

ELECTROMAGNETIC VULNERABILITY TESTING OF AIRCRAFT USING MODE-STIRRED TECHNIQUES

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ABSTRACT

Electromagnetic vulnerability (EMV) testing is typically performed on aircraft using a standard method where the aircraft is directly radiated by an antenna, with no mode-stirring. Since a standing wave pattern will cause peaks and nulls in the field inside the aircraft, many antenna aspect angles should be used to assure that all equipment on board the aircraft is exposed to the appropriate field. However, this is very time consuming and often not feasible. As a result, some equipment on the aircraft may not be exposed to the intended field level. Using mode-stirred techniques during EMV testing will provide improvement in field distribution throughout the aircraft so that the need to use several aspect angles would be eliminated, and a more controlled and thorough test would result. This study was performed to demonstrate this, by comparing cable coupling and field level measurements on a P-3 and an E-2C during EMV testing using both the standard method and mode-stirring.

INTRODUCTION

Several studies have been performed by Hatfield, et al, [1] and Crawford, et al, [2] to determine the reverberation characteristics of aircraft. They have demonstrated good reverberation characteristics of a Boeing 707, a Boeing 757, a Cessna 404, and a Beech U-21 even though the Q of each aircraft was considerably less than that of a mode-stirred chamber. Their data showed that the aircraft compartments were clearly complex cavities similar to the inside of a mode-stirred chamber. From their work, it follows that box level testing of aircraft equipment in a mode-stirred chamber is actually more realistic than in an anechoic chamber since the inside of an aircraft and a mode-stirred chamber are both complex cavities. It also can be concluded that advantages should be obtained if EMV testing was performed using mode-stirred techniques.

The presently used standard method of EMV testing uses many positions of the transmit antenna outside the aircraft in order to ensure that the equipment inside the aircraft is adequately tested. An antenna radiating into an aircraft with no mode-stirring sets up a standing wave pattern so that there are peaks and nulls in the field throughout the aircraft. If only one transmit antenna aspect angle is used at a given location outside the aircraft, it is possible that some of the equipment on board the aircraft may not see the intended

field level. Therefore, several antenna aspect angles are often used at each transmit location around the aircraft. This is very time consuming. Even when many aspect angles are used, it is unlikely that all equipment on the aircraft will be subjected to the same uniform field.

In the Navy Fleet, when there is an electromagnetic field outside the aircraft, the field that gets inside the aircraft will have peaks and nulls in the field levels. But, as conditions change from one moment to the next, since the Fleet is generally not a static situation, those peaks and nulls in the field will move. Therefore, if a piece of equipment happens to be in a low point of the field during an EMV test, there is no guarantee that this will always occur in Fleet use. If mode-stirring could provide a more uniform field inside the aircraft with one or a few transmit antenna locations, much time and money could be saved, and, at the same time, provide a more thorough test. Therefore, this study was performed to demonstrate the effects of mode-stirring during an EMV test, by comparing the field levels and cable coupling throughout the aircraft, with and without mode-stirring. This study consisted of two parts, testing on a P-3, and a simulated EMV test on an E-2C.

During EMV testing of a P-3 using the standard method, a susceptibility was found at 425 MHz. The test was repeated at 425 MHz using mode-stirring in order to determine its effects on finding the susceptibility of the equipment. Current probes were placed on several cables in the aircraft and the induced currents were compared during the EMV test with and without mode-stirring.

On an E-2C, field probe measurements were performed throughout the aircraft during a simulated EMV test. A transmit antenna was located outside the open entrance door of the E-2C to simulate a typical antenna position used during an actual EMV test. Three mode-stirrers were placed on the aircraft. Eight field probes were placed throughout the aircraft close to different equipment, in order to measure the field levels each piece of equipment was exposed to. Field probe readings were recorded with and without mode-stirring on the aircraft from 100 MHz to 10 GHz. Also, three different transmit antenna aspect angles were used to demonstrate the variation of the field levels throughout the aircraft with even slight changes in antenna placement during EMV testing when mode-stirring is not used.

TEST METHOD

P-3 Testing

The P-3 is a large Navy aircraft with a length of 116 feet, a wingspan of 100 feet, and a height of 34 feet. A susceptibility of the Control Group Assembly (CGA) for the ASQ-208 Digital Magnetic Anomaly Detection System had been found during a standard EMV test at 425 MHz. The test was repeated to determine the effects of mode-stirring on the susceptibility and on the current probe measurements of certain cables.

The transmit antenna was placed outside the aft observer window. A mode-stirrer measuring 3 feet in diameter was placed inside the aircraft near the aft observer window. Current probes were placed on cables in 6 different locations to measure the induced currents. These locations were as follows: two Inertial Navigation System (INS) wire bundles which were in direct line of sight of the transmit antenna; two INS wire bundles which were near the floor; a CGA cable; and the flux valve wires. The latter two were in the vicinity of the aft observer window, but were not in the direct line of sight of the transmitting antenna.

The peak measurements from the current probes were recorded for one revolution of the stirrer. The stirrer was turning at 1 rpm. The CGA's functions were monitored. The mode-stirrer was then removed and the test was repeated without stirring.

E-2C Testing

The E-2C is 58 feet long, has a wingspan of 81 feet, and a height of 18 feet. The aisle inside the aircraft is only 18 inches wide at many locations. A transmit antenna was located outside the open entrance door of the E-2C to simulate a typical antenna position used during an actual EMV test. Three mode-stirrers were placed on the aircraft; one inside the doorway, one in the cockpit, and one at the opening to the aft compartment. The stirrer in the doorway measured approximately 3 feet in diameter and the other two measured 1.5 feet. The latter two were smaller simply due to the limited amount of room available inside the E-2C. Eight field probes were placed throughout the aircraft close to different aircraft equipment, as shown in Figure 1, in order to measure the field levels each piece of equipment was exposed to. For frequencies above 1 GHz, probes were placed only at locations 2, 3, 5, and 7 due to the limited availability of high frequency probes. For both with and without mode-stirring, readings were taken with the field probes in identical locations at the same frequencies from 100 MHz to 10 GHz. The same transmitted power was used for both sets of measurements at each frequency. Since this study was mainly concerned with relative measurements, the absolute transmitted power was not monitored.

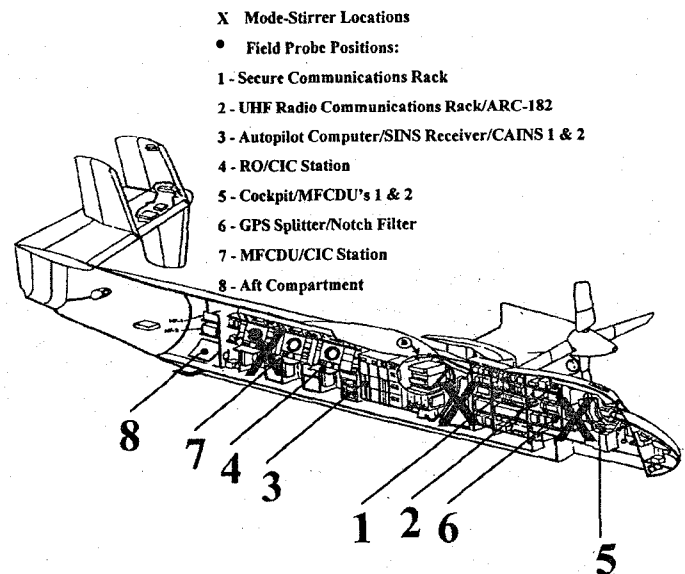


Figure 1.

Field probe measurements were recorded in the frequency range of 100 MHz to 1 GHz with the transmit antenna position at 0° (see Figure 2) for both mode-stirring and the standard method. In the frequency range of 1 to 10 GHz, the antenna was positioned at 0° , 5° and at 45° for the standard method, but only at 45° while mode-stirring. This was due to the limited amount of time that the aircraft was available for testing.

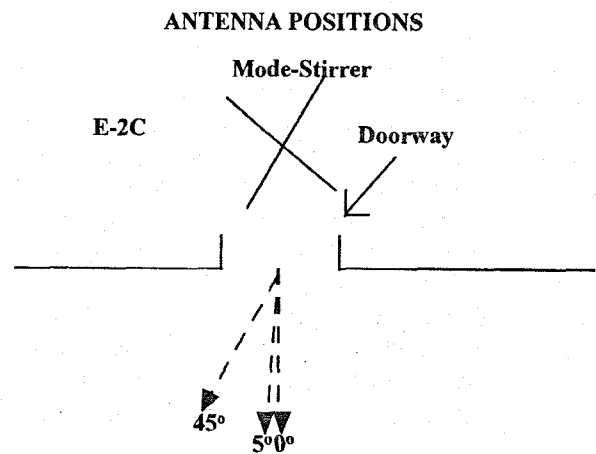


Figure 2.

RESULTS

P-3

Comparing the induced currents on various cables of the P-3 clearly illustrate the effects of mode-stirring. See Figure 3. Current probe locations A and B show very little difference whether or not mode-stirring was used. This was

expected since both locations were in the direct line of sight of the transmit antenna. The greatest effect of mode-stirring was seen at locations D and E. These were the INS wire bundles which were near the floor. Mode-stirring increased these induced currents by 8 and 12 dB. These cables may not normally be directly exposed to the RF field during a standard EMV test, but, certain Fleet environment scenarios could cause an RF field to enter the P-3 at such an angle where the resulting standing wave pattern would cause a greater induced current on certain cables than normally caused during an EMV test.

The susceptibility of the CGA observed during the standard EMV test was also observed when mode-stirring was used. The susceptibility was intermittent as the stirrer turned indicating how the CGA might be affected by different entrance angles of the RF field.

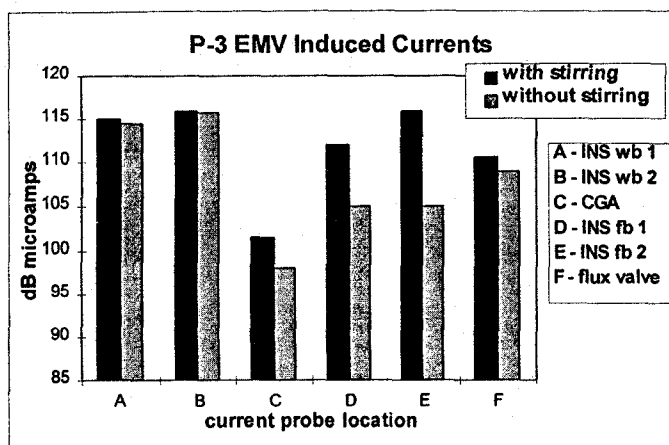


Figure 3.

E-2C

The highest field levels were observed at probes 1-4 which were located in approximately the middle third of the aircraft, closer to the entry point of the field. Since the internal E-2C aircraft cavity is as narrow as 18 inches in many locations and, therefore, is not an ideal shape for a mode-stirred chamber, it was difficult to distribute the field to the locations of probes 5-8. Since the field levels were much lower at probes 5-8, the results for each group of probes will be discussed separately.

Figures 4 and 5 show the field levels for all eight probes for the standard method and the mode-stir method, respectively, in the frequency range of 100 MHz to 1 GHz. Probes 1-4 are in solid lines and probes 5-8 are in dashed lines. Overall, the measured field levels were significantly higher when mode-stirring was used. It is important to note that the field probe measurement system has a slow sampling rate compared to an antenna/spectrum analyzer measurement system and it is likely that the highest peaks were missed.

Therefore, the peak field levels seen by each field probe during mode-stirring may actually have been higher than those recorded.

The fields on the aircraft are not actually higher when mode-stirring is used, but, the peaks of the field are moved throughout the aircraft cavity during one revolution of the stirrer, increasing the likelihood of measuring them with a field probe or antenna. At the same time, it increases the likelihood that each piece of equipment on the aircraft will be exposed to the worst case field level. When mode-stirring is not used, those peaks still exist on the aircraft, but the probability of seeing them with a field probe, antenna, or by a particular aircraft component is small.

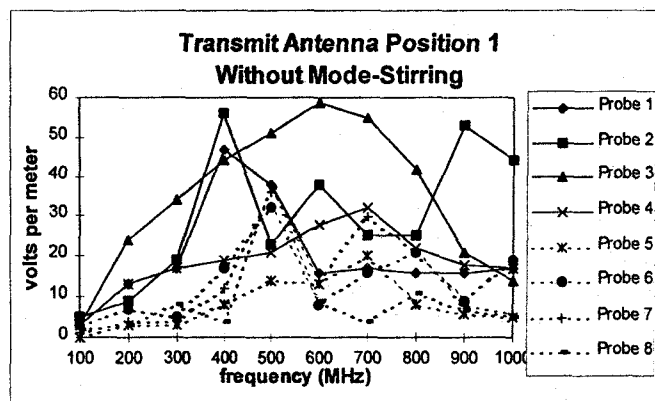


Figure 4.

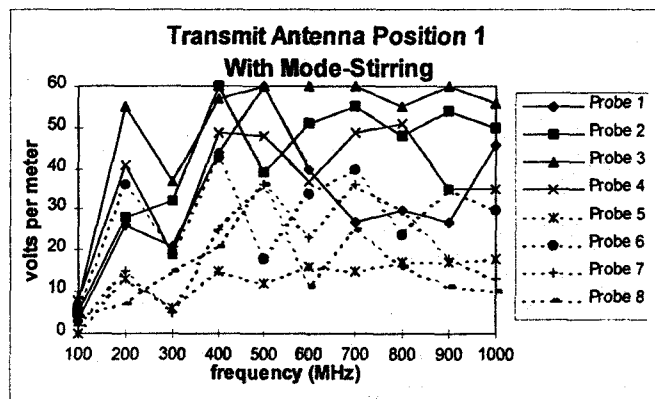


Figure 5.

Figure 6 shows the average measured field levels at probes 1-4 with and without mode-stirring from 100 MHz to 1 GHz. When mode-stirring was used, the average measured field levels were typically 15 to 20 V/m higher. For all frequencies except 100 MHz, the average measured fields were statistically significantly higher with a 95% confidence level when mode-stirring was used. Also, the standard deviations were smaller when mode-stirring was used.

showing that the field was more uniformly distributed throughout the aircraft.

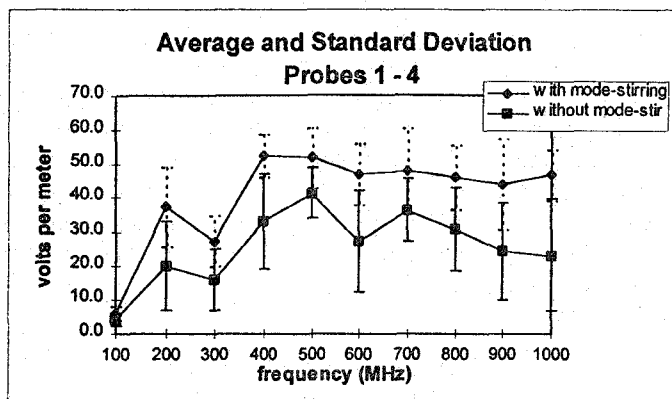


Figure 6.

Figure 7 shows the average measured field levels at probes 5-8 with and without mode-stirring from 100 MHz to 1 GHz. Even though the field levels were lower for these probe locations, the average measured field levels were still significantly higher when mode-stirring was used. It is important to note that if the entire aircraft was placed inside a mode-stirred chamber rather than just stirring the field inside the aircraft, better field distribution would be achieved when there are other locations for the field to enter in addition to the entrance doorway.

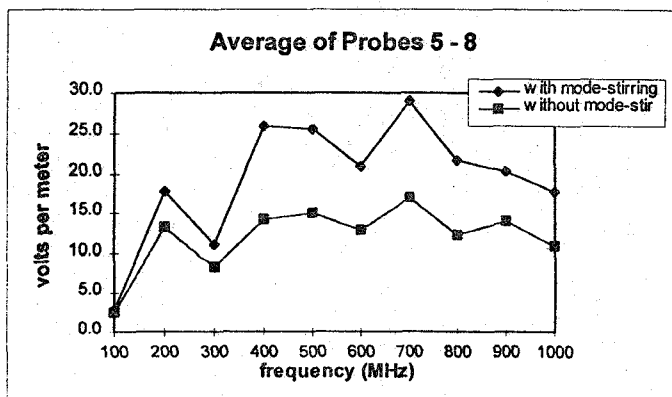


Figure 7.

In the frequency range of 1 to 10 GHz, data was recorded from only 4 probe positions due to the limited availability of high frequency probes and the time constraints of the test. Figures 8 and 9 show the fields at probes 2 and 3 when the transmit antenna was at 45° using the standard method and the mode-stir method, respectively. The measured field levels were generally higher for both probes when mode-stirring was used, and there was less difference

between the two probe readings. Probes 5 and 8 (data not shown) had lower field levels than probes 2 and 3, for both with and without mode-stirring, but the levels were higher when mode-stirring was used.

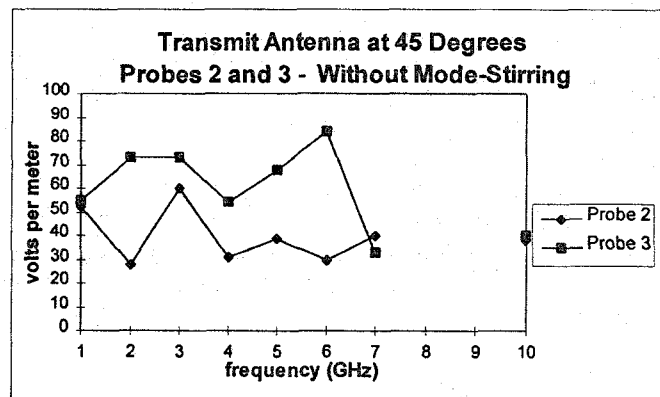


Figure 8.

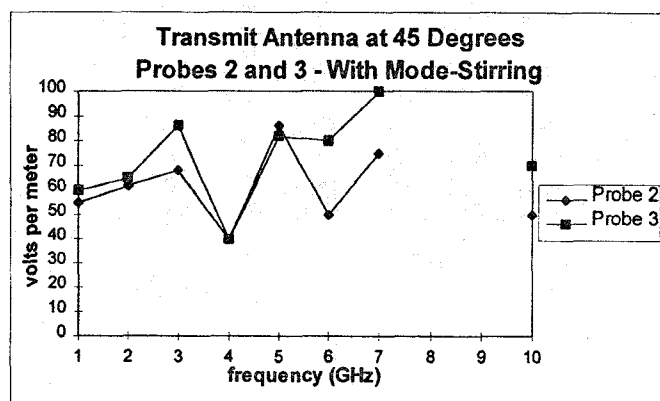


Figure 9.

The effect of changing the transmit antenna angle when using the standard method is apparent in Figures 10 and 11. Figure 10 shows the field levels measured at probe location 2 when the transmit antenna was at 0°, 5°, and 45°, as illustrated previously in Figure 2. There is clearly a significant effect on the field levels even when the antenna aspect angle was changed by only 5°. At 6 GHz there was almost a 70 V/m change in field level with only a 5° change in transmit antenna position. This illustrates the large effect a small change in test setup can produce and also how important it is to use many transmit antenna aspect angles and positions when standard EMV testing is performed. Figure 11 shows the field levels at probe position 3 with the three different transmit antenna angles. Again, it is clear that even a slight change in antenna position significantly affects the field level at a given probe location.

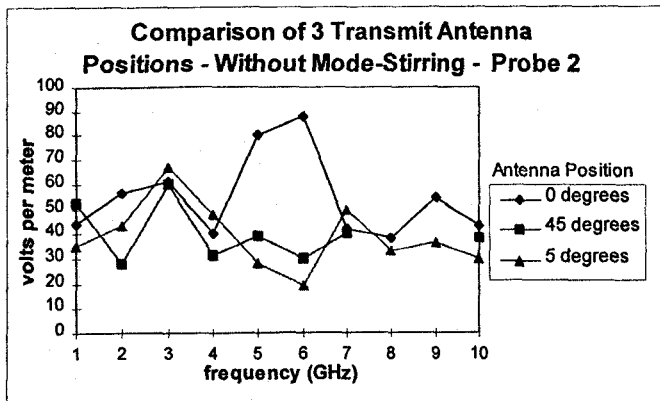


Figure 10.

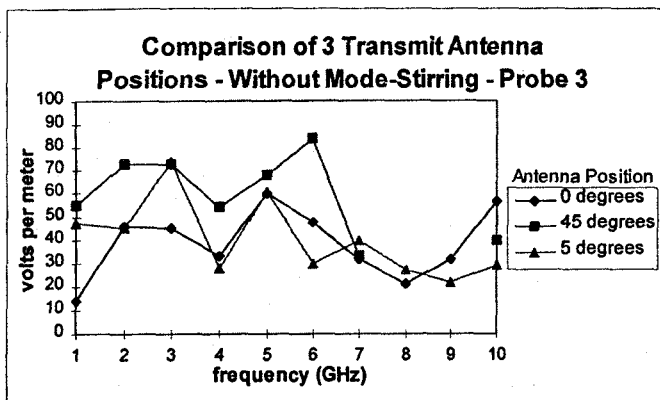


Figure 11.

CONCLUSIONS

In conclusion, comparing the field level measurements with and without mode-stirring clearly indicated a significant improvement in field distribution throughout the aircraft when mode-stirring was used. Even on the E-2C, where the size and shape of the internal cavity theoretically provided adequate modal density only above 300 MHz, and the two smaller mode-stirrers provided effective mode-stirring only at frequencies above 650 MHz (as determined from equations and guidelines in reference [3]), the data showed improved field distribution at frequencies as low as 200 MHz.

The data also clearly demonstrates that there is great uncertainty in the field level at the location of any particular piece of equipment, for a given transmit antenna location, when the present method of EMV testing is used. Many transmit antenna aspect angles must be used to ensure that all equipment on the aircraft is exposed to the intended field levels. If not, it is possible that EMV testing could be performed and some equipment could exhibit no susceptibilities, only to have a susceptibility show up while in Fleet use. Using many different aspect angles of the field

transmitting antenna would improve the chances that each equipment or system on the aircraft was exposed to the intended field. However, this is very time consuming and, therefore, very costly. Since mode-stirring greatly improves the field distribution throughout an aircraft, utilizing mode-stirred techniques could save much time and money while providing a more thorough test.

Further investigation to optimize the use and efficiency of mode-stirring during EMV testing of various aircraft should be performed. An aircraft size mode-stirred chamber would be ideal to further improve our EMV testing of aircraft. The use of aircraft size mode-stirred chambers would be very useful for EMV testing and other similar applications.

References:

- [1] Michael O. Hatfield, Gustav J. Freyer, D. Mark Johnson, Charles L. Farthing, "Electromagnetic Reverberation Characteristics of a Large Transport Aircraft." Naval Surface Warfare Center, NSWCDD/TR-93/339, July 1994.
- [2] David A. Hill, Myron L. Crawford, Robert T. Johnk, Arthur R. Ondrejka, Dennis G. Camell, "Measurements of Shielding Effectiveness and Cavity Characteristics of Airplanes", NISTIR 5023, July 1994
- [3] Myron L. Crawford, Galen H. Koepke, "Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements", NBS Technical Note 1092, April 1986