The Importance of Load Tolerance in Specifying RF Power Amplifiers

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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. Other less understood amplifier characteristics that are considered when specifying a power amplifier include noise figure, stability, and distortion. A major and often overlooked power amplifier characteristic is 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 article addresses the use of RF power amplifiers in applications characterized by mismatched loads. Voltage Standing Wave Ratio (VSWR) variations encountered in immunity testing are discussed as they relate 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 device with a poor VSWR.

THE PROBLEM

Real-life applications rarely involve driving an ideal 50-ohm load. More likely, the load varies with frequency over a wide impedance range. 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. 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 that most RF power amplifiers are not capable of providing full-rated power to loads that vary considerably from an ideal 50 ohms. This leaves EMC test engineers with the problem of inadequate power when significant mismatches occur.

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THE SOLUTION

There are two major types of RF power amplifiers used for susceptibility testing: Class A and Class AB. Since Class A linear amplifiers are designed to be "load tolerant," they are uniquely capable of handling applications involving varying load impedances. While Class A amplifiers are generally larger and more expensive than Class AB amplifiers, the electrical performance advantage outweighs other considerations.

To understand why Class A amplifiers are superior to Class AB amplifiers 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 ensure that collector or plate current flows for 360 degrees of input signal. When operated below the 1 dB compression point, the RF input signal 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. Unlike 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 run cooler.

Since they are thus running 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 regard to its ability to dissipate power, a Class A amplifier will undoubtedly be larger, heavier, more costly, and 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 somewhat 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 In), 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 compromised.

A typical Class A, 100-watt amplifier that requires 1000 watts of primary power can serve as an example. 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 case described assumes 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 affect 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 may have difficulty 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 versus 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 "fold back" 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 fold back 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 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.

MINIMUM AVAILABLE POWER (MAP)

While this article touches on the concept of load tolerance and available power, what is needed is a convenient means to determine the load tolerance of power amplifiers over a wide range of load impedances, and thus, the suitability to perform a particular task. Load tolerance is often specified by the equation:

$$\text{Load Tolerance (\%)} = \frac{\left(\text{Forward Power at 100\% Reflection}\right)}{\left(\text{Rated Power of Amplifier}\right)} \times 100$$

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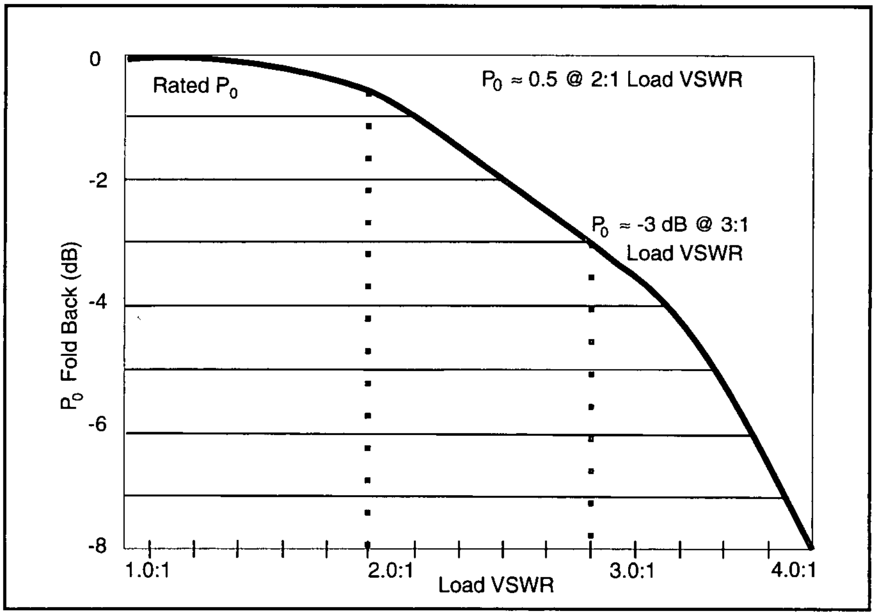

Figure 1. *Typical Class AB Output Power Fold Back vs. Load VSWR.*

This worst-case specification provides an indication of the suitability of a power amplifier for susceptibility testing applications. Often, this load tolerance is noted in specification sheets under the heading "mismatch tolerance."

A further refinement plots the percentage of output power (forward power) against the percentage of reflected power. Such a curve is referred to as the Minimum Available Power (MAP) of a power amplifier, and is offered here as a convenient "figure of merit." As an example, Figure 2 graphically depicts the MAP curve of a typical Class AB amplifier calculated from Figure 1, as well as a typical Class A amplifier that exhibits a load tolerance of 100% of rated output power at an infinite VSWR. The graph provides an unambiguous description of an amplifier's minimum available forward power as a function of VSWR. Furthermore, comparison between amplifiers is simplified by merely viewing respective MAPs.

As Figure 2 suggests, the power output from typical Class AB amplifiers begins to fold back for loads other than 50 ohms. A modest VSWR of 3.0:1 results in a 50% reduction of forward power. On the other hand, many Class A amplifiers can provide 100% forward power regardless of VSWR. Since VSWR conditions of 4.0:1 or greater are normally experienced when conducting susceptibility testing in a shielded enclosure, a Class A amplifier is clearly needed.

Figure 3 shows a Class A amplifier with a load tolerance of less than 100%. While the Class A amplifier depicted in this figure exhibits a worst-case load tolerance of 50%, it is important to note that the forward power does not begin to decrease until a VSWR of 6.0:1 is encountered.

RECOMMENDATIONS

The MAP concept introduced in this article is offered as a useful parameter to be considered when selecting a power amplifier. It is understood that MAP 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. When the application involves varying loads, such as those typically encountered in susceptibility testing, load tolerance is of paramount importance. To insure that a particular amplifier is up to the task, amplifier users are urged to specify required minimum power at the highest anticipated load VSWR when writing purchase requests.

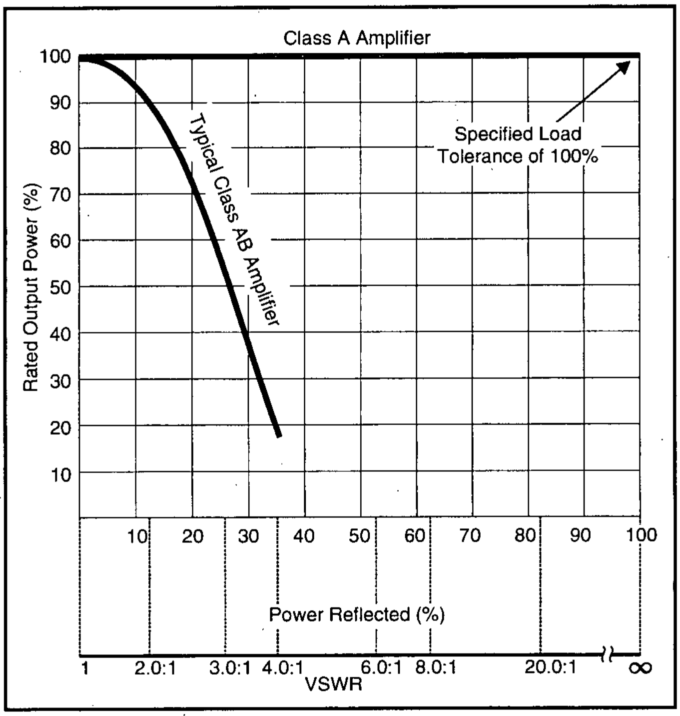

Figure 2*. Minimum Available Power (MAP) of Class A Amplifiers With 100% Load Tolerance and Typical Class AB Amplifiers.*

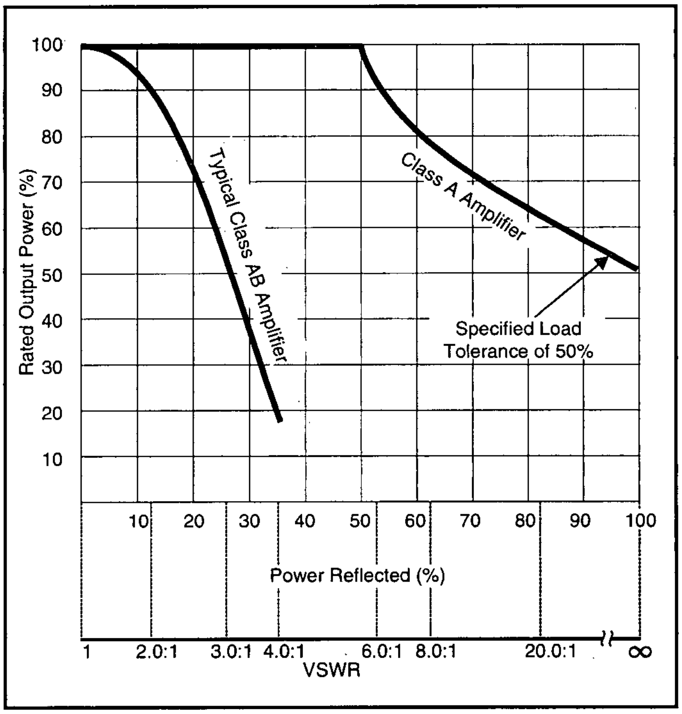

Figure 3*. Minimum Available Power (MAP) of Class A Amplifiers With 50% Load Tolerance and Typical Class AB Amplifiers.*

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