Cylindrical Dielectric Resonator Antenna Array with Beam Steering Capability

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Abstract: In the proposed work, linear array of four Cylindrical Dielectric Resonator Antenna having beam steering capability has been designed and investigated. A specific progressive phase distribution between the array elements is controlled by introducing the appropriate delay lines in the feeding network. No need of any phase shifter and biasing network make the array design simple and less costly. The proposed design with impedance bandwidth of 500MHz at 7.75GHz frequency along with the gain of nearly 8.5dBi could be used in radar communication and other wideband wireless applications operating in X-band for moving targets.
Keywords: Cylindrical Dielectric Resonator Antenna, Beam steering array, corporate feed.

I – INTRODUCTION

More degree of freedom of Dielectric Resonator Antenna (DRA) makes it suitable candidate for array design as compared to popular micro-strip patch antenna at microwave frequencies [1-9]. Previous research reported on phased array shows feed networks for antenna array and for other applications using MIC/MMIC technology [10-11]. Concept of Beam-formation by tuning the load reactance at parasitic elements surrounding the active central element has been investigated with DSP algorithm [12] and Dielectric Resonator antenna [13]. Frequency controlled active phased array [14], Reactively Steered Ring Antenna Array [15], Fabry–Pérot Antenna with two-dimensional electronic beam scanning [16] and liquid crystal phase shifter based dielectric resonator antenna array have also been proposed [17]. A transmissive meta-atom is also proposed with a full 360° phase circle using three and two metasurface layers to implement the phase distribution for X- band quad beam transmit array [18]. Above discussed array designs either concentrate on active elements and supporting biasing network or loading of parasitic elements for proposed phased network. However it increases complexity and also the cost of overall design. In the present work, progressive phase shift between the consecutive elements of array has been obtained through the feeding network itself by introducing suitable delay lines in feed path. Delay lines provide the excess time gap and hence corresponding phase delay for the excitation of antennas. Position of power distribution points in parallel feed lines has been shifted at appropriate amount to introduce extra delay in excitation of each element as shown in Fig. 1(a). In 2nd approach, suitable delay lines are introduced in feed path to provide excess time delay and hence phase delay to the excitation of antennas as shown in fig- 1(b). In contrast to putting additional delay lines in feed path to each element, this 1st approach has advantage of lesser feed length and hence less conductive losses. Proposed feed network is capable to steer the peak of beam in desired direction of up to 45°. Prototype of feed network of 1st design and cylindrical dielectric resonator antenna have been fabricated (fig. 1(c & d)) and experimental results are validated with simulation results. Array has shown the impedance bandwidth of nearly 500MHz at 7.75GHz frequency. Advantage of the proposed array is its large gain of 8.5dBi as well as beam steering capability for simple and low cost feed network without need of any phase shifter and biasing network.

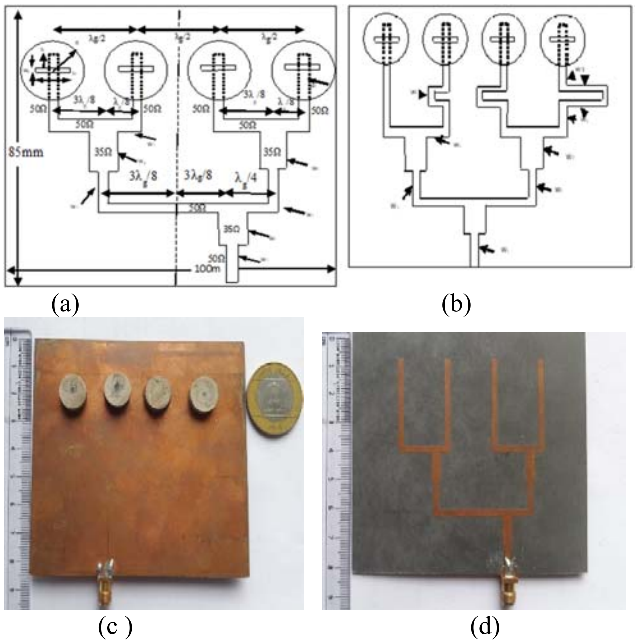


Fig. 1 – (a) Schematic diagram of static phased array using shifted feed point, (b) Schematic diagram of static phased array using multiple feed line (c) Feed network of array prototype, (d) top view of antenna array

II-BEAM STEERING ARRAY OF 4 CDRA ELEMENTS

Fundamental TM_{110} ($HE_{11\delta}$) mode of Cylindrical Dielectric Resonator Antenna (CDRA) has broadside radiation pattern and can be made narrow beam pattern by using the uniform array of CDRAs. The performance of individual CDRA is simulated by finite integration technique based commercial software CST [19]. Other important parameters of design are summarized in Table-**1.** Computed resonant frequency of CDRA has been found to be 7.69GHz for the dielectric material Rogers 3010 having permittivity of 10.2 [2-4]. CDRA is excited with rectangular slot etched on ground substrate of Rogers 5870 material with permittivity of 2.33. Antenna is perfectly matched at 7.65 GHz close to the predicted frequency of 7.69GHz with impedance bandwidth of 0.7GHz. Individual antenna has shown gain of 2dBi in H-plane while in E-plane, gain is 6 dBi at the direction of 39°. H & E plane linear array of 4 CDRA elements are spaced with $\lambda_g/2$(19.75mm).

Table-1 Design Parameters of Array

Parameters	Value	Parameters	Value
H (CDRAs height)	3.84mm	Ground plane	100*85mm^2
R (CDRA radius)	6mm	S_L (open stub length from slot)	4.5mm
h(substrate height)	0.787mm	Wavelength(λg)	39mm
L_S (length of slot)	6mm	W_s (Width of slot)	1mm
W_1(width of transmission line)	2.4mm	W_2 (width of λ/4 transformer)	4mm

To scan the moving target, beam of array has to be steered other than the boresite. To steer the peak in the direction of θ_0 , ψ must be zero as

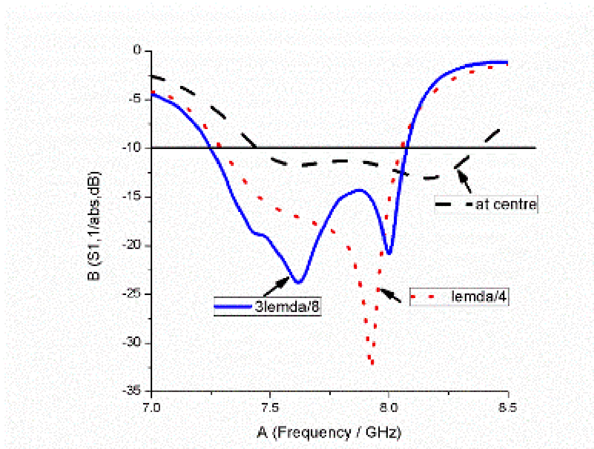
$$\psi = \beta d \cos\theta_0 \pm \alpha \qquad (1)$$

Where ψ = total phase difference in electric field of individual elements at far distance, β = phase constant, d = separation between the elements (λ/2 for proposed array design, θ_0 = angle at which peak has to steer, α = progressive phase difference between the elements. To steer the peak at 45°, the needed progressive phase difference between the excitation should be 127° as per eqn-1. However the parametric analysis in simulation shows that the desired tilt of 45° can be achieved with progressive phase difference of 90° between the elements. 90° phase difference between elements is achieved by introducing the λ/2 path difference as per equations – 2.

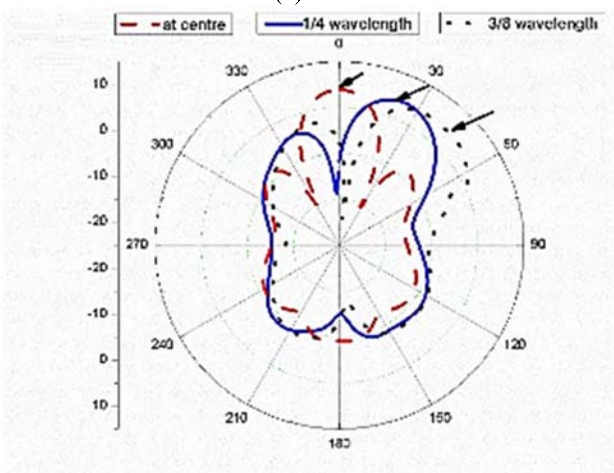
$$\Delta\theta = \left(\frac{2\pi}{\lambda}\right) \times \Delta d \qquad (2)\ \ [4]$$

Δθ= phase difference, Δd= path difference

Further needed phase difference has been compensated through propagation or dispersion induced phase variation in the design. In our design, the positions of power distribution to feed lines have been shifted in appropriate amount to introduce extra delay in excitation of each element as shown in fig 1(a-d). Peak of the pattern can be steered in any desired direction up to 45° by placing the junction or power distribution points at proper places corresponding to appropriate delay lines and phase difference to each elements of linear array. Simulated Return loss and Steering of peak as a function of shifting of power junction feed point has been shown in fig. 2 (a & b).



(a)

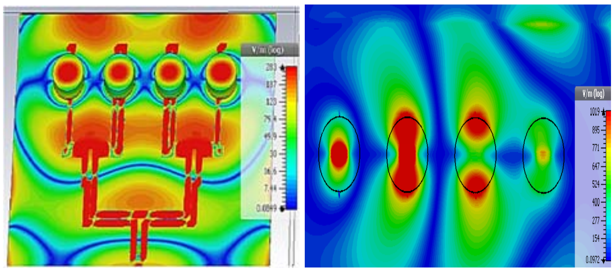


(b)

Fig. 2 – **(a)** Return loss curve (b) Far-field gain as a function of power junction feed point

III- RESULTS & DISCUSSION

Three λ/4 transformer having impedance of 35Ω have been used to distribute the equal amount of power to each individual CDRA array from the 50Ω feed line as shown in fig 1(a). To avoid large numbers of discontinuities, junction feed point has been shifted at one side by the amount of 3λ/8(14.80 mm) with reference to center and hence suitable delay lines have been introduced for required phase shift. Large numbers of discontinuities at short interval in feed lines and the phase variation as a function of frequency itself provide the impedance matching at 7.5GHz frequency in the 700MHz frequency band only in simulation, while at other frequencies impedance matching and efficiencies are going to be poor. Simulated electric field shown in fig. 3 (a-b) for equi-phased array and beam steered array (assymetric) verify the required phase delay for excitation of array elements and hence steering of beam in desired direction. Prototype of proposed array has been tested with Agilent vector network analyzer (E5071C) and radiation pattern in anechoic chamber at Microwave radiation laboratory. Measured return loss curve plotted in fig- 4 validates the concept and excitation of these modes. However modes are shifted to higher frequency side in the measurement. Measured impedance bandwidth for prototype has been observed around 500MHz (7.6GHz-8.1GHz) as plotted in fig-3. 1st mode obtained at 7.7GHz which was supposed to excite at 7.65GHz corresponds to dominant $HEM_{11\delta}$ mode of CDRA. 2nd resonance at 8GHz is due to rectangular slot which is verified in simulation without CDRA. As shown in Fig. 2, for the case of power junction at center, only two modes corresponding to dominant mode of CDRA and slots resonance is obtained. However when the power junction point is shifted from the centre, fundamental $HEM_{11\delta}$ mode is affected and hence another mode though not fully excited is seen in simulation as well as measurement results.



(a) (b)

Fig. 3 (a) Electric field distribution in equi-phased array at 7.5GHz, (b) Electric field distribution in beam steered array at 7.5GHz

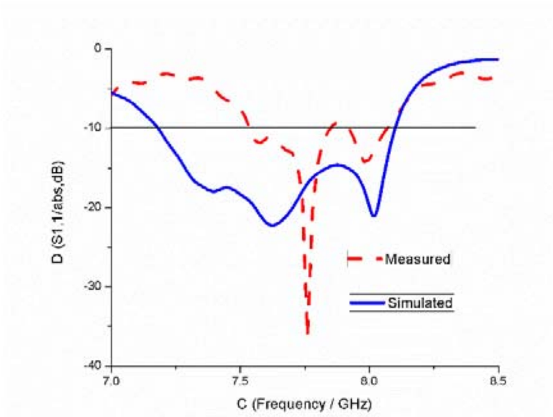
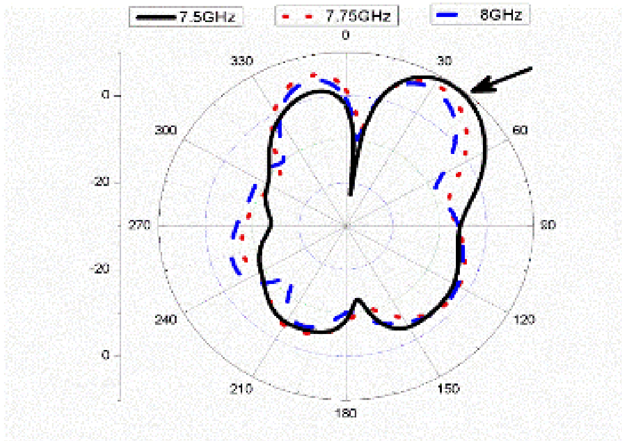
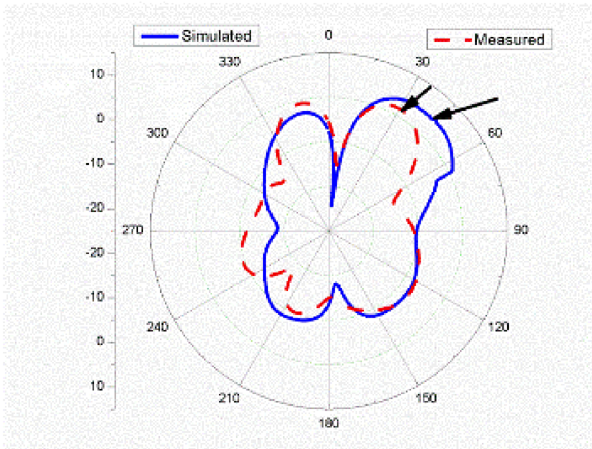


Fig. 4 **-** Return loss curve

Almost same far-field gain pattern has been observed at various frequencies in desired impedance band (fig.5-a) with null at θ=0° however peak gain is reduced as frequency has moved upward. Simulated gain of 9.56 dB peak , at targeted θ = -45° direction has achieved for design at 7.5GHz with beam-width of 30.9° and side lobe level of 6.2 dB while measured gain pattern have peak tilted at θ = -40° by proposed feed network as shown in fig. 7. Measured Gain pattern with peak of 8.5 dB achieved at 7.5GHz also validate the beam steering concept of array as proposed. Slight variation in simulated and measured results is attributed to 2% design tolerances in antenna height (due to layered material structure) and fabrication tolerance related to presence of possible thin air gap and glue in the proposed design.Nearly 90% radiation and total efficiency has been shown by the array in the proposed band.



(a)



(b)

Fig. 5 – (a) Simulated Far-field gain pattern at various frequencies (b) Far-field gain pattern at 7.5GHz

No need of phase shifter and associated circuitry to steer the beam is a big advantages of this simple feed network for conventional CDRA and is compared with previously reported linear dielectric resonator arrays in table-3. Comparison shows the acceptable performance along with beam steering capability by using simple and less costly feed network. Gain of the proposed array may be less compared to other designs as shown in table-2 as the present array design consists of only 4 elements however the design is simple, less costly, having beam steering capability without the presence of any external phase shifter and biasing network.

Table-2 Performance comparisons of proposed beam steered array of with previous reported work

Types of array	BW (%)	Frequency (GHz)	Gain (dBi)	Characteristics
Rectangular linear Dielectric Resonator Antenna array[5]	9.6%	6.7	11.8	4 element linear array with corporate micro- strip feed
Rectangular linear Dielectric Resonator Antenna array[6]	8%	2.3	-	Probe fed rectangular 4 element linear array for beam forming with mutual coupling compensation
Template based Dielectric Resonator Antenna[7]	12%	60	10.5	Monolithic Polymer-based DRA Array,
Proposed work	7%	7.75	8.5	4 element linear CDRA array with beam steering capability using slot fed corporate feed

IV-CONCLUSION

Asymmetric corporate feed network to get required delay line to steer the peak of beam is presented in this paper. Peak of the pattern is steered in any desired direction up to 45^o by placing the power distribution points at appropriate positions, corresponding to required phase difference to each elements of linear array. Advantage of the proposed array is its large gain of 8.5dB as well as beam steering capability for simple and low cost feed network without any additional phase shifter and biasing network. The proposed design with impedance bandwidth of nearly 500MHz at 7.75GHz frequency along with gain of nearly 8.5dB could be used in radar communication and other wideband wireless applications operating in X-band for moving targets.

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