Advancements in Broadband Amplifiers

White Paper

Products:

- R&S®BBA130

White Paper
Paul Denisowski
6.2018 – 01.00

ROHDE&SCHWARZ

Table of Contents

1 Amplifier Fundamentals

1.1 What is a "smart" amplifier?

In its simplest form, an **amplifier** is an active device that takes an input signal and produces an output signal that is a copy of the input signal, but having increased amplitude.

There have been many changes over the years in how RF amplifiers are constructed, such as tube (or "valve") amplifiers being replaced by solid-state, transistor-based amplifiers. The basic amplifier design and mode of operation have however remained relatively unchanged until recently. Traditionally, parameters such as operation class or output power were more or less "fixed" by the design of the amplifier, and could not be easily or dynamically changed. This, in turn, restricted one's ability to use a given amplifier in a wide variety of applications or to adapt the amplifier characteristics to meet different use cases or testing environments.

This whitepaper discusses several recent advancements in amplifier design. These innovations provide substantial improvements in terms of both flexibility and efficiency, creating a new class of "smart amplifiers." Unlike traditional amplifiers, these "smart" amplifiers allow user-defined, dynamic, and simultaneous variation of the core amplifier parameters (such as operating class and VSWR tolerance) during operation, thus enabling the optimization of performance for an extremely wide range of applications

1.2 Classes of Operation

Amplifiers are frequently grouped into **classes of operation** based on their bias point setting. Classes of operation are defined in terms of the amplifier's **conduction angle**, or the percentage of the time during which the amplifier is conducting power or "amplifying." For example, a conduction angle of 360° means that the amplifier conducts over the entire input power cycle (100%), whereas a conduction angle of 180° means that the amplifier only conducts over half of the input power cycle (50%). Higher conduction angles mean higher linearity (i.e. the output is a more precise reproduction of the input) but at the cost of lower efficiency. Furthermore, the operating class also can have a significant influence with regards to the time-domain representation of the signal, particularly in the case of non-continuous or pulsed signals.

Amplifiers with a 360° conduction angle are referred to as **Class A** amplifiers and amplifiers with a 180° conduction angle are referred to as **Class B** amplifiers. A compromise between the conflicting goals of linearity and efficiency is the **Class AB** amplifier, which has a conduction angle between 180° and 360°. An amplifier with a conduction angle of less than 180º is called a **Class C** amplifier. Class C amplifiers are even more efficient, but at the cost of significant distortion and non-linearities. There are other amplifier classes (Class D, F, etc.) but these are generally not used in RF applications.

In addition to differences in linearity and efficiency, the operating class of an amplifier also has a substantial influence on other amplifier characteristics, such VSWR tolerance, as well as on the amplifier's size, weight, and cost.

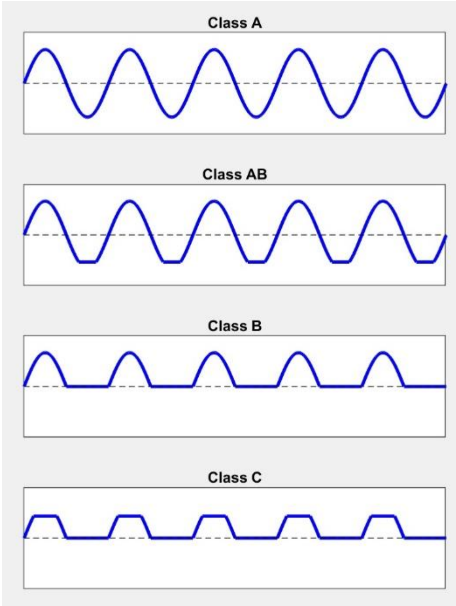

Figure 1 - Amplifier Class and Conduction Angle

The performance characteristics of an amplifier are largely a function of the amplifier's class of operation. We select a Class A amplifier when we need high linearity and a Class B amplifier when efficiency is paramount. As mentioned above, Class AB amplifiers enable a trade-off between linearity and efficiency by setting the bias point somewhere between Class B (180º) and Class A (360º), thus allowing the user to choose an amplifier whose linearity and efficiency most closely match the intended application.

Although Class AB amplifiers therefore would seem to provide the maximum flexibility when choosing an amplifier, it is important to keep in mind that for most traditional Class AB amplifiers, the conduction angle is **fixed**, i.e. it cannot be (easily) changed by the user. If it were possible to provide the user with a **variable** conduction angle, the same amplifier could be used in a much wider variety of applications with the user being able to dynamically alter, via software alone, this balance between linearity and efficiency.

Note too that for a given input power, Class A amplifiers always deliver more output power than Class AB. This is expected, since the slope of the transistor curve (Figure 2) is steeper in the Class A region than in the Class AB region (i.e. when we are "in the bend"). However, when the signal amplitude is very small, the part of the bend where the amplifier operates in Class AB is essentially quasi-linear and in this case we also get good results in terms of linearity.

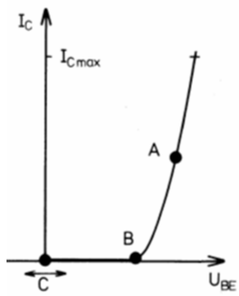

Figure 2 - Typical transistor curve - collector current as a function of the base-emitter voltage

On the other hand, for high drive power levels, the difference between Class A and Class AB is quite distinctive, both in terms of linearity and time domain response (pulse shape). Here a variable conduction angle becomes very helpful: we can operate in Class AB at lower drive power levels, but change to Class A when drive power levels are increased. Operating in Class AB whenever possible is often preferable because the amplifier has better efficiency in class AB (i.e. the transistor does not generate as much heat). This also has significant ramifications when we look at the time-domain response of signals, in particular pulsed signals.

1.3 Linearity and Compression

An amplifier is said to be operating in its "linear" region when there is a fixed increase in output power for a given increase in input power -- i.e. for every X dB increase in input power there is a Y dB increase in output power.

As we increase the input (or "drive") power to an amplifier, eventually a point will be reached where there is no longer a linear relationship between the increase in input power and the increase in output power. When this occurs, the amplifier is said to be in **compression** and amplifier linearity is normally specified in terms of a **compression point**.

The most commonly used compression point is the so-called 1 dB compression point, which is defined as the point at which the actual output power is 1 dB less than the expected output power (for a given input power).

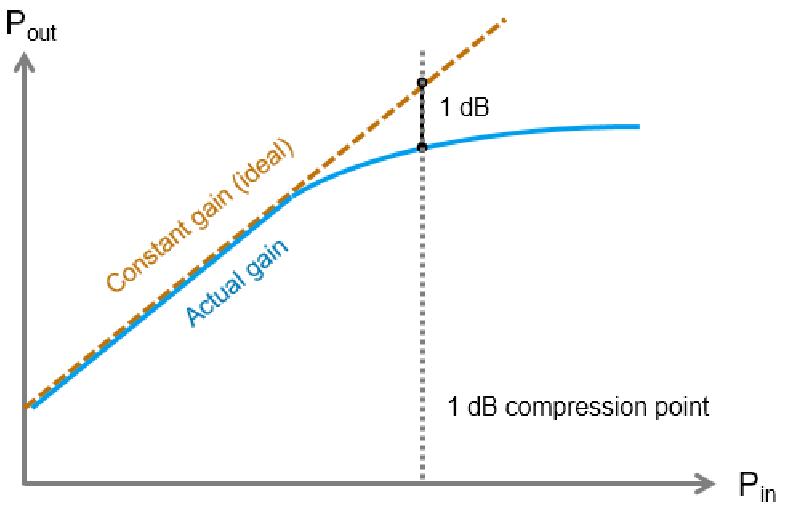

Figure 3 - Gain compression and 1dB compression point

There are numerous consequences that arise when operating an amplifier in compression. The first is rather straightforward: additional increases in input power no longer result in the same increase in output power, and eventually the maximum amplifier output power will be reached regardless of input power -- we simply can't get any more power out of the amplifier.

The second consequence is that amplifiers in compression typically produce harmonics and intermodulation products. These undesired products increase rapidly as the amplifier goes further into compression. This is undesirable for two reasons: the power in these unwanted products is power taken away from power at the desired frequency and these unwanted products may lead to spurious emissions and/or so-called spectral regrowth.

The linearity of an amplifier is almost entirely a function of its conduction angle. Class A amplifiers, with a 100% conduction angle, are the most linear, and linearity decreases with decreasing conduction angle. Although the 1dB compression point is the standard measurement of linearity, it is however a somewhat arbitrarily chosen value that provides very little quantitative information regarding the practical consequences of being "in compression." Many engineers simply choose to "play it safe" and avoid ever operating the amplifier beyond, or even close to, the compression point.

Having the ability to influence the compression point with a variable conduction angle can be highly beneficial in many cases, but in order to gain the maximum benefit from an amplifier with a variable conduction angle, we need information beyond the simple 1 dB compression point measurement. In many cases, the relationship between conduction angle and output signal characteristics is not a straightforward mathematical relationship, but rather a complex function of many variables which must be determined empirically or experimentally for a given application. This is an area of research that has not merited much attention or investigation, largely due to the (previous) lack of broadband amplifiers with adjustable conduction angles.

1.4 Voltage Standing Wave Ratio (VSWR)

1.4.1 What is VSWR?

Maximum power transfer of radio frequency energy to a load occurs when the impedance of the load is the same as the impedance of the source. In this case, these two impedances are said to be "matched," and given a lossless transmission line, all of the output power generated by the amplifier will be absorbed by the load. This represents the ideal situation and provides maximum power transfer to the load -- something that is clearly desirable in most applications.

What happens if the load impedance is not the same as the source impedance? In this case, some of the power transmitted towards the load (the **forward power**) is returned back to the source (the **reflected power**). This results in so-called standing waves on the transmission line between source and load - an undesirable, inefficient, and even potentially hazardous situation.

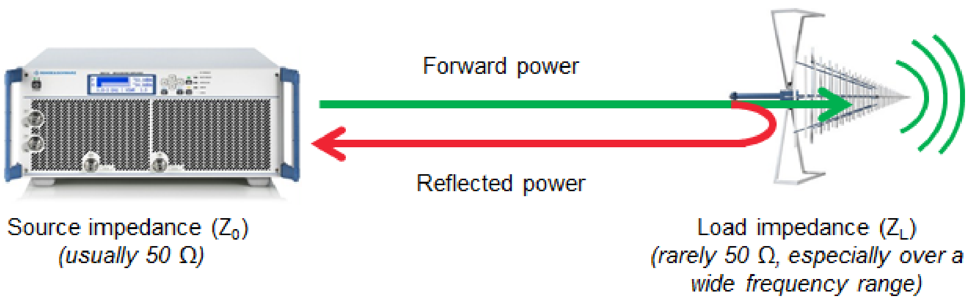

Figure 4 - Forward and Reflected Power

Reflection is quantified by means of a **reflection coefficient**, Γ, which is a function of the load impedance (Z_L) and the source impedance (Z_0).

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

As we will see, the fact that these impedances are complex, frequency-dependent values (R ± jX) has a tremendous impact on the selection and use of amplifiers. This is particularly true in the case of poorly matched or variable-impedance loads

The combination of the forward and reflected waves leads to standing waves on the transmission line. The ratio of the peak voltage to minimum voltage on a transmission line is called the **voltage standing wave ratio** (VSWR - often pronounced "viz-war"). VSWR can be derived from the reflection coefficient Γ as follows.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

VSWR is most often specified either as a ratio (e.g., 2:1) or as a normalized value (2). A VSWR of 1:1 (1.0) indicates a perfectly matched load with no reflected power. Obtaining a perfect or near-perfect match is highly desirable (again, since it maximizes power transfer and minimizes reflected power), but is difficult to obtain over the wide frequency ranges where broadband amplifiers are typically used.

One should also keep in mind that VSWR is a function of both the amplitude and the phase of the mismatch. A given VSWR value can be caused by impedance mismatches that are either higher or lower than 50 Ω. For example, a 2:1 VSWR can be created by either a 25 Ω or a 100 Ω load (in both cases, $|\Gamma| = 1/3$).

1.4.2 VSWR and reflected power

The other complication of higher VSWR is the effect of the reflected power on the amplifier itself. As mentioned above, high levels of reflected power can cause damage to the amplifier. A VSWR of 6:1 corresponds to 50% reflected power, and once VSWR reaches 15:1, more than 75% of transmitted power is reflected back towards the amplifier from the load. Depending on level, the reflected power can cause unacceptable levels of voltage and heating within the amplifier circuitry, resulting in temporary degradation of power output and/or permanent damage to the source.

VSWR	(Γ)	% reflected power
1.0	0.000	0.00
1.5	0.200	4.0
2.0	0.333	11.1
2.5	0.429	18.4
3.0	0.500	25.0
3.5	0.556	30.9
4.0	0.600	36.0
5.0	0.667	44.0
6.0	0.714	51.0
7.0	0.750	56.3
8.0	0.778	60.5
9.0	0.800	64.0
10.0	0.818	66.9
15.0	0.875	76.6
20.0	0.905	81.9
50.0	0.961	92.3

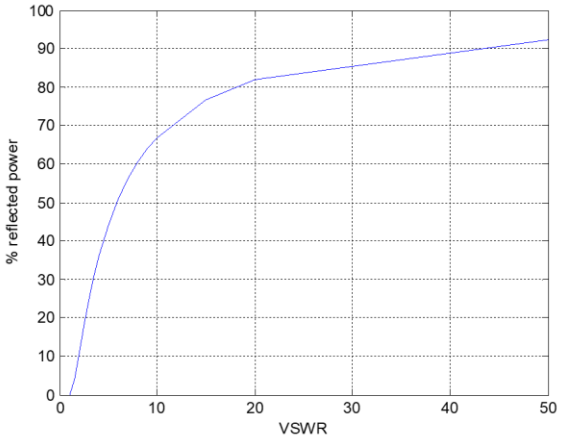

Figure 5- VSWR and % Reflected Power

The simplest way to protect an amplifier from reflected power is to put a fixed attenuator in the path. While this does reduce the level of reflected power seen at the amplifier, it obviously reduces the transmitted power as well.

A more sophisticated method of preventing damage from high reflected power levels is known as **foldback** -- as the reflected power level increases, the amplifier automatically decreases its output power until the magnitude of the reflected power falls to safe levels. Assuming the foldback circuitry can quickly sense and react to excessive reflected power, this approach is fairly straightforward and reliable. Foldback does however have one severe drawback: it reduces the power supplied to the load. Foldback can protect an amplifier from degradation or damage, but at the cost of (often significantly) reduced performance and the inability to achieve the target output power.

While VSWR is used to describe the percentage of power that is reflected, it is the absolute **level** of the reflected power that triggers the foldback mechanism. For example, at a 6:1 VSWR, 50% of the power is reflected, but the amount of reflected power presented to the amplifier depends on the amplifier output level: 50% of 100 watts is far less damaging than 50% of 1000 watts. Therefore it is not enough to simply specify at which VSWR value foldback occurs -- we must also know at what power levels foldback occurs for a given VSWR. An amplifier that folds back to 50% even at full output power and infinite VSWR is clearly superior to one that continues to decrease output power as the reflected power level increases.

1.4.3 Robustness and VSWR

In addition to affecting linearity, amplifier operating class (or conduction angle) also affects the amplifier's ability to tolerate high levels of reflected power -- its so-called VSWR tolerance or robustness.

Class A amplifiers are designed to operate with a 100% conduction angle, and these amplifiers are more robust with regards to high levels of mismatch (VSWR). On the other hand, Class AB amplifiers are much more sensitive to reflected power caused by impedance mismatches.

As mentioned above, when an amplifier is operating into a well-matched load, the percentage of power reflected by the load will be very small, and hence even very large forward power levels will not cause reflected power to reach dangerous (i.e. amplifier-damaging) levels. In other words, we can operate the amplifier in a so-called "high power" mode since the above constraints are not applicable. If, however, we either know or anticipate a non-trivial load mismatch, then it would be prudent to operate the amplifier in a "high VSWR" mode, limiting output power as necessary. One of the advantages of smart amplifiers is that they allow the user to alter the conduction angle and thus choose between high-power and high-VSWR operating modes.

2 Amplifier Parameters and Signal Types

2.1 Continuous Signals

When considering the effect of amplifier parameters on signals, it is helpful to divide signals into continuous (or non-pulsed) and non-continuous (or pulsed) signals. Further categorizing continuous signals into modulated and unmodulated signals is also helpful in understanding the effects of amplifier linearity and compression on real-world signals.

2.1.1 Unmodulated Continuous Signals

The most common application of unmodulated continuous signals is in radiated EMC immunity testing. Here we are primarily concerned with creating a given field strength at a given distance at a given frequency, and this is done by applying a large RF signal to a suitable transmitting antenna. If the amplifier is in compression, it becomes harder to create the desired field strength at the desired frequency because some energy is going into harmonics and intermodulation products.

An additional issue when using unmodulated continuous signals in radiated immunity testing is that the EUT (equipment under test) may appear to be adversely affected during testing at one frequency, whereas in actuality the EUT is being affected by a harmonic or intermodulation product.

In short, when amplifying unmodulated continuous signals, our primary concern is avoiding harmonics and intermodulation products because these will reduce the power at our desired frequency. Acceptable or appropriate levels of harmonics or intermodulation products are largely a function of the relevant EMC testing standards.

2.1.2 Modulated Continuous Signals

For modulated signals, the effects of compression depend on the nature of the modulation involved. In its most basic form, modulation involves changing the frequency, amplitude and/or phase of the carrier in order to convey information. Although there are still numerous wireless systems that vary only a single carrier property (amplitude or phase, e.g.), the majority of modern wireless communications technologies vary multiple properties (e.g. changing both amplitude and phases), on a dynamic basis. There are also applications, such as EMC testing, where pure amplitude modulation is frequently used.

Since operating an amplifier in compression normally causes non-linearities only in the amplitude of the signal, there are several types of continuously modulated signals that are essentially immune to all but the most extreme cases of compression. Simple on-off keying, where the receiver only needs to decide whether a carrier is present or not, is a good example of a modulation scheme that is robust against the effects of compression. Similarly, frequency- and phase-modulated signals are also relatively unaffected by even rather substantial levels of compression, as they convey information by means of changes in frequency and phase rather than amplitude.

As one might suspect, systems which use amplitude modulation or a combination of amplitude and phase modulation could be negatively impacted by non-linearities caused by operating in compression. However, as we will see below, the effects of non-linearities in systems using some form of amplitude modulation are not necessarily straightforward or easy to predict and quantify.

2.2 Pulsed Signals

Non-continuous or pulsed signals are used in a wide variety of real-world applications, including such well-known examples as radar. This is also an area in which conduction angle plays a perhaps somewhat unexpected role is the amplification of pulsed signals. Many applications involving pulsed signals require that the pulses maintain their original "shape" as closely as possible throughout the signal path, and this of course includes amplifiers. This requirement becomes even more critical when there is modulation on the pulse itself, since any distortion in the pulse envelope will lead to a degradation or corruption of information.

At first glance one might expect that the simple solution to providing maximum fidelity (i.e. minimal pulse envelope distortion) while amplifying pulsed signals would be to operate the amplifier with a 100% conduction angle (Class A), similar to the approach taken for maximum signal fidelity in other signal types.

But investigations into the relationship between pulsed envelope shape and amplifier class (using an adjustable bias broadband amplifier) have yielded some interesting results. It would appear that for a given pulse shape, there is clearly an optimal conduction angle that produces the most faithful reproduction of the original pulse envelope -- but this angle is not necessarily 100%. In the Figure 6, the best results were achieved when the conduction angle was at or slightly below 50%

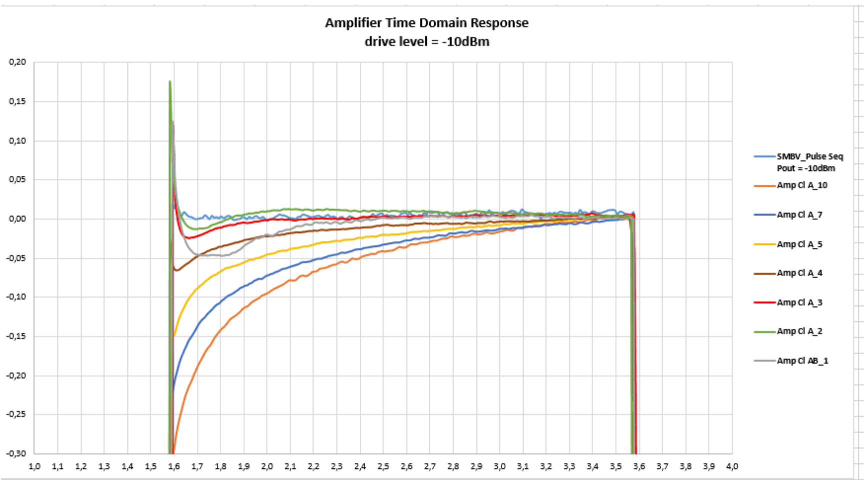

Figure 6 - Effect of conduction angle on time domain response

What are the possible reasons for this behavior? First we need to make several observations. With regards to pulse shape, we know that for small (or short) signal levels in Class A, the transistor temperature does not change much since very little RF is produced. Recall that in Class A, the transmitter has a high bias current and becomes quite hot even when not producing any RF power. This means that if the transistor produces a great deal of RF when being operated in Class A, the transistor will actually cool down, which in turn leads to an increase of gain and a blurred rising edge of a longer pulse.

Another thing to keep in mind is that the amplifier may be slightly overdriven in this case. In the above graph, overshoots can be seen for Class AB (the first 100µs before the forward limitation kicks in). For Class A this is unimportant because at the beginning of the pulse, the gain of the transistor is not as high as in Class AB. The basic rule of thumb here is that for an amplifier being operated in Class A, a "hot" transistor yields less gain.

Regardless of the mechanism involved, it should be clear from the above example that we cannot reliably predict the effect of amplifier operating class on pulse envelope, and hence the ability to alter amplifier operating class allows us to (empirically) determine the optimum conduction angle for a given pulsed signal type.

2.3 Crest Factor / Peak to Average (Power) Ratio

Many types of modulated signals exhibit dynamic changes in their amplitude -- that is, the peak value of the signal varies over time, sometimes significantly. The ratio between the peak transmitted power and average transmitted power is referred to as the **peak-to-average (power) ratio** (PAPR) or **crest factor**. For example, modulation schemes which change only the frequency and/or phase (such as the GMSK modulation used in GSM), the peak-to-average power ratio is very low or zero. In the case of the more "modern" modulation schemes based on OFDM (orthogonal frequency division multiplexing), such as the various flavors of Wi-Fi, LTE, etc., the progressively higher peak-to-average ratios are primarily due to the presence of a large number of OFDM subcarriers.

Standard	Typical PAPR (dB)
GSM	0.0
WCDMA	3.5
HSUPA	7.0
802.11	9.0
LTE	13.0

Signals with non-zero peak-to-average ratios present additional challenges with regards to amplifier design and selection. In order to avoid driving the amplifier (momentarily or periodically) into compression and creating non-linearities, a suitable degree of headroom must be incorporated into amplifier selection calculations. Selecting an amplifier solely based on the expected average value of the signal can cause significant and unexpected consequences when using signals with medium to high peak-to-average ratios.

3 Quantifying Amplifier Performance

3.1 Overview

The effects of amplifier parameters on real life measurements and modulated signals, can be divided into two general categories: in-band signal quality and out-of-band signal quality. Although there are numerous ways of quantifying these effects, the most important measurements with regards to amplifiers are **error vector magnitude** and **noise power ratio** (in-band), as well as **adjacent channel leakage ratio** (out-of-band).

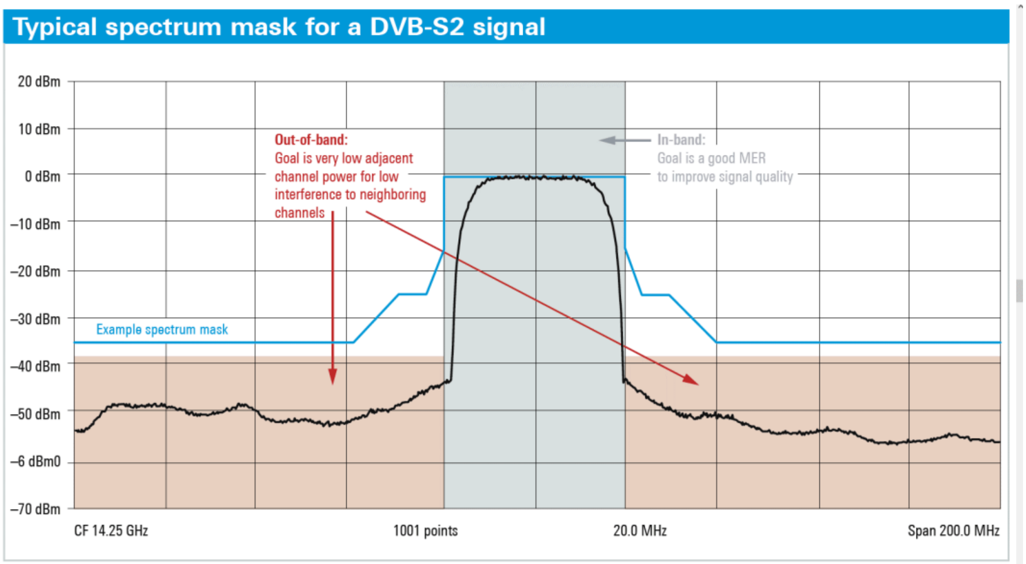

Figure 7 - In-band and Out-of-band measurements

3.2 Error Vector Magnitude Measurements

Many modern radio frequency data communications technologies, such as LTE or various flavors of Wi-Fi (802.11), modulate their OFDM subcarriers using a combination of both amplitude and phase modulation, commonly referred to as quadrature amplitude modulation (QAM). As the number of unique amplitude/phase combinations increases, the information-carrying capability of the system also increases. For example, if we have four unique amplitude/phase combinations or **symbols**, this allows us to send two bits ($4 = 2^2$) per symbol. If we increase the modulation **order** by having, say, sixteen unique amplitude/phase combinations, we now can send four bits per symbol ($16 = 4^2$).

These amplitude/phase combinations are often visualized using a so-called **constellation diagram**. The constellation diagram below shows the decision points for a 16QAM signal:

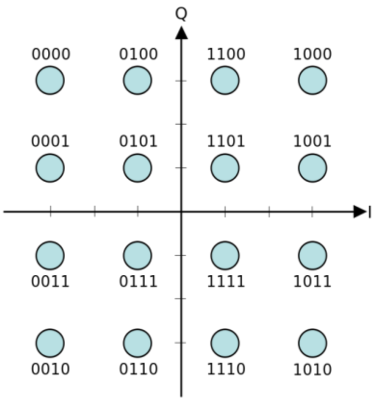

Figure 8 - Constellation diagram for a 16QAM signal

In real-world systems, there will be variation between the ideal constellation points and the actual amplitude/phase combinations in the received signal. In other words, the received signal points will not fall precisely on the ideal signal points. How much the received signal deviates from the ideal decision points is normally quantified in terms of **error vector magnitude**, or EVM. As the name implies, this measurement is the magnitude of the vector connecting the actual signal and the ideal signal as shown below.

There are a couple of important things to keep in mind with regards to EVM. First, if EVM increases above a certain level, the receiver may mistakenly assign the received signal to an adjacent decision point, resulting in (multiple) bit errors. Secondly, as modulation order increases (e.g. if we move from 16 decision points to 64 or 256 decision points), the decision points become closer and closer together and the acceptable level of EVM also decreases. In the case of LTE, for example, the specifications define progressively lower EVM limits as modulation order increases: QPSK (17.5%), 16QAM (12.5%), 64QAM (8%).

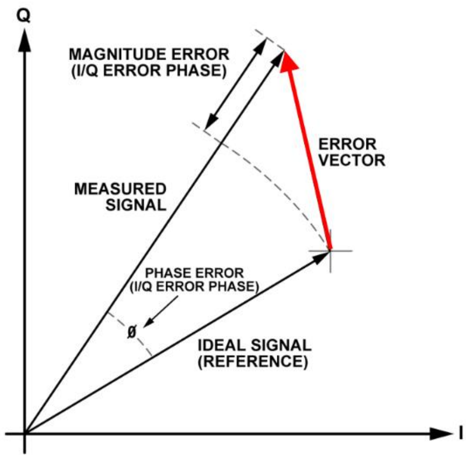

Figure 9 - Graphical representation of error vector magnitude

As we know, amplifiers operated close to or near compression can cause non-linear changes in both the amplitude as well as the phase of the output signal. Of these two, variations in amplitude are typically much more pronounced than variations in phase -- amplifiers in compression, by definition, show non-linearities in the output amplitude, whereas phase may (or may not) remain largely unchanged even when the amplifier is well into compression.

Numerous practical investigations of QAM modulated signals have shown that changes in amplifier class (and the corresponding levels of nonlinearity) have a minimal impact on EVM performance even when the amplifier is operated very close to, or even beyond, the compression point. This is most likely due to the fact that although compression causes the amplitude component to change in a non-linear manner, this non-linear change appears to affect all constellation points to roughly the same extent, so the decision points used for EVM measurements maintain the same relative distance between themselves. This behavior has been experimentally observed in the most common QAM modulation schemes currently used for modern cellular communications systems such as LTE (namely, QPSK, 16QAM, 64QAM).

3.3 Noise Power Ratio Measurements

Another common in-band test performed using high power amplifiers is the **noise power ratio** (NPR) measurement. In this measurement, multiple carriers are simulated by generating white noise, which is then passed through a bandpass filter with the same width as the simulated signal, resulting in a "pedestal" shape. A deep notch (50 dB or greater) is created in the center of this signal, which is then sent into an amplifier. Intermodulation distortion generated by the amplifier will "fill in" the notch. The ratio of the height of the "pedestal" to the "notch" yields the noise power ratio (expressed in units of dB). One of the advantages to NPR measurements over EVM measurements is their simplicity -- EVM measurements require a much more complex modulated source signal and demodulation of a (possibly impaired) signal on the receive side, whereas NPR measurements are simple RF power measurements.

As one would expect, the linearity of an amplifier will have a strong impact on the NPR measurement results. Modifying the conduction angle (and thereby the amplifier linearity) can be used to obtain the optimum mix between output signal power and notch depth. This is particularly important in areas such as satellite transponder test.

3.4 Adjacent Channel Leakage Ratio Measurements

Another important figure of merit in testing signals whose modulation is either wholly or entirely amplitude-based is the amount of the desired signal that leaks into adjacent channels (as opposed to intermodulation within the channel, as in NPR measurements). This is referred to as **adjacent channel leakage ratio** (ACLR) and is quantified in terms of the difference between the amplitude of in-channel signal and the amplitude seen "leaking" into the adjacent channel (expressed in dB). This unwelcome appearance of RF at nearby frequencies is commonly referred to as "spectral regrowth." The amount of spectral regrowth, itself a function of the number and level of intermodulation products, would also be expected to increase as amplifier linearity decreases.

Investigations have shown that the effect on ACLR is however much more pronounced than one might expect. The spectral regrowth caused when operating an amplifier in the non-linear region becomes progressively more objectionable (according to the relevant standards) as we back the conduction angle further away from a purely Class A (100%) environment. Recall that spectrum regrowth is not so much an issue for the in-channel signal itself but rather for any potential signals on neighboring channels. Here again we see the advantage in being able to control and adjust the conduction angle to meet our particular application requirements.

In conclusion, it is well-known that ACLR and NPR increase in a rapid, non-linear fashion as devices are operated near or in compression, and thus the desire for amplifier linearity is usually driven much more by ACLR and NPR considerations than by EVM considerations.

3.5 Slam Testing

Part of the testing performed on RF components (e.g. filters) involves subjecting the device under test to high levels of pulsed RF in order to determine the point at which the device fails -- this is often referred to as "slam testing." Although different parameters such as pulse width, duty cycle, pulse count, etc. are varied during the testing process, the most important parameter in this kind of testing is the input power. Essentially, the input power is slowly increased until a failure of the device is detected. As we have seen in the above discussion regarding pulsed signal amplification, the operating class of the amplifier can have a non-trivial impact on the pulse envelope and on the total power delivered by the pulse as well. For the purposes of slam testing, it is therefore important that we choose an operating class such that the power containing in the amplified pulses is both known and repeatable.

On the other hand, linearity of the amplifier signal (i.e. harmonics and intermodulation products) is not an issue in most slam tests since we are primarily interested in simply subjecting the device under test to high levels of RF energy. The amplifier robustness (i.e. its ability to tolerate high VSWR and high levels of reflected power) is not **initially** a concern, since most devices under test will have a nominal 50 Ω impedance. However, once the amplifier output power reaches a level which causes the device under test to fail, the device impedance can change rather quickly and dramatically (e.g. becoming an open or a short), presenting a significant challenge to the amplifier in terms of high reflected power levels.

3.6 EMC Measurements

One of the more common applications of broadband amplifiers is in the area of EMC testing; more specifically, radiated immunity testing. In this type of testing, being able to generate specific field strengths in a consistent fashion at a given frequency is extremely important. Furthermore, the generation of harmonics and intermodulation products is also to be avoided, since these both reduce the power at the desired frequency and may make it difficult to determine which frequencies cause a response in the equipment under test (EUT)

Using an amplifier with a variable conduction angle (and hence variable levels of linearity) allows the operator to dynamically and interactively control the levels of harmonics and intermodulation produced in the test environment. For situations in which field strength alone is the most important consideration, the conduction angle can be adjusted to allow for maximum power output despite increased levels of harmonics and/or intermodulation products. When the presence of these undesired signals is a greater concern, such as when the test engineers suspect the EUT may be responding to a spurious signal, the conduction angle can be increased to provide maximum linearly and a minimum level of spurious signals. This latter case becomes particularly valuable when the levels of these spurious signals can be detected in real time (e.g. by using a frequency-selective instrument) so that this information can be used to adjust the conduction angle of the amplifier accordingly.

Lastly, it should be noted that the impedance of broadband antennas used in EMC testing varies quite substantially with frequency. However, in most cases it is the VSWR robustness of the amplifier that becomes most important -- a slight reduction in output power (foldback) is often preferable to a complete shutdown of the amplifier due to high levels of reflected power.

4 Conclusions

Although broadband amplifiers can be designed and manufactured with almost any desired conduction angle (operating class, or bias/quiescent point), traditionally the conduction angle has either been fixed or cannot be easily adjusted by the end user (i.e. via user input or software commands). Newer "smart amplifier" designs with user-adjustable bias provide numerous benefits compared to fixed-bias designs. The ability to balance amplifier linearity vs. efficiency is clearly beneficial in a wide variety of applications, particular in the areas of both radiated and conducted immunity testing and communications technologies. Adjusting the conduction angle provides users with the ability to "tune" their amplifier for more precise reproductions of the time-domain response, and this is particularly valuable in the area of pulsed signals. Smart amplifiers with a variable conduction angle enable the use of a single amplifier in an extremely wide range of applications across many fields of RF design and testing.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1 888 TEST RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 |+86 400 650 58 96
customersupport.china@rohde-schwarz.com

Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

This white paper and the supplied programs may only be used subject to the conditions of use set forth in the download area of the Rohde & Schwarz website.

PAD-T-M: 3573.7380.02/02.05/EN/

01.00

Rohde & Schwarz GmbH & Co. KG
Mühldorfstraße 15 | 81671 Munich, Germany
Phone + 49 89 4129 - 0 | Fax + 49 89 4129 – 13777

www.rohde-schwarz.com