Analysis of Large E Field Generators in Semi-Anechoic Chambers Used for Full Vehicle Immunity Testing: Numerical and Measured Results

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Abstract— **There are several standards that recommend the use of transmission line systems (TLS) as the field generation equipment for immunity testing. In general the assumption is that these systems provide a uniform field that will illuminate the whole vehicle under test. Additionally, It is commonly 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 two facts. First, that the TEM field supported by these structures is not perfectly uniform over the volume occupied by the vehicle at all frequencies. Second, 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.**

Keywords— **Automotive EMC, TEM Devices, Immunity**

I. 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 30MHz. 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.

The main purpose of this paper is to bring attention to these effects. This is be done by showing both measured and computed data for a series of E field TEM generators. The goal is to provide the EMC test engineer with an understanding of the limitations of their field generating devices and to allow them to set up proper test procedures.

II. 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 model is prepared in which a generator is places inside a chamber, CST MW Studio is used to model the structure. The shield to shield dimensions of this chamber are 28.9 m long by 20.1 m wide by 9.6 m high. 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 ohm source and the termination load is 100 ohms. 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 again.

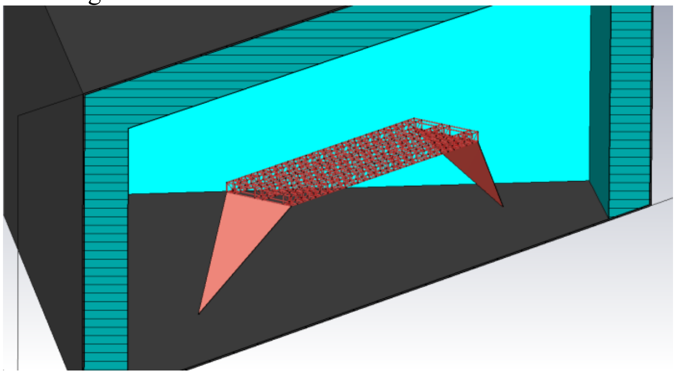

Figure 2. A field generator in a chamber with an absorber treatment.

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.

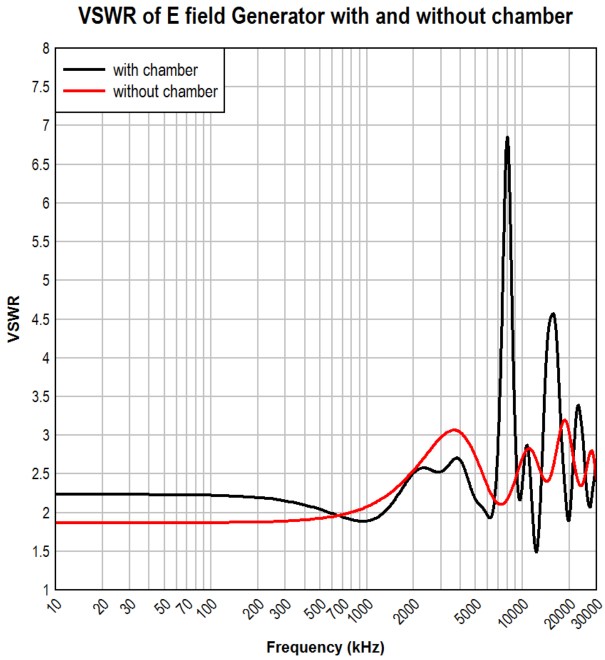

Figure 3. VSWR of the E field generator with and without the chamber.

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. 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.

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.

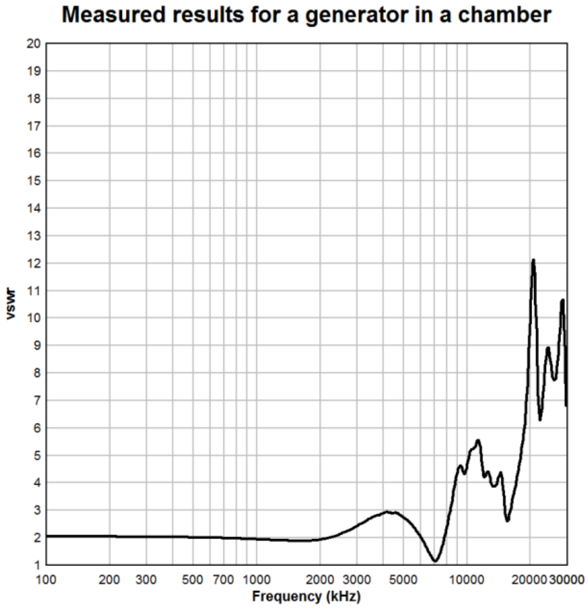

Figure 4. Measured VSWR for a E field generator similar to the one shown in figure 2 inside a chamber.

Another simulation can show the radiation pattern of the generator as well as the radiation efficiency of the structure at different frequencies. The radiation efficiency shows the level of energy radiated by the generator related to the total input power. In figure 5 the radiation efficiency in dB is shown versus frequency for the same generator structure when placed on an infinite ground plane.

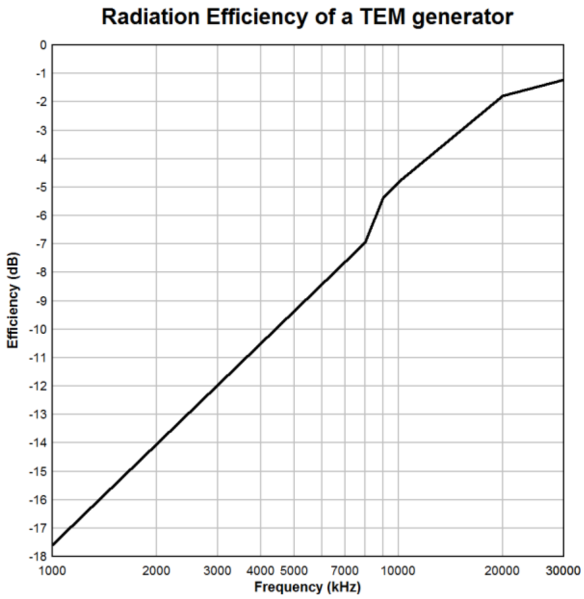

Figure 5. Radiation efficiency for a E field generator over an infinite ground plane. Notice how as the frequency increases more energy is radiated and therefore coupled into the chamber (if a chamber was present)

In figure 6 the radiation patterns are shown at different frequencies. 5 MHz, 10, 20 and 30MHz 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 1GHz. Empirical results show that a shielded room treated with absorber material was required. This was caused by resonant modes being excited in the shielded room as the energy radiated from the TEM device at high frequencies [5]

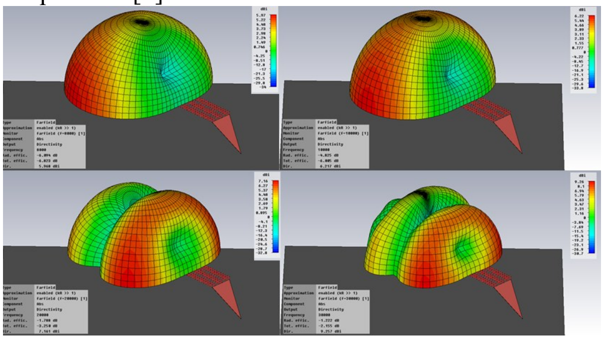

Figure 6. Radiation patterns of an E field generator over an infinite ground plane. (Clockwise from the upper left corner: 5 MHz, 10 MHz 20 MHz and 30 MHz).

III. 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 [6] it was shown that even TEM devices like the GTEM do not maintain a TEM mode at high frequencies and that at frequencies above 1GHz different modes other than the TEM mode are supported. In figure 7 and 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 watt input.

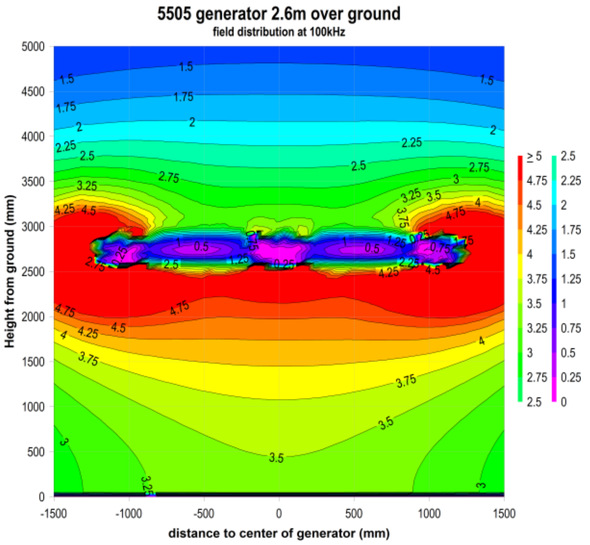

Figure 7. Field distribution supported by a E field generator at 100kHz. the generator is 3 m over the ground and the elements are 2.5 m wide.

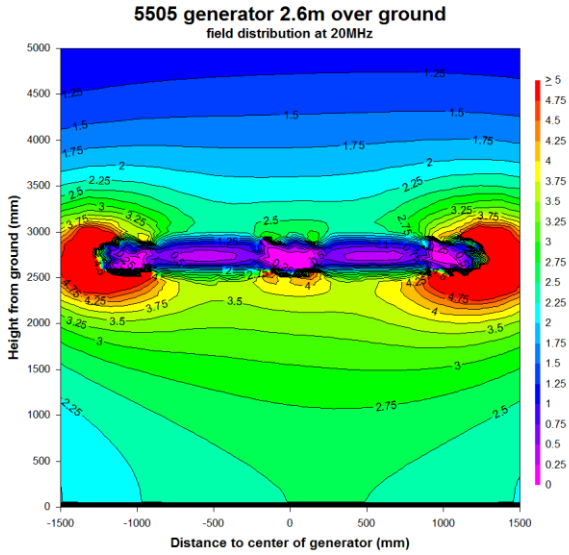

Figure 8. Field distribution supported by an E field generator at 20MHz. the generator is 3 m over the ground and the elements are 2.5 m wide.

These two plots show a fairly good uniformity under the structure. There is less than 6dB variation for the field if a vehicle of 2 m in height and 2m 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 6m long. Figure 9 shows the field distribution at 20 MHz

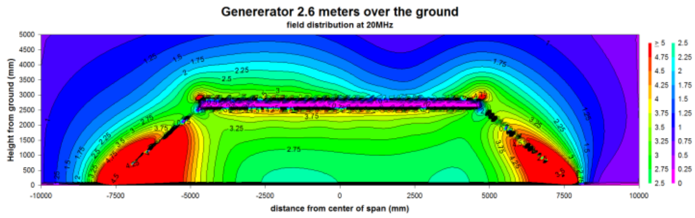

Figure 9. Field distribution on a vertical longitudinal plane at 20 MHz.

The plots above show that field uniformity better than 6dB over a typical vehicle of less than 2m in elevation, 2m 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. This will force the elements to be raised further over the ground. Measured data, shown in figure 10, show the field achieved with a 10kW input power. The field is measured at different heights for 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.

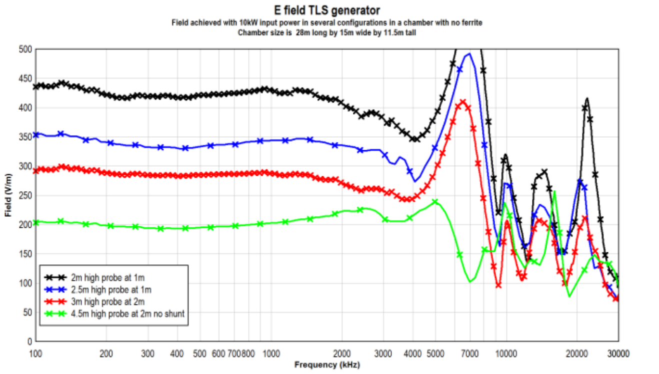

Figure 10. Measured performance of field achieved versus power for different heights.

The field distribution is computed for the generator at 5 m over the ground. This will be the appropriate height for a passenger bus [7] 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.

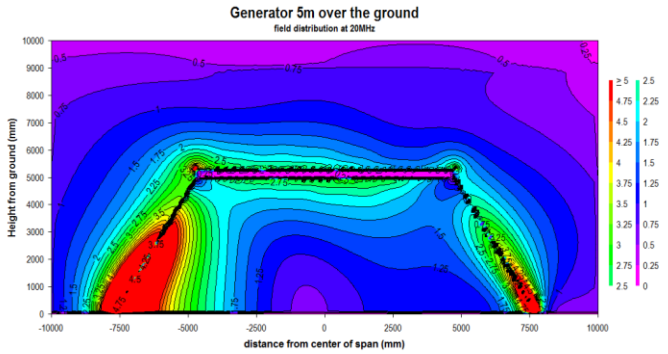

Figure 11. Field distribution on a vertical longitudinal plane at 20 MHz. computed with the generator raised to 5m over the ground.

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. Along the length of the generator, 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 6dB. 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), as opposed to what figure 9 shows. While it is understood that changing the height will change the impedance of the line and affect the matching, the other effect is that for a given frequency the structure may not support a TEM mode and that more energy will radiate as figure 5 shows. Inside a chamber the radiated energy will couple to the structure and resonate as we see in the data presented in figure 3.

IV. 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.

References

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