A Conformal Retrodirective Array for Radar Applications Using a Heterodyne Phased Scattering Element

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ABSTRACT

A 6 GHz retrodirective antenna array has been developed for use in radar and backscatter-mode communication systems. The array is based on a novel microstrip mixer-antenna element that provides the conjugate phase shift necessary for retro-reflection of incident signals, and which responds to all polarizations.

INTRODUCTION

Retrodirective antenna arrays have the interesting property that, when illuminated by a signal from some arbitrary direction, they focus the wave back toward the source without any prior knowledge of its location. This phenomena has found applications ranging from self-steering receiving antennas to radar transponders and non-contact identification systems [1], [2]. For retrodirection to occur, each element in the array must radiate an outgoing wave whose phase is the conjugate of the incoming wave phase, relative to a common reference. This allows the total path length from the source to an array element and back again to be constant for all elements in the array, such that each scattered signal arrives in phase back at the source [3]. Perhaps the most well known of these arrays is the Van Atta type, in which conjugate elements of a symmetric array are connected by transmission lines of equal length [4]. Although representing the most simple and reliable retrodirective array, this approach is limited by the requirement that both the array and the wavefront be planar. A more general approach is to use a heterodyne technique, where the phase shift required for retroreflection is obtained at each antenna element [5], [6]. This method exploits the conjugate phase shift incurred by the lower-sideband product of a frequency mixing operation; by mixing the incoming signal with a reference signal at twice the frequency, the original frequency is obtained as the difference but the resulting phase is inverted. Since inversion of the wavefront phase occurs directly at each element, retrodirectivity does not depend on the symmetry of the array nor the uniformity of the wavefront. This allows irregular element spacing and nonplanar arrays, making this method attractive for use in systems where external antennas must physically conform to a surface such as an aircraft fuselage or an automobile. One of the practical difficulties of this approach is that a coherent phase reference signal must be generated and distributed to each element in the array. In an identification transponder application, this signal could be modulated to transmit information back to an interrogator.

A HETERODYNE SCATTERING ELEMENT

For conformal retrodirective arrays, microstrip circuits are attractive due to a thin profile. However, the heterodyne approach requires the use of a mixer where the RF and IF frequencies are equal, or nearly so, but isolation between the two is required. Isolation prevents the converted (conjugate-phase shifted) 6 GHz product from being overpowered by the RF leakage signal, which would result in the main lobe scattered toward the Snell reflection angle rather than retrofire. Since filtering is impossible, isolation must be obtained through a hybrid structure such as a balun; however, at microwave frequencies where the RF and IF bands overlap, three-dimensional structures are usually employed. A uniplanar, two-dimensional alternative is the microstrip mixer structure proposed in Fig. 1. This is similar to a normal single-balanced "rat race" mixer [7] when the LO and IF are interchanged, so that isolation between RF and IF is effected via hybrid balance rather than the usual filter. However, since the LO frequency is twice the RF, the broadband effects of the ring must be considered. These effects are controlled by adopting a dual-frequency design approach for the ring hybrid, where port filters allow separate terminating impedances for the ring at RF/IF and LO. First, a 12 GHz bandpass filter couples the LO into the ring, and is designed to appear as an open circuit to the ring boundary at 6 GHz. This allows normal operation of the hybrid at 6 GHz, with sum and difference inputs feeding the mixer diodes at the remaining

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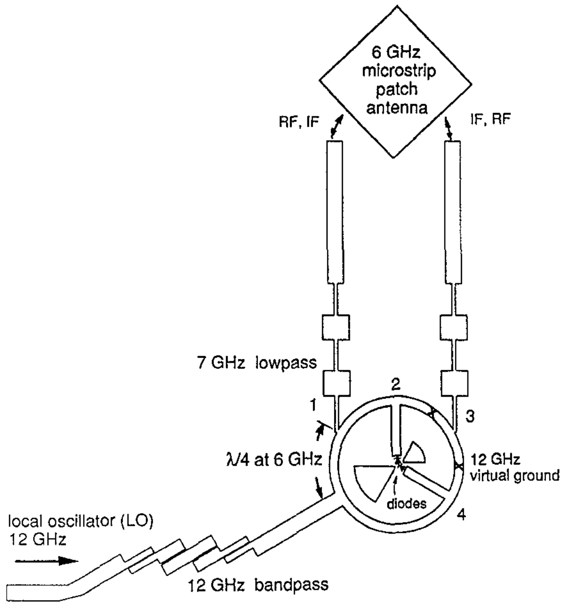

Fig. 1 Heterodyne-phased scattering element.

ports. Lowpass filters are used on the RF/IF ports which appear as open circuits to the ring at 12 GHz. Next, a point for the LO port is selected; since its wavelength is half that of the ring design wavelength, only a sum port can be formed to feed the diodes with equal power. Placing the LO port in the longer section of the ring at a 6 GHz quarter-wave from either port 1 or 4, two virtual ground points can be created in the matched ring as shown, such that the diode port impedances will appear in parallel at the LO port. Opposite mounting of the diodes allows the 12 GHz conductance waveforms to be antiphase, while allowing DC continuity for self-biasing without vias. Isolation between RF and IF is thus achieved, and the symmetry of the hybrid allows balanced mixing to occur between these two ports interchangeably. The symmetrical property is useful when the mixer is coupled to an antenna with two orthogonal feeds, such as the microstrip patch in Fig. 1. Provided the feed lines are equal length, this phase-conjugate scattering element will be compatible with any polarization -- linear and circular of either rotational sense. This is well suited for conformal array systems, where the incidence angle and polarization state of the impinging wave may vary significantly between array elements.

A prototype mixer of this type was designed for operation at 6 GHz (12 GHz LO), and fabricated on RT/Duroid 5870 substrate (31 mil dielectric, $\varepsilon_r = 2.33$). The mixer employed available Alpha DMK-6853 X-band mixer diodes. As shown in Fig. 2, the measured conversion loss was fairly flat, ranging from 5 - 7 dB over the RF frequency range 5.5 - 6.5 GHz. The LO power was +14 dBm. RF-IF isolation, for the case of equal frequencies, was also good over this range, with maximum isolation of 35 dB at 6.2 GHz and isolation exceeding conversion loss elsewhere by 10 dB.

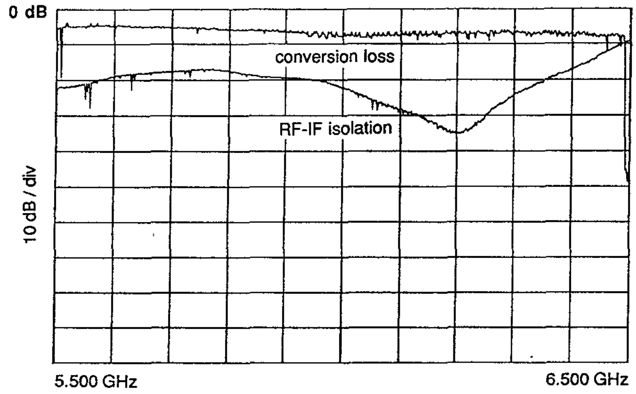

Fig. 2 Performance of prototype mixer (no antenna).

ARRAY DESIGN AND CONSTRUCTION

A prototype retrodirective array based on the mixer element was constructed, and is shown in Fig. 3. The radiating component was chosen to be an 8-element linear array of microstrip patch antennas, spaced 0.8λ apart. These are fed in two orthogonal modes TM(0,1) and TM(1,0) to enable the patch to handle arbitrary polarizations in conjunction with the mixer. For expediency, the microstrip patch antennas and feed lines were designed for 6.2 GHz; patch dimensions were 600 mil square, resulting in a resonant input impedance of approximately 150Ω at the center of the patch edge. The H-plane radiation pattern of a lone dual-fed patch is shown in Fig. 5, for both co- and cross-polarized field components. Over 30 dB of isolation was measured between the two orthogonal modes of the patch. This element is connected to the mixer by 120Ω microstrip lines, which are tilted 45 degrees so that a vertically-polarized incident wave is reflected with horizontal polarization, and vice versa; this was done for convenience in testing. With an ideal patch and a symmetrical linear mixer, incident waves polarized along the patch diagonal axis would be returned with the same polarization; all other polarization ellipses would be flipped around this axis (e.g., incident LHCP + phase-conjugate reflection + polarization flip = scattered RHCP). Mixer and antenna imperfections, such as asymmetry and spurious radiation from the feed lines, degrade this performance and must be minimized if copolarized backscatter is desired.

The retrodirective array was tested by illuminating it with an RF source and observing the wave scattered in various directions. An 18" dia. parabolic reflector was used to illuminate the array with a 6.215 GHz wave from a distance of 15 feet, resulting in a measured incident intensity of 0.76 W/m^2. The array was driven by a 12.460 GHz LO signal at +20 dBm, which is applied through a microstrip corporate feed to each mixer element (In a stand-alone retrodirective array, this signal could be derived by applying the received signal from a reference element to a frequency doubler. Lower-barrier diodes would also be used to minimize the LO power requirement).

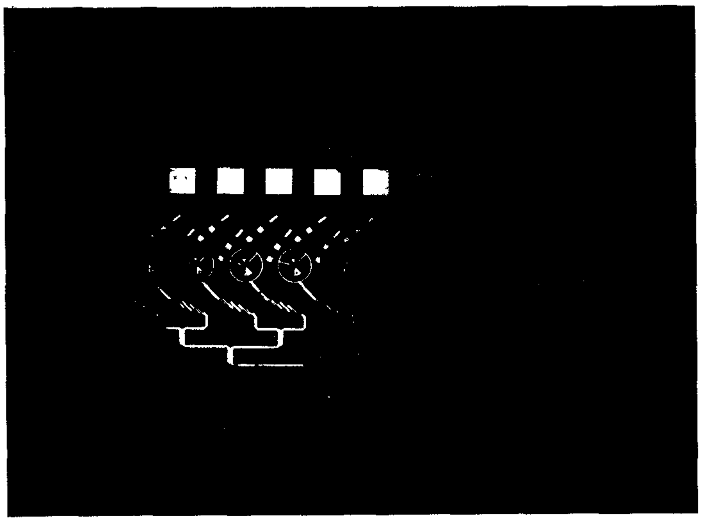

Fig. 3 6 GHz retrodirective array (7 x 13 inch).

Upon mixing with RF, a 6.245 GHz IF signal was produced and radiated back toward the source. The 30 MHz frequency offset was used to distinguish the array response from room backscatter; retrodirection still occurs, but with a slight beam squint (< 1° at incidence angles up to 75° from broadside) [8]. The retrodirected wave was received by a second, cross-polarized, antenna located either at the source (monostatic case) or at various azimuth angles from the array (bistatic case). The power was received by a small pyramidal horn feeding an HP 8562A spectrum analyzer; by measuring the scattered power, the radar cross section (RCS) of the array could then be calculated. The bistatic RCS is given in Fig. 4, showing the scattered response for waves incident on the array from the broadside, -20°, and +45° directions. Retro-reflection is observed, as the main beam of the response tracks the source.

If losses and structural scattering are neglected, the radar cross section of an antenna array can be expressed as the product of effective receiving cross section and transmit and receive gains. These latter two gains can be decomposed into element and array factors. For the retrodirective array, the transmitted phase distribution is the conjugate of the received phase distribution, which maximizes the product of the array factors for all angles of incidence. In effect, one always sees the main beam when illuminating a retrodirective array. For a linear array, the peak directivity is independent of scan angle; therefore, the only azimuthal dependence in the RCS is due to the element factor. This is evident in the monostatic RCS pattern, shown in Fig. 6. Note the similarity between the pattern shape of an isolated element (Fig. 5) and that of the entire retrodirective array, with the latter having a much greater peak directivity. The maximum radar cross section (RCS) of the array was found at broadside to be -10 dBsq.m., with high reflection available over 100 degrees of azimuth without any nulls. The bandwidth of the array is primarily limited by the microstrip patch element; as shown in Fig. 7, with the LO frequency fixed (12.4 GHz) the 3 dB bandwidth of this reflector is approximately 200 MHz.

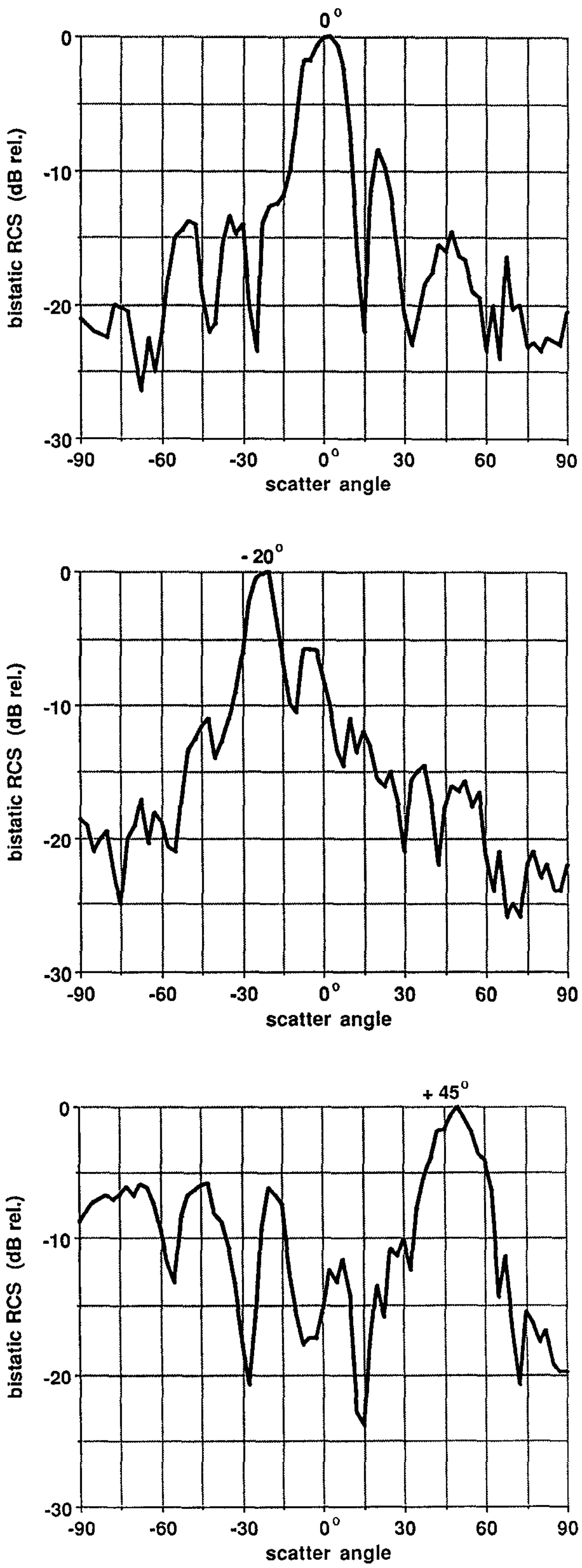

Fig. 4 Bistatic RCS of retrodirective array at 6.2 GHz for sources at 0° (broadside), -20°, and +45° azimuth.

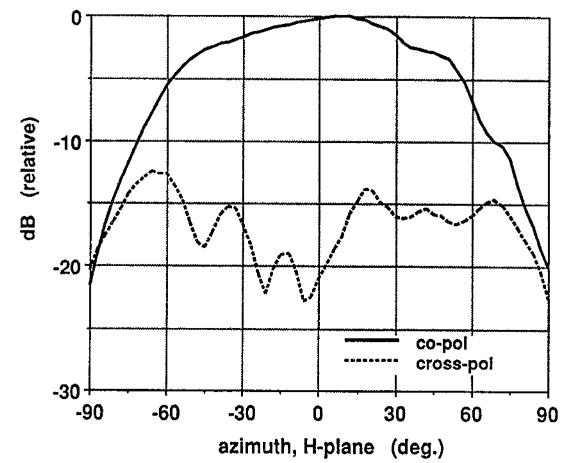

Fig. 5 Radiation pattern of single microstrip patch element.

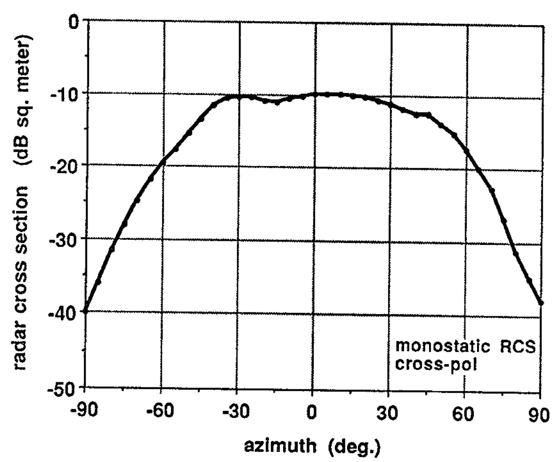

Fig. 6 Monostatic RCS of 8-element retrodirective array

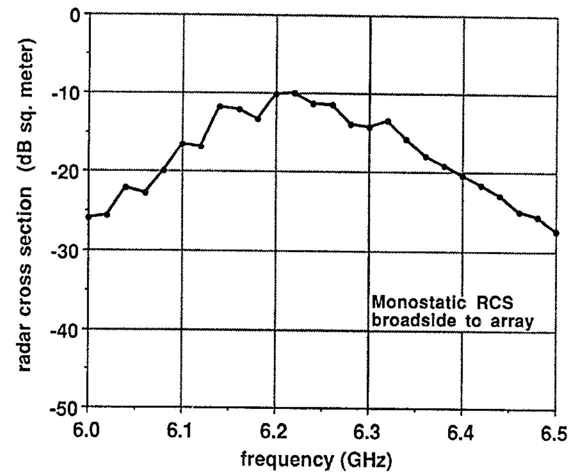

Fig. 7 Monostatic RCS of retrodirective array vs. frequency.

CONCLUSION

A retrodirective antenna array, based on a quasi-optical diode mixer, has been developed for microwave transponder applications. The array was shown to redirect an incident electromagnetic wave back toward the source, for any angle of incidence. The microstrip circuit is easily fabricated, and employs an element phasing scheme which is compatible with conformal mounting.

ACKNOWLEDGMENT

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REFERENCES

1) D.L. Margerum, "Self-phased arrays," in *Microwave Scanning Antennas,* Vol III, Ch. 5, R.C. Hansen, Ed. Los Altos CA: Peninsula 1985; pp. 366-382.

2) B.S. Hewitt, "The evolution of radar technology into commercial systems," *IEEE MTT-S Intl. Microwave Symposium Digest*, 1994, pp. 1271-1274.

3) M.I. Skolnik and D.D. King, "Self-phasing array antennas," *IEEE Trans. Antennas and Propagation,* Mar. 1964, pp. 142-149.

4) L.C. Van Atta, "Electromagnetic Reflector," U.S. Patent #2,908,002 (Oct. 1959).

5) C.C. Cutler, R. Kompfner, L.C. Tillotson, "A self-steering array repeater," *Bell System Technical Journal*, 52, Sept 1963, pp. 2013-2027.

6) C.Y. Pon, "Retrodirective array using the heterodyne technique," *IEEE Trans. Antennas and Propagation*, Mar. 1964, pp. 176-180.

7) S.A. Maas, *Microwave Mixers*, Norwood MA: Artech House, 1993.

8) R.C. Chernoff, "Large active retrodirective arrays for space applications," *IEEE Trans. Antennas and Propagation*, July 1979, pp. 489-496.