Digital Wireless Sensor Server Using an Adaptive Smart-Antenna/Retrodirective Array

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***Abstract*—A wireless sensor server is developed based on a reconfigurable active smart-antenna/retrodirective array. The system can serve as both a retrodirective array transponder and a smart-antenna receiver simply by changing the frequency of the local oscillator applied to the mixers, enabling it to best utilize its hardware to suit its communication environment. When operating as a direct-conversion receiver, the receiver array successfully demodulates a quaternary phase-shift keying (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 circuit gain and 20-dB radio-frequency–intermediate-frequency isolation at the center frequency as well as phase conjugation, exhibiting excellent retrodirectivity. The mixers perform phase conjugation and modulation simultaneously, enabling the transmission of locally stored data. The local data is successfully extracted by an interrogator.**

***Index Terms*—Digital communication, microwave receivers, phase conjugation, phased arrays, transponders.**

I. Introduction

In ORDER TO accommodate the need for high channel capacity in wireless communication systems, several techniques for efficient data multiplexing have been developed. Many of these schemes rely on multiplexing not only in time and frequency spectrum, but also in space. For this reason, multiband or wide-band multibeam array antennas are essential for optimal service area coverage. Smart-antenna technology was developed to satisfy these requirements. The use of a smart antenna increases the number of simultaneous users by using space-division multiple-access (SDMA) multiplexing, as well as providing a way to reduce the effect of multipath [1]–[3]. In a typical smart-antenna system, an antenna array is used as the radio-frequency (RF) frontend and signals from each individual element of the antenna array are combined after weighting functions are applied, such that a desired antenna beam pattern is formed. These weighting coefficients are determined by digital signal processing (DSP) and can be applied in either analog or digital domains [4].

A retrodirective array is a purely analog self-phasing array that transmits a signal toward the source when it is interrogated. This is done using the microwave phase conjugation technique [5]–[11]. Using this technique, the main beam of the retrodirective array automatically tracks the position of the interrogator. There is no need to rely on complex DSP algorithms and circuitry to determine the direction-of-arrival (DOA) and signal-weighting functions. This is especially useful when the communication environment is simple, as in communications in line of sight. Therefore, the retrodirective array is a good choice for remote data retrieval-on-demand applications where multipath effects are not significant.

Reconfigurablity brings about significant advantages in RF systems [12]. Because it allows front-end circuitry to share many components, whereby the circuit size and cost can be reduced significantly. The recent technology improvements in microwave devices and DSP chips has made it very easy to implement this kind of time-varying system. Integrating a direct-conversion receiver function followed by digital signal processing into the retrodirective array with reconfigurablity, the array can be used as a semiduplex communication system. This function allows the received signals to be processed in the digital domain, where sophisticated algorithms can be used to better cope with multiple users or multipath environment issues, which is often seen in ground-to-ground communications. At the same time, the interrogator can extract the stored data, taking advantage of the retrodirective array feature.

In this paper, a multifunctional array system using both retrodirective array and smart-antenna technologies is introduced. While using the same circuit hardware, the system can be reconfigured just by switching the frequency of the local oscillator (LO). 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 multiuser communications. The system can efficiently be used for mobile communication or high-end wireless sensor systems.

II. Proposed System

Fig. 1 shows the proposed wireless sensor system using a reconfigurable active retrodirective/smart-antenna array. In this scenario, the proposed multifunctional array is used as a transponder between deployed sensors and an interrogator. In the data collection mode (a), the array system works as a smart antenna and is used to collect data from various sensors. The circuit on each element in the array serves as a direct-conversion receiver and the downconverted base-band signals are sent to analog-to-digital converters for digital beamforming

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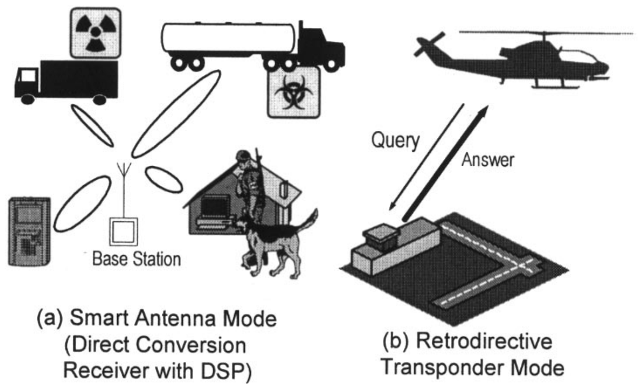


Fig. 1. Proposed sensor system.

processing and data recovery storage. The use of sophisticated algorithms allows the system to handle multiple sensor clients simultaneously, enabling SDMA.

Next, upon receiving an instruction signal from an interrogator, the system switches to retrodirective transponder mode (b) and sends the stored data to the interrogator. This switching is initiated by the header code contained in the signal from the interrogator. The retrodirective array always directs its peak beam toward the interrogator without having to identify its exact location. Contrary to a typical smart-antenna system, in this operating mode the system is able to track the target, relying solely on analog circuitry without the need for high-speed analog- to-digital converters, digital signal processing, and all the associated hardware circuitry. This greatly simplifies the overall system.

III. Circuit Overview

The schematic of the multifunctional circuit is shown in Fig. 2. The received signal is first amplified by a low-noise amplifier (LNA) and applied to the resistive field-effect transistor (FET) mixers in phase through a ratrace coupler. The use of resistive mixers minimize the direct-current (dc) separation issue. It also reduces dc power consumption as almost no current flows when no signal is applied. The mixers are fed by an LO signal in a phase relationship set by a phase-delay line. The phase delay is 180° at 11.6 GHz and 45° at 2.9 GHz. When a 2.9 GHz LO is applied, the circuit works as a subharmonic direct-conversion receiver (smart-antenna mode). When a 11.6-GHz LO is applied, the same circuit serves as a phase conjugator (retrodirective transponder mode).

A prototype circuit was fabricated on RT/duroid 6010 (0.635-mm thickness, dielectric constant $\epsilon_r = 10.2$) substrate, as shown in Fig. 3. The heterodyne FET mixers employ NEC NE76038 Gallium Arsenide (GaAs) metal semiconductor field-effect transistors (MESFETs) while the LNAs are Agilent MGA-86 576. GaAs MESFETs are economical as they provide high gain and low noise at higher frequencies. The approximate dc power consumption by the prototype circuit is 160 mW. The circuit size is approximately 9 cm $\times$ 2.5 cm. It is small enough to maintain half-wavelength array spacing, which is very important in order to avoid grating lobes.

A. Direct-Conversion Receiver Mode (Smart-Antenna Mode)

In the receiver mode, the received signal is first amplified by a LNA, then downconverted directly to baseband. A LO signal at half the frequency of the received RF signal is applied to the mixers with a 45° phase difference, enabling quadrature direct-conversion mixing. I and Q channels are obtained through lumped element lowpass filters from the drain sides of the resistive FET mixers. The direct-conversion receiver can accomodate quadrature type of modulation schemes, enabling more efficient data transmission. In addition, the image problem is eliminated in the direct-conversion scheme, eliminating the need for image-rejection filters.

First, the direct-conversion receiver was evaluated by applying an unmodulated RF signal (-50 dBm) at 5.79 GHz and an LO (10 dBm) at 2.8975 GHz (2.895 GHz + 2.5 MHz) so that the residual carrier of 5 MHz can be observed at the I/Q ports. Figs. 4 and 5 show intermediate-frequency (IF) power versus RF input power and the circuit gain versus LO input power plots. Since LNAs are integrated into the mixer circuit, signal gain is available although the mixers themselves have conversion loss. For 0-dB loss, the minimum LO power required is 2 dBm. The maximum circuit gain is obtained with LO power of 13 dBm. Fig. 6 shows the quadrature phase difference between two channels at an IF frequency of 5 MHz. The phase imbalance is within approximately 10°.

Next, a demodulation performance test is carried out. A QPSK-modulated RF signal is applied into the circuit. In this measurement, a RF signal applied to the circuit is QPSK-modulated by 10 MHz. For simplicity, identical "1010" signals generated by a function generator are applied to the I and Q channels. The RF center frequency is 5.79 GHz and the LO frequency is 2.895 GHz. Since the LO frequency is exactly half the RF frequency, there is no IF signal in this case. Therefore, the modulated RF signal is downconverted directly to baseband without any IF. Fig. 7 shows the demodulated baseband signals from the I and Q ports. The digital base-band signal was successfully recovered.

B. Phase-Conjugating Mode (Retrodirective Transponder Mode)

In this operating mode, LO frequency is switched to twice that of the received interrogating signal. The RF and IF frequencies are close together while the LO frequency is far from both frequencies. Therefore, it is possible to reduce the circuit size by applying RF and LO from the opposite sides of a FET and extracting the IF product from the RF input port [11]. The matching networks for RF and IF signals can be shared. There is no need for any coupler to combine signals at different frequencies. However, this architecture makes it difficult to insert additional active components, such as amplifiers. This issue is overcome by using a balanced architecture fed by a ratrace coupler. The RF signal is applied into the mixers in phase; hence, the rejected RF signals are also in phase while the phase-conjugated signals are 180° out of phase. The fundamental mixing process can be given by (1) and (2) as

$$\begin{aligned}\text{Ch1: } V_{\text{IF1}}(t) =& V_{\text{RF}}\cos(\omega_{\text{RF}}t+\theta_n)\cdot V_{\text{LO}}\cos(\omega_{\text{LO}}t)\\ =& \frac{1}{2}V_{\text{RF}}V_{\text{LO}}[\cos((\omega_{\text{LO}}-\omega_{\text{RF}})t-\theta_n)\\ &+\cos((\omega_{\text{LO}}+\omega_{\text{RF}})t+\theta_n)] \quad (1)\end{aligned}$$

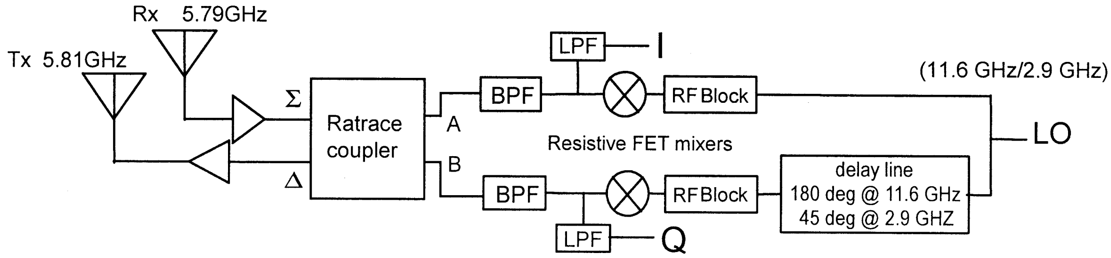


Fig. 2. Schematic of the multifunctional circuit.

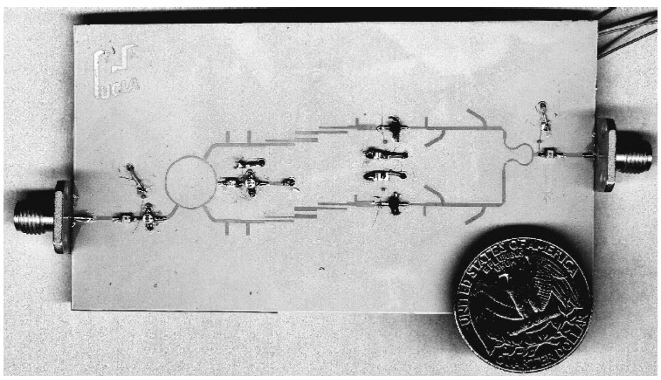


Fig. 3. Fabricated multifunctional circuit.

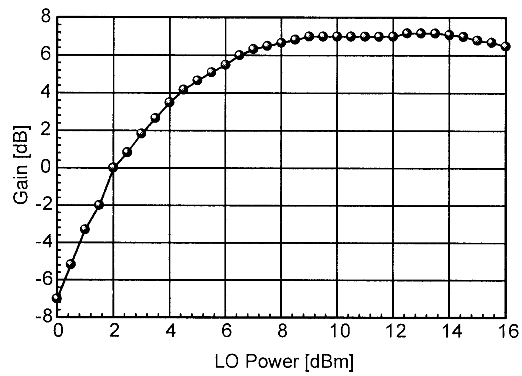


Fig. 5. Gain versus LO power.

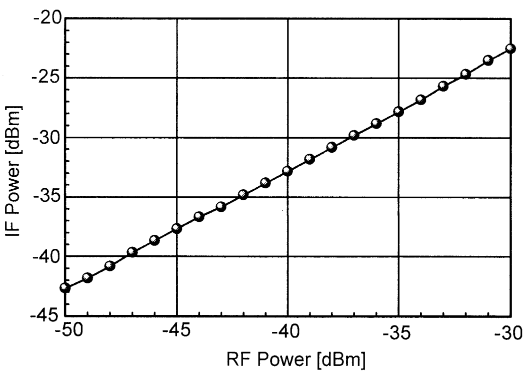


Fig. 4. IF power versus RF power.

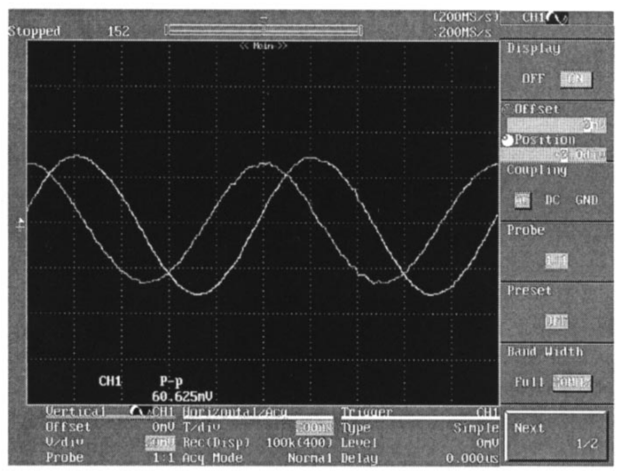


Fig. 6. Quadrature phase of the down-converted signals.

$$\begin{aligned}\text{Ch2: } V_{\mathrm{IF2}}(t) =& V_{\mathrm{RF}} \cos(\omega_{\mathrm{RF}} t + \theta_n) \cdot V_{\mathrm{LO}} \cos(\omega_{\mathrm{LO}} t - \pi) \\ =& \frac{1}{2} V_{\mathrm{RF}} V_{\mathrm{LO}} [\cos((\omega_{\mathrm{LO}} - \omega_{\mathrm{RF}})t - \theta_n - \pi) \\ &+ \cos((\omega_{\mathrm{LO}} + \omega_{\mathrm{RF}})t + \theta_n + \pi)]. \end{aligned} \tag{2}$$

If the LO frequency is set such that $\omega_{\mathrm{LO}} = 2\omega_{\mathrm{RF}}$, the lower side band signal at ω_{LO}–ω_{RF} is the phase conjugation of the RF signal. Since the LO signal is applied out of phase to the FETs, the phase-conjugated signals from the two channels are antiphase while the RF leakage is in phase. Thus, at the Δ port of the ratrace coupler, the rejected RF should cancel out and only the phase-conjugated signal can pass on to the next stage, providing 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. The LO leakage and upper side band can easily be filtered out, since the frequencies are far from that of the phase-conjugated signal.

The circuit performance for the phase-conjugating mode is 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 (10 dBm, 11.6 GHz) signals. A spectrum analyzer is connected to the output port to measure the signal spectrum. The phase-conjugated signal is at 5.81 GHz. Fig. 8 shows the circuit gain and the RF–IF isolation over the RF frequency range 5.75 –5.81 GHz. The conversion gain is fairly flat and the RF–IF isolation stays below 15 dB over the range. The maximum RF–IF isolation of 24 dB is achieved at 5.77 GHz.

In order to simulate the scenario in which the array is interrogated by multiple users simultaneously, the circuit is tested using two RF tones. First, a RF signal is applied into the input port of the circuit. Fig. 9(a) is the power spectrum at the output port. Then, the second RF signal at a different frequency is ap-

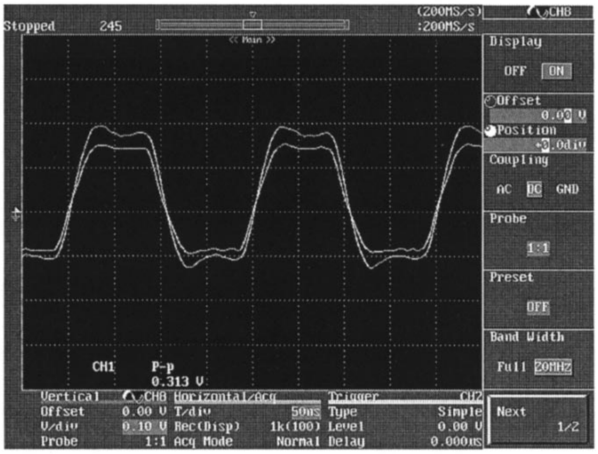


Fig. 7. Demodulated I and Q waveforms (10 Mb/s).

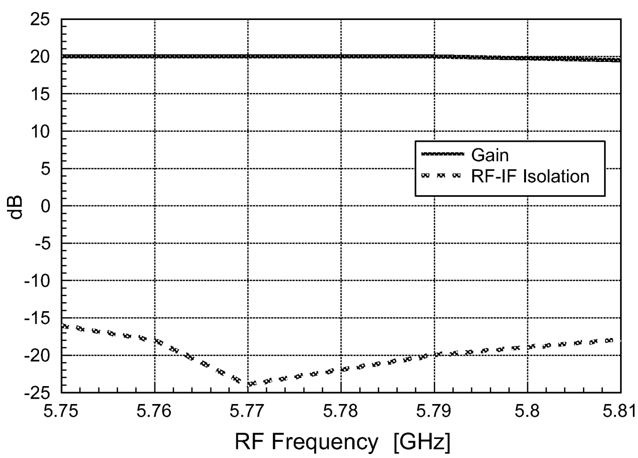


Fig. 8. Bandwidth of the circuit.

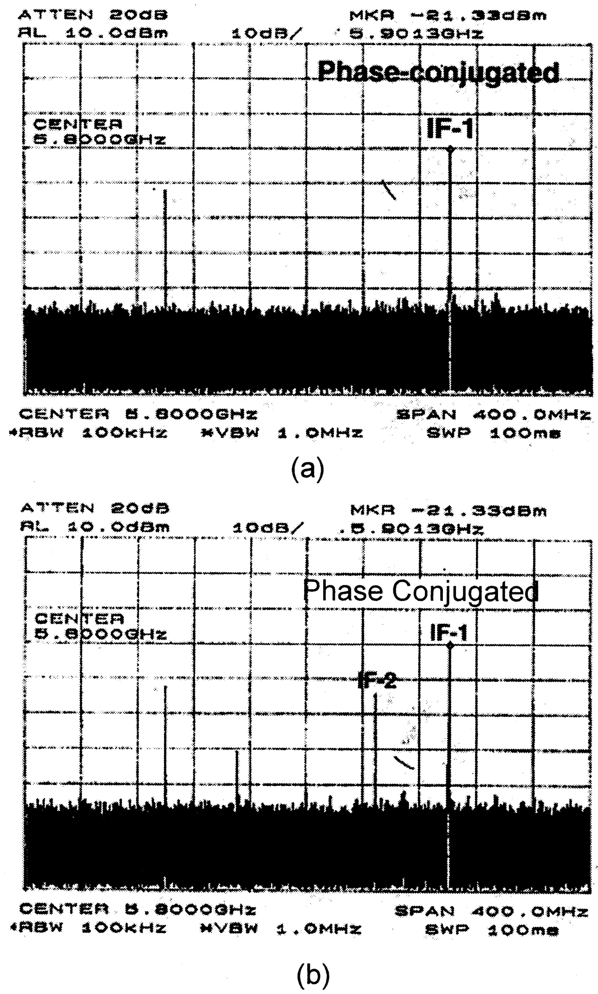


Fig. 9. Phase conjugation with multiple interrogations.

plied to the circuit. Fig. 9(b) shows output power spectrum of the two-tone interrogation case. The power of IF-1 stays at the same power level in both cases. These results show that two simultaneous interrogations do not make any significant performance change in this circuit.

The phase-conjugated signal can be modulated by applying bipolar non-return to zero (NRZ) binary signals into the base-band ports. This feature allows the retrodirective array to transmit local information on demand. Modulation of the return signal sent by the retrodiretive array is done by applying a bipolar NRZ signal at the FET mixer base-band ports. 1-Mb/s "1010" square waves generated by a function generator are applied into the base-band ports. The output spectrum shows a successful binary phase-shift keying (BPSK) modulation of the phase-conjugated signal. Also, the base-band signals are successfully recovered by a demodulator connected at the output.

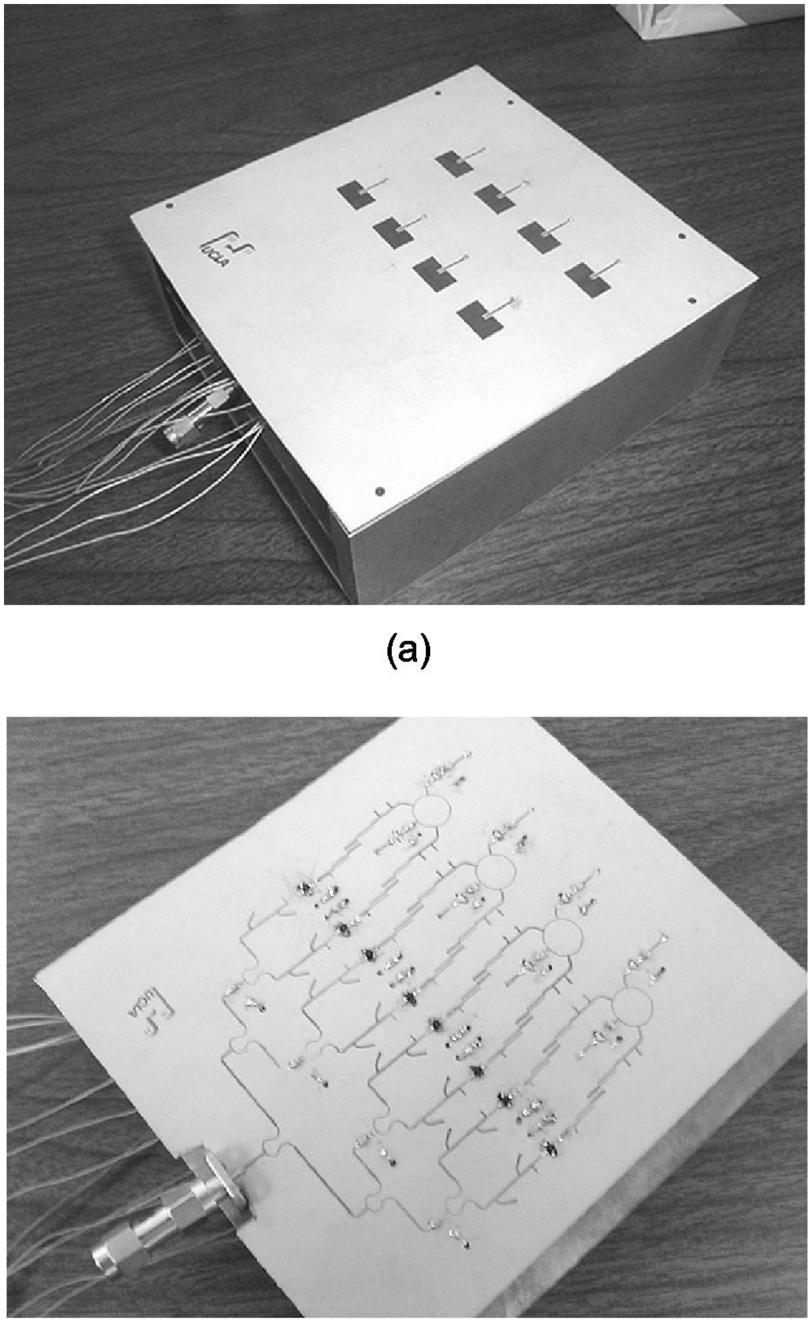
IV. System Measurements

A prototype reconfigurable array based on the proposed multifunctional circuit is fabricated and shown in Fig. 10. It consists of two sets of four-element patch-antenna arrays. One array is used for receiving and the other for transmitting. Antennas with broad radiation patterns are more suited for phased arrays, since received power is fairly constant within the scanning range. The antennas are attached to the back side of the circuitry, reducing the physical size of the sensor server system. The array spacing is set to approximately 0.45 freespace wavelength, enabling an 180° scan without having grating lobes, which becomes visible in arrays with array spacing $d > \lambda_0/(1+|\sin\theta_{\rm in}|)$ where $\theta_{\rm in}$ is the incident angle of the interrogating signal. The circuitry size is approximately 10 cm × 10 cm.

The system is evaluated in the two modes of operation: smart-antenna and retrodirective transponder. In the smart-antenna mode, bit-error rate (BER) measurements are carried out. The digital beam forming feature is tested using offline digital signal processing. As for the retrodirective transponder mode, the radar cross section (RCS) pattern is measured.

A. Smart-Antenna Mode

Fig. 11 shows the BER measurement setup. Both the receiver array and the transmitter are placed in an anechoic chamber. The receiver is located in the far field of the transmitting antenna. The receiver array is illuminated by a 5.79-GHz signal with a 2-Mb/s QPSK modulation from broadside. The level of noise generated by a noise source is controlled by an attenuator and



(a)

(b)

Fig. 10. Photos of the prototype four-element array system. (a) Antenna and (b) circuit sides.

combined with the RF signal. An NRZ base-band signal is generated by a BER tester. The data rate, 2 Mb/s, is selected due to the limit of the bit-error tester. The received signal is downconverted to baseband and the recovered base-band signal is amplified before being sent back to the BER tester along a coaxial cable. The theoritical BER of QPSK modulation is given by [13]

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$$
$$\text{where } erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} \exp(-t^2) dt. \quad (3)$$

Fig. 12 shows the BER measurement results and theoretical estimations under different SNR conditions. E_b/N_0 is measured at the transmitting antenna. The noise figure of the low-noise amplifiers is approximately 2.3 dB at this frequency. Therefore, the measurement results reasonably match the theory. E_b/N_0 for BER $= 10^{-4}$ is approximately 12 dB without any error correction.

Next, the array is illuminated by a 5.79-GHz wave coming from an angle and the LO frequency is $2.895 + \delta$ (offset) GHz, allowing the baseband to have a residual frequency. The signal is downconverted at each element and the downconverted signal

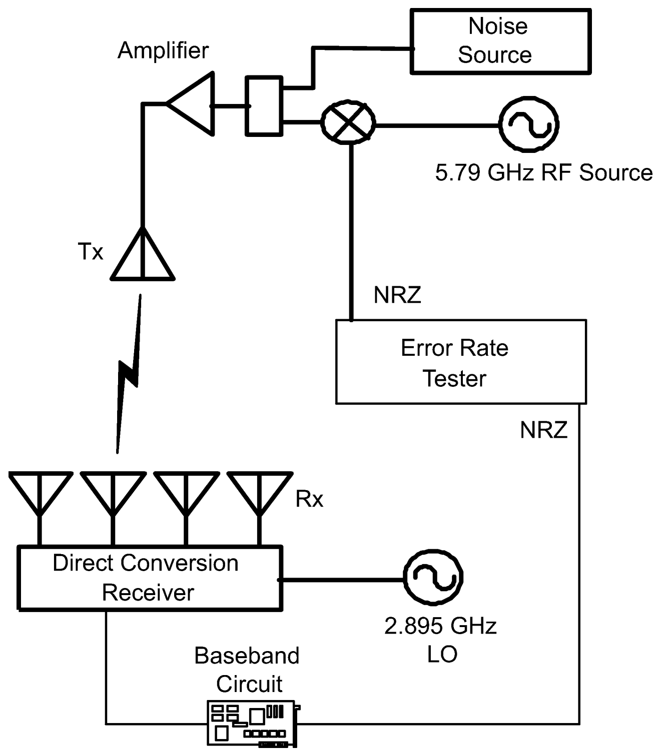


Fig. 11. BER measurement setup.

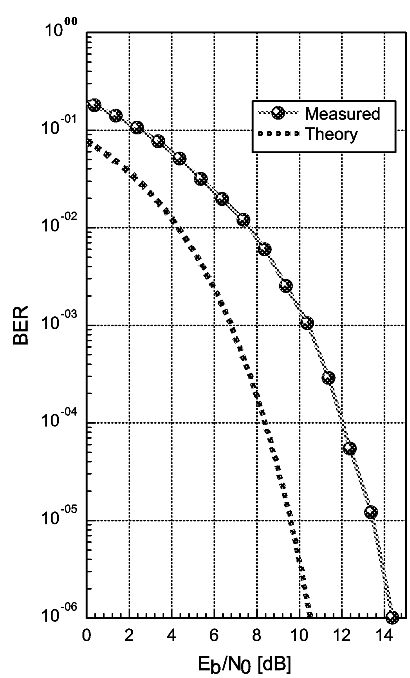


Fig. 12. BER versus SNR.

is sampled by using a digital oscilloscope. The sampled data is processed by a MATLAB program on a PC for digital beamforming using the MUSIC algorithm [2], [14]. Fig. 13(a) shows the normalized sampled data. DOA estimation is done using the MUSIC algorithm as shown in Fig. 13(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. Fig. 13(c) shows the comparison between the digital beam formed and raw

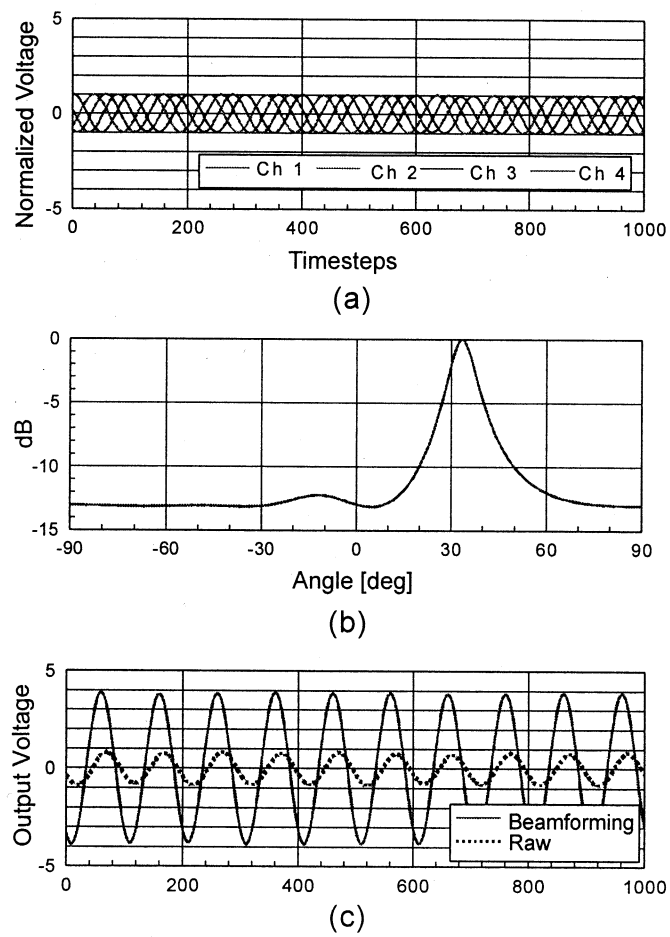


Fig. 13. Digital beamforming process for (a) sampled data, (b) DOA estimation, and (c) digital beamforming results.

data (combined without beamforming). Since the signal from each channel is coherent after the weighting function is applied, the signals are combined coherently to obtain higher amplitude. MUSIC DOA estimation can also be used to suppress undesired signals, reducing cochannel interference and intersymbol interference for multiuser systems.

B. Retrodirective Transponder Mode

To confirm the retrodirectivity, the monostatic radar cross section (RCS) pattern measurement is done. In this measurement, the array is illuminated with a 5.79-GHz wave generated by a synthesizer and was driven by an 11.6-GHz LO signal. The array is placed in the far zone of the transmitting horn antenna. The IF (phase-conjugated signal) power is measured by another horn antenna colocated with the transmitting antenna. Because the receiver antenna is colocated with the interrogator, it always "sees" the peak of the array radiation. The monostatic RCS pattern should not exhibit any nulls. Fig. 14 shows the monostatic RCS pattern. The monostatic RCS pattern is given by

$$\sigma_{\text{monostatic}} = \frac{\lambda^2}{4\pi} D_0(\theta_{\text{in}}) G_c {D_e}^2(\theta_{\text{in}}) \tag{4}$$

where D_0 is the directivity of the array, $G_c$is the circuit gain, D_e is the directivity of the patch-antenna element. Note that

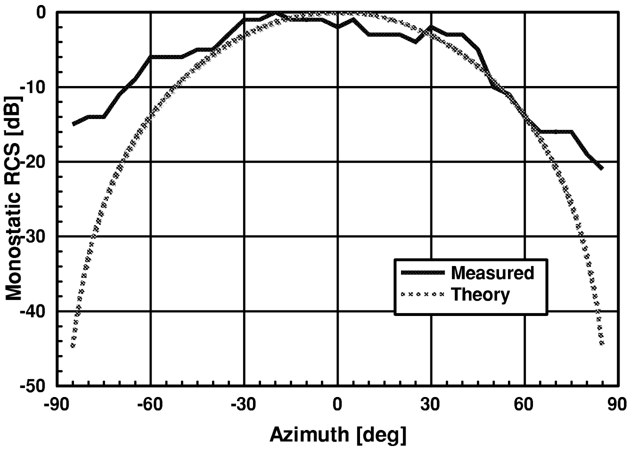


Fig. 14. Monostatic RCS pattern.

the array factor is not squared. This is because, in the receiving process, each element is separately processed without being combined. The antennas are not an array, but merely four separate antennas. The normalized monostatic RCS pattern is given by the multiplication of the array directivity and the square of the antenna directivity.

Normally, the gain of an array is constant around the broadside and higher at sharp angles, i.e., far from the broadside when it is scanned. Therefore, the monostatic RCS of the retrodirective array is flatter than the radiation pattern of the antenna element. The results agree reasonably well with the theoretical prediction. As shown in the measured results, the monostatic RCS of the retrodirective array has no nulls.

V. Conclusion

A reconfigurable smart-antenna/retrodirective array for wireless sensor server applications has been developed. The system operates in the 5.8-GHz industrial, scientific, and medical (ISM) band. The compact circuitry serves as both a phase-conjugator and a direct-conversion receiver. It can be reconfigured simply by switching the LO frequency. In the smart-antenna mode, 10-Mb/s QPSK signals are successfully recovered by the direct-conversion circuitry. E_b/N_0 for $\mathrm{BER} = 10^{-4}$ is approximately 12 dB without error correction. The digital beamforming feature takes advantage of SDMA; therefore, it increases the number of server clients handled by the server. In the retrodirective transponder mode, Circuit gain of 20 dB is obtained while good RF–IF isolation is maintained. The phase conjugated signal is successfully modulated by a 10-Mb/s data signal. The monostatic RCS shows a flat characteristic due to the excellent retrodirectivity.

The proposed system should also find a wide variety of applications as well as for wireless sensor servers. By applying time-division duplexing (TDD) and improving the base-band circuitry, it can be used for other digital mobile communications such as wireless local networks (LAN).

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References

[1] J.-I. Takada *et al.*, "A super resolution spatio-temporal channel sounder for future microwave mobile communication system development," in *IEEE. Asia Pacific Conference on Circuits and Systems (APCCAS) 1998 Dig.*, 1998, pp. 101–104.

[2] Y. Sanada, J.-I. Takdada, and K. Araki, "A novel cumulant based MUSIC like DOA estimation algorithm with multicarrier modulation," *IEICE Trans. Commun.*, vol. E81-B, no. 12, 1998.

[3] M. Tangemann and R. Rheinschmitt, "Comparison of upgrade techniques for mobile communication systems," in *IEEE SUPERCOMM/ICC 1994 Dig.*, vol. 1, pp. 201–205.

[4] S.-S. Jeon, Y. Wang, Y. Qian, and T. Itoh, "A novel smart antenna system implementation for broadband wireless communications," *IEEE Trans. Antennas Propagat.*, vol. 50, pp. 600–606, May 2002.

[5] C. Y. Pon, "Retrodirective array using the heterodyne technique," *IEEE Trans. Antennas Propagat.*, vol. AP-12, pp. 176–180, Mar. 1964.

[6] Y. Chang, H. R. Fetterman, I. Newberg, and S. K. Panaretos, "Microwave phase conjugation using antenna arrays," *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 1910–1919, Nov. 1998.

[7] S. L. Karode and V. F. Fusco, "Self-tracking duplex communication link using planar retrodirective antennas," *IEEE Trans. Antennas Propagat.*, vol. 47, no. 6, pp. 993–1000, Jun. 1999.

[8] C. W. Pobanz and T. Itoh, "A conformal retrodirective array for radar applications using a heterodyne phased scattering element," in *IEEE MTT-S Int. Microwave Symp. Dig.*, Orlando, FL, June 1995, pp. 905–908.

[9] C. W. Pobanz, "Time-Varying Active Antennas: Circuits and Applications," Ph.D. disseration, University of California, Los Angeles, 1997.

[10] L. D. DiDomenico and G. M. Rebeiz, "Digital communications using self-phased arrays," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 677–684, Apr. 2001.

[11] R. Y. Miyamoto, Y. Qian, and T. Itoh, "An active integrated retrodirective transponder for remote information retrieval-on-Demand," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 1658–1662, Sept. 2001.

[12] ——, "A reconfigurable active retrodirective/direct conversion receiver array for wireless sensor systems," in *IEEE MTT-S Int. Microwave Symp. Dig.*, Phoenix, AZ, June 2001, pp. 1119–1122.

[13] J. G. Proakis, *Digital Communications*. New York: McGraw-Hill, 1983.

[14] R. O. Schmidt, "Multiple emitter location and signal parameter estimation," *IEEE Trans. Antennas Propagat.*, vol. 34, pp. 276–280, Mar. 1986.

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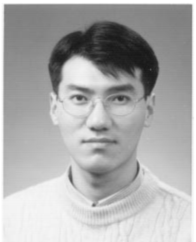

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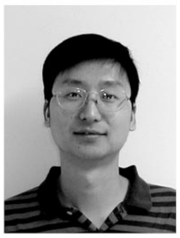
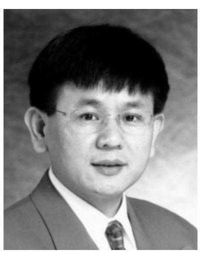
Dr. Jeon was a recipient of the Honorable Mention Award in the Student Paper Competition at the 2001 IEEE Microwave Theory and Techniques Society (IEEE MTT-S) International Microwave Symposium (IMS).



Yuanxun Wang (S'96–M'99) received the B.S. degree in electrical engineering from University of Science and Technology of China (USTC), Hefei, in 1993, the M.S. and the Ph.D. degrees in electrical engineering from University of Texas at Austin, in 1996 and 1999.

From 1995 to 1999, he was a Research Assistant in the Department of Electrical and Computer Engineering, University of Texas at Austin. From 1999 to 2002, he was a Research Engineer and Lecturer in the Department of Electrical Engineering, University of California at Los Angeles (UCLA), prior to joining the faculty. He is an Assistant Professor in Electrical Engineering Department since 2002. His work is focused on high performance antenna array and microwave amplifier systems for wireless communication and radar, as well as numerical modeling techniques. His current research interests feature the fusion of signal processing and circuit techniques in microwave system design. He has authored and coauthored over 60 refereed journal and conference papers.

Dr. Wang is a member of SPIE.



Yongxi Qian (S'91–M'93–SM'00) was born in Shanghai, China, in 1965. He received the B.E. degree from Tsinghua University, Beijing, Chian, in 1987, and the M.E. and Ph.D. degrees from the University of Electro-Communications, Tokyo, Japan, in 1990 and 1993, respectively, all in electrical engineering.

From 1993 to 1996, he was an Assistant Professor at the University of Electro-Communications, Tokyo. From April 1996 to January 2001, he was Post-Doctoral Fellow, Assistant Research Engineer and Lecturer in the Electrical Engineering Department, University of California, Los Angeles (UCLA). His research interests included numerical techniques for microwave and millimeter-wave circuits and antennas, generation and transmission of picosecond electrical pulses, crosstalk problems in high-density MMICs, miniature circuits for mobile communications, 60 GHz millimeter-wave focal plane imaging array, broadband planar antennas, smart antennas and arrays for wireless communications, high-efficiency microwave power amplifiers, RF interconnect for mixed signal silicon MMICs, quasioptical power combining, photonic band-gap (PBG) structures, active integrated antennas for indoor LANs, and high-power, broadband RF photonic devices for millimeter and submillimeter-wave photomixing. He has authored or co-authored over 200 refereed journal and conference papers, two books and several book chapters. He joined Microsemi Corporation in February 2001 and has been working as Director of Technology and Applications at the MicroWaveSys Division, Los Angeles, focusing on advanced HBT IC's for 3G, wireless LAN and high-speed fiber-optic applications.

Dr. Qian is the recipient of the Japan Microwave Prize at 1998 Asia-Pacific Microwave Conference, Best Student Paper at 29th European Microwave Conference, 1999, and ISAP Paper Award at International Symposium on Antennas and Propagations, 2000.

Tatsuo Itoh (M'69–SM'74–F'82) received the Ph.D. degree in Electrical Engineering from the University of Illinois, Urbana, in 1969.

From September 1966 to April 1976, he was with the Electrical Engineering Department, University of Illinois. From April 1976 to August 1977, he was a Senior Research Engineer in the Radio Physics Laboratory, SRI International, Menlo Park, CA. From August 1977 to June 1978, he was an Associate Professor at the University of Kentucky, Lexington. In July 1978, he joined the faculty at The University of Texas at Austin, where he became a Professor of electrical engineering in 1981 and Director of the Electrical Engineering Research Laboratory in 1984. During the summer of 1979, he was a Guest Researcher at AEG-Telefunken, Ulm, Germany. In September 1983, he was selected to hold the Hayden Head Centennial Professorship of Engineering at The University of Texas. In September 1984, he was appointed Associate Chairman for Research and Planning of the Electrical and Computer Engineering Department at The University of Texas. In January 1991, he joined the University of California, Los Angeles, as Professor of electrical engineering and holder of the TRW Endowed Chair in Microwave and Millimeter Wave Electronics. He was an Honorary Visiting Professor at Nanjing Institute of Technology, China, and at Japan Defense Academy. In April 1994, he was appointed as Adjunct Research Officer for Communications Research Laboratory, Ministry of Post and Telecommunication, Japan. He currently holds Visiting Professorship at University of Leeds, Leeds, U.K. He has 300 journal publications, 600 refereed conference presentations and has written 30 books/book chapters in the area of microwaves, millimeter-waves, antennas and numerical electromagnetics. He generated 56 Ph.D. students.

Dr. Itoh is a Member of the Institute of Electronics and Communication Engineers of Japan, and Commissions B and D of USNC/URSI. He served as the Editor of IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES for 1983–1985. He serves on the Administrative Committee of IEEE Microwave Theory and Techniques Society. He was Vice President of the Microwave Theory and Techniques Society in 1989 and President in 1990. He was the Editor-in-Chief of IEEE MICROWAVE AND GUIDED WAVE LETTERS from 1991 through 1994. He was elected as an Honorary Life Member of MTT Society in 1994. He was the Chairman of USNC/URSI Commission D from 1988 to 1990, and Chairman of Commission D of the International URSI for 1993–1996. He is Chair of Long Range Planning Committee of URSI. He serves on advisory boards and committees of a number of organizations. He received a number of awards, including Shida Award from Japanese Ministry of Post and Telecommunications in 1998, Japan Microwave Prize in 1998, IEEE Third Millennium Medal in 2000, and IEEE MTT Distinguished Educator Award in 2000. He was elected to a member of National Academy of Engineering in 2003.