Measurements of Electric and Magnetic Fields Using Optoelectronic Telemetry

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Abstract—**In the vicinity of the electric power network and near to the power electrical equipments the electromagnetic environment includes electric and magnetic fields, mainly at the spectral area of Extreme Low Frequencies (ELF). In some cases, very close to the working or areas of habitants, it is important to observe the values of the electric and magnetic fields and to compare those values with the appropriate biological limits and/or to the Electro-Magnetic Compatibility (EMC) limits. In these special cases the fields must be measured successfully and carefully. Therefore, the measurement equipment must have high accuracy and be as small as possible, in order to avoid any impact to the measured field values from the physical presence of the unit or of the observer. For application in these cases we develop an optoelectronic telemetry system, for measurements, of the ELF electric and magnetic fields, with small sensors in the measurement point and all the rest equipment in small distance.**

The system includes two electro-magnetic optoelectronic sensors, an optical transceiver and all the measurement electronic circuits. By that method we applied the two appropriate optoelectronic sensors at the measured point and in some distance (up to 100m) an optical (laser) transceiver followed by the measurement circuits. If the outcome laser beam from the transceiver strikes the optoelectronic part of these sensors. Then, that part is triggered to modulate the reflected and returned laser beam. The modulation value depends on the field value. At the receiver part of the optical transceiver, a special optical demodulator extracts the modulation signal from the incoming laser beam and the following measurement electronic circuits extracts the information with the measurement values of the electric and magnetic fields. We must point out that the few mW red beam from a diode laser, has very low power to be an injury problem to the observer or to any other person, except the case when someone stares at the laser beam (intrabeam view).

In our paper we give details of the optoelectronic measurement unit, followed by the calibrating and testing results in two applications in Athens.

I. INTRODUCTION

The man made activities, which produce ELF fields, may have negative impacts in the environment. The appropriate effects, from strong electric and magnetic fields, may be operational and/or biological. The operational effects are mainly EMC phenomena, White [1], as the interference from electrical networks and devices to the neighborhood electronics. The biological effects are mainly the non-thermal phenomena and the impacts to the bodies of workers or habitants exposed to the strong electric or magnetic fields.

The operational or biological hazard is a low possible case but it does not stop existing as a fact and the related research focuses on these problems in connection with the values of the ELF fields. Therefore national and

international bodies have proposed or set limits referring to the field values for the EMC phenomena and for the biological exposure. In some cases, in the vicinity of the electrical network or near to the electrical hardware or equipment, the appropriate EMC limits and/or the biological limits must be applied.

This is a complicated problem because in the ELF band, with the extreme long wavelengths, the combined field is better to be presented as separated electric and magnetic field. Therefore it is impossible to set power density (Poynting vector) limits and use one sensor only for the measurements of the electromagnetic field. Otherwise the sensor must be an antenna with extreme long dimensions. So the limits are given in electric or magnetic field values and for the separate measurement of the electric and magnetic field two appropriate sensors followed by the measurement electronic circuits are necessary. The Fig.1 is a general block diagram of an ELF measurement unit.
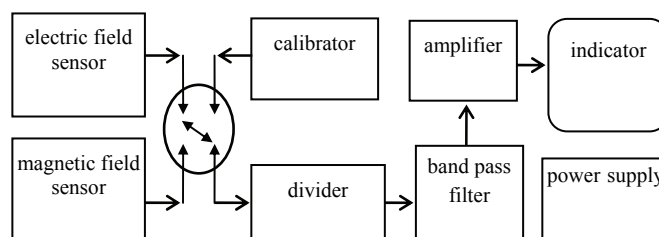

Figure 1. Block diagram of a measurement unit

At the ELF band the correct measurements of the electric and magnetic fields have difficulties, because the result depends on the material, geometry and position of the sensor, to the other objects (grounded or no) near to the sensor's position, to the electromagnetic environmental noise etc. Therefore the measuring equipment must be reliable by having high accuracy and be as small as possible, in order to avoid any impact to the measured field values, arising from the physical presence of the unit or of the observer.

II. THE SENSORS

The design and assembly of a measurement unit for ELF fields depends on the sensor type. The sensor specification captures the accuracy, the bandwidth and the sensitivity. In our equipment we select simple sensors for measurements in the band of 45-65Hz only. The electric field sensor in our equipment is a form of open capacitor (Fig.2), which interacts with the field.
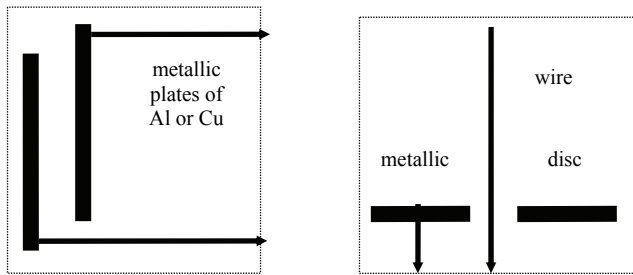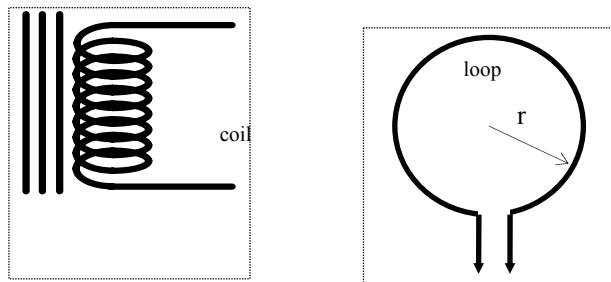
Figure 2. Electric field sensors

Figure 3. Magnetic field sreensors

In the right hand of the Fig.2 is a simple case of this type of sensor, with a wire of height x and diameter d vertical to the centre of a metallic disc. That sensor at the frequency F has capacitance, [2], given by

$$C = \frac{5,2.x}{\left[1 - \left(\frac{F.x}{766}\right)^2\right]\left[\ln\frac{287.x}{d} - 1\right]}$$

The typical sensor for measurements of the magnetic field is some shape of coil as in Fig.3, which interacts with the field. In the right hand of the Fig.3 is a simple case of this type of sensor, with a wire of diameter d in a circular loop with radius r. That sensor has induction (2) of

$$L = 4\pi r\left(\ln\frac{16r}{d} - 1,75\right).10^{-7}$$

With these passive sensors we can make signal captures and after the necessary filtering and amplification, we can read the measurement results into a high accuracy voltmeter, Fig.4.
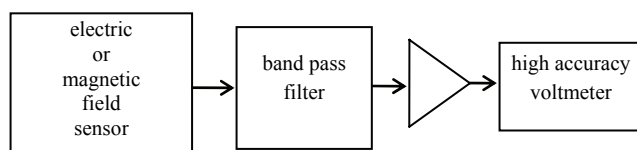

Figure 4. Block diagram of an 50/60Hz field meter

III. THE OPTOELECTRONICS

With the known specifications of the sensors, the only problem that remains is the possible interaction between the measured fields and the measurement unit. A solution to that problem is to measure the fields from a small distance with telemetry applications, by the splitting of the measurement and leaving in field the electric and magnetic sensors only. In that way we develop special measuring equipment that allows us to observe continuously the field values and compare them to the appropriate limits. The optical beam is the best telemetry carrier, because it is totally non interactive with the ELF fields. Therefore the optoelectronic measurements of the ELF fields are possible by the use of an electro-optic or a magnetic-optic modulator.
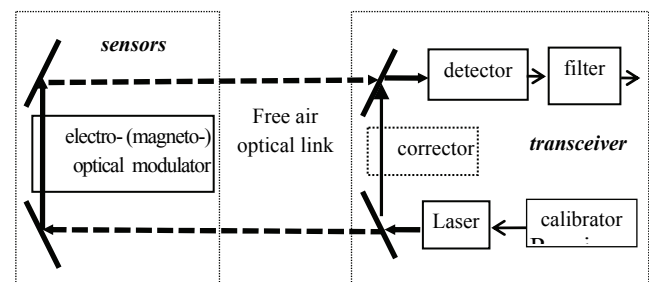

Figure 5.The splitting optoelectronic 50/60Hz field meter

If some optical characteristics of the modulator are variable according to the ELF field values, then the field effects on the Laser beam, passes inside the modulator. If the electric field value is E and the magnetic field value is H, then the impact of this field, Theophanous N. (3), is given by:

$$\Delta(n) \equiv n^{-2} - n_o^{-2} = aE + bE^2 + \cdots$$

$$\Theta = v.x.H$$

where
n=The refraction index of the electro-optic material when the electric field has the value E
n_o=The refraction index of the electro-optic material when the electric field has the value E=0
a=The linear Electro-optic factor of the electro-optic material
b=The square Electro-optic factor of the electro-optic material
Θ=The Faraday rotation of the beam into the magneto-optic material
v=The Verdet constant of the magneto-optic material
x=The length of the optical beam into the magnetic-optic material

For the optical carrier production is useful a low power laser (few mW) with a beam in the visible part of the spectrum (red or green), as is a laser indicator. In general a diode laser (InGaAlP or InAlAsP or GaAsP type) emitting in a spectral line at 633-650-670nm (±10nm) is sufficient. Using those types of laser, the transceiver may be up to a Km distance further, [4] from the ELF field measurement point. The transmission media of the laser beam can be the free atmosphere or up to a Km of fiber optic cable. At the optical receiver the incoming laser beam is directly

correlated to the transmitted beam and the electronic signal output is filtered, amplified and enters a special electronic circuit to extract the electronic value of the E or H (or B).

IV. RESULTS AND COMMENTS

Using the calibrated compact unit of the fig.4, for comparison purposes, we can extract the specification results of the above (Fig.5) splitting optoelectronic 50/60Hz field meter as follows:

-Sensitivity   20V/m & 200nT
-Measuring range $20{\sim}10^5$V/m & $0,2{\sim}10^4\mu$T
-Flatness   ±3db (45~55Hz)
-Accuracy   ±4.8%
-Laser output   5mW, 670nm

In case that we need to measure low values of the ELF field, which are near to the modulator limits, then we can adapt an appropriate operational amplifier, [5], to the electro-optic modulator (Fig.6), for the appropriate amplification of the output signal of the electric or magnetic field passive sensors.
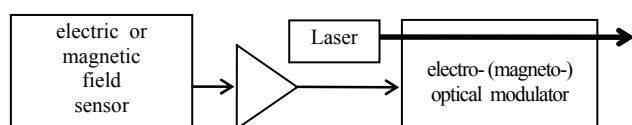

Figure 6.The optoelectronic 50/60Hz field sensor

With that circuit the sensitivity increases at least tenfold. When the laser beam returns to the photo receiver, then the same direct detection as presented in Figure 5, is sufficient enough to increase the measuring sensitivity. Using that increased sensitivity unit, the equipment can measure all the ELF fields near to the electrical power distribution lines. If we compare this equipment with a high sensitivity and accuracy compact field meter we will observe the increased characteristics of our method:

-Sensitivity   2V/m & 200nT
-Measuring range $2{\sim}10^5$V/m & $0,2{\sim}10^4\mu$T
-Flatness   ±2db (45~150Hz)
-Accuracy   ±2.5%
-Laser output   2mW, 670nm

Another sophisticated solution to measure the low values of ELF fields, using low power optical beam and passive sensors, without operational amplifier, is made by using Pockel's electro-optic modulator. In this modulator the electric or magnetic field modulates the phase of optical carrier. Therefore the transceiver-measuring unit can be at any distance in a free air optical contact with the modulator. Also, a double one-way fiber optic may be used so as to keep the phase of the optical carrier more stable. To cover all the possible cases we modify a similar older system, [6], in order to produce a high sensitive unit with coherent detection.
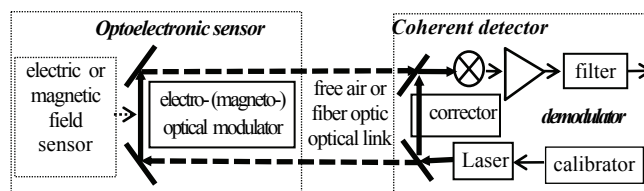

Figure 7.The coherent splitting optoelectronic ELF field meter

With this procedure the system has the advantage of reducing the component we need to place into the field without many active electronic components or metal parts. For the above reasons the measuring values cannot interact with the devices and the result is more reliable.

-Sensitivity   1V/m & 100nT
-Measuring range $1{\sim}10^5$V/m & $0,1{\sim}10^4\mu$T
-Flatness   ±1,5db (45~450Hz)
-Accuracy   ±2%
-Laser output   1mW, 670nm

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