A Low-Cost Direction Controller for Phased Array Antennas

Yao Liu, Michael McCarthy, and P. O'Leary

***Abstract*—**Direction control of continuous wave (CW) beams in phased array antennas is investigated in this work using Monolithic Microwave Integrated Circuit (MMIC) quadrature modulator control. The concept was simulated using Matlab and Agilent's ADS and then implemented using off-the-shelf quadrature modulators, more usually used in the signal chain for digital communications. These components were used as they have been optimised to smoothly and accurately modify the phase of a local oscillator input, for subsequent transmission as a modulated communications carrier, which is similar to the beam steering requirements of a phased array antenna. The phase controlled signals fed four simple patch antennas and the subsequent beam control characterised and presented here.

***Keywords*—**Phased array antennas, beam steering.

I. Introduction

PHASED array antennas offer great potential in medical applications, communications, radar and other areas of wireless deployment [1]. As deployments increase costs are falling and widespread use is more feasible. New techniques are continuing to appear, some even drawing from established techniques in other areas. This research adopts a technique, more usually used in the signal chain for digital communications, whereby phase and amplitude control of a carrier signal can be achieved using quadrature modulation. Such an approach of beam steering a CW would offer the advantage of low cost and continuous control of phase. The antennas used are simple micro-strip (patch) antennas [2].

However, using this MMIC In-phase/Quadrature phase (I/Q) modulator approach as a phase control element in a beam steering context could compromise its utilisation for non-CW phase control transmission and reception. Since the nature of the phase control is via low frequency, quasi-DC fluctuations, the dynamic range of superimposed modulating vectors (as is the case for normal communications modulation) is limited.

II. Hardware Description

This section describes the development of a low-cost, flexible, continuous phase programmable (digitally controlled) and accurate antenna direction gain platform through the use of standard off-the-shelf electronic components. A novel approach taken here is that off-the-shelf components are quadrature modulators, four in this case to control a four element phased antenna array, more usually used in the signal chain for digital communications. These components have been optimised to smoothly and accurately modify the phase of a local oscillator (LO) input, for subsequent transmission as a modulated communications carrier.

A. Modulator Role

Instead of the I/Q modulators performing their usual operation of frequency translation to mix a baseband signal onto the specified carrier frequency in the RF spectrum, here the I/Q modulators are instead used in the phase control of any (of many) of the RF signals feeding individual antenna array elements. This is possible by recognising the similarities in requirement between a phased array antenna control circuit and the specification of an I/Q modulator. An I/Q modulator consists of a local oscillator (LO) input that is split into in-phase (I) and quadrature (Q) components, which drive separate mixers/balanced modulators that are also driven by the I/Q baseband signals, with the mixer/balanced modulator outputs then being summed/power combined to provide a modulated carrier either at RF or IF. The quadrature modulator is able to control both signal phase (±180 degree) and amplitude, which makes them also potentially useful in smart antennas. In this instance the I/Q baseband signals are replaced by a digital stream tailored to control the combined signal's phase. The I/Q modulator used for this work is the AD8346, an RFIC for use from 0.8 GHz to 2.5 GHz that allows high performance direct modulation to RF.

B. Beam Steering Computer

While many possible candidates exist to control the steering vector synthesis, in this case as a Matlab pre-calculation was carried out (not necessarily a requirement for this concept), a simple Atmel microcontroller (ATMega128) with lookup table was chosen. The native SPI interface increases the compatibility with the SPI-compliant DACs. The simultaneous output update feature can minimize the transient error in trying to simultaneously control four (or more, later) antennas. This offers smoother trajectory variation, compared with the conventional strip-line counterpart. Also, the purposely higher DAC resolution increases the output accuracy and SNR.

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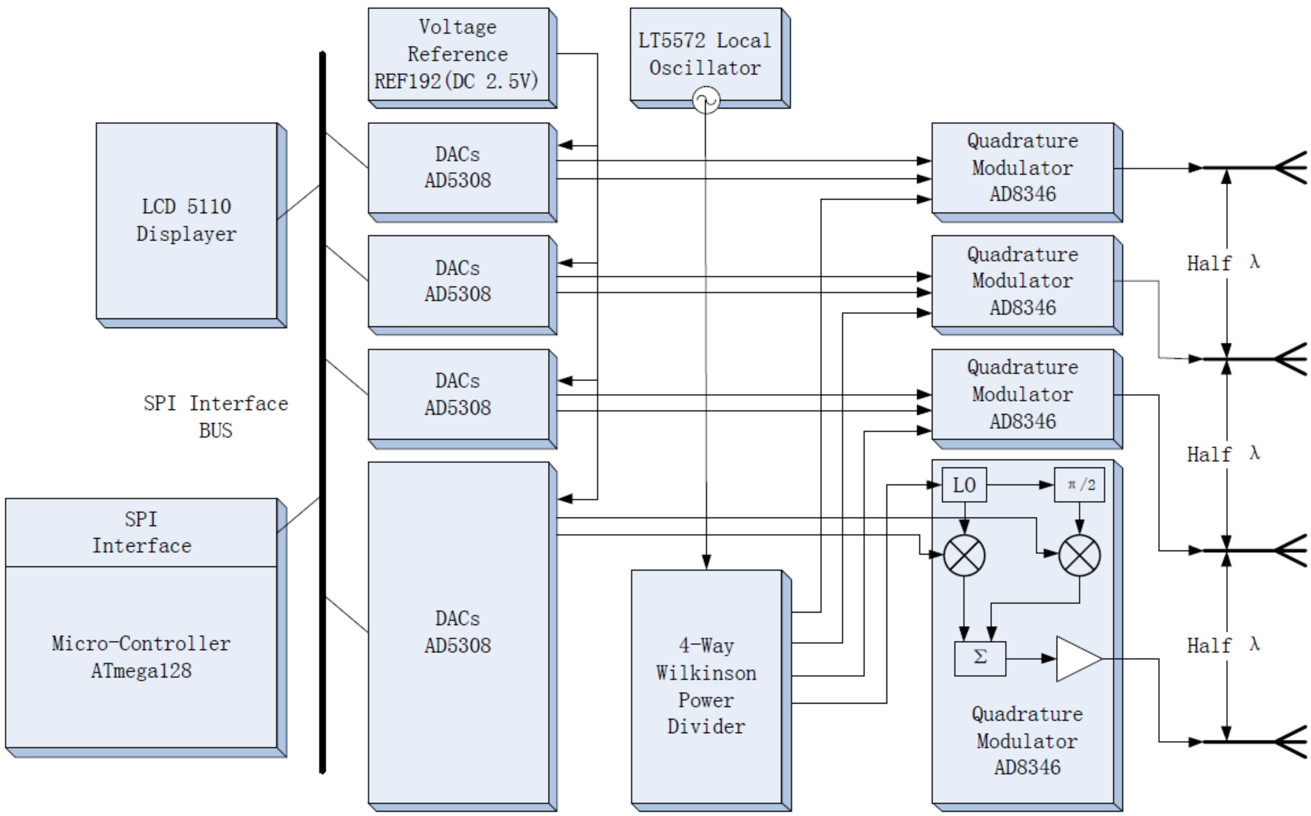


Fig. 1 Block diagram of test system

C. Steering Vectors

In this configuration, the I/Q modulators are used together with a microcontroller and two eight-output dedicated DACs (AD5308), configured as four differential outputs per DAC to make a Digital Beam Former. The DACs provide the low frequency, quasi-DC fluctuations that drive the mixer elements of the I/Q modulator. The microcontroller has a lookup table of Matlab pre-calculated phase trajectories, re-calibrated to accommodate system-specific variations, which can synthesise the desired dynamic antenna direction gain. The CW frequency is supplied by a 2.45GHz sine wave signal from a Vector Signal Generator (Agilent E8267D PSG) feeding each of the four I/Q modulator (AD8346) local oscillators, via a Wilkinson power splitter).

D. LO Drive

The LO input port (on the left in Fig. 2) is driven single-ended at a cost of slightly higher LO feedthrough. A LO drive level of between -6dBm and -12dBm is required. A drive level of -10dBm was ultimately selected for optimal performance. The Agilent ADS-simulated insertion loss for the Wilkinson Power Divider designed for this project was -10dB, thus the output power level of the signal generator was set to 0dbm.

E. RF Output

The AD8346 RF output interface is designed to drive a 50 ohm load. When the I- and Q- inputs are driven in quadrature by 2 V p-p signals, it results in approximately -10 dBm output power.

F. RF Simulations

Simulations were also carried out of a four-channel test platform in an attempt to characterize the performance. The simulated results are shown later in dashed red traces superimposed on the measured beams in blue traces.

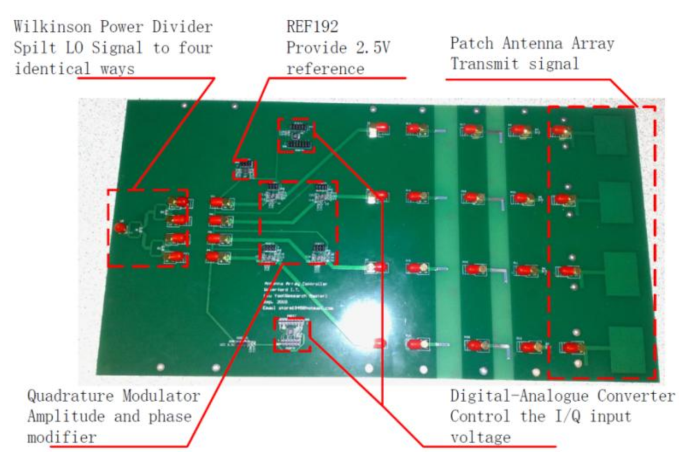


Fig. 2 Complete PCB fabrication (pre-separation)

III. MEASUREMENTS

The antenna gain was measured by mounting one antenna on a modified Pentax Total Station, for accurate distance and angular measurements and a second identical antenna at normal incidence, as shown in the photo in Fig. 3. The Two

Antenna Gain method was used, on the basis that both antennas are identical, with the Total Station providing the accurate angular measurements.

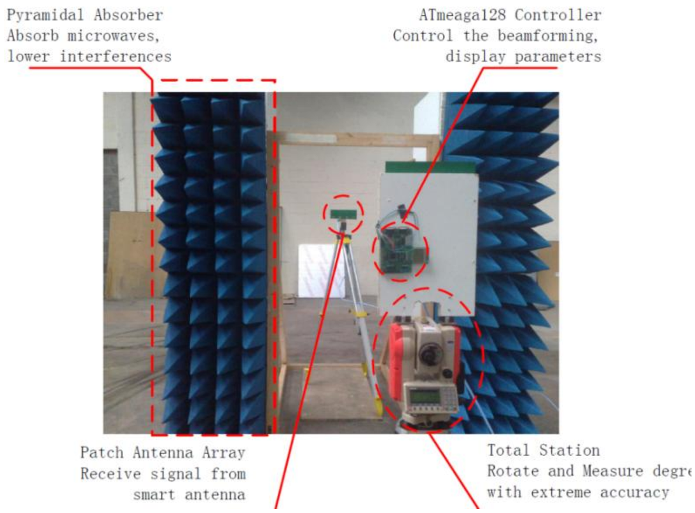
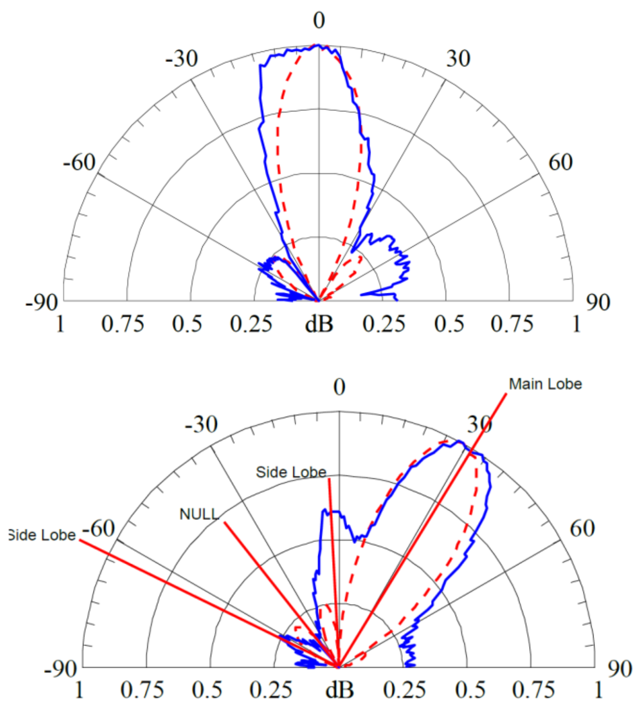


Fig. 3 Picture of antenna gain test set-up

IV. RESULTS

The experimental results demonstrated that the beam and the control of the beam are both similar to the results predicted by theoretical analysis, for a narrow cone of angles, with increasing side-lobe growth as the angles widen. However, it must be borne in mind that the phased array antennas are simple rectangular patch antennas on FR-4.



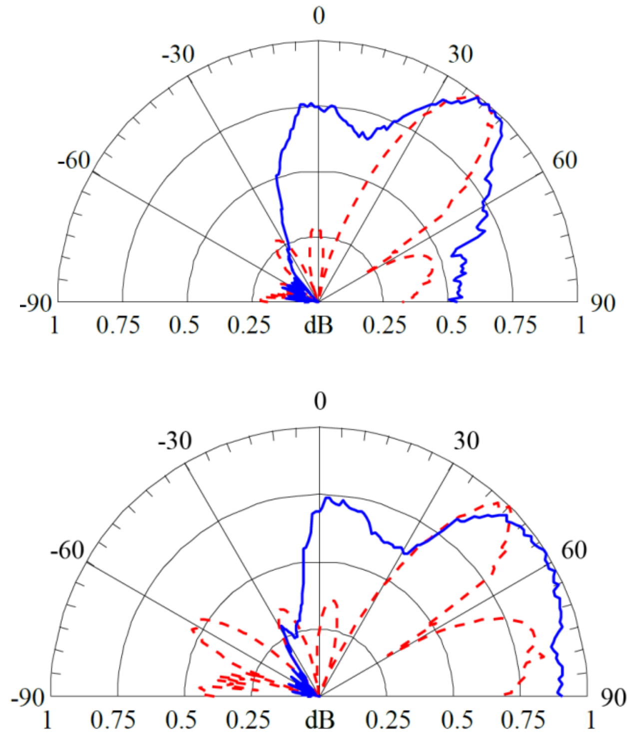


Fig. 4 Measured (blue, solid) and simulated (red, dashed) results

V. FUTURE WORK

With further research and improvements, the results achieved indicate that the technique is worth pursuing both in terms of cost, phase angle selection and improved continuity in phase angle transition. The processing unit, the ATmega128, could also be changed to a more powerful chip, such as an FPGA or DSP, to handle a more complex real-time digital beam forming algorithm, coding or MIMO technologies [4].

Different, more selective antennas, two-dimensional arrays would also be interesting.

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