Design And Performance Analysis Of Rotman Lens

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Abstract

This paper presents a trifocal Rotman lens antenna design approach. A three beam prototype feeding an 8-element antenna array working at C band has been simulated using RLD v1.7 software.Simulation results show that the designed lens shows good performance in the operating frequency band of (4-5GHz).

Keywords— **Array factor, beam ports, array ports, scanning angle, focal ratio.**

I. INTRODUCTION

Due to the advancements in wireless communication technology, smart antenna arrays which support multi beams and are capable of providing wide angle scanning over a broad frequency range have become an obvious choice in numerous cutting edge applications. In order to achieve reliable ,low cost, multi beam phased arrays, the Rotman lens is an attractive beam-forming network. Rotman lens is widely used in applications such as ECM, Radar systems, automotive adaptive cruise control (ACC) systems and satellite communication systems. The popularity of Rotman lens for many electronic scanning applications is due to its simple design and compact size. W.Rotman and R.Turner first proposed the Rotman lens which consist of air filled parallel conducting plates fed by co-axial probes [1]. D.Archer [2] gave a modified design of Rotman lens in which a dielectric material is filled between parallel conducting plates fed by microstrip lines. Rotman lens provides linear phase shifts at the output ports by utilizing different propagation paths within the lens structure. At high microwave frequencies the losses increase due to increase in surface resistance as-

$$R_s = \sqrt{\frac{\pi f \mu}{\nabla}}$$

$$\text{Rs} = \frac{1}{\sigma \partial}$$

Where $\sigma, \nabla, \partial, f, and\, \mu$ represents conductivity, skin depth , frequency and permeability respectively [3].

Design of physical structure at high microwave frequencies is challenging issue. Also at low frequencies the Rotman lens realization becomes quite larger and so it is difficult to integrate it in compact transceiver designs.

In this paper Rotman lens is proposed which is capable of scanning at an angle of ± 45 and has a medium of dielectric constant of 4.6 in between the two contours.The center frequency of lens is 4.6GHz which lies in the C band and the design of the lens is adapted from the formulas found in [1] and [4]. Simulations were carried out using RLD 1.7 designer software and various performance analysis parameters such as array factor, insertion loss, S-parameters and phase error are analysed to prove the effectiveness of the proposed Rotman lens design at such a high frequency.

This paper is organized as follows: Section II presents lens design approach in which trifocal Rotman lens design equations and its important design parameters are discussed.Section III presents a design example of Rotman lens. In section IV simulation results of the designed Rotamn lens are presented and finally in section V conclusions are drawn.

II. LENS DESIGN APPROACH

Fig.1 shows a schematic diagram of a trifocal Rotman lens. Input ports lie on contour C1 and the output ports lie on contour C2. C1 is known as beam contour and C2 is known as array contour. There are three focal points namely F1, F2 and F3. F1 is located on the central axis while F2 and F3 are symmetrically located on the array contour at an angle of +α and – α respectively. It is quite clear from Fig.1 that the co-ordinates of two off-axis focal points F2, F3 and on one axis focal point F1 are ($-f_2\cos\alpha$, $f_2\sin\alpha$), ($-f_2\cos\alpha$, $-f_2\sin\alpha$) and ($-f_1$, 0) respectively.

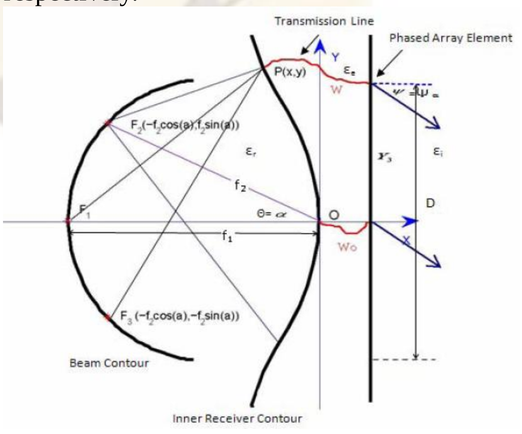

Fig.1 Trifocal Rotman Lens Schematic Diagram.

where

f_1-On axis focal length

f_2 -Off axis focal length

α -Off center focal angle

ψ_α -Scanning angle

$\gamma = \dfrac{\sin\psi}{\sin\alpha}$ - beam angle to ray angle ratio given as ratio of sine of their angles.

ε_r-Permittivity of medium in between the lens contour

ε_e - Permittivity of medium of transmission line

ε_i -Permittivity of medium of radiating element

$\beta = \dfrac{f_2}{f_1}$ -Focal ratio

w_o - Transmission line length between axis point 'O'and radiating element.

w -Transmission line length between point 'P'and radiating element.

FiP-It is the physical distance from focal point Fi to P.

ξ is another important parameter that relates the distance Y_3 of any point on the array contour from the axis, to f_1. ξ controls the portion of phase and amplitude error curves that the lens experiences [4].

It is given by- $\xi = \dfrac{Y_3\gamma}{f_1}$.

If we assume that the ideal focal points are located at $\theta = \pm\alpha$ and 0, and their corresponding radiation angles are $\Psi = \pm\Psi\alpha$ and $\Psi = 0$, given $\Psi\alpha$ is a known angle, simultaneous equations 1-3 are satisfied:

$$F_2P\sqrt{\varepsilon_r}+w\sqrt{\varepsilon_e}+Y_3\sqrt{\varepsilon_i}\sin\psi_\alpha = f_2\sqrt{\varepsilon_r}+w_0\sqrt{\varepsilon_e} \text{ --------(1)}$$

$$F_3P\sqrt{\varepsilon_r}+w\sqrt{\varepsilon_e}-Y_3\sqrt{\varepsilon_i}\sin\psi_\alpha = f_2\sqrt{\varepsilon_r}+w_0\sqrt{\varepsilon_e} \text{ --------(2)}$$

$$F_1P\sqrt{\varepsilon_r}+w\sqrt{\varepsilon_e} = f_1\sqrt{\varepsilon_r}+w_o\sqrt{\varepsilon_e} \text{ ----------(3)}$$

Also we have-

$F_2P^2 = (-f_2\cos\alpha - X)^2 + (-f_2\sin\alpha + Y)^2$ ------------(4)

$F_3P^2 = (-f_2\cos\alpha - X)^2 + (-f_2\sin\alpha - Y)^2$ ------------(5)

$F_1P^2 = (f_1 + X)^2 + (Y)^2$-----------------------------(6)

By algebraic manipulation of the above equations we can obtain geometric lens equation which is quadratic in nature and is given by-

$$a.\frac{\varepsilon_r}{\varepsilon_e}.W^2 + b\frac{\sqrt{\varepsilon_r}}{\sqrt{\varepsilon_e}}.W + c = 0 \text{ ----------------(7)}$$

Where-

$$a = 1 - \frac{(1-\beta)^2}{(1-\beta C)^2} - \frac{\varepsilon_i\xi^2}{\varepsilon_r\beta^2}$$

$$b = -2 + \frac{2\varepsilon_i\xi^2}{\beta\varepsilon_r} + 2\frac{(1-\beta)}{1-\beta\cos\alpha} - \frac{\xi^2S^2(1-\beta)}{(1-\beta C)^2}\frac{\varepsilon_i}{\varepsilon_r}$$

$$c = -\xi^2 + \frac{\xi^2S^2}{(1-\beta C)} - \frac{\xi^2S^4}{4(1-\beta C)}\frac{\varepsilon_i}{\varepsilon_r}$$

W -Normalized relative transmission line length and is given as $W = (\dfrac{w-w_o}{f_1})$.

S=sinα and C=cosα

It is important to note that the number of beams, number of elements, maximum beam angle and element spacing are known from the system requirement and so the task is to select the optimum values of α , β , γ and f_1/λ [4].

Element spacing d is also very critical as it controls the appearance of grating lobes. The spacing that just admits a grating lobe is given by-

$$\frac{d}{\lambda} = \frac{1}{2+\sin\psi_m} \text{ ------------------------(8)}$$

where Ψ_m is the maximum beam angle.

III. DESIGN EXAMPLE

The Rotman lens is designed in microstrip configuration to meet the following specifications: Angular coverage= ±45°, number of antenna elements=8, number of input beams = 3, central frequency = 4.6GHz. The lens structure is fabricated in a microstrip version on a substrate of thickness 1.2mm and dielectric constant of 4.6. The loss tangent is 0.0012. In order to guarantee a correct operation of the lens, reflections within the lens must be avoided. In microstrip configuration this is obtained by employing dummy ports.

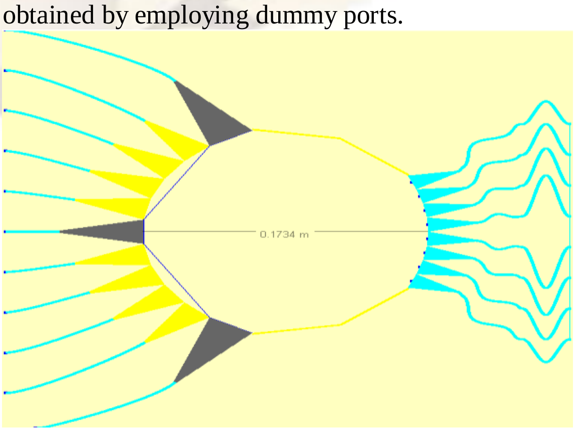

Fig.2 Simulated Rotman Lens.

IV.SIMULATION RESULTS

The Rotman lens with the specifications mentioned in section III is designed and simulated using RLDv1.7 software. The radiation pattern are shown in Fig.3 and from this it is quite clear that good results are obtained in terms of both the side lobe level and main lobe direction. There are three main lobes for the three beam port excitation. For plotting the radiation pattern all the beam ports are excited with equal amplitude and phase.

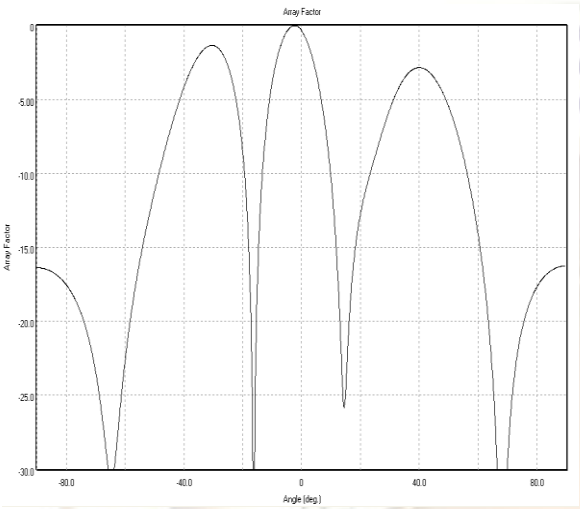

Fig.3 Array factor plot.

The phase distribution across the aperture is shown in Fig.4. Phase error across the aperture takes place for each beam port excitation. The curve in Fig.4 is for port2 excitation at 4.6GHz. It is observable that the highest phase error of the trifocal occurs at the edge receiving ports. Averagely low phase errors have been maintained across the array aperture. Port 4 and Port11 have exhibited the highest phase error of upto 0.35° for the given lens.

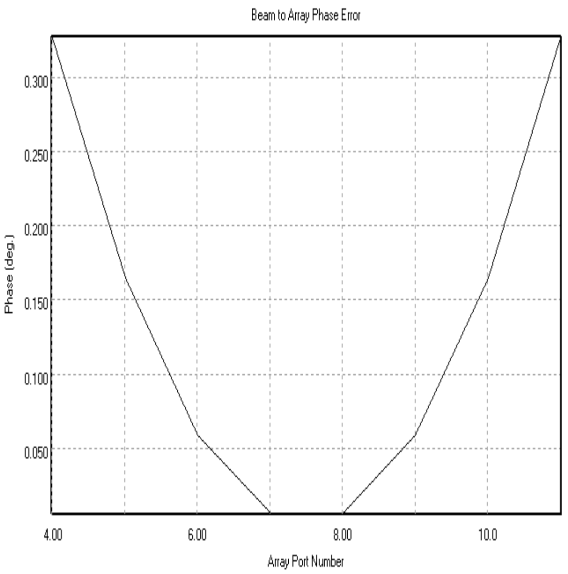

Fig.4 Phase distribution of Rotman Lens.

Fig.5 shows the array ports amplitude distribution for beam port2 excitation at 4.6GHz. It is observable that for array port 7 and 8 beam to array coupling amplitude is of the order of -11.9dB, which shows good coupling condition.

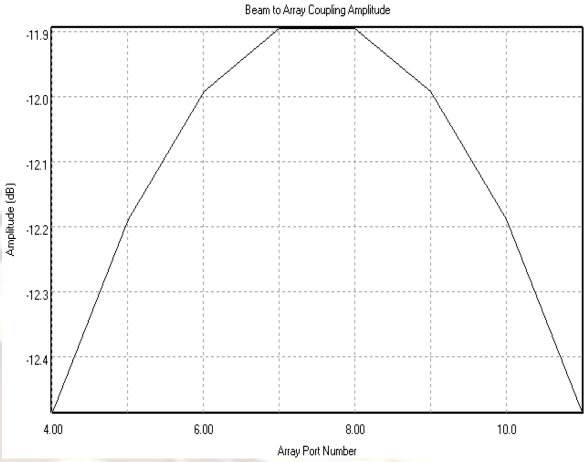

Fig.5 Amplitude distribution of array ports.

Fig.6 and Fig.7 shows the variation of S-parameters with frequency for port2 excitation. It is observable that within the operating frequency band of 4-5GHz S-parameter values are better than -10dB.

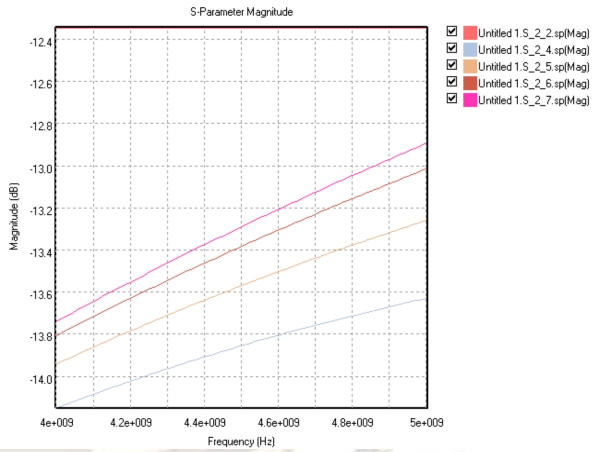

Fig.5 S-parameter(S2_2 to S2_7) magnitude vs. frequency.

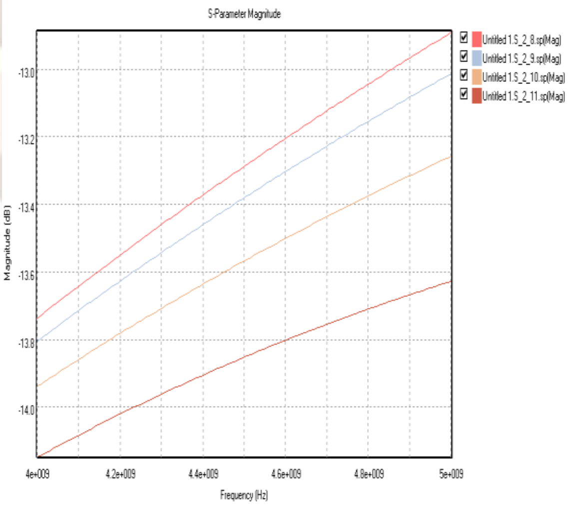

Fig.6 S-parameter(S2_8 to S2_11) magnitude vs. frequency.

V.CONCLUSIONS

A design approach for the trifocal Rotman Lens has been presented. A C-band lens prototype with three beam ports feeding eight-element array has been simulated. The simulated lens has shown very good performance in terms of radiation pattern and S-parameter values, beam port to array port coupling magnitude and also exhibits low phase errors. Future work will focus on further reducing the phase error, return loss and also enhancing the scanning capability of the Rotman lens.

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