Use of an Active Retrodirective Antenna Array as a Multipath Sensor

S. L. Karode and V. F. Fusco

***Abstract*— The use of an active retrodirective antenna as an indicator of multipath propagation effects is investigated in this letter. It is shown that the flat azimuthal gain response normally associated with a retrodirective antenna array can be significantly modified by the presence of multipath signals. These signals act as secondary sources impinging on the retrodirective antenna array and give rise to amplitude perturbations in its azimuthal gain response. Using a retrodirective antenna array, the relative amplitude and phase components for the multipath signals can be recovered. In this way, the retrodirective antenna can be used as a low-cost multipath sensor.**

***Index Terms*—Retrodirective antenna, microstrip patch, multipath.**

NOMENCLATURE

- N Number of elements in the array.
- θ_t Position of the transmitter measured from the broadside.
- θ_r Position of the receiver measured from the broadside.
- x_i Distance of ith element from array phase center.
- A_0 The Array factor due to primary source.
- m Number of multipath signals present.
- ψ_m Phase difference between primary and mth secondary signal.
- A_m Amplitude scaling factor.
- θt_m Position of the mth secondary source measured from the broadside of the retrodirective array.

I. INTRODUCTION

RETRODIRECTIVE arrays have found applications in radar transponder and other tagging applications [1]. It is known that retrodirective antenna arrays perform beam steering in an automatic fashion [2]. This is achieved by retransmitting an incoming self-phased signal in a phase conjugated manner. The received signal is then retransmitted in the direction it was originated from [3]. The Van Atta array is the simplest manifestation of a more general class of phase conjugate antenna which relies on heterodyning the incoming signal at f_o with a reference signal at $2f_o$ to automatically produce a conjugate phase shift [4]. This is obtained by selecting the resultant lower sideband mixing product. An active antenna embodiment using this principle type was developed in [5]. A simpler and more compact retrodirective antenna was given in [6], and it is this structure that is used as the multipath sensor in this work. In broad-band mobile communication applications, particularly at microwave and millimeter-wave frequencies, multipath reflections are extremely problematic due to the very large fade depths encountered. In this letter it is shown that an active retrodirective antenna array can be used to detect the multipath reflections and thus provide a diagnostic tool for mapping these reflections.

Manuscript received July 14, 1997. This work was supported by Commonwealth Scholarship Commission, Association of Commonwealth Universities, London, and by the Engineering and Physical Science Research Council.

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Publisher Item Identifier S 1051-8207(97)08976-9.

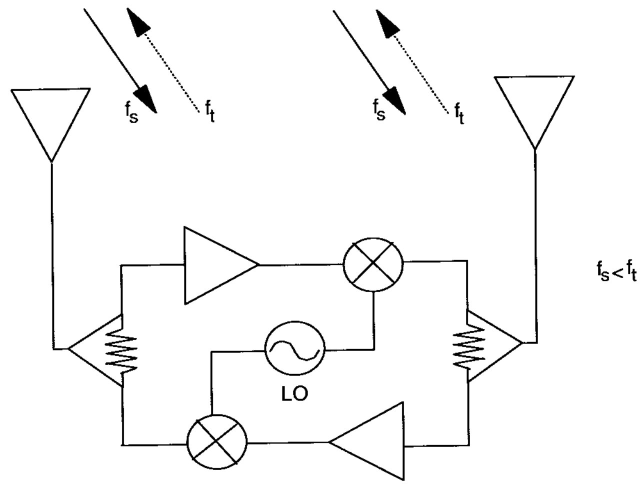

Fig. 1. Retrodirective antenna array circuit.

II. MULTIPATH SENSING USING RETRODIRECTIVE ARRAY

The phase conjugate retrodirective antenna array used in this work is that described in [6] and is shown in Fig. 1. Here the incoming signal f_s at 990 MHz is mixed with the local oscillator signal at 1.990 MHz ($\approx 2f_s$). The difference product f_t at 1 GHz, which bears a phase conjugate relationship with the incoming signal is retransmitted back in the direction of the source. The mixer sum product is filtered out by the limited bandwidth of the microstrip patch antenna. Different receive and transmit frequencies are used for easier identification of the received signal.

By noting that the retrodirective antenna has the property that the array will track and return multiple beams simultaneously [7], we have the prospect of producing a simple technique for mapping multipath effects.

Multiple reflections from different sources act as secondary sources incident on the retrodirective array. Hence, the single

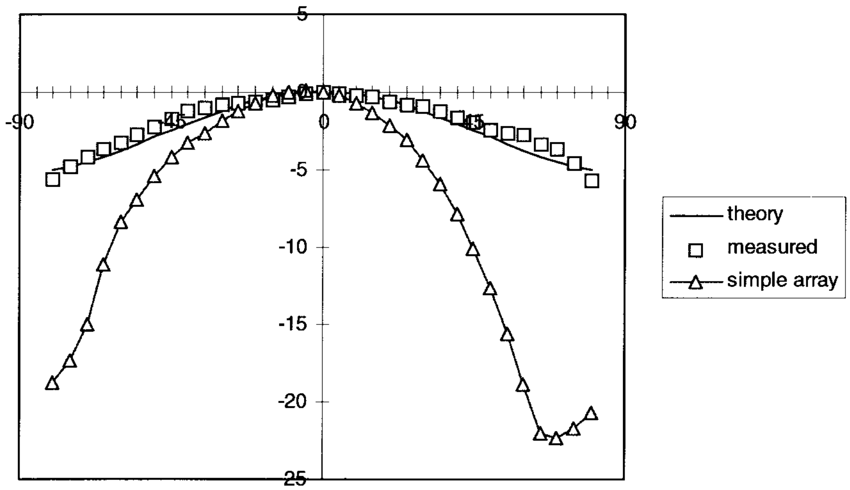

Fig. 2. Theoretical and measured MRCS patterns of the retrodirective antenna array with no reflections.

return beam that would be obtained under the condition of no secondary source presence splits under the condition of multipath signals and forms sidelobes in the direction of each source, and, as a consequence, the radiation response of the retrodirective antenna becomes more complex. Thus, the normally flat azimuthal gain response of the retrodirective antenna array in Fig. 1 will now have added structure due to the presence of secondary multipath signals. The overall effect of these secondary sources depends on their relative angular position and strength in relation to the antenna. The transmit and receive behavior of the retrodirective antenna, when operated with multiple sources, can be defined by using an "effective array factor" which is obtained by vectorially adding the array factors due to each source. Equation (1) gives the effective array factor due to multiple sources:

$$E_{\text{total}} = e^{j(\omega t+\phi)}\left[A_0 + \sum_{1}^{m} A_m e^{j\omega\psi_m}\right] \tag{1}$$

where

$$A_m = a_m \sum_{-(N/2)}^{N/2} e^{j(2\pi x_i/\lambda)(\sin\theta_{t_m}, -\sin\theta\text{r})}.$$

The effective array factor when multiplied with the element pattern gives the overall far field radiation patterns in the usual way.

III. Multipath Mapping

To understand the multipath effect of reflections on the retrodirective antenna measurement and hence to evaluate its potential as a multipath sensor, a monostatic radar cross section (RCS) measurement of the azimuthal gain response of the array was carried out with minimum reflections presented to the array. This was achieved by using the radar-absorbent material to suppress secondary reflections. The result is shown in Fig. 2, together with the theoretical prediction of azimuthal gain using effective array factor given by (1). For comparison radiation pattern of a passive two-element array is also shown

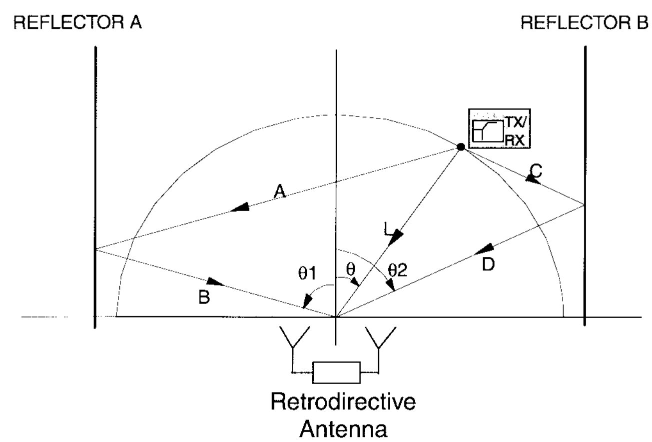

Fig. 3. Retrodirective antenna array in the presence of two reflectors.

in Fig. 2. Here the 3-dB beamwidth of the retrodirective antenna array is 110° compared to 60° for the passive two-element array. Controlled reflection when then added as shown in Fig. 3, with two metal sheets A and B present ($\Gamma \approx -1$), results in Fig. 4. Here the angle of incidence for secondary sources was calculated from simple geometry and their relative amplitudes were found using the path loss equation. The predicted response is in agreement with the experimental results, agreement over the range $-90°$ to $90°$ is within 3 dB and could be further reduced by using the actual antenna element radiation pattern instead of the theoretical pattern when calculating the overall array performance.

Least square optimization was used to minimize the difference between (1) and the actual data measured at 5° azimuthal steps in order to obtain the relative phase and amplitudes characteristics of the multipath signal present in an actual room. The azimuthal response due to actual multipaths in the room along with simulated response obtain using the numerical extraction procedure is shown in Fig. 5. Table I shows the amplitude and phase components of the three principle multipath wavefronts were needed to characterize the measured response within 0.3-dB error over the range $+81°$ to $-71°$.

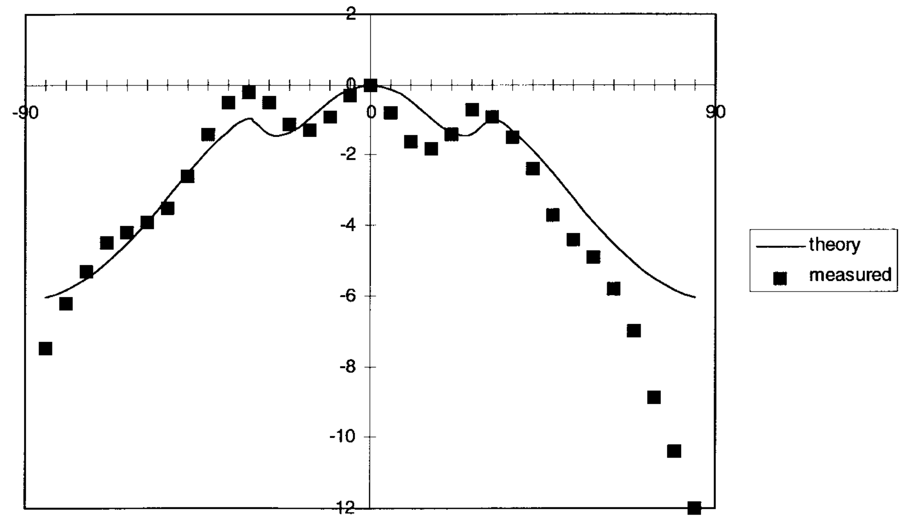

Fig. 4. Theoretical and measured MRCS patterns of the retrodirective antenna array in the presence of reflector A and B.

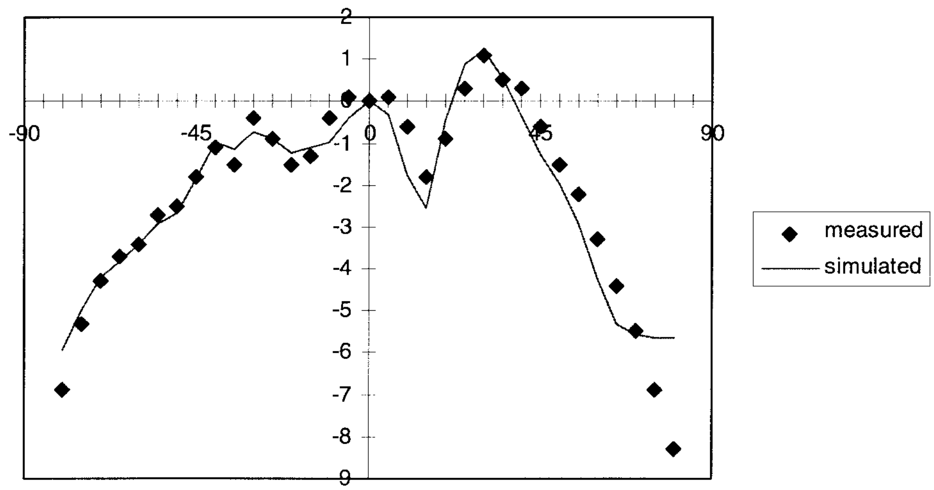

Fig. 5. Simulated and measured MRCS patterns of the retrodirective antenna array in the presence of multiple reflections.

TABLE I
AMPLITUDE AND PHASE COMPONENTS OF EXTRACTED MULTIPATH ENVIRONMENT

Angle	Amp1	Phase1	Amp2	Phase2	Angle	Amp3	Phase3
-90	0.2	180	0	0	0	0	0
-85	0.19	210	0	0	5	0.35	110
-80	0.18	230	0	0	10	0.38	150
-75	0.16	260	0	0	15	0.42	180
-70	0.14	290	0	0	20	0.44	270
-65	0.12	300	0	0	25	0.48	330
-60	0.1	310	0	0	30	0.58	360
-55	0.11	320	0	0	35	0.5	350
-50	0.13	330	0.06	200	40	0.4	330
-45	0.14	345	0.08	260	45	0.32	315
-40	0.2	360	0.1	280	50	0.31	300
-35	0.09	450	0.21	300	55	0.3	280
-30	0.07	490	0.16	360	60	0.2	250
-25	0.03	0	0.14	260	65	0.17	210
-20	0.01	0	0.15	210	70	0.14	205
-15	0	0	0.15	190	75	0.1	190
-10	0	0	0.17	160	80	0.07	180
-5	0	0	0.2	110	85	0.05	170
0	0	0	0.12	80	90	0	155

IV. CONCLUSION

It has been shown that perturbations in the gain response of a retrodirective antenna array can be directly attributed to multipath reflections acting as secondary sources impinging on the array. Further it has been shown that the individual components comprising the secondary signals can be identified by calculating an "effective" array factor to the measured data. In this way a novel multipath sensor has been developed using the inherent physical properties of a self-phasing retrodirective antenna array.

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