TRADEOFFS IN MULTICHANNEL MICROWAVE SYSTEM DESIGN

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ABSTRACT

The recent development of the Hughes AML® Microwave Line Extender block upconversion type multichannel transmitter provides additional options for the CATV system designer. To optimize the overall system, it is necessary to understand both the capabilities and limitations of this new type of AML transmitter. Power output may be traded off against composite triple beat. Secondarily, transmitter gain and noise need be considered with regard to desired triple beat performance. The impact of the microwave subsystem tradeoffs on the overall CATV system must also be taken into consideration since the block upconversion type microwave system is not nearly as "transparent" as the standard AML system. When these factors are properly evaluated, the all solid state, outdoor mounted AML Line Extender transmitter can provide attractive solutions to various CATV system design problems. Several recent implementation examples are described.

INTRODUCTION

Utilization of AML microwave within CATV systems has for many years been an established means of providing the local distribution of a large number of television signals from a central point to a multiplicity of microwave receiver hubs from which the signals are transmitted by cable to the individual subscribers. In such systems, the primary reasons for utilization of the microwave is to achieve better signal quality than would be possible with a long trunk amplifier cascade and to derive the economic benefits associated with the centralization of the headend processing functions. Recent developments have made possible the extension of these benefits to smaller systems and subsystems where utilization of traditional AML transmitters would be uneconomical due to the limited number of subscribers serviced through the microwave path.

The standard AML transmitter separately converts each VHF TV signal to microwave and then provides a passive microwave combining network to minimize distortion and maximize power output. This design is an outgrowth of the severe limitations experienced with the experimental block upconversion 18 GHz AML in the late 1960s. With the recent advent of medium power microwave GaAs FET technology, it has been possible to return to the simpler block upconversion techniques while achieving modest output power and acceptable intermodulation distortion within an outdoor, all solid state, transmitter unit. Applications of such a "Microwave Line Extender" transmitter to CATV system design include the surmounting of a natural barrier such as a river, the repeatering of a microwave path where direct line of sight between the central transmitter and the ultimate receive point is unavailable, the temporary restoration of service during planned outage or rebuild, and the feeding of the microwave signal to small isolated pockets of potential subscribers who cannot be economically serviced by alternative means.

AML TRANSMITTER COMPARISONS

The forerunner of the now familiar CARS band AML microwave system was an experimental 18 GHz AML system which operated within the Teleprompter Manhattan CATV system in the late 1960s.[1] This 12-channel system utilized separate low and high band block upconverters which in turn fed a high power traveling wave tube amplifier at the transmitter output. A block diagram of this transmitter[2] is shown in Figure 1. The high power amplifier had a saturated output capability of 250 watts and had to be liquid cooled to prevent it from overheating. Despite this high saturation power capability, the amplifier had to be backed off to a mere 50 mw (17 dBm) per channel output in order to obtain the desired synchronous crossmodulation performance in this 12-channel system. A consequence of this large backoff was that the C/N was limited at the transmitter to a maximum of 45 dB. A more serious drawback was the maintainability difficulties of the freon cooled TWT. Fortunately, the 1969 FCC decision[3] establishing the CATV local distribution service and allocating it into the 12 GHz CARS band necessitated a complete redesign of the microwave system.

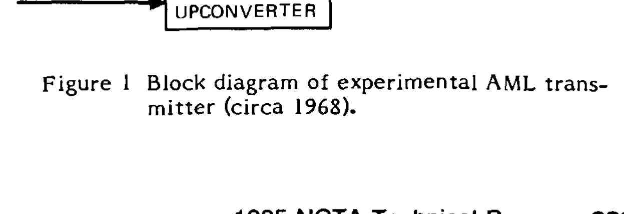

Figure 1 Block diagram of experimental AML transmitter (circa 1968).

With the bittersweet experience of the early 18 GHz AML transmitter in mind, the CARS band AML transmitter design introduced at the 1971 NCTA convention was based on a channelized high level upconverter approach.[4] A block diagram of the original two-bay MTX-132 transmitter, which soon became the industry workhorse, is shown in Figure 2. The individual VHF input signals are separately processed and provided to each upconverter input. A 40-watt klystron feeds up to eight separate parametric upconverters (a fail-soft redundancy feature allows the klystron output to be divided among 16 upconverters) with the required high level microwave "pump" power. Each upconverter incorporates a high Q bandpass filter to select the desired upper sideband mixing product at the upconverter output. The filter performs two additional key functions; it provides approximately 14 dB attenuation of the undesired $2f_{video} - f_{audio}$ third order mixing product which falls in the next adjacent lower channel and it also allows circulator multiplexing of the various channels when channel separation is greater than 10 MHz. "Magic Tees" are then utilized to multiplex adjacent channel circulator strings. As a consequence of the 3 dB hybrid combining, the number of outputs is doubled for each layer of Magic Tee combining. Thus in the 16-channel, two-bay configuration shown, there are four outputs, each carrying all 16 channels. This basic block diagram has remained unchanged as the required number of channels has increased over the years. With four bays, up to 32 channels can be accommodated and eight outputs are provided. The eight-bay configuration offers 64-channel capability at each of 16 outputs.

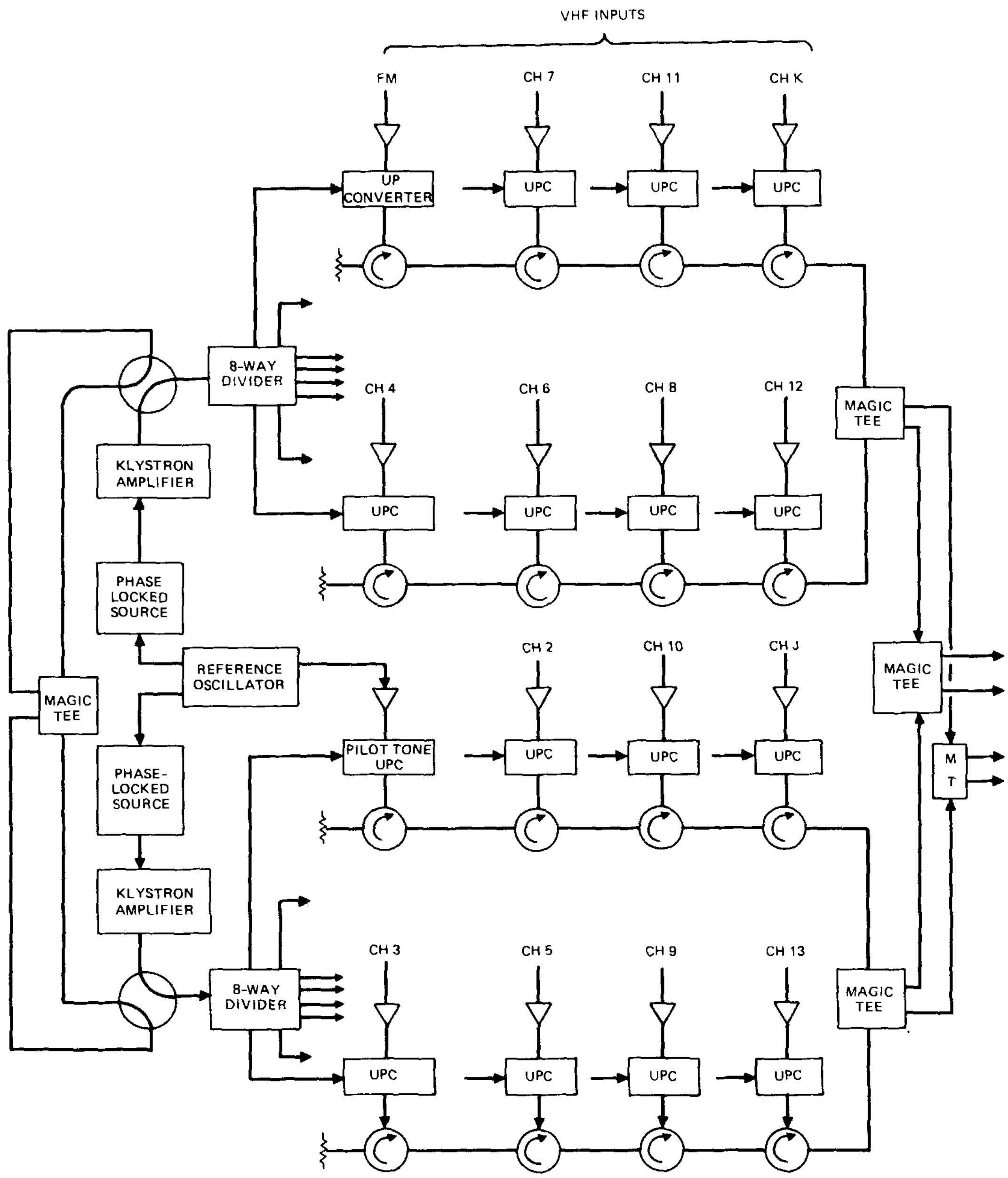

Figure 2 Block diagram of 2-bay MTX-132 channelized transmitter.

Table 1 summarizes the MTX-132 transmitter performance capability. The power output is limited by third order distortion in the upconverter which creates the undesired $2f_v$-f_a beat falling in the lower adjacent channel and the $f_v \pm (f_a - f_c)$ beats which fall in-channel. The specification stipulates that these beats are at least 58 dB down when the audio carrier is 17 dB down and the color subcarrier is 20 dB below the video. Since channel combination is strictly passive, no interchannel beat products are created in the AML MTX-132 transmitter. On the other hand, in both the AML receiver and in the cable system trunk and distribution amplifiers, video/audio and video/audio/color beats are essentially negligible because these broadband units must be designed to handle the much higher level multichannel video beats. Thus in designing the overall CATV system, there is nothing to tradeoff with respect to the transmitter output. The only microwave system tradeoff arises from the AML receiver which is specified to provide an 81 dB, 54-channel composite triple beat for a C/N of 53 dB. By changing the receiver AGC setpoint, the normal two for one trade between C/N and C/CTB can be made.

As the number of channels gets larger, both the size and cost of the MTX-132 transmitter necessarily increases. The number of available outputs may also be well in excess of the number of receive sites which are to be implemented. Clearly, for applications involving only one or two outputs and where cost is all important, the channelized transmitter approach for a very large number of channels is no longer an optimum solution. What if one returns to the simpler block upconversion approach? Fortunately, because of recent developments in medium power GaAs FETs, output levels which are usable for moderate path length microwave applications can be obtained provided antenna waveguide run losses are kept to a minimum. Table 2 summarizes the OLE-111 AML Microwave Line Extender output for a composite triple beat specification of 65 dB. Comparing this to Table 1, one sees a difference of up to 18 dB between the OLE-111 single output and any one of the multiple outputs from the MTX-132. Even if one were to allow a 4 dB waveguide loss advantage for the outdoor mountable OLE-111 transmitter, the power difference is still a husky 14 dB. Furthermore, a 65 dB composite triple beat might appear

TABLE 1

MTX-132 AML TRANSMITTER PERFORMANCE SUMMARY

No. of Channels	No. of Racks	No. of Outputs	Power Output* (dBm)
8	1	2	+16
16	2	4	+13
24	3	4	+12
32	4	8	+10
40	5	8	+9
48	6	16	+7
56	7	16	+7
64	8	16	+7

*For on-channel and adjacent-channel beats down 58 dB with audio -17 dB and color -20 dB below video.

TABLE 2

OLE-111 AML TRANSMITTER POWER OUTPUT - "TRANSPARENT" CTB OPERATION*

No. of Channels	Power Output (dBm)
12	-3
24	-6
35	-8
54	-10
60	-11

*"Transparent" operation defined as 65 dB composite triple beat (CTB) measured with CW carriers. Power output would be 4 to 6 dB greater if specification were given for modulated carriers.

to eat substantially into the NCTA recommended[5] CATV system CW CTB goal of 53 dB. Fortunately, this is not the case since power addition of the microwave FET amplifier generated CTB, rather than voltage addition with the CTB generated in the remainder of the cable system, can be anticipated. More about this later. If, then, one accepts that power addition will apply, the OLE-111 would contribute only 1/4 dB to the overall system CTB and can be considered as essentially transparent just like the MTX-132 transmitter. Nevertheless, the block upconverter type OLE-111 transmitter is clearly not even in the same performance ballpark as the channelized MTX-132 transmitter.

OLE-111 TRANSMITTER DESCRIPTION

The above related performance limitations exist despite the fact that the OLE-111 transmitter utilizes a state-of-the-art two-watt FET power amplifier. As shown in Figure 3, this output stage is preceded by a driver amplifier. Just as the power amplifier determines the transmitter CTB, the low noise driver amplifier in conjunction with the manually adjustable microwave gain determines the transmitter output noise level. The broadband microwave signal is generated in the mixer which combines the input VHF with a high level local oscillator. The upper sideband is selected by the image reject filter while the notch filter provides additional rejection of the local oscillator leakage. All of the microwave components benefit from the tightly controlled temperature environment provided by the field-proven (in the AML receiver) gravity gradient freon thermal control system. The constant temperature keeps the amplifier gains, and hence both output power and CTB constant. The temperature control also keeps the notch filter from detuning, thereby ensuring compliance with the FCC spurious emission requirements throughout the full -40°F to +120°F outdoor temperature range.

The VHF input sections of the AML Microwave Line Extender consist of totally passive components which provide for insertion of an internally generated 74 MHz pilot signal which is required when the AML phaselock receiver is utilized in the microwave link. Independent VHF level adjust attenuators are provided to set both signal and pilot tone to the desired microwave output levels. A built-in calibrated transmit monitor provides a

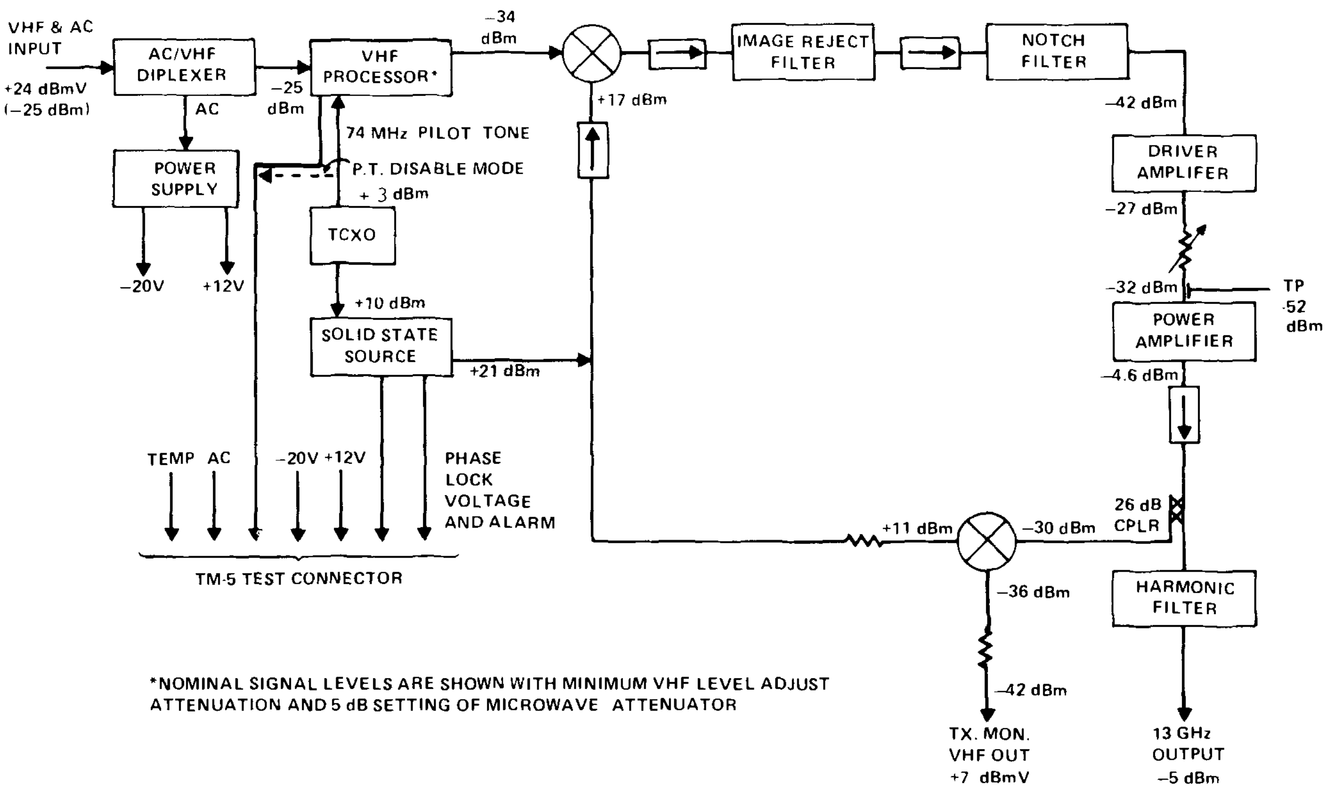

Figure 3 AML OLE-111 block diagram.

convenient test point at VHF frequency which can be used to check the transmitter power output external to the transmitter enclosure. A multipin test connector is also brought to the outside of the transmitter to enable routine maintenance monitoring of various voltages just as in the familiar outdoor AML receiver. However, a different test connector, which also allows monitoring of the temperature controlled crystal oscillator (TCXO) frequency, is utilized. This facilitates the once-a-year frequency measurement mandated by the FCC for microwave transmitters.

The OLE-111 transmitter is cable powered from 30 or 60 volts. A ferroresonant transformer and dc regulators convert this input to the desired internal operating voltages. The ac/VHF diplexer which separates the input ac and VHF is identical to that used in the outdoor AML receiver as also is the transmitter enclosure.

OLE-111 PERFORMANCE TRADEOFFS

If the OLE-111 were to be operated at the power levels summarized in Table 2, the microwave path length would be severely restricted, particularly for a large number of channels. For instance, using 10-foot antennas, the receiver input for a 54-channel application at a range of five miles is barely -47 dBm so that a standard 53 dB C/N cannot be maintained. However, since the path is short, microwave system availability to the commonly accepted 35 dB C/N level would still be excellent for average rainfall areas.

To improve the range capability of the block upconversion type transmitter, one can trade off CTB for power output. Just as with CATV amplifiers, a normal two for one tradeoff exists. This is illustrated by Figure 4. Note that all CTB performances are specified with CW carriers just as for CATV amplifiers. If the specification were in terms of modulated carriers, either the CTB would appear to be an 8 to 12 dB better number, or the power output would be 4 to 6 dB higher (5, 6, 7) but the actual transmitter performance would clearly not be thereby improved. In any case, increasing the transmitter power output will mean that it is no longer "transparent" if the 53 dB system CW CTB is required.

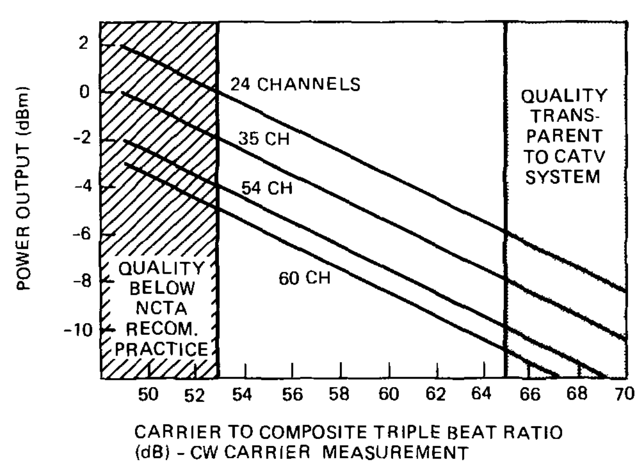

Figure 4 2 for 1 tradeoff of C/CTB for power output in OLE-111 block upconversion transmitter.

A second performance tradeoff involves transmitter gain and noise output. The maximum transmitter gain is specified to be a minimum of 20 dB. For instance, if -10 dBm output is desired, a -30 dBm (+19 dBmV) input will guarantee that this output can be obtained. However, with maximum microwave gain the noise output would typically be -60.5 dBm in a 4-MHz bandwidth and thus the C/N at the transmitter would be 50.5 dB. By setting the microwave interstage attenuator to 8 dB, the noise output is reduced to -66.5 dBm (noise from the power amplifier now contributes non-negligibly to the total noise output) and the transmitter C/N is improved to 56.5 dB for the same -10 dBm output. The VHF input may now have to be +27 dBmV to ensure this output. In either case, the transmitter noise power adds to the receiver noise as shown in Figure 5. The microwave system C/N is least affected by transmitter noise during deep fades since the transmitter noise is attenuated along with the signal.

As the microwave gain is decreased and the output maintained constant, the contribution of the mixer and the driver amplifier to CTB becomes evident as shown in Figure 6. The interesting phenomenon illustrated by this performance is that the curve is in almost perfect agreement with a calculation of CTB based on power addition. It had been assumed that the mixer, being an essentially different type of device than the FET amplifiers would power add its CTB contribution, but if the FET driver CTB had voltage added to the FET power amplifier CTB as expected, the transmitter CTB degradation at 10 dB interstage attenuator setting would have been a readily measurable 3.2 dB instead of 1.2 dB. A possible explanation is that the relative phase of the third order distortion products is randomly different when created in the power amplifier as compared to the mixer and driver amplifier combination. In any case, since CATV system VHF amplifiers are substantially different from microwave FET amplifiers, a realistic approach to system design should assume power addition of the CTB created at microwave to the CTB created at VHF. A further verification of this assumption has been provided by a laboratory experiment in which the CTB of the Microwave Line Extender was observed to power add, rather than voltage add, to the CTB of the AML receiver.

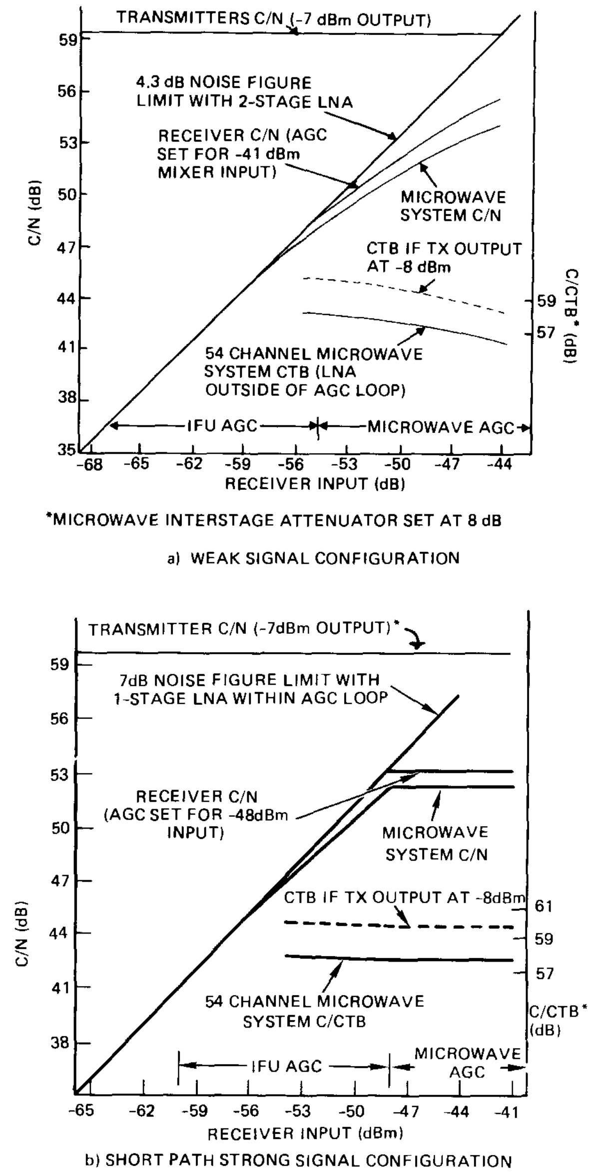

Figure 5 Microwave OLE-111 system C/N and C/CTB vs. receiver input (path fade).

SYSTEM APPLICATIONS

The Microwave Line Extender may be used in a variety of applications involving different types of situations. One such recent application which typifies the surmounting of natural obstacles was for a 6.6 mile path across Monterey Bay. The system carries 35 channels and can provide very high quality pictures because the CATV trunk cascade is only three amplifiers long as shown in Figure 7.

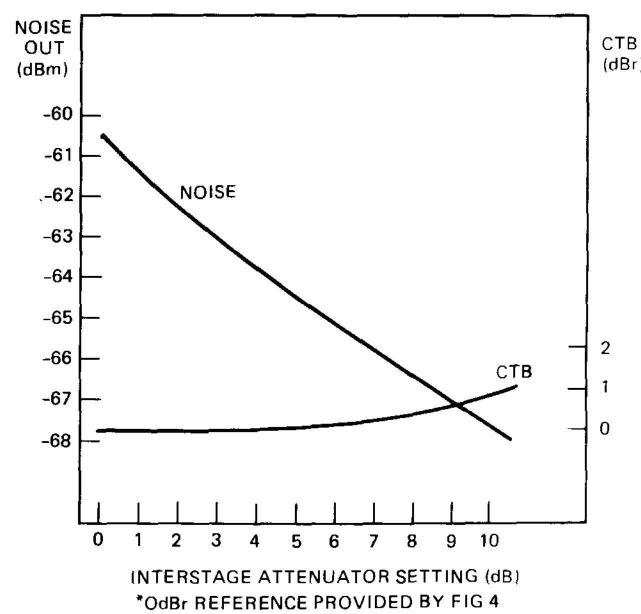

Figure 6 Noise and CTB vs. microwave gain (RF attenuator) at fixed output.

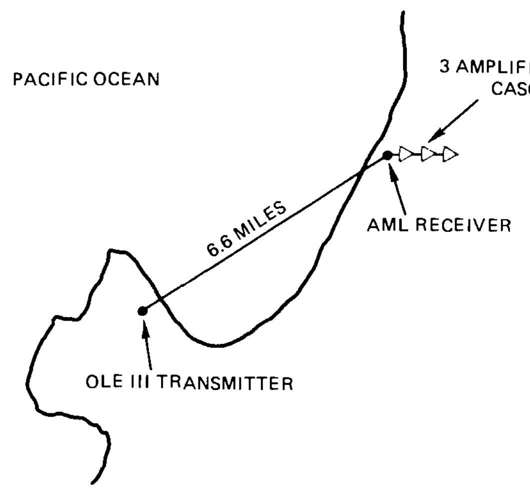

Figure 7 OLE-111 application across Monterey Bay.

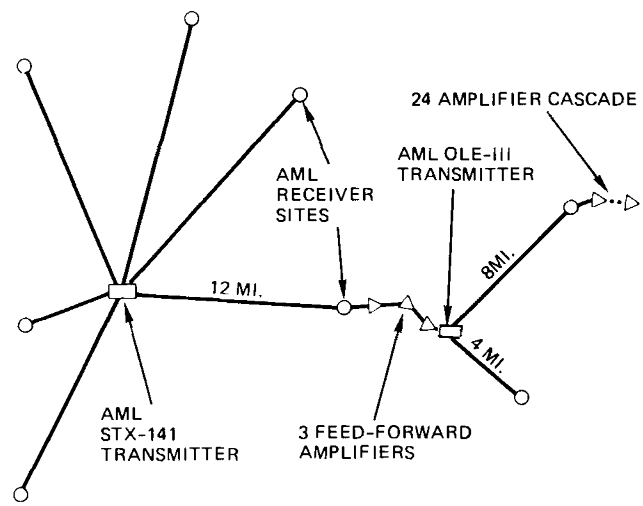

Figure 8 OLE-111 microwave repeater application in Oklahoma.

A second type of application is one involving repeatering of a microwave signal where the original AML transmitter does not have a direct line of sight to the ultimate receive point. An example is provided by a system in central Oklahoma. One of the receiver sites of a STX-141 microwave network feeds three feed forward trunk amplifiers carrying 21 channels. At this point, the cable is connected to the AML OLE-111 input. The Microwave Line Extender output is split by a 6 dB coupler which feeds paths of eight and four miles. As shown in Figure 8, at the receive point of the eight-mile path, the signals feed into a trunk amplifier cascade which is 24 amplifiers deep.

A third type of application involves the utilization of the OLE-111 as a frequency agile transmitter providing an emergency backup for a large channelized AML transmitter. In a not yet installed major urban application, the Microwave Line Extender provides backup for any one of 48 STX-141 channels being fed to four different receive sites. In single-channel applications, the high third order intercept point of the OLE-111 allows an output of +18 dBm while maintaining a 58 dB $2f_v-f_a$ intermodulation ratio. Unlike the situation which prevails with channelized transmitters, this intermodulation product cannot be suppressed with a filter in the broadband OLE-111. For the STX-141 backup application, the +18 dBm output is somewhat mismatched to the +23 dBm available from the STX-141 at this level of multiplex combining. A more optimum OLE-111 operating level for this case is +20 dBm which will result in 57 dB C/I in the channel just below that which is temporarily assigned to the OLE-111. Intermodulation in the OLE-111 channel resulting from products generated by the adjacent STX-141 channels will be better than 55 dB. The OLE-111 output capability is generally better matched to the MTX-132 channel module than to the high power STX-141. Figure 9 shows how the OLE-111 might be multiplexed into the 54-channel MTX-132 transmitter. Note that if the OLE-111 were to share a circulator combining string with other channel modules, it could neither provide backup to any such channels nor to the next adjacent frequency channels.

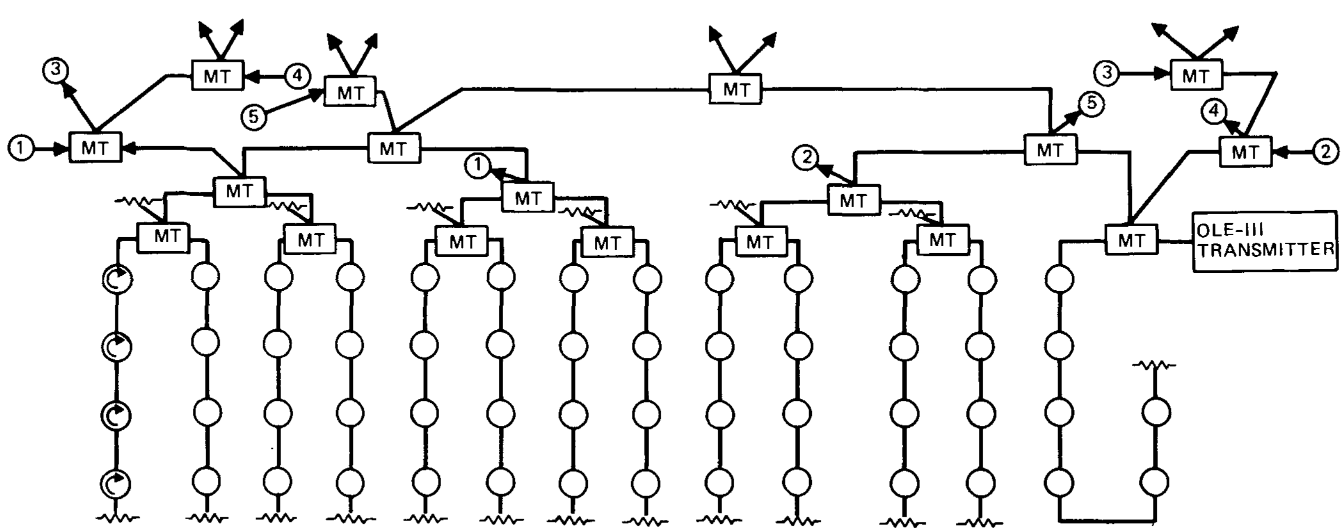

Figure 9 OLE-111 transmitter as frequency agile backup to 54-channel MTX-132 transmitter.

SUMMARY

A question which is often asked about the OLE-111 is: How far will it go? The answer, as we have seen, depends on a number of factors. The most important of these factors includes the number of channels and the signal quality expected at the end of the microwave link. This, in turn, will depend on the performance capability of the cable plant and on the required "last subscriber" picture quality. The largest acceptable antenna size will also play a key part in resolving the question. Once the major parameters are determined, the system can be optimized by trading power for CTB at the transmitter. If sufficient VHF input is available, microwave gain is reduced for best transmitter C/N. Selection of the receiver configuration usually dictates an LNA outside of the AGC loop for lowest possible noise figure. The receiver AGC threshold is then selected for further system optimization. Conservative CTB calculations are based on voltage addition of contributing VHF elements, including the AML receiver's mixer-amplifier followed by power addition to the voltage-added microwave distortion of the OLE-111 and the LNA preceding the receiver.

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