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Design of an 8X1 Square Microstrip Patch Antenna Array

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Abstract

Wind profiling radars operating in Doppler beam swinging mode needs to have large antenna array in order to have a narrow beam for wind direction accuracy. To meet the above requirement, in the present work an array with 8 elements configured in an 8X1 is designed. The antenna inserted is a co-axial probe (Probe feed) to the patch near its resonance in ‘L’ band is carried out. Principal plane 2-dimensional radiation patterns at 1.28GHz have been computed for single element and 8X1 linear array. The results of linearly polarized coaxial probe single element are generated using IE3D software. Using single element as basic building block, an 8X1 linear array was designed. The results obtained are presented succinctly. The inferences from the design of coaxial probe antenna are presented.

Introduction

Microstrip patch antennas (MPAs) have attracted widespread interest due to their small size, light weight, low profile and low cost as well as to the fact that they are simple to manufacture, suited to planar and non planar surfaces, mechanically robust, easily integrated with circuits, allow multifrequency operation to be achieved [1]. However, their further use in specific systems is limited because of their relatively narrow bandwidth. In principal, wide bandwidth of microstrip patch antennas (MPAs) or bandwidth enhancement can be achieved by several efficient approaches [2], namely (i) increasing the substrate thickness (ii) optimizing impedance matching (iii) reducing the substrate effective permittivity or (iv) incorporating multiple resonance. Much effort has also been increasingly devoted to increasing the frequency agility of (MPAs) [2].

At the same time, MPAs need to be extremely small and compact to satisfy the severe size constraints of some critical applications such as mobile cellular handsets, card less phones and blue tooth devices. The miniaturization of normal MPA size [1] has typically been accomplished by loading, which can take various forms, such as (i) using a high permittivity substrates, (ii) Using shorting ports or shorting pins, or (iii) modifying the basic patch shape [3].

In this paper, coaxial feed [4,5] techniques are applied to the square microstrip patch antenna. Because, coaxial feed is a widely used one. The inner conductor of coaxial cable is connected to the radiating patch and the outer conductor is connected to the ground plane. This feed is also easy to match, and it has low spurious radiation. However, it has a narrow bandwidth and is difficult to model, especially for very thick substrates. The advantage of this feed is that it occupies less space than the other feeds.

Radiation Mechanism

Microstrip antennas are essentially suitably shaped discontinuities that are designed to radiate. The discontinuities represent abrupt changes in the microstrip line geometry. Discontinuities alter the electric and magnetic field distributions. These results in energy storage and sometimes radiation at the discontinuity. As long as the physical dimensions and relative dielectric constant of the line remains constant, virtually no radiation occurs.

However the discontinuity introduced by the rapid change in line width at the junction between the feed line and patch radiates. The other end of the patch where the metallization abruptly ends also radiates. When the field on a microstrip line encounters an abrupt change in width at the input to the patch electric fields spread out [6].

Microstrip Lines

A microstrip line consists of a single ground plane and a thin strip conductor on a low loss dielectric substrate [11] above the ground plate. Due to the absence of the top ground plate and the dielectric substrate above the strip, the electric field lines remain partially in the air and partially in the lower dielectric substrate. This makes the mode of propagation not pure TEM but what is called quasi-TEM. Due to the open structure and any presence in discontinuity, the microstrip line radiates electromagnetic energy. The use of thin and high dielectric materials reduces the radiation loss of the open structure where the fields are mostly confined inside the dielectric.

Quasi TEM Mode of Propagation

The electromagnetic waves in free space propagate in the transverse electromagnetic mode (TEM). The electric and magnetic fields are mutually perpendicular and further in quadrature with the direction of i.e. along the transmission line Coaxial and parallel wire transmission line employ TEM mode. In this mode the electromagnetic field lines are contained entirely within the dielectric between the lines.

But the microstrip structure involves an abrupt dielectric interface between the substrate and the air above it. Any transmission line system which is filled with a uniform dielectric can support a single well defined mode of propagation at least over a specific range of frequencies (TEM for coaxial lines TE or TM for wave guides.) Transmission lines which do not have such a uniform dielectric filling cannot support a single mode of propagation. Microstrip falls [7,8] in this category. Here the bulk of energy is transmitted along the microstrip with a field distribution which quite closely resembles TEM and is usually referred to as Quasi – TEM.

The microstrip design consists of finding the values of width (w) and length (l) corresponding to the characteristic impendence (Z_o) defined at the design stage of the network. A substrate of permittivity (ϵ_r) and thickness (h) is chosen. The effective microstrip permittivity (ϵ_{eff}) is unique to a fixed dielectric transmission line system and provides a useful link between various wave lengths impedances and velocities.

The microstrip in general, will have a finite strip thickness,'t' which influences the field distribution for moderate power applications. The thickness of the conducting strip is quite significant when considering conductor losses [8]. For microstrip with $t/h \leq 0.005$, $2 \leq \epsilon_r \leq 10$ and $w/h \geq 0.1$, the effects of the thickness are negligible. But at smaller values of w /h or greater values of t / h the significance increases.

Design Principles

The designed antenna is an 8X1 linear array. The first step in the design is to specify the dimensions of a single microstrip patch antenna. The patch conductor can be assumed at any shape, but generally simple geometries are used, and this simplifies the analysis and performance prediction. Here, the half-wavelength rectangular patch element is chosen as the array element (as commonly used in microstrip antennas) [9]. Its characteristic parameters are the length L, the width w, and the thickness h, as shown in Figure 1.

To meet the initial design requirements (operating frequency = 1.28 GHz, and beam width = 9^0) various analytical approximate approaches may be used. Here, the calculations are based on the transmission line model [12]. Although not critical, the width w of the radiating edge is specified first. The square-patch geometry is chosen since it can be arranged to produce circularly polarized waves. In practice, the length L is slightly less than a half wavelength (in the dielectric). 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 [15-17], as;

$$L = \frac{c}{2 \times f_r \times \sqrt{\varepsilon_{reff}}} - 2\Delta l \tag{1}$$

Where c is the velocity of light and

$$\Delta L = 0.412 \times h \times \left[\frac{(\varepsilon_{reff} + 0.03) \times (W + 0.264h)}{(\varepsilon_{reff} - 0.258) \times (W + 0.8h)} \right]$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \left(1 + \left(\frac{12 \times h}{W}\right)\right)^{\frac{-1}{2}} \tag{2}$$

Here, ε_{reff} and f_0, ΔL are effective relative permittivity, the operating frequency, and the fringe factor respectively.

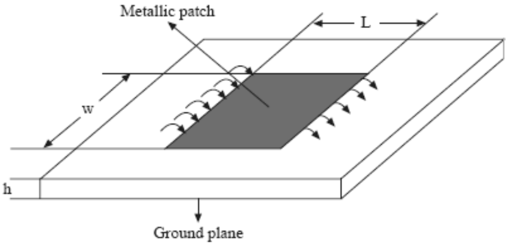

Figure 1: A Rectangular Patch Antenna.

From these approximate calculations, the dimensions of the square-shaped microstrip patch antenna element are specified as shown in Figure 2. For a linear array with a uniform excitation, the beam width is given by [14],

$$\theta_{3db} = \cos^{-1}\left[\sin(\theta_0) - 0.443\frac{\lambda_0}{\ell}\right] - \cos^{-1}\left[\sin(\theta_0) + 0.443\frac{\lambda_0}{\ell}\right] \tag{3}$$

where θ_0 is the main beam pointing angle, λ_0 is the free-space wavelength, and ℓ is the total array length.

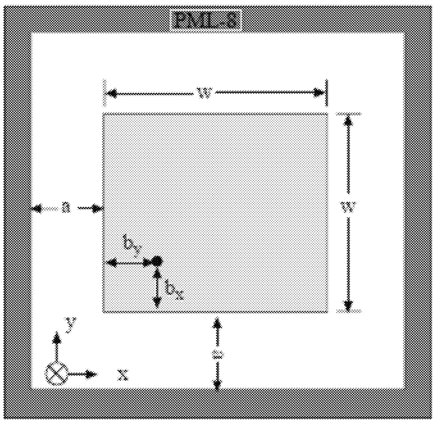

Figure 2: The Square Patch Element.

The dimensions are w = 7.6 cm, h = 3.175mm, ε_r = 2.2 and a = 9.5 cm.

When the inter-element distance is selected to be 0.73 λ, the 8X1 array satisfies 9^0 beam width. The 8X1 array is pictured in Figure 3.

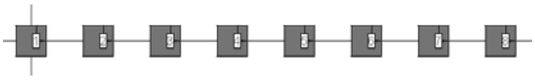

Figure 3: The 8X1 Array that Operates at 1.28GHz, and with 9^0 Beam Width.

Results

The narrow band antenna element and an eight element array are shown in figure .2 and 3.

After the simulation using IE3D software package [13], the antenna element exhibits a 19MHz bandwidth (VSWR<2) and 7.03dBi of gain as shown in figure.4

An 8X1 element array, shown in figure .3 was designed using the single element as a basic building block. The final array was built by etching on a metallized dielectric substrate (RT/Duroid 5880; h=3.175mm, ϵ_r=2.2 and tan δ=0.0004).

Figure 5 depicts the VSWR of the 8X1 element array measured at 1.28 GHz. The antenna exhibits a 20MHz band width same as a single element. The gain also shown in figure.6 the maximum gain reaches 16.75dBi at 1.28GHz. The radiation patterns have also been measured. Figur.7 shows the E-plane and H-plane patterns at 1.28 GHz frequency.

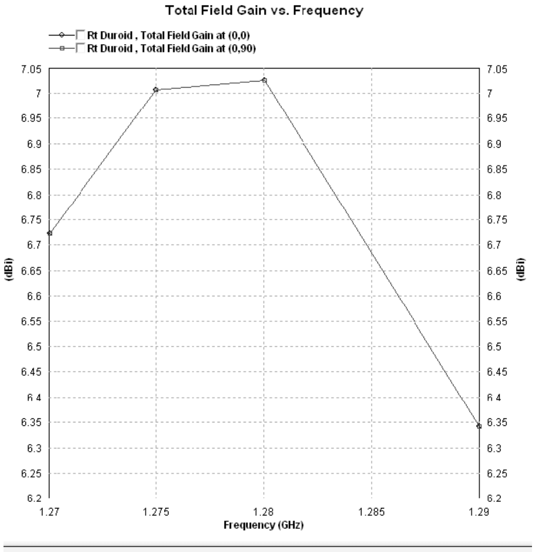

Figure 4: Gain Characteristics of the narrowband antenna element.

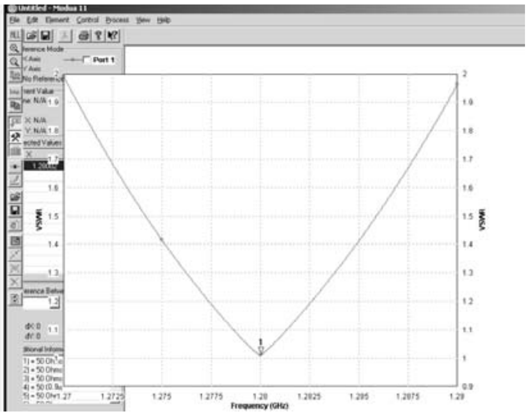

Figure 5: VSWR of an 8 element array.

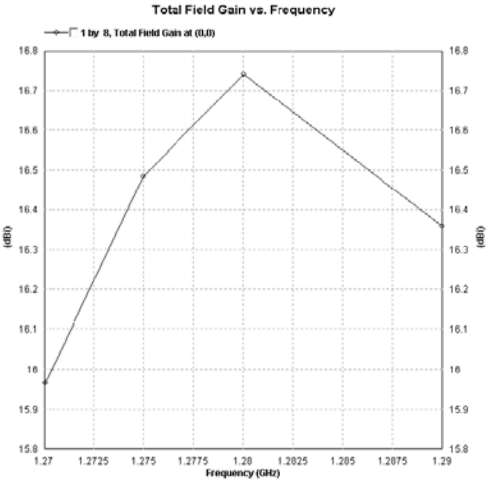

Figure 6: Gain Characteristics of an 8 element array.

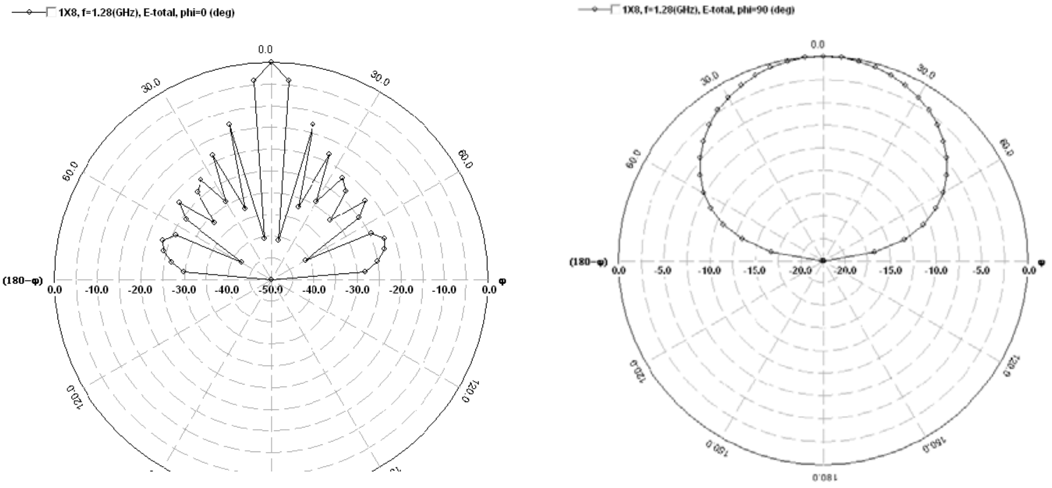

Figure 7: Radiation patterns of an 8 element array at 1.28GHz.

Conclusion

An 8X1 element array has been realized for wind profiling radars. It consists of a single layer narrow band antenna element based on this 8X1 element array was designed. Gain, Bandwidth and radiation patterns have been computed over a frequency at 1.28GHz. From the data analysis, it has been pointed out that the side lobe level is the most critical factor, and thus determines the operating bandwidth. However, considering the impedance, gain and maximum side lobe at 1.28GHz frequency, a 20 MHz bandwidth has been obtained.

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