

## NEAR FIELD CHARACTERISTICS OF MF MONOPOLE WITH A PARASITIC

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**Abstract**—This work is dedicated to the study and measurement of the electric and magnetic fields intensities in the vicinity of an antenna array that is used for broadcasting at medium frequencies. The far field distance of a radiating system is usually computed with  $2D^2/\lambda$  which is obtained from the geometry of the problem. Another method to obtain the far field distance using the wave impedance of the electromagnetic wave through the ratio of electric and magnetic field, has been measured and calculated theoretically. The classical and new method to compute the far field distance are compared in this paper in order to show the improves in the calculation.

The antenna array used in this work is a monopole plus a parasitic element at medium frequency, which generate a ground wave. Near the antenna, the electric field has vertical and radial components, and the areas are called the reactive near field and the radiated near field. The attenuation of the electric and magnetic fields due to the soil can be neglected for the near field study.

The prediction of the levels of field intensity is useful to analyze electromagnetic interference and electromagnetic compatibility. It is also important to verify the regulations of International Standard IEEE C95-1 and the Argentina Regulation 3690 of National Communications Commission (CNC).

### 1. INTRODUCTION

Monopole antennas of medium frequency type are usually connected to metallic radials at the base of the antenna to increase the conductivity of the earth. The calculation of the field close to the antenna will not be affected by the ground plane conductivity because the effect of dissipation depends on the distance traveled and for distances close to antenna this effect is negligible.

In the vicinity of a broadcasting antenna it is desirable to study and measure the intensity of the electric field radiated for safety reasons that people working there and to prevent electromagnetic interference problem.

A medium frequency antenna generates a ground wave in the far field with an electric field with vertical polarization. The intensity of the electric field is attenuated because the soil is not a perfect conductor. Also there will be a diffraction effect due the sphericity of the earth's surface [3, 5, 7, 10].

The coverage of a medium frequency radio station with polarization vertical is usually estimated with the Norton-Sommerfeld model, leading to the attenuation introduced by the soil, which depends on the electrical permittivity  $\epsilon_r$  and the electrical conductivity  $\sigma$  [6], for non magnetic soils.

## 2. FORMULATION AND EQUATIONS

### 2.1. Near Fields

Monopole antennas are commonly used in modulated amplitude in broadcasting applications, where the electromagnetic propagation desirable is the surface wave. These antennas generally are of a height ranging from  $\lambda/4$  to  $\lambda/2$ .

Considering a thin monopole antenna, which has a sinusoidal current distribution, the magnetic and electric field in the vicinity of the antenna [1, 4, 8, 9] can be expressed thus:

$$\mathbf{H} = \frac{1}{\mu_0} \nabla \times \mathbf{A}, \quad (1)$$

$$\mathbf{E} = \frac{1}{j\omega\epsilon} \nabla \times \mathbf{H}. \quad (2)$$

The electric and magnetic field vectors are:

$$\mathbf{H} = H_\phi \hat{\phi}, \quad (3)$$

$$\mathbf{E} = E_\rho \hat{\rho} + E_z \hat{z}. \quad (4)$$

The components of  $\mathbf{E}$  and  $\mathbf{H}$  can be written as:

$$H_\phi = -\frac{I_0}{j4\pi\rho} \left( e^{-jkR_1} + e^{-jkR_2} - 2 \cos kH e^{-jkr} \right), \quad (5)$$

$$E_\rho = j \frac{I_0 Z_0}{4\pi\rho} \cdot \left( (z-H) \cdot \frac{e^{-jkR_1}}{R_1} + (z+H) \cdot \frac{e^{-jkR_2}}{R_2} - 2z \cos kH \frac{e^{-jk\rho}}{\rho} \right), \quad (6)$$

$$E_z = -j \frac{I_0 Z_0}{4\pi} \cdot \left( \frac{e^{-jkR_1}}{R_1} + \frac{e^{-jkR_2}}{R_2} - 2 \cos kH \frac{e^{-jkr}}{r} \right), \quad (7)$$

where:

$$r = \sqrt{\rho^2 + z^2}, \quad (8)$$

$$R_1 = \sqrt{\rho^2 + (z - H)^2}, \quad (9)$$

$$R_2 = \sqrt{\rho^2 + (z + H)^2}, \quad (10)$$

$Z_0 = 377 \Omega$  is the wave impedance of the vacuum, and

$H$  is the monopole height

$\rho, z, \phi$  are cylindrical coordinates assuming the coordinate center at the monopole.

The total  $\mathbf{H}$  and  $\mathbf{E}$  fields can be expressed by contributions of the monopole plus the director, and can be expressed as:

$$\mathbf{H} = (H_{\phi 1} + H_{\phi 2})\hat{\phi} = H_{\phi}\hat{\phi}, \quad (11)$$

$$\mathbf{E} = (E_{\rho 1} + E_{\rho 2})\hat{\rho} + (E_{z 1} + E_{z 2})\hat{z} = E_{\rho}\hat{\rho} + E_z\hat{z}. \quad (12)$$

To obtain the components of all the fields contributions

$E_{\rho 1}, E_{\rho 2}, E_{z 1}, E_{z 2}, H_{\phi 1}$  and  $H_{\phi 2}$ , the expressions (5), (6) and (7) have been used. The Hallen equations have been used to obtain the monopole and director current distributions [2].

## 2.2. Far Field

An electromagnetic wave radiated from an antenna has a spherical wave front and for the large distances from the antenna the wavefront can be considered as a plane. An expression for the far field of the antenna, accepting an error of less than 22.5 degrees in the planicity wave front [2], can be written as:

$$R > \frac{2D^2}{\lambda}, \quad (13)$$

where

$D$  is the maximum dimension of the antenna

$\lambda$  is the wavelength of the EM wave in the vacuum,

and  $R$  is the distance where far field is produced.

The electric and magnetic radiated fields from a monopole have a  $1/R$  variations in a far field or Fraunhofer zone and the Poynting vector will have practically only one component. This radiated electric

field intensity in a far field of a vertical antenna can be calculated by means of Sommerfeld-Norton [7] equations, expressed as:

$$E = \frac{1}{R} \sqrt{30WD_tAA_1}, \quad (14)$$

where

$E$  is the electric field intensity of the Surface Wave [V/m],

$W$  is the transmitted power [W],

$D_t$  is the antenna directivity,

$R$  is the distance to the transmitting antenna where the electric field are calculating,

$A$  is an attenuation factor to the earth properties, and

$A_1$  is a attenuation Factor due to the diffraction factor of the earth.

The electric field intensity will be attenuated because the earth is not a perfect conductor and a diffraction factor of the earth also occurs [7].

The coverage of the medium frequency radio station with vertical polarization depends on the real part of the complex electrical permittivity  $\epsilon = \epsilon_R - j\epsilon_I$  and mainly depends of the dielectric losses. If the soil can be considered a non-magnetic media [6] and then dielectric losses are related with the electrical conductivity of a media as:

$$\sigma = \omega\epsilon_I, \quad (15)$$

### 2.3. Wave Impedance and Far Field

The wave impedance of electromagnetic plain wave is define as a ratio of the electric field and magnetic field Intensity:

$$Z = \frac{E}{H}. \quad (16)$$

In a vacuum that wave impedance is  $377\Omega$ . In the vicinity of the antenna the electric field has two components,  $E_z$  and  $E_\rho$ , and the magnetic field just one  $H_\phi$ . Then two wave impedances can be defined [1]:

$$Z_1 = -\frac{E_z}{H_\phi}, \quad (17)$$

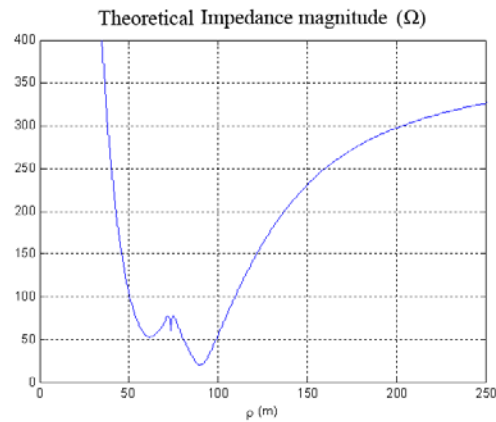
$$Z_2 = \frac{E_\rho}{H_\phi}. \quad (18)$$

If the distance to the antenna  $\rho$  grows, the far field can be considered, the wave impedance  $Z_1$  tends to  $377\Omega$ , and  $Z_2$  tends to zero, as:

$$Z_1 \rightarrow 377\angle 0, \quad (19)$$

$$Z_2 \rightarrow 0. \quad (20)$$

$E_\rho$  dominates near the antenna, but below 10 m,  $E_\rho$  can be neglected against  $E_z$ . For these reasons, in this work the wave impedance  $Z_1$  will be studied as a function of the distance to the antenna, as a way to observe the far field. The modulus and phase of the theoretical wave impedance as a function of the distance to the antenna can be observed in Figs. 1 and 2.



**Figure 1.** Modulus of the theoretical wave impedance  $Z_1$  as a function of the distance are replaced with magnitude of the wave impedance  $Z_1$  as a function of the distance.

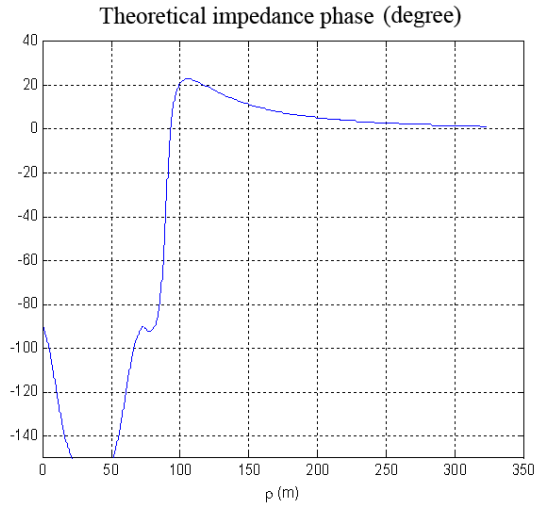
### 3. EXPERIMENTS

The medium frequency radio station has an array antenna of a monopole antenna with a parasitic element (director), as can be observed in the Fig. 3. The transmitter and the dimensions of the antenna array are:

#### Transmitter

Power  $W = 25 \text{ kW}$ ,  $W = 100 \text{ kW}$

Frequency  $f = 790 \text{ kHz}$



**Figure 2.** Phase of the theoretical wave impedance  $Z_1$  as a function of the distance are replaced with Phase of the wave impedance  $Z_1$  as a function of the distance.

#### Monopole

Height  $H = 197$  m ( $0.52\lambda$ ),  
 Radius 1.05 m ( $0.00276\lambda$ ),  
 Grounding System of 180 metallic conductors

#### Director

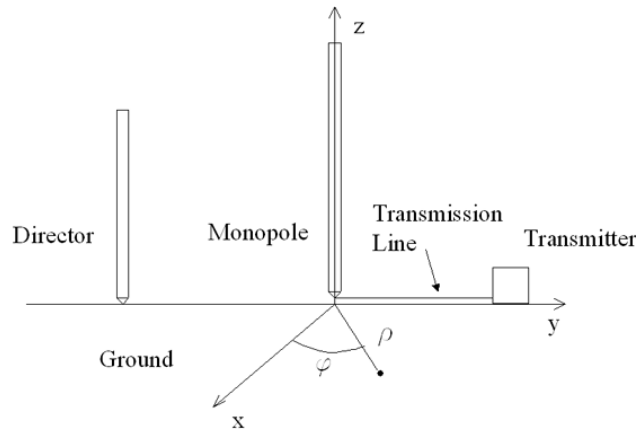
Height  $H = 87$  m ( $0.229\lambda$ ),  
 Radius 0.47 m ( $0.00123\lambda$ ),  
 Grounding System of 180 metallic conductors

Radials A, B, C, and D have been drawn, considering the monopole antenna at the center, as can be shown in Fig. 4.

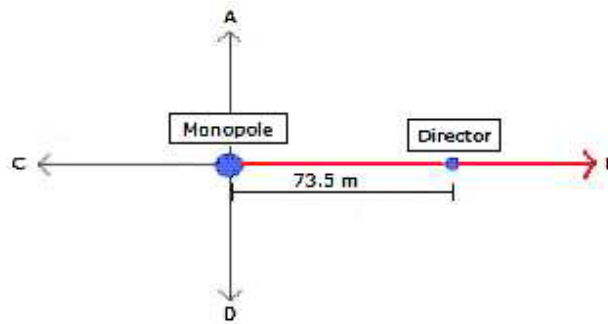
## 4. RESULTS

The measurements of the electric and magnetic field intensities can be observed in Figs. 5 and 6. Also in these figures, the theoretical curves calculated by (11) and (12) are depicted, where the abrupt increment in the level of the electric and magnetic field at  $\rho = 73.5$  m is due to the parasitic element.

The maximum permissible radiation exposure for uncontrolled environments have been suggested by the IEEE [11]:  $E = 614$  V/m



**Figure 3.** Monopole antenna for medium frequency of  $H = 197$  m of height, and with the director placed at the distance of 73.5 m which works at a frequency  $f = 790$  kHz.

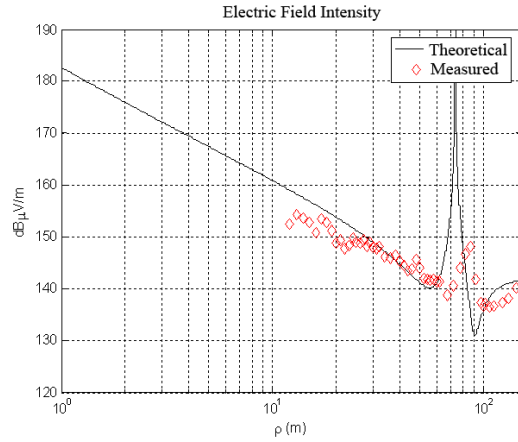


**Figure 4.** Picture of the radial B used for the measurements.

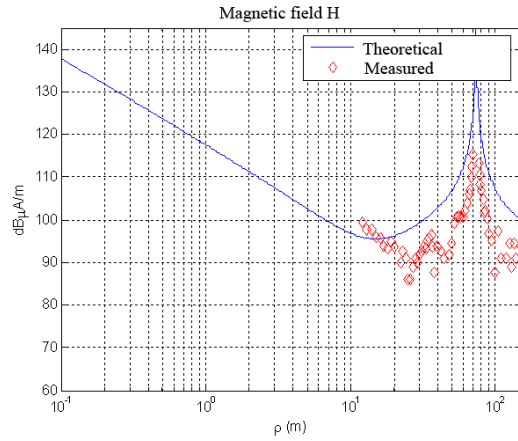
(175.7 dB  $\mu$ V/m) and  $H = 206.3$  A/m (166.3 dB  $\mu$ A/m). This  $E$  field level can be reach at 2 m of the antenna for 25 kW of transmitter power, as can be observed in Fig. 5.

#### 4.1. Comparison between Classical and New Approach of the Far Field Distance

a) The classical approach of the far field distance calculation, explained in subsection 2.2 of monopole antenna with a parasitic element can be



**Figure 5.** Electric field intensity measured and calculated on the radial B, at a height of 0.2 m and for 25 kW of transmitter power.



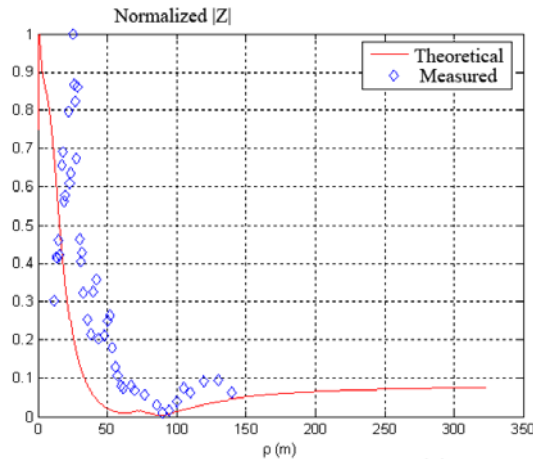
**Figure 6.** Magnetic field intensity measured and calculated on the radial B, at a height of 0.2 m and for 100 kW of transmitter power.

computed using the maximum dimension of the array  $D \cong 215$  m, then

$$R > \frac{2D^2}{\lambda} = 244 \text{ m.} \quad (21)$$

b) Using the new approach to calculate the far field distance, assuming that the maximum impedance difference between the magnitude of the vacuum impedance  $Z_0 = 377 \Omega$  and the magnitude of the wave





**Figure 7.** Normalized wave impedance measured and calculated on the radial B.

impedance  $Z_1$  defined in section 2.3, is 10%. This difference can be obtained from the Fig. 1, then the far field distance results:

$$R > 275 \text{ m.} \quad (22)$$

For  $R = 275 \text{ m}$  the phase difference between the wave impedance of the vacuum and  $Z_1$  is 3 degrees. This can be observed in phase of the wave impedance as a function of the distance as shown in Fig. 2. The planicity error in the wave front obtained for two methods are: a) 25 degree b) 20 degrees

Case b) have two parameters to study the behaviour of far field: the magnitude and phase of the wave impedance  $Z_1$  as a function of the distance as shown Figs. 1 and 1 Case a) has only one parameter and this one is geometric.

For the above consideration it can be observed that the approach b) is better than approach a).

## 5. CONCLUSION

The wave impedance in a region close to the antenna, depends on the source characteristics.

In the array antenna the monopole is interacting with the parasitic element and the current on the monopole increases. This can be observed at the center, and also an increase of the electric and magnetic fields of about 2dB compared with the isolated monopole in the parasitic direction is obtained.

The results obtained in this work present some differences from the theoretical computations, and this difference may be due to the errors in the measurement caused by the measurement set-up itself. Other disturbance effects probably can be a fence and a lighting pole.

The  $E_z$  components turns dominant versus  $E_\rho$  for  $\rho > 10$  m, and  $0 \text{ m} < z < 2 \text{ m}$ . For  $\rho < 10$  m,  $E_z$  can be neglected and  $E_\rho$  is dominant.

The Theoretical computations of the fields for a thin wire monopole plus a parasitic element agree with the measurements. The  $Z_{11}$  and  $Z_{22}$  impedances have been used for the computations.

The Theoretical predictions show that the electric and magnetic field intensities do not have much variation from  $0.2 \text{ m} < z < 2 \text{ m}$ , but the measurements show differences. These can be due to the experimental errors in the measurement system.

The far-field zone has been calculated using the wave impedance of the electromagnetic field, because in this way it is possible to obtain the far field of the array antenna consisting of a monopole antenna plus the parasitic element. This wave impedance concept improves the geometric approach usually employed as  $R = 2D^2/\lambda$ , because the wave impedance is purely an electromagnetic concept, and does not only take into account the geometry of the system.

The planicity error in the wave front obtained for two methods are: a) 25 degree b) 20 degrees. Case b) have two parameters to study the behaviour of far field: the magnitude and phase of the wave impedance  $Z_1$  as a function of the distance as shown Figs. 1 and 2. Case a) has only one parameter and this one is geometric.

For the above consideration it can be concluded that the approach b) is better than approach a).

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## APPENDIX A. VECTOR POTENTIAL **A**

In homogeneous media using Maxwell equations and applying the time harmonic field variations in a region of no sources and setting the Lorentz gauge, the differential equation of the magnetic vector potential **A** can be expressed thus [2]:

$$\nabla^2 \mathbf{A} + k^2 \mathbf{A} = -\mu \mathbf{J} \quad (\text{A1})$$

where:  $k^2 = \omega^2 \mu \epsilon$ .

The solution of this differential equation can be writing as:

$$\mathbf{A}(x, y, z) = \frac{\epsilon}{4\pi} \int_{v'} \mathbf{J}(x', y', z') \frac{e^{-j\beta R}}{R} dv', \quad (\text{A2})$$

where  $\mathbf{R} = \mathbf{r} - \mathbf{r}'$ .

The magnetic field can be obtained from

$$\mathbf{H} = \frac{1}{\mu} \nabla \times \mathbf{A}. \quad (\text{A3})$$

Operating [2]:

$$\mathbf{H}(x, y, z) = -\frac{1}{4\pi} \int_{v'} \left( \hat{\mathbf{R}} \times \mathbf{J}(x', y', z') \right) \frac{1 + j\beta R}{R^2} e^{-j\beta R} dv'. \quad (\text{A4})$$

The magnetic field from (A4) is general for any radiating system, because there is no one approximation.

## APPENDIX B. PICTURES OF THE EXPERIMENTAL SET-UP

The monopole antenna can be seen in Fig. B1, which is connected to the transmission line and the impedance matching circuit inside the container, between the antenna and transmitter.



**Figure B1.** Picture of the monopole antenna of  $H = 197$  m of height, and 790 kHz of frequency.

## APPENDIX C. EQUIPMENT

The electric field intensity radiated from the antenna has been measured with an ETS-LINDGREN probe model HI-4455 with a recorder HI-4460 to measure with a bandwidth between 200 kHz to 40 GHz.

## REFERENCES

1. Jordan, E. C., *Electromagnetic Waves and Radiating Systems*, Prentice-Hall, New York, 1950.
2. Balanis, C. A., *Advanced Electromagnetic Engineering*, J. Wiley, Arizona, 1989.
3. Collin, R. E., *Antennas and Radiowave Propagation*, McGraw-Hill Book Company, 1985.
4. Trzaska, H., *Electromagnetic Field Measurements in the Near Field*, Noble Publishing, USA, 2001.
5. Trainotti, V. and W. G. Fano, *Ingeniería Electromagnética*, Ed. Nueva Librería, Buenos Aires, Argentina, 2005.
6. Fano, W. G. and V. Trainotti, "Dielectric properties of soils," *IEEE Conference on Electrical Insulation and Dielectric Phenomena*, 75–78, 2001.
7. Lastname, F. M., "Simplified calculation of coverage area for MF AM broadcast stations," *IEEE Antennas and Propagation Soc. Magazine*, 41–44, June 1990.
8. May, G. C. and G. W. Raffoul, "A simple matlab program to calculate the electric field levels in the near field of a monopole antenna," *Electromagnetic Compatibility, 2004. EMC 2004. 2004 International Symposium*, 326–329, 2004.
9. Harrison, C. W., D. T. Clayborne, E. A. Aronson, and M. L. Houston, "An accurate representation of the complete electromagnetic field in the vicinity of a base-driven cylindrical monopole," *IEEE Trans. Electromagn. Compat.*, Vol. 12, No. 4, 1064–1076, 1970.
10. Green, F. M., "NBS field strength standards and measurements (30 Hz–1000 MHz)," *Proc. of the IEEE*, Vol. 55, No. 6, 970–981, 1967.
11. "IEEE guide for measurements of electromagnetic properties of earth," *IEEE Standards*, i–53, 2002.