A Reconfigurable Active Retrodirective/Direct Conversion Receiver Array for Wireless Sensor Systems

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***Abstract* — A reconfigurable active retrodirective/direct conversion receiver array is presented. The system can serve as both a retrodirective array transponder and a direct conversion receiver simply by changing the frequency of the LO applied to the mixers. In the retrodirective array mode, the circuit provides 20 dB gain and 20 dB RF-IF isolation. The mixers perform phase-conjugation and modulation simultaneously. When operating as a direct conversion receiver, both I and Q channels are successfully recovered.**

I. Introduction

Non-traditional, high-performance RF radio/sensor systems are required in various areas. These systems should satisfy the physical requirements such as simplicity, compactness, high efficiency and low cost. The integrated antenna approach has shown much promise in addressing these issues [1]. Transmitter and receiver sides can be improved by using high-efficiency amplifiers. At the same time, the communication links between these systems can be improved by adapting phased array systems such as retrodirective arrays [2] -[3].

A retrodirective array has the interesting trait that it sends an incoming signal back to the source direction without any a priori knowledge of the direction of arrival. One way to achieve the retrodirectivity is through phase-conjugation. This can easily be achieved by heterodyne mixing using an LO that has the twice the RF frequency [4]-[5]. In this scheme, the lower sideband product has the same frequency as the RF, but with a conjugated phase. One of the major advantages of this technique is that the incoming signal can be modulated and phase-conjugated at the same time. In a retrodirective system, the communication link between the transponder and base station can significantly be improved since the array effectively tracks the peak of radiation. Therefore, this kind of array system should find a wide range of applications in wireless transponder systems. Furthermore the integration of active devices into this kind of system will enhance the communication links and reduce the circuitry size [6]-[8].

Reconfigurablity is another significant advantage in an RF system because it allows the front-end circuitry to share many components. Since both the downconverter and phase-conjugator utilize microwave mixers, it is possible to design the two types of mixers which share a large part of the passive components and active devices and dynamically reconfigure the RF functionality by simply changing the LO frequency. In addition, the use of direct converters eliminates extra IF circuitry, significantly reducing the circuit size [9].

II. Proposed Wireless Sensor System

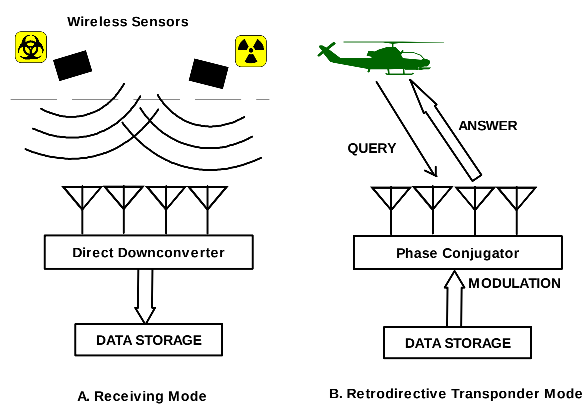

Fig. 1 The proposed wireless sensor system using a reconfigurable retrodirective/direct conversion receiver array

Figure 1 shows the proposed wireless sensor system using a reconfigurable active retroridirective/direct conversion receiver array. In the receiving mode (a), the array system works as a direct conversion receiver and stores data received from remote sensors. Next, upon receiving an instruction signal from an interrogator, the system starts working as a retorodirective transponder (b), and sends the stored data to the interrogator. This switching is initiated by the header code contained in the signal from the interrogator. Since the retrodirective array always direct its peak beam towards the interrogator

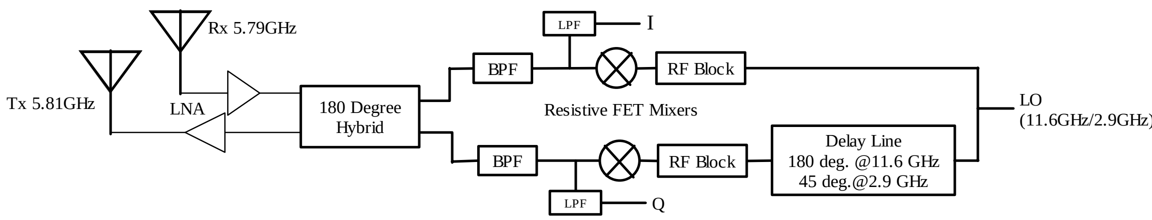

Fig. 2 The schematic of the reconfigurable phase-conjugater/direct downconverter element

without having to identify its exact location, the system effectively works as a smart antenna with greatly enhanced link gain. In contrary to a typical smart antenna system, however, the proposed system here realizes a peak radiation beam towards the target in the analog domain entirely, without the need for high-speed analog-to-digital converters (ADC), sophisticated digital signal processing (DSP) algorithms, and all associated hardware circuitry.

III. CIRCUIT OVERVIEW

The schematic of the multi-function circuit is shown in Fig. 2. The signal received by the receiving antenna is amplified by a LNA and applied into the resistive FET mixers in phase. An LO signal is divided into two and one side experiences a delay, which is 180 deg at 11.6 GHz and 45 deg at 2.9 GHz. When an 11.6 GHz LO is applied, the circuit works as a phase conjugator. At the same time, when a 2.9 GHz LO is applied, the circuit works as a subharmonic direct downconverter.

In the phase conjugating mode, the RF and IF frequencies are close together while the LO frequency is far from both the RF and IF frequencies. Therefore, it is possible to reduce the circuit size by applying RF and LO from the opposite sides of a FET, extracting the IF product from the RF input port [7]. However, this architecture makes it difficult to insert additional active components such as amplifiers. This issue can be solved by using a ratrace coupler. When the RF signal is applied into the mixers in phase, the rejected RF is in phase while the phase-conjugated signal is 180 deg out of phase. Thus, at the Δ port, the rejected RF should cancel out and only the phase-conjugated signal can passes on to the next stage. This scheme provides decent isolation between the phase-conjugated signal and RF leakage. The isolation is decided at this point and the signal can be amplified depending on the communication distance by inserting amplifiers between the output port and the transmitting antenna.

In the direct downconverting mode, a LO (2.895 GHz) is applied to the mixers with a 45 deg phase difference. This corresponds 90 deg at the carrier frequency of the received signal. I and Q channels are obtained through lowpass filters from the drain sides. Since resistive FET mixers are used, there is no biasing at the drain sides. DC separation problems are eliminated.

A prototype circuit was fabricated on RT/Duroid 6010 (25 mil thickness, ε_r=10.2) substrate and is shown in Fig. 3. The heterodyne FET mixers employ NEC NE76038 while the LNAs are HP MGA-86576. The circuit size is small enough to maintain half-wavelength array spacing.

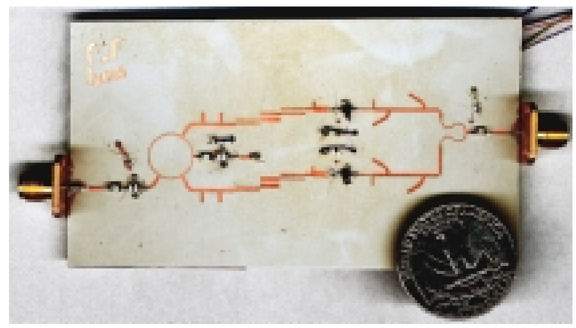

Fig. 3 The fabricated new multi-functional circuit

A. Phase Conjugating Mode

The circuit performance was first tested by using two synthesizers connected to the RF and LO input ports in order to provide the RF (-50 dBm, 5.79 GHz) and LO (10dBm, 11.6GHz) signals. A spectrum analyzer, HP 8562A was connected to the output port to measure the signal spectrum. Fig. 4 shows the power spectrum with a single tone RF signal. The phase-conjugated signal is at 5.81 GHz. The circuit achieved RF-IF isolation of 20 dB and gain of 20dB. By cascading amplifiers, the signal can be amplified more depending on the communication distance while maintaining the isolation. Fig. 5 shows the circuit performance over the RF frequency range 5.7 GHz – 5.9 GHz. The conversion gain is fairly flat and the RF-IF isolation stays below –10 dB over the range. The mixers serve as I/Q modulators as well when baseband signals are applied into the I and Q ports. Figure 6 shows the spectrum plot of the 10 Mbps BPSK modulated IF (phase-conjugated).

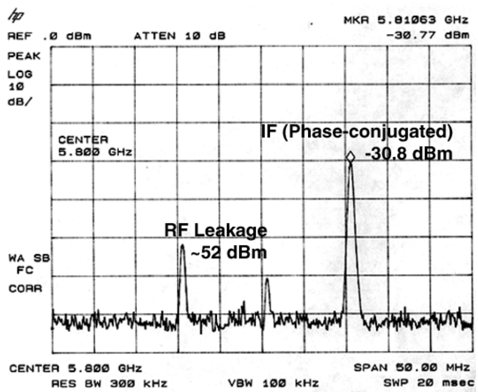

Fig. 4 The gain and RF-IF isolation at 5.79 GHz

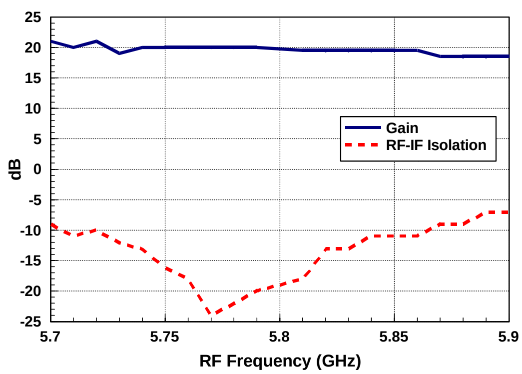

Fig. 5 The bandwidth of the circuit

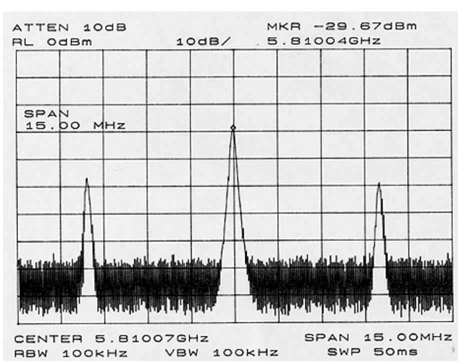

Fig. 6 10 Mbps BPSK Modulated IF (phase-conjugated) signal spectrum

B. Direct Downconverter

The measurement of the direct downconverter was done by using a LO at 2.895 GHz, which is half the frequency of the incoming signal. In this setup, the FET mixers function as subharmonic mixers. Since the LO is 45 deg out of phase, there is a 90 deg phase difference at the second harmonic frequency. Thus, I and Q channels should be obtained through the lowpass filters at the drain sides.

A unmodulated RF at 5.79 GHz and a LO at 2.8975 GHz are applied so that the IF offset is 5 MHz. Figure 6 shows the quadrature phase difference between two channels at an IF frequency of 5 MHz. The phase imbalance is approximately 10 deg. In this measurement, a RF signal applied to the circuit is modulated with a 10 Mbps BPSK signal. Figure 7 shows the demodulated baseband signals from the I and Q ports. The 10 Mbps BPSK signal was successfully recovered.

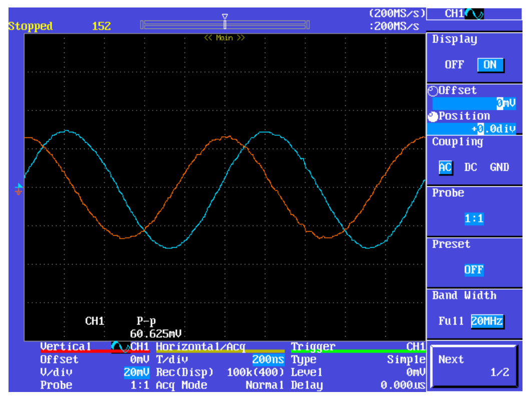

Fig. 6 10MHz IF waveforms

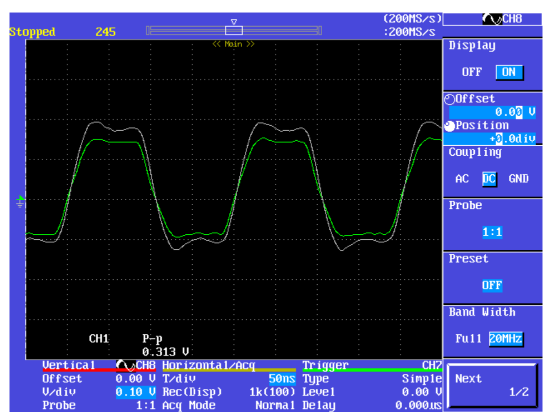

Fig. 7 Demodulated I and Q waveforms (10 Mbps)

III. System Measurements

A prototype reconfigurable system with a four-element array based on the proposed reconfigurable circuit is fabricated as shown in Fig. 8. 5.8 GHz Patch antennas are attached to the backside of the circuitry, reducing the circuit size. The array spacing is set to approximately 0.45

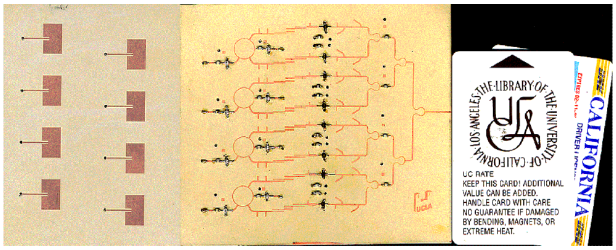

Fig. 8 The fabricated the reconfigurable system

freespace wavelength, enabling 180 deg scan. The circuitry size is approximately 4 in $\times$ 4 in.

To confirm the retrodirectivity, the monostatic RCS measurement was done. In this measurement, the array was illuminated with a 5.79 GHz wave generated by a signal source, and was driven by an 11.6 GHz LO signal. The IF (phase-conjugated) power was measured at the source location. Since the interrogator always 'sees' the peak of the array radiation, the monostatic pattern should not exibit any nulls. The monostatic RCS pattern should be the square of the antenna directivity in the direction of the interrogator. This is one advantage of using a retrodirective array. Fig. 9 shows the monostatic RCS pattern. The results agree reasonably well with the theoretical prediction.

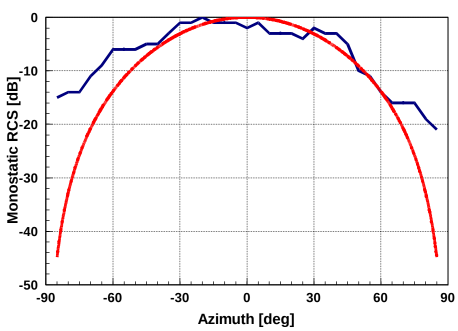

Fig. 9 The monostatic RCS pettern of the transponder

V. CONCLUSION

A reconfigurable retrodirective/direct downconverter receiver array for wireless sensor systems has been developed. The compact circuitry serves as both as the phase-conjugator and direct downconverter and can be reconfigured simply by changing the LO frequency. In the direct downconverter mode, the 10 Mbps BPSK baseband signal was successfully recovered by the direct conversion circuitry. The proposed system should find a wide variety of applications such as wireless sensor basestations. With a TDMA system, it also can be used for high data rate digital communications.

ACKNOWLEDGEMENT

The authors would like to thank Steve Jeon, James Sor, Ji-Yong Park and Matt Espiau for all the help they rendered. This work was supported by the Army Research Office MURI DAAH04-96-1-0005.

REFERENCES

[1] C. W. Pobanz and T. Itoh, "A microwave noncontact identification transponder using subharmonic interrogation," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-43, no. 7, pp. 1673-1679, July 1995.

[2] S. L. Karode, V. Fusco, "Self-tracking duplex communication link using planar Retrodirective antennas," *IEEE Trans. Antennas and Propagation*, Jun 1999, pp. 993-1000.

[3] L. D. DiDomenico, G. M. Rebeiz, "Digital communications using self-phased arrays," *IEEE MTT-S Intl. Microwave Symposium Digest, pp*. 1705-1708, Jun 2000.

[4] Y. Chang, H. R. Fetterman, I. Newberg, and S. K. Panaretos, "Microwave pahse conjugation using antenna arrays," *IEEE Trans. Microwave Theory and Techniques*, Nov. 1998, pp. 1910-1919.

[5] C.W. Pobanz and T. Itoh, "A conformal Retrodirective array for radar applications using a heterodyne phased scattering element," *IEEE MTT-S Intl. Microwave Symposium Digest*, pp. 905-908, Jun 1995.

[6] D. M. K. Ah Yo, W. E. Forsyth, and W. A. Shiroma, "A 360 degrees retrodirective self-oscillating mixer array [using HEMTs]," *IEEE MTT-S Intl. Microwave Symposium Digest*, pp. 813-816, Jun 2000.

[7] R. Y. Miyamoto, Y. Qian, and T. Itoh, "Active retrodirective array for remote tagging and wireless sensor applications," *IEEE MTT-S Intl. Microwave Symposium Digest*, pp. 1431-1434, Jun 2000.

[8] R. Y. Miyamoto, Y. Qian, and T. Itoh, "Recent progress in retrodirective arrays, " 2000 International Symposium on Antennas and Propagations (invited), Aug 2000.

[9] S. M. Lin, Y. Qian and T. Itoh, "Quadrature direct conversion receiver integrated with planar quasi-Yagi antenna," *IEEE MTT-S Intl. Microwave Symposium Digest,* pp. 1285-1288, Jun 2000.