The Development of a New Type of E-Field Generator

Descended from a folded-dipole antenna, a novel design offers improvements in bandwidth and field uniformity over conventional E-field generators.

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INTRODUCTION

E-field generators have historically fallen into two broad categories. The first is the unterminated type in which the electric field is drawn between two parallel open-ended conductors in a capacitor-like fashion. The second is the transmission line type in which a source and load are placed at opposite ends of a large two-conductor transmission line (this transmission line actually generates both E and H fields). The bandwidth of the unterminated type is quite limited, for as frequency increases and the conductors approach 1/4 wavelength (λ) in dimension, they effectively short out the source, making the generator unusable. The transmission line type does not have this limitation but, because the load and source are at opposite ends of the structure, they tend to be large, awkward, and expensive (Figure 1).

The new design described in this article was conceived to alleviate these problems and might be considered a hybrid of the unterminated and transmission line types. It does not suffer from the bandwidth limitation of the unterminated generator and is compact, simple, and easily supported and positioned using a tripod. An unforeseen and very pleasant surprise is the new generator's good spatial E-field uniformity over a broad frequency range.

CONFIGURATION

This E-field generator can be envisioned as a variation of a folded-dipole antenna. The folded dipole, which is well-known among FM broadcast enthusiasts, is a dipole consisting of two closely-spaced conductors joined at their ends and with the feed point at the center of one conductor. When operated as an antenna, the folded dipole has an impedance bandwidth of only about 10%. The addition of a resistor in the center of the non-driven conductor greatly extends the impedance bandwidth. In fact, with proper choices of the resistor and the diameter and separation of the conductors, a nearly constant input impedance can be achieved over a frequency range from dc up to the folded dipole's second resonance (where the dipole's total length becomes about 1λ). Of course, this lossy structure is not an efficient antenna, but high radiation efficiency is neither a necessary nor desirable characteristic for an E-field generator.

To form the E-field generator, each arm of the dipole is now bent up at 90° to form a "U" with the resistor and input connection at the bottom. This produces a region in which the E-field is concentrated and drawn between the two arms. Bending the arms does not substantially affect the impedance characteristics. The region of greatest field intensity and field uniformity will occur within this "U". This is the test zone where the equipment under test (EUT) will be placed (Figure 2).

An impedance transformer must be included in order to transform the 50-ohm impedance of the power amplifier up to the relatively high input impedance of the E-field generator. The transformer should also function as a balun to prevent antenna currents from flowing on the shield of the coaxial feed line, which would unbalance the generator and cause unpredictable distortion of the fields. The low frequency response of the transformer/balun will determine the lowest operating frequency for the E-field generator, for the generator itself can operate down to dc.

The shape and dimensions of the arms are design parameters and are chosen on the basis of the desired upper frequency of operation, the size of the EUT, and the required field intensity. Both the input impedance match and the field characteristics ultimately fall off as frequency is increased past a certain point. Larger,

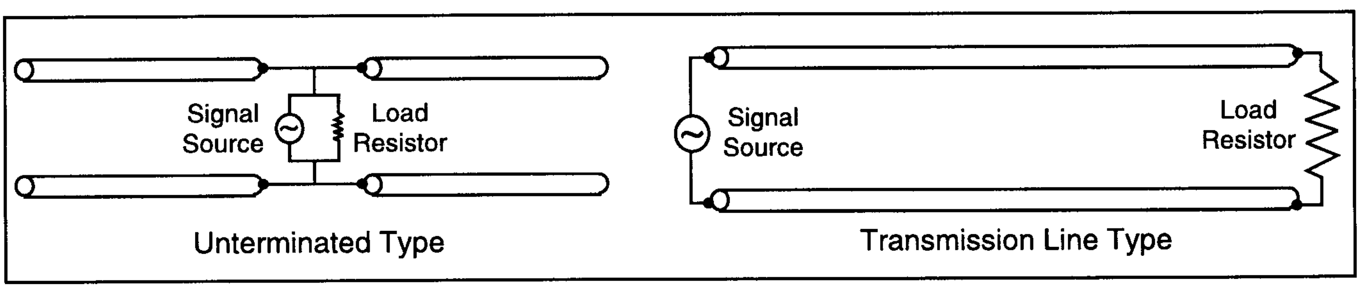

Figure 1. *Conventional E-field Generators.*

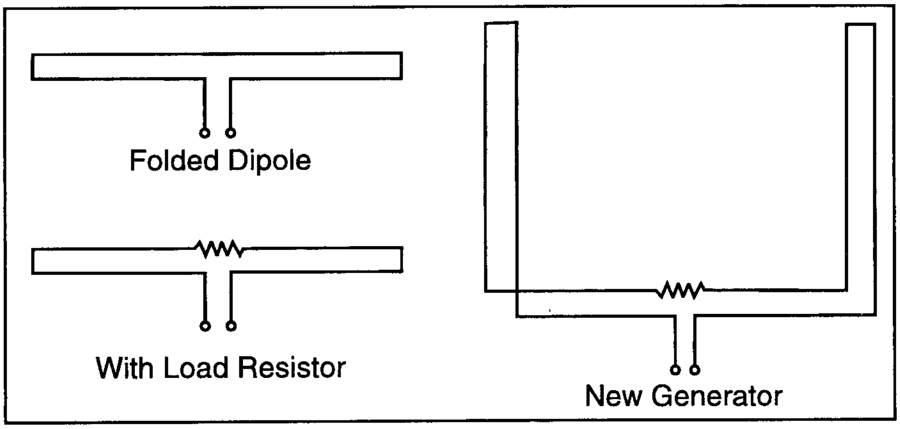

Figure 2. *Evolution of New E-field Generator.*

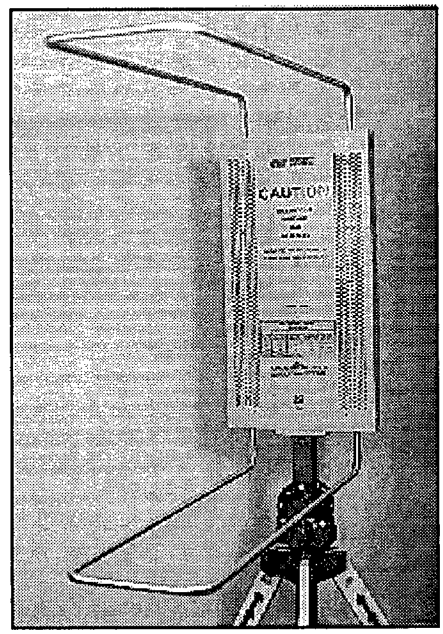

Figure 3. *Prototype of Field Generator.*

more widely-spaced arms provide lower upper frequency capability and weaker field strengths for a given power input, but will obviously accommodate larger EUTs. Several arm geometries might be desired in order to accommodate a variety of test scenarios. A set of small arms would allow testing of smaller EUTs up to perhaps 100 MHz. A larger set would allow testing of larger objects, but might have a lower upper frequency limit and would require more power than the small arms to provide a given field intensity.

PROTOTYPE

A prototype of the new field generator is shown in Figure 3. The high power resistor and transformer/balun are housed in an enclosure measuring 10 x 50 x 40 cm (4 x 20 x 16 in.). The transformer/balun is a low-loss impedance step-up design that operates from 10 kHz to 100 MHz. The enclosure is constructed using non-metallic materials to avoid distortion of the fields. The elements are attached to the enclosure using a quick-disconnect clamp attachment. This allows the element geometries to be changed easily without modification of the housing. The prototype is de-

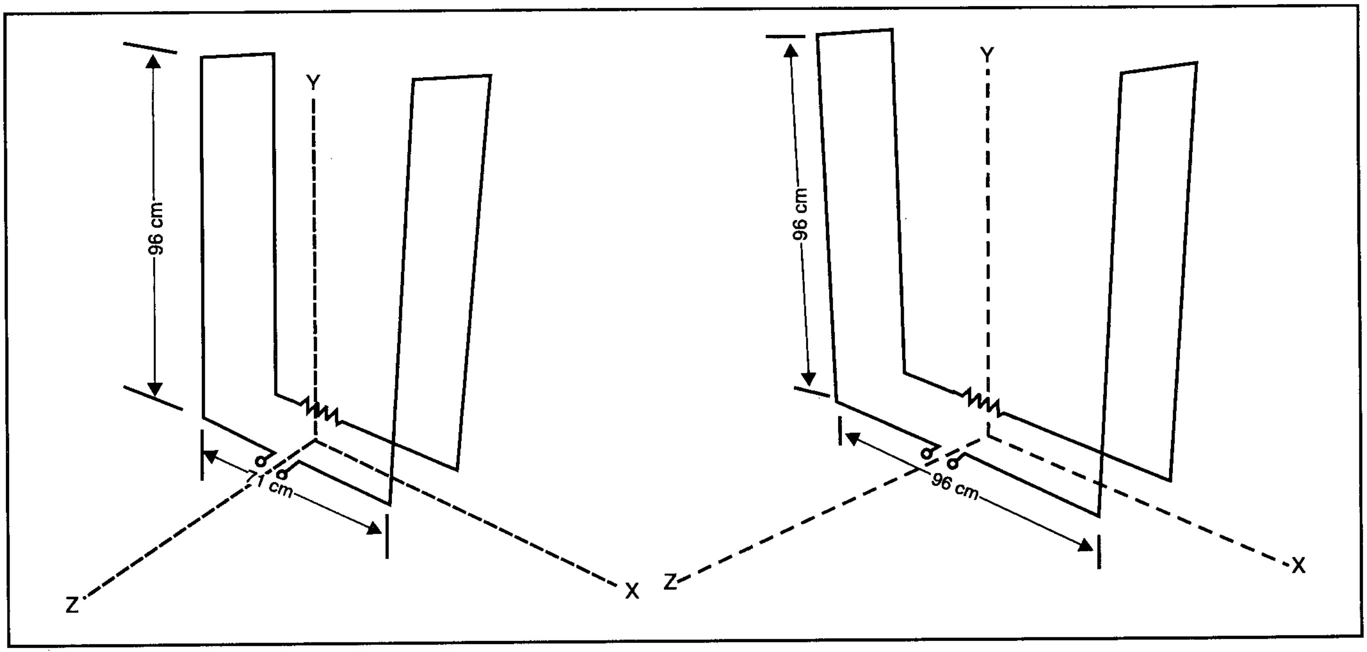

Figure 4. *Large and Small Arm Geometries.*

FREQUENCY RANGE	10 kHz - 100 MHz
INPUT IMPEDANCE	50 ohms
VSWR	2.2:1 maximum, 1.4:1 typical
POWER HANDLING	500 watts maximum
FIELD UNIFORMITY IN TEST ZONE	±3 dB
FIELD INTENSITY IN TEST ZONE using small arms using large arms	 nominally 350 V/m with 500 W input nominally 200 V/m with 500 W input
TEST ZONE VOLUME using small arms using large arms	 36 x 36 x 41 cm (14 x 14 x 16 in.) min. 48 x 36 x 41 cm (19 x 14 x 16 in.) min.
SIZE with small arms with large arms	 74 x 102 x 41 cm (29 x 40 x 16 in) max. 99 x 102 x 41 cm (39 x 40 x 16 in) max.
CONNECTOR	Type N female
WEIGHT	16 kg (35 lb.) maximum
MOUNTING	accepts standard tripod threaded stud on 3 faces

Table 1. *Performance Summary.*

signed to handle a power level of 500 W with the intent to provide conservative capability for 200 V/m testing.

The performance of the prototype was modeled using a method-of-moments electromagnetics computer code with near-field capability. The accuracy of the computer model was verified by spot comparison against measured field strength data. These measurements were made on the prototype using an E-field probe in a near free-space test environment. Agreement between the computer model and measured data was generally very good. The computer model was necessary because acquisition of measured data on a point-by-point and frequency-by-frequency basis is prohibitively time-consuming.

Two geometries of the arms were evaluated. The first, which measured 71 x 96 cm (28 X 38 in.) was chosen to approximate the size of a common E-field generator of the unterminated type (available from several manufacturers) so that direct performance comparisons could be made. The second, which measured 97 x 97 cm (38 x 38 in.) was intended to accommodate larger EUTs, including a standard 48 cm-wide (19 in.) equipment enclosure (Figure 4). The arms are formed from thin-wall aluminum tubing in order to reduce weight and displacement of the center of gravity.

PERFORMANCE

Typical characteristics of the field generator are summarized (Table 1). The input voltage standing wave ratio (VSWR) using the small arms was under 1.6:1 from 30 kHz through 100 MHz and under 2.2:1 from 10 kHz to 30 kHz. With the large arms, the VSWR was virtually identical below 20 MHz but increased gradually above 20 MHz to about 2:1 at 100 MHz (Figure 5). The rise in VSWR at the low end is attributed to the transformer, which is an area for improvement.

The Cartesian coordinate system shown in Figure 4 will be used in describing the field characteristics of the generator. The origin is located at the center of the base, lying in a plane with the resistor and transformer. The polarization of the electric field in the test zone is predominantly in the x direction with y and z components

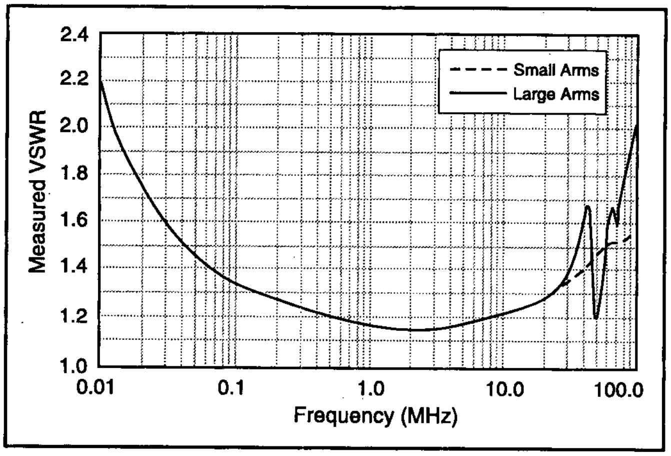

Figure 5. *Typical VSWR.*

generally down by 20 dB or more. The discussion that follows and the associated field plots pertain to the small arms. The characteristics of the E-field generator with the large elements are essentially similar except that the field levels are reduced to about 60% of their value with the small elements and the width of the test zone in the *x* direction has increased by about 30%. All of the field plots have been computed for an input power level of 10 W.

Plots of field strength versus the *y* position for the small arms are shown in Figure 6. These plots are along the center line of the generator, that is, at x = 0 and z = 0. The plot is virtually independent of frequency from 10 kHz through 10 MHz. Above 10 MHz the shape changes, flattening out at 30 MHz as shown and then developing a relative peak at 60 MHz as shown. Above 60 MHz the peak narrows and shifts higher in *y*, as shown in the 90 MHz plot. At 100 MHz the shape is similar to 90 MHz, but the level drops off from a maximum of 50 V/m at 90 MHz to a maximum of 43 V/m at 100 MHz. The field continues to drop off at frequencies above 100 MHz.

These plots show that when operating the field generator at frequencies below 40 MHz, the best field uniformity and field intensity, hence the best location for the EUT, occur at a *y* position of about 61 cm (24 in.). For operation between 40 MHz and 60 MHz, the best location is at a *y* position of about 74 cm (29 in.); for operation from 60 to 80 MHz the best position is at 81 cm (32 in.); and above 80 MHz the best position is 84 cm (33 in.). The best compromise position when operating over the full 10 kHz to 100 MHz band is at a *y* position of about 76 cm (30 in.).

Field strength plots showing the variation in field level in the *x* and *z* directions for the small arms are shown in Figure 7. These plots are computed at a y position of 76 cm (30 in.). The shapes of these plots are virtually invariant with frequency from 10 kHz through 100 MHz. However, their average levels shift up and down with frequency corresponding to the levels shown in Figure 6. Because of its four-dimensional nature (*x*, *y*, *z*, and frequency), field uniformity in the test zone *volume* is the

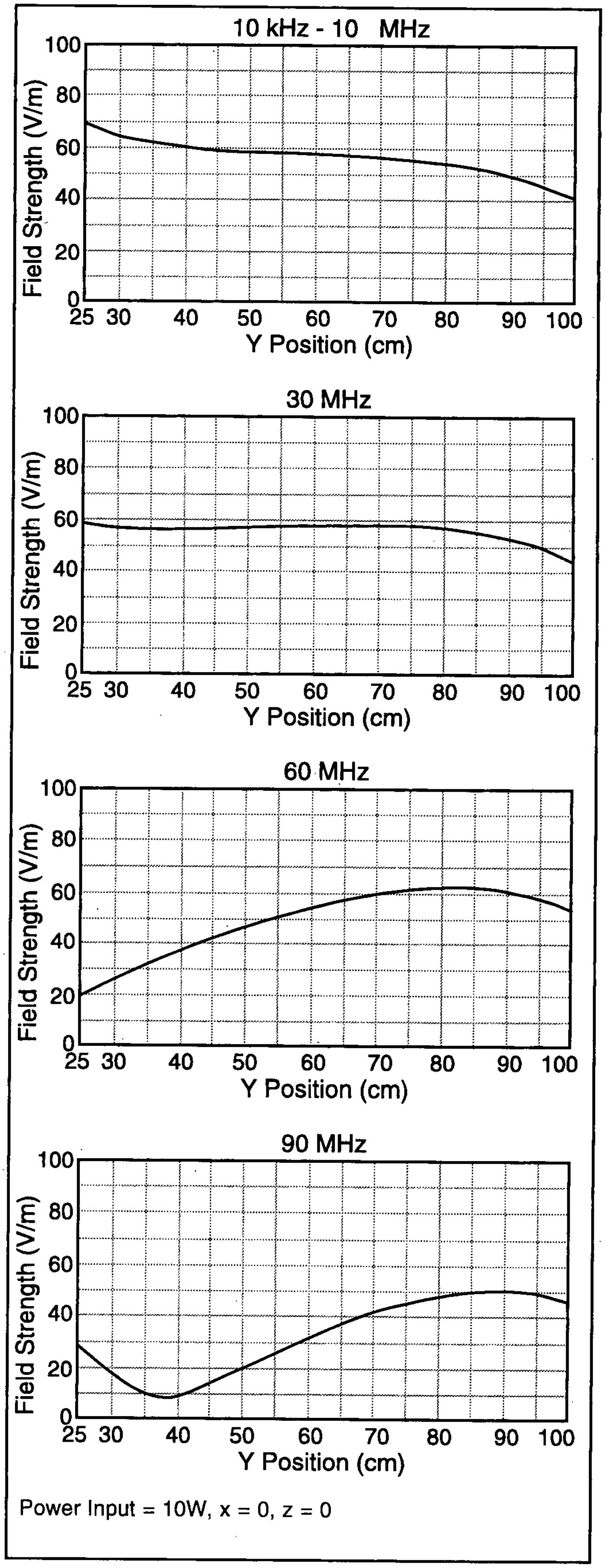

Figure 6. *Field Strength Versus y for Small Arms.*

most difficult characteristic to quantify and to describe. A common requirement for susceptibility testing is that the variation in field level within the test zone volume relative to some nominal field level be ±3 dB or less. Using this criteria to define the extent of the usable test volume, Table 2 shows the size and position of the test volume as a function of frequency, and the corresponding nominal field levels assuming an input power level of 10 watts. Figure 8 is a plot of typical test zone field strength versus the input power level.

Any E-field generator will radiate to some degree. The highest radiation efficiency for this E-field generator using the small elements occurs at a frequency of about 90 MHz and is approximately 20%. That is, 20% of the power is radiated and 80% is dissipated in the resistor and elsewhere. The maximum gain is approximately -2 dBi and the radiation pattern is bi-directional along the *x* axis. The large elements are expected to behave similarly.

SUMMARY AND COMMENTS

This article has introduced a type of E-field generator which, while simple in concept, to the author's knowledge was previously unknown. The salient features are broad bandwidth, good field uniformity, and a relatively high field intensity for a given power input. These

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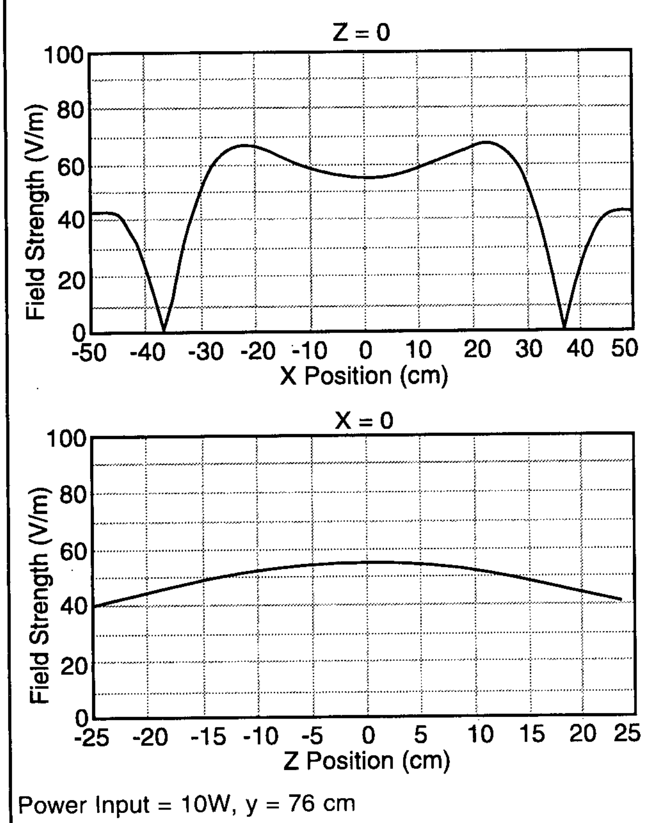

Figure 7. *Field Strength Versus x and z for Small Arms.*

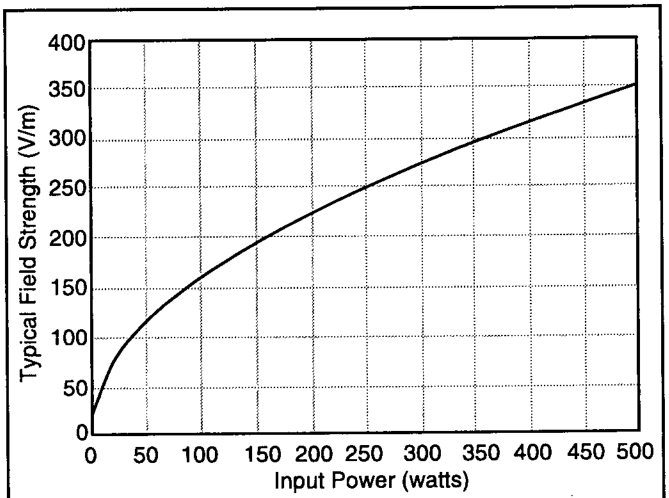

Figure 8. *Typical Field Strength in Test Zone Versus Input Power.*

Frequency	Nominal Field Level (10 watt input)	Test Zone Size Δx,Δy,Δz	Test Zone Center Location x,y,z
10 kHz - 40 MHz	52 V/m	41 x 71 x 41 cm (16 x 28 x 16 in.)	0, 61, 0 cm (0, 24, 0 in.)
40 MHz - 60 MHz	54 V/m	36 x 56 x 41 cm (14 x 22 x 16 in.)	0, 74, 0 cm (0, 29, 0 in.)
60 MHz - 80 MHz	54V/m	36 x 41 x 41 cm (14 x 16 x 16 in.)	0, 81, 0 cm (0, 32, 0 in.)
80 MHz - 90 MHz	52 V/m	36 x 36 x 41 cm (14 x 14 x 16 in.)	0, 84, 0 cm (0, 33, 0 in.)
90 MHz - 100 MHz	46 V/m	36 x 36 x 41 cm (14 x 14 x 16 in.)	0, 84, 0 cm (0, 33, 0 in.)

Table 2. *Test Zone Size and Nominal Field Levels for ±3 dB Field Uniformity, Small Arms.*

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features and its comparative simplicity should make it an attractive alternative for pre-compliance testing to existing field generators and TEM cells.

There are many avenues yet to explore. Plans are underway to evaluate a variety of element geometries with the objectives of accommodating larger EUTs and extending operation to higher frequencies. An evaluation of the use of partially curved elements with the objective of improving field uniformity and high frequency field intensity is also planned, as is an evaluation of the use of the resistively loaded, folded dipole as a *radiating* antenna for emissions and susceptibility work over moderate bandwidths.

Susceptibility tests are often conducted in shielded rooms. Unfortunately, the shielded environment has a tremendous impact on the performance of antennas, and to a lesser extent, field generators. Coupling to the walls, ceiling, floor, and the contents of the room can corrupt the uniformity of a field generator. The room may act as a large resonator, "ringing up" at specific frequencies. One should be conscious of the test environment. Field generators should be kept as far from conducting surfaces as possible. If in doubt, one should measure the field levels in the area of the EUT using a field probe. It may be necessary to experimentally reposition the field generator and EUT within the room in order to achieve satisfactory field levels and uniformity. The judicious placement of absorptive materials may help "calm down" a resonant room.

As a final comment, it should be mentioned that when using E-field generators, the EUT is ideally placed between the elements. The 1-meter and 3-meter distances specified for radiated susceptibility measurements are not appropriate when using an E-field generator. The fields created by E-field generators are predominately non-propagating and tend to diminish very rapidly with distance from the elements. However, larger EUTs that cannot be placed between the elements can be tested by locating them off to the side. In such situations one should determine the field levels using a probe and experimentally adjust the power level and EUT location accordingly.

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