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Design and Optimization of Genetic Algorithm (GA) based High Gain and Directive CPW-Fed Slot Dipole Antenna for Wideband Applications

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Abstract*: Genetic Algorithm (GA) is proposed in this paper for the design of a wide bandwidth, high gain and directive CPW-fed slot-dipole antenna. The proposed antenna is built on a FR4 substrate that is cheap and easy to produce. Genetic Algorithm is used to select parameters that reflect antenna geometry to achieve wider bandwidth and reduced return loss (parameter S11) and high gain values at resonant frequency. The antenna design shows a wide operating bandwidth of 1.4 GHz (simulated) and 1.3 GHz (measured) over the X-band, a return loss (S11) of -25.83 dB (simulated) and -23.08 (measured) and a gain and directivity of 5.61 dB (simulated) and 11.87 dB (simulated) at 10.5 GHz resonating frequencies. In this work, all simulations were performed using the ANSYS HFSS v14.0 software. A prototype antenna was produced and then characterized using VNA to validate the design. Measurement results were in good agreement with the results simulated using ANSYS HFSS.

Keywords :Antenna Optimization, CPW-fed Slot Dipole Antenna, Genetic Algorithm, High Gain, High Directivity Antenna.

I. INTRODUCTION

Many successful wireless communication applications are expected from microstrip antennas due to its attractive low profile, lightweight, fast manufacturing and strong circuit integration capabilities [1]. Because of their excellent electrical and mechanical properties, compatibility with other RF systems [2], printed patch antennas are suitable for wide-band applications. However, the standard microstrip patch antennas have very small operating bandwidth. There have been several attempts to deal with this problem to a certain degree such as the use of a dielectric high-permit substrates [3], the use of defective ground structures (DGS) [4], or combining several substrates [5], addition of air gaps and shorting of pins [6], use of metamaterials [7], addition of slots on patches [8], use of modified patches are used instead of conventional shapes [9], use of various optimization algorithms e.g. PSO [10] and creating complex patch structures using GA [11], or using slot dipole CPW-fed antenna design [12]. High impedance bandwidth (S11 < 10 dB), flat gain response over the radiating bandwidth are the major challenges for an efficient wideband antenna. In all weather conditions, including fog, sandstorm and other difficult condition, X-band has exceptionally high connectivity. X-band supports voice, information, images and HD video communication.In this paper, a modified CPW-fed slot dipole is optimized to achieve high gain, bandwidth and minimum return losses.

This paper is made up of four sections. Section II presents the steps followed in GA optimization, antenna design and fabrication. Section III discussed the performance of slot-dipole antenna using the simulated and measured results. Section IV, finally, summarizes the paper.

II. OPTIMIZATION, DESIGN AND FABRICATION OF CPW-FED SLOT DIPOLE ANTENNA

The antenna proposed is in X-band of super high frequency to radiate at a resonating frequency of 10.5 GHz. The main design objective was to achieve minimum values of S11 at resonating frequency, to have a minimum bandwidth of 500 MHz and to achieve minimum gain of 5dB at resonating frequency. A simple Genetic Algorithm (GA) based optimization is utilized to achieve the design objectives.MATLAB is integrated with HFSS environment to implement GA algorithm code. Figure 1 is the flow-chart representation of Genetic Algorithm (GA) optimizer [11]. Table 1 addresses selection of Genetic Algorithm parameters for optimization e.g. population type and size, number of generations, selection criteria, etc. Figure 3 displays the corresponding converged antenna using GA. Proposed design is simulated and characterized on FR4 substrate, as it is inexpensive and easier in fabrication. The FR4 substrate has a height of 1.6 mm, a dielectric constant of 4.3 and a tangent loss of 0.02.

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Table 2 describes the overall dimension of the antenna as well as all simulated and calculated performance. Equations (1-5) shows the cost function utilized for the purpose of optimization and Figure 2 demonstrates the convergence rate for the Genetic Algorithm (GA) based optimization technique.

$$Cost = \left[-(3 * Gain) - (20 * BW) + S_{11(Res)}\right] \qquad \text{Eq 1.}$$

$$Gain = \begin{cases} 10\ dB; & for\ Gain_{Cal} \geq 10\ dB \\ Gain_{Cal}; & for\ Gain_{Cal} < 10\ dB \end{cases} \qquad \text{Eq 2.}$$

$$BW = \begin{cases} 1.5\ GHz; & for\ BW_{Cal} \geq 1.5\ Ghz \\ BW_{Cal}; & for\ BW_{Cal} < 1.5\ Ghz \end{cases} \qquad \text{Eq 3.}$$

$$BW_{Cal} = f_H - f_L \qquad \text{Eq 4.}$$

$$S_{11(Res)} = \begin{cases} -30\ dB; & for\ S_{11} \leq -30\ dB \\ S_{11}; & for\ S_{11} > -30\ dB \end{cases} \qquad \text{Eq 5.}$$

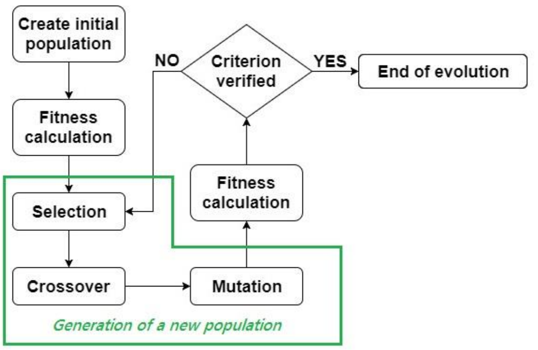

Fig. 1: Flow chart representation of Genetic Algorithm (GA) optimizer [11].

Table 1: Selection of Genetic Algorithm parameters for optimization

Parameters	Selected Values
Population Type	Bit String
No. of decision variables (in Bit)	34
Total number of Generations and Population Size	200
Scaling Basis	Rank
Selection Criteria	Roulette
Reproduction Elite Count	2
Mutation	Uniform (0.01)
Crossover and its fraction	Single Point Crossover (0.8)
Penalty factor and Initial Penalty	100 and 10

Table 2: Parameters of Converged Antenna

Antenna Parameters	Values
Resonating Frequency (Band of Operation)	10.5 GHz (X-Band)
Reflection Coefficient (S_{11})	-25.83 dB (Sim) and -23.08 (Meas.)
Bandwidth	1.4 GHz (Sim) and 1.3 GHz (Meas.)
Gain at Resonating Frequency	5.61 dB (Sim)
Directivity at Resonating Frequency	11.87 dB (Sim)
Antenna Dimensions	102 x 98 x 1.58 mm^3
Substrate Material	FR4 (Thickness 1.58 mm)

The antenna simulation is carried out with the ANSYS HFSS v14.0. Mechanical etching with CAD assistance is done for the manufacturing of the antenna. Return losses (S11) and bandwidth of the manufactured antenna is characterized using VNA. Figure 3 displays the antenna dimensions and the manufactured antenna. Figure 4 displays the simulated vs. measured return losses (S11) of the converged antenna prototype.

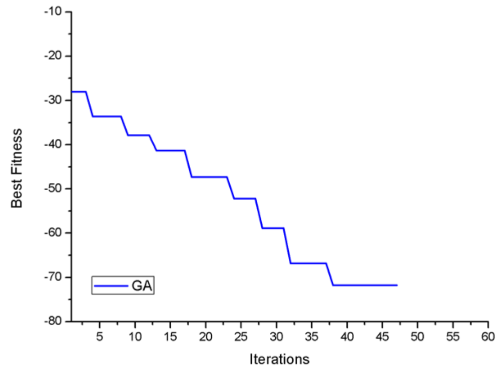

Fig. 2: Rate of convergence

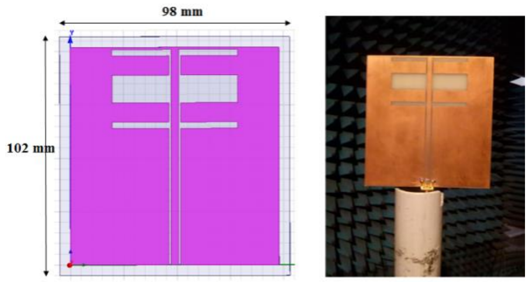

Fig. 3: (A) Proposed antenna with dimensions (B) Manufactured antenna

III. RESULTS AND DISCUSSION

The proposed antenna shows -25.83 dB (simulated values) and -23.08 (measured values) of S11 at the resonant frequency of 10.5 GHz. The proposed antenna shows 1.4 GHz (simulated values) and 1.3 GHz (measured values) of bandwidth.

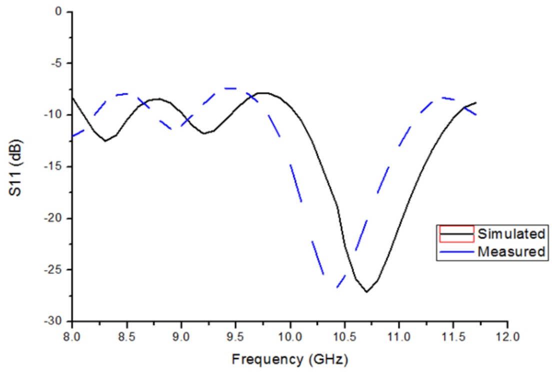

Fig. 4: Plot of measured vs. simulated return losses (S11) of the converged antenna design.

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Figures 5 and 6 show two and three dimensional (2D and 3D) radiation patterns. The 2D plots in Figure 5 shows the E-Plane, H-plane, Co and Cross polarization plots at 10.5 GHz resonant frequency.

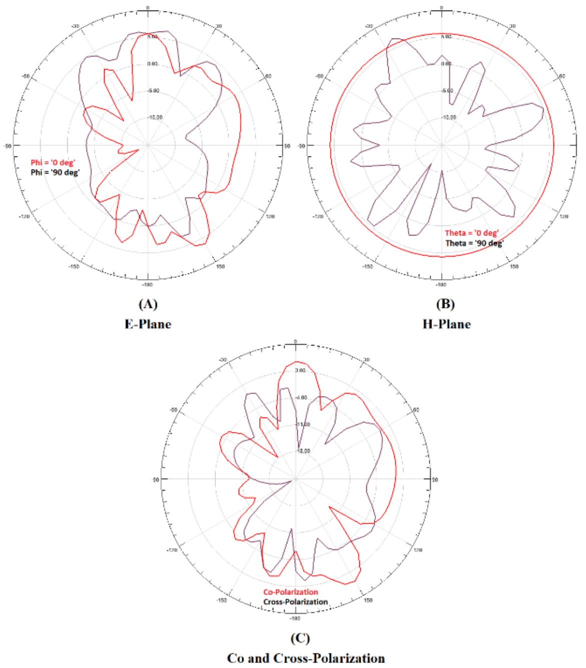

Fig. 5: Simulated Radiation Patterns at resonant frequency of 10.5 GHz - (A) E-Plane, (B) H-Plane, (C) Co and Cross-polarization

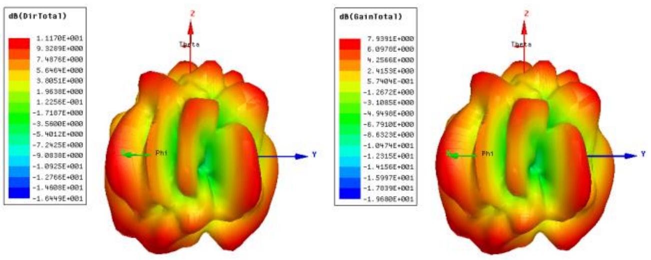

Fig. 6: Simulated values of 3D Radiation Pattern at resonant frequency of 10.5 GHz

A plot of gain and directivity with respect to the bandwidth of the antenna is presented in Figure 7. At the resonant frequency of 10.5 GHz, proposed antenna exhibits higher values of simulated gain and directivity (5.61 dB and 11.87 dB respectively).

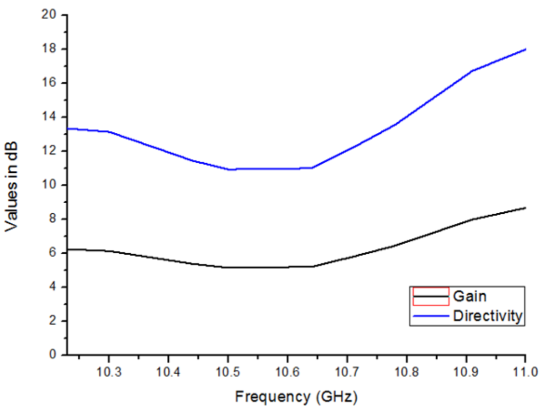

Fig. 7: Simulated values of directivity vs. gain of the converged antenna design

IV. CONCLUSION

The discussion in this paper incorporates genetic algorithm to optimize the design of a high gain X-band CPW-fed slot-dipole antenna. The antenna is built on an inexpensive and easy to produce FR4 substratum. The proposed antenna design has a wide operating bandwidth of 1.4 GHz (simulated) and 1.3 GHz (measured) over the X-band, a return loss (S11) of -25.83 dB (simulated) and -23.08 (measured) and a resonating frequency gain and directivity of 5.61 dB (simulated) and 11.87 dB (simulated) at 10.5 GHz. The simulations and the results measured are in good agreement.

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