Amplitude Modulation of a Resistive Phase Conjugator based on Dual-Gate FET Technology

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Abstract: - In this paper, the control over the second gate voltage in a dual-gate FET resistive mixer is employed for amplitude remodulating the response signal in a retrodirective array. A resistive mixer is integrated with an aperture coupled square patch, and a data signal voltage, \( V_{g2}(t) \), is appropriately conceived in order to control the magnitude of the device time-varying output conductance. Measurements of the response signal in a backscatter test set-up validate the proposed solution for carrying information back to the interrogator position in full-duplex communications links.

Key-Words: dual-gate FET; phase conjugation; resistive mixer; retrodirective arrays.

1 Introduction

Adaptive beamsteering and beamforming techniques are being continuously introduced in modern wireless systems, as a way to reduce interference while simultaneously improving link gain and system capacity [1].

As it is widely known, adaptive beamsteering may be obtained through the use of digital signal processing techniques. However, the required response speed may turn the hardware and algorithms so complex and sophisticated that this solution may result prohibitive for a lot of applications. Retrodirective arrays [2] – [7] are thus standing as a promising alternative, as they are able of automatically transmitting a signal back to the interrogator’s position without any priori knowledge of the incidence angle, employing simple analog signal processing circuits.

Array retrodirectivity may be assured if each element responds with a phase conjugated version of the signal it receives. This concept was first introduced by Van Atta [2], using equal length transmission lines to connect pairs of antennas equidistant from the center of the array. Later, a heterodyne approach was proposed by Pon [3], selecting the lower side band product from the mixing process between the incoming signal and a local oscillator (LO) at twice its frequency.

The introduction of phase-conjugating arrays in wireless communication systems is still limited, mainly due to the need for a simultaneous transmission and reception of information. Taking into account that the response signal should be constructed from a phase reversed version of the incoming excitation, this is certainly not a trivial task. Two kinds of solutions have been reported in the literature, which avoid undesired interference in the response due to the modulation format employed in the interrogation. In one of them, the received information is simply removed previous to the remodulation process [4], [5]; while a mutually-exclusive format is superimposed in the other [6].

In this paper, a phase conjugating antenna with amplitude modulation capability is presented for its use in retrodirective arrays. The resistive conjugator, based on dual-gate FET technology, would be valid for its use in full-duplex communication links, following either of the above mentioned approaches.

2 Dual-Gate FET Resistive Mixer

Diode and FET mixers have both been used in the past for phase-conjugator design [7]. In the case of FET’s, the resistive mixing topology [8] is highly appreciated, as the interrogating and response signals share the same device terminal (the one to be connected to the antenna).

Although dual-gate FET’s have been extensively employed for variable gain amplifier and mixer design [9], the dependence of their drain-to-source conductance in cold operation on both gate voltages have not been completely exploited.
The nonlinear behaviour of a dual-gate FET can be described as that of a cascode of two single-gate FET’s [9]. At $V_{DS} = 0V$, this means that the conducting channel may be equally controlled by the first and second gate voltages. In Fig. 1, the measured drain to source conductance dependence is depicted in such condition, as extracted from [S] parameter measurements over a NEC device, NE25118.

![Figure 1](image1)

**Fig. 1.** Drain to source conductance evolution with $V_{GIS}$ and $V_{G2S}$ at $V_{DS} = 0V$ for a NE25118 FET.

As can be appreciated, the output conductance profile in terms of the first gate voltage is modulated by the selected second gate DC value, being its maximum variation placed at pinch-off, as expected.

Taking into account that in a resistive mixer the time-varying conductance is employed for generating the response,

$$G_{ds} = G_{ds1} + G_{ds2} + G_{ds3} + \ldots + G_{dsn}$$

the response component in the drain-to-source current could be expressed as function of the interrogating voltage phasor ($Vin.e^{j\omega t}$),

$$ids_{res}(t) = \frac{1}{2} \cdot G_{conv} \cdot V_{in} \cdot \cos(\omega_{LO} \cdot t + \varphi_{LO} - \varphi_{in})$$

Where the conversion conductance term ($G_{conv}$) may be derived through Eq. 4 once the reactive elements in the device equivalent circuit have been neglected (memoryless approach). Using $Rs$ and $Rd$ to represent the parasitic source and drain resistances,
states corresponding to \( V_{G2S} = -2.5V \) and \( V_{G2S} = -0.3V \), the generated response may carry information back to the interrogator position in an Amplitude Shift Keying (ASK) format. If properly predistorting the modulating data signal according to the conversion loss dependence on \( V_{G2S} \), analogue amplitude remodulation would be also possible.

3 Phase Conjugating Antenna

The previously optimized resistive mixer was then integrated with a 900MHz printed radiator to be used as retrodirective array element. The phase-reversed signal was ASK modulated inserting the data signal with a high performance Agilent pulse generator.

3.1. Printed Patch

For the radiator, an aperture coupled square patch was selected [10] due to its known suitability for inserting active circuits. The conjugator and the feed line were printed on ARLON N25 substrate with a dielectric constant of \( \varepsilon_r = 3.38 \) and thickness of 0.78mm, see Fig. 3 for details. The patch was built on an auxiliary layer using the same material, being placed in an inverted position thanks to the use of plastic posts. In this way, the substrate below the patch is air, with the advantages in gain and bandwidth related to its low permittivity.

Fig. 3. Geometric details of the antenna. Dimensions in mm.

In Fig. 4, results for the measured input matching are presented. Although the antenna was designed to present a 50\( \Omega \) input impedance in the operating band, the slot and stub dimensions could be modified to match the drain impedance at the interrogating frequency, reducing undesired radiation due to the reflected component of the incoming interrogation.

Fig. 4. Input matching (\( S_{11} \) [dB]) characteristic.

3.2 Phase-conjugating antenna measurement results

A backscatter test set-up was finally implemented for characterizing the integrated antenna. An 885MHz CW signal was transmitted as interrogation. An Agilent 89600 Vector Signal Analyzer allowed measuring the amplitude or phase evolution of the 915MHz (\( f_{LO} - f_{in} = 1800MHz - 885MHz \)) retransmitted signal back at the interrogator position, both in time or frequency domain. After applying a 1MHz rate pulsed signal at the second gate mixer terminal, while keeping \( V_{G1S} = -1.5V \) and \( V_{DS} = 0V \), the measured amplitude component of the response envelope may be observed in Fig. 5. ASK modulation at the original 1MHz pulse rate is perfectly validated with 30dB level difference between states.

Fig. 5. Envelope amplitude evolution in time of the response signal, as received back at the interrogator position.

The relative radiation pattern, measured from the power level evolution of the “1” state with the elevation, is plotted in Fig. 6. The minimum value was used as reference for the polar plot. As expected, it approximately follows a square patch diagram.
The here developed phase-conjugator/modulator, based on a dual-gate FET resistive mixer, would be valid for its use in full-duplex retrodirective communication links if the incoming interrogation were angularly modulated. In case of an impinging AM interrogation, it could be also possible extracting the envelope and clipping the received signal previous to the proposed phase reversal solution.

4 Conclusion

A phase conjugating antenna with amplitude modulation capability, based on the use of dual-gate FET technology, has been presented. Despite the modest conversion efficiency obtained from resistive mixing, it constitutes a simple and unexpensive solution for implementing full-duplex retrodirective communication links.

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