A Frequency Autonomous Retrodirective Array Transponder

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***Abstract* — Retrodirective arrays are able to radiate a signal in response to a signal transmitted by an interrogator back toward the transmitter position with no a priori knowledge of the arrival direction. We present a novel architecture that enables the retrodirective array to respond to an interrogator at the same transmitted frequency with no previous knowledge of the transmission frequency. The frequency agile prototype array shows excellent retrodirectivity at various frequencies.**

I. INTRODUCTION

The detrimental effect of multi-path fading on data integrity and signal-to-noise ratio is one of the driving factors in smart-antenna research [1]. By applying digital algorithms, smart-antenna receivers are able to first determine the direction of the desired signal, then by applying spatial correlation functions the receiver is able to suppress interference signals and enhance the desired signal. Likewise, transmitters are able to adjust beam directions to strengthen the link gain between transmitter and receiver.

When receiving a signal from an unspecified direction, retrodirective arrays [2-7] are able to transmit a signal response to that same direction without any previous knowledge of the source direction. This is accomplished without the use of phase shifters or signal processing, by relying on phase conjugating mixers. This function is done automatically, avoiding the digital circuit speed 'bottle-neck' related to conventional smart antenna systems. Such unique features make the retrodirective array an attractive candidate for advanced digital mobile communication systems where high link gain is required.

In this paper we present a retrodirective array with an added autonomous feature. Using this new retrodirective array architecture, the array is able to respond to a query without knowing the source direction as in conventional retrodirective arrays, but the added feature will allow it to respond without knowing the exact source frequency as well. This adds another dimension in system flexibility and increases the covert nature of the retrodirective array. Frequency automatism is accomplished by using the received RF frequency power to generate LO power used by the phase-conjugating mixers. Therefore, the retrodirective array is now able to respond at the same frequency as the interrogation frequency automatically.

II. CIRCUIT OVERVIEW

A schematic of the proposed retrodirective array is shown in Fig. 1. It is comprised of two main sub-circuits, namely an array of phase-conjugating mixers and the LO generator circuit. The signal received by the phase-conjugating mixers first passes through the circulator placed closes to the antenna, then is fed to one of the ports of a 3-dB branch line coupler, via a second circulator. The signal is then spilt equally, feeding each Schottky diode mixer in quadrature phase. The RF signal is then phase-conjugated using heterodyne mixing. Because the LO frequency is exactly twice the RF frequency, the IF frequency will be the same as the RF frequency, making it impossible to provide IF-RF isolation using a filter. IF-RF isolation is achieved by using the relative phase relationship of the IF and RF leakage signals at each individual diode mixer. The phase-conjugated IF signals from the mixers combine at the same port where it entered while the non phase-conjugated RF leakage is dumped into the 50 Ω load terminating the opposite port of the branch line coupler. The phase conjugated IF signal passes back to the antenna through the circulators and is retransmitted. This circuit also allows for amplifiers to be included in either receive or transmit paths or both paths.

The performance of a single Schottky diode phase-conjugating mixer was evaluated using two frequency synthesizers acting as the RF and LO signal sources. Because the circuit input and output port are shared, a 10 dB directional coupler was used to separate the incoming RF and outgoing IF phase-conjugated signal. The measurement of the circuit was done by applying LO power at a frequency twice that of the RF frequency with a 50 MHz offset, so that the IF and RF leakage frequencies can be distinguished. Fig. 2 shows a maximum IF-RF isolation of 43 dB at 5. 3 GHz. The isolation remains better than 20 dB from 5.15 GHz – 5.35 GHz. The isolation is better than 7 dB from 5 – 5.9 GHz. By adjusting LO power the minimum mixer conversion loss was measured to be 5.1 – 9.1 dB over a 5 -5.9 GHz frequency range. The optimum LO power was typically 3 dBm per diode mixer. For this reason diode mixers are better suited for this system architecture than FET mixers because of the limited LO power. In addition, in hybrid-circuit fabrication, phase balance between a diode pair is more easily achieved

RF power received by the LO generator is first amplified, and then fed into a frequency doubler. A filter is used to reject any RF leakage. The doubled signal is further amplified and used to feed the phase-conjugating mixer array.

III. RETRODIRECTIVE ANTENNA ARRAY

A prototype 4-element retrodirective antenna array based on the proposed phase-conjugating mixer was built on RT/Duroid 25 mil $\varepsilon_r = 10.2$. To facilitate the relatively wide bandwidth of this system, the quasi-Yagi antenna [8], which is reported to have a wide operational bandwidth, 3.74 – 6.22 GHz (50%) was used. The antenna's radiation pattern is quite broad and it has low adjacent-element mutual coupling (-20 dB), making it suitable for use in antenna beam scanning array applications. The antenna radiates in the endfire direction making the overall array circuit easily expanded into a 2-D array. The array spacing was chosen to be half-wavelength at 5.2 GHz. The small array spacing allows the array to avoid scan angle limitations due to grating lobes, which become visible when the array spacing is large.

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, a 25 KHz sinusoidal modulation signal was mixed with the response signal transmitted by the retrodirective array. This demonstrates the arrays' functionality as an information transponder.

As with all mixers, the phase-conjugating mixers' conversion loss is greatly dependent on the amount of LO power used to pump the mixers, therefore overall circuit performance relies on the LO generator sub-circuit. In this proof-of-concept array, the LO power level was manually controlled by adjusting the gain of the amplifier used to amplify the LO signal generated from doubling of the RF signal.

Fig. 3 shows the measured bistatic RCS of the retrodirective array with the interrogator source at broadside (0°), 15°, and -30° at 5.2 GHz. Retrodirectivity is clearly observed in all three cases. 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 order to qualify that this newly proposed array is frequency autonomous, bistatic RCS was measured using an interrogation frequency of 5.8 GHz (Fig. 4.). Again, we see that the array is able to track the position of the interrogator quite well, with no grating lobes. For this measurement only the interrogator frequency was changed.

IV. CONCLUSION

A novel frequency indiscriminate retrodirective array has been developed. The array is able to respond in an interrogator at the same signal frequency with no a priori knowledge of its position as well as its transmission frequency.

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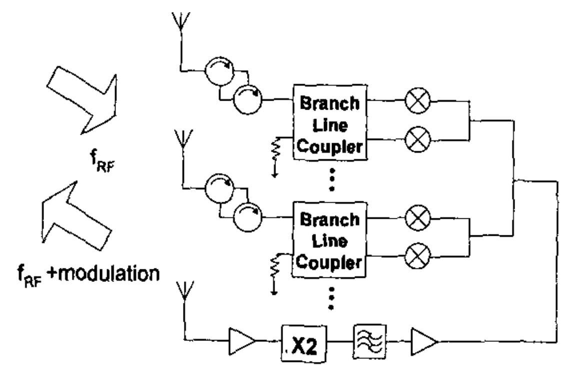


Fig. 1. Schematic of the proposed frequency autonomous retrodirective array.

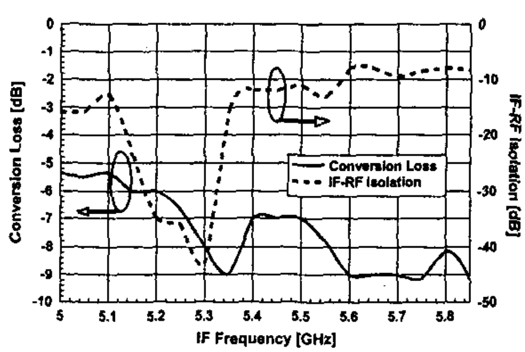
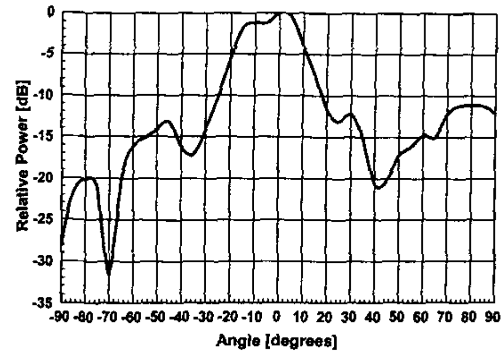
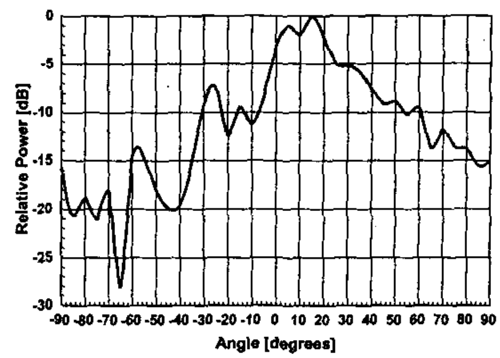


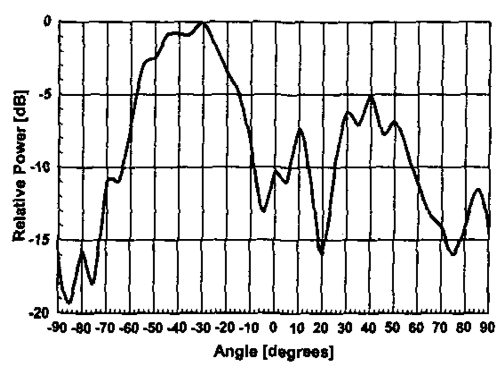
Fig. 2. Phase-conjugating mixer performance.



a). Interrogator at broadside (0°), Frequency=5.2 GHz

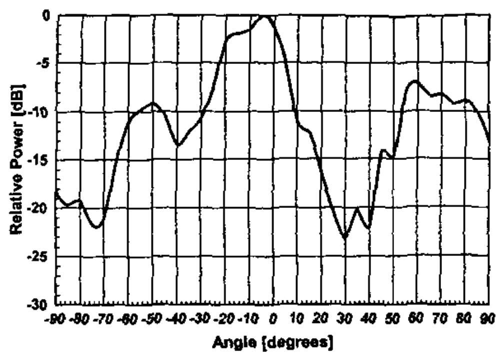


b). Interrogator at broadside (15°), Frequency=5.2 GHz

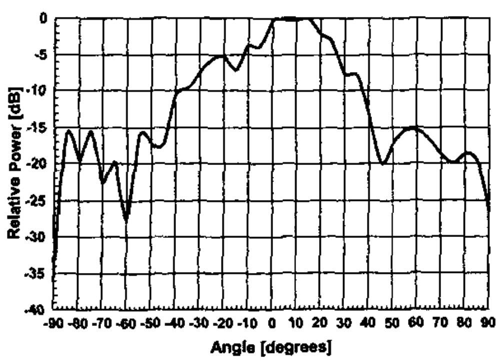


c). Interrogator at broadside (-30°), Frequency=5.2 GHz

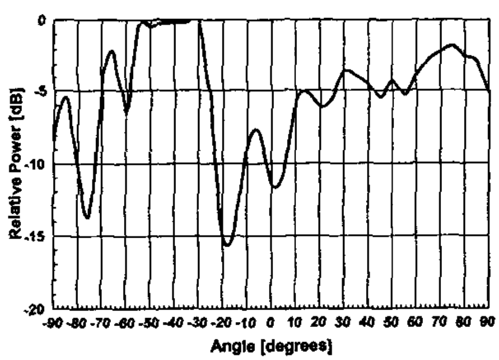
Fig. 3. Measured bistatic RCS at frequency = 5.2 GHz.



a). Interrogator at broadside (0°), Frequency=5.8 GHz



b). Interrogator at broadside (15°), Frequency=5.8 GHz



c). Interrogator at broadside (-30°), Frequency=5.8 GHz

Fig. 4. Measured bistatic RCS at frequency = 5.8 GHz.