The Auto-Tracking Communication Link Using Planar Active Rectrodirective Array

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Abstract—In this paper, a planar active retrodirective four-element array with subharmonic phase conjugation mixers based on anti-parallel diode pairs (APDPs) is designed, and its application in the auto-tracking duplex communication link is presented.
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. The proposed architecture, which conventionally performs the function of the transmission of an incident signal back in the direction of its source, is modified in order to include a receive function. Experimental verification of these architectures is performed at 1GHz and the results from the prototypes are compared with a theoretical model.

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.

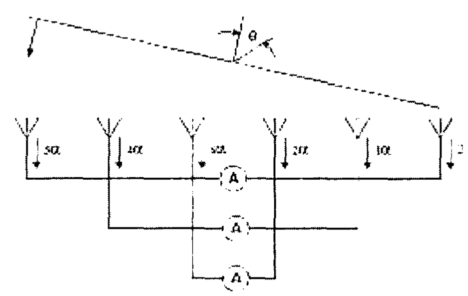
Another method of retrodirective is phase conjugation using active devices [5][6]. Miyamoto proposed an active retrodirective array with MESFET phase conjugation mixers, which needs an LO frequency equal to twice the RF frequency[6].

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

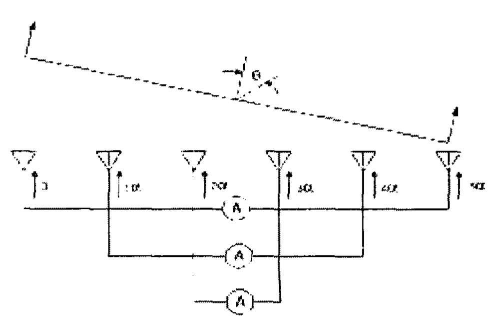
In this paper, a planar active retrodirective array with subharmonic phase conjugation mixers using APDPs is proposed. In this new scheme the LO frequency needs not be twice of the RF frequency. The subharmonic mixers with APDPs make it possible to reduce the LO frequency asthe second or fourth harmonics. 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

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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 subarrays are interconnected as shown in Fig. 2 for a linear array. Extensions are easily made to planar arrays. We assumed the length of transmission lines and element spacing in the two arrays is equal. 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.

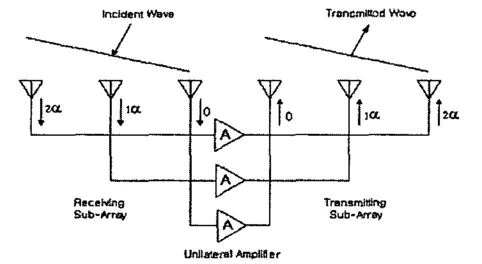


Fig. 2 Active retrodirective array; separated receiving and transmitting subarrays

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

A. 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.

$$f_T(\theta) = \sum_{n=0}^{n-1} e^{jnkd\cos\theta_o} . (e^{-jnkd\cos\theta_o})^* \qquad (1)$$

The planar active retrodirective array is fabricated on an RT/Duroid 6010 substrate with a dielectric constant, ε_r=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.

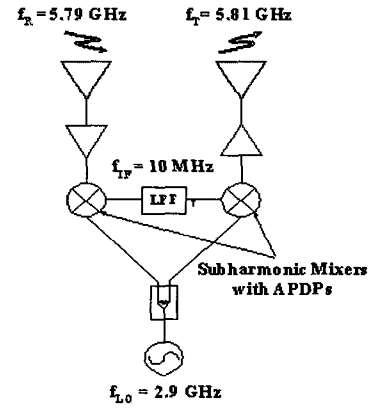


Fig. 3 Schematic of the subharmonic phase conjugator integrated with each receive and transmit antenna element.

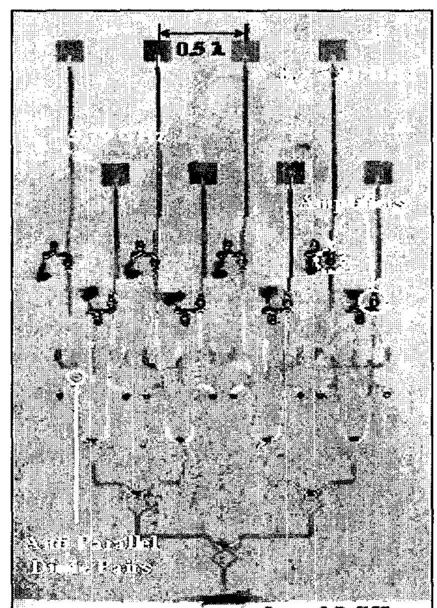


Fig. 4 Photograph of the proposed active retrodirective array with subharmonic phase conjugation mixers

B. Results

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. 6(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. 6(b) show the measured and calculated bistatic RCS with source locations at -20°. Retrodirective transmission of the array is successfully demonstrated without any grating lobe observation.

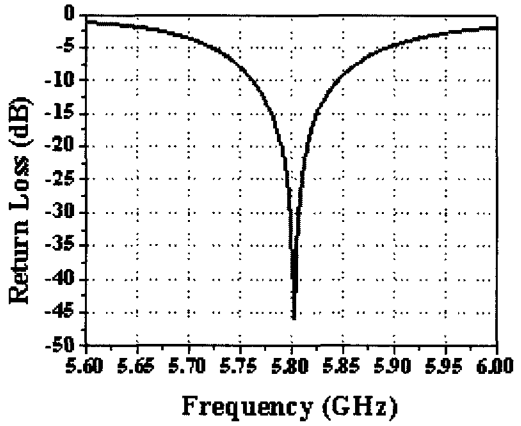
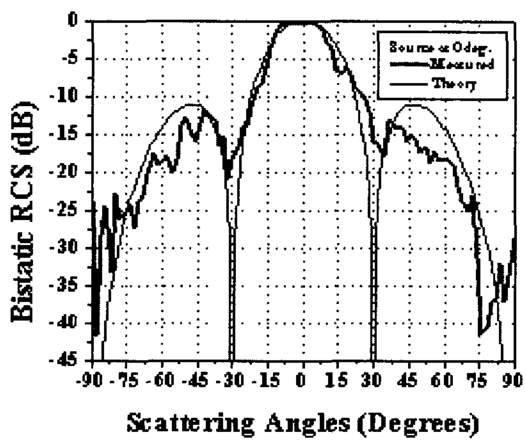
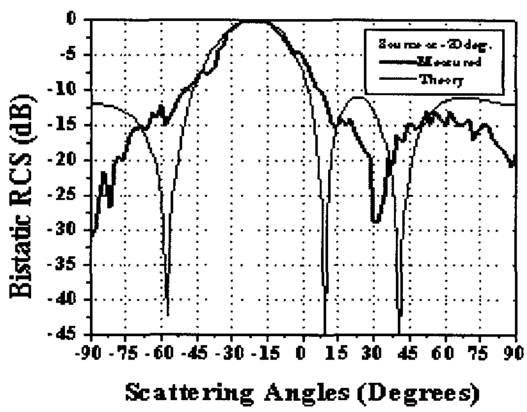


Fig. 5 Measured return loss of the microstrip patch antenna.



(a) Monostatic RCS



(b) Bistatic RCS for source location at -20

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

C. Appplication

A duplex communication link can be formed using a pair of the retrodirective transceiver antennas described above, Fig. 7. Here a pilot signal is used to initiate the communication between cooperating antennas.

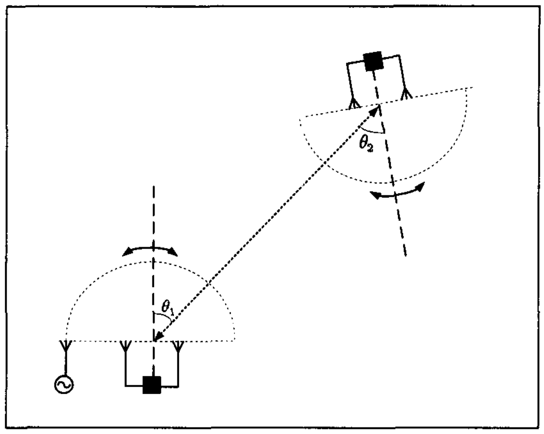
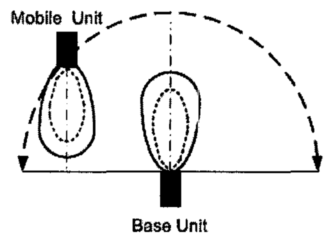
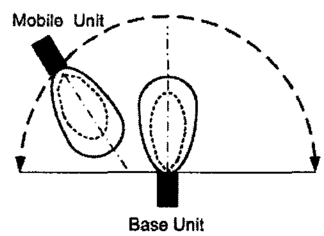


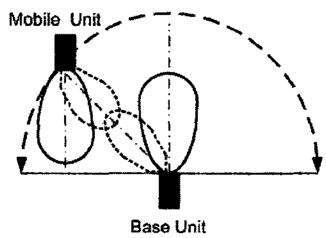
Fig. 7 Application - Retrodirective Communication Link.



(a)



(b)



(c)

Fig. 8 Measurement setup for the communication Link (a) Passive Link (parallel) (b) Passive Link (radial) (c) Retrodirective link (parallel)

Such a communication link is useful when the communicating antennas are mobile and it is necessary for these antennas to track each other without prior information regarding their relative positions. Improvements in gain with subsequent relaxation in the power budget together with reduced multipath effects accrue by using this approach. The power received by the receive sections of the arrays depends on the separation between receive and transmit units and their relative orientation with the respect to each other. For the land mobile communications we need to consider only the azimuthal plane shown in Fig. 7.

Figs. 7 and 8 shows the layout for the link based on dual polarized retrotransceiver array. Here for ease of measurement one unit is held stationary - the base unit - while the other unit is allowed to roam - the mobile unit. The base station houses a .separate microstrip patch antenna for the transmission of the pilot signal. When synchronized retrodirective action has been estabilished the pilot tone can be switched off and mutual auto-tracking communication is initiated.

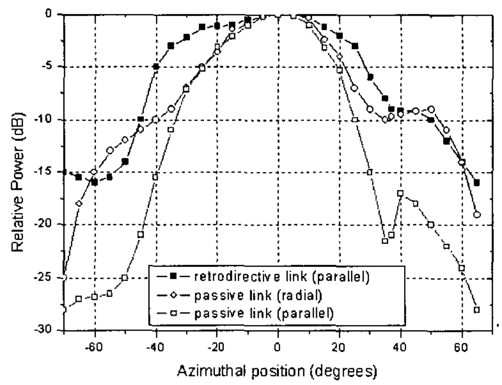
Measurements on the link were obtained by keeping the base station stationary and moving the mobile unit around it in an azimuthal plane, as shown in Fig. 8(c). To evaluate the performance of the system, a reference measurement was also performed on the passive communication link with arrays oriented as per the passive configurations in Fig. 8(a) and 8(b). Two different types of measurement were carried out on the communication links. In the first measurement, th mobile unit is moved in the azimuthal plane and has its nominal boresight facing radially inward [Fig. 8(a)]. In this situation, the measured receive/transmit radiation pattern is essentially the radiation pattern of the base station array. In the second measurement, the nominal boresight of the mobile unit was alwayskept parallel to the nominal boresight of the base station array [Fig. 8(b)].

Fig. 9(a), shows the measured receive radiation patterns at the mobile unit and Fig. 9(b) at the base station. Here it can be seen that with the measurement performed on the retrodirective link [Fig. 8(c)] and the passive link [Fig. 8(a)], the results obtained are as expected almost identical. Similarly, in Fig. 9(b), identical results were obtained for the passive array Fig. 8(a) and the retrodirective array Fig. 8(c).

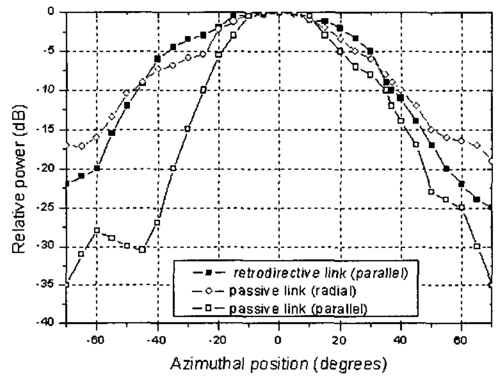
Relative to the measurement in configuration in Fig. 8(b), configurations in Fig. 8(a) and (c) show a gain of 12dB at +/-70 degree positions. This gain occurs because the power received for the passive link is the product of the multiplication of radiation patterns of the receive beam at the mobile unit and the transmit beam at the base station, both of which are that of a two element passive array. In the case of retrodirective link, again, the received power is the product of radiation patterns of receive beam at the mobile unit and the transmit beam at the base station, but now the receive beam is that of a passive two element array and the transmit beam is retrodirective in nature and remains relatively flat at all the azimuthal positions as if the transmitter was radially directed.

IV. 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. This use was demonstrated with the help of proto type duplex communication link. It was shown that such a link allows the potential with far more freedom of movement for the communicating at a reduced power budget and with reduced multipath effects when compared to classical passive communication links. Such a structure has a variety of communications in mobile communications and transponder applications.



(a)



(b)

Fig. 9 Measured received radiation pattern for the communication links (a) pattern at mobile unit (b) pattern at base station

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