THE APPLICATION OF LOW LEVEL SWEPT RF ILLUMINATION AS A TECHNIQUE TO AID AIRCRAFT EMC CLEARANCE

A new technique measures the transfer function relating the external RF fields to equipment loom currents. This data can be used in aircraft clearance procedures.

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INTRODUCTION

For several years, the RAE has been involved in research into new EMC test methods. In conjunction with A&AEE and AES4c, MOD(PE), the RAE has recently produced an EMC specification for avionic equipment to be used as a base document for future projects.[1] The main susceptibility test developed for that specification was bulk current injection (BCI), which has been gradually developed to a degree such that it can provide information to aid aircraft clearance.[2] Recent joint trials between RAE and A&AEE have further enhanced the use of the test for complete aircraft clearance purposes.

Before it could be used for aircraft clearance, a technique had to be developed to measure the transfer function relating the external RF fields to equipment loom currents. Since the transfer function relates cable currents to the external field, the bulk currents causing equipment malfunction can be readily related to a field that would cause malfunction.

This requirement has been met by the simple low level swept field technique outlined in this article. Apart from providing the correlation data, this technique also enables the determination of the worst case aircraft configuration and accurately measures any resonant coupling frequencies. The latter can then be used to confirm high field tests to ensure that worst case conditions are measured.

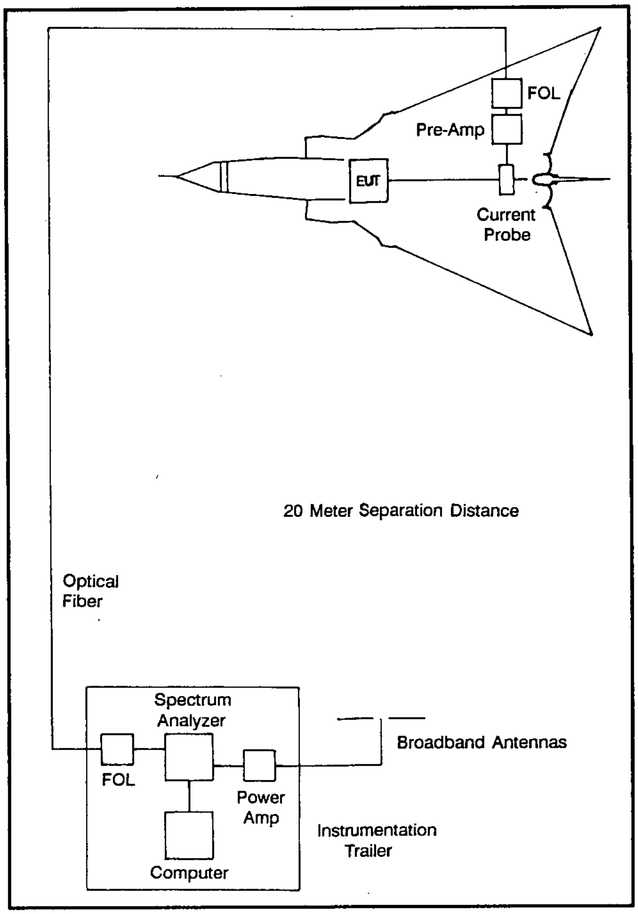

Figure 1. Measurement of RF Currents in a Low Level Swept Field.

REQUIREMENTS

The normal spot frequency high field tests used as part of the aircraft EMC clearance procedure were too slow and cumbersome to provide the correlation data and did not give complete frequency coverage. The new method had to be portable, enabling evaluation of aircraft at any site, and yet be capable of uniform illumination of the whole aircraft.

The measurement had to continuously cover the frequency band of the BCI test, yet accurately determine the frequency of any resonances where maximum coupling occurred. Since it is essential to sweep the specified frequency band, the field had to be sufficiently low level to minimize interference to other users, but high enough to produce a measurable current flow in the aircraft's wiring looms. To further minimize interference and test costs, the technique had to be rapid -- this meant it had to be fully computer controlled with computer storage of the data.

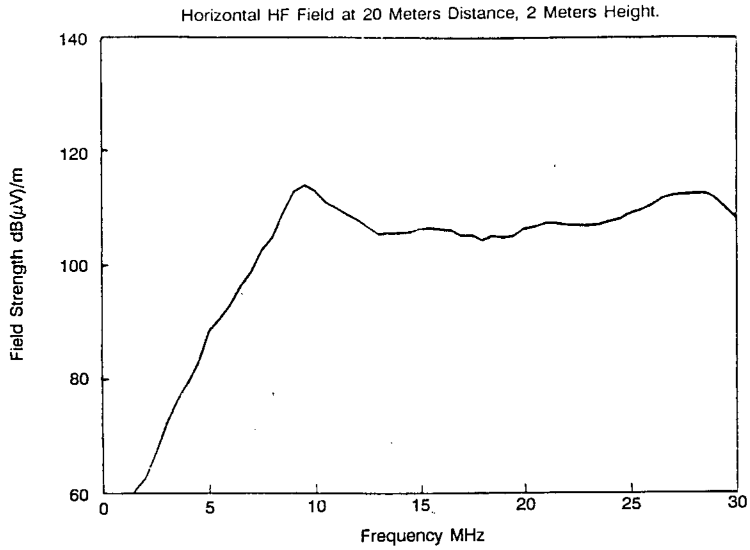

Figure 2. Typical Horizontal Field Strength in the HF Band.

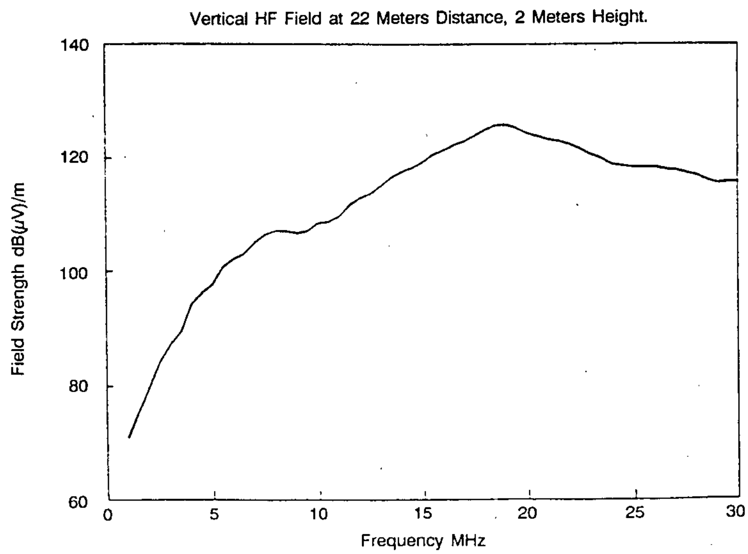

Figure 3. Typical Vertical Field Strength in the HF Band.

TEST METHOD

The test consists of two phases. Firstly, the field generated over the measurement frequency range at the location of the aircraft (prior to its installation) is measured, and secondly, the currents induced in the aircraft's wiring looms by the field are determined and normalized to a unit field strength. Figure 1 shows the test layout for the measurement of induced currents.

The radiating antenna is placed as far as possible from the intended location of the aircraft to provide uniform illumination over the required test area. A compromise must be made between having a high enough signal to produce measurable current flow on the aircraft wiring and yet not so high as to cause interference to other spectrum users. With the present system described here, the separation distance is at least 20 meters from the center of the test site. This produces less than a 1 dB variation over the length of a fighter aircraft. A measuring antenna is situated at the location of the aircraft prior to its placement. (The antenna normally used is a DDot sensor which is effectively a broadband short dipole. A BDot sensor is also used to assess the magnetic field.) The received signal is fed via a 1 GHz bandwidth fiber optic link to the input of a computer controlled spectrum analyzer; the whole measurement is computer controlled. The fiber optic link is essential to provide isolation and prevent stray pick-up problems. The head of the fiber optic link is placed as close as possible to the receive antennas to keep the length of the interconnecting cable short.

The test field is radiated by various antennas which are selected depending on the frequency range. For the band 2 MHz to 30 MHz, a "fat dipole" nominally tuned to 10 MHz is

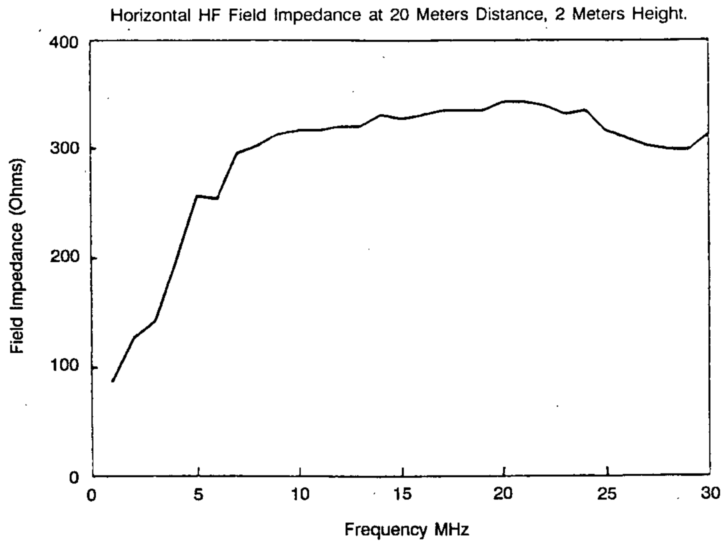

Figure 4. Typical Wave Impedance of the Horizontal Field.

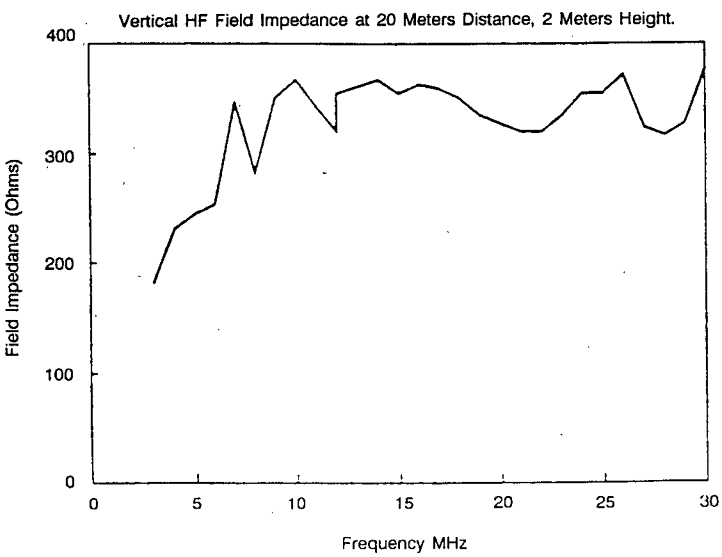

Figure 5. Typical Wave Impedance of the Verticial Field.

used. Figures 2 and 3 show typical measurements of the field generated by this antenna at 20 meter range for vertical and horizontal polarizations. As can be seen, the field is free of deep resonances, and field strengths of up to 1 V/m are obtained. Figures 4 and 5 show the wave impedance of these fields which, within measurement error, do not deviate excessively from that of free space down to 7 MHz. The antenna is fed via a broadband balun and a 100 watt broadband power amplifier. In the band 30 MHz to 200 MHz, a biconical antenna is used, and from 200 MHz to 1 GHz, a log conical antenna is used. This latter is circularly polarized, whereas the other antennas are linearly polarized and separate runs must be made in each polarization to ensure that the maximum coupling is measured. The antennas presently used are to be revised with the intention of using no more than two to cover the complete frequency range.

The signal to the transmitting antenna is derived from the tracking generator output of the spectrum analyzer and amplified to the required level by means of a linear power amplifier. The power required depends on the coupling to the aircraft looms -- the higher the coupling, the less the transmitted power to produce a measurable signal. The output power from the amplifier is measured by an in-line directional coupler, which is automatically interrogated by the computer. This information is stored to ensure that the same power is used for all the runs. The same power used for calibrating the test volume must be used for measuring the induced current. The computer measures the field induced at the test site over the frequency range of the test (with antenna changes as necessary) and stores this calibration data on a disk. This data is used to normalize the induced loom currents to any required reference field strength.

After calibrating the pan, the measuring antenna is replaced by the aircraft and current probes are placed on the looms to be monitored. A four input fiber optic link is used to connect the current probes to the spectrum analyzer; the software sequentially measures the currents induced onto the four looms. Recently, the software has been modified to drive up to three fiber optic links enabling twelve looms to be monitored at a time. The fiber optic link connection to the aircraft is essential to preserve the aircraft screening and to provide isolation.

To maintain isolation, the aircraft is usually tested while unpowered, as the connection of ground power and hydraulics to the aircraft produces erroneous results due to the coupling of the field into these systems and to the aircraft. It could be argued that the system should be powered for these measurements to give the normal impedances at each end of the line. However, if the loom under test is a multi-wire type, this effect is not as significant as extraneous cables being connected to the aircraft. If the loom under test is of only 1 or 2 wires leading, for example, to a relay, then being unpowered could produce significant errors. The optimum solution is to use aircraft engine power but this is expensive and hazardous and hence is only performed as a confirming test.

With the probes in place, the currents induced on the looms as a result of the low level swept field are measured and normalized to the desired field strength using the calibration figures stored previously. The results can be plotted or stored for later evaluation.

Because of the inherent noise floor of the fiber optic link, miniature quad preamplifiers have been developed to improve sensitivity below 5 MHz and these are situated between the current probes and the fiber optic link transmitter head.

The test is repeated for several orientations of the aircraft and for other stores loading if a worst case value of induced current is required. The time required for each run over the complete frequency range is on the order of 5 to 10 minutes per loom, compared with the present times of nearly 2 hours for conventional high power testing. It therefore offers considerable time advantages.

Figure 6 shows typical results with the currents induced for a normalized field of 1 V/m for both vertical and horizontal polarizations. Although the horizontally polarized field usually produces the highest currents, this is not always true and for the results shown, the vertical field has produced the highest currents over large parts of the frequency band. This shows how essential it is for both polarizations to be measured.

The results for the various orientations and stores configurations are superimposed to enable a worst case current profile to be produced for each loom for comparison with the BCI results.

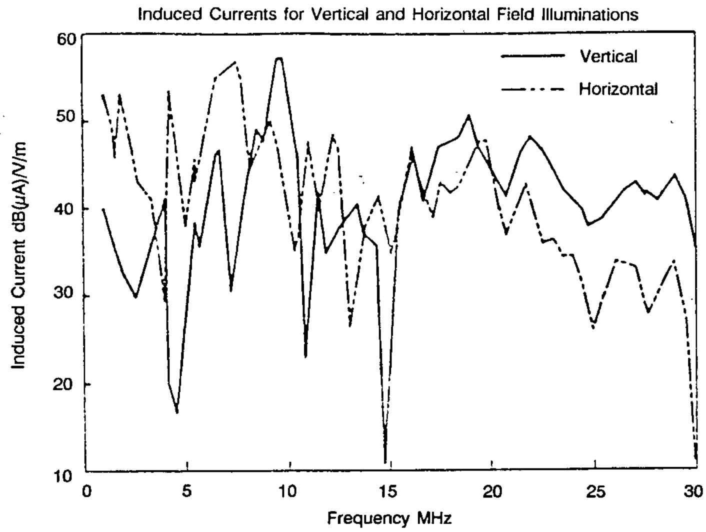

Figure 6. Currents Induced on a Loom by Vertically and Horizontally Polarized Fields.

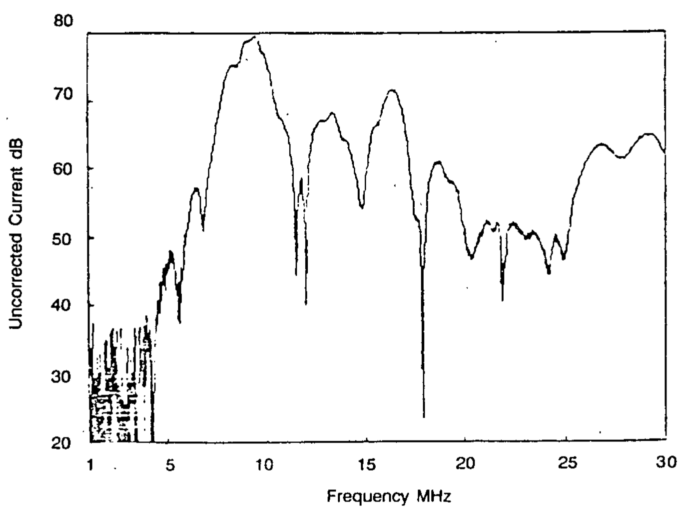

Figure 7. Typical Plot of the Uncorrected Induced Current in a Loom.

SOFTWARE

To provide the required speed of test and rapid result evaluation, the whole test is computer controlled by an HP200 series computer. Three options are provided -- the measurement of power to the transmitting antenna, measurement of the resultant field, and measurement of the induced currents. The correction factors for the various sensors used to make these measurements are stored within the program.

At the start of the measurement, softkey options enable the frequency range and the frequency incremental steps to be selected. These two parameters determine the number of measurement points. Although the frequency coverage is continuous, measurements are made in a series of incremental steps with the maximum and minimum values in each step being recorded. This technique ensures that all resonances are accurately measured without recording excessive data. The smaller the step size, the greater the frequency measurement accuracy. Normal step sizes used are 1 MHz in the HF band and 5 MHz to 10 MHz above this.

The results of the measurements are hard copied as well as stored on disk. As a back-up measure, after the stepped measurement run is completed, the spectrum analyzer display is set to cover the whole frequency band of the test and this raw data is recorded. This enables verification of any anomalies in the stepped data which may have been caused by extraneous transmissions, as well as providing a complete record for future use. Figure 7 shows a typical plot of the uncorrected current. This illustrates the need for continuous swept measurements with the presence of sharp resonances in the induced current. Below 5 MHz the signal is below the noise floor of the analyzer.

Comparison measurements have been made of currents induced by high level illumination to those extrapolated from low level illumination to determine whether the extrapolation was valid. For multi-line looms this has been found to be so.

INTEGRATION OF THE TECHNIQUE INTO A REVISED CLEARANCE PROCEDURE

The revised approach[3] consists of four parts. The objective of the first is to determine the malfunction levels of the equipment over the complete frequency range. The objective of the second is to determine the coupling between external electromagnetic fields and cables inside the aircraft. The objectives of the third are to determine the full threat cable current and then to determine the equipment's susceptibility to these levels. Finally, as a confirmation test, the aircraft is exposed to high fields.

The four parts involve testing as shown below:

1. The equipment is tested using the bulk current test method during its qualification testing; this is already being done for certain types of equipment. This test will enable the electrically weak cable looms to be highlighted and possible failure modes to be determined. During testing, the current at malfunction for each frequency on each loom is measured and recorded for later comparison with the results from the whole aircraft tests. This enables equipment testing and hardening to be undertaken during the development phase and before an aircraft is available. The power required by the injection probe to cause malfunction is recorded and compared with the limits set by the EMC standard.

2. The aircraft is placed in a uniform low-level swept RF field as described above and the loom currents are measured on the system under test over the required frequency band. The currents measured can be used to determine what currents would be present on the looms if the full threat field, including safety margins, were present. This is conducted for several aircraft orientations and stores configurations to produce worst case profiles for the various looms being measured.

3. The system is tested using BCI with the test levels derived from Part 2. Every loom is tested in the system by injecting and measuring the induced current on each loom in accordance with RAE Tech Memo FS(F)442. If a loom branches, each branch is also tested. The level injected is limited to that which causes the defined malfunction or by an upper power limit. The number of looms tested can probably be reduced by comparing the extrapolated currents with the currents at malfunction obtained in Part 1. If they are significantly lower (20 dB for example), that loom could be eliminated.

4. Confirmatory high field illumination tests of the whole aircraft are made using the worst case configurations determined in Part 2 to confirm the validity of the results. These can only be performed if the field is high enough to cause malfunction of the aircraft systems.

One shortcoming of this technique is that, until recently, the BCI test in Parts 1 and 3 has been applied to looms individually, which was not the same as when the whole aircraft was illuminated. However, it is feasible to inject on several looms at once. If, during aircraft illumination, the currents at the various connectors on a LRU are measured, it is possible, under computer control, to inject the same ratio on each loom, simultaneously using multiple injection and monitoring probes. It is probably easier to do this on a full system rig than on the aircraft since accessibility is much better. Multiple injection is also required for systems having a built-in redundancy capability. For example, single loom injection tests on a full authority fly-by-wire aircraft showed the faulty channel was voted out, allowing the system to continue normal operation; in an external field all the channels could be affected simultaneously.

Multi-loom injection techniques have been developed and used successfully on aircraft. The software allows for constant power to be fed to the injection probes, or constant current to be induced on the wiring looms, or the level of the induced currents to be maintained at the same ratio as produced by low level field illumination (using the worst case profile).

In terms of power, the current injection technique efficiently gives the desired injection current. Typically, between 5 and 50 watts are needed to produce the currents that would be obtained in a field of 200 V/m in the HF frequency band, depending on loom location. By comparison, the present high field generation facilities would require several hundred kilowatts of power to generate the same field intensity 20 meters from the aircraft. Since BCI couples the electromagnetic energy where it is required, no interference is emitted to airfield or other equipment. Also, the cost of the equipment is much less than that required to produce the equivalent high power fields.

The technique described is more complex than that currently used, but needs to be applied only to flight safety critical equipment or armament systems where a safety implication exists. It does, however, allow clearance to be given to higher levels than those previously possible or practical, and in all probability, gives more consistent results due to the uniform illumination of the aircraft, continuous frequency coverage, and determination of the "worst case" induced current profile.

The main criticism of the technique is that during the BCI tests the current divisions on the wiring looms are not necessarily the same as those produced by the external field. No unique external field configuration exists, and the possible ratio of currents induced in the looms by the action of an external field is probably infinite. It is expected that this procedure will cover the worst case situation with adequate safety margins, since it involves injection on defined looms until upset occurs.

CONCLUSIONS

- The low-level swept technique has been extensively used and refined over the past two years, and has proved to be an extremely useful aid in aircraft clearance procedures.
- The technique enables rapid evaluation of various aircraft and stores configurations for various polarizations and directions of illuminations to produce a worst case profile. This was not practical with spot frequency, high field illumination testing used previously.
- The facility developed at RAE for the test is inexpensive and readily transportable in a small equipped trailer, enabling measurements to be made at remote sites.

FURTHER DEVELOPMENTS AND IMPLICATIONS OF THE SWEPT FIELD TECHNIQUE

Since this is a new technique which produces more information than was previously available, several implications result from its use which will need to be explored in the future. For example, in some cases, a vertically polarized field may induce greater currents into certain looms than does a horizontally polarized field. This may have implications for current aircraft clearances. The techniques for re-clearing aircraft after refitting with new equipment should be re-examined, as should the clearance for the carriage of new external stores.

The production of large amounts of coupling data may require the establishment of a data bank to be used during future clearance activities. This data can also be used to determine the impulse response of the cables. This requires further work to evaluate the use of numerical transforms with no phase information. If this is successful, then the technique could be extended to EMP and lightning testing of aircraft.

ACKNOWLEDGEMENT

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