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Counter Measures for Null Direction Propagation of Antennas in Tactical High Frequency Sky Wave Communication

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ABSTRACT

In High Frequency (HF) communication, both sky wave and ground wave plays an important part. During a communication trial, it was observed that duplex communication was established over the range of 250 kilometers using dipole and rod antenna. There is null in the vertical direction of rod antenna and hence sky wave communication theoretically is not possible. Thus there is a need to study the radiation pattern in null direction as effect of main lobe is already known. This phenomenon needs to be understood so as to stop unintended transmission in the null direction. This paper describes the simulation of radiation pattern of HF antennas and proposes a hardware blocking model to stop them from emission in the null direction.

Keywords*:* Null direction propagation, duplex communication, Tactical communication, Mathematical model optimization, Hardware blocking model.

1. INTRODUCTION

It is well known that HF working in the frequency range of 3-30MHz is used for long distance communications and ionosphere plays an important part [1]. The sky waves are used to communicate over long ranges whereas the ground waves travel for a shorter distance as compared to the sky wave. Ionosphere plays an important part in the propagation of waves[2][3].During a communication trial it was noticed that for the range of more than 250 km, a HF radio link was having both way communication with one end having dipole antenna and other end having the rod antenna. Based on the knowledge of antennas and radiation pattern of rod antenna, theoretically communication with each other should not be possible. This shows that some radio waves are getting emitted in the null direction resulting in establishment of communication between two ends. Thus there is a need to analyze the radiation pattern and the emission in the null direction so that same can be controlled in order to prevent unintentional emission of radiation. HF radio sky wave communication is extensively used by security forces for tactical communication. This unintentional emission of radiation can be a security hazard if the same is used by armed forces for their operational tasks.

The antennas radiate maximum power in the direction of main lobe and some negligible power in the other directions. In case of rod antenna, this negligible power in the null direction is sufficient enough to establish communication over extended ranges.

The radiation parameters which were analyzed for the study of radiation pattern are its intensity, directivity, polarization, gain antenna efficiency, beam efficiency, input impedance and beam width. Depending upon these parameters the radiation pattern of an antenna shapes up and this behavior is well defined.

Radiation pattern is also known in simpler terms as electromagnetic power distribution. Various parts of a radiation pattern are referred to as lobe, which are classified as major, minor, side and back lobes as shown below in Fig.1 [4].

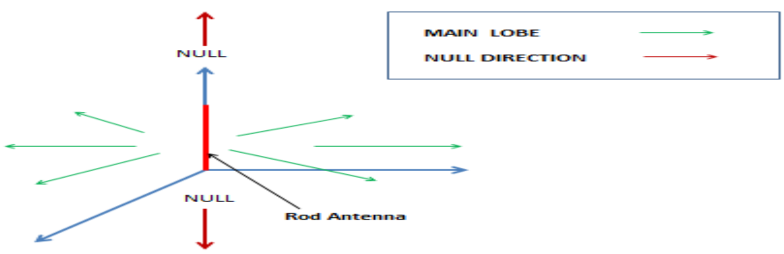

Fig 1 Radiation pattern of rod antenna

The fig. 1 above shows the various lobes of radiation pattern along with the null direction of propagation. Null direction is the zone where effective radiated power is negligible and has minimum directivity compared to the main lobe [5] [6]. The power output in the direction of null lobe is considered as negligible and thus it is ignored theoretically however the power emitted is strong enough to achieve the long distance communication through sky wave mode[7][8].

2. SIMULATION TOOLS

The analysis of radiations of various antennas can be carried out by simulation as it can help in designing an antenna and simulate radiations over different frequencies, different ground conditions and using different materials as blocks. Various software both open and licensed version were studied and checked for simulation of radiation. Finally software selected was able to perform the tasks as mentioned subsequently i.e. design of antennas, elaborate radiation pattern over different frequency, ground condition and able to produce graphs and results in both two/three dimensional pattern. The software used for the simulation of radiation pattern was 4NEC2 and Computer Simulation Technology. These software helped in analysing the radiation pattern of antennas and were able to produce the results which can be studied and compared with results obtained from the ground trials.[10][11].

This paper focuses on blocking the unintended transmission of radiations in the sky wave direction which is creating a security hazard as loss of information may take place. The results will help the users in ground wave mode to avoid the unintended transmission of various antennas specially rod and whip antennas.

3. OBJECTIVES

This paper studies null direction radiation pattern of HF antenna, its blocking and countermeasures in tactical HF sky wave communication. The objective of the study focuses on:-

a. Study of variables affecting the radiations in the null direction.
b. Study of effect of various materials on antennas and radiation pattern [9].
c. Design of antenna radiation block.
d. Field trials to verify the results.

4. ANTENNA RADIATION PATTERN VARIABLES

The antenna radiation pattern is dependent on various variables and the same can be studied with the help of electric field and magnetic field.

The electric and the magnetic field can be calculated at near field and the far field. For various values of r, θ, ϕ directions of the plot, the values of electric field and the magnetic field can be calculated. The various values obtained depict the structure of the radiation pattern in the ideal condition and can be analyzed to obtain the similarity with the simulated result.

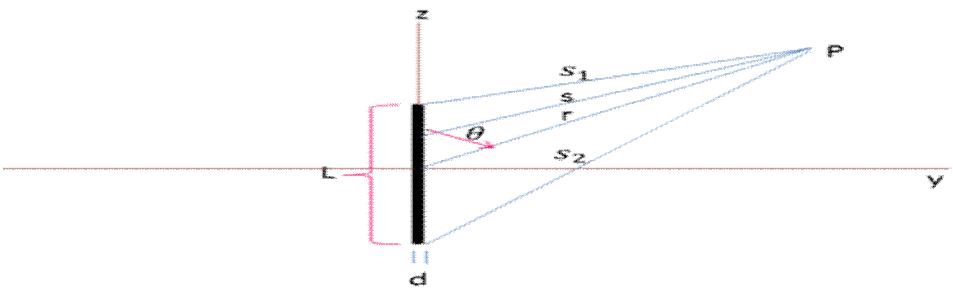

Fig 2. Dipole antenna

The various equations used for calculating the electric field and the magnetic field at point ‘P’ located at distance ‘r’ from the center of the dipole are as follows.

For the near field effect the various equations for calculating the electric field and magnetic field are mentioned below.

$$E_r = \frac{I_o L\cos\theta}{2\pi\varepsilon_o} e^{j\omega\left(t-\left(\frac{r}{c}\right)\right)} \left(\frac{1}{cr^2} + \frac{1}{j\omega r^3}\right)$$

$$E_\theta = \frac{I_o L\sin\theta}{4\pi\varepsilon_o} e^{j\omega\left(t-\left(\frac{r}{c}\right)\right)} \left(\frac{1}{cr^2} + \frac{1}{j\omega r^3} + \frac{j\omega}{c^2 r}\right)$$

$$H_\phi = \frac{I_o L\sin\theta}{4\pi}\left(\frac{j\omega}{cr} + \frac{1}{r^2}\right)$$

$$E_\phi, H_r, H_\theta = 0$$

The various parameters for the far field effect can be calculated using the equations mentioned below.

$$E_\theta = \frac{I_0 L j\omega sin\theta}{4\pi\varepsilon_0 c^2 r}$$

$$H_\theta = \frac{I_0 L j\omega sin\theta}{4\pi c r}$$

$$E_r, E_\emptyset, H_r, H_\emptyset = 0$$

These parameters mentioned above will provide the values of the electric fields and magnetic fields in the ideal conditions and can be set as a benchmark for studying the simulation result.

5. MATERIALS EFFECT ON ANTENNAS

The various parameters which affect the material characteristics are its permeability, electrical and thermal conductivity, Young's modulus, Poisson ratio and diffusivity. Based on these parameters the material characteristics vary and are seen to influence the radiation pattern to a large extent. They decide how a material will behave. Based on the various characteristics of these materials it was observed that block made up of silicon and Beryllia has significant effect on the radiation pattern in the null direction. The various characteristics of these materials are shown in Table 1.

Table1. Material properties

Material Parameters	Beryllia	Silicon	Zirconia	Alumina	Ceria
Electrical conductivity (S/m)	$2.1\text{x } 10^{-12}$	$2.3\text{x } 10^{-12}$	$5.9\text{x}10^{-9}$	$3.7\text{x}10^{-9}$	$4.2\text{x}10^{-8}$
Thermal conductivity ($Wm^{-1}K^{-1}$)	300	149	309	204	134
Young's Modulus (GPa)	345	130-188	121	145	189
Poisson ratio	0.26	0.28	0.17	0.15	0.14
Permeability	1	1	2.1	2.3	3.1
Diffusiblity cm^2/s	0.000115	0.8	0.112	0.341	0.541
Specific heat J/g/C	0.65	0.7	0.03	0.006	0.05

This table depicts the material characteristics of various materials generally used for fabrication of antennas. It is observed that out of five materials the most suitable are Beryllia and Silicon. Both the materials are having the more or less same electrical conductivity, Poisson ratio, permeability and diffusiblity. These are important parameters for antenna design and even for block fabrication. Thus the above said materials can successfully block the radiations if placed at proper location and made up of proper size. After the study of material characteristics, it was obvious that the blocking performance, in blocking antenna radiations, emitting from the antennas are better in Beryllia and Silicon as compared to any other material[14][15]. Thus the same were selected to be used so that efficient blocking of radiations from the antennas in the null direction can be done and unintentional emission of radiations can be avoided.

6. ANTENNA RADIATION BLOCK

To facilitate the design of antenna block, a rod antenna was taken on one side and wire dipole on the other side. The arrangement for experimental setup is shown in Fig. 3. The frequency of operation was kept at 14.5 MHz and accordingly the wire dipole of 9.86m length was taken. The power output of the radio was set at 25W. The length of antenna is d and the distance of block from bottom of antenna is x. To measure the radiation emitted at transmitter end, an isotropic antenna was placed at a height of 1m vertically above the top of rod antenna. For measuring the radiation received at the receiver end, wire dipole antenna was placed at the far end. The readings were taken at both day and night to rule out the dependence of the behavior of location of block on ionosphere height.

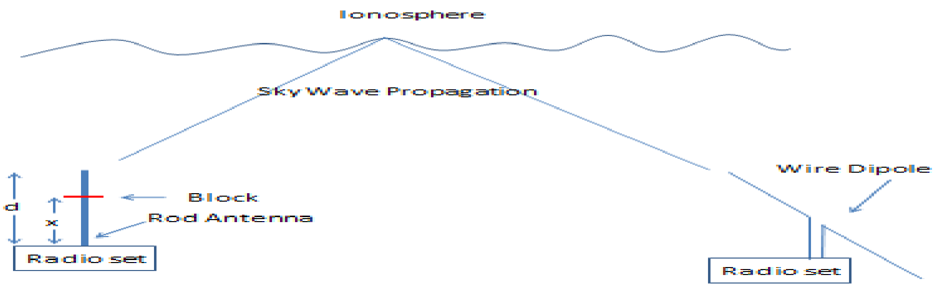

Fig 3 Experimental Setup

Initially readings were taken without block in place. Then a circular disc of Beryllia of diameter 15 cm was taken and placed at a distance of x from bottom of the rod antenna. The power output of radio set received in null direction at a distance of 1m vertical from the top of rod antenna was measured. The block was moved from bottom to the top of the rod antenna. The behavior of power output in null direction as a function of distance of block from the bottom of rod antenna was observed. Graph plotted between power outputs received in null direction and distance of block depicts the variation of power received as position of block. Similarly graph was plotted for the power received at the receiving antenna (wire dipole) and position of the block at a distance of 250 Km.

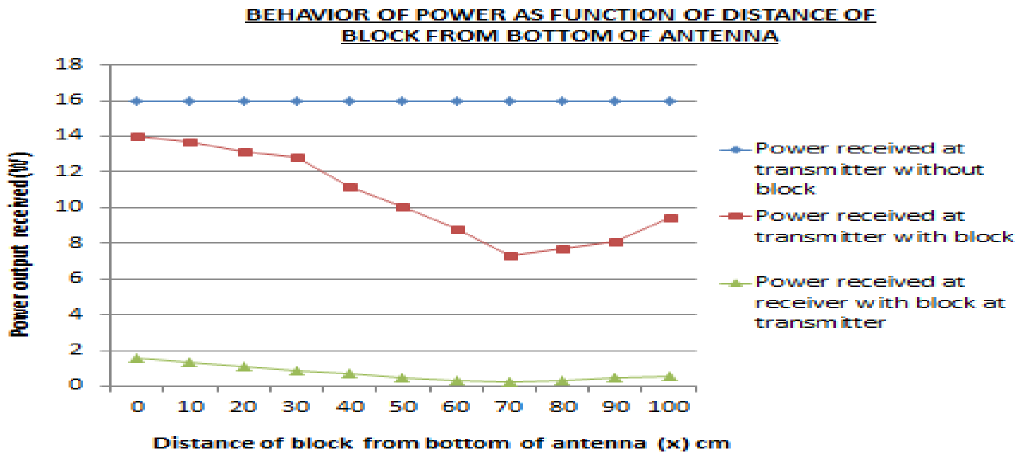

Fig 4 Graph depicting the optimum location of the block for maximum effectiveness.

Next the size of the disc was varied keeping other parameters same. The variation of power received at transmitter end can be seen to decrease with increase in size of block disc as visualized Fig.5. However it is seen that the slope is more in case of disc size 15 cm. as the bulkiness of disc creates difficulty in actual handling of radio set, it is prudent to arrive at optimum size.

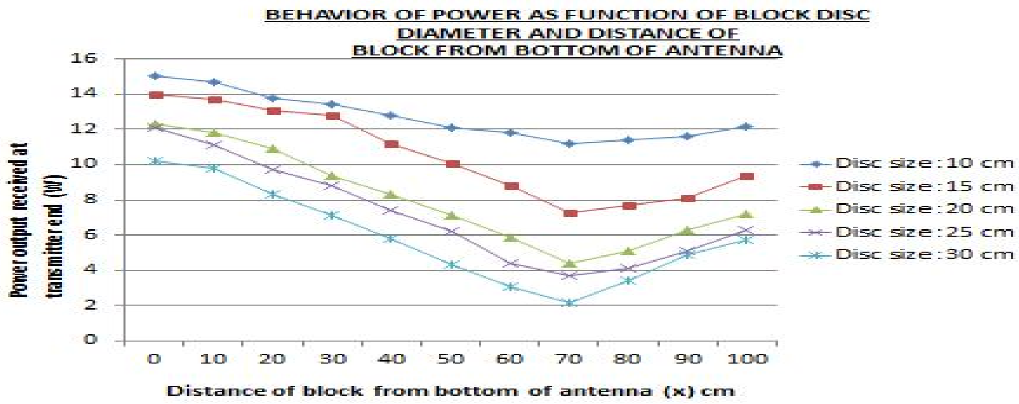

Fig 5 Variation of power output received at transmitter end for various sizes of disc.

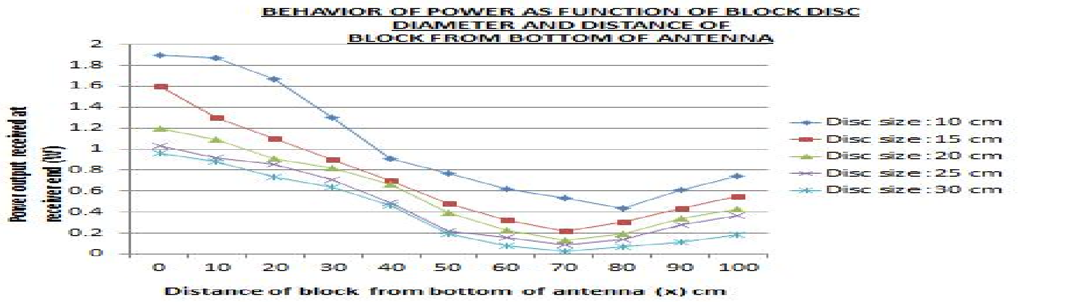

Fig 6 Variation of power output received at receiver end for various sizes of disc.

Similarly the same experimental trial was set up for observing the behavior of power received at the receiver end using a wire dipole. As visualized the variation of the power received with change in disc size is similar to previous experiment as evident from Fig.6 [16][17].

The next is to find out the optimum shape of the block. Although keeping in view the radiation pattern shape at the main lobe and in null direction, it is apparent that for an antenna of homogeneous diameter the torus shaped pattern can be blocked by circular shaped block. However to ascertain the fact various shapes were taken of similar area(equivalent to disc of size 15cm) at a distance of 70 cm from the bottom of the rod antenna. The results are in consonance with the predictions. Fig. 7 depicts that a circular shape is best suited for blocking the radiations in null direction at the transmitter

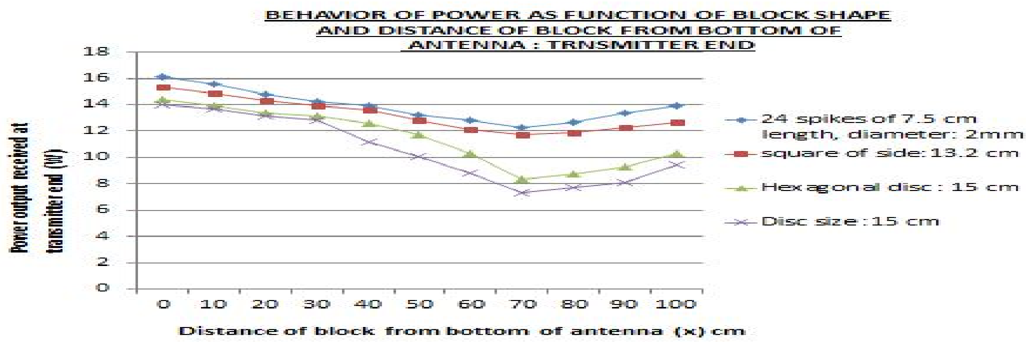

Fig 7 Effect of shape of block at transmitter end.

The effect of shape of block on the power received at the receiver end is given at Fig.9. The results are in consonance with the predictions and have the same effect as at transmitter end. It is clearly emerging out that the circular shaped block is having maximum efficiency in blocking the radiations in null direction [17].

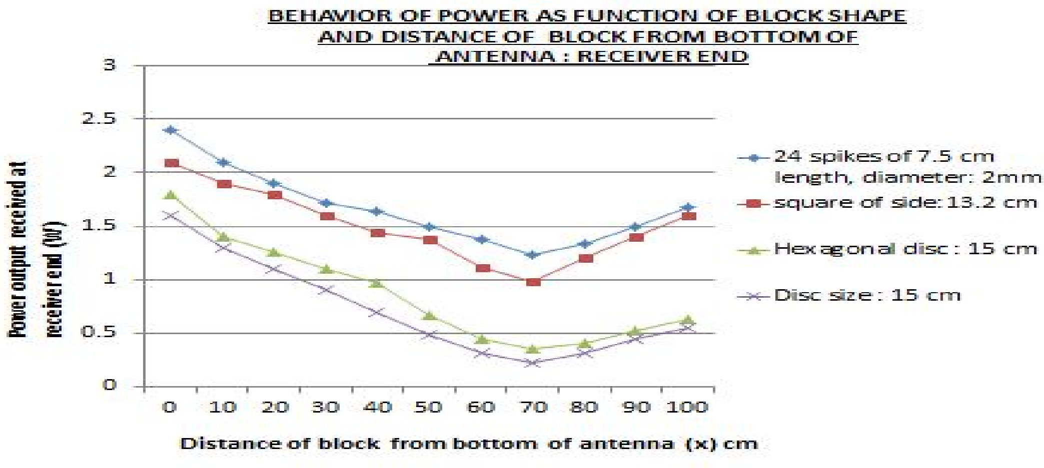

Fig 8 Effect of shape of block at transmitter end.

The next trial was carried out to determine the effect of thickness on the blockage behavior of the block. The disc of 15 cm size was used at a distance of 70 cm from the bottom of the rod antenna. Keeping all other parameters like frequency and length of wire dipole fixed, the thickness of the disc was varied and its effect on blockage of radiation was observed. For this 0.1 mm thickness discs were taken and were placed in increasing order to increase the thickness of the circular disc. The graph indicates that although there is increase in the blocking efficiency with increase in thickness but this is not remarkable and results in increase in weight of the block thereby making the block unstable and wobbly[16]. Fig.9 brings out the effect of thickness of the block on blocking efficiency.

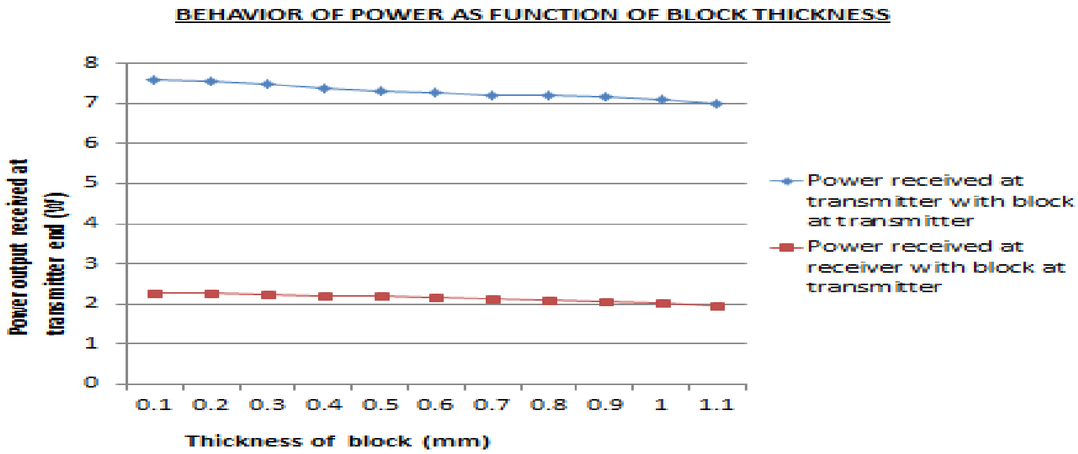

Fig 9 Effect of thickness of block at both ends.

The above study and trials indicate that a circular disc at a distance of 70 cm from the bottom of the rod antenna with thickness up to 0.2 mm is best suited for blocking unintended radiations in null direction. This block can be modified to have variable diameter so that it can be fitted on any diameter rod. Also the block can be made collapsible so that it can reduce in size when it is to be carried.

7. UTILITY

The study and fabrication will have double advantages. First the radio transmission using ground wave communication will have sky wave component thereby increasing the range of transmission with same power transmission. This is not explored by most of the radio manufacturers. Secondly this study will assist in securing radio communication without using a secrecy device thereby maintaining the range and avoid spill over in undesired direction [12].

8. CONCLUSIONS

The study of null direction radiation pattern of rod antenna helped in understanding the phenomenon of null direction propagation of HF radiations using sky wave mode. The fabrication and trials of the block made helped in eliminating the unintentional emission of radiation and also prevents loss of information. The future study may result in eliminating the skip zone thereby increasing the range of tactical communication over HF thus helping in enhancing the range. Moreover now it is known to the communicator fraternity that sky wave and ground wave antennas can co work at extended ranges. The same can be utilized articulately during planning and design of communication systems. More studies can be done to reduce the size of the block achieving the same blocking efficiency. Also diverting the null direction radiation into main lobe thereby increasing the output of the antenna can be other field to work on.

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