Review on Rectangular Microstrip Antenna Optimization for Mm-Wave Applications

Omer A. H.[1], Dr.Elessaid S. S.[2], Dr. Ahmed A. A.[3]

[1] *Department of Electrical and Electronic Engineering, Faculty of Engineering, ELdeain University, Sudan*
[2] *Department of Electrical and computer Engineering, Faculty of Engineering, Karary University, Sudan*
[3] *Department of Electrical and computer Engineering, Faculty of Engineering, Karary University, Sudan*

Abstract: *Milli-metric bandwidth (above 6 GHz) is the candidate frequency band for 5G applications due to high speed and in order to miniaturization of communication systems. Here, we provide an overview of some recent research advancement of millimeter wave microstrip antenna design and optimization methods.*
Keywords*: Microstrip Antenna, Mm-wave, Neural Network (ANN), Genetic Algorithms (GA).*

I.   Introduction

Microstrip Patch Antenna is suitable to use for miniaturization of the devices due to its low profile. However, it has some disadvantages like narrow bandwidth and low gain, which make it great challenge to use this antenna with the technology of 5th generation of mobile communications.

II.   Methodology

The essential parameters for designing rectangular microstrip antenna element are: the resonant frequency (f_r), relative dielectric constant (ε_r), and substrate height (h), which are using to evaluate the width (W) and length (L) of rectangular patch. The performance of the rectangular patch can be obtained by using computer aided design (CAD) systems.

III.   Review and Discussion

Various efforts have been made by researchers for the advancement of the design process of microstrip patch antenna. Many of that works have been focused in the direction of enhancing the performance of patch antenna in order to use it at the mm-wave frequencies and reducing the operational disadvantages and side lobe level.

A multiband 9-shabed microstrip patch antenna using epoxy substrate has been designed, simulated, and optimized to meet the best possible result using two simulation software: HFSS (High Frequency Structure Simulator) software and CST Microwave Studio Software. The performance of the designed antenna was analyzed in term of bandwidth, gain, return loss, VSWR, and radiation pattern [1].

An investigation of a rectangular patch antenna arrays fed by microstrip and coaxial lines at 28 GHz for future 5G applications. A 4-element antenna array with a bandwidth higher than 1 GHz and a maximum radiation gain was proposed. The performances of the rectangular 4*1 and 2*2 patch antenna arrays designed on Rogers RT/Duroid 5880 substrate were optimized and the simulation results reveal that the performance of 4*1 antenna array fed by microstrip line is better than 2*2 antenna array fed by coaxial cable [2].

A compact size dual bands patch antenna for the next generation 5G devices was proposed to operate at 10.15 GHz and 28 GHz which are two of the candidate frequencies for the 5G mobile communications. The proposed design provides a gain of 5.51 dB at 10.15 GHz and 8.03 dB at 28 GHz and a directional the radiation pattern. The antenna was designed on Rogers5880 substrate with a thickness of 0.787mm [3].

There is a contribution present a two practical implementation cases of single patch antenna at 28 GHz and 60 GHz describe the design challenge of conciliating the antenna performance specifications and fabrication restrictions [4].

A multiple input multiple output (MIMO) 4 antenna linear array operating at 28 GHz, 37 GHz, 41 GHz and 74 GHz bands for 5G mobile communication is presented. The antenna is designed based on the resonant cavity model and the dominant mode of (0,1,1) which has maximum field distribution TE_{011} at the edge of the patch. Multiband operation is achieved by introducing slits and slot on the patch were the magnetic field is maximum when the patch is considered as resonant cavity. The antenna is fed by microstrip transmission line and impedance matching between patch and feed line is achieved through inset feed techniques [5].

A low profile microstrip patch antenna was presented for using for next generation (5G) devices. The proposed antenna has compact structure of 20mmX20mmX1.6mm including the ground plane, which is suitable to be used in handheld devices. The antenna resonates at 10.15 GHz covering 5G frequency band. The proposed design provides a gain of 4.46 dBi and the radiation pattern is omni-directional [6].

A comparative analysis of various designs was presented with design considerations for compact antennas and antennas in package/on chip, mostly in the 60 GHz band [7].

A square shape patch antenna is proposed to obtain large bandwidth with compact ground plane for wireless applications. The proposed antenna is designed using dielectric material of FR4 having height of 1.6mm and having dielectric constant of 4.4. The proposed design achieved bandwidth from 2.33 GHz to 12.4 GHz with radiation efficiency more than 90% in ultra-wideband range. This antenna covers the range of ultra-wideband from 3.1 GHz to 10.6 GHz, the range of local area network, wide area network, and also covers the range of satellite communications [8].

MIMO (Multiple-Input Multiple-Output) technology is expected to be one of the key technologies in the field of 5G wireless communications. A 4 pairs of microstrip MIMO conformal antennas of 35 GHz have been designed. 8 elements microstrip Taylor antenna array with series – feeding not only achieves the deviation of the main lobe of the pattern but also increases the bandwidth of the antenna array and reduces sidelobe. MIMO antennas have been fabricated and measured. Measurement results match the simulation results well. The return loss of the antenna at 35 GHz is better than 20 dB, the first sidelobe level is 16 dB, and the angle between the main lobe and the plane of array is 60° [9].

A low profile microstrip antenna was presented for next generation 5G devices. The proposed antenna has compact structure of 5.5mmX4.5mmX0.4mm including the ground plane. The antenna resonates at 28 GHz covering the 5G frequency band. The proposed design provides a gain of 2.87 dB and radiation pattern is omni – directional [10].

A 28 – GHz U – slot array antenna for wideband communication system is proposed. The U –slot patch antenna structure consists of patch, two U – shaped slot, and ground plane. With the additional U – slot, the proposed antenna has around 10% of bandwidth at 10 dB. To increase gain, the U – slot antenna is arrayed to 2X2. The proposed antenna was measured and compared with the simulation results to prove the reliability of the design [11].

Teaching Learning Optimization algorithm is applied in order to design a dual band E shaped patch antenna. The geometrical parameters of the aperture – coupled antenna are the inputs of the optimization algorithm. Solutions achieving simultaneously S_{11} minimization and low VSWR at the frequencies of interest (25 GHz and 37 GHz) [12].

Three different configurations of patch array antennas are designed to investigate their radiation pattern with different orientation and excitation phase at 28 GHz for 5G applications. All antennas are fed by inset feed line. The excitation phases are changed to study the radiation pattern of each array antenna with different orientations. Simulated and measured S_{11} ,S_{12} and simulated radiation patterns are presented. The simulated result showed that the designed antennas are able to be operate at 28 GHz [13]

A design and development of a new broadband planar slot antenna for 5G wireless communication applications. The proposed antenna is suitable to operate at 8.5 GHz with return loss less than 10 dB. To develop this structure we have conduct a design based on the microstrip line combined with a slot technique and a modified geometry antenna in order to enlarge the bandwidth and adopt the impedance thus minimizing distortion in order to avoid high crosstalk and radiation. The proposed antennas have been designed, optimized, miniaturized and simulated by using Momentum software integrated into ADS. To validate the ADS results before the antenna achievement, we have conducted another study by using CADFEKO. The prototype of the antenna was achieved, measured and tested. [14]

Design and optimization of 2X4 microstrip antenna array within the millimeter wave range at the frequency of 26 GHz was presented. A tripolar metamaterial structure was designed and adds to this antenna array. The goal was to increase the bandwidth in comparison to the results reached for regular antenna array geometry without metamaterial. [15]

IV. Optimizations Methods

Neural Networks Optimization (ANN)
Neural network or artificial neural network is an information processing system or a computing system which consists of highly interconnected processing elements called as neurons working in parallel to solve particular problems [17]. It is inspired from the biological brain system's capability to recognize and perceive for processing information.

Implementation

ANNs are used for both analysis and design of microstrip patch antenna. On analysis, it uses for calculation of resonant frequency, bandwidth and input impedance. On design, it can use for finding the patch size of some regular shapes for specific operating frequency. The paradigm of application for design of a square patch antenna is shown in figure (1). In this design, the resonant frequency in the dominant mode is given, ε_r and h are supplied and l is calculated. The Wolf-Knoooik formula [18] is used to find the resonant frequency of the square patch antenna for different input parameters (ε_r, h and l) in specified ranges. The generated data were arranging in two matrices. A three-column matrix containing the values of ε_r, h and f_r is used as the input training data for the network, the other one column matrix containing the corresponding values of l is used as the output training data for the network.[16]
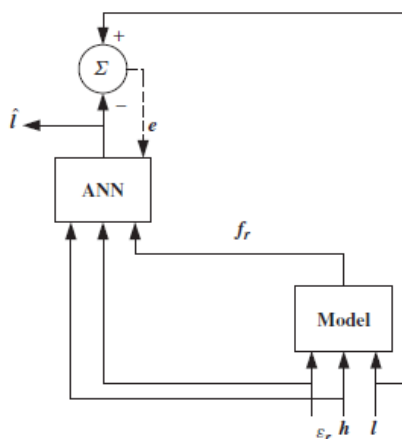

Figure (1): Calculation Paradigm of Design of Square Patch

Disadvantages
1. Time required to generate sufficient training, validation and testing samples.
2. Unreliability of the optimal solution when it lies outside the training region.
3. The number of learning samples needed to approximate a function grows exponentially with the ratio between the dimensionality and its degree of smoothness.

Genetic Algorithms Optimization (GA)

Genetic algorithm is an optimization procedure based on genetic inheritance and natural selection. Basic concept of optimization is based on evolution and concept of survival of the fittest. GA is inspired by Darwin's theory of natural evolution. According to Darwin's theory, the well-suited organism survives in the natural world and poorly suited organism dies off. The algorithm starts by generating the population randomly. Population is set of initial solutions. Then, the algorithm includes three operators such as selection, crossover and mutation.[17]

Implementation

GA is used for optimizing microstrip patch antennas. One of the goals of using GA is to find optima patch size which gives wide patch bandwidth. For example, applying GA to a rectangular patch element for circular polarization at 10 GHz. A diagram of the patch antenna is shown in figure (2). [16]
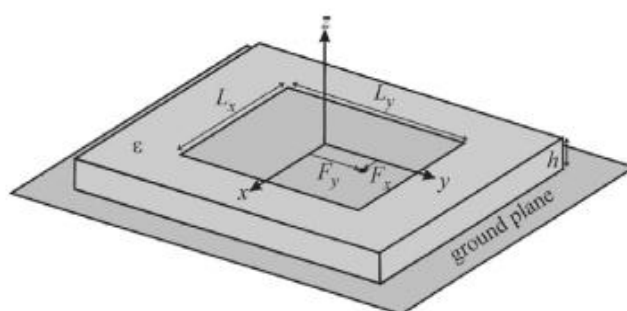

Figure (2): Diagram of Probe-fed Microstrip antenna

The cost function is calculate using the method of moment and returns the following values:

$$cost = max\left\{ \frac{\left| |E_\theta| - |E_\varphi| \right|}{|E_\theta| + |E_\varphi|}, \left| |\angle E_\theta - \angle E_\varphi| - \frac{\pi}{2} \right|, |S_{11}| \right\} \quad (1)$$

An infinite ground plane and dielectric were assumed in the model. The first two term in Equ. (1) are zero for circular polarization and $|S_{11}|$ is zero for a perfect match at 50□, thus: $cost = 0$.

V. Conclusion

Rectangular microstrip antenna can be optimized to work at mm-wave frequency band by using the techniques:

- Selecting a proper substrate material, considering its main critical properties such as dielectric constant, thickness of substrate and loss tangent. In order to enhance the bandwidth and the gain of a single patch element.
- Using optimization techniques, which called Evolutionary Optimization such as Neural Network (NN) and Genetic Algorithm (GA), in order to find the optimal patch element size and optimal positions of elements in the array to find a good trade-off solution for the challenge of mutual coupling between array elements.

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