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A Radar Target Transceiver Using a Full Duplex Capable Retrodirective Array System

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***Abstract* — This paper discusses the development of a radar target/communication device which is intended to both facilitate radar imaging and establish a self-tracking communication link between ground terminal and mobile radar station. The device is realized using a retrodirective array with full duplex capability. Demonstration of 10 Mbps data receiving and transmitting functions are presented along with its automatic beam-steering ability.**

I. INTRODUCTION

Retrodirective arrays have been of particular interest due to its cost effectiveness and compactness among numerous phased array systems [1-3]. A retrodirective array transmits a signal back to the interrogator's position without any a priori knowledge of the incoming angle, without relying on sophisticated digital signal processing algorithms. In previous years, this ability to retrodirect signals was seen as an interesting feature that could be exploited for use in stealth and radar applications. However, in more recent years researchers have focused on incorporating such arrays in advanced digital mobile communication systems where high link gain and self-beam-tracking are desired. A retrodirective array can efficiently be used in a mobile communication system such as from a ground station to moving vehicles, aircrafts or satellites.

An interesting idea would be to combine the two applications, such that both functions could be carried out simultaneously. Radar systems often operate by transmitting short pulses or chirped carrier waves, and based on the received reflections of these signals a radar image can be constructed. In some sense, since the radar is transmitting and receiving signals this is already a form of communication system.

This paper presents a novel radar target transceiver which both aids in radar mapping, especially synthetic aperture radar (SAR) [4] which often requires a central point with strong reflection to act as an imaging reference point for motion compensation or autofocus image processing and serves as a transceiver for communication. Fig.1 shows the scenario in which SAR can be simultaneously used for communication. The system consists of airborne or space borne platforms such as a satellite, ground based mobile terminals and the communication devices mounted on top of the ground terminals. The satellite platform will have dual functions. First, it works as a regular SAR system. At the same time, the satellite will also be able to send and receive communication information on top of the radar waveform.

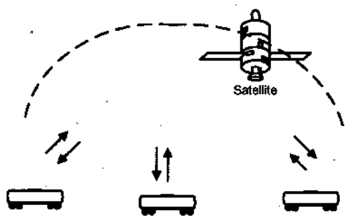

Fig. 1. Scenario for the use of the radar target transceiver.

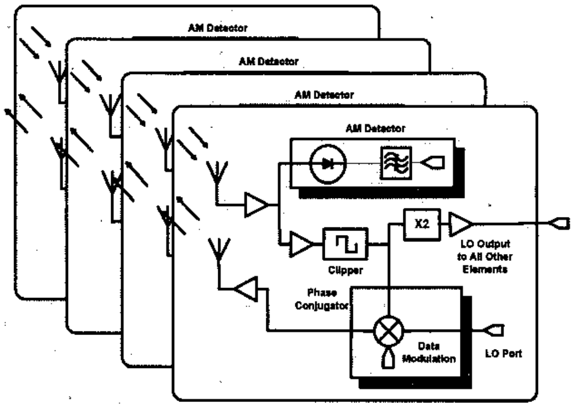

Fig. 2. Schematic diagram of radar target transceiver.

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The focus of this paper is the radar target ground terminal. The self-steering capability of retrodirective arrays is used to act as a point of strong or even amplified reflection for SAR calibration. In addition, the ability to communicate with the airborne platform by re-modulating the interrogating signal is also exploited. This brings about several foreseen benefits. The ground terminal can transmit other information about its surroundings which cannot be attained from radar imaging, making the area mapping that much more complete. Also, coded information can be broadcasted to multiple "friendly" radar targets by the SAR air platform. This two-way exchange of information necessitates full-duplex functionality. And because SAR often uses chirped signals, frequency indiscriminateness is also required.

II. SYSTEM OVERVIEW

A system capable of full-duplex communication is able to transmit and receive information simultaneously. In most retrodirective arrays, this is a challenging task. Retrodirective arrays that operate on the basis of phase conjugation simply operate by mixing the incoming signal with a frequency that is nearly twice of the incoming frequency. This is a simple analog process which is able retransmit a signal directly back to its source of origination. However, because the retrodirected signal is merely a phase reversed version of the incoming wave, any data transmitted by the interrogator would also be retrodirected.

Fig. 2 shows the schematic of the retrodirective array that can be used as a full duplexing system. This system assumes that the received signal is modulated using AM modulation. This ensures that the added modulation does not interfere with the normal operation of the SAR, which traditionally transmits a simple carrier wave. The receiving function of the array is carried out by a simple AM Schottky diode detector circuit.

A. Clipper circuit for carrier recovery

For retrodirective transmission, the original modulation is first removed using a clipper circuit. The clipper limits the varying envelope of the received signal to a signal of constant envelope. After filtering, the carrier can be recovered. A clipping circuit can be realized using a number of techniques, including using anti-parallel diodes and saturated amplifiers. In this paper the latter approach was taken. In the frequency domain, the limiting effect can be seen by the reduction of modulation sidebands (for single tone modulation). The reduction is dependent on the modulation index as well as the input power. The reduction of modulation sidebands was observed to be approximately 15 dBc with an input power of 4 dBm.

The recovered carrier then is fed to a phase conjugating mixer. And in only one of the array elements, the received carrier is doubled in frequency and used to generate a reference LO signal that is inputted to the entire array. This ensures that the returned frequency is always the same as the incoming frequency; demonstrating the array's frequency autonomous character. This is important for the radar target function of the array because the interrogating chirped interrogation frequency is also a function of movement of the air platform and is impossible to predict. Therefore, to match the reflected frequency of the target's surroundings, this is the simplest possible approach. LO is amplified to an appropriate level depending on the mixer array pump power requirements.

B. Phase conjugation mixer

The phase conjugation mixer in this system is actually a four frequency mixer. First, the RF and LO is mixed to generate an IF at exactly the same frequency as the RF. Next, the IF is modulated by baseband data using the same mixer. Isolation between the RF and IF is achieved by feeding two identical single Schottky diode mixers 180° out of phase using a rat race coupler and feeding the LO power 180° out of phase using a simple delay line. The resulting mixed in-phase IF signal will be combined at the in-phase port of the rat race where as the out of phase RF signals will be rejected at this port. This scheme provides decent isolation between the phase-conjugated signal and RF leakage. Measurements show that RF-IF isolation better than 20 dB is achieved for a frequency range from 5.7 – 5.9 GHz, with conversion loss of 6 dB over the same range. Baseband modulation is fed to the diodes using low pass filters. The mixing efficiency between the IF and baseband data is quite low, approximately 20 dB less than the RF carrier power. However, the alternative approach is to use an additional mixer to modulate the IF carrier. This approach comes at the cost of additional power amplification to drive the mixer. Our approach is more suited to our proposed application. The poor mixing efficiency implies high carrier leakage (15 dB). This carrier leakage ensures that the function of the SAR system will not be compromised by the introduction of modulation side bands.

The output of the phase conjugating mixer is amplified and retransmitted using an identically spaced array as the receiving antenna array.

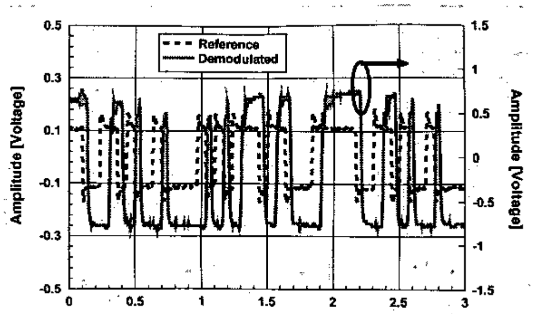

Fig. 3. Demodulated digital AM signal.

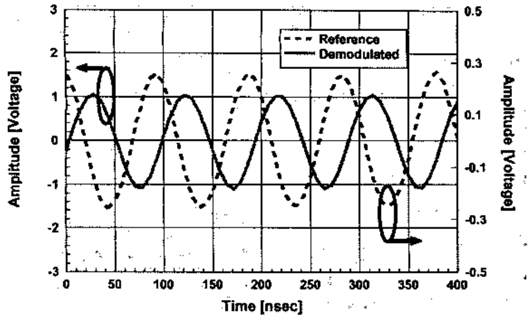

Fig. 4. Demodulated 10 MHz sinusoidal waveform.

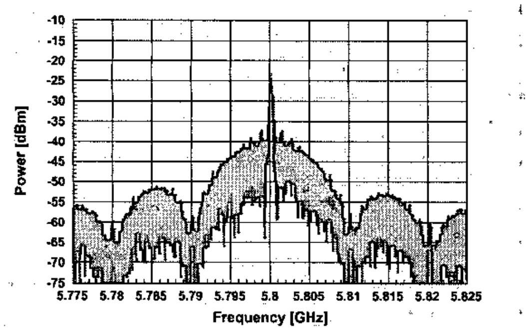

Fig. 5. Spectrum of digitally modulated phase conjugated signal.

III. MEASUREMENTS

A full duplex array was built based on the system overview. The full duplex capability of this system was tested using a single element. Additionally, receiving and retrodirective transmission of the array was measured.

A. Full Duplex Measurement

A single element consisting of input amplifier AM detector, clipper, phase conjugating mixer, and LO generator was tested. The input signal was AM modulated onto a carrier frequency of 5.8 GHz. A very low modulation index of 5% was used. This corresponds to a carrier to modulation sideband ratio of 35 dBc. The appropriate input power to incite the clipping action was adjusted using a variable attenuator. The clipper reduces the modulation sidebands down to 50 dBc. Next, this signal was doubled in frequency and amplified to 4 dBm at 11.6 GHz to feed the phase conjugating mixer. Baseband data was applied to the circuit using an arbitrary waveform generator. Simultaneously the received AM signal was demodulated using the AM detector.

Several modulation combinations were experimented with. These combinations include receiving a sinusoidal signal while transmitting a digital signal, receiving a digital signal while transmitting another digital signal, and finally receiving a digital signal while transmitting a sinusoidal signal. The results from the latter case are shown in Fig. 3 and Fig. 4. The AM demodulated waveform in Fig. 3 follows the 10 Mbps pseudo-random digital reference signal quite well. Discrepancies in pulse width can be reduced by tuning the output resistances and capacitances of the of the output filter to compensate for the diode resistance and capacitance. Conversion loss is dependent on input power as well as the modulation index of the received signal. Additionally, diode DC bias can be used to tune the receiver conversion loss. Fig. 4 clearly shows the demodulated waveform of the phase conjugating mixer output that was re-modulated with a 10 MHz sinusoidal wave. This experiment obviously shows the validity of this system. Although, the input digital signal contained numerous frequency components the retransmitted signal contained only the 10 MHz signal.

Fig. 5 shows the output spectrum of the phase conjugating mixer while modulated with a digital waveform. Carrier leakage is about 15 dB. This can be adjusted by varying the modulation level and offset voltage.

The efficiency of the receiving and transmission functions is codependent on the modulation index of the received signal. If the modulation is set higher, receiver conversion loss can be reduced; however this will have a detrimental affect on the BER of the retrodirected signal. This system aspect needs to be studied further. Moreover, because of the resilience of digital signals, the modulation index can best be maximized if both received and transmitted modulation is in digital form.

B. Array Performance

After measuring a single element of the array a four-element prototype array was fabricated. All of the circuitry, excluding LO amplifiers and doubler was built

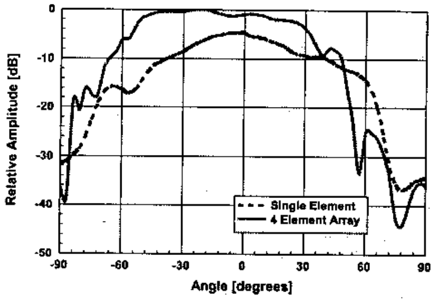

Fig. 6. Measured array receiving pattern.

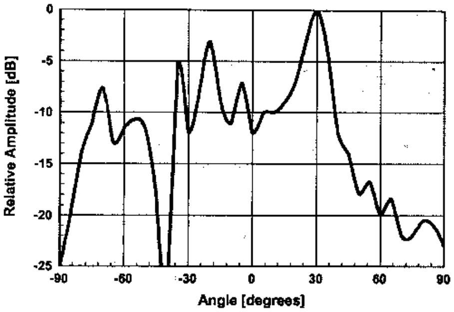

Fig. 7. Measured array transmission response (interrogator at 30°).

on a single RT/Duroid board with $\varepsilon_r = 10.2$ and 25 mil thickness. As stated in a previous section LO power was generated by doubling the RF power of a single element and used to feed the entire array. A $\lambda/2$ array of inset fed patch antennas were connected to the appropriate input/output ports of the array.

First, the receiving pattern of a single element was measured in an anechoic chamber. In this measurement a 1 MHz signal was AM modulated onto a 5.8 GHz carrier. The measured radiation pattern in Fig. 6 tracks the received power of the demodulated 1 MHz signal. Next, the radiation pattern of the combined total power of the four-element array was measured. The outputs of the four AM detectors were directly connected together. Ideally this pattern should look exactly the same as the pattern of a single element with increase of power proportional to the number of array elements; in this case a 6 dB increase in power is expected. However, a 4 dB power increase is measured at broadside due to element power imbalance. Note that the array pattern is omni-directional because the power from each element is in-phase at all angles because down conversion is obtained from mixing the transmitted RF and the modulation sideband, which are always in-phase.

Retrodirectivity was measured by transmitting a single tone interrogation signal at a fixed position and measuring the radiated response of the retrodirective array. Because of the system architecture, the return signal must be at exactly the same frequency of the interrogator signal. In order to allow the receiver to distinguish between the array response and the interrogator signal, an 8 MHz sinusoidal modulation signal was mixed with the response signal transmitted by the retrodirective array. A radar receiver uses time multiplexing and high isolation circulators to distinguish the two signals. Fig. 7 shows the resulting radiation pattern of the array with the interrogator located at 30°. Note that no grating lobes are observed due to the small array spacing. Because this experiment could not be done in an anechoic chamber, scattering due to the measurement environment noticeably influences the measured radiation patterns. This is thought to be the reason for ripples present in the radiation patterns.

In both receiving and transmitting, the array has an omni-directional nature. The received power follows the element pattern, while for transmitting the array main beam is able to steer over a half-space, depending on the element pattern.

IV. CONCLUSION

A new full duplex retrodirective array architecture demonstrating simultaneous receiving and transmitting of 10 Mbps signals has been presented. It presents interesting possibilities in developing SAR systems with communication capabilities.

ACKNOWLEDGEMENT

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