An Active Self-Steering Array Using Self-Oscillating Mixers

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Abstract — **A retrodirective array using self-oscillating mixers (SOMs) is presented. SOMs allow for easier implementation of larger two-dimensional arrays by eliminating the complex local-oscillator (LO) feed structure. A four-element linear retrodirective array using SOMs is demonstrated at a LO frequency of 8.87 GHz. Each element is successfully phased locked at the LO frequency while 33 dB of isolation between adjacent elements is measured at the RF frequency. The LO power generated by a single SOM element at the fundamental frequency is +3 dBm. Retrodirectivity is successfully observed for scattering angles of -30°, 0°, and +15°.**

I. Introduction

Retrodirective arrays [1] have attracted a great deal of interest for their self-steering capability in wireless communications and solar power satellite systems (SPS). These arrays have the unique property in that when the array is interrogated, the array automatically points its beam towards the interrogator. In contrast to conventional beam steering in a phased-array antenna, a retrodirective antenna is self-steering, and does not require any phase shifters or digital signal processing.

The heterodyne technique [2] is a popular method for realizing retrodirective arrays. As shown in Fig. 1, this type of array employs mixers coupled to each antenna element. The mixers are designed so that an incoming RF signal of frequency f_{RF} mixes with a local oscillator (LO) at twice the RF frequency $2f_{RF}$. The resulting intermediate frequency (IF) signal is a phase-conjugated duplicate of the incoming RF source wave and reradiates in the direction of the source.

For a phase-conjugating array to achieve retrodirectivity, the LO applied to each element must have the same phase. The conventional way of achieving this is to carefully design a corporate feed network so that the path lengths to each mixer are identical. However, feed networks become quite complicated for large 1D linear arrays and severely limit the size of 2D arrays as shown in Fig. 2 [3].

Also, for efficient mixing, providing enough LO power to each element from a single source is challenging. Although a spatially fed LO [4] can eliminate the complex feed network, the amount of LO power delivered to the mixer is limited.

A solution to complex LO feed networks and LO power requirements is to eliminate the external LO source by basing the individual phase conjugating elements on

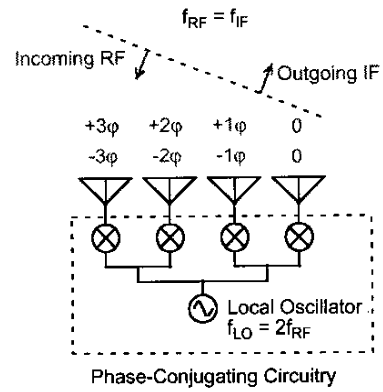

Fig. 1: Schematic of a heterodyne retrodirective array. The LO is provided from a corporate-fed transmission-line network.

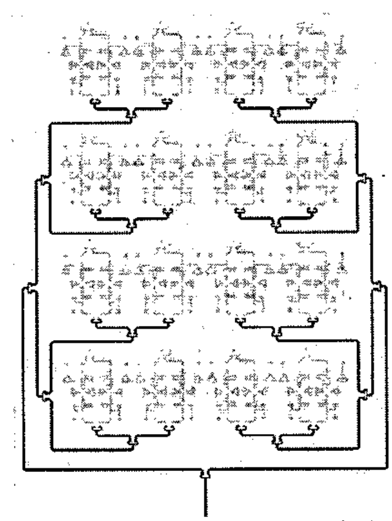

Fig. 2: LO feed network for a 2D 4x4 retrodirective array.

self-oscillating mixers (SOMs). A retrodirective array can then by realized by phase locking the SOM elements at the LO frequency [7] while isolating them at the RF frequency.

Although the idea of an SOM-based retrodirective array was proposed in [5], the first such array was demonstrated in [6], but this array radiated its LO in addition to the retrodirected IF signal and its usefulness was therefore limited. This paper presents the first SOM-based array that was specifically designed for retrodirective applications.

II. PHASE-CONJUGATING CIRCUIT BASED ON SOMS

Fig. 3 shows the schematic for one unit cell of the retrodirective SOM array. The SOM was optimized such that it oscillates at twice the RF frequency.

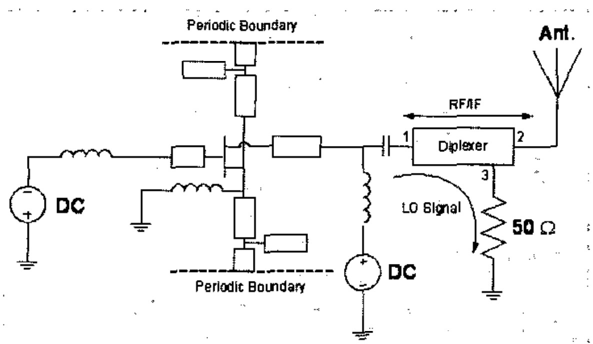

Fig. 3: Schematic of a phase-conjugating element using a self-oscillating mixer.

A diplexer is employed to isolate the antenna from the termination of the oscillator. At the LO frequency, the output port of the SOM only sees the 50-Ω load while only the antenna is visible at the RF frequency.

The self-oscillating frequency of each SOM is synchronized to each other by connecting the transistor source terminals with transmission lines. At the same time, each SOM is isolated at the RF frequency since the interconnecting lines also function as RF band stop filters.

Fig. 4 shows a four-element prototype phase-conjugating array. Fabrication is done modularly on *RT/duroid* 5880 substrate (thickness 0.7874 mm, ε_r=2.2). The SOMs employ Agilent ATF-36077 ultra low noise pseudomorphic high electron mobility transistors. Gate and drain bias is applied through 220-nH chip inductors. Each of the three modules (SOM, diplexer, and antenna array) is built and tested independently and then connected using cables to form the phase-conjugating array. Commercial fabrication of the phase-conjugating array would be done together on one board.

For proper operation of the SOM array, the SOMs have to be turned on at the same time. This is achieved by using a common DC supply for all the SOMs. The circuit is optimized such that it oscillates at 8.5 GHz. Fig. 5 shows the measured spectrum of the LO signal. The measurement results show that the SOM elements are phased locked with a fundamental oscillation frequency of 8.87 GHz.

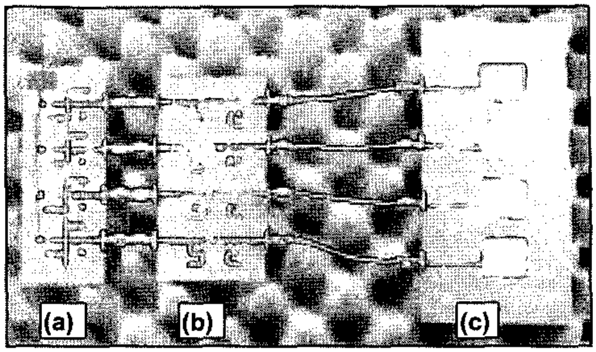

Fig. 4: Prototype phase-conjugating array based on self-oscillating mixers: (a) SOMs (b) diplexers (c) antenna array.

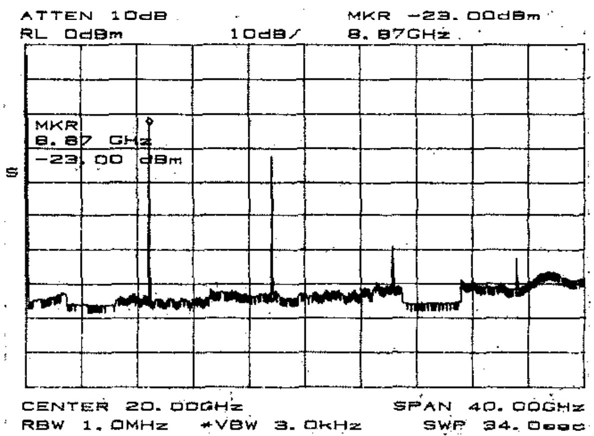

Fig. 5: LO spectrum of a single SOM element measured at the RF/IF port (Port 2) of the diplexer.

Measurement of the LO power of a single SOM element is taken at the RF/IF port (Port 2) of the diplexer. At the fundamental frequency, -23.0 dBm is measured from a single element while terminating the other elements. After compensating for the diplexer (S21) and cable losses, the LO signal power from the SOM is 3.0 dBm at the fundamental frequency, and -25 dBm at the second harmonic.

Next, mixing performance is evaluated by applying an external RF signal to the SOM circuit through a directional coupler [8]. The phase-conjugated IF signal is measured using a spectrum analyzer from the coupled port of the directional coupler. Fig. 6 shows the RF–IF conversion gain vs. RF frequency deviation from $f_{LO}/2$. By optimizing the diplexer for a flat response around the RF frequency, the measured conversion gain is relatively flat (-18 to -24 dB) over the entire ±400 MHz bandwidth.

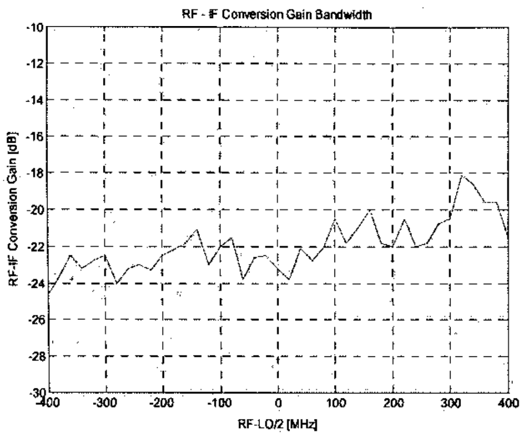

Fig. 6: Measured RF-IF conversion gain vs. RF frequency deviation from $f_{LO}/2$.

For an array of phase-conjugating elements to properly function as a retrodirective array, each element must be isolated from each other. The RF isolation between elements is measured by injecting a RF signal to an element and measuring the coupled signal at an adjacent element. At a RF frequency of $f_{LO}/2$, the measured isolation between adjacent elements is 33 dB.

III. RETRODIRECTIVE ARRAY

Four patch antennas spaced a free-space half-wavelength apart are attached to the phase-conjugating circuit to complete the retrodirective array. Retrodirectivity is verified by taking bistatic radiation measurements using the setup shown in Fig. 7. A RF signal of frequency slightly higher than $f_{LO}/2$ is used so that both RF and IF signals can be monitored on the spectrum analyzer. The

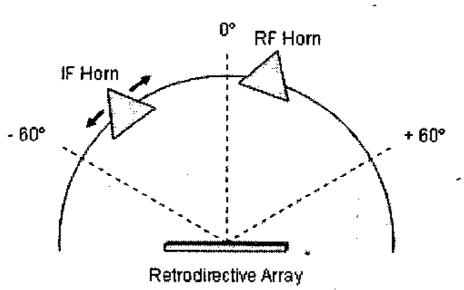

Fig. 7: Setup for measuring the bistatic radiation pattern.

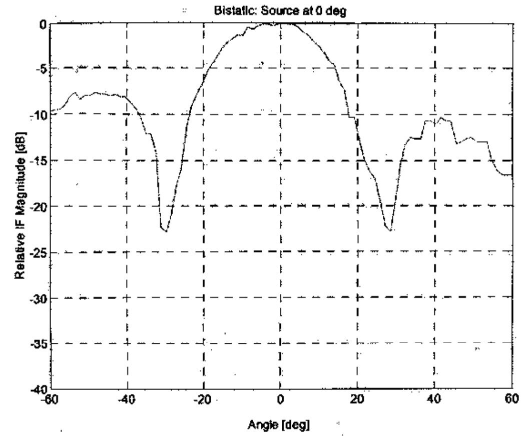

Fig. 8: Measured bistatic radiation pattern. RF source at 0°.

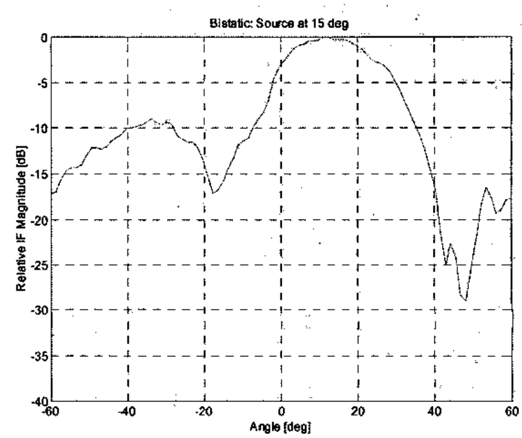

Fig. 9: Measured bisatic radiation pattern. RF source at +15°.

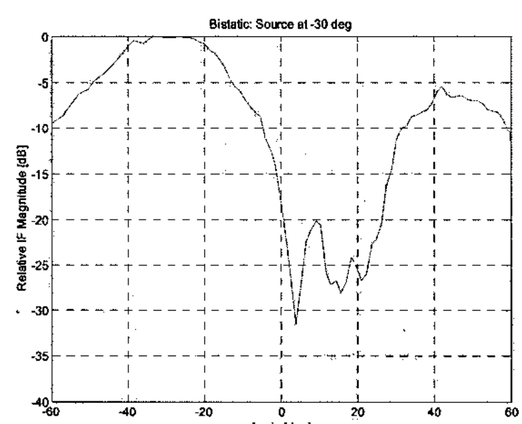

Fig. 10: Measured bistatic radiation pattern. RF source at –30°.

position of the RF horn is fixed while the IF horn is mounted on a computer-controlled rotational arm that scans ±60°. Absorbers are placed around the test setup to reduce interference caused by multipath. The measured bistatic patterns shown in Figs. 8-10 confirm that the array successfully tracks the direction of the source for angles of −30°, 0°, and +15°.

IV. Future Work

With complicated LO feed networks and limiting LO power eliminated through the use of SOMs, a streamlined design becomes the limiting factor in building a large 2D array. Ideally, the circuitry of a 2D retrodirective array should fit in a $\lambda/2 \times \lambda/2$ cell. However, that is not the case for the prototype circuit shown in Fig. 4.

The size of the prototype circuit can be reduced by locating the patch antenna behind the SOM circuit. Further reduction of circuit size can be achieved by optimizing for a substrate with a higher dielectric constant. RF-IF conversion can be improved by optimizing the design for mixing performance.

V. Conclusion

A phase-conjugating array based on self-oscillating mixers is presented. A four-element linear retrodirective array is realized with a LO frequency of 8.87 GHz. Each element is successfully phased locked at the LO frequency while obtaining good isolation between adjacent elements at the RF frequency. The LO power generated by a single element at the fundamental frequency is +3 dBm. Retrodirectivity is observed for scattering angles of -30°, 0°, and +15°. Retrodirective arrays using SOMs do not require complex LO feed networks, thereby allowing the realization of larger, 2D arrays.

Acknowledgement

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