GENERAL DYNAMICS
SATCOM Technologies

Characterizing SSPA Linearity

Figure 1: MPKOG141100M 1100W Ku-Band GaN ModuMAX System

Introduction

Perhaps the most important performance parameter for high power amplifiers (HPA) used in SATCOM applications is the ability to amplify signals with minimal added distortion. Distortion is present to some degree in every type of power amplifier, and results from nonlinear amplification as the output level generated by the HPA increases. The most problematic side-effects of non-linearities are unwanted frequency products, spectral spreading, reduced signal-to-noise ratio (C/I), and phase changes with amplitude variation. All of these result in reduced link performance through higher bit error rates. Additionally, the requirements for simultaneously amplifying multiple carriers and digitally modulated carriers with high peak-to-average power ratio can further impact HPA linearity. This paper describes and defines several key methods for characterizing amplifier nonlinearity, and presents the linear performance capability for General Dynamics SATCOM Technologies' new generation, GaN-based, 1100W Ku-Band ModuMAX SSPA system based on those methods.

ModuMAX Product Family

General Dynamics SATCOM Technologies' ModuMAX product line has set the standard in SATCOM SSPA performance and reliability for two decades. The multi-module ModuMAX platform form offers high power and linearity, with the added reliability of soft-fail, hot-swap operation for SSPA modules, power supplies, and fans. The product line has recently been upgraded to employ higher power/higher linearity GaN transistor technology. This newest ModuMAX product attains saturated output power of 1100 Watts, with guaranteed linear power of 540 Watts.

Defining Linearity

SATCOM system integrators and SSPA designers need clear and acceptable criteria to determine, specify, and compare SSPA linearity. To this end, three common definitions have been developed for quantifying SSPA linearity. These include: Two-Tone Intermodulation Suppression, Spectral Regrowth, and Noise Power Ratio. A brief discussion of each method follows.

2-Tone Intermodulation Suppression

Measuring 2-tone intermodulation suppression is the simplest and most widely used method for determining amplifier linearity. This test involves injecting 2 CW tones at different frequencies and of equal level into the amplifier. When these fundamental tones are amplified, non-linear effects within the amplifier generate a wide spectrum of additional products at known frequencies based on frequency separation of the input tones. These additional frequencies are called intermodulation products, often shortened to 'intermods'.

The power levels of the indexed intermodulation products are directly related to the mixing order of the 2 fundamental tones and how hard the amplifier is driven. Fortunately, many of these non-linear products have little impact on overall amplifier linear performance because they are either located at frequencies far offset from the input carriers, or at a low power levels. Figure 2 shows a typical output spectrum for a 2-tone intermodulation test.

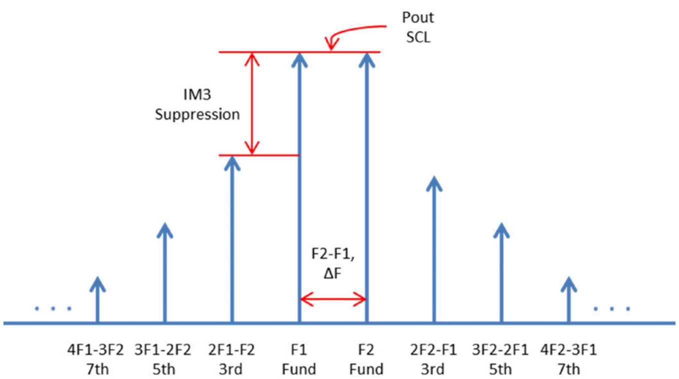

Figure 2: 2-Tone Intermodulation Spectrum

Of primary concern are the intermod products located nearest to the fundamental tones. Due to level and proximity to adjacent channels, these products offer the greatest concern for signal integrity and interference. These close-in intermod products are generally limited to 3rd and 5th order pairs.

Commercial satellite operators typically require the level of any intermodulation product must be at least 25dB below the level of the fundamental tones. This is depicted as IM3 Suppression is Figure 2, but applies in an equal manner to 5th or 7th order products.

The concept of linear output power level, or Plinear, is defined as the sum of the average output power of the 2 fundamental tones (or Total Output Power, 'TOP') when the highest generated intermod product is 25dB below either fundamental tone power. For the MPKOG141100M ModuMAX system, Plinear is defined to be +57.3dBm (540W), minimum, for tones separated by 5MHz.

Spectral Regrowth

Spectral regrowth is a phenomenon related to digitally modulated carriers, and is generated in SSPAs through the same non-linear mechanisms as intermodulation. Digitally modulated carriers appear as finite bandwidth signals in the frequency domain. That bandwidth is dependent on the modulation type and data rate. Much like intermodulation products, spectral regrowth appears as lower level products or 'shoulders' on either side of the digital carrier. These shoulders act to reduce C/I ratio and spread the carrier bandwidth, thereby, presenting the potential to cause interference with adjacent carriers. Unlike 2-tone intermodulation, spectral regrowth can develop for the case of an SSPA amplifying a single digital carrier. This is driven by the inherent bandwidth of the modulated carrier.

Since there are finite carrier bandwidths to consider, and the regrowth shoulders often slope away from the main carrier, spectral regrowth is most often characterized at a given offset from the center of the modulated carrier. This is often expressed as a multiplied factor of signal symbol rate, normally 1.0 or 1.5 times the symbol rate. Figure 3 is a spectrum analyzer screen capture for a typical spectral regrowth measurement.

Commercial satellite operators typically define linear power for digital carriers to be the total output power where spectral regrowth levels are 30dB below the main carrier level at an offset of 1.0xSymRate.

In terms of spectral regrowth-defined Plinear, the MPKOG141100M ModuMAX system offers output power greater than +57.3dBm (540W) for single OQPSK or QPSK carriers with symbol rates of 2.048Mbps and filter factor α=0.2. Typical performance exceeds +58dBm (630W).

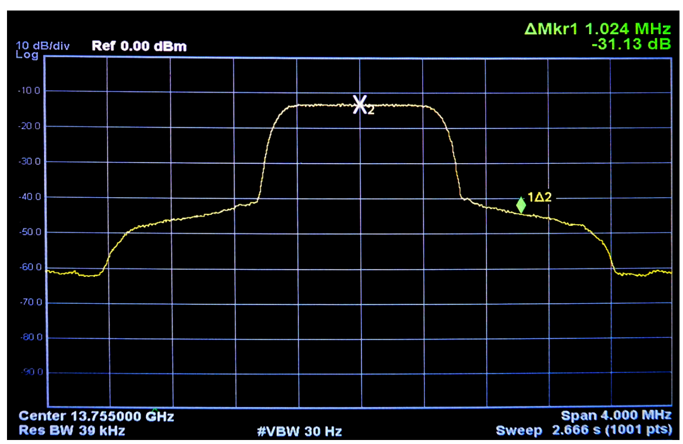

Figure 3: Spectrum Analyzer Response for QPSK Spectral Regrowth Measurement. Delta marker is positioned at 1.0xSymbol Rate

Noise Power Ratio

Noise power ratio ('NPR') was devised as a measure of SSPA linearity for systems that uplink many carriers simultaneously. In effect, an NPR measurement is an extension of the 2-tone intermodulation technique, but with 10s or 100s of carriers present. Intermodulation product generation for the multi-carrier condition develops a highly populated spectrum. This results in the intermod products becoming closely spaced ultimately resembling an elevated noise floor. To better utilize this elevated noise floor, the NPR measurement setup typically employs a narrow band notch filter to effectively remove carriers from the center of the carrier bandwidth. This collective spectrum, with notch, is then injected into the amplifier under test.

For a perfectly linear amplifier, the output level of the multiple fundamental tones will increase, but the notch will remain unpopulated with intermod products. For a nonlinear amplifier, the output signal will show this notch partially filled. As output signal level increases, the amplitude of the intermod products will also increase, but at a higher rate than the fundamental tones. This effectively reduces the difference in power levels between the amplified tones and the intermods generated within in the notch. This difference in power levels represents a C/I ratio and defines NPR. Satellite operators typically require NPR greater than 25dB when operating at Plinear. Figure 4 illustrates a typical output spectrum for an NPR measurement.

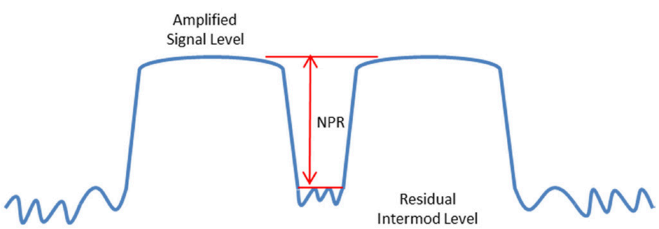

Figure 4: Typical NPR Measurement Output Spectrum

When tested in a multi-carrier environment, the MPKOG14100M ModuMAX SSPA system produced greater than +57dBm (500W) at an NPR of 25dB. This test condition represented 400 carriers equally spread over a 40MHz bandwidth.

Summary

Distortion-free, linear performance for SSPAs employed in SATCOM applications is a critical performance parameter. Several methods have been developed to characterize linearity, including 2-Tone Intermodulation Suppression, Spectral Regrowth, and Noise Power Ratio. The goal of all these measurements is to define a maximum output power, Plinear, for which guaranteed linearity can be obtained under specific conditions. General Dynamics SATCOM Technologies' new Ku-band ModuMAX SSPA system, MPKOG141100M, has been developed to utilize the higher power capabilities offered by GaN transistor technology. The system offers excellent linearity for modern SATCOM installations. Table 1 summarizes typical Plinear capabilities for the MPKOG141100M when tested under conditions described by 2-tone IM suppression, spectral regrowth for digital carriers, and multi-carrier noise power ratio.

Test Method	Condition	Definition	Plinear
2-Tone Intermodulation Suppression	2 Equal-Power CW Tones Separated by 5MHz	Total Average Output Power when IM Suppression is -25dBc	>+57.3dBm (540W)
Spectral Regrowth	QPSK, 2.048Msps, α=0.2 OQPSK, 2.048Msps, α=0.2	Total Average Output Power when Spectral Regrowth Suppression at 1.0xSR is -30dBc	>+58dBm (630W)
Noise Power Ratio	400 Carriers Spread over 40MHz	Total Average Output when NPR is -25dBc	>+57dBm (500W)

Table 1: MPKOG141100M Typical Plinear Performance

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