Non Ideal Cylindrical Monopole Antenna Array

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Abstract—This paper presents a study of a Two Monopole Antenna Array. The design takes into account considerations of non sinusoidal current distribution of each monopole antenna approximated by the three term theory developed by King et al. in 1966 and effects of mutual coupling between the two radiating elements. A physical implementation was done to verify the simulated results with good accuracy.

Index Terms—Antenna array, monopole antenna, non ideal current distribution.

I. INTRODUCTION

An antenna is the transitional structure between free-space and a guiding device [1], in other words an antenna is used to propagate signals through electromagnetic fields in free-space in order to accomplish wireless communication.

For some applications, a single antenna elements, may not be adequate to meet some technical requirements for high gain, narrow and/or steerable beams, pattern nulls, and low sidelobes. An array of discrete elements can, however, cover most of these constraints [2], the simplest wire array is the two wire elements array. Nevertheless, the design of single wire antennas and antenna arrays is often done by making ideal assumptions of wire parameters as: radius, conductivity of the material among others. In 1966, King et al. [3] developed a whole theory related to the non ideal wire antennas by making considerations of a complex propagation constant which is relates the current distribution in the antenna with the real characteristics of the wire.

In this paper the idea of the Imperfectly Conducting Cylindrical is taken into account to design a two monopole antenna array, making considerations of non ideal conductors, in order to contribute to the theory of non ideal antenna arrays.

II. CURRENT IN CYLINDRICAL CONDUCTORS

The antenna characteristics like driving point impedance and field pattern can be determined by knowing the current in the cylindrical conductor. The current in an ideal wire antenna is assumed to be sinusoidal, thus, this consideration ignores as an example, the effect of the ohmic resistance along their lengths, which is used in some applications in the designing of broadband antennas.

A well approximated expression for the current on a non ideal wire antenna has been developed for a non ideal dipole antenna [3], the proposed expression for a half length dipole antenna is shown in 1. Where T_U, T_D, Φ_{dR} are complex constants, β is the complex propagation constant which depends on the impedance per unit length of the conductor $z^i = r^i + jx^i$, ζ_0 is the characteristic impedance of the radiation media, in this case vacuum:

$$\begin{aligned} I_z(z) = \frac{2j\pi V_0^e \beta_0}{\zeta_0 \Phi_{dR} cos(\beta h)\beta}&[(sin(\beta(h-|z|)) \\ &+T_U(cos(\beta z) - cos(\beta h)), \\ +T_D(cos(\frac{1}{2}\beta_0 z) &- cos(\frac{1}{2}\beta_0 h))] \end{aligned} \quad (1)$$

$$\beta = \beta_0 \left[1 + \frac{4\pi x^i}{\beta_0 \zeta_0 \Phi_{dR}} - j\frac{4\pi r^i}{\beta_0 \zeta_0 \Phi_{dR}}\right]^{1/2}, \quad (2)$$

$$z^i = \frac{1}{\pi a^2 \sigma_1}\left(\frac{\kappa a}{2}\right)\frac{J_0(\kappa a)}{J_1(\kappa a)}, \kappa = \sqrt{\omega \mu_1 \sigma 1} e^{-i\pi/4}. \quad (3)$$

These equations have been evaluated by King giving several examples [4].

III. ARRAY OF CYLINDRICAL ANTENNAS

Since the distance between elements is short, the currents of the antennas interact between them. Thus, the current distribution depends not only on the radius, conductivity, length and driving point voltage, but also on the other current distribution of all the elements in the array. The driving point impedances and radiation field are computed from these currents, they cannot be assumed to be identical.

A. Mutual Coupling

The interaction of two radiating elements near alters the currents of each element and therefore their respective impedance. This interaction is called mutual coupling and changes the current magnitude, phase and distribution on each element from their free-space counterparts [6].

For two monopole antennas, let $I_{1z}(z)$ and $I_{2z}(z)$ be their respective current distributions. It has been shown that, for a coupled array the expression in 4 is valid; $I_z^{(0)}$ and $I_z^{(1)}$ are found by shifting the V_{20} driving point voltage 180º respect the V_{10} voltage:

$$\begin{aligned} I_{1z}(z) &= I_z^{(0)} + I_z^{(1)} = V_{10v}(z) + V_{20w}(z), \\ I_{2z}(z) &= I_z^{(0)} - I_z^{(1)} = V_{10v}(z) + V_{20w}(z). \end{aligned} \quad (4)$$

Where $v(0) = Y_{s1} = Y_{s2}$ being Y_{s1} the self admittances of each element, and $w(0) = Y_{12} = Y_{21}$ the mutual impedance of the two element array [5].

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The last has been developed for ideal cylindrical conductors. Thus, by combining the results on the current distribution of (1), making the same considerations and including the complex propagation constant that takes into account the surface impedance per unit length (3), it is possible to get an even more accurate expression for the currents and admittances of (4):

$$v(z) = \frac{j2\pi\beta_0}{\zeta_0\beta_0\Phi_{dR}cos(\beta h)}[sin(\beta(h-|z|)) + \frac{1}{2}(T_U^{(0)} + T_U^{(1)})(cos(\beta z) - cos(\beta h)), + \frac{1}{2}(T_D^{(0)} + T_D^{(1)})(cos(\frac{1}{2}\beta z) - cos(\frac{1}{2}\beta h))] \quad (5)$$

$$w(z) = \frac{j\pi\beta_0}{\zeta_0\beta_0\Phi_{dR}cos(\beta h)}[(T_U^{(0)} - T_U^{(1)})(cos(\beta z) - cos(\beta h)) + (T_D^{(0)} - T_D^{(1)})(cos(\frac{1}{2}\beta z) - cos(\frac{1}{2}\beta h))]. \quad (6)$$

IV. Implementation of a Two Monopole Array

A Monopole array of copper wires (σ_1 = 5.96x10^7[S/m], $\mu_1 = \mu_o\mu_{copper} \approx \mu_o$[$H/m$]) was used, both elements with a heigth of 5 [cm], diameter 2a = 0.81 [mm], it is expected a resonance frequency of about 1.363 [GHz] and, the model for the surface impedance is as shown in (3). The monopoles are two parallel wires prolonged from their respective transmission line over an aluminum squared ground of length $3\lambda/2 = 30[cm]$ of sides, separated $\lambda/2 = 10[cm]$.

A. Calculating Mutual Impedance from the Implemented Array

In [6] there is a procedure used to find the mutual impedance of an array, which is cited up-next:

- Open circuit (or remove antenna 2. Measure $Z_{oc} = Z_{11}$ at the terminals to antenna 1. For identical antennas, $Z_{22} = Z_{21}$.
- Short circuit antenna 2. Measure Z_{sc} at the terminals to antenna 1.
- Comute Z_{12} using $Z_{12} = \sqrt{Z_{oc}(Z_{oc} - Z_{sc})}$.

Using a *Vector Network Analyzer* it is possible to measure the respective impedances in terms of the total reflection coefficient Γ, next, the mutual impedance is then measured in terms of the reflection coefficients using (7), the monopoles were feed using a signal splitter to divide the signal of the VNA into two coaxial transmission lines of the same length (15 [cm]), thus guaranteeing both monopoles were feed at the same phase:

$$S_{12} = \frac{2Z_oZ_{12}}{(Z_{11}-Z_o)(Z_{22}-Z_o) - Z_{12}^2}. \quad (7)$$

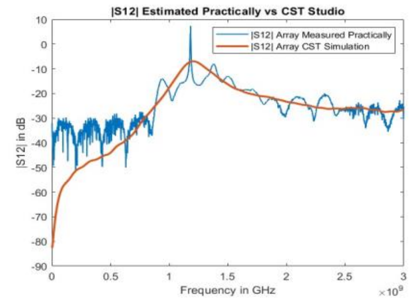

Fig. 1. Comparison between the method described in [6] and the results from CST Studio for two quarter wavelength monopoles separated $\lambda/2$ to obtain the $|S_{21}|$ in dB.

The previous procedure was done comparing experimental process with the mutual coupling in CST Studio assuming a transmission line of Z_o = 50 [Ω].

In the Fig. 1, the result of estimating practically the mutual impedance and a comparison of the results obtained by CST studio is shown. Using Kings method the driving point impedance magnitude was found to be 35.1299 [Ω] at the resonance frequency, by CST Studio was 36.981 [Ω] and practically 37.42 [Ω]. The model in CST Studio didn't take into account the effects on the phase of the feeding transmission line coaxial cable type.

V. Conclusion

Several methods to determine the effects of non ideal conductors in a two monopole antenna array were presented, it is shown that there is a difference between the procedures in order to find the magnitude of the mutual impedance, this because the effects of the imaginary part which in the Kings method is not accurate, nevertheless, the procedures were evaluated and tested, proposing tools for future work related to Non-Ideal Cylindrical Conductors.

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