Application Note 14.001

ETS-Lindgren EMField™ Generator

1 – 6 GHz Radiated RF Immunity Testing

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1. Introduction

In this application note we will address the generation of RF fields in the 1 to 6 GHz frequency range, discuss conventional methods of field generation, and introduce the ETS-Lindgren EMField Generator, a revolution in field generation.

This discussion will be in the context of RF immunity standard EN-61000-4-3. The standard describes how 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 Device Under Test (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.

For traditional RF immunity systems built for testing to this standard, the engineer must select and source system components from various vendors, analyze and evaluate their performance, choose carefully, and then assemble and integrate everything into a working system.

We will explain how the EMField Generator has simplified this process and given engineers an efficient tool that uses less power to produce equivalent field strengths while saving both time and money.

2. Power or Field?

When designing and building a conventional RF Immunity system, a lot of time is spent analyzing amplifier power, antenna gain, H/V antenna beam width, and cable losses. This is necessary to determine if the combination of all the individual components will produce results in compliance with the standard in regard to uniform area and field level.

The EMField Generator offers an integrated system that guarantees the generation of an electromagnetic (EM) field in an anechoic test environment that complies to standard. The user does not have to worry about amplifier power levels, 1dB compression points, cable losses, illumination area's etc.

In this application note we will consider a number of classic design considerations like:

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

3. The conventional RI setup

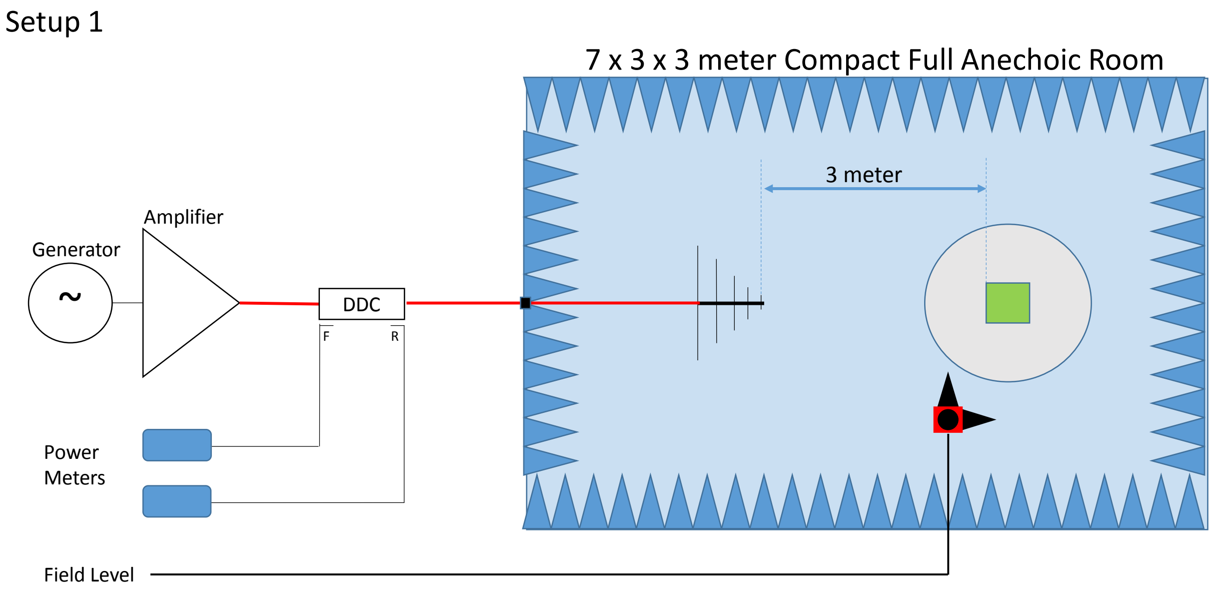


Figure 1 Conventional Chamber and RI System Setup (System is outside of Chamber)

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 coupler output and feed through on the chamber wall.
- From the chamber feed through to the antenna input.

Taking the red coaxial cables (Figure 1) into account, the engineer needs be aware of the frequency dependent losses of these cable sections. Losses ranging from 1 to 2 dB are typical. This does not include the insertion losses of the six coaxial connections. When everything is added up, the overall loss can be as much as 2.5-3.0 dB!

An alternative, but less preferable solution, is to place the system equipment inside the test-chamber. Although this setup reduces the length of the cable between antenna and system output, it is not compliant with the standard, and losses will never be zero.

Other disadvantages of placing the setup inside chamber are that it influences the measurement and stresses the equipment -- the equipment must be able to withstand the field-levels inside the chamber (self-influence).

4. 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 MHz 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.

4.1. Frequencies below 80 MHz

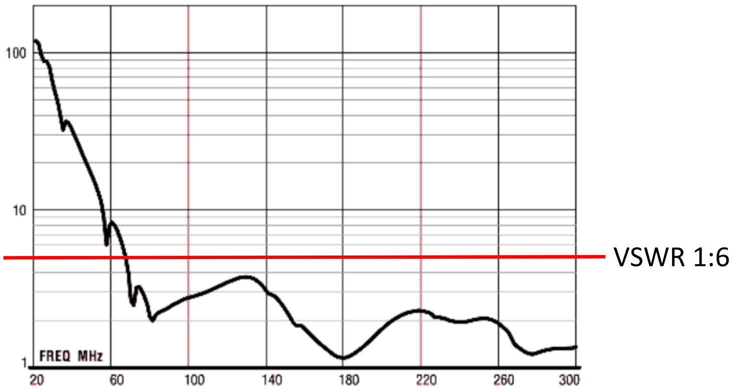


Figure 2 Typical VSWR Graph of a Biconical Antenna

High VSWR ratios are mainly found when testing is performed at low frequencies between 20 and 80 MHz as shown in Figure 2. 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 in the anechoic testrooms.

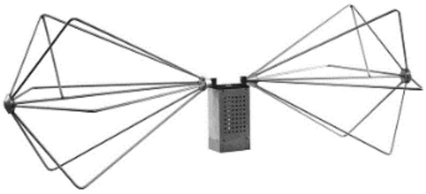


Figure 3 ETS-Lindgren Biconical 3109

4.2. What about the higher frequencies up to 1 GHz?

As frequencies increase, wavelengths are shorter and the size of the antenna 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.

4.3. The 80 to 1000 MHz and above

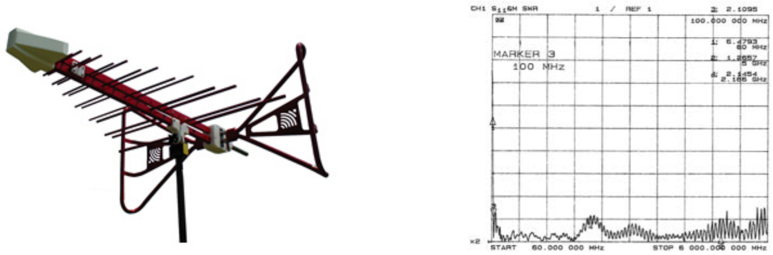


Figure 4 ETS-Lindgren 3149, max VSWR 1:6.5 @ 80 MHz (50% of power)

The bent elements at the backside of this antenna create a shorter distance between the antennas phase center and the DUT. The result is better efficiency between antenna input power and generated field. The graph of the power versus field (@ 3m) for this antenna is shown in Figure 4.

For frequencies above 1 GHz, the most common types of antennas are the (stacked) LPDA and horn antennas. In general, these types of antennas provide a very good 50 ohm match to the amplifier's output.

4.4. RF Power considerations 80 – 1000 MHz with an LPDA

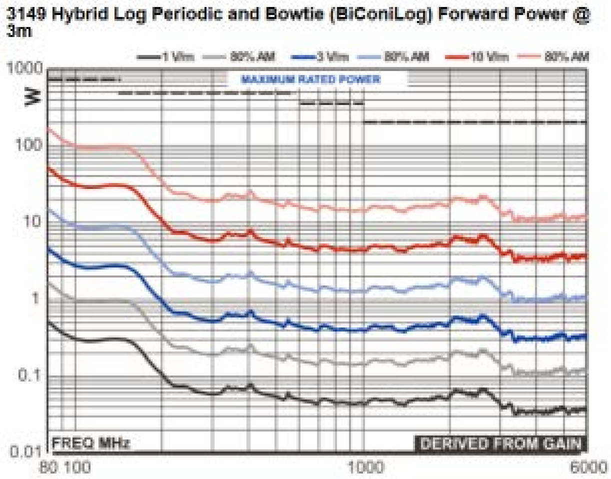


Figure 5 Input Power to Field @ 3 meter, Model 3149

Reading the graph in Figure 5, 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 its maximum.

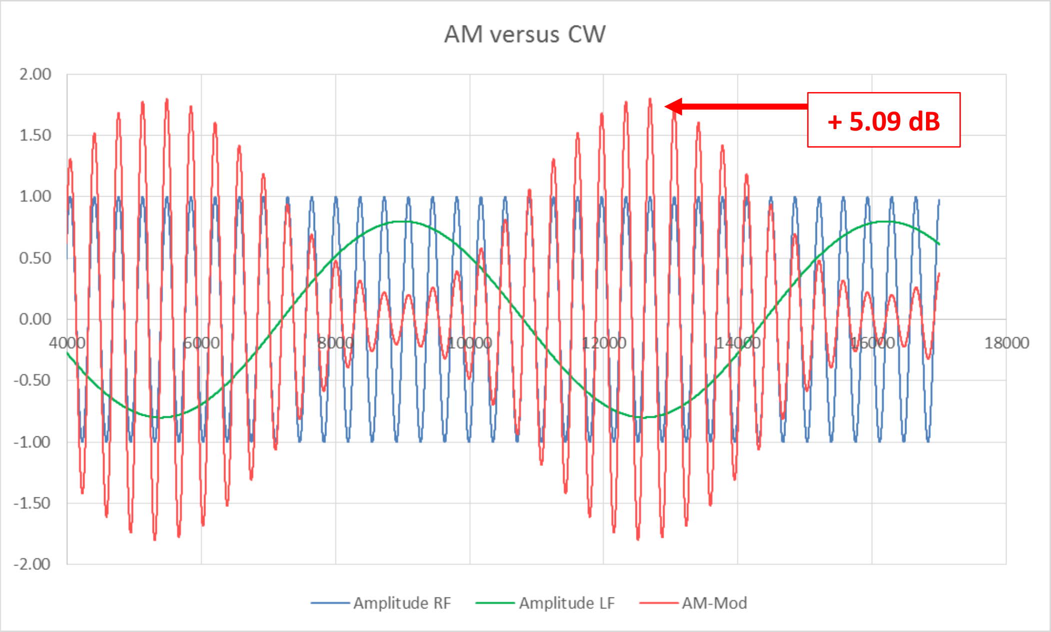


Figure 6 Comparison between a CW and 80% AM modulated signal

4.5. CW versus modulated

In Figure 6 above, 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, $P = \frac{U^2}{R}$, 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 types of antennas. Is a Class A really needed 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 $\text{Watts}_{\text{PEP}}$. 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.

4.6. The 1 to 6 GHz band

4.6.1. Antenna-types

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

4.6.2. Gain and area of illumination

An LPDA will have in general a 7 to 8 dBi of gain, 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, compliance with EN-61000-4-3 will not be possible.

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, compliance to the 1.5 * 1.5 meter uniform field area as required by EN61000-4-3 cannot be accomplished.

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.

4.6.3. 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 usually a good solution.

5. Selection of the RF power amplifier

5.1. Class A or AB amplifier?

In the EMC immunity test world, the type of amplifier class 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: the design criteria and the operational limitations of each class.

5.2. 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 (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.

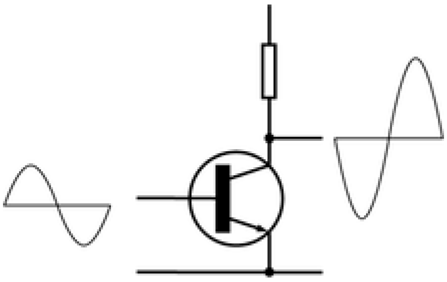


Figure 7 Class A (Single-Ended) amplifier

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

5.3. 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 Figure 8. 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, as only half of the original signal is available at the output of this stage.

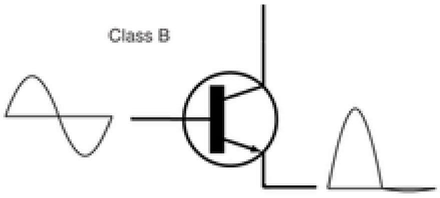


Figure 8 Class B (Single-Ended) amplifier

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

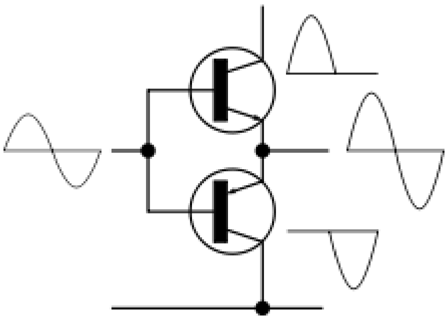


Figure 9 Class B (Push-Pull) amplifier

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 junctions 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.

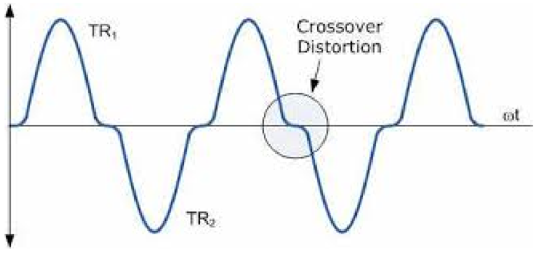


Figure 10 Class B (Push-Pull) amplifier Crossover Distortion

5.4. Moving to Class AB

By inserting a DC voltage of twice the value of a BE junction between the base inputs of the two transistors, both start to conduct, removing the unwanted behavior around the zero volt line (Figure 11). As bias current is increased in the final stage, we go from full Class B towards a Class A amplifier, or what is known as a Class AB amplifier – a very efficient amplifier.

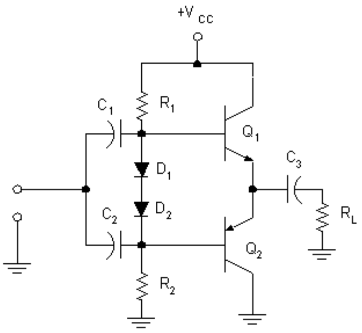


Figure 11 Class AB (Push-Pull) amplifier

5.5. 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 analyze test applications and the 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 heat which has to be removed through heat sinking.

5.6. Reflected Power

When a 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 (**S**afe **O**perating **AR**ea) 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 (Figure 11).

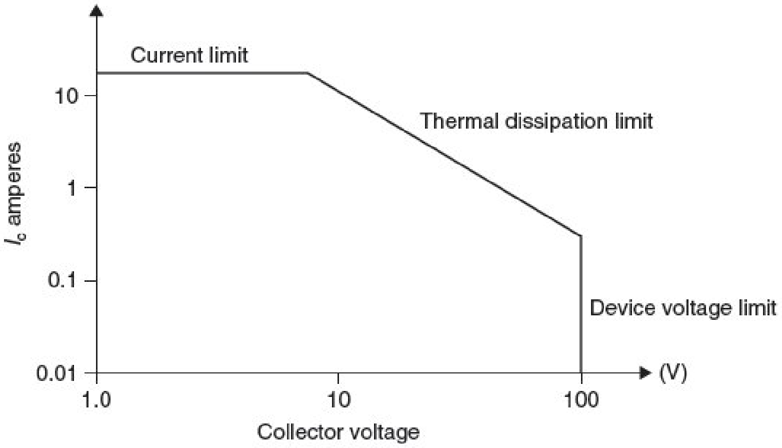


Figure 12 Typical SOAR Curve of a Solid State device

It 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 temperature beyond the SOAR curve. When protection measures are not taken, the device will be damaged due to this additional 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.

5.1. 1 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.

6. Reducing Complexity of the System

Comparing the traditional setup of an RF immunity test system with the EMField Generator, it becomes clear that the EMField Generator with its high level of integration provides a solution to how space and cost can be reduced.

6.1. 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
5. RF Switches (not needed with a single band amplifier)

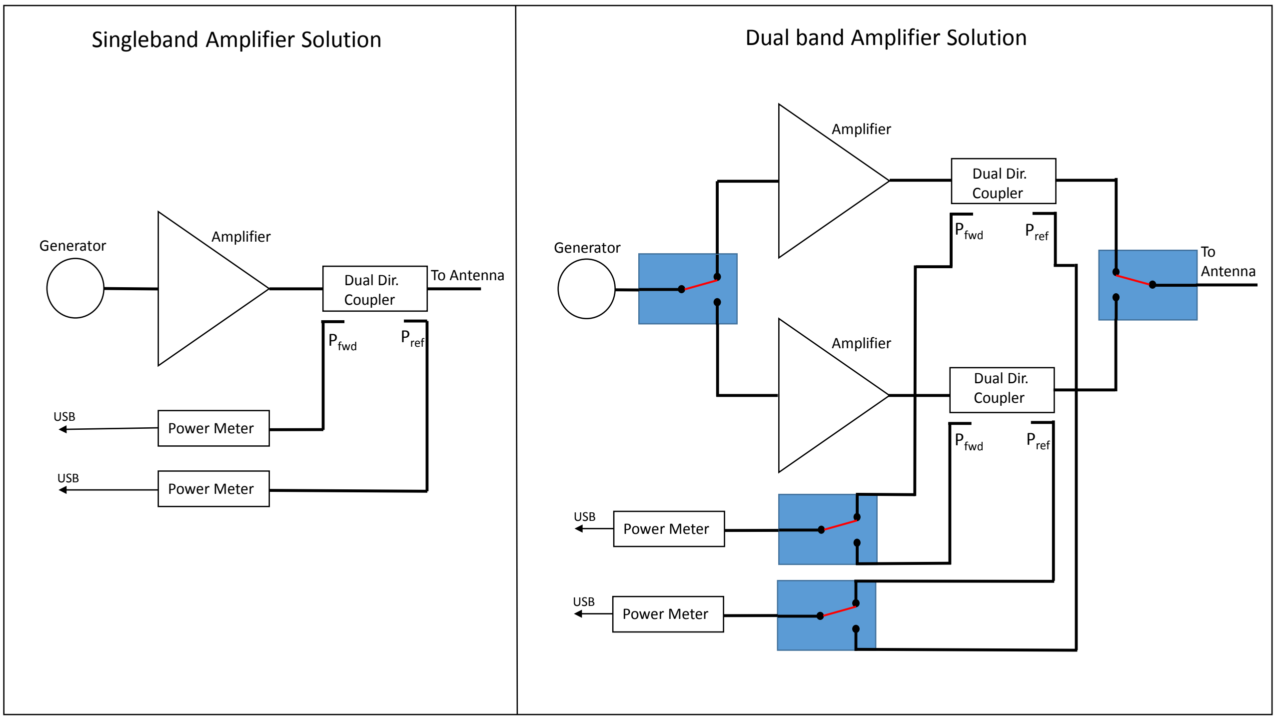


Figure 13 Generic System Layouts with Single and Dual Band RF amplifiers

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.

6.2. The EMField Generator

The EMField Generator sets a completely new standard for immunity testing. This system offers:

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

Comparing the two setups in Figure 13, the EMField Generator drastically reduces system complexity (see Figure 14). The supporting instrumentation – a signal generator, laser probe controller, and EMField power supply – are all plug-and-play card modules that slide into the backplane of the EMCenter, an intelligent console only 3U high. The card module instruments are:

EMGen	6 GHz Signal Generator
EMSense	6 GHz Field Probe Laser card
EMField	Power Supply and Control Card

This system uses just two coaxial cables. One coaxial cable runs from the EMCenter’s EMField power supply card module to the EMField Generator, supplying:

- Power
- Control / Communication
- Driving RF signal

The second cable runs from the output of the EMGen to the RF input of the EMField power supply card in which a special Bias-Tee combines DC power, Control and driving for the EMField Generator.

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.

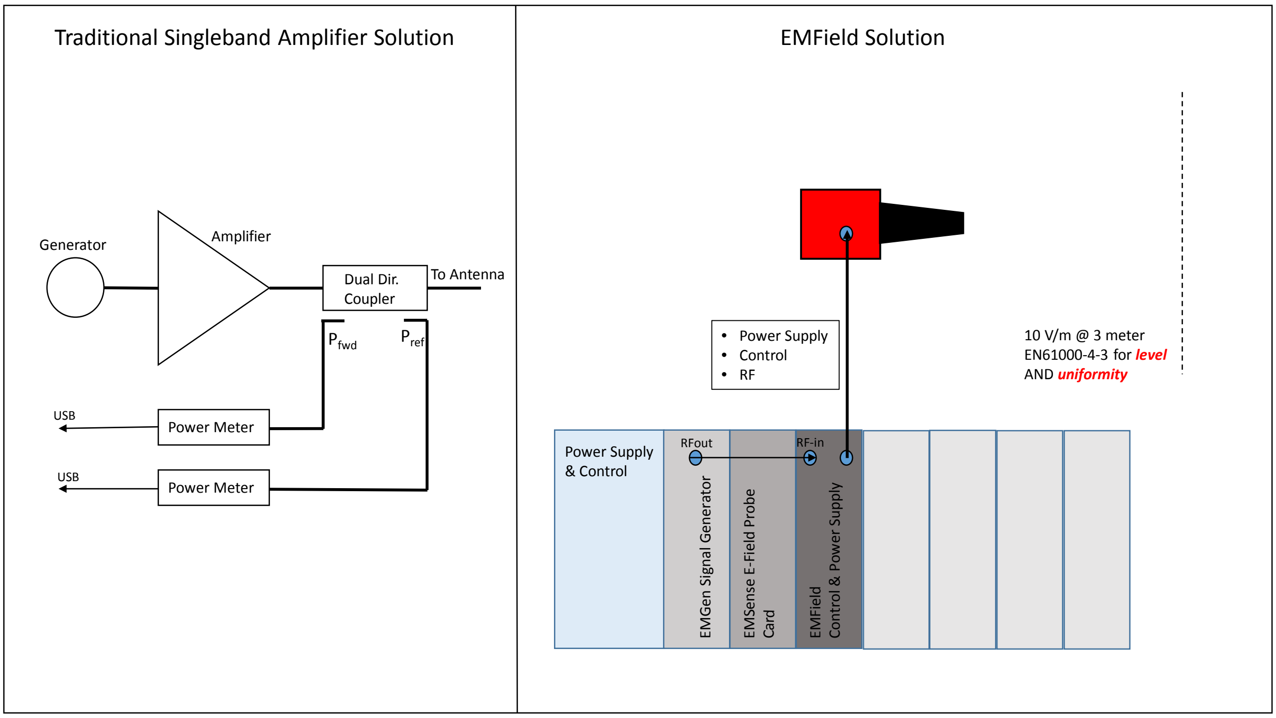


Figure 14 Comparison between conventional and EMField Generator solution

7. Minimum installation time

The design concept of the EMField Generator ensures a very short installation time for the user.

Sing an EMCenter located in the control room (loaded with a Signal Generator, EMField Card and Laser Driven Field Probe system), only two coaxial cables (from the EMCenter to the anechoic chamber's bulkhead feed through panel and from the bulkhead feed through panel to the EMField Generator) are required to start generating an electromagnetic field.

8. Three Meter Equivalent (TME) field

With the EMField Generator, 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:

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

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.

There is no more worry about amplifier power, antenna gain, and gain calibrations at various distances, cable losses versus frequency, etc. All that is needed is to establish your required field level, the distance and frequency range, and select the EMField Generator that covers your needs for the required test distance and field level.

TME Table				
Levels in V/m	Frequency	Test distances		
Model	Frequency	**1m**	**TME**	**10m**
RFS1006A	1 - 6 GHz	9.0	3.0	0.9
RFS1006B	1 - 6 GHz	30.0	10.0	3.0
RFS1003A	1 - 3 GHz	9.0	3.0	1.0
RFS1003B	1 - 3 GHz	30.0	10.0	3.0

Figure 15 TME (Three Meter Equivalent) selection table

9. 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.

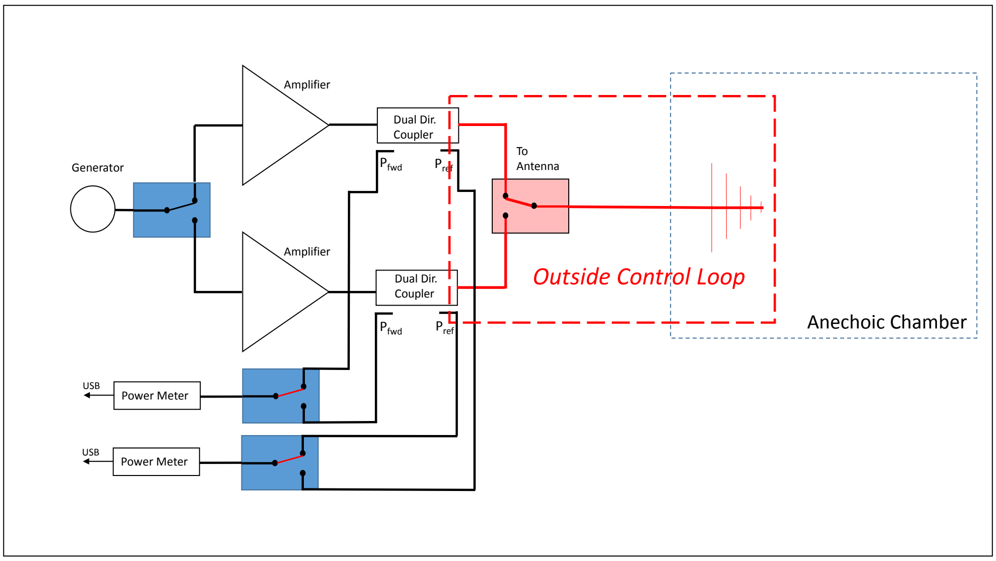


Figure 16 Identification of error sources in an immunity setup

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 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 EMField Generator, 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.

10. Cost of Ownership Considerations

The total cost of ownership of the EMField Generator is very attractive compared with traditional test setups. It is less expensive to own since there is no need for separate calibration of cable losses, antenna gain, coupler and RF power meters. It also requires less time for installation and reinstallation (e.g. changing antennas for band breaks), and reduces mistakes resulting from the complexity of conventional systems.

A conventional setup contains:

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

The complete EMField Generator system contains:

- EMField Generator
- EMCenter intelligent console w/backplane accepting:
  - EMField power supply card module
  - EMGen, 6 GHz Signal generator card module
  - EMSense, 6 GHz Field Sensor card module
- Cables and connectors (2 sets)

11. Annex, Active Antenna Array CST plots

11.1. Planar Plots AT 4.5 GHz

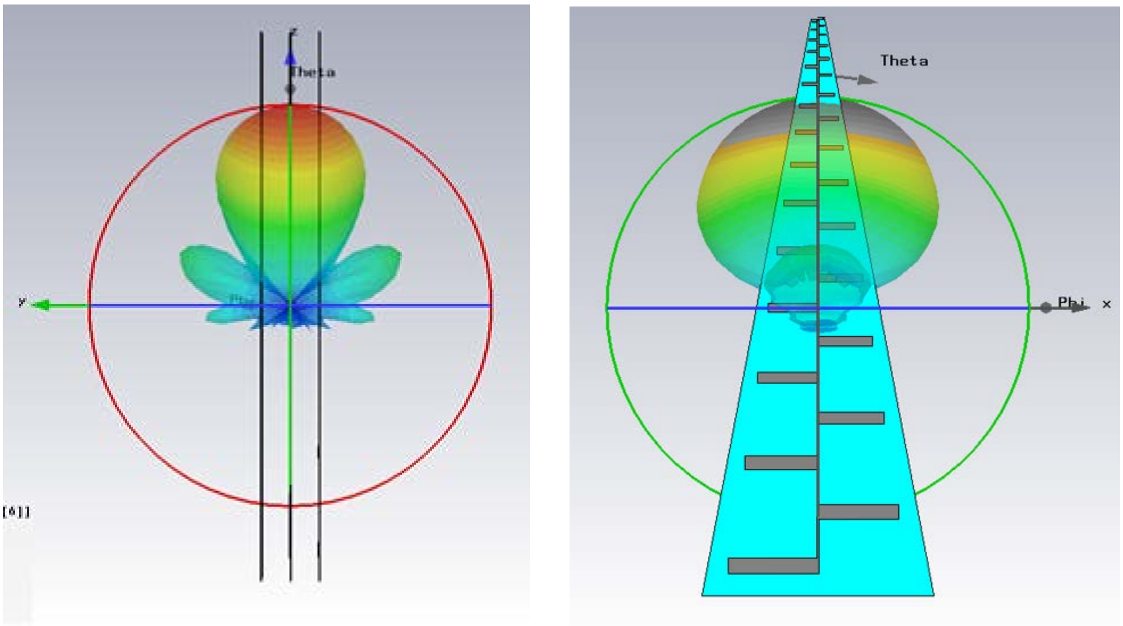
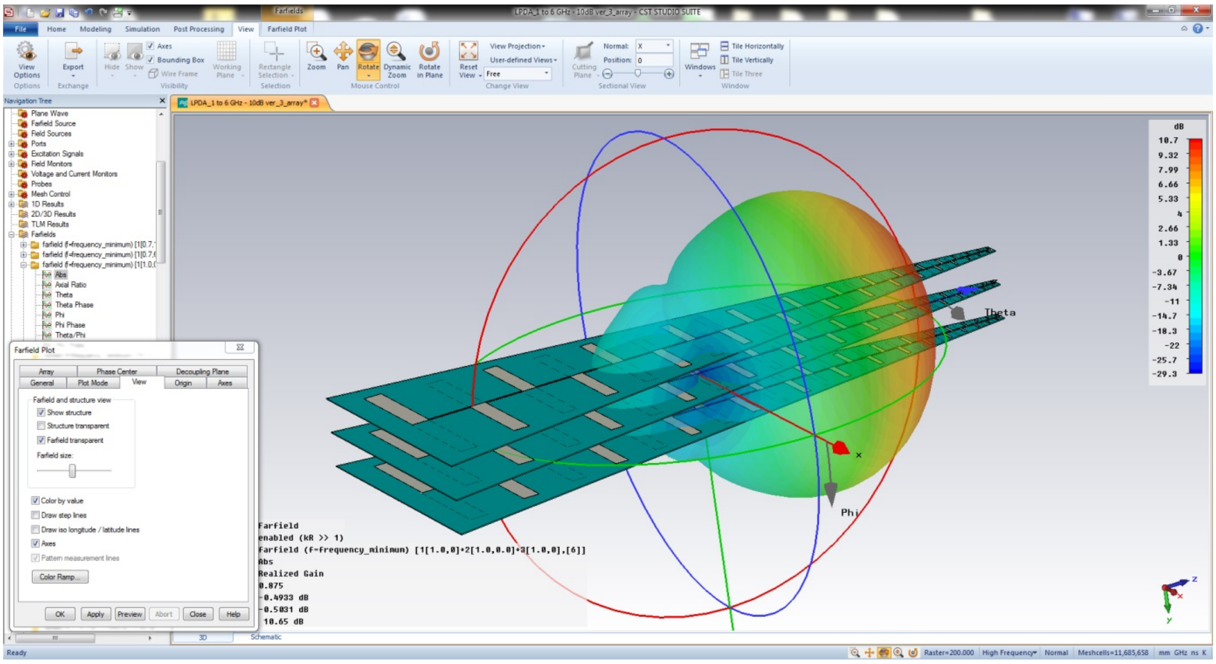


Figure 17 Antenna Patterns at 4.5 GHz

11.2. 3-D Plots



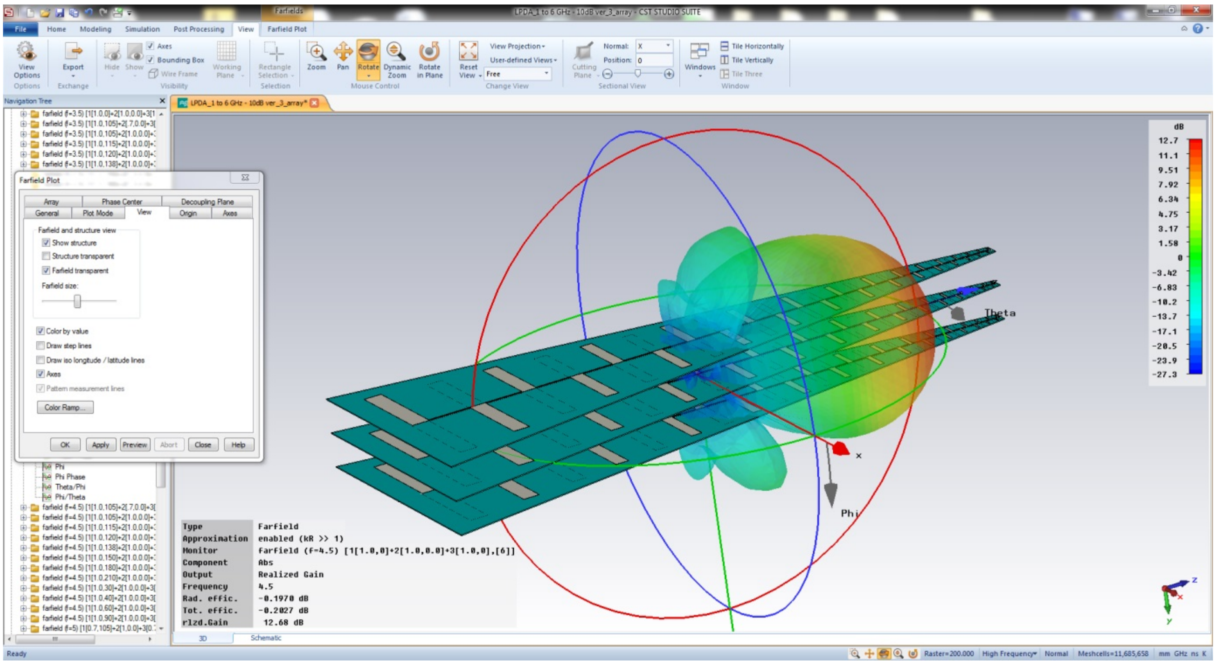
Farfield Plot – View

Farfield and structure view
☑ Show structure
☐ Structure transparent
☑ Farfield transparent
Farfield size:

☑ Color by value
☐ Draw step lines
☐ Draw iso longitude / latitude lines
☑ Axes
☑ Pattern measurement lines

```
Farfield
enabled (kR >> 1)
Farfield (f=frequency_minimun) [1[1.0,0]+2[1.0,0.0]+3[1.0,0],[6]]
Abs
Realized Gain
0.875
-0.4933 dB
-0.5031 dB
 10.65 dB
```

Figure 18 3D plot at 1 GHz



Farfield Plot

Array | Phase Center | Decoupling Plane | General | Plot Mode | View | Origin | Axes

Farfield and structure view

☑ Show structure

☐ Structure transparent

☑ Farfield transparent

Farfield size:

☑ Color by value

☐ Draw step lines

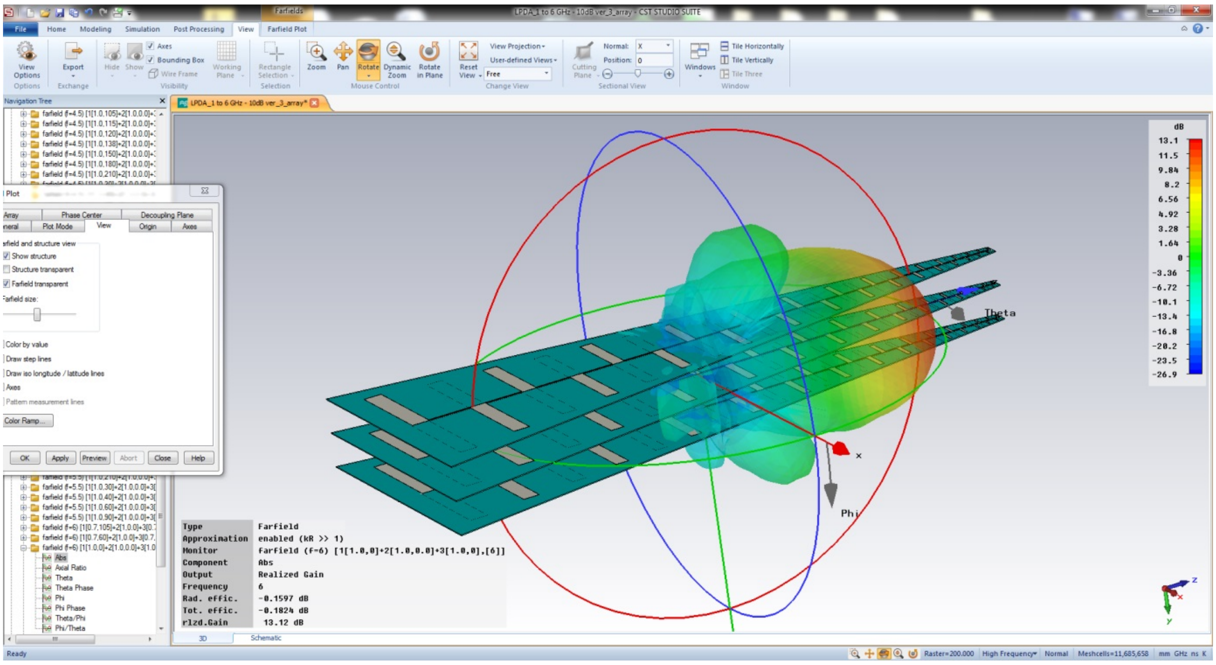
☐ Draw iso longitude / latitude lines

☑ Axes

☑ Pattern measurement lines

```
Type           Farfield
Approximation  enabled (kR >> 1)
Monitor        farfield (f=4.5) [1[1.0,0]+2[1.0,0.0]+3[1.0,0],[6]]
Component      Abs
Output         Realized Gain
Frequency      4.5
Rad. effic.    -0.1970 dB
Tot. effic.    -0.2027 dB
rlzd.Gain       12.68 dB
```

Figure 19   3D plot at 4.5 GHz



```
Type           Farfield
Approximation  enabled (kR >> 1)
Monitor        farfield (f=6) [1[1.0,0]+2[1.0,0.0]+3[1.0,0],[6]]
Component      Abs
Output         Realized Gain
Frequency      6
Rad. effic.    -0.1597 dB
Tot. effic.    -0.1824 dB
rlzd.Gain       13.12 dB
```

Figure 20   3D plot at 6.0 GHz

11.3. Far field gain plots

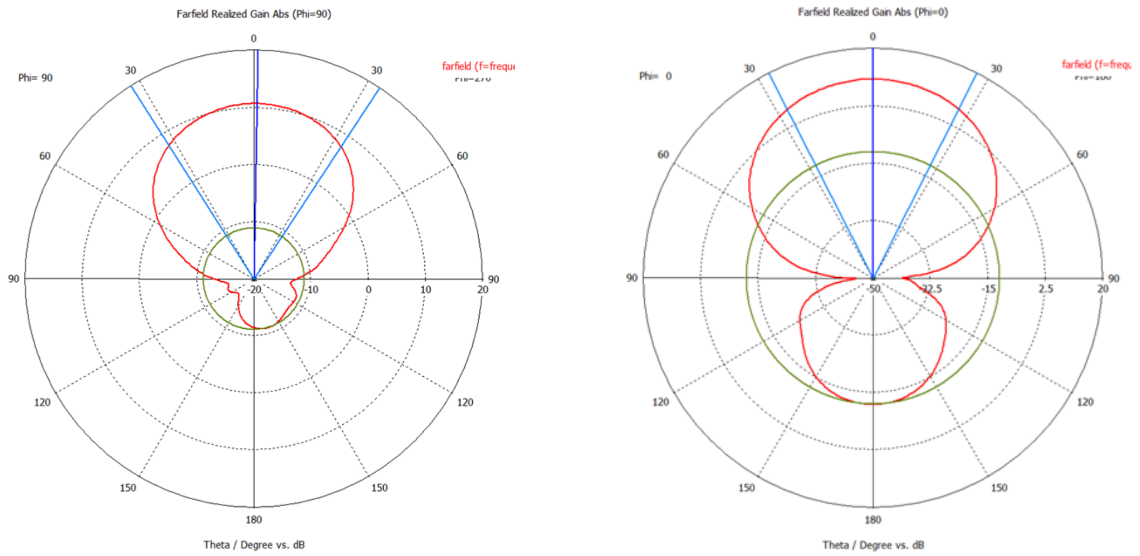


Figure 21 Far field gain at 1 GHz

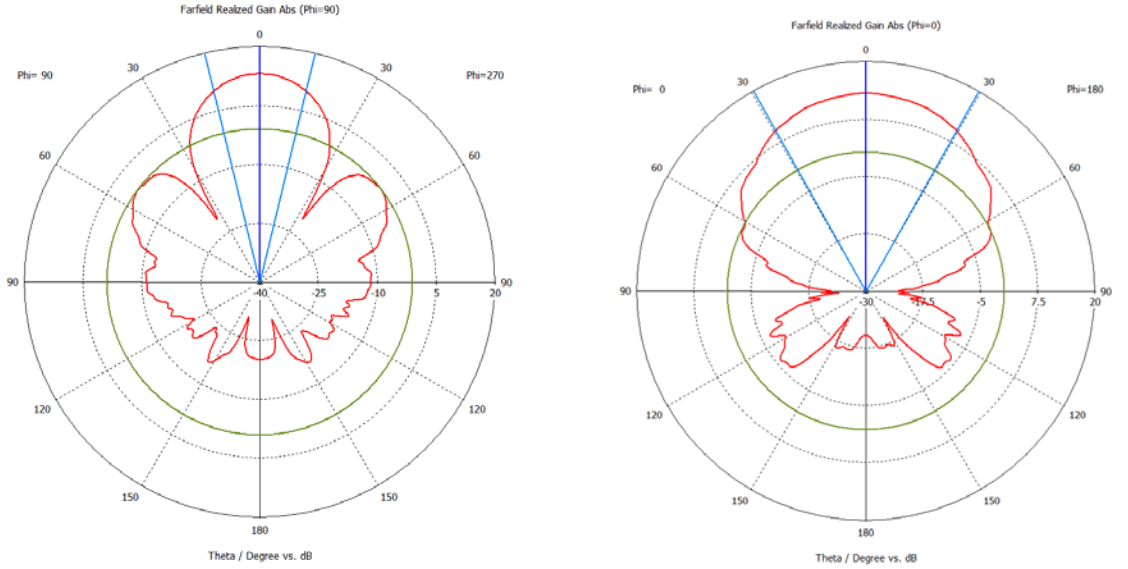


Figure 22 Far field gain at 6 GHz