An Indoor Transmission Line Type of EMP Simulator

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INTRODUCTION

A new EMP simulator has been designed to generate a planar transient electromagnetic wave over a volume of 3 m x 1 m x 1 m. Named SEMIRAMIS (Simulateur Electromagnetique a Impulsion Raide pour des Industrielles et Scientifiques), the simulator consists of two conductors with a central parallel plate region. The simulator generates the wave by launching a spherically expanding transient electromagnetic wave onto a conical transmission line formed by two triangular shaped plates. The conical transmission line is followed by a cylindrical transmission line formed by two parallel plates. The spherical TEM wave evolves into a planar TEM wave in the central parallel plate region, which is then terminated by a distributed terminator consisting of eight parallel resistor chains.

The working volume of 3 m x 1 m x 1 m is large enough to accommodate equipment racks for EMP vulnerability tests. SEMIRAMIS can also be excited by a CW source at a single frequency or swept over a band of frequencies. For this reason, it is useful for certain types of EMC testing. The desired working volume has a height of 1 m, which leads to a top plate height of 1.6 m. Previous studies[1] have considered current distributions induced on cylinders when they are placed between two parallel plates. A comparison of these currents with currents induced on isolated cylinders under plane wave excitation

A transmission-line type of EMP simulator, consisting of two conductors with a central parallel plate region, has been designed and fabricated.

shows that they differ by less than 20 percent if the plate separation is at least 60-percent more than the height of the cylinder. For this reason, the parallel plates are separated by 1.6 m.

DESCRIPTION OF SEMIRAMIS

Figures 1 and 2 show the side and plane views of this design. In the central parallel plate region, both the top and bottom plates are 3.2 m (2a) wide and they are separated by a distance of 1.6 m (2b). A cross-sectional view in the central parallel plate region is shown in Figure 3. The ratio (b/a) has a value of 0.5, for which the TEM characteristic impedance from Reference 2 is about 115 ohms. If the bottom plate were an infinite ground plane, then (b/a) would become 1, for which the full impedance (between the top plate and the image plate in the ground plane) is 178 ohms. This means the impedance between the top plate and a very wide bottom plate which acts like an image plane would be 89 ohms. This design of SEMIRAMIS has been tested while placed on the floor of a shielded room and on a ground surface outside the building. Under both of these conditions, the impedance varied between 90 and 115 ohms, and reflections from the 100-ohm terminator can be observed if the time domain measurements are Fourier transformed. It is also apparent that neither of these placements of the line is optimal. The ideal situation would be to have a bottom plate that is sufficiently wide to act as an image plane, in which case the pulser can have a single-ended output.

The top and bottom plates of the SEMIRAMIS are constructed with a welded wire mesh (about 5 cm by 5 cm) over a metallic framework. For the frequencies of interest (dc to about 150 MHz), the mesh simulates a solid metallic surface very well. A pulser characterized by a 20 kV to 100 kV frequency range, 7 to 9 ns risetime, and 150 ns FWHM has been employed in driving this simulator. This pulser consists of a charging and control unit, a pulse generator and a gas pressure regulation unit; its electrical characteristics are summarized in Table 1.

It is also noted that the pulser output is available on a coaxial cable which presently has a characteristic impedance of about 80 ohms, resulting in a 20-ohm mismatch at the input terminal. This leads to an 11-percent reflection at the input port, which is of no major consequence. The output from the pulser is single ended and not differential and is better suited

Output voltage	20 kV-100 kV into R>10 ohms
Rise time (10% to 90%)	8 ns into a 50-ohm load
Maximum stored energy	375 joules
e-fold decay time into 50 ohms	Adjustable from 250 ns to 12.5 μs
Storage capacitance	Selectable in the range of 5 nF to 75 nF
Charging voltage	±50 kV
Insulating medium in the pulser	Transformer oil

***TABLE 1.** Electrical Characteristics.*

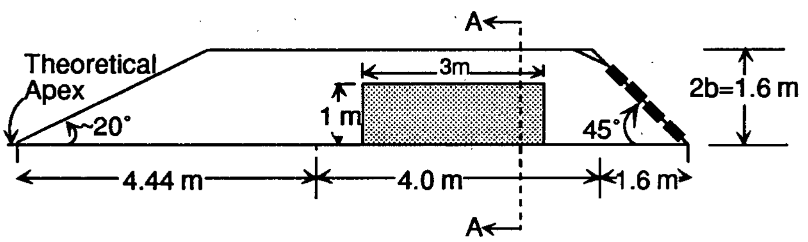

***FIGURE 1.** Side View of SEMIRAMIS.*

to drive a top plate above an image plane rather than a line formed by two parallel plates.

At the far end of the transmission-line simulator is a distributed terminator which consists of eight parallel chains of resistors. Each chain measures roughly 2.2 m in length, and consists of four resistors in series, each of which is 200 ohms, for a total dc resistance of 100 ohms. In addition, the terminator has a net inductance which can be evaluated as follows. The resistors are of the low-inductance type, about 10 cm long. The length of the leads that interconnect the four resistors in each chain is about 1.8 m, which results in approximately 1.8 μH. In comparison with this lead inductance, the intrinsic inductance of the resistors is perhaps negligible. The eight parallel resistor chains will then have an inductance of 0.225 μH. To this, one has to add the external sheet inductance of the eight resistor chains, which can be estimated using the information given in Reference 3.

$$L(\text{leads}) = 0.225\ \mu H : L(\text{intrinsic}) = 10\ nH \cdot (4/8) = 0.005\ \mu H$$
$$L(\text{sheet}) = (\mu_0/2)\, d \sin^2(\xi)\, \ell n(d/2\pi a) = 0.090\ \mu H \tag{1}$$

with
d = separation between resistor chains = (3.2m/7) = 0.457m
a = resistor radius = 1 cm
ξ = terminator angle = 45 degrees : L(net) = (0225 + 0.005 + 0.090) μH

The estimates given above result in a net inductance of the terminator of 0.32 μH. On the other hand, one can also estimate the desirable inductance value in the terminator using an equation given in Reference 3.

$$L_{opt} = \left(\frac{\text{Terminator length}}{\text{Terminator width}}\right) \cdot \text{Terminator height} \cdot \mu_0 \sin^2(\xi) f_a \tag{2}$$
$$= (2.2/3.2) \cdot 1.6 \cdot 4\pi \cdot 10^{-7} \cdot (0.707)^2 \cdot 0.5$$
$$= 0.345\ \mu H$$

Since the terminator inductance is seen to be near optimal, only minor experimental refinement may be needed, if at all. Furthermore, the resistor chains are spaced along the transverse direction in such a way that the currents that flow down each chain are approximately the same. This is done by first estimating the TEM current density (A/m) along the transverse direction. This current density has a square root singularity at the two edges of the top plate and is fairly constant in the middle of the plate. This density distribution then may be used in defining the widths of eight teeth-like structures that are attached to the top plate, where the individual teeth then connect to the resistor chains. The purpose of requiring equal currents in the resistor chains is to avoid the creation of loop currents, which could lead to non-uniform field distribution in and near the terminator region.

EXPECTED PERFORMANCE

One evaluates the performance characteristics of a transmission line type of EMP simulator by finding the characteristic impedance of the propagating TEM mode and its field distribution in a transverse plane. The relative field distribution is similar in all cross-sectional planes, except that the absolute value of the fields falls off as one moves away from the source towards the terminator. Experimental characterization of the simulator lies in measuring impedance matching by TDR, in op-

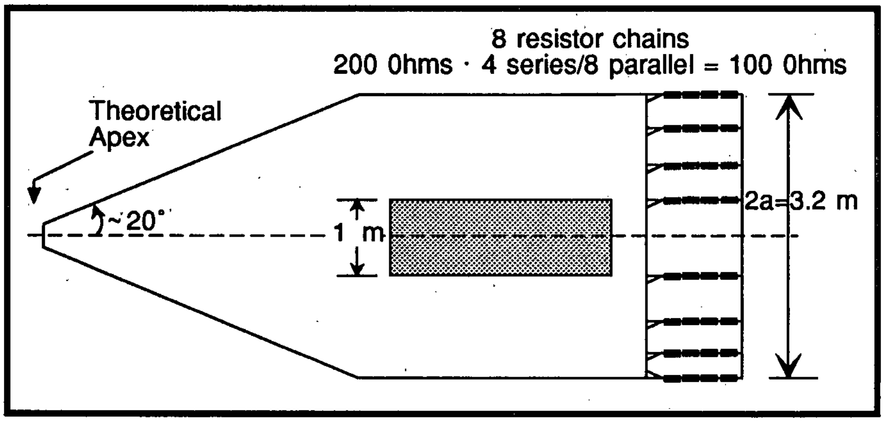

***FIGURE 2.** Plane View of SEMIRAMIS.*

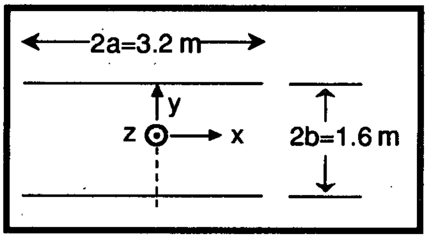

***FIGURE 3.** Cross-Sectional View AA in the Central Parallel Plate Region of SEMIRAMIS.*

timizing the terminator, and in field mapping in the working volume. In this section the expected impedance and relative field distribution in the initial design version of the simulator are summarized.

It has already been noted that the (b/a) value for the initial design is 0.5 (see Figure 3) and consequently, the characteristic impedance is 115 ohms (Reference 2). The y component of the TEM field is shown plotted in Figure 4. In this figure, contours of constant values of the normalized y component are plotted. The normalization is with respect to the uniform field that results when the top and bottom plates are infinitely wide. The x component of the field, not shown here, is used in finding the total field as a vector sum of x and y components.

$$E_{rel}(x,y) = \sqrt{E^2_{x_{rel}}(x,y) + E^2_{y_{rel}}(x,y)} \quad (3)$$

An interesting quantity in simulation is the uniformity of simulated fields over the working volume. In previous studies,[2] the following quantity has been defined. It is shown plotted in Figure 5.

$$\Delta(x,y) = \left| \frac{E_{rel}(x,y) - E_{rel}^{(0,0)}}{E_{rel}^{(0,0)}} \right| \quad (4)$$

The calculated TEM fields are expected to be quite uniform in the transverse plane in both x and y directions. An extensive set of measured data has been gathered on SEMIRAMIS and is reviewed in the following section.

PRELIMINARY MEASUREMENTS AND INTERPRETATION

This section gives a representative sample of the extensive data acquired on the design of SEMIRAMIS. Measurements were performed in two locations: Set 1 on the floor of a shielded room, and Set 2 on air/earth interface outside the building.

Neither of the above locations of SEMIRAMIS is optimal. In the first case, the bottom plate of SEMIRAMIS is in some contact with the metallic floor of the shielded room. Depending on the nature of the contact, the metallic floor of the shielded room acts as an image plane and affects the TEM impedance. Also, reflections from the walls of the shielded room affect the results. In the case of the second location, on an air or earth interface outside the building, since the top and bottom plates are of the same size and the bottom plate is in contact with the ground, one has an imperfect image plane. The effect of the ground medium is frequency dependent. Up to about a few MHz, the ground behaves like a good conductor and an image plane results. At higher frequencies, the lossy ground perturbs the TEM fields, possibly resulting in non-TEM modes. A preferred location for this simulator should avoid or minimize the effects due to extraneous factors such as metallic objects or lossy media. Such a preferred location is considered and described later.

Measurements were made with the following equipment and in accordance with the following parameters:

- A transient pulser was operating at a voltage of ± 50kV.
- All of the available data were free-field measurements taken with sensors characterized as shown in Table 2.
- A passive integrator with a time constant of 10 μs was used with the sensors to integrate the sensor output voltage.
- The field waveforms were displayed on an oscilloscope and photographs were taken.

Although a lot of data was taken, one measurement from each set above is reviewed here. Both are principal electric field measurements at a location of 1 m above the bottom plate or 0.6 m below the top plate, at the center of the simulator. They are shown plotted in Figures 6a and 7a. Figures 6b and 7b have

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performance was satisfactory. Installation conditions will be improved in the future to further enhance the performance of the EMP simulator. More details about the improvements made and the performance of the simulator thereafter appear in the proceedings of the 10th International Zurich Symposium on EMC.

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***FERRITE MATERIALS AND THEIR USE IN ANECHOIC CHAMBERS** . . . Continued from page 124*

provide the 1.5 m by 1.5 m uniform field required by IEC801-3.

Ferrite absorbers also represent a practical solution for compact susceptibility chambers. Ferrite tiles used in conjunction with 18-inch urethane allow for chambers that are 10 feet by 23 feet by 13 feet high in which susceptibility testing can be performed. As these compact work areas are quite confined, durability of the grid is an important feature. All of these compact chambers are fully anechoic and have absorber material on all surfaces.

MILITARY TESTING

MIL-STD-461 and 462 have been revised and deal more specifically with the issue of anechoic materials. Quite simply, an absorber that provides 6 dB of attenuation from 50 to 250 MHz and 10 dB above 250 MHz will be required. The recommendation is to place the absorber on the EUT end wall, to each side of the EUT, above the EUT, and behind the test antenna. Urethane cones can be used to meet this requirement, but again have the disadvantage of their inefficient use of chamber space. Ferrite tile hybrids lessen this problem to some extent, but still require up to 18 inches of absorber height. This is particularly cumbersome in bench-tested equipment. Once again, the ferrite grid absorbers offer the best alternative. The grid's upper frequency must be extended and with a 5-inch urethane overlay, can meet the 10-dB requirement to 20 GHz. In chambers where high-power testing is required (200 V/m and up), the urethane can, with a temporary mounting system, be removed, leaving only the non-flammable grid.

CONCLUSION

Recently ferrite absorber products have found widespread acceptance in anechoic chamber construction. They offer increased space efficiency, long performance life, and are not flammable. The newest generation of ferrite grid absorbers now provides for chamber construction without the use of any urethane products. As international and domestic regulations demand more complete testing of commercial products, there will be an increased need for compliant chambers. Ferrites will provide additional solutions for new chamber construction.

***DAVID SEABURY** formed IBEX Group, Inc., a supplier of EMC products and materials, in 1990. He is a graduate of Lehigh University and was formerly with RFL Industries (Radio Frequency Labs), resigning as President in 1989. He has over 20 years of experience in the manufacturing and marketing of electronic instrumentation and communications products. He can be reached at IBEX Group, Inc. in Somerville, NJ. (908) 722-8085.*