Communications

Trees Performing as Radio Antennas

KURT IKRATH, WILLIAM KENNEBECK, AND ROBERT T. HOVERTER

Abstract—**Radio transmission and reception experiments conducted in a tropical jungle are described. The performance of conventional whip antennas is compared with the performance of trees utilized as antennas in conjunction with hybrid electromagnetic antenna couplers (HEMAC's). The trees were found to outperform the whip in some cases by up to 20 dB.**

I. INTRODUCTION

"It would seem that living vegetation may play a more important part in electrical phenomena than has been generally supposed.··· If, as indicated above in these experiments, the earth's surface is already generously provided with efficient antennae, which we have but to utilize for communications,···" These words were written in 1904 by Major George O. Squier, U.S. Army Signal Corps, in a report to the U.S. Department of War in connection with military maneuvers in the Pacific Division [1].

In 1969, personnel of the U.S. Army Electronics Command again employed trees as antennas. In this case, the trees were used as transmitter antennas for frequencies ranging from medium to short wavelengths. In the experiments to be described, the tree trunk was used as a single-turn secondary winding in a resonant toroid-type transformer, wherein the primary winding was a flexible toroidal spiral wrapped around the tree trunk. When stretched out completely, the toroid becomes a 24-ft long electrical wire antenna; when pushed together, it becomes a coiled magnetic loop antenna of about 8-in diameter. Because of its intrinsic electrical and magnetic properties, the toroid was given the name HEMAC, an acronym for hybrid electromagnetic antenna coupler. With 12-W RF power and at frequencies between 4 and 5 MHz, signal transmissions ranging from 7 to 11 mi were achieved using HEMAC coupled oak and pine forest trees for transmission and a vertical whip antenna for reception. With 35-W RF power and at frequencies of 425 kHz and 460 kHz, signal transmission ranges from 30 to 35 mi were attained using very large oak trees coupled by a HEMAC toroid designed for the medium frequency range. Furthermore, as demonstrated by HF radiation patterns from differently oriented natural tree loops [2] and by MF radiation patterns from large oak trees near swampy water-filled gullies [3], the interaction of a toroidal HEMAC coupled tree with adjacent trees and features of the local terrain can be exploited to launch HF and MF signal emissions into desired geographic directions.

However, the deciduous forests in New Jersey are a poor substitute for dense tropical jungle forests in which ferns and palms grow as tall as trees, and which present a great obstacle to tactical radio communications by conventional whip antennas. In order to evaluate the ability of an HEMAC to overcome these obstacles, an impedance matchbox was designed to connect a standard PRC-74 HF transceiver with the HEMAC coupled tree. This impedance matchbox provided a match to the empirically determined equivalent series tuned load impedances of pine and oak trees ranging from $\sim 1.5\ \Omega$ to $\sim 5\ \Omega$ [4].

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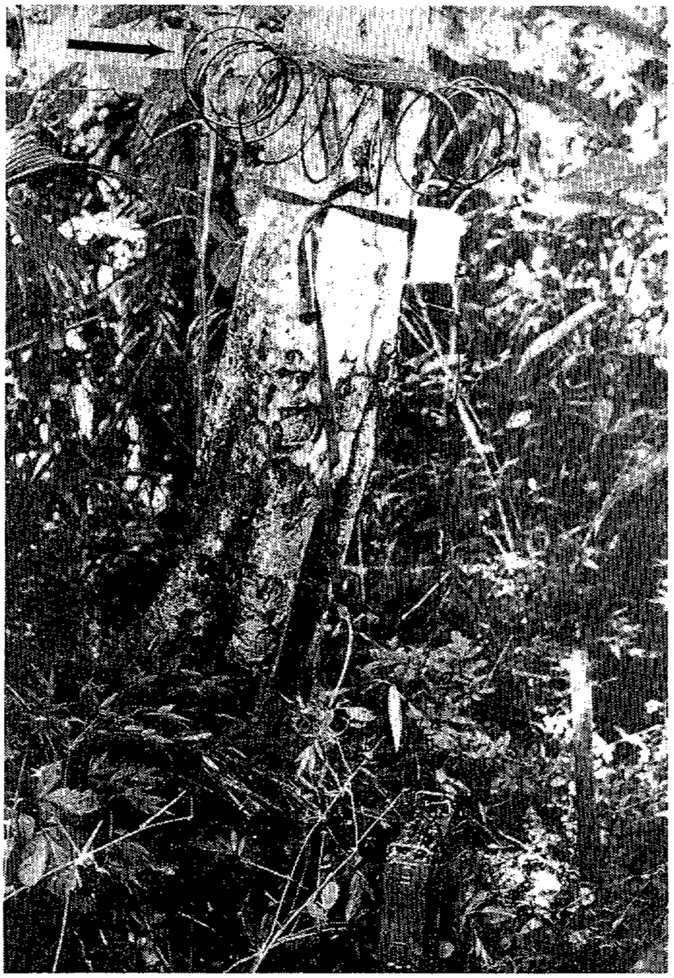

Fig. 1. HEMAC toroid coupled tree and PRC-74 set at jungle hole site, Chiva Chiva Area, Panama Canal Zone, Sept. 1971.

II. MEASUREMENTS

A. The Decays with Distance of 4.650 *MHz Signals Emitted from the Whip and from Jungle Trees* (*Aug.* 26, 1971)

Setup: Jungle trees located within dense underbrush vegetation were coupled by HEMAC's to a PRC-74 set. Used with its whip, the set was placed a few feet away from the same trees. Vegetation within 1 ft of the whip was cut away (Figs. 1 and 2).

Through adjustment of the matching and tuning controls on the PRC-74, maximal available power was delivered to the whip at each location. Similarly, with the HEMAC toroid coupled trees connected by a series tuned matchbox to the PRC-74 set, the tuning capacitor of the matchbox and the output controls of the PRC-74 were adjusted for relative maximal RF current flow through the toroid; e.g., 1.00 A on the first tree, 0.75 A on the second (more distant) tree, and 1.00 A on the third (most distant) tree. The corresponding maximal readings on the PRC-74 output meter were about 50 to 70 percent of full scale.

Signals radiated from the whip and from the toroid coupled jungle trees were received with a horizontal wire dipole antenna and an HRO-500 receiver. The strengths of the received CW signals as

Fig. 2. PRC-74 set and whip at jungle hole site, Chiva Chiva Area, Panama Canal Zone, Sept. 1971.

displayed on the HRO-500 *S*-meter were measured using an HF signal generator as substitution standard.

Results: Using 150 μV as the zero dB reference, the signal levels produced by the toroid coupled trees and the whip radiator are plotted in Fig. 3 as functions of the distance from the horizontal dipole receiver antenna.

Considering the spatial limitations in the Chiva Chiva Test Area and the corresponding small number of data points, the lower attenuation of signals from the toroid coupled trees could be dismissed as a statistical coincidence. However, previous measurements in New Jersey [2] and the subsequently described measurements in the Gamboa Jungle Area prove the deterministic nature of the divergency between signal decays as a function of distance as measured with whips and with trees. Similar divergencies were also observed with different types of antennas in microwave modeling experiments in which grasses, herbs, and shrubs were used to model RF scatter in jungle forests [5].

B. Gamboa Jungle Area Experiments

Measurements in the Gamboa Jungle Area were carried out to determine to what extent the relative dryness and wetness of the jungle vegetation affects the signal-versus-distance decays as sensed by whip and by trees.

Measurement setups: The XMTR and the receiver locations (R_1 to R_6) are marked on the map of the Gamboa Test Area in Fig. 4. The 4.650 MHz signals were transmitted from the PRC-74 whip on the jungle road and from a toroid coupled jungle tree about 20 ft away at the side of the road. The signal decays were measured by CW transmissions from whip to whip, whip to trees, tree to whip, and trees to trees.

Similarly, as in the Chiva Chiva Test Area, the radiated signals were received and measured with the URM-85 RFI Analyzer-Field Strength Meter connected to either the tripod-mounted URM-85

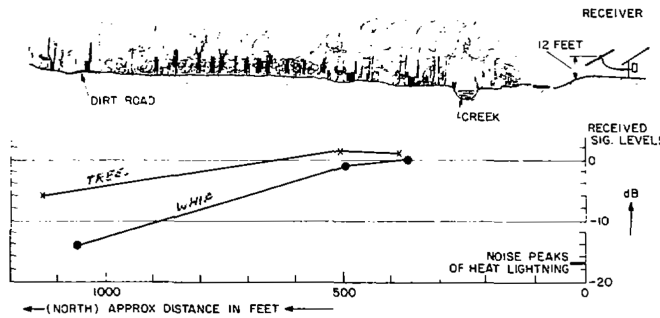

Fig. 3. Relative levels of 4.650-MHz CW signals radiated from, respectively, PRC-74 whip and HEMAC toroid coupled jungle trees powered by identical PRC-74 transceiver set and received by horizontal wire dipole antenna, Chiva Chiva Test Area, Panama Canal Zone, Aug. 26, 1971.

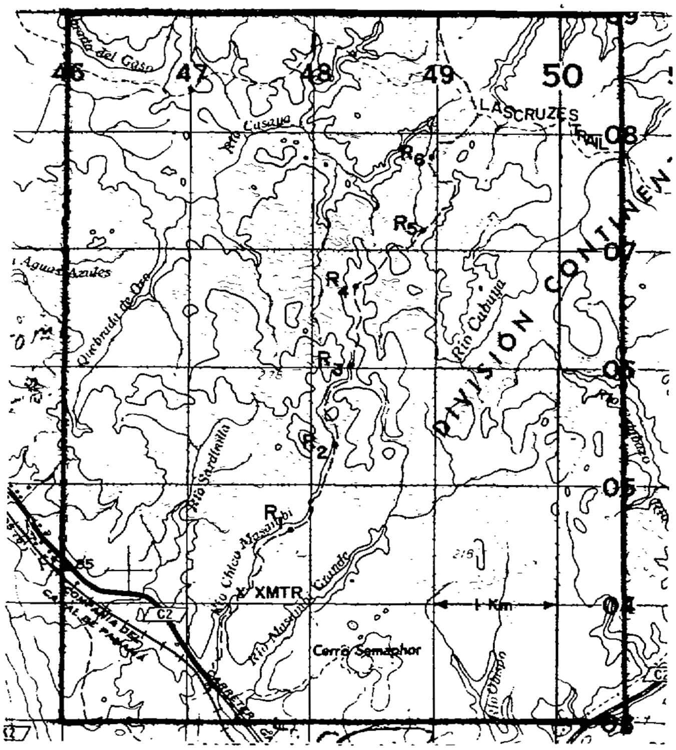

Fig. 4. Transmitter and receiver locations, R_1 to R_6, Gamboa Area, Panama Canal Zone, Sept. 5, 7, and 8, 1971.

whip on the road or to toroid coupled jungle trees at the edge of the road. A typical receiver setup is seen in Fig. 5, which shows the toroid coupled tree on the right side of the road behind the Landrover vehicle.

Measurements were made at intervals of 0.5 mi up to 3 mi distance along the road, i.e., from 0.4 to 2.5 mi air line distance from the transmitter site.

In the initial Sept. 5 measurements when the vegetation was dripping wet after heavy rains, the toroid tree transmitter output was adjusted to produce at a distance of 0.4 mi about the same field strength as that produced by the PRC-74 Whip Transmitter. For this purpose the signal field strength was measured with the URM-85 whip.

The same settings of the controls of the toroid coupled tree transmitter were reproduced again on Sept. 8 in hot sunny weather, when the vegetation was relatively dry.

Results: The drastically different types of signal decays-with-distance as sensed with the whip and with toroid coupled trees in the dripping wet and in the dry jungle is quantified by the corre-

Fig. 5. Typical receiver setup. From left to right: HEMAC toroid coupled tree, PRC-74 set with whip, URM-85 field strength meter in vehicle, URM-85 whip on tripod, Gamboa Area, Panama Canal Zone, Sept. 1971.

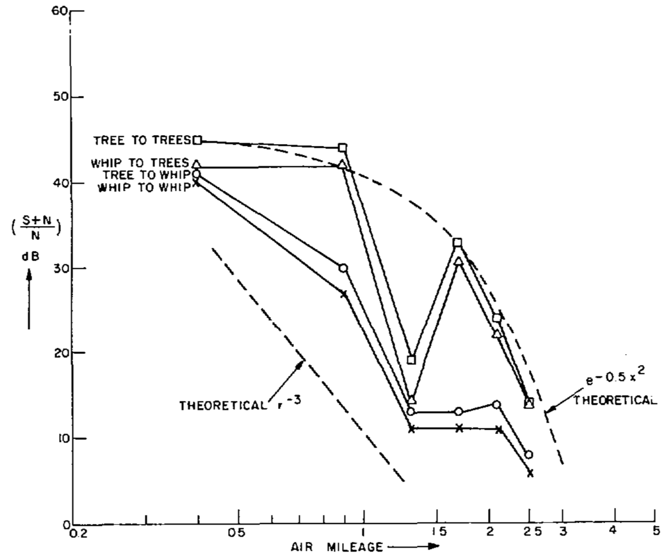

Fig. 6. 4.650-MHz signal-plus-noise/noise versus distance from XMTR site, jungle vegetation dripping wet after heavy rainfall, cloudy weather, Gamboa Area, Panama Canal Zone, Sept. 5, 1971.

sponding signal-plus-noise to noise-ratio-versus-distance curves in Figs. 6 and 7.

These curves conform to x^{-3} and $\exp(-0.5x^2)$ type laws within the measurement range $0.4 \leq x \leq 2.5$ mi.

The influence of the terrain on the shape of these and other signal-decay-versus-distance curves is deduced in [4]. In particular, on Sept. 5 and 8 over only 1.3 air mi voice communications by the whip equipped PRC-74 sets used by the transmitting and receiving parties were hardly audible as the voice signal levels on both ends faded almost into the relative low noise backgrounds. (During a similar test on Sept. 7, lightning noise blocked voice communications by whip completely.)

The overall results show that the obstructing influence of the hilly terrain was felt more severely when the jungle vegetation was dripping wet than when it was dry, and in all cases more severely with the whip than with HEMAC toroid coupled trees.

Considering the results of the previously mentioned modeling experiments [5] in connection with the data from the Chiva Chiva Gamboa jungle tests [4], one must conclude that the superior performance of the trees is in a large part due to their ability to

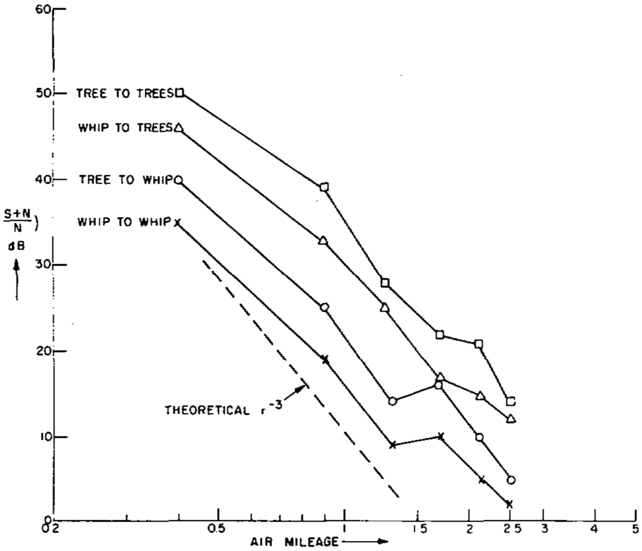

Fig. 7. 4.650-MHz signal-plus-noise/noise versus distance from XMTR site, jungle vegetation surfaces relatively dry in sunny weather, Gamboa Area, Panama Canal Zone, Sept. 8, 1971.

produce and to sense the dominant horizontal polarization, i.e., the polarization that has the greater survival rate in the dominant vertically structured roughness of terrain and vegetation.

C. *Qualitative Tests*

Different foreign radio stations were received using toroid coupled trees on the Las Cruzes Jungle Trail and voice communications tests were carried out between different locations on the Las Cruzes Jungle Trail in the Gamboa Area and a location in the Chiva Chiva Jungle Area. Additional details of tests and related measurement data can be found in [4].

III. CONCLUSIONS

The phenomena that govern radio emission and reception at ground locations in jungle forests are easily recognized by considering the jungle as a maze of aperture-coupled screen rooms. In the jungle case, the screens, in the form of vertical tree and fern trunks, and the horizontal forest canopy are of variable thickness, have variable shaped apertures, and are composed of diverse substances that contain mostly water.

The local forest structure determines the directivity of radiation. However, the directional radiation bias of local forest structures can be overcome by employing phased twin tree arrays, [6] and [7].

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Prediction of Active Array Impedance from Simulator Measurements Using Rounded Ramp Function Interpolation

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***Abstract*—In order to extend the active reflection coefficient of a phased array to general scan angles from measurements on a multielement phased array waveguide simulator, a new interpolation technique using rounded ramp functions (RRF's) is presented. The interpolation formula is tested on an array, simulated by a 25-element simulator, with stripline-fed slots as radiating elements. Contour plots showing the magnitude and the phase of the active reflection coefficient are included. The described interpolation scheme gives a much smoother behavior than a Fourier series expansion published earlier.**

INTRODUCTION

The waveguide simulator is a powerful tool in designing phased array antennas. Recently Gustincic [1] described a new multielement waveguide simulator technique where a single simulator can be used to determine the active array impedance at a number of discrete scan angles. In the same paper an interpolation scheme to predict the array performance at more general scan angles is presented. The scheme is given by an expansion of the array excitation into Fourier series. With this interpolation formula the magnitude and the phase of the active reflection coefficient of an infinite phased array, simulated with a 25-element waveguide simulator, have been calculated and plotted. For scan angles more than 45° from the H-plane scan axis, an increased ripple can be observed in the contour plots between the measured values. Furthermore, when the array is scanned along the E-plane axis, the formula breaks down.

In the present communication, a new interpolation scheme is presented, where a summation of suitably shifted rounded ramp functions (RRF's) is used. The formula is then tested on the same set of measurements as those used for the previously mentioned simulator. This new interpolation technique gives in the whole space a much smoother behavior than the Fourier expansion formula.

RRF INTERPOLATION

The RRF is defined by

$$f_{rr}(x,\alpha) = \frac{1}{\alpha}\ln\left[1 + \exp\left(\alpha \cdot x\right)\right]. \tag{1}$$

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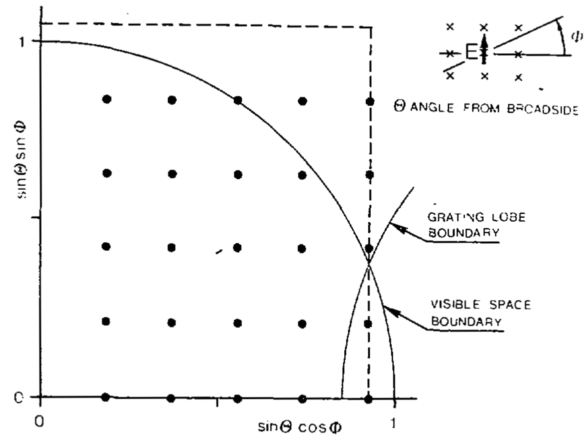

Fig. 1. Simulated scan angles with 25-element waveguide simulator.

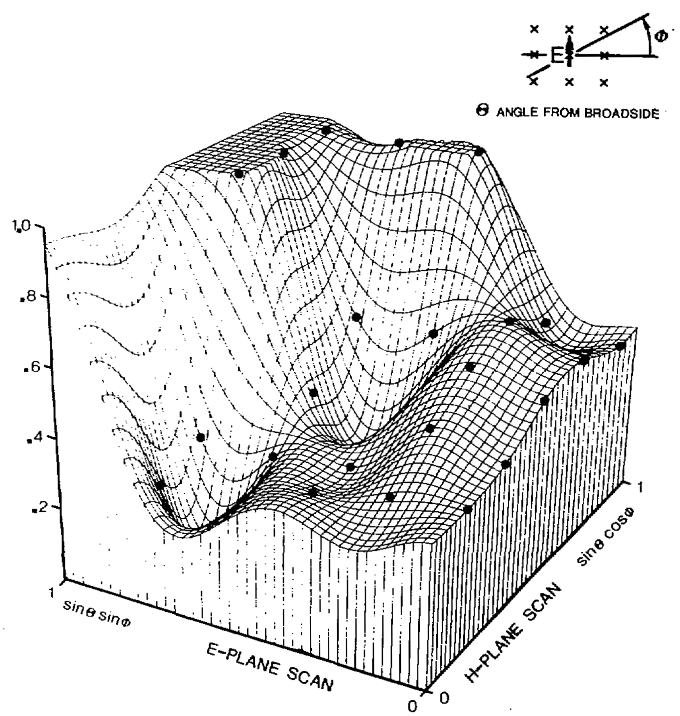

Fig. 2. Magnitude of active reflection coefficient.

The function has the asymptotes

$$f_{rr}(x,\alpha) = \begin{cases} x, & \alpha \cdot x \to \infty \\ 0, & \alpha \cdot x \to -\infty. \end{cases} \tag{2}$$

The parameter α determines the rounded transistion between these asymptotes. By a composition of suitably shifted RRF's, the following interpolation formula is achieved in the two-dimensional direction cosine space:

$$\begin{aligned} f(x,y) &= \sum_{k=1}^{2} a_k(y) \cdot x^{k-1} + \sum_{k=3}^{N} a_k(y) \cdot f_{rr}\left(\frac{x - b_k}{c_k}, \alpha\right) \\ a_k(y) &= \sum_{i=1}^{2} r_{ki} \cdot y^{i-1} + \sum_{i=3}^{M} r_{ki} \cdot f_{rr}\left(\frac{y - s_i}{t_i}, \alpha\right), \qquad k = 1,\cdots,N \end{aligned} \tag{3}$$

where

$$x = \sin\Theta \cdot \cos\Phi$$

$$y = \sin\Theta \cdot \sin\Phi$$