An Adaptive Multi-Functional Array for Wireless Sensor Systems

Ryan Y. Miyamoto, Kevin M. K. H. Leong, Seong-Sik Jeon
Yuanxun Wang, and Tatsuo Itoh

Department of Electrical Engineering, University of California, Los Angeles
405 Hilgard Ave., Los Angeles, CA 90095

Abstract **— Smart antenna and retrodirective array technologies are combined to establish a reconfigurable phased array communication system. The array serves as a retrodirective transponder with a LO frequency at 11.6 GHz. By changing the LO frequency to 2.9 GHz, the array can be reconfigured to a smart antenna enabling multi-user communications. The retrodirective transponder provides 20dB circuit gain and 20 dB RF-IF isolation exhibiting excellent retrodirectivity. When operating as a smart antenna, the receiver array successfully demodulates a QPSK modulated signal with circuit gain of 7 dB and E_b / N_0 for $BER = 10^{-4}$ is approximately 12 dB without any error correction. In the retrodirective array mode, the system provides 20 dB**

I. Introduction

Next generation sensor systems should be multimedia compatible. The use of microwave frequencies is required for high data rate wireless sensor systems [1]. A time division duplex (TDD) retrodirective array has shown much promise in enabling high efficiency, low cost wireless sensor systems using a microwave frequency band [2]. With a retrodirective array the system efficiently transmits a signal towards the interrogator without any digital signal processing. Integrating a direct conversion receiver function to it, the array can be used as a semi-duplex communication system. However, the retrodirective array often fails to establish a decent radiation pattern when the array receives signals from multiple directions. This problem is inevitable in a multipath or multi-user environment. Therefore, the use of a retrodirective array is limited to a line-of-sight communication such as ground-to-air kind of communications.

Adopting the space division multiple access (SDMA) to the direct conversion receiver array, the capacity of users can be increased by improving the signal-to-interference ratio (SNIR) [3,4]. This also overcomes the multipath environment issue, which is often seen in ground-to-ground communications.

In this paper, a multi-functional array system using both retrodirective array and smart antenna technologies is introduced. The system can be reconfigured just by changing the frequency of the local oscillator. As shown in Fig.1, the retrodirective array mode is used for data extraction, which is a ground-to-air communication while the smart antenna mode is used for ground-to-ground multi-user communications. The system can efficiently be used for mobile communication or high-end wireless sensor systems.

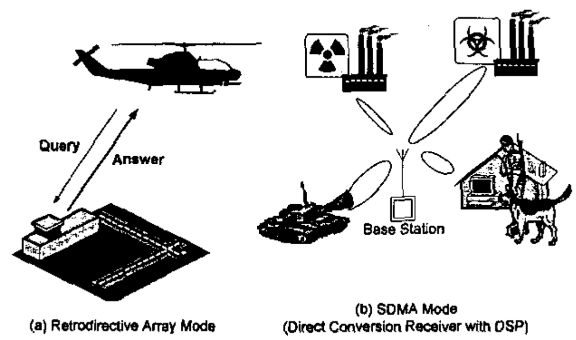

Fig. 1 Reconfigurable System using a Multi-Functional Array

II. Reconfigurable Circuit

Figure 2 shows the diagram of the reconfigurable circuit. The received signal is applied to a pair of resistive FET mixers in phase through a ratrace coupler, which isolates the ingoing and outgoing signal paths. The reconfigurable element serves as a phase conjugator with a LO at twice the RF frequency. In this mode, the LO is applied to the mixers 180 degree out of phase. Since RF leakage is cancelled at the port connected to the transmitting antenna while the phase-conjugated IF is added in phase, good RF-IF isolation can be obtained. With this circuit placed in an

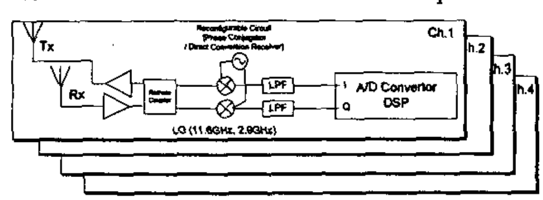

Fig. 2 The System overview

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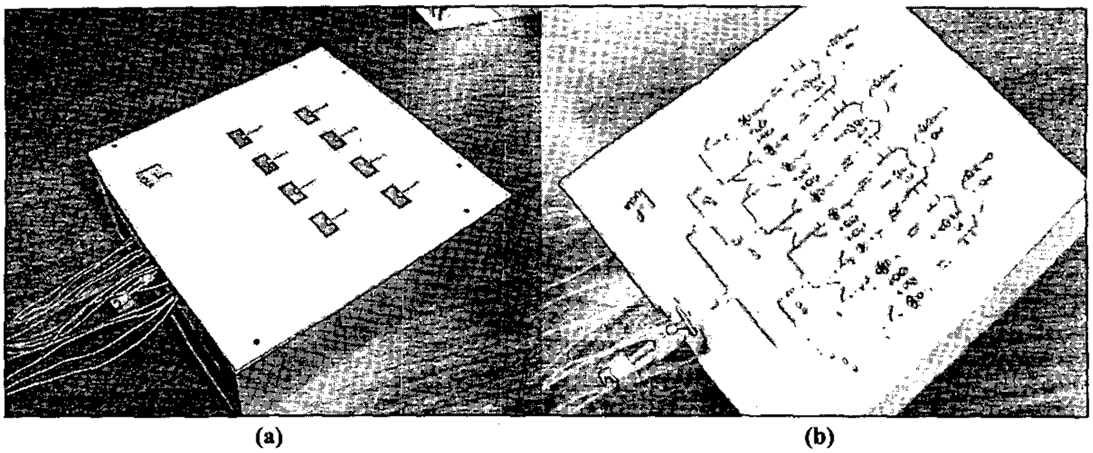

Fig. 3 Prototype Four Element Multi-Functional Array (a) antenna side (b) circuit side

array, the system becomes a retrodirective transponder. The modulating signal can be applied through the baseband ports, enabling the array to send information to the interrogator.

At the same time, the circuit works as a sub-harmonic direct conversion receiver or transmitter when the LO frequency is set at half the frequency of the RF signal. The LO is applied 45 deg out of phase, enabling quadrature direct conversion mixing. With digital signal processing (DSP), the array is capable of digital beamforming. Therefore the system can serve as a smart antenna in this mode.

Figure 3 shows a prototype four element array. The circuitry is placed in the back of patch antennas. The system is designed small enough to maintain the array spacing less than half-wavelength at the RF (5.8GHz) frequency. This keeps the array from suffering from grating lobes at endfire directions in both retrodirective transponder and smart antenna modes. NEC NE76038 FETs are used for resistive mixers while the LNAs are Agilent MGA-86576.

III. Retrodirective Transponder Mode

In this operating mode, a LO at 11.6 GHz is applied to the mixers and the circuitry behaves as phase conjugators. The received signal is phase-conjugated by the circuitry and the transmitted phase conjugated signal creates a main beam in the incoming direction. Therefore, the array points a radiation peak at the source direction. By modulating the phase-conjugated signal with a baseband data signal, the array can transmit information to the interrogator when the array is illuminated by a signal.

The prototype system shows total circuit gain of 20 dB and RF-IF isolation of 20 dB with a RF at 5.81 GHz. The signal can be amplified more by adding more amplifiers. The phase conjugated signal is successfully modulated by a 10Mbps data signal. Figure 4 shows the monostatic radar cross section pattern of the array. Since the interrogator always sees the peak of the array radiation pattern, the monostatic RCS shows a flat characteristic.

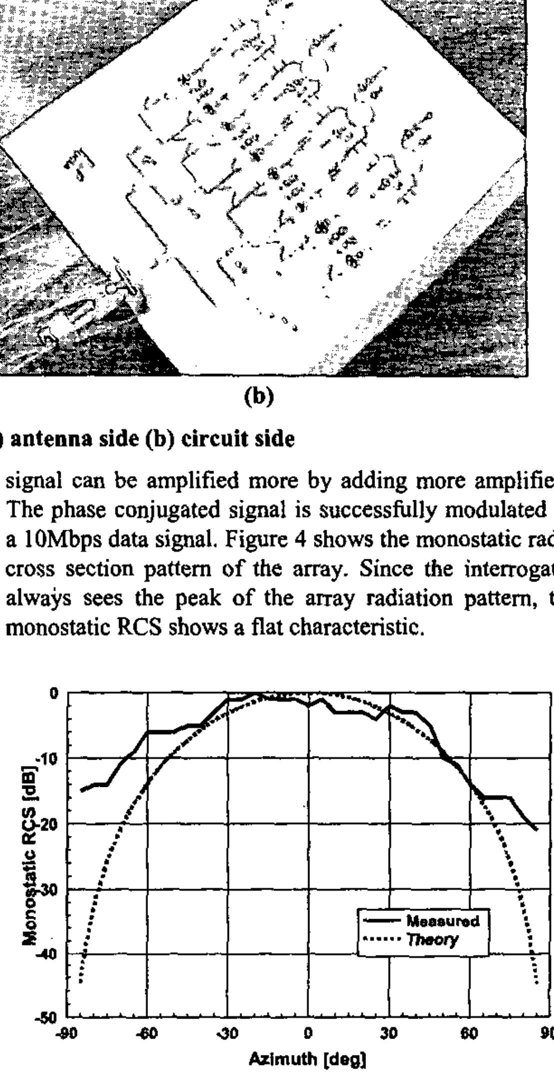

Fig. 4 Monostatic RCS pattern

IV. Smart Antenna Mode

When the LO frequency is set to 2.9 GHz which is half the RF frequency, each element serves as a direct conversion receiver. The recovered baseband signal is digitized and processed for digital beamforming based on direction-of-arrival (DOA) estimation using multiple signal classification (MUSIC) algorithm. Since the circuit can work as downconverter and upconverter, this smart antenna can efficiently be used for semi-duplex communications by using time division duplexing.

A. Receiving Mode

Figure 5 shows the circuit gain vs. LO input power plots. Since low noise amplifiers (LNA) are integrated into the mixer circuit, circuit gain is available though the mixers themselves have conversion loss. The minimum local oscillator power required to avoid the circuit loss is 2 dBm. The maximum circuit gain is obtained with LO power of 13 dBm.

Figure 6 shows bit error rate (BER) test results and theoretical estimations under different SNR conditions.

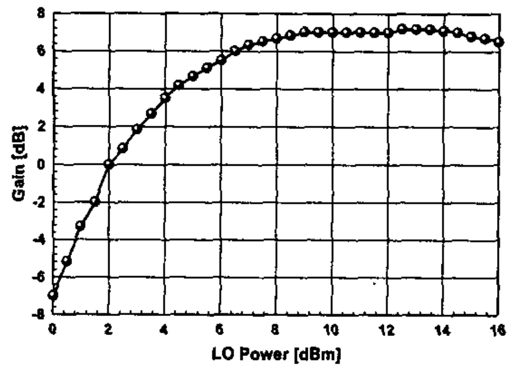

Fig. 5 Gain vs. LO Power in the receiving mode

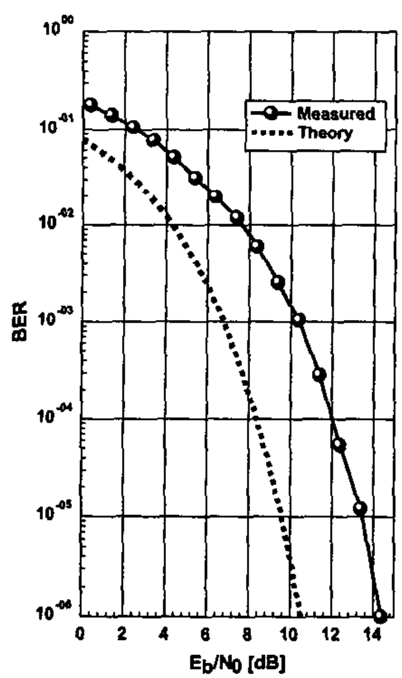

Fig. 6 Bit Error Rate test results

E_b / N_0 is measured at the transmitting antenna. The noise figure of the low noise amplifiers is approximately 2.3 dB. Therefore, the measurement results reasonably match the theory. E_b / N_0 for $BER = 10^{-4}$ is approximately 12 dB without any error correction. The difference between the measurement data and the theoretical estimation is mainly due to the noise figure of the low noise amplifier at the input port.

B. Transmitting Mode

The circuit can also serve as a direct conversion transmitter. The baseband signal is applied through I/Q ports. The maximum circuit gain is about 12 dB, and the minimum LO power required for circuit gain is about 2.8 dBm. The modulated output signal shows a typical QPSK power spectrum.

C. DOA Estimation and Digital Beamforming

The array is illuminated by a 5.8 GHz wave coming from an angle and the LO frequency is 2.9+δ (offset) GHz, allowing the baseband to have a residual frequency. The signal is downconverted at each element and the downconverted signal is sampled by using a digital oscilloscope. The sampled data are processed on a PC.

Figure 7 (a) shows the normalized sampled data. The data is Hilbert-transformed and DOA estimation is done using MUSIC algorithm as shown in Fig. 7 (b). Weighting functions are created based on the DOA estimation and applied to the data such that the main peak is at the incoming angle. Figure 7 (c) shows the comparison between digital beam forming and raw data. Since the signal from each channel is coherent after applying a weighting function, the waves are combined efficiently.

The MUSIC DOA estimation can be applied to suppress undesired signals, reducing co-channel interference and inter-symbol interference for multi-user systems.

V. CONCLUSION

The fusion of a smart antenna and a retrodirective array is successfully achieved. The system can easily be reconfigured by changing the LO frequency. The reconfigurability brings about reduction of the system size and cost. When the circuitry serves as a direct conversion receiver, the array is used as a smart antenna, enabling SDMA. The retrodirective array mode is used for remote data retrieval on demand, enhancing the communication link between the server and an interrogator.

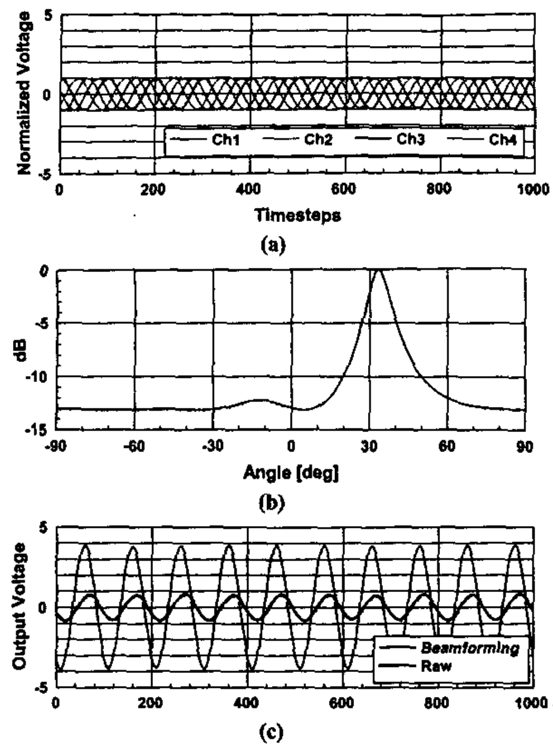

Fig. 7 Smart antenna measurements (a) normalized sampled data (b) DOA estimation (c) combined signal.

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