App Notes

Application Note #77 Specifying RF/Microwave Power Amplifiers for EMC Testing

rf/microwave instrumentation

rf/microwave instrumentation

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Introduction

Can you imagine the world without Electronic devices? Today's electronic gadgets, machines and appliances have become an integral part of our lives. This is most apparent with recent developments in technology like drones, Mobile internet, medical devices, Internet of Things (IoT) and autonomous vehicles. These technologies are used across military, aviation, automotive and commercial sectors. The result is a higher potential for harmful electromagnetic interference. This interference ranges from a small nuisance to complete product or system failures.

Historically, amplifier selection for Electromagnetic Compatibility (EMC) testing was based mainly on tribal knowledge and information scattered across the EMC industry. However, proper EMC amplifier selection is an important step in achieving required RF levels. Considerations are numerous. This application note provides the EMC test engineer, or technician with the information necessary to make the proper decision. Areas covered in this selection guide include:

- Common EMC test standards
- Amplifier specification definitions
- Types of amplifiers
- Amplifier Accessories
- Systems
- Improving test efficiency and reliability – MT06002 Multi-tone
- Other Considerations
- Summary

It should be noted that quality and support are of equal importance as technical features when selecting an amplifier. Down-time often means test lab throughput slows, thus impacting the labs profitability and customer schedules.

Common EMC Test Standards

EMC can be defined as the ability of systems and equipment to operate in their intended environments without suffering unacceptable degradation or causing unintentional degradation due to electromagnetic spectrum interference. Threats to a system can be both naturally-occurring and man-made and can be categorized into 4 main types of tests: Radiated Immunity, Radiated Emissions, Conducted Immunity and Conducted Emissions. The limits and levels used for these tests are defined in various standards and adopted by various organizations. It is imperative that products meet the requirements set forth in these standards because public safety, among other things, relies on the products to perform as intended.

Standards commonly used in sectors such as military, aviation, automotive and consumer are shown below. This guide will provide amplifier characteristics necessary to identify the appropriate amplifier for these standards. In many instances the standard drives the selection of the amplifier. In addition, the end user often has unique requirements. End user considerations are as important as the industry standards.

Radiated Immunity

- IEC 61000-4-3: Commercial
- MIL-STD-461, RS103: Military Components
- MIL-STD-464: Military Systems
- DO-160, Section 20: Aviation
- ISO 11451, ISO 11452-2: Automotive

Radiated Emissions

- FCC Part 15
- CISPR 11, 22, 25, 32: Commercial
- MIL-STD-461, RE102: Military Components
- DO-160, Section 21: Aviation

RF Conducted Immunity

- IEC 61000-4-6: Commercial
- MIL-STD-461, CS114: Military Components
- DO-160, Section 20: Aviation
- ISO 11452-4: Automotive

Conducted Emissions

- CISPR 11, 22, 25, 32: Commercial
- MIL-STD-461, CE101, CE102: Military Components
- DO-160, Section 21: Aviation

Amplifier Specification Definitions

The foundation for proper selection amplifier is in understanding critical amplifier specifications. While amplifiers have a broad spectrum of specification parameters, there are a few key parameters to keep in mind relating to EMC testing. These parameters and their relevance to EMC testing are shown on the next page in **Table 1: Amplifier ParametersTable 1**.

Table 1: Amplifier Parameters

Parameter	Definition	Relevance
Frequency Response	Instantaneous operational frequency band	Amplifiers are only specified to operate within this defined frequency band. Some solid-state amps will operate just outside of the band with significant power reduction (Figure 1), whereas TWTAs have much harder cutoff due to waveguide (Figure 2). Figure 1 shows the performance of the AR Model 500S1G6 amplifier. This amplifier operates over the 700 MHz to 6 GHz frequency range.

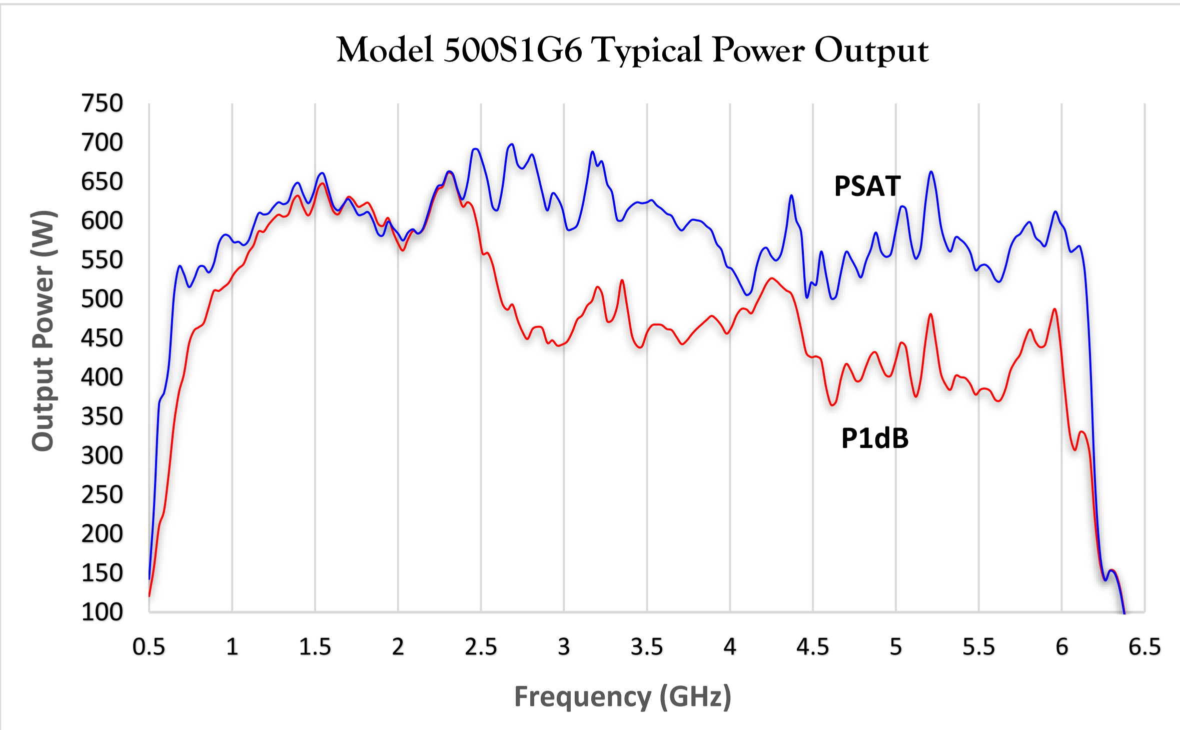

Figure 1: Example of Solid State Amplifier Output Power Over Frequency

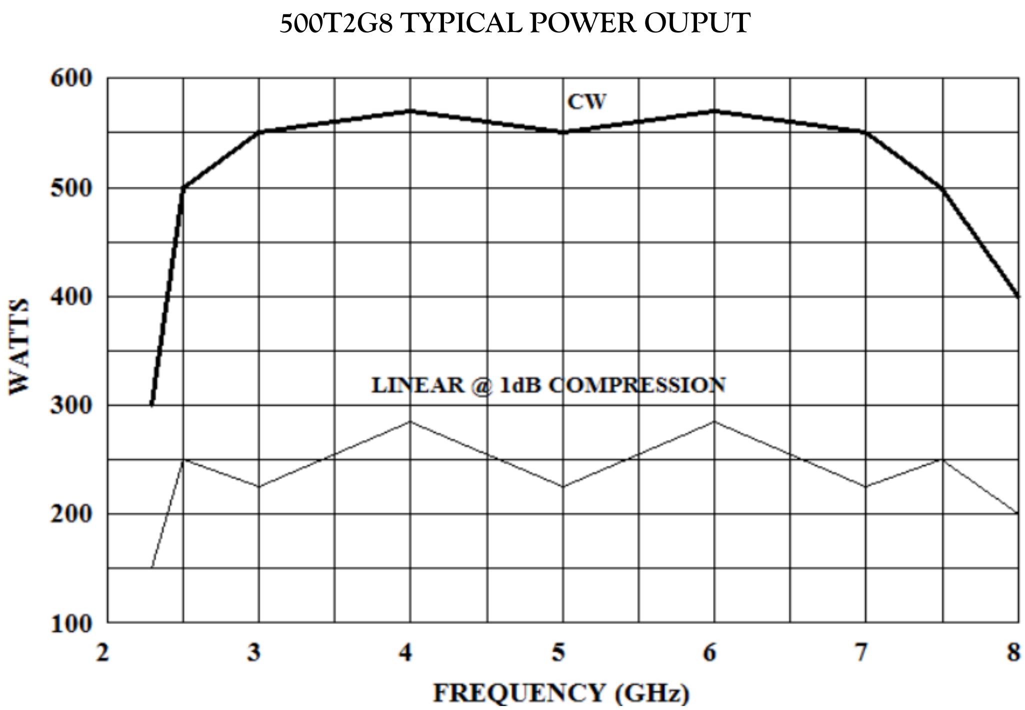

Figure 2 : Example of TWTA output power over frequency

Rated Output Power	AR's definition: Power generated by amp at 1.0 mW (0 dBm) input	Important power rating for applications where there <u>are</u> <u>not</u> strict linearity requirements (MIL / DO / Automotive). 'Rated' power is similar to (but not necessarily) 'Saturated' power.
Power Output @ 1 dB Compression	Power generated by amp at the 1 dB compression point	Important power rating for applications where there <u>are</u> strict linearity requirements (IEC / EN). Can be considered the top-end of linear power. Amp saturation increases after P1dB. Shown in Figure 3 is an example of P1dB and P3dB levels for the AR Model 50U1000 amplifier.

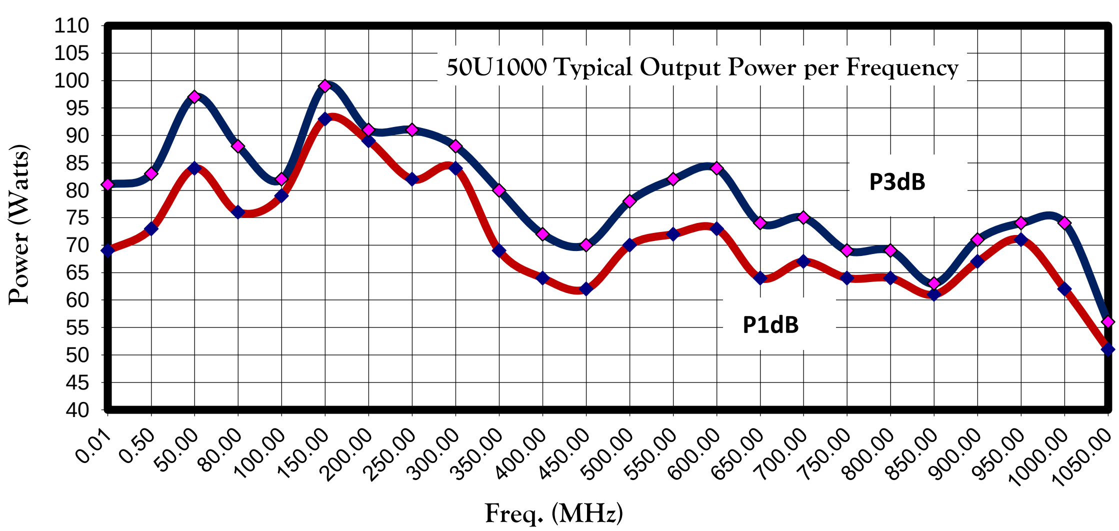

Figure 3 : Example of P1dB and P3dB levels for the 50U1000

Parameter	Definition	Relevance
Harmonic Distortion	Amplitude of harmonic distortion produced by amp	Majority of AR amps are -20 dBc @ P1dB, see Figure **4**. Many test specifications require at least -6 dBc. See App Note #60.

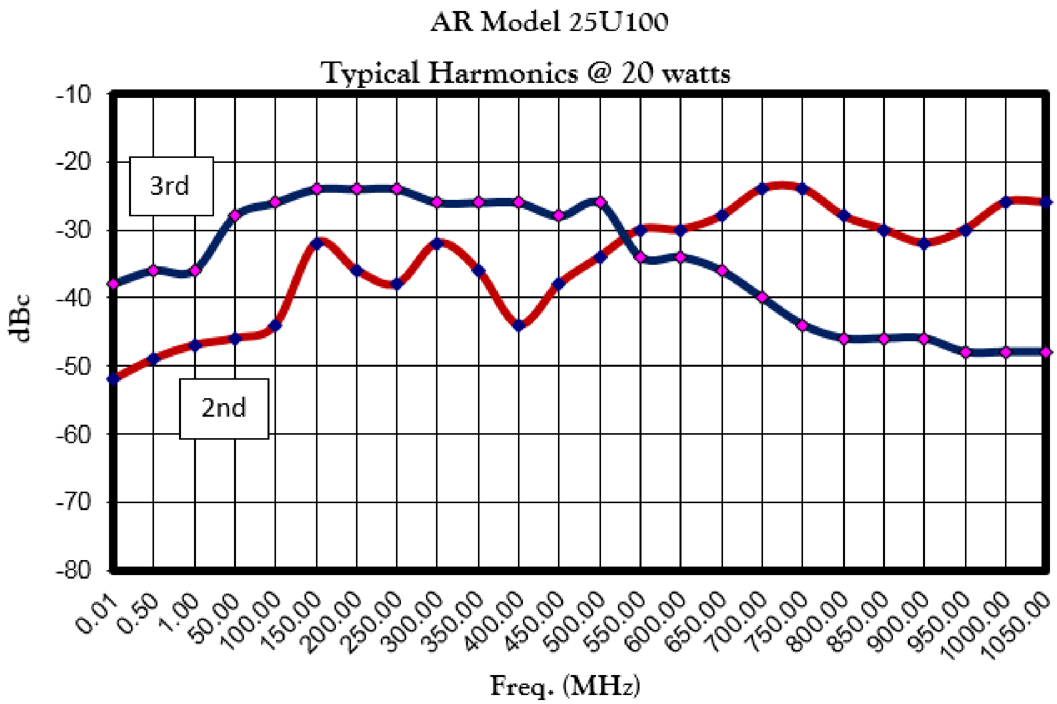

Figure 4: Example of Amplifier Harmonics

Gain	The amplification factor, also called gain, is the extent to which an analog amplifier boosts the strength of a signal. Amplification factors are usually expressed in terms of power.	Many amplifier factors are a result of an amplifier's gain, such as output power, size, and the power required to operate that amplifier. Gain is called S21 using S-parameter terminology
Flatness	Flatness specifies how much the amplifier's gain can vary over the specified frequency range.	Variations in the flatness of the amplifier's gain can cause distortion of signals passing through the amplifier.
Efficiency	The ratio between the power of the output and total power consumption	Although Class A amplifiers are inherently inefficient, design techniques can improve amplifier efficiency as seen by AR's amplifiers which are smaller and require less input power than other amplifiers equivalently rated.
Pulse Capabilities	Limitations on Pulse Width, Pulse Rate and Duty Cycle	Pulsed SSPAs and TWTAs produce higher-peak power than-CW power, but are limited in how much RF can be passed through amp. See App Note #39.

Parameter	Definition	Relevance
Mismatch Tolerance	Ability of an amplifier to handle un-matched loads and thus varying amounts of reflected power	In EMC applications, especially at lower frequencies, transducers (antennas / clamps / etc.) can be a very poor match to 50 Ohms. Field reflections / standing waves can cause significant reflected power as well. During test, it is important to continue to deliver forward power as well as protect the amp from reflected power damage. See App Note #27.
Pulse Capabilities	Limitations on Pulse Width, Pulse Rate and Duty Cycle	Pulsed SSPAs and TWTAs produce higher-than-CW power, but are limited in how much RF can be passed through amp. See App Note #39.

Amplifier Input and Output Requirements

How much input power is required to achieve full rated output power is a common concern when choosing an amplifier, AR and other amplifier manufacturers have specified an input of 1 milliwatt. (Note that this is not the case for every manufacturer – be sure to verify). While the rated input power is defined as 1 milliwatt, most amplifiers provide rated output power with less than 1 milliwatt input. This is because the specified value will often have built-in conservatism.

AR Amplifier typical input levels:

Signal Generator: 1 milliwatt which is equivalent to 0 dBm

Function Generator: 1 milliwatt or 224 millivolts into 50 Ω

Max input before damaging amplifier +13 dBm or 20 milliwatts (20 times more power than 0 dBm)

Note: Pay close attention to an amplifier's maximum input. It varies by vendor and possibly by model family.

The input signal strength has a profound effect on the amplified output signal. It determines the operating region and thus, the degree to which the amplifier output is compressed. Ideally, an amplifier will simply amplify the input signal without adding any additional signals or artifacts. Unless operated in the extreme linear region, amplifiers will distort the input to some degree. The extent to which the amplifier affects the input signal is a function of the output compression. The higher the amplitude of the input signal, the risk of higher the output compression increases. At the 1dB compression point there may be a slight flattening at the top and bottom of a CW sine wave signal. As the amplifier is driven further into saturation, additional distortion will become apparent and eventually the CW input signal will approach a square wave output (See Figure 5). The 1 dB and 3 dB compression points are further shown in Figure 6 (next page).

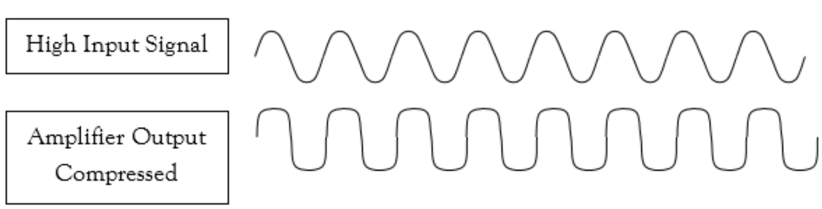

Figure 5: Example of Amplifier Saturation

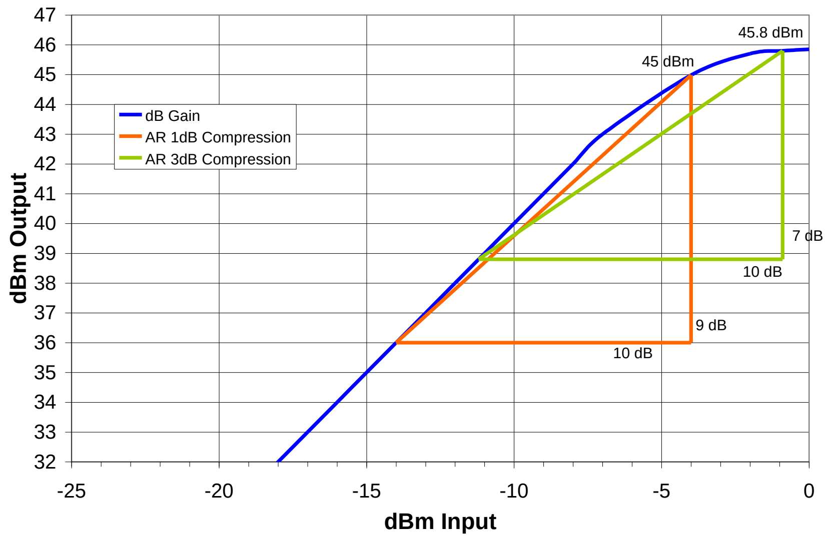

Figure 6: Linearity Characteristics

Distortion creates new unwanted signals at frequencies not present at the input of the amplifier, as observed in the frequency domain with a spectrum analyzer. Figure 7 shows the effect of driving a TWTA amplifier into saturation. This figure shows the harmonic having only a slightly lower amplitude compared to the fundamental signal. This situation causes unnecessary problems for the test engineer. Under this scenario, if the EUT fails during radiated immunity testing, the test engineer will not know if the cause of the failure were due to the fundamental or the harmonic. To further complicate matters, if additional harmonics have high amplitudes the test engineer must evaluate all harmonics to determine the cause of the failure. It is also possible that neither the fundamental or a single harmonic causes a failure, but a combination of the fundamental and harmonic(s). Measuring the amplifier output power or the generated field are further complicated since most commonly used power meters and field probes are themselves wideband measurement devices and will display the total energy across the entire band, fundamental, harmonics, and spurious. It should be noted that AR's solid state Class A amplifiers produce far less harmonics than TWTAs, they are rated for -20 dBc at the 1 dB compression point. This greatly reduces the EUT's exposure to unwanted RF energy during radiated and conducted susceptibility testing.

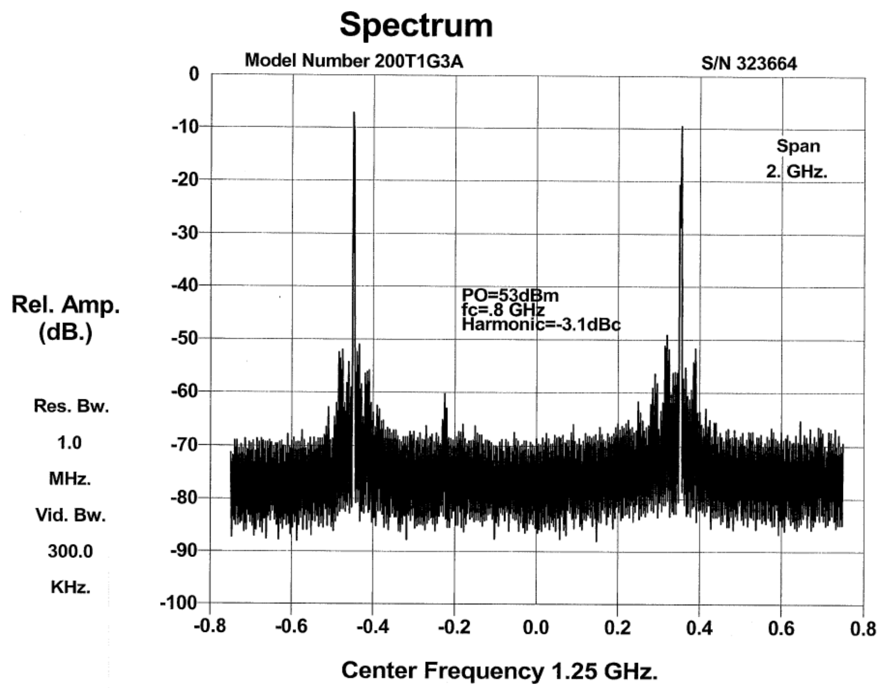

Figure 7: Image of the Fundamental Signal and harmonic

For additional information on effects of input power see: Application Note #45 Input Power Requirements for AR RF/Microwave Instrumentation's Amplifiers.

Types of Amplifiers

In general EMC amplifiers range in type, such as: Solid State, TWTA, CW, Pulse, and their class of operation - Class A and Class AB.

Class A and Class AB Amplifiers

Class A, and Class AB amplifiers have their strengths and weaknesses. Class A amplifiers are the most robust. They provide the highest levels of mismatch tolerance which is needed when significant RF levels reflect into the amplifier. This is a common effect with many EMC antennas and other transducers. Additionally, linearity and harmonic distortion are much better with Class A amplifiers compared to other amplifier classes.

Class AB amplifiers have their own benefits. Generally, the cost of the amplifier is less than Class A amplifiers. The physical size of these amplifiers is also generally smaller. These amplifiers are much better suited for use with matched loads. See AR App Note 27A.

Shown in Table 2 (next page) is summary of the differences between Class A, and Class AB amplifiers.

Table 2: Comparison of Amplifier Class of Operation

Characteristic	Class A Amplifier	Class AB Amplifier
Output distortion	Low distortion, highest Linearity	Higher distortion, poor Linearity than Class A
Bias Scheme	Output current flows for 360° of the input signal	Output current flows somewhere between 180 and 360° of the input
Ruggedness	Amplifier will safely operate without damage regardless of load mismatch	Output limits are generally used to protect the amplifier when operated beyond a stated level of mismatch
AC power to RF power efficiency	Less efficient	More efficient than Class A amplifiers
Construction	More components required to share the heat load	Less components required to share the heat load than Class A amplifiers
Size/Weight	Larger/Heavier	Smaller/Lighter than Class A
Cost	Higher than Class AB	Lower than Class A

A summary of mismatch performance for typical Class A and AB amplifiers is shown in Figure 8. The 100 Watt curve is representative of most AR amplifiers below 500 watts. It is clearly seen that the amplifier delivers a Minimum Available Power (MAP) of 100 watts irrespective of the load VSWR, including output load opens and shorts. As output power increases it becomes increasingly difficult to absorb 100% of the

reflected power uniformly. Hot spots at these elevated power levels can cause damage or at least affect reliability. Nevertheless, AR high-power amplifiers continue to offer 100% mismatch tolerance up to a load VSWR of 6:1 (lower-power amplifiers deliver full power regardless of mismatch). Once this level is reached, the output power is limited to 50% of rated power. For example, the AR model 2500A225A amplifier will provide a MAP of 2500W up to a load VSWR of 6:1. At this point, approximately 1250 watts is reflected. From this point on, as load VSWR increases the output power is gradually reduced until it reaches 1250 watts for an infinite load VSWR. Figure 9 clearly shows the advantage of this implementation when compared to the conventional “foldback” scheme used by typical Class AB amplifiers.

In practice, the AR’s conservative VSWR compromise of 6:1 works well in that the VSWR of EMC antennas and transducers is often held to this value or better. If it strays beyond, rest assured your AR amplifier has sensed the increase and has implemented sufficient limiting to protect the amplifier from any damage. Based on the above, mismatch tolerance can make the difference between meeting or failing the required power or field levels. As a result, mismatch tolerance is an important specification to consider when comparing offerings from different manufacturers, and where some manufacturers with use terms such as typical, or protection to confuse the issue.

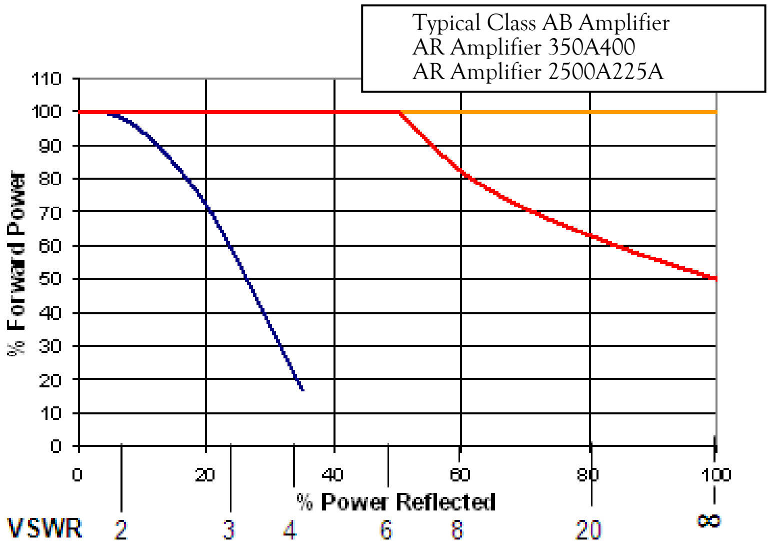

Figure 8: Minimum Available Power

TWTA Amplifiers

For years, when discussing microwave, high field-strength electromagnetic compatibility (EMC) radiated susceptibility testing, Traveling Wave Tube Amplifiers (TWTAs) were the only choice for wide frequency coverage, and power. TWTAs are lower cost solutions, in most cases, but do have drawbacks. Their unique properties allow them to be used in a pulsed mode, that can lower the total required average power, but maximize their peak power and thus reducing cost further. However, TWTAs produce high harmonics,

have a greater noise floor, longer purchase lead times, longer repair times, and lower reliability than solid state amplifiers. Some advanced TWTAs combine multiple tubes together to reduce harmonic content and increase total power. Another solution to reduce harmonics is to use filters on the amplifier output. It's important to remember that there are always losses associated with filters that must be considered for amplifier power sizing. The VSWR associated with the filters is another consideration, which can cause amplifier foldback.

Solid State Pulse Amplifier

The difficulties associated with pulse TWTAs are mitigated with a new, very attractive alternative. Solid state pulse amplifiers now offer high-power RF levels that rival those of TWTAs. AR's SP-series amplifiers include various frequency ranges and output power levels to meet several standards and user requirements. These solid-state pulse amplifiers offer higher reliability, better mismatch tolerance, much better harmonic distortion, and better MTBF (Mean Time Between Failure) than TWTAs. Figure 9 show an image of a 1 to 2 GHz, 1000W solid state pulse amplifier.

Figure 9: Solid State Pulse Amplifier

Dual Band Amplifiers

If a single band amplifier is not available over a desired frequency band, a dual band amplifier may be an attractive solution. A dual band amplifier consists of two amplifiers that are combined into one "box" with a single I/O interface, RF input and output, and two bandwidths equivalent to the two amplifiers it replaced. This approach simplifies the test setup.

While on the surface the system seems simplified, a closer look within the "box" reveals a different story. While the two amplifier modules in a dual-band amplifier may share a common power supply, the overall system is complicated by the fact that it now consists of not one, but two complex amplifier modules.

Furthermore, additional RF switching, cabling and connectors are required which will adversely affect the RF output of both amplifiers. The additional components add insertion loss that may not present a

problem at lower frequencies but can account for significant losses at higher frequencies. Also, simultaneous signal generation across the entire band is not possible, due to the required switching from one frequency band to the other. So, as you can see there are pros and cons to dual band amplifiers.

Figure 10 and Figure 11 show the schematic differences between a single band and dual band amplifier, respectively.

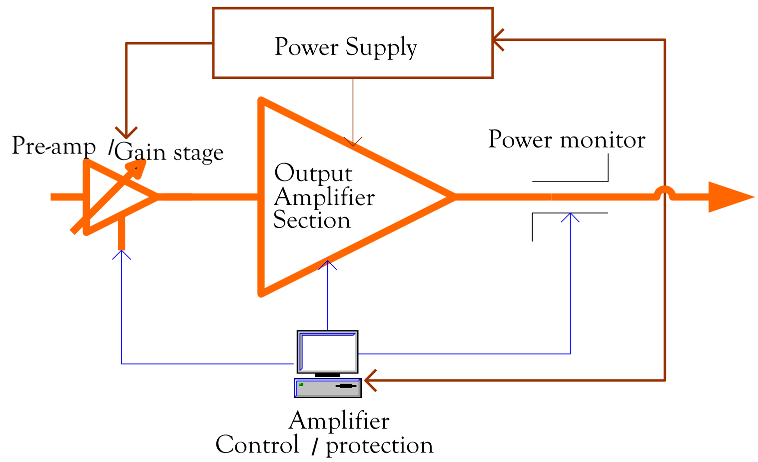

Figure 10: Basic Diagram of a Single-Band Amplifier

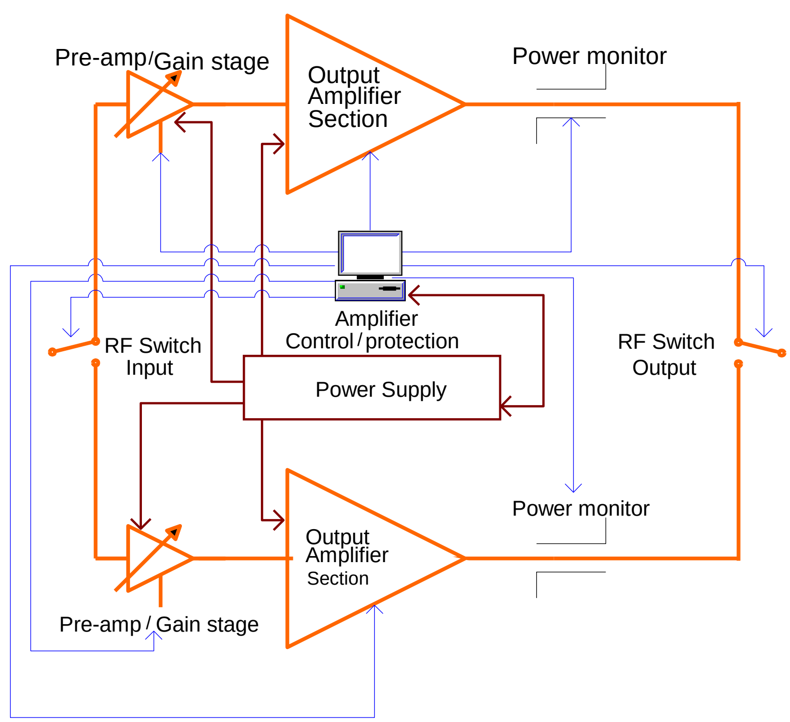

Figure 11: Basic diagram of a Dual-Band Amplifier

Amplifier Accessories

An often-overlooked important part of an EMC test setup are the accessories. The cost and time associated with EMC testing warrants the use of high quality accessories. AR offers all the accessories needed to round out your system. This includes a family of antennas that operate up to 50 GHz and handle up to 20 kW. AR's inhouse antenna designers and experience EMC design engineers have collaborated over the years to develop antennas that provide very attractive alternatives to traditional antenna designs. Examples include the models Radiant Arrow, ATT Pyramidal Log Period and AA series amplifier antenna products.

AR offers these accessories, with an experienced sales and engineering organization available to offer customers the best solution. Figure 12 and Figure 13 are examples of accessories used in radiated and conducted RF immunity test setups, respectively.

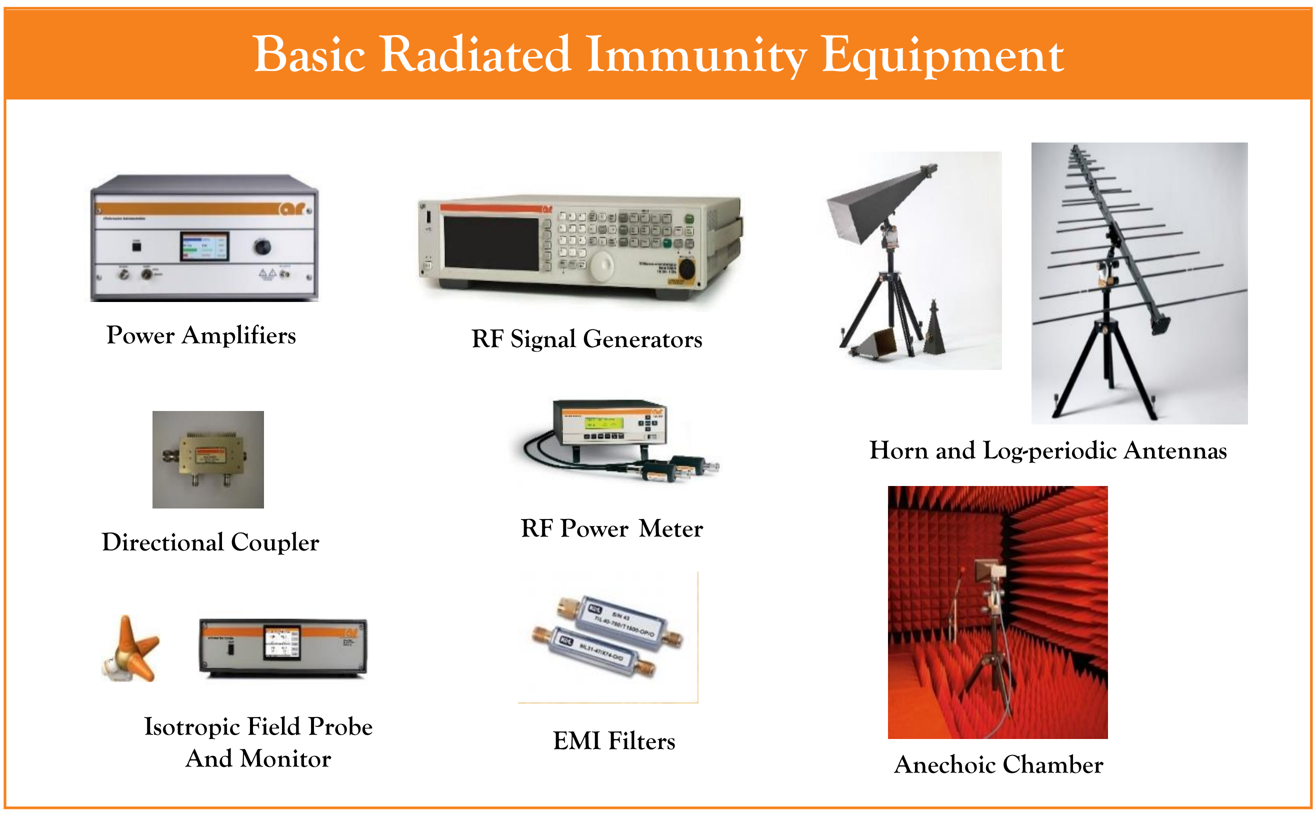

Figure 12: Components Used In a Typical Radiated Immunity Test Setup

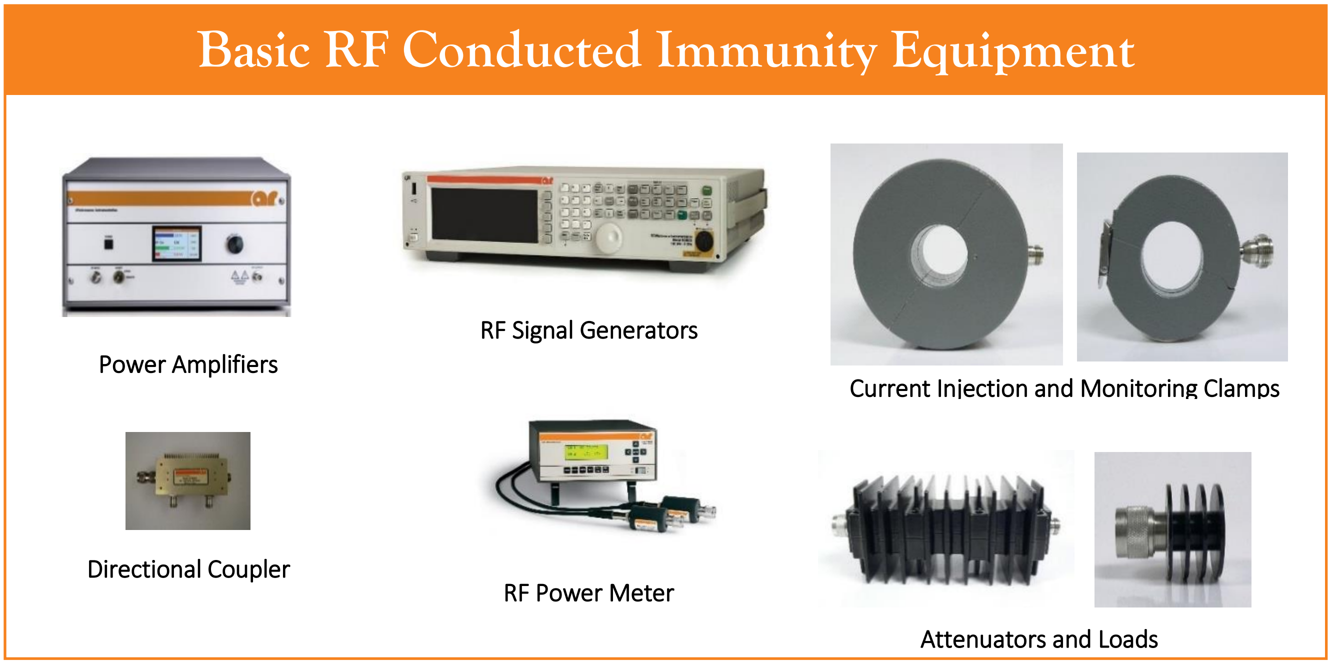

Figure 13: Components Used In a Typical Conducted Immunity Test Setup

Systems

Manufacturing a wide range of the most common, to the largest and most complex EMC systems in the world sets AR systems apart from the competition. The ability to pull together the right amplifiers for the job, with training and ongoing support is one of the many elements AR prides itself on. This approach allows test engineers and technicians the ability to do what they do best: test. AR's systems engineers will work closely with customer to define the requirements. Once all system requirements are gathered, and system losses and gains are totaled, component selection is made to identify the best amplifier solution for specific customer needs. AR uses the most advanced technologies to achieve the desired outcome.

Figure 14: Mobile Radiated Immunity Test System

Complete EMC RI and CI systems are available up to 50 GHz. Everything is provided from: amplifiers, antennas, couplers, signal generators, system controllers, receivers, and more, along with the software to control it – all in one comprehensive test system.

An example of a mobile RI test system is shown below, in Figure 14. This system was designed meet HIRF (High Intensity Radiated Fields) levels, in accordance with MIL-STD-464C testing.

This figure shows a shielded rack (doors not shown) containing; amplifiers, RF switch matrix (SCP2000), power measurement equipment and a signal generator. Also shown are the antenna mast, antenna assembly, and motor drive to raise and lower the antenna assembly. All components are mounted to a heavy duty mobile cart.

Other examples include; full emissions test capabilities, low, medium, and high power radiated and conducted immunity test systems. These systems are fully automated with AR's emcware.

As important as the system components, the support is equally important. AR's System's engineers, with significant experience, will aid you at each step, from specification, installation, training, and ongoing support.

The below system, Figure 15, shows additional components of a HIRF system, capable of producing > 1kV/m. The frequency and power requirements dictate the number of mobile structures and fixed amplifiers subsystems.

Figure 15: HIRF Test System

High-Frequency Field Generating Systems

Traditionally, generating low-level electric fields in the 18 – 40 GHz frequency band has been performed using traveling wave tube amplifiers (TWTA's). These TWTAs often produce much more power than is required to generate the required field strengths while also being an extremely costly solution. Why pay for unnecessary power? AR has the answer with the introduction of its AA-Series field generating systems, see Figure 16. These systems produce field strengths of up to 50 V/m in the 18 – 26.5 GHz and 26.5 – 40 GHz bands. See ARI Application Note #75.

Figure 16: AA18G26-20

The AR models AA18G26 and AA26G40 each consists of an antenna directly mounted to a solid-state amplifier, along with sufficient heat sink and overtemperature fault detection. By connecting the antenna directly to the amplifier, we have eliminated cable losses and can deliver maximum amplifier power to the antenna. The RF loss associated with the cable can be significant, requiring a higher power amplifier to generate the same RF field as the amplifier/antenna unit. Within each frequency band, there are two available options. The model suffixes -20 and -50 associated with each model indicates the guaranteed minimum field strength (20 V/m or 50 V/m). To minimize amplifier size, the AA-Series uses antenna gain, rather than amplifier gain to achieve higher field strengths. Table 3 gives a listing of all the available AA field generating units with their associated frequency ranges, field strengths and antenna spot sizes

Model Number	Frequency Range (GHZ)	Guaranteed Field Strength (V/m)	Spot Size (m)
AA18G26-20	18 – 26	20	0.31 x 0.31
AA18G26-50	18 – 26	50	0.14 x 0.17
AA26G40-20	26 – 40	20	0.29 x 0.32
AA26G40-50	26 – 40	50	0.15 x 0.17

Table 3: AA Series Options

Conducted Immunity Test System

Constantly improving the AR product offering provides customers with the latest technologies and best return on investment. The new CI00402 CI test system (see figure 18), which comes with a standard 100W, 10 kHz to 400 MHz amplifier, replaces three older models; CI00250A, CI00400A, and CI00401A. The new CI00402 provides all the capabilities of the older CI systems, with the bonus of providing the user will full access to; the 100A400 amplifier, a spectrum analyzer, and a signal generator. This allows the lab to continue testing in the event other test equipment must is due for calibration, or a failure occurs.

Complete Testing Solutions to the following standards:

- MIL-STD-461 CS114
- DO160 (Section 20) BCI Testing
- EN/IEC 61000-4-6
- IEC 60601-1-2
- EN 50130-4
- EN 61000-6-1/2
- EN 55024

Figure 17: CI00402 Conducted Immunity Test System

Radiated Immunity Multi-Tone Test System

For radiated and conducted immunity testing, the Multi-tone approach has many benefits.
While the multi-tone methodology, specifically the MT06002 Multi-Tone System (see **Error! Reference source not found.**), was initially implemented to increase the speed of immunity testing, it has been found that this method also makes the most out of available amplifier power. Figure 19 shows an example of the efficiency of the Multi-tone system. The traditional IEC 61000-4-3 method requires one tone swept from 80 to 1000 MHz. Multi-tone methodology utilizes a group of tones, which are simultaneously stepped through the required test band. As shown in the Figure 19, the amplifier only uses 100 W at the lowest frequencies for a single tone.

Figure 18: MT06002 Multi-Tone System

At higher frequencies power is wasted if the single tone test method is used. However, with the MT06002, the full power of the amplifier is used by producing additional tones, thereby saving time by a factor approx. equal to the numbers of tones used.

IEC 61000-4-3 Vertical 10V/m @ 3 meters Resultant From UFA

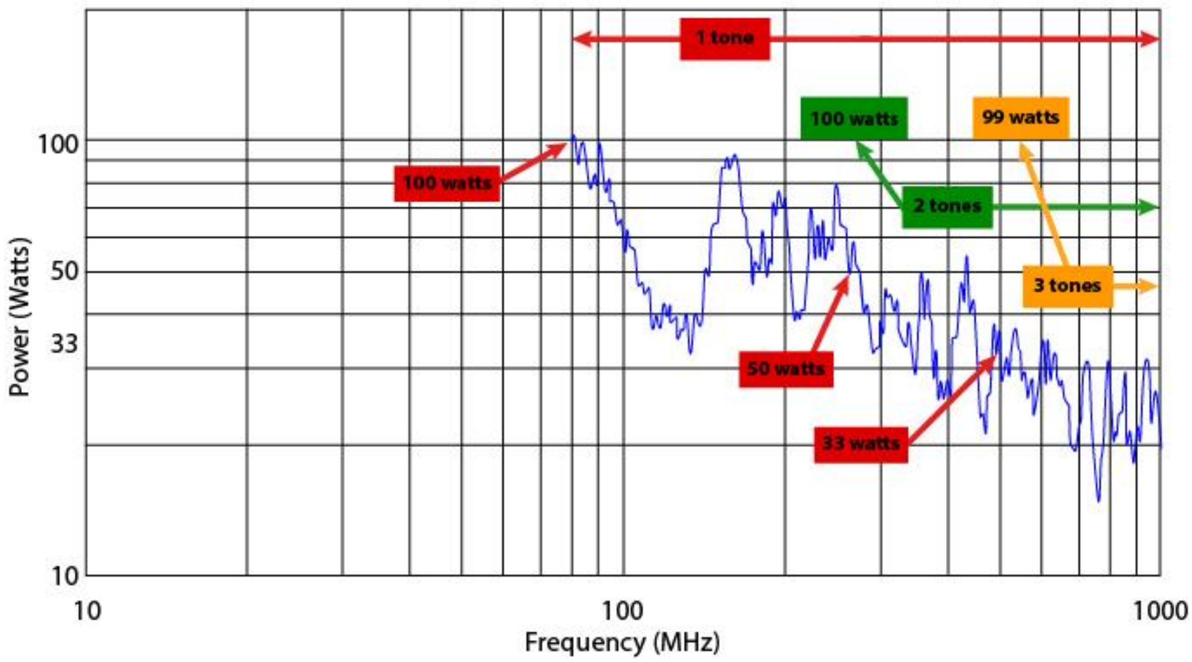

Figure 19: Multi-Tone VS. Available Power

This efficiency is only achieved by using AR's propriety software, which reviews output power, amplifier compression, and measures intermodulation products. In addition, a Multi-tone system, with the appropriate amplifier offers greater flexibility to truly test the equipment (EUT) to threats that are more representative of real-world conditions, as well as testing in accordance with EMC standards. Benefits also include more efficient use of financial and human resources as well as faster time-to-market for new and enhanced products.

Other Considerations

Transistor

The transistors used in the amplifier are a main component of the amplifier and can provide hints about the design and provide you with another data point in your purchasing decision. For instance, AR has used GaN technology in its higher frequency amplifiers for a longer period than the competition. The benefit of GaN is greater power density than other technologies, which translates into higher power amplifiers and smaller overall packages compared to competitor's similarly powered amplifiers. AR continues to use the latest technologies, from DC to 50 GHz, to develop state of the art amplifiers.

Build versus Buy Modules

Another important point is having the ability to develop one's own module using die bonding technologies. This allowed AR to be the first to offer a continuous frequency range amplifier from 0.7 to 6 GHz. Not only are these modules beneficial for EMC purposes, but they are also widely used by wireless component and product manufacturers for R&D purposes. The overall importance is a demonstration to the commitment of AR to provide customers with alternatives with clear benefits.

Amplifier Regulatory Compliance

Almost always forgotten is the importance of product regulatory compliance. It is crucial for amplifiers to undergo safety, EMC, and hazardous substance evaluations. Although only required in some regions of the world, AR has made compliance to these requirements mandatory on all newly developed products, thereby reducing potential harm to users and the environment. AR uses independent third-party laboratories to evaluate AR products to international safety and EMC test standards, so there is no question about validity of compliance compared to those manufactures who choose to perform in-house evaluations.

Summary

As you can see there are many factors to consider when selecting an amplifier. AR's Applications engineers have years of amplifier experience in areas such as EMC, wireless component R&D testing, and more, and can help you select the right amplifier for your specific purpose. If you need assistance, please feel free to call at 215-723-8181.