ADVANCES IN AML TRANSMITTER AND RECEIVER TECHNOLOGY

R. T. Hsu, T. M. Straus, and J. L. Wrona

Hughes Aircraft Company
Microwave Products Division
Torrance, CA 90509

ABSTRACT

New technologies have recently led to a substantially wider choice of both transmitters and receivers that can be utilized in local distribution microwave CATV systems. One area of particular interest to smaller CATV systems involves the increased power available from low cost multichannel block upconverter type transmitters. The highest output power with this type of transmitter is now made possible by the development of a microwave feedforward amplifier, which provides up to 10 dB improvement relative to the standard AML® Microwave Line Extender transmitter. At the other end of the application scale, the continued expansion of the number of channels carried by CATV systems in major markets has led to the expansion of AML capability to 550 MHz. In addition to incorporating the latest low noise VHF hybrids to fulfill this need in AML receivers, circuit modifications, which include a built-in microwave LNA and VHF AGC, have led to significant improvements in distortion performance without sacrificing system C/N. Design criteria are provided to guide the proper application of these new microwave components in CATV systems.

INTRODUCTION

The first application of AML microwave to provide local distribution of multiple television signals in the 12 GHz band was in 1971.[1] The transmitter consisted of a 2-bay MTX-132, with 16 channelized high level upconverters and passive multiplexing of 14 TV channels, an FM broadcast band channel, and a pilot tone. The receiver was phaselocked to the pilot tone[2] and utilized a ferrite attenuator to provide a microwave AGC, which maintained a constant carrier-to-noise ratio (C/N) and synchronous cross-modulation distortion performance for input signals above the AGC threshold. The outdoor mountable receiver housing was temperature controlled through the use of a gravity-gradient cooling system,[3] which maintained the internal temperature constant over a wide range of external ambient conditions.

Over the years, significant changes were made in both the transmitter and receiver to enlarge the system capacity to 60 channels. Although improvements in receiver noise figure, including the introduction of microwave low noise amplifiers (LNAs),[4] compensated to some extent for the increased multiplexing losses associated with the increase in channels, the application of AML to longer path distances led to the wide use of the channelized STX-141 high power AML transmitter first introduced in 1974. More recently, a much lower power block upconversion type transmitter, referred to as the Microwave Line Extender,[5] was developed to meet the needs of smaller CATV systems, in which isolated pockets of potential subscribers could not otherwise be economically serviced.

The inherent differences between the channelized and block conversion transmitters led to a large 18 dB performance gap between the MTX-132 and the Line Extender transmitter. Recent developments that substantially narrow this gap are described in the following section. These improvements in the block conversion type transmitter, while leaving the inherent multiple output advantage of the channelized transmitter unchallenged, can lead to respectable path length capability and wider applicability of the block conversion approach.

The second section of the paper deals with the new approaches employed in the 550 MHz system. Traditionally, AML systems have generally incorporated an Interface Unit (IFU) between the receiver output and the trunk cable. This unit, originally developed in 1973, serves a number of purposes. Key among these functions is the provision of an IF AGC to optimize total cable system C/N during microwave fades and a trap for the 74 MHz AML pilot tone. These functions are now incorporated in the 550 MHz receiver. But most importantly, the new design leads to substantial improvement in the distortion performance of the overall receiver. This is particularly of interest in CATV systems carrying 80 channels, but could also be an important factor when fewer channels are carried.

The final section of the paper provides a typical example that may serve as a guide to proper application of these more recent AML transmitters and receivers.

ALTERNATIVES FOR HIGHER POWER BLOCK CONVERSION TRANSMITTERS

The key to the performance of the block upconversion transmitter is its high power output FET microwave amplifier. The problem is essentially the same as with CATV hybrid amplifiers. Thus, one obvious solution is power doubling. The output amplifier in the AML Microwave Line Extender utilizes this technique. Two 1-watt FET stages are paralleled, and the outputs are combined in the internal microstrip circuit of the 2-watt amplifier. Could such power doubling be extended to 4 or even 8 branches? In principle, the answer is yes; but there are some important drawbacks. Aside from the added cost and power dissipation, the technique is limited by the losses associated with the microstrip combiner. Moreover, the FET stage gain is quite low (5 to 6 dB) for high power K_u-band FETs. Thus, if the driver stage is to avoid becoming the limiting distortion generator, it also must be doubled. Thus, circuit complexity multiplies even as the microstrip combining losses eat up a substantial portion of benefits obtainable from power doubling.

If power doubling is not as attractive as it might otherwise seem, what about utilizing higher power FETs? To some extent, this option suffers the same drawbacks as power doubling. This is due to the approach taken by the transistor manufacturer in obtaining the higher power capability. Internal to the packaged FET, in essence the same power doubling techniques are employed, although on a much more intimate scale. Combining losses are therefore somewhat less. Figure 1 shows a photograph of an internally matched 4-watt IMFET 1-1/4 inch wide package, in which two high power FETs are paralleled. Note the FET that has been placed on top of the package (near the letter H) to illustrate the relative size. Such FETs employ many parallel gate fingers, which serve to increase the power handling capability of the device. A key design consideration of a high power FET is thermal impedance, which largely determines the operating temperature of the FET gate channel. For long life ($>10^6$ hours), the channel temperature must be less than 120°C. The reliability deteriorates exponentially with temperature, so care must be taken throughout the transmitter design to provide for adequate cooling. An appreciation of the problem may be gained by recognizing that for each transistor die, approximately 6 watts are being dissipated in an active area smaller than 0.4 sq. mm. Nevertheless, the present state-of-the-art high power FET technology has shown itself capable of providing 5 to 6 dB more output power than the devices utilized in the standard AML Line Extender.

In contrast to the somewhat brute force techniques described above for increasing the available transmit power, a more subtle approach is to improve the transmitter linearity. This option results in greater available power without increasing the saturated output power capability, since less backoff is required for acceptable distortion performance. Both predistortion and feedforward techniques have been investigated. The results obtained with the former approach were no better than those obtainable with high power FETs. On the other hand, feedforward is not only well known by the CATV industry, albeit at VHF frequencies, but also proved to be by far the most attractive in terms of its performance capability.

Figure 1 Ku-Band FET chip with 4-watt IMFET package.

Figure 2 shows the block diagram of the microwave feedforward amplifier. The input signal is split by directional coupler C1 into two paths. The top path passes through main amplifier modules A1 and A2. Amplifier A2 is identical to the output amplifier used in the standard AML OLE-111 transmitter. Part of the amplified signal, along with the distortion generated by A2, is sampled by directional coupler C2. By adjusting attenuator R1 and phase shifter P1 for minimum power at test point TP, leakage of signal into distortion amplifiers A3 and A4 is suppressed by at least 20 dB. Therefore, amplifier A4 need only have half the output capability of A2 while still performing its amplification function without introducing any of its own distortion. Attenuator R2 and phase shifter P2 are adjusted to cancel out the distortion in the main signal path and therefore optimize C/CTB at the output.

The feedforward circuit is constructed in order to match the absolute delays encountered in the main and distortion amplifiers, respectively, by the delays T_1 and T_2. These are implemented in waveguide in order to minimize loss that would otherwise be excessive at these high frequencies. Although the resulting circuit, shown in Figure 3, is somewhat cumbersome, it was possible to package it within the temperature controlled AML outdoor housing. This is vitally important, since at these frequencies, the feedforward circuit is particularly sensitive to change in temperature. Other lower frequency microwave feedforward investigations have been reported,(6,7,8) but to our knowledge, the present application is the first at K_u-band. The availability of the temperature-controlled AML outdoor housing provides the key element, which makes this feedforward amplifier a practical part of an LDS microwave system.

Table I summarizes the performance parameters of the amplifier. When compared to the standard AML Microwave Line Extender, the power output capability of the feedforward amplifier is approximately 10 dB greater, even though the identical FET amplifier is used in both units. Indeed, in the feedforward unit, an additional 2 dB insertion loss follows amplifier A2 so that distortion

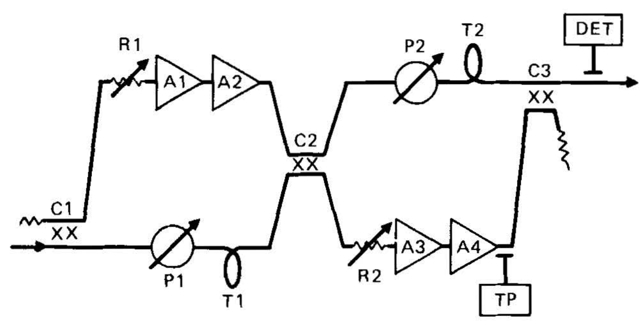


Figure 2 Microwave feedforward block diagram.

a new transmit monitor design was utilized to extend the range up to the full 550 MHz. This last was an outgrowth of the new 550 MHz receiver.

Figure 5 shows a block diagram of the 550 MHz indoor phaselock receiver. It differs from previous AML receivers in a number of key parameters summarized by Table II. Aside from the obvious extension to 550 MHz, the most significant change is the inclusion of a VHF AGC in addition to the standard microwave AGC. The VHF AGC, which also operates off the pilot tone level, provides a minimum of 12 dB additional AGC control if the receiver input signal drops below the microwave AGC threshold. The 74 MHz AML pilot signal is trapped out at the receiver output. As with previous receivers, the microwave AGC threshold is adjustable, but is normally factory set for 53 dB C/N. Since at minimum VHF gain the noise figure is 8 dB, this corresponds to -47 dBm receiver input. The noise figure improves to 7.3 dB as the PIN attenuation in the VHF AGC module decreases as would happen in a deep microwave fade. This noise figure is established by the combination of 1 dB input attenuation, a nominal 3.5 dB noise figure of the LNA, and 5 dB noise figure of the VHF preamplifier following the combined 6 dB filter plus mixer conversion loss. Although lower overall noise figure is possible by putting the LNA outside the AGC loop or by use of a 2-stage LNA, the receiver sensitivity improvement is generally not worth the impact on second and third order distortion performance. Exceptions may occur when the maximum received signal is low or if distortion is in any case limited by a block converter type microwave transmitter. Note that when calculating the maximum expected signal level, the so-called "field factor" should not be utilized. Note also that the maximum input level can be influenced by so-called multipath up-fades that can occur on some paths.

TABLE II

AML RECEIVER CHANGES

54 to 550 MHz output frequency range
Built-in VHF AGC and pilot-carrier trap
Standard 1-stage LNA in microwave AGC loop
Nominal +21 dBmV output level
8 dB NF at microwave AGC threshold (7.3 dB at small signal)
80 channel C/CTB 80 dB
2nd order beat -82 dBc
Phase-lock in indoor rack-mount configuration
AGC and phase lock disable switches for troubleshooting

Figure 6 shows C/N, 80-channel C/CTB, and second order beat performance as a function of received signal level for four different 550 MHz receiver configurations. The mixer is the largest contributor to both second and third order distortion. Therefore, the microwave AGC is in all cases essential to satisfactory performance at higher input level. When the LNA is outside the AGC

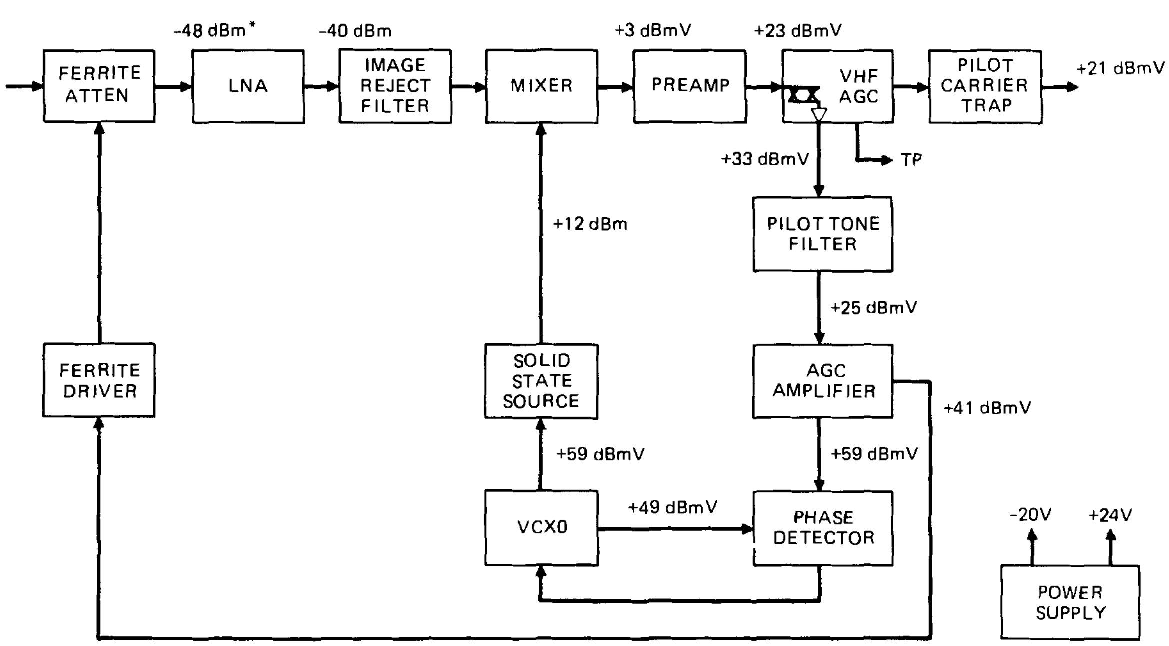


Figure 5 550 MHz receiver block diagram.

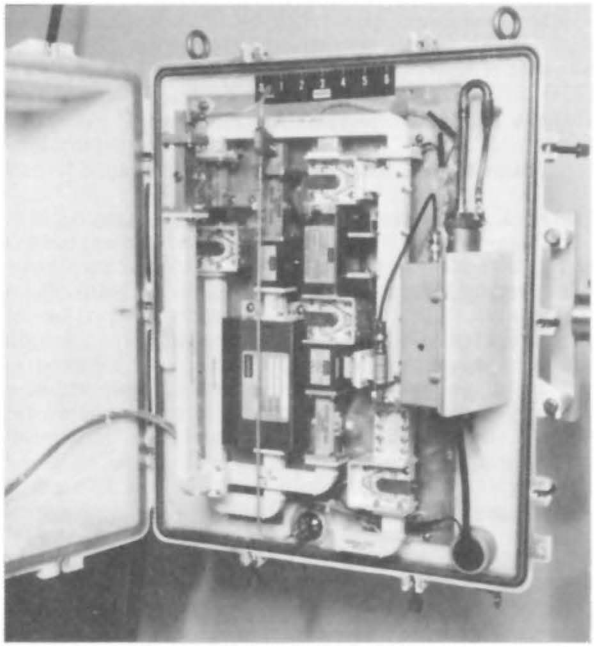


Figure 3 Microwave feedforward implementation.

cancellation in the output loop is on the order of 24 dB. Because of its relatively narrow percentage bandwidth, the constant temperature provided by the AML housing, and also because it would typically not be employed in long cascades, the microwave feedforward amplifier does not suffer some of the limitations pointed out by Preschutti[9] for CATV feedforward units. However, just as with VHF amplifiers, the C/CTB degrades somewhat faster than 2 for 1 as the total power in the amplifier is increased. The typical degradation is 3 for 1 with increased power so that, for instance, a C/CTB of 53 has been measured for 30 channels each at 8 dBm. The power

TABLE I

FEEDFORWARD AMPLIFIER PERFORMANCE SUMMARY

Frequency Range	12.7 -13.2 GHz
Nominal Gain	20 dB
Noise Figure	15 dB
Power Output/Channel at 65 dB C/CTB	
No. of Channels	Po (dBm)
12	+7
21	+5
35	+2
60	-1

out versus input transfer function approaches that of an ideal limiter, so even at +29 dBm output, a single channel VSBAM TV signal appears essentially free of distortion. This last point has implications with regard to the potential utilization of the feedforward amplifier as a frequency agile backup to substitute for any failed channel in a high power AML STX-141 transmitter array.

Figure 4 summarizes the relative output capabilities of multichannel AML transmitters now that the gap between the channelized MTX-132 and the block conversion OLE-111 is somewhat filled in. Note that the comparison is for "transparent" 65 dB C/CTB operation of the lower powered units compared to a single output of the MTX-132 and STX-141. These latter automatically provide increasing numbers of multiple outputs as the increased number of channels leads to a greater multiplexing complexity. However, as the number of outputs increases, the per channel level at each output decreases. In the block conversion type amplifiers, the per channel power output drops to maintain required C/CTB for an increased number of channels. The reasons are different, but the results of increased channel loading on per channel power output capability are essentially the same, so the comparison made in Figure 4 holds over a wide range of channel loading.

550 MHz AML

The multiple output capability of the MTX-132 transmitter is well illustrated by the 16 outputs provided with the recent expansion to 80 channel loading. Each output is rated at +6 dBm per channel. Achieving this power, following transmitter multiplexing losses, required that the high level upconverter be redesigned for operation up to 550 MHz input. The design modification involved extensive change to the upconverter VHF input circuitry, but the operating principle remains unchanged from lower frequency modules. The transmitter VHF driver amplifiers also required complete redesign to operate with required linearity at the higher output power necessitated by reduced gain in the upconverter. Finally,

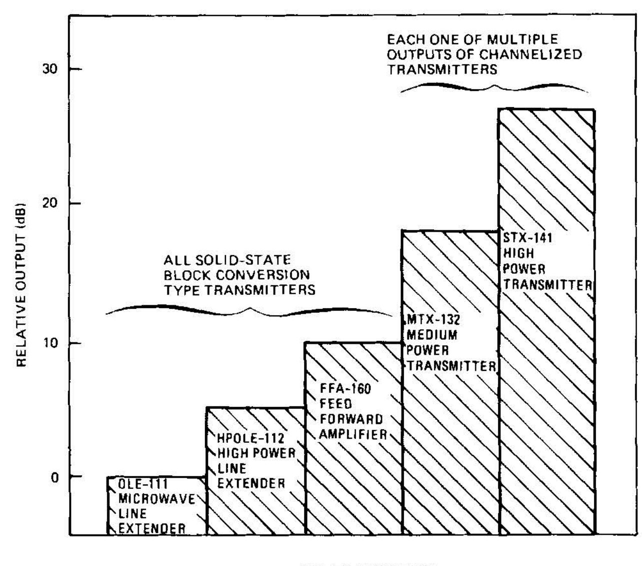
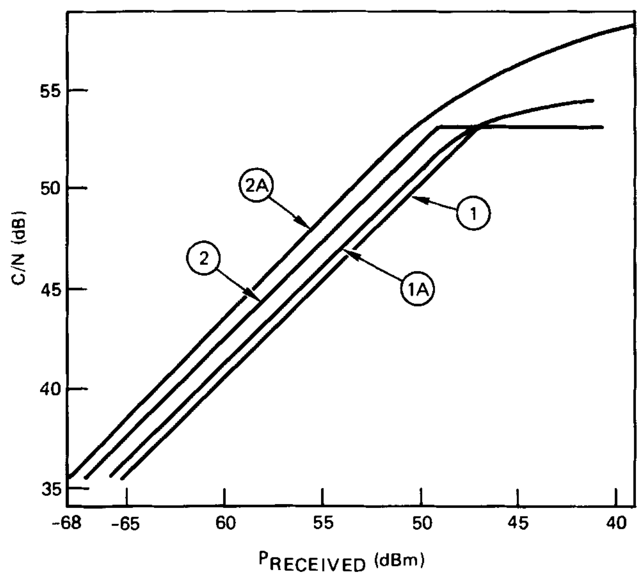
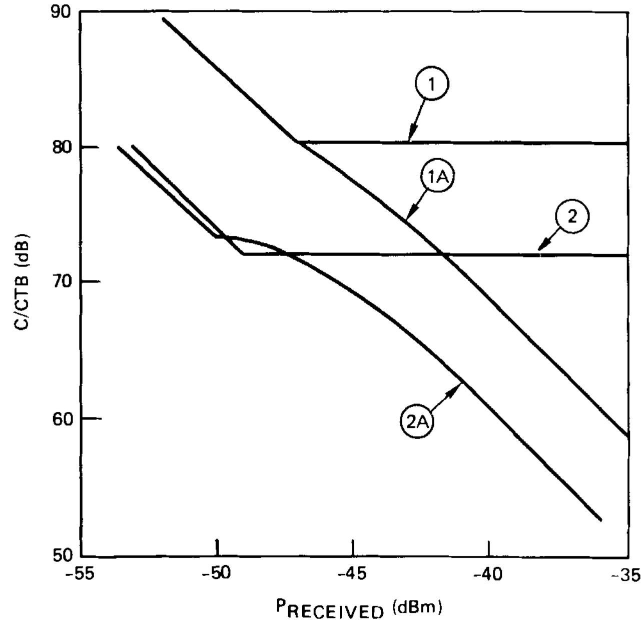


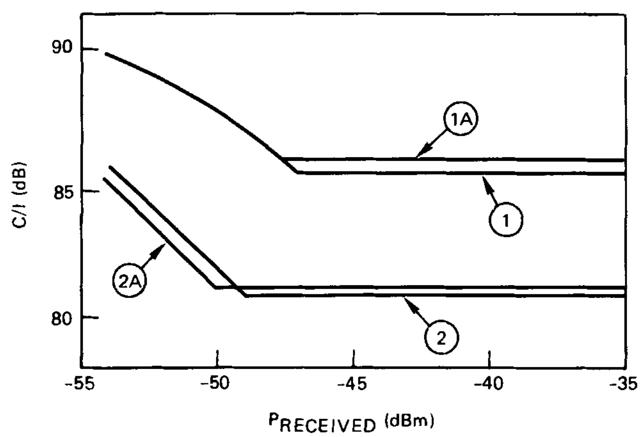
Figure 4 Relative output capability of AML transmitters.



a) CARRIER TO NOISE RATIO



b) COMPOSITE TRIPLE BEAT



c) 2ND-ORDER BEATS

(1) SINGLE STAGE LNA IN AGC

(1A) SINGLE STAGE LNA OUTSIDE AGC

(2) DUAL STAGE LNA IN AGC

(2A) DUAL STAGE LNA OUTSIDE AGC

Figure 6 80-channel performance of various 550 MHz receiver configurations.

loop, the shape of the C/N and C/CTB curves is influenced by the choice of microwave AGC threshold. For the 2-stage LNA, the threshold was selected to yield 56 dB C/N at -45 dBm input; while for the single-stage LNA outside the loop, the illustration shows 53 dB C/N at -47 dBm input. If the LNA is inside the AGC loop, the tradeoff between C/CTB and C/N is a straightforward 2 for 1 function of the AGC set point.

Figure 7 shows the indoor 550 MHz phaselock receiver as it normally appears and with the front panel dropped to provide access to the phase detector balance adjustment. The receiver is designed to facilitate maintenance by making all controls accessible through either the front or back panels. To further aid in troubleshooting, AGC and phaselock disable switches are provided. The latter automatically sets the VCXO to a free-run mode.

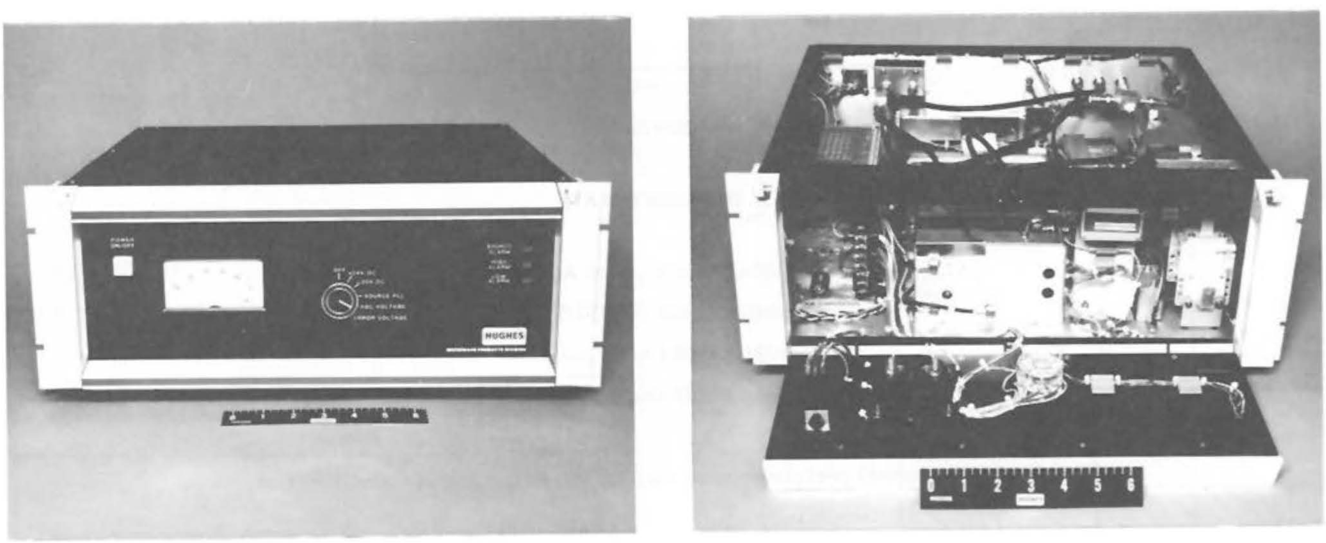
The main features of the indoor 550 MHz receiver are designed into the outdoor receiver retrofit kit, which permits upgrading of existing phaselock receivers. In particular, the VHF preamp and AGC modules and LNA are incorporated. One change not required by the indoor unit is the AC/VHF diplexer which had to be completely redesigned to accommodate 550 MHz. Insertion loss of this module is less than 0.2 dB and return loss better than 20 dB.

APPLICATION CONSIDERATIONS

Figure 8 shows how the feedforward amplifier is typically used in tandem with the Microwave Line Extender. In establishing the desired operating levels, the first question to ask might be what level of C/CTB is acceptable, since block conversion transmitter output levels are generally limited by this parameter. If the microwave feedforward amplifier is to be the primary contributor to C/CTB, the OLE-111 must be backed off from its normal output level. The difference in level between the feedforward input and OLE-111 output represents the permissible loss that might take the form of a long waveguide run if the FFA-160 is to be tower mounted to achieve the greatest possible path length. With this allowance, the OLE-111 might still be at the base of the tower, where maintenance should be much easier. In any case, the next concern is to reduce the noise power output of the OLE-111, since its output level is quite low. By setting the interstage attenuator between the LNA and 2-watt amplifier to 14 dB, the primary source of noise is then the 2-watt amplifier. Finally, one must check to see whether third order distortion generated by the LNA and by the upconversion mixer, as well as second order distortion of the mixer, are still acceptable. Since a high power local oscillator is utilized in the OLE-111, mixer distortion is minimized. The LNA is also designed with distortion in mind - having a 3 IM intercept point of +27 dBm. The noise and distortion contribution of each stage is shown in Figure 8 assuming 40-channel loading. The overall transmitter performance is also summarized. If the LNA is replaced with a piece of waveguide and the interstage attenuator reset to 0 dB, a further 1 dB improvement in transmitted C/N is possible.

Note that power addition, rather than voltage addition, is applied to C/CTB. This is because each contributing stage is different from the others, resulting in a randomness of the relative phases of the intermodulation products. The necessity to back off the driver stage and the concomitant concern with C/N is a feature common to all post-amplifier installations, not just when the post amplifier is of the microwave feedforward variety. However, if the post amplifier is a standard power amplifier, the intermodulation distortion from the intermediate power amplifier may more likely add in-phase with that of the output amplifier, since their characteristics are very similar.

Consider next an application involving a 13-mile path with 10 foot antennas at both receive and transmit ends. Even with only 0.3 dB waveguide loss



a) FRONT PANEL

b) INTERNAL CONFIGURATION

Figure 7 Indoor 550 MHz phase-lock receiver.

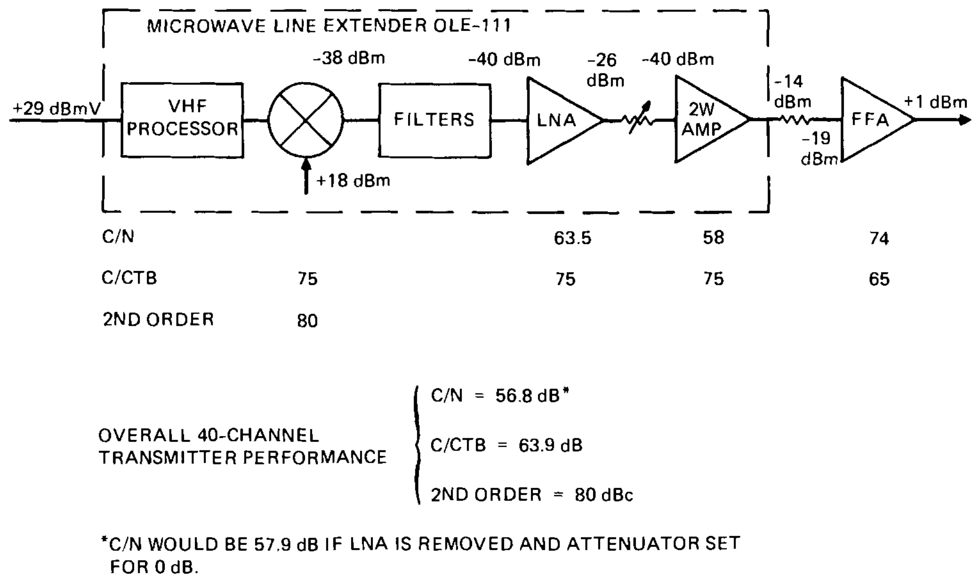


Figure 8 Typcial feedforward application.

interconnecting to each antenna, the maximum clear weather signal input to the receiver would be -43 dBm. Despite allowing for some multipath up-fade, this weak signal example suggests that consideration be given to a 2-stage LNA outside the AGC loop. For this 40-channel case, the receiver C/CTB will be 6 dB better than that shown in Figure 6b, so even in the maximum signal condition the total microwave link contribution to C/CTB is 63 dB. The second order beat for the total link is 77.5 dBc. The C/N provided to the last subscriber is determined by the sum of the contributions of transmitter, receiver, and cable system. This is illustrated by Figure 9, in which it has been assumed that the normal cable system contribution is 47 dB. Even allowing for a 2 dB "field factor," an 8 dB fade margin exists to a very respectable total system 45 dB C/N. The margin to 35 dB C/N is 22 dB, which for average rainfall and multipath conditions leads to a predicted 99.7 percent path reliability. Note, in Figure 9, the influence of the receiver VHF AGC down to -62 dBm input signal. Here, it is assumed that once this AGC runs out, no further AGC is available in the cable system to counteract the drop in signal level.

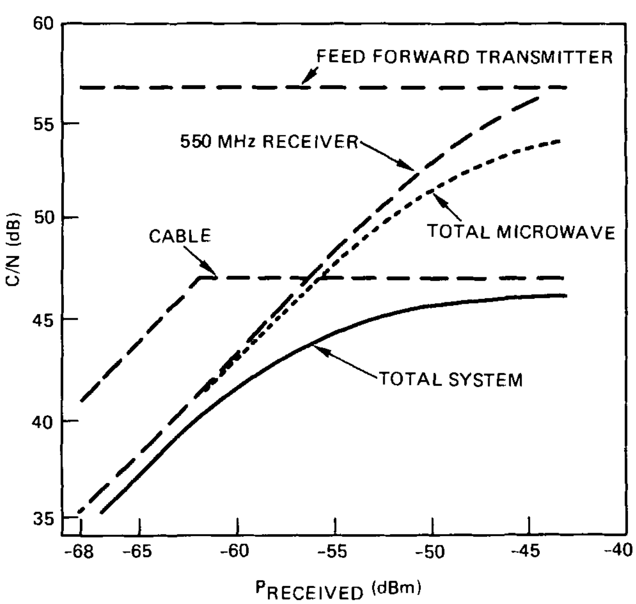


Figure 9 40-channel performance for 13-mile microwave feedforward system.

SUMMARY

The increased output capability of block conversion type transmitters utilizing feedforward post amplifiers has further expanded the potential range of application of cable-fed broadband microwave transmitters. In many cases, the maximum received signal level will dictate the use of a receiver with a 2-stage LNA outside the microwave AGC loop. Nevertheless, this microwave AGC is still important to controlling second and third order distortion of the receiver mixer, while the VHF AGC extends the range of the constant level output signal fed to the cable system. Improvements in the receiver design with alternative types of LNA implementation facilitate a wide range of AML applications, including those involving up to 80 channels.

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