A Novel Concept for EMC Radiated Immunity Testing using Field Generators

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Abstract— **To improve efficiencies and reduce costs in Electromagnetic Compatibility (EMC) testing, a new instrument is developed which merges antennas and amplifiers to overcome difficulties in the traditional EMC Radiated Immunity (RI) setup. A power amplifier is one of the most expensive instruments in an EMC RI test setup. In the conventional setup, according to IEC-61000-4-3, up to 6 dB of the amplifier's rated power is lost for several reasons, e.g., internal cabling within the amplifier, the amplifier's output combiner stage, directional couplers, and cables between the coupler and antenna itself. In this paper a novel concept is presented where active antenna arrays, amplifier stages and directional couplers are combined into one unit, termed a field generator. In this configuration, the E-field (V/m) requirement is emphasized rather than the rated power (W) of the amplifier. Although this concept is not limited to a certain field strength or frequency range, we will discuss the validation of this concept in the 1-6 GHz frequency range to generate 10V/m E-field at a 3m distance to meet the requirements specified in IEC-61000-4-3. The advantages of this concept and a few design challenges in implementation will be discussed. Simulation and measurement results will be presented.**

Index Terms—**EMC, RI Testing, Field Generators**

I. INTRODUCTION

THE pressure to bring new products to the market, with reduced time to market (TTM), high quality, and reduced cost, has never been greater. For most electrical and electronic products, the necessity of complying with electromagnetic compatibility (EMC) regulations in order to sell in global markets, add to these pressures. Considering the increased importance of EMC testing for electronic systems, the associated challenges seem to grow simultaneously. These challenges range from increased importance of EMC in the product design phase, to improving EMC test standards for new technologies to developing more efficient instrumentation for EMC testing.

The RF Immunity standard IEC-61000-4-3 specifies a requirement to generate a uniform field at a test distance of 3m between the tip of antenna and Device Under Test (DUT). Such an area with a uniform field is termed a quiet zone in the EMC industry. A certain level of E-field is applied to the DUT, placed in the quiet zone for immunity testing. The area

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of uniform illumination is 1.5 by 1.5 meters, to ensure that portions of any interconnecting cable to the DUT is illuminated by the field. The field is deemed uniform when 75% of 12 points in this area comply with the 0 to +6 dB rule [1]. In RF immunity systems using traditional design techniques, the designer has to analyze a large number of individual specifications of the system components, and take into considerations for their integration into the test system.

II. CONVENTIONAL SETUP

A typical RI test setup consists of many components including antennas, amplifier, signal generator, power meters, directional couplers and E-Field probe. Fig. 1 presents a typical RI setup according to IEC 61000-4-3. The DUT is placed on the turntable inside the chamber and is placed 3m away from the tip of the antenna [1]. Typically, long runs of RF cables are used to connect from the amplifier output to the input of the Dual Directional Coupler (DDC), from the coupler's output to the feed-through connector on the chamber wall, and from the chamber feed-through to the antenna input.
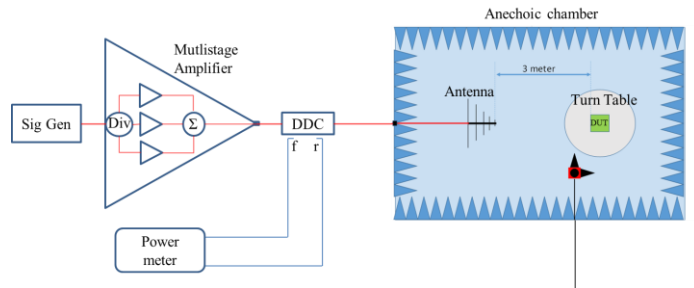

Fig. 1. Conventional RI setup

The power amplifier is one of the most expensive components in an EMC test system. However, in the conventional EMC radiated immunity (RI) setup such as the one shown above, up to 3-6 dB of an amplifier's rated power is lost at multiple stages in the setup itself.

TABLE I. LOSS VALUES IN A RI TEST SETUP

Typical loss values (dB)					
Freq (GHz)	Combiner	Coupler	RF cable	Total Loss	
				3m cable	10m cable
1	0.6-0.8	0.2-0.4	0.1 dB/m	1.1-1.5	1.8-2.2
6	1.5-1.8	0.5-0.8	0.25 dB/m	2.75-3.35	4.85-5.1

The power loss in the test setup mainly comes from the connecting cables between different parts in the setup. Such pieces of cable from the amplifier output to the input of the

Dual Directional Coupler (DDC), between the coupler's output and feed-through on the chamber wall, and from the chamber feed-through to the antenna input. The amplifier itself also adds to these losses as it consists of multiple stages and a combiner which eventually combines the output of the multiple stages. In addition, the frequency dependent losses of the RF cables exacerbate the situation.

Therefore, on one hand EMC standards specify the test setup requirements in terms of E-field strengths within the quiet zone, while on the other hand such power losses force us to design systems in terms of amplifier rated power and safety margins. Eventually a much higher rated power amplifier is required to overcome the power loss occurring from the inefficient test setup.

A typical alternate approach used to reduce such losses is to put the immunity rack inside the test chamber. This approach is not only non-compliant with the standard, but it can also impact the immunity measurement results.

III. FIELD GENERATORS

A. Concept

To achieve high output power, the traditional approach is to combine power from small amplifiers, and then this high power is supplied to a single antenna through a path comprising of a directional coupler and a long RF cable.

The proposed model is comprised of active antenna arrays, integrated amplifiers, and directional couplers. Each antenna element in the array has its own amplifier and directional coupler. Instead of adding power in a multi-stage amplifier, field generators combine the E-fields generated by each chain of antenna and amplifier. The amplifiers and antennas are coupled together in the design. Therefore such field generators not only remove the internal loss within multiple stages of the amplifier rack, but also remove the losses due to the cabling within amplifier and antenna themselves.
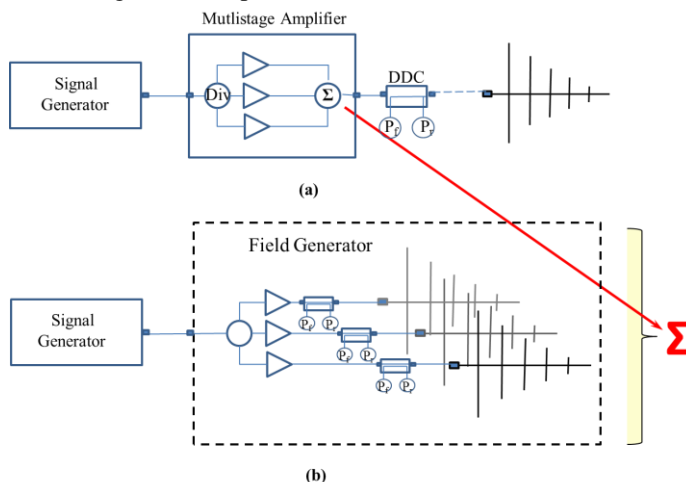

Fig. 2. Difference between the typical set up (a) and the new proposed setup (b)

In the following sections, the design of such field generators for the RI test setup in compliance with IEC 61000-4-3 is presented with simulation and measurement results.

B. Design Considerations

There are several considerations which needed to be kept in mind while designing such field generators, the important items are discussed in this section.

1) Antenna selection

Log-periodic dipole array (LPDA) antennas used in broadband applications can achieve high directivity and low cross-polarization ratio over a very large frequency range. Such wideband antennas have typically been constructed using metallic booms and dipole radiating elements. In applications where space and weight is restricted, antennas need to be light-weight and have a small physical size and increase frequency. Microstrip antennas that operate as a single element usually have a relatively large half power beamwidth, low gain and low radiation efficiency. In order to improve on these parameters, microstrip antennas are used in array configurations to increase the gain and range of the radiating structure [2]. There are many effects such as mutual coupling between elements which must be taken into consideration when analyzing an array structure. As a result, full wave analyses are usually used to model arrays. The log periodic antenna structure is similar to a proximity coupled antenna; however, the elements are designed such that they follow logarithmic sizing and spacing [3]. These structures have relatively broad bandwidth. The antenna array in such field generator is comprised of three log-periodic antennas. The antenna array has been designed and simulated in Microwave Studio CST. The simulation model of the designed array is shown in Fig. 3. The LPDA antennas have 29 elements, resulting in a very low "ripple" on the frequency response. The spacing between the antenna array elements has been optimized for gain and phase matching.
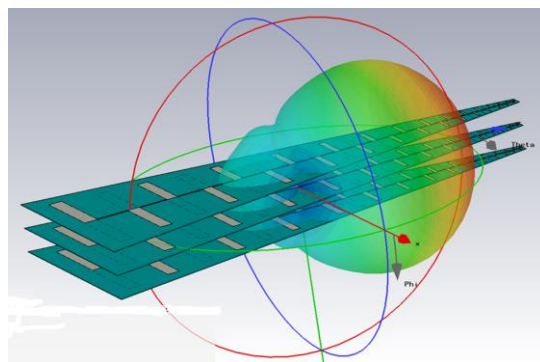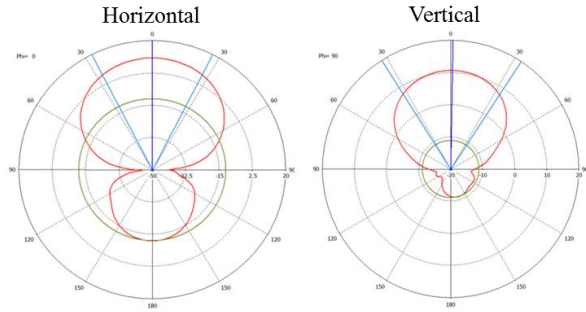

Fig. 3. 3D model of the antenna array with highlighted radiation pattern (at f = 1 GHz).

The far field realized gain polar plots of the simulated antenna array are shown in Fig. 4, with some results summarized in Table II. It has been shown that the gain of the antenna array is slowly increasing from 1 GHz to 6 GHz (around 11 dB @ 1 GHz and 13 dB @ 6 GHz).

TABLE II. SIMULATION RESULTS OF LPDA ANTENNA ARRAY

	At f = 1GHz		At f = 6 GHz	
	Horizontal Pol.	Vertical Pol.	Horizontal Pol.	Vertical Pol.
Main lobe mag.	11 dB	11 dB	13.1 dB	13.1 dB
Angular width (3dB)	53.8°	65.7°	59°	27°
Side lobe level	-22.1 dB	-21.8 dB	-12.8 dB	-14.1 dB
Aperture	~30°x30°		~20°x30°	

At f = 1 GHz

Horizontal   Vertical
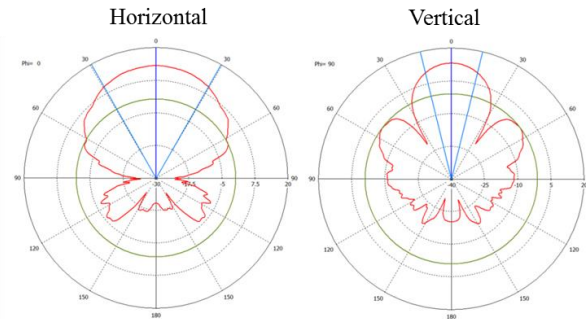

At f = 6 GHz

Horizontal   Vertical

Fig. 4. Simulated antenna array aperture

2) Amplifier selection

For a trouble-free and long life operation of power semiconductor devices (such as BJT, MOSFET, IGBT), it is critical to keep the overall power dissipation of the device within SOAR (safe operating area) [4]. In this regard, much emphasis is given on choosing the optimal class of the amplifier for heat generation and dissipation. The class of the amplifier mainly influences its overall efficiency and the load driving capability of an amplifier's output stage. Theoretically, in Class A amplifiers 50% of the power is heat whereas in Class AB designs it is only 12.5%. Class A amplifiers can achieve efficiency from only 20% to 30% in reality as compared to 60% efficiency in the case of class AB. The Class AB amplifier is chosen for such field generators as it offers the higher efficiency for given output levels.

A field generator presented here has three amplifiers, one for each antenna. Each amplifier has three amplifiers stages, where the final stage is a GaN amplifier. Each amplifier module has its own microcontroller, in order to control all amplifier parameters independently for each amplifier module (bias currents, protections, amplifier gain etc.).

Apart from this, each amplifier module has its own coupler, forward power meter and reflected power meter. The gain of each amplifier can be adjusted independently to ensure all antennas are fed with the same RF power. Also, the phase difference between all amplifiers has to be minimized to maintain the desired beam shape.
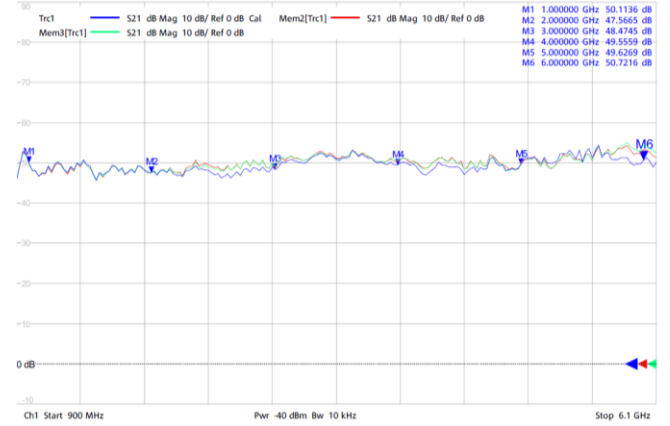

Fig. 5. Frequency response measurement of an amplifier

Fig. 5 shows a graph for the overall frequency response from the input connector (at the power supply side) to the output of one of the amplifiers, including a 3 meter N type cable. As can be seen, the frequency response has a slight up tilt at the higher frequency end. This compensates for the frequency response of longer N-type cables.

3) Integration of the parts

The rectangular metallic housing at the back side is designed as part of the overall radiating element. Therefore, this block does not negatively affect the antenna array performance. A single coaxial cable performs a dual function. It carries RF input signal to the amplifier, and it also carries the DC power supply signal to power up the electronic circuitry inside the unit. Fig. 6 shows the complete assembly of a field generator design.
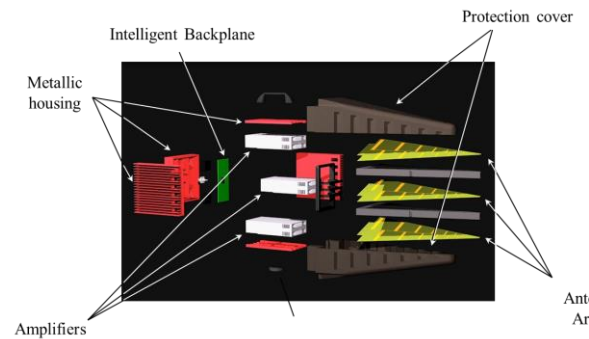

Fig. 6. Field generator design

IV. PROPOSED RI TEST SETUP

The new proposed setup with a field generator comes with a slightly different setup than a traditional setup. It is still in full compliance with IEC 61000-4-3. The new setup uses less equipment thus less complexity and less installation time.

Fig. 7 shows the new setup for RI testing according to IEC 61000-4-3. The field generator is placed inside the chamber at a 3 meter distance from the DUT. ETS-Lindgren's modular

platform, EMCenter, is used as the main supporting equipment in the new setup. EMCenter has seven slots for plugin cards, thus is capable of providing seven functionalities at the same time. In the current setup, EMCenter is configured to be used as a signal generator, power meter, and power supply for the field generator.
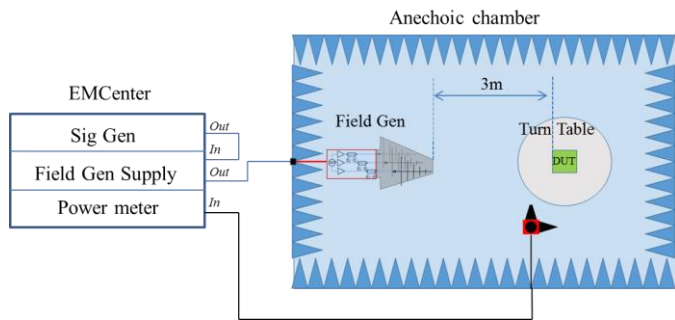

Fig. 7. Test setup with field generator

The field uniformity tests have been performed at 10 V/m to validate the performance and to ensure sufficient linear behavior of the system. In order to determine if the system produces enough field level, the available power of the system must be at least 5.1 dB (factor 1.8) higher than the highest recorded power of the 16 points at each frequency. This is because although the validation is performed using CW signals, the standard requires the final tests be performed with a 80% amplitude modulation applied. According to IEC 61000-4-3, the available power may be determined at 2 dB compression of the output. The available power of the field generator is 10W per amplifier or 30W in total (44.7 dBm) which means the maximum power in the measurement should not exceed 44.7 dBm – 5.1 dB = 39.6 dBm so that the system has enough headroom to allow for the 80% amplitude modulation (AM).
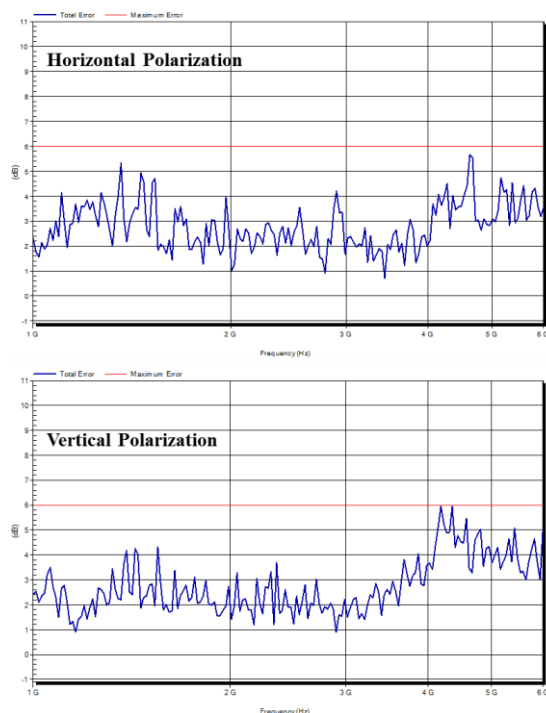

Fig. 8. Error graph for the forward power required for the uniform 10V/m

The red line in both the graphs in Figure 8 represents the maximum error limit for 6dB error. The error graph for 75% of the measured points in the vertical and horizontal planes are shown in Fig. 8. It shows that 12 out of 16 points are within the specified 6 dB error limit.

V. CONCLUSION

In this paper, the concept of field generators is presented and validated as per the RI testing requirements specified in IEC 61000-4-3, i.e. 10V/m at a 3m distance between the DUT and the tip of the antenna. They simplify the test setup in terms of setup complexity and also allow easy installation. The concept is scalable to much higher field strengths and different frequency ranges with design modifications, e.g. varying the number of antenna array elements and modifying the integrated amplifier design. Such field generators not only introduce a new instrument category in the world of EMC testing but also provide a cost-effective solution to the existing challenges in RI testing.

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