A 62/66 GHz Frequency Offset Retrodirective Array

N.B. Buchanan, T. Brabetz, V.F. Fusco

The Department of Electrical and Electronic Engineering
The Queens University of Belfast, Ashby Building, Stranmillis Road
Belfast, BT9 5AH, N Ireland
Tel: +44 +(0)28 9027 4578, Fax: +44 +(0)28 9066 7023
e-mail: n.buchanan@ee.qub.ac.uk

***Abstract* — Measured and predicted results are presented for a 62/66GHz frequency offset retrodirective array. Measurements show the array to produce a self steered monostatic 3 dB beamwidth of 22.5°. Predictions carried out using an active element approach showed close agreement with a theoretical value of 21°, confirming for the first time, frequency offset retrodirective action in the millimetre wave region. In addition, amplitude/pulse modulation was shown to be readily applied to the re-transmit self-steered signal. This work enables a variety of short range mm-wave broadband wireless links and sensor applications such as asset tagging.**

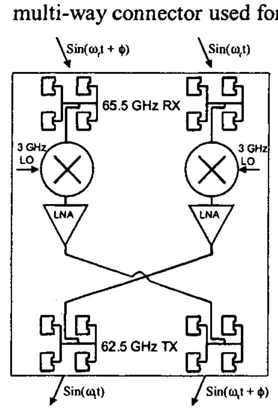
I. INTRODUCTION

The first antenna array displaying retrodirectivity was reported by Van Atta in 1959 [1]. A number of active retrodirective antenna array structures have been reported at frequencies of up to 24 GHz, e.g. [2] and a planar passive structure at 65 GHz [3]. Recently, frequency offset retrodirective structures have been reported [4], [5] offering the advantage of a further degree of isolation between transmit and receive signals. This paper demonstrates practical results of the highest frequency (62/66 GHz) active frequency offset retrodirective array reported to date. The device presented should find application in a variety of mm-wave broadband wireless links for Pico cell applications, and for mm-wave sensor applications. The operating frequencies were selected as part of a paired frequency allocation for broadband wireless applications, [6], 62/65GHz.

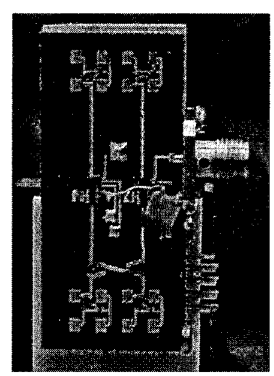
II. OPERATION OF RETRODIRECTIVE MODULE

The schematic for the retrodirective module is shown in Fig. 1(a). A signal presented to the 65.5 GHz receive antennas is down converted to 62.5 GHz, amplified, and then re-transmitted by the 62.5 GHz antennas. In this circuit isolation between received and re-transmit signals is achieved using frequency diversity, this is unlike previous work were both polarization and frequency diversity has been used, [4]. By crossing over the 62.5 GHz re-transmit antennas as shown in Fig. 1(a) the phase relationships are correct to allow the retransmitted signal to be self-steered to the source. An additional advantage of using separate transmit and receive arrays for frequency offset operation, is that the inter-element spacing for each may be scaled to the frequency of operation. This reduces beam pointing error caused by the frequency offset, compared to the case where a single antenna performs both transmit and receive functions [7]. The circuit in Fig. 1(a) uses horizontal linear polarization for both receive and re-transmit.

A photograph of the fabricated module is shown in Fig. 1(b). The module consists of 4 GaAs MMICs, fabricated using the OHMMIC ED02AH process and a Taconic TLY softboard substrate material MIC patterned with patch antennas. The overall assembly was contained on a brass carrier. RF and DC interconnections were carried out using wire bonding. The 3 GHz local Oscillator signals were fed by means of SMA connectors with a multi-way connector used for DC bias.



(a) Retrodirective configuration



(b) Photograph of Retrodirective Module

Fig. 1 Frequency Offset Retrodirective Array

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III. MEASURED RESULTS

A) Experimental Configuration for Monostatic Pattern Measurement

The experimental setup for Millimetre-Wave Monostatic Pattern Measurement (Fig. 2) used a mm-wave synthesized source as the transmitter and a spectrum analyser as the receiver. The measurement antennas were 20 dB horns, stacked in the H-Plane to facilitate monostatic pattern capture by minimizing direct coupling between them. Equal local oscillator power was fed to each cell of the repeater module via a power divider with an adjustable phase being applied to Cell 1 to compensate for unequal LO to mixer interconnect lengths. An initial measurement showed the receive-transmit conversion gain of the module to be 27.1 dB.

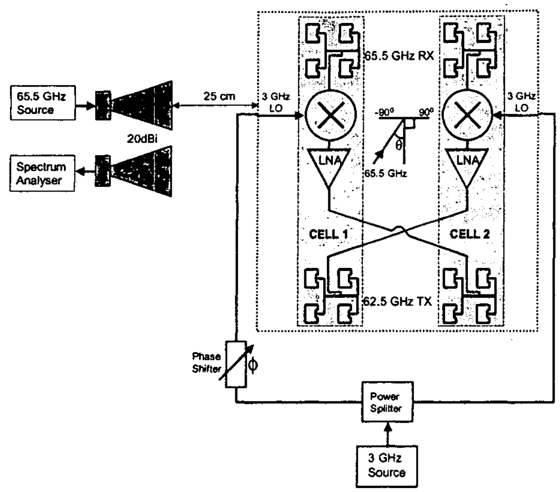

Fig. 2 Experimental Setup for Monostatic Radiation Pattern Measurement

B) Modulation Capability

This measurement showed that the frequency offset repeater had an integral capability to amplitude modulate the re-transmitted signal. The LNA MMICs used for the repeater normally function with no gate bias, i.e. they were left floating. Application of a negative voltage to the LNA gate bias connections has the effect of pinching off the PHEMTs in the LNA's, thus switching them off. Applying a modulating signal to the LNA bias produced amplitude modulation on the re-transmitted signal. Fig. 3 shows the effect of applying a 20 KHz, 0.175Vp-p, -0.5V DC offset sine wave to the LNA gate bias connections of both cells during self-steering operation. The spectrum clearly shows that the re-transmitted signal was amplitude modulated, with the modulation sidebands 9dB less in amplitude than the carrier indicating a modulation index of 0.5. This method has the advantage that only a very small modulating signal amplitude and current is sufficient to produce a useable modulation index.

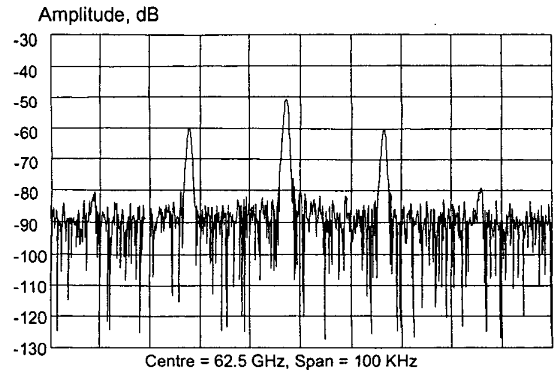

Fig. 3 Retransmitted spectrum with application of 20 KHz Modulating signal to LNA Gate Bias

C) Self Steering Mode

Before each monostatic measurement was carried out the phase shifter in Fig. 2 was set for maximum re-transmitted signal at boresight when the illuminating signal was also located at boresight. This ensured that the local oscillator signals were arriving at the frequency offset module to allow in-phase spacial millimetre-wave power combining at boresight, thus producing optimum conditions for retrodirectivity. In addition to measuring the monostatic self steered response, the individual monostatic radiation patterns of each retrodirective cell were measured. These are known as the 'active element patterns' and are useful since they allow the predicted self steered response to be accurately calculated as they include mutual coupling effects.

Fig. 4 shows the monostatic pattern results obtained. The active element patterns were measured by applying bias voltage to the low noise amplifier of the cell being measured. The other cell was effectively switched off since the LNA with no bias voltage provided a high attenuation in the signal path. The measured monostatic self steered response of Fig. 4 was shown to have a 3dB beamwidth of 22.5°. The active patterns of retrodirective Cells 1 & 2 had 3 dB beamwidths of 14° and 26° respectively.

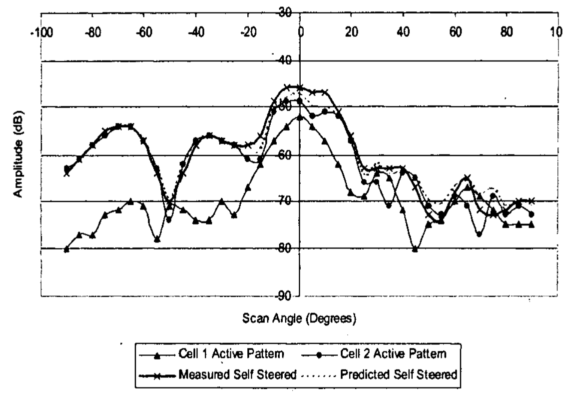

Fig. 4 Monostatic Pattern Results, Self Steered 3dB beamwidth = 22.5°, Predicted = 21°

III. Retrodirective Prediction using Active Element Patterns

Retrodirective antenna array radiation pattern predictions have for decades been carried out using an isolated element approach [8]. This array theory ignores mutual coupling and physical antenna structure effects which are subjected to antenna elements within an array. The isolated element approach represents the array pattern by an antenna pattern measured in isolation multiplied by an array factor. The more accurate active antenna pattern is produced by measuring each element of an array in turn in the presence of the neighboring elements which are terminated in their load impedance. All the active patterns of the array elements are then multiplied to produce the predicted array pattern. This method has only recently been reported [9] for modelling of retrodirective arrays.

The radiation pattern of a retrodirective antenna in a finite size array of N-elements is predicted as follows [9]:

$$E_{RDA}=\sum_{i=-\frac{N}{2}}^{+\frac{N}{2}} g_a^i \times AF_{RDA}$$

$$\Rightarrow E_{RDA}=e^{j(\omega t+\psi)}\sum_{i=-\frac{N}{2}}^{+\frac{N}{2}} g_a^i(\theta)\times C_i\, e^{j\left[\frac{2\pi x_i}{\lambda}(\sin\theta_t-\sin\theta_r)\right]} \tag{1}$$

Where:

N = the total number of antenna elements

λ = free-space wavelength of the array's operating frequency

θ_r = angle (from boresight) of the received signal arriving at the array

θ_t = angle (from boresight) of the retransmitted signal leaving the array

$|C_i|$ = magnitude of the signal radiated from the i^{th} element of the array

x_i = distance of the i^{th} element from the centre of the array

ω_{IF} = angular frequency of the array

g_a^i = active Pattern of the ith element

ψ = constant phase delay in each element of the retrodirective array

For a monostatic pattern prediction (1) reduces to:

$$E_{RDA}=e^{j\omega t}\sum_{i=-\frac{N}{2}}^{+\frac{N}{2}} g_a^i(\theta)\times C_i \tag{2}$$

Equation (2) was used here to predict the monostatic retrodirective pattern from the active element patterns, shown as dotted lines in Fig. 4. They were found to be slightly lower in amplitude by several dB from the measured monostatic response, although exhibited the same trend. In the case of Fig. 4, the measured self steered 3dB beamwidth was 22.5°, compared to the predicted value of 21°.

IV. Discussion of Results

Active element monostatic pattern measurements produced 3dB beamwidths of retrodirective cells 1 & 2 of 14° and 26° respectively. Combining these in self steering mode produced a monostatic 3dB beamwidth of 22.5°. The predicted monostatic self-steered 3dB beamwidths were in close agreement with the measurements, producing 21° predicted, compared to 22.5° measured.

In the frequency offset module described here, the active element pattern of one cell had a 3dB beamwidth of 14°, which was significantly lower than 26° presented by the second cell. These results have shown that the combining of the two cells to form a self steered array produces a response in accordance with retrodirective theory.

V. CONCLUSION

A millimetre-wave frequency offset retrodirective array has been demonstrated to produce a self steered monostatic 3 dB beamwidth of 22.5°. Predictions carried out using an active element approach showed close agreement with a theoretical value 21°, confirming that retrodirectivity was taking place. These measurements and predictions have reinforced the fact that the beamwidth of a retrodirective array's self steered pattern is limited by the basic building blocks used for the array, i.e. the active element patterns. It was also shown that the 62.5 GHz retransmitted signal of the frequency offset repeater during self steering operation can be readily amplitude/pulse modulated by applying a modulating voltage to the LNA gate bias.

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