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Recent Progress in Retrodirective Arrays

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I. Introduction

Next generation wireless applications have continually increased the demands on system designers. These systems require easy deployment, low-cost and high-efficiency. Recently, the active integrated antenna approach has shown much promise in addressing these issues. Transmitter and receiver sides can be improved by using high-efficiency amplifiers [1-3]. At the same time, the communication links between these systems can be improved by adapting phased array systems such as retrodirective arrays [4,5] to communication purposes. Retrodirective arrays have the unique characteristic that they reradiate an incoming signal back towards the source with no a priori knowledge of the arrival direction, without relying on sophisticated digital signal processing algorithms as utilized by so-called “smart antennas”. Such unique features make the retrodirective array an attractive candidate for advanced digital mobile communication systems where high link gain and self-beam-tracking are desired. A retrodirective array can efficiently be used in a mobile communication system such as from a ground station to moving vehicles, aircrafts or satellites.

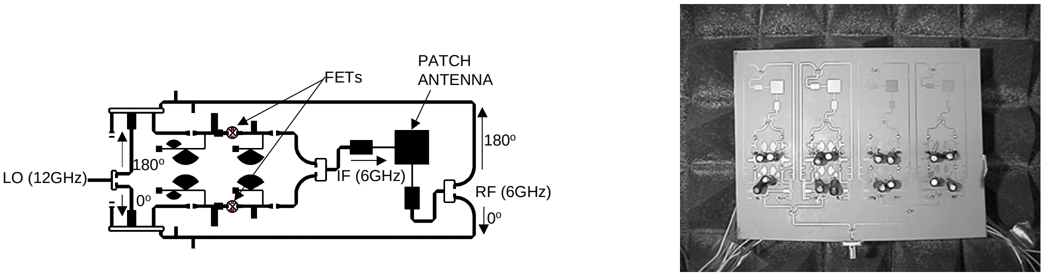
Phase conjugation with heterodyne mixing is a simple and effective technique to achieve retrodirectivity using an LO that has twice the RF frequency [5-9]. In this scheme, the lower sideband product has the same frequency as the RF, but with a conjugated phase. When combined with an antenna and placed in an array, the phase-conjugated signal from each antenna element will be reradiated towards the source direction. The phase conjugation technique has several advantages. One thing is that phase conjugators can provide conversion gain by using active devices for the mixer circuitry. Another is it is easy to apply modulation to the re-sent signals, allowing the pass of information. In this method, one task that should be achieved is riddance of undesired signals, i.e. non-phase-conjugated signals [5,7]. Especially burdensome in the phase conjugation approach is that the IF frequency is the same as that of the RF. This fact makes it impossible to filter out undesired signals. For this reason, hybrids are usually used to eliminate undesired signals.

This paper presents our recent advance in retrodirective arrays, which are particularly advantageous for RF tag applications and remote information retrieval-on-demand. Adopting active devices, the phase conjugating circuitry provides conversion gain in addition to phase conjugating performance. The RF and IF signals share one port, resulting in reduced system size. The novel active circuitry architecture is simple and extremely compact, enabling array spacing small enough to avoid grating lobes. The whole circuitry can be fabricated on the same substrate as the antennas, enabling one card transponder. A prototype 4-element array showed excellent retrodirectivity. Further, a BPSK signal transmitted by the array was successfully recovered at the source location. These characteristics make the retrodirective array a good candidate for future remote tagging and wireless sensor applications.

II. Retrodirective Array Based on Active Gate Mixers

Figure 1-(a) shows the phase conjugating element of the retrodirective array based on active gate mixers. Both LO and RF are applied to the mixers anti-phase. Therefore, the RF and LO leakage is canceled at the output port while the IF is combined in phase. The incoming and outgoing signals use orthogonal polarizations. The mixers use so-called gate mixer

configuration which provide 6 dB conversion gain. The elements are aligned linearly with 0.68 free space wavelength at the RF frequency.



(a) **(b)**

Figure 1 The 1st generation active retrodirective array

III. Retrodirective Array Using Compact Phase Conjugator

The basic schematic of the balanced quasi-optical phase conjugator is shown in Fig. 2. The circuit contains two ports, one for the LO which is applied in phase to the two channels and the other port is shared by the incoming RF and outgoing IF. The channels are identical except for a 90° phase delay line at the RF frequency. This delay line provides cancellation of the returned RF signal at the RF/IF port for isolation. Since the LO frequency is twice that of the RF frequency, the LO from the two channels will experience a 180° delay when combined at the RF/IF port, providing good LO isolation. At the same time, the 90° delayed IF is phase conjugated and combined in phase at the port after another 90° delay. When a modulated LO is applied, the information on the LO will be passed to the IF signal through the mixing process. This novel architecture allows an extremely compact design.

A prototype circuit was fabricated on a Rogers RT/Duroid 6010 substrate (25 mil thickness, εr=10.2) and shown in Fig 3. The heterodyne mixers used NEC NE76038 MESFETs. The circuit performance is first tested by using an SMA connector at the RF/IF port instead of an antenna. Two synthesizers are used to provide the RF (5.99 GHz, -30 dBm) and LO (12 GHz, 0 dBm) signals. By using slightly different frequencies for the RF and IF, the IF signal can be readily distinguished from the returned RF. The signals going toward the output port are tapped off through a directional coupler to a spectrum analyzer. The circuit achieves RF/IF isolation of 20 dB and conversion gain of 3.2 dB at the output port.

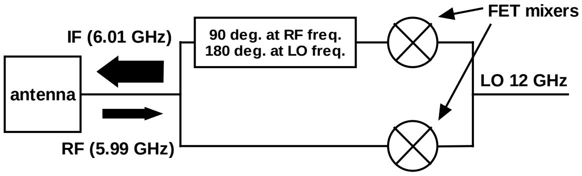


Figure 2 Schematic of the phase conjugating mixer

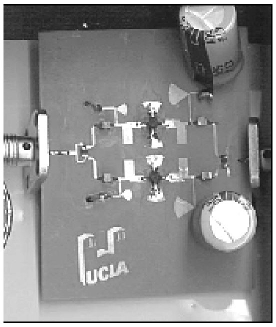


Figure 3 Photo of the prototype

A prototype 4-element retrodirective antenna array based on the proposed phase conjugator was fabricated and is shown in Fig. 4. The array uses 6 GHz patch antennas with element spacing of 1 inch, approximately one half of a free space wavelength at the RF frequency. The entire system is fabricated on a 4.5 in x 3 in substrate. The small array spacing allows the array to avoid the scan angle limitations due to grating lobes, which become visible in arrays with array spacing $d > \lambda/(1+|\sin\theta_0|)$ where θ_0 is the incident angle of the incoming signal. At the same time, the array factor pattern has low side lobes (<-10 dB). The array was illuminated with a 5.99 GHz wave generated by a signal source, and was driven by a 12 GHz LO signal. Radiation patterns of the array were measured at different source directions. Fig. 5-(a-c) show the bistatic RCS with the source at broadside (0°), -30° and +45°. Retrodirectivity of the array is clearly observed. Note that no grating lobe is observed in all three cases. The monostatic RCS should only depend on the element factor since the main beam of the array always is at the incident angle. Therefore, the array should not give any null in the monostatic RCS pattern. This is one of the fundamental advantages of retrodirective arrays. The measured results are shown in Fig. 5-(d) and they agreed reasonably well with the theoretical predictions.

Using a modulated LO allows the retrodirective array to send a unique ID code or other local information back to the source location. In this case, the data signal on the LO signal is transferred to the IF product through the mixing operation. For simplicity, the LO was modulated with 1 kHz square wave in this demonstration. Figure 6 shows the demodulated response waveform from the retrodirective array. It was successfully recovered at the source location. By further improvement in modulation schemes, the system should also be useful in advanced applications requiring higher data rate, such as remote information retrieval-on-demand.

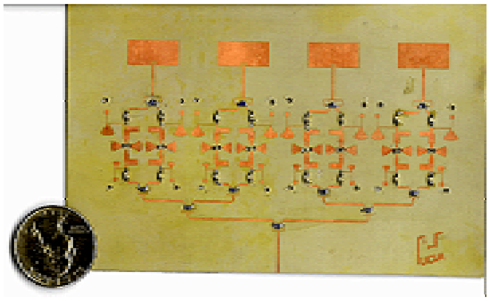
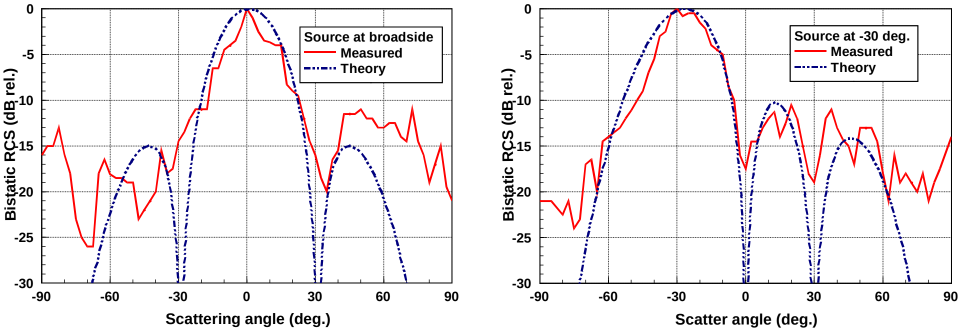
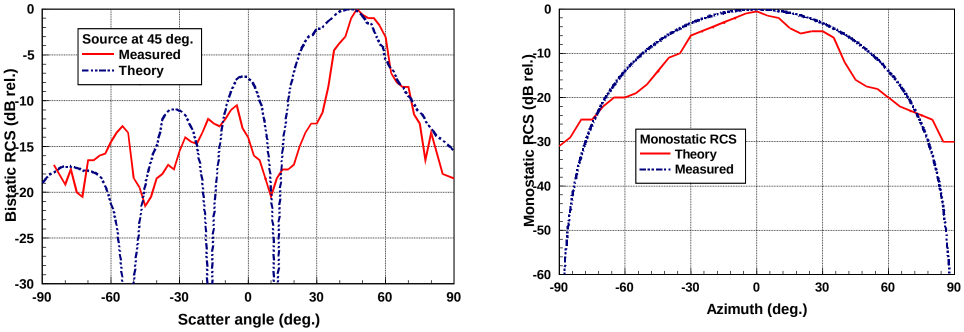


Figure 4 Photo of the four-element retrodirective array



(a) source at broadside (0deg).

(b) source at –30 deg.



(c) source at 45 deg.

(d) monostatic RCS

Figure 5 Radar cross section of the retrodirective array

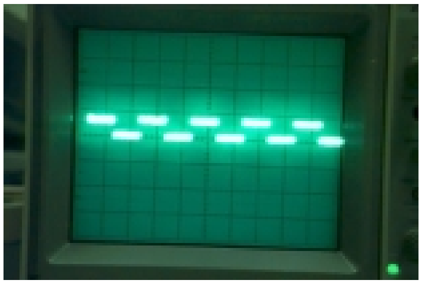


Figure 6 Demodulated response from the retrodirective array

IV. Conclusion

Retrodirective arrays provide an attractive solution for efficiency of RF transponders and wireless communication links. An active retrodirective array based on a novel, compact phase conjugator has been developed. The 4-element prototype array demonstrated excellent retrodirective performance. The baseband signal on the transmitted signal from the retrodirective array was successfully recovered at the source location. This type of self-tracking system should find uses in advanced wireless applications such as RF ID tags and remote information retrieval. By using two sets of the retrodirective array, duplex retrodirective communications are possible also.

Acknowledgements

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