GENERATING HIGH-INTENSITY ELECTROMAGNETIC FIELDS FOR RADIATED-SUSCEPTIBILITY TEST

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SUMMARY

This paper discusses a feasibility study covering the generation of high-intensity electromagnetic fields for radiated susceptibility or ordnance hazard tests. A new type of antenna using an elliptic-cylinder reflector is discussed. The results of laboratory measurements made with such an antenna are displayed graphically and discussed in the text of the paper. The advantages and limitations of this device are discussed. It is demonstrated that such an antenna is feasible, and plans for a proposed follow on effort are discussed.

BACKGROUND

Problem

Current Military Electromagnetic Interference Control Specifications such as MIL-STD-826, or MIL-STD-461, or MIL-STD-462 require radiated susceptibility testing of electronic devices with fields of relatively high electromagnetic intensity. MIL-STD-826 requires fields of intensity ranging from 10 volts per meter down to 2 volts per meter. MIL-STD-461 and MIL-STD-462 require field intensities of one volt per meter.

These fields must be developed over a relatively wide frequency range and the signal generators developing these fields are supposed to be swept rather than tuned to a series of discrete frequencies. To generate such fields requires either high-power signal sources or high-gain antennas. In addition, the requirement for swept frequency testing requires signal sources that are essentially single-knob tuned with constant output over a wide frequency range.

Laboratory secondary standard signal generators do not produce enough power to allow the generation of fields with intensities of volts per meter if normal antennas are used. They would, however, be attractive for this purpose for several reasons. They offer basically constant output as frequency is varied. They are essentially single-knob tuned devices, and they are normally in a calibrated state. They are readily available so their use as sources of electromagnetic susceptibility test signals does not require the purchase of additional equipment which makes the use of these generators attractive to management.

Existing Techniques

Several methods have been employed in the past to increase the field intensities which can be generated by use of these secondary standard laboratory signal generators or audio-oscillators.

Figure 1 shows one of these methods. A parallel plate test setup can be used in frequency ranges where the test unit is small by comparison to one wavelength. If the item under test is a squib or detonator, this condition may exist up to a frequency of 1000MHz. If, however, the item under test is an electronic black box such as a receiver or inter-phone system, the useful frequency range of the parallel plate method is normally limited to frequencies below 60 or 100MHz.

The item shown under test in Figure 1 is a bomb fuze and is, therefore, a very small device so the parallel plate method was used throughout the UHF frequency range. The requirement, however, was for a field intensity of 200 volts per meter, and thus the use of the Boonton power amplifier was required to generate enough signal strength to meet this requirement.

Another approach which is sometimes used for testing screen rooms is the use of a voltage step-up transformer between the signal generator and the antenna. This technique, unfortunately, has been found useful only at frequencies below 1MHz. It might be interesting to note at this time that it is possible to generate fields of 10 volts per meter intensity using the 41-inch rod, no matter what you may have heard in the past. It is, however, a little impractical as it requires an input of approximately 1500 volts to the base of the antenna to generate a field of 10 volts per meter at a distance of one meter.

Generating high-field intensities in microwave frequency ranges is not too difficult as horn antennas with gains of 15 to 20 db are of reasonable size and easily handled. The major difficulty lies in the VHF and UHF frequencies, roughly from 65 to 1000MHz. In this area the antennas customarily used for susceptibility testing are tuned dipoles or conical logarithmic spirals with a gain of approximately 2.3 db. Higher gain antennas are available such as Rhombic arrays or large logarithmic periodic arrays. However, these devices require many acres for their setup and are thus impractical for use within the confines of a small screen room. Further, these antennas are essentially narrowband devices and require either retuning or reassembly as frequency is changed. Such antennas do not meet the requirement for swept frequency testing.

Parabolic reflectors have much higher gains than the tuned dipoles which are customarily used in the UHF and VHF frequency ranges. However, the size of these antennas is frequency dependent and for them to be useful in this range would require paraboloids of many feet in diameter, which again are too cumbersome to use in the average screen room.

Theory

An isotropic radiator radiates equally in all directions. That is to say, the wave it generates is spherical in shape. Antennas which offer more gain than does an isotropic source do so solely because they do not radiate energy in all directions of the sphere. Thus, a dipole antenna radiates power in a doughnut-shaped pattern whose axis is coincident with the dipole. Since there is little or no radiation in the direction of the dipole, and the major radiation is in a direction perpendicular to the dipole, gain is achieved. The smaller the three-dimensional pattern radiated from an antenna, the higher its gain is.

Various methods can be used to increase the gain of antennas. Some of these include arrays of elements properly spaced and phased. Passive elements such as reflectors or directors can be used to concentrate the beam of energy radiated from an active element. Directional horn antennas can be used. Each of the normal methods of achieving antenna gain has some problem which makes it undesirable for the purpose of generating high-field intensities over wide band widths. In most cases these problems are either excessive size or narrow band width.

It was, therefore, decided to try to determine whether a new type of antenna could be developed which would have wide band width and small size and would be usable in the VHF and UHF frequency ranges. Various geometric shapes were considered and it was finally decided that the ellipse and its derivatives such as the elliptic cylinder or the ellipsoid seemed to offer the most promise.

Geometrically speaking an ellipse is the locus of a group of points arranged such that the sum of their distance from two fixed points referred to as the foci of the ellipse is always a constant. Albegraically, as ellipse is described by the equation $\frac{X^2}{A^2} + \frac{Y^2}{B^2} = 1$.

A plane ellipse is shown in Figure 2. The points marked F and F' are the foci of the ellipse. As has been stated before, the sum of the distances from any point on the edge of the ellipse to both foci is always a constant no matter what point is selected. The sum of the distances is, in fact, 2A.

This suggests that if a metallic elliptic cylinder is excited with a line source such as a rod antenna or dipole located at one of the foci, energy radiating from this driving antenna will be reflected from the walls of the ellipse and will be recombined at the second focus of the ellipse. It was assumed that if a reflector was built in the form of a right elliptic cylinder with one portion removed and with a driving source located at the focus within the remaining portion of the ellipse that the elliptic cylinder would form an electromagnetic reflector producing a beam which converges in the region between the two foci and diverges after it passes in the second focus. It was also assumed that in the region about the second focus a high-intensity beam would be formed which would be suitable for susceptibility testing of electronic boxes or for ordnance hazard testing of explosive devices such as squibs and detonators.

The prospect appeared so appealing that it was decided to determine the feasibility of such an antenna. A right elliptic cylinder of copper foil over a base of plywood was constructed for this investigation. The test ellipse has semi-major and semi-minor axes of approximately 56 cm and 25 cm respectively. This cylinder has a height of approximately 30 cm and was constructed for use in the 400 to 1000MHz frequency range. 16 cm of the elliptic cylinder has been removed at one end of the major axis on a separation line parallel to the minor axis. The plane of separation was chosen in such a way that the second focus of the ellipse lies 10 cm outside of the elliptic cylinder.

Figure 3 shows the elliptic cylinder setup for testing with a receiving dipole positioned at the exposed focal point of the cylinder.

LABORATORY INVESTIGATION

The first phase of testing was intended to determine whether this elliptic cylinder did indeed provide any gain in field intensity over that produced by an antenna in free space. The original driving source for the ellipse was a small whip antenna approximately 15 cm long. These measurements were taken in the following manner. Preliminary data was taken by setting up the 15 cm rod source and a standard field-intensity meter receiving antenna separated by a distance of one meter. A known signal was applied to the base of the driving antenna and the field intensity at a distance of one meter was measured with a calibrated field intensity meter. This data was recorded and the driving antenna was inserted into the elliptic cylinder through a hole provided in the top surface. The receiving antenna was positioned at the exposed focal point of the ellipse which was exactly one meter from the driving antenna location. The signal level was reapplied and the radiated field was again measured with the calibrated field-intensity meter.

The difference between the two readings was taken as the effective gain of the elliptic reflector. Figure 4 is a plot of gain versus frequency for the elliptic cylinder reflector over the frequency range of 450 to 1000MHz. This frequency range was chosen for the following reasons. The signal source used was a Hewlett-Packard HP 612A signal generator which has a lower frequency limit of 450MHz. The receiver used was a Stoddart NM 52A field-intensity meter which has an upper frequency limit of 1000MHz. In order to avoid changing signal sources or receivers during the course of the test, the frequency range was limited to the range that these two instruments have in common.

It can be seen in Figure 4 that the elliptic cylinder reflector did provide a useful gain over the field intensity radiated by the rod antenna in free space. The magnitude of gain was between 15 and 20 db except at frequencies of 475 and 500MHz where the gain was 13 db and 14 db respectively. It was felt that this was significant gain and justified continuing the experiment. It was noted, however, that the gain was not constant with respect to frequency, and it was decided that a different type of source antenna would probably be required to maintain a relatively constant output as frequency was varied.

The same experiment was rerun using the small segment which had been removed from the elliptic cylinder as the reflector. The previously discussed method was used and the results were plotted in Figures 5. The small reflector offers less gain than did the large reflector. Figure 5 indicates that in the range of 600 to 1000MHz the small reflector had a gain of approximately 8 db. Interestingly enough however, the gain of the small reflector appears to be far more constant as frequency is varied. The reason for this is not known at this time; however, the figure is plotted on data gathered from a smaller number of measurements and it might be that had more measurements been taken a greater variation in the curve would have been noted.

It was felt that even the gain of the small reflector was significant and re-enforced the conclusion that the elliptic reflector provided useful gain.

During the next portion of the measurements several other antenna configurations were investigated as driving sources for the elliptic reflector. These antennas included tuned dipoles, longer rod antennas, a conical unipole with a half-cone angle of 30° and a biconical horn with half-cone angles of 30°. The conical unipole and each cone of the biconical horn had lengths of 12.6 cm.

The tuned dipole antenna when used as a driving source provided a relatively high-intensity radiated field at the second focal point of the elliptic cylinder, but it proved to be unattractive because it had to be removed at every test frequency. This was a cumbersome and time-consuming process. Of the antennas investigated, the biconical horn proved to be the most suited for use as the driving source for the elliptic cylinder. This biconical horn is shown in Figure 6. The cones were constructed of the same lightweight copper foil which was used for the elliptic cylinder, and .141-diameter copper-jacket coaxial cable was used to connect the feed points. The connector at the top end of the cable is a type N jack which can be used to determine relative size of the biconical horn.

Figure 7 is a plot of radiated field intensity versus frequency. The data shown on this figure was taken using the large portion of the elliptic cylinder with a biconical horn source. An input signal level of +7 dbm was maintained across the frequency range. The five horizontal lines on this figure indicate signal levels of 1, 2, 3, 4, and 5 volts from bottom to top. The heavy line indicates the radiated field intensity at the exposed focus of the ellipse as measured with a Stoddart NM 52 field-intensity meter. It can be seen that at all frequencies above 500MHz the radiated field intensity is in excess of two volts per meter. In the frequency range between 900 and 1000MHz the radiated field intensity is in excess of 4 volts per meter. These field intensities are comfortably above that required for susceptibility testing to MIL-STD-461 and 462, but are somewhat short of that required for susceptibility testing to MIL-STD-826.

Figure 8 is a plot of radiated field intensity versus frequency for the small segment of the elliptic cylinder. Again the signal applied to the driving source was +7 dbm. The horizontal line in this figure indicates a radiated field intensity of one volt per meter. The heavier line indicates radiated field intensity again as measured with a Stoddart NM 52 field-intensity meter. It can be seen that the radiated field intensity of the small segment of the ellipse is approximately one-half volt per meter and is, therefore, not high enough for susceptibility testing to either MIL-STD-826 or MIL-STD-461 or 462.

Since only one elliptic cylinder configuration and a limited number of driving sources have been investigated to date, it is very probable that this is not an optimum configuration. The use of an ellipse with a different degree of eccentricity or the use of a different driving source might well afford enough gain to allow this technique to be used for MIL-STD-826 testing.

Figure 9 is a plot of field intensity versus frequency measured at the second focal point of the elliptic cylinder when the large segment and the small segment are mated to form the complete cylinder. In this instance the data covers the range of 600MHz to 1000MHz.

The frequency range was limited because the height of the cylinder was not great enough to allow the receiving dipole to be adjusted to the full half wave antenna length. It can be seen that when the frequency range of 900 to 1000MHz there is little difference between the field intensity generated by the large end of the elliptic cylinder and the total elliptic cylinder. In the frequency range of 600 to 900MHz the complete cylinder does appear to offer an increase in field intensity. The use of the complete elliptic cylinder may prove to be of value when testing ordnance items such as squibs or detonators to very high electric-field intensities in the order of hundreds or thousands of volts per meter.

The next phase of the laboratory investigations consisted of an attempt to determine the size of the high-intensity field about the second focus of the large segment of the ellipse. These measurements were taken at three frequencies: 450MHz, 600MHz, and 1000MHz. Only the XY plane has been investigated to date. It can be seen from the data shown in Figure 10 that at each of these frequencies the radiated field is uniform within ±1 db over a distance of approximately 15 to 20 cm laterally and 10 to 15 cm longitudinally.

The size of the radiated uniform field is slightly larger than was anticipated. This is probably due to the fact that one portion of the ellipse is missing and also due to imperfect ellipticity of the reflector. It is also possible that the driving source antenna may not have been located exactly at the first focus of the elliptic cylinder. A combination of these inaccuracies would tend to generate a slightly larger though also slightly less intense field than would have been achieved if the ellipticity of the reflector and the position of the driving source had been more accurately maintained.

PLANS FOR FUTURE EFFORT

It is felt that the elliptic cylinder is worthy of further consideration. Therefore, further effort in this field is planned. Future work will involve the investigation of other types of driving sources; namely , a conical dipole with a wide band frequency independent balun transformer. Also to be investigated is the affect of progressively removing more and more of the elliptic cylinder to determine the relationship between the amount of the ellipse which remains and the gain or radiated-field intensity which can be achieved. The construction and evaluation of an elliptic cylinder with a different degree of eccentricity is also planned. The construction of an elliptic cylinder of greater height to determine the feasibility of the technique at lower frequencies such as in the range of 65 to 450MHz, is also planned. Field uniformity measurements will be made in the X Z plane.

CONCLUSIONS

An attempt was made to determine whether a wide-band frequency-independent antenna could be used to generate high-intensity radiated electromagnetic fields in the VHF and UHF ranges. It was also attempted to determine whether the use of such a device would allow radiated susceptibility tests in accordance with MIL-STD-826 or MIL-STD-461 and 462 to be performed using secondary standard laboratory signal generators as the signal sources. An elliptic reflector configuration was chosen for investigation and it has been proved that this reflector does indeed provide significant amounts of gain over the frequency range of 450 to 1000MHz. It has also been shown that it is feasible to generate the radiated susceptibility fields required by MIL-STD-461 and 462 in the frequency range of 450 to 1000MHz using secondary standard laboratory signal generators as the signal sources.

It is felt that this technique merits further study, especially in the 65 to 400MHz frequency range. It is felt that if this technique can be utilized in this frequency range, that it merits consideration as an approved method for susceptibility testing in accordance with the applicable military standards.

It is acknowledged that the elliptic cylinder reflector will always be limited in the scope of its application. Such an antenna can only be used in a static situation where both the source and receiving elements can be located at the foci of the ellipse. Such an antenna cannot be used for mobile communications or airborne communications.

ACKNOWLEDGEMENTS

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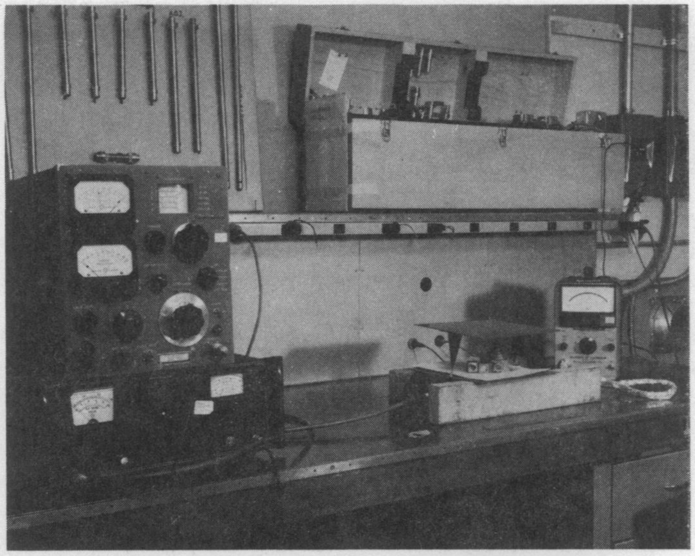
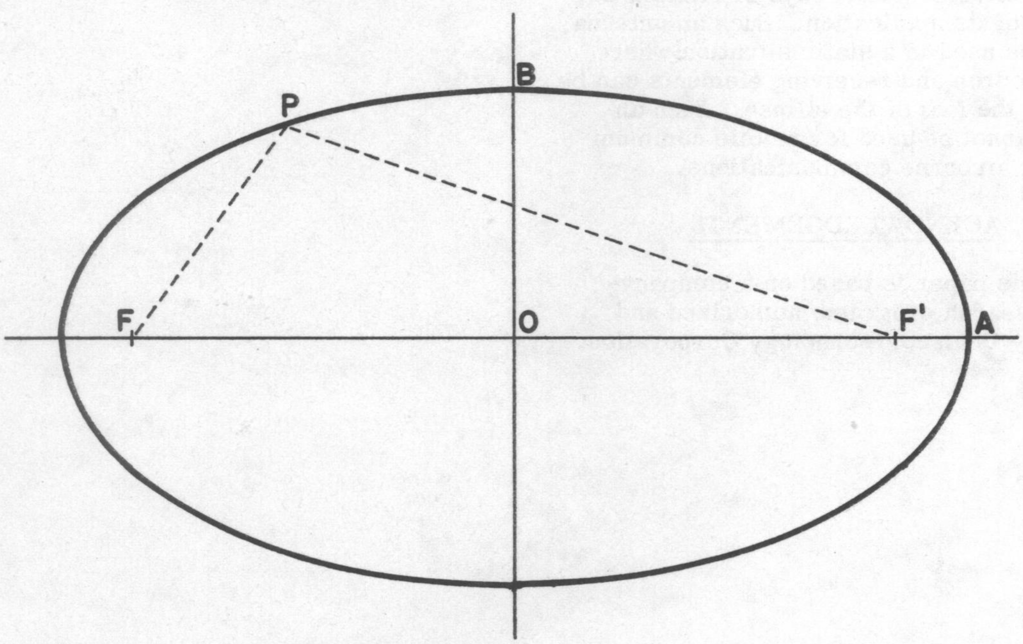


FIGURE 1 PARALLEL PLATE TEST SETUP FOR SUSCEPTIBILITY TESTING OF ORDNANCE DEVICE



$$\frac{X^2}{A^2} + \frac{Y^2}{B^2} = 1$$

$$\overline{FP} + \overline{F'P} = 2A$$

FIGURE 2: PLANE ELLIPSE

FIGURE 3

ELLIPTIC REFLECTOR TEST SETUP

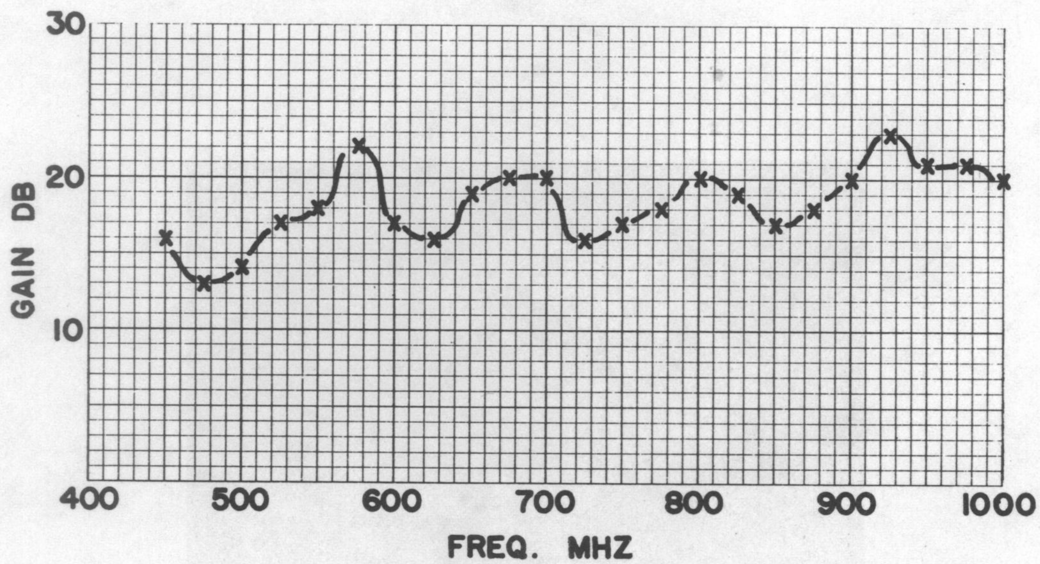


FIGURE 4:

GAIN VS FREQUENCY- LARGE ELLIPTIC SEGMENT

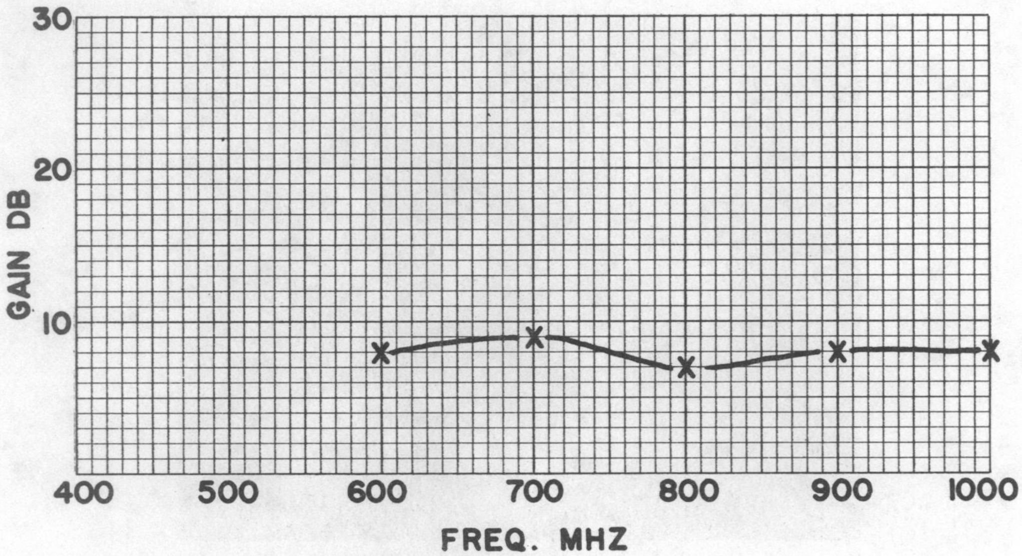


FIGURE 5:

GAIN VS FREQUENCY- SMALL ELLIPTIC SEGMENT

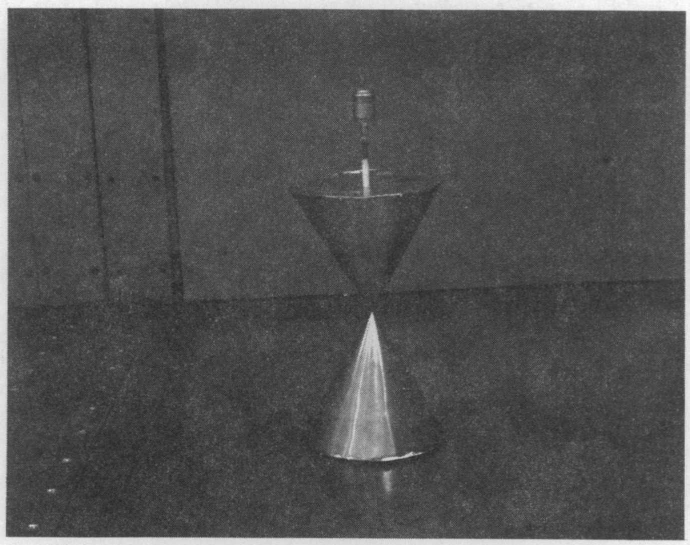


FIGURE 6

BICONICAL HORN ANTENNA

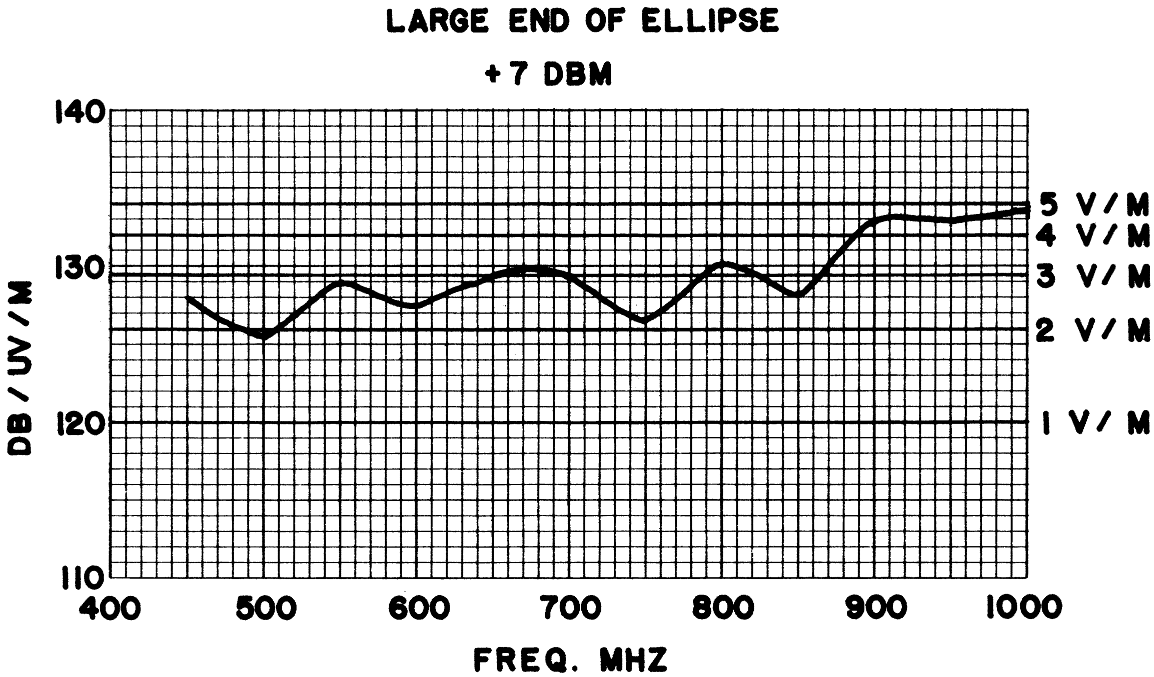


FIGURE 7: FIELD INTENSITY VS FREQUENCY

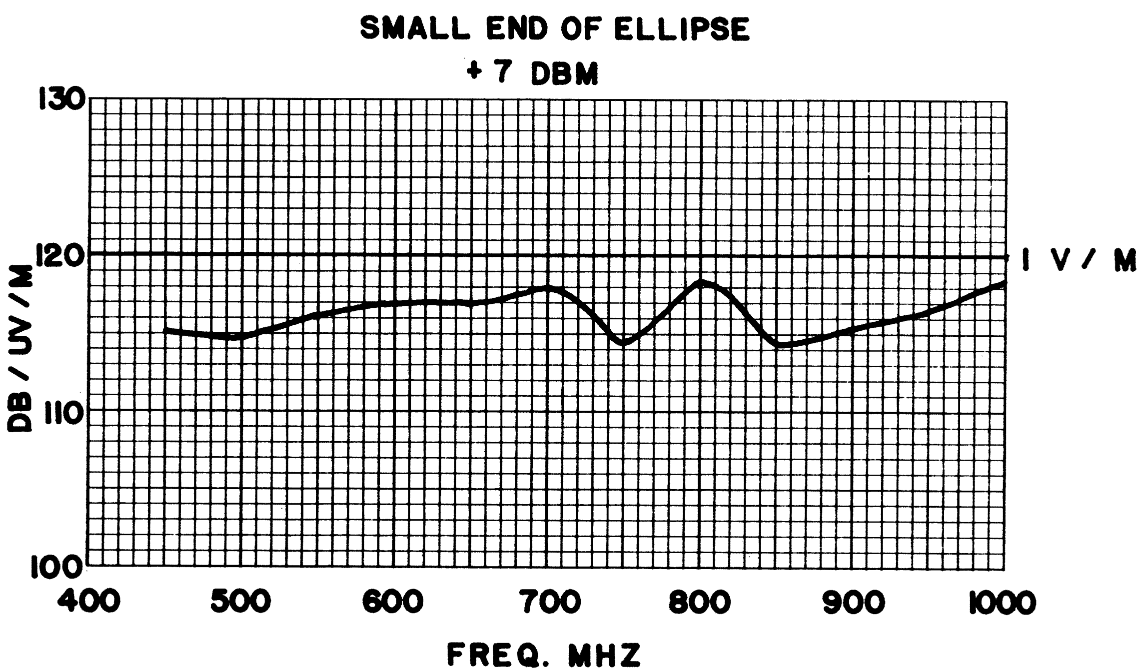


FIGURE 8: FIELD INTENSITY VS FREQUENCY

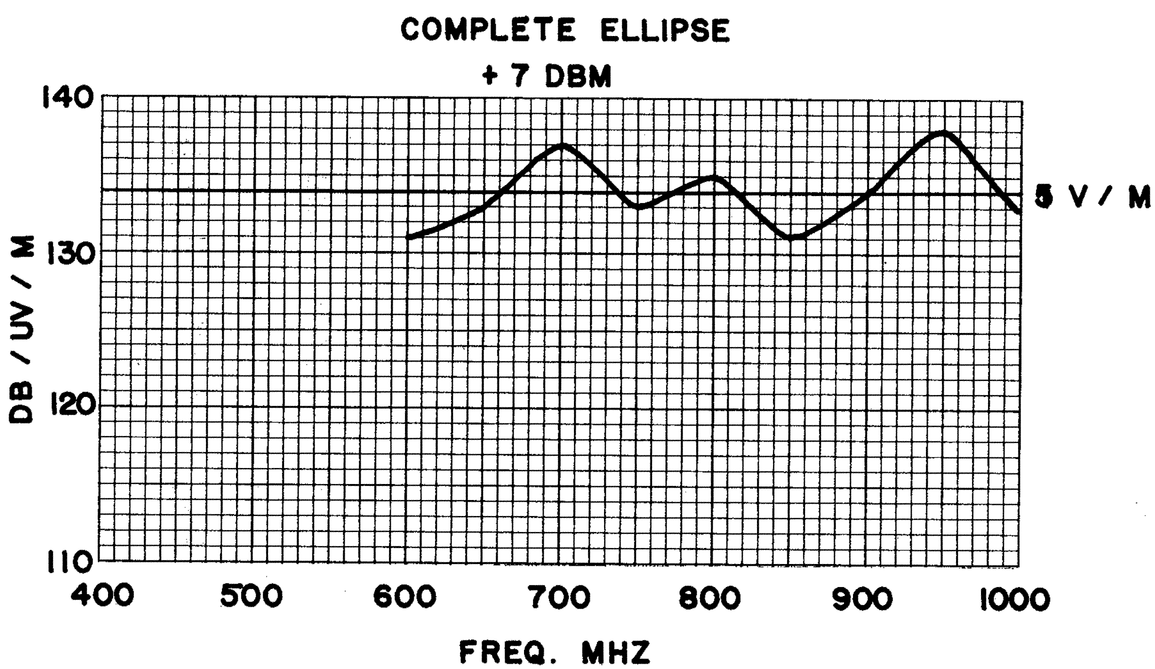


FIGURE 9: FIELD INTENSITY VS FREQUENCY

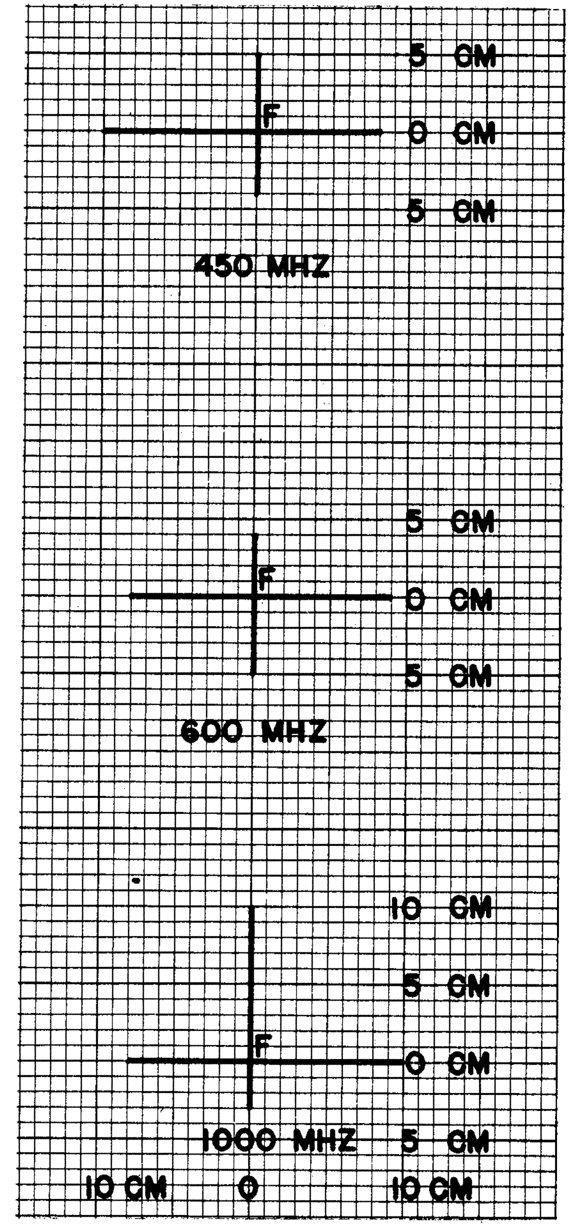


FIGURE 10: FIELD UNIFORMITY