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Design of Phased Array System Using V-Antennas For Beam forming Applications

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Abstract

This paper presents the design of phased array system using planar technology for beamforming applications.The prototype comprises of V-antenna, integrated with butler-matrix. The novelty in this approach is the design of V-antenna using planar technology which results in high directivity and multiband operation. The designed array structure is having maximum directivitiesby the individual antennas in the direction -44°, 136°, -136° and 44° which are approximately equal to theoretical values. The operating frequency of design is 2.4GHz. And the complete phased array structure is working at multiple frequencies, that is, at 2.4GHz as well as at 4.5GHz. As the size of the V antennas is smaller than the conventional microstrip antennas, the complete phased array system is compact in size. This is an added advantage along with multi band operation that can be used in devices of smaller size. The proposed design is well suited in satellite communications. The simulations were carried out in Advanced Design System Tool.

Index Terms: V-antennas, Butler Matrix, Phased array system, Beamforming.

Introduction

Since the advent of telecommunications, Omni-directional antennas were used. Most of the time the specific location of the mobile user is unknown. Therefore, a lot of power is wasted to increase the power level so as to increase the number of users in a telecom system. This problem, to some extent, was solved by the use of sectored antennas. Although increased frequency reuse leading to increased gain is achieved by treating each sector as an individual cell, transmit power is still not efficiently utilized because the antenna beams are still fixed in direction and do not adapt to radio conditions and the environment. With the innovation of smart antennas, the power was directly intended to the desired user and a lot of power is saved. Beamforming applications of smart antennas in the field of cellular systems, also in satellite systems, and act as countermeasure to electronic jamming in electronic warfare etc. are being harnessed these days.Smart antenna is an antenna technology which aids to increase the system capacity by reducing the co-channel interference and increase the quality by reducing the fading effects.

Butler matrix is an integral part of the smart antennas. It is used to create a phase difference without causing any interference between adjacent radiating antennas.

In designing the complete phased array system we require the butler matrix and V-antennas using the microstrip layout.

V-Antenna

It is an antenna created from an array of wires which overcome the effects such as low directivity, high side lobes posed by long wire antennas.

The structure is described in the figure below

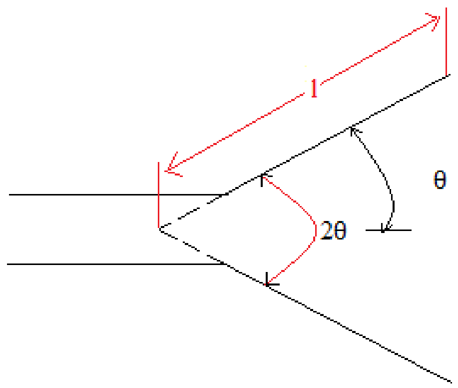

Figure 1: V-Antenna

The angle 2θ is given by the following equation [1]:

$$2\theta = \left(-149.3\left(\frac{l}{\lambda}\right)^3 + 603.4\left(\frac{l}{\lambda}\right)^2 - 809.5\left(\frac{l}{\lambda}\right) + 443.6\right);\ \text{For } 0.5 \le l/\lambda \le 0.9$$

The length of each leg of each V-Antenna must not be greater than 5λ, to keep the leakage of field in control. The values of substrate used in the antenna design are as follows:

Table 1: Substrate Parameters

Substrate Parameters	
Permittivity (ε_r)	4.6
Operating frequency (f)	2.4 GHz
Height of substrate (h)	1.6 mm
Thickness of substrate (T)	35 µm

After the proper optimization we got the length and width of the legs of the V-Antenna, designed using the microstrip circuits. The antenna is designed in ADS software is shown below:

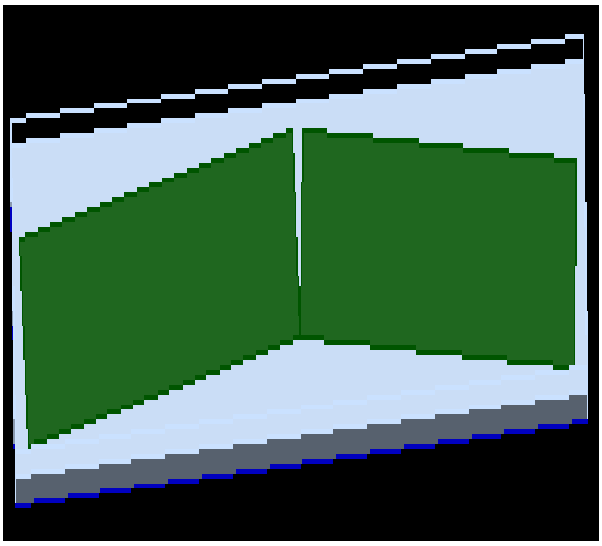

Figure 2: V-Antenna

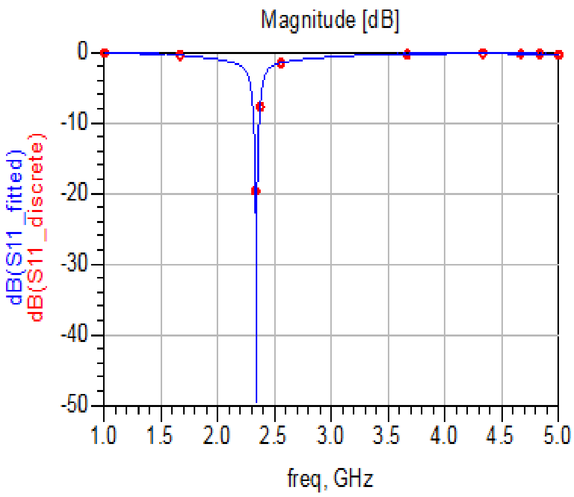

Figure 3: Return loss of V-Antenna

Butler-Matrix

Butler-Matrix is a part of smart antennas which is used in beamforming networks. It consists of the following components:

i. Hybrid Coupler

It is also known as 3db coupler.

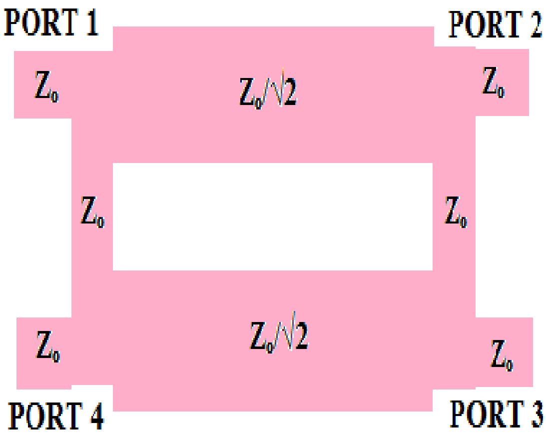

Figure 4: Hybrid Coupler

The input at port 1 creates an output 90° out of phase at port 3 and is isolated from port 4. The output at port2 and port3 are equal in magnitude.

ii. Cross-Coupler

This coupler is used to efficiently cross two transmission lines with minimal coupling.

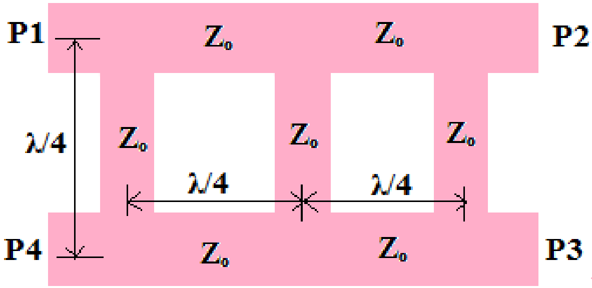

Figure 5: Cross-Coupler

The input at port1 is transmitted to port3 without any loss.

iii. 45° Phase Shifters

The Phase shifter is designed using the transmission line calculation provided in the ADS software.

The complete butler matrix after integrating four hybrid couplers, two cross-couplers and two 45° phase shifters is shown in the figure below:

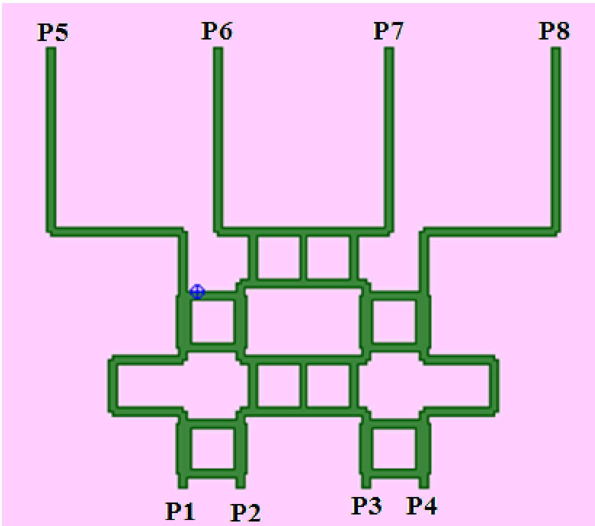

Figure 6: Butler-Matrix

The return loss of at the input ports is shown in the figure below:

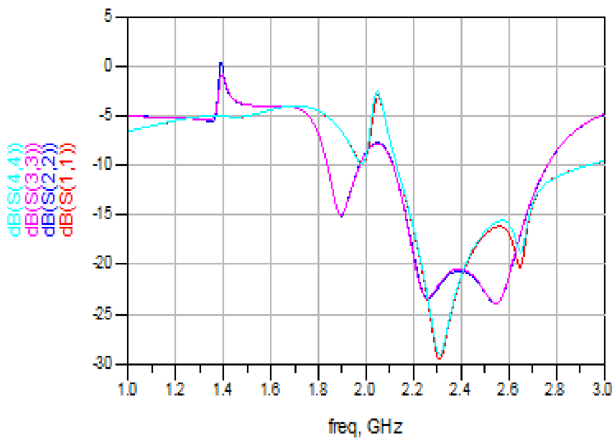

Figure 7: Return loss of 4 ports of butler matrix

The phase output at ports 5, 6, 7, 8 when input is given at ports 1, 2, 3 and 4 respectively is shown in the following figures:

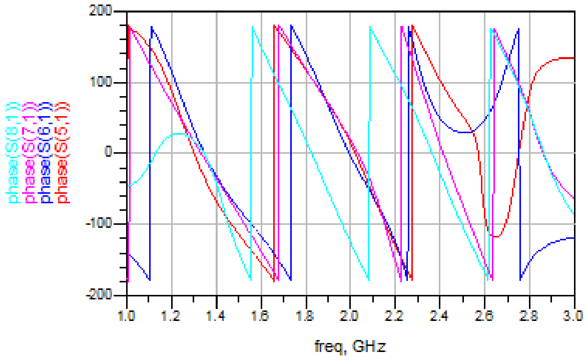

Figure 8: Phase output at ports5, 6, 7, 8 when input is given at port1

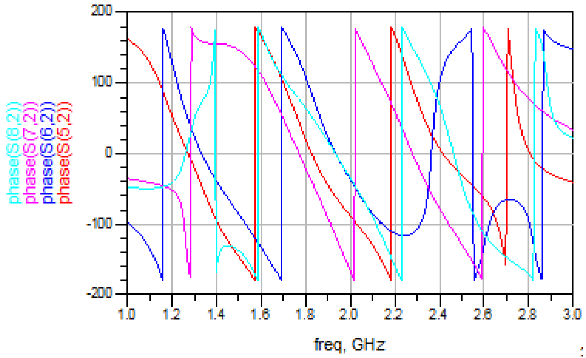

Figure 9: Phase output at ports5, 6, 7, 8 when input is given at port2

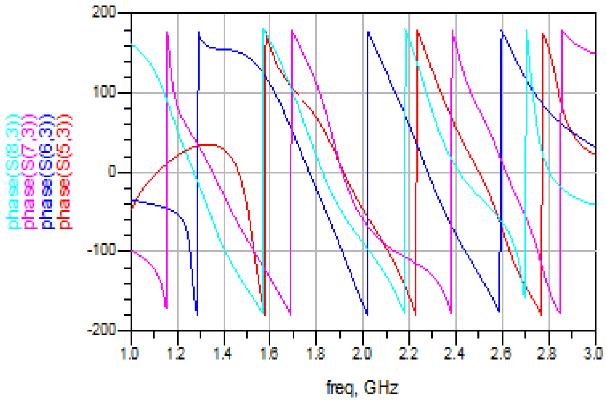

Figure 10: Phase output at ports5, 6, 7, 8 when input is given at port3

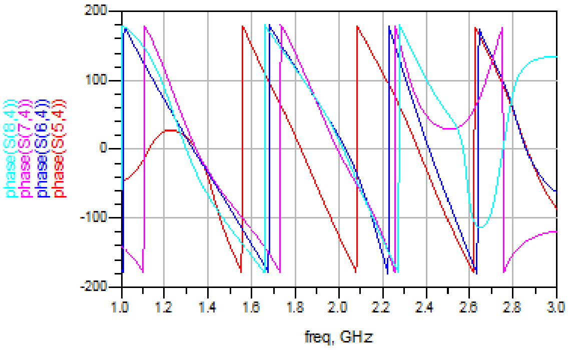

Figure 11: Phase output at ports5, 6, 7, 8 when input is given at port4

Table 2: Comparison of theoretical and practical values phase difference at output ports of butler matrix

Output Ports	Phase Difference (theoretically)	Phase Difference (practically)
P5	-45	-44
P6	135	136
P7	-135	-136
P8	45	44

Complete Phased Array Structure

The butler matrix is now integrated with the V-Antennas using a port matching transmission lines (obtained after transmission line calculations). The figure below shows the complete phased array structure designed in ADS software.

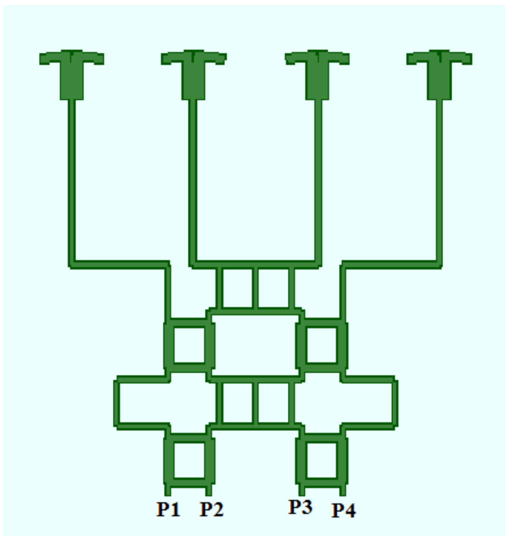

Figure 12: Integrated structure of butler matrix and V-Antenna

The return loss of port1, port2, port3 and port4 are shown in the figures below:

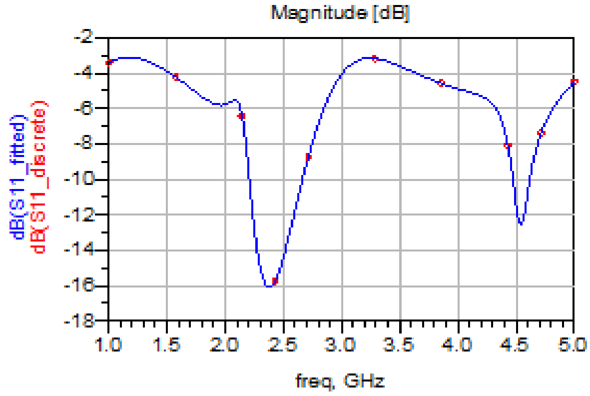

Figure 13: Return loss of port1

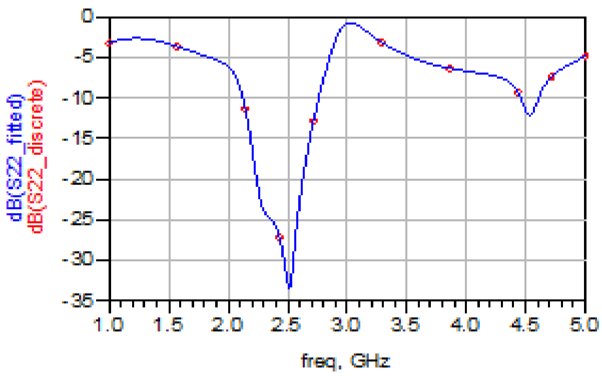

Figure 14: Return loss of port2

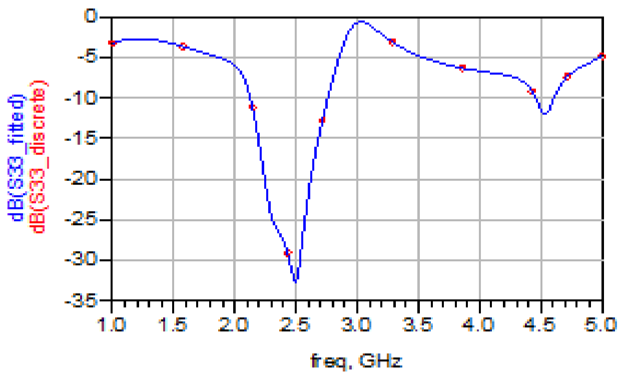

Figure 15: Return loss of port3

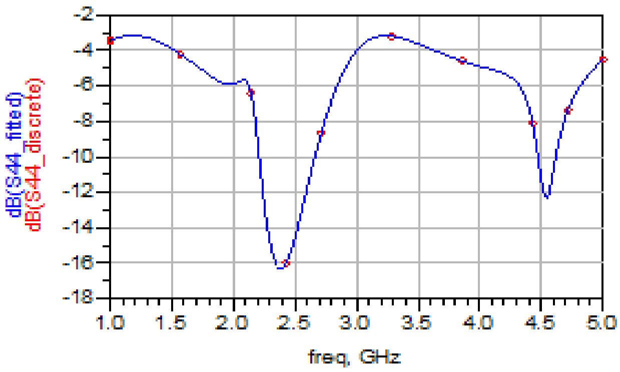

Figure 16: Return loss of port4

Conclusion

The butler matrix which is the integral part of the smart antennas is being designed and simulated in ADS software and its output results are being discussed in this paper. The V-Antennas working as the radiating elements, when analyzed individually have a high return loss of about (-50db). In the design of complete phased array structure we also saw that it's working at multiple frequencies that is, at frequency 2.4GHz as well as at frequency 4.5GHz. So the designed antenna is not only used in the ISM band as well as in satellite communication operating at C-band. From the complete phased array structure design we can conclude that it is compact in size, that is, the size of V-Antennas is much smaller than the traditionally used rectangular microstrip patch antennas. And with compact size these structures can easily be flush mounted on smaller devices.

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