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SUPERPOSITION OF REFLECTARRAY ELEMENTS FOR BEAM SCANNING WITH PHASE RANGE ENHANCEMENT AND LOSS IMPROVEMENT

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ABSTRACT

The utilization of varactor diode is advantageous as it offers the beam scanning capability as required for reflectarray antenna but it often said as the contributor to high losses. A superposition of reflectarray elements controlled by varactor diode is evaluated with dynamic phase range enhanced and loss improved at Ku-band for a successful design of an antenna element in the array environments. Simulated results of reflectarray element under normal incidence of two designs with capacitive variation integrated represents the use of varactor is executed by CST Microwave Studio. In capacitance range of 0.08p to 1.0pF, a dynamic phase range of 323^0 demonstrates at 13.964 GHz and 14.828 GHz with reflection loss 1.66 dB and 0.99 dB respectively as a result of superposition.

Keywords: beam scanning, reflectarray, linear array, capacitive, varactor.

INTRODUCTION

The best features of phase array and parabolic reflector antenna is combined in reflectarray design. It consists of a primary feed that illuminates a flat or curved reflecting surface made up of radiating printed elements as shown in Figure-1. These elements are designed to reradiate the incident field with a phase distribution on the aperture to produce a shaped beam with scan angle required in the far-field. The phases introduced by each of the elements are those that compensate the different path lengths from the primary feed.

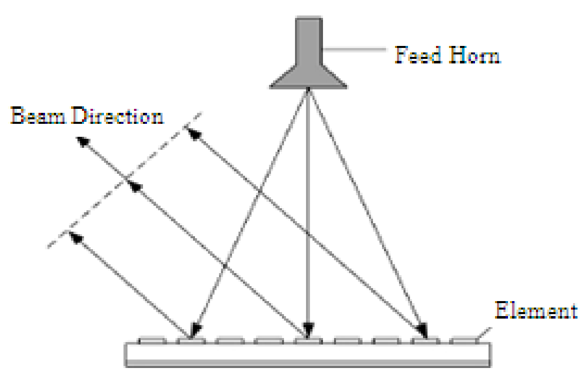

Figure-1. Geometry of reflectarray antenna.

In reflectarray design with the ability to scan the beam, the phase of each element needs to be changed dynamically in the range up to 360^0 (Targonski and Pozar, 1994). Reconfigurable reflectarray can produce different patterns on the same structural elements electronically. It was done with the integration of elements with components such as PIN diodes (Kamoda, Iwasaki et al. 2011) and varactor diode (Hum and Okoniewski 2004) which both of this component have the advantageous because of the maturity of the technology. The integration with varactor in single element demonstrates a great phase range but the S-curve is too steep with high reflection loss. This shortcoming can be overcome with superposition of two different element designs proposed that is Concentric Circle Square Ring (CCSR) and Circle Ring Patch (CRP) which will present lower loss with greater phase range at Ku-band.

ELEMENTS DESIGN

The proposed reflectarray design is a combination of CCSR and CRP with varactor diode integrated at the same position depicted in Figure-2 and specifications are mentioned in Table-1. The Roger 5880 substrate (dielectric constant, ε_r = 2.2 and tan δ = 0.0009) with height, h = 0.787 mm has been used. The cell dimension, d is $0.42\lambda_o$ in preventing the grating lobes (A. M. Abd-Elhady, 2012).

A single component varactor diode of MGV-125 from Aeroflex will be integrated to the element as shown in Figure-2. The MGV-125 varactor diode is hyperabrupt, gallium arsenide (GaAs) diode can be operated at high frequencies and provides higher degree of tunability which also offers low capacitance range below 2.0pF and low series resistance. The package parasitic effects with estimated parasitic resistance 1.7 ohm from material itself and 0.4 nH inductance by the installation of package material are taken into account. The capacitance value is simulated from 0.08p to 1.0p in order to tune the phase of the field reflected by the element while maintaining the size of patch.

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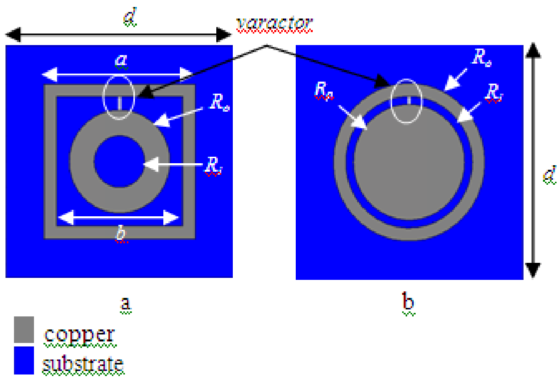

Figure-2. Dual elements design in proposed reflectarray element a) CCSR design b) CRP design.

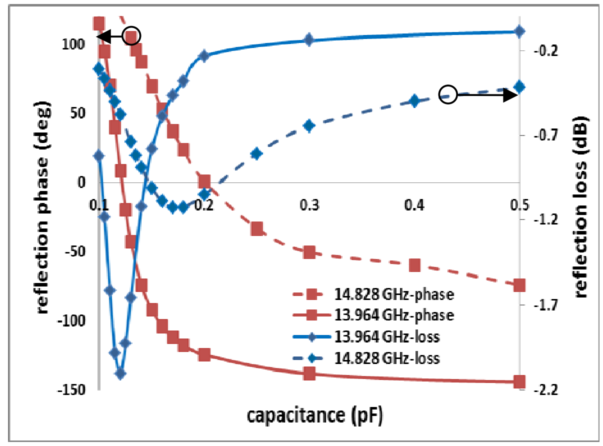

Figure-3. Reflection loss and reflection phase versus capacitance–design in dual configurations.

Table-1. Dimension of elements.

CCSR (mm)	CRP (mm)
a = 6, b = 5	R_p = 2.2
R_o = 2, R_i = 1	R_o = 3, R_i = 2.5

SCATTERING CHARACTERISTICS

The phase range is computed at dual operational frequencies which are 13.964 GHz and 14.828 GHz. The performance of scattering characteristics for individual design of CCSR and CRP at both frequencies for capacitance variation in range of 0.1 to 0.5 pF is shown in Figure-3. It can be seen that CCSR design will contribute 304^0 phase variation at 13.964 GHz and 256^0 at 14.828 GHz with reflection loss up to 2.1 dB and 2.2 dB respectively. Whereas CRP design provide 77^0 phase range at 13.964 GHz with 0.3dB losses but contribute greater phase range which is 229^0 at 14.828 GHz with only 0.99 dB losses. By combining two designs of CCSR and CSRP element, it can be observed in Figure-4a and 4b the scattering phase will overlay at both operational frequencies. A dynamic phase range will possible increased to 323^0 with lower reflection loss than single design itself and can be accomplished by superposition of two element designs. It will overcome the shortcoming of individual design in term of dynamic phase range and loss. The comparison between three configurations is summarized in Table-2.

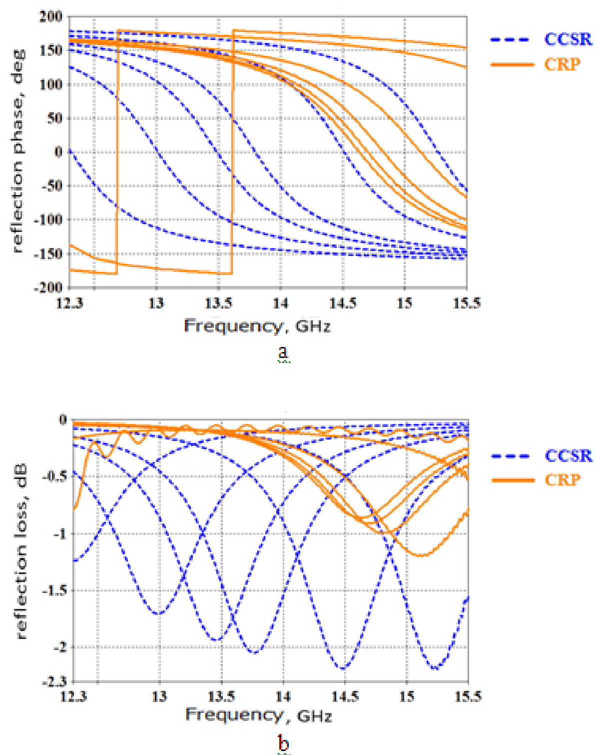

Figure-4. Scattering properties of dual elements a) Reflection phase versus frequency b) Reflection loss versus frequency.

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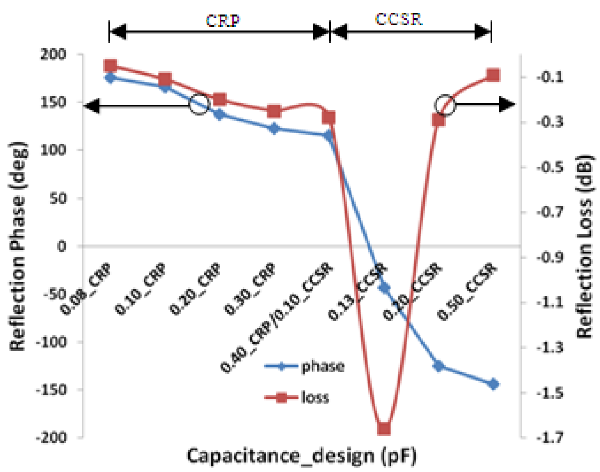
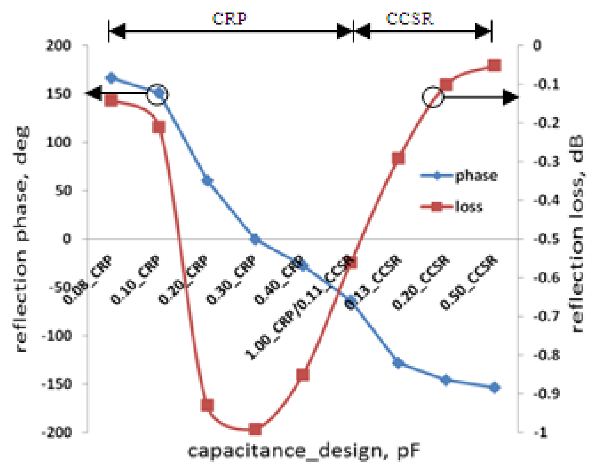
Table-2. Comparison between configurations.

Frequency	**13.964 GHz**		**14.828 GHz**	
Configuration	Phase range (deg)	Max. Loss (dB)	Phase range (deg)	Max. Loss (dB)
CCSR	304	2.1	256	2.2
CRP	77	0.3	229	0.99
CCSR+CRP	323	1.66	323	0.99

The reflection loss and scattering phase are plotted as a function of capacitance and radius as a superposition result from dual configurations. It can be seen in Figure-5a, that CCSR contributes 260^0 phase variation whereas 63^0 come from CRP at 13.964 GHz. By this combination, the loss can be reduced to 1.66 dB which is 68% reflected of incident wave. For 14.828 GHz, CRP contributes more that is 230^0 from the total phase range whereas 93^0 come from CCSR as can be observed in Figure-5b. By this superposition, the loss is reduced to 0.99 dB which is 80% reflected of incident wave. The slope of 14.828 GHz scattering phase is also less steep and hence provides greater bandwidth and low loss.



a



b

Figure-5. Reflection loss and reflection phase versus capacitance–design in dual configurations
a 13.964 GHz, b 14.828 GHz

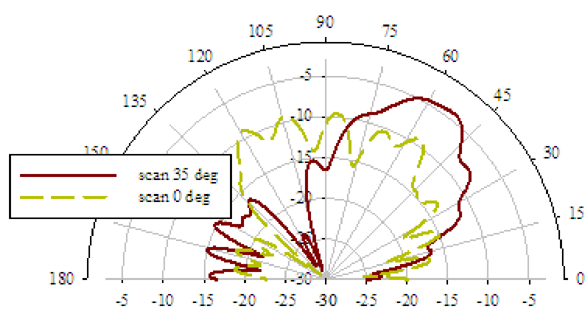


Figure-6. Electric far field simulation results for 35^0 scan angle.

LINEAR REFLECTARRAY DESIGN

The combination of two elements design will be revealed the possibility to produce the beam scanning for reflectarray antenna. The beam scanning capabilities of capacitive loaded element is indicated in linear array architecture to analyse the concept. The radiation patterns for 4x4 superposition of both designs is simulated in CST to scan the beam in the E-plane. From (1), the required progressive phase shift, Φ between elements is determined to get desired scan angles (Hajian, Kuijpers *et al*., 2006),

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(Ronald D. Javor, 1995). Where *d* is the element spacing, λ_0 the free space wavelength and Θ_0, the scan angle. The elements are geometrically identical but the diodes are switched in different positions in x-direction to control the beam scanning far-field characteristics.

$$\Phi = -\frac{2\pi}{\lambda_0} d \sin(\theta_0) \quad (1)$$

The different capacitance value is specified and extracted based on single element characteristic illustrated in Figure-5. The simulation result with 0^0 and 35^0 scanning angle generated by different value of capacitance is presented at 14.828 GHz in polar plot from broadside direction. It is demonstrates clearly that the superposition of dual configurations will perform desired scanning angle and the potential for future reflectarray realization.

CONCLUSIONS

A superposition of two reflectarray element designs with capacitive embedded to control the phase-shift of reflected wave is investigated to operate in dual frequencies at Ku-band. The combination of dual configurations provide a low complexity with a dynamic phase range up to 323^0 with the maximum reflection loss below 2 dB. The ability to scan the main beam is performed with superposition of both designs at two different frequencies.

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