INPUT VOLTAGE[1]	40 - 60 VAC	40 - 60 VAC
POWER REQUIRED (WATTS)	50	60
TEMPERATURE RANGE	-40° TO +120°F	-40° TO +120°F

[1]CABLE POWERED. -48 VDC INPUT ALSO POSSIBLE.

loading and/or strong signal conditions, careful consideration should be given to assess which receiver/LNA configuration is most suitable.

Further improvement in overall receiver performance is possible if the LNA noise figure is improved without degrading the third-order distortion performance. Recent FET technology improvements make a 2-stage LNA noise figure of 2.5 dB readily achievable. Investigation is presently under way to determine whether this can be done while maintaining the 24 dBm 3-IM intercept. If so, the aforementioned overall 6- and 5-dB receiver noise figures would improve to better than 5 and 4 dB, respectively.

The receiver is not the only possible source of thermal noise. The transmitter, particularly a low cost block conversion transmitter in which the output signal must be backed way off to avoid excessive C/CTB, can also degrade overall link C/N. Of course, if a path fade occurs, the transmitter noise is attenuated along with the signal, so the transmitter's contribution to a faded 35-dB C/N is negligible. However, during clear weather, the transmitter contribution (as well as any other headend noise) must be considered. Careful design is required to ensure that no active element within the transmitter operates at a signal level low enough to significantly degrade the microwave system C/N. The problem is really no different than in classic CATV system design, when both distortion and noise need to be taken into account. The situation becomes particularly acute if the microwave link is to provide 56-dB C/N with 65-dB C/CTB. For instance, this level of performance with 40-channel loading of the microwave feedforward transmitter is possible only if the noise figure of the 2-watt amplifier within the OLE-111 drive stage is lowered to 6 dB. Fortunately, a solution seems near at hand so that, even with a heavily loaded feedforward transmitter, the 56-dB link C/N criterion can be maintained. The block upconversion type transmitter link calculation is summarized in Table II, which further illustrates that with average propagation conditions, the feedforward amplifier can support a 6-mile path with less than 1 hour per year fade below 35 dB C/N. Note that the requirement is made tougher, by waveguide losses, in that both transmitter and receiver are assumed to be ground-mounted for ease of maintenance and minimum downtime in the event of a component failure.

If the link calculations indicate that insufficient signal level is supplied to the receiver to obtain the desired C/N, use of an active repeater may solve the problem. Generally, the repeater is used only in situations where direct line-of-sight cannot be established between transmitter and receiver. If the repeater is used to improve C/N, this is usually possible only if the repeater output capability is equal to or greater than that of the originating transmitter. This is because the repeater will itself degrade system C/N (and C/CTB). For instance, consider a repeater at the midpoint of a longer path (a direct antenna pointing between the transmitter and receiver cannot be allowed, since the direct and repeated signal could then interfere with one another at the receiver). The input signal at the repeater is 6 dB higher than what the receiver could receive if transmit and receive antennas were repointed at each other. Assume further that the repeater noise figure is equal to the receiver noise figure and that the repeater output (in AGC) is equal to that of the transmitter. This means that

TABLE II

A HIGH QUALITY MICROWAVE FEED FORWARD LINK

TRANSMITTER OUTPUT POWER	40 CHANNELS (dBm/CH)	0.8
TRANSMIT CIRCULAR WAVEGUIDE	100 FEET	-1.6
TRANSMIT ELLIPTICAL WAVEGUIDE	15 FEET	-0.6
TRANSMIT ANTENNA	10 FOOT	48.8
FREE SPACE LOSS	6.0 MILES	-134.3
RECEIVE ANTENNA	10 FOOT	48.8
RECEIVE CIRCULAR WAVEGUIDE	100 FEET	-1.6
RECEIVE ELLIPTICAL WAVEGUIDE	15 FEET	-0.6
RECEIVER INPUT AGC ATTENUATION		-2.5
FIELD FACTOR		-2.0
RECEIVE CARRIER LEVEL		-44.6
RECEIVER NOISE FIGURE	6 dB	

TRANSMITTER C/N	61.7	TRANSMITTER CTB	65.9
RECEIVER C/N	57.4	RECEIVER CTB IN AGC	72.5
*OVERALL C/N IN AGC [+]	56.0	*OVERALL CTB IN AGC [+]	65.0

STATISTICAL ESTIMATES

MULTIPATH FACTOR (A x B) = 0.25
CCIR CLIMATE REGION = D2

HOURS PER YEAR BELOW 35 dB CARRIER-TO-NOISE: MULTIPATH	0.0
HOURS PER YEAR BELOW 35 dB CARRIER-TO-NOISE: RAIN	0.6
TOTAL HOURS PER YEAR BELOW 35 dB CARRIER-TO-NOISE	0.6
PERCENTAGE RELIABILITY	99.993

[+] DENOTES POWER ADDITION (+) DENOTES VOLTAGE ADDITION
*OVERALL C/N AND CTB TO BE ADDED TO THOSE OF TRANSMITTER INPUT

the signal at the receiver is also 6 dB higher than it would be if no repeater were used. Since, however, both repeater and receiver contribute to C/N, the improvement is at best 3 dB. Note also that repeater gain is critical if both C/N and C/CTB are to be maintained at acceptable levels.

The block diagram of the FFR-123 microwave feed-forward repeater (Figure 3) illustrates the point. The AGC threshold is set to obtain the desired CTB. Table III summarizes the key FFR-123 repeater performance parameters. Consider, for instance, a 40-channel application in which the repeater C/CTB link contribution is 65 dB. The output is then set for 1 dBm per channel. Since the gain is 45 dB, the input level at AGC threshold is -44 dBm. With 6-dB noise figure, C/N must then be 58 dB. Since this must still add to receiver C/N, a repeater with too much gain cannot provide the desired quality signal. Where input signal level to the repeater is always below -42 dBm, the LNA could be taken outside of the AGC loop shown in Figure 3 without excessive degradation of C/CTB, but this would limit the range of possible system application.

TABLE III

MICROWAVE FEED FORWARD REPEATER PERFORMANCE

POWER OUTPUT FOR 65 dB C/CTB, dBm	
21 CHANNELS	+5
35 CHANNELS	+2
60 CHANNELS	-1
GAIN, dB	45 ± 1/2
NOISE FIGURE	6 dB
AGC	
RANGE	25 dB
FLATNESS	1 dB
THRESHOLD ADJUSTMENT RANGE	10 dB
FREQUENCY RESPONSE, 12.7 - 13.2 GHz	±1 dB

Even channelized transmitters can sometimes be a significant contributor of thermal noise when overall 56-dB C/N is demanded from the microwave link. Noise power output of the STX-141 transmitter is determined by the klystron gain and noise figure. After attenuation by the output filter and allowance for spillover from the adjacent channels, noise power is typically -30 dBm/4 MHz. Comparing this to the +33 dBm signal, the C/N is seen to be 63 dB. As the klystron current drops due to cathode aging, both gain and noise figure can be expected to deteriorate. If, then, the klystron is retuned to reestablish 45-dB gain, the output noise may be a few dB larger than when the unit was delivered from the factory. With the introduction four years ago of the long-life klystron, one can expect that the aging process will be stretched out to over 10 years.

One solution for obtaining better C/N in STX-141 type transmitters is to upgrade the unit so that its output capability is raised to 36 dBm. The difference lies in the linearity of the upconverter, which is provided with a higher level local oscillator (LO) signal. A further 3-dB

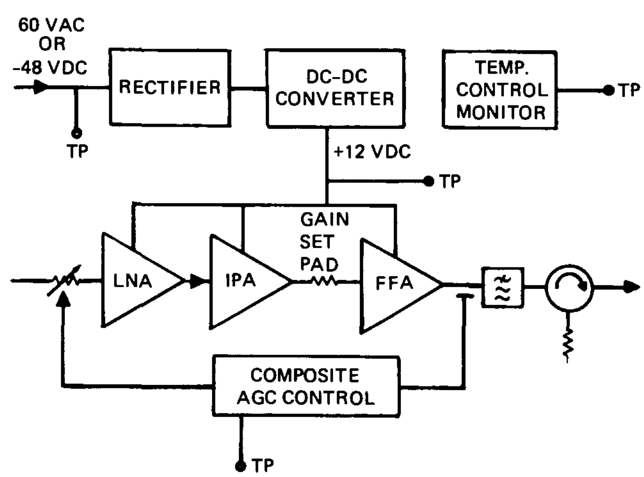


Figure 3 Microwave Feed Forward Repeater block diagram.

increase in output power capability is possible with a predistortion circuit.[11] It is, of course, obvious that increasing transmit output power has the double benefit of increasing link margin and, therefore, the ability to better sustain 56-dB C/N at the receiver, as well as make transmitter noise contribution an all but negligible entity.

Another possible approach to obtaining better C/N in a channelized high power AML is to utilize a high power FET amplifier in place of a klystron in the output stage of the transmitter.[12] The noise figure of the FET amplifier is much lower than that of the klystron, thereby making transmitter C/N contribution as insignificant as it is in the medium powered MTX-132 transmitter. The drawback in the FET amplifier approach is that with currently available devices, one must give up several dB in output power capability (relative to the +33 dBm of the STX-141 transmitter) to maintain good distortion performance. AM-to-PM conversion in FET amplifiers operating close to saturation may be a particular limitation for some types of ATV signals. The primary advantage of this new type of channelized all solid-state transmitter has less to do with HDTV than with floor space and prime power requirement in new or expanding transmitter system installations.

A final thought dealing not so much with C/N as with baseband S/N is that, if the television signals carried by the AML supertrunk are frequency modulated rather than VSBAM, one can, of course, more easily obtain very high quality signals. The drawback, as with any other supertrunk scheme carrying FM video, is the cost and complexity of converting each of the FM signals back to the VSBAM format before delivering the product to the subscriber. Table IV summarizes the various means for achieving very high quality S/N on AML links.

2. Distortion - In the channelized AML transmitters, the distortion is similar to that encountered in other headend equipment. In particular, the rise of third-order intermodulation products limits the output power of the MTX-132 and the high power STX-141 transmitters. Those products fall both in-band (the 920-KHz beat caused by a combination of video, color, and audio carriers) and into the next lower channel (audio-video beat 1.5 MHz above the adjacent video carrier). The transmitter specification for the audio 17 dB below video and color 20 dB below video (cw measurement) is C/I of 58 dBc. Since there is then considerable margin with

TABLE IV

MEANS OF ENHANCING AML S/N

ADJUSTMENT OF MICROWAVE RECEIVER AGC THRESHOLD
COMPACT OUTDOOR RECEIVER WITH 2-STAGE LNA
LOWER NOISE FIGURE LNA
REDUCED OLE-111/FFA-160 TRANSMITTER OUTPUT NOISE
FFR-123 MICROWAVE FEEDFORWARD REPEATER
HIGHER OUTPUT POWER STX-141 TYPE TRANSMITTER
HIGH POWER CHANNELLIZED ALL SOLID STATE TRANSMITTER
FM TV SIGNALS INSTEAD OF VSBAM

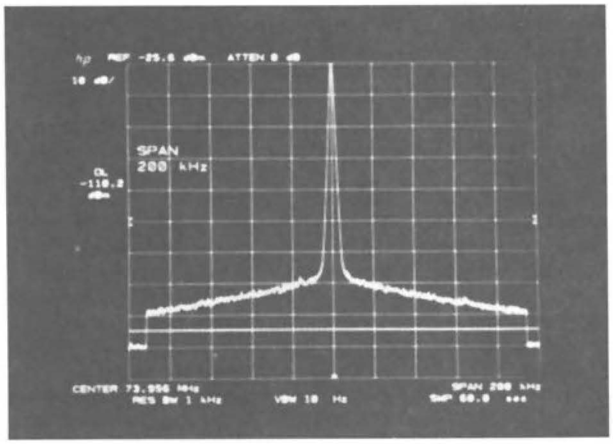
respect to the "W-curve" specified by BP-23, the 58-dBc specification will presumably also be adequate for most ATV systems. If an even better number is desired, one can back off the transmitter output to obtain a 2-dB improvement in C/I for each dB reduction in output power. Alternatively, high power transmitter linearity can be improved through higher LO power or predistortion.

Differential gain is typically better than 3 percent and differential phase is under 2 degrees. However, if a significant performance degradation is introduced by overdriving the upconverter or klystron, a phenomenon somewhat akin to differential gain can interfere with proper operation of descrambler units in the home. This is caused by transfer of AM onto the FM audio subcarrier. Normally, the effect is barely measurable, and well below the threshold of greater than 0.5-dB modulation riding on top of the audio signal, at which certain types of descrambler units may begin to experience some problems. Generally, keeping the C/I to 58 dBc will keep AM transfer to audio at a negligible level.

Another type of distortion that occurs in AML systems can be found in the broadband receivers and the block upconversion type transmitters. This distortion is the second- and third-order intermodulation between video carriers. In discussing C/N, reference has already been made to the improvement in C/CTB and C/CSB (composite second-order beat) in the COR receiver with a dual-stage LNA. Second-order distortion does not play a role at microwave, since the percentage bandwidth is only 4 percent, but it does occur in the VHF end of the block upconversion and downconversion process.

In CATV system calculations, such third-order distortions as composite triple beat are assumed to add on a voltage basis in a cascade of amplifiers. If, however, the distortion generating elements in the cascade are not identical, it is not necessarily true that the phase vectors representing the distortion products will all line up with one another. In a careful set of experiments involving a Microwave Line Extender, a Microwave Feedforward Amplifier, a two-stage LNA, a 440-MHz AML receiver, and a CATV hybrid amplifier, it was found that C/CTB did not always add on a voltage basis. Sometimes it added on a power basis (90-degree angle between voltage vectors) and sometimes it didn't add at all (120-degree angle between vectors). Therefore, although it may not be totally rigorous, as a practical matter, the C/CTB performance of a CATV system including AML can be conservatively calculated by first separately voltage-combining the microwave-based elements and then power-combining the microwave resultant with the VHF (i.e., receiver and cable amplifier) resultant.

3. Phase Noise - Figure 4 shows the phase noise on the AML pilot tone signal as it appears at the output test point of the receiver. The performance shown is typical of present production. Note in particular the value at 20-KHz offset from the carrier: better than 70 dBc in a 1 KHz resolution bandwidth. Depending on the phase noise limitation of the spectrum analyzer and the thermal (flat) noise at the measurement point, corrections to the apparent measured value may be required at this low level of phase noise. Thermal noise limit after external amplification of the test point signal is indicated by the display line while the thermal noise of the analyzer itself is shown at the start and end of the trace. The analyzer



VERTICAL SCALE:	10 dB/DIV
HORIZONTAL SCALE:	20 kHz/DIV
RESOLUTION BANDWIDTH:	1 kHz

Figure 4 Receiver pilot tone output spectrum.

phase noise contribution can be calibrated by using a known ultralow phase noise signal, such as the 74-MHz crystal oscillator within the AML transmitter. This crystal reference must be extremely clean, since it is multiplied up in frequency by a factor of 171 before emerging as the microwave LO signal. The multiplication process worsens the crystal phase noise by a factor of $(171)^2$ or 45 dB. The phase noise is also degraded by contributions internally generated within the transmitter solid-state source. The same elements exist in the receiver and, in addition, one has the contribution of the receiver phase-lock loop. The bandwidth of this loop is quite narrow, so only at offset frequencies under 5 KHz is there any hope of tracking out any of the incoming phase noise.

It can be shown that the phase noise of the magnitude shown in Figure 4 would, through conversion to AM by the Nyquist filter of an ideal VSBAM envelope detector, contribute better than 65-dB baseband S/N. With that type of TV receiver, one would expect that phase noise could be worse by as much as 15 dB before becoming visible on the screen. Recent tests with quasi-synchronous type television receivers indicate visibility thresholds on the order of 53 to 60 dBc phase noise at 20 KHz offset in 1 KHz resolution bandwidth.[13] Although phase noise in a CATV system is typically limited by elements other than AML, investigations have been under way to see whether AML phase noise performance can be further improved in case ATV requirements eat substantially into the existing margin.

4. Reflections - It is expected that some forms of ATV signals will be much more sensitive to close-in ghosts than with standard NTSC. In particular, reflections as close in as 30 ns may become a concern. It has been suggested that an overall CATV system echo rating objective of 34 dB may be suitable.[8] To contribute negligibly to this objective, reasonable care should be taken in the design of the microwave system.

Consider Figure 3 again. Note the isolator at the output of the transmitter. Because it is implemented in waveguide, a return loss of 23 dB should be achievable if required. The transmitter must be connected to an antenna, which is typically specified to have a VSWR of 1.1:1. This is equivalent to a return loss of about 26 dB. Thus round-trip return loss with a 15 foot length of elliptical waveguide interconnection would be about 50 dB when waveguide loss is taken into account. Longer waveguide lengths will lead to greater than 30 ns delay echoes, but not necessarily greater round-trip loss, since a circular guide may be used. In either case, microwave return loss should contribute negligibly to the overall CATV system echo rating.

5. Frequency Response - Two types of frequency response are of concern. ATV signals could require greater bandwidth and thus push out the maximum frequency limit on the CATV system. AML equipment can be fully compatible with operation to 550 MHz. As an example, HPOLE-112 transmitters are now designed for 550-MHz operation. Most broadband units, whether they are transmitters or receivers, can be upgraded to 550-MHz operation if they are not presently compatible with this requirement.

If CATV system requirements were to expand to a maximum of 600 MHz, AML systems could conceivably still fit within the broadened 12.7- to 13.25-GHz frequency allocation. Another option, and one which would not be limited by the 550 MHz wide microwave allocation, would be to employ microwave frequency reuse, such as that demonstrated in Dallas.[14] A suitable choice of LO frequency would automatically keep the UHF signals carried on the auxiliary microwave link within the CARS-band limits.

The second question relating to frequency response concerns itself with the limitations of the channelized transmitters. The TE_{011} mode filters used in such transmitters can be designed for bandwidth as large as 30 MHz. Existing transmitters designed for 6-MHz channel plans would require modification for wider band ATV signals.

6. Group Delay - Group delay is of concern only in the channelized transmitters. The MTX-132 type transmitter typically exhibits less than ±15 ns delay. The STX-141 transmitter may have as much as ±35 ns delay. This can, however, be reduced by exchanging the upconverter output filter for a broader bandwidth unit. Since the klystron is typically the primary source of video-audio intermodulation (falling in the next lower channel) and the output multiplexing filter attenuates this product, performance should otherwise be unaffected. With the modification, delay may typically run about ±20 ns.

7. Availability - The calculation in Table II resulted in a predicted path reliability of 99.993 percent. Similar reliabilities are possible over considerably longer paths using channelized transmitters. Since there is no threshold effect with VSBAM, the pictures are still viewable, even below 35 dB C/N. Nevertheless, one can speak of an availability of signal for the indicated percentage taking only rain and multipath into account. One also needs be concerned with the twist of the antenna during high wind conditions. The design must be consistent with the 1/2 degree beamwidth for 10-foot dishes.

Availability is, of course, a key element of the quality of signal provided to the subscriber. If pictures are simply not available, this is the worst kind of quality imaginable. Fortunately, the microwave link service interruption is not influenced by such factors as drunken drivers knocking down telephone poles, intentionally severed cables during labor disputes, and "backhoe fades" resulting from construction activities. If an equipment failure occurs, it can be rapidly localized to either of two sites: the transmitter or receiver.

Since a failure in the receiver will affect all channels, the desirability of a redundancy arrangement has long been recognized. In many systems, a simple headend for local off-air channels (note the VHF antennas in Figure 1) is automatically switched in if the signals are temporarily unavailable over the microwave path. A more sophisticated redundacy arrangement is provided with the receiver redundancy unit (RRU), which monitors the pilot tone output level and phase lock alarms from a standby receiver, as well as a primary receiver. If the RRU logic circuits detect a failure in the primary receiver, the switch is automatically activated to connect the standby unit directly to the antenna. If the problem lies with the microwave path or the transmitter, the RRU will automatically switch to the local headend signals. The RRU has recently been redesigned to make it fully compatible with carriage of signals to 550 MHz.

Another application of the RRU is shown in Figure 5. Here, automatic redundancy is applied to the transmit end of a broadband AML link. Another form of block conversion transmitter redundancy,[6] although not automatic, provides an added 3-dB output capability when the application calls for two or more receive sites.

Fail-soft redundancy of the klystron and high-voltage power supply has long been a standard feature of the MTX-132 transmitter. This was provided because a single failure would affect eight channels. Most recently, a new means of backing up a single channel failure has been developed. This is the frequency-agile upconverter (AUPC) shown installed (Figure 6) in the lower right side of an MTX-132 transmitter rack. The AUPC takes a VHF input and provides a microwave output. If an upconverter failure occurs, the VHF input signal to that upconverter is patched over to the AUPC input. The AUPC output is connected to the bottom of one of the circulator strings

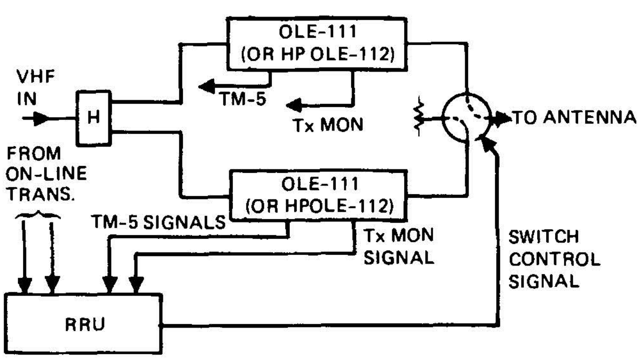


Figure 5 Microwave line extender automatic redundancy arrangement.

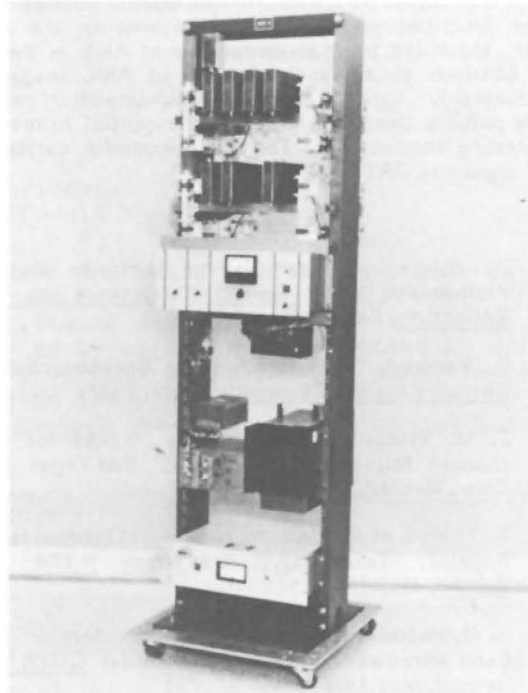


Figure 6 Frequency agile upconverter in MTX-132 transmitter.

in which the standard output multiplex rules would not be violated. The AUPC thus essentially provides for immediate back-up (assuming the transmit site is manned) for any upconverter failure. The AUPC can also serve as a premium channel back-up when carrying a low priority "9th channel" in an MTX-132 rack.

SUMMARY

Technology improvements recently incorporated in the AML receiver design enhance the ability of LDS type microwave to fulfill CATV system needs, such as a 56 dB C/N, which may be required by ATV. Noise figure and linearity are the key parameters determining overall capability. Improved output power capability is achieved through linearization techniques, such as those illustrated in the microwave feedforward repeater, and by the application of predistortion to the high-power STX-141 transmitter. The typical AML phase noise of 70 dBc/KHz at 20-KHz offset is well below the visibility threshold in present TV receivers. With reasonable care, microwave reflections should contribute negligiby to overall CATV system echo rating even for ATV systems capable of distinguishing ghosts as close in as 30 ns. Bandwidth requirements of ATV signals can presently be met with broadband AML equipment, and even channelized transmitters can be designed for up to 30-MHz channel bandwidths. Group delay in these transmitters can be kept under ±20 ns. Signal availability in a well-designed microwave link can be better than 99.99 percent if redundancy techniques are employed. Because equipment is located only at the transmit and receive points, catastrophic outages are more easily avoided with microwave than with other forms of signal transportation. In view of the above described performance improvements, the advantages, which led to wide-spread use of AML in the past, can continue to apply to the use of AML in an ATV environment. Indeed, shorter trunk amplifier cascades made possible through AML may be essential to meet the demanding requirements for the successful carriage of ATV signals in CATV systems.

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