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Design of a Wide-Band Blade Monopole Antenna in 135–175 MHz Band

Bandhakavi S. Deepak[1, *], Khumanthem Takeshore[2], Panakala R. Kumar[1], and Chandana Sairam[2]

Abstract—This paper presents the design of a wideband blade shaped monopole antenna with a horizontally mounted aluminium tube on top of the blade covering 135–175 MHz frequency band using Electromagnetic Simulation software (CST Microwave Studio^{TM}) along with a matching network whose characteristics have been evaluated by the Optimal Matching Network Identifier (OMNI) algorithm. OMNI algorithm is a search technique used in computing, to find the optimum solution. The conventional quarter wavelength monopole antenna is a narrow band antenna with bandwidth of the order of 5% to 10% at its centre frequency. In order to increase the bandwidth of the antenna, a proper matching network has been incorporated along with it. Toroidal inductor based matching networks have been designed, and their characteristics are evaluated using Optimal Matching Network Identifier (OMNI) program in MATLAB software. By consolidating MATLAB and CST simulated results, the antenna prototype along with the optimal matching network has been practically implemented, and corresponding results have been verified. The details of simulated and measured results are also included. The proposed antenna finds numerous applications in various wideband communication systems.

1. INTRODUCTION

Most of the modern day communication systems demand wideband antennas for almost all applications. However, traditional monopole [1] and dipole antennas are narrow band antennas by nature, and they only offer bandwidths of the order of 5% to 10% at their centre frequencies. Using an efficient wideband matching network [2–6] the narrow band antenna can be converted to a wideband antenna. For this to happen, the main parameters such as antenna input impedance (Z_a), characteristic impedance (Z_0), matching network impedance (Z_m), reflection coefficient (Γ) and the voltage standing wave ratio (VSWR) should be characterised. By using these parameters and their mutual relations, the VSWRs can be calculated over the frequency bandwidths of interest. All those antenna matching configurations for which the VSWR is within the required specification are segregated. Later the efficiencies of these configurations are calculated in the form of antenna gains. Then the matching configuration which provides better gain is chosen and finally implemented with the antenna. Depending upon the required band of frequencies for operation, the characteristics of matching networks gets changed. The changes in matching networks may be in terms of network elements, network topology, type of elements used, type of combination (parallel or series), etc. The design of these matching networks and evaluation of their characteristics can be done in the MATLAB software [7–10]. For identifying the optimum matching network for the antenna to operate in the desired frequency band, the *Optimal Matching Network Identifier* program is written in MATLAB software.

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* Corresponding author: Bandhakavi Srikanth Deepak (deepak.bsd@gmail.com).
[1] Prasad V. Potluri Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh 520007, India. [2] Defence Electronics Research Laboratory (DLRL), Hyderabad, Telangana 500005, India.

The proposed wideband antenna is designed envisaging its application for aircraft communication. Since the body of an aircraft is metallic, monopole topology finds suitable for this application and the aircraft's body itself acts as its ground plane. Moreover, to reduce the air drag, the antenna is printed on thin FR4 substrate resembling a blade shaped structure. An aluminium tube is placed horizontally on top of the antenna as capacitive loading. This will ensure lesser air drag as well as better matching and efficiency of the antenna. Hence, a monopole antenna with the above mentioned shape is designed in the CST Microwave Studio, and its characteristics are optimised.

2. DESIGN FEATURES

The CST design model of blade monopole antenna [12–18] along with the matching network, operating in 135–175 MHz band is shown in Fig. 1. The antenna ground plane is a circular aluminium plane of 1.2 metres diameter. The blade portion of the antenna constitutes a pentagon shaped copper plate of dimensions 15 cm × 6 cm (length × width) fabricated on a thin FR4 substrate of dimensions 15 cm × 8.4 cm (length × width), and the radius of the horizontally mounted aluminium tube is 19 mm with a tube length of 30 cm.

After completion of the design of blade monopole antenna with the above mentioned specifications, the antenna is first simulated to obtain the antenna input impedance data and then subjected to co-simulation process with the matching network S-parameter data (imported as touchstone files from the VNA) in the CST software. The simulation process has been carried out for the blade monopole antenna with and without the aluminium tube on top of the blade. The simulation results proved that the contribution of the horizontal radiating element (aluminium tube) has been most significant in the design of this particular antenna w.r.t the antenna gain, radiation pattern and voltage standing wave ratio (VSWR).

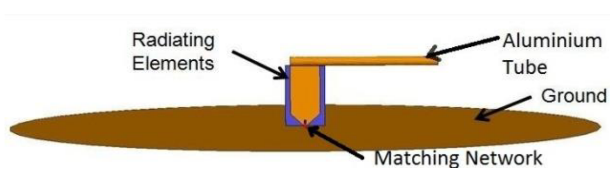

Figure 1. CST design model of blade monopole antenna along with the matching network operating in 135–175 MHz band.

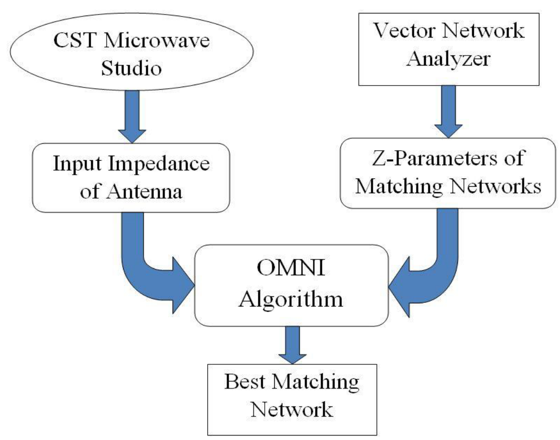

Figure 2. Extraction flow of best matching network using OMNI algorithm.

In order to find the best matching network for the proposed antenna to operate in the desired frequency (135–175 MHz) band, initially the input impedance data of the antenna is extracted through the CST Microwave Studio, and the Z-parameter data of all the requisite matching networks (i.e., ring shaped toroidal ferrite core inductor combinations) are extracted through the vector network analyzer (VNA) as shown in Fig. 2. Later, by using them in OMNI algorithm, the best matching network for the antenna is identified.

3. ALGORITHM

For transforming a narrow band antenna into a broad band antenna [11], a proper matching network is required. Depending on the operating frequency bandwidth, the characteristics of the matching network to be incorporated with the antenna differs. There are various matching networks which uses lumped elements such as resistors, inductors and capacitors or ferrite core inductors of different shapes with distinct combinations (series/parallel) that too with different topologies.

There are many complex algorithms and optimizing tools for predicting the elements of matching network and to give the best combination. However, for evaluating a group of matching networks of different combinations and topologies, those algorithms need complex programming along with the conversion codes from analog to digital and vice versa. Also, those algorithms work on probability

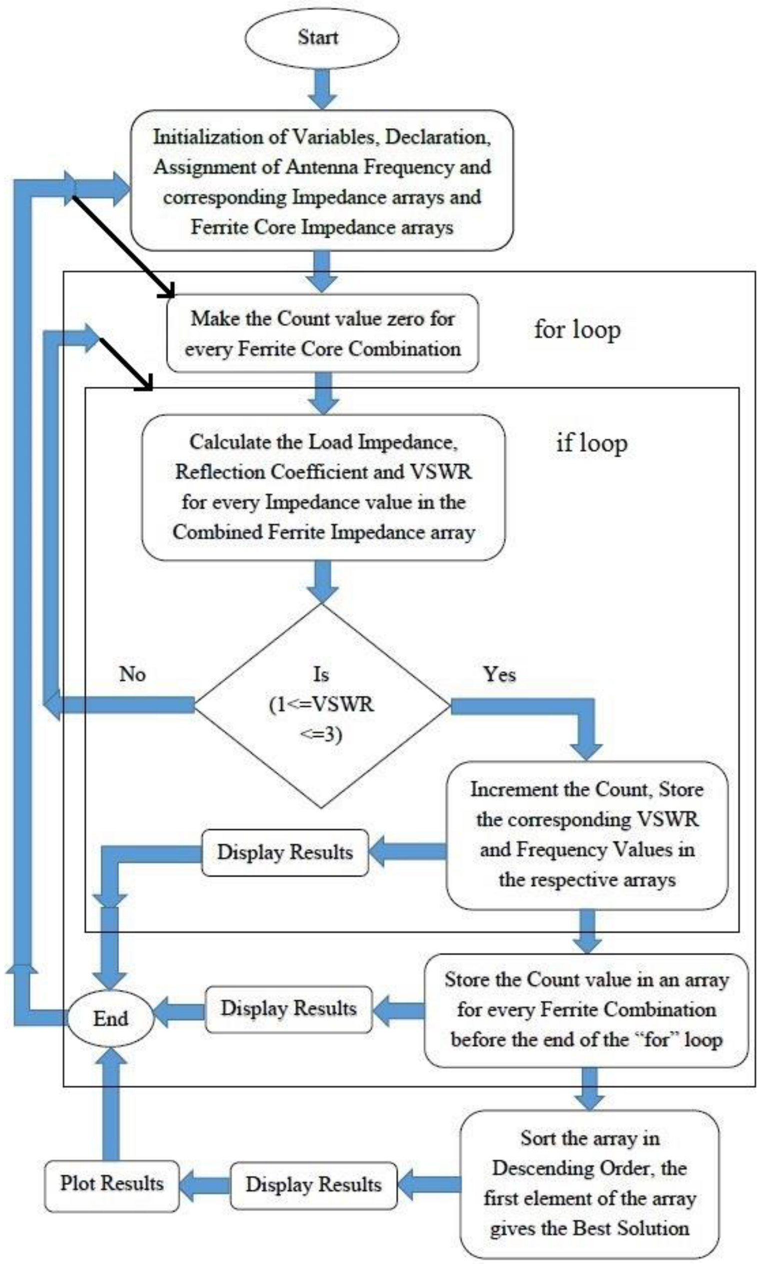

Figure 3. Optimal matching network identifier (OMNI) operational flow chart.

and random processing theme. For these reasons, there is a need for designing an efficient, simple and faster computing algorithm that can evaluate the parameters of all the possible matching networks which comes under the pool of operating frequency band, of the selected antenna and produce the best of networks that will properly match the input impedances of the antenna. The proposed Optimal Matching Network Identifier (OMNI) algorithm maps this requirement quite closely. The operational flowchart for OMNI is shown in Fig. 3, which has been implemented in the MATLAB software.

This OMNI algorithm does not require any conversion codes and does not rely on the concept of random processing too, unlike the optimizing tools. The most important characteristic of this particular algorithm is that once all the required matching networks are designed, i.e., coded in MATLAB, then it evaluates all those networks sequentially by using the *Function Call* mechanism, and eventually with

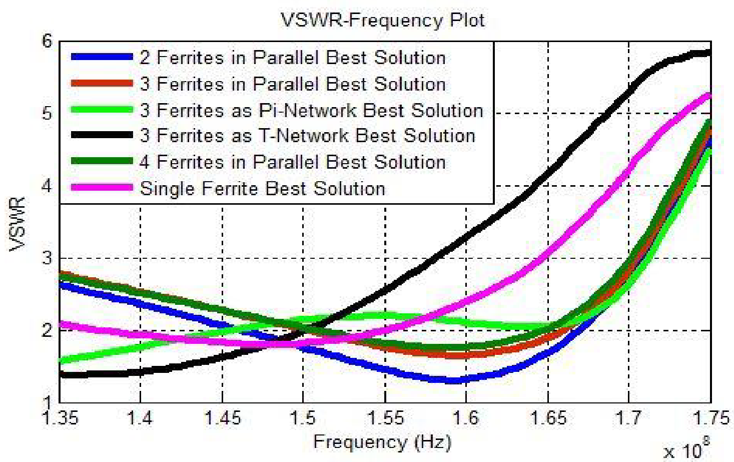

Figure 4. The combined VSWR-Frequency plot showing the VSWR plots of best solutions for different matching networks (of toroidal ferrite cores of different permeabilities) over the entire bandwidth required (135–175 MHz).

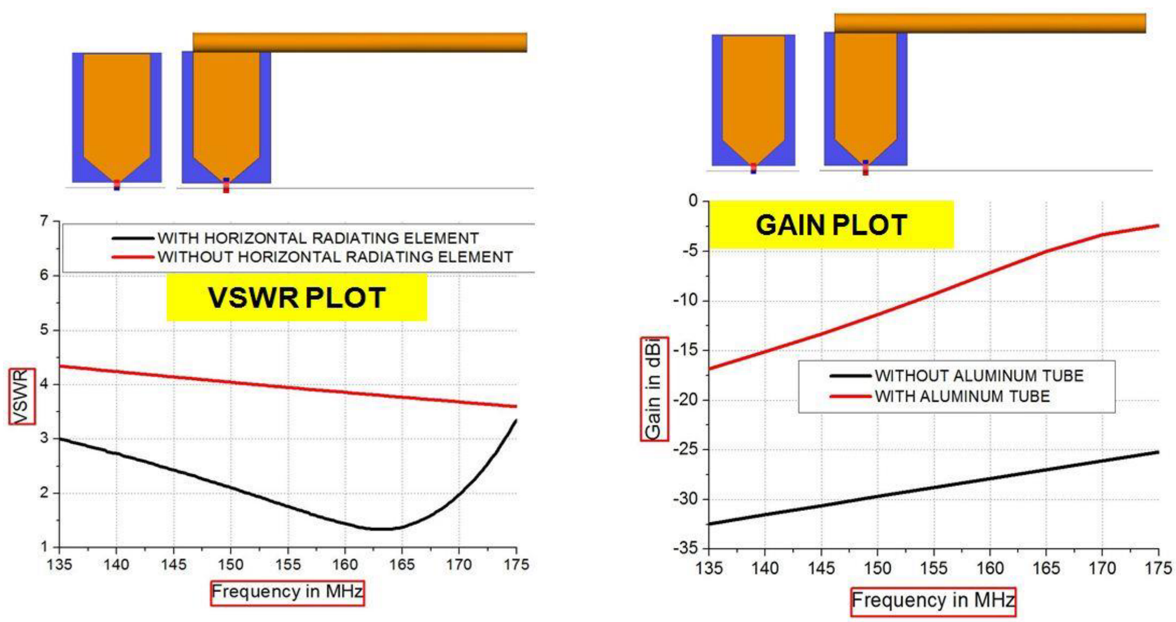

Figure 5. CST simulated VSWR and gain plots for blade monopole antenna along with the matching network with and without the horizontal radiating element.

simple manual support at the code execution stage, it produces the best matching network for the operating frequency band with the help of combined VSWR-Frequency plot. The combined VSWR-Frequency plot is a collaboration of the VSWR plots of the best solutions among all combinations of considered network topologies over the entire operating band of frequencies as shown in Fig. 4. Thus, it becomes very easy to pick the best possible matching network combination that covers the desired bandwidth approximately.

4. RESULTS AND DISCUSSION

The simulated results for the proposed blade monopole antenna with and without the horizontal radiating element are shown above.

From Fig. 5 it is clear that the blade monopole antenna with horizontal radiating element (Al tube) has better impedance matching and gain. The Al tube acts as capacitive top hat loading and thereby increasing the effective height of the antenna. Gain improvement of 20 dB is seen with horizontal radiating element over the entire frequency band.

As the aluminium tube has been placed horizontally over the blade, there exist two prominent polarizations. One is the vertical polarization due to the blade part of the monopole antenna (as the feed is aligned vertically), and the other is the horizontal polarization due to the horizontal radiating element. The co- and cross-polarization patterns (in both elevation and azimuthal planes) for blade monopole antenna with and without horizontal radiating element at the centre frequency (155 MHz) are shown in Fig. 6 and Fig. 7. From the figures it is observed that the cross-polarization level is more in antenna with horizontal radiating element. As long as the receiver sensitivity is well above the noise floor, this will give no threat to the communication system.

The practically fabricated antenna along with the ground plane is shown in Fig. 8. After implementing the antenna practically, it is tested in the open air ground reflection test range for evaluating the radiation patterns both in elevation and azimuthal planes. The measured radiation

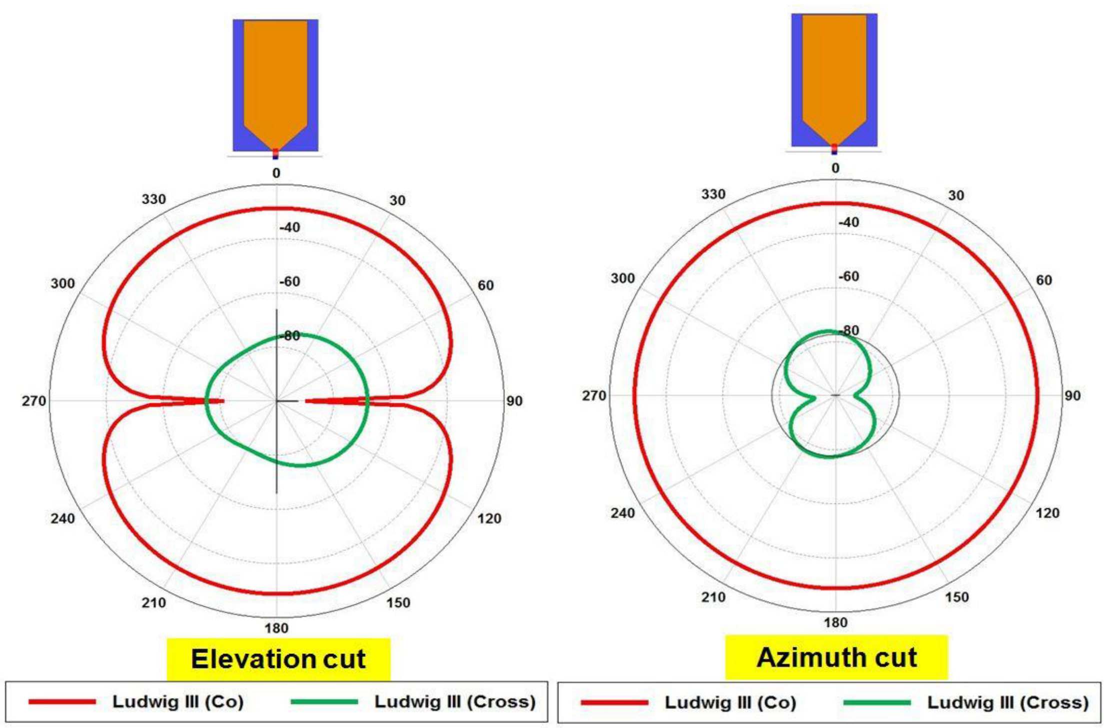

Figure 6. Elevation and azimuth cuts of co and cross patterns of blade monopole antenna without horizontal radiating element at the centre frequency (155 MHz).

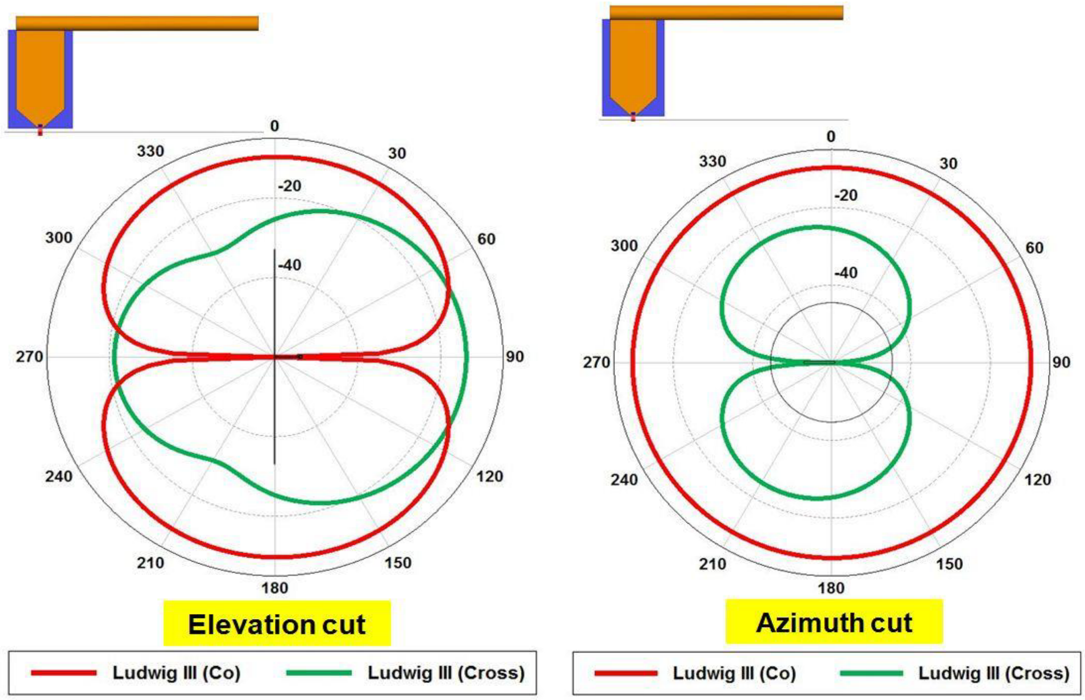

Figure 7. Elevation and azimuth cuts of co and cross patterns of blade monopole antenna with horizontal radiating element at the centre frequency (155 MHz).

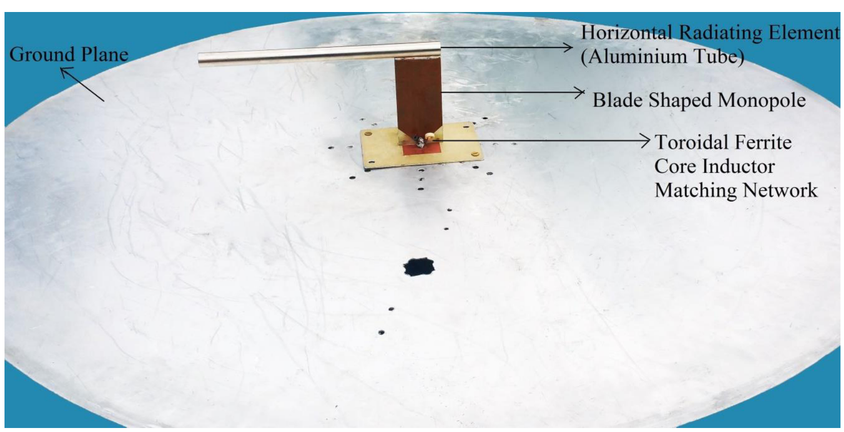

Figure 8. Practically fabricated antenna along with the ground plane.

patterns (in both elevation and azimuthal planes) for the proposed antenna at 135 MHz, 155 MHz and 175 MHz frequencies are shown in Fig. 9.

Finally, the antenna will be placed inside a Radome made of single layered monolithic fibre glass of 2 mm thickness. Since the operating frequencies of the proposed antenna are in the VHF band, the presence of Radome will show no effect to the overall characteristics of the antenna.

The comparisons of simulated and measured VSWRs and gains are shown in Fig. 10, and there is a good agreement.

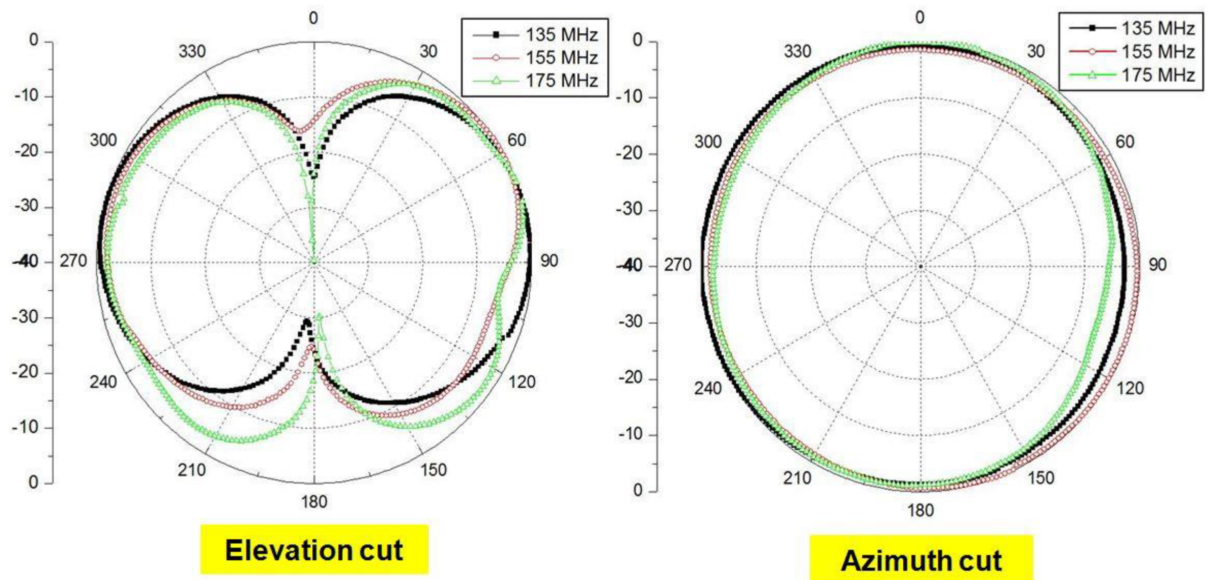

Figure 9. Measured radiation pattern of blade monopole antenna in elevation and azimuthal planes.

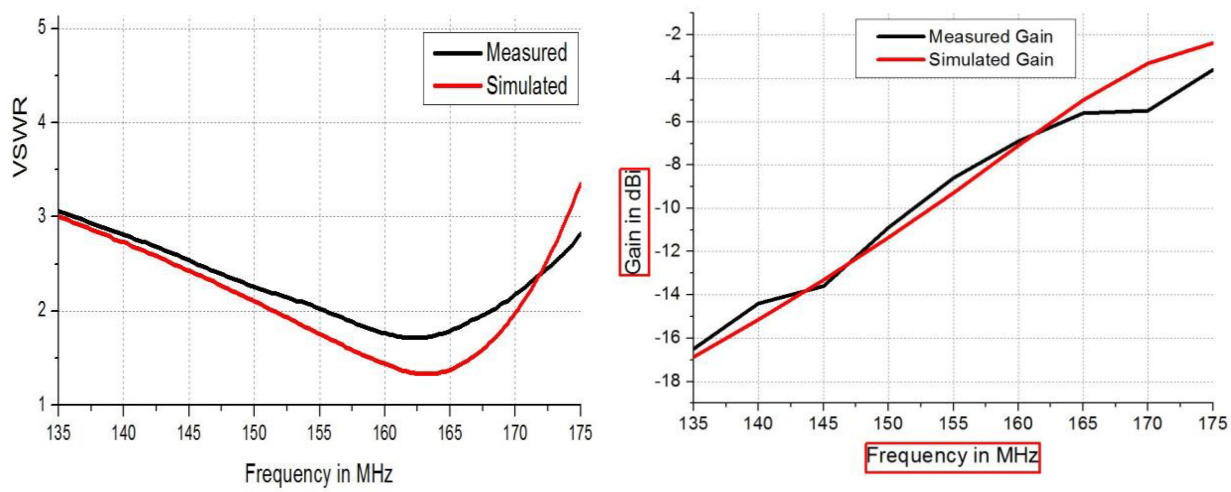

Figure 10. Comparison of simulated and measured VSWR and gain plots.

5. CONCLUSION

The optimal matching network identifier (OMNI) algorithm MATLAB program has been developed, which identifies and brings out the best matching network combination out of a large pool of toroidal ferrite core inductor matching network combinations (of different permeabilities), for the blade monopole antenna (designed in CST) to operate in the desired band of frequencies. Both MATLAB and CST simulated results have been consolidated, and then the best matching network combination is practically implemented along with the antenna, to operate in the desired frequency band. Also, the contribution of the horizontal radiating element present on top of the blade portion of the proposed monopole antenna has been discussed, and the corresponding results are verified. One of the most important applications of the proposed blade monopole antenna is in aircraft, as it offers resistance to the air drag, and at the same time, the aircraft's body acts as ground plane for the antenna.

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