Repeatable Low-cost Radiated Susceptibility Tests in a Standard Shielded Enclosure

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A test method for performing radiated susceptibility tests improves the consistency and accuracy of the tests at a reasonable cost.

INTRODUCTION

During the past few years, many articles have been published concerning electronic systems that have been adversely affected by radiated RF energy. Viewers have seen strange patterns on TV screens and computer users have had scrambled or lost computer data. While these problems can be annoying, they are not life threatening. Responses of other systems have resulted in death. For example, some of the automotive anti-skid brake systems will not brake in the presence of RF energy, and several of the Army's Blackhawk helicopter crashes have been attributed to RF fields affecting the flight controls. Even though many of the responding systems were tested for radiated susceptibility and were reported to have passed, the actual levels applied may or may not have been the levels which were required by the specification. Anyone who has been involved with radiated RF susceptibility testing has probably heard the terms "voodoo" and "black magic," and of systems which pass one day and fail the next. Systems which fail at 10 V/m one day cannot be made to fail the next. It is not "black magic"; it is lack of consistency between various laboratories or even within the same laboratory which causes the problem. A standard test method which provides consistent results is required. This article presents a method of performing consistent RF radiated susceptibility testing at a reasonable cost.

As electronic systems become smaller, consume less power and operate at higher frequencies they are becoming more susceptible to RF energy. Typically, military specifications require systems to operate satisfactorily when immersed in field intensities of between 1 and 200 V/m. Commercial systems, such as vehicles, are also using levels up to 200 V/m and European Community Specification 801-3 requires 1 to 10 V/m.

HISTORY

In the 1950s and 1960s, when susceptibility tests were first mandated, a typical test requirement was that a 0.1-volt signal from a 50-ohm signal generator be connected to an antenna located one foot from the test item. Even with exposed leads and poor shielding, very few systems responded and none were ever physically damaged. As each new specification was published, the required levels increased. Levels jumped to 1 V/m, 5 and 10 V/m, and 20 V/m and are presently at 200 V/m or even higher. Requests for levels in excess of 1000 V/m are becoming more prevalent and 200 V/m is now common. RF power levels required to generate the specified fields have steadily risen from 1 mW to 2 kW. At 200 V/m there is a far greater risk of malfunction and a real potential for physical damage to the equipment under test (EUT).

As a point of reference, a field intensity of 200 V/m corresponds to a power density of 10 mw/cm sq. At this level we have seen vinyl insulation soften and run off wires, small incandescent lamps light (even with the switch open), arcing from cables to ground, flames, and destruction of ICs, transistors, resistors, circuit traces, etc. While under-testing is certainly not desirable, over-testing can destroy test samples.

TEST SETUP

The ultimate goal is to immerse the test sample in a completely homogeneous and known field. Radiated susceptibility tests are typically performed within a shielded enclosure which has reflective walls, floors, ceiling, table top, etc. The enclosure size is not specified; however, typical sizes range from 10' x 20' x 8' high to 25' x 25' x 10' high.

For the frequency range below 30 MHz, the test sample is normally placed between the plates of a parallel plate antenna (or similar antenna). At these frequencies, reflections from the enclosure walls are not a problem and therefore will not be addressed in this paper.

Above 30 MHz, RF energy is normally transmitted into the entire enclosure. Even when a directional antenna structure is used to beam the energy directly at the test sample, RF energy is reflected from the walls, ceiling, etc. At these frequencies, reflections are a problem. Incident and reflected waves add and subtract vectorially, producing standing wave patterns within the enclosure. This typically starts in the 30 MHz frequency range and extends to the highest test frequency. It is the standing wave patterns which cause most of the test inconsistencies. Variations in field intensity of 20 to 30 dB are common within the enclosure. In terms of power density, variations of 100 to 1 and 1000 to 1 are common. This is the main reason for inconsistent data.

Several different schemes are being used by test facilities to determine the "true field intensity." The best methods (including Method RS03 of MIL-STD-462) use two antennas: one to transmit and a second to monitor the applied field intensity. The method described in MIL-STD-462 is certainly not without faults. If the monitor antenna is placed at a node where the field intensity is higher than at the EUT, the EUT is under-tested. Conversely, over-testing occurs when the test sample is at a node which is higher than the field intensity at the monitor antenna. Both are highly undesirable.

POSSIBLE SOLUTIONS

Since it is the reflections which create the problems, one solution is to remove the reflecting surfaces and test outdoors (or at least outside of a shielded enclosure). This has and is being done; however, it is illegal. Since the entire frequency spectrum is being scanned at high power levels, interference to licensed radio transmissions may occur throughout the frequency spectrum.

The use of RF absorbent materials provides a second method of reducing reflected waves. While this method is useful, it is also very costly. To be effective, the absorber pyramids should be at least 1/4 wavelength long. At 30 MHz, this is more than 8 feet. A minimal 12' x 12' x 10' working volume would require an outer enclosure measuring 28' x 28' x 26' high. At approximately $70/ft. sq., over $300,000 of anechoic material is required. The physical size and cost are prohibitive for most small companies. Shorter anechoic sections, while less costly, do not provide adequate absorption in the 30 to 200 MHz frequency range where it is most needed. Newer ferrite and combination ferrite/absorber technologies reduce the size requirements but the material is substantially more expensive. Another problem with using anechoic material for high level testing is the toxic emissions generated when the material is burned. Since RF energy is absorbed by the anechoic material, localized hot spots and burning of the material occur.

A third alternative is the use of TEM cells, but they are limited to very small test samples or to low frequencies.

Other test methods do not measure the actual field intensity within the enclosure, but use some form of "precalibration." The calculations are based on either applied RF power and antenna gain, or on field intensities measured in an open field. These methods are often used with power amplifiers which use power leveling to maintain a constant power output. While these processes are fast and easy to use, they do not eliminate the problem; they simply ignore it.

A variation of the solutions discussed above is the method specified by MIL-STD-462, Method RS03. This attempts to measure the field intensity at the position of the test sample (without the test sample) and then to duplicate the condition with the sample in place. Several problems occur when this is done. First, most subsystems are tested on a ground plane. This physically prevents placing the large specified monitor antennas where the test sample will be located. Second, if small broadband probe antennas are used with vertical antenna polarization, the horizontal component is not measured for horizontally polarized transmit antennas. If positioned horizontally (parallel to the ground), there is substantial capacitive loading of the probe antenna from the ground plane. In addition, there is a distorted field in the proximity to the conductive surface, since by definition an E field cannot exist at a conductor. Broadband E field probes also have the disadvantage of not being frequency selective. They measure total RF energy present, and in many cases this is harmonic energy, not the desired fundamental energy. Third, introducing the test sample will probably change the standing wave pattern. Fourth, below several hundred MHz, the point of entry is normally not the test sample case but the power or signal leads. Is the small monitor antenna placed at the case, or somewhere along the power or signal leads? Again this method does not solve the problem; it ignores it.

Another method has been to either physically move the monitor antenna or to use multiple antennas to search for the maximum field intensity. This is time-consuming and still does not measure the field intensity actually present at the test sample; it only measures the maximum level found. It is probably not the field intensity present at the EUT.

A modification to this technique is the RF stirring or "paddle wheel" method. This uses a constantly moving reflector to move the positions of the maximum nodes throughout the enclosure. The concept is not new. Most microwave ovens use RF stirring to distribute energy and provide uniform cooking. That fan inside the plastic cover is not a fan, it's an RF stirrer.

The field produced as the paddle wheel rotates is not homogeneous. However, the maximum nodes obtained within the enclosure are almost independent of position. That means that at some time during the rotation, the same maximum field occurs at the monitoring antenna and at the test sample. If the maximums are used, the result is a very consistent and repeatable test. The maximums are easy to detect and control if a spectrum analyzer or EMI receiver is used.

STIRRER CONSTRUCTION

Paddle wheel stirrers use the general design of Method 3008 of MIL-STD-1344A, Notice 1. One was constructed from a 20" x 40" aluminum plate. This was originally designed for the frequency range above 1 GHz. Tests showed that it was effective down to approximately 100 MHz with reduced effectiveness down to 50 MHz. The general design requirements of MIL-STD-1344 are given in Figure 1.

A larger version, constructed from an 8' x 3' sheet of aluminum, has proven to be effective over the frequency range from 30 MHz to 40 GHz. This includes the frequency range from 30 MHz to 400 MHz, where most responses occur.

STIRRER OPERATION

While rotational speed does not affect the maximum or minimum field levels, it does affect the time required to perform the test. Smaller high frequency stirrers can be rotated rapidly, e.g., approximately 40 rpm. Larger stirrers, such as those required for the 30 MHz range, must be turned more slowly for personnel safety and momentum requirements. Approximately 6 to 10 rpm has proven to be adequate.

Reflector position does not have a significant impact on the usefulness of the stirrer. Experimentation has shown that they work best if positioned so that the base plate is not parallel to a wall or ceiling. A position approximately 45 degrees from the wall seems to be the best.

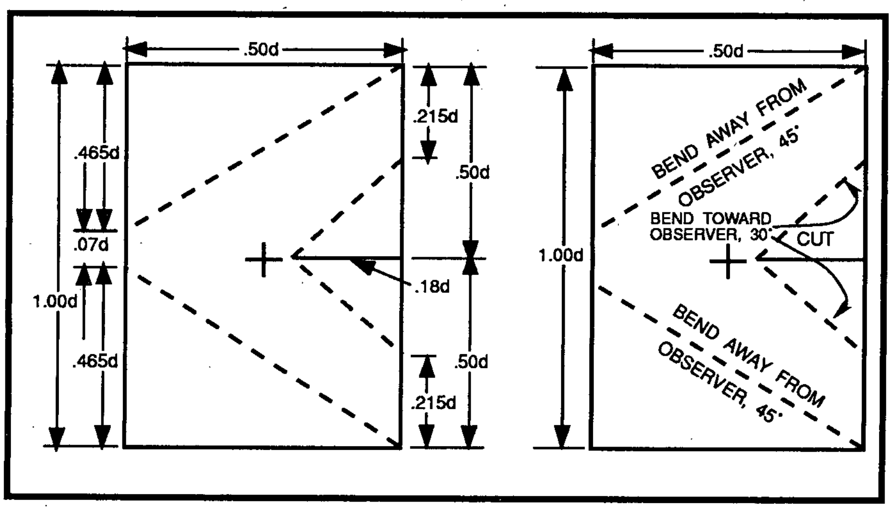

***FIGURE 1**. Stirrer of MIL-STD-1344.*

TEST RESULTS

To show comparative results, with and without paddle wheel stirring, a synthesized signal generator was set to step through the frequency range from 25 to 200 MHz with a constant power output level. No attempt was made to obtain a specified field intensity, only to obtain a repeatable test condition. The frequency range from 25 to 200 MHz was selected since it is the band where most EUTs respond. Step size was set to 100 kHz and each frequency was held for one second. The signal generator was connected to a broadband biconical antenna placed near the center of a 20' x 15' x 10' high shielded enclosure. A second biconical antenna was used as the monitor device; this was located one meter in front of the transmitting antenna, in the standard test configuration. The monitor antenna was then connected to a spectrum analyzer.

Figure 2 shows the field intensity variations with the standard test configuration (reflective walls, no mode stirrer and no absorber). It can be seen that variations of approximately 30 dB are present. This is typical and depicts the standing wave patterns within the enclosure. It represents the field intensity variations at a fixed position within the enclosure. The same variations would be found if frequency was fixed and the monitor antenna was moved throughout the enclosure. It should also be noted that as long as nothing is moved, these standing waves do not change in either position or amplitude.

Figure 3 shows what happens when a paddle wheel stirrer is placed in the enclosure. Two

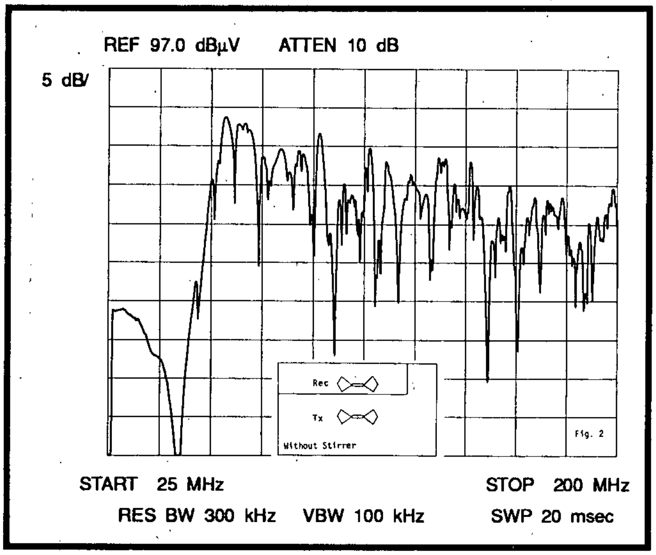

FIGURE 2. *Field Intensity Variations.*

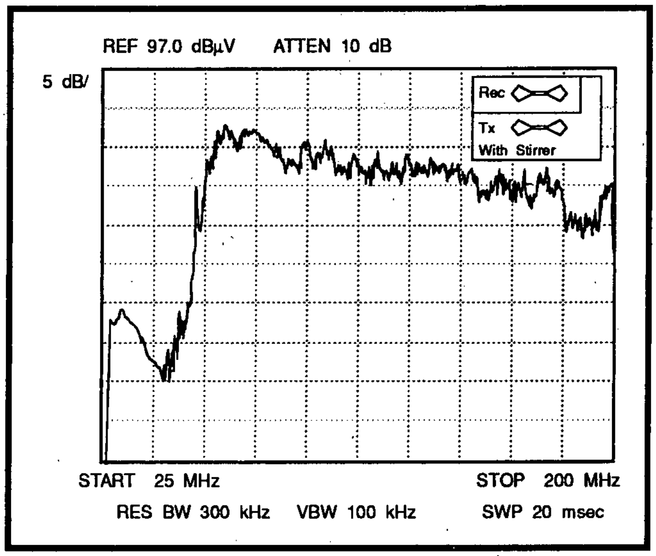

FIGURE 3. *Field Intensity Variations with Paddle Wheel.*

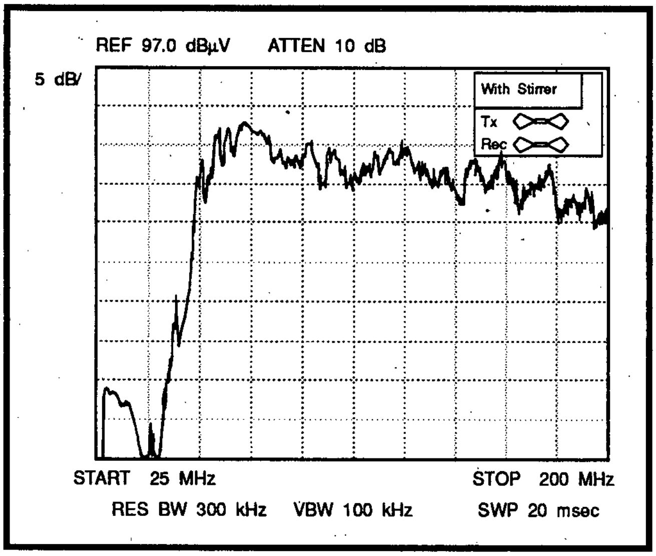

FIGURE 4. *Field Intensity Variations with Monitor Antenna at Alternate Position, Stirred.*

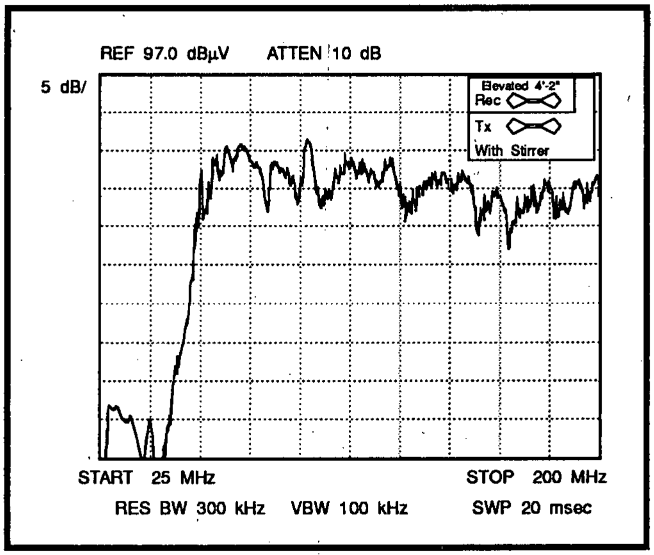

FIGURE 5. *Field Intensity Variations with Monitor Antenna at Alternate Position, Stirred.*

stirrers were used to reduce the test time. The 30 dB variations are now reduced to approximately 2 to 3 dB. Even smaller variations could be obtained by increasing the dwell time to obtain absolute maximum field intensities as the stirrer rotates. A comparison of Figure 2 with Figure 3 shows that the maximum levels are the same. This indicates that the stirrers are not changing the fields; they are only removing the test variations.

One might argue that the monitor antenna is in the direct radiation pattern of the transmitting antenna. If the paddle wheel performs as desired, the field intensity should be independent of position, and the same results should be obtained at all other locations within the enclosure. Figures 4 through 9 show results with the monitor antenna moved to six other locations within the enclosure. The positions are shown in Figure 10. The positions selected include both typical test sample points and positions which are not at the normal test locations. By comparing the plots it can be seen that the same results are obtained at each position. Figure 11 depicts a composite plot showing the maximums and minimums of Figures 3 through 9. It can be seen that while the mode stirrers do not completely eliminate the standing waves, they significantly reduce the effects.

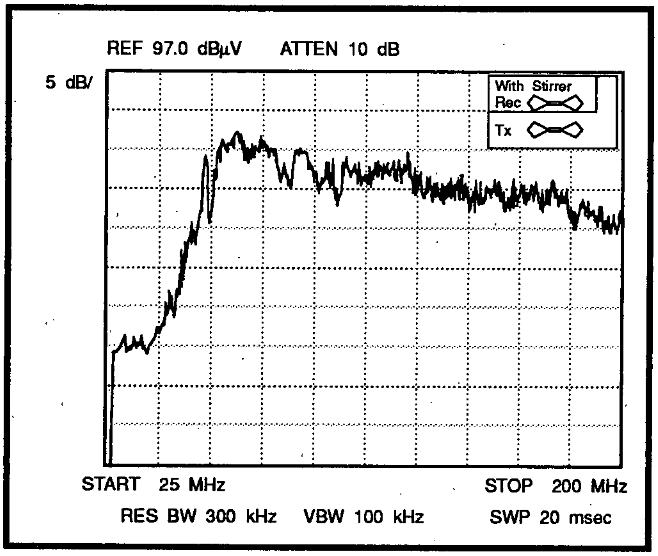

***FIGURE 6.** Field Intensity Variations with Monitor Antenna at Alternate Position, Stirred.*

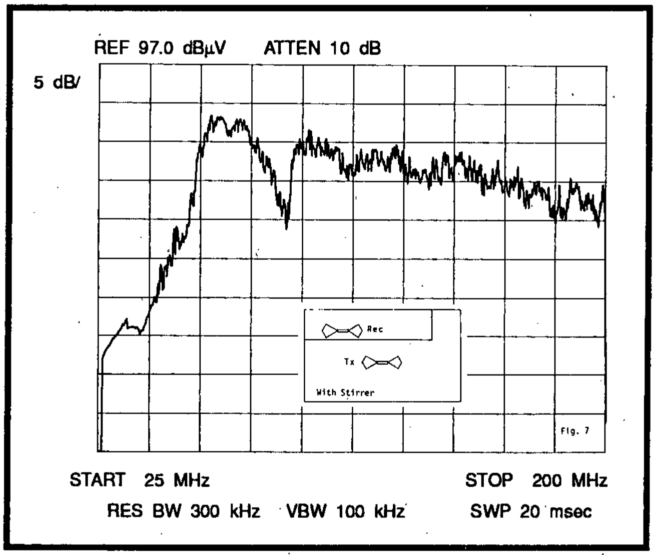

***FIGURE 7.** Field Intensity Variations with Monitor Antenna at Alternate Position, Stirred.*

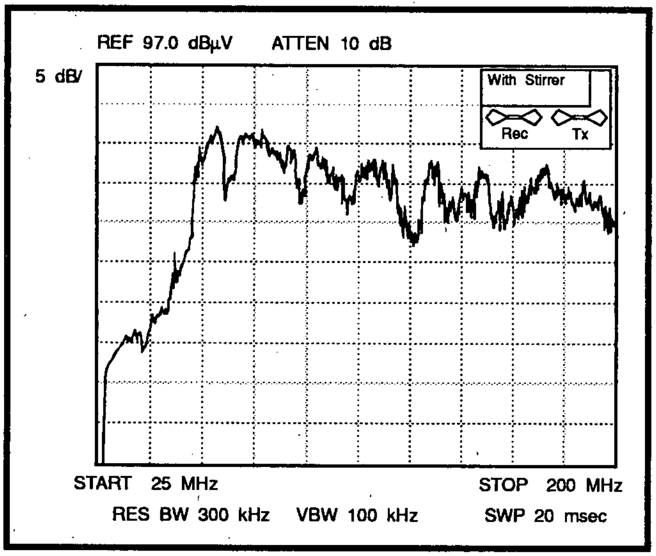

***FIGURE 8.** Field Intensity Variations with Monitor Antenna at Alternate Position, Stirred.*

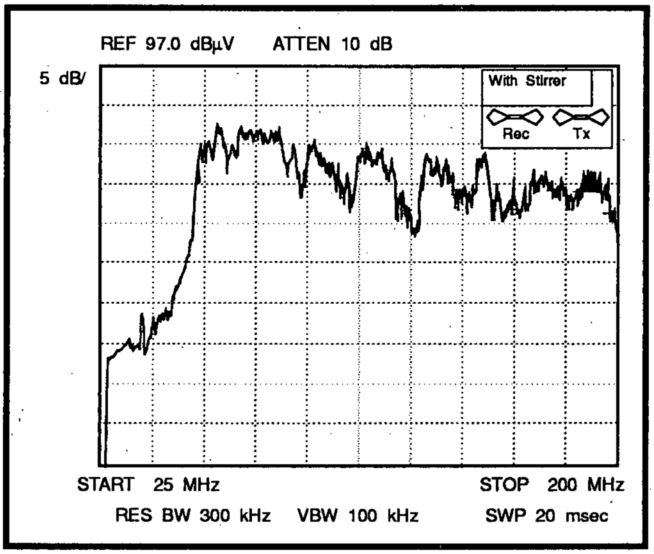

***FIGURE 9.** Field Intensity Variations with Monitor Antenna at Alternate Position, Stirred.*

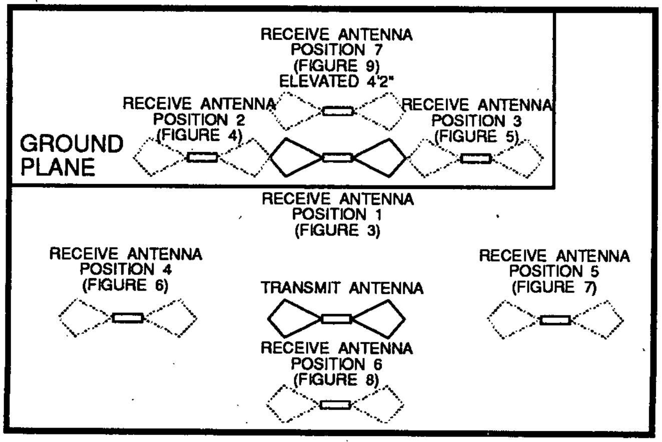

***FIGURE 10.** Positions of Monitor Antennas.*

The chamber used was a typical 20' x 15' x 10' high enclosure with a 5' x 16' copper ground plane and tiled wooden floor panels. The wood and tile absorb some of the RF energy and prevent total reflection. With stirring, total reflection is desirable and provides the most consistent results. Anechoic or other absorbent material absorbs some of the reflections and yields less consistent results.

Multiple reflections from enclosure walls and/or the paddle wheel stirrer also eliminate the fixed polarity of the field. Figure 12 depicts the results with the transmit antenna in the horizontal polarization and the receive antenna in the vertical polarization, without stirring. Again it can be seen that variations

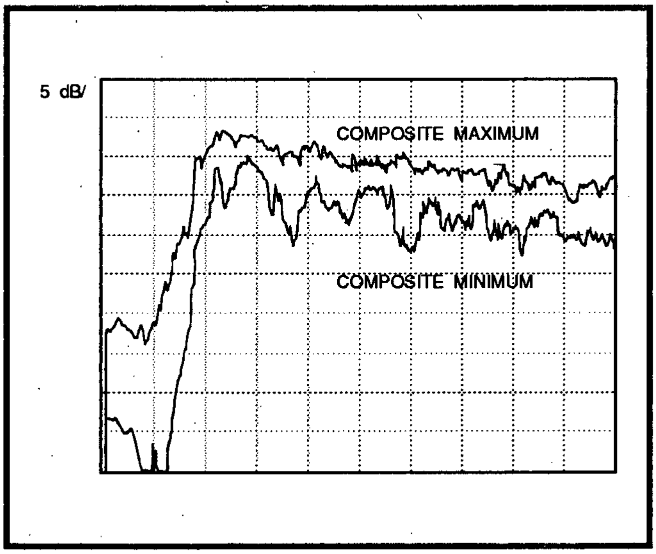

FIGURE 11. Envelope of Maximums and Minimums of Figures 3 to 9.

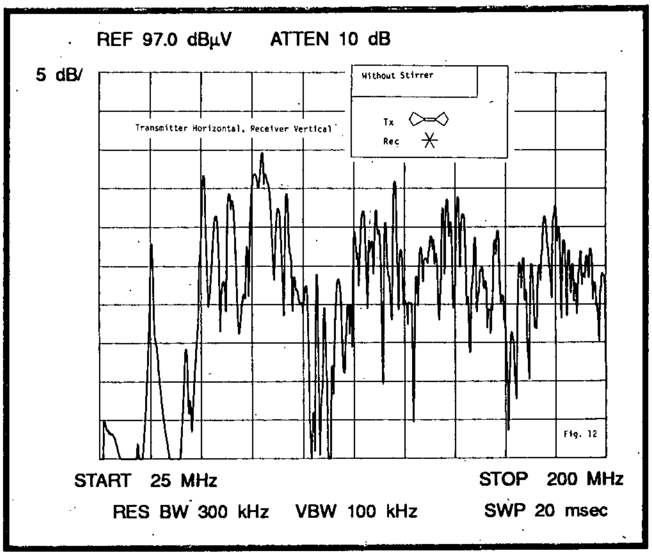

FIGURE 12. Transmit Antenna in Horizontal Polarization; Receive Antenna in Vertical Polarization without Stirring.

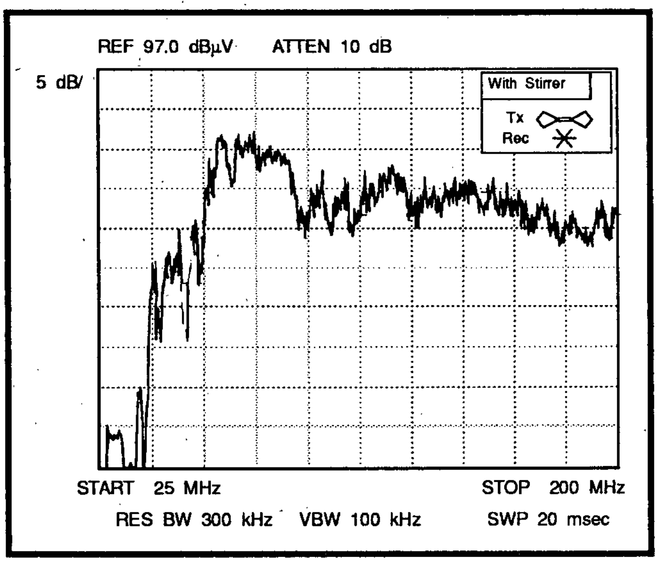

FIGURE 13. Transmit Antenna in Horizontal Polarization; Receive Antenna in Vertical Polarization; Stirred.

of 30 to 40 dB are present throughout the frequency range. Addition of the stirrers yields far more consistent results (Figure 13). A comparison of Figure 13 with the composite graph for horizontally polarized antennas, Figure 11, shows that approximately the same results are obtained regardless of polarization. This provides a more consistent test since all sides and polarizations of the test sample are tested, not just horizontal and vertical polarizations from the front.

For purposes of this paper, the frequency range was limited to 25 to 200 MHz. It should be noted that the same results are obtained for the entire frequency range above 200 MHz.

In actual use, the frequency is not stepped but is continuously swept across the frequency band. A computer is used to generate the spectrum analyzer levels required to represent the specified field intensity. The calculations include the specified field intensity, appropriate antenna factors, cable loss, and internal and external pads. The computer then draws the computed "limit" on the face of the spectrum analyzer screen. This represents the specified level. As the frequency range is slowly swept, the amplitude is maintained at or just above the "limit line." Since the amplitude is a function of the stirrer position, the maximum hold function of the analyzer is used, and it records the maximum levels actually applied.

CONCLUSIONS

An ideal test would have a homogeneous constant level field intensity applied to the system under test. While paddle wheel stirring does not provide a homogeneous field, it does significantly improve the accuracy and repeatability of the test. In addition, it is not costly and can be used by anyone.

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