EXPERIMENTAL COMPARISON OF BURIED AND ELEVATED ELF TRANSMITTING ANTENNAS

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Abstract

During the last week in March and the first week in April, 1973, the Naval Underwater Systems Center measured the 76 Hz magnetic field strength (in Wisconsin and Texas) produced by both the elevated and (newly installed) buried Wisconsin Test Facility (WTF) north-south (NS) antennas. The principle result obtained from these measurements is that there is no measurable difference in performance between the WTF buried and elevated NS antennas.

Introduction

The U. S. Navy Project SANGUINE Wisconsin Test Facility is located in the Chequamegon National Forest in north-central Wisconsin about 8 km south of the village of Clam Lake. This particular location was chosen because of its low electrical conductivity and sparce population density. This facility was designed to test and demonstrate interference mitigation techniques. It has also been used for ecological studies and as the source for ELF propagation measurements.

The WTF consists of two 14 mile NS antennas (one elevated, the other buried at a depth of approximately one meter) and one 14 mile elevated EW antenna - with the transmitting station at the intersection near the midpoints of the antennas. Each antenna is grounded at both ends. The average direction is 19° E of N for the NS antenna, and 109° E of N for the EW antenna. Although the Wisconsin Test Facility was designed for a maximum current of 540 amps into each antenna, it has been operated to date at only 300 amps, which is about one-third of its power output capacity.

During August of 1972 we measured the effective earth conductivity (σ_e) beneath both elevated antennas of the WTF at 45 and 75 Hz (1). The H/I method was utilized with each WTF antenna alternately employed as the source. (In the H/I induction method, a long insulated wire grounded at both ends is energized by an AC generator at the frequency of interest. The magnitudes of the magnetic fields are then measured at various distances and angles from the wire (2).) These measurements were performed mainly at distances of 45 to 75 km from the transmitter, in line with and broadside to each WTF antenna. The principal result obtained from these measurements is that the effective conductivity under the EW antenna is greater than that under the NS antenna.

During the last week in March and the first week in April of 1973, we measured the 76 Hz magnetic field strength (in Wisconsin and Texas) produced by both the elevated and (newly installed) buried WTF NS antennas. The main purpose of these measurements was: (a) to compare the buried and elevated NS antennas; and (b) to ascertain the repeatability of the August, 1972 (1) measurements.

Wisconsin Results

During this latest test, measurements were performed at distances (ρ) of 10-70 km from the WTF transmitter -- approximately broadside to the NS antennas. Presented in Figure 1 is a plot of the H_ρ component versus range for the elevated NS antenna. These H_ρ values are normalized to a transmitter current (I) of 300 amperes and azimuth angle (ϕ) of 90° (i.e., directly broadside to the antenna). The solid line in Figure 1 was derived (1,3) by assuming an effective conductivity under the NS antenna of 2.2×10^{-4} mhos/m. This is the value that was measured during the August, 1972 test (1). From this curve it is observed that the theoretical and experimental values of H_ρ are in excellent agreement for measurement distances greater than 26 km. Thus, the repeatability of the August, 1972 measurements is excellent.

It has been shown (4) that for the homogeneous isotropic earth case, the measurement distance must be greater than seven skin depths ($\delta \sim 500/\sqrt{f\sigma}$, where f is the frequency in Hertz and σ is the uniform earth conductivity) in order for the H_ρ component to be inversely proportional to $\sqrt{\sigma}$. Referring to Figure 1, we see that the measurements taken at ranges less than 26 km are grossly different east and west of the NS antenna. Since 26 km is approximately seven effective earth skin depths ($\delta_e \sim 500/\sqrt{f\sigma_e}$ meters) at 76 Hz, it appears that the $7\delta_e$ criterion is also valid for the geoelectrically complex WTF area. (It should be noted that Wait (5) has recently shown that -- for certain two-layered earth conditions -- even the $7\delta_e$ measurement distance is too close for determining σ_e).

Presented in Figure 2 is a plot of the H_ρ component versus range for the buried NS antenna at 76 Hz. The H_ρ values are normalized to I = 300 amperes and $\phi = 90°$. These measurements were taken at distances of 36-71 km from the WTF transmitter, approximately broadside to the buried NS antenna. They were repeated at each of the 35 sites. The solid line in Figure 2 was derived (1, 3) by assuming an effective conductivity under the buried NS antenna of 2.2×10^{-4} mhos/m (i.e., the same σ_e as measured under the elevated NS antenna). From this curve it is observed that the theoretical and experimental values are in excellent agreement. Thus, within the experimental accuracy of the measurements (± 0.1 db), there is no difference (in produced field strength) between the buried and elevated WTF NS antennas. There is also no difference in the pattern of these two antennas ($\pm 1°$).

Texas Measurements

During the period extending from mid-March through early April, 1973, the Naval Underwater Systems Center performed a conductivity survey of the Llano Uplift area of Texas using the wave impedance measurement technique (with the WTF NS antenna as the transmission source). An additional task, the far field comparison of the WTF elevated and buried NS antennas, was performed during the first week in April in Kingsland, Texas. This far field site ($\rho \sim 1.85$ Mm) is approximately in line (i.e., $\phi = 0°$) with the WTF NS antennas. The measurement period was divided into two segments (1030 - 1430 GMT and 1530 - 2330 GMT) during which the elevated and buried NS antennas were utilized. (The first two hours (1030 - 1230 GMT) were not used for the buried versus elevated comparison as this period coincided with Texas sunrise.) At 1430 GMT each day, the transmitter was switched from the buried to elevated antenna (or vice-versa).

The measured daily averages for the H_ϕ magnetic field strength component are presented in Figure 3. It should be noted that some of the atmospheric noise estimates taken during this period were upper bounds to the noise (i.e., these noise estimates are suspected to be contaminated with 60 Hz). Therefore some of the 80% confidence intervals (computed for each of the daily averages) may be too large.

Receiver integration times of 30 minutes per sample were employed for the majority of these measurements resulting in 36 samples for the buried NS antenna and 34 for the elevated. Referring to Figure 3, we see that the six day H_ϕ average is -142.6 ± 0.5 dBAm for the buried NS antenna and -143.2 ± 0.6 dBAm for the elevated NS antenna. Since these confidence intervals overlap, there is no discernible difference between the buried and elevated NS antennas.

(The buried antenna appears to be slightly better although not enough data exists to make it statistically significant.)

Conclusions

The principal results obtained from these two different range measurements are:

1. There is no difference in performance between the WTF buried and elevated NS antennas (within the experimental accuracy of the measurements).

2. The NUSC August, 1972 WTF effective earth conductivity measurements are repeatible, and

3. The measurement distance must be greater than seven effective skin depths in order for the H_ρ component to be inversely proportional to $\sqrt{\sigma_e}$.

It should be noted that Lincoln Laboratory personnel measured in Norway during the same time period. Their results (6) also indicate that there is no measurable difference in performance between the WTF buried and elevated NS antennas.

References

1. Bannister, P. R., and F. J. Williams, "Results of the August, 1972 Wisconsin Test Facility Effective Earth Conductivity Measurements," (to be published in Journal of Geophysical Research).

2. F. C. Frischknecht, "Electrical Methods in Geophysical Prospecting," Pergamon Press, Oxford, 1966, Chapters IV and VI.

3. Bannister, P. R., "The Image Theory Quasi-Static Magnetic Fields of a Finite Length Horizontal Electric Antenna Located Near the Earth's Surface," NUSC Tech. Report 1011, 4 June, 1969.

4. Bannister, P. R., "Quasi-Static Fields of Dipole Antennas at the Earth's Surface," Radio Science, vol. 1 (New Series), no. 11, p. 1321 - 1330, November, 1966.

5. Wait, J. R., "Note on the Surface Impedance and Wave Tilt for a Line Source - Excited Two-Layer Earth," (Private Communication, April, 1973).

6. White, D. P. (Private Communication, April, 1973).

Figure 1. H_{ρ} vs. ρ - elevated NS antenna, 76 Hz

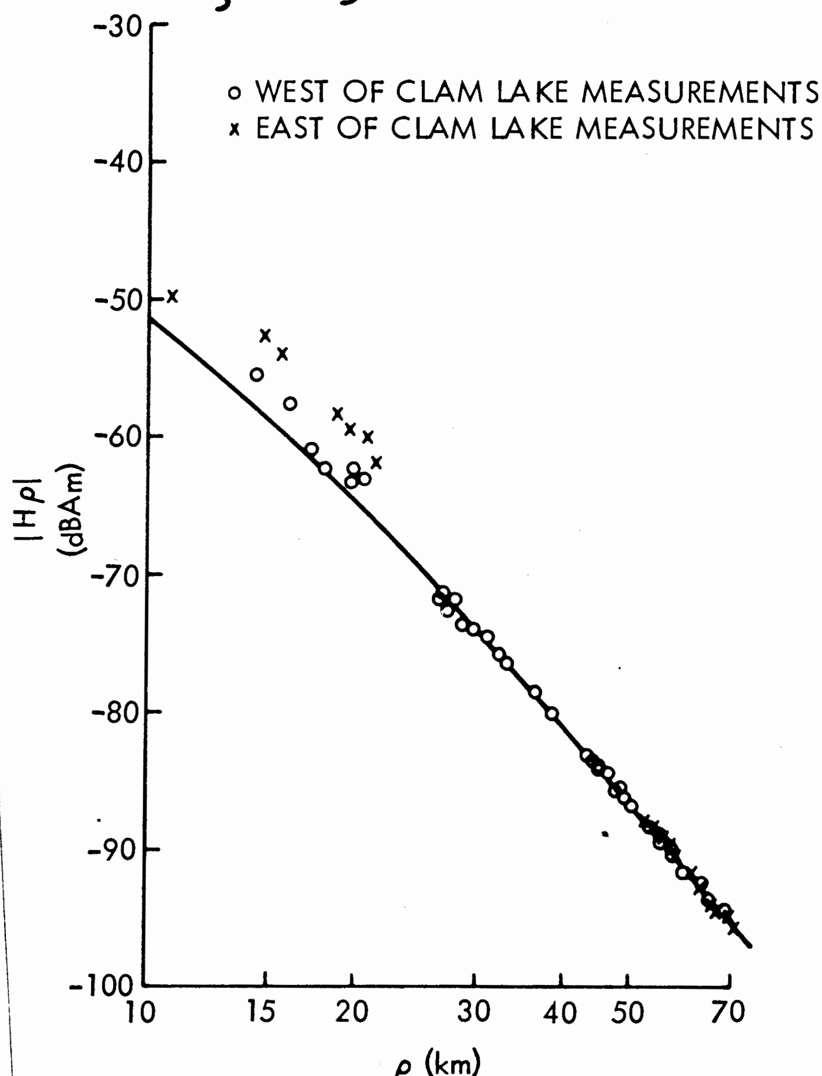

Figure 2. H_ρ vs. ρ - buried NS antenna, 76 Hz

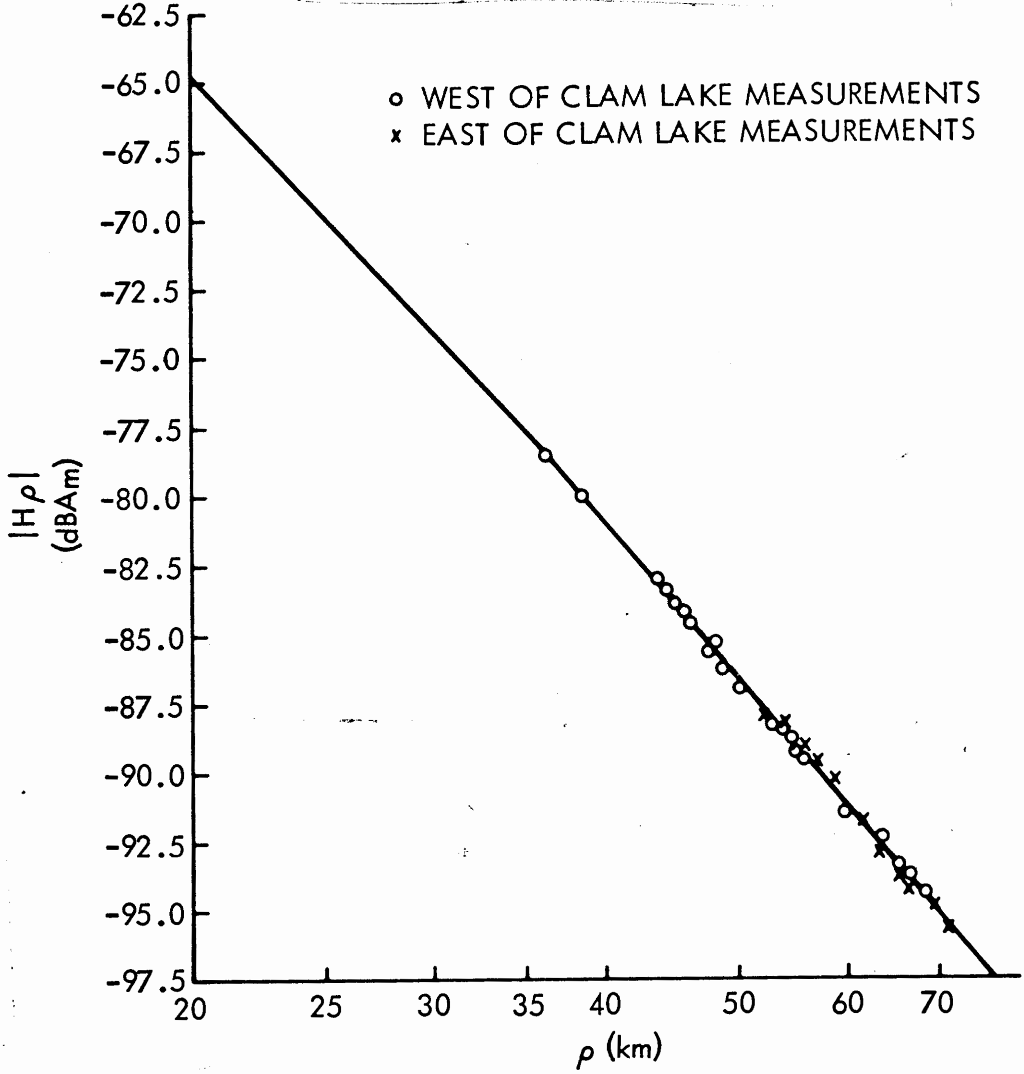

Figure 3. TEXAS H_ϕ daily averages