Large E Field Generators in Semi-anechoic Chambers for Full Vehicle Immunity Testing

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Abstract

Several standards recommend the use of transmission line systems (TLS) as the field generation equipment for immunity testing. The assumption is that these systems provide a uniform field that will illuminate the whole vehicle under test. Additionally, it is assumed that these systems do not radiate and that the shielded semi–anechoic chamber has no effect on their performance. In this paper the reader will be educated on the fact that the TEM field supported by these structures is not perfectly uniform over the volume occupied by the vehicle at all frequencies, and that the structure will radiate and that it will couple to the chamber enclosure. The coupling will produce potential resonances at certain frequencies depending on the size of the chamber and the height of the generator.

Keywords

automotive EMC; immunity; generator

Introduction

A transmission line system (TLS) or TEM wire, or E field generator is a device commonly used in EMC to perform radiated immunity. Figure 1 shows a typical TEM structure. The structure behaves like a terminated transmission line guiding the EM field between one set of conductors (commonly referred as elements) and the ground plane of the shielded structure or OATS.

Figure 1 A typical TEM field generator. The wires connect to the elements parallel to the ground. A vertical E field is established between the elements and the ground

The SAE J551/11 and the ISO 11451-2 standards and by extension all those national and company specific standards that are based on those two recommend the use of TLS[1-2] for testing full vehicle immunity under 30 MHz. The TLS method has been adopted by industry as the most common method for testing immunity at lower frequencies. For some unknown reason, other low frequency methods that may be more economical are not pursued. One of these other methods is the one described by the SAE J551/13 and by the ISO 11451-4 which use bulk current injection (BCI) to couple radiated energy to the electrical network and cable harnesses in the vehicle[3-4]. The BCI method is however restricted to continuous narrowband EM fields and also for the 1 MHz to 400 MHz range while the SAE J551/11 covers the 100 kHz to 18 GHz and assumes that the TLS can be used below 200 MHz[1]. The ISO document[2] follows the same methodology and test set up as the SAE one[1]. Hidden in [2] are some wording related to the fact that the TLS may radiate and couple to the chamber and that cavity resonances may occur since the absorber does not usually operate at frequencies below 20 MHz, but the meaning of it may not be clear to the users of the standard document.

The purpose of this paper is to convey more information than what was presented in [5]. It is of high importance to bring to the attention of the EMC Engineer performing tests for the automotive industry these chamber effects that will affect the performance of the TLS device.

Chamber Effects

The first fact that must be remembered is that a TEM device will also radiate, and as it radiates some of the energy it guides that energy will couple to the surrounding environment. A chamber is for all purposes a loaded cavity and resonant modes will be present. To show the effects of the chamber, a numerical model is prepared in which a generator is placed inside a perfect electric conducting box. The shield to shield dimensions of this chamber are 28.9 m long by 20.1 m wide by 9.6 m high, these dimensions are not atypical for a chamber designed to do EMC testing of a vehicle. The chamber model is treated with a solid layer of lossy dielectric to simulate the effects of an absorber treatment. The generator is 9.4 m long and the elements are placed 3 m over the ground. It is fed with a 50 Ω source and the termination load is 100 Ω. Figure 2 shows the structure in the chamber. The structure is analyzed inside of the chamber and then the shield and the absorber are defined as vacuum and the simulation is executed a second time to get the solution of the case of the generator in a half-free space condition.

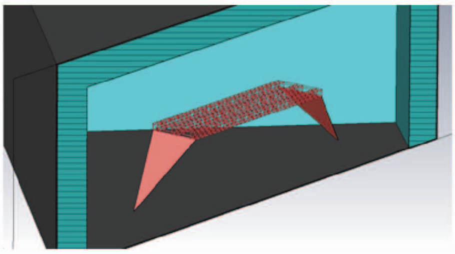

Figure 2 A field generator in a chamber with an absorber treatment

In Figure 3 we can see the difference in VSWR for the structure with and without the chamber, at 8 kHz there is a strong resonance as the energy couples to the chamber. This is caused by the energy coupling to the structure and a resonant mode being generated.

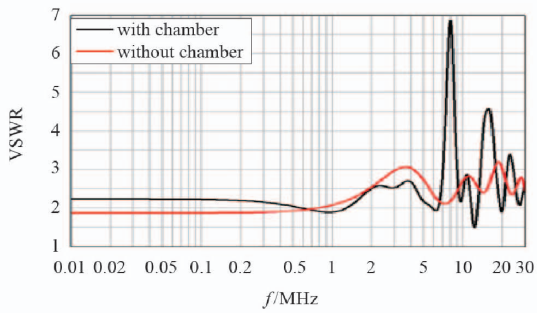

Figure 3 VSWR of the E field generator with and without the chamber

Measurements conducted inside chambers have shown this similar behavior. This is specially the case in chambers with no ferrite, since the ferrite can provide some loading down to 10 MHz, however, the behavior is presented in all semi-anechoic chambers. Simulations can predict, but it is always better to demonstrate by showing measurements. Figure 4 shows a chamber not lined with hybrid absorber. Notice that the VSWR is very well behaved until the upper frequencies where a combination of resonances and multi-moding, as higher order modes start to propagate down the structure, causes the VSWR to increase.

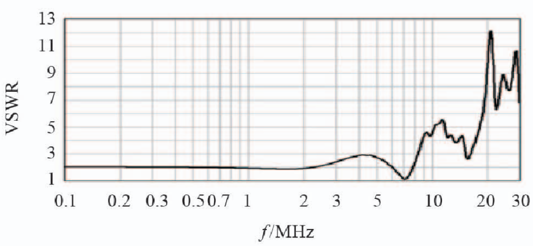

Figure 4 Measured VSWR for an E field generator similar to the one shown in figure 2 inside a chamber

Related to this chamber effect of the performance is the fact that different chambers with different absorber treatments will have different effects on the performance of the generator. Understanding the absorber performance is critical to the designer of the TLS.

How strong is the coupling of the energy traveling in the transmission line system to the chamber? To answer this question we can run a simulation of the TLS without the chamber. The model can be used to compute the radiation pattern from the generator. Once the radiation pattern is computed, we can integrate over the pattern to obtain the total radiated power from the structure. By dividing the total radiated power by the input power we can get the efficiency of the E field generator as a radiating structure. In Figure 5 the radiation efficiency in dB is shown versus frequency for the same generator structure when placed on an infinite ground plane. This is the total radiated power from the structure divided by the total input power into the structure. The efficiency is expressed in dB where 0 dB will be total efficiency with no losses, that is, all the power into the structure is radiated. Figure 5 shows that at 15 MHz about half of the power into the TLS is radiated. If this structure was inside a chamber half of the power into the structure will couple to the semi-anechoic chamber.

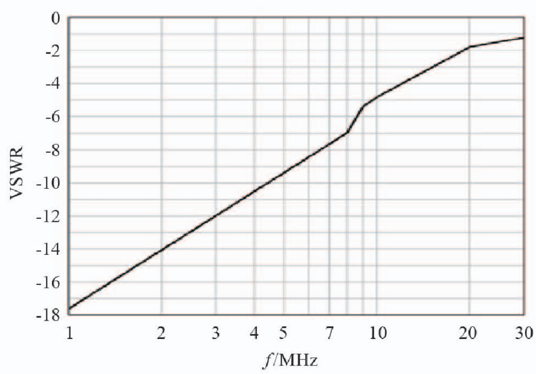

Figure 5 Radiation efficiency for an E field generator over an infinite ground plane. As the frequency increases more energy is radiated and coupled into the chamber (if a chamber was present)

In Figure 6 the radiation patterns are shown at different frequencies. 1 MHz, 10 MHz, 20 MHz and 30 MHz are shown. The load is one the right side while the feed is (hidden by the pattern) on the left side. It is clear that these open transmission lines radiate. This should not come as a surprise to engineers familiar with some other TEM devices. The SAE J1113/25 proposed a method using a TEM device. In the 1999 version of that standard, the frequency range of application was increased to 1 GHz. Empirical results showed that a shielded room treated with absorber material was required. This was required to reduce the resonant modes excited in the shielded room by the energy radiated from the TEM device at high frequencies[6].

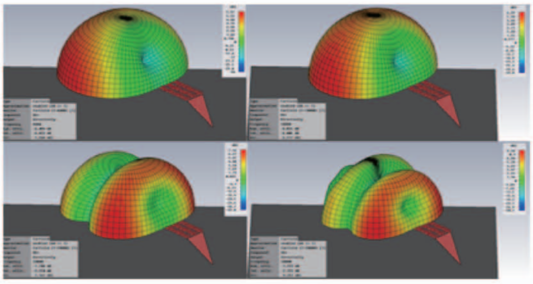

Figure 6 Radiation patterns of an E field generator over an infinite ground plane

Field Uniformity

As with other TEM devices, the field uniformity issue has been ignored by a lot of EMC test engineers. Decisions are taken to use these structures beyond their frequency. In [7] it was shown that even TEM devices like the GTEM do not maintain a TEM mode at high frequencies and that at frequencies above 1 GHz different modes other than the TEM mode are supported. In Figure 7 and Figure 8 the field uniformity is shown at a plane perpendicular to both the ground plane and the length of the elements. The field at 100 kHz is plotted in Figure 7 and at 20 MHz in Figure 8, both for a 1 W input.

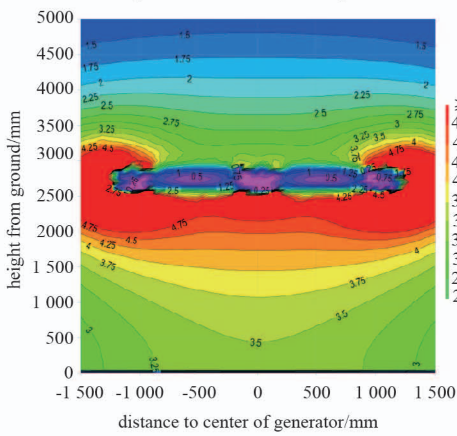

Figure 7 Field distribution supported by an E field generator at 100 kHz. the generator is 3 m over the ground and the elements are 2.5 m wide

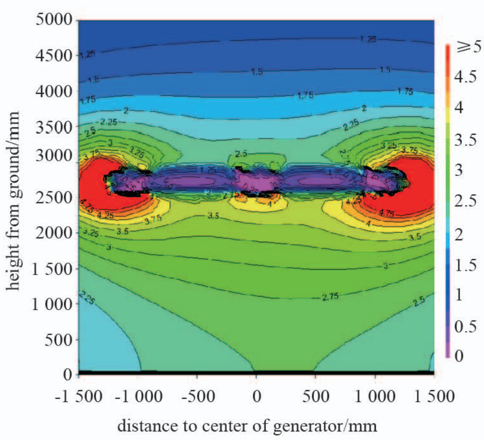

Figure 8 Field distribution supported by an E field generator at 20 MHz. the generator is 3 m over the ground and the elements are 2.5 m wide

These two plots show a fairly good uniformity under the structure. There is less than 6 dB variation for the field if a vehicle of 2 m in height and 2 m in width was to be tested. If we look at the longitudinal plane for the 20 MHz results we see that the variation is also acceptable for vehicles up to 6 m long. Figure 9 shows the field distribution at 20 MHz

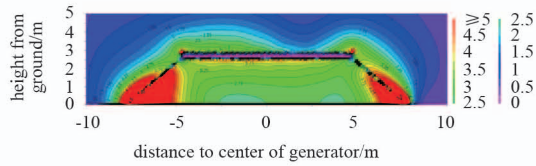

Figure 9 Field distribution on a vertical longitudinal plane at 20 MHz

The plots above show that field uniformity better than 6 dB over a typical vehicle of less than 2 m in elevation, 2 m in width and 6 m in length is achievable. Also this plot at shows the field extending over the generator as it radiates like in the lower left corner of Figure 6.

Next step is to understand the limitations as we try to test larger and taller items. It is common to use these devices to test large vehicles like buses and trucks. Since the elements must be a minimum of 50 cm from the outer edges of the vehicle, a larger and taller vehicle will force the elements to be raised further over the ground. Measured data, shown in Figure 10, show the field achieved with a 10 kW input power. The field is measured for different heights of the main element of the TLS. The field probe is also moved from 1 m for heights under 2.5 m (corresponding to vehicles under 2 m in height[1-2]) to 2 m for heights above 3 m. It is shown that the higher the elements the less field is achieved for a given power. While under 5 MHz the field levels are fairly constant the field changes rapidly versus frequency above 5 MHz there are large variations in the field as the resonances on the chamber affect the performance of the generator. The next results show how the uniformity is affected by the height of the elements when the generator is inside a chamber.

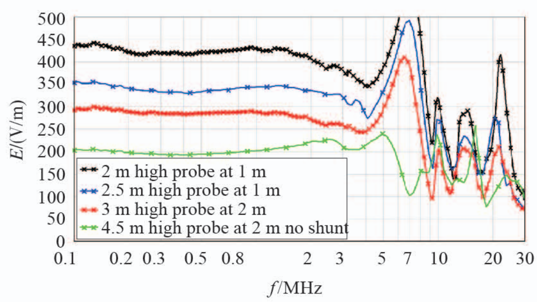

Figure 10 Measured performance of field achieved versus power for different heights

The field distribution is computed for the generator at 5 m over the ground. This will be the appropriate height for a passenger bus[8] which can be as tall as 4 m.

In Figure 11 we can see how as the height of the generator increases the uniformity in the longitudinal direction worsens.

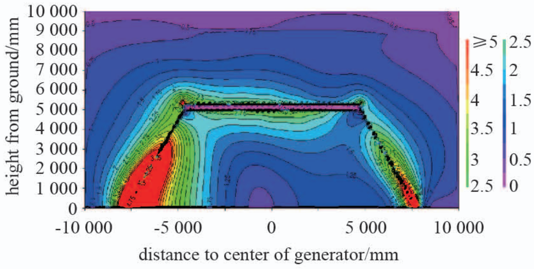

Figure 11 Field distribution on a vertical longitudinal plane at 20 MHz. computed with the generator raised to 5 m over the ground

In addition it becomes clear the immunity level that can be achieved for a given input power is much less. In Figure 9 for a 1watt of input power levels between 2.75 and 2.25 V/m could be achieved. While Figure 10 shows that the levels for the same input power are as low as 0.5 to 0.25 V/m length-wise. It can be seen that the variation of the field is quite large. A 10 m long bus will be in a region where the field will change from 3.25 down to 0.5 V/m a variation larger than 6 dB. Additionally, Figure 11, shows that much more power has been radiated from the structure as a larger difference can be seen between the feed side (on the left of the figure) and load side (on the right of the figure). In the next plots we show the field uniformity in two cuts at different frequencies. The field is displayed in dB related to the field level at a point centered under the generator and 1 m over the ground. This gives a better idea of the field uniformity as a function of frequency for a generator located 5 m over the ground.

Notice that the field distribution at 100 kHz and 500 kHz (Figures 12 to Figure 15) is very similar under the elements, although at low frequencies there is more coupling to the chamber walls even when these are covered with lossy material simulating foam RF absorber. These field distribution extends to 1 MHz and 5 MHz as seen in Figure 16 through Figure 19.

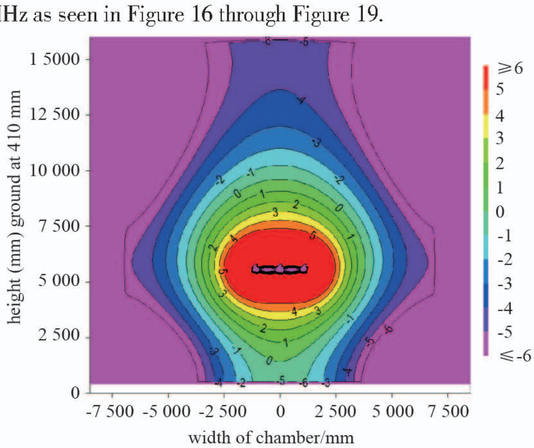

Figure 12 Field uniformity on an E field generator in a large chamber 5 m over the ground. 100 kHz crosswise

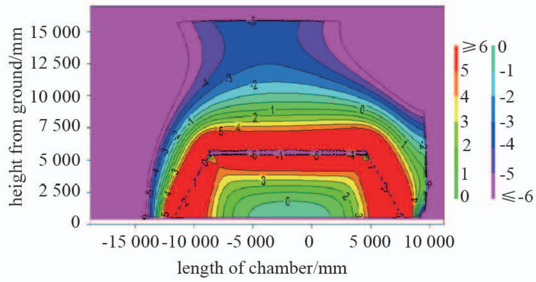

Figure 13 Field uniformity on an E field generator in a large chamber 5 m over the ground. 100 kHz lengthwise

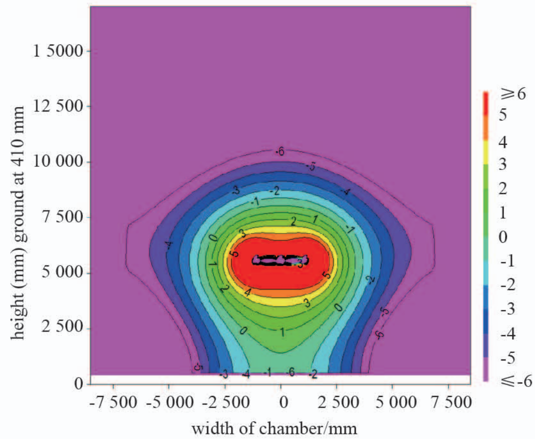

Figure 14 Field uniformity on an E field generator in a large chamber 5 m over the ground. 500 kHz crosswise

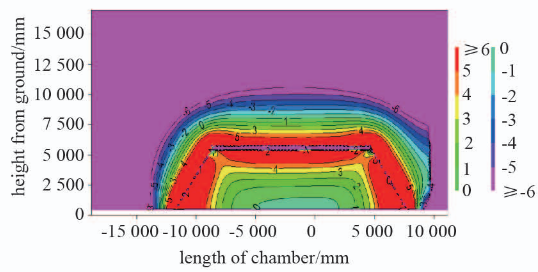

Figure 15 Field uniformity on an E field generator in a large chamber 5 m over the ground. 500 kHz lengthwise

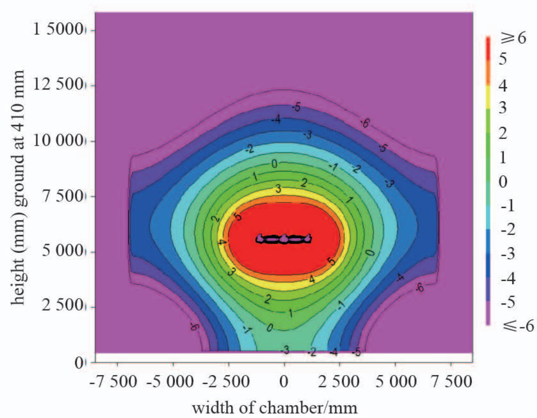

Figure 16 Field uniformity on an E field generator in a large chamber 5 m over the ground. 1 MHz crosswise

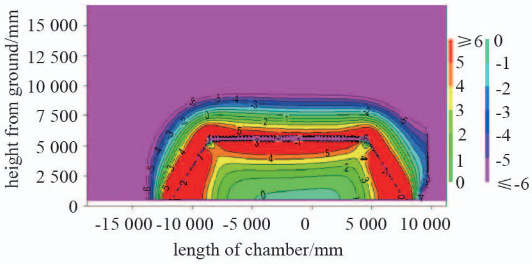

Figure 17 Field uniformity on an E field generator in a large chamber 5 m over the ground. 1 MHz lengthwise

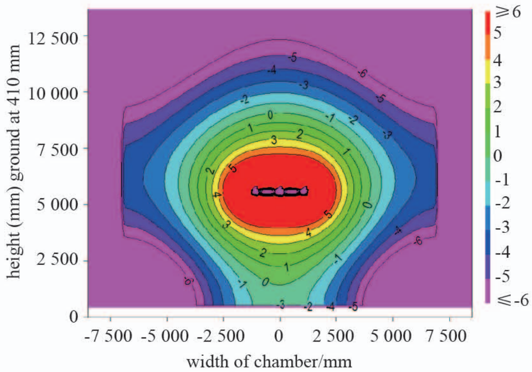

Figure 18 Field uniformity on an E field generator in a large chamber 5 m over the ground. 5 MHz crosswise

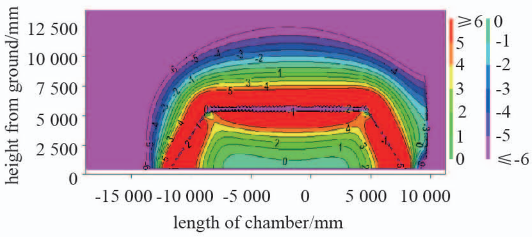

Figure 19 Field uniformity on an E field generator in a large chamber 5 m over the ground. 5 MHz lengthwise

At frequencies above 10 MHz we start seeing that the structure starts coupling more to the chamber structure as higher order models are supported by the generator in the chamber.

If the plot of Figure 25 is compared with the plot on Figure 11, we can get a good idea of the great effect of the chamber. The generators on the figures are the same length, and they are both 5 m over the ground. However, the chamber in Figure 25 is much larger than the chamber in Figure 11. The field distribution is clearly different.

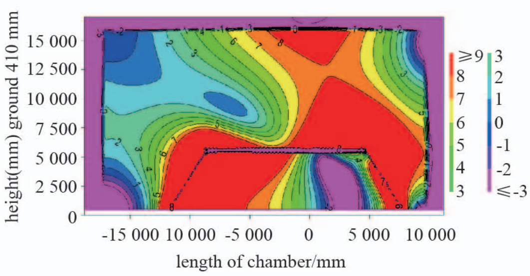

Figure 20 Field uniformity on an E field generator in a large chamber 5 m over the ground. 10 MHz lengthwise

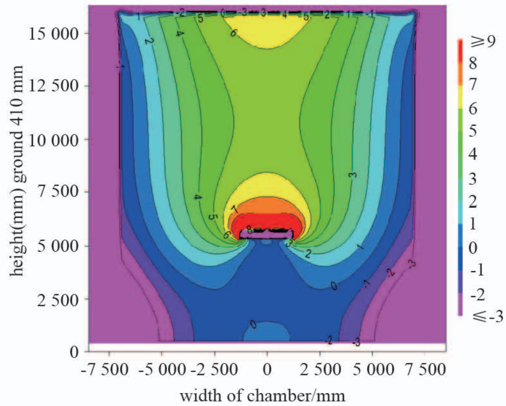

Figure 21 Field uniformity on an E field generator in a large chamber 5 m over the ground. 10 MHz crosswise

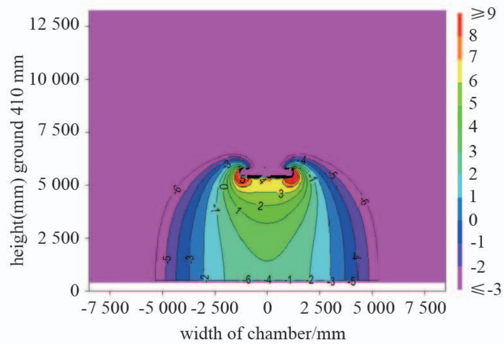

Figure 22 Field uniformity on an E field generator in a large chamber 5 m over the ground. 15 MHz crosswise

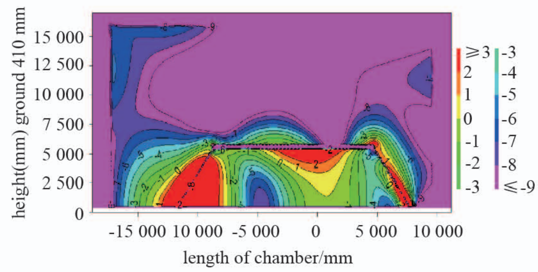

Figure 23 Field uniformity on an E field generator in a large chamber 5 m over the ground. 15 MHz lengthwise

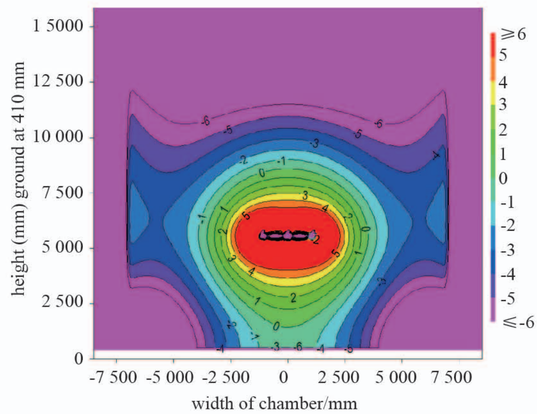

Figure 24 Field uniformity on an E field generator in a large chamber 5 m over the ground. 20 MHz crosswise

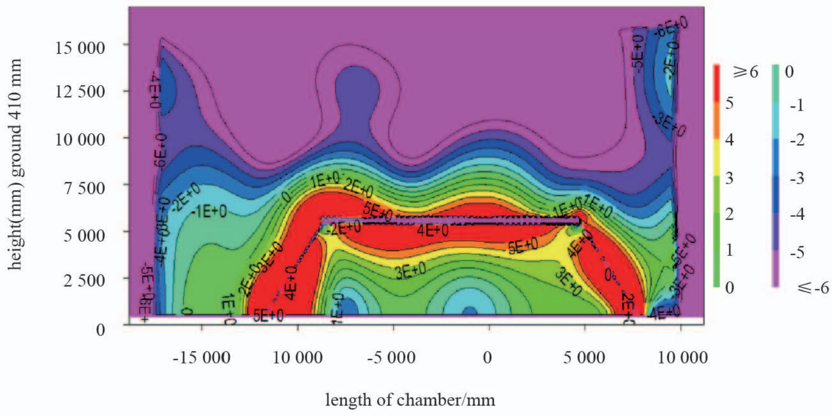

Figure 25　Field uniformity on an E field generator in a large chamber 5 m over the ground. 20 MHz Lengthwise

Conclusion

While this paper has shown some of the limitations of TLS when used inside chambers, these systems remain the most efficient method of generating high fields at low frequencies (other than coupling energy into the cable harness of the system via BCI). Understanding the limitations of these devices will help the EMC test engineer come with realistic expectations of the field levels and of the field uniformity that can be achieved. The height of the vehicle under test has also been shown to have a huge effect on the operating range of these devices since the higher the elements are set to accommodate tall vehicles the lower the fields that can be achieved and the lowest the frequency at which the device radiates efficiently.

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