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Analysis and Design of Microstrip Array for Radar Applications

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Abstract: In aircraft and satellite applications, where size, weight, cost, performance, ease of installation and aerodynamic profile are major constraints, a microstrip antenna which has low profile can be used because it meets the above requirements more than a conventional antenna. The main aim of this paper is to analyze and design a rectangular microstrip antenna with specific parameters like length, width, height of the patch, and dielectric constant of the substrate using MATLABR2014b and labVIEW software's and is extended to an array of microstrip elements. The microstrip antennas are being used broadly in various radar applications such as GPS (Satellite Navigational System) technology, mobile satellite communications, the Direct Broadcast Satellite (DBS) system, remote sensing, air traffic control and also in military applications for target detection, target tracking and weapon control. The usage of the microstrip antennas is spreading widely in all the fields and areas and now they are booming in almost all commercial aspects.

Keywords: Antenna, Rectangular patch, Microstrip array.

I. INTRODUCTION

In recent years, microstrip antennas have been widely used. To overcome the shortcoming of size, weight, cost and performance of a conventional antenna, a microstrip antenna, which has a low profile, has been designed and the radiation pattern of elements and arrays are demonstrated [1]-[2]. A microstrip patch antenna was invented by Bob Munson in 1972, but earlier work was done by Dechamps in 1953 [3]. The design of array elements involves outlining of rectangular microstrip patch antennas that operate at required frequency. This paper presents recognized formulas that describe the operation of rectangular microstrip patch antennas [4]. Several articles were proposed for obtaining the radiation pattern of E- and H-planes [5]-[7].

The main objective of this present work is to design and analyze the microstrip element for E- and H-plane radiation patterns and also the work is extended with increasing the number of elements for the array of microstrip antenna using labVIEW software.LabVIEW is a very simple and most powerful global optimizer and has been successfully applied for the design of microstrip antenna and also in other areas of applied electromagnetic problems and radar applications.

The proposed method is useful for finding the optimal solution of a given depicted problem. The efficiency and accuracy of this technique are demonstrated by making comparisons with the obtained results of MATLAB. The simulation results observed in labVIEW are faster and compatible than MATLAB. With the help of labVIEW, we can slow down the execution and see the dataflow in our result, or we can use common tools such as break points and data probes through our program node-by-node. The time required for tracking down bugs is reduced.

A microstrip patch antenna is the most commonly used antenna amongst all other antennas used for radar applications. Low fabrication cost, easy to manufacture and easy integration with microwave integration circuits are the primary advantages of microstrip patch antennas. They are mostly used at higher frequencies because the size of the antenna is directly related to the wavelength at the resonant frequency [8].

II. MICROSTRIP PATCH ANTENNAS

A microstrip patch antenna is a narrowband, wide-beam antenna constructed by engraving the antenna element pattern joined to an insulating dielectric substrate on one side and a continuous metal layer joined to the opposite side of the substrate which forms a ground plane [9]. Few microstrip antennas do not use a dielectric substrate and alternatively are made of a metal patch mounted above a ground plane using dielectric spacers. The resulting structure is weak but has a wider bandwidth. The bandwidth can be improved by introducing an air gap between the patch substrates [10]. Since these antennas have a low profile and are mechanically rugged, they can be shaped to conform to the curving skin of a vehicle. They are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications. There are several advantages of this type of antenna versus a conventional antenna. First, no complex feed is required which results in high loss or phase shift of the transmitted or received signal. Second, these antennas can besubjected to a given surface shape, reducing the bulk, mechanical complexity and manufacturing cost of the antenna.Common microstrip antenna shapes are square, rectangular, circular, elliptical, or any continuous shape is possible as shown in figure 1. The most commonly employed microstrip patch element is the rectangular patch.

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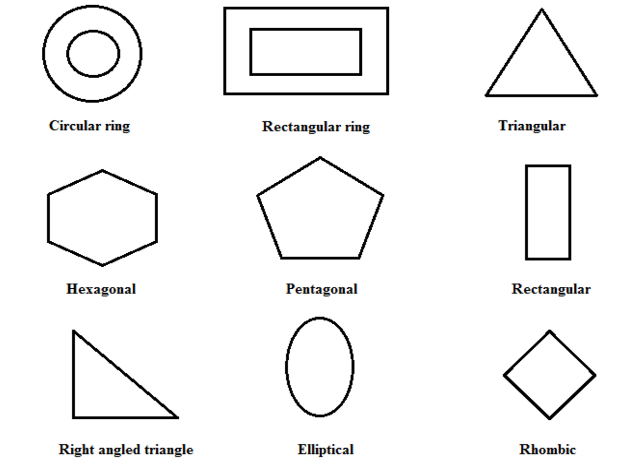

Fig 1 Different shapes of microstrip patch elements.

A. Feeding techniques in microstrip patch antennas
Previously, the patch antenna was fed at the end as shown in Fig. 2.

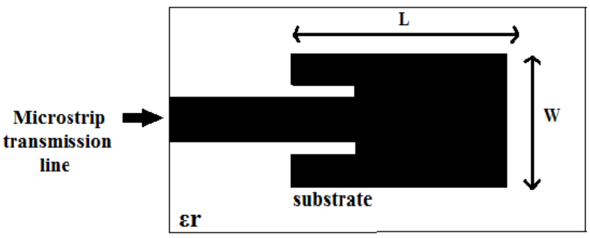

Fig. 2.Feeding in microstrip antenna

This method produces high input impedance and hence the feed has to be changed. Since the current is low at the ends of the patch and increases magnitude towards the center, the input impedance will be reduced if the patch was fed to the center. A feed line is generally used to excite an antenna to radiate by direct or indirect contact. There are different methods of feeding and four most popular methods are microstrip line feed, coaxial probe, aperture coupling and proximity coupling [11]. In coaxial probe feed, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. In aperture coupled feed, two dielectric substrates are used. The microstrip patch is placed at the upper surface of the upper dielectric substrate and the feed line is placed between the two substrates. Feeding techniques reduce spurious radiation from the microstrip line and provide good polarization with higher bandwidth [12].

III. ANALYTICAL CONSIDERATIONS

The effective design of microstrip antennas requires good knowledge of the effects of the physical and mechanical properties of the patch, the ground plane, and the substrate material of the antenna.

A. Element Width
The width of the patch is equal to about half a wavelength and leads to good radiation efficiencies.The width of the microstrip patch antenna is given by

$$W = \frac{c_o}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \qquad (1)$$

Where,
c_o is the speed of the light
ϵ_r= Relative permittivity and
f_r= Resonant frequency for maximum radiation.

B. Element Length
The length of the patch L controls the resonant frequency. The length may also be specified by calculating the half wavelength value and then subtracting a small length to take into account the fringing fields. The length of the patch is given by

$$L = \frac{c_o}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L \qquad (2)$$

Where,
ΔL = Distance between patch and edge of the substrate and ΔL is given by

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (3)$$

Where,
h = height of the substrate.
W= width of the patch
f_r= Resonant frequency for maximum radiation and f_r is given by

$$f_r = \frac{c}{2L\sqrt{\epsilon_r}} \qquad (4)$$

ϵ_{reff} = Effective permittivity of the substrate and ϵ_{reff} is given by

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}, \frac{W}{h} > 1 \qquad (5)$$

Where,
c is the velocity of light.
f_0 is the resonant frequency and
ϵ_r is the dielectric constant of the substrate.

C. Field Expressions
E plane is the plane in which the electric filed is dominant and this is justified for H plane too.The expressions for E- and H-planes are given by

$$E_\theta = \frac{\sin\left[\frac{kwsin\ \theta sin\ \emptyset}{2}\right]}{\frac{kwsin\ \theta sin\ \emptyset}{2}}\cos\left[\frac{kLsin\theta cos\emptyset}{2}\right]\cos\theta \qquad (6)$$

$$E_\phi = \frac{\sin\left[\frac{kwsin\ \theta sin\ \emptyset}{2}\right]}{\frac{kwsin\ \theta sin\ \emptyset}{2}}\cos\left[\frac{kLsin\theta cos\emptyset}{2}\right]\cos\theta\sin\phi \qquad (7)$$

When,
Φ=0, represents E plane and
θ=0, represents H plane.
D. Array Equation
The microstrip array equation is given by

$$E = \sum_{n=1}^{N} e^{(j*\frac{N}{2}*\pi*\sin(\theta)*((2*n)-1-N)/N)} \qquad (8)$$

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Where,
N= number of microstrip elements and
n is an integer value.

IV. NUMERICAL AND SIMULATION RESULTS

In this section, the radiation patterns of E- and H- planes at different frequencies for elements and arrays are presented.

A. E- plane Results for Single Microstrip Element
The radiation pattern for an element E- plane at 10 GHz frequency is shown in Fig. 3. Here, the patch dimensions are W=1.186 cm, L=0.906 cm, h=0.1588 cm and k=2.094.

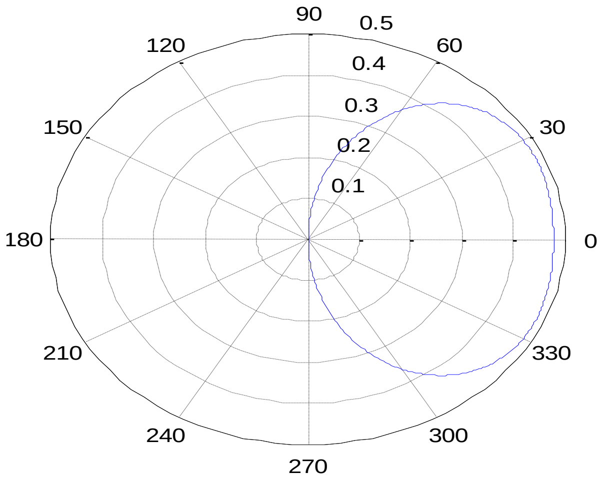

Fig. 3 Radiation pattern of Microstrip Antenna in E-plane at 10GHz

The radiation pattern for an element E- plane at 30 GHz frequency is shown in Fig. 4. Here, the patch dimensions are W=0.3968 cm, L=0.099 cm, h=0.1588 cm and k=6.283.

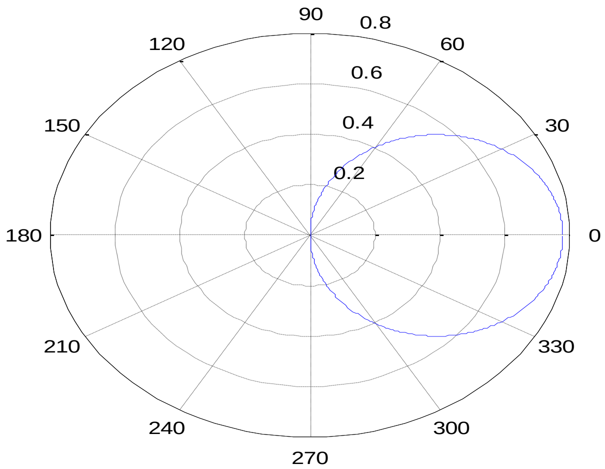

Fig. 4.Radiation pattern of microstripAntenna in E-plane at 30GHz

B. H- plane Results for Single Microstrip Element
The radiation pattern for an element H- plane at 10 GHz frequency is shown in Fig. 5. Here, the patch dimensions are W=1.186 cm, L=0.906 cm, h=0.1588 cm and k=2.094.

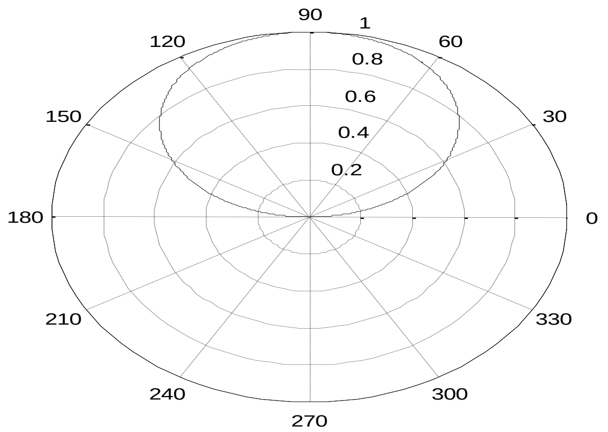

Fig. 5 Radiation pattern of microstripAntenna in H-plane at 10GHz

The radiation pattern for an element H- plane at 30 GHz frequency is shown in Fig. 6. Here, the patch dimensions are W=0.3968 cm, L=0.099 cm, h=0.1588 cm and k=6.283.

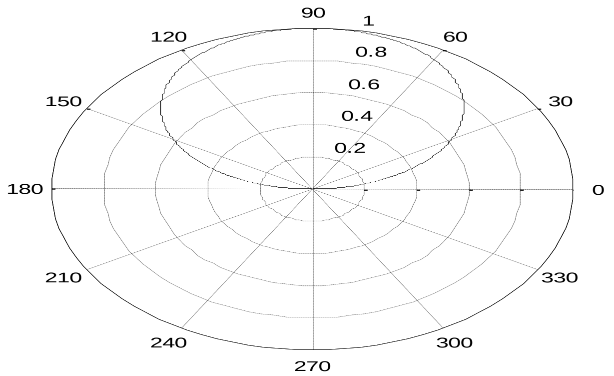

Fig 6 Radiation pattern of microstripAntenna in H-plane at 30GHz

C. E- plane Results for Single Microstrip Element in LabVIEW
The radiation pattern for an element E- plane at 10 GHz frequency simulated in labVIEW software is shown in Fig. 7. Here, the patch dimensions are W=1.186 cm, L=0.906 cm, h=0.1588 cm and k=2.094.

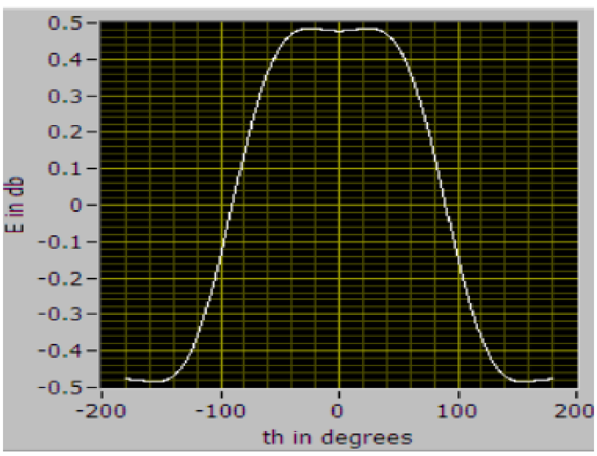

Fig. 7. Radiation pattern of microstripAntenna in E-plane at 10GHz in labview with θ value on x-axis and electric field on y-axis

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The radiation pattern for an element E- plane at 30 GHz frequency is shown in Fig. 8. Here, the patch dimensions are W=0.3968 cm, L=0.099 cm, h=0.1588 cm and k=6.283.

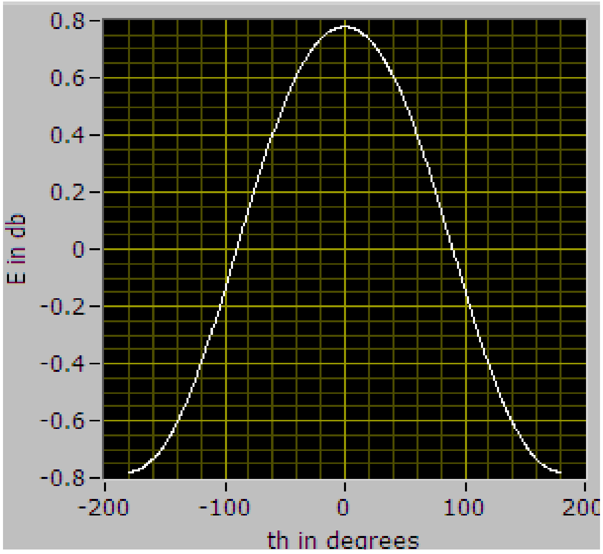

Fig. 8. Radiation pattern of microstripAntenna in E-plane at 30GHz in labview with θ value on x-axis and electric field on y-axis

D. H- plane Results for Single Microstrip Element in LabVIEW

The radiation pattern for an element H- plane at 10 GHz frequency simulated in labVIEW software is shown in Fig. 9. Here, the patch dimensions are W = 0.3968 cm, L = 0.099 cm, h = 0.1588 cm and k = 6.283.

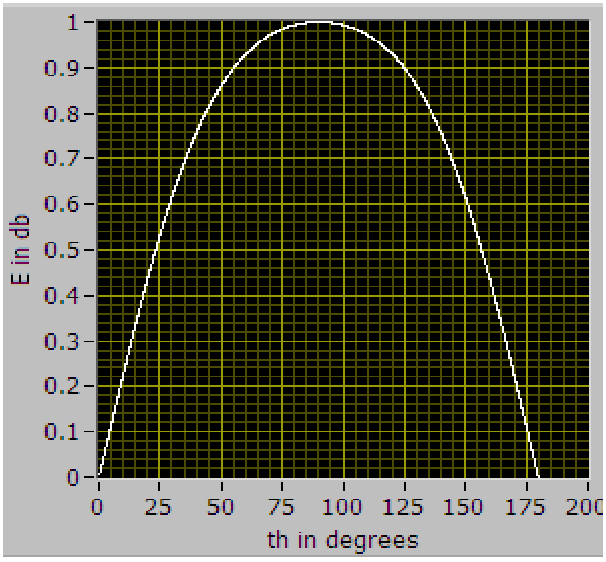

Fig. 9.Radiation pattern of microstripAntenna in H- plane at 10GHz in labview with θ value on x-axis and electric field on y-axis

The radiation pattern for an element H- plane at 30 GHz frequency simulated in labVIEW software is shown in Fig. 10. Here, the patch dimensions are W = 0.3968 cm, L = 0.099 cm, h = 0.1588 cm and k = 6.283.

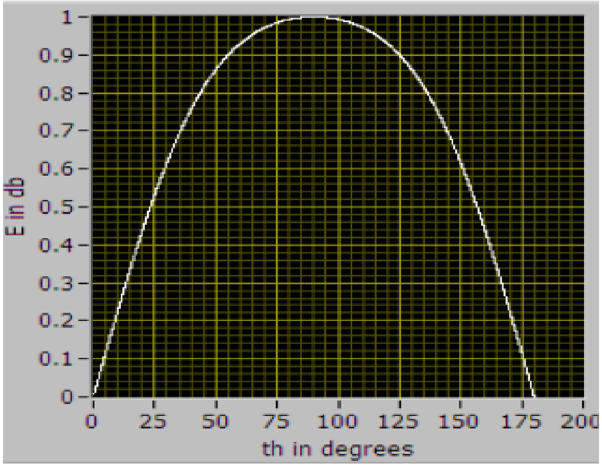

Fig. 10.Radiation pattern of microstripAntenna in H- plane at 10GHz in labview with θ value on x-axis and electric field on y-axis

E. E- plane Results for Microstrip Array Elements

The radiation pattern for an array in E- plane for 20 and 40 elements at 10 GHz frequency are shown in Fig. 11 and Fig. 12 respectively. Here, the patch dimensions are W=1.186 cm, L=0.906 cm, h=0.1588 cm and k=2.094.

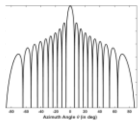

Fig. 11.Radiation pattern of microstriparray for 20 elements

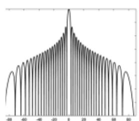

Fig. 12.Radiation pattern of microstriparray for 40 elements

F. Results for Microstrip Array Elements in LabVIEW

The radiation pattern for an array in E- plane for 20 and 40 elements at 10 GHz frequency are shown in Fig. 13 and Fig. 14 respectively. Here, the patch dimensions are W=1.186 cm, L=0.906 cm, h=0.1588 cm and k=2.094.

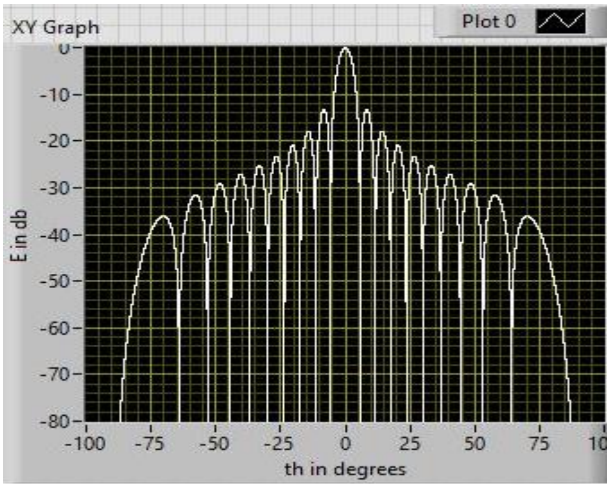

Fig. 13.Radiation pattern of microstriparray for 20 elements with θ value on x-axis and electric field on y-axis

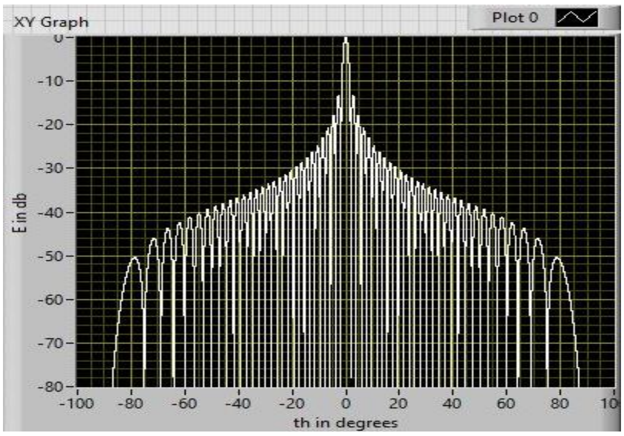

Fig. 14 Radiation pattern of microstriparray for 40 elements with θ value on x-axis and electric field on y-axis

V. CONCLUSION

Over the last two decades, microstrip antennas have progressed from a simple single patch structure to complex multilayer configurations. The study and design of a simple rectangular patch microstrip antenna and its radiation properties in E- and H- planes were described. The synthesis method is achieved with the help of MATLAB and LabVIEW software's simultaneously and the simulation results are depicted in the present work. The computational method developed in this work has been shown to be an efficient method for dealing with large arrays. It is also observed that the labVIEW computation method is a very reliable scheme for acquiring fast, error-free and elegant presentation of the results and is very suitable for full-wave analysis of large microstrip antenna arrays. A basic set of design specifications were presented to achieve specific performance characteristics at a specified operating frequency. In addition to this, various advantages of a microstrip patch antenna and its numerous applications in radar services were presented.

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