Planar Active Rectrodirective Array With Subharmonic Phase Conjugation Mixers

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***Abstract*—**A planar active retrodirective four-element array with subharmonic phase conjugation mixers based on anti-parallel diode pairs (APDPs) is proposed. As compared to previous phase conjugation mixers using twice RF frequency for LO frequency, the proposed conjugation mixers need only half RF frequency so that it can be easily applied for millimeter-wave applications. Receiving, transmitting, local oscillator, and intermediate frequencies are 5.79, 5.81, 2.9 GHz, and 10 MHz. Monostatic RCS and Bistatic RCS measurements at source locations of 0°, -20°, and 28°show good agreement with the calculated data.

***Index Terms*—**APDP, retrodirective array

I. INTRODUCTION

A retrodirective array retransmits an incident signal to a source which conveys the signal to the array without a priori knowledge of the location of the source. The most well-known retrodirective antenna is the coner reflector, where the geometry of the structure results in retrodirective beam formation[1]. The array equivalent of the coner reflector is the Van Atta array, where the particular form of array element interconnection results in retrodirective beam formation[2][3]. Active variety of the retrodirective array make use of the amplifier gain provided in the transmission line paths interconnecting the antenna elements[4]. The advantage of this arrangement over its passive equivalent is that a smaller aperture is required for prescribed incident power density and radiated power. The fundamental requirement for retrodirectivity is that each element in the array must have an outgoing wave, which is phase delayed with respect to a reference phase by exactly as much as the incoming wave was phase advanced, i.e., a phase-conjugate relationship between incoming and outgoing wavefronts must exist. In order to automatically generate an outgoing retrodirective signal, there are many methods including the corner reflector and the Van Atta array.

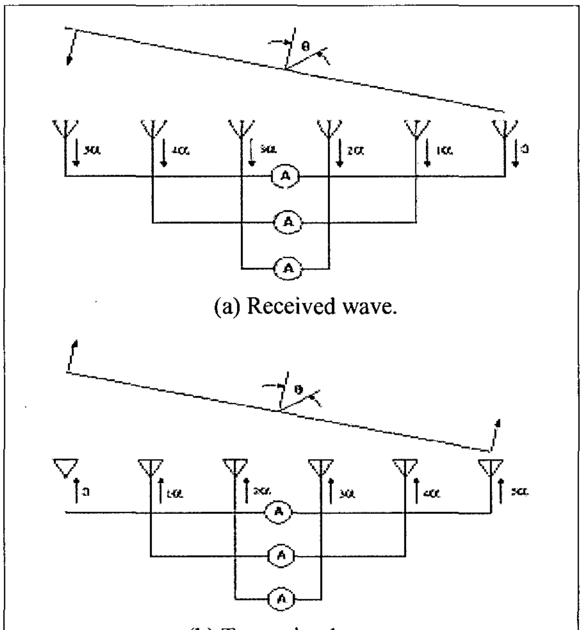
Another method of retrodirective is phase conjugation using active devices [5][6]. Miyamoto proposed an active retrodirective array with MESFET phase conjugation mixers, which needs an LO frequency equal to twice the RF frequency[6].

When this concept is applied for millimeter-wave retrodirective applications, it becomes difficult to use LO sources at twice the RF frequency.

In this paper, a planar active retrodirective array with subharmonic phase conjugation mixers using APDPs is proposed. In this new scheme the LO frequency needs not be twice of the RF frequency. The subharmonic mixers with APDPs make it possible to reduce the LO frequency asthe second or fourth harmonics. Furthermore, thanks to inherent advantages of APDPs such as the suppression of first order mixing products as well as the suppression of LO noise, the mixer can provide low conversion loss, which is helpful for communication link budget [7].

II. ACTIVE RETRODIRECTIVE ARRAY

An active retrodirective array makes use of amplifier gain, as exemplified in Fig. 1, to increase the radiated power. The fundamental reason for using an Active Retrodirective (AR) array rather than a passive Van Atta Array is to reduce the required aperture of the array for a prescribed incident power density and effective radiated power.



(a) Received wave.

(b) Transmitted wave.

Fig. 1 An active retrodirective array

When two "subarrays," one for receiving and one for transmitting, are used, the retrodirective properties of the single Van Atta array are identically realizable. The two

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subarrays are interconnected as shown in Fig. 2 for a linear array. Extensions are easily made to planar arrays. equal length transmission lines and equal element spacing in the two arrays is assumed. A plane wave incident on the receiving subarray is redirected from the transmitting array back in the direction of the incident wave. In the interconnecting transmission lines, only unilateral amplification is required.

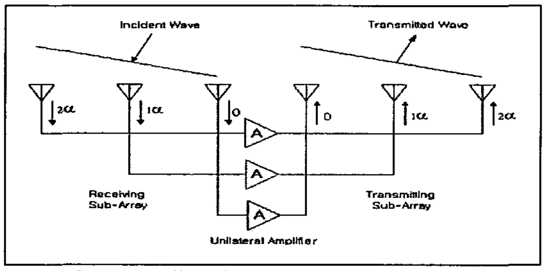


Fig. 2 Active retrodirective array; separated receiving and transmitting subarrays

III. A PLANAR ACTIVE RETRODIRECTIVE ARRAY WITH SUBHAMONIC PHASE CONJUGATION MIXERS DESIGN

A retrodirective phase conjugator integrated with each receive and transmit antenna element is depicted in Fig. 3. The phase conjugator consists of subharmonic mixers based on APDPs, amplifiers, Wilkinson power divider, and low pass filter (LPF). In order to obtain retrodirective mode from the received signal, two APDPs are used as a down- and up-converter and amplifiers are used for the decision of signal path and gain. A receive frequency of 5.79 GHz is mixed with an LO frequency of 2.9 GHz to produce an IF frequency of 10 MHz. This down-conversion process also phase-conjugates the received RF signal. Next, the IF frequency is up-converted with the same LO frequency to generate a transmit frequency of 5.81 GHz. This mixer configuration allows easy filtering between the different frequencies involved in mixing, while still using a single subharmonic LO source. By two mixing process, the phase of signals received at the receive element is reversed. By equation (1), N-element transmit array factor in terms of the phase conjugation, the direction of outgoing signal can be the location of the source. Fig. 4 shows the photograph of the whole four-element active retrodirective array with subharmonic phase conjugation mixers.

$$f_T(\theta) = \sum_{n=0}^{N-1} e^{jnkd\cos\theta} \cdot (e^{-jnkd\cos\theta_0})^* \tag{1}$$

The planar active retrodirective array is fabricated on an RT/Duroid 6010 substrate with a dielectric constant, ξr =10.2 and a substrate thickness, h = 50 mils. Agilent Beam Lead Schottky Diode Pairs (HSCH-5531) are used for the sub-harmonic phase conjugation mixers. Agilent GaAs low noise MMIC amplifiers are mounted between the patch antennas and the mixers at each receive and transmit port. CAD tools, Agilent ADS circuit and Momentum full-wave simulator are utilized to predict the performance of the sub-harmonic mixer, amplifier, and overall passive circuits including the antenna.

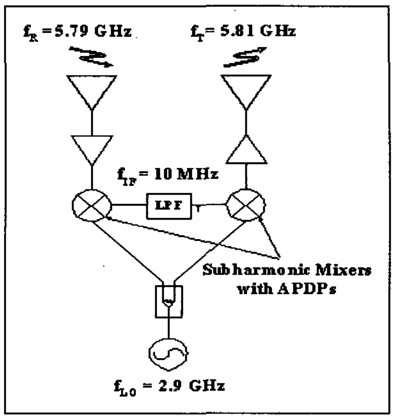


Fig. 3 Schematic of the subharmonic phase conjugator integrated with each receive and transmit antenna element.

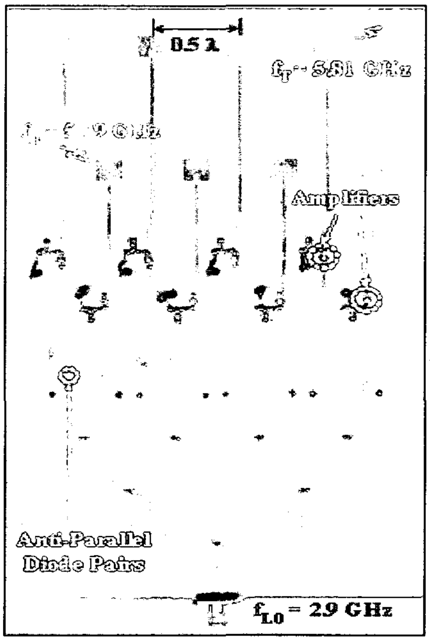


Fig. 4 Photograph of the proposed active retrodirective array with subharmonic phase conjugation mixers

IV. RESULTS AND DISCUSSION

Fig. 5 shows the measured return loss of microstrip patch antenna. The central resonant frequency of the antenna is 5.803 GHz and its -10 dB bandwidth is 84 MHz, which is 1.45 %. The measured and calculated monostatic RCS, as in Fig. 5 (a), are agreed well.Since the main beam direction of the array is always dependent of an angle of incident signal, the monostatic RCS depends on the element factor[2]. Fig. 5 (b), (c), and (d) show the measured and calculated bistatic RCS with source locations at 0°(broadside), -20°, and 28°. Retrodirective transmission of the array is successfully demonstrated without any grating lobe observation. However, the side lobe level at source location of 28° is higher than the calculated side lobe level of a four-element linear microstrip patch array. The non-uniform phase and amplitude errors cause the higher side lobe level along with multipaths in measurement environment and fabrication errors.

The proposed retrodirective array can be further investigated for 60 GHz wireless applications under consideration at UCLA. It is difficult to generate an LO frequency of 120 GHz, which is twice RF frequency, with the previous phase conjugation method. With the subharmonic phase conjugation mixers based on APDPs, the expensive millimeter-wave LO generator can be substituted with the second or fourth subharmonic of RF frequency. It easily makes it possible to extend the subharmonic phase conjugation mixers for millimeter-wave retrodirective implementation.

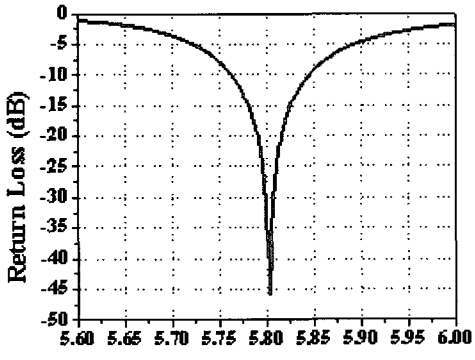
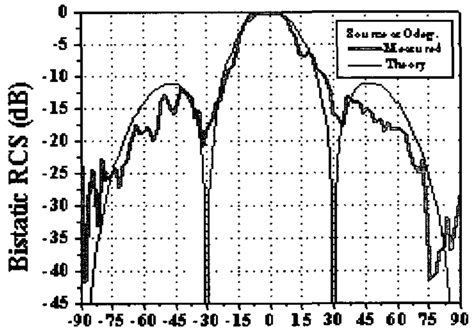
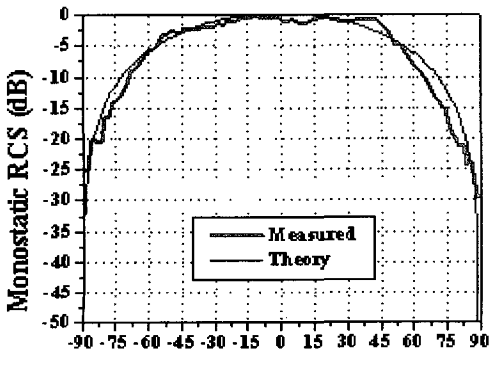


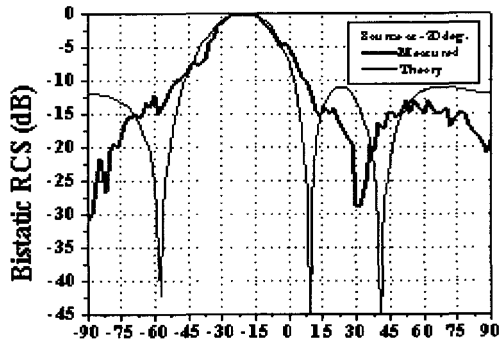
Fig. 5 Measured return loss of the microstrip patch antenna.



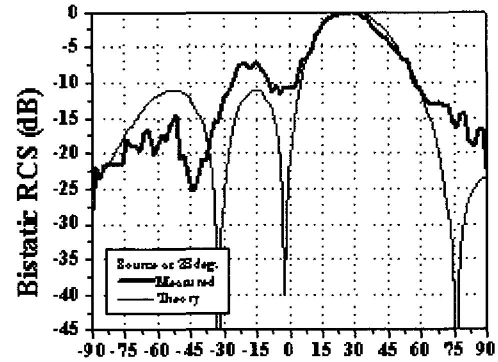
(a) Monostatic RCS



(b) Bistatic RCS for source location at 0



(c) Bistatic RCS for source location at -20



(d) Bistatic RCS for source location at 28.

Fig. 6 Measured and calculated monostatic and bistatic RCS of the active retrodirective array with subharmonic phase conjugation mixers

V. CONCLUSIONS

A planar active retrodirective array with subharmonic phase conjugation mixers has been proposed. In order to employ the half LO frequency of the RF frequency, APDPs was used as subharmonic mixers for the phase conjugator. The subharmonic phase conjugation mixers can be applied for millimeter-wave retrodirective array systems under the consideration at authors' group for the substitution of expensive millimeter-wave LO generator.

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