DESIGN OF BEAM STEERING RECTANGULAR MICROSTRIP ANTENNA ARRAY

FOR 2.45 GHZ

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ABSTRACT

This paper presents design and experimental analysis of Linear Phased Array Antenna System operating at 2.45 GHz. In this research work beam steering is achieved by adjusting the phases of antennas. Antenna element excitation phases are adjusted at the intermediate frequency and amplitudes are kept constant. The obtained radiation patterns provide steerable main lobes and nulls at predefined directions. Units of the system are presented in detail and their architecture is explained. A phase calibration is used to compensate the system. Measurements of radiation patterns are presented and are compared with calculated patterns.

KEYWORDS: Array, Beam Steering, Microstrips Patch Antennas, Phase Shifter

INTRODUCTION

Antennas play an integral part in wireless communication system at both, transmitter as well as receiver end. It has been stated that any communication system is only as good as its antennae. Microstrip patch antennas are versatile in terms of their geometrical shapes and implementations. Inhibiting characteristics of a single microstrip patch, like low gain and smaller bandwidth, make it more popular for array configuration. Microstrip antenna is printed type of antenna consisting of a dielectric substrate sandwiched in between a ground plane and a patch [1]. The Microstrip antenna is physically very simple and flat, these are two of the reasons for the great interest in this type of antenna [2].

Microstrip antennas have several advantages compared to other bulky type of antennas. Some of the main advantages of the microstrip antennas are that it has low fabrication cost, its lightweight, low volume, and low profile configurations that it can be made conformal, it can be easily mounted on rockets, missiles and any conformal shaped satellites without major Modifications and arrays of these antennas can simply be produced. Beam-steering phased antenna arrays find many Applications in microwave radar and communication systems.

In the proposed system, for the beam steering use only single phase shifter in prévois system requière séparâtes phase shifter for each patch, the total 1200 angle is covered with discrete beam forming in desired direction. The direction of transmission is controlled through personal computer and controller unit. To change the direction of transmission, the PC is interfaced to the antenna hardware circuitry, the angle in which the direction to be changed is given through the PC.

To demonstrate the implementation of the digital beam forming, phase array is to be built for 2.4 GHz [3]. In order to allow Transmission, testing and demonstrational use of the array in the unrestricted Industrial, Scientific and Medical (ISM) band. The demonstrated technique, however, can be implemented at any frequency and with minor changes for a transmitting array as well.

The aim of this work is to design and implement a microstrip phased array antenna, printed on a composite ferrite-dielectric substrate. Two rectangular radiating patches on a low dielectric constant substrate are arranged in linear
configuration to achieve required radiation properties. The microstrip array feeder network, consisted of integrated power divider and phase shifters, is realized on an externally magnetized ferrite substrate. Tunable progressive phase shift is produced by varying the magnetic bias that changes the permeability of ferrite material, which in turn changes the phase velocity and, hence, the insertion phase of the propagating microwave signal. The two-way power splitter is attained power dividers, which improves the isolation and matching of the ports. The antenna array is designed using standard equations and simulated by professional software called, High Frequency Structural Simulator (HFSS). Among many antenna simulators, HFSS is selected as it allowed the inclusion of anisotropic ferrite material in the simulation process. The antenna prototype is printed using the PCB plotter and manually transferred on the composite substrate, which introduced some inaccuracy. Finally, the simulated reflection response and radiation characteristics of the designed antenna array are corroborated using experimental results obtained from the Network Analyzer and the Antenna Transmission & Measurement System respectively. The designed array exhibited very close radiation response to that of design objective.

**SYSTEM ARCHITECTURE**

![Figure 1: System Block Diagram](image)

Shown in figure 1, prototype model is designed for 2.45 GHz to steer the beam for 120° range. To steer the beam the antenna phase excitation technique is selected. Here 1x2 patch array antennas is designed, to excide the antenna patches different phase shift is applied. To produce the 2.45 GHz signal VCO is used ,The range of VC0 is 2100-3000 MHz, with the help of variable power supply VC0 is tuned for 2.45Ghz.To produce the exact 2.45 GHz frequency 2.7 V bias potential is required. The output of VC0 is applied to two way power splitter. One end of power splitter is connected to antenna first patch and another end connected to phase shifter to differentiate the phase between two patches. Phase shifter operates on 0-15 volt to vary phase shift from 00 to 3600, to control the phase shift from computer the digital potentiometer is interface between computer and phase shifter. The output of phase shifter is applied to second patch of the array antenna. Control the phase shift between patch 1 and patch2 by varying the output potential of digital potentiometer by changing the value from computer.

**DESIGN PROCEDURE**

The designed antenna is a 2x1 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) \[4\]. Its characteristic parameters are the length \(L\), the width \(w\), and the thickness \(h\), as shown in below Figure.

![Figure 2](image)

To meet the initial design requirements (operating frequency = 2.4 GHz, various analytical approximate approaches may be used. Here, the calculations are based on the transmission line model \[5\]. Although not critical, the width \(w\) of the radiating edge is specified first. 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 \[2\]-\[4\].

Therefore many kinds of miniaturization techniques, such as using of high dielectric substrates, resistive or reactive load and increasing the electrical length of the antenna, Also it gives a good directivity and high gain with good performance characteristics \[6\]. The proposed array Antenna will be working on 2.45Ghz frequency range, i.e.(ISM-band). The patch resonate to produce a broadband response. Representative results for the VSWR response, \(S\)- parameter and radiation patterns are shown in Figures 8, 9, 10 and 11 respectively. The gain of the antenna is higher than the traditional Microstrip antenna. The dimensions of the antennas array are listed in Table 1.

### Table 1: Dimensions of the Antenna

<table>
<thead>
<tr>
<th>Antenna</th>
<th>(\varepsilon_r)</th>
<th>(W) (mm)</th>
<th>(L) (mm)</th>
<th>(H)</th>
<th>(S)</th>
<th>(D) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.4</td>
<td>38.89</td>
<td>102</td>
<td>1.588</td>
<td>9</td>
<td>36.51</td>
</tr>
</tbody>
</table>

An inset feed microstrip antennas is designed to resonate at 2.45 GHz frequency with dielectric constant \((\varepsilon_r) = 4.4\), substrate thickness \(h=1.588\) mm, \(L=28.49\) mm, \(W=28.49\) mm on a ground plane. All dimensions of the antenna are in mm.

The length and the width of the patch are calculated initially by the relationships (1)-(6) given in

\[
W = \frac{V_0}{2F_r} \sqrt{\frac{2}{\varepsilon_r + 1}}
\]

(1)

Where \(V_0\) is the free space velocity of the light.

\[
L = \frac{C}{2 \times F_r \times \sqrt{\varepsilon_{\text{eff}}}} - 2 \Delta l
\]

(2)
\[
\Delta L = 0.412 \times h \times \left[ \frac{\varepsilon_{\text{reff}} + 0.03}{\varepsilon_{\text{reff}} - 0.258} \times (W + 0.26h) \right]
\]

(3)

Where \( \varepsilon_L \) is extension in length due to fringing effects.

The effective dielectric constant is given by,

\[
\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \sqrt{1 + \left( \frac{12 \times h}{W} \right)^{-1}}
\]

(4)

The ground plane dimensions would be given as,

\[
L_g = 6(h) + L = 6(1.588) + 28.49 = 38.018 \text{ mm}
\]

(5)

\[
W_g = 6(h) + W = 6(1.588) + 28.49 = 38.018 \text{ mm}
\]

(6)

Figure 3 show the geometry of inset feed microstrip array antenna with two patches in the array. The patch is energized electromagnetically using 50 ohm SMA connector.

Hence wide bandwidth is generated as the resonant circuits become coupled. The slots aggregate the currents, which give additional inductance controlled by the patch width [8]. HFSS software has been used to calculate the

Return loss (S11)

Directivity vs. frequency,

3D radiation pattern

Field gain Vs frequency.

The present work signifies that by introduction of two Patch in the same size, the Directivity gets enhanced to about 9 dB i.e., Figure 8 and Figure 9 show the return loss (S11) vs. Frequency curve for the proposed coaxial feed.[7].

It is observed that as the distance between two patches is changed, the gain and side lobe level is changing. The distance between two patches is kept to optimize the gain and minimize side lobe levels [9].

**Figure 3: 2×1 Array Antenna**

The actual prototype model is shown in figure 4, Figure 5 is full model
ACTUAL EXPERIMENTAL SET-UP OF PATCH ANTEENA ARRAY SYSTEM

Figure 4: Transmitting Antenna with Beam Control Mechanism (VCO, Splitter, Phase Shifter etc)

Figure 5: Experimental Testing Setup

Figure 6: Transmitter and Receiver Antenna on Reference Line (Front to Front on 0 Axes)

Figure 7: Receiver is Line of Sight (Poor Strength on Spectrum Analyzer)

SIMULATED RESULTS FOR 1X2 PATCH ANTEENA ARRAY

Return Loss Measurement

From figure 8 The Return loss obtained at 2.45 GHz is -30 dB and band width obtained at -10 dB is about 40 MHz.

Directivity vs. Frequency

Shown in figure 9 directivity of array is 9 dBi at exact 2.5 GHz. single patch provide directivity up to 6 dBi here directivity is increased by 3 dBi.
From the figure 9, directivity obtained at 2.4 GHz is 9 dBi

**Dimensional Radiation Pattern**

- E=2.450(GHz), E-theta, phi=0 (deg), PG=4.608578 dB, AG=+4.14284 dB
- E=2.150(GHz), E-theta, phi=0 (deg), PG=2.41209 dB, AG=+6.2021 dB
- E=2.450(GHz), E-left, phi=0 (deg)
- E=2.150(GHz), E-right, phi=0 (deg)

**Figure 10**

Radiation Pattern (3-D) for 1x2 Arrays: E–Theta Pattern

Shows the figure 11 is 3-D radiation pattern:
PRACTICAL RESULT FOR 1X2 PATCH ANTENNA ARRAY

Figure 12: Output of VCO Measured Directly on Spectrum Analyzer to Set at 2.45 GHz

The system is tested and taken live results on spectrum analyzer, figure 12 indicate the output of VCO. The VCO is tuned for 2.45 GHz by adjusting the control voltage applied to VCO. Figure 13 represents the signal strength received by the receiver end.

POLAR PLOTS

Figure 14: Polar Plot for Voltage = 0V

Figure 15: Polar Plot for Voltage = 7V
In this above figure 14, the beam direction for \( \theta = 110^0 \) when \( 0^0 \) phase shift applied to both the patches. This is initial radiation direction

![Figure 16: Polar Plot for Voltage = 0V](image)

Shows the figures 15 and 16 for \( \theta = 160^0 \) and \( 30^0 \) respectively when applied potential is 7V and 15 volt respectively. When analog phase shifter bias potential is increased the beam is also increased from \( 110^0 \) to \( 30^0 \).

**CONTROL WINDOW FOR BEAM STEERING**

![Figure 17: Initial Window](image)

![Figure 18: Example for Intermediate Direction](image)

In this system beam steering is done by using computer, to change the direction of radiation in specific angle is achieved with minimum time using digital potentiometer. Digital potentiometer is in interface to PC and Analog phase shifter. To change the output potential GUI is made to enter the bits into control window phase shift is occurring respectively.

Shows the below figure to introduce the operation of Beam steering. Figure 17 is Initial look of GUI before entering any parameters, In this control window total output voltage is divided into 128 points SDI write button varies from 1 to 128 times and output is changed respectively. Shown in figure 18 is the value is entered in the GUI then the position of SDI is shown 33 and data write is also 33, after click on RUN buttons the data is transmitted to digital potentiometer.

**CONCLUSIONS AND FUTURE OUTLOOK**

An experimental phased array antenna system is developed in this project. The use of digital potentiometer and phase shifter to control the radiation pattern characteristics proved to be an efficient approach providing stability and easy control of the radiation patterns as verified by the measurements and comparison with theoretical results, which shows
good agreement. System provides radiation patterns with steerable main lobes and nulls at prespecified positions within the azimuth region $0^\circ \leftrightarrow 120^\circ$. Here array of only 2 rectangular patches is considered for experimental purpose.

It is possible to obtain more directive, confined and precise beam steering using more than 2 elements (typically 2N) in array for relatively low increase in cost. In this system linear array are use because of that beam steering is done for $120^\circ$, but this is possible to steer the beam by $0^\circ$ to $120^\circ$ using dipole antenna. The possibility of using the developed conformal array as focal plane radiator in a large reflector antenna is an interesting application being considered.

REFERENCES


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