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Compact Microstripline Phase Shifter Design for C band Frequency Range using RT Duroid 5870 Substrate

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Abstract- This paper presents design and implementation of compact microstripline phase shifter at C band frequency range using RT Duroid 5870 substrate. Phase shifters are key elements of beam-steering antennas which are very useful for Synthetic Aperture Radar (SAR) and microwave communication system. Phase shifters are used to control the main-beam of the phased array antenna. Microstripline phase shifter is used since it is simple to design and easy to fabricate. The main objective of this paper is to design and implement a phase shifter for four elements linear sub array for SAR application. This phase shifter is provided using different lengths for scan angle 0º to 135º. RT Duroid 5870 substrate is used for its lower insertion loss. The important mathematical calculations for finding the dimensions of all the individual component is done using MATLAB and then individual components are designed and simulated using Ansoft Designer (SV) and Sonnet Lite v13.35. The presented phase shifter is designed to operate in C band frequency range between 4 and 8 GHz and center frequency is 5.3 GHz , with low insertion loss and reflection coefficients. This proposed phase shifter is suitable for a modified class of feeding networks for phased antenna arrays.

Index Terms- Microstripline phase shifter, C band, RT Duroid 5870, phased array antenna, feeding networks.

I. INTRODUCTION

Microstrip phased array antennas have been very popular for their low profile, small size, light weight, low cost, high efficiency and easy to fabricate. Many phased array antenna applications require that the direction of the main-beam lobe be changed with time, or scanned. This is usually done by mechanically rotating a single antenna or an array with fixed phased to the element. However, mechanical scanning requires a positioning system that can be costly and scan too slowly. For this reason, electronic scanning antennas which are known as phased array antennas are used. It can sweep the direction of the beam by varying electronically the phase of the radiating element, thereby producing a moving pattern with no moving parts. Figure 1. illustrates a phased array antenna and it consists of a power distribution network, phase shifters and antenna elements.[1]

Phase shifters are key elements in electronically steered phased array radar and microwave communication systems. Phase shifters are two port devices providing a change in phase of the microwave signal with very low attenuation. Depending on the manufacturing method, phase shifters can be classified into the following categories; mechanical phase shifters, ferrite phase shifters, semiconductor device phase shifters and transmission line phase shifters.

Phase shifters are mainly used in phased array radars. Because radars use typically thousands of phase shifter device elements in their structure, phase shifter performance strongly affects the phased array radar performance and cost. Phase shifter design should cater to the important design parameters such as insertion loss, power handling capability, physical size and weight.

Since typical phased array radars have large numbers of phase shifter devices, the size and weight of the device is a major design criterion while designing a phase shifter. Microstripline phase shifters have advantages over other types of phase shifters like large phase change, low insertion loss and high power handling capability. Also planar designs can be easily integrated with other subsystems such as phased array radiating elements and monolithic circuits.[2][3]

New designs of microstripline phase shifters have been considered to reduce the device weight considerably and open up possibilities of designing electrically tunable compact phase shifter devices.

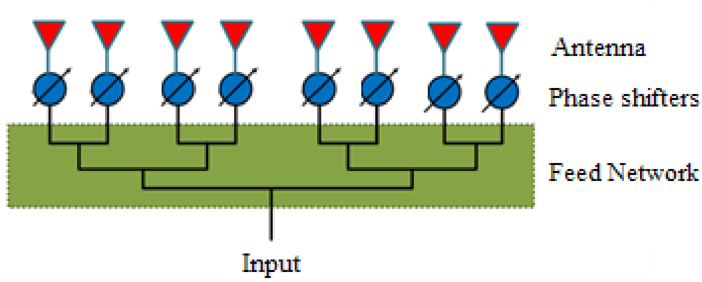

Figure 1: Phased array antenna[2]

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II. MICROSTRIPLINE PHASE SHIFTER

Among the various types of phase shifters, microstripline phase shifter type is selected for proposed system mainly because of its planar configuration. Planar designs can be easily fabricated using standard photolithography process and can be easily integrated with other microwave devices and MMICs. Design of microstripline width being one of the tasks of the device fabrication, it would be useful to understand the theory of microwave propagation on the microstripline configuration. The geometry and field lines of the microstripline configuration are shown in Figure 2. Conductor of width, *W*, is placed on the dielectric substrate of thickness, *h*, and dielectric constant, ε_r. Dielectric substrate is grounded by the brass mount. Microstripline thickness is negligible, ~ 15μ*m* in our design, when compared to the width of microstripline. Unlike stripline design, in which dielectric fills both sides of the conductor, microstripline configuration only has the dielectric filled at the bottom. Because of this structure, only partial field lines are coupled with bottom ground plane through dielectric substrate and remaining are in the air region above the substrate. So instead of fields are pure TEM wave, they are characterized by hybrid TM-TE wave combination. In order to simplify the analysis, fields are considered to be quasi-TEM wave.[4]

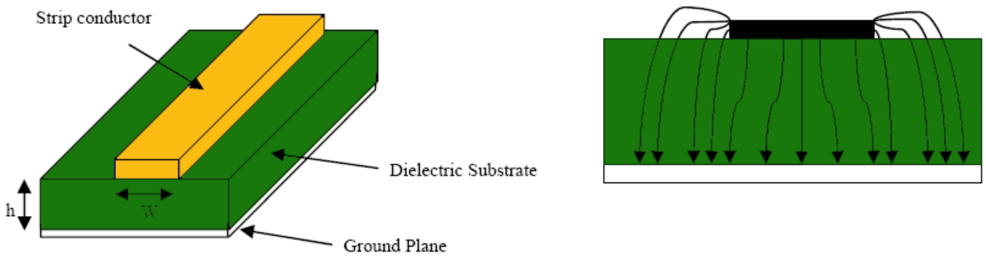

Figure 2: Microstripline geometry and EM field configuration in the microstrip on the dielectric substrate [4]

In this design, it can be shown that by varying the phase of the two transmissions, the radiation pattern is changed. The microstripline phase shifter model best describes the phase shifting process of this design. These phase shifters are similar to their attenuator equivalent where two SPDT switches are used to switch two line lengths, one of which is X degrees longer in electrical length than the other.[5]

For this phase shifter to be integrated into the feeding network of this antenna array which is used the same kind of substrate with the same height, and the input and output microstriplines must be in the same layer.

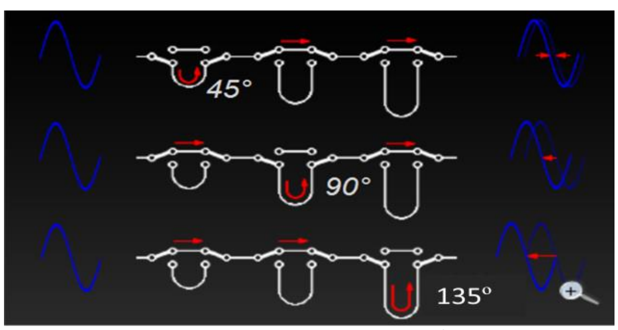

Figure 3: Microstripline phase shifter

III. DESIGN STEPS OF MICROSTRIPLINE PHASE SHIFTER

A . The Length of the Microstripline Calculation

The selected parameters for the microstripline phase shifter design are as follows:

f = Operating frequency = 2.45GHz
ε_r = Dielectric Constant of the substrate
(here ε_r = 2.33 for RT Duroid 5870 substrate)
h = substrate height = 1.5mm (59 mils)

In this schematic, the lower path has transmission length L, while the upper path has a transmission length L+ΔL. The path length L acts as a reference line as well as the reference phase. The additional length ΔL that gives the phase delay is determined by the equation given defined by:[6][8][9]

$$\Delta L = \frac{\Delta\varphi}{\beta}$$

$$\lambda_{air} = \frac{c}{f}$$

$$\lambda_g = \frac{\lambda_{air}}{\sqrt{\varepsilon_{eff}}}$$

$$\beta = \frac{2\pi}{\lambda_g}$$

Where, $\Delta\varphi$ is phase shift degree, c is the speed of light, f is operating frequency and ε_{eff} is effective dielectric constant

B. The Width of the Microstripline Calculation

$$\frac{W}{h} = \frac{8e^A}{e^{2A} - 2}, \qquad \text{for} A > 1.52$$

$$A = \frac{Z_0}{60}\left[\frac{\varepsilon_{eff} + 1}{2}\right]^{\frac{1}{2}} + \frac{\varepsilon_{eff} - 1}{\varepsilon_{eff} + 1}\left[0.23 + \frac{0.11}{\varepsilon_{eff}}\right]$$

$$\frac{W}{h} = \frac{2}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_{eff} - 1}{2\varepsilon_{eff}}\left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_{eff}}\right]\right\}, \qquad \text{for} A \le 1.52$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}}$$

Where, W is width of the microstripline, h is the height of the substrate and $Z_0$is the Input impedance. These equations are based on the work done by Hammerstad.[7]

C .The Insertion Loss of the Microstripline Calculation

The insertion loss provides information about the signal quality of the transmitted signal and the bandwidth of the interconnect. The total insertion loss is the sum of the conductor loss and dielectric loss. The insertion loss can be calculated by the following equations:

Conductor loss,

$$\alpha_c = \frac{R_s}{Z_0 W} \text{ Np/m}$$

$$R_s = \sqrt{\frac{\omega\mu_0}{2\sigma}}$$

Where, α_c is conductor loss, Z_0 is input impedance and W is width of the microstripline.

Dielectric loss,

$$\alpha_d = \frac{k_0\varepsilon_r(\varepsilon_{re} - 1)\tan\delta}{2(\varepsilon_r - 1)\sqrt{\varepsilon_{re}}}$$

$$k_0 = \frac{2\pi\pi}{c}$$

Where, α_d is dielectric loss, $\tan\delta$ is dielectric loss tangent and ε_{re} is effective dielectric constant.

Table I: Parameters of microstripline phase shifter

Parameters	**Values**
Substrate Material	RT Duroid 5870
Relative Permittivity of the substrate	2.33
Height of the substrate	1.5 mm (59 mils)
Frequency range	C band (4 – 8 GHz)
Operating frequency	5.3 GHz
Width of microstripline	4.6 mm
Length of microstripline	4.66 mm (45º) 9.33 mm (90º) 13.986 mm (135º)

IV. SIMULATED RESULTS AND DISSICUSION

The physical parameters and insertion losses of the microstripline were obtained by using MWI 2014 calculator of Rogers Corporation. The designed parameters are utilized on Sonnet Lite software and Ansoft Designer (Student Version) for performance simulations.

A. Insertion Loss

The insertion loss provides information about the signal quality of the transmitted signal and the bandwidth of the interconnect. Insertion loss is measured in unit of dB. The ratio of the amplitude of the signal at the end of the interconnect to the incident signal should be 1. In dB, a ratio of the amplitudes of 1 corresponds to 0 dB. As attenuation increases, the value of the insertion loss, in dB gets to be a larger, negative number. Insertion loss is the total of conductor loss and dielectric loss. The insertion loss is down to -3 dB as a measure of the bandwidth of the interconnect.[11] Figure 4. illustrates the comparison of the insertion losses on three different materials. From the figure, RT Duriod 5870 material has the lowest insertion loss and it is chosen for proposed system.

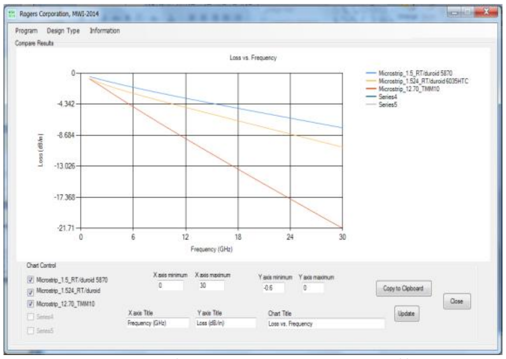

Figure 4: Comparison of the insertion losses on different materials

The necessary conductor loss and dielectric loss could be calculated using Rogers Corporation's MWI 2014 microstrip calculator. The relative permittivity and loss tangent, per Rogers Corporation, of the RT Duroid 5870 is 2.33 and 0.0012, respectively. For the first build, the substrate thickness is 59 mils or 1.5 mm and the thickness of the copper tape is 15.24 µm.

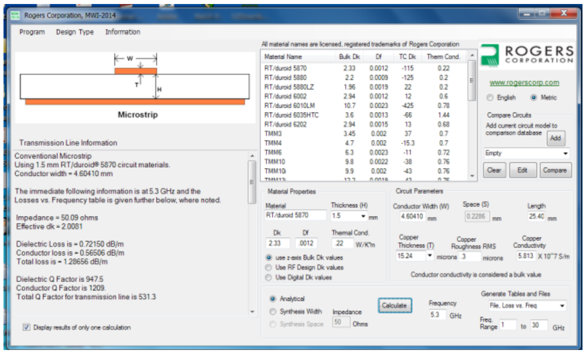

Figure 5: Insertion loss calculation using MWI 2014 calculator

The calculated insertion losses of the RT Duroid 5870 substrate is shown in Figure 6. Insertion losses were calculated for various frequency ranges. Insertion loss is the total of dielectric loss and conductor loss. From the figure, the insertion is about 1.3 dB/m at 5.3 GHz frequency. This value is good agreement for microstripline phase shifter design.

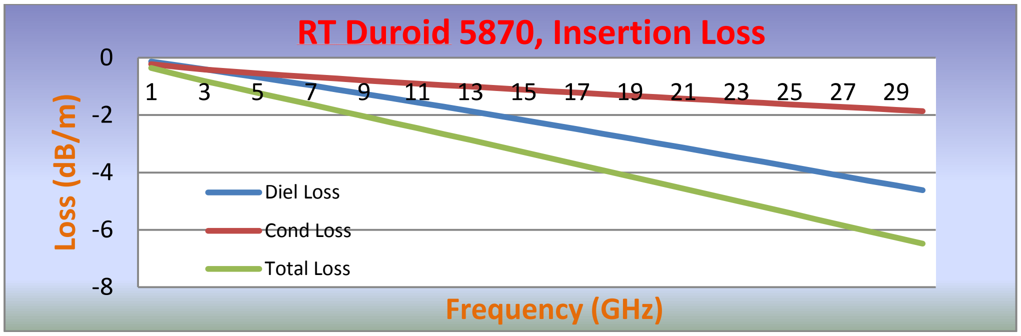

figure 6: Insertion loss of RT Duroid with various frequencies

B. Impedance Matching (Return Loss)

The return loss provides information about the impedance match of the interconnect to a 50Ω system, while the insertion loss provides information about the signal quality of the transmitted signal and the bandwidth of the interconnect. The bandwidth, of course, is a rough indication of the highest data rate that can be transmitted through the interconnect. Return loss is measured in units of dB. This is a great source of confusion. A small amount of reflected amplitude, an indication of a good impedance match, would be a large, negative number in dB. An exceptionally well matched interconnect would have a return loss of -40 dB. If there is a 5Ω impedance mismatch somewhere in the system, out of 50Ω, the reflected signal amplitude would be about 5%. This corresponds to a return loss in dB of -25 dB. A marginally acceptable return loss, especially at high frequencies, is typically about -15 dB. An open, a really bad interconnect, would be 0 dB.

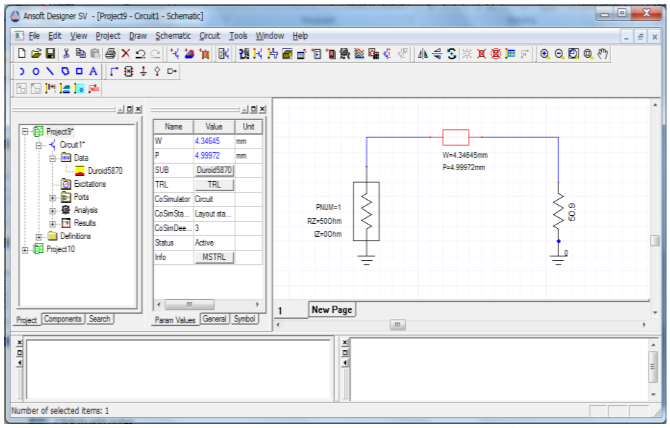

Figure 7: Impedance matching simulation set up on Ansoft Designer (SV)

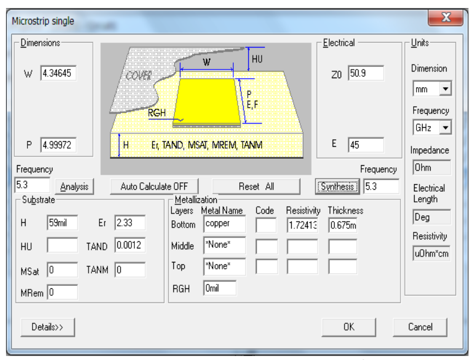

Figure 8 : Microstripline calculation on Ansoft Designer (SV)

The S11 parameter for the proposed phase shifter design was calculated and the simulated return loss results are shown in Figure 9. The value of return loss is -55.90 dB in this proposed phase shifter design. The achieved return loss value is small enough and frequency is very closed enough to the specified frequency band for 5.3 GHz. The value of return loss i.e. -55.90 dB shows that at the frequency point i.e. below the -10 dB region there is good impedance matching. A negative value of return loss shows that this microstripline phase shifter design had not many losses while transmitting the signals.

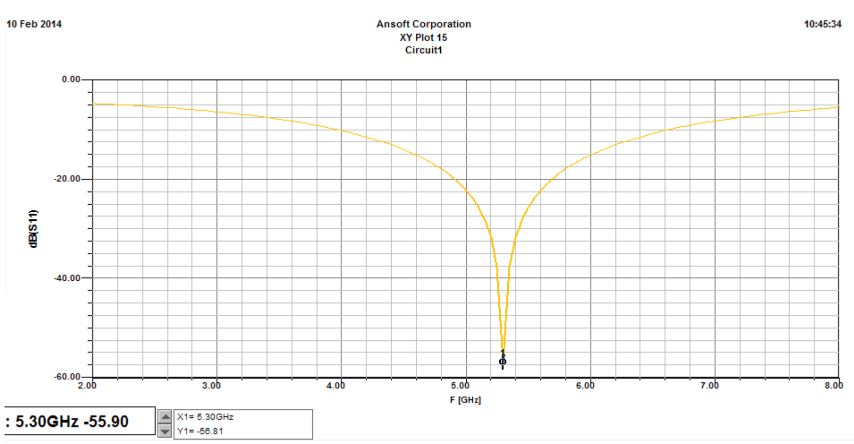

Figure 9 : Return loss of microstripline phase shifter

C. Current Distribution

At first the important mathematical calculations for finding the dimensions of all the individual components is done using MATLAB and then the individual components are designed and simulated using Sonnet Lite. After getting good results all the individual components are combined on a single substrate to implement and simulate using Sonnet Lite. In this paper -45º phase shifter is simulated as an example. The phase shifter is implemented using the microstriplines and the length of the microstriplines are calculated using MATLAB. Optimum design is given below:

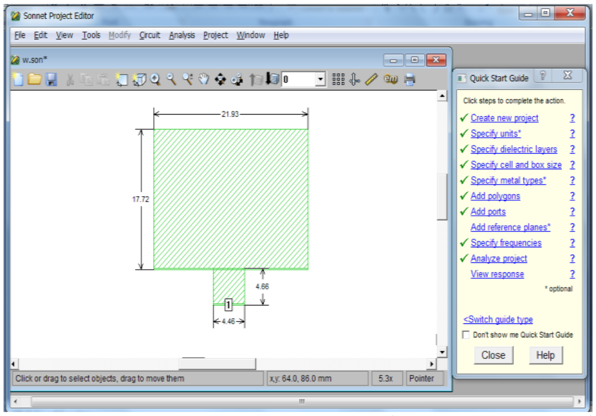

Figure 10: Patch and microstripline geometry for 45 degree phase shift

Figure 11. demonstrates the current distribution on the single patch element and microstripline phase shifter at operating frequency 5.3 GHz and figure shows simulated results of the -45º phase shift at 5.3 GHz frequency. The phase shift value is -44.83º and it is very close to the target value -45º phase shifting.

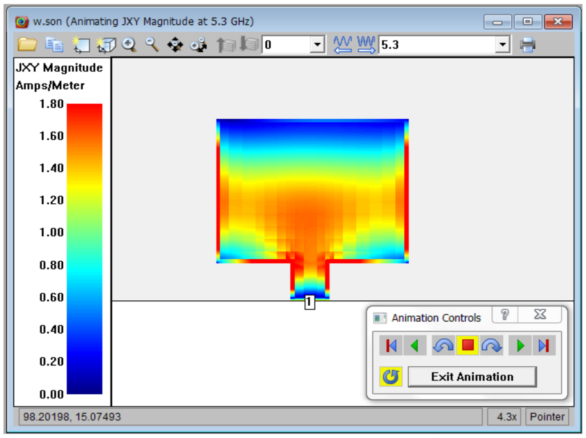

Figure 11: Current distribution at 5.3 GHz frequency

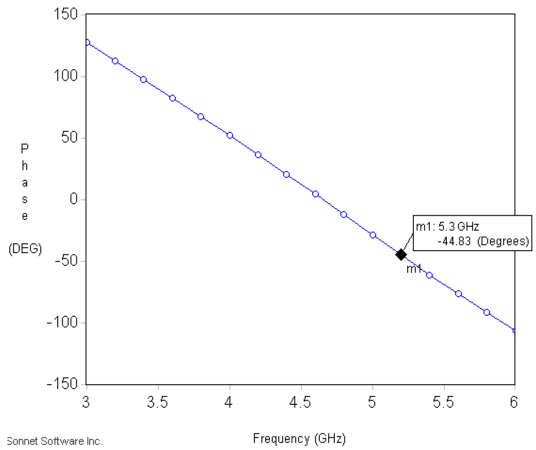

Figure 12: Phase shift degree at 5.3 GHz

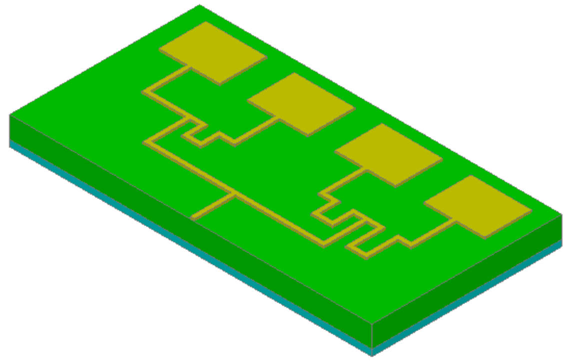

Figure 13: Auto CAD model of four element sub array and microstripline phase shifter

V. Conclusion

This paper has been presented the design and performance analysis of Microstripline phase shifter for four elements sub array system for Synthetic Aperture Radar (SAR) application. Important physical dimensions were calculated in MATLAB and MWI calculator 2014. Sonnet Lite software and Ansoft Designer (SV) were used to implement the performance of the microstripline phase shifter. Four patch elements were arranged in linear array form for sub array of SAR antenna application. Four different length microstriplines were selected to achieve 0º, 45º, 90º and 135º phase shift angle. This proposed phase shifter model is cost effective, high efficiency and impact design for the applications in C band (4-8 GHz) frequency range. The optimum design parameters (dielectric material=RT Duroid 5870, height of the substrate=1.5 mm, operating frequency=5.3 GHz) were used to achieve the compact array-feeder network and integrated phase shifter design on the same substrate material. It provides a insertion loss of 1.28 dB/m, -55.90 dB return loss and VSWR < 2 is achieved over the complete frequency band with linear polarization of antenna in the desired part of the beam.

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