LNAs FOR MULTICHANNEL MICROWAVE RECEIVERS

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ABSTRACT

The fade margin of any microwave path can be extended by reducing the noise figure of the receiver. Low noise Ku Band gallium arsenide FET amplifiers and image reject filters have been developed specifically for multichannel microwave receiver application in the 12.7 - 13.2 GHz band. Incorporation of the the amplifier into such receivers either as a retrofit or in new designs generally requires built-in AGC circuitry to control the signal level and optimize performance. Without AGC ahead of the LNA, the third order distortions can build up to unacceptably large levels during unfaded conditions. Performance tradeoffs of various typical system configurations are examined. These tradeoffs illustrate the regimes in which AGC utilization is required.

INTRODUCTION

Steady improvements in GaAs FET technology has led to the development of amplifiers with noise figure on the order of 3 dB in the 12.7 - 13.2 GHz band. This type of LNA, if properly employed, can be incorporated into a multichannel microwave receiver with substantial system benefits. On newly installed paths, the improved receiver noise figure can be traded off against increased antenna diameter. Alternatively, longer path distances are feasible with acceptable system performance. For existing paths, the retrofit of a low noise amplifier and image noise rejection filter into a receiver will lead to increased path margin to overcome rain and multi-path fades. However, the retrofit usually must utilize an AGC to avoid the generation of excessive composite triple beat and other distortions.

LNA WITHIN RECEIVER

As a point of comparison consider first a standard multichannel CARS band receiver operating without an LNA. The receiver is designed to maintain a constant signal level not only at its output, but also at the input to all circuits within the receiver capable of generating any third order distortion. Figure 1 is a simplified block diagram of such a receiver. Its noise figure is specified to be less than 10 dB. The AGC can maintain the VHF output constant over a 35 dB range of microwave input. Throughout this region, both S/N and third order distortion are constant. One can be traded off against the other by adjustment of the AGC level. For instance, the 54 channel carrier to composite triple beat ratio is 81 dB for a S/N of 53 dB. At 56 dB S/N composite triple beat degrades 6 dB to 75 dB. Alternatively, at 50 dB S/N the composite triple beat is 87 dB. In any practical path, the

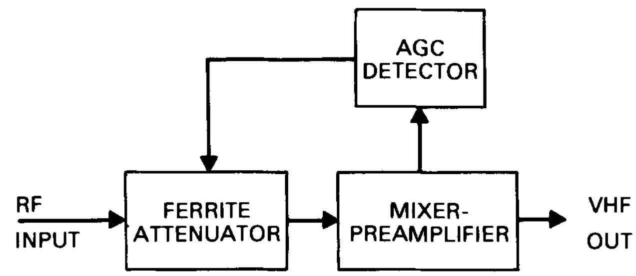

Fig. 1. Multichannel AML receiver simplified block diagram.

maximum signal available at the input of the receiver is limited by fixed path losses. The difference between this maximum signal and the signal at which the output signal starts to fall is the available AGC range. If rain or multipath attenuation exceeds this range S/N at the output of the microwave receiver will be degraded.

This drop in S/N at low input levels is illustrated in Figure 2. The figure also shows the extension of the AGC range to 3.5 dB lower input level by utilization of an LNA between the ferrite attenuator and the mixer as shown in Figure 3. The 3.5 dB improvement in available AGC range also shows itself as a 3.5 dB improvement in fade margin to an "outage level" S/N of 35 dB. The typical 3.5 dB improvements should not be confused with the 3.5 dB noise figure specification of the single stage LNA. The receiver fade margin improvement, ΔF, is a function of both LNA noise figure and gain, G, as well as the receiver noise figure before installation of the LNA. The higher the LNA gain, the greater, up to a point, the improvement in fade margin. However, in order to maintain the S/N within the AGC range at 53 dB, the AGC operating point must be raised by $(G - \Delta F)$ dB. This establishes the correct input level at the LNA. Note however the mixer-preamp is driven harder than before. As a result the C/CTB is degraded by just $2 \times (G - \Delta F)$ dB. For single stage LNAs the gain, less filter loss, is typically 7.5 dB.

A dual stage LNA with 15 dB of gain would further increase ΔF by 1-1/2 dB to 5 dB. At a S/N of 53 dB the 54-channel C/CTB would then by on the order of 61 dB, a value too low for most cable system applications. This is the reason why the LNA gain must be restricted in this configuration. On the other hand for 21 channel applications the C/CTB would be approximately 72 dB and the

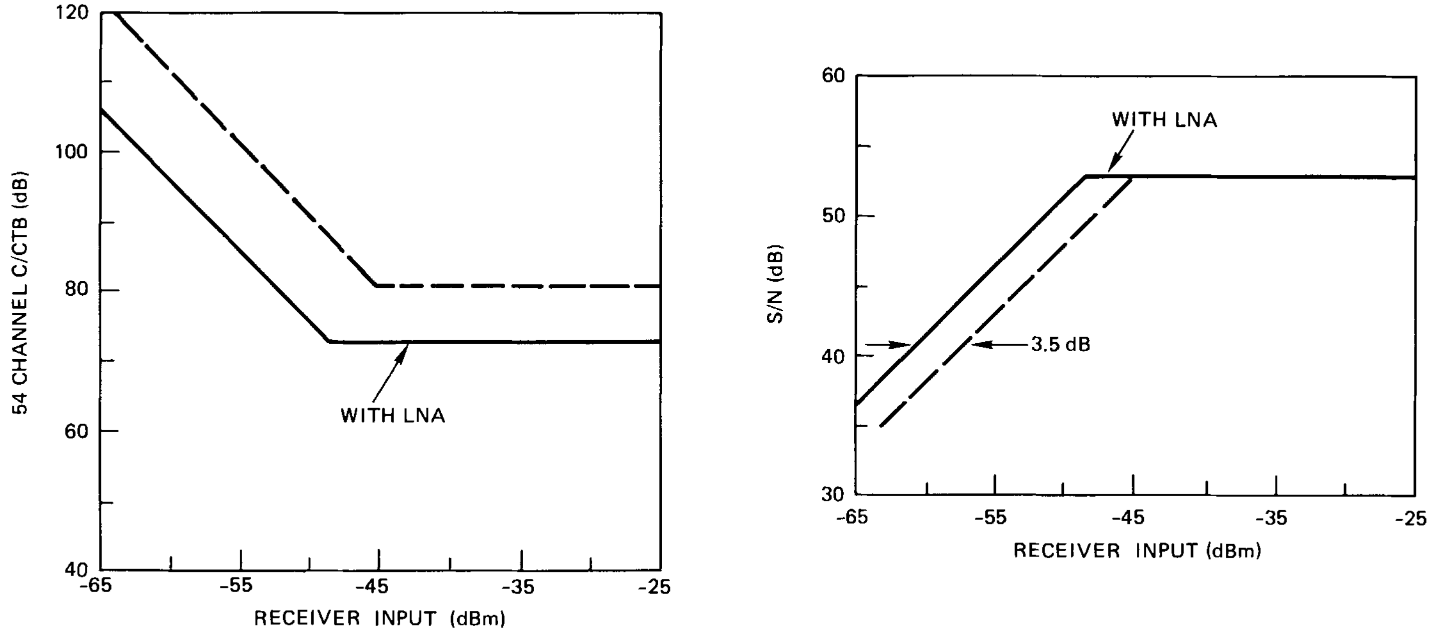

Fig. 2. Receiver S/N and C/CTB with and without built-in LNA.

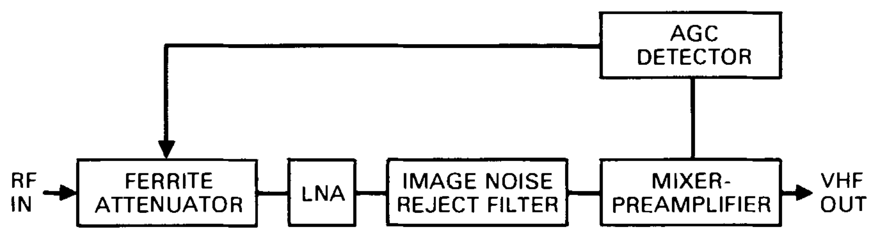

Fig. 3. AML receiver with integrated LNA.

built-in dual stage LNA would therefore become a viable candidate.

Note that in all of the above cases the LNA contributes negligibly to the composite triple beat. This is due to its high 3 IM intercept point, +21 dBm in the case of the single stage LNA and +24 dBm for the dual stage LNA. This high intercept point is achieved by means of a balanced design. A close examination of Figure 4 shows how this design is implemented in the MIC hardware. It should also be pointed out that full advantage of the LNA low-noise performance can only be obtained by providing an image noise reject filter as shown. This is particularly true with high LNA gain since the LNA is then by far the dominant source of noise at the output of the receiver. Since the LNA is a broadband device typically having full gain at the image frequencies, deletion of the filter would degrade the receiver sensitivity by as much as 3 dB.

EXTERNAL LNA CONFIGURATIONS

In contrast to the arrangement shown in Figure 3, CATV systems have often installed an LNA preceding the broadband microwave receiver, either with or without an image reject filter. The generalized arrangement is shown in Figure 5. The deleterious consequence of working without a filter has already been discussed so it will be assumed that the filter has been installed to obtain the largest possible fade margin improvement. Any waveguide loss between the LNA and the receiver is represented by the loss, L, in Figure 5. This arrangement permits mounting of the LNA directly behind the antenna while the bulkier receiver can be more readily serviced at ground level. If then one were to compare the fade margin performance of such a ground-mounted receiver with and without the antenna-mounted LNA, the improvement would be very dramatic particularly if the waveguide loss is substantial. This is illustrated by Figure 6 which assumes the existance of 5 dB of waveguide loss. The improvement in fade margin is 9.4 dB. Naturally, this improvement would be less if L were smaller, but a part of the improved fade margin is also due to the fact that the LNA now preceeds the ferrite attenuator and its unavoidable minimum insertion loss. Thus, this configuration yields the largest fade-margin improvement. The receiver AGC threshold is again set for 53 dB S/N at an antenna input of -40 dBm (corresponding to -45 dBm at the receiver input in the absence of the LNA) but the S/N is not constant in the AGC range. As the signal level increases, S/N at first improves dB for dB until the receiver AGC sets in. In this example, the AGC is set only 1/2 dB higher than usual with respect to the mixer-preamp input level. With this setting, the S/N rises to 53 dB at -40 dBm antenna input. The gradual rise in S/N is due to the fact that while the signal is kept constant

Fig. 4. Balanced LNA design implementation.

after the -53.8 dBm antenna input threshold, the LNA's contribution to noise is increasingly attenuated by the ferrite attenuator. Ultimately preamp noise predominates and the S/N flattens out at high signal level.

Third order distortion at low signal levels is primarily due to the mixer preamp. However, at -49 dBm antenna input the contribution from the LNA equals that of the mixer preamp whose distortion remains constant above the AGC threshold. As the antenna signal continues to increase the LNA's contribution to 3rd order distortion dominates. The actual number depends on both the LNA gain and 3 IM intercept point. The lower the gain and higher the intercept, the better the C/CTB at the high signal levels. Nevertheless, despite the high +24 dBm intercept specification for the 2-stage LNA, it is evident that 3rd order distortion is unacceptably high for LNA input levels in excess of -40 dBm. Even 62 dB C/CTB would hardly be "transparent" when added to the cable system were it not for the fact that LNA caused intermodulation is likely to add on a power basis rather than a voltage basis to that of the cable system. In phase voltage addition is probable only when like devices are generating the distortion products. Power addition of composite triple beat generated by a microwave FET amplifier and a VHF hybrid amplifier has been verified in the laboratory.

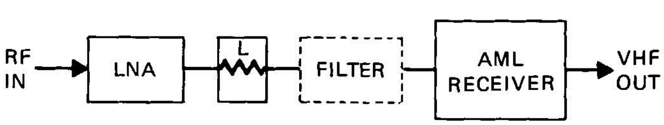

Fig. 5. External LNA arrangement.

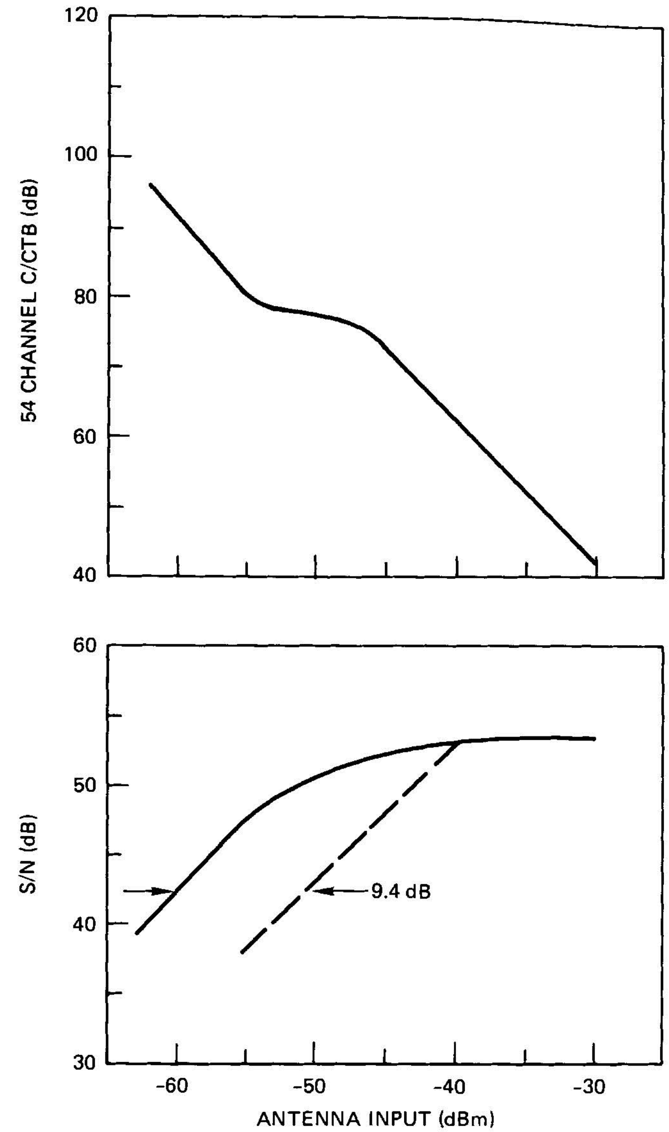

Fig. 6. Tower mount dual stage LNA (5 dB waveguide loss).

EXTERNAL AGC

To extend the useful range of application for the tower-mounted LNA it is necessary to place the AGC function in front of the LNA as in the previous configuration. This is conceptually achievable by removing the ferrite attenuator from the AML receiver and mounting it instead in front of the LNA. Figure 7 shows the performance obtained. The fade margin improvement is 0.7 dB less for the same LNA and waveguide as in Figure 6 because the small signal insertion loss of the ferrite attenuator is now in front of the LNA instead of following it. The 8.7 dB fade margin improvement dictates that the AGC commence at -48.7 dBm at the antenna input. This translates to 5.6 dB higher than normal signal level at the mixer preamp input to achieve the 53 dB S/N. As in Figure 2, C/CTB is dominated by the mixer-preamp.

Even better performance could be obtained with a dual AGC control. In this case the ferrite attenuator remains inside the AML receiver but an additional ferrite attenuator is added in front of the LNA. At very low signal levels neither AGC is activated. At threshold, the attenuator internal to the receiver becomes active and maintains constant input level to the mixer-preamp. As the antenna signal level continues to increase, this attenuator takes on a fixed value and control shifts to the pole-mounted attenuator. Thereafter, a constant signal level is maintained throughout the remaining AGC range at the LNA as well as at the mixer. Despite the added complexity that this concept embodies, improvement in C/CTB is a modest 3.5 dB relative to the case illustrated in Figure 7. A more fruitful approach to further improving intermodulation would seem to be a direct improvement of the linearity of the mixer-preamp. In any case the performance indicated by Figure 7 should be satisfactory for most cable systems.

SUMMARY

In conclusion, LNAs can be used to increase fade margin on a microwave path. However, care must be taken to avoid excessive generation of third-order distortion products. This is best done with AGC which maintains both S/N and C/CTB constant as with standard multichannel broadband receivers. If LNAs are used without AGC the range of permissable applications is severely limited. In any case it is important to specify a high LNA 3-IM intercept point and to utilize an image-noise reject filter to achieve the best possible performance.

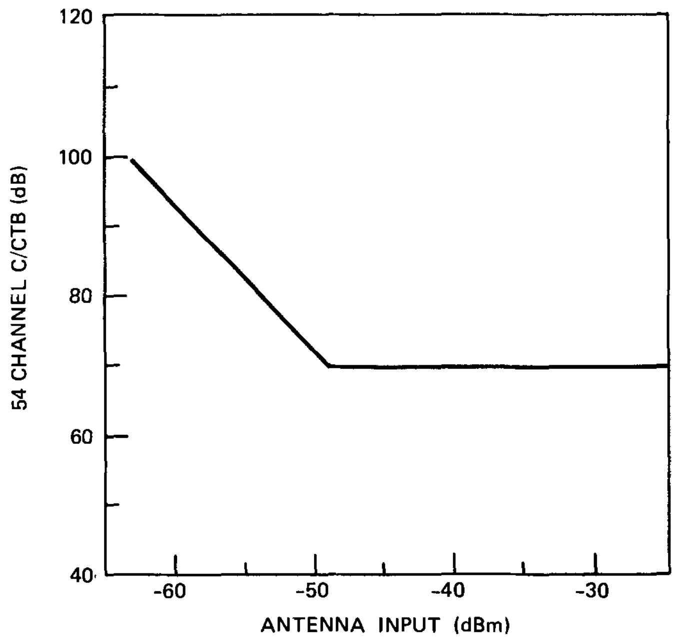

Fig. 7. Tower mount LNA with AGC (5 dB waveguide loss).