Procuring useful power for Test and Measurement Applications
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Introduction

This article outlines some fundamental questions to be asked prior to committing to the purchase a high power, multi-octave band amplifier for test and measurement purposes.

These amplifiers represent a significant capital equipment purchase, with values in the range of RMB 200,000 to RMB1, 000,000 and therefore all stages of the decision process require rigorous attention.

Typical test and measurement amplifier applications include generating the power for the electromagnetic fields required in EMC test labs, which then test for compliance to RF immunity standards. They will also be used as sources of high power RF for the testing of the constituent components of new wireless basestation configurations (e.g. new RF transistors).

This article focuses on two related amplifier parameters - "linearity" and "useful power".

Amplifier Linearity

All linear systems, when given a sufficiently strong input signal, will reach a point where the system departs from a linear relationship between input and output. At this point the system is said to be going into compression or beginning to saturate.

An example of this would be the amplifier represented in the graph in Figure 1 (a MILMEGA AS0822-200). This is a plot of input power vs output power for a CW (continuous wave) input and a pulsed input at a spot frequency of 1900MHz. (Note that the result will be different for different frequencies in the operating frequency band of the amplifier)
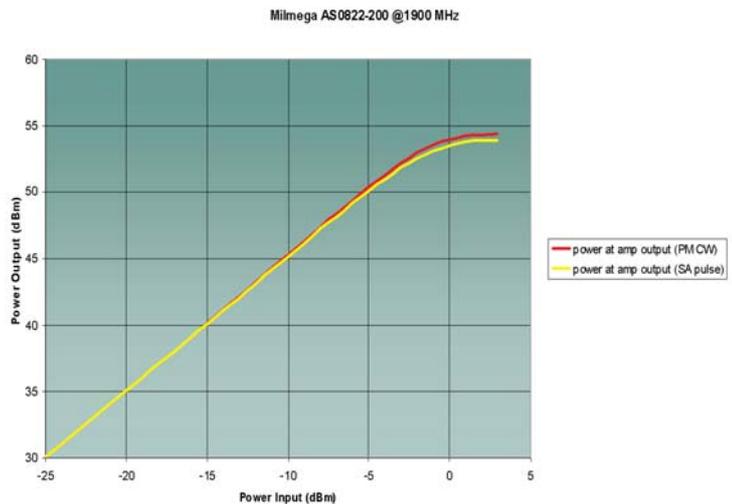

Figure 1

In the example, the performance of the amplifier is linear up to an input signal of value –3dBm. This means there is fixed value relationship between the input power and corresponding output power, up to an input value of –3dBm. This fixed value is referred to as the gain of the amplifier. From Figure A it can be seen that an input power of -20dBm produces an output power of 35dBm i.e the amplifier gain is 35 – (-20) = 55dB. Similarly, for an input of –10dBm, the output is 45dBm i.e. the gain is 45 – (-10) = 55dB. The gain is therefore constant at 55dB up to the point when compression begins.

Beyond this point, the linear relationship between input and output is no longer valid and the amplifier is no longer considered to be linear.

The output power of an amplifier cannot increase indefinitely and when an increase in input power generates no discernible increase in output power, the amplifier is said to be saturated, and by definition the output is not proportional to the input signal. This point is often referred to as Psat on a datasheet or sometimes P3dB. For the amplifier in the graph, this occurs at an output power of approximately 54.5dBm

Generally, saturated power is simply unusable in the majority of test measurement applications, for reasons that will become apparent later.

An internationally recognised figure of merit, used for defining the extent of linearity of an amplifier, is the 1dB compression point. This is the point of –1dB departure from linearity. In Figure A, this will occur when (Pout –Pin) = 54dB. This corresponds, in this example, to an output power of approximately 53dBm. The minimum compression power available is usually specified on a datasheet as P1dB minimum.

In the context of the test application, when looking at an amplifier datasheet, the first questions to ask are therefore:

- Does the frequency band of the amplifier meet the frequency response requirements of the test system?
- Is the power defined in terms of saturated (Psat or P3dB) or linear (P1dB) power?

Power related distortion products –the concept of useable power

All power transistors, used in the design of RF and Microwave amplifiers, are essentially non-linear devices. This non-linear behaviour causes distortion products to be generated as the amplifier compresses. As the amplifier approaches saturation, a sine wave at the input of the amplifier will be transformed into a square wave at the output. This gives rise to a rich harmonic content at the output - as would be expected from the mathematical analysis of a square or "close to" square wave.
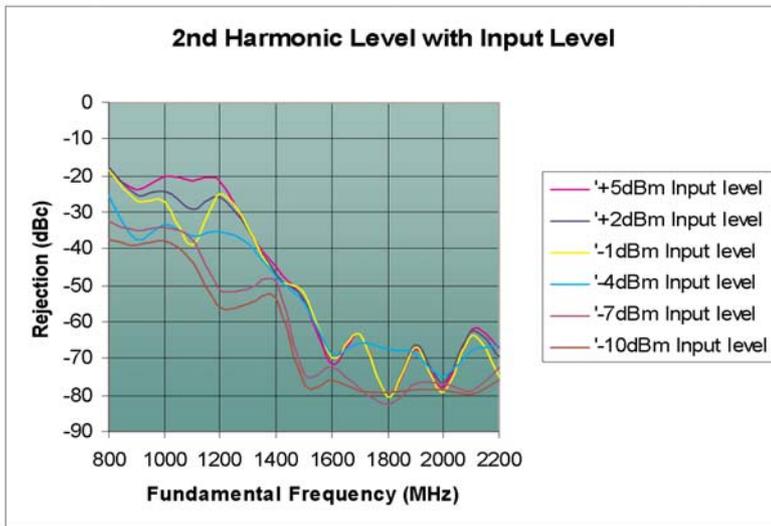

Figure 2

Typically the harmonics of interest are those that are twice and three times the fundamental frequency i.e. the second and third harmonic.

How harmonic content increases with input power can be seen in Figure 2. The diagram shows the level of second harmonic present in a MILMEGA 800MHz to 2200MHz, 200W P1dB amplifier at various drive levels.

A +5dBm input power level corresponds to the amplifier being fully saturated. An input power level of minus (-)10dBm corresponds to the amplifier operating in a very linear manner. As an example, if you look closely at the data for the fundamental frequency of 1000MHz you will see that the 2nd harmonic increases by 20dB as the amplifier goes from linear operation to saturation.

There is therefore a 100 fold increase in harmonic power at Psat compared to the linear region. Ensure that the amplifier manufacturer defines where the harmonic level for the amplifier has been measured and satisfy yourself that this corresponds to the maximum power at which you intend to use the amplifier.

During a RF test scenario, the presence of harmonic power will distort the accuracy of the calibration results, as the test engineer cannot separate out the field of the fundamental frequency and the field created by harmonic power

As a rule of thumb, if the harmonic energy is 20dB lower than the fundamental energy, the impact of harmonic energy can probably be ignored.

It is important to ensure that the maximum amplifier harmonic levels quoted by the manufacturer are referenced to a power that is either equal to, or greater than, the power you need to deploy in your test set up. You can then be confident that harmonics will not adversely impact on your test system.

We now have some further questions to ask when looking at an amplifier datasheet. These are:

- Is there a declared harmonic level specification? If not, then why not?
- Does the specification state at what power the harmonics were measured at?
- Is this power level either equal to, or greater than, the power you require for your test application?
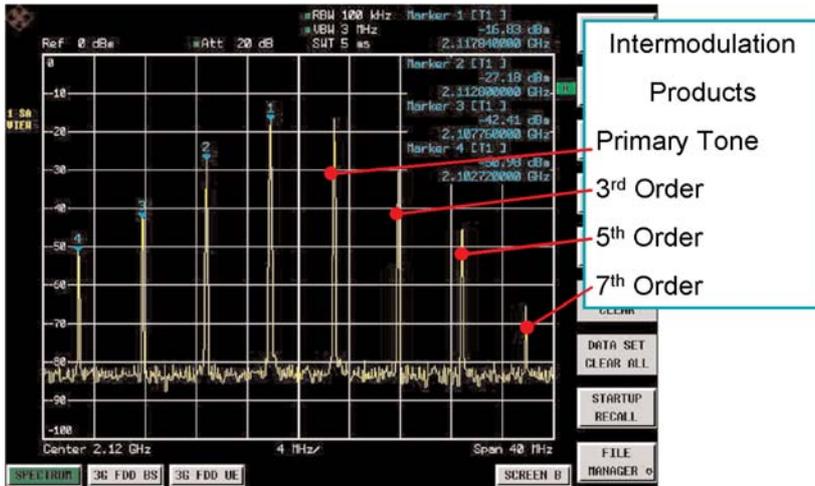- Is the amplifier power, from a harmonic perspective, therefore useable?

Figure 3

From a communications test systems perspective the concept of intermodulation distortion (IMD) has been used as a traditional measure of linearity. Of particular interest is how the system performs when two tones, closely spaced in frequency, are introduced to the input of the amplifier. If we designate these two tones to be F1 and F2, they will generate, because of the non-linearity of the amplifier, additional tones of frequencies 2F1-F2 and 2F2-F1. These new spectral components are termed third-order intermodulation distortion products (IM3) and cannot be removed by filtering (see Figure 3).

If the manufacturer provides the value for the amplifier's third order intercept point (OIP3), then it is possible to calculate the magnitudes of the distortion products. This done by noting that, for a 0dBm two-tone signal input, the third order intercept is equal to minus 0.5 of the third order product magnitude for a unity gain device. For example, given a third order intercept point of +20dBm and a two tone input signal with magnitude 0dBm, the third order distortion product magnitudes would be 20 divided by (-0.5) = -40dBm.
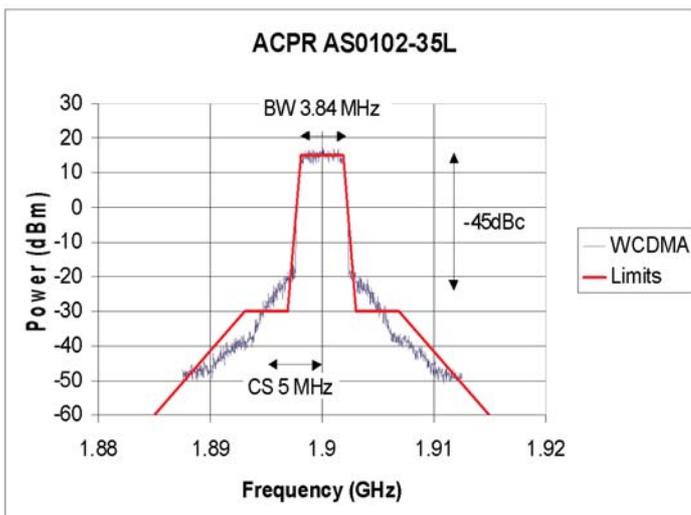

Figure 4

Modern communication systems, utilising some form of digital modulation to encode information on to an RF carrier, will use ACPR (Adjacent Channel Power Ratio) in preference to IMD as a quality measure. ACPR is a measure of how much energy is leaking into adjacent communication channels, as a result of non-linearities in the amplifier. Each modulation type will define acceptable performance via a "spectral mask".

Such an example is shown in Figure 4 with the spectral requirements for a WCDMA system defined by the red mask and the amplifier performance defined by the blue frequency response

We now have some two further questions to ask when looking at an amplifier datasheet. These are:

- Has the amplifier manufacturer specified the amplifier's third order intercept point?

- Are they able to provide data showing compliance to the appropriate spectral mask requirements?

Spurious signal products

Spurious signal products are those introduced by the amplifier but which are non-signal related i.e. they are neither harmonics nor IM products. They may be caused by a low level instability in the amplifier (evidence of poor design) or they may be introduced into the amplifier from external sources e.g via the power supply, radiated interference or even local lighting.

Spurious signal power is usually defined at a level relative to the fundamental signal and levels of minus 70dBc are typical for a good amplifier design.
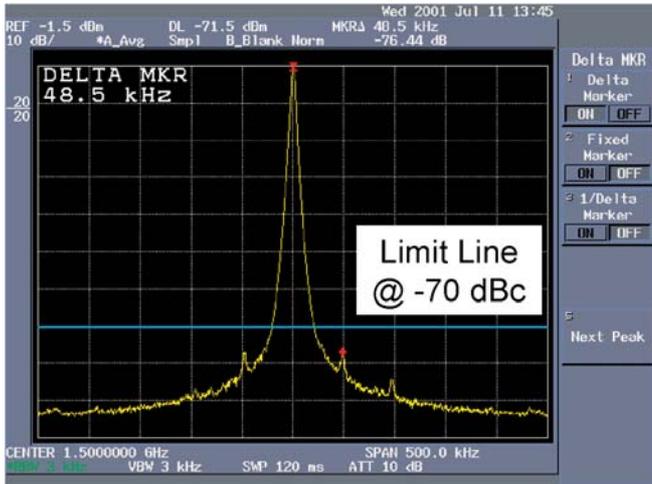

Figure 5

The most likely source of spurious in a well designed amplifier will be the switching power supply, generating spurs at it's operating frequency – which is usually 100's of kHz. Figure 5 shows an example of power supply induced sidebands.

The area between the maximum spurious power level and P1dB, is the usable range over which the test engineer can be confident that the device under test is subjected only to an amplified reproduction of the input signal i.e. that it is not being modulated by the presence of spurs or high harmonic levels.

We now have another question to ask, in the context of communication test system:

- Does the level of spurious defined for the amplifier ensure an adequate operating power range for the test system application?

The use of the descriptors "rated" and "typical"

Having ascertained the definition of power, in terms of Psat and P1dB, and determined the potential usability of the product (with respect to harmonic distortion), the next area requiring attention are the parameter qualifiers attached to the data entries on the amplifier data sheet.

There are several qualifiers of particular interest that are in general usage. These are rated, typical and guaranteed minimum.
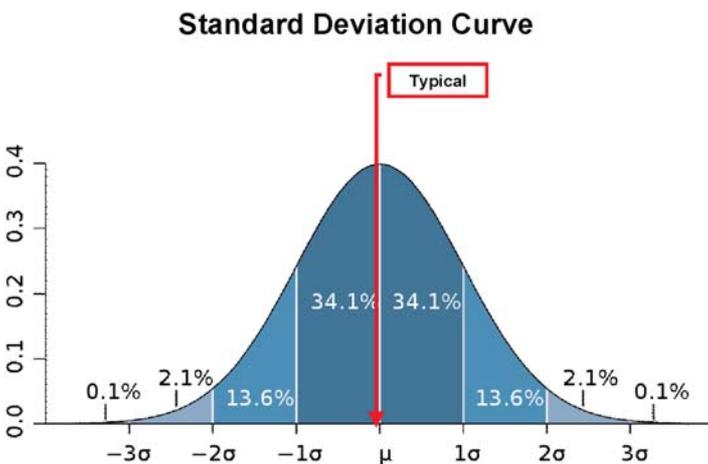

Figure 6

The qualifier "rated" is essentially meaningless from a user perspective – it is the descriptor that the manufacturer has assigned to a product and it comes with no guarantees of performance. It is a term that is best ignored when making a purchasing decision.

The descriptor "typical" (or "nominal") has widespread usage. In general terms it describes the most likely occurring value within a process which outputs a product of naturally occurring variances.

The output variation of such a process can be described in terms of a distribution around a mean (or typical) value. Figure 6 shows the most commonly occurring distribution in processes with natural variations. This is often referred to as a Bell Curve.

On a Bell Curve, the vertical axis is scaled appropriately to reflect the sample size so that a user can determine the cumulative values within a particular range or a sum of ranges. The horizontal axis maps the process variation, centred on a mean or typical value, in 6 equal steps – called standard deviations. There are 3 negative values to get from the minimum value outputted by the process to the typical value and 3 positive values to get from the typical value to the maximum value outputted by the process.

The curve shows that for a standard industrial process a manufacturer can expect 50%of their output to be above an average level (the typical value) and 50% to be less than average. The lower the deviation value, the more tightly controlled the process.

In an amplifier these deviations (the horizontal axis) would be in watts. As an example, suppose we had a process that produced an amplifier of output power 200W typical and the deviation step size was 10 Watts. From these numbers we could determine facts such as the following:

1. The minimum value (or minimum power amplifier) produced by the process would then be 200W minus (3X10) = 170W.

2. The maximum value (or maximum power amplifier) produced by the process would be 200W plus (3X10) = 230W.

3. A purchaser can expect that 34% of amplifiers produced, using this process, to have values between 200 and 190W (i.e. within one standard deviation from the mean).

It can be seen that purchasing a product on typical values, without knowledge of the process variations, is a high risk strategy. It is essentially a gamble that you will get what you need.
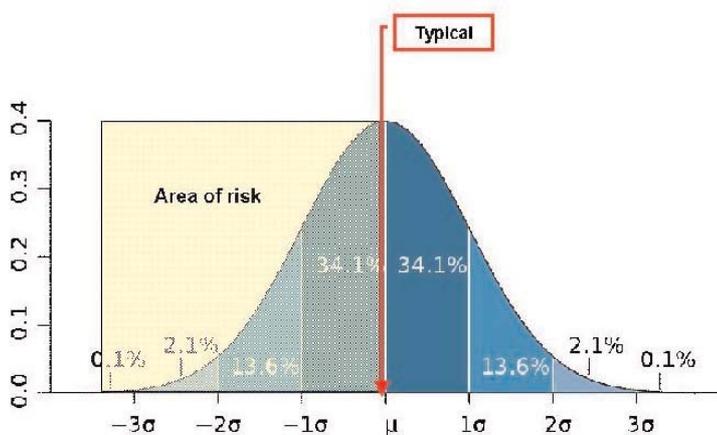

Figure 7

In the above example if you require 200W for your application but the manufacturer delivers you a 170W amplifier (the minimum value for the process) then you have a problem and the manufacturer does not

If you purchase typical performance, the yellow shaded area in Figure7 is the area of risk that you are operating in. If the amplifier you buy was sold on typical performance and you need typical performance then you are likely to be disappointed.
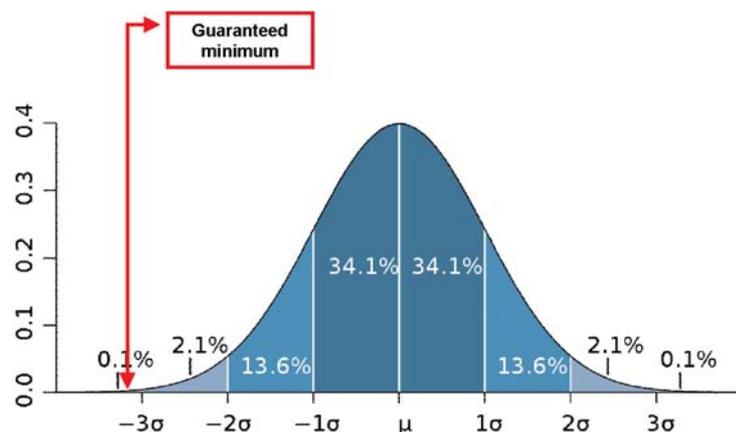

Figure 8

The way to avoid disappointment is to work with guaranteed minimum values (see Figure 8). By doing this you can be certain that what you will purchase will meet all aspects of your test system power amplifier requirements.

Good advice would be to avoid making a large capital purchase based on typical data. Asking the following questions though will help de-risk the process:

- What is the sample size on which the stated typical power is based? If it is 1000 then it represents a mature process. If it is smaller than 10 it is evidence of an immature or statistically inadequately defined process.

- What is the standard deviation step size for the process?

- Given the step size, what is the probability that I will be disappointed if I purchase using typicals?

Summary

Prior to making your decision on your capital equipment purchase, a decision which you will have to live with for up to 5 years, review each amplifier manufacturer's specifications carefully. Ask yourself the following questions:

1. Does the frequency band of the amplifier meet the frequency response requirements of the test system?

2. Is the power defined in terms of saturated (Psat or P3dB) or linear (P1dB) power?

3. For the parameters important to my application, has the manufacturer defined guaranteed minimum performance levels or have they described performance as typical?

4. Am I prepared to take the risk that I may get a typical amplifier? If I am prepared to take the risk, can the manufacturer help to mitigate the risk by defining the probability that I will be disappointed?

5. Have the expected harmonic levels been defined? Have they defined these as guaranteed maximum or as typical values?

6. Are the harmonics defined at a power that is useful in the system?

7. Has the amplifier manufacturer specified the amplifier's third order intercept point?

8. Is the manufacturer able to provide data showing compliance to the appropriate communication system spectral mask requirements?

Having asked the above questions and satisfied yourself regarding the quality of the answers, you should be in a good position to proceed with your purchase

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