Multipath Communications Using a Phase-Conjugate Array

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Abstract — **A new microwave wireless communications scheme based on a phase-conjugating retrodirective antenna is introduced for maintaining a reliable radio link in a severe multipath environment. The method does not eliminate multipath, but uses it advantageously and is better suited to cope with mobile receivers than other methods. In the ideal case, the negative effects of multipath propagation can be completely avoided and multipath propagation only improves reliability of the radio channel. The principle is experimentally verified at 5.35 GHz, and demonstrates that severe fading can be avoided and variation of received signal power can be reduced.**

I. Introduction

Wireless radio communications is used in an increasing number of applications. In addition to current and well-known applications such as mobile phones, wireless radio systems are foreseen to connect practically all items used in homes and offices. Applications such as wireless local area networks (WLAN) and Bluetooth are first steps toward this direction. One of the challenges in such applications is mitigating the fading due to multipath propagation. Multipath can be reduced by using antennas with tightly focused beams, signal processing, or special modulation schemes. While high-gain antennas with focused beams are useful for fixed point-to-point communications, mobile and general-purpose communication applications require antennas with wide beams or capabilities for smart beam steering. However, smart beam-steering antennas are usually complex as they require controlling electronics and computational power.

All of the methods described above are employed to *reduce* the effects of multipath. In this paper, we present an alternative scheme in which multipath signals are used to *enhance* the communications in severe multipath environments. The method is based on phase-conjugating retrodirective antennas [1]-[5], which are well-known for their self-tracking capabilities and their ability to correct for phase aberrations due to effects of disturbing and unknown media in the signal path.

It is important to note the distinction between this paper and other recent work in retrodirective antennas. Previous work involving communication with phase-conjugating antennas [6]-[8] emphasized automated beam pointing or self-steering in an environment with or without disturbing objects, and not on the actual use of multipath propagation for communication. In [9], a retrodirective antenna was demonstrated as a multipath sensor, but not for communications.

The new method proposed here is designed to solve problems caused by multipath propagation or disturbing objects in the signal path. In the proposed method, the multipath propagation is used as a positive, rather than negative, contribution in the communication. In the ideal case, the fading can be completely avoided and multipath propagation only improves the radio channel. The use of multipath propagation for communications using audio waves was described in [10]. In this paper, the principle of operation is demonstrated for the first time using radio waves.

II. Description of the Method

In a typical point-to-multipoint communication link, an omnidirectional base station transmits its signal in all directions. If the communication channel contains scatterers, the mobile receiving station may encounter fading due to the resulting multipath effects. Similarly, multipath affects communication from the mobile station back to the omnidirectional base station.

Now consider the situation in Fig. 1, where the mobile station has an ideal phase-conjugating retrodirective antenna that is infinitely directive – *i.e*, it reflects a ray or a narrow beam only towards the direction of the incoming field. The return signal from the retrodirective antenna, which could be modulated, consists of phase-conjugated rays that add coherently at the omnidirectional source. In this way, retrodirectivity completely eliminates the fading effects of multipath propagation in the roundtrip communication link. In fact, multipath actually increases the reliability of the link since it is unlikely that all of the available paths between transmitter and receiver can be blocked simultaneously. Furthermore, since the retrodirective antenna can change its radiation pattern in real time, the scheme will still work even if there is motion of the receiver or transmitter or both.

Fig. 1 shows how simplex communications can be carried out from the retrodirective antenna to the wide beam antenna by modulating the reflected signal during the mixing process. For full-duplex communication, both a retrodirective antenna and a wide beam antenna are needed at both ends of the link.

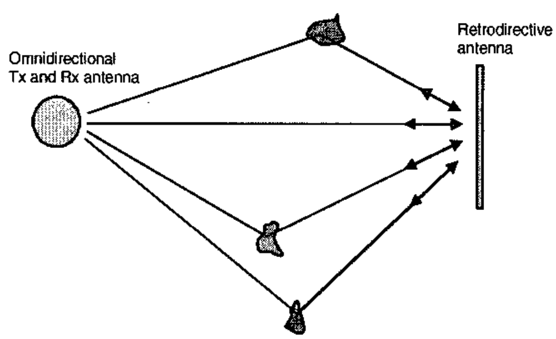

Fig. 1. An ideal point-to-point communication link with a phase-conjugating retrodirective antenna in a multipath environment with reflecting objects.

A comparison of the ideal and practical situations is shown schematically in Fig. 2. For the practical case of finite antenna size, the retrodirective antenna has a nonzero beam width and sidelobes. Hence, beams reflected back from the practical retrodirective antenna not only return through the main beam path, but also through the side lobes. All of the signals corresponding to the main beam rays add up coherently whereas all the rays created by the sidelobes have random phases and add up incoherently at the omnidirectional antenna. This limits the method in practical systems. However, reductions in deep fading and overall signal-level variations are still expected. Obviously, the situation gets more ideal as the directivity of the phase-conjugate array increases and sidelobe level decreases.

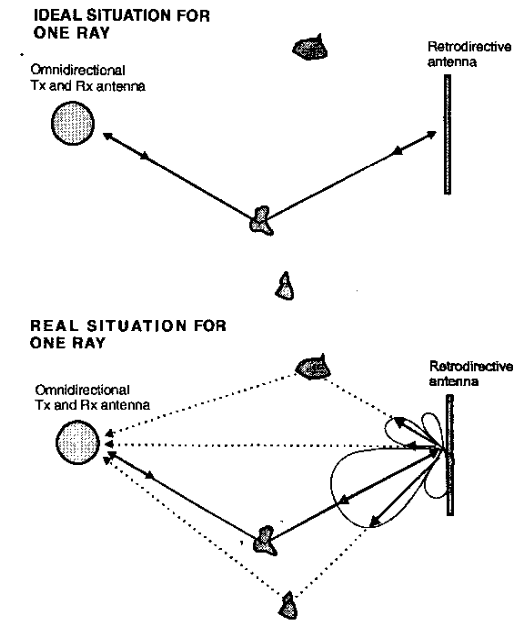

Fig. 2. Propagation of one ray from the omnidirectional antenna to retrodirective antenna and back in an ideal and a real situation.

III. Experimental Verification

To verify the concept, an experiment was set up at 5.35 GHz, as shown in Fig. 3. A signal from a synthesizer is fed through a directional coupler to a horn antenna mounted on a computer-controlled x-z stage, allowing two-dimensional movement in the horizontal plane. The horn antenna is placed 1.26 m away from the retrodirective antenna and is able to move 0.74 m in the perpendicular x-direction, as shown in Fig 4. A local oscillator (LO) signal of 10.7 GHz is supplied from a synthesizer to the retrodirective antenna using a quasi-optical feed system. An LO frequency with a small offset from exactly twice the incoming signal is used so that the return signal is slightly different from the 5.351-GHz signal originally transmitted from the horn antenna. The phase-conjugating retrodirective antenna is a four-element patch array with FET-based mixers [11], with bistatic and monostatic patterns shown in Figs. 5 and 6, respectively. A mixing product with conjugated phase is reradiated by this antenna at 5.349 GHz. The returned signal at the horn is detected using a spectrum analyzer attached to the directional coupler.

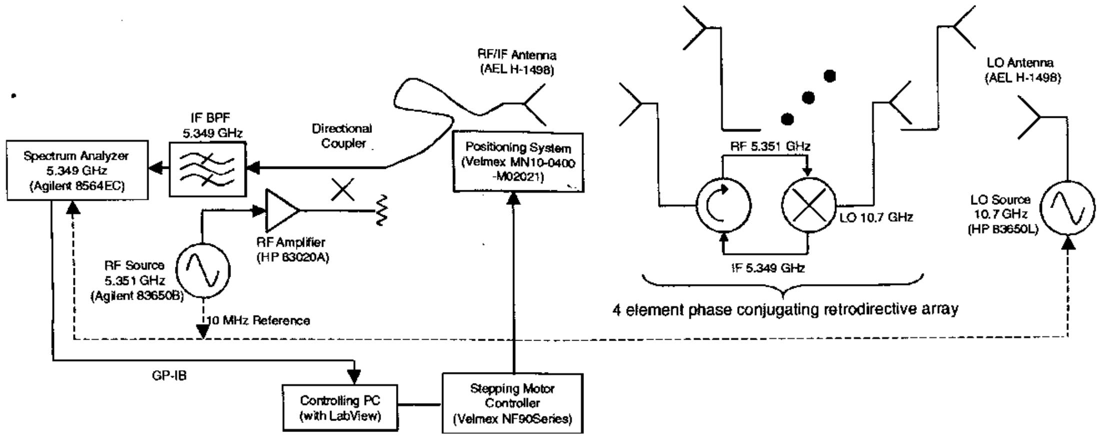

Fig. 3. Configuration of the automated experimental set-up at 5.35 GHz.

As a baseline comparison, a passive four-element patch antenna array with a Wilkinson power-divider feed was used in place of the retrodirective antenna. The far-field radiation patterns of the two arrays are shown in Fig. 7.

The measurements were carried in a standard laboratory with absorber positioned in critical areas. To create a severe multipath situation, a reflective object (a metal plate) was placed in the vicinity of the antennas, as shown in Fig. 4. The horn antenna on the moving stage was pointed so that the direct signal and reflected (multipath) signal were comparable in amplitude. Using this same horn antenna setting and while moving it 0.74 m, the signal level was recorded for two cases: 1) the passive reference array used as a transmitting antenna and 2) the phase-conjugate antenna used to reflect the signal back. Comparison of the recorded signal levels is shown in Fig. 8. For the reference array, the signal level varies strongly over a 40-dB range and also includes a deep dip indicating a fading point in the scan. In contrast, for the phase-conjugate antenna, the signal level varies by only 9 dB with no deep dips. This measurement shows that multipath propagation can be actually used for advantage and that the proposed method works.

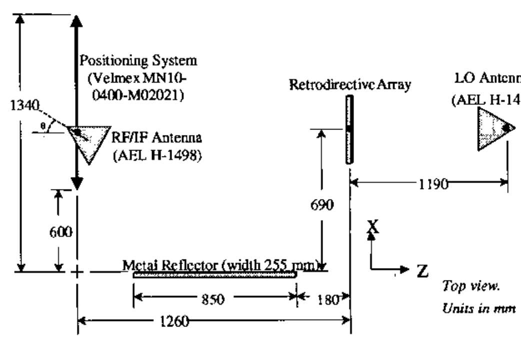

Fig. 4. Physical layout of the experimental set-up.

IV. CONCLUSION

A method for reducing the effects of fading and signal level variation in a severe multipath environment has been presented. The method is based on the use of a phase-conjugating retrodirective antenna, in which the multipath propagation is used advantageously to increase the reliability of the communication link. The principal of operation was demonstrated using a four-element phase conjugating array at 5.35 GHz. In the experiment, severe multipath propagation was caused by a metal reflector. The retrodirective antenna demonstrated a 31-dB improvement in signal-level variation compared to that of a passive reference antenna.

ACKNOWLEDGEMENT

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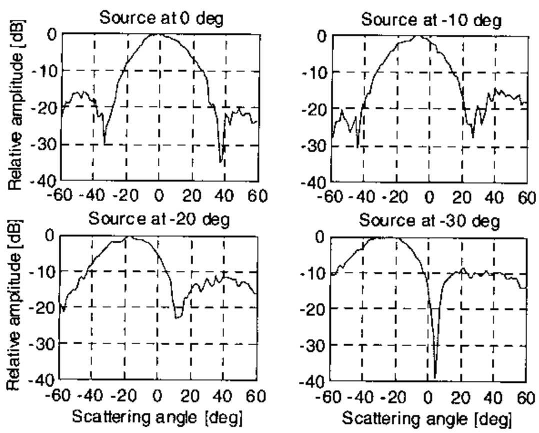

Fig. 5. Measured far-field bistatic radiation patterns of the retrodirective antenna at 5.35 GHz, when RF source signal is incident at 0°, -10°,- 20°, and 30°.

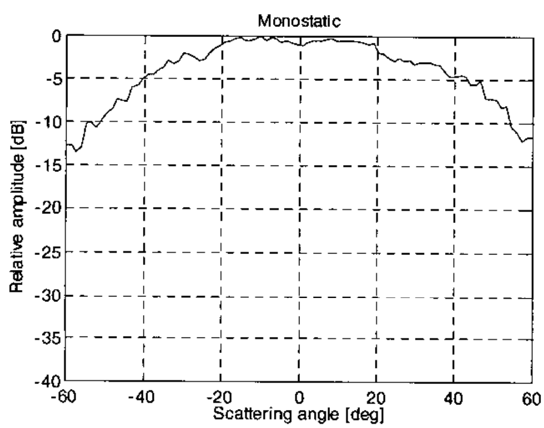

Fig. 6. Measured monostatic response of the retrodirective antenna at 5.35 GHz.

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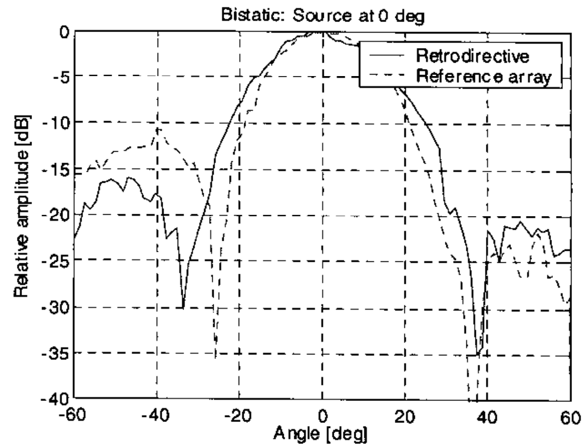

Fig. 7. Measured bistatic radiation pattern of the retrodirective array and the reference patch array antenna without retrodirective properties at 5.35 GHz.

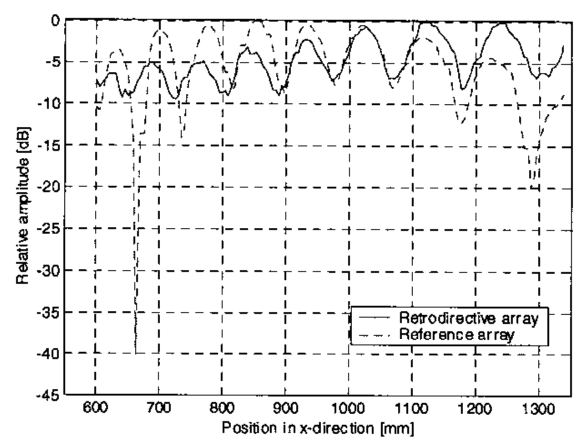

Fig. 8. Measured power level variation using a phase conjugate retrodirective antenna and a reference array antenna at 5.35GHz. The probe antenna is pointing towards the reflector in an angle of θ=50°.