"PERFORMANCE OF MULTI-CHANNEL MICROWAVE LOCAL DISTRIBUTION SYSTEMS"

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It has now been about seven years since the development of multi-channel microwave local distribution systems for the CATV industry first started in 1965, although it seems like yesterday to those of us who have been so heavily involved in this exciting and dynamic field. More progress has been made during the past year, since the 1971 NCTA convention, than in all prior years, insofar as putting multi-channel local distribution systems in actual operational day to day use. It can now be said that AML microwave is no longer a developmental technique, but a technique which is essential to progressive cable operators who wish to achieve optimum financial performance for themselves and optimum signal quality for their subscribers.

Before getting into a detailed discussion of AML's performance capabilities, I think that it would be desirable to briefly review the equipment's salient design features. A simplified block diagram of the AML system is shown in Figure 1.

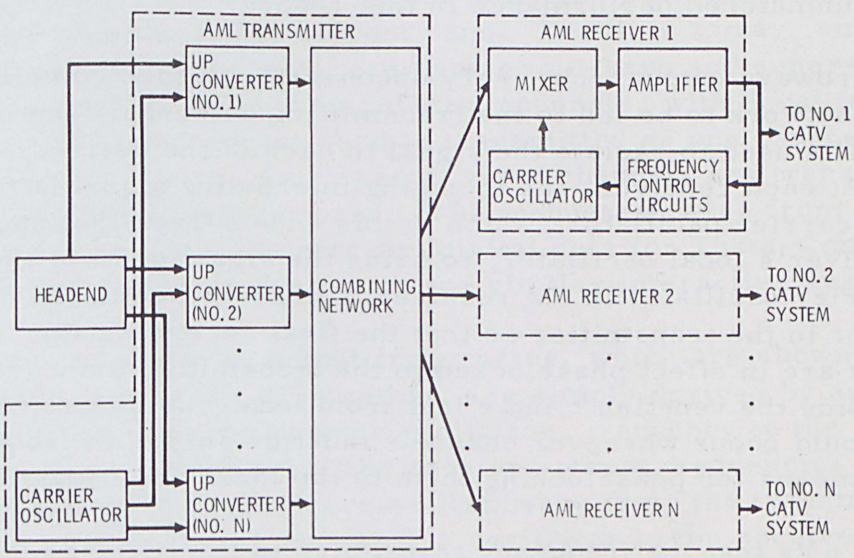

Figure 1. AML System - Simplified Block Diagram

Signals are fed to the AML transmitter from a conventional headend, where they should be processed by conventional heterodyne processing equipment. The AML does not require the use of video carriers with phaselocked frequency spacings in order to minimize intermodulation products. This avoids the necessity for going down to video baseband by demodulating and remodulating with phaselocked modulators. It further eliminates the necessity for non-standard channel assignments, which would require special channel converters in all subscribers' homes and which would severely aggravate venetian blind phenomena resulting from co-channel interference from off-the-air radiation into your subscribers' sets.

The processed VHF signals from the headend are then translated in frequency into the microwave range; i.e., into the 12 GHz CARS band. This is done by a parametric upconverter, wherein the VHF signals are mixed with a carrier oscillator. The upconverter selects the sum of the VHF and carrier frequency and rejects the carrier itself as well as the lower sideband which is the difference between these two frequencies. One way of looking at the action of the upconverter is therefore to consider it as a single sideband suppressed carrier AM system. Another way of looking at it, is that the VHF signal is maintained with its modulation intact and merely translated in frequency into the microwave range. The modulation of the microwave signal therefore remains in the form of vestigial sideband AM. This is the designation which the FCC has assigned to our type of modulation.

You will note that all channels are processed separately in all the active stages of the AML transmitter. This is the design feature which virtually eliminates the possibility of crossmodulation and intermodulation from arising in the transmitter and is what enables the AML system to achieve unmatched performance in this regard.

The microwave output from every upconverter is then combined in a passive network to be fed to the transmitting antennas. One of these antennas is used to radiate the signal to each of the desired receiving sites. At each receiver, the incoming microwave signal is mixed with another carrier oscillator, which in this case serves the function of the receiver's local oscillator, to bring the signal down to VHF again. The carrier oscillator in the receiver is phaselocked to the carrier oscillator in the transmitter so that the final receiver output frequencies are in effect phaselocked to the transmitter input frequencies. This avoids the venetian blind effect from local off-the-air radiation, which would occur whenever channels must be shifted in frequency without means for phaselocking them to the local off-the-air stations.

You will note that the frequency translation in the receiver is handled in one block. The reason why this is feasible, is that the signal levels in the receivers are, of course, much lower than those in the transmitter, so that the types of non-linearities which give rise to intermodulation and crossmodulation are not a limiting factor here.

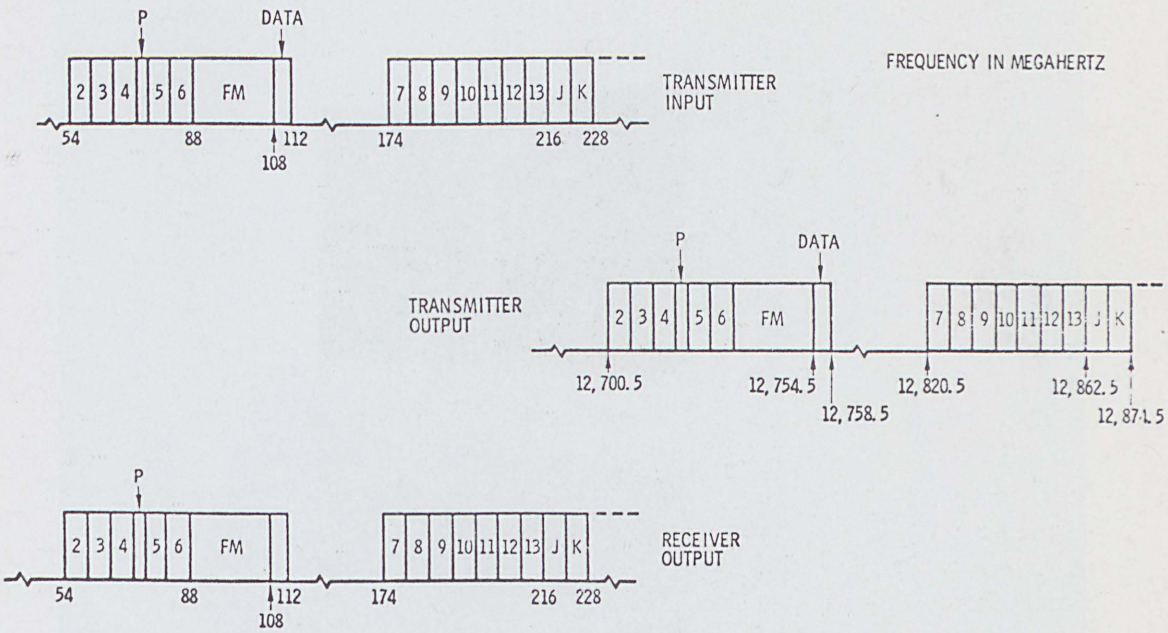

Figure 2. AML Frequency Chart

The frequency relationships involved in the AML system operation are shown in Figure 2. The upper portion of this illustration shows VHF channel assignments. I have only shown the 12 standard VHF channels plus the FM broadcast band. Needless to say, subject only to FCC approval, the AML can handle mid-band and super-high channels, and actually even sub-low channels, with equal facility. The entire FM broadcast band is transmitted as one channel. In some cable systems, four special video channels are transmitted in lieu of the FM broadcast band. The frequency range from 108 to 112 is used to carry the downstream digital data for Theta-Com's Subscriber Response System or for similar interactive systems.

The AML transmitter output frequencies, which are shown in the middle portion of the illustration, are simply derived by adding the transmitter pump, or carrier oscillator, frequency to the VHF input frequencies. Conversely, the receiver output frequencies are derived by subtracting the same carrier frequency from the transmitted frequency. Evidently, if the carrier oscillator in the receiver is phaselocked to the carrier oscillator in the transmitter, the final receiver output frequencies are precisely equal to the transmitter input frequencies. A pilot tone is transmitted in the AML system in the frequency range between channels 4 and 5 for the purpose of phaselocking the local oscillator in the receiver to the pump frequency in the transmitter. The pilot tone is also used for automatic gain control in the receiver in order to reduce the effect of atmospheric fading phenomena.

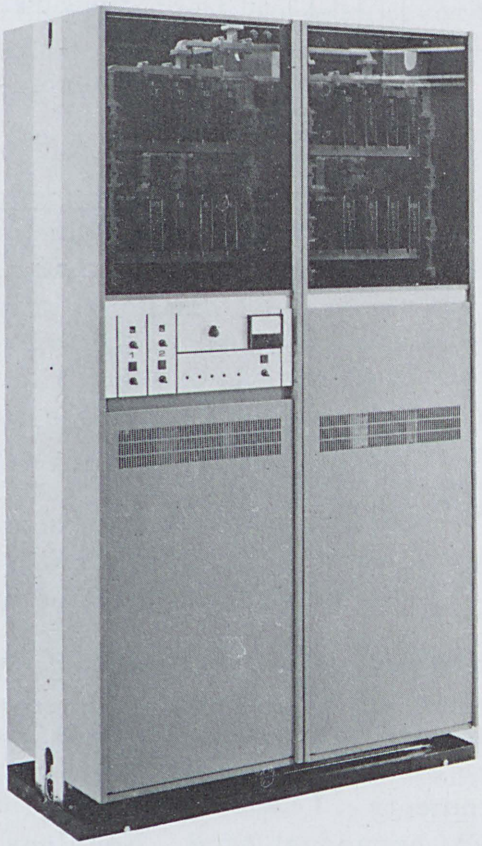

Figure 3. AML Transmitter

Figure 3 shows an AML transmitter. This particular two-rack configuration can handle up to 15 channels as well as the pilot tone. Or this might be 14 video channels, the FM band, and the pilot tone. Each rack accommodates up to 8 channels and the system employs modular techniques so that only as many racks or channels within racks need to be procured as may be required for the particular application. Additional channel modules or additional racks can be added from time to time as the number of channels carried by the cable operator increases.

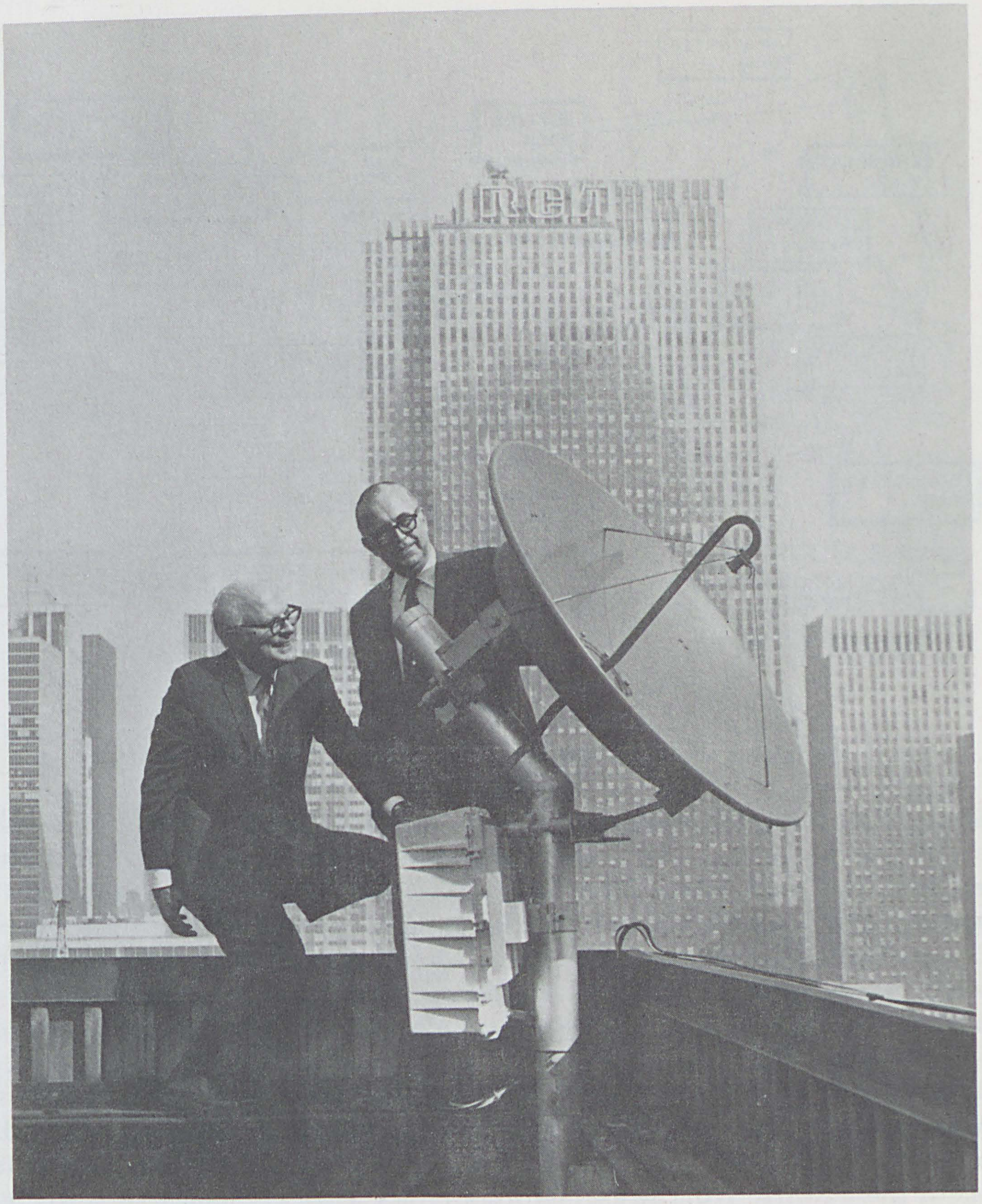

Figure 4. AML Receiver Installation

An actual receiver installation is shown in Figure 4. The receiver is cable powered, in a fashion similar to that of a conventional trunkline amplifier, and is capable of operating outdoors over a temperature range from -40^{o}F to +120^{o}F.

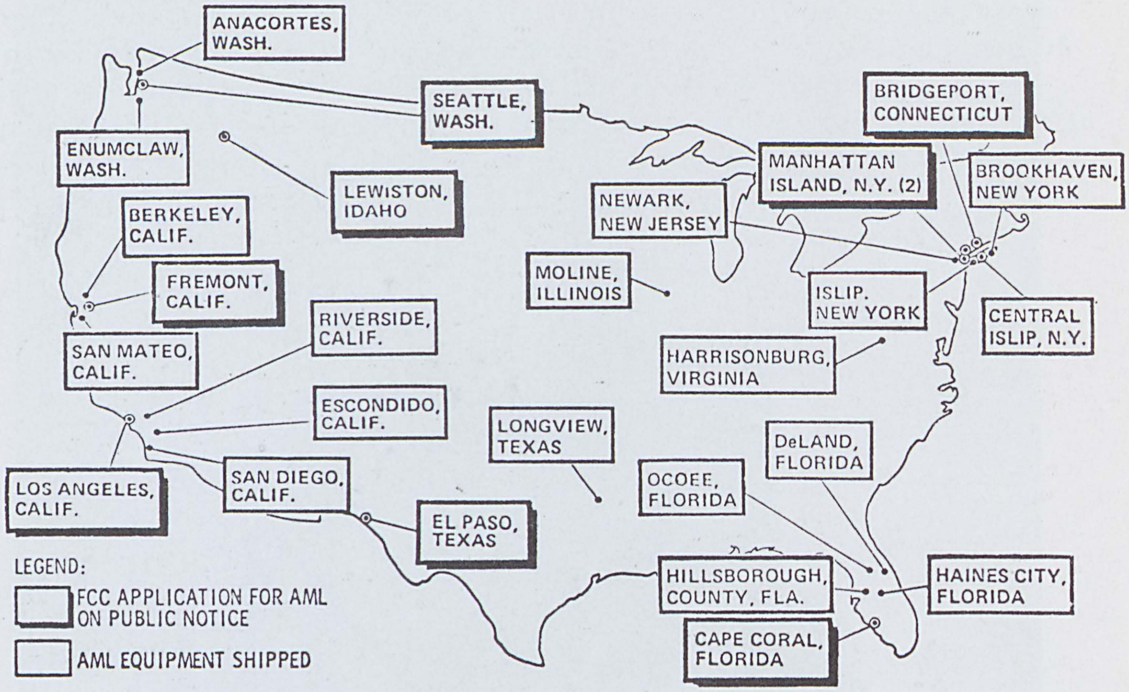

Figure 5. AML Installation Status as of April, 1972

Figure 5 shows the status of AML installations throughout the country as of April, 1972. The locations having a heavy border show actual equipment shipments. The other locations shown indicate those FCC applications for AML, which have gone on public notice. At the present time, Theta-Com's AML leads in the number of FCC filings and I would like to emphasize that all these filings are bona fide filings made and paid for by our customers. Insofar as actual shipments and installations are concerned, as of the time of the writing of this paper, Theta-Com's AML is still the only multi-channel local distribution system in actual subscriber service by cable system operators all over the country. The climatic conditions encountered range widely from the Pacific Northwest, Northern as well as Southern California, Texas, Florida and the New York and Long Island areas. The number of FCC filings, the granting of FCC construction permits, and the number of AML shipments and installations has been rising exponentially and it is really quite difficult to keep these statistics up-to-date.

But picture quality is really the name of the game. Let us now go to my primary topic, some hard numbers concerning actual performance. In each case, I plan to show you the block diagram of our test instrumentation, photographs of the instrumentation employed, as well as the data itself.

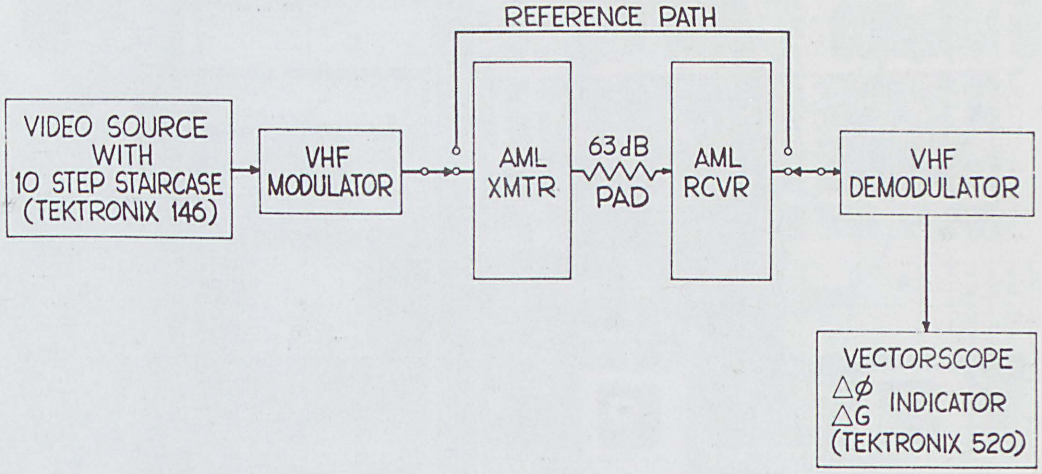

Figure 6. Block Diagram - Differential Phase and Gain Tests

Figure 6 shows a block diagram of the test setup employed to make differential phase and gain measurements. These measurements are accomplished at video baseband using a Model Tektronix 146 TV Signal Generator and a Tektronix Model 520 Vectorscope as a differential phase and a differential gain indicator. The necessity for making these measurements at video baseband is unfortunate, inasmuch as it requires the use of a VHF modulator and a VHF demodulator, the combination of which has much more differential phase and gain deterioration than does the AML system. It is therefore necessary prior to each measurement to calibrate the reference path without the AML and subsequently to measure the change of differential phase and gain when the AML system is inserted.

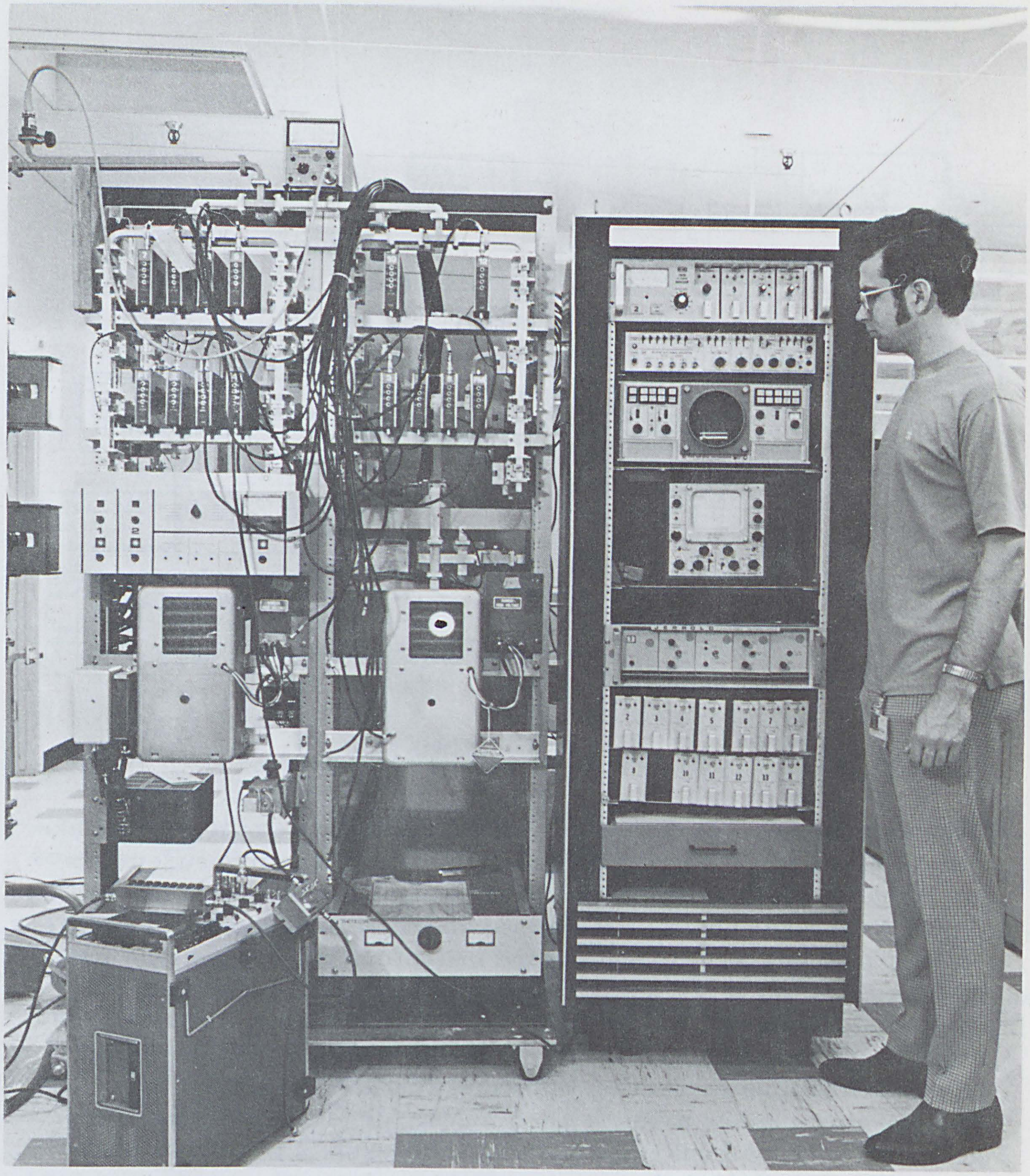

Figure 7. Differential Phase and Gain Instrumentation

The actual instrumentation employed for the differential phase and gain measurement is shown in Figure 7. The rack of equipment at the right-hand side of this photograph contains the test equipment. The unit at the top of the rack is the modulator, the unit just below it is the Tektronix test signal generator, and the third unit from the top is the Vectorscope. The equipment below the oscilloscope is the demodulator. Shown below that are various plug-in tuning units for the modulator and the demodulator in order to permit measurements on all channels.

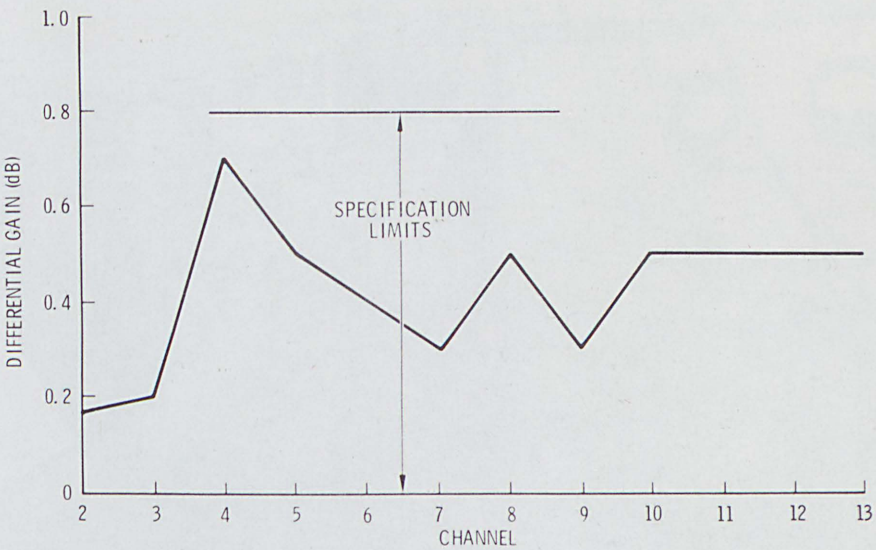

Figure 8. Differential Gain Response of AML System

The results of the differential gain response of a complete AML system, that is including the transmitter as well as the receiver, may be seen on Figure 8 to be well within the specification limits of plus or minus 0.4 dB on all channels.

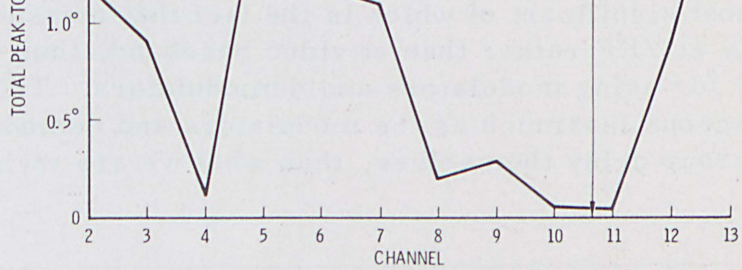

Figure 9. Differential Phase Response of AML System

The differential phase response of the AML system is shown on Figure 9. Excessive phase shift would result in changes in color, as a function of changes in color intensity. The response of the AML system may be seen to be well within specifications and far better than CATV system requirements.

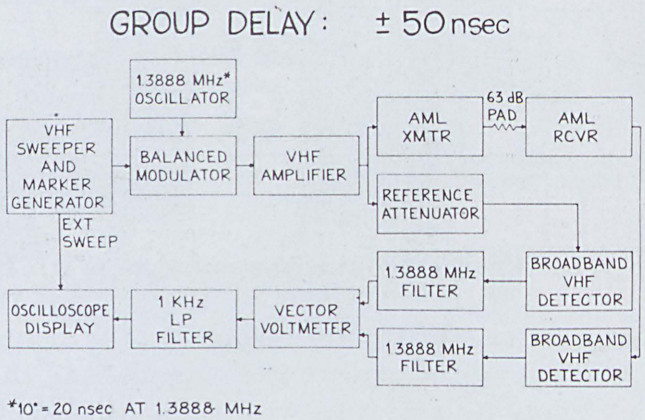

Figure 10. Block Diagram - Group Delay Instrumentation

The block diagram of the test setup for group delay measurements is shown in Figure 10.* Essentially, this method of measurement employs a Vector voltmeter to measure the phase shift of the 1.3888 MHz modulation on a VHF carrier, as the latter is swept through all channels. The odd modulation frequency is chosen for convenience of calibration so that a 10 degree phase shift, as measured on the Vector voltmeter, is equivalent to a time delay of 20 nanoseconds. This makes it convenient to use the angular offset switch on the Vector voltmeter to calibrate the oscilloscope display to read directly in nanoseconds. The measurement technique shown on this block diagram has several advantages, the most significant of which is the fact that measurements are made directly at VHF rather than at video baseband, thus eliminating the necessity for using modulators and demodulators. This is particularly advantageous inasmuch as the modulators and demodulators have much more group delay themselves, than what we are trying to measure on AML.

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*I am indebted to William H. Lambert and Andrew W. Barnhart for suggesting this method of measurement to us.

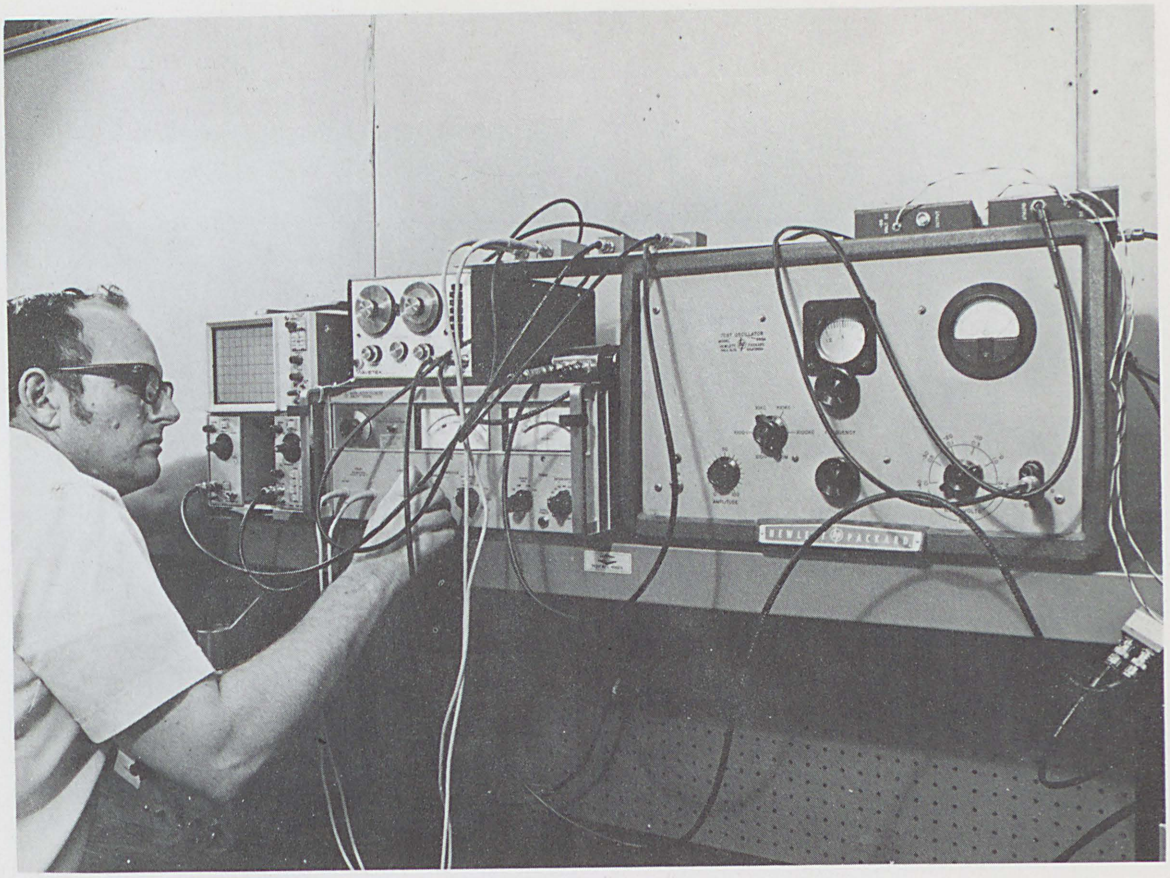

Figure 11. Group Delay Instrumentation

A photograph of the actual instrumentation employed is shown in Figure 11. The technician's hand is on the Vector voltmeter. Directly above the Vector voltmeter is the sweep generator which is used to sweep across the entire VHF band. The test oscillator on the right side of the bench is being used to furnish the 1.3888 MHz modulation signal, but we will replace this shortly with a small fixed frequency oscillator. The oscilloscope shown on the left side of the bench is a storage oscilloscope, which makes it more convenient to make accurate measurements while sweeping very slowly across the band for each channel.

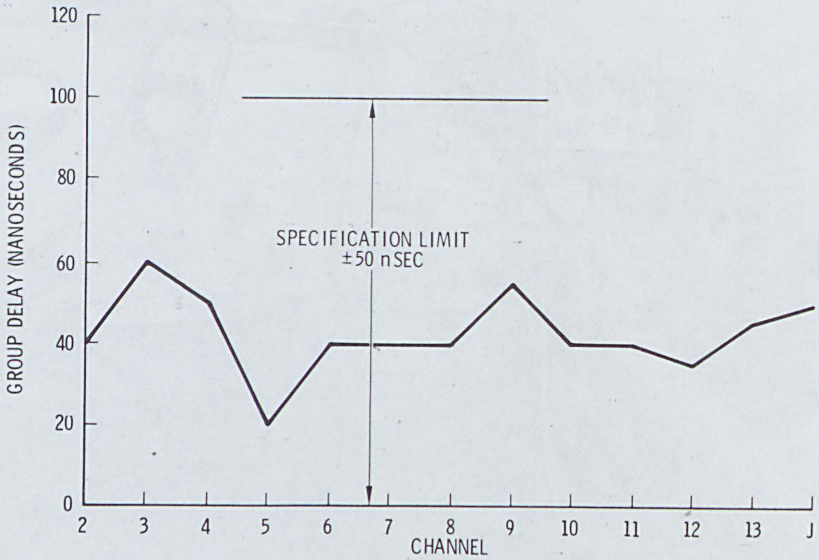

Figure 12. Group Delay Response of AML System

The group delay response of the AML system is shown on Figure 12. It may be seen to be well within specifications and again much below the threshold of discernibility.

For a fixed transmitter power output and a fixed path, the major remaining parameter affecting the AML system's propagation reliability, is the receiver noise figure.

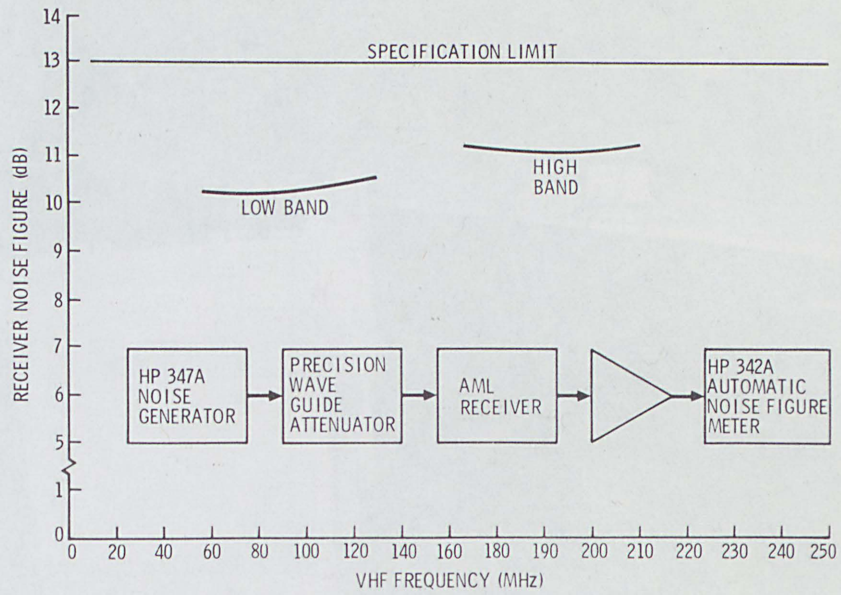

Figure 13. AML Receiver Noise Figure Measurements and Block Diagram

A graph of the noise figure of a typical AML receiver is shown on Figure 13, together with a block diagram of the test instrumentation. The discontinuity in the curve is due to the fact that the current receiver configuration processes the low and high band separately. We will have a new receiver design available shortly which can also handle the mid and super-high bands with performance comparable to that shown here. It may be noted that the noise figure measured is well within specifications. Measurements made on a single receiver are, however, not particularly conclusive.

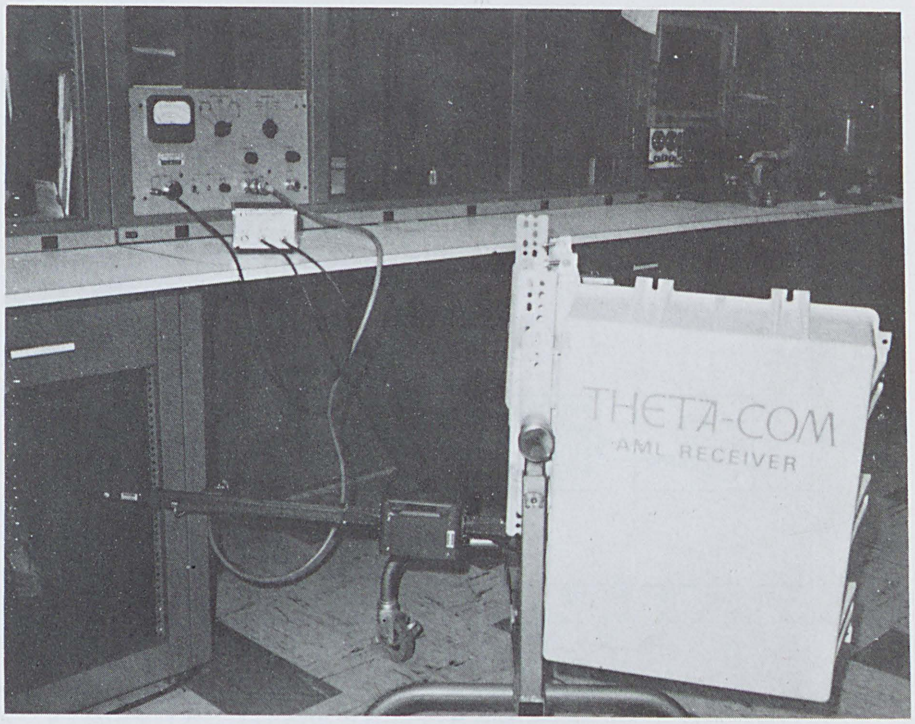

Figure 14. Noise Figure Measurement Instrumentation

Connected to the lower end of the AML receiver are a Hewlett Packard Model 347A noise generator and a precision waveguide attenuator. On the bench are a small VHF amplifier and a Hewlett Packard Model 342A Noise Figure Meter. The latter is operated at a signal level where changes of ± 10 dB do not affect the measurement. The entire setup is periodically recalibrated at the Hughes Primary Standards Laboratory. We have found our test results to be significantly more conservative than the conventional Field Intensity Meter method.

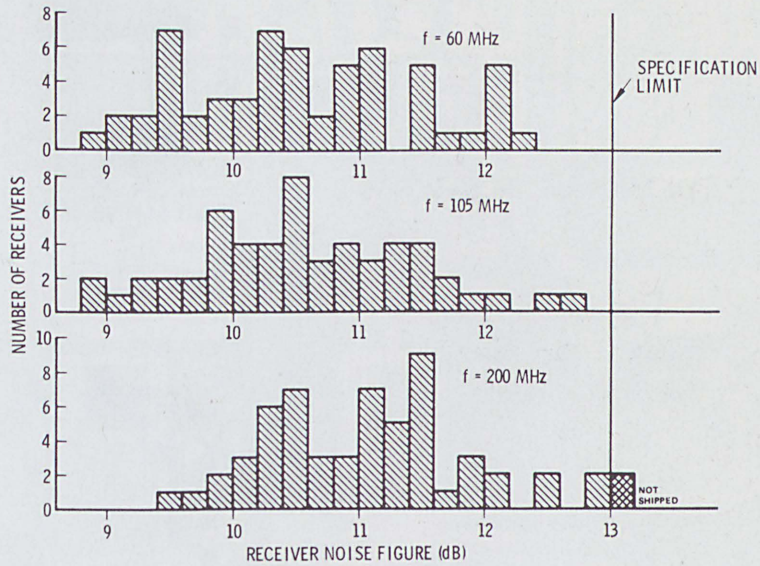

Figure 15. Statistical Distribution of Receiver Noise Figure

Figure 15 illustrates the statistical distribution of receiver noise figure measurements made on a very large number of different receivers. Measurements are shown here at both ends of the band as well as in the middle. Plotted on the horizontal scale is the receiver noise figure and plotted on the vertical scales are histograms of the number of receivers having the various noise figures. It may be noted that the measurements are scattered over a range of in excess of 3 dB, and that all measurements (except for two receivers that were obviously not shipped) are well within specification. There is, however, an unmistakable trend indicating that the average noise figure at the high end of the band is slightly inferior to that at lower frequencies, but nevertheless well within specifications.

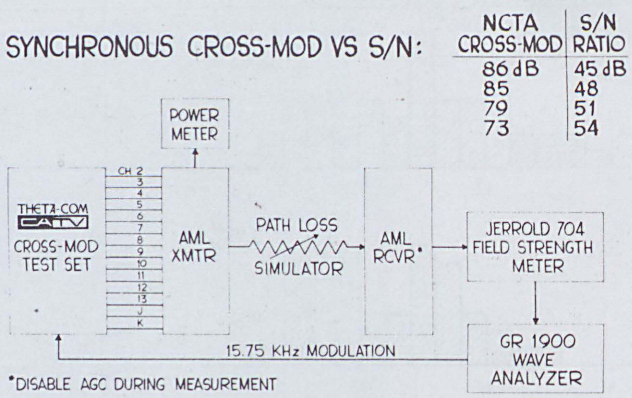

Figure 16. Block Diagram - Crossmodulation Measurements

A block diagram of the synchronous crossmodulation measurement setup is shown in Figure 16. The instrumentation employed is the Theta-Com (former Kaiser) CATV Division's Model KTSS crossmodulation test set with the Jerrold 704 field strength meter and a General Radio Model 1900 wave analyzer. Measurements are made synchronously in accordance with the NCTA method. I am sure that you are all familiar with this method and I need not dwell on it. The AML system's crossmodulation specifications are tabulated in the upper right-hand corner of this chart. Various different specification limits are given because it is possible to trade off signal-to-noise ratio versus crossmodulation performance. For instance, if the microwave path is long and the amplifier cascade is short, overall performance can be improved by driving the receiver harder to a higher signal-to-noise ratio. Conversely, on short microwave paths with relatively long cascades, overall performance and reliability are improved by choosing a lower signal-to-noise ratio and a higher crossmodulation performance.

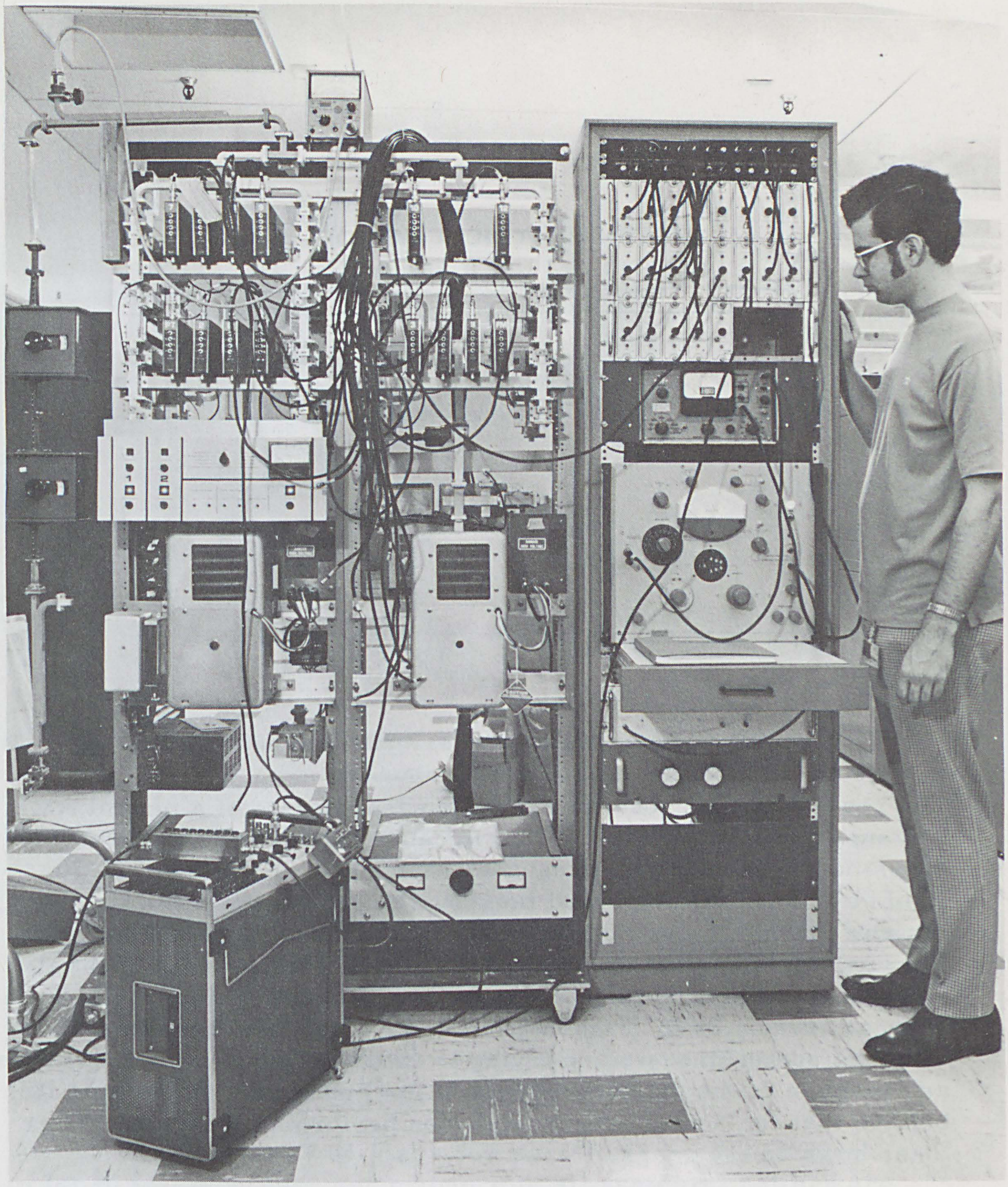

Figure 17. Synchronous Crossmodulation Instrumentation

A photograph of the actual crossmodulation instrumentation employed is shown in Figure 17. The test instrumentation is shown in the third rack at the right. The three rows of modules shown at the top are the various channels of the crossmodulation analyzer. Just below them is the field strength meter and the large instrument in the center of the rack is the General Radio wave analyzer. Incidentally, the test setup shown here is one of our final quality assurance test stations, and all AML equipment currently being shipped goes through this test station, not on a sampling basis, but on a one hundred percent test basis.

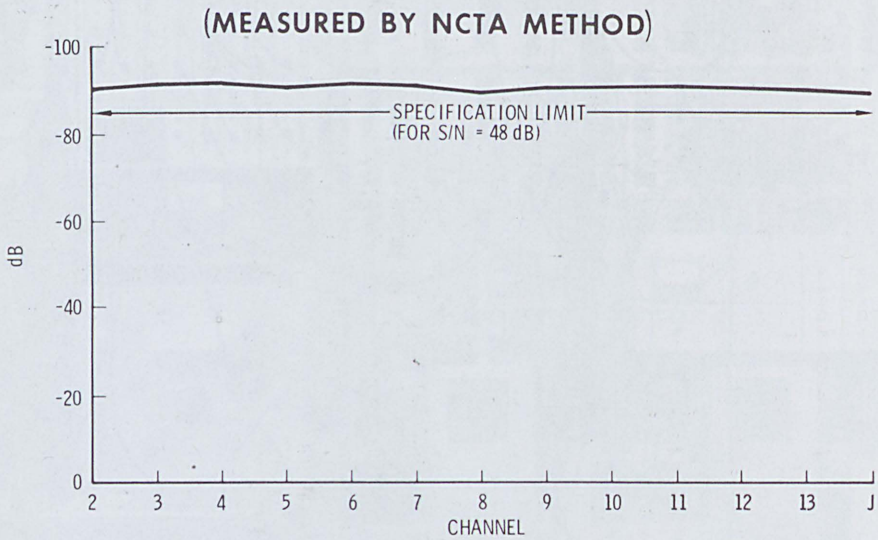

Figure 18. Crossmodulation Performance of AML System

The results of the crossmodulation measurements of a typical AML system are shown in Figure 18. Because of the high degree of crossmodulation suppression, the graph is somewhat difficult to read, expanded versions will be shown later. In the meantime, you can see that the crossmodulation hovers within several dB of 90 dB. This is well within the specification limits indicated. It should also be pointed out that because of the practical limits of the instrumentation employed, the instrumentation noise level is of the same order of magnitude of what we are trying to measure here. For that reason, and because of the masking effects of the instrumentation noise, I believe that the actual crossmodulation performance is even better than shown on the graph.

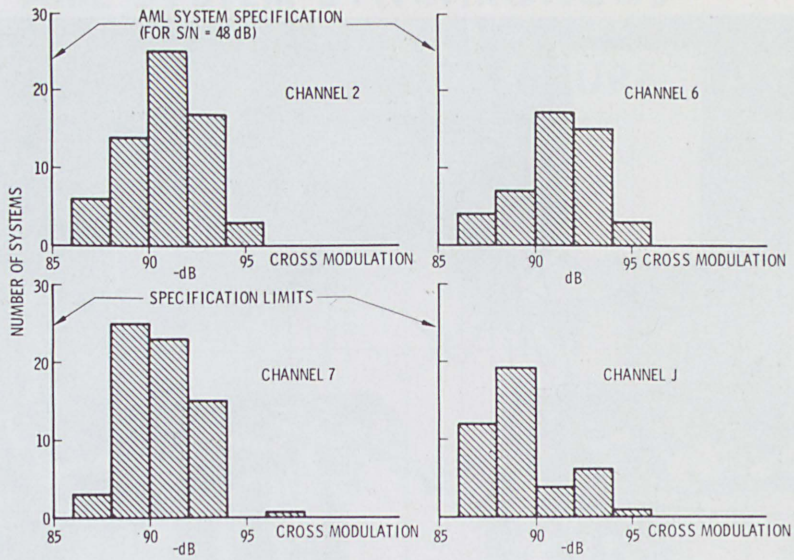

Figure 19. Statistical Distribution of AML System Synchronous Crossmodulation

Here again measurements on a single AML system are not necessarily conclusive. I am therefore showing on Figure 19 the statistical distribution of AML system crossmodulation in several typical channels at both ends as well as in the middle of the band. The horizontal axis shows the synchronous crossmodulation and the vertical axis shows the number of AML systems having any given crossmodulation performance. You will note that the average of the measurements is significantly better than the specification limit and that no measurement falls below the stated limits.

Just as measurements on just a few systems are not sufficient in order to insure proper performance of all systems, neither are measurements at normal room temperature particularly meaningful. The performance of all AML equipment is therefore carefully checked over the entire range of environmental test conditions specified.

Figure 20. Environmental Test Chamber

Figure 20 shows an AML receiver being set up for testing in one of our environmental test chambers. The reels of cable and trunk-line amplifiers in the test chamber have nothing to do with the measurements which I will report shortly, but may be of interest to you inasmuch as they are the 16 amplifier dual cable two-way CATV system which is currently being installed in El Segundo, California for the purpose of testing our new Subscriber Response System. To get back to the AML, we have tested a large number of AML receivers and transmitters in combination as well as separately, in this test chamber, over the various temperature ranges specified in each case.

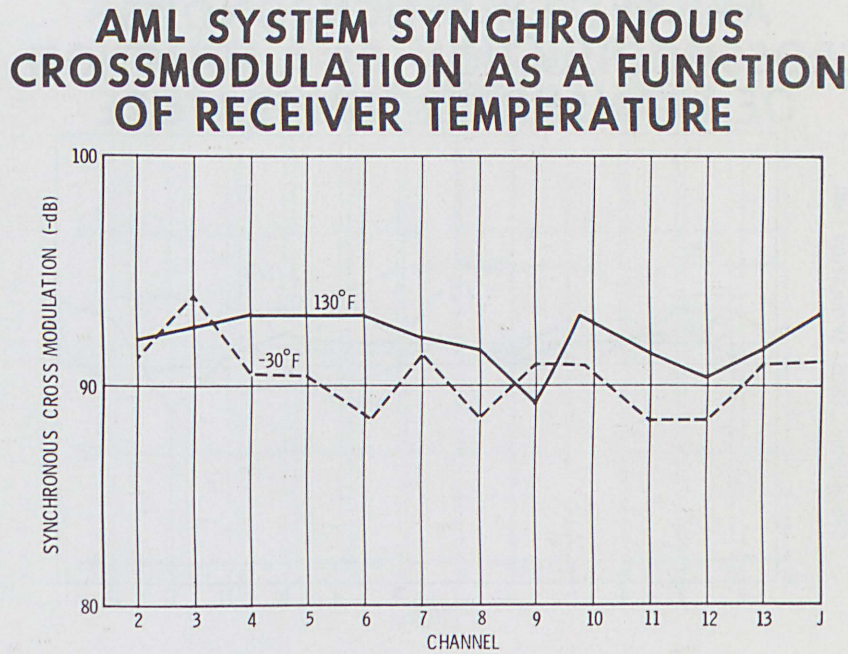

Figure 21

Figure 21 shows the effect on synchronous crossmodulation performance as the receiver temperature is varied from -30°F to +130°F. Performance remains well within specification.

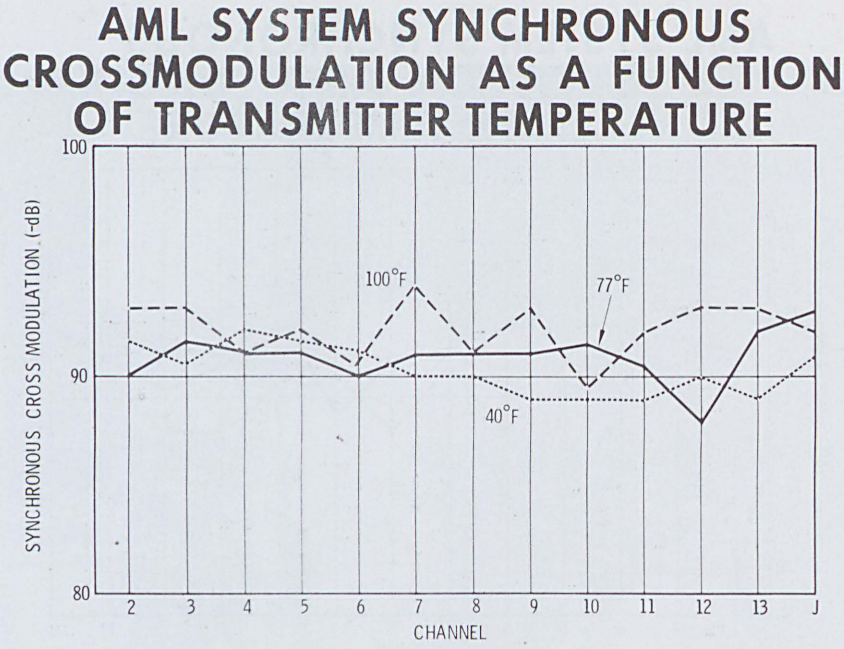

Figure 22

Figure 22 shows the effects on crossmodulation performance as the transmitter is varied in temperature from 77°F up to +100°F and down to 40°F. Here again performance remains well within the specification of 85 dB. You will have noticed that the temperature range for the receiver, which is intended for outdoor mounting under extreme environmental conditions, is much wider than that for the transmitter which will usually be mounted in the headend.

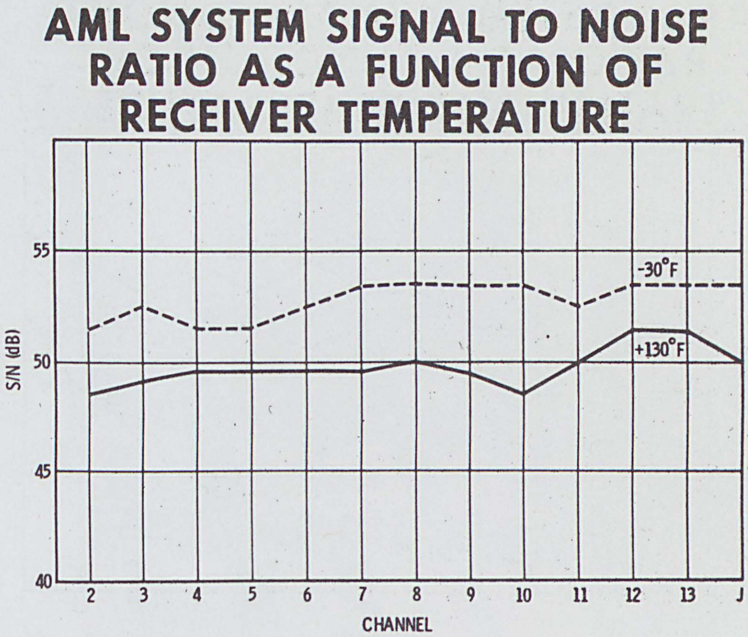

Figure 23

Figure 23 shows the overall AML system signal-to-noise ratio as a function of receiver temperature. It may be seen that lowering the receiver temperature significantly improves system noise figure. Measurements were made at a temperature of 130°F, which is 10° higher than the specification limit of 120°F. We do not wish to imply that the equipment should be operated beyond its specifications.

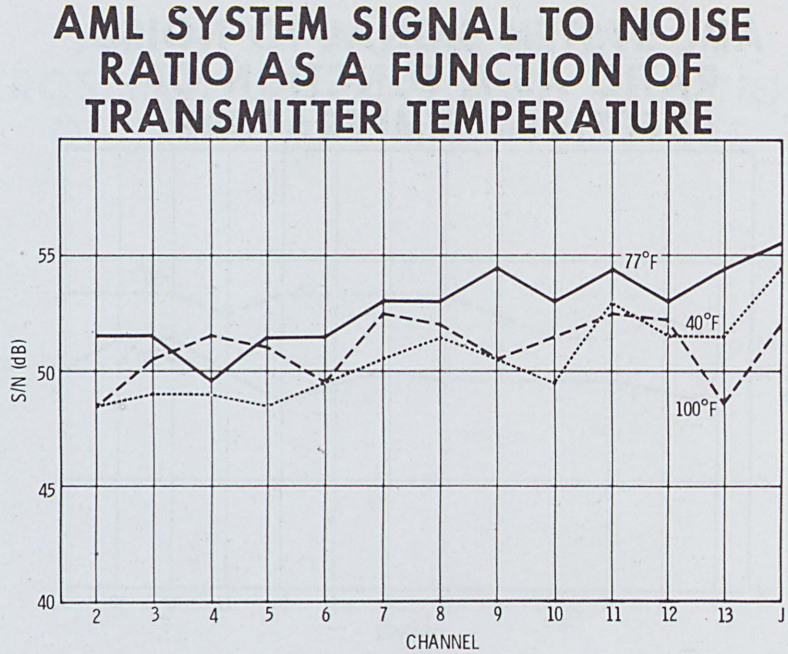

Figure 24

Finally, on Figure 24 is shown the effect on AML system signal-to-noise ratio as the transmitter temperature is varied. You might ask what will happen if the transmitter temperature should deviate from the limits shown here. Actually very little, certainly nothing from the reliability or signal quality viewpoints. The temperature limits specified are solely to keep the transmitter performance within its extremely stringent specifications.

This essentially concludes my discussion of the performance of the AML system operating by itself and let me turn now to the even more interesting topic of the combined operation of AML and conventional CATV systems. After all, the AML system does not feed subscribers directly, and its performance must therefore accommodate the further signal degradation encountered in the cable system itself. For the purpose of these composite performance measurements we employed the 32 amplifier cascade shown in Figure 25 in series with the AML system.

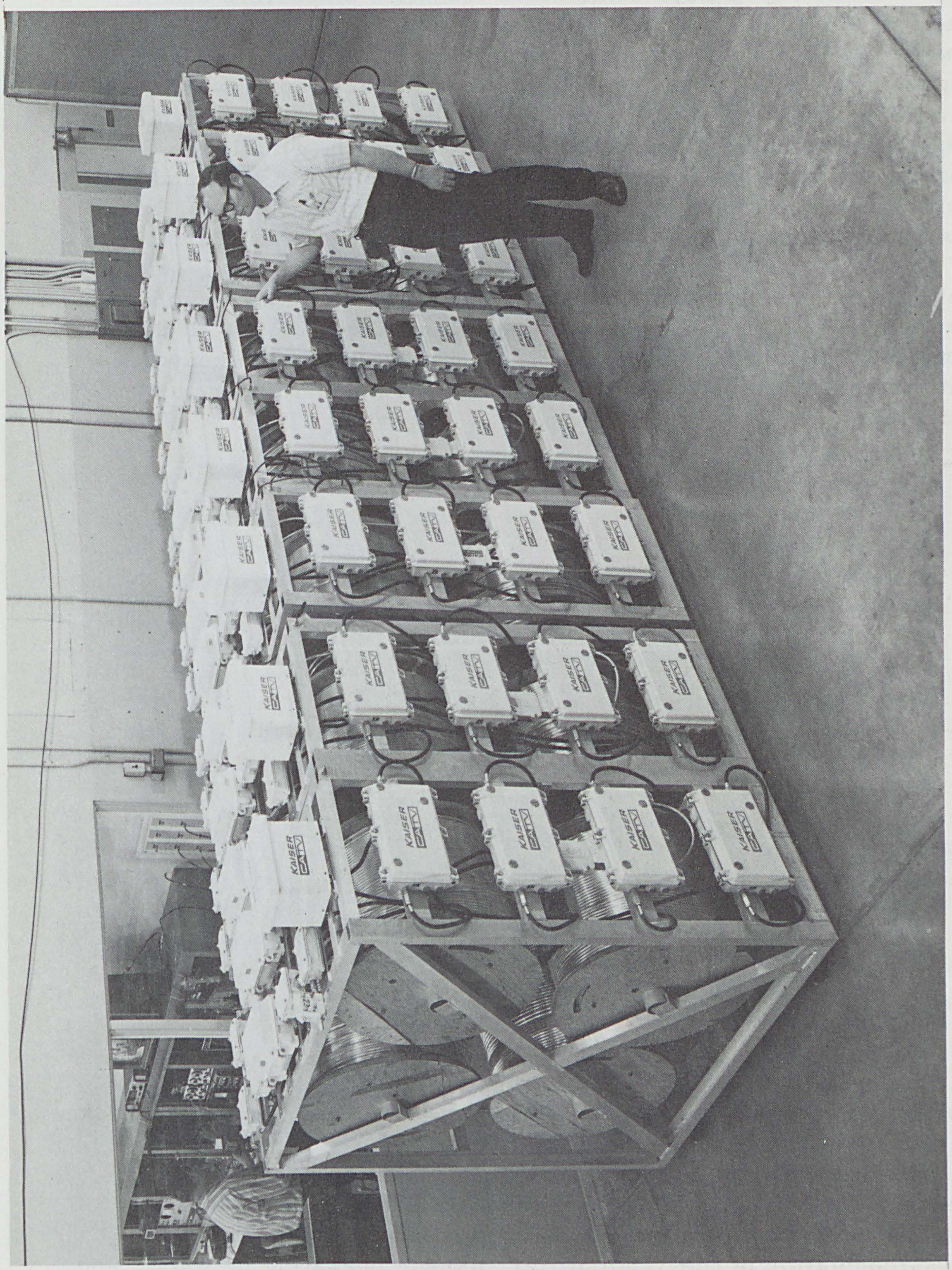

Figure 25. 32 Amplifier Cascade

The cascade shown here contains 32 trunkline amplifiers and 32 reels of 412 cable having the appropriate 20 dB of attenuation at channel 13 between successive amplifiers. The amplifiers shown mounted in the vertical plane are the downstream or forward direction amplifiers employed in these tests. At the top of this cascade are shown upstream or reverse direction amplifiers together with their associated bypass filters. These are used for Subscriber Response System tests, and two-way AML tests, but not for the tests reported herein. Incidentally, this entire cascade of 32 amplifiers and 32 reels of cable is mounted on wheels and is usually rolled into the environmental test chamber which you saw earlier, together with the AML transmitter and receiver so that the composite performance of the AML system operating in conjunction with the amplifier cascade can be measured under temperature extremes.

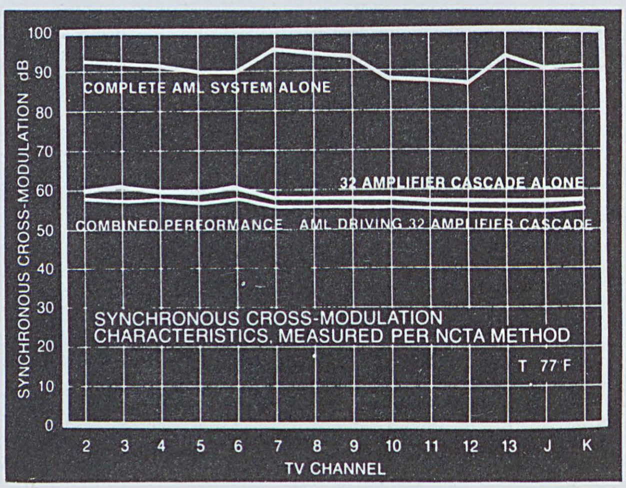

Figure 26. Composite Crossmodulation - AML Plus Amplifier Cascade

Figure 26 shows the results of the first of this series of measurements. The top curve shows the synchronous crossmodulation of the AML system operating by itself, the second curve shows the crossmodulation of the 32 amplifier cascade operating by itself, and the lowest curve shows the combined performance of the AML driving a 32 amplifier cascade. The deterioration is less than 3 dB for all channels because the crossmodulation of the AML is so much better than that of the cascade.

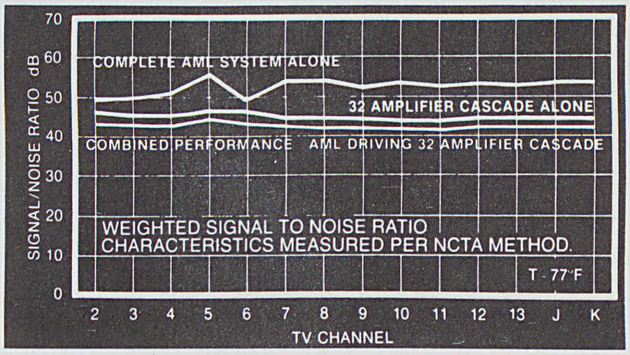

Figure 27. Composite S/N - AML Plus Amplifier Cascade

Figure 27 shows similar curves for signal-to-noise ratio. The top curve shows the signal-to-noise ratio for the AML system by itself, the middle curve shows the signal-to-noise ratio of the cascade by itself, and the bottom curve shows the combined performance of the AML driving a 32 amplifier cascade. In this case, the degradation of the cascade signal-to-noise ratio is also small, in spite of the fact that the differential between the AML system performance and the cascade performance is not quite as large for signal-to-noise as it is for crossmodulation. The reason for this is, of course, that signal-to-noise combinations are made on a power basis whereas crossmodulation combinations are made on a voltage basis. By way of illustration, two signal-to-noise ratios that are equal in magnitude combine for a composite signal-to-noise ratio that is only 3 dB worse, whereas two crossmodulation values that are equal in magnitude can combine to result in a composite performance that is 6 dB worse. Note, however, that the curves which I have shown are all plots of measurements and not of calculations.

The previous two illustrations showed the composite actual performance with a 32 amplifier cascade. The effect of different cascade lengths is shown on Figure 28.

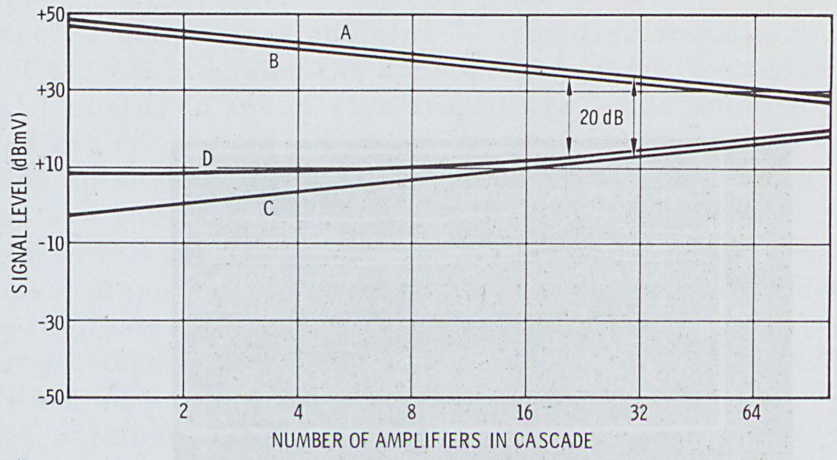

Figure 28. Composite AML Cascading Characteristics

The abscissa on this illustration is the number of amplifiers in the cascade plotted on a logarithmic scale. The vertical axis is signal level in dBmV. Curve "A" is the maximum trunkline amplifier output level for a cascade operating by itself, which cannot be exceeded if the synchronous crossmodulation at the end of the cascade is not to be worse than -57 dB down. Curve "B" is a similar curve for the maximum output level of the trunkline amplifiers in cases where an AML system is connected ahead of the amplifier cascade. The small spacing between Curves "A" and "B" is due to the fact that the crossmodulation of the AML is very much better than that of the amplifier cascade.

Curve "C" is the minimum input level of a cascade of trunkline amplifiers operating by itself which must be exceeded if the signal-to-noise ratio at the end of the cascade is not to be worse than 45 dB. Curve "D" is a similar curve for situations where an AML system is connected in series with the amplifier cascade. In this case the spacing between the curves does not begin to get small until the amplifier cascade gets rather long. This is, of course, the area of interest inasmuch as it is trivially easy to feed a short cascade.

Obviously if the upper sets of curves represent the maximum output level from the amplifiers, and the lower set of curves represents the minimum input level to the amplifiers, then the minimum separation between the upper and lower curves is equal to the gain of the amplifiers. This is in turn equal to the attenuation of the cable connecting successive amplifiers. This spacing is 20 dB at channel 13. The maximum cascade is shown in the illustration for both the cascade operating by itself as well as the cascade operating in series with an AML system. In the former case, the maximum length of the cascade is 31 amplifiers, and in the latter case it is 25 amplifiers. In a manner of speaking, the AML system may then be said to be equivalent to a cascade of 6 amplifiers. This is an over-simplification, however.

The crossmodulation of an AML system is much lower than that of a 6 amplifier cascade.

It should be noted that the reduction in the length of the tolerable cascade with AML does not represent a reduction in the area to be covered. On the contrary, since the AML can easily cover a distance of the order of 20 miles before the cascade even starts, the total distance to be covered with AML is three times as great as without and the total area or the number of subscribers which can be covered with the same quality of signal is nine times as large. Conversely, if the intention is to improve signal quality rather than to expand the system, the total length of amplifier cascades can be vastly reduced and signal quality correspondingly increased.

In conclusion, the AML local distribution multi-channel microwave system is finding increasing acceptance among sophisticated cable operators. Its performance fulfills the most exacting requirements.