SUSCEPTIBILITY TESTING IN SHIELDED ROOMS

Electromagnetic susceptibility (EMS) and electromagnetic vulnerability (EMV) testing requirements exist in both military and industrial communities. Most EMI engineers are familiar with the radiated susceptibility requirements of MIL-STD-461. For avionics equipment (Part 2), RS03 fields as high as 10V/m are required for 14 kHz thru 30 MHz, 5V/m from 30 MHz thru 10GHz, and 20V/m from 10 thru 40 GHz for special applications. For equipment mounted external to the aircraft or within non-metallic aircraft, the field is defined as 200V/m over a specified frequency range. In Part 5of the standard for surface ships, 100V/m is required from 14 kHz thru 30 MHz and 200V/m from 30 MHz thru 10 GHz and above. MIL-STD-461B also states that the environments specified in MIL-HDBK-235A shall be used to modify the RS03 requirements. Although the technical portions of this handbook are classified, one should note that specific frequencies are given and levels up through 200V/m are required over the entire usable RF spectrum.

The limits specified in MIL-STD-461B are normally referred to as susceptibility criteria, whereas the requirements of MIL-HDBK-235A are referred to as vulnerability criteria. Additional vulnerability criteria exists in MIL-STD-1385 (Navy)[1]. This standard is concerned with the preclusion of ordnance hazards in electromagnetic fields and are often referred to as HERO requirements, Hazards of Electromagnetic Radiation to Ordnance. The vulnerability levels required by this standard are shown in Table 1.

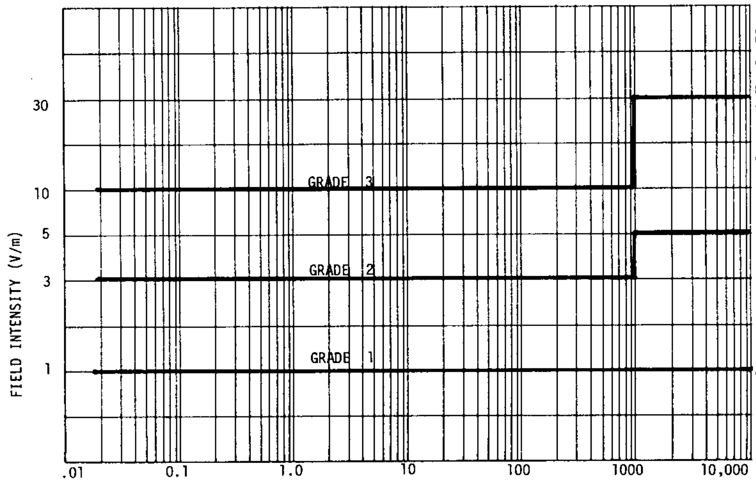


FIGURE 1: RADIO ENVIRONMENT IMMUNITY GRADES

TABLE I - ELECTROMAGNETIC ENVIRONMENT LEVELS

FREQUENCY (MHz)	FIELD INTENSITY [VOLTS (RMS)/METER]	AVERAGE POWER DENSITY (MILLIWATTS/SQUARE CENTIMETER)
Communications		
0.25 - 0.535	300	
2 - 32	100	
100 - 156		0.01
225 - 400		0.01
Radars/Other Electronic Equipment		
200 - 1215		10
1215 - 1365		5
2700 - 3600		78
5400 - 5900		105
7900 - 8400		175
8500 - 10440		150
33200 - 40000		4

*These intensities apply to the smaller of the following field components:

(a) The vertical component of the electric field (E).

(b) The directional maximum component of the horizontal magnetic field in ampere turns/meter (H), multiplied by 377 ohms.

Although there are no industrial criteria for RF environments which are mandatory for radiated susceptibility evaluation, the FCC has looked into this matter with a Notice of Inquiry on interference to electronic equipment[2]. The government of Canada, Department of Communications, however, issued an Electromagnetic Compatibility Advisory Bulletin[3] which recommends radio environment community levels over the frequency range of 14 kHz thru 10 GHz. Although this is a voluntary standard, it does recommend that equipment be labelled as to its ability to withstand these levels as shown in Figure 1.

Many computer manufacturers now have in-house standards for evaluating the susceptibility of their equipment to RF environments. These standards vary in both level and test method. The automotive industry is evaluating its vehicles to levels up to 200V/m. (It is important to note that 194V/m represented the old radiation hazard level over the frequency range of 10 MHz thru 100 GHz.)

Other than the metnods shown in MIL-STD-462 there are no specified methods of performing susceptibility or vulnerability tests. MIL-STD-462, therefore, is followed for most applications. This method involves testing in a shielded enclosure. The enclosure will confine the fields to avoid their interaction with other equipment, and avoids the violation with FCC requirements. Unfortunately, shielded elnclosures are known to create standing waves due to an infinite number of resonances. To help eliminate these resonances, a method using a mode stirrer has been proposed by the Navy[4] or anechoic chambers must be used. The stirrer technique has not proven to be satisfactory in many applications and the prohibitive cost of an anechoic chamber and its limitations at lower frequencies have limited their use. At the 1981 IEEE EMC-S Symposium, a Paper entitled "A Low Cost RFI Susceptibility Test System"[5] presented a test method in a shielded enclosure containing a small cavity of anechoic material around the equipment to be tested, to eliminate the effect of room resonance and to minimize the cost of anechoic materials.

Another difficulty in performing EMS and EMV tests is the poor efficiency of the radiating antenna systems and the high level and cost of high power required to drive antenna systems. Also, the tests normally are tedious, requiring accurate monitoring of the radiated field with many critical parameters being overlooked.

Test Objective

With the above background in mind, a series of R & D tests were performed in a joint effort by R & B Enterprises and Amplifier Research Corporation (Other cooperating organizations are listed in the acknowledgement.) The purpose of the tests was to develop a simplified, low cost, automatic test system and procedure for EMS and EMV testing in a shielded room. In this process, a new antenna, the CAVITENNA*[6], was evaluated in conjunction of the concept of using a limited quantity RF absorbent anechoic material around the item which was to be tested. Another objective of the test was to develop a test system to rapidly evaluate antennas and the performance of anechoic materials.

Test Set-Up

The tests were performed in a solid shielded enclosure which was 20′ long, 10′ high, and 12′ wide. This was a 3/4″ plywood structure with 60 mil galvanized shell on both the inside and outside of the plywood. Consisting of 4 x 10 foot panels, the structure was bolted together and was self-supporting.

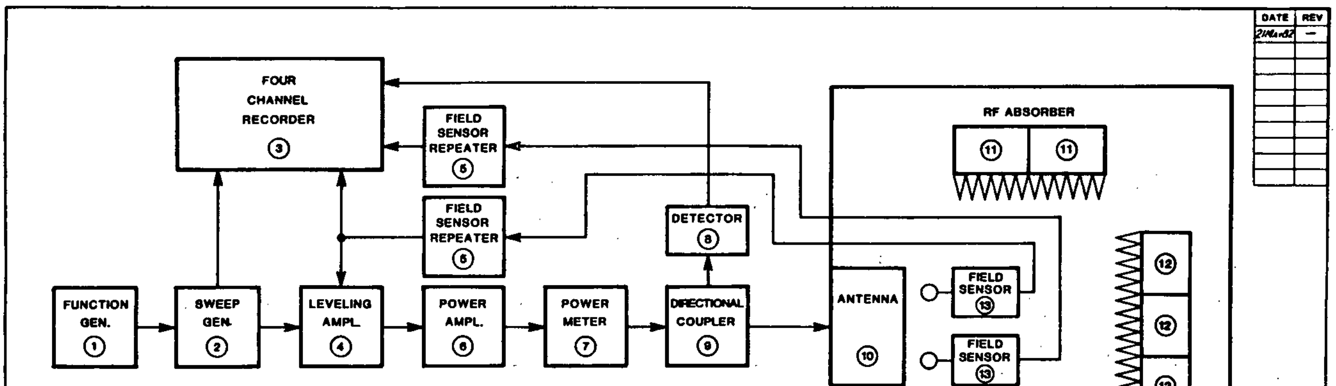
The CAVITENNA was mounted on the inside wall above the access panel and a copper clad tet bench. The CAVITENNA has magnetic mounts and has an operating frequency of 30 MHz through 1000 MHz. Isotropic field sensors were placed where actual equipment would be placed. Figure 2 shows a block diagram of the general test configuration and the test system. The chart recorder was used to monitor the power to the antenna, the measured field from both the field sensors, all as a function of frequency.

The anechoic material was not used for the first series of tests, but was later placed in the room around the field sensors at different positions. Only vertical columns of anechoic material were used, with none placed over or under the field sensors.

Two sizes of material were used, 24″ and 36″ deep. Both sets of materials were specially designed for improved performance down through 30 MHz. This EMC type material is essentially a pyramidal form material, loaded to match successive layers of graded dielectric layers. This design was to allow for the proper matching of the material to free space by initially providing a tapered impedance match through the pyramidal front. After the energy enters the material, it then is passed successively on to higher and higher dielectrically loaded materials which enhances its energy dissipation characteristics. It is through this gradual change in dissipation that high loss at low frequencies is achieved.

The field sensors were isotropic and were connected to the repeaters located outside of the shielded room via a fiber optic link. In most cases, one sensor was used for leveling and for recording, while the other was used for recording only.

*CAVITENNA is the trademark of Amplifier Research Corporation, Souderton, PA.



EQUIPMENT LIST

ITEM	QTY.	MODEL	MANUFACTURER
1.	1	3310A	HEWLETT-PACKARD
2.	1	XR1500	TEXSCAN
3.	1	2400	BRUSH
4.	1	999	AMPLIFIER RESEARCH
5.	2	TE308	AERITALIA
6.	1	10W1000	AMPLIFIER RESEARCH
7.	1	43	BIRD ELECTRONICS
8.	1	CD-50	TEXSCAN
9.	1	DC3000	AMPLIFIER RESEARCH
10.	1	AT2000	AMPLIFIER RESEARCH
11.	16	AEP-24-EM	ADVANCED ELECTROMAGNETICS
12.	12	AEP-36-EM	ADVANCED ELECTROMAGNETICS
13.	2 Ea	TE307 13RV1001-1 14RV1001-1	AERITALIA

Figure 2

See LMI on back cover.

Test Results

The tests were performed sweeping the frequency range of 2 MHz in eight minutes. Although a slower sweep rate could have been used, this rate was used to demonstrate resonance effects, repeatability in results, and to conserve the time required to evaluate many different test configurations and experiments. A total of 32 different configurations and/or experiments were performed during 24 hours of actual testing. When the test method is perfected, this would imply that over 10 tests can be performed in one work day.

It is impossible to present all of the test results in this paper due to time and to space limitations. Therefore, only the most significant results are highlighted. The charge numbers referenced herein are taken from the actual data and test sequence, and have been retained for ease of direct reference to the original data. The location of the sensors and anechoic material for each test configuration has been overlayed on each chart.

The first series of tests performed were to evaluate the field uniformity from the CAVITENNA over the copper clad test bench with no anechoic material. The results are shown on Chart 2. The field sensor used to level the intensity at 25 volts per meter was located under the CAVITENNA, 18 inches from the wall and 18 inches above the ground plane on the bench. Located 18 inches to the left was the second sensor measuring the unleveled field.

The results show that the "leveled" intensity varied from a low of 10V/m to a peak of 50V/m. These variations (on this and ensuing charts) can be reduced using a slower sweep rate, improved AGC speed in the monitoring system, and/or the use of effective anechoic material. The top graph of Chart 2 shows the power required as a function of frequency, and the bottom graph shows the large variance of intensity only 18 inches away. Note that 100V/m was obtained at about 930 MHz where the intensity was unleveled. At this frequency, only 5 watts of power was applied to the antenna and the leveled intensity was less than 30V/m. Thus, Chart 2 shows that severe variations exist at different locations on the test bench. Careful scrutiny of the chart also shows that low frequencies (less than 150 MHz) look best, but at higher frequencies the fine grain variations are very bad.

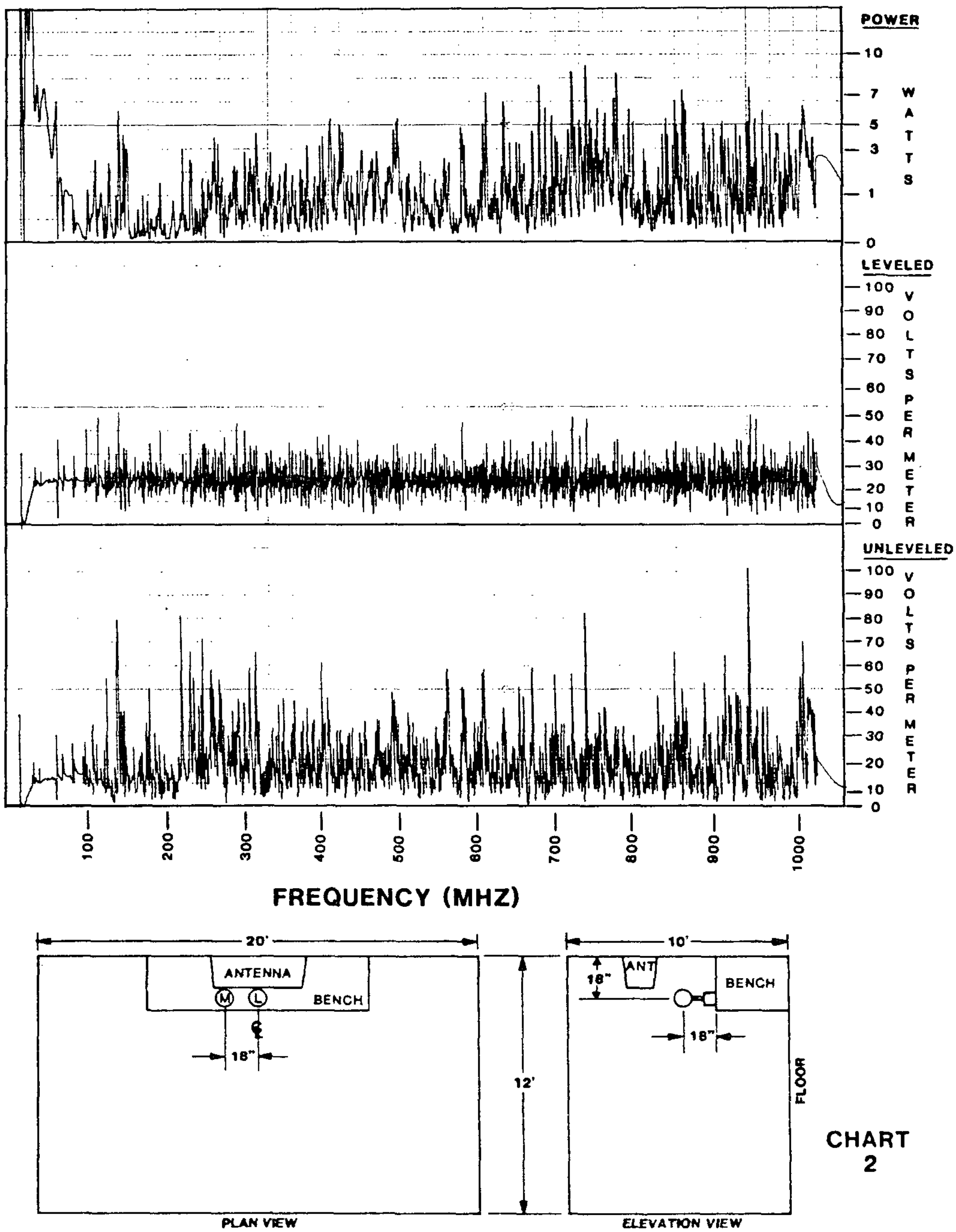


CHART 2

Chart 7 shows similar results. However, these measurements were made with the field monitors located in the center of the shielded room. The CAVITENNA produced an average of 25V/m with an average of 3 watts of input power; but, the field uniformity at low frequencies (less than 200 MHz) were affecteds severly by room resonances.

After a series of measurements of this nature, the anechoic material was placed inside of the room. With the sensors placed in the center of the room and surrounded on three sides by the anechoic material, the results obtained are illustrated by Chart 10. Careful examination of the three graphs shows that a drastic change in room performance was observed with the following results:

1. The Q of the fine grain variations were reduced by a factor of approximately 10.
2. The low frequency fields were more uniform and controllable.
3. The power required to generate the fields increased beyond the 10 watt amplifier's capability, causing leveling to be inadequate.

Thus, the addition of the anechoic material improved the leveling capability and low frequency uniformity while reducing the fine grain variations by a factor of 10. Due to a significant reduction of standing waves, approximately 6 dB more power is required to produce the same field level.

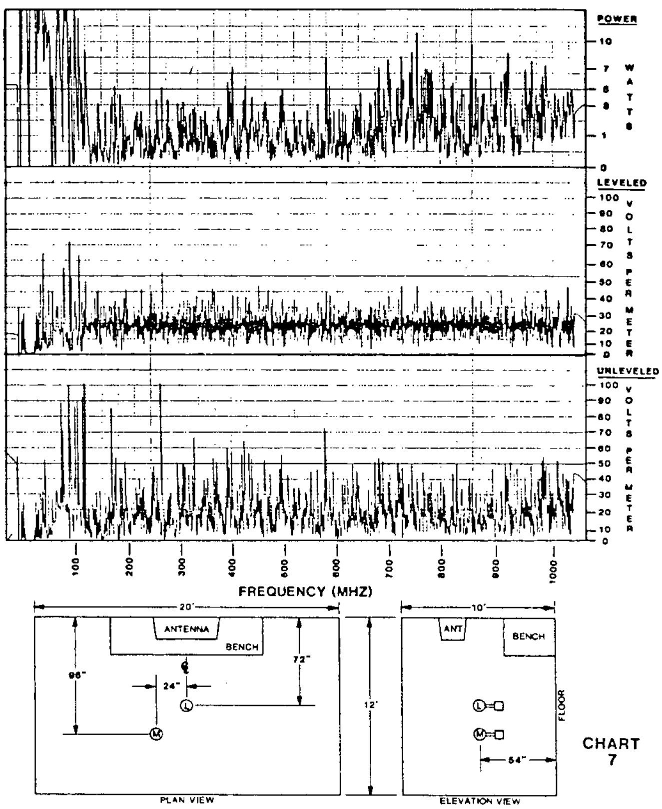


CHART 7

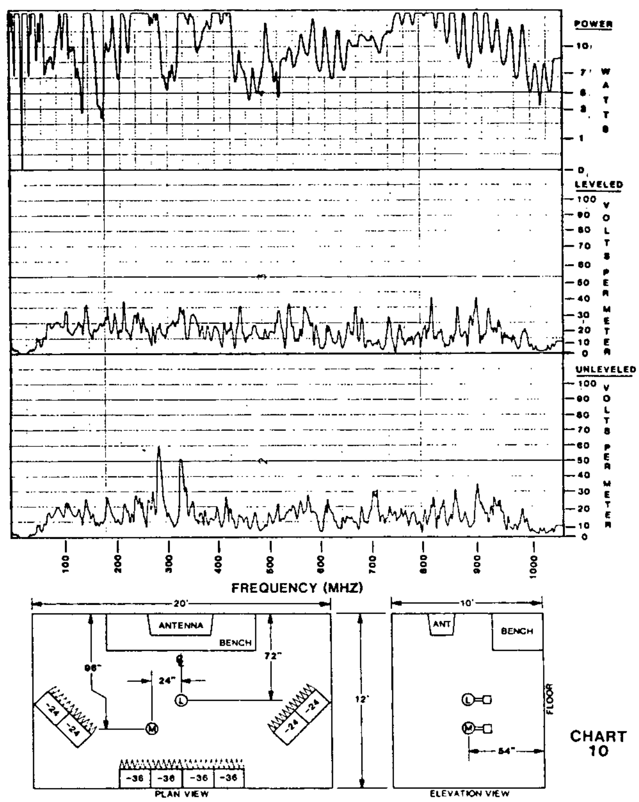


CHART 10

At this point, the 25V/m objective was reduced to 5V/m so that the same amplifiers could be used. The results are shown on Chart 11. The only difference in test method between Charts 10 and 11 is the leveled intensity. Chart 11 shows that the leveling was improved greatly and the field uniformity below 250 MHz was ± 3dB. The unleveled graph shows the tremendous variances measured only 24 inches away.

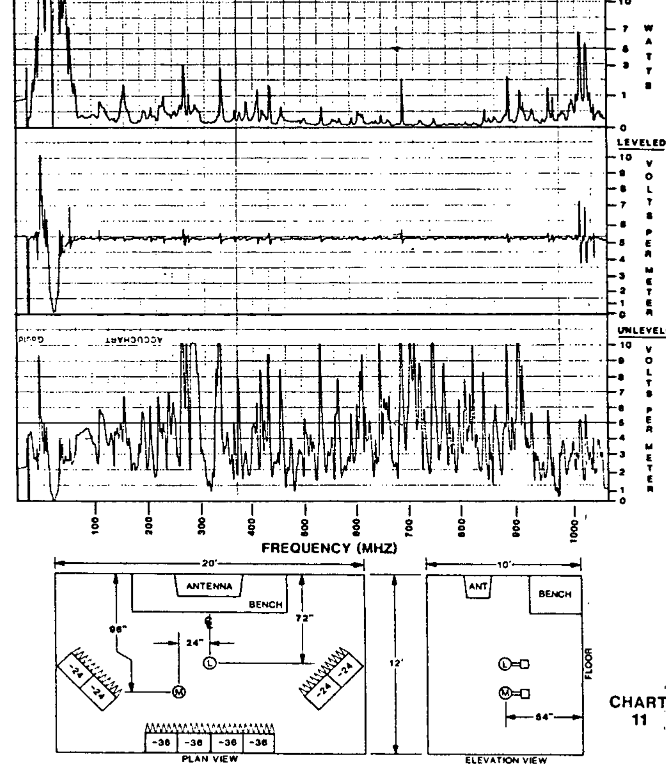


CHART 11

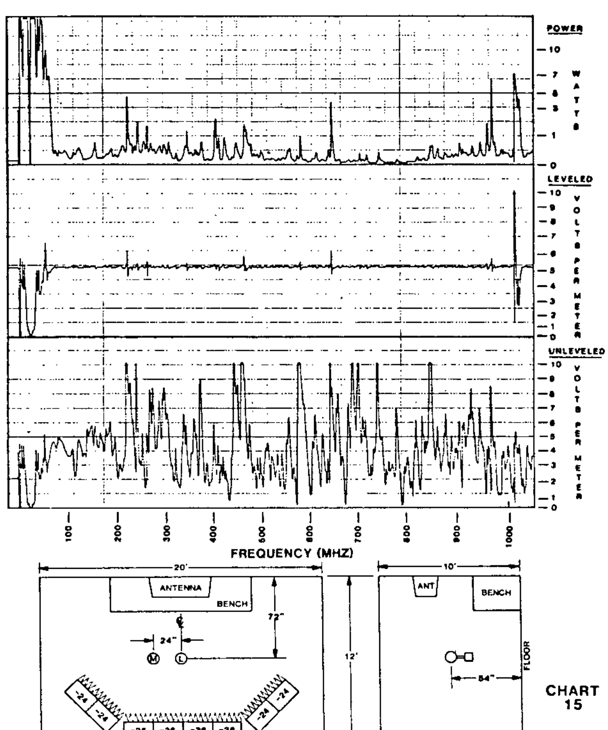


CHART 15

The anechoic material then was rearranged and the test, as presented in Chart 11, was repeated. The results are presented on Chart 15. Again, relatively good results were obtained below 200 MHz where adjacent field uniformity was approximately + 3 dB. This verifies the anechoic material effectiveness at lower frequencies. The large variances at higher frequencies was still a problem.

The field sensors were returned to the top of the copper clad test bench and the anechoic material was placed around the bench. Several variations of material location were tried, with the typical result shown in Chart 17. Chart 17 should be compared to Chart 2, the case where anechoic material was not used. It should be noted that the presence of the material significantly reduced the fine grain variances, leveling was easy to achieve in spite of the relatively fast sweep rate; but the adjacent level, now 24 inches away, still varied by 6 dB or more at resonant frequencies. Nonetheless, the potential improvement which can be obtained with the proper or optimum location of the anechoic material has been demonstrated. Also, note the low amount of power required to obtain the leveled 5V/m field.

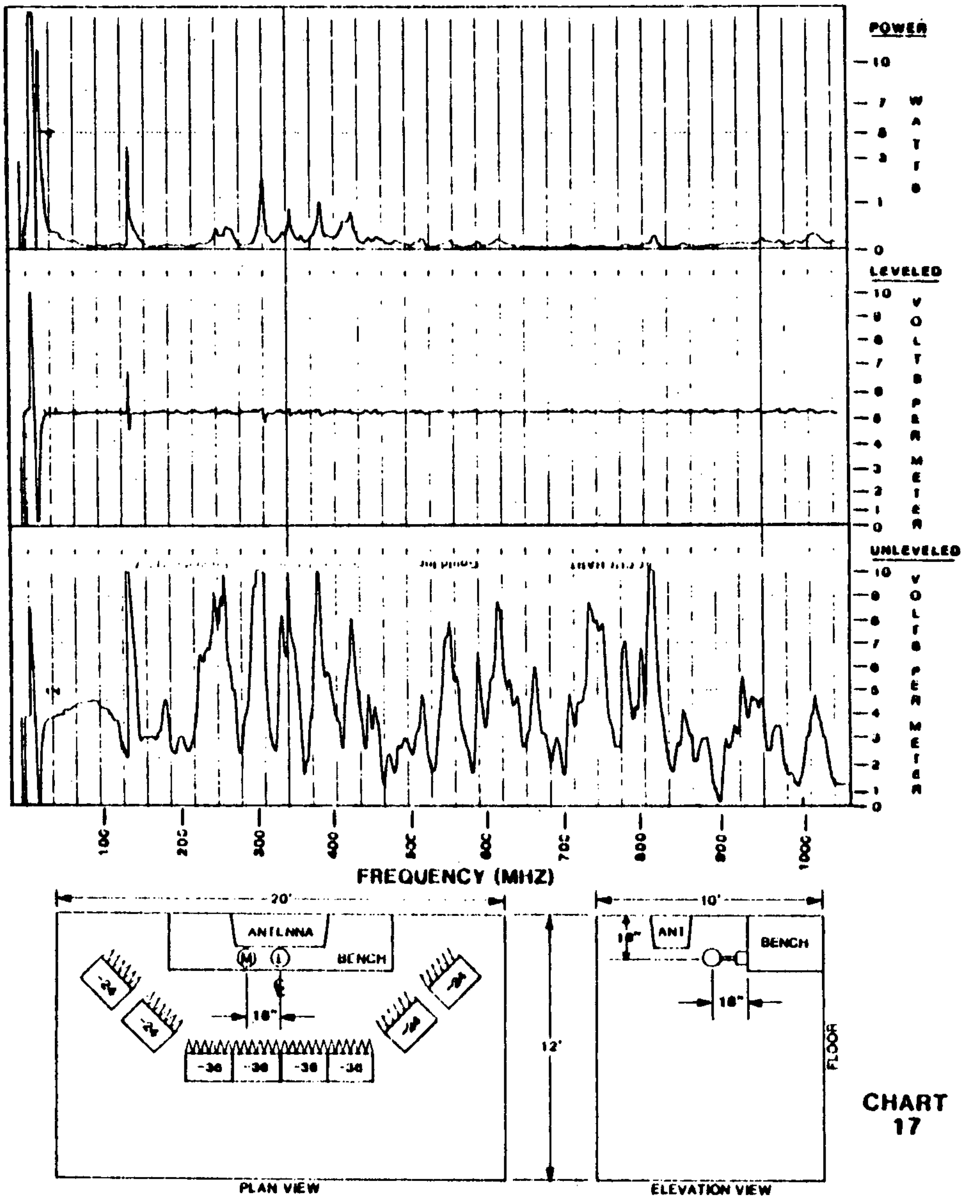


CHART 17

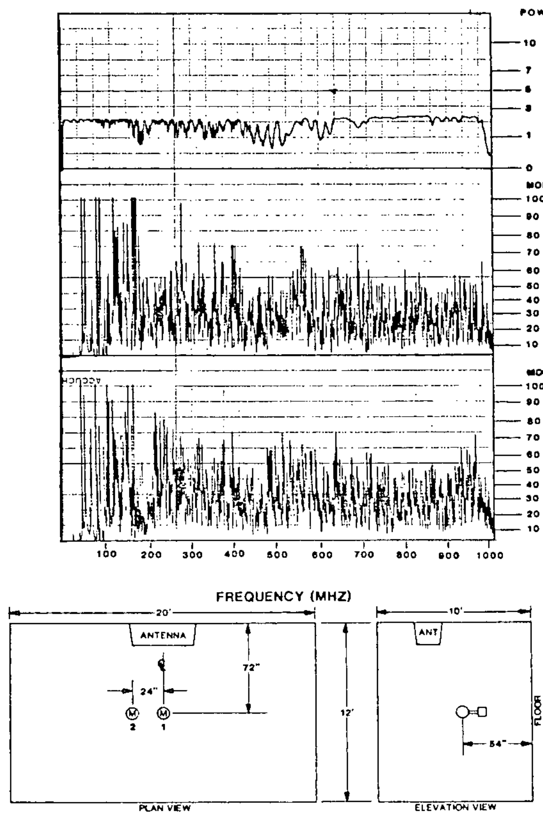


CHART 19

In order to observe the CAVITENNA and room performance, measurements using different variables were performed. Chart 19 shows the results of keeping the input power to the antenna relatively constant at 2½ watts. Because of room resonance, the antenna impedance varies from a short to an open. In this measurement, no anechoic material was used in the room. The results indicate the good efficiency of the CAVITENNA and verify that leveling overshoots are not causing the severe field variations as seen by the sensors. It also demonstrates the need for some anechoic material in order to make reproduceable test possible.

The sweep system then was slowed in order to examine one of the peaks, at approximately 42.5 MHz, as shown in Chart 22. The power was leveled and the Q here was calculated to be approximately 250 to 300. Other similar measurements show the Q's to be as high as 500. One must realize that different sized rooms will have different resonant frequencies, resulting in varied Q values.

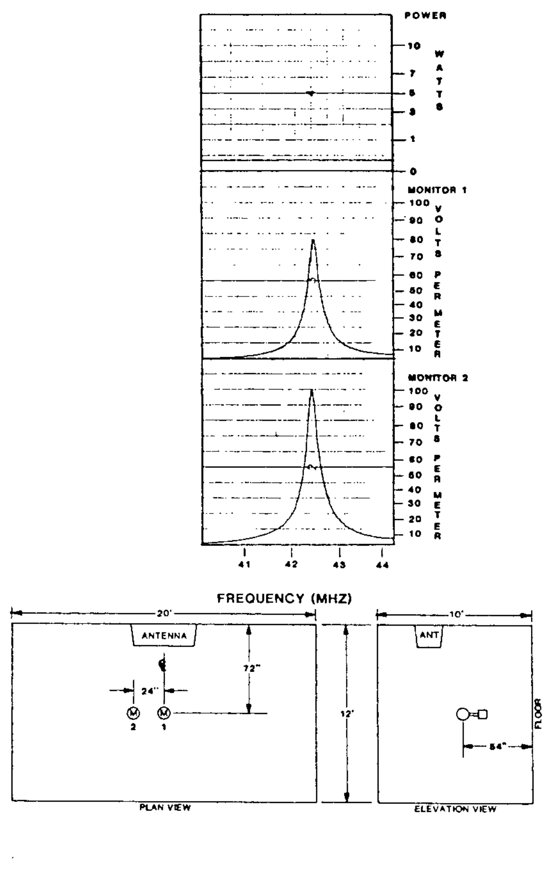


CHART 22

Finally, the anechoic material again was placed inside of the room and another series of measurements were performed. However, the effects of the copper clad test bench in the room were of concern, and thus the test bench was removed. The results shown on Graph 23 indicate that the field variations are as severe in amplitude as with the test bench in the room, but they were spaced further apart in frequency. Thus, some reflections were occuring due to the proximity of the antenna and the bench.

Test Summary

A test system was designed and tested which yields rapid test results over the 30 MHz to 1 GHz range. The system uses commerically available components to provide an economical solution to RF susceptibility test requirements. It includes a dual isotropic field intensity measurement system used to determine field uniformity and enable rapid evaluation of anechoic material.

The test results clearly demonstrated the following:

1. Effectiveness in small shielded rooms with limited quantities of anechoic material, thereby greatly reducing the cost of a fully anechoic test facility.
2. Use of an economical frequency swept system, employing a low cost sweep generator instead of a computer, and its attendant interface and software problems.
3. Use of active isotropic electric field leveling to provide a constant field intensity at the leveling probe as the frequency is varied.

Conclusions

1. The new type broadband radiator can be used effectively. As seen in Charts 7 and 19, it provides wideband performance at high efficiency. Particularly impressive is its efficiency in the difficult 30-200 MHz region. Also, the antenna can produce fields over 200 volts per meter because of its unique combination of high power rating and high efficiency.

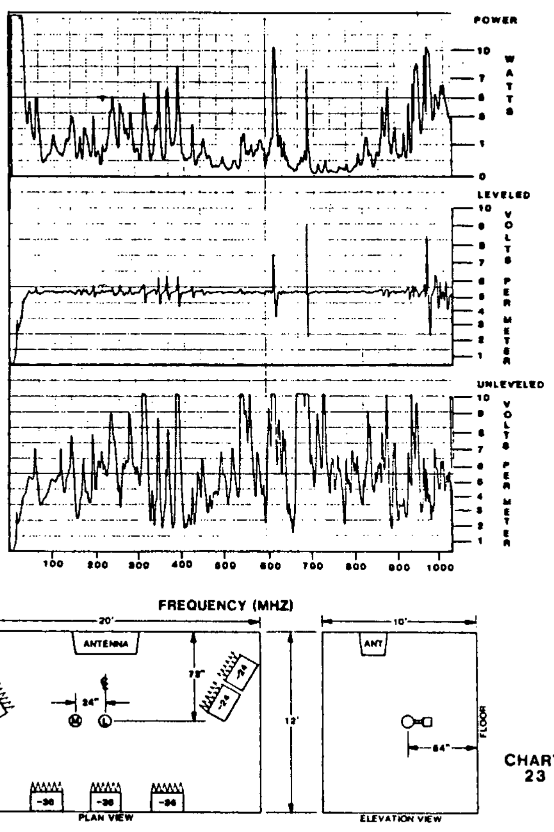


CHART 23

2. Field uniformity measurements made simultaneously with a second unleveled probe yielded startling results. Large field variations existed over the commonly tested rack-sized equipment, and leveling alone does not solve the problem because the second field monitor can be a significant part of a wavelength away. In fact, leveling one channel increased the peak-to-peak variations in the second field monitor when the null of one coincides with the peak of the other.

3. Electric field variations without anechoic material, as a function of frequency, are very severe. The Q of these variations as illustrated by Chart 2 can be very high (approximately 250). With Q variations of even 30 dB, test repeatability is virtually non-existent. Hence, susceptibility testing, while commonly carried out under test conditions, can be of questionable validity.

4. The answer to the problem of shielded room Q is, of course, to put RF anechoic material in the room with the goal of this test being to reduce the size and amount of material so that the price does not approach that of a full anechoic design. Fortunately, improved anechoic material is now available which provides good low frequency and wide angle performance in a reasonable size. The use of the anechoic material (see Charts 2 and 11) greatly reduced the Q of the room. Reasonable variations and uniformity were encountered at low frequencies (less than 200 MHz) where the wavelength is long enough for both field sensors to measure similar voltages. Additional anechoic material will be required, perhaps over the test sample, to reduce variations at higher frequencies where the field sensors are at significantly different electrical positions. Fortunately, the material required should be lower in cost due to its being a higher frequency (hence smaller) material. Unfortunately, improvement realized by the addition of anechoic material exacts an additional price, in that it takes approximately 6 dB more RF power to develop a given field level.

5. This initial test program was limited in scope and time did not allow complete investigation of several important ramifications. The following additional areas are recommended for further investigation.

a. Use additional material and investigate the optimum location for the existing material with goal of achieving field variations of ± 3 dB maximum.

b. Improve the response time and dynamic range of the leveling system.

c. Develop means to automatically insert crystal controlled markers provided by the sweep generator onto the chart recorder. (Present markers inserted by hand.)

d. Develop a similar test system for 10 kHz to 30 MHz to enable coverage from 10 Hz to 1 GHz in only two bands.

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