**Technical Article**

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Author:

Dipl.-Ing. (FH) Peter Mosshammer
*emv* GmbH
Wallbergstraße 7
D-82024 Taufkirchen

http://www.emvgmbh.de
mailto:info@emvgmbh.de

# RF Broadband Power Amplifiers

## Choosing an Amplifier above 30 MHz

An amplifier must be chosen in accordance with the requirements of its intended use. Here we concentrate on amplifiers used to load test objects with electromagnetic radiation above 30 MHz. But many of the criteria hold also for similar amplifiers used for other applications. The strength and characteristics of such loads are described in detail in the test method descriptions of the relevant EMC (Electro-Magnetic Compatibility) standards. These standards determine the minimum requirements for such amplifiers. Nevertheless, among amplifiers applicable for given standards, there are considerable differences between those from different suppliers. These differences strongly influence price/value calculations.

**Electromagnetic Amplitude of the Load on the Test Object**
Before selecting an RF-amplifier, one must consider the performance required to load the test object according to standard. For each frequency range, electric and magnetic field strengths, or supplied voltage and current are specified. The required performance can be estimated using the relationship that the RF-power P is proportional to the square of the impedance-related electromagnetic amplitude $X$, ($\vec{E},\vec{H},\vec{U},\vec{I}$). The corresponding formula is:

$$P = X^2 \cdot k$$

The proportionality factor $k$ is derived from all connection and transmission attenuation, adaptations, modulations, gains etc. For an accurate calculation of P, $k$ must be exactly known or calculated. Unfortunately, particularly for field amplitudes, this is often difficult or impossible. An estimation error of 3 dB results in halved or doubled RF-power, which is very significant regarding cost. For instance, when generating an electric field with far field conditions, the field strength can be calculated roughly as follows

$$E = \frac{\sqrt{30 \cdot P \cdot G}}{d}$$

Where:
$E$: Electric field at a point
$P$: RF-power antenna input
$G$: Gain of the antenna for far field
$d$: Distance of the field point from the phase center of the antenna

As stated earlier, the amplifier performance needed to generate this field can then be calculated as:

$$P = E^2 \cdot k$$

To avoid disturbing nearby systems and ensure accurate results in tests with electromagnetic radiation, the test object is normally in a screened room, which is clad in absorbers, and which often has a conducting ground plane. But in such rooms, frequency dependent effects occur, which affect the power needed to generate a given field strength. Since the antenna is not directly connected to the amplifier, attenuation between amplifier and antenna cannot be avoided. If the CW-signal is modulated, a further power reserve is necessary. The above mentioned factors contribute to the parameter $k$ as follows:

$$k = \frac{d^2 \cdot (m+1)^2 \cdot A \cdot R}{30 \cdot G}$$

Where:

$d$: Distance of the field point from the phase center of the antenna
$m$: Degree of amplitude modulation
$A$: Attenuation between amplifier output and antenna input, due to cables, connectors, etc.
$R$: Room dependant adjustment for the relevant frequency and field strength
$G$: Antenna gain, valid for the environment (room and frequency)

The required amplifier power is thus:

$$P = E^2 \cdot \frac{d^2 \cdot (m+1)^2 \cdot A \cdot R}{30 \cdot G}$$

This formula has the following essential aspects:

1. The required amplifier output power is proportional to the square of the distance between antenna and test object.

2. The required amplifier output power is proportional to the square of the required field strength, see the following Figure 1:

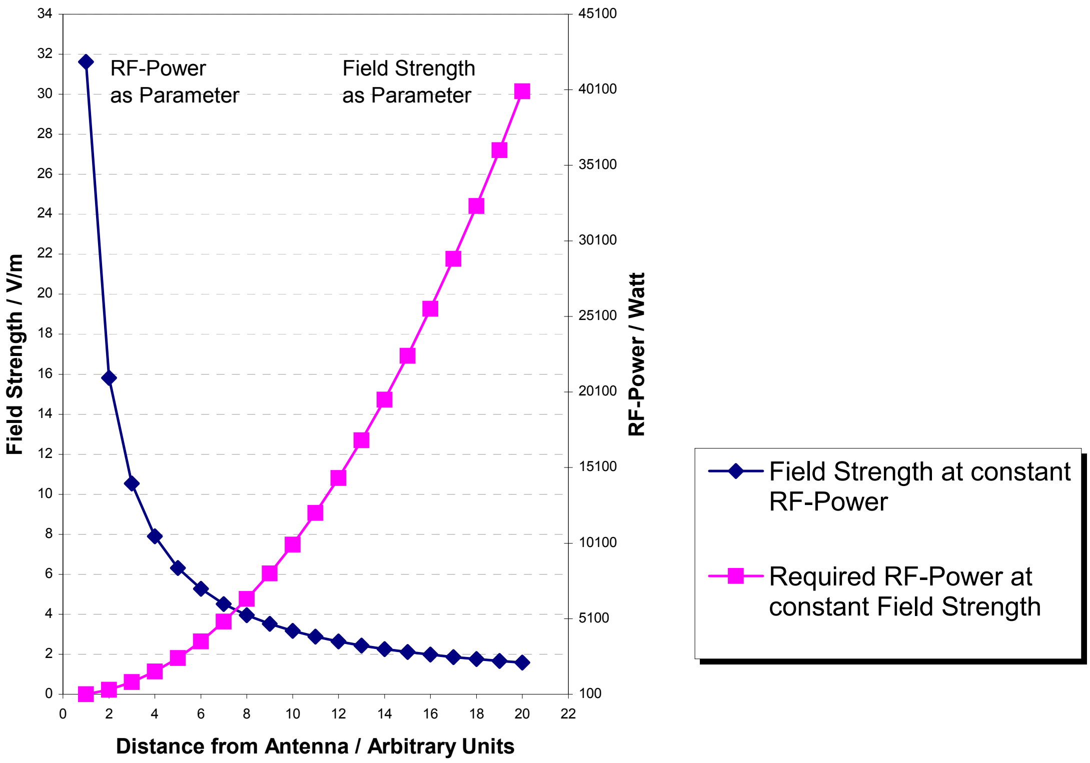


*Figure 1: Amplifier-Power and Field strength dependent on distance.*

3. The required RF-power is inversely proportional to the gain of the antenna. With a better gain, one needs less amplifier power. To obtain enough field strength, tests are often carried out near to the antenna. But antenna manufacturers normally only give accurate gain values for far field. Near field values of the gain are variable and often lower than far field, so that results are less accurate, and more amplifier RF-power is needed. A gain reduction of 3 dB is not unrealistic.

4. Attenuation and room dependant adjustment are linear effects. One tries to minimize attenuation between amplifier and antenna. One reduces the room dependant adjustment by avoiding room resonances and removing all unnecessary objects from the room. Attenuation and room dependant adjustment often require 3 dB more power.

5. Many tests are made with the aggressive 80 % AM-Modulation. This Modulation, as shown in Figure 2: AM-Modulation - Definition of Carrier Voltage and Peak Voltage, introduces voltage peaks that also require more amplifier power. The degree of modulation is defined as:

$$m = \frac{\left(U_{\max} - Uc\right)}{Uc}$$

Where:
$U_c$: The peak of the unmodulated Carrier
$U_{max}$: The peak of the modulated Carrier

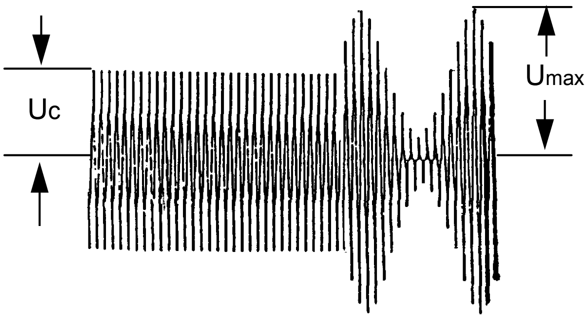


*Figure 2: AM-Modulation - Definition of Carrier Voltage and Peak Voltage*

So with 80 % AM-Modulation $U_{max}$ is 1.8 times the unmodulated value, i.e. $(m+1)\cdot U_C$. Since the voltage, according to the following formula:

$$P = \frac{U^2}{R}$$

contributes quadratically, the power requirement is increased by factor 3.24 (not 1.8). Put another way, this is a 5.1 dB increase

## What further criteria matter when choosing a broadband amplifier

**Versatility**
For cost and time efficiency, it is important to have an amplifier that is suitable for various different tests. This requirement affects the criteria frequency range, performance, and type of modulation, which are considered below. Supported by automated test methods and configuration, it is desirable that both signal generator and amplifier are suitable for many different tests. Integration in different sorts of fixed test systems can easily be organized via appropriate RF switching. This saves time and avoids the risk of mistakes during reconfiguration.

**Frequency range**
The test standards determine required amplifier frequency ranges. The amplifier manufacturers orient their product lines accordingly. But some manufacturers, e.g. "Amplifier Research", try to cover as wide a frequency range as possible. Often corresponding broadband antennas are also available. This is important regarding measurement ergonomy. If one calculates the time taken in test reconfiguration during the expected life of the amplifier, it becomes clear that the extra cost of an amplifier with greater bandwidth will be quickly amortized.

So a wide frequency range is an important consideration when choosing an amplifier. A broadband amplifier is generally preferable to the purchase of multiple band solutions, which also tend to fail more often. Of course there are technical boundaries, where a change of amplifier can hardly be avoided.

Besides the suitability of an amplifier for varied test processes, through covering a wide frequency range with constant amplitude response, there are a further important requirements that a modern broadband power amplifier should meet.

**Behavior with mismatch**
Here we mean the robustness of the amplifier with regard to a mismatch at its output. This has practical consequences because the connecting media such as antenna, coupling device and strip line often show some incompatibility when connected to an ideal 50 ohm system, purely due to their construction. Part of the RF output power of the amplifier is reflected back from the connected components. Voltage Standing Wave Ratios > 6:1 are not unusual.

This causes a significant power loss in the last stage of the amplifier. To avoid damage from a bad VSWR, a high robustness is needed. Class A amplifiers, in contrast to Class AB amplifier, due to their construction are particularly appropriate as broadband amplifiers when output mismatch is to be expected. With good output matching, a Class A amplifier is more expensive than a Class AB amplifier of the same power. But a Class AB amplifier, working according to the push-pull principle, requires additional protection circuitry when confronted with mismatch. to reduce the output performance and avoid damage.

The mismatch behavior of the amplifier shows itself in its load tolerance. This is defined as follows:

$$Load\,Tolerance / \% = \frac{P_v}{P_n} \cdot 100$$

$P_v$: Power output with 100% reflection
$P_n$: Nominal power

Optimally the amplifier should deliver full power regardless of VSWR at its output. A load tolerance of 100% means that the amplifier delivers the specified power even as the VSWR tends to ∞.

**Definition of the minimum output performance**
Because of the different load tolerance of the different amplifier classes, we need a clear criterion for comparing amplifiers when there is mismatch.

So the Minimum Available Power (*MAP*) is defined. A graph plots the real output performance against the reflected performance or VSWR, see *figure 3*. The MAP gives a clear statement of the power capability of an amplifier depending on VSWR. A manufacturer who is unable to provide this graph cannot say anything very significant about the performance of his amplifier.

When choosing an amplifier, the technical details must be carefully studied, in relation to cost. An apparently cheaper amplifier may turn out to be a very expensive choice, when MAP and load tolerance are considered.

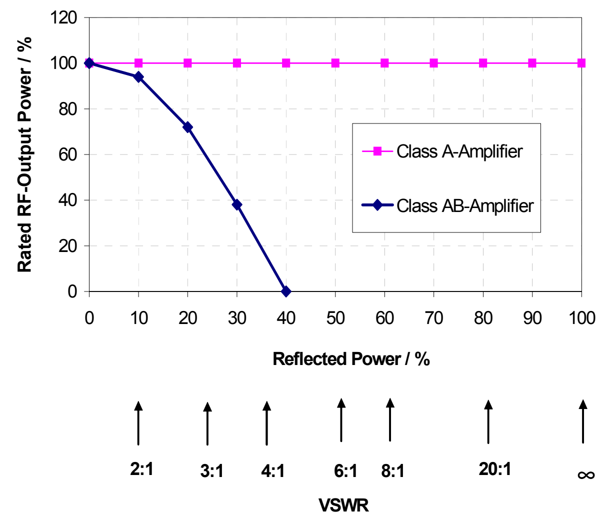


*figure 3* *Minimum available RF output power related to the ratio of reflected output power, (VSWR)*

For a given nominal output power, a class AB amplifier costs about 30% less than a class A amplifier, assuming similar properties such as frequency range, amplification and linearity. This is relevant, with ideal test conditions, i.e. a VSWR ratio less than 2:1. But in practice, a test configuration may well have a VSWR ratio of 4:1, 6:1 or even 10:1. An amplifier that is not constructed to cope with such a mismatch will cut back power or even turn off. Such an amplifier must be much more powerful, in order to deliver the required performance. For instance, when 100 Watts are required from an AB amplifier with VSWR of 4:1, at least a 500 Watt amplifier is needed. As shown in Figure 4, the price of a 500 Watt AB amplifier is typically 140% higher than that of a class A amplifier that delivers 100 Watt with 100% load tolerance. Choice of a "cheap" amplifier can lead to a nasty surprise.

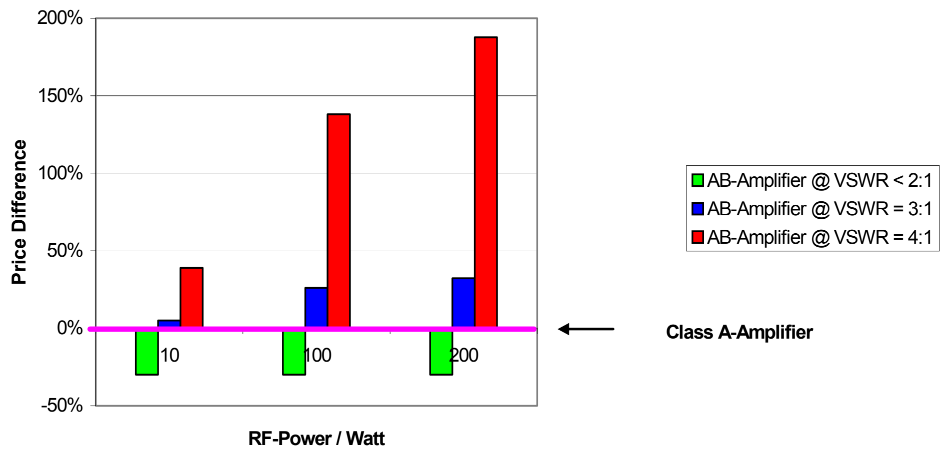


*Figure 4* *Price of a Class AB-Amplifier, relative to Class A-Amplifier, depending on required power and VSWR.*

### Linearity

Linearity is a very important factor when choosing a broadband power amplifier. According to the standard, the test object should be exposed to electromagnetic radiation of a particular frequency. A non-linear amplifier response curve means that the amplifier will generate harmonics, so that the test will not conform accurately to the frequency defined in the test standard. Different amplifiers will then produce different test results although the test conditions are supposed to be the same. It is important to suppress the generation of harmonics, and to generate the correct output performance over the whole supported frequency range.

Amplifier linearity is characterized by the output power at the 1 dB compression point, and by the interception points IP2 and IP3 which give the intensities of the first and second harmonics relative to the base (carrier) intensity, (expressed in dBc). Every manufacturer must be able to give these parameters. No amplifier can be sensibly chosen without taking them into account.

The 1 dB compression point is normally taken to be the point where the output performance ceases to be linearly related to the amplifier input strength. Beyond this point, the amplifier becomes increasingly overloaded, and test result distortions increase.

Of course, the output power at the 1dB compression point will not be the same throughout the advertised frequency range of the amplifier. So a statement of power at **typical** 1dB compression point is not enough. Especially if tests are to use the whole stated frequency range, the customer must know the **minimum** power at maximum 1 dB compression within this range.

### Construction

Regarding cost saving, aspects such as size, weight, type of cooling and construction (semiconductor or tube amplifiers), are also significant. Naturally, a very powerful amplifier needs a lot of space, which entails extra costs, particularly when an existing system is enhanced, and then no longer fits in the existing room. The heat generated by a new amplifier may also overload the existing air conditioning. This may require a new water cooling, which is more expensive than air cooling. The total weight of amplifier and cooling may even cause problems regarding the strength of the floor.

Both heat loss, size and weight of an amplifier of given power are all reduced when semiconductors are used, rather than tubes. Where practicable, for instance up to 1 GHz, tube broadband power amplifiers are hardly sold. The manufacturers are working hard to extend the use of high power semiconductor amplifiers to 20 GHz. In addition to the size, weight and heat disadvantages of the tube amplifiers still used for high power GHz frequencies, semiconductor elements generally have longer working life than equivalent tubes. So maintenance costs are higher for tube amplifiers than for semiconductor amplifiers.

### Summary

The choice of an amplifier depends on two main criteria:

1. Maximum RF performance,
2. Minimum cost.

The two aims conflict, so whoever chooses the amplifier must find a sensible compromise, between maximum technical requirements and a solution that saves costs over the expected lifetime of the amplifier.

To calculate the required amplifier performance, one must consider the distance between antenna and test object, wandering of the antenna phase center, antenna gain, power losses, required modulation, influences from the room and test-object, and the total VSWR. Sufficient power reserves are required accordingly. Class A amplifiers are much better for EMC testing than class AB. Only exact consideration of frequency range, minimum available power, load tolerance, and amplifier linearity permits a reliable statement whether an amplifier is capable of providing the required power and field characteristics.
Only consideration of all these technical parameters without forgetting cost factors such as size and construction form gives an objective picture of the suitability of an amplifier for a given purpose.

**Sources:**

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