EVALUATION AND CORRECTION OF TIME DEPENDENT AMPLIFIER NON-LINEARITY

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ABSTRACT

Both very high linearity and wide bandwidth are required by many new microwave and wireless systems. The linearity of power amplifiers degrades with increasing signal bandwidth. This paper shows that this degradation is related to time-dependent changes in amplifier transfer characteristics. A new method for evaluating an amplifier's wide-band, *dynamic*, linearity is introduced, and strategies for improving the performance of both conventional and linearized amplifiers are discussed.

INTRODUCTION

The ability to linearly process wide-band signals is essential for acceptable performance of many microwave and wireless communications systems. Phased array systems, for example, must employ amplifiers with low intermodulation distortion to accommodate multi-carrier traffic. Simultaneously, they must operate over a wide enough bandwidth to deliver a high information through-put. Unfortunately, the linearity of high power amplifiers generally degrades when operated with signals of bandwidths greater than several MHz. This degradation is demonstrated by the decrease in carrier-to-intermodulation ratio (C/I), as the frequency separation of two-carriers is increased. Figure 1 shows the change in 2-tone C/I as a function of carrier spacing, for an output power backoff (OPBO) of 4 dB. The amplifier under test (AUT) was a 40 watt, C-band, GaAs MESFET solid-state power amplifier (SSPA), designed for satellite service. The level of both upper and lower, third and fifth order intermodulation distortion products are shown.

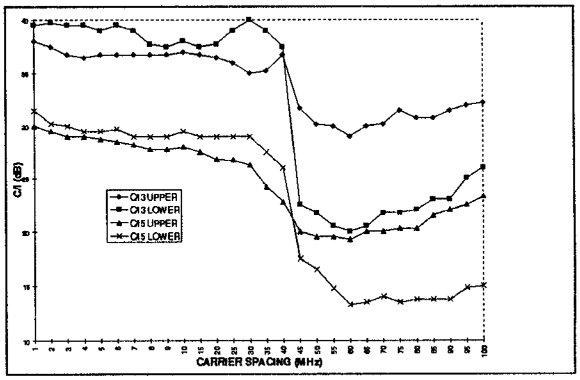

Figure 1. The linearity of Amplifiers Degrades with Increased Carrier Spacing.

The non-symmetry of upper and lower products is an indicator of the relative levels of AM/AM and AM/PM distortion [1,2]. As carrier frequency spacing is increased, C/I decreases noticeably. At a spacing of 30 MHz, C/I degrades by more than 2.5 dB. At 60 MHz, C/I is down by more than 6 dB. Some SSPAs have been found to degrade by more than 10 dB, for a 100 MHz carrier spacing. TWTAs are less sensitive to carrier separation, but start to degrade for separations of greater than 250-300 MHz.

A similar phenomenon is displayed by noise power ratio (NPR) tests. NPR provides a measure of an amplifier's linearity, when it is excited by many simultaneous carriers [3]. Figure 2 shows the change in NPR as a function

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of noise bandwidth, for the same amplifier and OPBO as Figure 1. Although less of a change, (1 dB at 58 MHz), NPR still shows a distinct decrease. This degradation increases at higher levels of linearity (NPR), and can be especially severe for linearized amplifiers. Figure 2 also shows the change in NPR with bandwidth, for an AUT with predistortion linearization. Here the linearized NPR degrades by 2 dB. Such a change can cause several dB of reduction in output power and a related loss in efficiency [4].

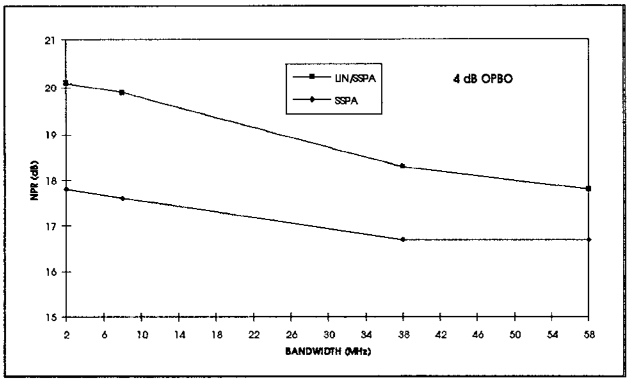

Figure 2. The NPR of Amplifiers Also Degrades with Larger Noise Bandwidths.

CAUSE OF DEGRADATION

The ability of an amplifier to handle a signal with a rapidly changing envelope is sometimes referred to as its *dynamic* bandwidth. When the frequency separation of carriers is increased, the resulting signal's time-envelope changes more rapidly. For 2-carriers, the frequency of this envelope is

$$Fe = F_{\Delta}/2 \qquad (1)$$

where F_{Δ} is the carrier separation. For purposes of analysis, distortion of the envelope can be thought of as producing the intermodulation products. The time-envelope, and related linearity, are dependent on the shape of the amplifier's gain and phase transfer characteristics. Assuming an amplifier with a flat frequency response, these parameters are normally considered time-invariant. When C/I changes with F_{Δ}, this indicates that the system is time-dependent. Time related change is particularly troubling for linearized amplifiers. In such systems, the amplifier transfer characteristics are corrected to provide a near constant gain and phase, with input power level, up to saturation. Change with F_{Δ} will cause the linearizer to be in alignment for one particular frequency, and out of alignment for another.

MEASUREMENT OF DYNAMIC TRANSFER CHARACTERISTICS

A technique for measuring the change in amplifier transfer characteristics for different carrier separations was devised, and is illustrated in Figure 3.

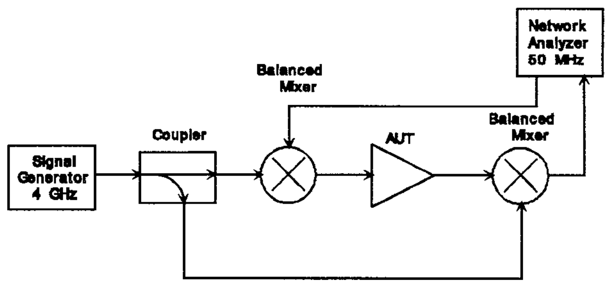

Figure 3. System for Measuring an Amplifier's Dynamic Gain and Phase Transfer Characteristics.

Unlike earlier work, this approach is easier to implement, employs a single vector network analyzer (NWA), and measures the envelope directly [5]. An HP 8753 NWA was used to provide an envelope signal, which can be varied in frequency, (Fe), from 300 KHz to 3 GHz. A two-tone test signal was generated by up-converting the output of the NWA, to the operating frequency of the AUT, using a balance mixer and a local oscillator (LO). A secondary cancellation loop around the mixer, (not shown in the figure), was required to ensure the LO frequency was suppressed by more than 50 dB. The output signal from the AUT was mixed down to the envelope frequency, using the same local oscillator, and supplied back to the NWA. A filter is not required after the second mixer, since the NWA is phase locked to the envelope frequency. By power sweeping the HP 8753, the AUT's gain and phase transfer characteristics, at different envelope frequencies, was obtained. Figure 4 shows the 2-tone gain and phase transfer characteristics, as a function of input power, with carrier frequency separation as a parameter, for the amplifier which produced the C/I performance of Figure 1. The shape of the two-tone gain curves, (at $F_{\Delta} < 10$ MHz), were in very close agreement with the amplifier's single carrier transfer response. The 1 dB compression point is degraded at higher separation frequencies. More significant is the dramatic change in phase transfer characteristics above 30 MHz; this is the frequency where the non-symmetry of upper and lower C/I products increased abruptly. This change is likely due to a resonance in the AUT's bias circuitry.

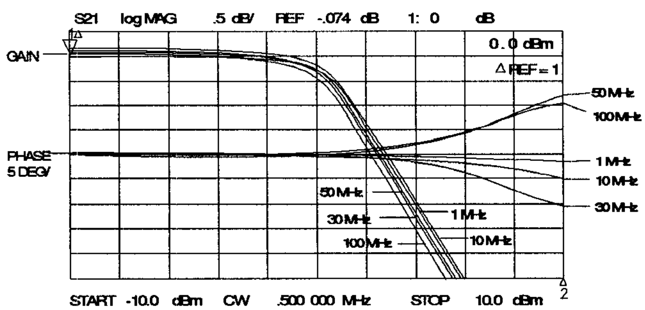

Figure 4. Two-Tone Gain and Phase Transfer Response of C-Band SSPA.

SOLUTIONS

The principal cause of the AUT's linearity degradation is believed to be due to changes in the bias currents. As an amplifier is driven harder, to insure the ampifier's drain voltage does not change with signal envelope:

$$Z_{source} << Z_{amp} \qquad (2)$$

where Z_{source} is the impedance of the dc power supply, and Z_{amp} is the load impedance presented by the amplifier to the power supply. When Fe is a significant fraction of an amplifier's operating frequency, Z_{amp} becomes complex, and condition (2) becomes difficult to achieve. The uniform gain characteristics and related slump in saturated power, displayed by the AUT at higher carrier spacing, indicates a problem in the drain circuitry. Large, low inductance drain capacitors (7 μf) were specifically included in the AUT's design to alleviate this problem, however, a significant induced voltage was found on the drain lines when 2-carrier and NPR excitation was present. Figure 5 shows the variation in drain supply voltage as a function of carrier separation. Induced voltages were also observed at the gate, but at a much lower level.

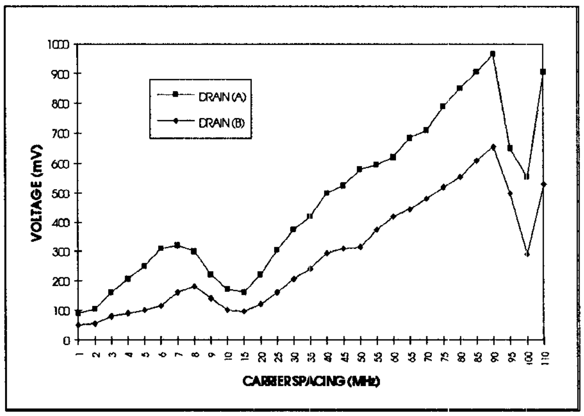

Figure 5. Induced Voltage in the Drain Circuit is Believed the Principle Cause of the Degradation in Amplifier Linearity at Higher Signal Bandwidths.

Evaluation of the drain capacitors revealed that they resonated near 0.5 MHz. Smaller, special low inductance capacitors were added on the device side of the drain de-coupling circuitry. These capacitors resonated at about 12 MHz. This change enhanced the 2-carrier transfer characteristics, and improved amplifier linearity at wider carrier spacing. The resultant C/I as a function of OPBO for a 30 MHz carrier spacing is given in Figure 6. Performance of both the AUT and a linearized AUT, with and without the added capacitors is shown. For reference, the C/I with a 1 MHz carrier spacing is also included. Only one curve is shown as performance with and without capacitors was essentially identical. Figure 7 shows similar data for NPR with 57 MHz and 2.5 MHz (reference) noise bandwidths.

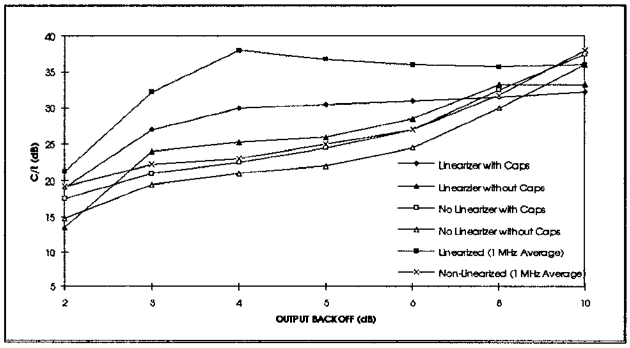

Figure 6. Improvement in C/I Resulting From the Addition of Low Inductance Drain Capacitors.

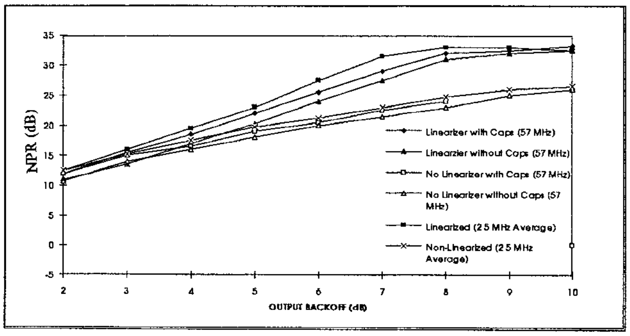

Figure 7. Improvement in NPR Resulting From the Added Drain Capacitors.

Although amplifier linearity is significantly improved for wideband signals, it still does not match the narrow band case. This difference is believed due to the remaining bias voltage variations, at the device drains due to a still finite Z_{source}, and at the gate, uncorrected by any circuit change.

CONCLUSIONS

Amplifier linearity can degrade significantly when excited by wideband signals, such as multiple widely spaced carriers. Insight into the cause and cure of this problem can be obtained by observing amplifier 2-tone dynamic gain and phase transfer characteristics, using balanced mixers and a vector network analyzer. The linearity degradation is often caused by induced voltage on the drain, and to a lesser degree on the gate lines of the amplifier. Using special, low inductance capacitors, an SSPA's wideband C/I degradation was reduced by more than one half.

References:

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