FOUR-ELEMENT BEVERAGE ARRAY

D. V. Campbell
P. Cunningham
P. Dubowicz
K. Loffer
U.S. Army Communications-Electronics Command
Fort Monmouth, New Jersey 07703-5202

An experimental four-element high frequency Beverage antenna array has been devised for tests on medium range and long range ionospheric circuits. The radiation pattern of the experimental array was calculated using Numerical Electromagnetics Code (NEC) and found to be skewed in azimuth. The antenna installation was subsequently modified in accordance with NEC predictions and the desired beam direction was obtained. Measurements confirmed that the NEC predictions were valid.

I. INTRODUCTION

The Beverage Antenna (H. H. Beverage, C. W. Rice, and E. W. Kellogg, The Wave Antenna, A New Type of Highly Directive Antenna, Trans. AIEE, 1923) can provide a marked unidirectional pattern. This property and its inherent simplicity and broadband behavior make the wave antenna an attractive option for use on medium and long range HF ionospheric radio circuits.

An experimental four-element Beverage array has recently been investigated and tested on HF long range circuits between Fort Monmouth, New Jersey and Los Banos, California and several intermediate sites. Some results are discussed below.

II. SINGLE WIRE WAVE ANTENNA

The simplest Beverage wave antenna consists of a single long horizontal wire terminated in its characteristic impedance to ground at each end. See Fig. 1. It is known that the wave antenna depends for its operation on the finite conductivity of the earth and, in fact, it operates better over poorly conducting ground. For an incident plane wave over imperfect ground there is a horizontal component of the electric field intensity due to the power absorbed by the earth. This horizontal component induces the voltage in the wire and gives the Beverage antenna its directivity.

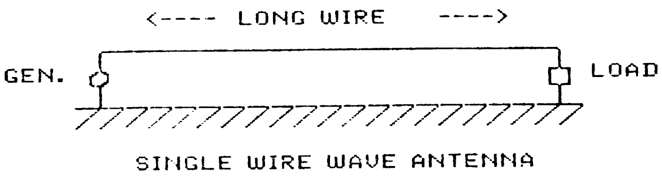

Figure 1.

The efficiency of a single element Beverage wave antenna is usually low. The power available from the wave antenna over real ground can be compared with that available from a lossless short vertical antenna over perfect ground (S. A. Schelkunoff and H. T. Friis, Antennas-Theory and Practice, J. Wiley and Sons, 1952, pp. 492-497). This power ratio can be roughly approximated as follows.

$$\frac{\text{P WAVE ANTENNA}}{\text{P VERTICAL ANTENNA}} = \frac{8\pi^2}{3\lambda\sigma Z_o}\left(\frac{\ell}{\lambda}\right)^2$$

Where σ is the earth conductivity, λ the wavelength and ℓ and Z_o are respectively the length and "characteristic impedance" of the wire.

For example, with $\sigma = .01$ (good ground), $\lambda = 150$, $Z_o = 400$ we find that

$$\text{PW.A./PVERT.} = 0.0439 \left(\frac{\ell}{\lambda}\right)^2$$

and in this case a wave antenna about 4.8 wavelengths long should give as much power output as a lossless short vertical antenna over perfect ground. If the conductivity is low, for example $\sigma = .001$, $\lambda = 150$, and $Z_o = 400$ as before, we find that

$$\text{PW.A./PVERT.} = 0.439 \left(\frac{\ell}{\lambda}\right)^2$$

and a shorter wave antenna 1.5 wavelengths long should give the same power output as a lossless short vertical antenna over perfect ground. The above approximation is optimistic but is useful for rough estimates of wave antenna performance over actual ground.

III. ARRAYS OF WAVE ANTENNAS

An array of wave antennas can be used to offset the low efficiency of the single element antenna. The array technique is certainly not new and has in fact often been used to overcome the low efficiency of various electrically small antennas.

Recently a four-element wave antenna was investigated at Fort Monmouth as part of an HF test series which also included a terminated sloping V antenna. This wave antenna array consists of four parallel horizontal wires 143 meters in length strung 2.4 meters above ground and 6.7 meters apart. See Fig. 2. The wires are individually excited through step-up transformers and a power divider with equal amplitude in-phase signals and terminated at the ends nearest the distant station in grounded 400-ohm resistors. Because of an access road at the test site, the antenna wires had to be installed in a staggered arrangement so that the maximum wire length (470 feet) could be accommodated without crossing the road. This unconventional antenna installation turned out to be unacceptable, however, because it resulted in skewed radiation patterns.

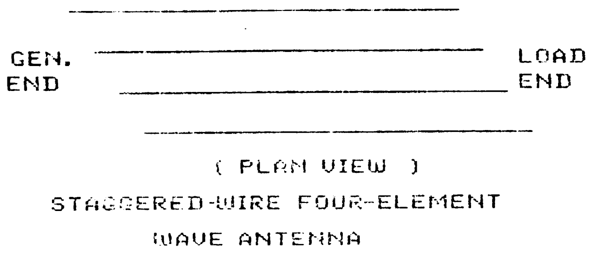

Figure 2.

IV. NEC MODELS OF WAVE ANTENNA ARRAYS

First performance tests of the staggered wire wave antenna array operated in the transmitting mode were not up to expectations. Faulty antenna operation was brought to light by an analysis of the signal strength received at the Los Banos test site where it was noticed that a single-wire Beverage antenna at Fort Monmouth was outperforming the Beverage array. The single-wire Beverage antenna was obtained by simply disconnecting three of the wires comprising the experimental array.

Subsequent analysis using NEC (Numerical Electromagnetics Code) showed that the Beverage array radiation patterns were shifted nearly 20-degrees off bearing as a result of the misaligned (staggered) wire arrangement.

The aligned (correct) and skewed-wire (incorrect) experimental arrays were modeled with NEC-2. The ground connections were approximated in the NEC computer model by open-ended quarter wavelength wire extensions as shown in Fig. 3 (Laport, p. 309). An open quarter wavelength wire gives an impedance at its inner end that is low over a narrow frequency band near its resonant frequency. These quarter wavelength wires thus provide artificial "ground" connections at the wire ends of the excitation and for the resistive terminations.

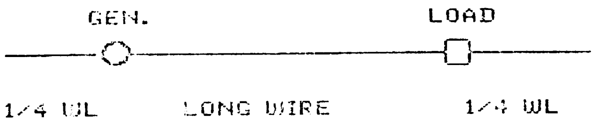

Figure 3.

The NEC "Sommerfeld ground" option was used in the computer models and "good" ground was assumed (σ = .01 mhos/m and $\varepsilon/\varepsilon_0$ = 15). The actual ground constants at the antenna test site are as yet unknown but will eventually be determined from in situ measurement by the wave-tilt method and/or the transmission line method.

A. Calculated Radiation Patterns of Misaligned Four-Element Beverage Array

The computed azimuthal and elevation radiation patterns of the staggered wire four-element wave antenna are shown in Figs. 4 and 5 (8 MHz) and in Figs. 6 and 7 (15 MHz). These patterns show the main beam to be skewed so that it does <u>not</u> lie along the bearing to the distant station.

B. Calculated Radiation Patterns of Aligned Four-Element Beverage Array

The computed azimuthal and elevation radiation patterns of the aligned four-element wave antenna are shown in Figs. 8 and 9 (8 MHz) and in Figs. 10 and 11 (15 MHz). These patterns show that the main beam lies along the array axis and on the correct bearing to the distant station as intended.

Comparison of these computed patterns shows that the array gain on the main bearing was reduced by 7 db (at 8 MHz) and by 15 db (at 15 MHz) as a result of the misalignment of the antenna wires.

V. EXPERIMENTAL RESULTS

As mentioned earlier it was noticed during preliminary operational tests that a single-wire

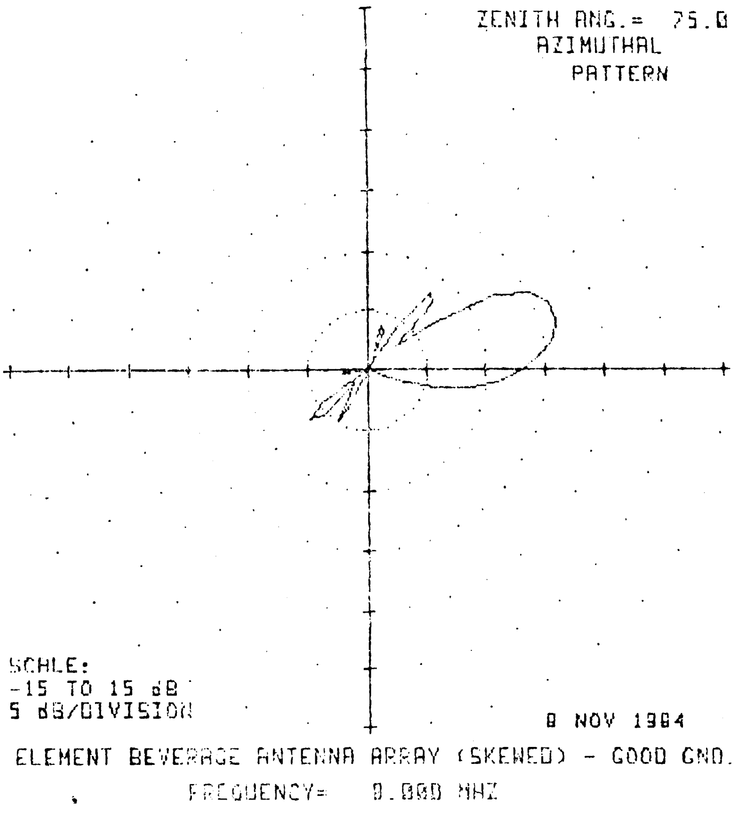

Figure 4.

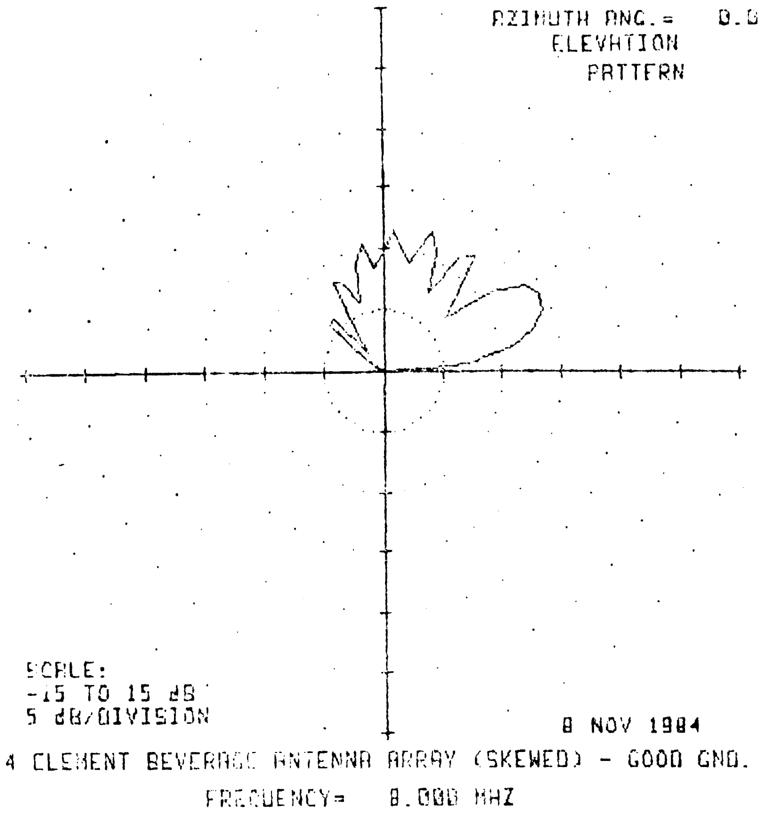

Figure 5.

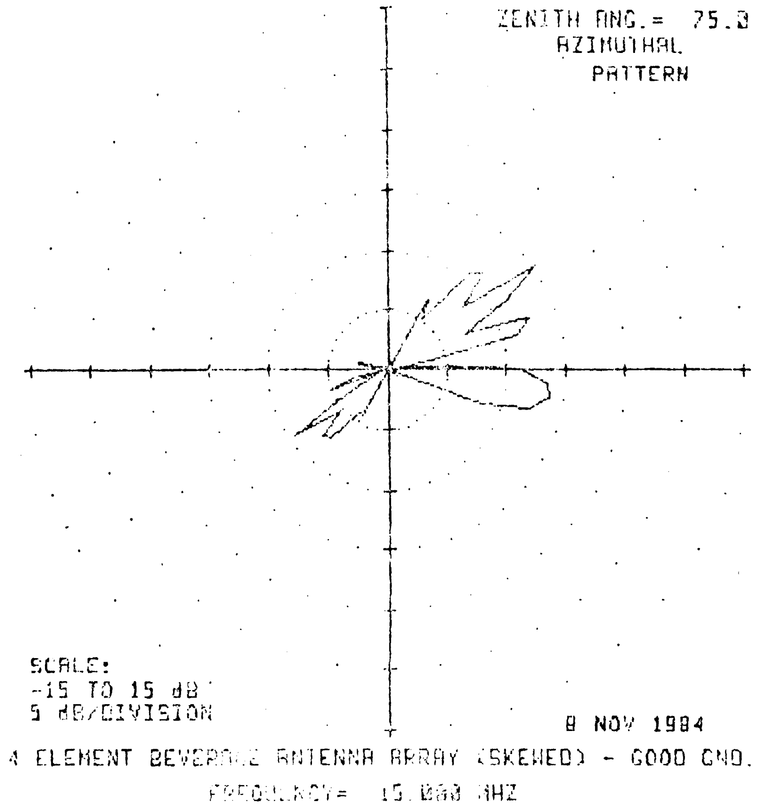

Figure 6.

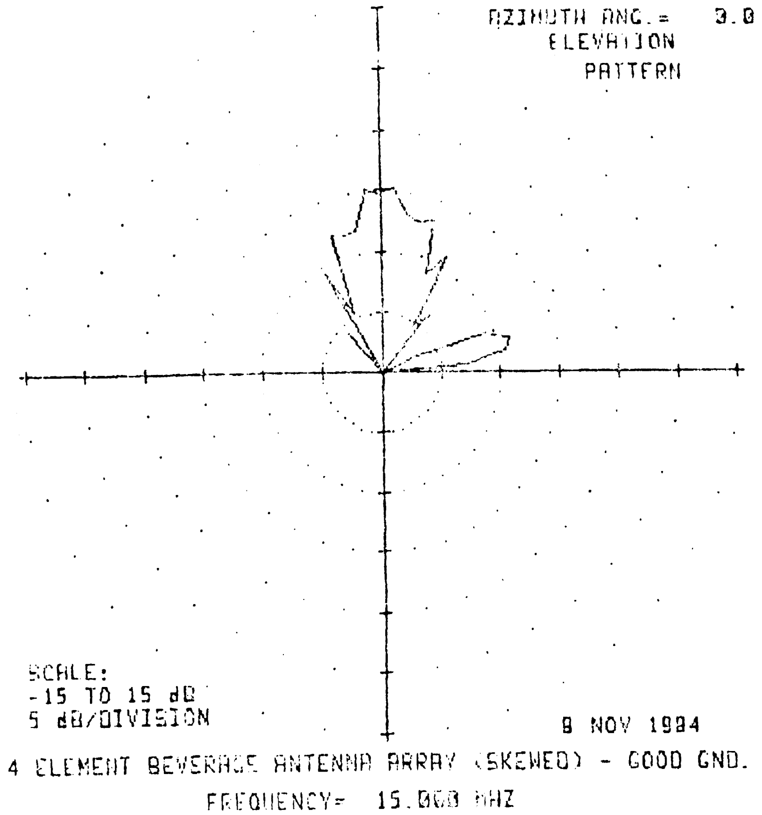

Figure 7.

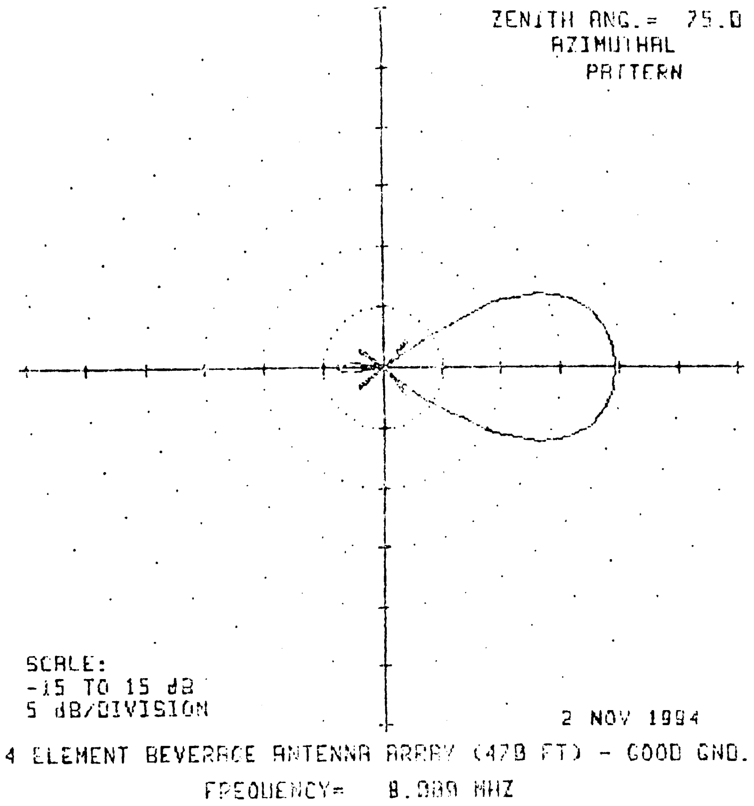

Figure 8.

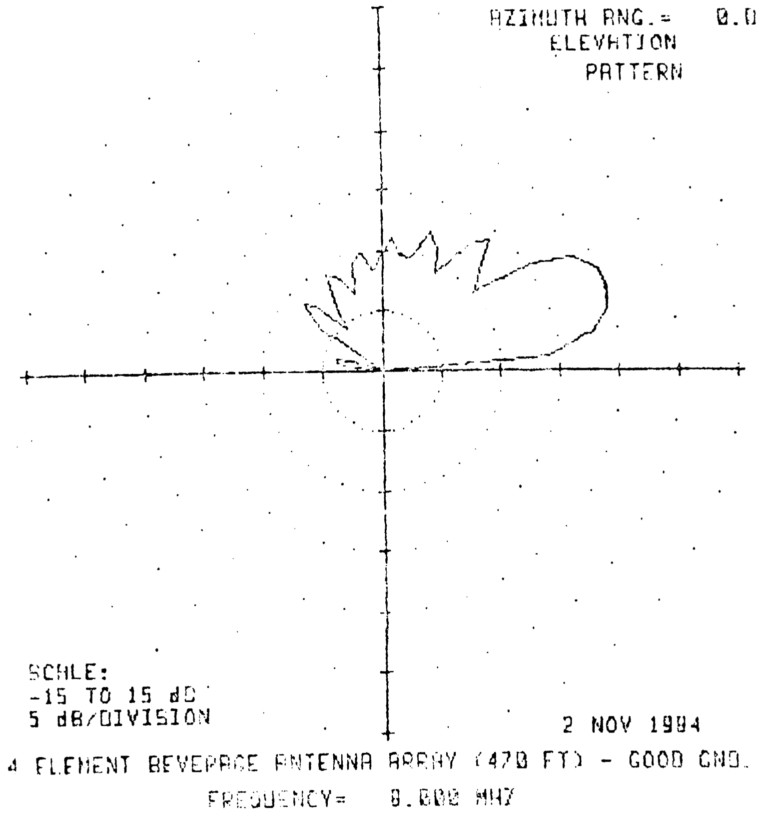

Figure 9.

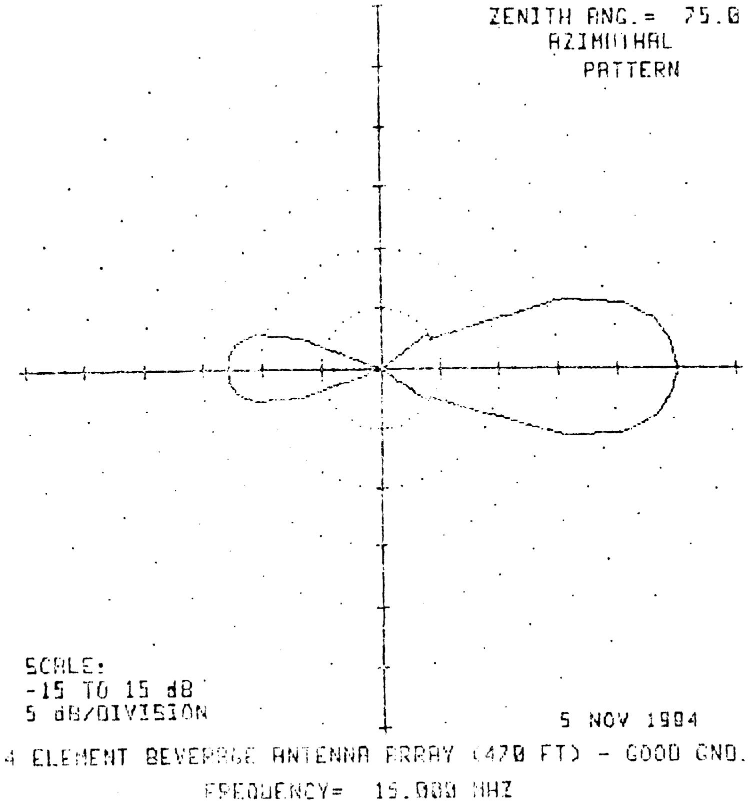

Figure 10.

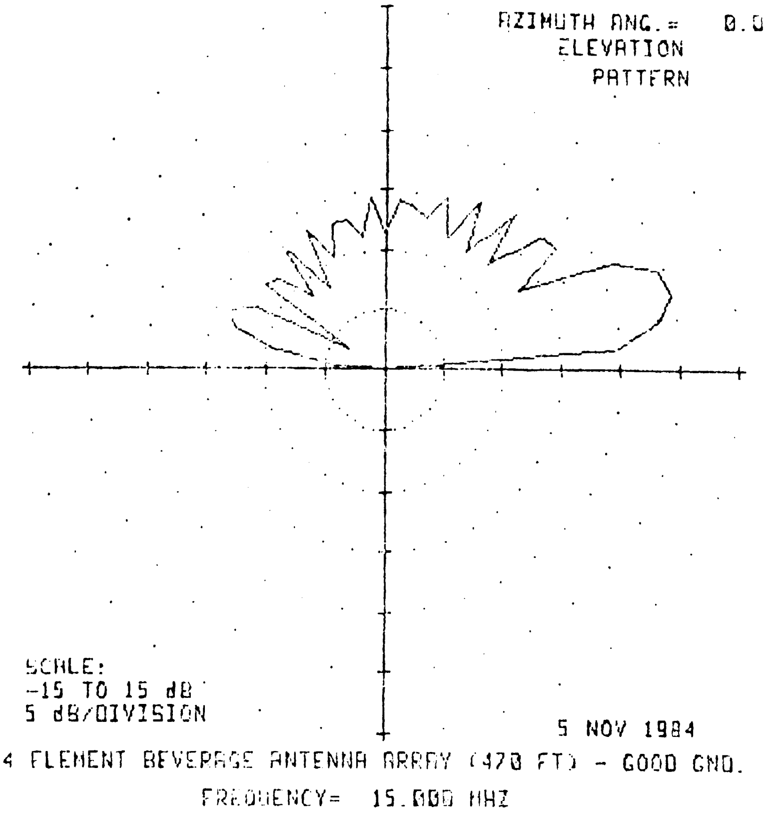

Figure 11.

Beverage antenna outperformed the misaligned Beverage array. This discovery and the subsequent NEC analysis confirmed that the poor performance of the first array was due to the staggered wire arrangement. A 15 db increase in received signal strength at the Los Banos site resulted when the array wires were properly aligned. The wires also had to be somewhat shortened to a length of 125 meters because of the access road.

VI. CONCLUSION

The NEC program was successfully used to determine the radiation characteristics of an experimental four-element array of Beverage antennas and correctly predicted pattern distortion and gain reduction caused by misalignment of the antenna wires.