Frequency Selective Measurements of Electric Field (100kHz-2.5GHz) and Magnetic Field (100kHz-120MHz) with Active Electro-Optical Receiving Antennas

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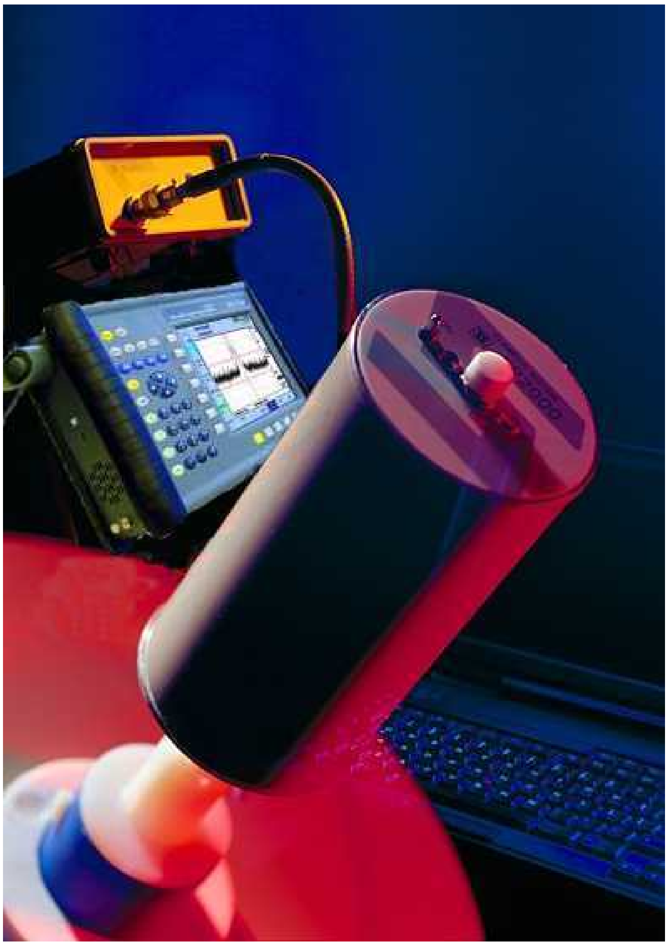
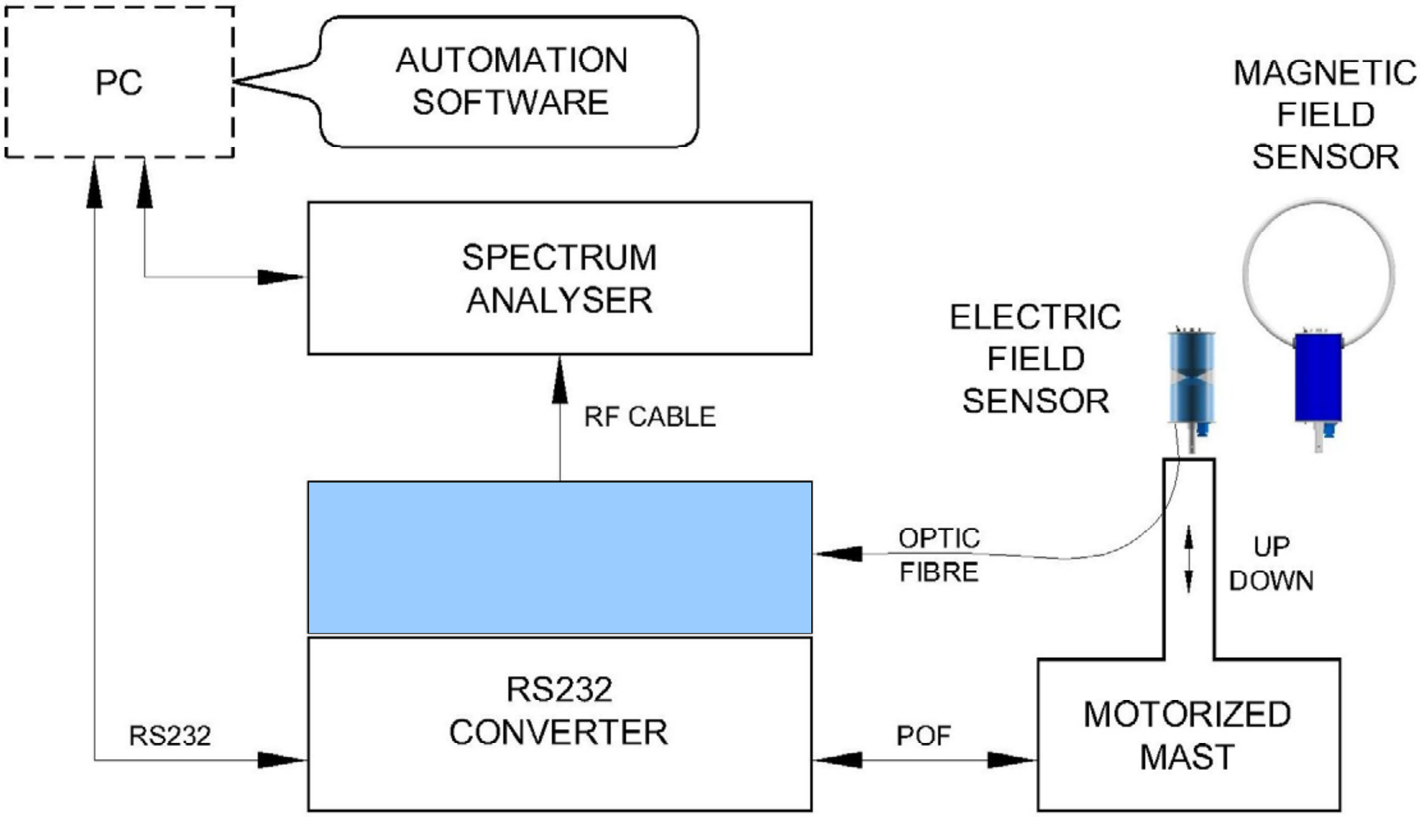
These small-size active electro-optical receiving antennas, developed in our laboratory NIRLab, transmit on an optical carrier the time-varying electric (or magnetic) field signal detected in the air, while maintaining amplitude and frequency information for each line of the spectrum present in the passband (analog link). The optical carrier, modulated by the signal detected by the antenna, is transferred by means of a optical fibre to an opto electric converter that extracts the signal, converting it back to an electrical signal (50 ohm). Here the signal is picked up by means of a coaxial cable and sent to a receiving instrument, typically a spectrum analyser. Of course these devices can be fully characterised by means of their antenna factor (K). Software for automating measurements and a tripod for automatic movement of the antenna (spatial averaging or change of polarization) are available as extra, add-on components. These features make this system very attractive for almost all frequency selective measurements, as far as human protection from EM-radiation is concerned.



Components of the System

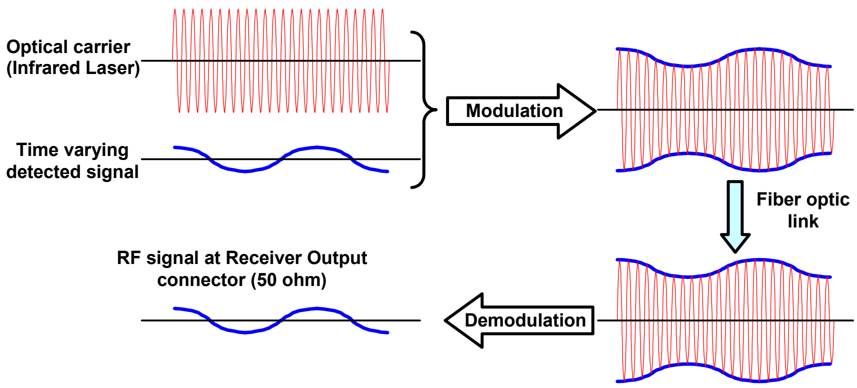
The basic component of the system (blue parts of the diagram) is the receiving electro-optical antenna which is able to transfer, on an optical carrier, the individual electric (or magnetic) field component picked up and to return it in the form of an electrical signal at the output port (50 ohm) of the opto-electric converter. Both electric and magnetic field antennas are sensitive to a single linear polarisation.



The measurement system consisting of a sensor, converter and spectrum analyser allows maximum operating flexibility when connected to a personal computer (PC) and used in conjunction with a motorised tripod specifically designed for the antenna.

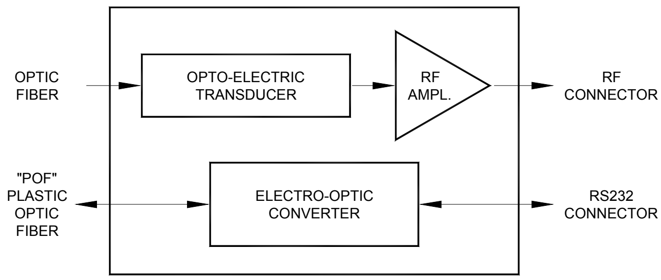
System Operation Concept

The modulated optical carrier is transferred by means of a fibre optic link to a converter which extracts the modulating signal and converts it back to an electrical signal that is made available on a standard RF connector (50 ohm).



The electrical signal thus obtained can be picked up by means of a common RF cable and sent to a spectrum analyser.

Opto –Electric Converter RC200A



The RC200A converter contains, within it, two opto-electric conversion sub-systems.
The first is an opto-electric converter that performs the function of converting the optic signal received from the sensor via the fibre optic link, back to an electric signal.
The second is an opto-electric converter for two-way flow of serial data on the RS232 line to the plastic optical fibre (P.O.F.) used only for controlling the motorised tripod (optional).

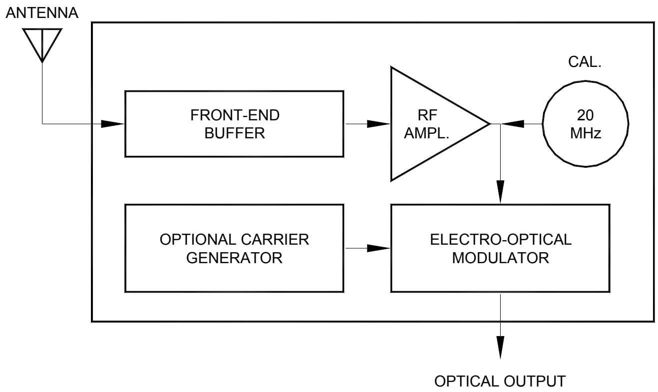
The optical fibre cable is connected to special quick connectors on the bottom panel of the Sensor and on the back panel of the Converter.

Motorized Tripod for Spatial Averaging

The motorised tripod, powered by internal rechargeable batteries, enables the antenna to be moved vertically (from 1.1 to 1.9 m).
The electric (magnetic) antenna is fixed on a special support, located at the end of the movable arm, so as to allow manual adjustment in three orthogonal directions in space for measurement of the three components of the electric (magnetic) field.
A second model is available that allows automatic, sequential positioning of the antenna on three axes mutually orthogonal to each other (x, y, z); on this model, the antenna height is adjusted manually.

The motorised tripod is controlled by means of a serial plastic optical fibre link, using a suitable opto-digital converter installed in the sensor's receiver. The PC is connected by means of a normal RS232 cable to the converter, which redirects the serial commands to the motorised tripod.
In this configuration, the system is entirely managed by the PC. The dedicated automation software allows centralised manual control of the whole system and also enables measurements to be made in fully automatic mode.

Electric Field Measurements with FP2000 Active Antenna



The FP2000 sensor is an active, omnidirectional dipole receiving antenna, powered by internal rechargeable batteries, sensitive to the electric field component parallel to its axis of symmetry.

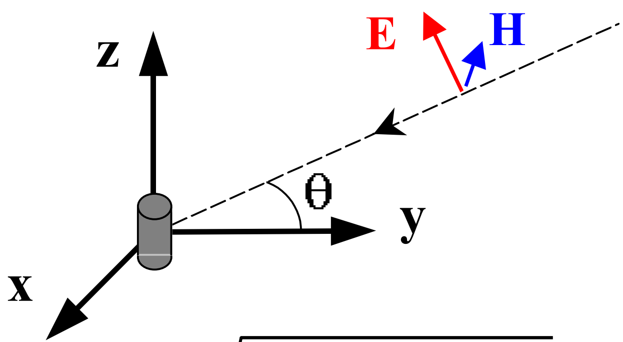
The RF signal detected by the antenna, constituted by the outer surface of its metal housing, is conditioned within the antenna using high impedance active circuits and then used to modulate an optical carrier. The modulated optical signal is carried to the RC200A opto-electrical converter by a glass optical fibre connected to the sensor by means of the special optical connector on its bottom panel.

FP2000 Technical Data

Dimensions: 65 mm Ø x 123 mm H ***Weight:*** 0.5 kg ***Connectors:*** Battery charge connector Optical fibre connector, SC/PC. ***Power supply:*** Internal rechargeable battery ***Battery operation time :*** 8 hours ***Protection level:*** IP 42. ***Operative conditions:*** ***Temperature*** from –20°C to 50°C. ***Humidity:*** Max 95% a 40°C. ***Frequency Range:*** 100 kHz to 2.5GHz	***Compression point at 1 dB:*** From 40 V/m to 200 V/m ***Maximum applicable field:*** From 100 V/m to 250 V/m ***Linear dynamic range:*** Greater than 75 dB ***Antenna factor:*** Individually characterized ***Polarization:*** Linear ***Orthogonal polarization component rejection*** Greater than 30 dB. ***Omnidirectional error (H plane)*** < 0.5 dB up to 1.5 GHz < 1 dB from 1.5 GHz to 2.2GHz < 1.5 dB from 2.2 GHz to 2.5GHz ***Isotropy total error*** < 0.5 dB up to 1.5 GHz < 1.5 dB from 2 GHz to 2.2GHz < 2 dB from 2.2 GHz ato2.5GHz

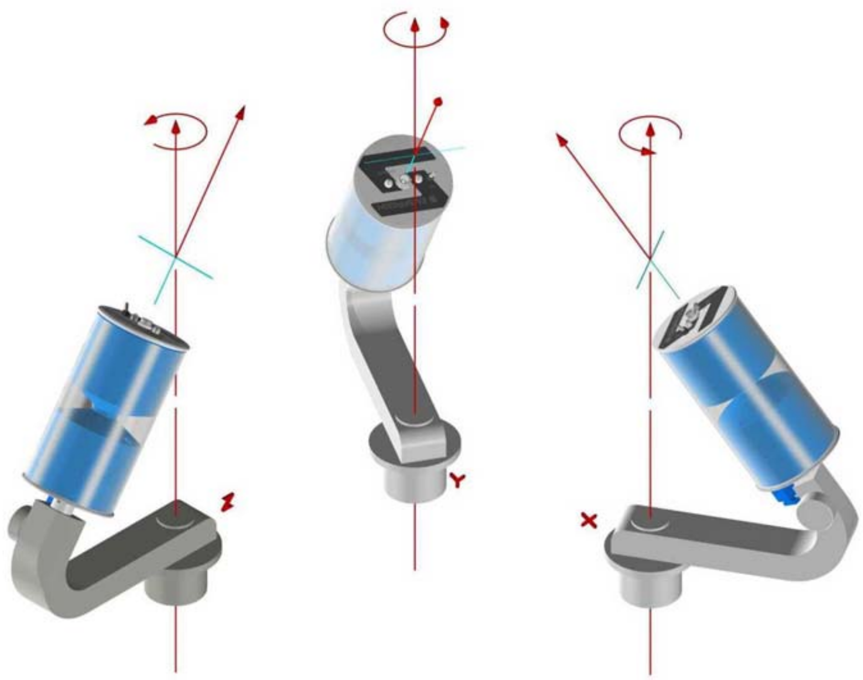
Total Field Measurements using tri-axial Ortho-angular Support for FP2000 Active Antenna

The electric field sensor is sensitive to the electric field component parallel to the direction of its axis of symmetry. In these conditions, where **E** is the amplitude of the incident electric field, and θ is the amplitude of the angle formed by the axis of the sensor with the direction of the electric field **E**, the signal transferred on the optical carrier and transferred to the converter is proportional to $|\mathbf{E}| \cdot \cos\theta$.



$$|E| = \sqrt{E_x^2 + E_y^2 + E_z^2}$$

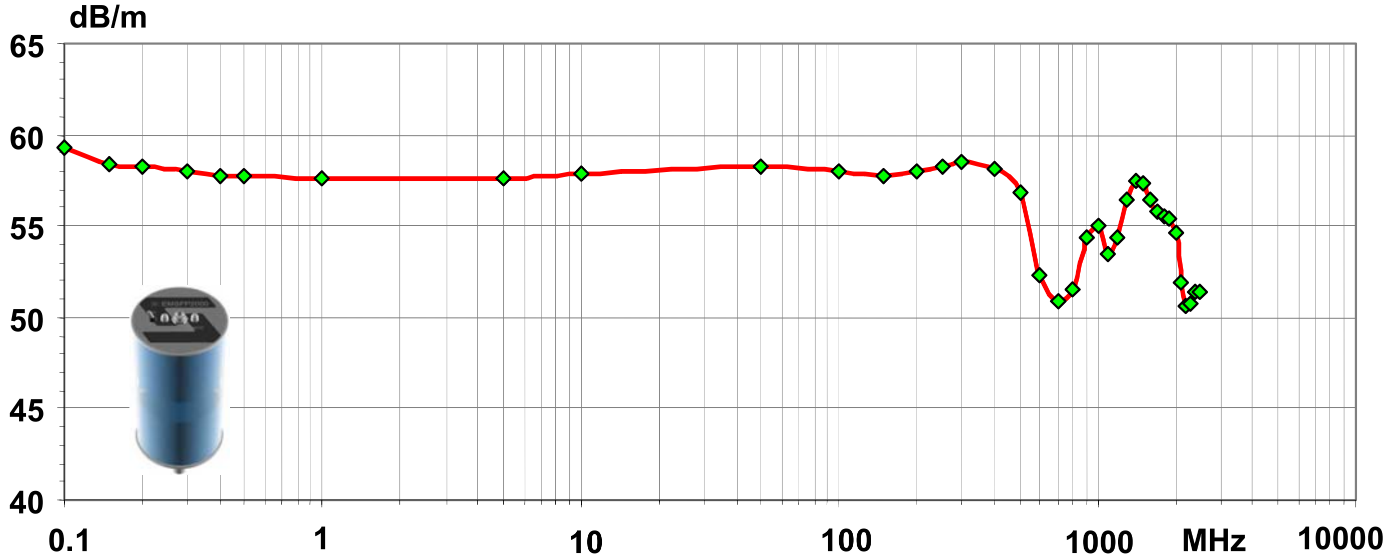
To reconstruct total amplitude of the local electric field, it is therefore simply necessary to take three measurements with the axis of the sensor set up along three directions mutually orthogonal to each other.



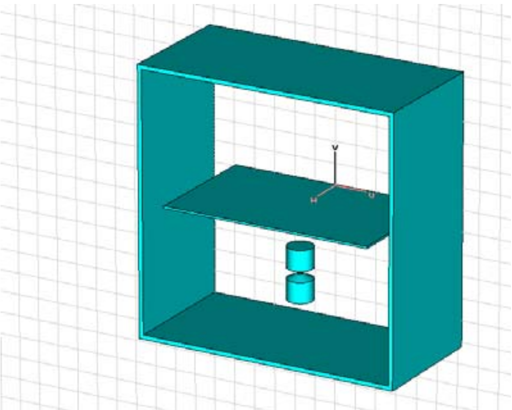
There is of course no need for one of the three measuring directions to be vertical, since the sensor is capable of operating with any spatial arrangement of its axes. In particular, this enables the sensor to be set up along three mutually orthogonal directions, by simple rotation through 120° round a special axis (ortho-angle).

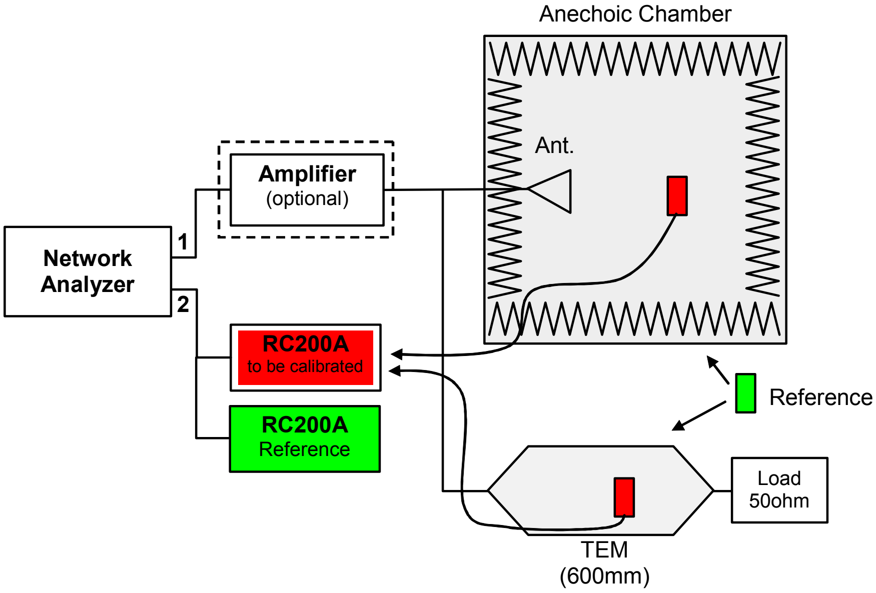
Typical FP2000 Antenna Factor

The antenna factor represents the value in dB to be added to the indication in dBµV of the signal extracted by the spectrum analyser, in order to obtain the intensity value of the incident electric field on the sensor in **dBµV/m**.



Calibration of the FP2000

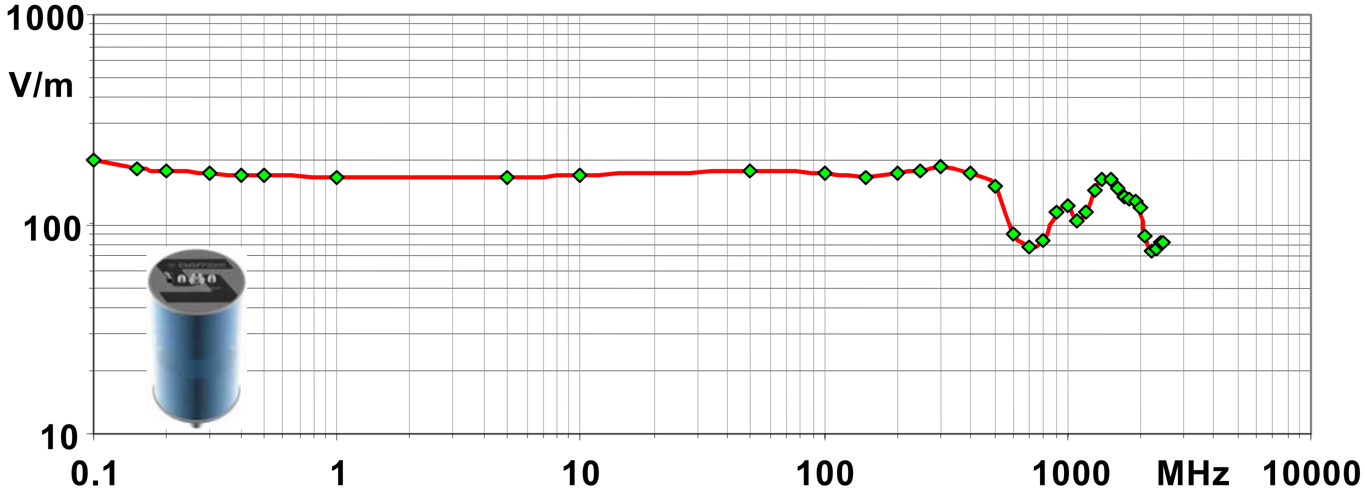




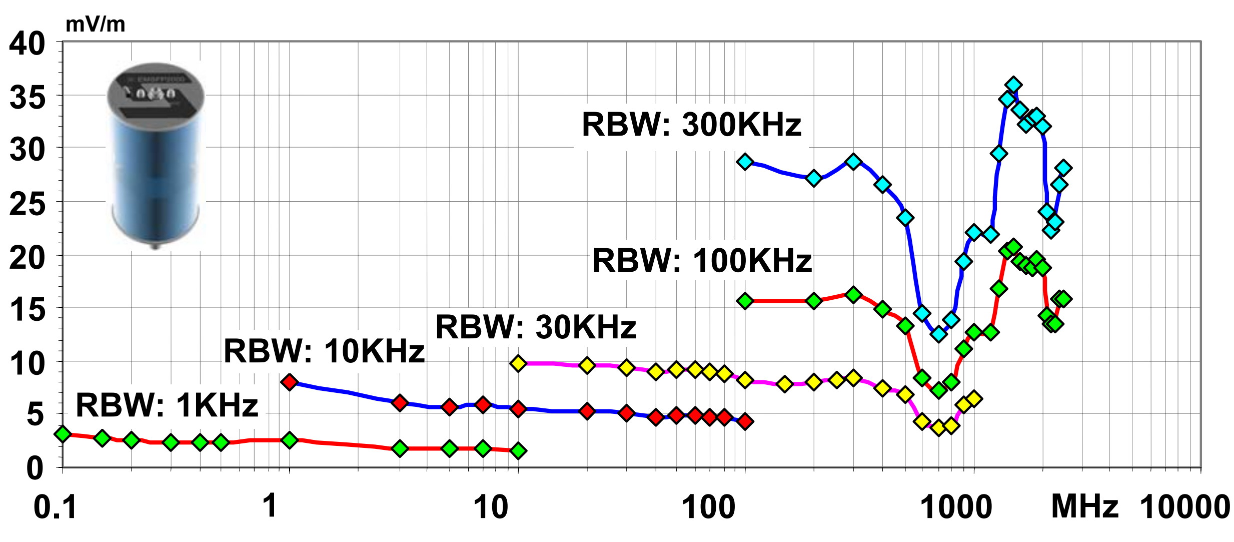
The procedure for calibrating the sensor and its accessories (converter and optical fibre) is based on the method of replacing the device being calibrated with a sample of identical model with known characteristics, calibrated in an EA accredited laboratory.
A TEM cell is used up to 200 MHz, while an anechoic chamber is used for higher frequencies.

FP2000 Linear Dynamic Range and Sensitivity

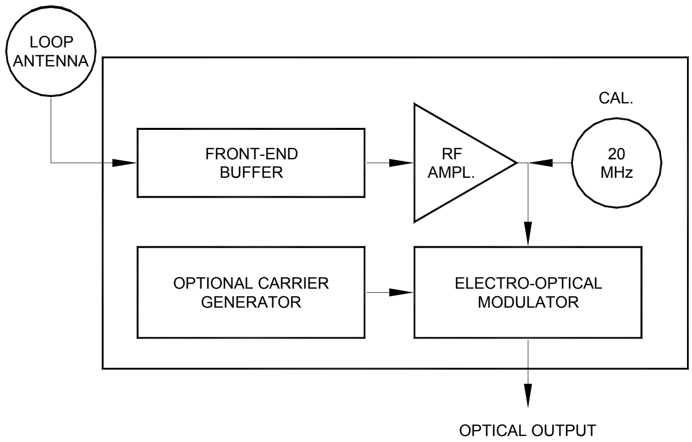
The maximum measurable field amplitude depends on whether non-linearity occurs in the signal processing chain. This characteristic is documented by indicating the **point of compression at 1 dB** of the system, defined, at each frequency, as the amplitude value of the field in free air at which the antenna factor is increased by 1 dB, in relation to that certified in the presence of signals sufficiently small to exclude the presence of saturation phenomena in the processing chain.



The reconstructed signal is sent to the spectrum analyser and, in order to be distinguishable as such, it must emerge from the background noise appearing on the analyser screen. The position of the background noise therefore determines the minimum amplitude of signals that can be safely detected by the system. The chart below shows the **noise level** as it appears on the screen of a spectrum analyser connected to an FP2000, with different RBW settings. Note that noise power is roughly proportional to the Resolution Band Width used.



Magnetic Field Measurements with FP030H Active Antenna



Sensor FP030H consists of an active loop antenna, powered by internal rechargeable batteries, sensitive to the magnetic field component orthogonal to the plane containing the detecting loop.
The RF signal detected by the antenna is internally conditioned by means of high impedance RF circuits and then used to modulate an optical carrier. The modulated optical signal is carried to the RC200A opto-electric converter by means of a glass optical fibre.

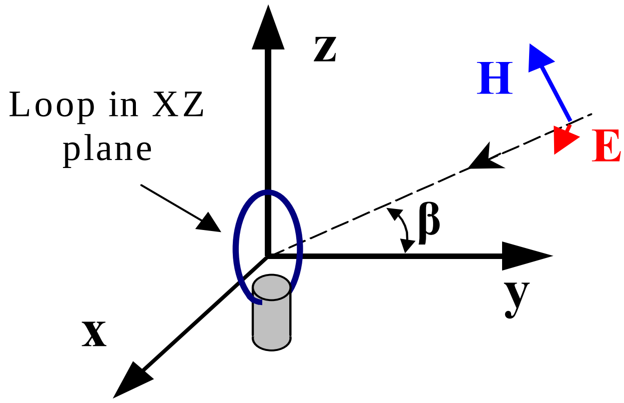
FP030H Technical Data

Dimensions: 65 mm Ø x 300 mm total H
Weight: 0.85 kg
Connectors
Battery charge connector
Optical fibre connector, type SC/PC.
Power supply
Internal rechargeable battery (NiCd)
Battery operation time: 8 hours
Protection level: IP 42.
Operative conditions:
Temperature from –20°C to +50°C.
Humidity: Max 95% a 40°C.

Frequency range: 100 kHz to 120 MHz

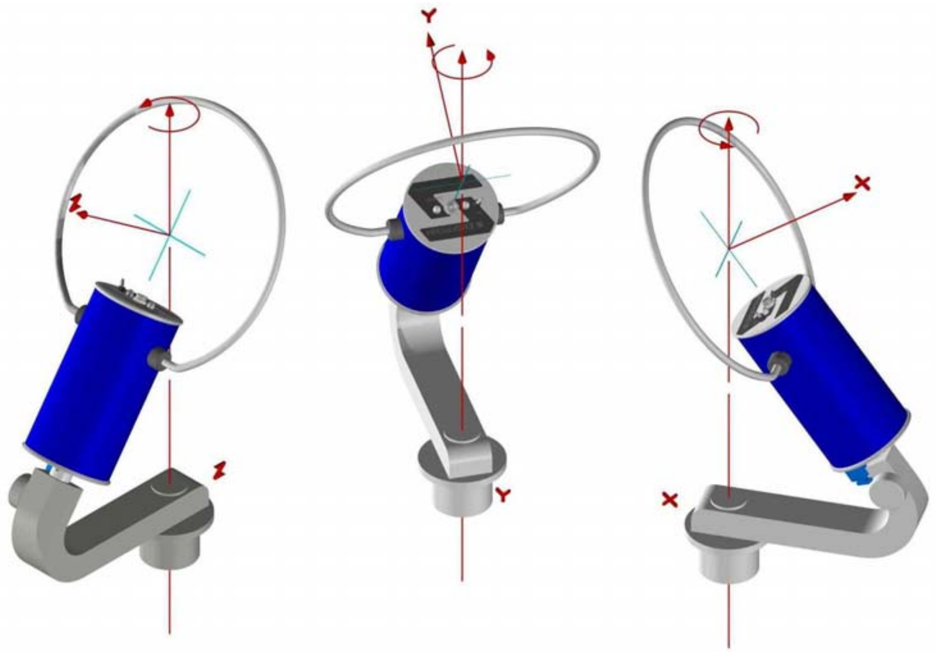
Compression point at 1 dB: 0.5 mA/m÷1 A/m
Maximum applicable field: 5 A/m
Dynamic linear band: Greater than 65 dB
Antenna factor: Individually characterized
Polarization: Linear, uniaxial.
Total electric field rejection (E/H=377 ohm)
> 20 dB up to 30 MHz
> 15 dB from 30 to 80 MHz
> 10 dB from 80 to 110 MHz
Cross-polar component rejection
> 30 dB up to 80MHz
> 20 dB from 80 to 110MHz
Total isotropy error: < 0,5 dB

Total Field Measurements using tri-Axial Ortho-angular Support for FP030H Active Antenna



$$|H| = \sqrt{H_x^2 + H_y^2 + H_z^2}$$

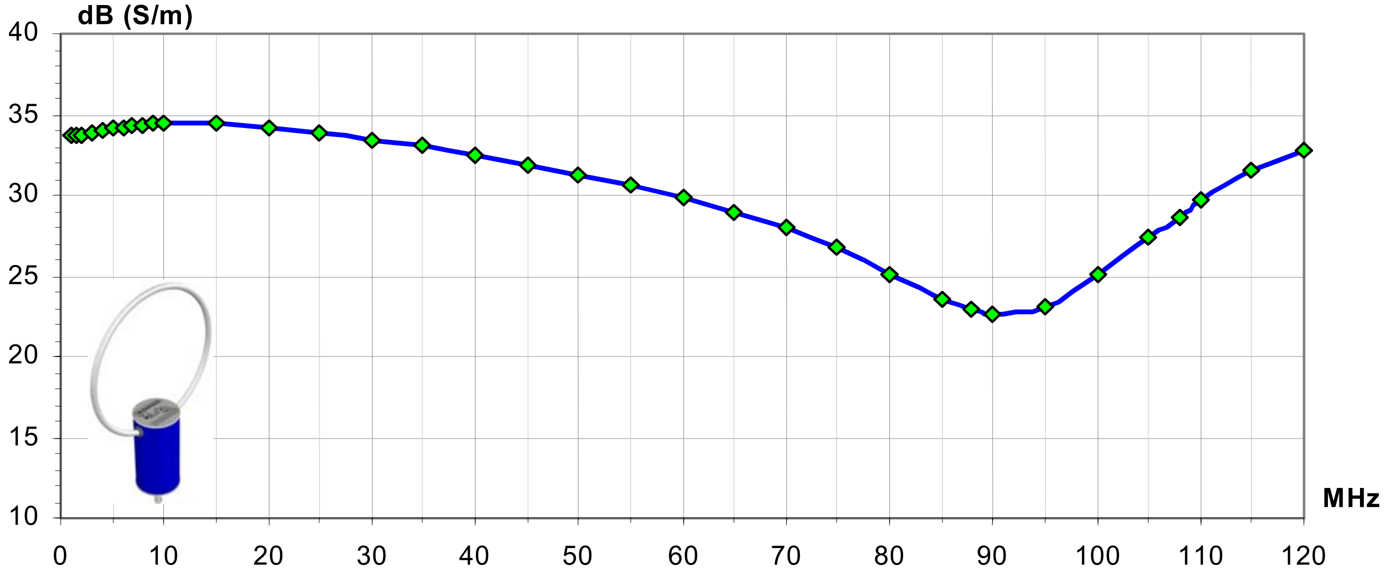
This sensor is sensitive to the magnetic field component orthogonal to the plane containing the antenna loop.
In these conditions, where **H** is the amplitude of the incident magnetic field, and **β** is the amplitude of the angle formed between the plane containing the sensor loop and the direction of the magnetic field **H**, the signal transferred on the optical carrier and transferred to the converter is proportional to $|\mathbf{H}|\cdot\sin\beta$. To reconstruct total amplitude of the incident magnetic field it is therefore simply necessary to take three measurements, adjusting the sensor so that the loop plane is set up along three mutually orthogonal directions.



There is of course no need for one of the three measuring directions to be vertical, since the sensor is capable of operating with any spatial arrangement of its axes. In particular, this enables the sensor to be set up along three mutually orthogonal directions, by simple rotation through 120° round a special axis (ortho-angle).

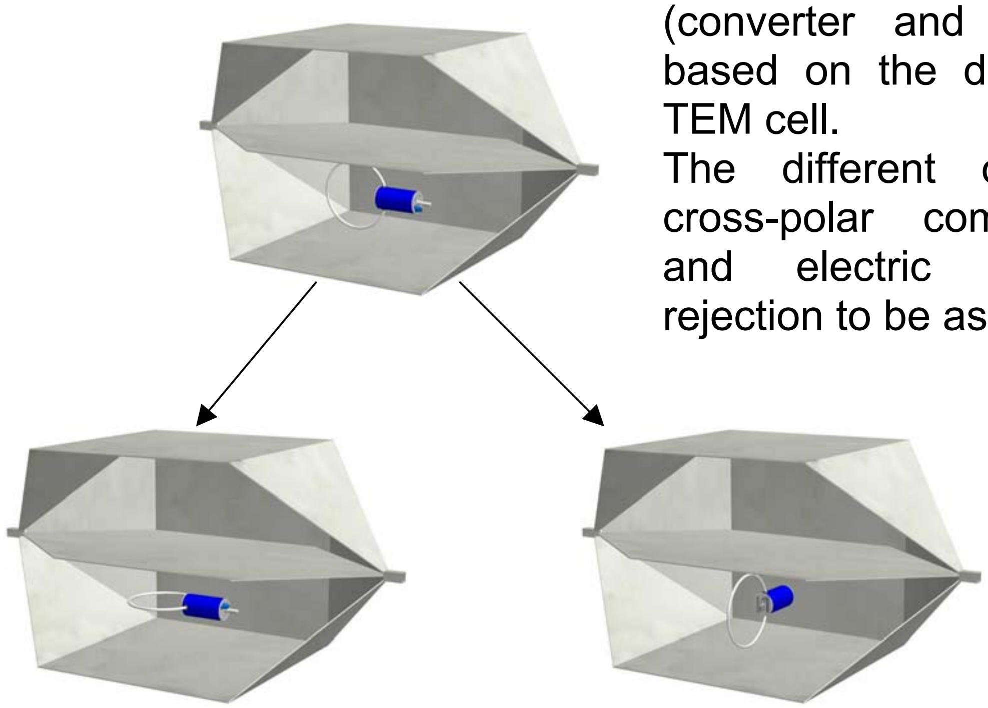
Typical FP030H Antenna Factor

The antenna factor represents the value in dB to be added to the indication in dBμV of the signal extracted by the spectrum analyser, in order to obtain the intensity value of the incident magnetic field on the sensor in **dBμA/m**.



Calibration of the FP030H

The procedure for calibrating the sensor connected to its accessories (converter and optical fibre), is based on the direct method in a TEM cell.
The different orientation allows cross-polar component rejection and electric field component rejection to be assessed.

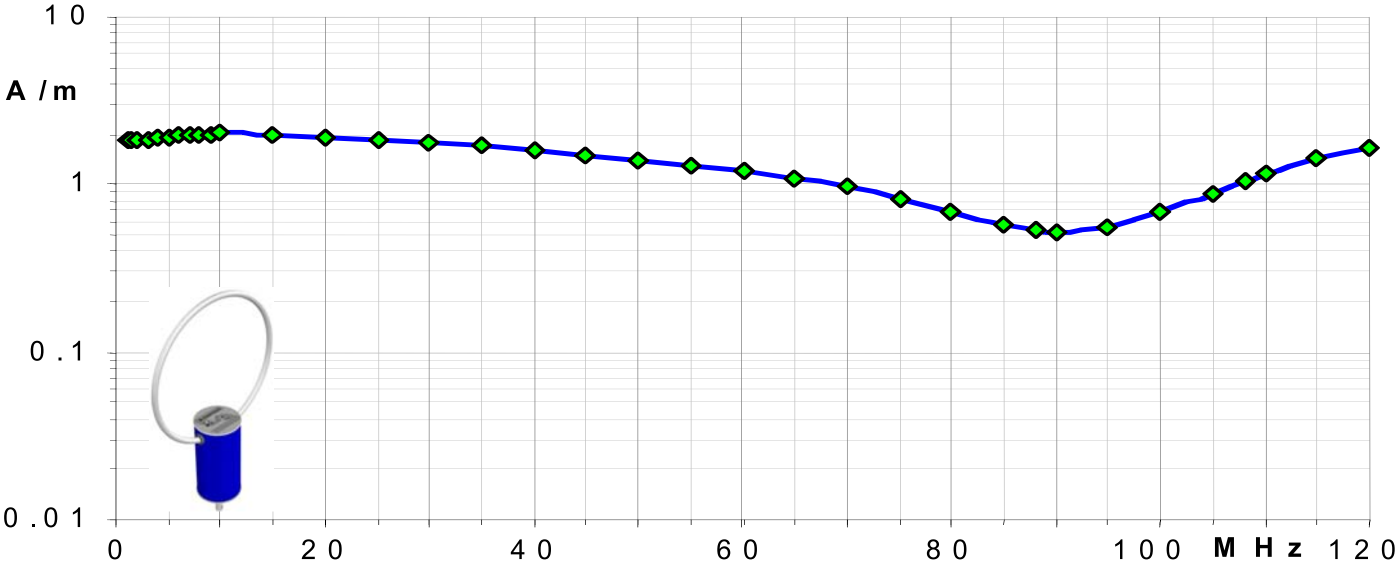


Cross-Polar Component Rejection

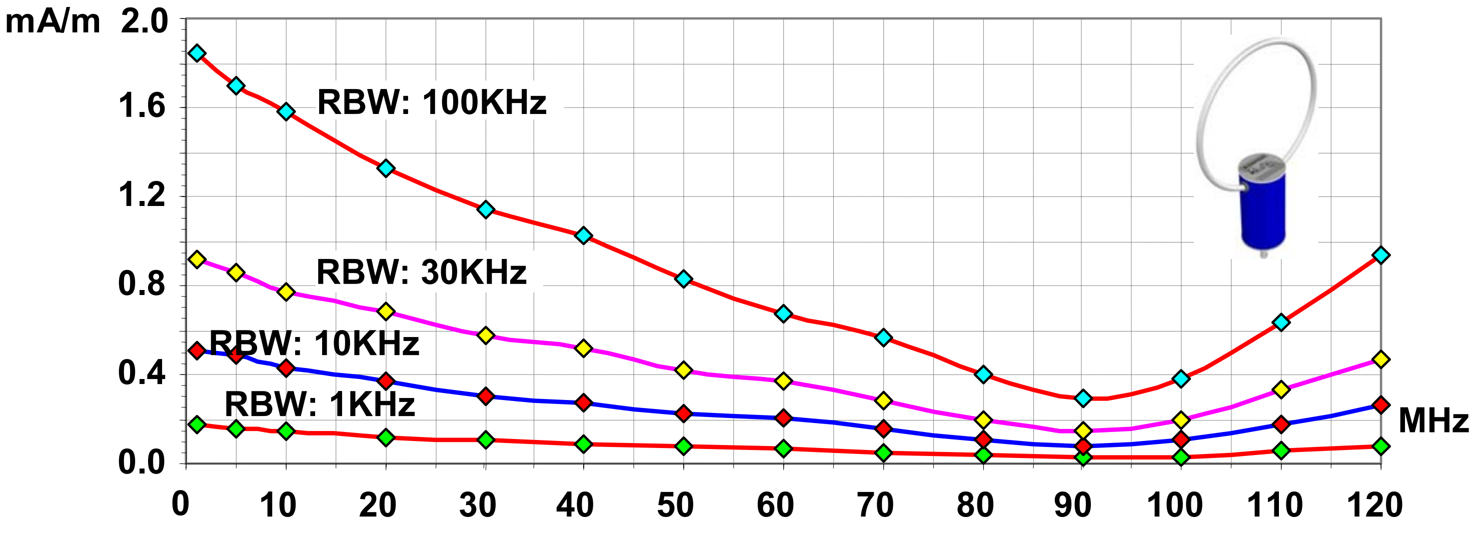
E-Field Component Rejection

FP030H Linear Dynamic Range and Sensitivity

The maximum measurable field amplitude depends on whether non-linearity occurs in the signal processing chain. This characteristic is documented by indicating the **point of compression at 1 dB** of the system, defined, at each frequency, as the amplitude value of the field in free air at which the antenna factor is increased by 1 dB, in relation to that certified in the presence of signals sufficiently small to exclude the presence of saturation phenomena in the processing chain.

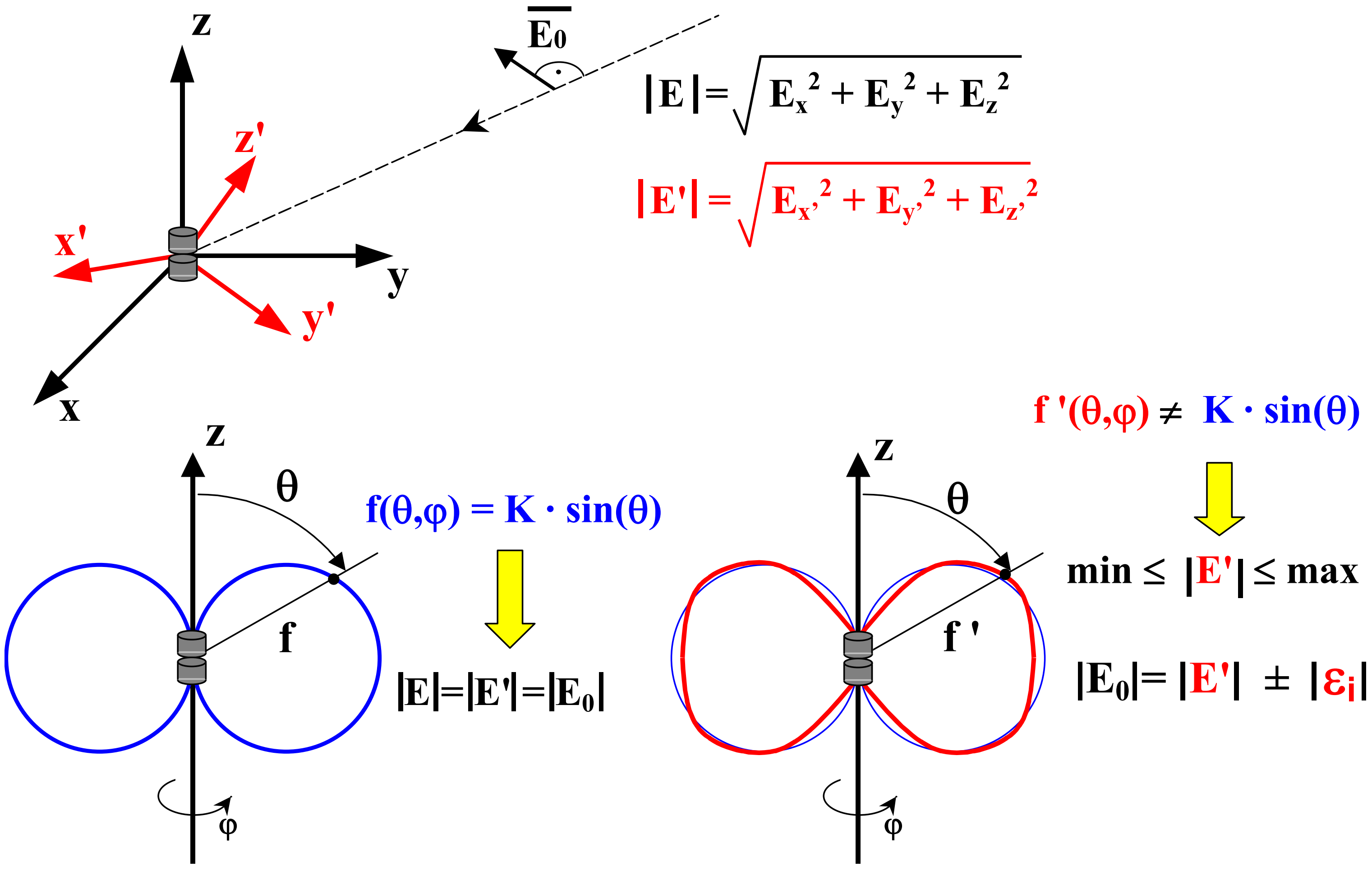


The signal sent to the spectrum analyser must emerge from the background noise appearing on the analyser screen. The level of the background noise therefore determines the minimum amplitude of signals that can be safely detected by the system. The chart below shows the **noise level** as it appears on the screen of a spectrum analyser connected to an FP030H, with different RBW settings. Note that the noise power is roughly proportional to the Resolution Band Width used.



Antenna Radiation Diagram vs Isotropy in Electromagnetic Field measurements

Reconstruction of the total field measured by the antenna must be independent of the tri-axial orthogonal arrangement chosen for orientation of the antenna itself (isotropy).
This situation in fact only arises if the radiation diagram of the antenna is of the omnidirectional type (sin θ), like that of short dipole and small loop antennas.

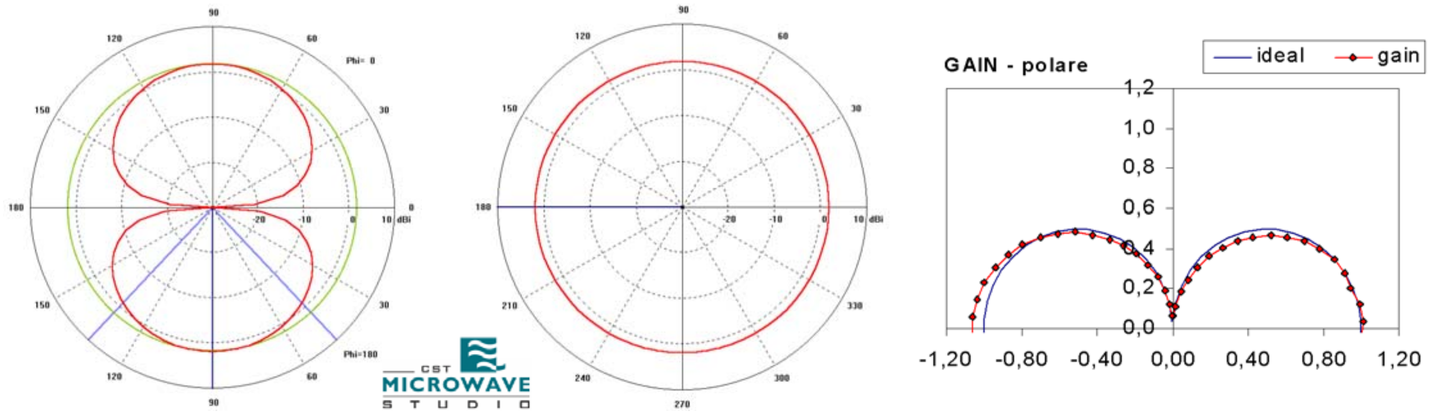


If omnidirectional antennas are not used, deviation from this characteristic causes a measurement error that cannot be corrected, since normally neither the propagation direction nor the polarisation of the field to be measured are known.

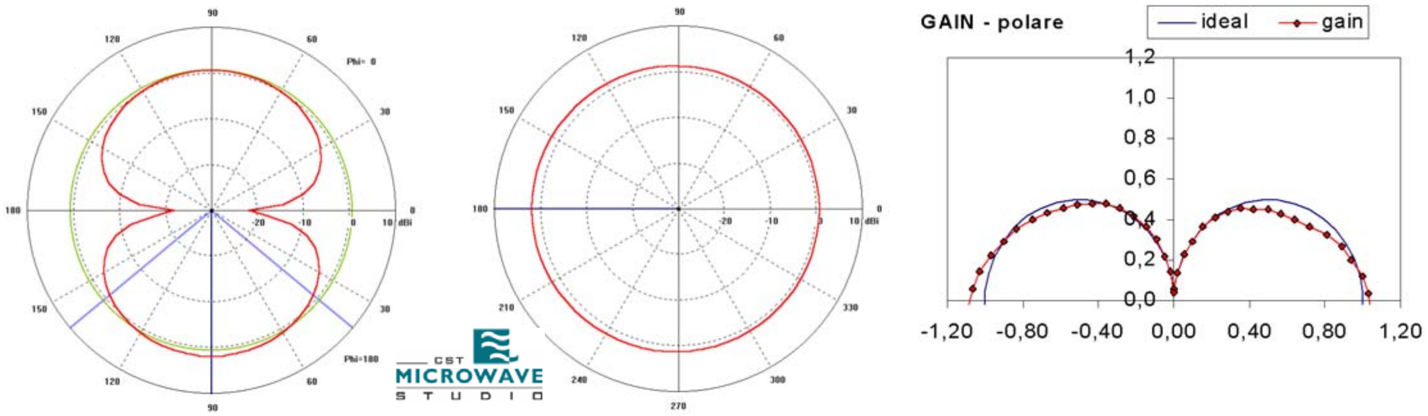
Simulation and Measurements of Radiation Pattern for FP2000

From both simulations and measurements, it can be seen that active antenna EMSFP2000 has a radiation diagram of the sin(θ) type up to relatively high frequencies.

100KHz ..1GHz



2GHz



As the frequency increases, and in particular above 2.5 GHz (out of band), the characteristic radiation diagram distorts. It is therefore not possible to make correct measurements out of band due to the antenna's loss of omnidirectional capability.

On the other hand the magnetic loop antenna exhibits very good omnidirectional behaviour in its overall frequency range.

Principal advantages of using active antennas with optical fibre output:

- One single antenna covers the whole broadcast and mobile frequency band, whereas generally it would be necessary to have a set of 3 or 4 calibrated antennas;

- Allow accurate, low cost calibration, because it is possible to use a TEM cell (up to 150-200 MHz), as for common wide band diode detectors.

Furthermore the absence of any coaxial cable connected and the high impedance of internal circuits:

- Allow accurate E and H field measurements, even in near field region of sources, where passive antennas traditionally encounter serious problems. For example, measurements in the vicinity of AM and FM radio transmitters or close to high frequency industrial sources (VLF; LF, MF,HF, VHF);

- Ensure that there is no disturbance of the field being measured;

- Allow the antenna to be positioned a long way away from the operator and the spectrum analyser, so resolving serious immunity problems of the latter.

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