Digital beam forming on transmit and receive with an AESA FMCW radar

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***Abstract*— This paper describes an active electronically scanned array (AESA) FMCW radar with eight transceivers. Each transceiver has its own Direct Digital Synthesizer (DDS) for signal generation which enables digital beam forming on transmit as well as on receive. The coherent operation of the eight transceivers and the capability to perform digital beam forming on transmit and receive is demonstrated.**

I. INTRODUCTION

FMCW radars are becoming increasingly popular due to their compact size and low power consumption. In surveillance and tracking applications, FMCW radars are often employed with mechanically scanning antennas. An FMCW radar with an active electronically scanned array (AESA) offers the potential to improve the scanning speed and to perform multiple functions, such as surveillance, tracking and non-cooperative target recognition, with the same antenna.

In [1] and [2], an FMCW active phased array radar is described with a dual linear array antenna. It uses transmit/receive modules with a homodyne receiver in each element and a low frequency combiner. The FMCW waveform is generated digitally with a direct digital synthesizer (DDS). Compared to traditional signal generation with a Voltage Controlled Oscillator (VCO), a DDS has several advantages. These advantages include an extremely fast frequency hopping speed, a microHertz tuning capability of the output frequency, and a sub-degree phase resolution [3]. The major drawback of a DDS is that the output signal contains spurious frequencies. These spurious frequencies can be minimized by good filtering and a smart choice of frequency bands. Moreover, a DDS has the extra advantages of its increased flexibility due to its ease of programming, its long term stability (due to its digital nature) and, with the advent of digital communications, its reduced price. Therefore, direct digital synthesis is expected to play an important role in future radar systems.

In this paper, a novel AESA FMCW radar is described that is not only capable of digital beam forming on receive but also on transmit. The AESA FMCW radar was built by TNO Defence, Security and Safety in The Hague, The Netherlands. The radar front-end contains eight FMCW transceivers each equipped with a DDS. This makes it possible to transmit space-time coded waveforms because each DDS can transmit a different waveform [4]. This paper, however, only addresses the use of a single waveform with digital control of the phase and amplitude of the waveform transmitted by each channel.

This paper is organised as follows. In section II, the hardware of the AESA FMCW radar front-end is described. Sections III and IV present measurements of the antenna pattern on transmit and receive, respectively. Section V describes some adaptive beam forming results and conclusions are drawn in section VI.

II. THE HARDWARE

Figure 1 shows a picture of the front-end of the AESA FMCW radar. The eight small boards visible in the picture are the transceiver. Each transceiver contains a complete transmit part based on a 400 MHz clocked DDS as well as a low-noise downconverter. On the motherboard, a “master” DDS is operating, programmed by a microcontroller which also controls each DDS of the transceivers. The DDS of every transceiver is phase-locked to the master DDS on the motherboard, making a fully coherent system possible. Since the DDS is not able to generate X-band frequencies directly, a linear single side band (SSB) upconverter is used to translate the DDS output. The upconverter uses a 10 GHz local oscillator (LO) signal from a miniature synthesizer located on the motherboard.

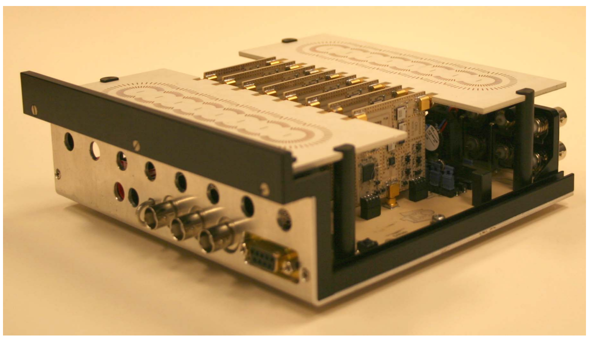

Figure 1: Picture of the AESA FMCW radar front-end.

The AESA FMCW radar is programmed through a serial computer interface enabling control over several radar parameters. The transmit frequency, FMCW bandwidth, sweep duration and the transmit phase and amplitude of every transceiver can be programmed.

The radar uses separate transmit and receive antennas to enable a high dynamic range FMCW radar system. The antenna used is an 8-element patch array with Electronic Band Gap (EBG) structures around the elements to suppress the surface waves in the substrate, giving an improved antenna performance even on a relatively small board [5].

The receive part of the transceivers uses the signal from the DDS to down convert the received and amplified X-band signal to baseband, and delivers a filtered and buffered in-phase and quadrature-phase signal output for every channel.

III. Measurements on Transmit

A. Introduction

In this section, measurements of the transmit antenna pattern of the AESA FMCW radar are compared with computer simulations. The goal of the measurements is to demonstrate that the transceivers transmit a coherent waveform and that nulls in the transmit antenna pattern can be formed.

B. Measurement Setup

The first measurements with AESA FMCW radar were performed in the near field facility of TNO. An overview of the test setup is shown in Figure 2. The centre of rotation is located at the phase centre of the antenna.

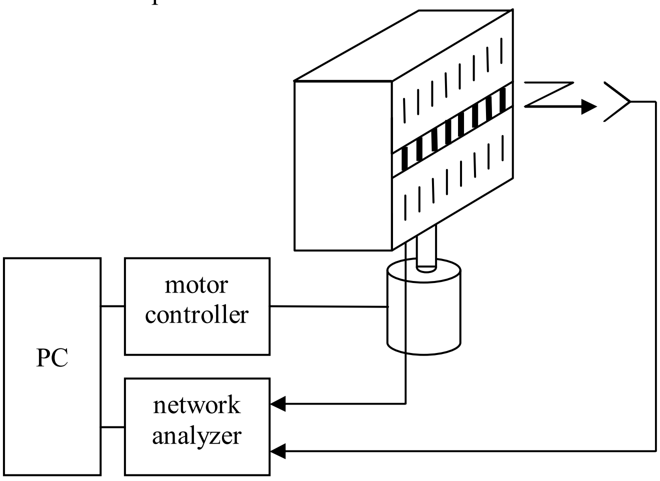

Figure 2: Measurement setup

The transmitted signal from one transceiver was tapped and compared to the received signal by a network analyzer (NWA). A PC was connected to both the NWA and the motor controller. The distance between the radar and the probe was 2.25 m, which is in the far-field of the antenna.

C. Measurement Results

Two measurement series were performed at two different constant DDS frequencies: 60 and 100 MHz. At each frequency the transmit antenna diagram was measured as a function of the angle. Figures 3 and 4 show a comparison of the simulated and measured antenna diagrams at a 60 MHz DDS frequency for main beam directions of 0° and 40°, respectively. In both cases a uniform amplitude taper was used. The measured antenna pattern in Figure 3 shows that the first sidelobe on the left-hand side of the mainlobe occurs at the expected level of -13 dB. The first sidelobe on the right-hand side is slightly above the -13 dB level.

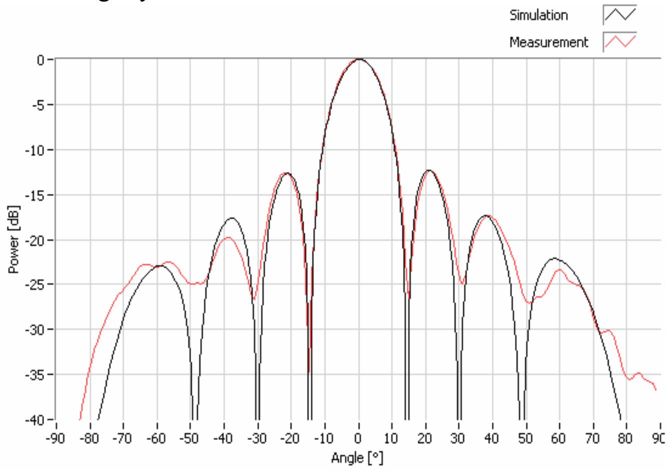

Figure 3: Antenna diagram comparison, simulation vs measurement with the main beam at 0°.

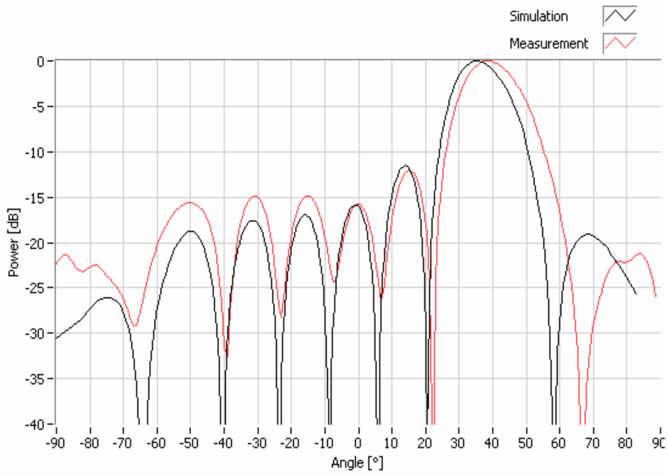

Figure 4: Antenna diagram comparison, simulation vs measurement with the main beam at 40°.

The measurements shown above were performed without calibration to correct phase and amplitude differences between the eight transmit antennas. This is probably the cause of the differences between the simulations and the measurements.

The results in Figures 3 and 4 show a sum beam pattern with a uniform amplitude taper and a linear phase progression over the array. By adding 180° phase shift to the elements in the left half of the array, a null is obtained in the main beam, i.e. a difference beam. Figure 5 shows the results of the simulations and measurements when the difference beam is pointed at 0°. The deep null at 0° in the measured antenna pattern demonstrate that the eight DDSs are operating in a coherent fashion.

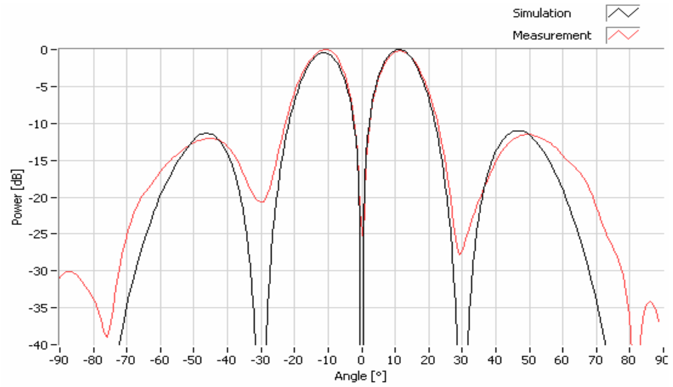

Figure 5: Antenna diagram comparison, simulation vs measurement with a null at 0°.

IV. Measurements on Receive

A. Introduction

This section describes the measurements that have been performed to test the antenna pattern of the AESA FMCW radar on receive. A dataset has been collected for off-line beam forming.

B. Measurement setup

These measurements were also performed in the near field facility of TNO. The measurement setup was similar to the measurements on transmit, except for:

- the network analyzer was not used;
- the motor controller was used to rotate the antenna in a 180° sector, generating a trigger each 2°;
- the analogue beat signal of each of the 8 receive antennas was connected to an 8 channel ADC measurement card.

At each trigger of the motor controller, data from all ADC channels was recorded.

C. Measurement Results

The complex element pattern at all measured angles was calculated off-line. The calculated values were calibrated using the following assumptions:

- during a rotation the phase at the rotation point does not change;
- at broadside the amplitudes of all elements are equal.

The phase offset around broadside without calibration is shown in Figure 6.

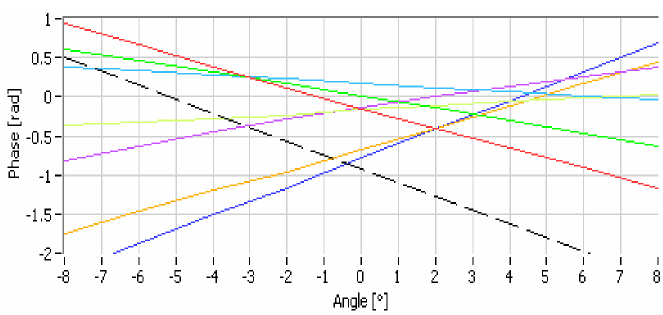

Figure 6: Uncalibrated phase of the 8 element patterns around broadside.

After the expected phase for the probe at a distance of 2.25 m was calculated, the difference with the measured phase was used to calibrate the array. In total 7 calibration scans were made. The phase differences for the 8 elements derived from the 7 calibration scans are shown in Figure 7.

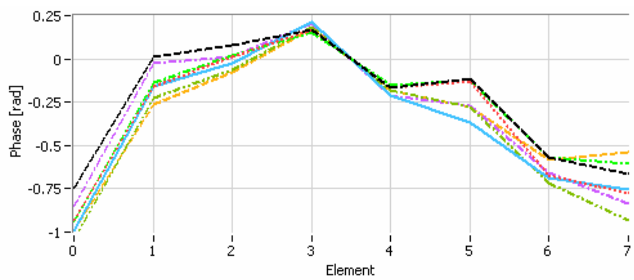

Figure 7: Phase differences at broadside derived from 7 calibration scans.

Figure 8 shows the calculated complex antenna patterns of the 8 elements after application of the calibration procedure.

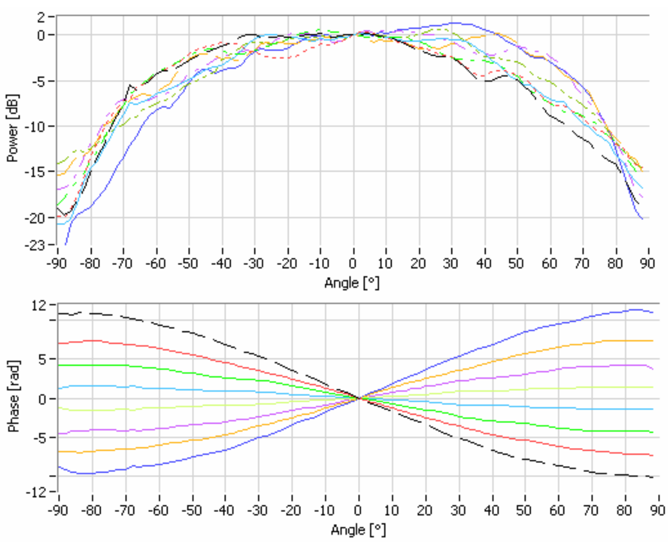

Figure 8: Complex element patterns after phase and amplitude calibration.

After application of the calibration procedure, a Fourier transform was applied to the measured output signals (80 MHz DDS frequency and 4 MHz beat frequency) of the 8 elements at each angle. The resulting antenna patterns are shown in Figure 9.

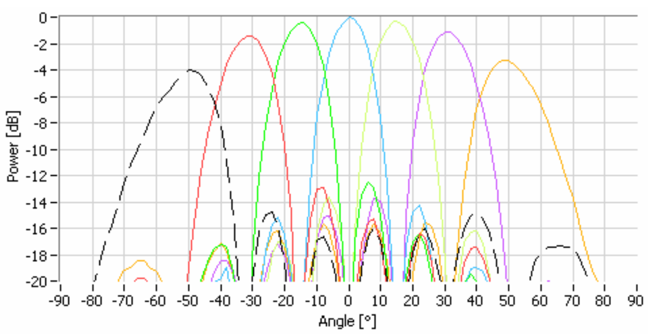

Figure 9: Antenna pattern for a 80 MHz DDS frequency and 4 MHz beat frequency.

To analyse the frequency sensitivity of the antenna pattern, measurements have been performed at three different DDS frequencies: 40, 80 and 120 MHz. Figure 10 shows the receive antenna patterns for these DDS frequencies with the main beam at 0° and a 4 MHz beat frequency.

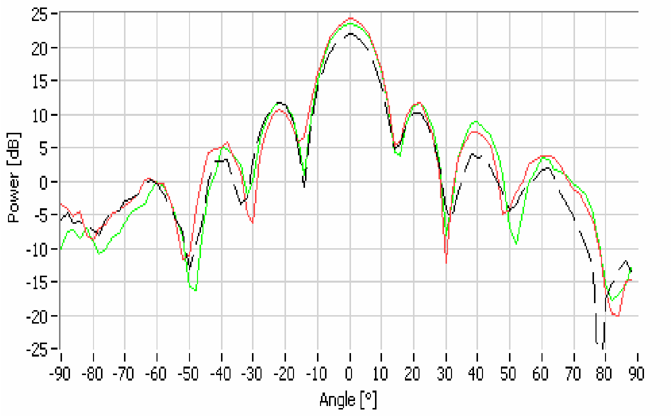

Figure 10: Zero azimuth antenna pattern at 40, 80 and 120 MHz DDS frequency and 4 MHz beat frequency.

Figure 10 shows that the gain of the main beam varies approximately 2.5 dB over the total bandwidth of the radar (40 to 120 MHz). The same variation is measured at a beat frequency of 1 MHz

V. Adaptive Beam Forming

Adaptive array processing can create antenna pattern nulls in the direction of jammers or strong reflectors [6]. Figure 11 shows a simulation result for a main beam pointed at 11.5° and two nulls at -30° and 36°. A cosine-shaped element pattern was assumed in the simulation.

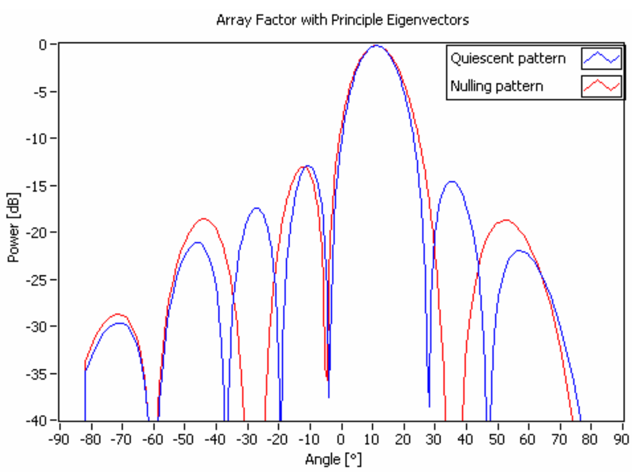

Figure 11: Simulated antenna patterns for the quiescent beam (no adaptive nulls) and with nulling at -30° and 36°. The main beam is pointed at 11.5°.

The amplitude and phase settings of the elements used in the simulation were applied to the AESA FMCW radar on transmit and receive and the corresponding antenna patterns were measured. The differences in the antenna patterns on transmit and receive shown in figure 12 are caused by the lack of calibration during the measurements on transmit. A comparison of the measured and simulated receive antenna patterns shows a good similarity except for the sidelobe behaviour below -20 dB. These differences are still under investigation but are most likely caused by reflections in the near field facility.

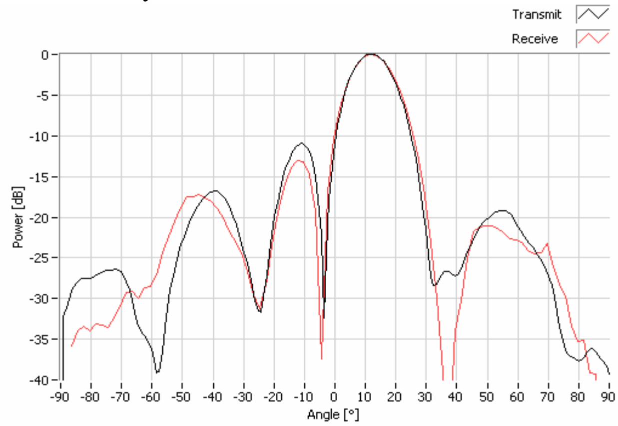

Figure 12: Measured antenna patterns on transmit and receive.

VI. Conclusions

In this paper an AESA radar has been described with eight FMCW transceivers, each equipped with a DDS. Measurements of the antenna pattern on transmit and receive show that coherent operation of the DDSs can be achieved and that deep nulls can be created in the antenna pattern.

Future work will involve simulations and radar measurements with jamming and adaptive processing both for the transmit and the receive array.

Acknowledgment

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