NEARLY SEVEN YEARS OF SUCCESS USING MININEC FOR ANALYSIS AND DESIGN OF STANDARD BROADCAST MEDIUM WAVE AM DIRECTIONAL ANTENNAS [1]

JAMES B. HATFIELD, P.E.
HATFIELD & DAWSON CONSULTING ENGINEERS

INTRODUCTION

In the nineteen sixties, Robert Silliman was one of the first consulting radio engineers to use computer point matching techniques based on Hallen's integral equations to analyze broadcast antenna behavior. In succeeding decades Grant Bingeman, Jerry Westberg, Stan Kubina, G.M. Royer, Dave Pinion and others applied various moment method programs to the analysis of AM standard broadcast directional antennas. By the end of the nineteen eighties NEC, MININEC and a program from Ohio State University were in common use for AM antenna analysis.

Consulting engineers such as this writer, Ron Rackley and Karl Lahm (now at VOA) have used MININEC since the mid nineteen eighties for the analysis and adjustment ("tune up") of AM directional antennas. Advantages that MININEC offers for modeling medium wave monopoles over radial wire ground screens are ease of use, the centering of current pulses on segment junctions, and greater accuracy handling abrupt radius transitions. Good agreement with measured and FCC computed far field patterns is achieved with MININEC using just seven segments per radiator. Experience impedance curves can be duplicated with a reasonable margin of error if the base region of the tower is modeled in detail and an impedance correction is added to the computed results. Near electric and magnetic field human exposure from AM towers can also be computed using MININEC if the modeling is performed carefully. RF shock hazard estimates for workers on de-energized power lines and container loading cranes near AM stations have been computed using MININEC. Conversely the effects of power lines and cranes upon AM directional antenna patterns and Federal Communications Commission (FCC) mandated monitor points have been computed using the near field provisions of MININEC.

ADJUSTING AM DIRECTIONAL ANTENNAS

FCC directional antenna pattern computations are based upon point sources and parallel ray geometry (See Figure One). The design specifications used to determine pattern shape include the relative contribution to the far field of each radiator in terms of the field ratio and phase of the radiation from each point source. Since the horizontal plane far field of each radiator, in milliVolts per meter at one Kilometer, is $120\pi/\lambda$ times the total current moment of the radiator the relative contribution of each radiator to the far field is found by taking the ratios of the total current moments of the radiators. The MININEC drive voltages for a given set of FCC design

[1] Paper presented at 1994 ACES Symposium

parameters can be found by inverting a matrix whose constants, derived from MININEC computations, relate the drive voltages to the far fields. The FCC requires that directional antenna performance be monitored. This is accomplished by measuring the relative magnitude and phase of the tower currents, usually at the base. The matrix inversion process produces the voltage drives that can be used to compute the base currents and phases for a given set of field ratios and phases.

The computed base current values are used to adjust directional antennas. After the adjustments have been made ground level measurements are performed along radials extending 30 Kilometers from the center of the array. These measurements are used to prove that the directional pattern is within the limits prescribed for it by the FCC.

Over the years we have adjusted or assisted others in adjusting nearly 100 directional antennas using the MININEC / matrix inversion technique. In all but two of the adjustments the measurements verified the accuracy of the procedure. In both of the exceptions the horizontal plane field was perturbed by nearby scatterers. In one case there was re-radiation from nearby office buildings and in the other case there were terrain irregularities. In those situations it was less expensive and time consuming to adjust the array by trial and error than it was to model complex objects in the environment in order to account for their effects.

Most AM directional antennas are used to control skywave radiation at night at some angle above the horizon. The adjustment of arrays so that horizontal plane measurements can be made in the presence of re-radiating or scattering objects to show the proper pattern can have a deleterious effect upon the performance of the antenna array at a vertical angle. Less interference would therefore be caused by simply adjusting the array to base current parameters based upon method of moments computations and not worrying about making accurate horizontal plane measurements. Such a proposal is now before the FCC.

DE-TUNING AM TOWERS

If one sets the field ratio of a tower to zero and then follows the procedure outlined above, the computed drive voltage for that tower will result in current moments that sum to zero for that tower, or at least to a value five or six orders of magnitude below the reference tower. The computed currents for the array and the de-tuned tower will show an active base impedance with a resistive component that is usually a few percent of the reactive component. This means that the conjugate of the reactance can be applied to the base of the tower for de-tuning purposes. This impedance should be trimmed by measuring the current minimum at the height where the phase reversal in the computed current distribution occurs. The base reactance is then adjusted for a minimum reading.

Since the de-tuning process reduces the field in the horizontal plane where field strength measurements are made the radiation at vertical angles increases. For nighttime operation the horizontal plane pattern is therefore within limits while the vertical angle radiation increases potentially creating greater skywave interference (See Figure Two). For this reason de-tuning unused towers in a nighttime array is not necessarily a good idea.

MITIGATING RADIO TOWER / POWER LINE INTERACTIONS

It sometimes happens that power lines are constructed near existing AM directional arrays. If the power poles or towers are 30 meters or more tall their re-radiation and mutual coupling effects can distort the far field pattern of the station. Additional problems are created when there is a "skywire" or "shield" wire running along the tops of the poles for lightning protection and electrically connected to the poles. The poles and towers used for power transmission usually provide a conductive path to ground. The RF current flowing in the loops thus created causes directional antenna pattern distortion. The meters used to measure the AM stations fields employ shielded loop antennas to measure the magnetic field component of the transmitted wave. Since the electric field is the desired measurement parameter, the magnetic field magnitude is multiplied by the impedance of free space and depicted on the meter face in terms of electric field. When measurements are made within the near field of the RF currents circulating in the loop created by the power line erroneous readings result. This effect can be predicted using the near magnetic field computation of MININEC. Re-adjustment of the array can then be made based upon MININEC computations so that the FCC monitoring points near the power line are brought into tolerance while arrangements are being made to either de-tune the power poles or float the "skywire".

When electric power transmission lines are in close proximity to AM radio towers serious RF shock hazard to electric utility linecrews can result. In one instance two AM towers were located near a 150 KV line. One of the towers was only 23 meters from the line. Several instances of RF burns were reported to the utility safety officer. The work crane, power line, and power poles were modeled in a simplified schematic fashion. Computations of the RF current that flows through an equivalent human impedance at the crane work platform at various locations were made to determine the potential shock hazard.

AM TOWER BASE IMPEDANCE

The measurements and computations of R.W.P. King and other academic workers are usually used to benchmark antenna impedances computed by moment method programs. The center conductor of a coaxial cable poked through a sheet of copper, used by King and others as a model for computations and measurements of a monopole over a ground plane, is not the same as a base insulated tower fed by a horizontal half inch pipe. When the base capacitance and the radius disjunction between the base and the feed line are carefully modelled (See Figure Three) the base impedance given by MININEC is much closer to the measured impedance of the typical AM tower. The match between the computed values and the curves showing the measured base impedance for towers of various heights is improved when one adds a correction of 5 + j43 Ohms to all computed values (See Figure Four).

COMPUTING BANDWIDTH

Programs such as WCAP (a specialized program similar to SPICE written for the analysis of directional antennas and their feed circuitry) can be used for dynamic modeling of the combination of the directional antenna and its feed system. The frequency response of the transmitted signal can be determined in this manner. MININEC can be used to compute the self and mutual admittances for the antenna array over a specified range of frequencies. This is useful for determining why a station's sound quality varies in different directions in a directional pattern.

RF HAZARD COMPUTATIONS

The FCC requires a showing from licensees that the provisions of ANSI C95.1-1982 <u>Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields</u> are met. MININEC can be used for this purpose, but its accuracy decreases as one approaches the tower. The electric and magnetic near field computations provided by MININEC are useful if one is careful to check for convergence. Seven segments per wire gives a lumpy and unrealistic result. Fifty segments show a computed field that varies smoothly with distance and is a reasonable approximation of measured values. Figure Five shows the computed near fields with a measured data point for comparison. Figure Five also shows the effect of insufficient segmentation upon accuracy. Ric Tell, Bob Cleveland of the FCC, and Ed Mantiply of the EPA have explored this issue in several papers.

NIGHTTIME INTERFERENCE

The method that has been used for FCC purposes since the nineteen thirties to compute vertical angle radiation from AM towers utilizes simple trigonometric functions to represent tower current distributions. The impact of mutual coupling between towers upon the current distribution is ignored in these calculations. Nighttime interference can be affected by inaccurate computations of the antenna current distributions since the vertical angle radiation, computed from the current distribution, contributes to the increased coverage a station provides at night due to skywave propagation. The vertical angle fields computed using the more realistic MININEC current distributions provide a more accurate picture of potential skywave interference (See Figure Six).

NEAR FIELD COMPUTATIONS AND MEASUREMENTS OF ARRAY PERFORMANCE

In order to provide performance verification information for an array that is located at the shoreline of a tropical island, Ron Rackley and Ben Dawson used the nearfield computation feature of MININEC to calculate magnetic field values for specified locations very close to the array. Measurements were made at these locations using a conventional magnetic field intensity meter desensitized by shorting the loop antenna shield. The meter, with the shield shorted, was then calibrated in a known field. The same MININEC model that was used for array pattern, current distribution, and impedance calculations predicted near magnetic fields that agreed with measured values to better than 2% accuracy. The data provided by this technique was used to demonstrate proper operation of the antenna system despite the fact that complete far field measurements were virtually impossible due to open ocean on one side of the array, and dense roadless tropical jungle on the other.

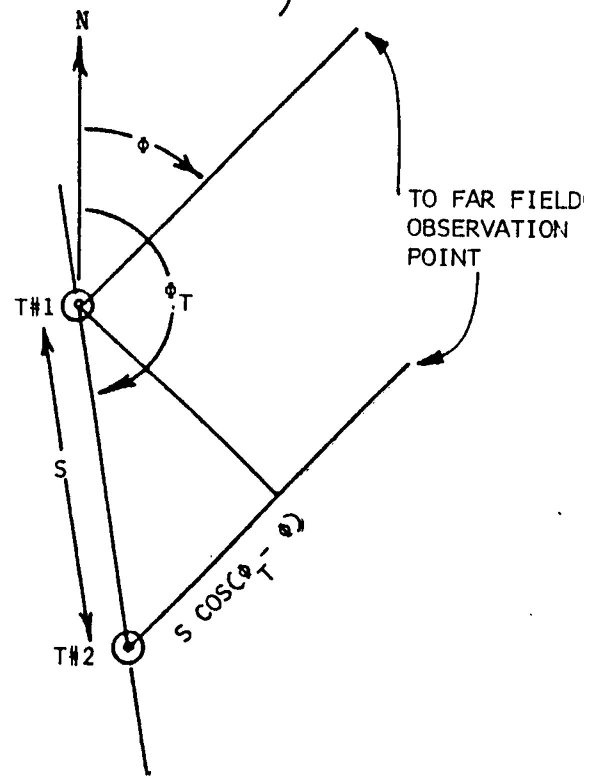
CONCLUSION

Programs like NEC and MININEC have enabled the practicing radio engineer to analyze antennas in new ways to solve problems for which there was previously no exact solution. For AM medium wave directional antennas this means that the effects of coupling between antenna elements upon the antenna current distributions can be included in the design and analysis process and precise relationships between antenna currents and radiated fields can be computed. Directional antenna adjustment and pattern verification based upon NEC and MININEC computations has been successfully performed for hundreds of AM arrays all over the world by a cadre of international radio engineers. These programs have also been helpful for the analysis of the interactions of radio towers with cranes and power lines and the human exposure to electromagnetic fields. Newer versions of NEC and MININEC, such as NEC4, VLF+, and MININEC Professional have the potential to help engineers analyze finer structures in greater detail with higher accuracy.

The FCC is currently investigating whether its Rules & Regulations regarding AM pattern verification should be updated to include numerical electromagnetic modeling techniques. The burden and expense of detailed measurement and data analysis could be replaced in the future by stricter requirements for antenna current or voltage monitoring and computations using NEC, MININEC or other moment method computer programs.

We have finally reached the point where simplified directional AM antenna pattern analysis based upon trigonometric functions is about to be replaced by more exact moment method techniques. A further benefit of this change will be the ability for the AM radio engineer to analyze complex electromagnetic environments using a desk top computer. The responsibility incurred through use of these programs will be to always check for stability and convergence in the computed results and to verify that the results agree with measured data.

$$E = K\left(F_1 + F_2 \angle S\cos(\Phi_T - \Phi) + \Psi_2\right) \text{ FAR FIELD}$$



Ψ_2 = PHASE OF TWR#2 RELATIVE TO TWR#1

F_1, F_2, RELATIVE FIELD RATIOS OF TOWERS

Φ = AZIMUTH FROM TRUE NORTH OF OBSERVER

Φ_T = AZIMUTH OF TOWER #2 FROM TRUE NORTH

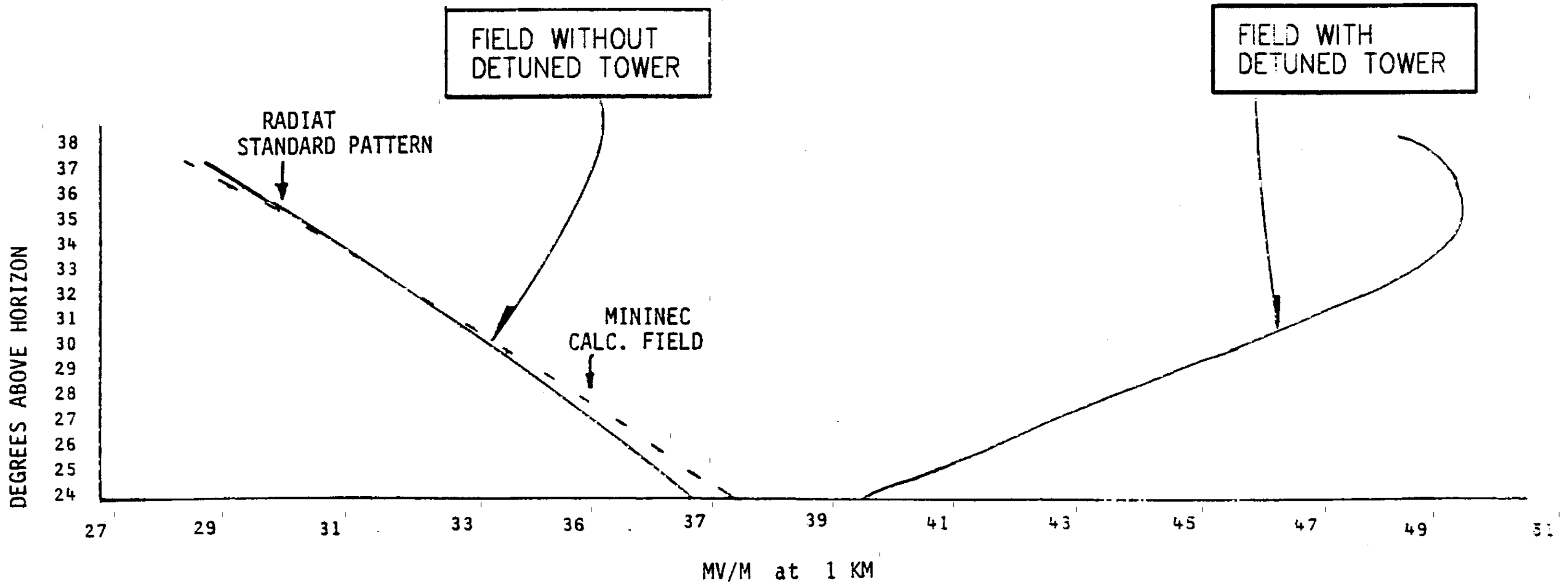
S = SPACING BETWEEN TOWERS

K = PATTERN SIZE CONSTANT

HATFIELD & DAWSON
CONSULTING ENGINEERS

FIGURE 1

HORIZONTAL PLANE FAR FIELD CALCULATED FROM POINT SOURCES

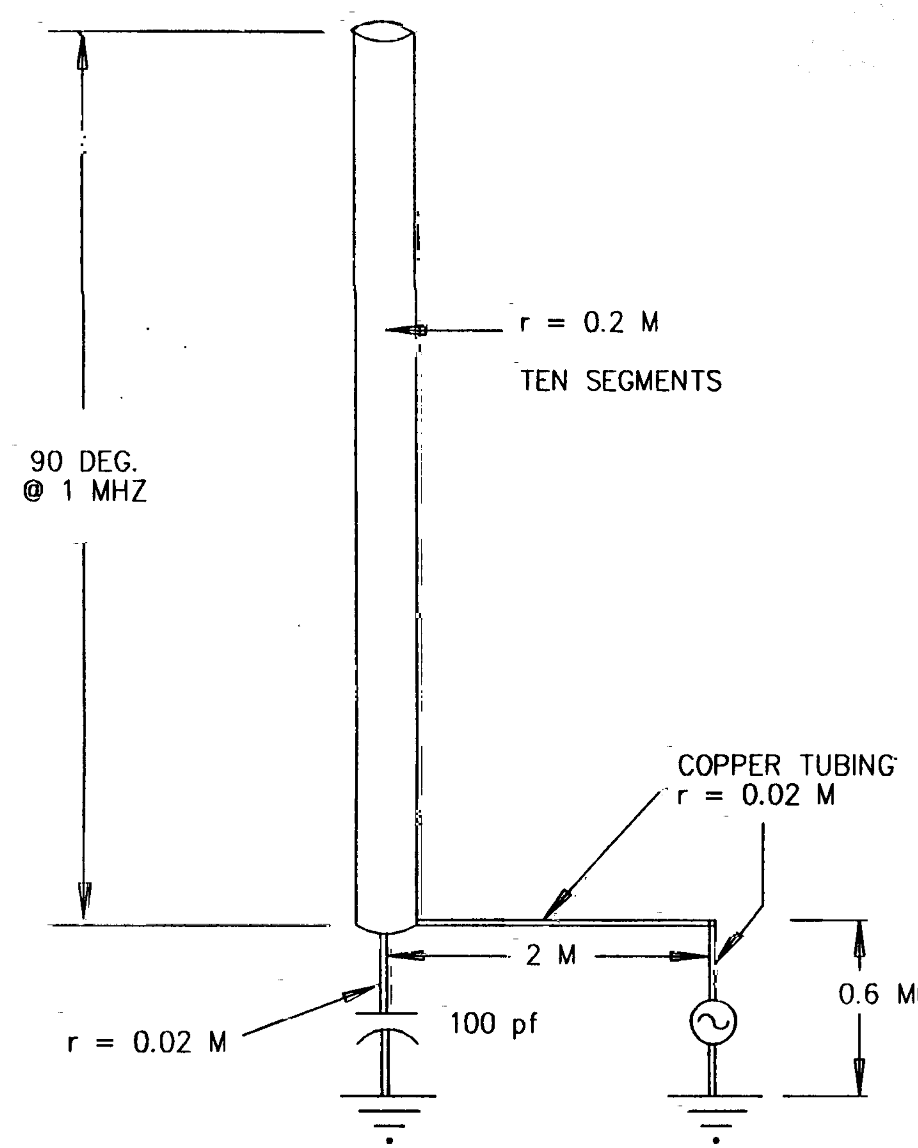


HATFIELD & DAWSON

CONSULTING ENGINEERS

FIGURE 2

EFFECT OF DETUNED TOWER
ON VERTICAL ANGLE RADIATION

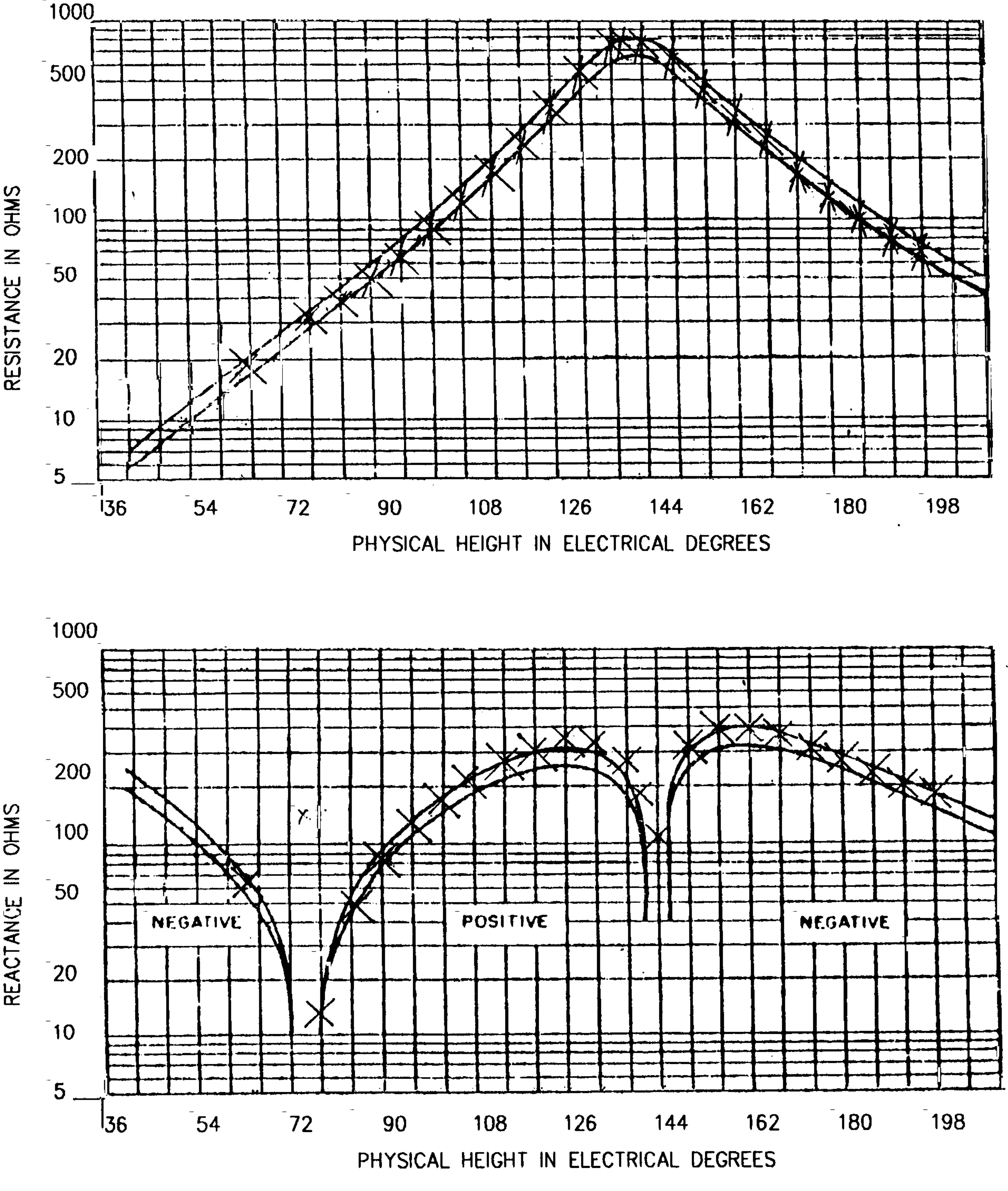


HATFIELD & DAWSON

CONSULTING ENGINEERS

FIGURE 3

TOWER & FEED MODEL
FOR MININEC IMPEDANCE COMPUTATIONS



HATFIELD & DAWSON

CONSULTING ENGINEERS

FIGURE 4
SELF IMPEDANCE OF MONOPOLE OVER A RADIAL WIRE GROUND SCREEN. MODELED BY MININEC (SEE FIGURE 3) AND CORRECTED BY ADDING 5 +j43 TO COMPUTED IMPEDANCE. COMPUTED DATA POINTS PLOTTED ON EMPIRICAL CURVES FROM ELECTRONICS MAGAZINE ARTICLE (JUNE 1952 pg.143)

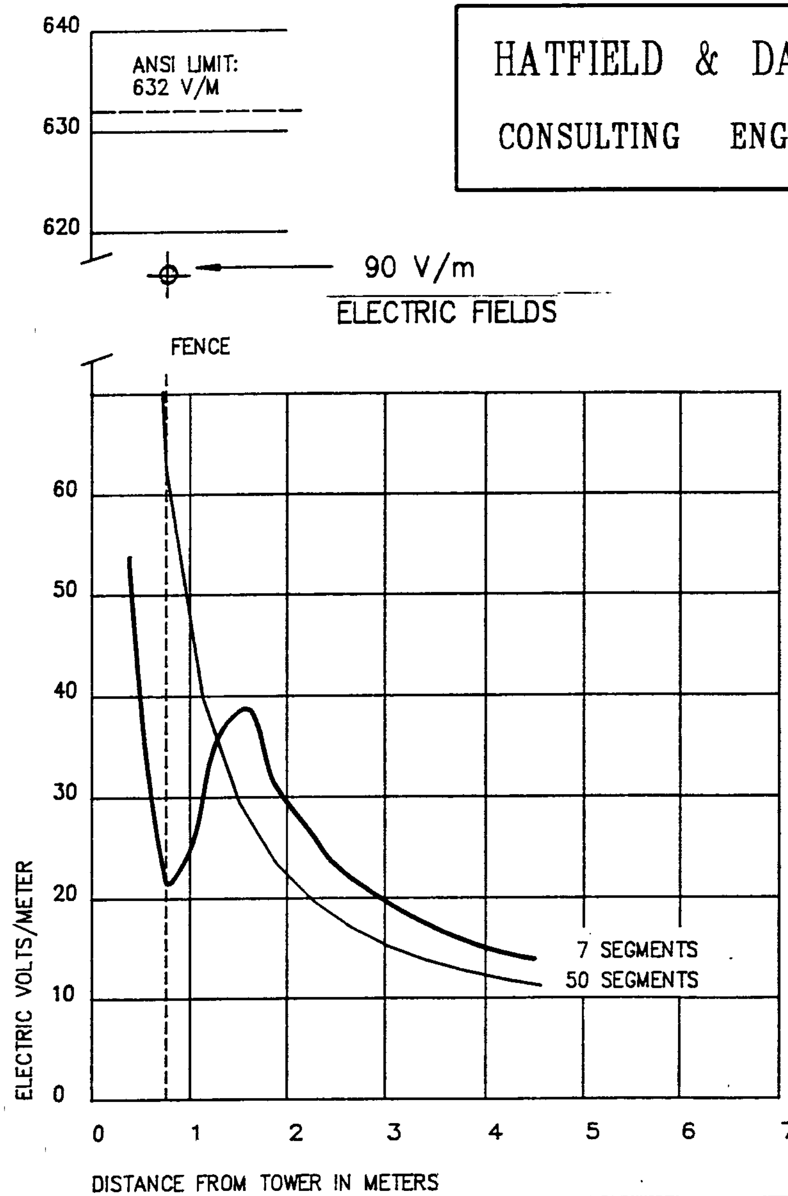
HATFIELD & DAWSON

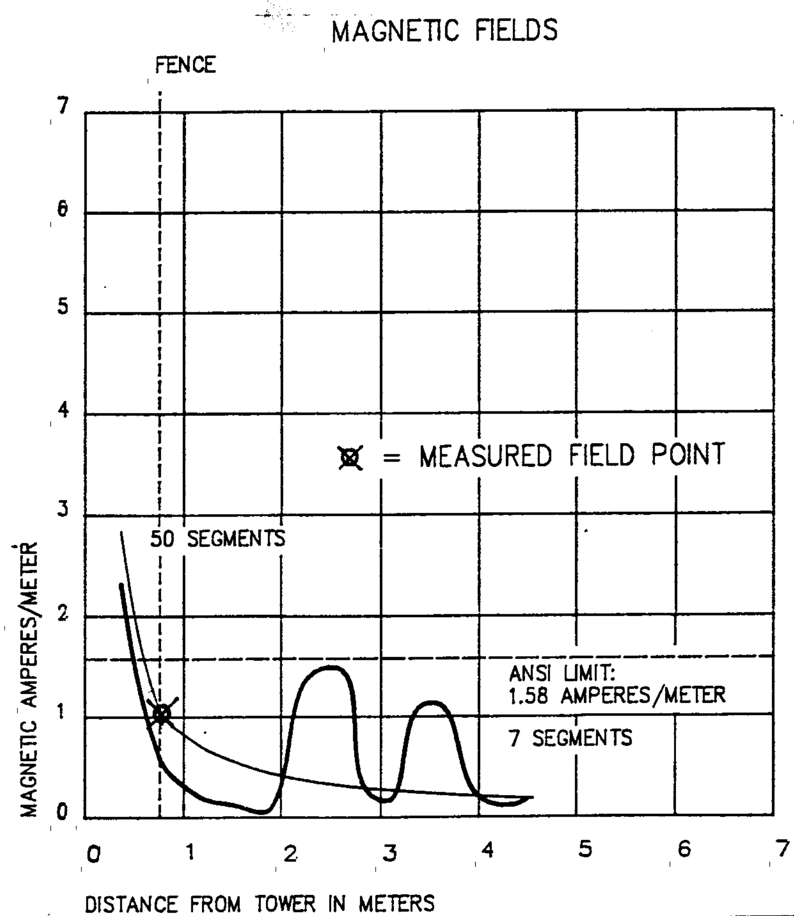
CONSULTING ENGINEERS

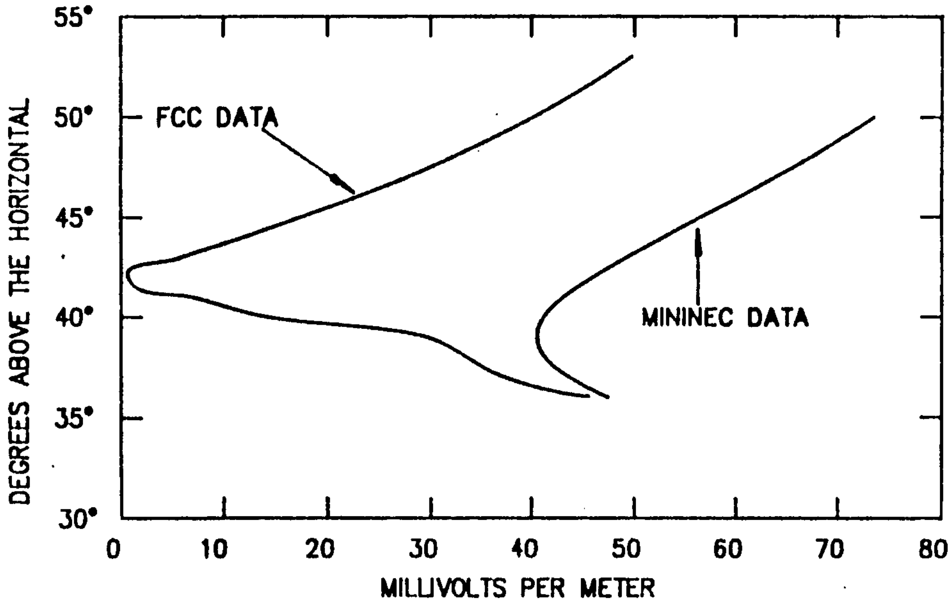
FIGURE 5

ELECTRIC AND MAGNETIC FIELDS AT 1 METER ABOVE GROUND NEAR AN AM TOWER

TOWER HEIGHT: 50.3 METERS
FREQUENCY: 1450 kHz
POWER: 1000 WATTS







HATFIELD & DAWSON
CONSULTING ENGINEERS

FIGURE 6

COMPARISON OF VERTICAL ANGLE AM FIELD FROM A 0.6 WAVELENGTH TOWER AS COMPUTED BY FCC METHODS AND MININEC