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Investigation of the Electrical Properties of a Forest and Its Impact on Radio Wave Propagations

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Abstract

Two important parameters represent the forest's electrical properties. They are permittivity, $\mathcal{E}_r$, and conductivity, δ of the forest. These parameters were observed to affect the radio wave propagation in the forest. The study of radio wave propagation in the forested environment becomes necessary since radio communication is propagated by electromagnetic wave (EMW) traveling through different environments, The main objective of this research was to investigate a simulated model for radio wave propagation in a forested environment The computer simulation technology (CST) microwave suite version of the software was installed in a system with a high RAM size, followed by settings and configurations of the different parameters defined in CST. CST is a simulation method used in the simulation of EM-wave which can be applied to propagation, radiation, and the speed of EM-wave. Using a 3D computer simulator tool, the simulation model was then created around the idea of depicting the forest as a single dielectric block. In doing this, many factors like the forest's size, material dielectric properties, and antenna placement were considered. The values used for $\mathcal{E}_r$ and δ in the simulated model were obtained from measured data in the real forest using a RESPER probe After the simulation, MATLAB and other statistical methods were used to analyze the field data.

Keywords: Electrical properties, radio wave, forest, permittivity, conductivity

INTRODUCTION

Radio wave propagation is a stream of uncharged elementary particles that travels across different media and environments [1]. Interaction between radio wave propagation and environments causes path loss, attenuation, and drop calls which is a reduction in signal strengths which are always observed in forested zones [2]. We aimed to investigate the electrical properties of a forest and their impact on radio wave propagation. Because of the lack of knowledge about the electrical characteristics of a real forest, there have been very few attempts to perform simulation studies on the electrical characteristics of a forest to ascertain its effect on radio wave propagation in the forest.

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The forest zone is dominated by tree species [3]. These tree species possess both physical and electrical properties. Physical properties such as foliage, trunk, twig, and leaf size have been discussed in the literature to affect radio wave propagation in the forest and contribute to variations in the electrical properties of the forest [4].

With the use of computer simulation technology (CST) software in studying radio wave propagation in the forest, we discovered that it is not the physical properties of the forest that affect radio wave propagation rather it is the electrical properties (permittivity, Ɛr, and conductivity, δ) which affect it by causing poor electric signal strength in the forested area.

Figure 1. Map of the study area.

Figure 2. The study sites.

The electrical characteristics of a forest refer to the ability of materials within the forest to conduct electric currents. These are unseen properties of the forest. They are specified by their constituent parameters, which are permittivity, permeability, and conductivity [5, 6]. Permeability is always one (static); hence, we concentrate on permittivity and conductivity. The study was carried out in the Ikot Offiong forest in Akpabuyo L.G.A. of Cross River State, Nigeria, chosen because of its forested nature (Figures 1 and 2) [7].

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MATERIALS

Research materials are sub-divided into two categories namely;

1. Hardware, which are:
   - i. The laptop and its accessories are used for software installation and simulation.
   - ii. A phone with a GPS facility is used for locating the study site and map.
   - iii. RESPER probe is for measuring permittivity and conductivity.
2. Software which are:
   - i. CST software is for creating a model and simulation.
   - ii. MATLAB for analyzing simulated results.

METHODOLOGY

A methodological flowchart was designed for the accurate execution of the study (Figure 3). The CST studio suite was selected for this study. The software suite contains a transient solver with 3D simulation tools and other features, set up and configured as in Figure 4.

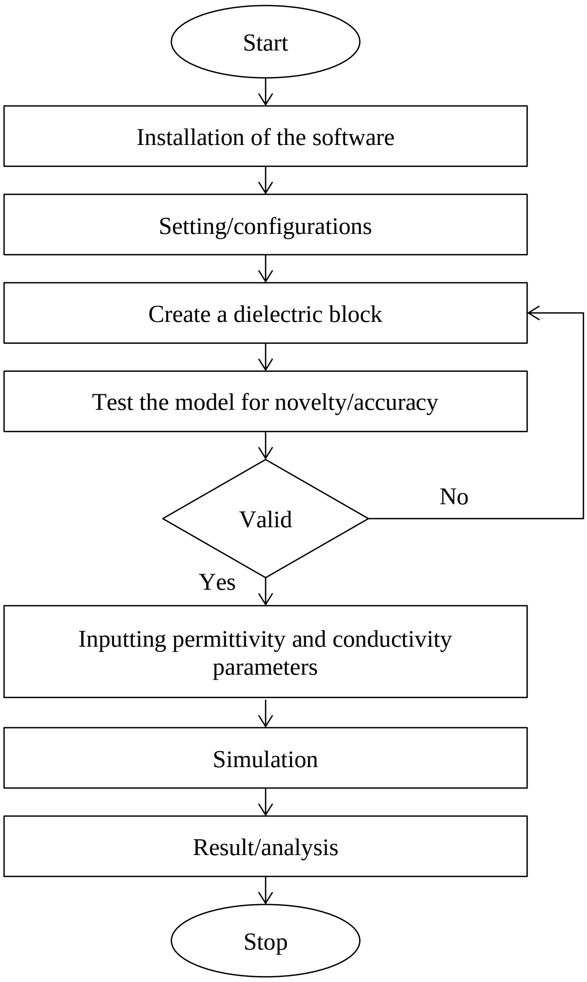

Figure 3. Methodology flowchart.

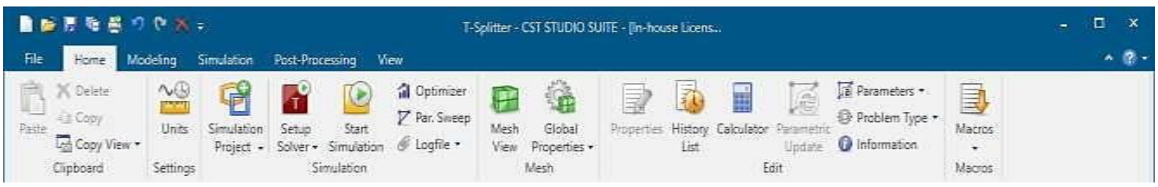

Figure 4. CST (MWS) studio suite user interface.

Mesh Configuration

In the mesh property configurations, the hexahedral type is selected. A synchronized balance between calculation time and precision was achieved by setting the number of lines per wavelength to 10m. By default, the mesh line ratio limit is set to 10.

Configuration of the Boundary Condition

The option components are Xminimum (Xmin), Xmaximum (*Xmax)*, Yminimum (*Ymin*), Ymaximum (*Ymax),* and Zmax. The *boundary conditions* were defined as "*open (add space)*," a configuration that functions as a free space to avoid wave reflections. The "*electric (Et = 0)*". was used to set the Zmin border as a round plane [8–10].

Frequency, Time, and Temperature Settings

The dimensions were defined in megahertz (MHz), nanoseconds (ns), and Kelvin. The frequency range parameter was used to establish the range of frequencies, which is the minimum frequency to be used in the simulation.

Brick Tool Configurations of in CST

The following characteristics were used to describe a brick object tool: Zmin: Zd - 0.5d; Zmax: Zd + 0.5d; Ymin: Yd - 0.4; Ymax: Yd + 0.3, Xmin: Xd - 0.5; Xmax: Xd + 0.4. Using a *Boolean subtract* operation in CST, the brick object is subtracted from the cylindrical object to generate the gap space for inserting the discrete port.

Configuration of the Discrete Edge Port for the Antenna Excitation

For the simulation, a separate connection was required to supply power to the dipole antenna. A discrete edge port was defined with the following properties: S-parameter; Impedance: 73 Ohms, radius: 0.0, X1: Xd, Y1: Yd, Z1: Zd - d/2, X2: Xd, Y2: Yd, Z2: Zd+d/2. To construct the dipole antenna, a cylinder object with the following properties was configured: outer radius, r; inner radius, 0; Xcenter, Xd; Ycenter, Yd; Zmin, Zd - l2/2; Zmax, Zd + l2/2; segments, 0.

Field Monitor Settings

E-field and power flow monitors were defined to monitor the fields produced by the simulation. Electric field and power flow monitors were used to monitor the fields generated by the simulator. In CST, the pointing vector of the electromagnetic field is stored in the power flow monitor, whereas the electric field vectors are stored in the electric field monitor. Field and power flow monitors were assigned to each frequency that needed to be monitored.

Variables Defined in CST User Interface

It is possible to define the variables for the simulation model at the CST user interface. The command ribboned graphic user interface (Figure 4) menu contains tools to be used for keying in the variables. To create the model, the variable parameters defined in Table 1 are keyed into the parameter list menu of the model. The transient solver was then selected for the stimulation.

Construction of Dielectric Block

A frequency of 100 megahertz was used to create a single homogenous dielectric block with length (L), width (W), height (H), and a transmitting half-wave dipole antenna. The variables required to create the dielectric block were obtained from the variable list in Table 1.

The dielectric block was constructed using CST tools, as shown in Figure 4, to select the dielectric material of the electric block to be the normal type with each simulation run set to the value of *Epsilon* (relative permittivity ε_r) based on the test case. The value of *Mue* was set to one because the forest is regarded as a non-magnetic structure. A transient solver of the 3D simulator was then used to simulate the created model (Figure 5). The electrical permittivity Ɛ and electrical conductivity σ were set according to each simulation run.

Table 1. List of variable parameters defined in CST.

S.N.	Variables	Designations	Description	Units
1.	H	Varies according to the simulation run	Height of dielectric block	Meters
2.	L	Varies according to the simulation run	Length of dielectric block	Meters
3.	W	Varies according to the simulation run	Width of dielectric block	Meters
4.	C	3×10^8	Speed of light	Meters/second
5.	F	Varies according to the simulation run	Transmission frequency	MHz
6.	Lamda	$c/(f\cdot 10^6)$	Wavelength	Meters
7.	*l* 2	Varies according to the simulation run	Dipole length	Meters
8.	R	0.0005·lamda	Dipole radius	Meters
9.	Xd	Varies according to the simulation run	X-coordinate of dipole	Meters
10.	Yd	Varies according to the simulation run	Y-coordinate of dipole	Meters
11.	Zd	Varies according to the simulation run	Z-coordinate of dipole and represents the transmitter height, h_t	Meters
12.	D	0.025·lamda	For mating discrete port to dipole	Meters

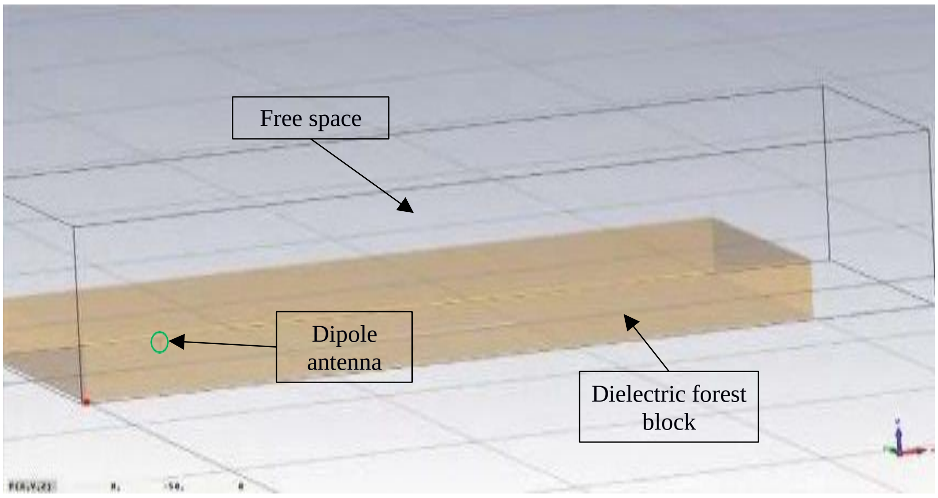

Figure 5. Forest dielectric block constructed using CST tools.

The variables defined in Table 1 and the CST tools were used to construct the dipole. The length of the antenna is calculated as follows:

V = fλ from the general wave equation,

Where, V is the speed of light = 3×10^8 m/s
F is the frequency = 50 MHz
Λ is the wavelength = V/F = $3\times10^8/50000000$ = 6 m
Hence, length of dipole used = λ/2 = 6/2 = 3m

DISCUSSION OF THE RESULTS

From the simulated results and graphs (Figures 6–11), the following conclusions were drawn:

- *Transmitted power loss:* In free space, its zero indicates no obstruction/attenuation. For sparsely forested areas, is low (i.e., 30.3 dBW), while for densely forested areas, it is high (i.e., 38.5 dBW)
- *Receiver power loss:* In free space, we observed low power loss (i.e., -60 dBW) For sparsely forested areas is high (i.e., -41.7 dBW), While for densely forested areas shows higher power loss (-41.5 dBW)
- *E-field strength:* In free space, a high E-field strength is observed (-15.4 dBV/m), while for sparsely forested areas, E-field strength is low (-25.4 dBV/m), while for densely forested areas, E-field strength is very low (25.9 dBV/m)
- *Path loss:* In free space, we observed the lowest path loss (-60 dB), while for the sparsely forested area, a high path loss was seen (-11.4 dB), while for densely forested areas, the highest path loss was observed (-3.0 dB).

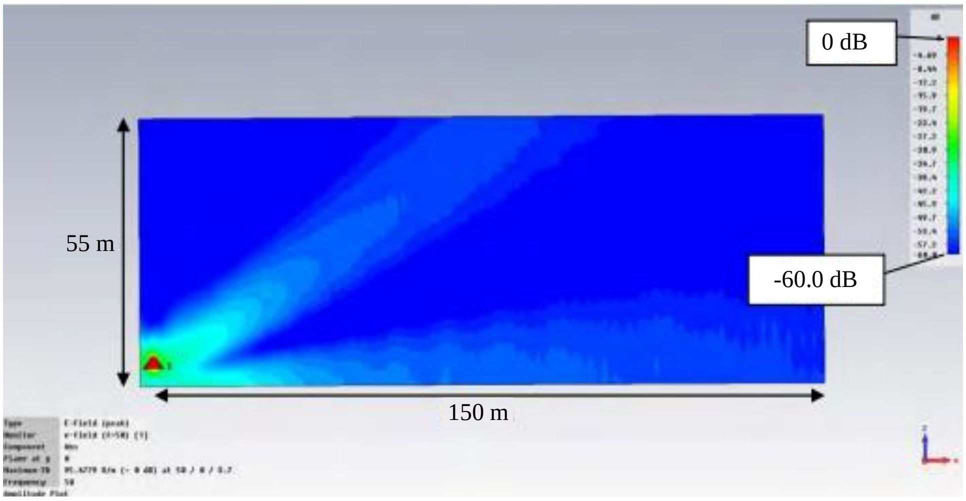

Figure 6. Simulated result of propagation in free space (CST suite, 2023) [8].

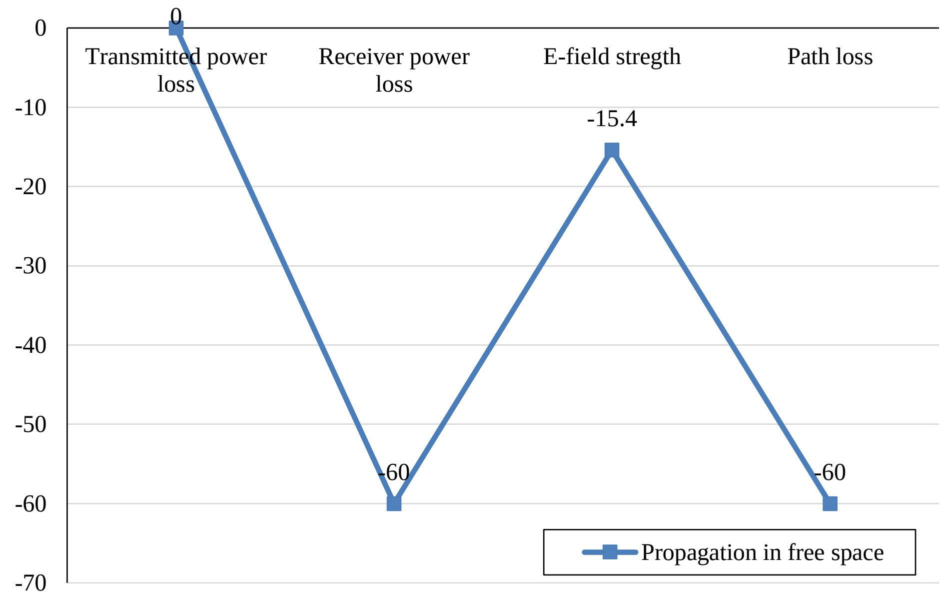

Figure 7. Graph of the simulated result of propagation in free space.

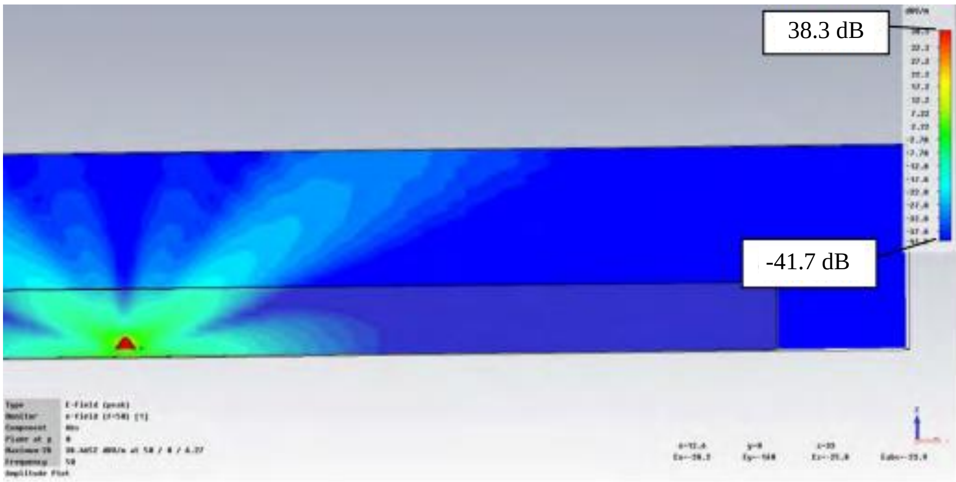

Figure 8. Simulated result of propagation in a sparsely forested area (CST suite, 2023) [8].

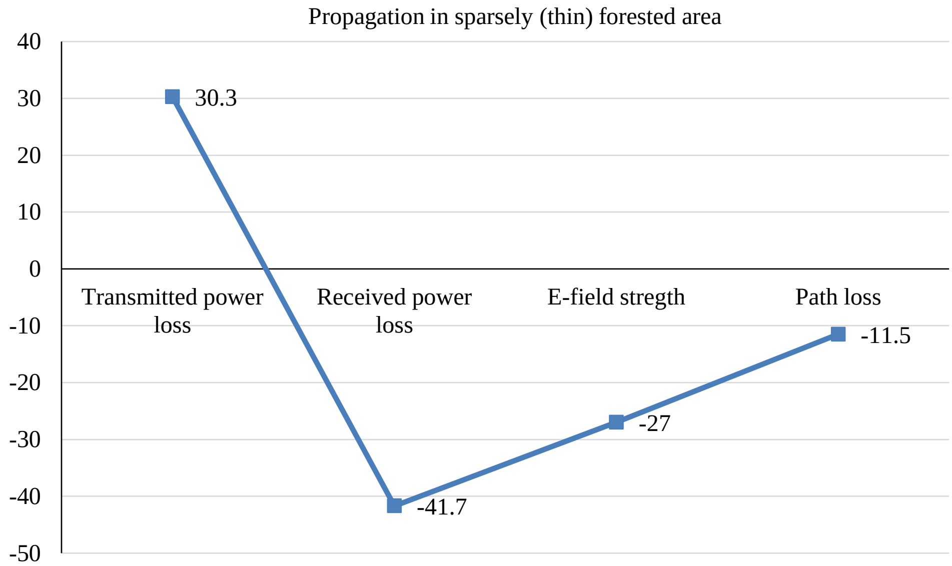

Figure 9. Graph of the simulated result of propagation in a sparsely forested area.

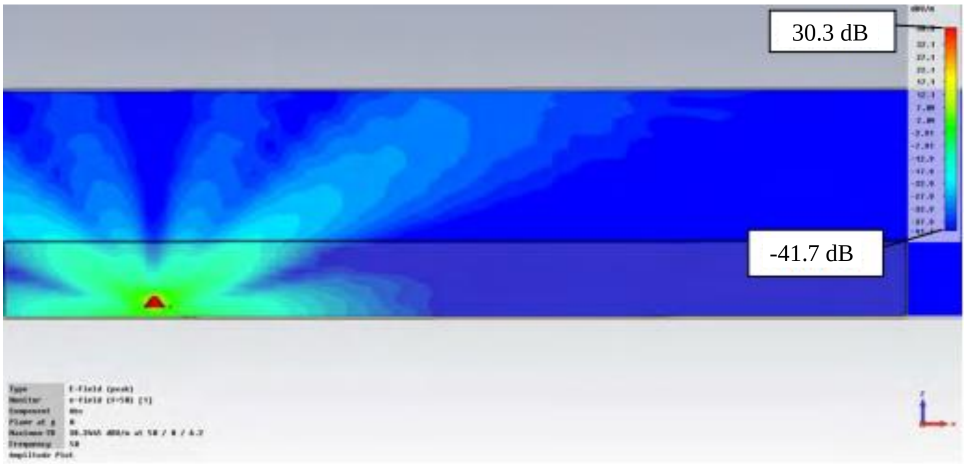

Figure 10. Simulated result of densely forested area (CST suite, 2023) [8].

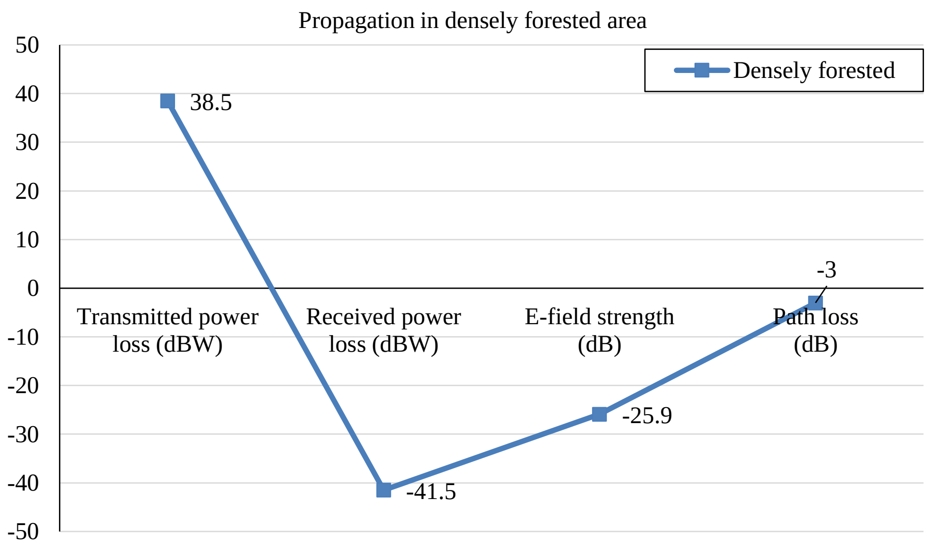

Figure 11. Graph of simulated result of propagation in a densely forested area.

CONCLUSION

From the simulated results, it was concluded that the electrical properties (permittivity and conductivity) of the forest affect the radio wave propagation. The higher the permittivity and conductivity values, the less E the E-field strength, and the lower the values of permittivity and conductivity, the higher the E-field strength. Higher permittivity and conductivity values denote densely forested areas, whereas lower permittivity and conductivity values denote sparsely forested areas. This research was conducted using a single dielectric block to model propagation in a forested environment at frequency bands within 100 Mhz.

Recommendation

Based on the research results, telecom operators should site more buffered antennas in forested zones to reduce incessant drop calls, attenuation, and poor quality of service in forested areas. We also advise that more research be conducted to ascertain the values of the novel physical fidelity model of the forest by dividing the forest into smaller chunks (sub-sections) rather than depicting it as a single dielectric block.

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