IF Conjugated Frequency offset Retrodirective Array

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Abstract— **A new approach for retro directive array (RDA) system is proposed in this work. This approach is based on the IF conjugated frequency offset techniques which is useful for full duplex communication and avoid RF leakage. The comparison of simulated result between RF and IF conjugated RDA system is performed. In IF conjugated scheme, ± 11 degree Beam pointing error (BPE) is reduced which is for maximum range of angle of arrival of RF conjugated RDA.**

Keywords— Antenna array;Beam pointing error;IF phase conjugation; Retro directivity; Introduction

Retro directivity is an ongoing research in the field of antennas. Van- atta was the first man who discovered the retro directivity. The retro directive antennas have many applications [1-7] such as in Microwave tracking beacon, RFID, and enhancing the RCS of the ships and airplanes. Retro directive array systems are capable to re-transmit signal towards interrogator without knowing any prior location of interrogator. Basically the directive antenna array system conjugated phase of incoming signal, so signal will be directed towards its previous location when it is retransmitted. There are different types of phase conjugating circuit topology which are already implemented by researchers [8-11]. The IF conjugation techniques is simpler than other techniques such as RF conjugation and the conjugation using PLL. The leakage problem due to RF signal at mixer can be avoided in IF conjugation scheme. Also the frequency offset RDA systems could be configured with this technique. Therefor to avoid RF mixer requirement in which IF frequency is same as RF frequency, IF conjugation is used for phase conjugation in this work. The frequency off set retro directive array system is proposed to avail the additional advantage of this scheme so that it can be applicable for radar and communication purpose. The proposed RDA configuration is shown in Figure1. Incoming RF signal is at 2.51GHz and transmitting phase conjugated signal is at 2.68 GHz. In the following section, the brief idea about RF and IF conjugation techniques is presented with the simulation results. The beam pointing error due to leakage problem in mixer is addressed and also the possible solution for reducing the leakage effect is discussed.

A. RF Conjugation

In RF conjugated phase conjugated scheme, phase conjugation with heterodyne mixing uses an LO signal at twice the RF frequency. In this case, the lower sideband product has the same frequency as the RF but with conjugated phase. When combined with an antenna and placed in an array, the phase-conjugated signal from each element will be re-radiated towards the direction of interrogator. The process of RF-phase conjugation is described in Eq.1.When the LO frequency is twice the RF frequency.

$$V_{IF} = V_{RF}\cos(\omega_{RF}t+\theta_n)\cdot \mathrm{V_{LO}}\cos(\omega_{LO}t)$$
$$= \frac{1}{2}V_{RF}\mathrm{V_{LO}}\left[\cos\left((\omega_{\mathrm{LO}}-\omega_{\mathrm{RF}})\mathrm{t}-\theta_{\mathrm{n}}\right)+\cos\left((\omega_{\mathrm{LO}}+\omega_{\mathrm{RF}})\mathrm{t}+\theta_{\mathrm{n}}\right)\right] \quad (1)$$

If the RF and IF are not identical, but the phase is conjugated, there will be a pointing error in the return beam, depending on the frequency difference [20]. Since it is difficult to differentiate between the RF and IF signal if both are the same frequency, either the frequencies should be offset slightly, or the circuit should be designed such that the RF frequency is suppressed. In this method it is important to eliminate undesired signals,i.e.,non-phase conjugated signals since they are transmitted to the direction that follows Snell's law.The upper sideband signal and LO leakage can easily be removed since the frequency is far apart from the phase conjugated signal. The requirements for frequency of Local oscillator is the challenging isue for RF-conjugated phase conjugation circuit. It is difficult to genarate twise of incoming RF signal frequency when the interogator transmitted higher frequency of signal. As an example, when interrogating signal is above 70GHz, LO signal should be 140GHz which makes the systems more complex and unstable.The simulation results for RF phase conjugated Retro directive array is presented in following Figure. An interesting observation has come from the simulation results which insist towards an alternative scheme for retro directive array. It is observed that the grating lobe becomes more prominent with increasing element number of array when the ratio of L/C (Leakage RF signal level/Conjugated signal level) exceeds 0.5. It can be concluded that though the beam pointing error decreases with increasing number of element but the grating lobes are more prominent at present of RF-leakage. Therefore, the RF-conjugation techniques are having the drawback for RDA performance due to the generation of additional lobe. This problem can be mitigate using frequency offset techniques but the re transmitted beam will be tilted from the desired direction. In this case additional beam pointing error will occur. The problem of RF leakage can be avoided using IF conjugation techniques with frequency off set. Therefore, leakage problem mitigation is possible with this approach.

B. RF leakage and Grating lobes

RDA is used to re-transmit the signal to the interrogator without having prior information of its locations, so interrogating signal without phase conjugation should not be re-transmitted by the RDA. This can only be possible when RF (incoming) signal should not be leaked out form conjugating circuit. The Prediction of RDA performance for different array element can be simulated as it was discussed in [12]. The RDA system performances in terms of beam pointing error is shown in Figure 1.

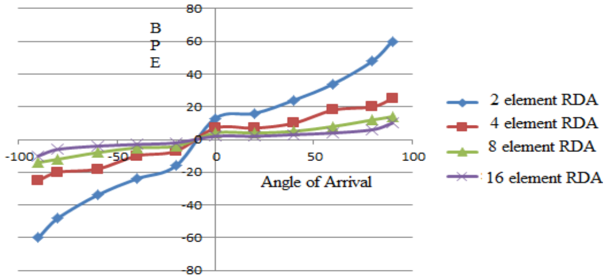
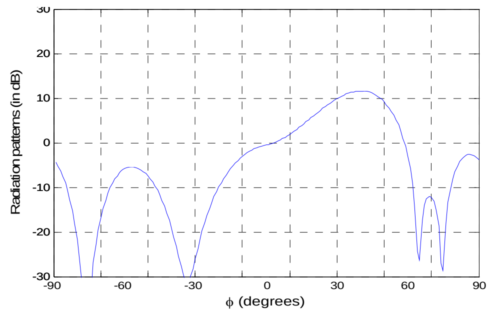


Fig. 1. Beam pointing error for RF conjugated RDA without RF leakage.

$$E_{\mathrm{RDA}} = \text{Coupled Element Pattern} \times (\text{Conjugate Signal} + \text{RF Leakage Signal})$$

It is observed that, when RF-leakage signals less then -3dB does not affect the performance of RDA. The RDA pattern for different values of L/C is presented for different number of array element in Figure 2.



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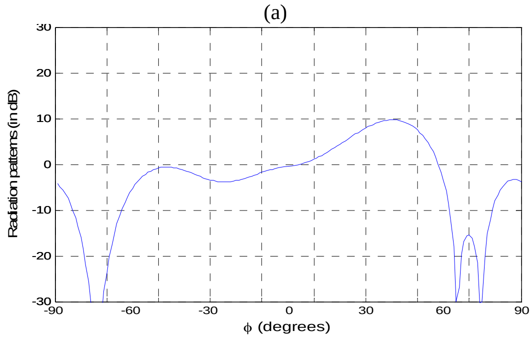

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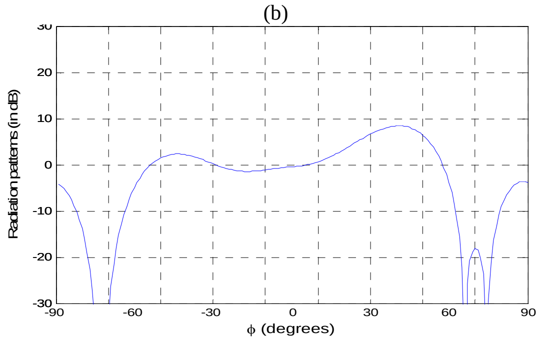

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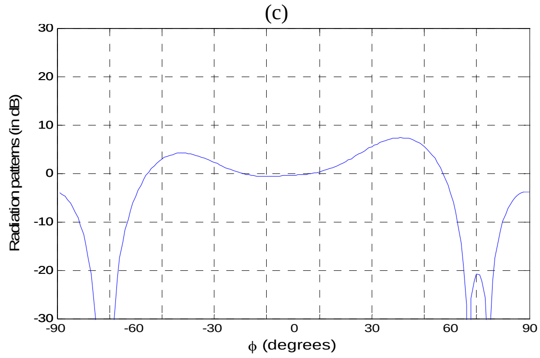
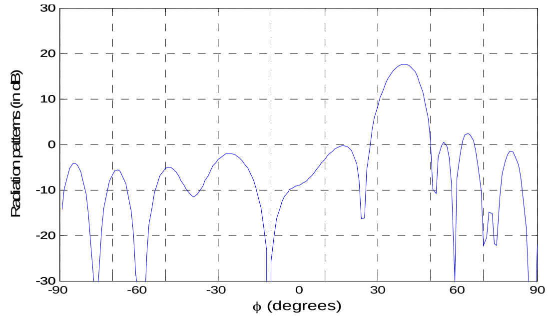


(d)

Fig. 2. RDA response for 4 element ,AOA=40 deg (a)L/C=0 (b) L/C=0.5 (c) L/C= 0.6 (d) L/C=0.8.



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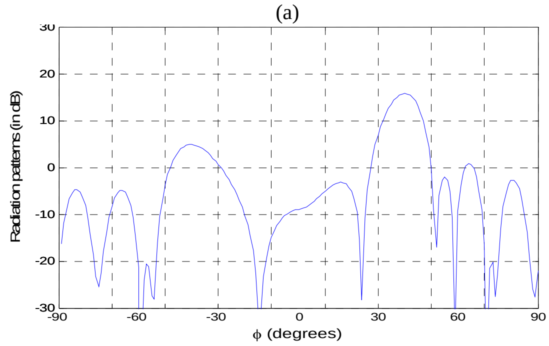

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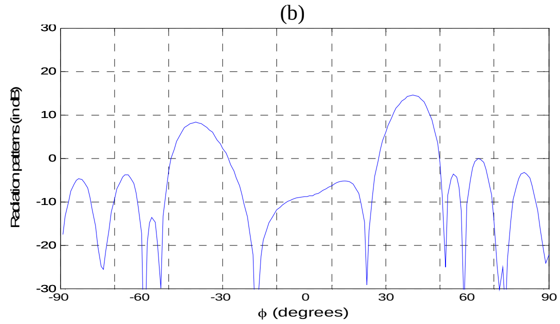

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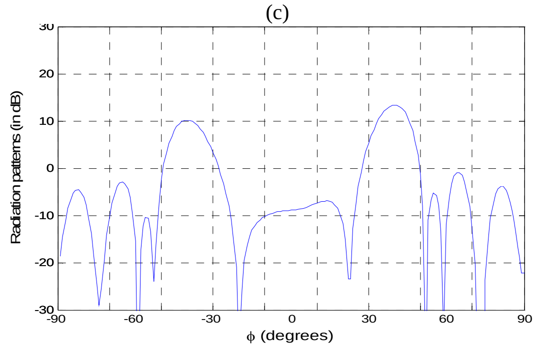


(d)

Fig. 3. RDA response for 8 element ,AOA=40 deg (a)L/C=0 (b) L/C=0.5 (c) L/C= 0.6 (d) L/C=0.8.

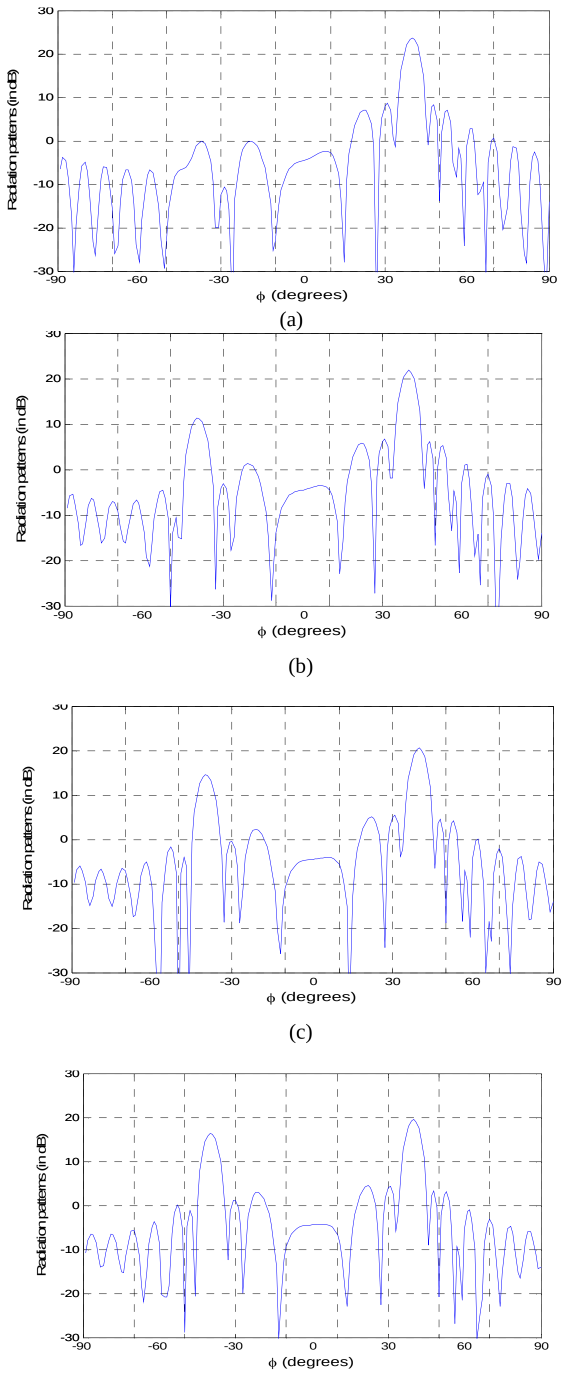


Fig. 4. RDA response for 16 element ,AOA=40 deg (a)L/C=0 (b) L/C=0.5 (c) L/C= 0.6 (d) L/C=0.8.

II. Proposed RDA Configuration

A. *IF Conjugated Frequency offset RDA*

The basic concept of IF conjugated circuits is given in figure below. The incoming signal from interrogator after receiving by antenna is down converted to an IF frequency by mixing which is define here as V^*_{IF}. Thereafter, this IF signal is up converted (V^{**}_{IF}) by mixing process to desired frequency and retransmitted by the antenna towards the location of interrogator. In this case, generation of grating lobes due to RF leakage can be mitigated since the frequency of re-transmitted signal is different from the receiving signal frequency. In this work, the four element array is used to predict the RDA performances. The propose RDA system is shown in Figure 5 and 6. The four element patch antenna array is used for this systems and a separate layer is used for phase conjugated circuit.

$$V^*_{IF} = V_{RF}\cos(\omega_{RF}t+\varphi)V_{LO_1}\cos(\omega_{LO_1}t) \qquad \text{Where } \omega_{LO_1}t = (\omega_{IF1}+\omega_{RF})t$$

$$= \frac{1}{2}V_{RF}V_{LO_1}[\cos((\omega_{LO_1}-\omega_{RF})t-\varphi)+\cos((\omega_{LO_1}+\omega_{RF})t+\varphi)]$$

$$= \frac{1}{2}V_{RF}V_{LO_1}[\underline{\cos((\omega_{IF1})t-\varphi)}+\cos((2\omega_{RF})t+(\omega_{IF1})t+\varphi)]$$

$$V^{**}_{IF} = \underline{\cos((\omega_{IF1})t-\varphi)}\cos(\omega_{LO_2}t) \qquad \text{Where } \omega_{LO_2}t = (\omega_{RF'}-\omega_{IF_2})t$$

$$= \underline{\cos((\omega_{RF'}-\omega_{IF_2}+\omega_{IF1})t-\varphi)}+\cos((\omega_{RF'}-\omega_{IF_2}-\omega_{IF1})t+\varphi)$$

$$(\omega_{RF'}-\omega_{IF_2}+\omega_{IF1}) = 2.68\text{ GHz} \;\&\; \omega_{RF} = 2.51\text{GHz}$$

$$\text{therefore } \omega_{IF1}-\omega_{IF_2} = 0.17\text{ GHz}$$

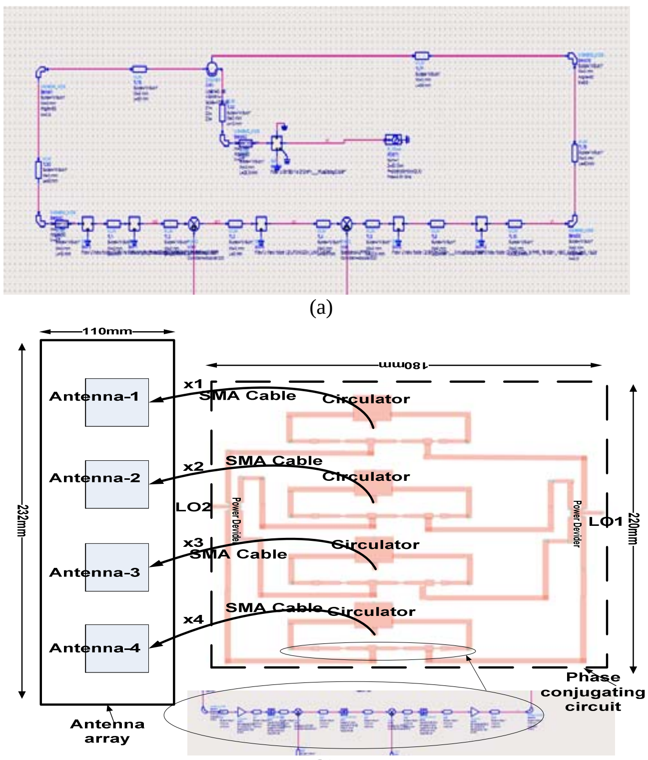
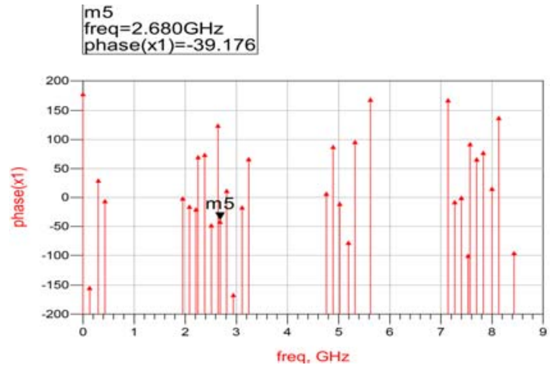


Fig. 5. IF phase conjugating circuit for (a) each element and (b) RDA system.

III. Performance of RDA System

The IFconjugated phase conjugated circuit for each element of array is identical which is already shown in Figure 5a. In Figure 5b, the layout of proposed RDA system is presented.The simulation for Phase conjugated circuit is performed in ADS. Asuming x1,x2,x3,x4 are the frequency offset phase conjugated signal which are input for each antenna element for re transmission. The simulation results for x1,x2,x3,x4 are presented in Figure 6.



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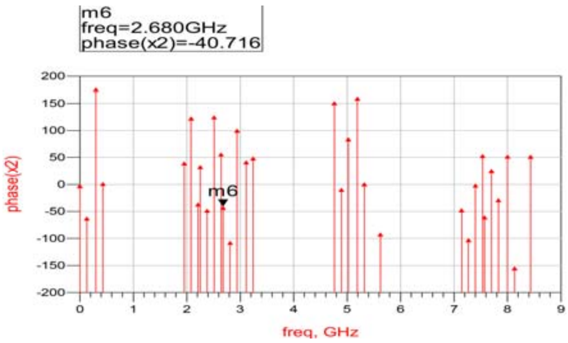

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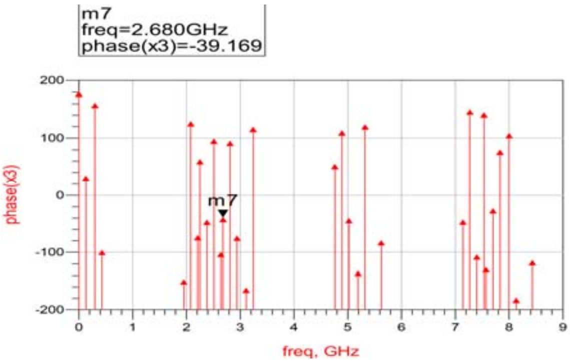

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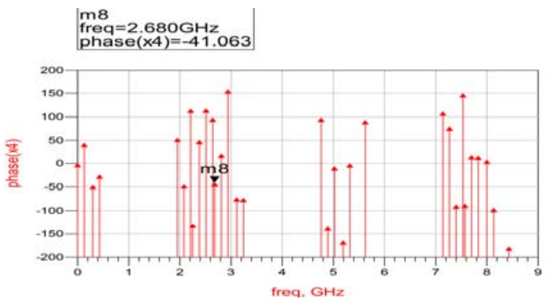
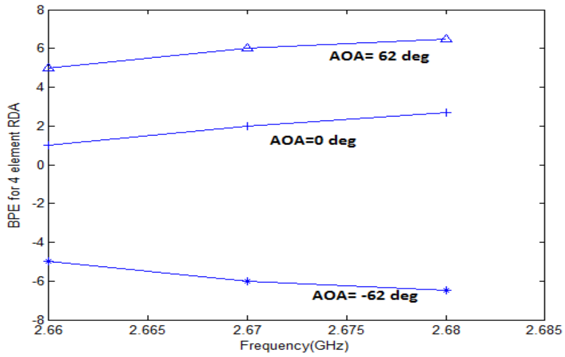
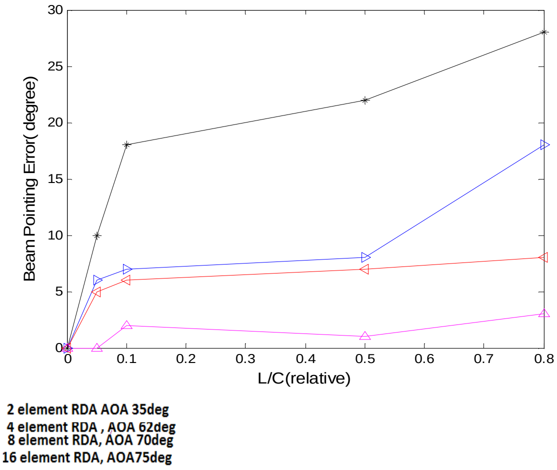


(d)

Fig. 6. Response for 4 element phase conjugated circuit ,when AOA=40 deg input signal phase at (a)1st (b) 2nd (c) 3rd(d) 4 th antenna for re transmission.



(a)



(b)

Fig. 7. Beam pointing error for (a) four element and (b) different element frequency offset RDA.

The beam pointing error for four element array is shown in Figure 1 where the angle of coverage is taken as $\pm$62 degree. In If conjugated RDA system, it is observed that the beam pointing error for maximum angle of arrival is having better response compare to RF conjugated RDA system. It is observed from Figure 7a, BPE is nearly $\pm$6 degree for AOA $\pm$62 degree but it was $\pm$17 degree for RF conjugated RDA system.

IV. CONCLUSION

A new scheme for RDA performance improvement is proposed which is based on IF conjugation frequency offset techniques to avoid RF leakage problem and also generation of grating lobes which will more effectively improve large number of array element for RDA performances. This scheme reduces BPE by $\pm$ 11 degrees for maximum range of angle of arrival of RF conjugated four element RDA systems.

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