APPENDIX - E

PIN DIODE DISTORTON

NOTES

PIN DIODE SIGNAL DISTORTION

INTRODUCTION

Signal Distortion in electrical networks is caused by the non-linear characteristics of the circuit elements and components of which the network is comprised. All electrical components exhibit some degree of non-linear behavior under certain operating conditions but the principal contributors are active devices such as semiconductor diodes and transistors. Non-linear distortion [1] may be described in terms of gain compression, AM-PM distortion, and intermodulation products (specified in terms of intercept point).

DISTORTION - BASIC CONCEPTS

(Signal) distortion has been defined [1] as an "undesired change in input signal wave form as the signal passes through an electrical network". The principal sources of waveform distortion are:

A. Non-linear relationship between the input and output ports of the network.

B. Nonuniform transmission at different frequencies in the transmission band.

C. Phase shift not proportional to frequency.

Source A degrades the waveform of a signal traversing a specific electrical network. Sources B & C can degrade signal waveforms propagating through the RF Channel between the two antennas of a wireless radio network (Chapter 6 and Appendix C).

To clarify the effects of component non-linearity on the signal waveform, consider the unmodulated waveform in Figure 5.1 and the amplitude modulated waveform in Figure 4.1. A purely linear transformation of these signals would mean that only the amplitude of these waveforms would change. A linear gain block would increase the amplitude of the wave, but otherwise, the exact shape of the wave would remain intact. Similarly, a linear attenuator section would decrease the amplitude of the wave, but would not change its shape otherwise. A non-linear device changes the input wave form, thereby introducing frequency components that do not exist in the input wave form.

NON-LINEAR EFFECTS IN SEMICONDUCTOR DEVICES

Semiconductor diodes and transistors are composed of pn-junctions or of Schottky junctions. The "I-V" characteristic (or the junction current as a function of the impressed voltage) of either junction is exponential in nature [2]. These I-V characteristics of these junctions are inherently non-linear, in fact, they rectify an impressed signal.

Rectification [1] is generally defined as the process of converting an alternating current to a unidirectional current. A rectifier conducts current substantially in one direction only. The output waveform is definitely not a faithful replica of the input!

PIN diodes behave linearly and exhibit low distortion over the ranges of input power, frequency, and bias conditions specified by their manufacturer. This is due to the presence of stored charge in the I-region, as discussed in Chapter 1 and Appendix A. But at sufficiently low frequencies and /or high RF power, they will begin to rectify because the stored charge is insufficient to control the large RF current present. In general, non-linear effects in PIN diode circuits can be minimized by choosing the appropriate PIN diode and bias conditions for the application.

Distortion Parameters:

All circuits which contain non-linear elements such as diodes and transistors produce certain kinds of distortion to various degrees. The primary source of distortion in PIN diodes is conductivity modulation of the charge within the I-layer of the diode under forward bias and capacitance modulation of the diode under reverse bias. Distortion can be controlled by the proper choice of diode characteristics and by the design of the switch circuit itself. The three types of distortion which are most often of concern are as follows:

HARMONIC DISTORTION:

This is a single-tone distortion product, resulting when a voltage at a single frequency f, applied to a non-linear device, creates spurious voltages at frequencies 2f, 3f, …, Nf. Of most concern, because they are the closest to the desired signal, are the second and third harmonics. The order of the distortion product is given by the frequency multiplier; for example, the second harmonic is a second order product.

INTERMODULATION DISTORTION:

This is a multi-tone distortion product. It results when two or more signals, of equal or unequal amplitude, mix in a non-linear device to produce unwanted signals whose frequencies are related to these of the original input. The number of signals may exceed 10, and analysis becomes very complex. To keep matters as simple as possible, many semiconductor manufacturers make two-tone measurements using two voltages which are equal in amplitude and closely spaced in frequency. Given two such input signals at frequencies f_1 and f_2, one can compute several significant intermodulation distortion products from the equation

$$Mf_1 \pm Nf_2$$

where M, N = 1, 2, 3, ….

The order of the distortion product is given by the sum M + N.

Of the infinite number of distortion products described by this equation, one is of special significance. The third order products:

$$2f_1\text{-}f_2 \text{ and } 2f_2\text{-}f_1$$

These are important because they exist on either side of the original signals f_1 and f_2 and they cannot be removed by filtering in a narrow band system.

CROSS MODULATION DISTORTION:

This is another form of multi-tone distortion. The non-linear device causes modulation on one signal of frequency f_1 to be transferred to a second signal or carrier of frequency f_2. The intercept point for this distortion product is generally 2.5 dB below that for the third order harmonics [3]. Figure E.1 shows the output of a bridge-T attenuator fabricated with UM9552 devices with the following test conditions:

f_1 = 99 KHz f_2 = 101 KHz
f_2 is AM modulated at 50% with a 400 Hz signal
The attenuation is 23.9 dB and the return loss is 23.9 dB

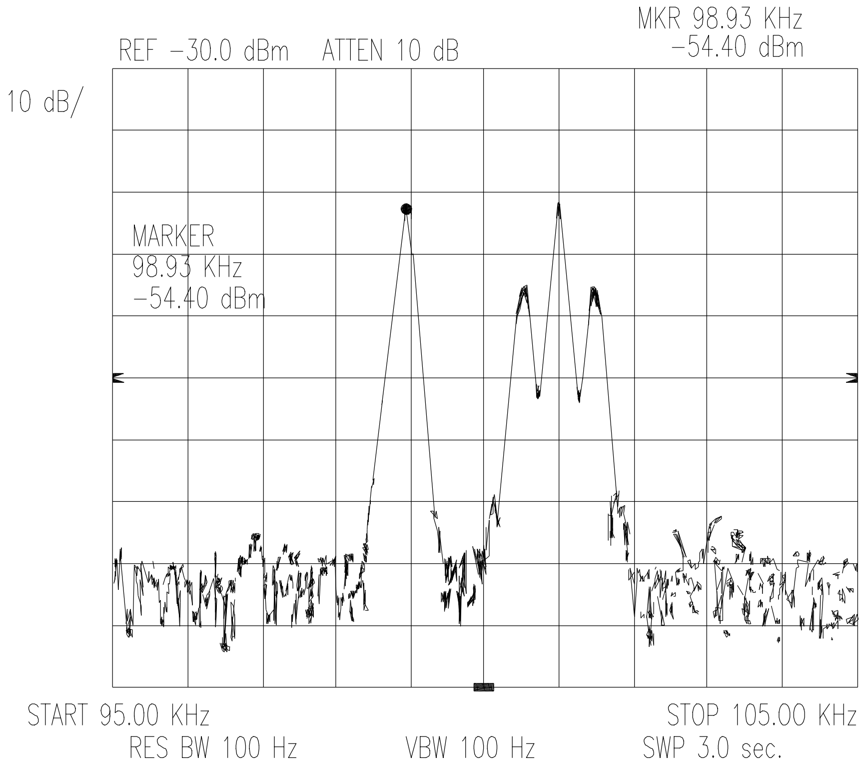


FIGURE E.1 CROSS MODULATION

A theoretical treatment of the effect of non-linearities on multitone signals can be found in reference (4).

Why do we measure third order intermodulation distortion (IMD)?

Two-tone third order intermodulation is a common problem in narrow-band systems. When two (or more) signal are present in a system, strong harmonic components are often generated (See Figure E.1). In cases where two signals are present, the two signals (f_1 and f_2) mix with each other's second harmonic ($2f_1$ and $2f_2$) and create distortion products evenly spaced about the fundamentals ($2f_1$-f_2 and $2f_2$-f_1). Components such as amplifiers, mixers, and filters can generate third order intermodulation products. These distortion products can degrade the performance of many communication systems, such as FM and AM transceivers and high frequency radio teletypes. For example, signals transmitted with excessive third order IMD can interfere with other transmissions. Receivers must also be distortion-free, especially in the preamplifier stages, to prevent crosstalk between adjacent channels.

A good example is using the IS-54 standard for North American Digital Cellular.

Tx = 824 - 849 MHz
Rx = 869 - 894 MHz

For third order IMD, assume two transmitters

f_1 = 824 MHz f_2 = 849 MHz

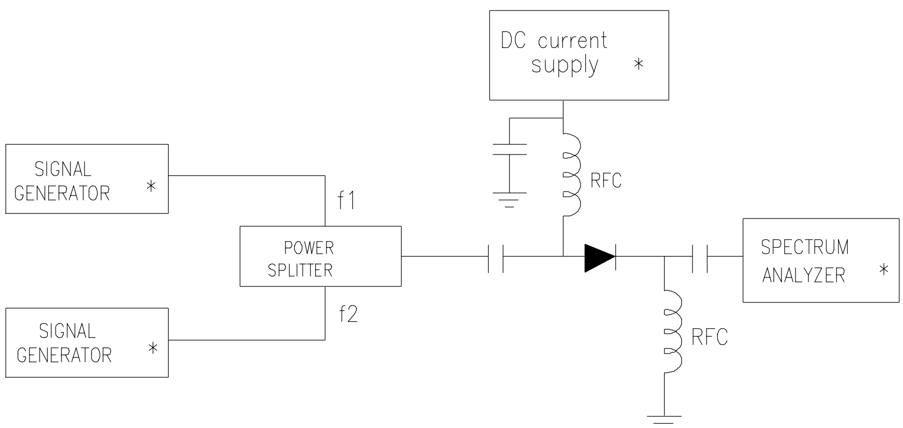
Then $2f_1 - f_2$ = 799 MHz
$2f_2 - f_1$ = 874 MHz this in the middle of the receive band !

This is the reason why component engineers are wanting to specify switching devices with IMD products that are >80 dB below the carrier level.

DISTORTION TEST PROCEEDURE AND SETUP

Distortion is by the two tone Third Order Intermodulation Distortion method. The test setup for the IM3 measurements is show in Figure E.2. This setup was adapted from Hewlett Packard's Product Note 8566B/8568B-1. [Third Order Intermodulation Distortion Measurements. A Downloadable Procedure for HP 8566B and 8568B Spectrum Analyzers]. Our setup is basically the same as HP's without the low pass filters. We use only low power generators but with very low noise and avoid the problem of noisy power amplifiers. The two signal generators are HP 8656B. We have standardized on setting the frequency of the two tones at ± 1 KHz of the required frequency. This makes it next to impossible to filter some of the noise the you are trying to measure. It also allows the spectrum analyzer to display the two IM3s and the two tones together.

The two tones, f_1 and f_2, are combined with a HP 11667A power splitter and feed directly to the PIN under test. The PIN is biased [forward or reverse] by inserting two bias tees. If the PIN has any nonlinearity this will generate distortion products. In cases where two signals are present, the two signals (f_1 and f_2) mix with each other's second harmonic ($2f_1$ and $2f_2$) and create distortion products evenly spaced about the fundamental ($2f_1$-f_2 and $2f_2$-f_1). The fundamentals and the IMD products are then displayed on the spectrum analyzer.



- May be controlled with the IEEE-488 BUS CIRCUIT

FIGURE E.2