DEPENDENCE OF THE ANTENNA FACTOR ON THE ENVIRONMENT IN WHICH THE ELECTRIC FIELD SENSOR IS LOCATED
VLF - LF, 15 kHz to 515 kHz

1.- Introduction.

As can be deduced from the analyses presented in the documents in References [1] and [2], the antenna factor (Fa) of the Electric Field Sensor is dependent not only on the height at which the electrode is installed but also on the distribution of the electric field lines.
As the electric field is influenced by any conductive or dielectric object located in the vicinity of the Sensor installation, the antenna factor (Fa) is inevitably influenced by objects in the Sensor's environment such as trees, living fences, fences, electrical and communications networks, wooden, brick and metal constructions.
In the documents of References [1], [2] and [3] the analyses of the Electric Field Sensor with its corresponding impedance adapter have been carried out considering ideal conditions where the sensor is installed at a height (H) on an equipotential flat surface without disturbing elements in the vicinity.
When this ideal installation condition is not met, as is the case with most practical installations in urban or suburban areas, the unavoidable alteration of the distribution of the electric field lines will result in the antenna factor (Fa) being different from that obtained under ideal theoretical installation conditions.
In order to determine a more realistic antenna factor in the particular case of the installation of the Electric Field Sensor in the author's home, which is inevitably disturbed by trees, fences, brick constructions and metal masts of HF and VHF antennas in a suburban area, determinations were made of the electric field levels (E) of the electromagnetic radiation coming from two distant emitters operating in LF corresponding to the NAVTEX system.
These transmitters are located on the coast of the Atlantic Sea in Mar del Plata and Punta Indio at distances of 400 and 100 km respectively and generate very stable signals during daylight hours.
Both transmitters operate on the frequencies of 490 kHz and 518 kHz alternately following a predetermined time sequence.
With the measured levels and using the theoretical antenna factor of the Electric Field Sensor, the corresponding electric field level (E) of the received electromagnetic radiation expressed in [µV/m] was calculated.
At the same time and using a Magnetic Field Sensor, Active Loop for MF-HF described in Reference [4], the electric field level corresponding to the same signal was determined using its corresponding antenna factor calibrated according to the guidelines of References [5] and [6].
Although a loop is only sensitive to the magnetic component (H) of the radiation, it is possible to determine the corresponding magnitude of the electric field (E) corresponding to the electromagnetic radiation received by the relationship between the two fields in free space, as expressed in Equation A1.1 of Annex A at the end of this document.
As the magnetic field (H) of the radiation is only influenced by large metallic elements, if the Loop is away from metallic disturbing objects, it is possible to use it as a reference to determine the magnitude of the equivalent electric field (E) and with this value make the comparison with the one determined by the Electric Field Sensor and thus calculate the magnitude in which its antenna factor (Fa) is affected by the surrounding environment to the installation site.

With this result, a corrected antenna factor (Fa corrected) was determined for the Electric Field Sensor, which allows later to make practical, more realistic measurements of the magnitude of the electric field strength (E) of the signals received with it, having corrected the disturbances caused by the environment of the installation site.

2.- Characteristics of the elements involved in the measurements.

An SDR-type receiver was used as a power meter element of the received signal (Pr), whose power meter, with a reading in [dBm], is correctly calibrated with reference to an input impedance of 50Ω.
The field sensing elements are the Electric Field Sensor under analysis, installed at the height and in the normal place of operation with its corresponding frequency converter from VLF - LF to HF and a Magnetic Field Sensor (Loop MF-HF) whose antenna factor (Fa) is calibrated following the procedures indicated by the standards of References [5] and [6].

2.1.- SDR receiver.

Frequency range:	f = 480 kHz to 30 MHz
Input Impedance:	Ze = 50 Ω
Power measurement range:	Pr = - 100 dBm to + 20 dBm
Measurement error :	e = ± 0.5 dB

2.2.- Electric Field Sensor.

Frequency range:	f = 15 kHz to 520 kHz
Installation height:	H = 8.60 m above ground level
Theoretical antenna factor:	Fa = 0.235 [1/m] @ 490 and 518 kHz
VLF - LF to HF converter attenuation:	Ac = 6 dB
Output Impedance:	Zo = 50 Ω

2.3.- Magnetic Field Sensor.

Frequency range:	f = 450 kHz to 10 MHz
Installation height:	H = 4.50 m above ground level
Calibrated antenna factor:	Fa = 3.63 [1/m] @ 490 and 518 kHz
Output Impedance:	Zo = 50 Ω

3.- Measurement results.

The measured power levels (Pm), with the SDR receiver expressed in [dBm], were corrected according to the attenuation between the respective sensors and the receiver in each case with the following values:

- Electric Field Sensor Measurement: Ae = 26 dB
- Magnetic Field Sensor Measurement: Am = 20 dB

Each received power value (Pr) measured in [dBm] corresponds to a power value expressed in [mW] whose value is calculated as:

$$Pr\ [mW] = \text{antilog}\ \{ Pr\ [dBm] / 10 \} \qquad (1)$$

This power value corresponds to a potential Ur expressed in [μV] over a load of 50 Ω according to the ratio:

$$Ur\ [\mu V] = \{ 10^{9} \cdot Pr\ [mW] \cdot 50 \}^{1/2} \qquad (2)$$

This potential is translated, by means of the antenna factor (Fa) corresponding to each sensor, into an electric field level (E), expressed in [μV/m], which quantifies the electromagnetic radiation received by the expression:

$$E\ [\mu V/m] = Fa\ [1/m] \cdot Ur\ [\mu V] \qquad (3)$$

The table below summarizes the values obtained from the measurements taken on 01/11/2022:

Time (Tx)	***Freq. [kHz]***	***Pm [dBm] SCE / SCM***	***Pr [dBm] SCE / SCM***	***Ur [μV] SCE / SCM***	***E [μV/m] SCE / SCM***	***K***
11:40(M)	*518*	*- 82,2 / - 92,5*	*- 56.2 / - 72,5*	*346 / 53,0*	*81,4 / 193*	*2,37*
11:50(P)	*518*	*- 65,8 / - 76,9*	*- 39,8 / - 56,9*	*2288 / 320*	*538 / 1160*	*2,16*
13:40(M)	*490*	*- 81,0 / - 94,1*	*- 55,0 / - 74,1*	*398 / 44,1*	*93,4 / 160*	*1,72*
13:50(P)	*490*	*- 62,4 / - 74,7*	*- 36,4 / - 54,7*	*3384 / 412*	*795 / 1494*	*1,88*
15:40(M)	*518*	*- 82,4 / - 92,5*	*- 56,4 / - 72,5*	*384 / 53,0*	*79,5 / 192*	*2,42*
15:50(P)	*518*	*- 65,8 / - 76,8*	*- 39,8 / - 56,8*	*2288 / 323*	*538 / 1173*	*2,18*
17:40(M)	*490*	*- 81,3 / - 94,3*	*- 55,3 / - 74,3*	*384 / 43,1*	*90,3 / 156*	*1,73*
17:50(P)	*490*	*- 62,5 / - 74,8*	*- 36,5 / - 54,8*	*3346 / 407*	*786 / 1477*	*1,88*
19:40(M)	*518*	*- 81,2 / - 92,0*	*- 55,2 / - 72,0*	*389 / 56,2*	*91,3 / 204*	*2,23*
19:50(P)	*518*	*- 65,8 / - 77,0*	*- 39,8 / - 57,0*	*2288 / 316*	*538 / 1147*	*2,13*

Tx : ***(M) : Mar del Plata*** ***(P) : Punta Indio***
SCE : ***Electric Field Sensor***
SCM : ***Magnetic Field Sensor***
K : ***Correction factor***

4.- Determination of the corrected Antenna Factor.

On the basis of the correction factors (K) determined from the measurements presented in Section 3, it is possible to determine an average correction factor, the value of which is:

K average = 2,07 ± 0,24

The corrected Antenna Factor results:

Fa corrected = **Fa** theoretical·**K** average = 0,235·2,07 = 0,486 ± 0,06 [1/m] (4)

The magnitude of the actual electric field at the Sensor installation site is obtained using the corrected Antenna Factor in Equation (3):

$$\boldsymbol{E\ [\mu V/m] = Fa\ corrected\ [1/m]\cdot Ur\ [\mu V] = 0{,}486\ [1/m]\cdot Ur\ [\mu V]} \qquad (5)$$

The results of the measurements are obtained with a percentage uncertainty of:

Uncertainty [%] = (± 0,06 / 0,486)·100 = ± 12,3 %

5.- References.

[1].- Theory of operation of the VLF - LF Electric Field Sensor. 15 kHz to 515 kHz. Rev.I01. Eng. Daniel A. Esteban. January 2024.

[2].- Electromagnetic Analysis of Short Monopole and Electric Field Sensor as Receiving Antennas for VLF - LF. Rev. I01. Eng. Daniel A. Esteban. January 2024.

[3].- Impedance Adapters for Electric Fields Sensors for VLF- LF. 15 kHz to 515 kHz. Rev. I01. Eng. Daniel A. Esteban. January 2024.

[4].- Active Loop for MF - HF. 450 kHz a 10 MHz. Rev. V2. Eng. Daniel A. Esteban. September 2019.

[5].- IEEE Std 291-1991. IEEE Standard Methods for Measuring Electromagnetic Field Strength of Sinusoidal Continuos Waves. 30 Hz to 30 GHz.

[6].- NBS. Circular 517. Frank M. Greene. December 1951. Calibration of Commercial Radio Field-Strength Meters at the National Bureau of Standards.

[7].- ELECTROMAGNETICS, Secon Edition.- 1973. John D. Kraus, Keith R. Carver. Mc Graw - Hill Kogakusha Ltd.

ANNEX A.

A1.- Links between the electric and magnetic fields in an electromagnetic wave.

The link between the electrical (E) and magnetic (H) components of an electromagnetic wave, in the far field, is through the characteristic impedance of medium (ξ). Reference [7]. That's how you have to:

$$E = H \cdot \xi \quad [V/m] \qquad (A1.1)$$

Where:

E = Electric field. [V/m]
H = Magnetic field. [A/m]
ξ = Characteristic impedance of the medium. (Vacuum or air = 377 Ω)

The relationship between magnetic induction (B) and magnetic field strength (H) is the permeability of the medium (μo). Like this:

$$B = \mu o \cdot H \quad [T] \qquad (A1.2)$$

Where:

B = Magnetic induction. [Tesla]
H = Magnetic intensity. [A/m]
μo = Permeability of the medium. (For vacuum or air = $4 \cdot \pi \cdot 10^{-7}$ A/m)

By relating equations (A1.1) and (A1.2) we can obtain the magnitude of the magnetic induction (B) produced by the electromagnetic wave from the strength of the electric field (E) of the wave as:

$$B = E \cdot \mu o / \xi \quad [T] \qquad (A1.3)$$

In the case of vacuum or air, if the values of μo and Zo are replaced, the result is:

$$B = E \cdot 3{,}333 \cdot 10^{-9} \quad [T] \qquad (A1.4)$$

Where:

B = Magnetic induction of the received field. [Tesla]
E = Received electric field. [V/m]