Comparison of Failure Mode Criteria in Electromagnetic Environments

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Abstract—**Open field/ground plane test methods are generally used to evaluate the performance of equipment in electromagnetic environments. Laboratory enclosures with controlled environments in the form of transverse electromagnetic (TEM) cells, reverberation chambers, and anechoic chambers can overcome the disadvantages of remote outdoor test facilities.**

I. Introduction

THE PURPOSE of this paper is to develop a procedure, using a simple probe, for comparing various methods of testing for Electromagnetic Susceptibility (EMS). The object is to qualify laboratory-closed chamber devices for EMS testing.

Open field/ground plane methods used as industry standards have inherent encumberances that equipment manufacturers find difficult to use in order to verify compliance with standards of performance for their end product. The necessity of having a remote location for open field/ground plane installations immediately makes the test site less accessible. Being out-of-doors the test site use and the test results are subject to seasonal variations and atmospheric conditions.

Testing is further complicated by the requirement for an assortment of antennas which need considerable care in their application. Determining antenna factors and mismatch loss or developing impedance matching for each setup can be problematic. Test site requirements and test procedures for ground plane testing are further discussed in [1], [2].

Although effective in making measurements of radiated field strength, ground plane installations are not commonly owned by equipment manufacturers and the testing requires special supporting equipment including high-powered transmitters. Furthermore, the levels of radiation could be injurious to operating personnel, unless they are housed a reasonable distance from the transmitting antenna.

II. Laboratory Test Chambers

As quoted in [3], "Transverse electromagnetic (TEM) cells have shown great potential for performing electromagnetic interference/electromagnetic compatibility (EMI/EMC) measurements with substantially improved ease, versatility, and accuracy." A sketch of a typical TEM cell is shown in Fig. 1. For small equipment requiring testing in the frequency range of 2–50 MHz the TEM cell provides a controlled atmosphere and laboratory-oriented method. Field strengths of up to 100 V/m can be produced using 10 W RF sources instead of the high-powered equipment typically required in open site/ground plane methods. Testing is manageable by one or two people. Radiation is confined to the inside of the cabinet. A typical test arrangement is shown in Fig. 2.

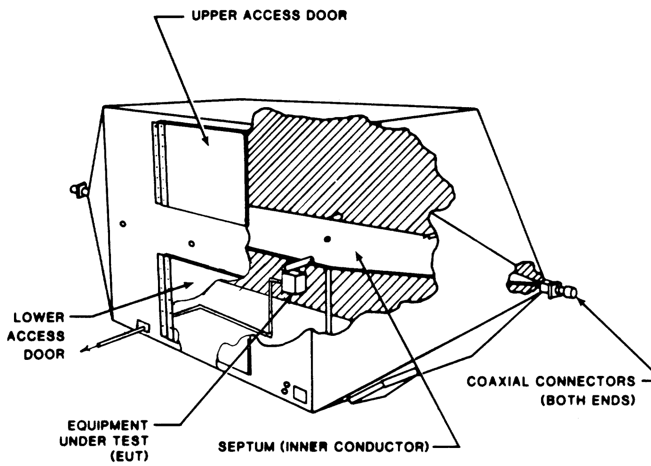

Fig. 1. Transverse electromagnetic (TEM) cell.

Conventional shielded enclosures used for EMI/EMC testing yield results that are dependent on the room's physical characteristics and the location of equipment and personnel in the room. Reverberation chambers (stirred mode) offer a considerable advancement over screen-room testing, providing consistent and reliable results. The advantages of reverberation chambers are discussed in [4]. Room size chambers (as an example, 2.74 × 3.05 × 4.57 m and larger) suitable for testing large equipment are available. A testing frequency range of 0.2–18 GHz is realized at levels of 100 V/m. As with the TEM cell, radiation is contained within the chamber presenting no hazard to personnel. Atmospheric conditions are not a factor in the testing. Tests may be conducted by one or two people. A typical test arrangement is shown in Fig. 3.

Anechoic chambers provide an alternate to the reverberation chamber for testing large equipment in the high-frequency ranges. The anechoic chamber has the same advantages of in-door testing as the TEM Cell and the reverberation chamber.

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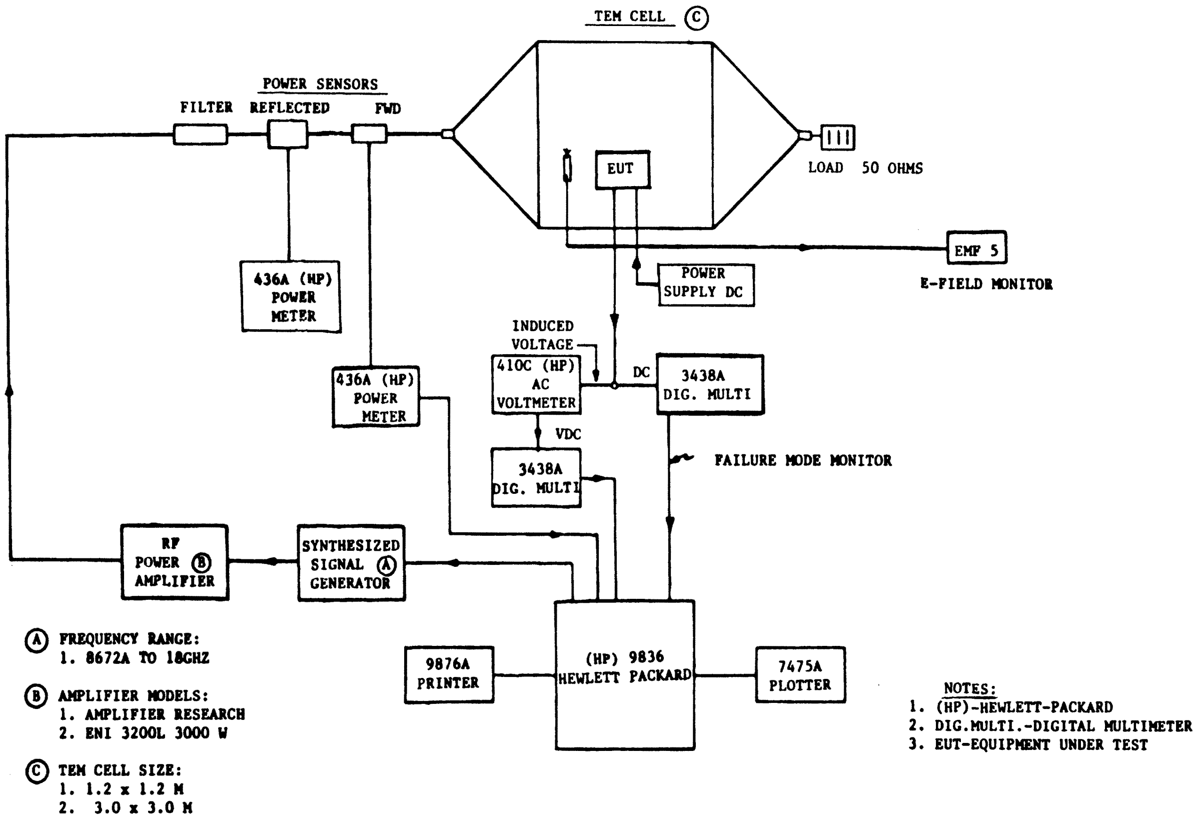

Fig. 2. TEM cell test control and instrumentation.

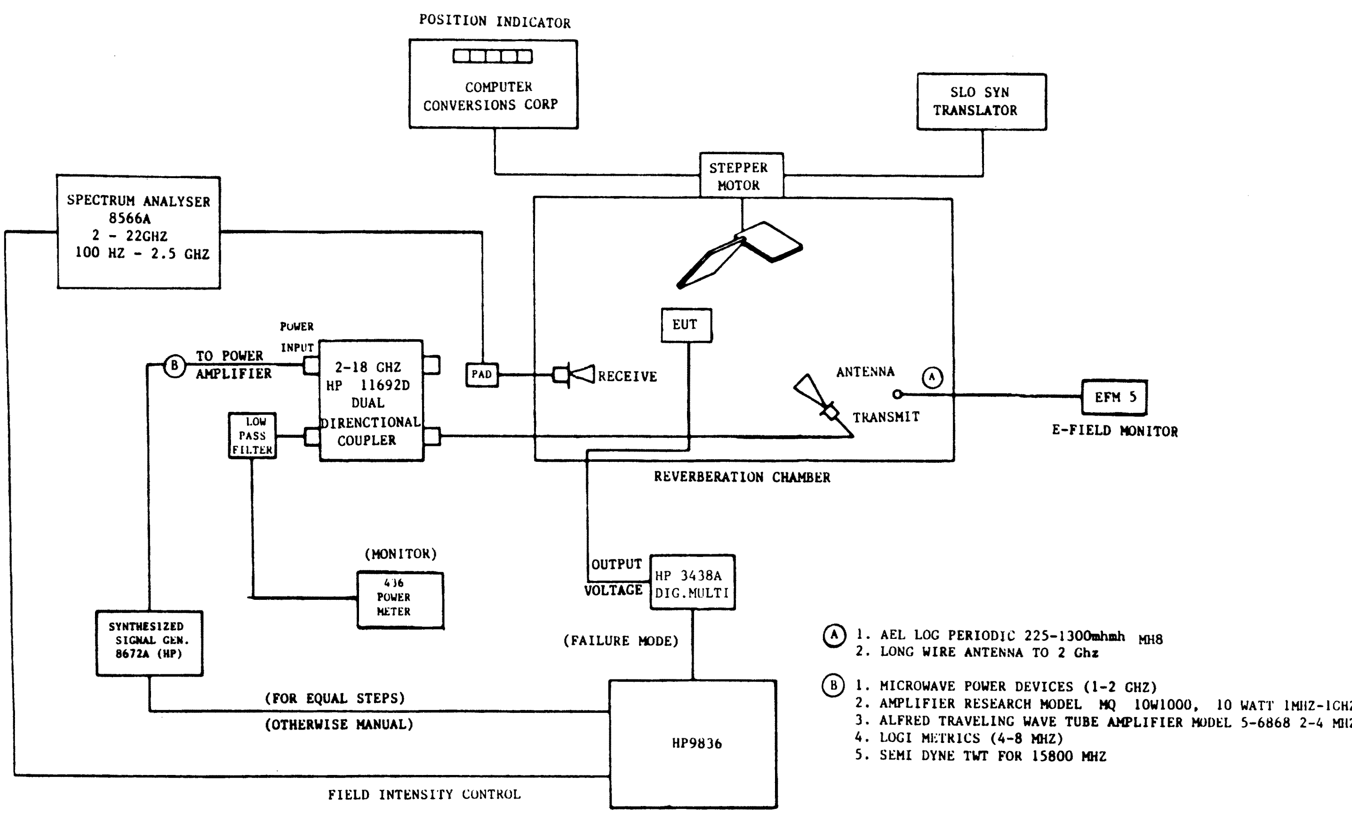

Fig. 3. Reverberation chamber test control and instrumentation.

III. EMS Testing of Proximity Switches

EMS testing of proximity switches was performed at the National Bureau of Standards (NBS) at Boulder, CO, in February 1984 [5]. Testing was performed using the TEM cell for frequencies in the 0.2–33 MHz range and a reverberation chamber for frequencies in the 2–18 GHz range. Fig. 2 and 3, show test arrangements for each of the procedures. Instrumentation and test programming for the TEM cell testing were computer controlled using the

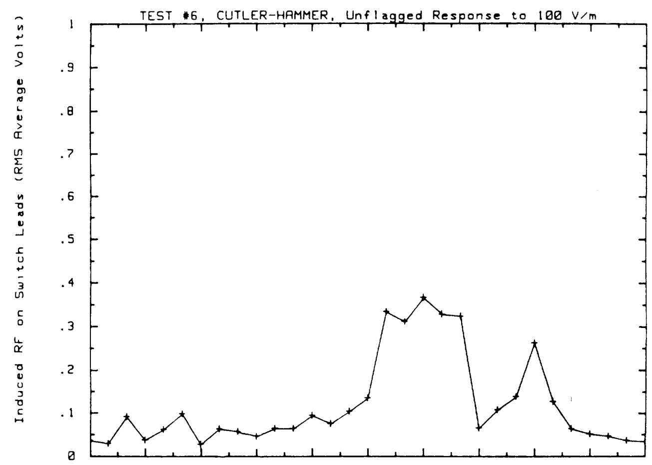

Fig. 4. TEM cell test.

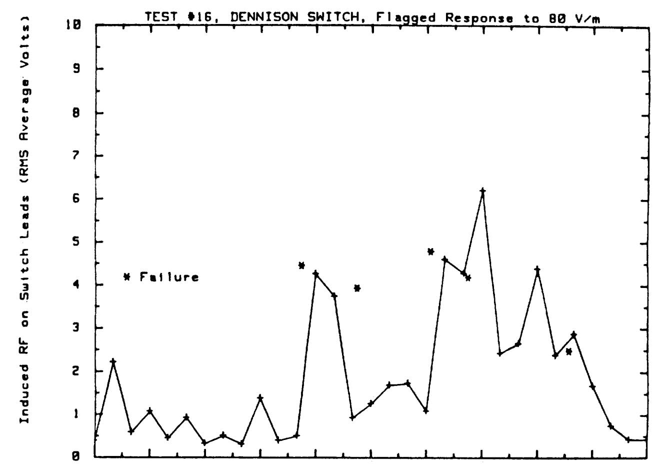

Fig. 6. TEM cell test.

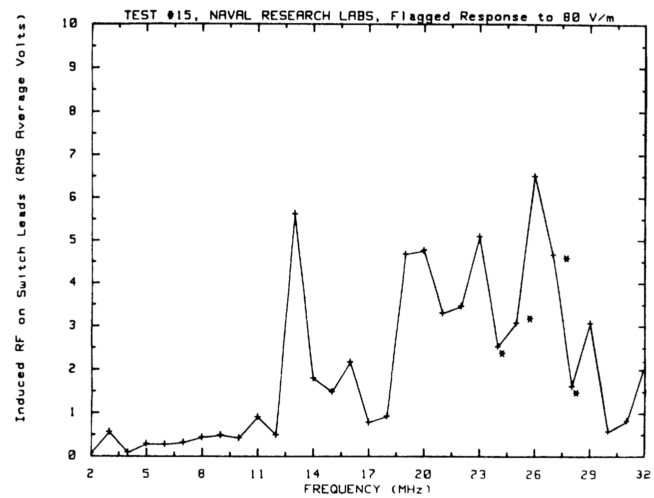

Fig. 5. TEM cell test.

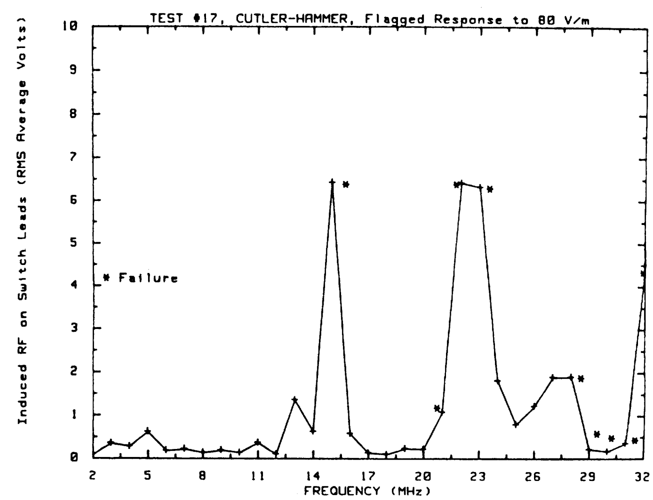

Fig. 7. TEM cell test.

Hewlett Packard (HP) 9836. Instrumentation and control, although planned as computer controlled, were manual for the reverberation chamber.

Results of the tests revealed that certain properties of the proximity switches informed the observer about the cell or chamber in addition to the performance of the switch. Induced voltages through connecting cables caused a change in the output mode in predictable patterns. This defined "failure mode" although not necessarily implying an equipment failure was kept within narrow bounds to enable recognition of susceptibility of the unit under test by the computer system. Induced voltage on the switch leads was calculated and plotted against frequency. Of the various tests performed typical patterns of response are shown in Figs. 4, 5, 6, and 7. Fig. 8 shows the performance of a proximity switch in the reverberation chamber with changing field strength.

It is interesting to note that unique patterns had developed for the various switches and that shifts in output, outside the defined "failure level," occurred within certain frequency ranges and often coincided with peaks in the induced voltages. Fig. 4 and 7 show results of TEM cell tests using the same switch, but with different exposed cable lengths. The length of exposed cable was 38 cm in Fig. 4 (Test #6) and 114 cm in Fig. 7 (Test #7). It is significant that the increase in exposed cable caused a change in the pattern of response and induced "failure modes" in the switch not experienced in tests with the shorter exposed cable.

Fig. 8, showing a pen recording of the output voltage of a switch, gives ample evidence of a "failure mode" as the field strength was increased from 25.5 to 53.5 to 105 V/m. The recording was made while the unit was in the reverberation chamber and exposed to a frequency of 225 MHz.

IV. The Nature and Properties of Proximity Switch Circuits

How the offset in output voltage of the proximity switch occurs is important in understanding how to use the phenomenon when comparing various test methods. Proximity circuits consist of semiconductor devices which are prone to produce "spurious" responses when exposed to an RF environment. As shown above (Tests 6 and 17) voltage is induced in the cable and is conducted into the internal circuits. As quoted in (6), "The RF voltages are rectified by the semiconductor devices, and offset voltages and currents are produced to upset the operation of the

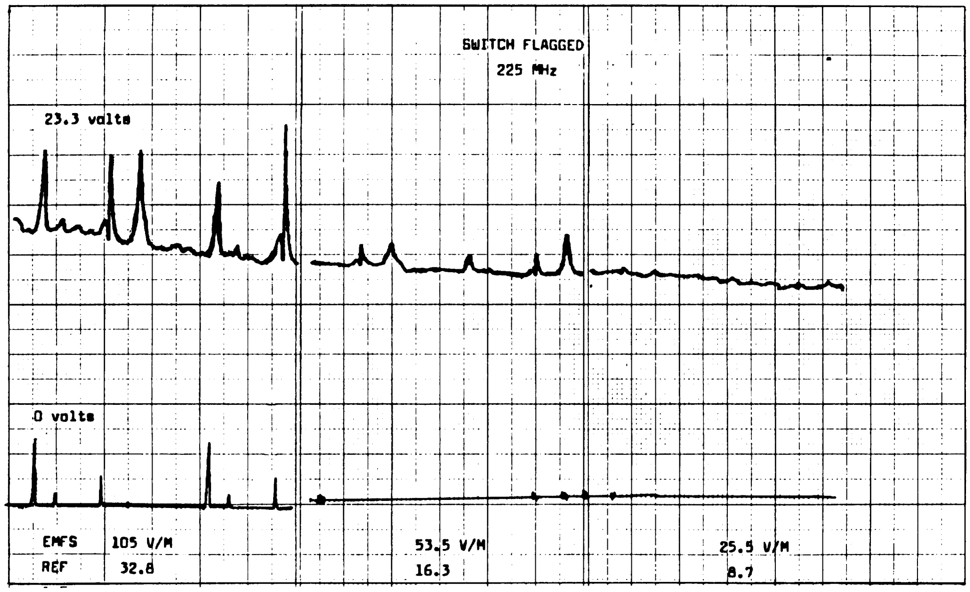

Fig. 8. Reverberation chamber test.

electronic circuits," This relationship of connecting cables and circuitry is further discussed in [7]–[12]. Detector action in proximity switches is predictable and the effects on output voltage are repeatable.

V. Conclusions

By using a known device such as a proximity switch, acting as a detector, information regarding the device's performance in various environments can be compared to determine the equivalence of the test environments. It has been shown that proximity switches have useful properties that can be used to inform the observer about the RF environment to which it is exposed. The change in output mode is a simple method of "fingerprinting" that environment.

By performing the same tests with a proximity switch using various laboratory chambers and using an outdoor/ground plane test site, the test results can be compared to determine the equivalence of the methods.

Acknowledgment

M. Crawford set up and ran the tests. With his TEM cells and his guidance, he provided a unique opportunity for testing the proximity switches. G. Koepke wrote the Software for data acquisition. It was a pleasure being a part of their working group.

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