APPENDIX - C

OPTIMIZATION OF OUTPUT POWER AND IM3'S OF WIRELESS RADIO TRANSMITTERS

NOTES

RF Application Note MPD 102A

The Use of Low Distortion PIN Diode Switches in Digital Communications Links

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Introduction

The digital communication link [1] encompasses the entire communication path, from the transmitter's input signal source, through all the encoding and modulating steps, through the transmitter and the RF channel, up to and including the receiver with all its signal processing steps, and terminating at the receiver's output load. Thus the link is more than just the free space RF channel.

In this paper, the overall performance parameters of the digital communications link are described. The non-linear distortion characteristics of Silicon and GaAs switching devices are discussed and related to the the optimization of the RF transmitter's linearity. A comparison of the inter-modulation performance of these switches enables a system engineer to select a switch design for a specific system application.

Digital communications system performance degradation can be related to two major contributors:

The deleterious effects of the RF Communications Link on the propagation of the RF signal

The non-linear noise effects on signal processing in the RF sections of the transmitter and receiver.

The Digital Communication Link

A digital communications link is the free space path between the antennas of two communications units. Propagation through the atmosphere and near the ground results in absorption, reflection, refraction, and diffraction, which modify free space transmission characteristics and cause signal fading.

Signal fading has many forms [2] such as frequency independent and frequency dependent fading, atmospheric multipath fading, and ground reflection multipath fading. RF signal fading effects cause increased Bit Error Rate and Inter-symbol Interference. These effects are offset somewhat by the following techniques:

Slow varying fading can be avoided by handing off a mobile connection to an adjacent cell that offers less fading [3].

Code Division Multiple Access (CDMA) is the usual solution to multipath fading and co-channel interference [3].

Spread-spectrum techniques improve the bandwidth efficiency and interference characteristics of cellular radio systems [4].

Smart antenna techniques overcome many of these various impairments [4].

Non-linear Effects in the RF Sections of the Transmitter & Receiver

Deterioration in communications link performance is also related to nonlinear noise effects in the RF sections of the transmitter and receiver. The effects of these sources of noise or interference are increased by the nonlinear behavior of the transmitter RF power amplifier and the T / R switch.

In evaluating communications system performance, the most important quantity is the Signal-to Noise Ratio (SNR), because the system design depends on the ability of the system to detect a signal in the presence of noise, with an acceptable probability of error. Since the RF output signal is a modulated carrier wave form, it is useful to refer to the average carrier power-to-noise (C/N) and the SNR of interest.

Non-linearity in Silicon PIN Diodes and GaAs MESFET's

The Third Order Inter-modulation Product (IP3) is one measure of device non-linearity and its use implies that the device is a "third -order device" ie, the curve of the third -order inter-modulation power vs input power has a constant slope (Figure 1).

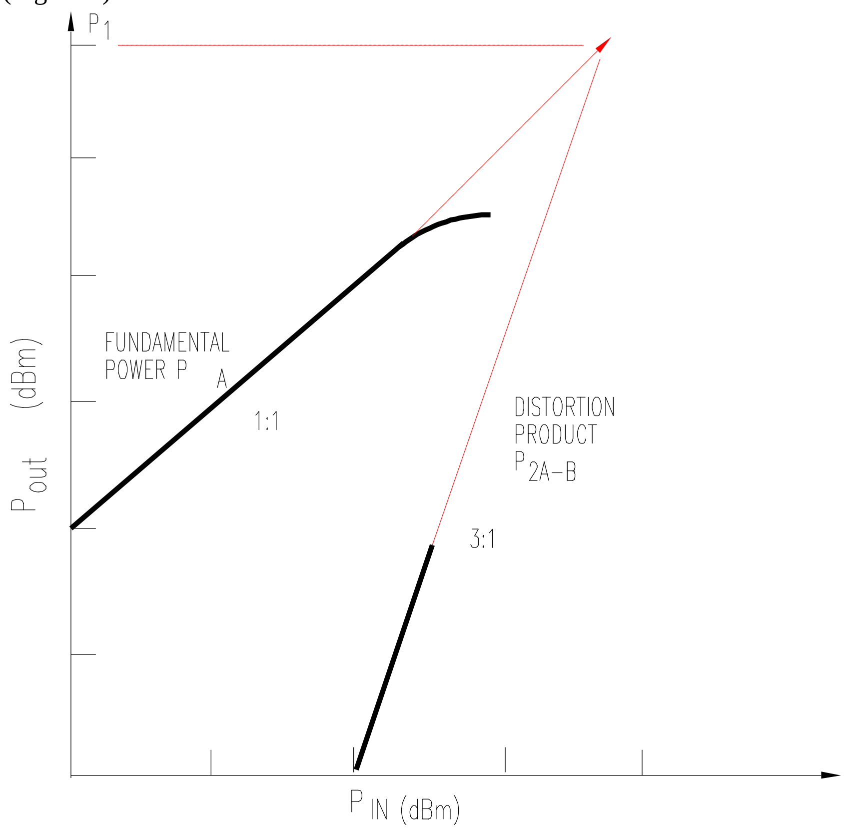

Figure 1. Definition of the Intercept Point

Silicon PIN diodes are third-order devices and their specified IP3 values are valid up to and beyond 10 Watts, depending on the design parameters of the specific PIN diode. Silicon PIN diodes are inherently higher power, lower distortion devices than GaAs MESFETs. In the forward biased "ON" state, the effect of conductivity modulation by the RF signal is minimized by the stored charge, $Q_S = I_F\tau$ in the PIN diode's intrinsic region [5,6]. If the transmitter power is increased, the forward bias current can be increased to obtain the same IM3 as specified.

GaAs MESFETS are not third-order devices [7]. IP3 data, measured with input tone power of 5 to 7 dB, is not valid at higher input power levels. GaAs MESFET manufacturers cite the 1 dB compression point, P_{1dB} as a measure of distortion. But P_{1dB} is not indicative of AM to PM phase distortion. GaAs MESFETs are inherently lower power switching devices. The gate -source junction is a rectifying Schottky junction with higher distortion properties that a PIN diode, at any power level. Table I shows typical T/R switch data for both Silicon and GaAs MESFET switches.

Table I

Typical T/R Switch Device Specifications

	Silicon	**GaAs MESFET**
IL	**0.25 dB**	**1.0 dB**
ISO	**40 dB**	**40 dB**
IP3	**65 dBm**	**45 dBm**
PS	**10 W**	**2 W**
"ON"	**10 mA**	
"ON"		**-10 V**
Test Tones	**1 W**	**10 mW**

Non-linear Distortion Effects

Device Non-linearity

All physical devices have some degree of non-linearity and thus distort the signal transformation process. The elements of a linear equivalent circuit are derived from small variations about the d-c operating point. Thus linear or "small signal" means that the circuit is limited to the first order derivative (of the device's I (v) function. By extension, a non-linear device's equivalent circuit is defined by higher order derivatives.

Non-linear distortion may be specified in terms of gain compression, AM - PM distortion, and inter- modulation products (specified in terms of intercept point, Figure 2). For devices with a well-behaved third order IMD performance (3:1 slope), the intercept point definition enables the inter-modulation performance to be specified independently of incident power level.

Optimization of RF Transmitter Linearity

The important performance parameters for optimizing the Power Amplifier - Transmit / Receive Switch combination [8] are shown in Figure 2. Each RF components makes its own contribution to the overall system's inter-modulation distortion level. In hand-held transceivers, the power amplifier may be a "linearized" class AB amplifier to achieve the desired CNR or IM3 and power-added efficiency.

Often a GaAs MESFET is chosen for the T/R Switch because of convenience and apparent cost saving. Their catalog specifications can be misleading, especially regarding IM3 performance at the power amplifier's output level. Since the GaAs switch's IM3 level is a function of the input ower, the P/A-T/R combination is optimized by backing off the P/A output power until the transmitter distortion specification is met.

The optimum solution is to improve the distortion performance of the T/R switch by using a Silicon PIN diode switch design. C/N and BER improve because the PIN diode's IM3's are much lower (typically 3 to 4 dB. The power amplifier's output power can be increased until the IM3 of the amplifier equals the IM3 of the switch

(Figure 2).This solution can be quite cost effective because the use of a Silicon PIN diode switch dramatically improves the system without resorting to more expensive alternates to raise the Carrier to noise ratio. The IM3 of a Silicon PIN Switch is typically 70 dBc at the 1 Watt input power level . For new designs, a Silicon Pin Switch can be combined with a more highly linearized P/A to achieve a CNR improvement of 8 to 10 dB, without the cost of increasing the system/s carrier power level.

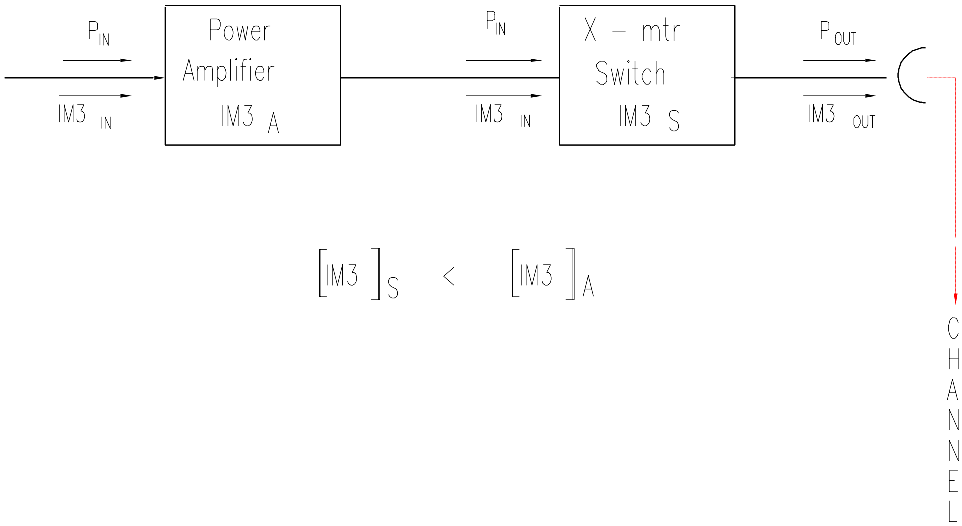

Figure 2. RF Transmitter Optimization

Conclusions

Recent trends in Telecommunications and Wireless Networking place greater linearity demands on RF components. Bit Error Rates (BER) of E -03 are adequate for digital voice transmission. Nomadic Data/ Miltimedia services require a BER of E -10 which relates to an end-to-end IM3 performance of -80 dBc at 36 dBm of effective radiated power. GaAs IC's cannot provide this level of linearity.

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