IMPROVED AM MICROWAVE PERFORMANCE WITH PREDISTORTION

R.T. Hsu, Dr. T.M. Straus, P.A. Vogt and J.L. Wrona

HUGHES AIRCRAFT COMPANY, Microwave Products Division
Torrance, California 90509-2940

ABSTRACT

Predistortion provides an effective means of improving the linearity of an AM microwave transmitter. Unlike power doubling and feed-forward, predistortion can be implemented with a relatively simple VHF circuit that partly compensates for the nonlinearity of the microwave klystron amplifier utilized in the output of the high power Hughes AML® STX-141 transmitter. The resultant improved overall linearity could permit additional channel loading of an FM band transmitter, the running of either FM or TV channel audio at a higher level than the normally specified -17 dB relative to video without compromising the transmitter C/IM performance, or a 3 dB increase in TV channel transmitter output while maintaining intermodulation distortion and differential gain and phase within specified limits.

INTRODUCTION

In AM systems the amount of intermodulation distortion depends on the signal level and on the linearity of the input/output transfer characteristic. Ideally, the amplitude transfer is perfectly linear right up to saturation and the phase is unaffected by the level at which the signal operates. Real amplifiers, such as the klystron utilized in the AML transmitter, will differ significantly from this ideal. However, by placing a predistortion module in series with the amplifier, the overall transfer characteristic can be made to be more linear. This results in less distortion at a given output level, or alternatively, in a greater output capability at a specified level of distortion.

An alternative view of predistortion which is most useful in the band-limited small signal regime is to consider the predistortion module as a generator of third order distortion products. These intermodulation products are controlled in amplitude and phase so as to just cancel out the intermodulation products created in the output power amplifier. The paper decribes the implementation of such a predistortion circuit operating at VHF. Performance improvement of a typical high power AML transmitter incorporating this form of predistortion is also detailed.

LINEARITY IMPROVEMENT ALTERNATIVES

The problem of non-linearity in CATV systems is a familiar one. Together with noise, it is the mechanism which limits system performance and the ability of the cable to reach out to a greater distance and service a wider geographical area from a single headend. Nonlinearity also limits the performance of AM microwave transmitters and usually requires substantial backoff from the saturated output power capability. Since the power is thus reduced, the range, although generally much greater than what can be obtained with cable alone for equivalent distortion performance, is again limited by considerations of noise in the microwave receiver and signal distortion in the microwave transmitter.

Both power doubling and feed forward are extensively used in modern CATV amplifiers. These techniques of linearity improvement are however not limited to the VHF regime. Power doubling is widely applied to obtain increased output capability in microwave GaAs FET amplifiers. For instance, Figure 1 shows a block diagram of

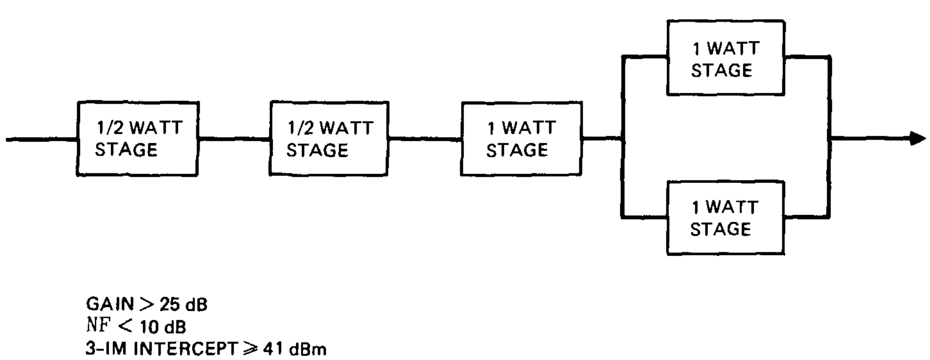

Figure 1 2-watt GaAs FET amplifier with power doubling.

the 2-watt amplifier utilized in the Hughes AML OLE-111 transmitter[1]. In such amplifiers the phase shifts of the paired output stages are well matched to obtain the full benefit of the power doubling technique. Feedforward has also been utilized at microwave frequencies since the classic paper by Seidel[2]. However, just as in VHF application, the feedforward technique requires a substantially greater level of complexity resulting in higher cost and reduced reliability due to increased component count.

A far simpler technique, which has been used for many years to improve the efficiency of TV broadcast equipment, is predistortion. This technique has also been applied at microwave in various forms to optimize traveling wave tube amplifier performance[3]. The principle underlying this form of predistortion is illustrated in Figure 2. Both the amplitude and phase input/output transfer functions are linearized by preceding the TWTA with a predistortion circuit which compensates for the amplifier nonlinearity. As a goal, the overall amplitude transfer would provide a 1 dB output change for 1 dB input change while the phase transfer characteristic would remain constant up to the point where the amplifier reaches saturated output.

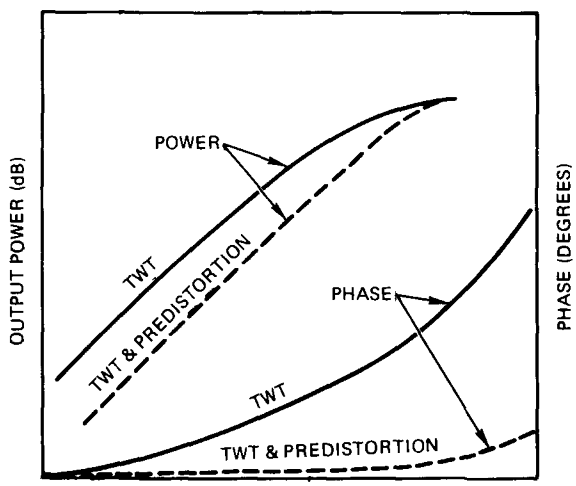

Figure 2 Typical TWT transfer characteristics with predistortion.

Another way of understanding predistortion is to consider the predistortion unit as a generator of intermodulation products which are 180° out of phase with the intermodulation products generated within the output amplifier. By further adjusting these IM products to be of equal relative amplitude, complete cancellation of the principle IM products is ideally possible. This concept is illustrated in Figure 3. The viewpoint is particularly useful when the output amplifier backoff must still be substantial due to the large C/IM requirements of typical SSB-AM systems.

The predistortion circuit may be implemented at VHF frequency even if the transmitter output stage is at microwave[4,5]. The only requirement is that the phase of the IM product generated at VHF is 180° out of phase with the distortion produced in the microwave output stage so that the overall IM is cancelled. This necessitates that the intervening circuits be sufficiently broadband so as not to introduce group delay or amplitude distortion as a function of frequency lest only some of the IM products are properly cancelled.

PREDISTORTION IMPLEMENTATION

Figure 4 shows a block diagram of an STX-141 transmitter modified to include VHF predistortion. Two new parts were added to the standard transmitter: the predistorter module which includes a +12 volt power supply, and a GaAs FET microwave amplifier. The FET amplifier is included so as to be able to broadband tune the klystron without requiring additional signal level output and consequent intermodulation products from the upconverter. The klystron must be sufficiently wideband in order to prevent phase shift in its input sections from interfering with the IM cancellation near the FM band edge. Predistorter IM phase and amplitude adjustments are made available at the rear panel to facilitate correct alignment during initial installation and in the event klystron replacement is required. Touch up adjustment may also be required to reoptimize long term performance as the klystron amplifier ages.

The predistortion module block diagram is shown in Figure 5. The input VHF signal is split into two arms - a distortion arm and a linear arm. The main signal goes through the linear arm which includes a delay line to match the delay in the distortion arm. This helps the circuit to maintain relatively constant phase relationships between desired carriers and IM products over a wide percentage bandwidth. The intermodulation (IM) product

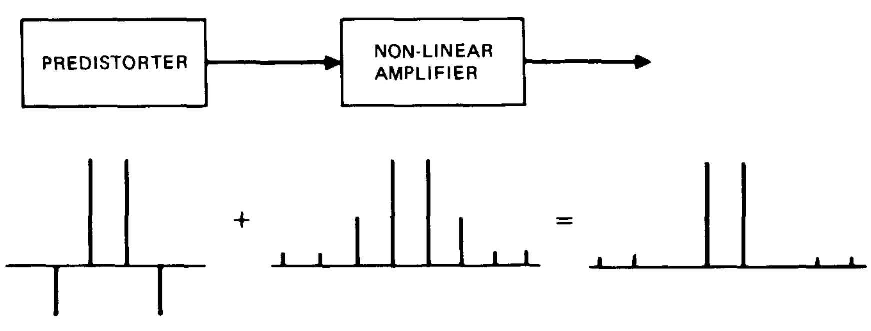

Figure 3 IM cancellation with predistortion.

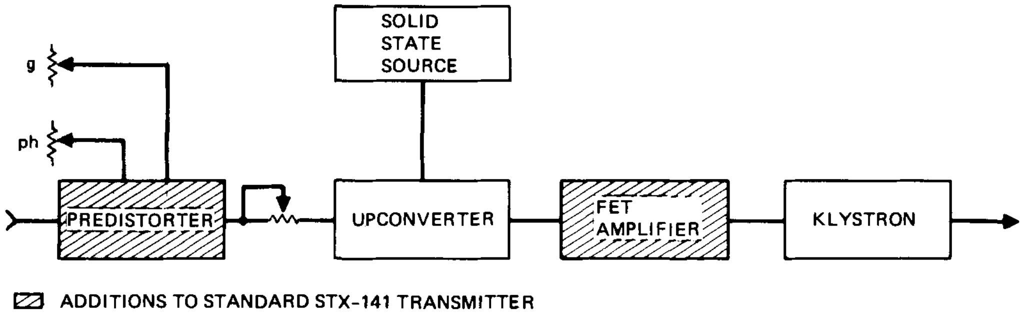

Figure 4 FM-band STX-141 including predistortion modification kit.

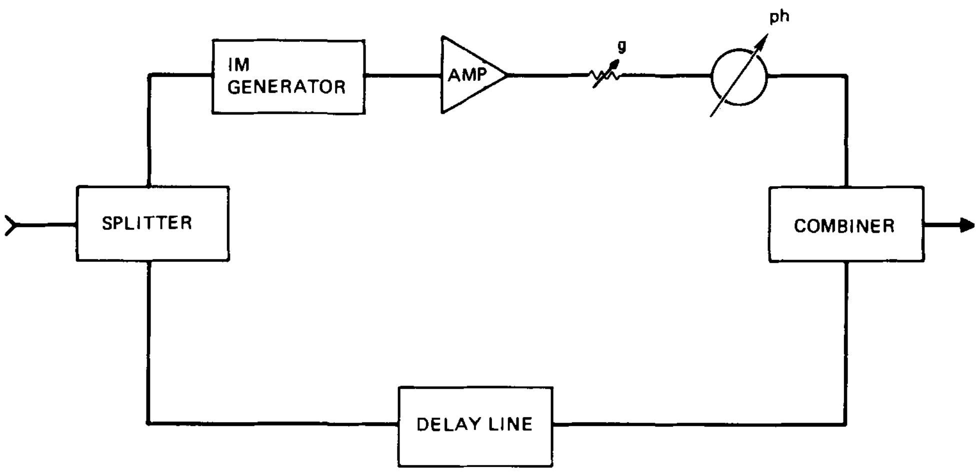

Figure 5 Predistorter block diagram.

generator also acts to suppress the input carriers in the distortion arm. An internal adjustment maximizes carrier suppression so that only IM products pass through the amplifier, attenuator, and phase shifter. In this way the IM amplitude and phase are precisely controlled relative to the output VHF carriers after recombination in the output combiner. Figure 6 summarizes the theoretical amplitude and phase error limits for various levels of IM improvement. Phase error limits are particularly stringent. For instance, to maintain 20 dB improvement over the 88-108 MHz FM band requires less than 2 ns of group delay. This cannot be achieved without broadbanding the upconverter output filter and klystron employed in the Standard AML STX-141 transmitter.

Figure 7 shows the internal construction of the predistortion module. The coaxial delay line is evident in the photograph. Figure 8 shows the same module with cover and attached power supply. The wires lead to the rear panel mountable gain and phase adjust potentiometers. The unit is designed so that a field retrofit kit implementation is possible.

EFFECT OF PREDISTORTION ON AML TRANSMITTER PERFORMANCE

The standard 6 MHz wide STX-141 transmitter is tested at the factory with three cw tones, representing the video, color, and audio carriers respectively at 0/-20/-17 dB from the reference output of +33 dBm. The $f_V \pm (f_C - f_A)$ beat that results is specified to be at least 58 dB below the reference level. One can describe this linearity performance with a single parameter, the 3-IM intercept, which in this case is 46.5 dBm. By contrast, the broader bandwidth 88-108 MHz FM channel STX-141 transmitter performance may be as much as 2.5 dB less, i.e. 3-IM intercept of +44 dBm. Efforts to improve this performance are particularly important in European applications where the FM deviation is considerably less than in the U.S. For this reason, the predistortion technique previously described by Figure 4 has initially been applied to the 87.5-104 MHz European FM band. Results to date have been very encouraging. 3-IM intercept points as high as 54 dBm have been obtained. The circuit is stable as a function of time but, at this writing, requires retuning for wide temperature excursions.

A word of caution is required when applying the 3-IM intercept point concept to circuits involving predistortion. For normal "well-behaved" circuits, third order distortion products increase at the rate of 3 dB for each 1 dB increase in output level. However, when predistortion is applied this is often not the case and thus the circuit must be tested for stability as a function of drift in input level. Table 1 describes a specific measurement with the predistortion adjusted for operation at the 0 dB reference level. It is seen that the IM increases faster than 3 for 1 at output levels exceeding

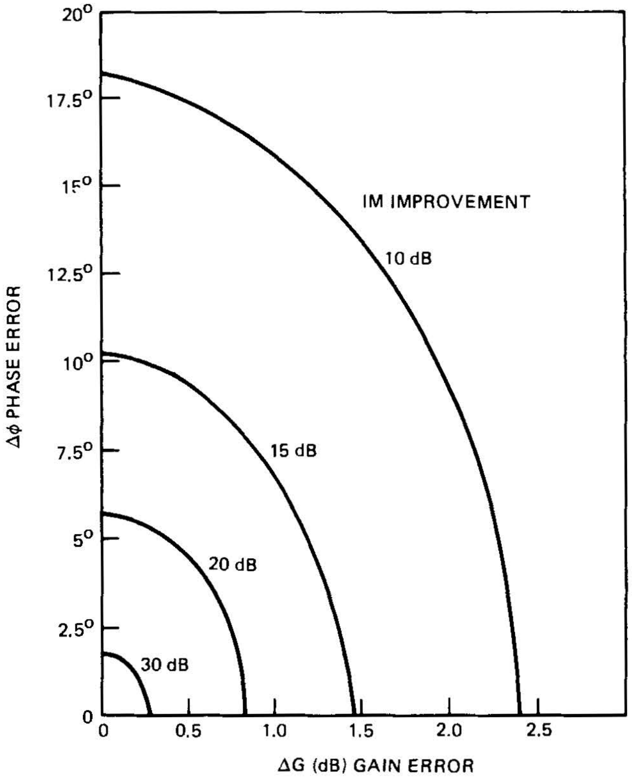

Figure 6 Allowable gain and phase error versus IM reduction.

the reference level by 2 dB and acts irregularly, i.e. "better" than normal, at 1 dB above the reference. At power levels below the reference level the IM exhibited a monotonic decrease ensuring that the specification would be met at any level up to the reference level.

The LNA (FET driver amplifier) serves two functions in the predistortion scheme reported here. First, it permits the klystron to operate at reduced gain corresponding to maximum broadband tuning. This reduces the

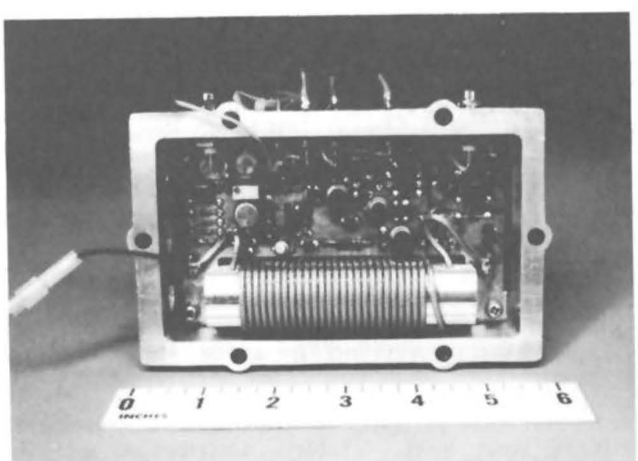

Figure 7 Predistorter internal construction.

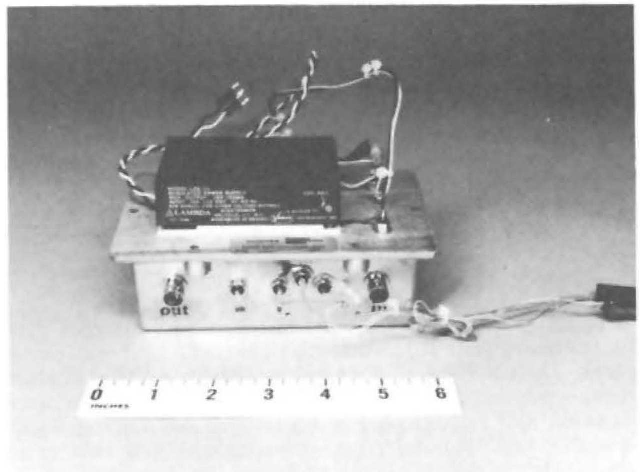

Figure 8 Predistortion module with power supply.

gain and group delay variation with frequency to a minimum and permits better IM cancellation as was shown in Figure 6. Secondarily, the reduction in klystron gain is more than compensated by the LNA gain so that the signal level at the upconverter can be reduced. In this way the upconverters contribution to the IM becomes entirely negligible. The 3-IM intercept point of the LNA is also sufficiently high to ensure that its IM generation can be neglected.

With the LNA removed from the transmitter, overall performance was still significantly better than with no predistortion. For the 87.5-104 MHz FM channel a 3-IM intercept point of +49 dBm was obtained. These results are summarized in Table 2.

The table also shows comparisons for video signal applications. Three key differences must be noted. First, the signal bandwidth is only 6 MHz so that broadband tuning of the STX-141 klystron is much less important. However, note that the $2f_V$-f_A intermodulation product would be 14 dB greater than the in-band 3-tone IM were it not for the fact that the single side band filter provides the necessary attenuation. Unfortunately, group delay is unavoidably associated with this attenuation characteristic. Thus it is not possible for the predistorter to simultaneously and completely cancel both the in and out-of-band IM generated by the klystron. A possible solution to this dilemma would be to replace the upconverter output filter with a broader band unit to reduce group delay, and then again back off upconverter drive level by using an LNA. It is doubtful that such an extensive modification to the standard STX-141 would be justified by the possible supplementary linearity benefits which in any case would be limited by the third key difference.

TABLE 1

VARIATION OF C/IM WITH OUTPUT LEVEL

Output (dB_{ref})	0	+1	+2	+3	+4
C/IM	70	70	66	60.5	56

TABLE 2

TRANSMITTER LINEARITY SUMMARY

Type Trans-mitter	Signal	Pre-distortion	LNA	3-IM Intercept (dBm)
STX-141	87.5-104 MHz	Yes	Yes	+54
STX-141	87.5-104 MHz	Yes	No	49
STX-141	88-108 MHz	No	No	44
STX-141	Video	Yes	No	49.5
STX-141	Video	No	No	46.5
MTX-132	Video	Yes	No	36.5
MTX-132	Video	No	No	35.5

This third difference is tied to the fact that unlike the FM signals, TV signals vary in amplitude. Thus IM cancellation is not the only criterion by which to judge the non-linear performance. Differential phase and gain must also be taken into account. The klystron transfer characteristic must be more precisely matched over a wider range of amplitude level variation with the compensation provided by the relatively simple predistortion circuit described by Figure 5. The optimum tuning condition is a compromise between the various parameters and cannot be adequately described by just the 3-IM intercept point. Table 3 provides the additional detail comparing the STX-141 performance with and without the predistortion module. The LNA was not used in these experiments. Tuning was optimized for operation at 4 watts output and shows that the AML transmitter can provide good linearity performance at an output 3 dB higher than normal.

TABLE 3

EFFECT OF PREDISTORTION ON STX-141 VIDEO PERFORMANCE

	2 Watts Output		4 Watts Output	
	Std.	With Pre-distortion	Std.	With Pre-distortion
Differential gain (%)	3	3	7	4
Differential phase (°)	2	1	3	1
In-band C/IM, (dB)	61	65	55	62
Adjacent channel C/IM, (dB)	58	66	49	64

The final two entries in Table 2 refer to the Hughes AML MTX-132 transmitter in which a high level parametric upconverter is the distortion limiting element rather than a klystron. The situation is considerably simplified in that there is no high Q microwave filter introducing group delay between the predistorter module and the transmitter distortion limiting circuit. Nevertheless, the results were disappointing although not entirely unexpected. Figure 9 shows that the amplitude transfer characteristic of the parametric upconverter is nearly ideal to begin with. The +22 dBm operating point is typically within 6 dB of hard saturation. Comparing this to the 13 dB klystron output backoff it is readily apparent that linearity improvement of the MTX-132 transmitter cannot be expected to be as large as that obtained with the STX-141 transmitter.

SUMMARY

Improved linearity performance of AM microwave transmitters may be obtained through the technique of predistortion. In particular, it has been found that a relatively simple VHF predistortion circuit can be tuned to partially compensate for the klystron amplifier distortion in the AML STX-141 transmitter. With a FET driver amplifier additionally inserted between the upconverter and the output klystron, up to 10 dB increase in transmitter 3-IM intercept performance has been obtained over the European 87.5-104 MHz FM band. Between 5 and 7 dB improvement is anticipated over the wider 88-108 FM band used in the U.S. Preliminary experiments with the same type VHF predistortion module, and without the FET driver amplifier, indicate that the STX-141 transmitter power output can be increased by 3 dB to 4 watts while maintaining the TV channel intermodulation specification at 58 dB. When the same technique is applied to the MTX-132 transmitter, only 1 dB improvement was obtained. This is attributed to the already excellent linearity performance of the MTX-132 high level upconverter up to within a few dB of saturation.

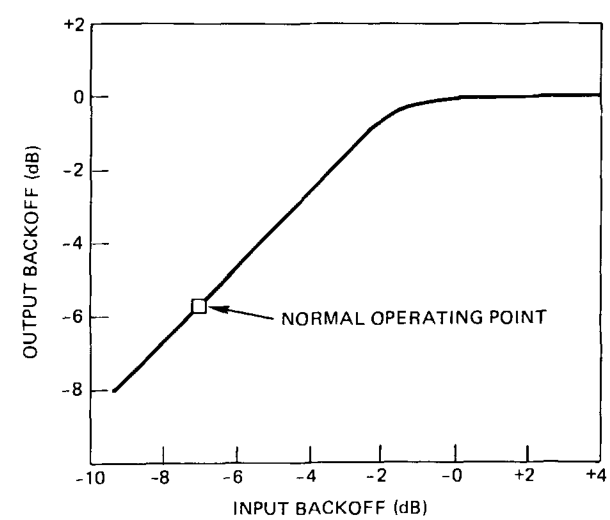

Figure 9 MTX-132 up-converter amplitude transfer characteristics.

REFERENCES

1. T.M. Straus, "Tradeoffs in Multichannel Microwave Transmission System Design," Las Vegas NCTA Convention, June 1985.

2. H. Seidel, "A Microwave Feed-Forward Experiment," BSTJ 50, No. 9, Nov. 1971.

3. M. Kumar, J.C. Whartenby, and H.J. Wolkstein, "GaAs Dual-Gate FET Linearizer for Traveling Wave Tube Amplifiers," Microwave Journal, August 1984.

4. R.P. Hecken and R.P. Heidt, "Predistortion Linearization of the AR 6A Transmitter," ICC 1980 Convention Record 33.1.

5. T. Nojima and Y. Okamoto, "Predistortion Nonlinear Compensator for Microwave SSB-AM System," ICC 1980 Convention Record 33.2.