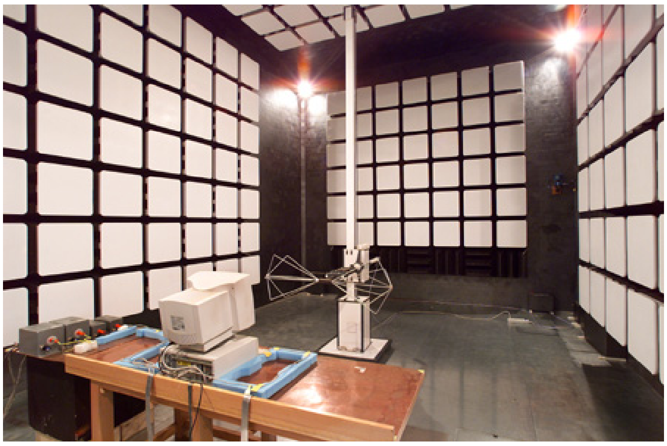
The Laboratory of Electromagnetic Fields

The **Laboratory of Electromagnetic Fields** – located in the ENEA Casaccia Research Centre, near Rome – was established in 1983 with the aim of supporting the **electromagnetic compatibility** qualification tests on electronic and electromechanical components of nuclear or industrial plants operating in hostile environments.

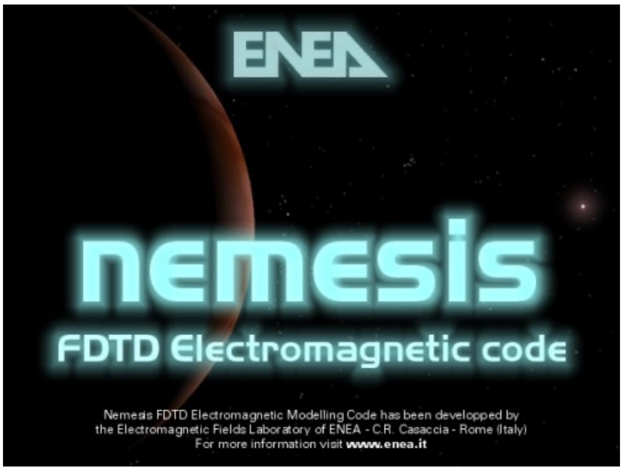
In the following years, activities evolved in support to the civil, military and avionic sectors, with a special care to SMEs test activities and research projects in collaboration with university institutes and departments.



From 1990, the Laboratory started to perform R&D on the **numerical modelling** of propagation and scattering of electromagnetic waves in complex environments. In such a framework, several numerical codes have been developed (e.g., the hybrid FDTD/Kirchhoff **Nemesis** code, a semiautomatic FDTD mesher) implemented in both sequential and parallel (cluster), and massively-parallel computers.

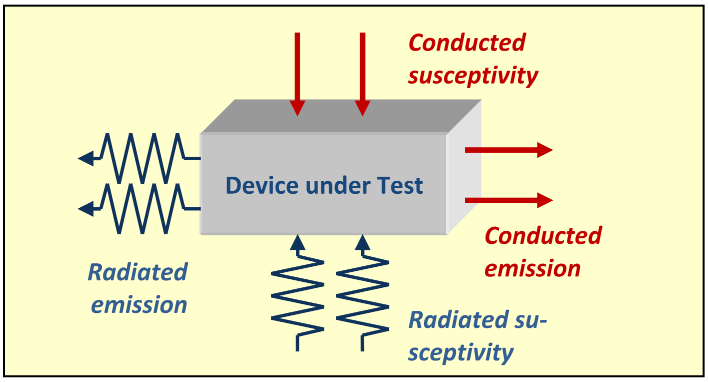
In 2000, the Laboratory widened its experimental facilities by building the **"Vecuvia" semi-anechoic shielding chamber** for electromagnetic compatibility measurements and tests in compliance with the civil and military standards at a 3 m distance from the radiation source and 10 kHz - 18 GHz frequency range.

In 2004, the Laboratory started a new research activity on the **numerical modelling and experimental characterization of new materials for electromagnetic applications**, such as shielding materials and coatings, radiation absorbing materials, frequency selective materials, metamaterials.



On behalf of Public Authorities, the Laboratory performs **environmental measurements** of electric field levels for human health protection (e.g., the measurement of electric field levels from broadcasting antennas on behalf of Italian Ministry for the Environment) and special measurements for which no standard can be adopted (e.g., characterization of the shielding power of devices to reduce mobile phone emissions; electric and electromagnetic characterization of personal security devices on behalf of the Italian State Police). Furthermore, the Laboratory performs more general measurements on electromagnetic fields such as the **characterization of field sensors and antennas**, the measurement of **antenna radiation patterns** and the validation of numerical modelling results.

Electromagnetic Compatibility Tests

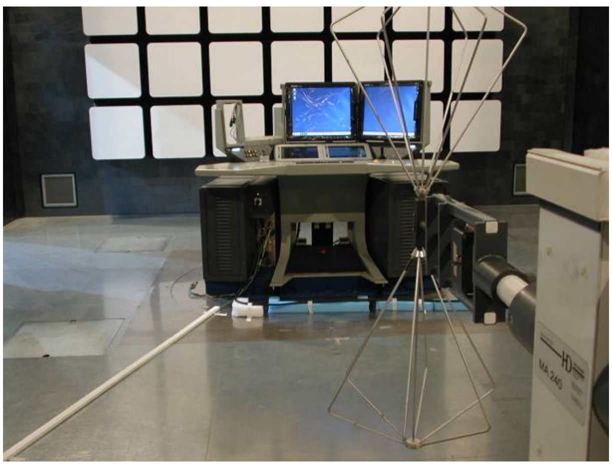


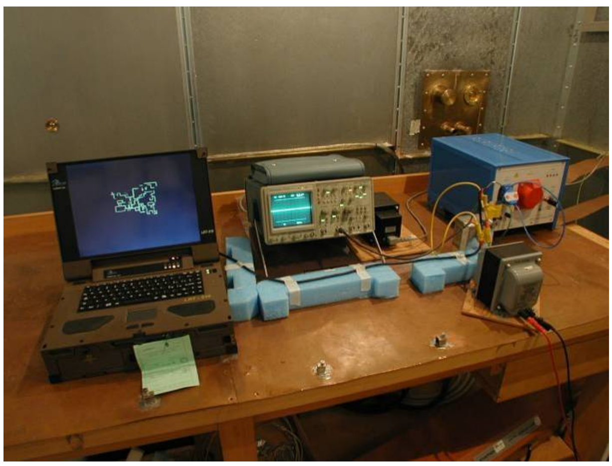
On demand by external customers, both public and private, the Laboratory of Electromagnetic Fields performs electromagnetic compatibility tests on electric and electronic devices and systems.

The experimental equipment allows to execute a large range of tests of **radiated and conducted emission** and **radiated and conducted susceptivity**, compliant with the civil, military and avionics standards, as explained in the following table.

Test description	***Reference Standards***
Tests on avionic systems	**RTCA/DO-160C**
Tests on military systems	**MIL STD 461 rev. C/D/E** **MIL STD 462 rev. C/D**
Tests of radiated and conducted emission on information technology equipments	**EN 55022**
Tests of radiated and conducted emission on industrial, scientific and medical (ISM) radio-frequency equipments	**EN 55011**
Tests of immunity to electrostatic discharge	**EN 61000-4-2**
Tests of radiated susceptivity	**EN 61000-4-3**
Tests of immunity to bursts	**EN 61000-4-4**
Tests of conducted susceptivity	**EN 61000-4-6**

The Laboratory of Electromagnetic Fields performs electromagnetic compatibility qualification tests particularly favouring the support and technical advice aspects, especially during the product engineering stage. This activity is also performed for test campaigns not immediately classifiable as qualification test requests.





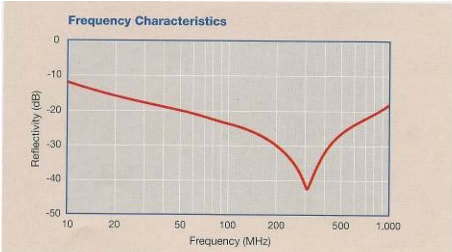
The VECUVIA Semi-Anechoic Chamber

The **VECUVIA** semi-anechoic chamber is the main test facility of the ENEA Laboratory of Electromagnetic Fields performing **electromagnetic compatibility** tests and measurements at a 3 m distance from antennas. Its external dimensions are (9.00 x 6.00 x 5.60) m^3.

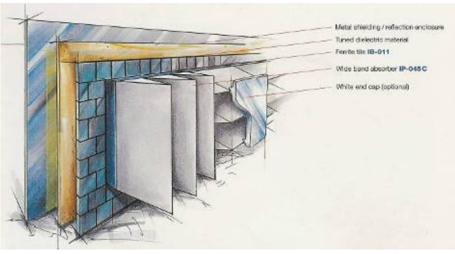
The outer **shielded chamber** cuts off the radiation fields which are in the external environment and prevents fields generated inside from propagating outwards. It ensures attenuation levels higher than 80 dB in the 10 ÷ 100 kHz frequency range and higher than 100 dB in the 100 kHz ÷ 18 GHz frequency range.

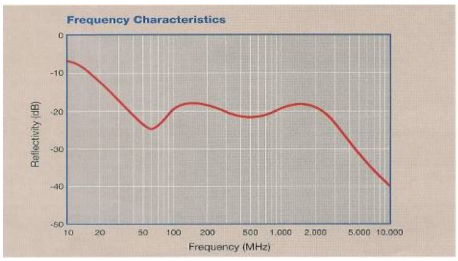
The internal side walls and ceiling have been entirely covered by **TDK IB-011 ferrite tiles** having dimensions (10 x 10 x 0.65) cm^3 in order to absorb the incident radiations up to 1 GHz.

The operative range of the **VECUVIA** semi-anechoic chamber has been extended up to 18 GHz by installing an ultra wide band **TDK IP-045C absorber** on its side walls and ceiling.

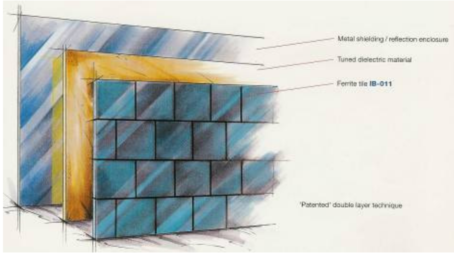


The absorbing layer strongly weakens the electromagnetic fields generated inside the chamber that hit the walls and also reduces electromagnetic echoes (from which the term **anechoic** takes origin). In this way it is possible to simulate the performance and the characteristics of an **Open Area Test Site**.





Inside the semi-anechoic chamber a raised technical metal-plated floor has been installed so to function as a **reflecting plane** for electromagnetic radiations (**ground plane**).

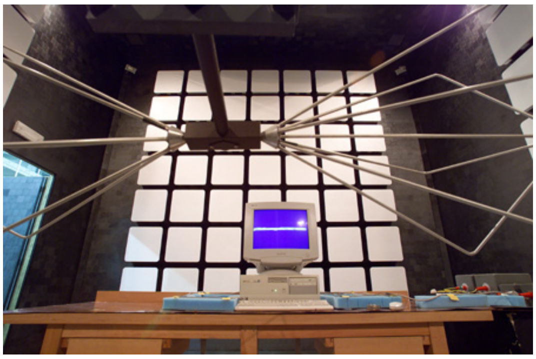


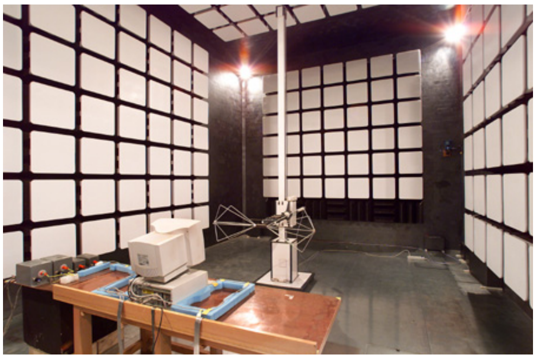
It is possible to modify the **VECUVIA** semi-anechoic chamber in order to simulate – especially for the radiated immunity tests – a **fully anechoic chamber** appropriately disposing several panels covered with ferrite tiles or absorber panels on the ground plane.

The equipment under test is placed over a **turntable** having a 2 m diameter and 1000 kg as maximum permissible load. It has been embedded in the ground plane so to ensure electrical continuity with it.

Antennas are placed on a **mast** allowing a vertical elevation from 1 m up to 4 m and a 90° rotation around the horizontal axis (horizontal and vertical polarization).

Both devices can be remote-controlled by optical fibers thus avoiding any possible interference with the measuring process.





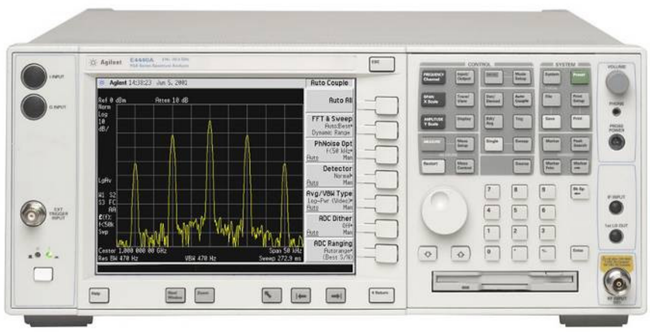
Rotating the device under test and modifying, at the same, time the elevation and polarization of the antenna mounted on the mast made it possible to identify the maximum emission configurations as required by some important electromagnetic compatibility standards (**EN 55022**, **EN 55011**).

Laboratory Equipment

The main instrument used in the Laboratory of Electromagnetic Fields to perform tests and measurements is the spectrum analyzer.

The Laboratory is equipped with three spectrum analyzers:

- the **Agilent E4440A spectrum analyzer**, operating between 3 Hz and 26 GHz, is used for radiated and conducted emission qualification tests and for study and research on new-generation telecommunication devices and systems (GSM, UMTS, WLAN, Bluetooth);
- the **EMI (ElectroMagnetic Interference) HP 8574A receiver** is an integrated system consisting of a spectrum analyzer, a quasi-peak adapter and a frequency pre-selector. It is suited for electromagnetic compatibility tests in the range 100 Hz ÷ 1.5 GHz. The whole equipment is controlled by a computer code for complete management of the emission tests (test setup, transducer database, acquisition and storage of experimental data);
- the **HP 8594E spectrum analyzer**, operating between 9 kHz and 2.9 GHz, is used as a selective meter in laboratory and for narrow-band measurements in open field.



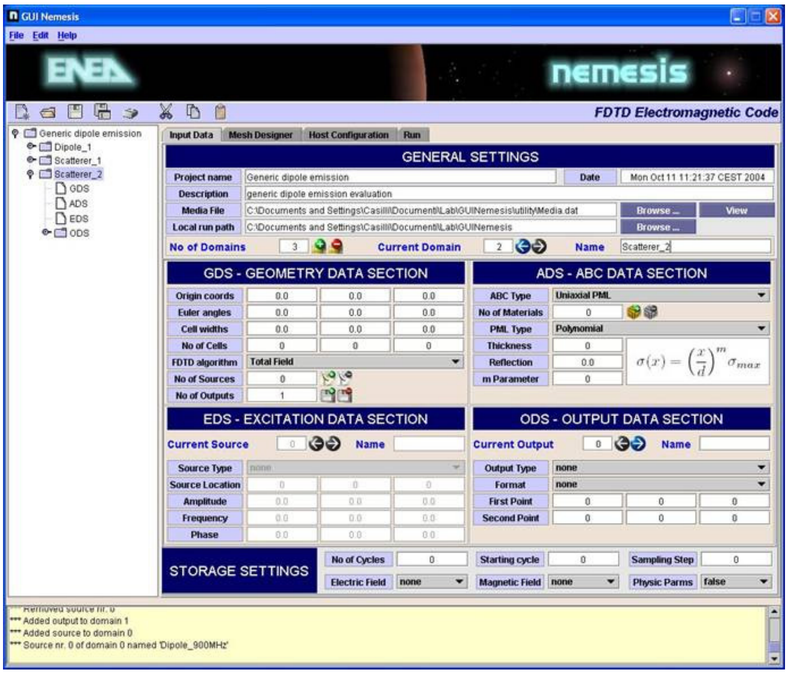
Furthermore the Laboratory is endowed with several Radio Frequency instruments including:

- **power amplifiers** in the frequency range 10 kHz ÷ 1 GHz with a maximum power of 100 W;
- **signal generators** from 9 kHz up to 4 GHz;
- **isotropic sensors of electric field** from 10 kHz up to 3 GHz;
- **Helmholtz coil** to generate magnetic fields.
- **TEM cell** and **double TEM cell** to generate electric fields up to 200 MHz;
- **power meters**;
- several kinds of **antennas** (rod, biconic, log-periodic, horn) in the frequency range 10 kHz ÷ 18 GHz;
- several equipments and instruments for electromagnetic compatibility qualification tests, in compliance with different standards, such as **LISN**, **CDN**, **current clamps**, **transient generators**, and **electrostatic discharge generators**.

Moreover, the laboratory is equipped with a **LeCroy WaveMaster 8500 digital oscilloscope**, which is able to sample signals at a maximum speed of 20 GS/s up to 5 GHz. This instrument is used to characterize waveforms and pulses with high frequency content.

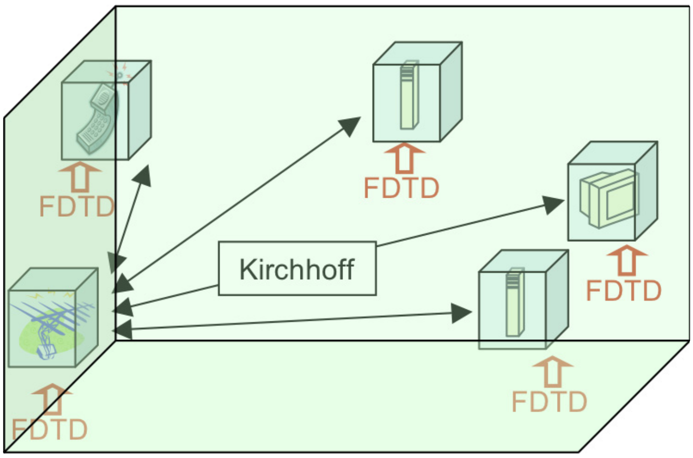
Numerical Methods to Model Electromagnetic Fields

Nemesis is a computer code allowing modeling the physical phenomena of propagation and scattering of electromagnetic fields. It has been developed by the ENEA Laboratory of Electromagnetic Fields.



The **Maxwell's differential equations** are discretised and integrated by using the **finite-difference time-domain (FDTD)** method. At the border of the computational domain, the **Mur's second order absorption conditions** or the **Bérenger's Perfectly Matched Layer conditions** are applied so to simulate the physical conditions of open space.

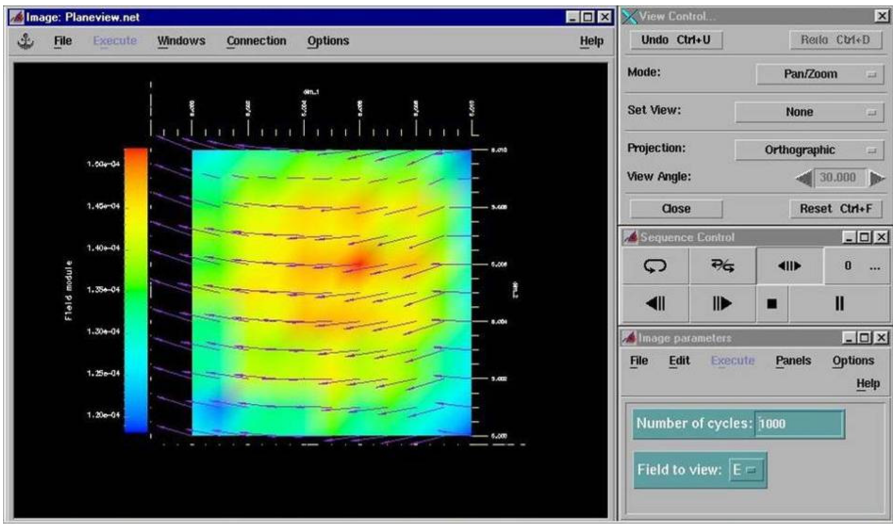
When simulating very large domains (of the order of **one hundred or one thousand of wavelenghts**), the constrains imposed on the minimum length of the grid cells ($\leq \lambda/10$) make it practically impossible to use the FDTD method due to the huge memory required by the algorithm (of the order of **$40 \cdot N^3$ bytes**, where N is the number of cells along a direction in the model coordinate system).



To get round this kind of difficulties and at the same time preserve all the benefits of the FDTD method, a modified code has been implemented where the **Kirchhoff's integral** has been used to perform a **"near-field to far-field" transformation**, thus obtaining a hybrid code.

The basic idea underlying the **FDTD/Kirchhoff hybrid method** (also known as **"Multiple-Region FDTD" [MR/FDTD]**) is to exploit the fact that propagation of electromagnetic fields mostly occurs in free space or homogeneous media. Hence, modelling those portions of space by adopting the same space resolution by which electromagnetic sources or scatterers are modelled is very memory consuming and no interesting data will generally be obtained.

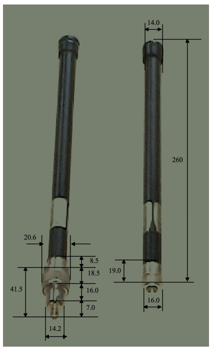
The whole simulation domain can therefore be divided into smaller sub-domains surrounding more interesting electromagnetic structures such as sources or scatterers which will be modelled by the classical FDTD method. The electromagnetic fields will be then propagated towards the other sub-domain surfaces by using the **Kirchhoff's integral solution** of Maxwell's equations.



The adoption of the **FDTD/Kirchhoff hybrid method** allows to save a considerable quantity of memory and, therefore, to simulate more complex and larger domains, at the cost of an increase in computational times.

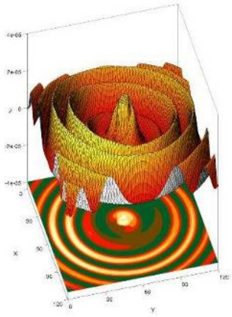
Numerical Methods to Model Electromagnetic Fields

An antenna for GSM telecommunications is shown in the left figure while the right one represents a tridimensional graph of the electric field emitted along the *z* direction as calculated with the **NEMESIS** hybrid code (collaboration **ENEA – TELECOM Italia Lab**).



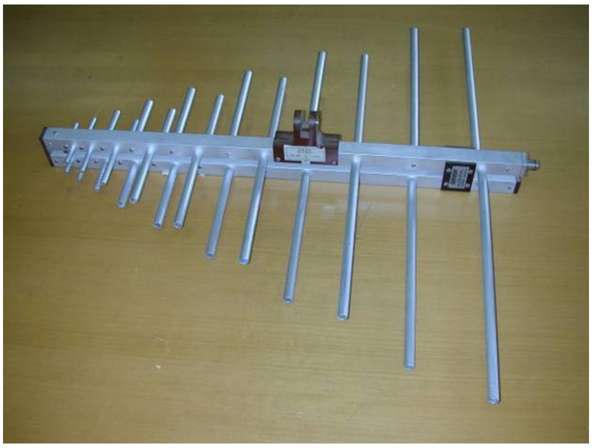
Antenna GSM Jay-Beam 7276
(*End-feed sleeve-dipole*)

Center band frequency:
2 GHz

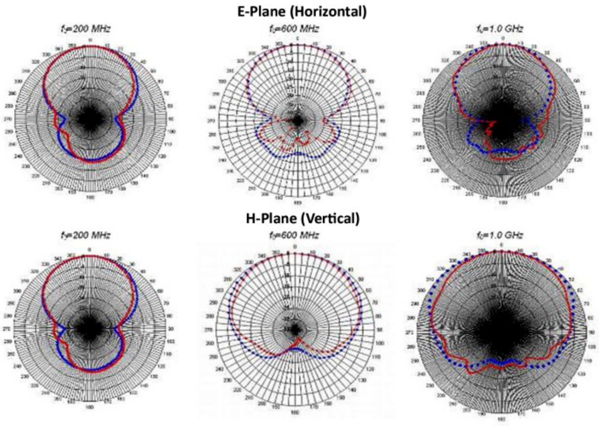


Numerical results for the electromagnetic field emitted by the Jay-Beam 7276 antenna

A further example is given by the simulation of an antenna for electromagnetic compatibility tests.



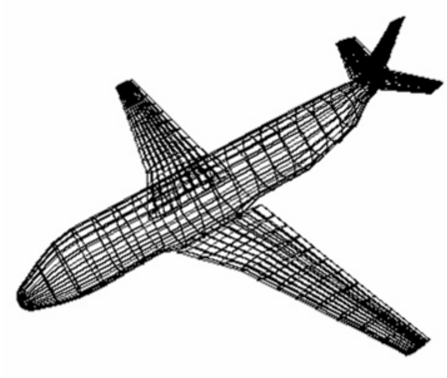
***Log-Periodic Dipole Array Antenna* (LPDA)**
operating between 200 MHz and 1 GHz



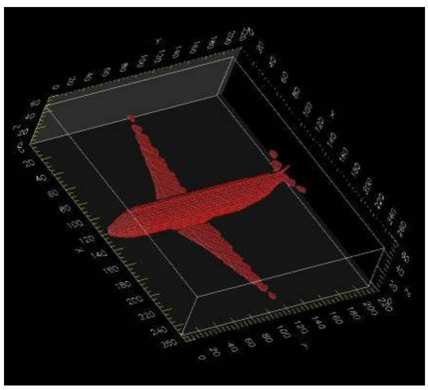
Radiation patterns of LPDA at different frequencies
(• Numerical results – ▪ Experimental data)

The codes developed by the Laboratory of Electromagnetic Fields have been an integral part of the activities of the project **"Protection of human and natural environment from electromagnetic emissions"** developed by the **Italian National Research Council** and **ENEA** and co-financed by the **Italian Ministry of Scientific Research**.

In the ambit of the Project, the Laboratory of Electromagnetic Fields has improved the FDTD/Kirchhoff **NEMESIS** code. It has also developed a graphical user interface (**Aphrodite**) to manage the input and output files, besides a prototype of an automatic FDTD mesh generator from CAD files (**Dxf2msh**).



CAD model of an airplane



Automatically generated FDTD mesh of the airplane

Environmental Measurements and Electromagnetic Characterisation

On behalf of public authorities (Ministry of the Environment, Local Authorities) the Laboratory of Electromagnetic Fields measured the electromagnetic field values in the environment in order to verify they were compliant with the Italian law standards.

In particular, during Spring 2001 the Laboratory of Electromagnetic Fields monitored the values of the electromagnetic field in the area surrounding the Vatican Radio Station in Santa Maria di Galeria (Rome).

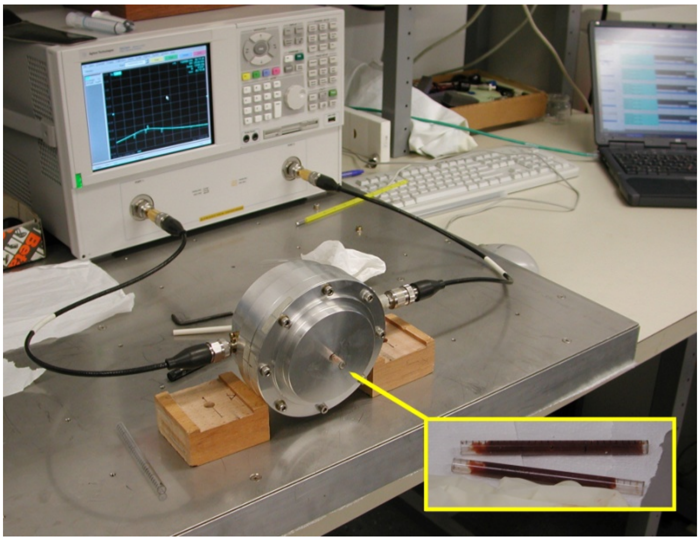
In 2005, on behalf of the Local Authority of Anguillara Sabazia (Rome), the electromagnetic field was measured to verify the existing values before installing some UMTS mobile antennas.

The Laboratory of Electromagnetic Fields also performs measurements of the electromagnetic characterisation of electric and electronic devices on behalf of and in support to Public Authorities. To make an example, the electromagnetic characterisation of an electrostatic discharge gun, performed on behalf of Italian State Police.

ENEA

Electromagnetic Equipment for Medical Applications

The Laboratory of Electromagnetic Fields started researching on the study and development of electromagnetic equipment for medical applications: *ex vivo* and *in vivo* **electromagnetic characterisation of biological tissues**; **early detection of tumours** of prostate, bladder, breast; **microwave imaging** to detect and locate tumours.



As an example, the side picture shows the experimental setup to measure the **electric permittivity ε** of steer liver (in quartz tubes) by using a cylindrical resonant cavity.

Currently the possibility to develop special probes to measure the electromagnetic properties of *in vivo* tissues instead of exsected tissues is being studied in order to obtain more realistic experimental data to be used in theoretical models and numerical simulations.

In the framework of collaboration agreements with the **II Faculty of Medicine and Surgery** and with the **Department of Electronic Engineering of the University "La Sapienza" of Rome**, the Laboratory of Electromagnetic Fields started a study on the electronic and electromagnetic characterisation of **TRIMprob™**, an instrument detecting prostate cancers. The study is aimed at collecting the experimental data processed by the device and at verifying the physical principles of operation and interaction with biological tissues.

Finally, the Laboratory is involved in the study and research on **microwave imaging equipment** allowing to detect and locate breast tumours.