Application Note 27

THE IMPORTANCE OF LOAD TOLERANCE IN SPECIFYING RF POWER AMPLIFIERS FOR IMMUNITY/ SUSCEPTIBILITY TESTING APPLICATIONS

Real world variations in load VSWR cause Class AB amplifiers to "foldback". Minimum Available Power (MAP) is presented as a clear and distinguishing measure of a Class A amplifier's ability to deliver rated power under these realistic test conditions.

Overview... The salient specifications that are used to characterize RF power amplifiers are well known, and generally accepted without question. The list includes Gain, Frequency Response, and of course, Output Power. There are, however, lesser understood amplifier characteristics, such as noise figure, gain stability, distortion, etc. that are considered when specifying a power amplifier. This note covers a major and often overlooked power amplifier characteristic--**LOAD TOLERANCE**. Depending upon the application, the ability to provide power to loads that vary from an ideal 50 ohms can be crucial. Such variations in load impedance are commonplace, especially in immunity testing applications. *In applications of this nature, load tolerance ultimately determines the effectiveness of the power amplifier.*

This Application Note addresses the use of RF power amplifiers in applications characterized by mismatched loads. VSWR variations encountered in immunity testing are discussed in relation to amplifier design. The concept of MINIMUM AVAILABLE POWER (MAP) is introduced as a quantitative measure of an amplifier's capability to supply power into a poor load VSWR.

The problem... Real life applications rarely involve driving an ideal 50 ohms load. More likely, the load varies with frequency over a wide range of impedance. A case in point is immunity testing. This application is plagued by widely varying load impedances due to variations in antenna characteristics, room reflections and resonances, imperfect cables and connectors, and reflections from the device under test. Specifically, starting with a typical antenna VSWR of 2.5:1 and factoring in room and signal path effects, it is not uncommon to experience a VSWR in excess of 5.0:1. The problem stated quite simply is, "Most RF power amplifiers are not capable of providing full rated power to loads that vary considerably from an ideal 50 ohms." The market thrust at Amplifier Research over the last 25 years has been RF susceptibility testing. EMC Test Engineers have had to deal with the problem of delivering power into significant mismatches on a regular basis, and as a result, Amplifier Research has developed a line of Class A linear amplifiers with characteristics that particularly lend themselves to this difficult application.

The solution... There are two major types of RF power amplifiers used for susceptibility testing...Class A and Class AB. Class A amplifiers exhibit characteristics that particularly lend themselves to applications requiring load tolerance. By specializing in Class A linear amplifiers especially designed to be "load tolerant", Amplifier Research products are uniquely capable of handling applications involving varying load impedances. While Class A amplifiers are generally larger and more expensive than Class AB amplifiers, we feel that the electrical performance advantage far outweighs all other considerations. To understand why Class A amplifiers are superior to Class AB in this particular application, it is necessary to consider the inherent differences which lead to their respective strengths and weaknesses.

In Class A operation, the active devices are biased to insure that collector or plate current flows for 360 degrees of input signal. When operated below the 1dB compression point, the RF signal input and RF output waveforms vary uniformly about the DC quiescent point, and lie within the linear region of the characteristic curves of the active device. This biasing scheme provides excellent linearity and low distortion.

An additional characteristic is that a properly designed Class A amplifier dissipates maximum power in its quiescent state. Thus, it must be built to handle a great deal of power dissipation. Contrasted to a Class AB amplifier, the Class A design necessarily requires the use of larger active devices, and quite often, a larger number of devices to share the heat dissipation. Furthermore, additional attention is paid to heat sinking, cooling considerations, and rugged component selection. When an input signal is applied and RF power is dissipated into a load, the RF devices actually run cooler. Since they are thus operating below their normal operating temperature, power reflections resulting from operating into high levels of VSWR are not a problem. While the design is inherently superior to a Class AB amplifier in regards to its ability to dissipate power, a Class A amplifier will undoubtedly be larger, heavier, cost more, and be less efficient with respect to its use of primary power.

The active devices in a Class AB amplifier are biased to produce output current for somewhere less than 360 degrees and more than 180 degrees of the input signal. A Class AB design consumes less power in its quiescent state than when an input signal is applied. Since it consumes less power and is thus more efficient than a Class A amplifier (efficiency = RF Power Out / Primary Power Input), fewer transistors are required and the silicon chips used can be smaller in area. Less heat sinking is required, and the cooling schemes tend to be less elaborate.
Accordingly, the ability of a Class AB broadband amplifier to absorb reflected power is severely compromised.

At this point, an example will serve to illustrate the above comments. Consider a typical Class A, 100 Watt amplifier that requires 1000 watts of primary power to provide 100 watts of RF output power. With no signal input, this amplifier must be capable of dissipating 1000 watts. When a signal is applied, the amplifier dissipates 900 watts while delivering 100 watts to the load.

A typical broadband Class AB 100 watt amplifier dissipates considerably less than 100 watts with no input. When an input signal is applied, the internal dissipation may rise in excess of 500 watts.

The above illustrations assume a perfect 50 ohm load. How do these amplifiers fare with real life loads encountered in typical susceptibility testing situations or applications where impedances may vary widely? As the load varies from an ideal 50 ohms, output power is reflected back into the output stage. Since the Class A amplifier has been designed to dissipate at least 1000 watts, power reflected back into the output stage of the amplifier does not present a problem. Even if the output were shorted or opened, the resulting total reflection of 100 watts would not adversely effect the amplifier. Since the additional 100 watts of reflected power does not increase the device dissipation above design value, the amplifier would continue to supply a forward power of 100 watts without overheating ....*regardless of the load*.

On the other hand, a Class AB amplifier has a serious problem dealing with load variations. Its design assumes nearly ideal loads, and the slightest amount of reflected power can cause severe damage to its output stages.

Accordingly, Class AB amplifiers employ a protection scheme to limit the amount of reflected power. Figure 1 is a typical Class AB output power vs output VSWR curve taken from published literature. This curve shows an alarming inability of the RF devices to sink even a minimal amount of reflected power. The amplifier must implement a "foldback" of the available RF output power in an effort to protect its output stages. Specifically, the curve clearly shows that a 100 watt amplifier could not sustain 100 watts into a VSWR of 2.0:1 (typical antenna VSWR), but would foldback to 89 watts. Thus, with as little as 11% of the output power reflected, the forward power has dropped to 89 watts. Considering a modest increase in VSWR to a value of 3.0:1, with only 25% of the output power reflected back, the Class AB amplifier has cut back its forward power to a meager 50 watts...*clearly not the kind of performance needed in a susceptibility test system which must maintain prescribed field levels in spite of VSWR variations*.

Definition of MAP... While the above discussion touches on the concept of load tolerance and available power, what is needed is a convenient means to determine the load tolerance of a particular amplifier, and thus, the suitability for a particular task. This application note offers a graphical figure of merit called *Minimum Available Power* (MAP). To show the significance of this approach, we begin by noting the typical Class AB curve in Figure 1. This graph plots two non-linear quantities and therefore the results are somewhat vague. A much clearer picture of actual amplifier performance can be obtained by plotting percentage of output power (forward power) against percentage of reflected power. The resulting graph presents a clear and unambiguous prediction of an amplifier's MAP.

Figure 2 graphically depicts the MAP curve for the Amplifier Research 100W1000B, as well as the MAP for a typical Class AB amplifier calculated from Figure 1.
The MAP curve in Figure 2 clearly shows that the Class A 100W1000B provides 100% of rated power regardless of VSWR and therefore is ***superior*** to Class AB amplifiers. This curve applies to all "W" series amplifiers with less than 500 watts output. Higher power "W" series amplifiers (up to 3000 watts) exhibit the MAP shown in Figure 3. This MAP is characteristic of an amplifier with a load tolerance equal to 50% of rated output power at infinite VSWR. The Class AB MAP curve generally applies to all amplifiers of a given classification regardless of output power.
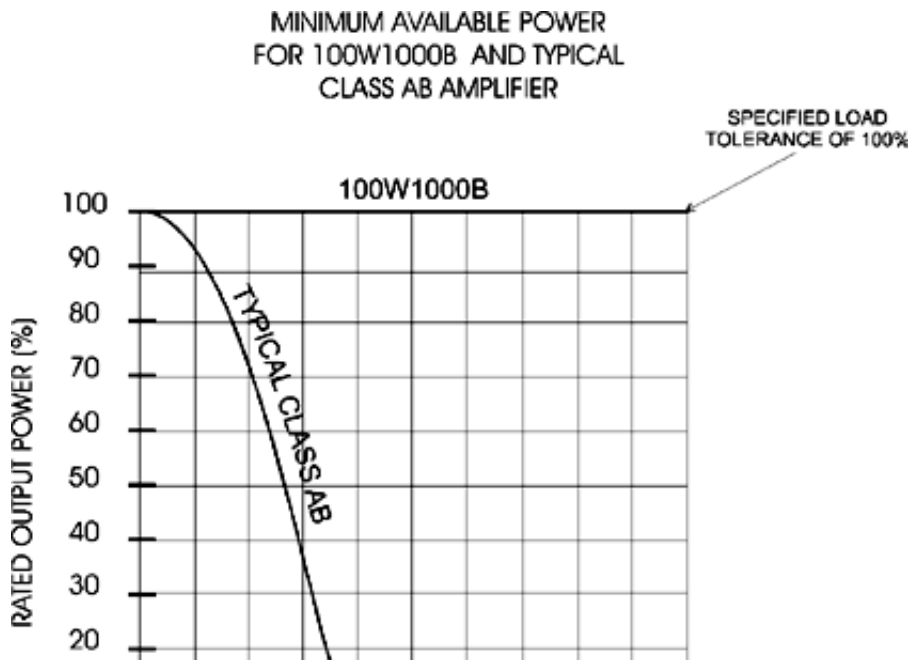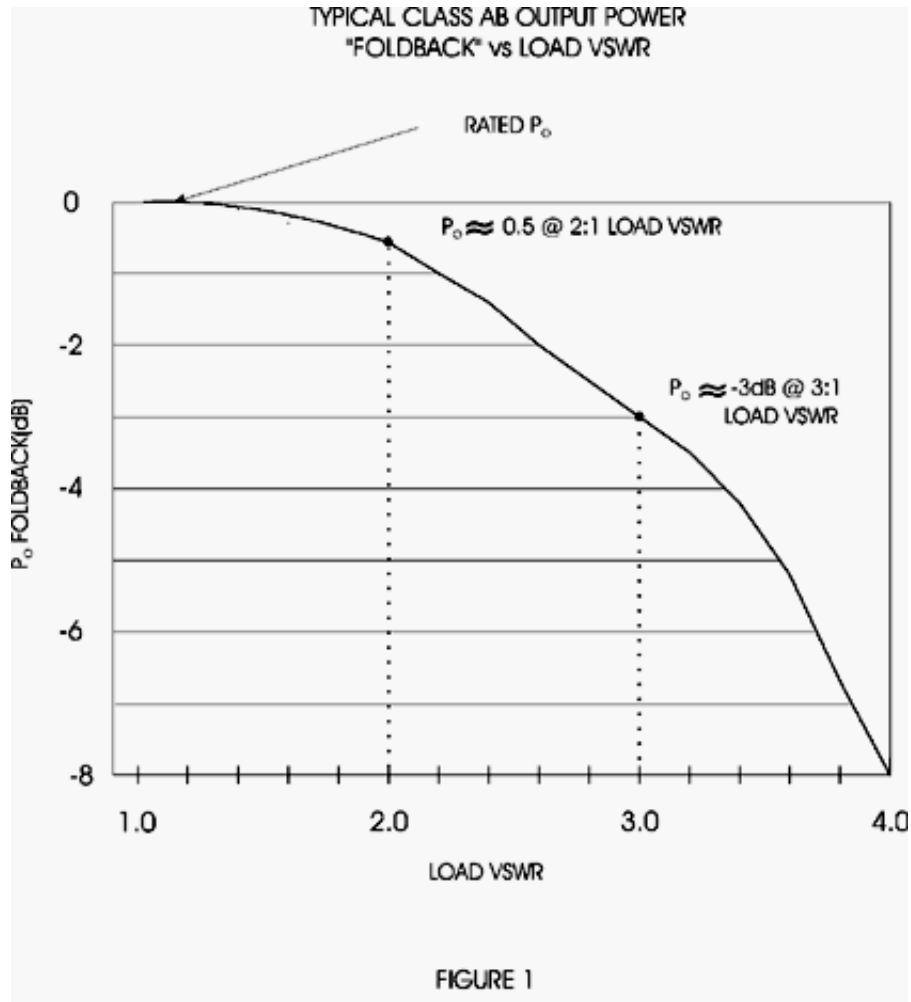
$$\text{Load Tolerance (\%)} = \frac{\left(\begin{array}{c} \text{Forward Power} \\ \text{@ 100\% Reflection} \end{array} \right)}{\left(\begin{array}{c} \text{Rated Power} \\ \text{of Amplifier} \end{array} \right)} \times 100$$

The load tolerance of all our amplifiers is stated in their respective specification sheets under the heading of Mismatch Tolerance.

Recommendations... The MAP concept introduced in this application note is offered as a "figure of merit" to be considered when selecting a power amplifier[1]. When the application involves varying loads, such as those typically encountered in susceptibility testing, load tolerance is of *paramount* importance. To insure that only load tolerant amplifiers are purchased, users are urged to specify amplifiers with load tolerance expressed in percentage of rated power when writing purchase requests.

[1] It is understood that the MAP concept refers to the available forward power, and not the power dissipated in the load. For example, in the extreme case of infinite VSWR (a short or open), no power is dissipated in the load. The MAP concept helps to visualize the effects of load VSWR on output power. Other amplifier characteristics such as low

power line voltage, temperature, input/output VSWR, etc. may affect available output power.
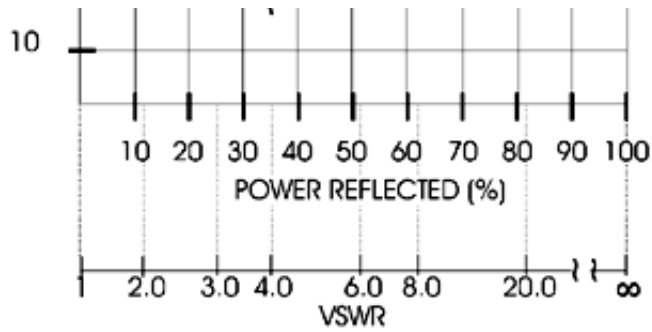
TYPICAL CLASS AB OUTPUT POWER "FOLDBACK" vs LOAD VSWR

RATED P_o

$P_o \approx 0.5$ @ 2:1 LOAD VSWR

$P_o \approx -3dB$ @ 3:1 LOAD VSWR

P_o FOLDBACK(dB)

LOAD VSWR

FIGURE 1

MINIMUM AVAILABLE POWER FOR 100W1000B AND TYPICAL CLASS AB AMPLIFIER

SPECIFIED LOAD TOLERANCE OF 100%

100W1000B

TYPICAL CLASS AB

RATED OUTPUT POWER (%)

FIGURE 2

MINIMUM AVAILABLE POWER
FOR 1000W1000A AND TYPICAL
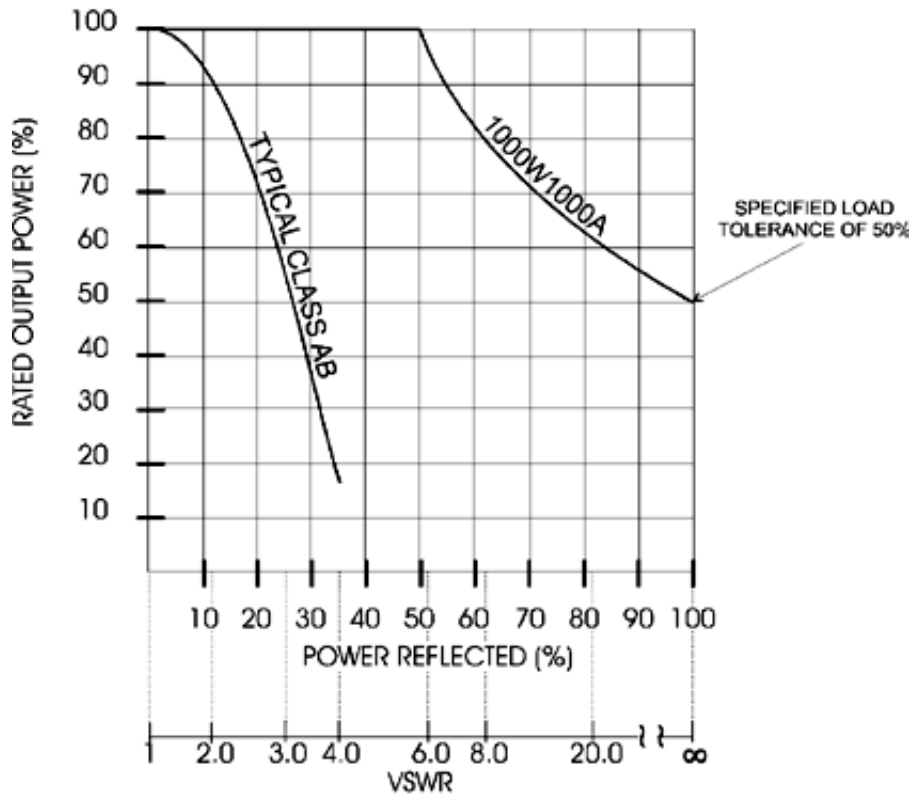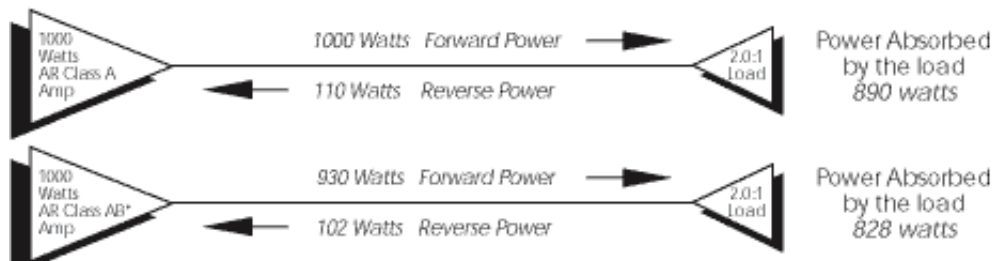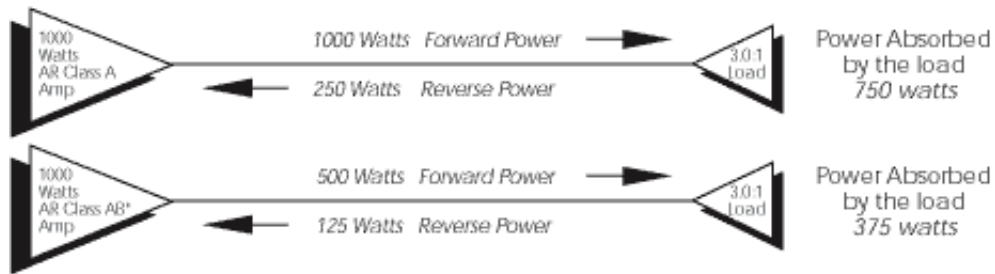CLASS AB AMPLIFIER

FIGURE 3

Amplifier Research Class A amplifier Vs Typical Class AB amplifier
Power Absorbed by the Load

In the above example, the Class A amplifier is able to provide full rated output to the load. Since 110 watts is reflected back into the output port, 890 watts is actually dissipated in the load.

The Class AB amplifier has already employed foldback protection therefore limiting its output power to approximately 930 watts. Since 11% of the forward power is reflected back to the amplifier, only 828 watts is dissipated in the load.

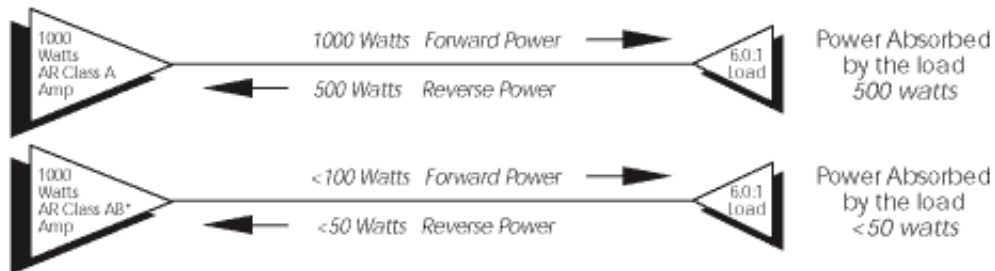| 1000 Watts AR Class A Amp | 1000 Watts Forward Power →
 ← 250 Watts Reverse Power | 3.0:1 load | Power Absorbed by the load
 750 watts |
| 1000 Watts AR Class AB* Amp | 500 Watts Forward Power →
 ← 125 Watts Reverse Power | 3.0:1 load | Power Absorbed by the load
 375 watts |

In the above example, the Class A amplifier is able to provide full rated output to the load. Since 250 watts is reflected back into the output port, 750 watts is actually dissipated in the load.

The Class AB amplifier has employed additional foldback protection therefore limiting its output power to approximately 500 watts. Since 25% of the forward power is reflected back to the amplifier, only 375 watts is dissipated in the load.

| 1000 Watts AR Class A Amp | 1000 Watts Forward Power →
 ← 500 Watts Reverse Power | 6.0:1 load | Power Absorbed by the load
 500 watts |
| 1000 Watts AR Class AB* Amp | <100 Watts Forward Power →
 ← <50 Watts Reverse Power | 6.0:1 load | Power Absorbed by the load
 <50 watts |

In the above example, the Class A amplifier is able to provide full rated output to the load. Since 500 watts is reflected back into the output port, 500 watts is actually dissipated in the load.

The Class AB amplifier must employ even more foldback protection thus limiting its output power to less than 100 watts. Since 50% of the forward power is reflected back to the amplifier, less than 50 watts is dissipated in the load.

* Also representative of less capable Class A amplifiers.