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AUTOMATED LARGE-SIGNAL LOAD-PULL CHARACTERIZATION OF ADJACENT-CHANNEL POWER RATIO FOR DIGITAL WIRELESS COMMUNICATION SYSTEMS

Abstract

Large-signal adjacent-channel power ratio load-pull contours of a GaAs MESFET and a GaAs HEMT excited by π/4-DQPSK modulation are demonstrated for the first time using an automated load-pull system. It is shown that in general there is only a weak relationship between two-tone third-order intermodulation and adjacent-channel power ratio for the (Japanese) Personal Digital Cellular standard. The relationship is both load impedance and device technology dependent insofar as two-tone linearity characterization cannot generally be used to optimize adjacent-channel power. The load-pull system presented here is modulation and device technology independent.

Introduction

Digital wireless communication systems are based on signals represented by power spectral densities. In contrast, analog wireless communication systems are based on signals typically represented by discrete spectra. Consequently, discrete Two-tone Third-order Intermodulation (TTIM) linearity characterization is not generally well-suited for linearity characterization of microwave power transistors used in digital wireless applications. Alternatively, the Adjacent Channel Power Ratio (ACPR), defined as the power ratio of two neighboring frequency continuum, is often used to characterize the linearity of a transistor (and amplifiers as well)[1]. Characterization and subsequent optimization of ACPR in the load impedance domain is critical as it directly impacts efficiency, and therefore, subscriber-unit talk-time.

Large-signal automated load-pull measurement is a well known technique for characterizing the non-linear behavior of microwave power transistors[2]. This technique has been limited to one and two-tone tests in the past, and has been sufficient to enable optimization of output power and third-order IM performance when signals are represented by discrete spectra. In this letter we report the development of a large-signal automated load-pull system for the measurement of ACPR contours for linearity characterization of transistors used in digital wireless communication systems. The (Japanese) Personal Digital Cellular System Standard (PDCS) is followed, although the method can be used with other digital wireless standards, e.g. the North American Digital Cellular Standard (NADCS)[3]. Measurement of ACPR provides an accurate indication of linearity in the context of digital modulation, precluding the necessity of a TTIM/ACPR correlation exercise, which is an often used but frequently tenuous design practice. The approach presented here directly facilitates a trade-off analysis of transistor linearity, power-added efficiency, gain, and output power.

Description of Automated Load-Pull System

The new large-signal automated load-pull system consists of a Maury Microwave Automatic Tuner System coupled with an Anritsu Digital Modulation Analyzer. Measurements up to 4.0 GHz with a typical $|\Gamma_L| \leq 0.90$ at 10.0 W are achieved with this system. Both upper and lower ACPR are measured, as well as upper and lower alternate channel power ratio and error vector magnitude. Gain, power-added efficiency, and average output power are measured as well. **Figure 1** shows a diagram of the automated load-pull system.

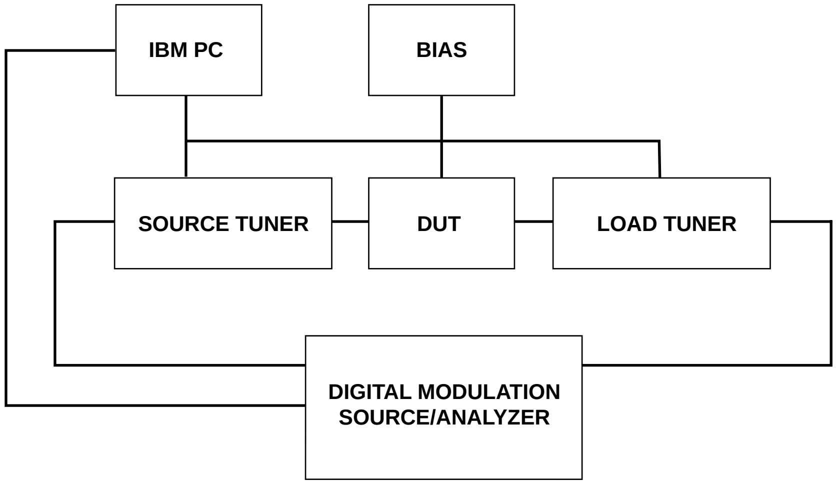

Figure 1: Diagram of the automated large-signal load-pull system.

Results

Two different devices, representing different physical technologies, were examined with the load-pull system: a 30mm Motorola GaAs MESFET and an 18mm Motorola GaAs HEMT. A fundamental difference between these particular Motorola technologies is that while each exhibits strong third-order nonlinearities, the MESFET exhibits a strong fifth-order nonlinearity as well. Both devices were characterized at 1440 MHz, a drain-source voltage of 5.8 V, and a drain current of $0.1I_{dss}$. A return loss of better than -10.0 dB was maintained over the load impedance domain. A 512 bit pseudo random sequence (PN9) was used as the data source.

Figure 2 compares load-pull plots of constant TTIM and minimum ACPR (upper and lower ACPR are seldom equal, differing by typically less than 0.5 dB) for the MESFET. Chart normalization is 10 Ω and contour steps are 2 dB. It is clear that for this process technology there is very little correlation between TTIM and ACP. Figure 3 compares third-order IM power and minimum adjacent-channel power (ACP) as a function of average input power under maximum output power loading. ACP follows approximately a 4.5:1 slope in the back-off regime, while third-order IM follows close to a 3:1 slope. Presumably this difference is because ACP for this device is a composite of third- and higher-order nonlinearities. Note also that ACP nulling is not as distinct as is third-order IM nulling, further demonstrating that ACPR consists of third- and higher-order nonlinearities.

These measurements were repeated on the HEMT device. Figure 4 compares load-pull plots of constant TTIM and ACPR for this device. For this process technology there appears to be reasonable correlation between TTIM and ACPR. Figure 5 corroborates this conclusion, showing that third-order IM and ACP both exhibit slopes of approximately 3.2:1 in the back-off regime. In contrast to the MESFET, TTIM and ACP nulling are both distinct and correlated.

Discussion

A simplified power series analysis can be used to explain why correlation between TTIM and ACPR may in general be weak, and also to explain under what conditions correlation may exist. A band-limited finite-time digitally modulated signal may be approximated in the frequency domain by a finite summation as

$$X(\omega) = \frac{1}{2}\sum_{k=-q}^{q} H(\omega_q)\, \delta_q\, (\omega - \omega_q)\exp(j\phi_q) \qquad (1)$$

where $H(\omega_q)$ is the filter response[1]. Assuming equally likely data points, (1) indicates that $X(\omega)$ will consist of uniformly spaced discrete spectra. The spectral

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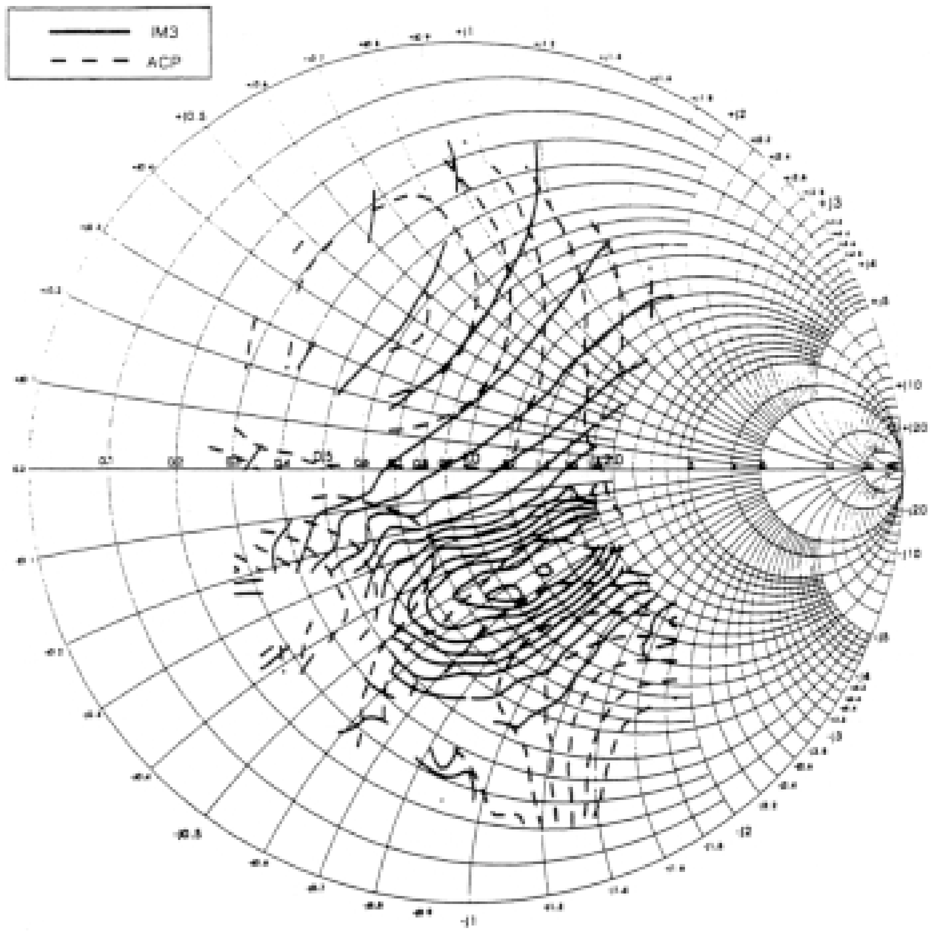

Figure 2: **Third-order IM and ACPR contours for the GaAs MESFET.**

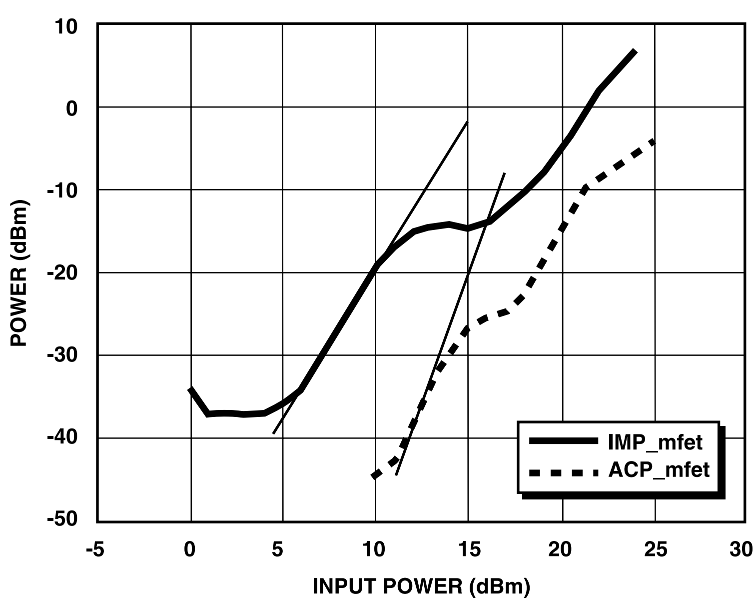

Figure 3: **Comparison of third-order IM power and adjacent-channel power for GaAs MESFET.**

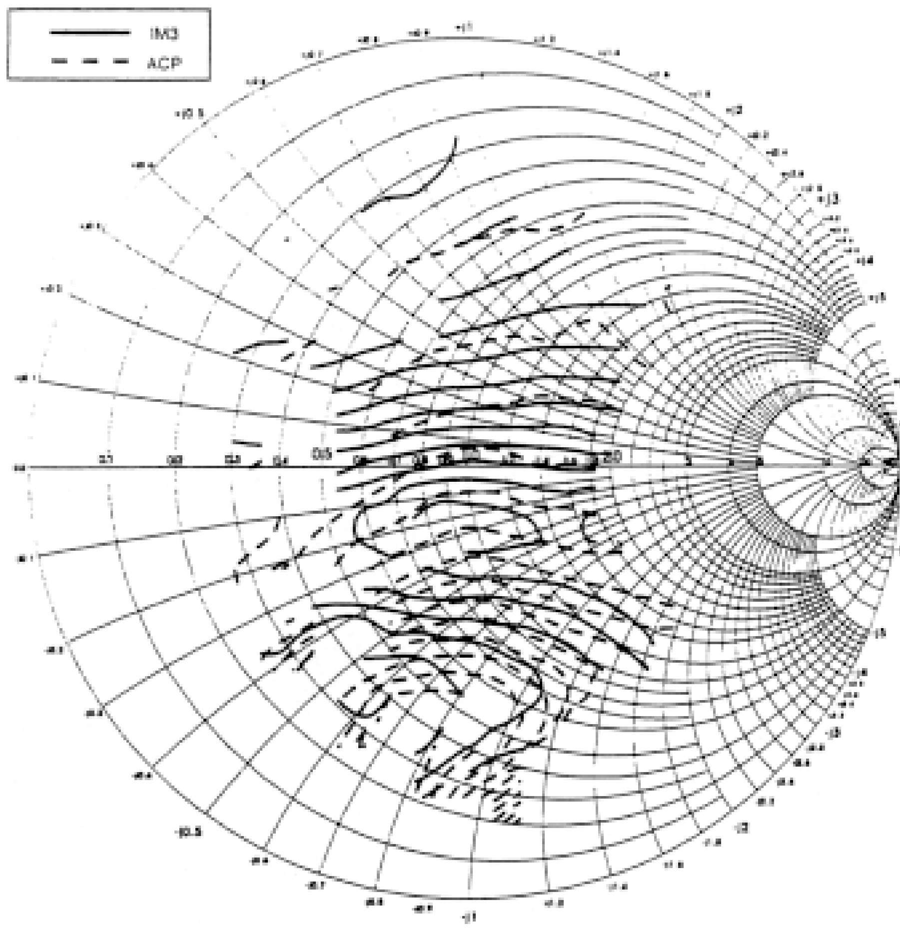

Figure 4: **Third-order IM and ACPR contours for the GaAs HEMT.**

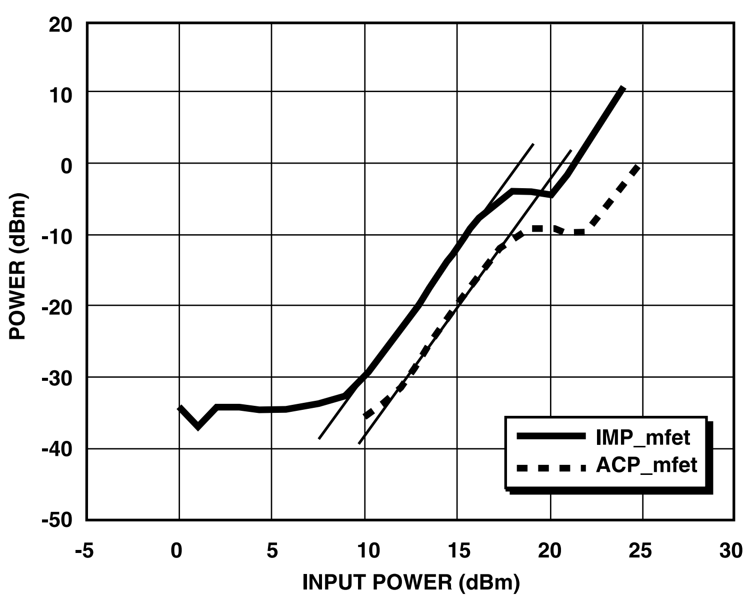

Figure 5: **Comparison of third-order IM power and adjacent-channel power for GaAs HEMT.**

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spacing, ω_q, is proportional to the sequence length, while spectral amplitude is a function of spectral spacing and the band-limiting filter. Now the PDCS adjacent-channel offset is 50 kHz with an occupied bandwidth of 31.5 kHz. Passing X(ω) through a memoryless zero feedback nonlinearity, the frequency-domain output is

$$Y(\omega) = a_1 X(\omega) + a_2 X(\omega) * X(\omega) + \ldots a_n X(\omega) * \ldots * X(\omega) \quad (2)$$

where ''*'' denotes convolution. Observe that spectral components with spacing less than 25 kHz will result in no third-order mixing products present in the adjacent-channel. Fifth-order and higher mixing products exclusively are present. Only as spectral spacing is increased above 25 kHz about the carrier frequency will third-order mixing products impact ACPR. Filtering further reduces the impact of third-order IM on ACPR for spectral spacings greater than 21 kHz. Modifying (2) to include feedback shows that ACPR is in general a function of third- and higher-order nonlinearities due to even- and odd-mode mixing currents within the device[4]. It would appear that devices with weak fifth-order nonlinearities, such as the HEMT process examined here, may exhibit reasonable TTIM to ACPR correlation.

Conclusion

The use of a large-signal automated load-pull system for the measurement of ACPR contours for the linearity characterization of transistors used in digital wireless communication systems has been reported. Excitation representative of the (Japanese) Personal Digital Cellular System was used. The method enables device linearity characterization in the context of digital modulation as a function of load impedance, directly facilitating a trade-off analysis between linearity and efficiency. Both a MESFET and HEMT were examined, demonstrating that in ACPR is both load impedance and device technology dependent. It was shown that in general TTIM may be a poor predictor of ACPR for the PDCS format, and that the correlation is load impedance and device technology dependent. Use of the large-signal automated load-pull system demonstrates that in general device linearity performance for digital wireless communication systems is best examined with contours describing adjacent channel power.

Acknowledgment

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References

1. Research and Development Center for Radio Systems (RCR), "Digital Cellular Communication Systems," RCR STD-27, April 1991.
2. J. Nebus, P. Bouysse, J. Villotte, and J. Obregon, "Improvement of the Active Load-Pull Technique for the Optimization of High Power Communication SSPAs," *Int. Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, Vol. 5, No. 3, pp. 149-160.
3. TIA/EIA IS-54, "Cellular System Dual-Mode Mobile Station-Base Station Compatibility Standard," Telecommunications Industry Association, April 1992.
4. P. J. Lunsford and M. B. Steer, "The Relationship Between Bi-Variate Volterra Series Analysis and Power Series Analysis with Application to the Behavioral Modeling of Microwave Circuits," *Int. Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, Vol. 1, No. 3, 1991, pp. 253-262.

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