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A REAL SCALE SIMULATOR FOR HIGH FREQUENCY LEMP

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ABSTRACT : The paper describes the real scale simulator designed by the Centre d'Etudes de Gramat (CEG) to study the coupling of fast rise time Lightning Electromagnetic pulse with a fighter aircraft. The system capability of generating the right electromagnetic environment has been studied using a FDTD computer program.
First data of inside stresses are then shown. A time domain and a frequency domain approach are exposed and compared.

1. INTRODUCTION

Nowadays aircrafts become more and more sensitive to the high frequency electromagnetic pulses generated during a lightning strike event. This is due to the extensive use of both composite material in the fuselage and digital electronic whose susceptibility towards High Frequencies (HF) is important. Recent in flight lightning measurement campaign [1], [2] have revealed significant single current pulses whose rise time can be much faster than the micro second range. Such pulses seem to originate from the re-ignition phase when the lightning channel is already ionized. Their spectrum can show a significant frequency content up to few tens of Megahertz.

It is not yet well established whether this new kind of threat has to be normalized or not and taken into account during qualification process. In order to study the coupling of such high frequencies Lightning Electromagnetic Pulse (LEMP) with inner aircraft cables a simulator has been designed by the Centre d'Etudes de Gramat (CEG).

The fast rise times associated with high current amplitude suggest to use a coaxial return path technique to be able to simulate faithfully the electromagnetic environment created by lightning.

2. OVERVIEW OF THE SIMULATOR DESIGN

The simulator is based upon the coaxial return path technique. This technique has previously been used with Transall and Mirage Scale Model Studies [3]. The aircraft under test is considered as the central conductor of a coaxial line whose outer conductor is made by a set of wires surrounding the aircraft (see fig 1). Under the aircraft the return current is driven through a copper ground plane. The distance between the central core and the return path is adjusted to avoid any air breakdown during the high voltage tests. Two other parameters which are of great importance for the set up of the return wires are the electric field at the fuselage surface and the characteristic impedance of the line. We tried to maintain the second around the fixed value of 50Ω, while the first one is compared with 3D computer calculations (see next section).

The aircraft stands on metallic adjustable posts. Those three posts are situated inside the line. It has been checked that the change in the characteristic impedance due to this configuration does not affect strongly the rise time of the injected current. The current is injected at the nose of the aircraft, the end of the line can be terminated by various charge impedance or short circuited.

The following experiments have been performed using a low level generator (Ic = 500 A). Future works will be proceeded with a variable (5 - 15 kA) high level generator whose rise and decay times will as well be adjustable.

3. OUTER COUPLING

As a first step it seems of the greatest interest to measure the electromagnetic environment created by the simulator using Finite Difference Time Domain (FDTD) computer program. The code called GORFF-VE has previously been used to interpret the data from in flight lightning measurement campaign [4]. The good agreement between real data and numerical calculations has allowed to get a good confidence in the ability of the code to reproduce in flight lightning electromagnetic environment. Hence numerical calculations are now used to validate the simulation tool.

Accurate description of the GORFF-VE 3D code can be found in numerous publications [5], [6].

The current shapes injected at the nose of the aircraft experimentally and numerically are presented figure 2.

Electric and magnetic fields have been measured for various points on the half of the total fuselage by reason of symetry. Measurements have been performed using active sensors and fiber optic link. Mappings of the peak values of the electric and magnetic fields are reported figure 3 and 4.

For a better understanding temporal shapes of the recorded signals are compared with numerical ones. This is only possible using a transfer function technique because of the difference in the experimental and numerical injected currents (see fig 2).

To be consistent and to eliminate the mismatch problems at the aircraft nose, value of the major magnetic field component at the nose (Hy1) is taken as a reference.

Only the time domain derivative is compared for the electric field because the numerical decay time is strongly dependent upon the aircraft capacitance.

Both equations are used :

$$\overset{m\ \mathrm{Grdf}}{H_{y,x}}(\omega) \times \frac{\overset{1}{H_y}\ \mathrm{paris}}{\overset{1}{H_y}\ \mathrm{Grdf}}(\omega) = \overset{m}{MIR}(\omega) \qquad (1)$$

$$- \frac{dE^{n}_{\mathrm{Gaf}}}{dt}(\omega) \times \frac{\overset{\circ}{E}{}_z^{1}\,\mathrm{pars}}{\dot{E}_z^{1}\,\mathrm{Gaf}}(\omega) = d\,\mathrm{MIR}^{n}(\omega) \qquad (2)$$

Fourier transform analysis are performed in the 10^4 - 10^8Hz range. After inverse Fourier transform (1) and (2) are compared with the experimental signals (fig 5, 6). A study of all the experimental points allow to conclude that two zones appear on the aircraft :

- *Booster and back fuselage zone* where experimental recordings are much higher than what is expected from the calculations,
- Everywhere else experimental signals fit quite well the theoretical predictions.

Hence, comparison between the electromagnetic environment created by the simulator and calculated from the 3D FDTD GORFF-VE code indicates that the coaxial return path simulation is appropriate to reproduce the fast rise time lightning electromagnetic stress. Due to the good agreement on the outer electromagnetic peak values and time domain shapes, inner coupling results should be representative of the in-flight situation.

4. INNER COUPLING

Ten different points have been instrumented inside the Mirage aircraft. Six cable currents have been measured and for four points inner fields have been recorded. The levels recorded are significant, six typical recordings are presented fig. 7. As well as time domain measurements, frequency domain measurements have been performed using a vectorial network analyser. From those experiments transfer functions up to 200 MHz, normalized to Hy1 value are deduced (fig. 8).

Using these functions and the Fourier transform of Hy1 at the nose of the aircraft, we have been able to deduce stresses inside the aircraft. Theses stresses are compared with the measured one for four different cases (two currents, two H fields).

As the frequency spectrum of Hy1 is well defined only up to 20 MHz a good agreement can be obtained as long as the inner signal does not contain too high frequencies (HYIPPB, ITPBC). If this is not the case discrepancies are observed (HXIS, ITSER) because the high frequency exitation is not the same in the two cases (fig 9). As the frequency spectrum of Hy1 is limited to 20 MHz (due to the 80 dB dynamic measurement range), only noise is then recorded after this limit and the frequencies higher than 20 MHz are then altered. Limiting the analysis up to 20 MHz then cancel out those frequencies.

5. CONCLUSION

We have presented a real scale simulation tool able to reproduce quite faithfully the electromagnetic environment generated by fast rise time lightning pulses.

The first series of measurements inside the aircraft have been presented. They show the limitations of the frequency domain analysis. Still more work has to be done on a more realistic aircraft and at real threat to define Thevenin equivalent generators for the stress on the inner cable bundles and to compare those values with advisory circular recommended waveforms for aircraft certification.

A link between Thevenin generators and cables bundle currents would also be helpful for future qualification tests.

AKNOWLEDGEMENTS

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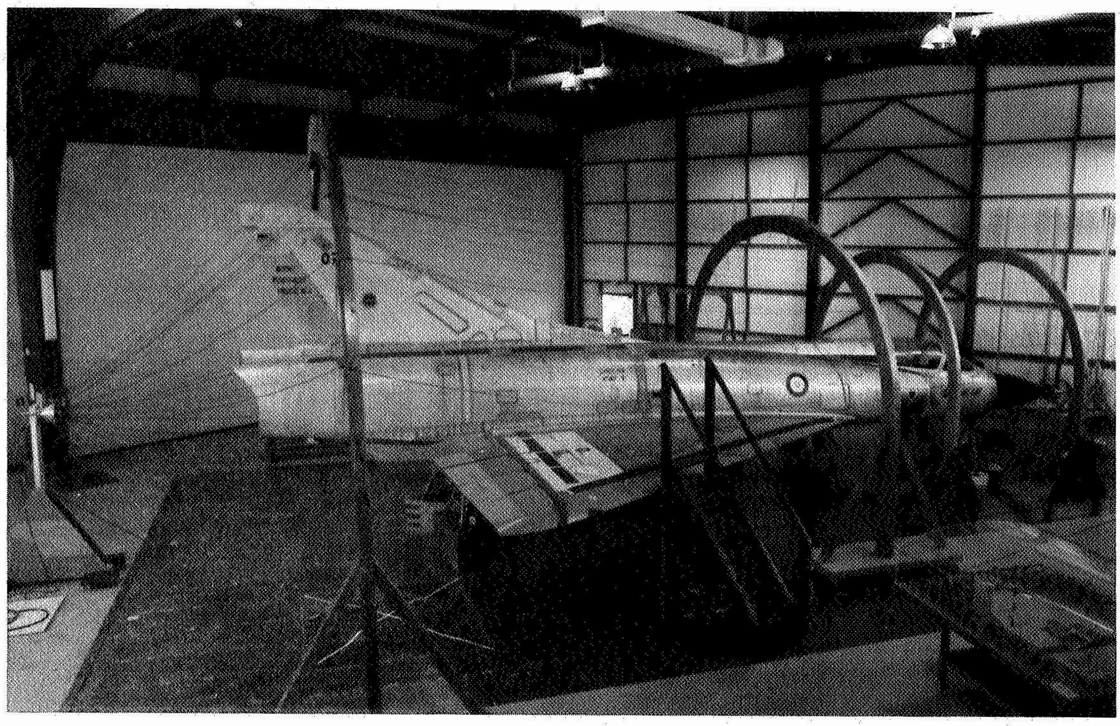

FIGURE 1 : Picture of an overall view of PARSIFAL simulator

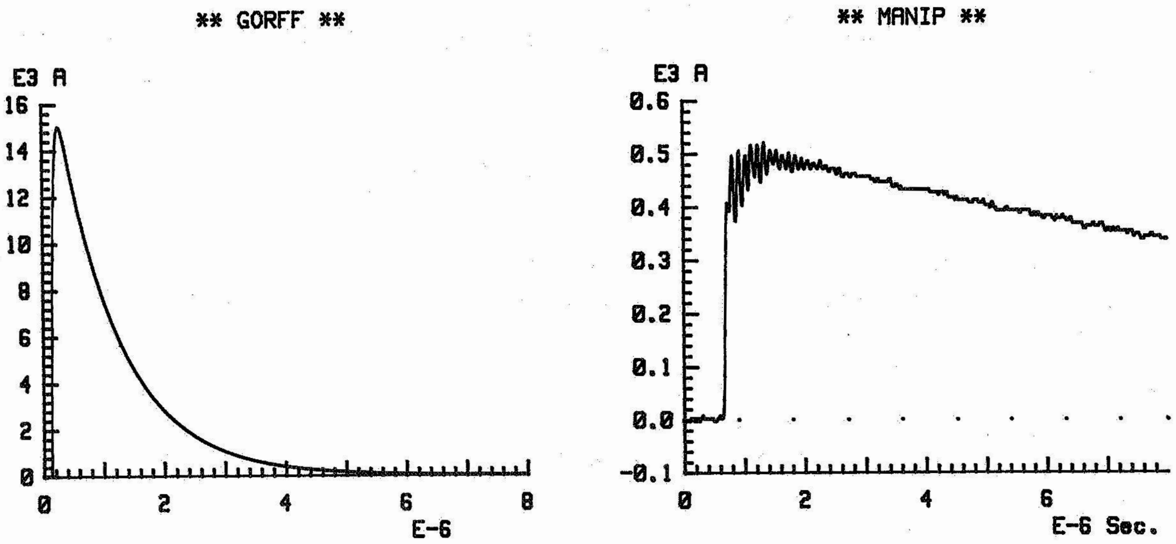

FIGURE 2 : Time domain behavior of the experimental and the numerical currents injected on the Mirage

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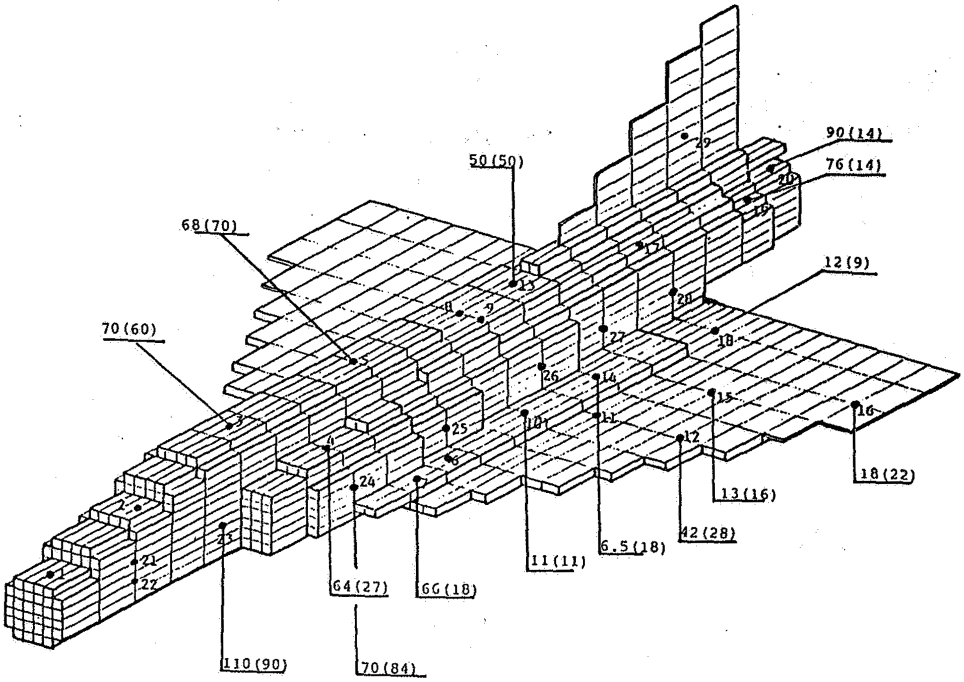

FIGURE 3 : Peak values of Hy fields on the fuselage. Numbers in brackets are from the calculations. Units are in A/m

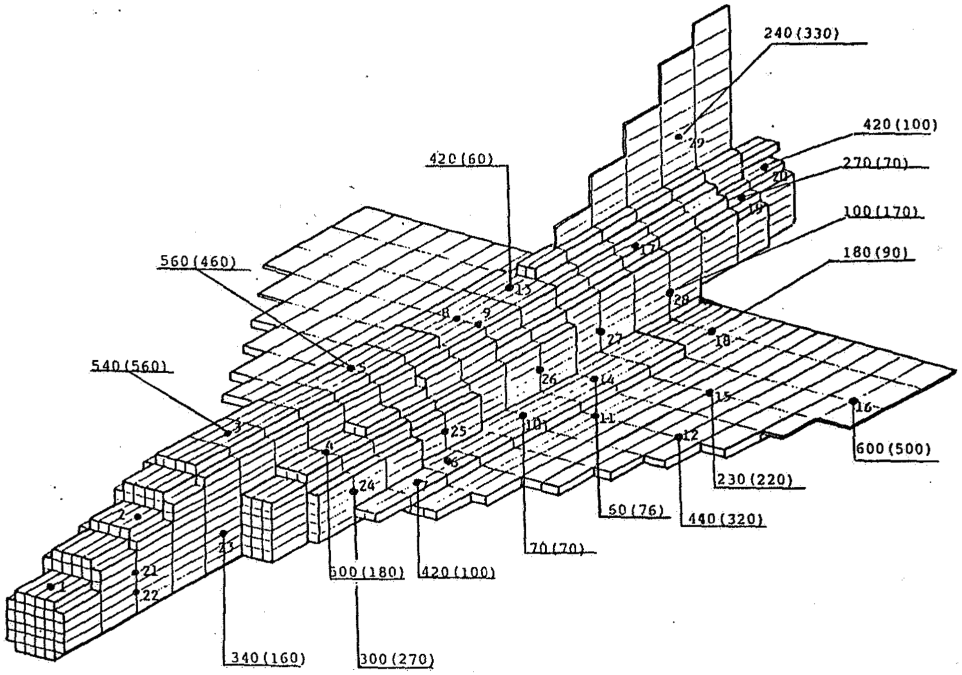

FIGURE 4 : Same representation as figure 3 for the E peak values. Units are in E9 V/m/s

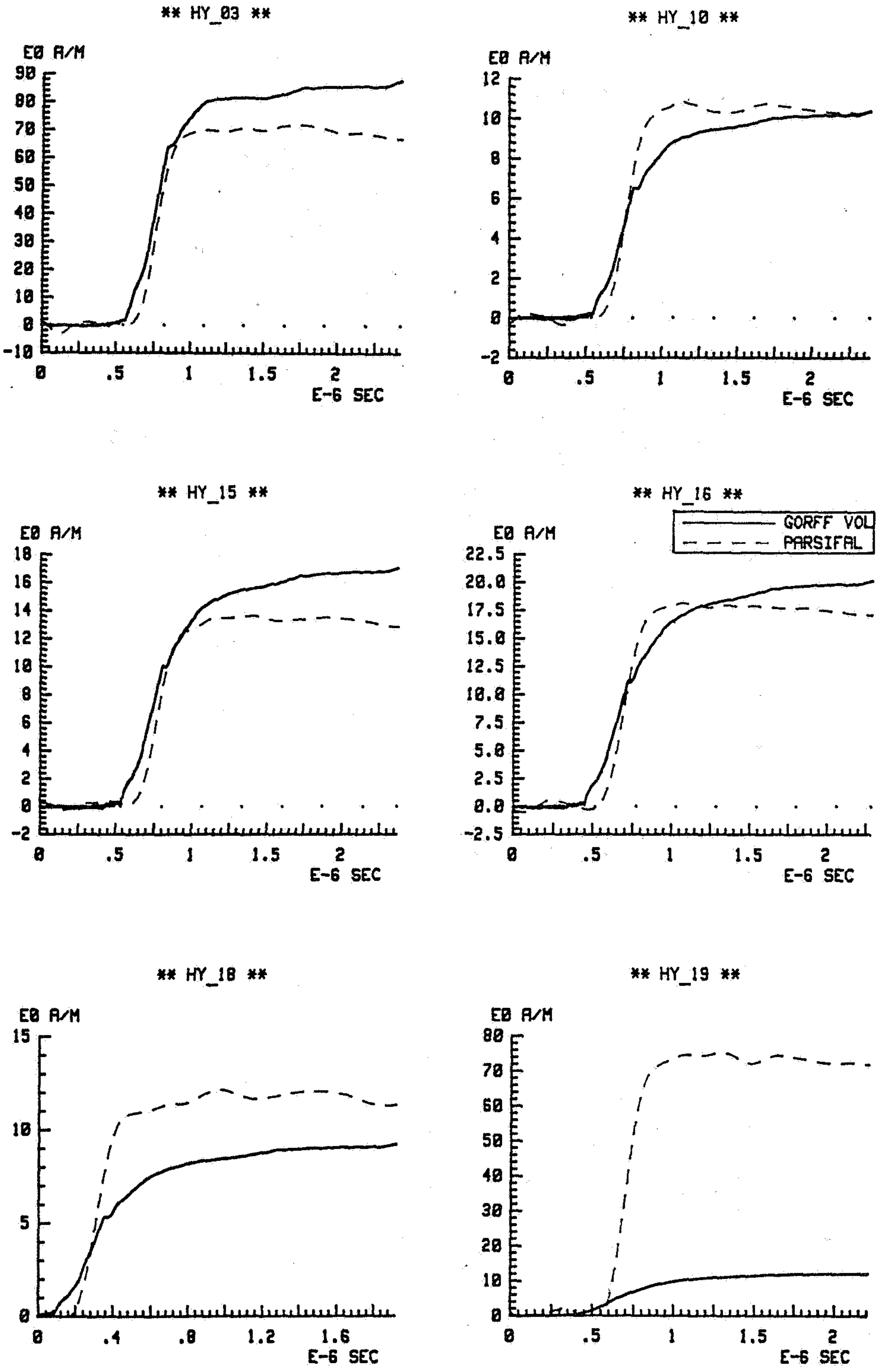

FIGURE 5 : Time domain comparison for 6 Hy points of the fuselage

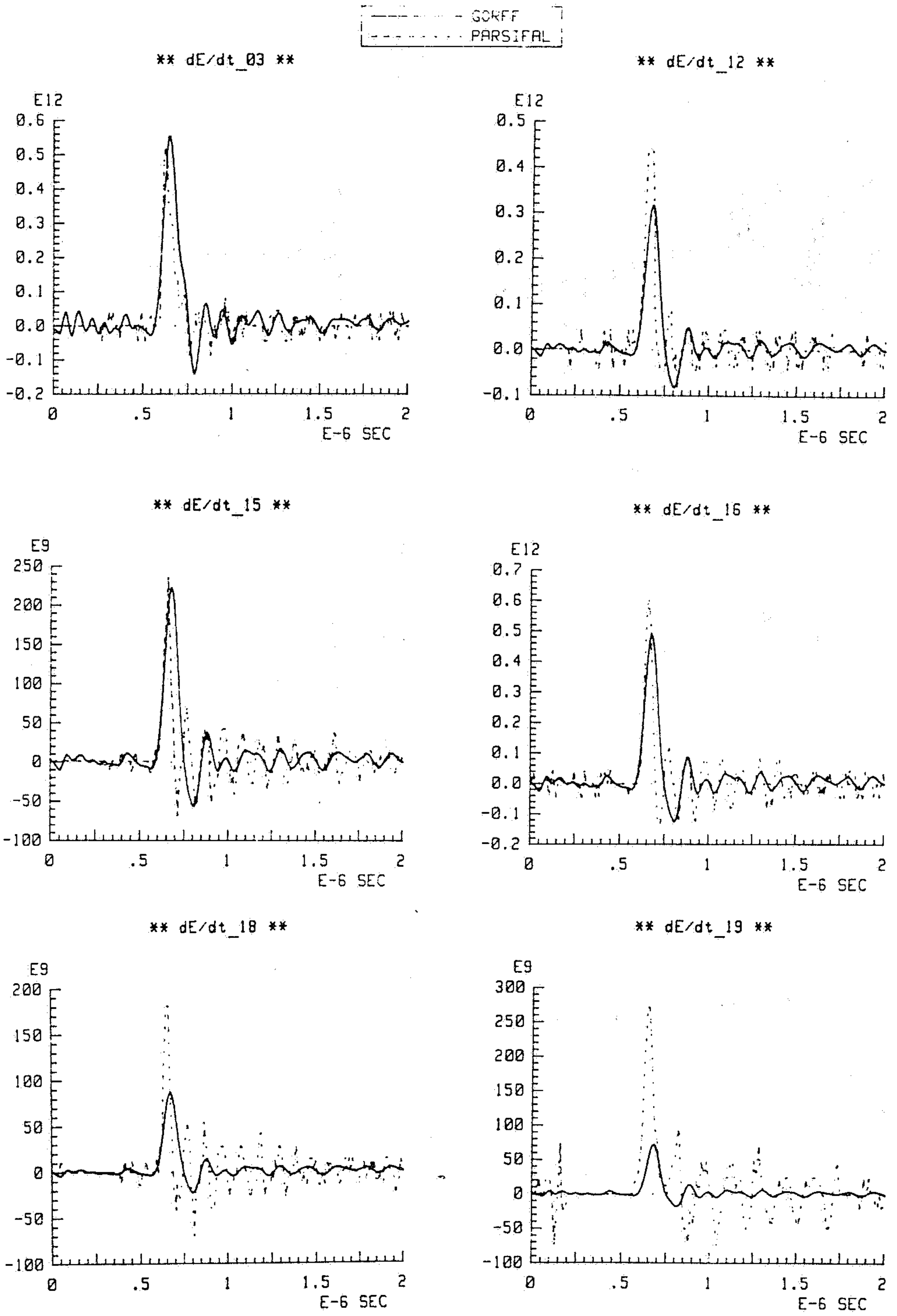

FIGURE 6 : Same comparison as figure 5 for the $\dot{E}$ time domain values

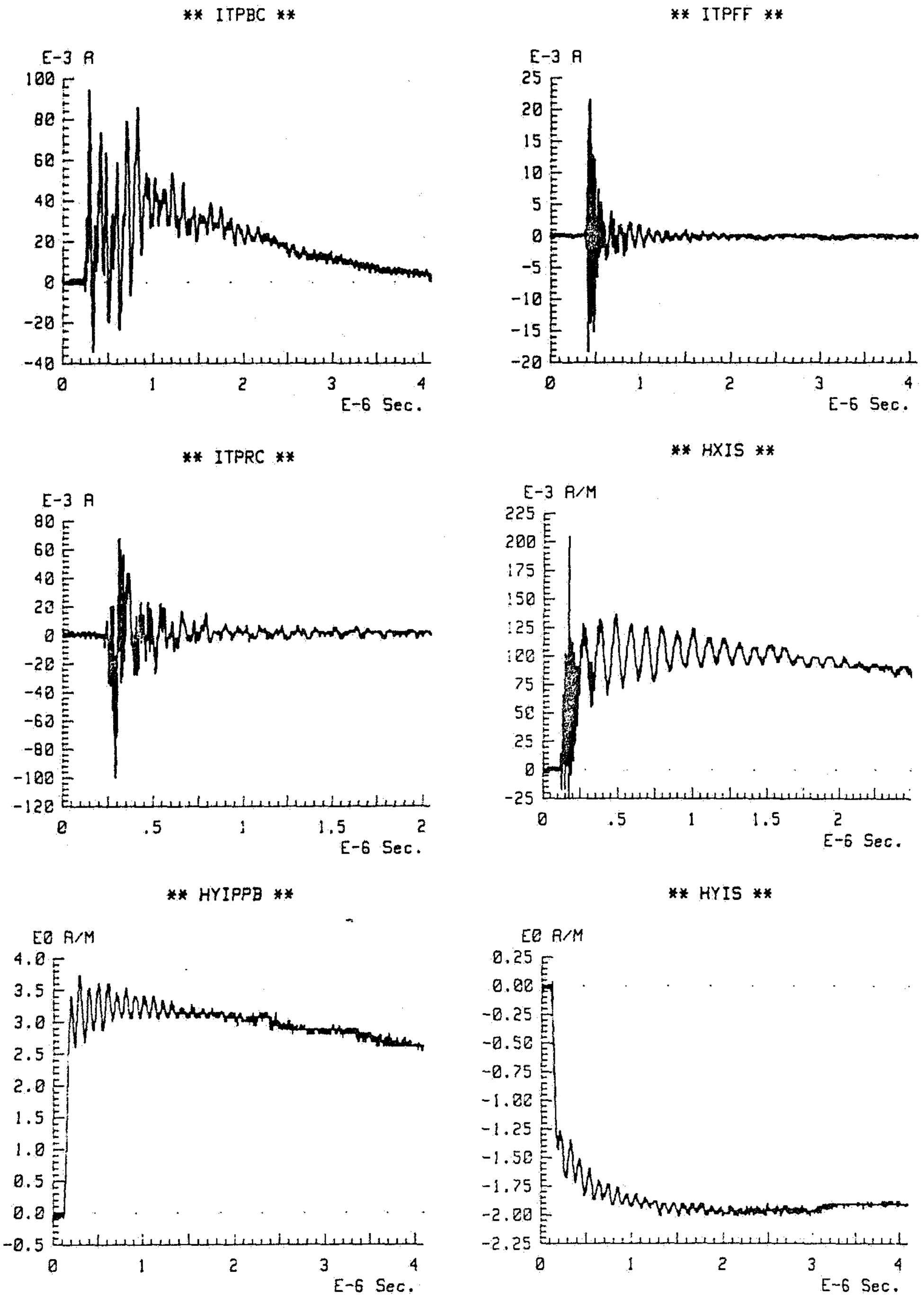

FIGURE 7 : Samples of currents and fields measured inside the aircraft

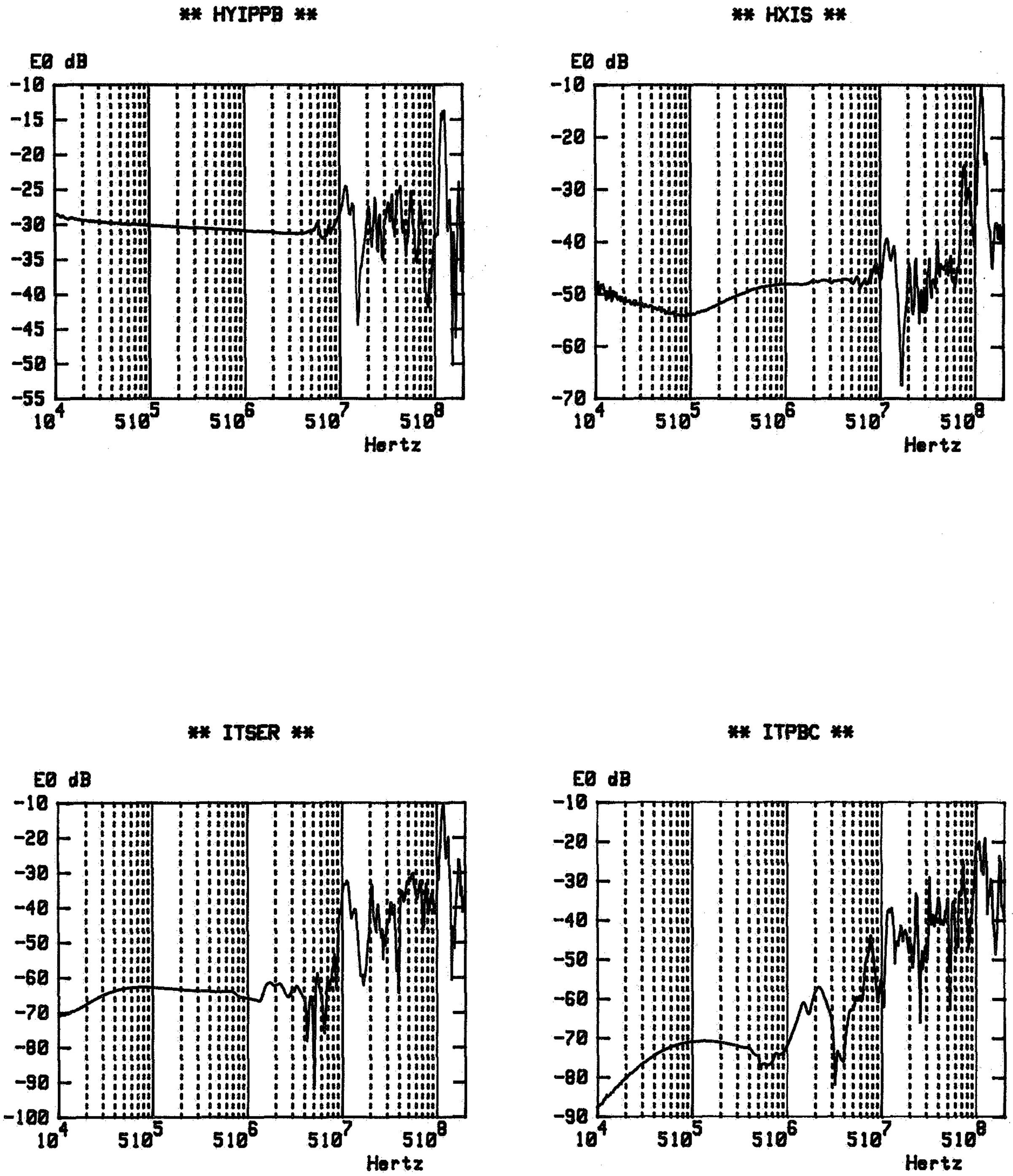

FIGURE 8 : Examples of transfer function measured with a network analyser :

HYIPPB :	Hy field in the cockpit, near the UHF command box
HXIS :	Hx field in the equipment compartment
ITSER :	current on the cable bundle of the emitter
ITPBC :	current on the cable bundle of the UHF emission box

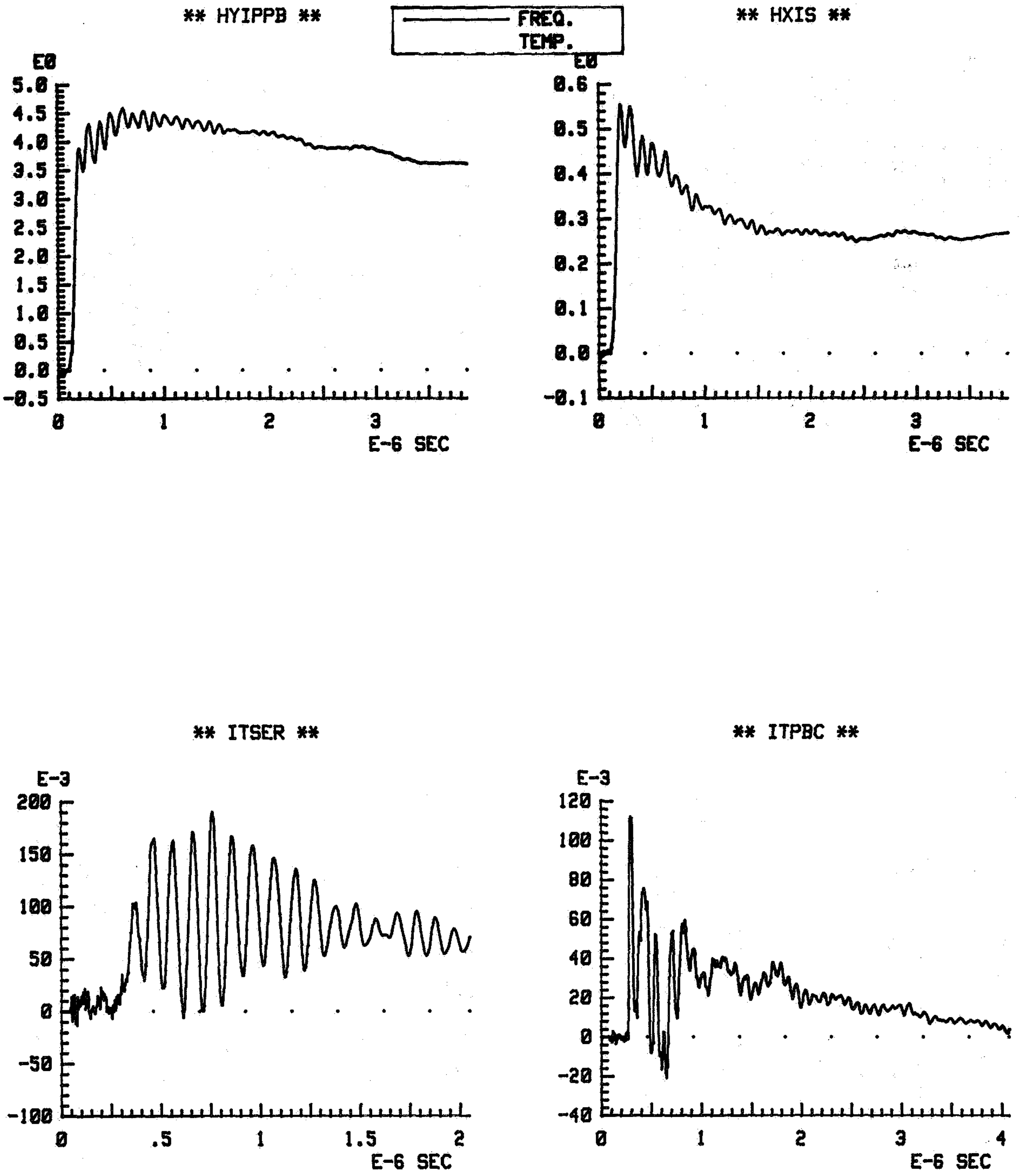

FIGURE 9 : Experimental and frequency domain calculated inner currents and fields. The points presented are the same as for figure 8