EMC Amplifiers – Going Beyond the Basics to Ensure Successful Immunity Tests

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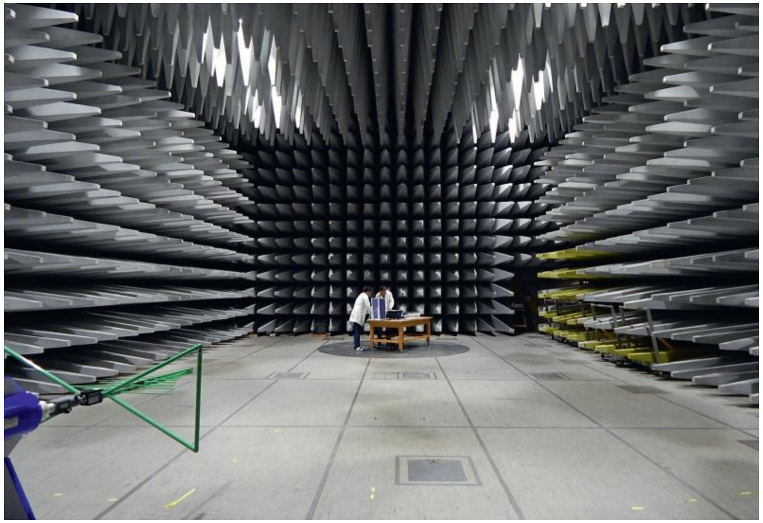
Broadband amplifiers are used to generate the high field strengths required by EMC radiated immunity testing standards. This webinar focuses on the basics of EMC amplifiers, including a technical overview as well as a practical discussion of how amplifier class, compression points, VSWR, foldback, etc. impact performance in real-world scenarios.

Outline

- Amplifiers in EMC testing
- Amplifier fundamentals
- Linearity and compression
- Understanding VSWR
- Protection methods
- Additional considerations
- Summary / question and answer



An Overview of EMC Testing

- **Emissions testing** (or **interference testing**) - measure electromagnetic signals emitted by the EUT to determine if these emissions exceed the permissible limits.
- **Immunity testing** (or **susceptibility testing**) - verify a device can function properly when exposed to (significant) levels of RF energy.
- There are numerous examples of devices that have malfunctioned or failed when exposed to high levels of RF energy -- in some cases resulting in injury and death.

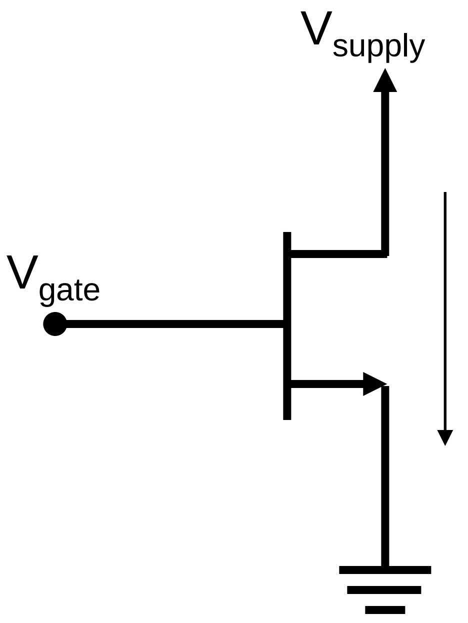
Amplifiers in EMC Testing

- In immunity testing the device is subjected to RF over a wide range of frequencies.
- RF energy may be **conducted** into a device via its attached cables or be directly picked up "over-the-air“ from **radiated** signals.
- Challenges of radiated immunity testing:
  - Very high **field strengths** (3 - 200 V/m) are required
  - Antenna efficiency varies greatly over the wide frequency ranges
- **EMC amplifiers** are used to generate the power needed to create the high field strengths required in radiated immunity testing.

Amplifier Fundamentals

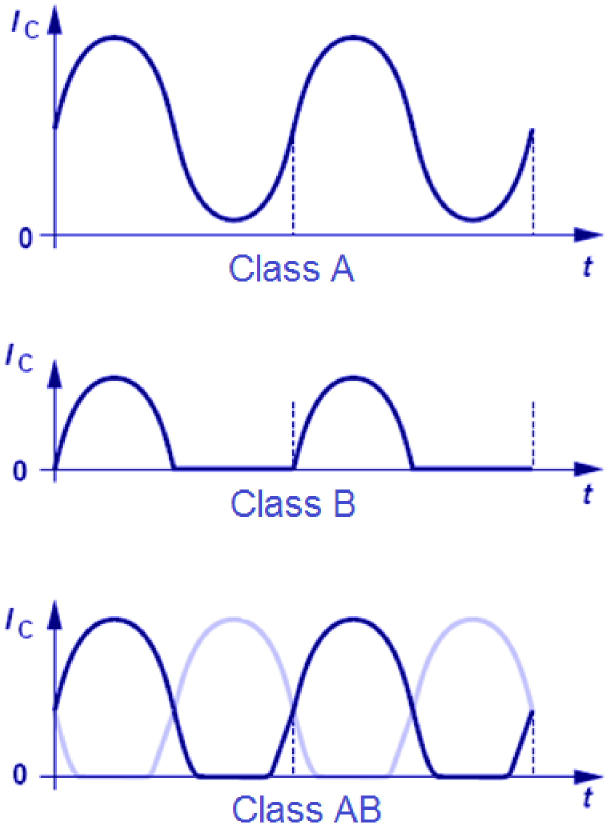
- An **amplifier** takes an input signal and produces an output signal that is a copy of the input signal, but with increased amplitude.
- Variety of construction methods:
  - Traveling wave tubes (TWTs)
  - Klystrons
  - Magnetrons
  - Transistors
- EMC amplifiers below 6 GHz usually use solid state RF transistors.

Amplifier Classes of Operation



- The **conduction angle** is percentage of the time during which the amplifier is "amplifying" or conducting power.
- For example:
  - Angle = 360° : amplifier conducts over entire input power cycle
  - Angle = 180° : amplifier conducts over half of input power cycle.
- 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 and higher temperatures.

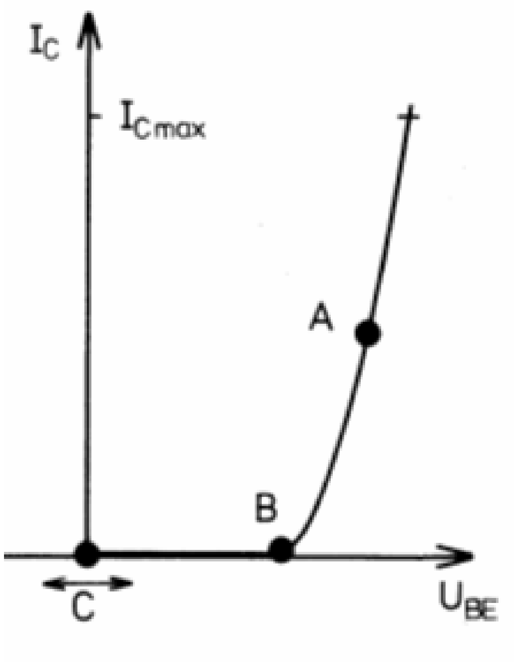
Class A, B and AB



- Amplifiers with a 360° conduction angle are called **Class A** amplifiers
- Amplifiers with a 180° conduction angle are called **Class B** amplifiers.
- **Class AB** amplifiers have a conduction angle between 180° and 360°. This represents a compromise between the conflicting goals of linearity and efficiency.

Amplifier classes and EMC

- Class A provides high linearity but low efficiency.
- Class AB amplifiers advantages:
  - lighter weight / lower cost
  - increased efficiency
  - reasonably linear performance
- Class AB disadvantages:
  - reduced ability to dissipate heat
  - more susceptible to damage resulting from high VSWR
- Class A amplifiers are generally preferred over Class AB amplifiers in EMC testing.



Output power

- Output power (specified in watts or dBm) is the most fundamental performance parameter for any amplifier. Usually a function of input (drive) power.
- Immunity testing requires output power in the range of hundreds or thousands of watts to generate the field strengths specified in most immunity testing standards.
- The **gain** of an amplifier is simply the ratio of output power over the input power, usually given in dB.

$$gain = 10\log\left(\frac{P_{out}}{P_{in}}\right) dB$$

Output power vs. field strength

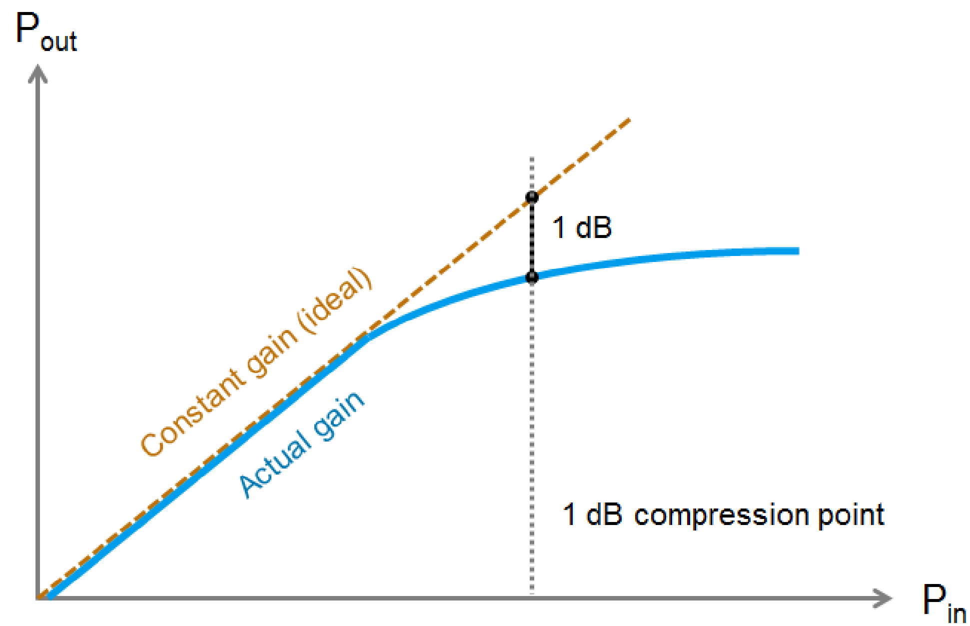
- Amplifiers are specified in terms of their output power.
- However, the purpose of amplifiers in radiated immunity testing is to generate a **field strength** of a given intensity at a given distance from the antenna.
- Field strength is a function of many variables.
- The amplifier output power needed to create a given field strength is highly frequency-dependent.
- For example, a field strength of 10 V/m may require 100 watts at one frequency and 1000 watts at a different frequency.

Linearity and compression

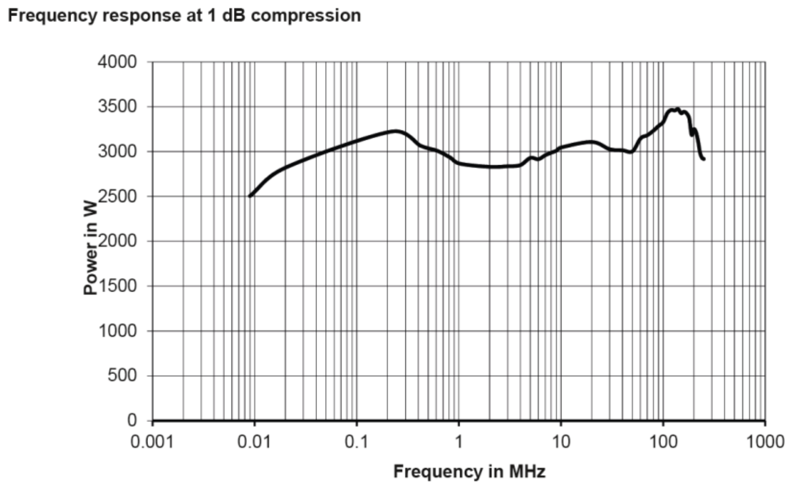
- An amplifier is operating in its **linear** region when there is a fixed increase in output power for a given increase in input power -- i.e. for every N dB increase in input power there is a N dB increase in output power.
- When there is no longer a linear relationship between the increase in input power and the increase in output power, the amplifier is said to be in **compression**.

Compression point

- Compression is specified in terms of a **compression point** at a given power level.
- The most commonly used compression point is the **1 dB compression point** (P1dB), where the actual output power is 1 dB less than the expected (linear) output power.



About compression points



- P1dB is the standard measure of amplifier linearity.
- Some amplifiers are specified using 2 dB or 3 dB compression points, even though harmonics and IMD are significantly higher at these points compared to P1dB.
- Impossible to evaluate the performance of a 1000W amplifier if the P1dB is specified at only 700W.

Consequences of compression

- Operating an amplifier in compression has two consequences:
  - Increasing input power no longer results in the same increase in output power. Eventually the maximum amplifier output power will be reached regardless of input power.
  - Amplifiers in compression produce **harmonics** and **intermodulation products** which increase rapidly and unpredictably as the amplifier goes further into compression.

Harmonics and intermod

- The presence of harmonics and intermodulation products makes it very difficult to determine which frequency components are responsible for undesirable EUT behavior.
- Harmonics usually have lower power than the fundamental, but the harmonic may actually yield a higher field strength due to the frequency response of the antenna.

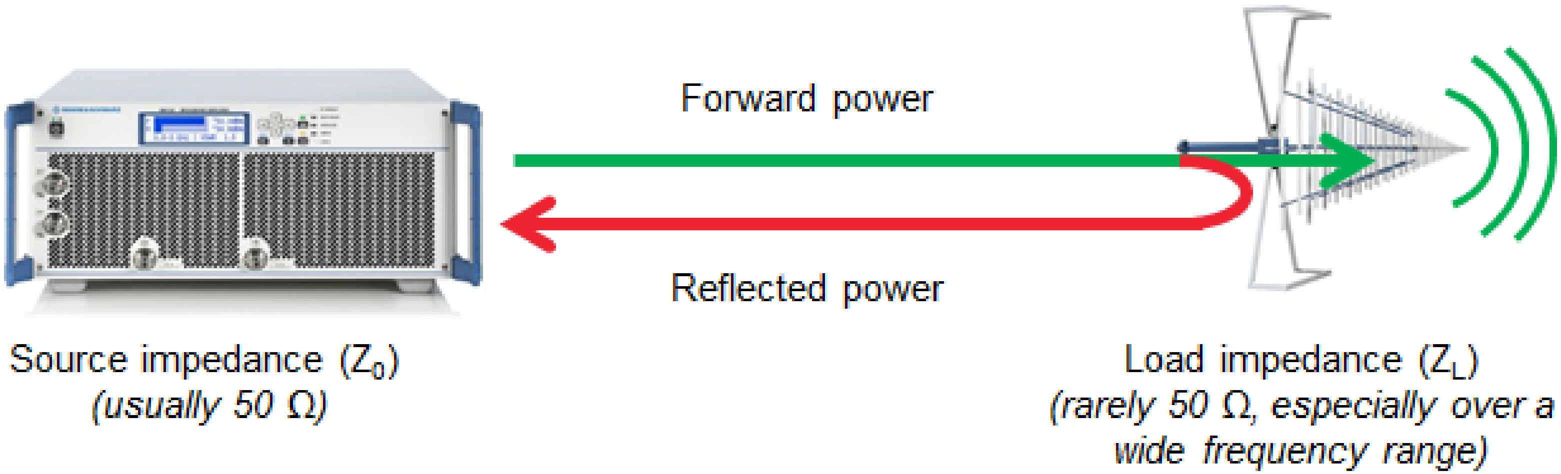
Measuring field strength

- Most field strength probes are not frequency-specific and cannot determine the presence of harmonics and intermodulation products.
- Frequency-selective devices such as EMI receivers or spectrum analyzers can be used to detect and measure any harmonics and intermodulation products present in the transmitted signal.
- Safest way is to use an amplifier with good linearity and to operate that amplifier within its linear region.

Forward and reflected power

- Maximum power transfer occurs when source and load impedances are equal ("matched") and all output is absorbed by the load.
- If load impedance is not the same as the source impedance, some of the power transmitted towards the load (the **forward power**) is returned back to the source (the **reflected power**).
- This mismatch causes **standing waves** on the transmission line between source and load.

Forward and reflected power



Reflection coefficient

- Reflection is normally quantified by means of a **reflection coefficient**, Γ, which is a function of the load impedance (Z_L) and the source impedance (Z_0).
- Impedances (Z) are complex (R ± jX), frequency-dependent values. This has a tremendous impact on the selection and use of amplifiers for radiated immunity testing.

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

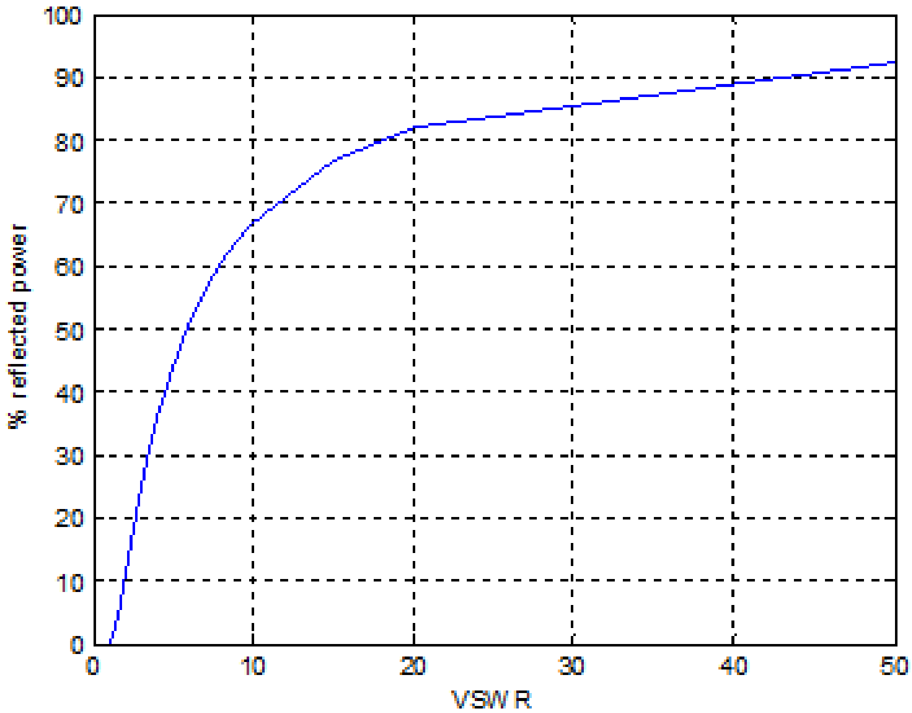
VSWR Formula

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

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

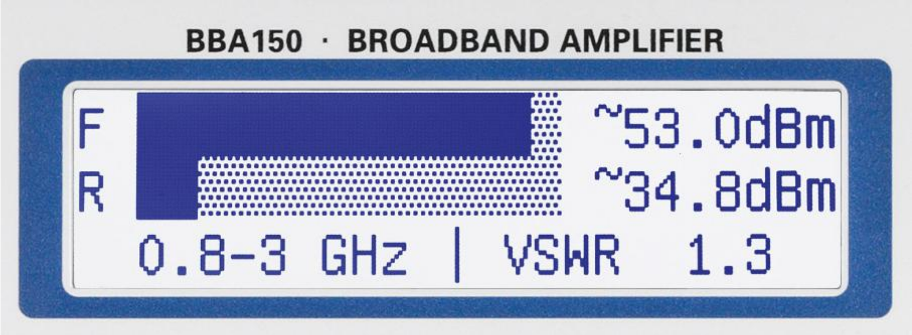
VSWR and % reflected power

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



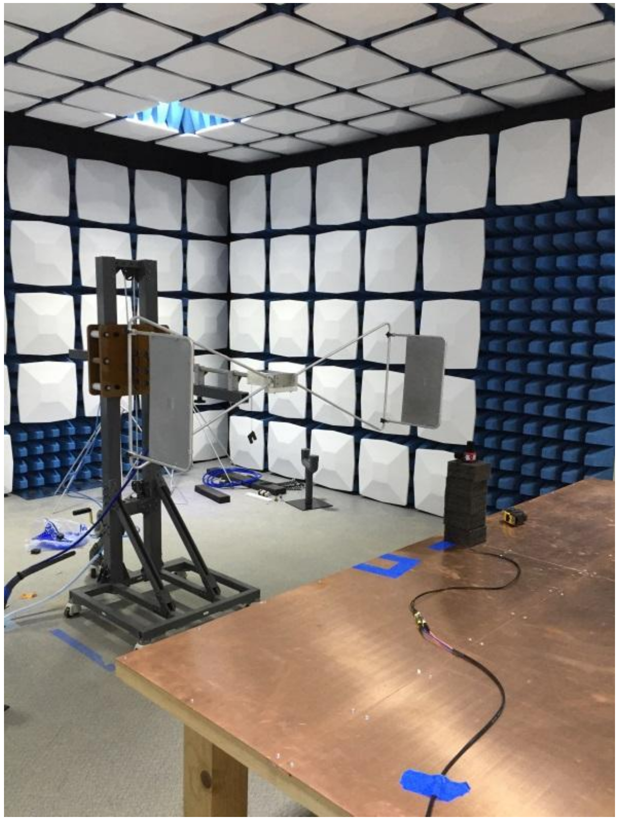
Specifying VSWR

- VSWR is most often specified either as a ratio (2:1) or as a normalized value (2).
- VSWR of 1:1 (1.0) indicates a perfectly matched load.
- Obtaining a (near-)perfect match is highly desirable because it maximizes power transfer and minimizes reflected power.
- A perfect match (1:1) is rarely obtainable in radiated immunity testing.

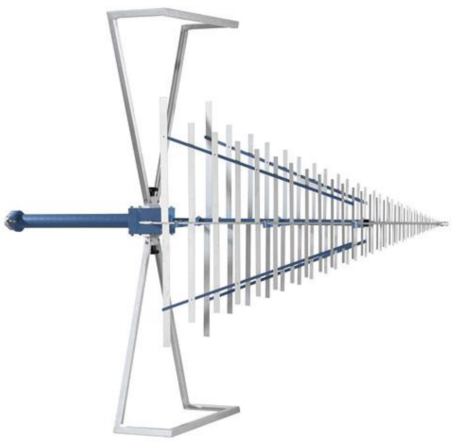


Antennas and VSWR

- EMC amplifiers normally have a fixed, non-reactive source impedance (50 or 75 Ω).
- However, the **load** (antenna) impedance varies tremendously as a function of frequency.
- Difficult to design antennas with low (< 2:0) VSWR over moderately large frequency ranges.
- Even for well-designed antennas, VSWR can easily exceed 6:1 over the nominal operating range.



Multiple antennas and VSWR



- One way to obtain “manageable" VSWR values over a wide frequency ranges is to separate the range into smaller subranges and use a different antenna over each of these ranges.
- The number of subranges is usually limited to six or less.
- Common in radiated immunity testing, but requires switching between antennas.
- Even with multiple antennas, it can still be difficult to obtain a "good" VSWR over even a single subrange.

Matching networks and VSWR

- Another approach: alter the (apparent) impedance of the load.
- Since high VSWR is caused by a significant impedance mismatch, so-called **matching networks** are sometimes used in an attempt to make the load impedance "match" the source impedance.
- Matching networks are used in many applications, but it is difficult to design matching networks that are effective and/or efficient over very wide frequency ranges.

Mutual coupling and VSWR

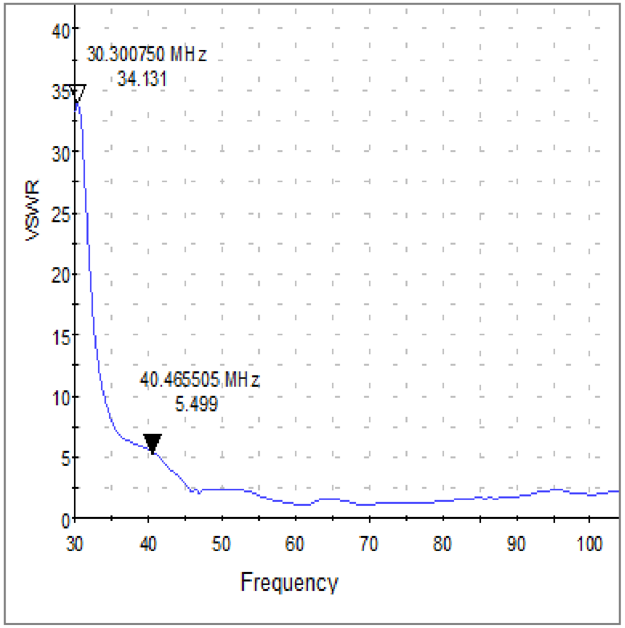
- The antenna has by far the greatest influence on VSWR, but other factors can also affect the VSWR during radiated immunity testing.
- Interaction or coupling between the EUT and antenna can influence field strength and VSWR.
- The degree of coupling depends on distance between the EUT and the antenna, the aspect angle, EUT composition, etc.

Chamber and VSWR

- VSWR can also be affected by chamber itself.
- Generally the smaller the chamber, the greater the effect on VSWR.
- There may be a sharp increase in VSWR when the wavelength of the transmitted signal becomes close to one or more linear internal dimensions of the chamber.
- Size, location, and electrical characteristics of the ground plane can also affect VSWR.

Power vs. field strength

- We are interested in **field strength,** not **power** in and of itself.
- The higher the VSWR, the lower the percentage of amplifier power that is delivered to the load and the lower the resulting field strength.
- As VSWR increases, amplifier output power must also be increased in order to maintain a given field strength.
- An amplifier faced with high VSWR may be unable to produce the necessary output power needed to generate the desired field strength.



Power leveling

- Creating a uniform field strength across a wide range of frequencies can be very challenging.
- Power leveling algorithms are often included as part of EMC test automation environments.
- Algorithms are usually vendor specific – the speed and efficiency of these proprietary algorithms can vary tremendously between platforms.

VSWR and amplifier protection

- High levels of reflected power can be very harmful to an amplifier
- Immediate damage can be caused by internal arcing or transistor breakdown.
- Damage or degradation of amplifier performance may also occur more gradually when reflected energy generates excessive heat within the amplifier itself.
- Simplest solution is to put a fixed attenuator in the path. This reduces the level of reflected power, but also reduces the transmitted power level.

Foldback

- The most common amplifier protection method is **foldback.**
- As reflected power increases, output power is decreased.
- However, this also reduces the output power and consequently the radiated field strength.
- Foldback can protect an amplifier, but reduces performance.

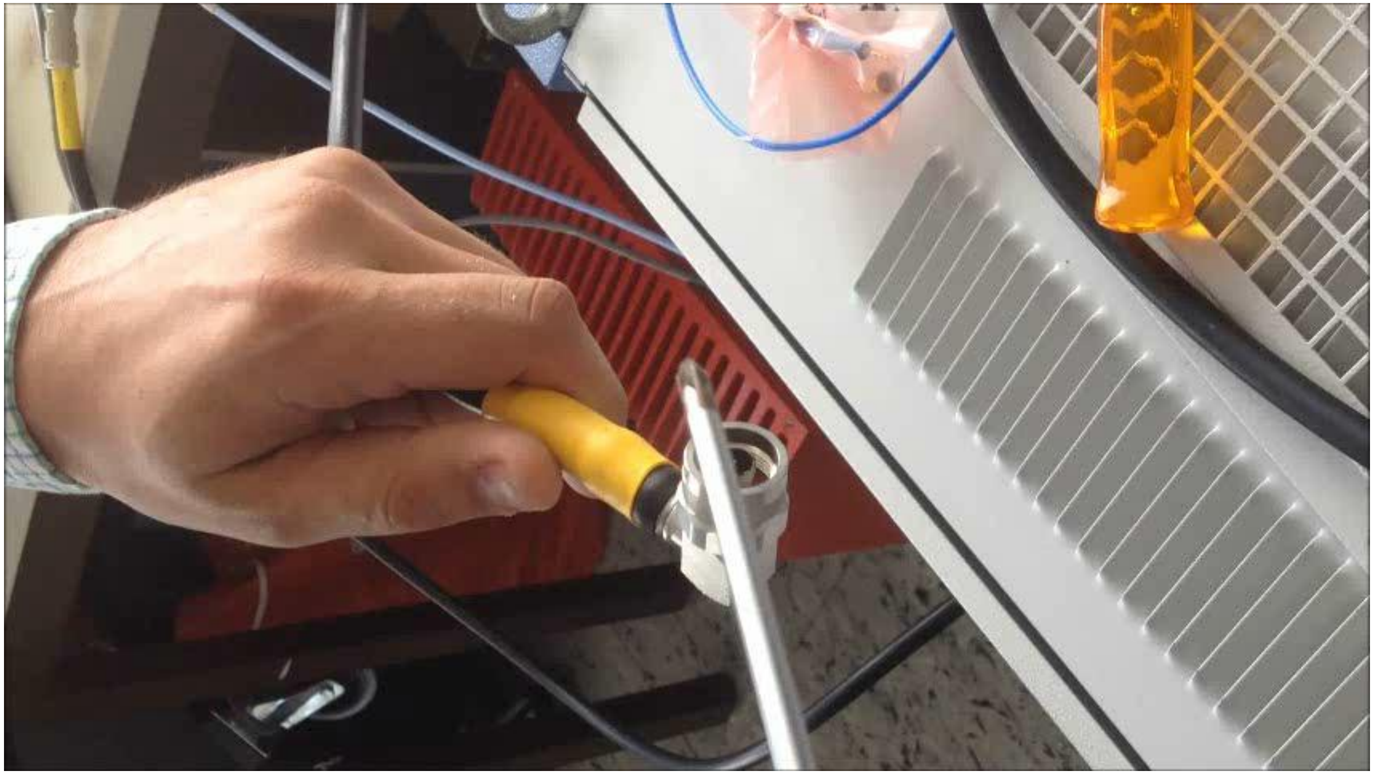
Foldback triggering

- While VSWR describes percent reflected power but absolute **level** triggers foldback.
- For example, at VSWR of 6:1 equals 50% reflected power is reflected. However, 50% of 100 watts is far less damaging than 50% of 1000 watts.
- Foldback should therefore be specified at a given power, not a given VSWR.

VSWR and open / short circuits

- High VSWR values are often unavoidable during normal radiated immunity testing.
- Two abnormal situations : short or open circuit.
- Can be the result of equipment failure and/or human error
- In both cases VSWR = infinity : 100% reflected power
- Broadband amplifiers vary tremendously in terms of how long they can continue to operate without damage when connected to a large mismatch such as an open or short.

Extreme VSWR event



Handling excessive VSWR

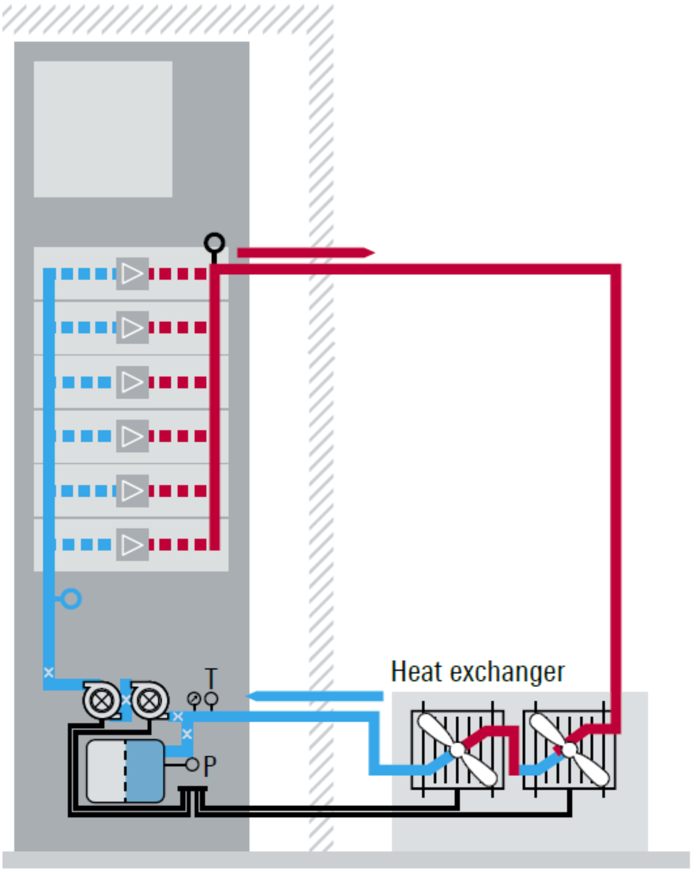
- Excessive VSWR may be encountered
  - continuously (open/ short)
  - temporarily (e.g. during a frequency sweep).
- Some amplifiers can only deal with short periods of high VSWR, others are capable of running for extended periods (hours) into an open, shorted, or high VSWR load.
- Especially important in automated testing, when quick manual intervention may not be possible.

Additional amplifier considerations

- Numerous other important considerations in EMC amplifiers:
  - Heat dissipation
  - Noise level
  - Construction method
  - Control and operation
  - Sample ports
  - Safety
  - Modularity
  - Power density

Heat dissipation

- Amplifiers generate heat in proportion to output power and VSWR.
- Consequences of excessive heat:
  - degrade amplifier performance
  - reduce the operational life
  - permanent amplifier damage.
- Heat can also adversely affect nearby external devices.
- Cooling methods:
  - air cooling
  - liquid-based cooling

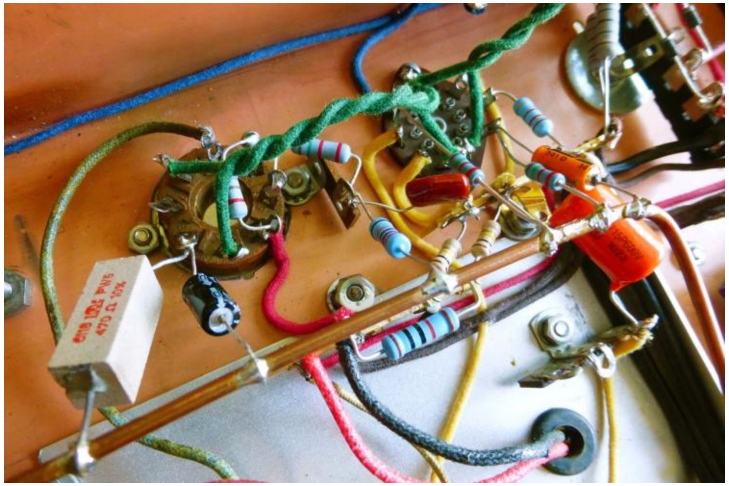


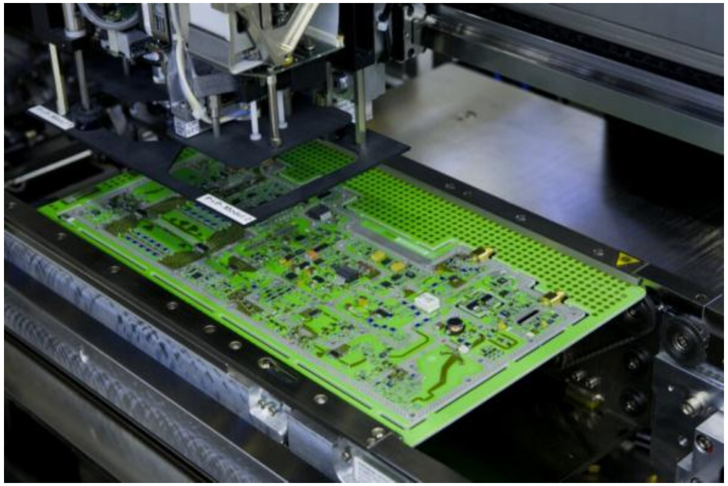
Noise level

- Air-cooled systems typically require fans.
- Fan noise can be continuous and substantial.
- High noise levels can lead to health, safety, and other workplace issues.
- A properly designed and efficient air cooling system should not require extremely loud and/or bulky fans.

Construction method

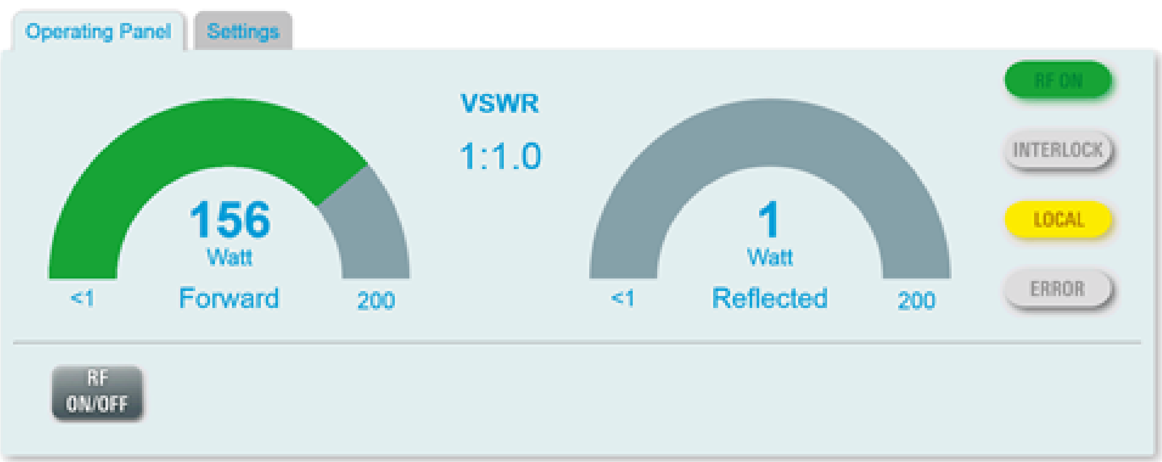
- Manual amplifier assembly leads to variability between amplifiers and greater risk of faults.
- Modern manufacturing techniques greatly improve quality, consistency, and robustness.





Control and operation

- Amplifiers may be operated as standalone, manually-adjusted devices or as part of a larger test automation environment.
- Amplifiers should have easy-to-understand controls, preferably with visual indications of parameters like output power and VSWR.
- Remotely access and control is extremely useful as well.

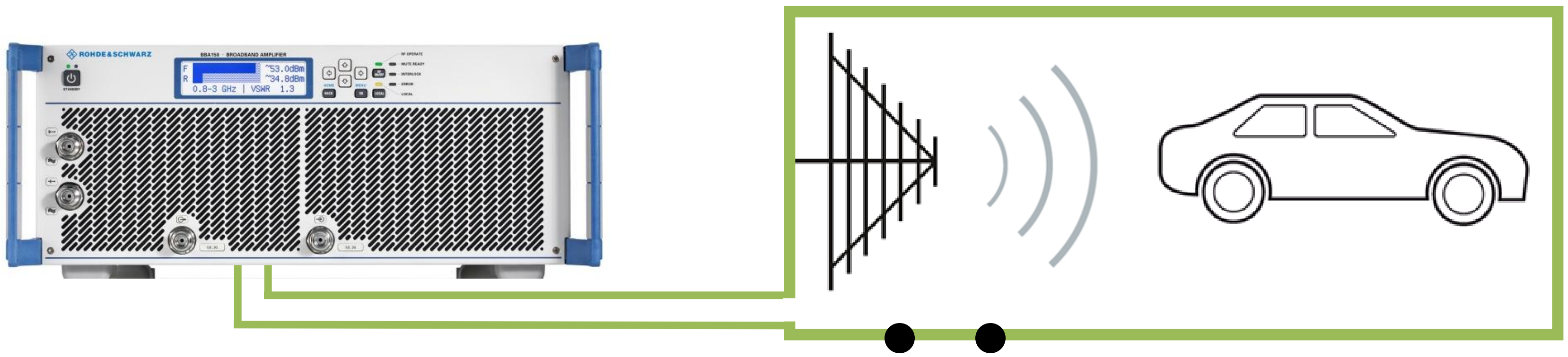


Sample ports

- Directional power meters can be used in-line to make direct measurements of forward and reflected power.
- Built-in sample ports on an amplifier make this task both simpler and safer.
- Directivity and degree of isolation between ports can differ substantially between amplifiers.

Safety features

- Most important safety feature is an **interlock**.
- Interlocks are used to automatically turn off power (e.g. when a chamber door is opened).
- Multiple independent interlocks can be a useful feature for amplifier systems having multiple paths to different chambers.



Modularity

- Modular amplifiers can be configured for different (or multiple) frequency bands.
- Modularity provides advantages both in terms of flexibility as well as ease of replacement / upgrade.

Power density

- The physical dimensions of the amplifier itself, such as size and weight, are also important.
- Ideally we would like an amplifier that produces maximum power output with minimum physical volume.
- This ratio is sometimes referred to as “power density.”

Summary / conclusion

- EMC immunity testing requires the use of high-power, broadband amplifiers for generating high levels of RF field strength.
- Amplifiers must be able to provide sufficient output power under widely varying VSWR conditions.
- Amplifiers must be able to deliver this power with good linearity (i.e. without going into compression).
- Amplifiers must be able to handle high levels of reflected power for both performance and safety reasons.
- Additional usability considerations also play an important role.

Thanks for attending!

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