raditeq

White Paper

White Paper
Radiated RF Immunity Testing

EM Field Generation

Electric Magnetic Field Generation

All you need is field!

Introduction

In this application note we address the generation of RF fields in the 1 to 6 GHz frequency range, looking to conventional methods of field generation and Raditeq cutting edge technology in field generation with the RadiField Triple A. According the RF immunity standard EN-61000-4-3, a uniform field must be generated at a distance of three meters from the tip of the antenna in this so called homogeneous area or quite zone. The Device Under Test (DUT) is tested with respect to its immunity to the applied uniform field. The area of uniform, illumination is 1.5 * 1.5 meters, to ensure that also 1 meter of cable to the DUT is in the field. The field is considered to be uniform when 75% of 12 points in this area comply with the 0 to +6dB rule. In RF immunity systems using traditional design techniques the designer has to analyze a large number of individual specifications of the system components that are taken into consideration for integration into the test system. This application note explains how Raditeq has simplified the configuration of RF immunity test systems compared to the conventional designs.

Power or Field?

Quite often many engineering hours are needed to analyze amplifier power, antenna gain, H/V antenna beam width and cable losses. This is to establish whether the combination of all these individual components offer the required compliancy towards the standard with respect to uniform area and field level. The RadiField Triple-A offers the user a guaranteed EM field in an anechoic test environment and compliancy to the uniform field area. The user does not have to worry about amplifier power levels, 1dB compression points, cable losses, illumination area's etc. Just a field level to test his products. In this application note we will look to a number of classic design considerations like:

- · **Class A versus Class AB with respect to reflected power handing and 1dB compression power capability**
- · **Power versus Field**
- · **Complexity of the design**

The conventional setup

Figure 1 Conventional Chamber and System Setup, system is outside In a traditional RF Immunity setup, the Amplifier-rack (Single or Dual band) is preferably located outside the test chamber together with all the other supporting equipment like signal generator, power meters, couplers and control PC. Critical items influencing the final field level of are the following coaxial cables and connection joints:

- From the amplifier output to the input of the Dual Directional Coupler (DDC).
- Between the DDC output and feed through pannel on the chamber wall.
- From the chamber feed through panel to the antenna input.

Taking the purple coaxial cables into consideration, the engineer designing the system needs to take into account all the frequency dependent losses of these red cable sections. Losses ranging from 1 to 2 dB are typically reached. Not embedded in the loss figure are also the insertion losses of the coaxial connections, total 6 pieces. Taking all losses into account the overall loss may mount up to 2.5-3.0 dB! An alternative, less preferable, solution that is often seen with the RF immunity rack is placed inside the test-chamber. The reasons to do this are clear, however it is not compliant with the standard! And although this setup reduces the length of the cable between antenna and system output, losses will never be zero! Another disadvantage of this method occurs when immunity test racks are moved inside chambers is that this will influence the measurement. At the same time test equipment which is integrated in the rack must be able to withstand the field-levels inside the test chamber (self-influence). another time consuming aspect of a conventional system is the process of moving setup's inside the chamber and moving it out again.

Conventional and high cost solution with high RF power losses!

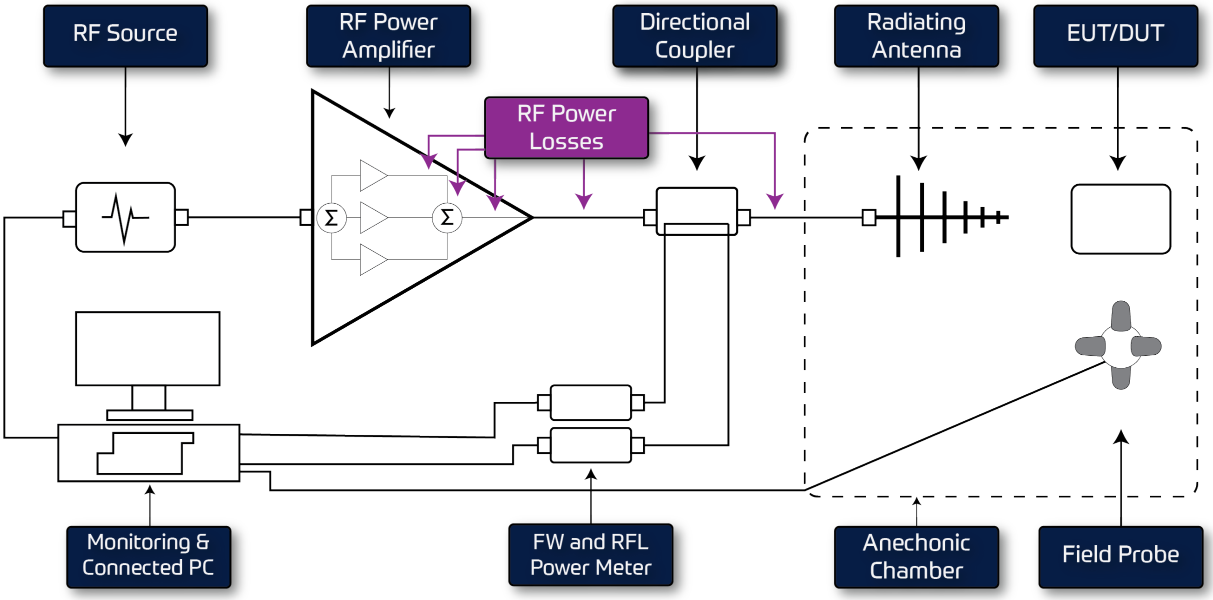


Figure 1.

Antenna and Amplifier considerations

In EMC applications loads having VSWR ratios > 1:6 are quite often encountered. A 1:6 VSWR means that 50% of the output power is reflected and returned to the amplifiers final stage. In the following sections some application examples in the 20 to 1000 MHz (and above) frequency range are described, showing the effects of the VSWR and how these effects have to be taken into account with respect to selecting the correct amplifier with respect to it's class of operation.

Frequencies below 80 MHz

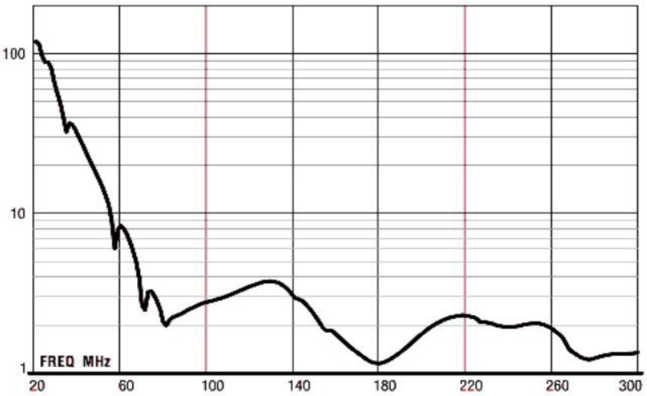


Figure 2 Typical VSWR Graph of a Biconical Antenna

High VSWR ratios are mainly found when testing is performed at low frequencies between 20 and 80 MHz. In this frequency range wavelengths are long and compact EMC antennas are a compromise between matching, efficiency and size. An example of such an antenna is the Biconical and other small sized compromise designs that can fit into the anechoic test rooms.

Figure 3 ETS-Lindgren Biconical 3109

What about the higher frequencies up to 1 GHz?

For increasing frequencies, wavelengths are getting shorter and the size of these antennas is much closer to the respective wavelengths causing the antennas to be a much better match to the RF amplifier. Antenna types in the higher frequency regions are Log Periodic Dipole Arrays (LPDA's), Horns and Ridged structures that have VSWR ratios well below 1:3

The 80 to 1000 MHz and above

Some examples of these antennas (left) and their corresponding VSWR curves (right)

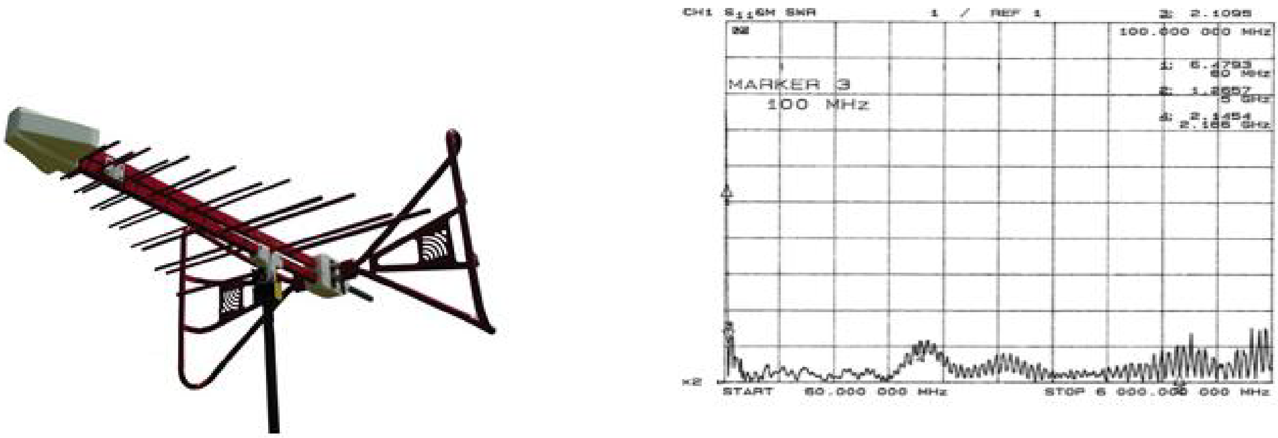


Figure 4 ETS-Lindgren 3149, max VSWR 1:6.5 @ 80 MHz (50% of power)

The bent elements at the backside of this antenna create a shorter distance between the antennas phase center and the DUT. This results in a better efficiency between antenna input power and generated field. The graph of the power versus field (@ 3m) for this antenna looks as follows, see figure 5. For frequencies above 1 GHz the most common type of antenna is the (stacked) LPDA or Horn antenna. In general these type of antennas provide a very good 50Ω match to the amplifiers output.

RF Power considerations 80 – 1000 MHz with an LPDA

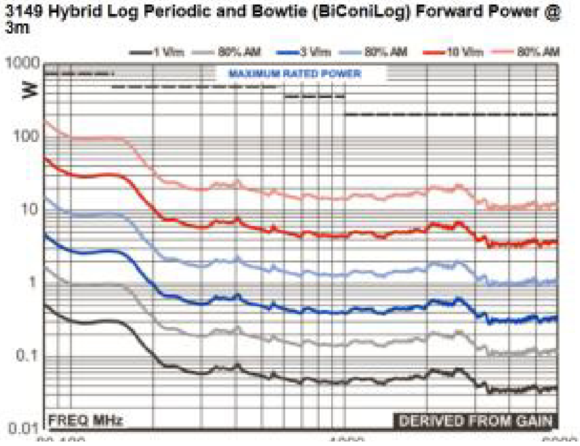


Figure 5 Input Power to Field @ 3 meter, Model 3149

Reading the graph we can conclude as follows for the lowest frequency, 80 MHz:

- Power to create 10 V/m unmodulated CW 50 Watt CW
- Peak Envelope Power to create 10 V/m + 80% AM = 161.5 Watt PEP* (+ 5.1 dB to the CW power level)
- Average Power with 80% modulation 66 Watt Average (+ 1.2 dB to the CW power level)

*The definition of PEP power in AM modulated signals is the power-level when the modulation is at

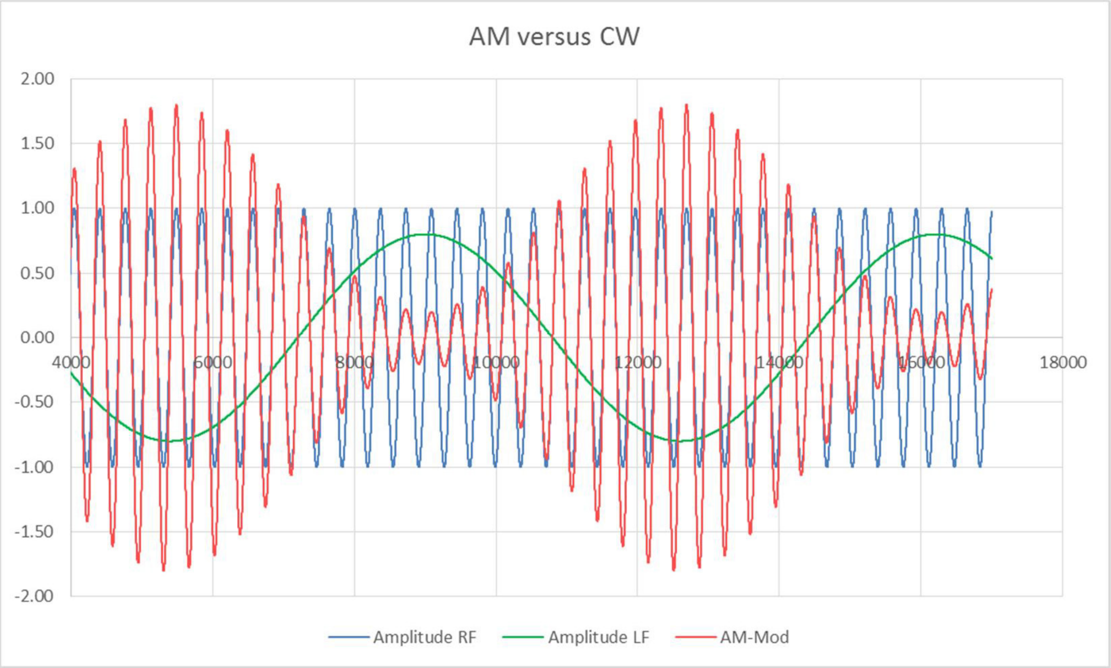


Figure 6. AM vs CW

CW versus modulated

In the graph above can be seen that the AM Modulation envelope is symmetrical around the peak voltage of the CW carrier. This means that the average voltage of the modulated signal is the same as the average voltage level of the CW signal.

However this does not apply to the power of the signal! As signal power is a function of the power of two of the rms voltage. The average power of the AM modulated signal is slightly (1.2 dB) higher compared to the power value of the unmodulated Power.

Quite often 150 Watt amplifiers are seen, driving these type of antennas. Is a class A really needed here? Or is Class AB sufficient? Next to the power requirements, let’s have a look at power reflection and distortion requirements.

At 80 MHz the required forward (PEP) power is 162 Watts PEP. However, we are still running the amplifier at 66 Watts average as the AM modulation is symmetrical around the CW power level. This is the power level generating the heat in the final stages.

The average reflected power resulting from the antenna VSWR is 50% (1:6) of the forward power, i.e. 33 Watts. This means that this antenna can easily be driven with a 160 Watts (P1dB) Class AB amplifier having a max VSWR spec of 1:3 (maximum reflected power is 25% of the forward power i.e. 40 Watts)

When designing a conventional EMC immunity system the two main parameters to take into account are:

- The 1 dB compression point, to ensure an undistorted test signal in the peaks of the modulation
- The VSWR handling capability. This occurs when the antenna VSWR mismatch is high and as a result much of the transmitted power is returned to the amplifier.

The 1 to 6 GHz band

Antenna-types

For the 1 to 6 GHz frequency range mainly two different antenna are available, a LogPeriodic Antenna (LPDA) or a Horn type antenna. The main difference between the two antennas is the gain figure.

Gain and area of illumination

An LPDA will have in general a gain of 7 to 8 dB, while horn antennas have much higher gains increasing with frequency as the aperture size becomes larger for the higher frequencies. If the gain increases above the 12dBi level, and compliancy with EN-61000-4-3 will not be possible anymore. The higher gain of the horn antenna is appealing but there is also a negative side effect. The larger gain shrinks the area that is illuminated by the antenna. In other words by using the higher gain, compliancy to the 1.5 * 1.5 meter uniform field area as required by EN61000-4-3 cannot be accomplished anymore. With the lower gain and large -6dB angle of the LPDA, the illumination of the area is no issue. However, the lower gain requires more net antenna power into the LPDA to create the required field level.

VSWR at higher frequencies

The VSWR of these high frequency antennas in general is much lower than 1:3. For this reason Class A is not a real need and Class AB is mostly a good solution.

Selection of the RF power amplifier

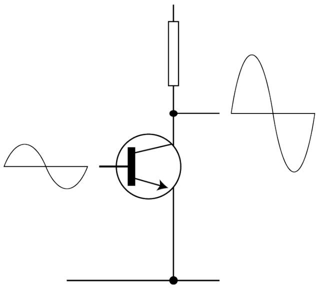
Class A or AB amplifier?

In the EMC immunity test world, the class of operation of the amplifier is often a point of discussion. A Class A amplifier is seen as “a must” for EMC immunity testing in order to ensure that the power that is driven into the load, i.e. the antenna, is not influenced by an increasing VSWR mismatch. Before drawing a conclusion which amplifier Class should be used, let’s first have a look at the differences between these two operation classes. What are the design criteria and what are the operational limitations of each Class.

Class A amplifier

The main specification influenced by the Class of operation of any amplifier is the overall efficiency of the amplifier and more specifically the final stages that are driving the load. An example of a simple Class A amplifier, as shown in the figure 7, is the most linear type available where the signal currents and voltages are well within and much smaller than the set points of the bias values. On the final stage however, these amplifiers can only achieve a maximum (theoretical) efficiency of 50%. In reality efficiencies from 20% to 30% are realized.

Figure 7 Class A (Single-Ended) amplifier



In the single-ended Class-A amplifier the transistor amplifies the full cycle of the signal without any or very low distortion.

Class B

When the bias current is reduced to zero, the steady state current through the transistor will stop. This also reduces the power dissipation. The input signal is only amplified on its positive cycle, as can be seen in the figure 8 below. The input signal needs to 'open' the base-emitter diode of the transistor to get the output current flowing and create amplification. This effect immediately

increases the efficiency of this amplifier, but the signal distortion in the single ended stage is enormous c only half of the original signal is available at the output of this stage.

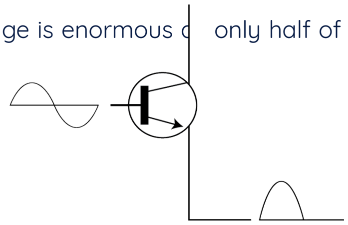


Figure 8 Class B (Single-Ended) amplifier

The output signal can be improved by adding the other half of the signal in so called Push-Pull design, where two transistors act together and each one of the pair takes care about one half of the signal. See figure 9.

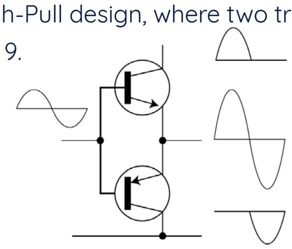


Figure 9 Class B (Push-Pull) amplifier

As the bias current in the Class B amplifier is close to zero, each half of the output signal is not an exact copy of the input signal. Each of the two transistors Base-Emitter junction must be 'opened' by the input signal causing the signal to look like the waveforms shown in figure 10. Each transistor just starts to conduct after the signal voltage crosses the BE diode voltage of approximately 0.7 Volts to start the collector currents. The point where the current flow switches between the transistors is the crossover point, the associated distortion is called crossover distortion. If we look to the overall distortion performance of this stage, the crossover distortion has a larger effect at low power levels

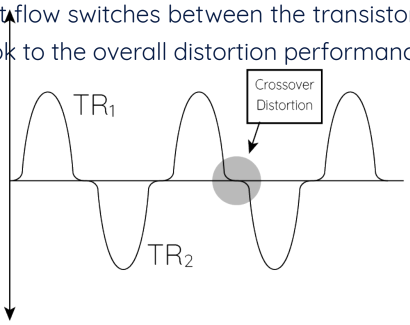


Figure 10 Class B (Push-Pull) amplifier Crossover Distortion

Moving to Class AB

By inserting a DC voltage of twice the value of a BE junction between the base inputs (see figure 11) of the two transistors both start to conduct, removing the unwanted behavior around the zero volt line. As we have increased the bias current in the final stage, going from full Class B towards Class A, we call this efficient amplifier a Class AB amplifier

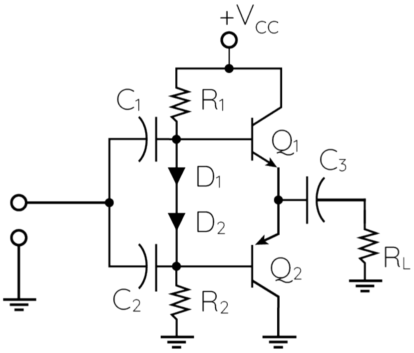


Figure 11 Class AB (Push-Pull) amplifier

Class A versus Class AB in EMC applications

The use of Class A versus AB amplifiers has always given rise to an interesting and lively discussion in the world of EMC testing. Let’s analyse test applications and the real requirement for either of the classes of Amplifiers. If we go back to the Class A output stage, we have seen that the signal current is much smaller than the steady state current. Even with no signal the final stage will produce a lot of or heat which has to be removed from the device through heat sinking.

Reflected Power

When the Class A amplifier drives the amplified signal into a matched load, we still see the high power dissipation level in the final stage. When there is NO LOAD, or even a SHORT, the final stage is subjected to 100% reflection of the power of the output signal. All this power returns back into the final stage and is then converted to heat. When designing transistor amplifiers the developer looks to the SOAR (Safe Operating ARea) to ensure that the total power dissipation of the device is within the SOAR area for a troublefree and longlife operation.

In a solid-state Class A design the output transistors operate well in their (SOAR) and all the reflected power causing additional heat can easily be accepted by the amplifier’s output stage without being damaged. This area has to do with maximum device voltages, current ratio’s (power) and the thermal power dissipation limts. See figure 12 for this graph.

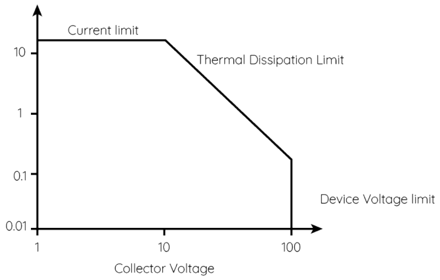


Figure 12 Typical SOAR Curve of a Solid State device

From figure 11 is becomes clear that the device has limits for maximum collector current and maximum collector voltage. The thermal dissipation limit (which is the product of voltage and current, minus the net power delivered to the load) shows how far you can go with heating up the device.

In Class A designs (theoretical) 50% of the power is heat, in Class AB designs just 12.5% (theoretical) .

A device set in the Class AB mode has a limited steady state power dissipation with a quiescent current that varries with the drive power. The same transistor used in the Class A design can deliver less power when used in a Class AB mode due to the thermal constraints under normal load conditions. The Class AB design has smaller heatsink requirements resulting from the increased efficiency.

The efficiency of the AB type amplifier is best at its high power output levels, which in practice provide up to 60 % practical efficiency approximately. But, what happens if the VSWR of the load increases. Again reflected power from the load returns back into the output devices and is converted in additional heat that can increase the device emperature beyond the SOAR curve. When protection measures are not taken, the device will be damaged due to this extra heat.

For this reason, class AB amplifiers are fitted with a VSWR protection system that lowers the drive to the final stage and reduces the (average)power that must be dissipated.

dB compression point

Differences in compression characteristics between Class A and AB are not so large as long as the load has a good VSWR performance. As such, the 1dB compression point performance is quite comparable between these two Classes.

The RadiField Triple A

With the RadiField Triple A (AAA stands for Active Antenna Array) Raditeq sets a complete new standard for immunity testing. RadiField Triple A offers:

- A simplified system approach
- Guaranteed EM field level
- High level of integration
- No loss of expensive RF power
- Low cost of ownership

Comparing the two setups in Figure 13 it is obvious that the complexity is drastically reduced in the case if the RadiField Triple A solution (see Figure 14). The system is build up with a RadiCentre modular system. In the RadiCentre the following modules are inserted for this application:

- RadiGen 6 GHz Signal Generator
- RadiSense 6 GHz Field Probe Laser card
- RadiField Power Supply and Control Card

This system uses just two coaxial cables. Only one coaxial cable runs from the RadiCentre RadiField power supply card to the RadiField Triple A carrying:

- Power
- Control / Communication
- Driving RF signal

The second cable runs from the output of the RadiGen to the RF input of the RadiField power supply card in which a special Bias-Tee combines DC power, Control and driving for the RadiField All cable losses lapse. All generated RF power is directly injected in the antenna and converted into an EM field. Where in the conventional setup also Low-Loss coaxial cables are a must to ensure that as much as possible of the expensively generated RF power is transported from the output of the system to the antenna many meters away.

Reducing Complexity of the System

Comparing the traditional setup of an RF immunity test system with the RadiField Triple A it becomes clear that the RadiField Triple A, with its high level of integration, is the answer how to reduce space and costs.

The conventional approaches

Looking to the basic setup of a conventional system, generally the following system components can be recognized:

1. Signal Generator
2. RF Power Amplifier(s), single or dual-band
3. Dual Directional Coupler(s), one or more bands
4. 2 RF power meters (forward and reflected power)
5. RF Switches (not needed with a single band amplifier)

Next to the system components in the Single Band Solution, 5 coaxial, and at least 4 control cables are needed. When a Single Band amplifier is not available, the complexity drastically increases to 12 coaxial cables and 5 control cables in case of the Dual Band approach.

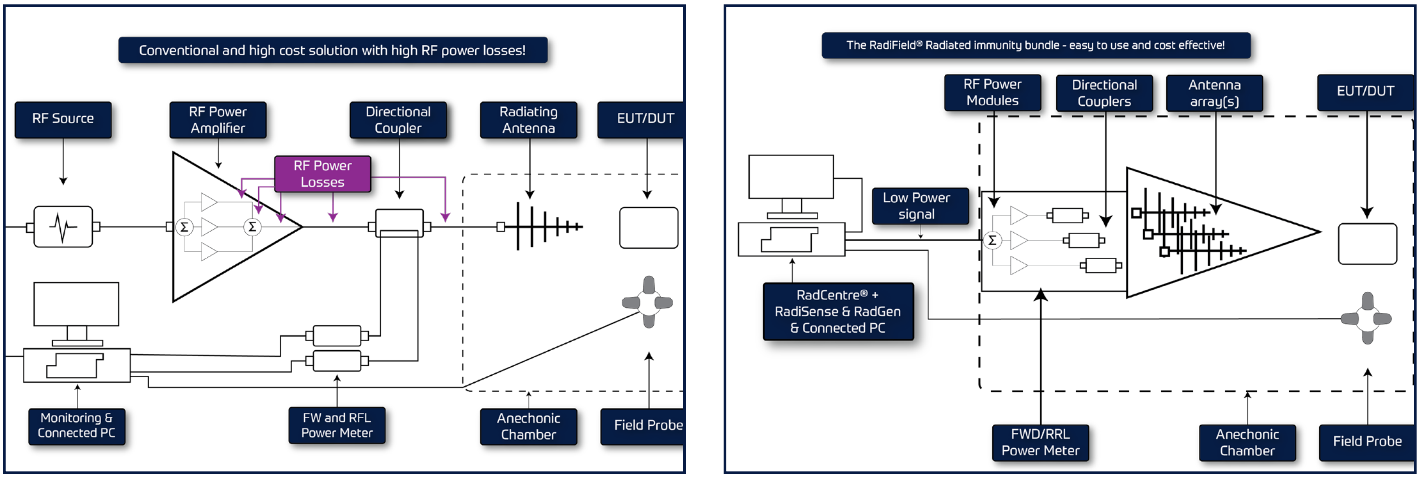
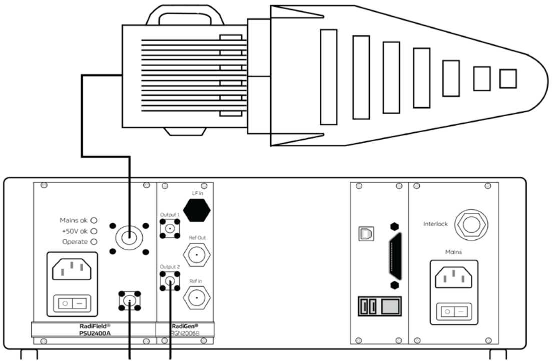


Figure 14 Comparison between conventional and RadiField Triple A solution



Minimum installation time

The design concept of the RadiField ensures a very short installation time for the user. With the RadiCentre (loaded with a Signal Generator, RadiField Card en Laser Driven Field Probe system), located in the engineers control room only two coaxial cables (from RadiCentre to the anechoic chamber's entry panel and from the entry panel to the RadiField) are sufficient to start the
generation of an EM field!

Three Meter Equivalent (TME) field

With the RadiField the determination and definition of the required field level is easier than ever before. A newly defined parameter, the Three Meter Equivalent or TME allows easy recalculation of field strengths at different distances with respect to the value at 3 meter. The formula for recalculating fields at different distances is:

$$3 * \mathrm{TME} / d$$

Thus given a system with a TME of 10V/m, an easy recalculation, shows that this system will generate:

- 10 V/m * 3 / 10 equals 3.0 V/m @ 10 meters
- 10 V/m * 3 / 1 equals 30.0 V/m @ 1 meter.

No more worry about amplifier power, antenna gain and gain calibrations at various distances, cable losses versus frequency etcetera. Just establish your required field level, distance and frequency range, and select the RadiField that covers your needs for the required test distance and field level.

TME Table		Test Distance		
Model	Frequency	1m	TME	10m
RFS2006A	800 MHz - 6 GHz	9.0	3.0	0.9
RFS2006B	800 MHz - 6 GHz	30.0	10.0	3.0

Figure 15 TME (Three Meter Equivalent) selection table

Accuracy and reliability

Radiated Immunity testing is based on placing the DUT in a pre-calibrated uniform field. This calibration is performed by a field-probe placed in the 16 equidistant spaced positions of the uniform area. During execution of the test, the field probe is removed and the field illuminates the DUT with the pre-calibrated values.

During the field calibration process, relationships are recorded between the measured field levels and the power levels measured on the output ports of the directional couplers positioned behind the RF power amplifiers. During the test, after the field probe is removed from the chamber, the control software "replays" the power levels using the directional coupler's forward and reflected power data.

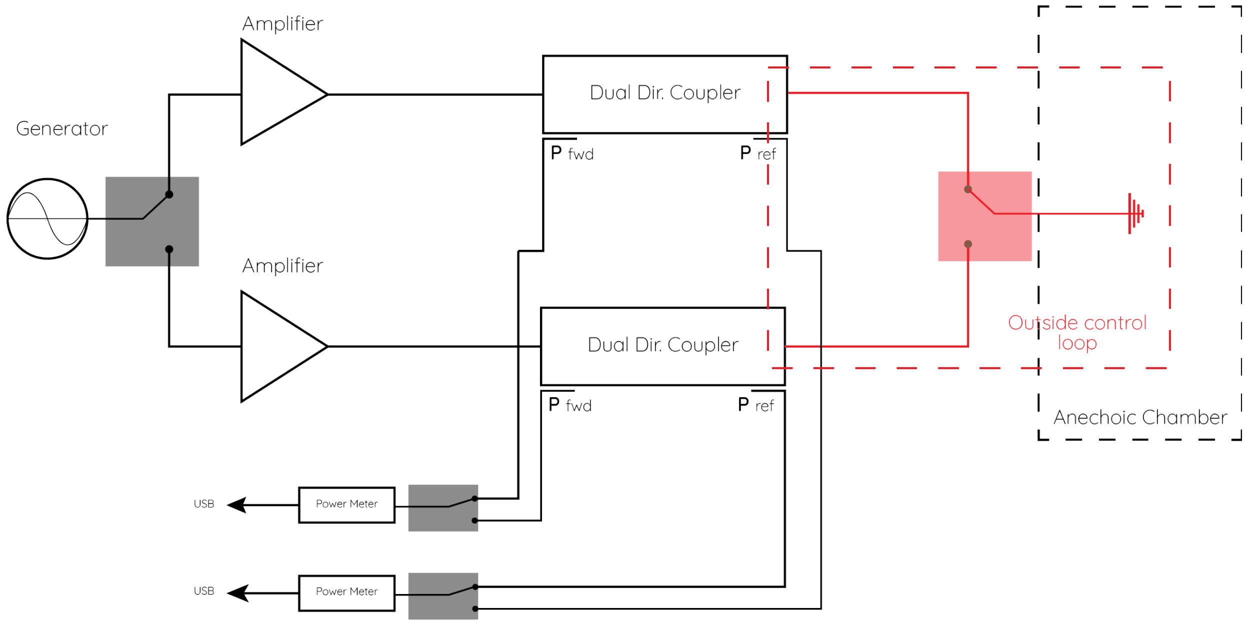


Figure 16 Identification of error sources in an immunity setup

From the signal generator up to the directional couplers, everything is measured. However any change in signal attenuation (change of field) due to changes in cable loss, switch-loss and connector loss, in the cables marked RED marked are in figure 16, is not measured and thus not corrected. The operator is under the impression that the test runs correctly, but there is no guarantee whatsoever that this test is the same as during the calibration run. With the design of the RadiField all these sources of errors are completely removed. The radiating antennas are integrated together with the RF power amplifiers and couplers in one single system removing any possible source of errors in these parts.

Cost of Ownership Considerations

Last but not least the total cost of ownership of the RadiField is very attractive compared with the traditional setups. For this we have made a comparison table to compare the RadiField with a number of other combinations of amplifiers and antennas. Not only the base price of the unit is approximately 50% lower than for conventional setups also maintenance is lower due to less wear and tear and no need for separate calibration of cable losses, antenna gain, coupler and RF power meters.

Less easy to value is the time needed for installation and reinstallation (e.g. antenna switch) and mistakes that can easily be made due to the complexity of conventional systems. First comparable setups are defined as follows:

Conventional Setup contains:

- Signal generator
- Power amplifier
- Coupler
- Forward power meter
- Reflected power meter
- Antenna
- Field Sensor
- Cables and connectors (6 sets)

The RadiField Triple A Setup contains:

- · RadiCentre including
  - RadiSupply®
  - RadiGen® Signal generator
  - RadiSense® Field Sensor
- RadiField® Triple A
- Cables and connectors (2 sets)

Accredited Test Laboratory Results.

We have tested the RadiField in anechoic test chambers of KIWA DARE Services to obtain a validation of this test system towards the proposed field levels and the uniformity of the illuminated area. The results of this test can be found in this paragraph

List of Abbreviations

DEF	Distance Equivalent Field level
DUT	Device under Test
DDC	Dual Directional Coupler
EM	Electro Magnetic
LPDA	Log Periodic Dipole Array
PEP	Peak Envelope Power
Triple A	Active Antenna Array

Annex, Active Antenna Array CST plots

Planar Plots AT 4.5 GHz

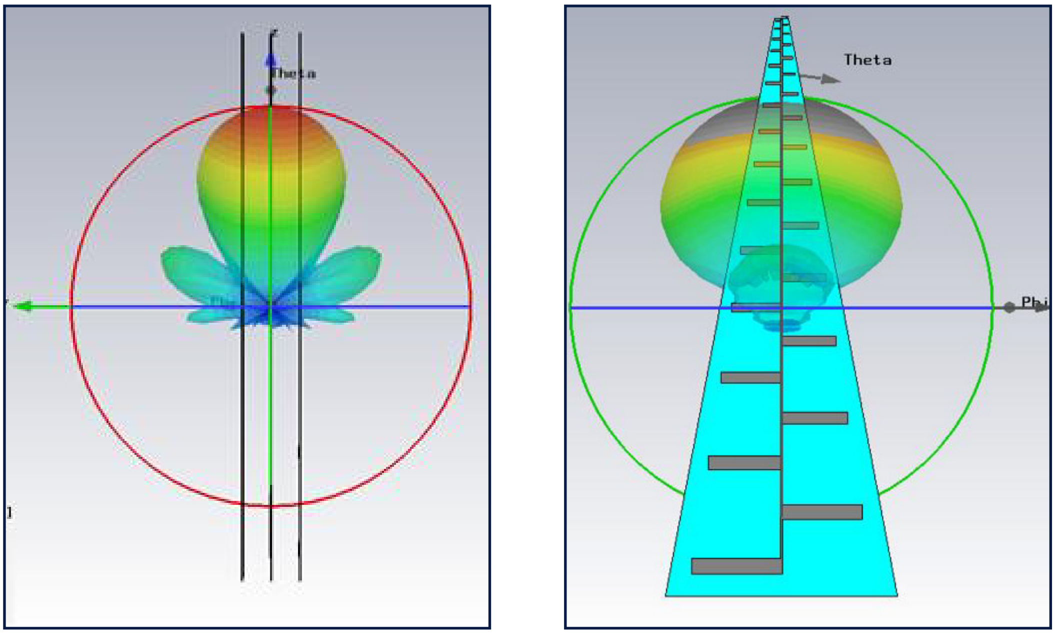


Figure 17 Antenna Patterns at 4.5 GHz

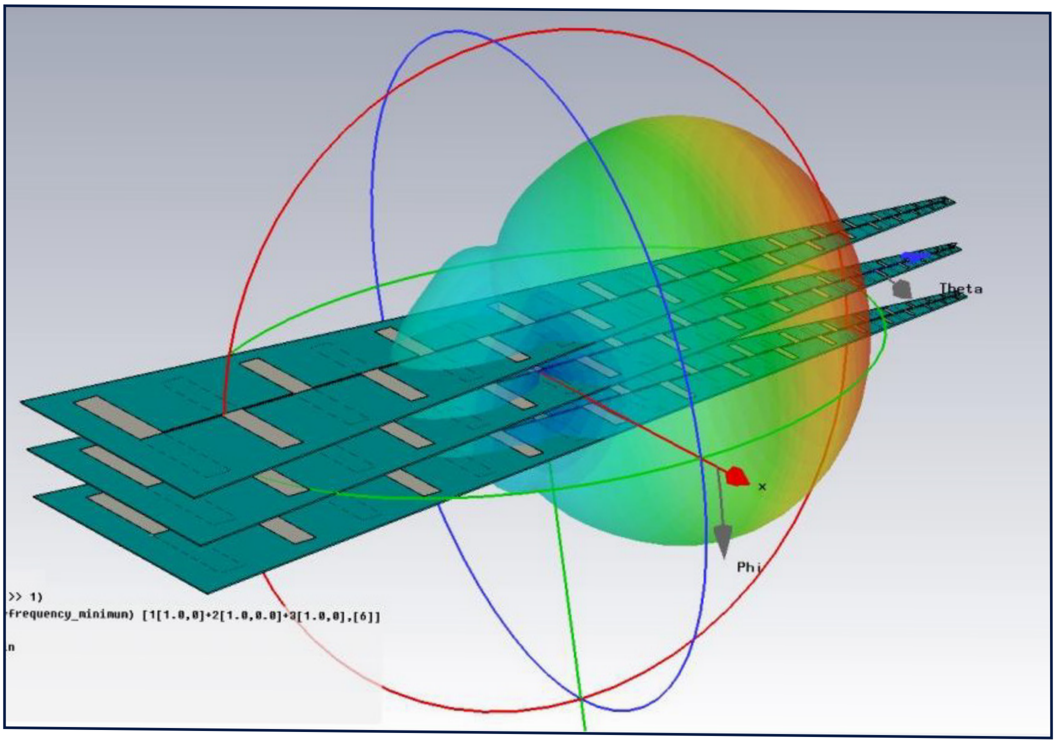
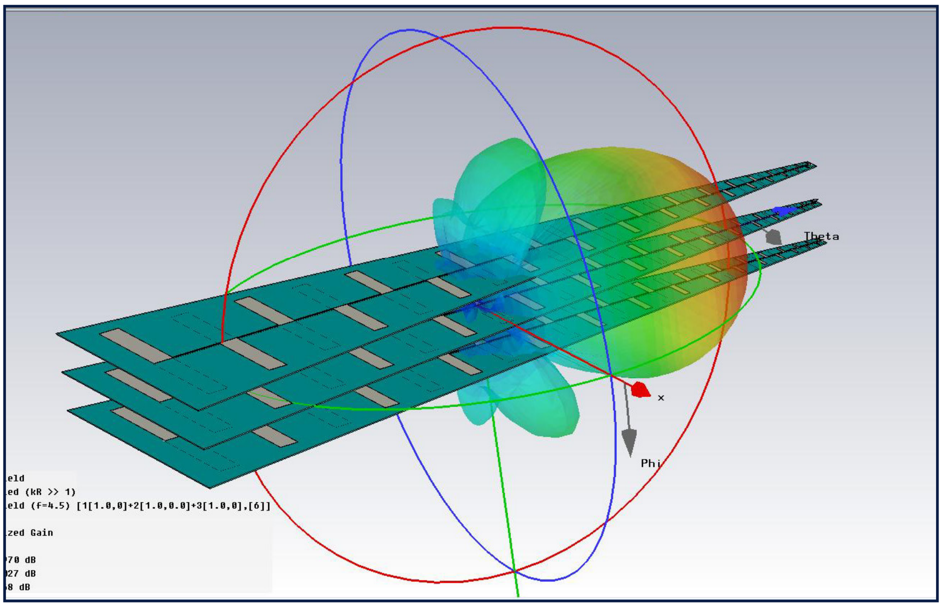


Figure 18 3D plot at 1 GHz

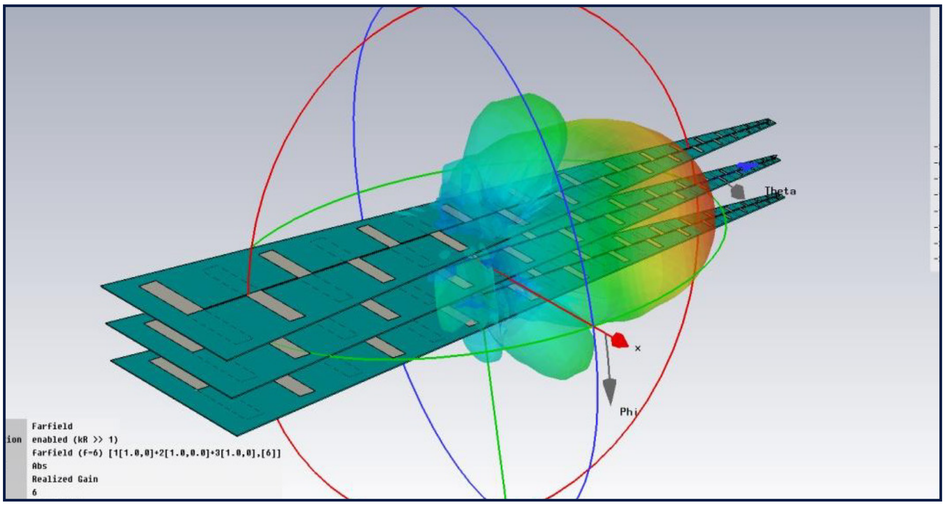
Figure 19 3D plot at 4.5 GHz



```
eld
ed (kR >> 1)
eld (f=4.5) [1[1.0,0]+2[1.0,0.0]+3[1.0,0],[6]]

zed Gain

70 dB
27 dB
8 dB
```



```
         Farfield
ion      enabled (kR >> 1)
         Farfield (f=6) [1[1.0,0]+2[1.0,0.0]+3[1.0,0],[6]]
         Abs
         Realized Gain
         6
```

Figure 20 3D plot at 6.0 GHz

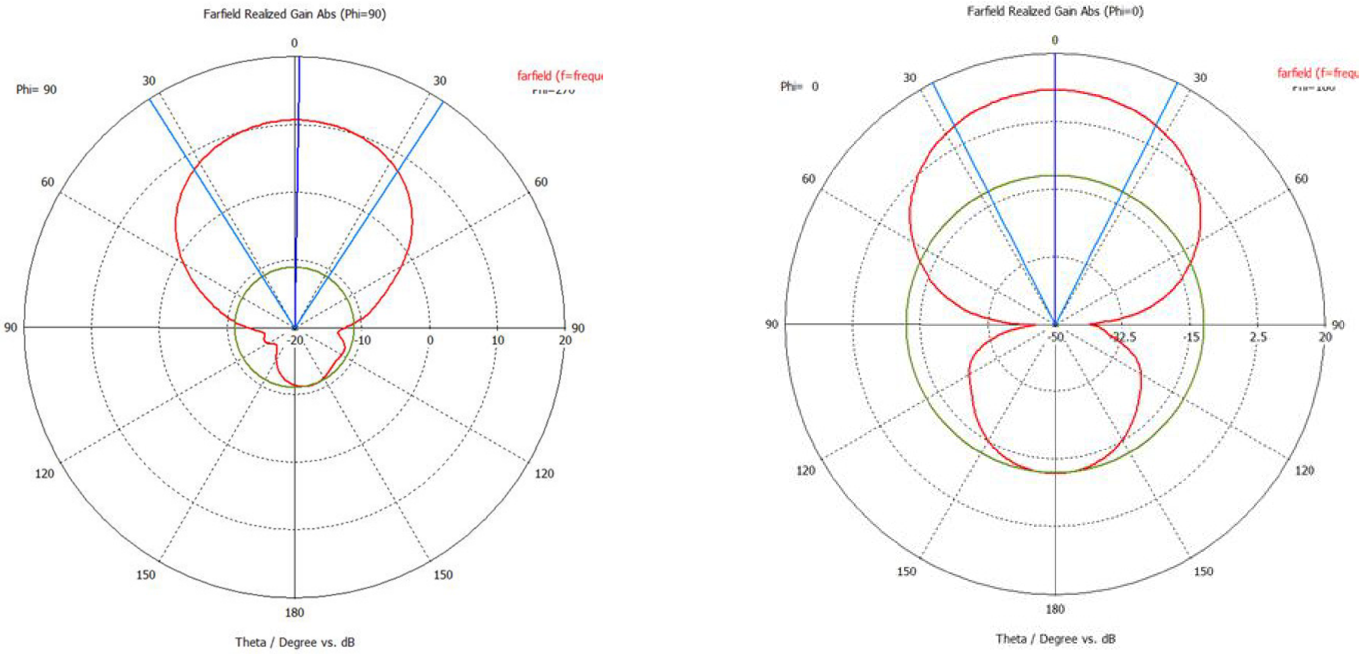


Figure 21 FAR field gain at 1 GHz

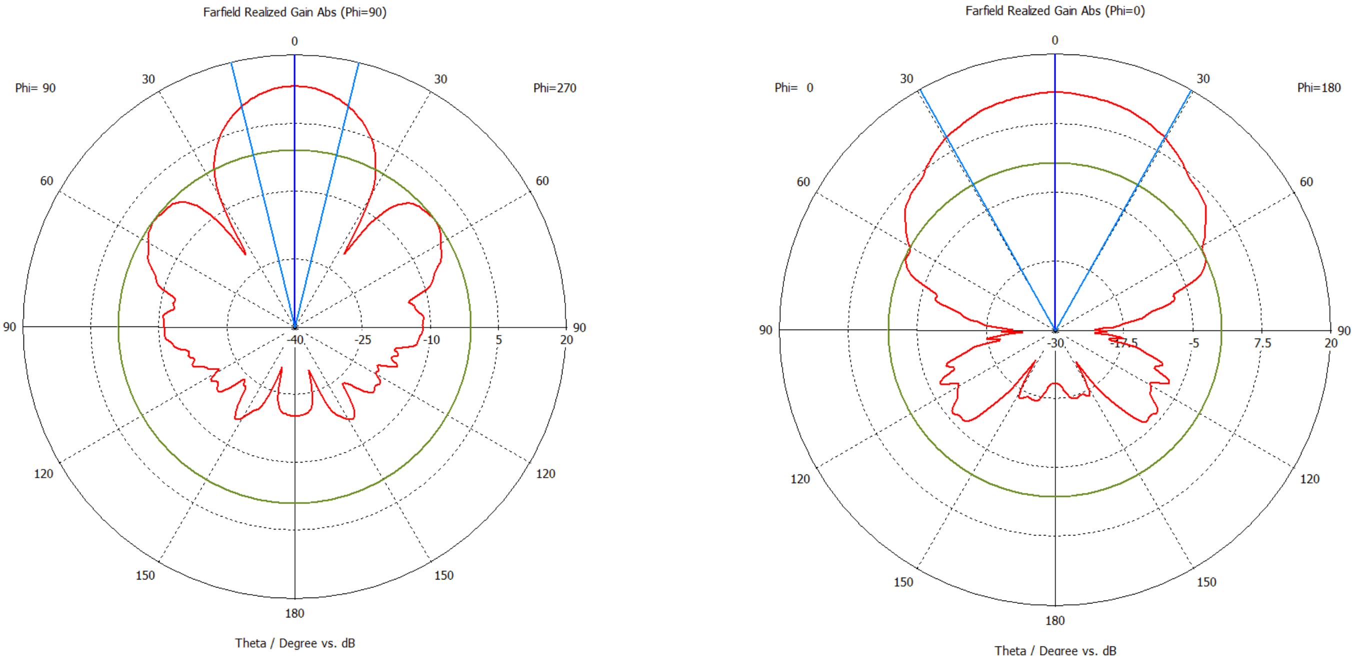


Figure 22 FAR field gain at 6 GHz

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