BROADCAST ANTENNA OPTIMIZATION WITH MICROCOMPUTERS

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INTRODUCTION

Increasingly intense competition for the limited frequency allocation in the AM broadcast band (550-1600 kHz) has led to the use of directional array antennas to reduce interference. In this band, all available channels have been assigned, and for a new station to receive a frequency assignment they must guarantee no interference with existing stations. Thus, new stations must be located a significant distance away from any existing station on that frequency, and often additional protection must be provided by using directional array antennas. In the U.S., more than 25% of the AM broadcast antennas are directional arrays. This allows considerably more use of each channel and is perhaps the first attempt at practical "frequency reuse" [1].

Typically, the directional antenna design is based on a coverage and protection specification. Typical specifications cover the following:

(a) Radiation is maximized over the sector covering the city of license;

(b) Radiation is minimized at headings where distant locations are to be protected.

The level of protection (null depth) varies with frequency, distance, and power level of the local transmitter and transmitter to be protected. The required width of the nulls depends upon propagation conditions and geometry of the region to be protected.

For daytime coverage, only ground wave propagation is considered and the required nulls are all at 0° elevation.

For night time, the existence of sky wave propagation forces elevation pattern nulls at various azimuths. This usually results in designs combining both quarter wave and taller towers.

In the past, standard practice has been to calculate the array excitation voltages, mutual impedance, and pattern on the basis of a sinusoidal current distribution on each element, and superposition of the field from each element individually [2]. A problem results from this because the currents are not sinusoidal. Consequently, the actual mutual impedance is not as predicted, and the actual field for each element (with the others open circuited) must account for scattering from the other elements. This scattering arises from the fact that a current distribution can exist on a tower even though the input is open circuited. The sinusoidal current distribution assumption does not allow this. In general, the taller the towers the more pronounced will be the difference between actual results and those calculated on the basis of sinusoidal currents. In fact, determining the actual excitations to give a desired pattern can be extremely difficult since they may be considerably different than the calculated factors [3].

There now exists a computer program, Mini-Numerical Electromagnetics Code (MININEC) [4], which can be run on various microcomputers that gives acceptably accurate calculations of antenna characteristics, including actual current distribution, self- and mutual impedance and far fields. A procedure for the optimization of the feed excitation voltages of a broadcast array antenna to yield a given antenna radiation pattern is described. The procedure makes use of MININEC [4] and can be used on a microcomputer.

MININEC

The MINI-NUMERICAL ELECTROMAGNETICS CODE is a frequency domain Method of Moments computer code for the analysis of wire antennas. MININEC is written in the BASIC language for use on microcomputers with as little as 64k memory. The MININEC program is based on the numerical solution of an integral representation of the electric fields. A modified Galerkin procedure is used to solve the integral equation. This formulation results in a uniquely compact (i.e., requiring little core computer storage) code suitable for implementation on a microcomputer. The MININEC code solves for the impedance and currents on arbitrarily oriented wires in free space and over a flat perfectly conducting ground plane. Configurations with multiple wire junctions can also be used. Options include lumped parameter impedance loading of the wires and calculation of far-field patterns.

The solution to an antenna problem generated by a thin wire method of moments computer program is at best an approximation. Nonetheless, highly accurate answers can be obtained by careful modeling of the antenna configuration, taking into account the inherent limitations of the computer code.

POWER GAIN

The broadcast antenna specifications are given in terms of power gain or directive gain in db. In the direction (θ,ϕ)

$$G = 4\pi\frac{P(\theta,\phi)}{P_{IN}} \tag{1}$$

where $P(\theta,\phi)$ is the power radiated per unit solid angle in the given direction and P_{IN} is the total power accepted by the antenna.

$$P_{IN} = \frac{1}{2}\,R_e(V\cdot I^*) \tag{2}$$

where V is the applied source voltage and I^* is the conjugate of the resulting feed point current.

$$P(\theta,\phi) = \frac{R^2}{n}\,\bar{E}\cdot\bar{E}^* \tag{3}$$

where R is the observation sphere radius, $\bar{E}$ is the far electric field, and n is the intrinsic impedance of free space.

The only difference between directive and power gain is that P_{IN} is replaced by P_{rad}, where

$$P_{rad} = P_{IN} - P_{loss} \tag{4}$$

and P_{loss} is calculated as the power loss in the antenna system. The gain in db is expressed

$$G_{dB} = 10 \log G \qquad (5)$$

For the purpose of feed point optimization, the multiple feeds of the antenna are considered to be an N-port network, where N is the number of feeds. The relationship between the port voltages and currents can be expressed

$$I_i = \sum_{j=1}^{N} Y_{ij} V_j \qquad (6)$$

where Y_{ij} are the traditional short-circuit admittance parameters. The Y-parameters are defined and calculated under short-circuit conditions at either the input or the output port [5].

MININEC is used to calculate the field caused by having one element excited, with the others open circuited. NEC calculates the currents flowing on all elements, and from these currents the field at a distant point. The total field pattern of the antenna is equal to the sum of the fields due to the individual elements excited. Changing the magnitude and phase of the individual element excitation voltages amounts to multiplying the fields from each individual element (with the others open circuited) by the appropriate amplitude and phase prior to summing.

If ei(θ,ϕ) is the far electric field due to the implied voltage of $V_i = 1 + 0j$, the total far electric field is

$$\bar{E}(\theta,\phi) = \sum_{i=1}^{N} V_i e_i(\theta,\phi) \qquad (7)$$

where V_i would be the actual feed point voltages impressed on the antenna. Substituting equations (2), (3), (6), and (7) into equation (1)

$$G(\theta,\phi) = \frac{4\pi R^2 \sum_{i=1}^{N} V_i e_i(\theta,\phi) \cdot \sum_{i=1}^{N} V_i e_i(\theta,\phi)^*}{n \sum_{i=1}^{N} R_E \; V_i \left(\sum_{j=1}^{N} Y_{ij} V_j\right)^*} \qquad (8)$$

Thus power gain can be calculated for any set of feed point voltages if ei(θ,ϕ) and the short-circuit admittance parameters, Y_{ij}, are known. These values can be calculated using MININEC.

OPTIMIZATION

For the purpose of optimizing the excitation voltages of an array antenna system to provide for a desired radiation pattern, the following error function is defined:

$$\text{Error} = \sum_{j=1}^{M} W_j(\theta,\phi)[R_j(\theta,\phi) - G_j(\theta,\phi)]^2 \qquad (9)$$

where M is the number of pattern points used to define the required radiation pattern, Rj(θ,ϕ) is the required radiation pattern at point j, and Gj(θ,ϕ) is the achieved antenna pattern given by equation (8). The error is defined over the entire synthesis range. The reason for the squares is to ensure that, when the error is a minimum, each component of the sum is also a minimum. Therefore, the best approximation to Rj(θ,ϕ) by Gj(θ,ϕ) is achieved in the mean. Wj(θ,ϕ) is a weighting function that allows the synthesis precision to be changed over the synthesis range.

The objective of optimization is to minimize the error function of equation (9). A BASIC program, called OPTIMAL, was written to perform this optimization using the NEWTON-RAPHSON method [6]. The NEWTON-RAPHSON method is the most widely used of all iteration formulas. Note that the error function of equation (9) is a function of 2N parameters. There is both a real and an imaginary voltage for each of the feed points. Using v to denote each of these 2N parameters, each successive iteration of all 2N parameters is given by

$$V_{n+1} = V_n - \frac{\text{Error}(V_n)}{\frac{d[\text{Error}(V_n)]}{dV_n}} \qquad (10)$$

Analytical expressions have been obtained for each of the required derivatives and are used in OPTIMAL.

SUMMARY

Using the programs MININEC and OPTIMAL, a microcomputer can be used to optimize the antenna system feed points for a desired radiation pattern. Example calculations are given. The procedure demonstrates the growing importance of the microcomputer in antenna modeling.

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