Wideband Digital Beamforming in the E-band

ICT Centre Conference 2010

Paper ID: 047

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Introduction

The use of adaptive antenna arrays for long-range millimeter-wave ad-hoc communication networks is particularly critical due to increased free space loss and reduced level of practically achievable output power. A hybrid array approach [1-3] where digital beam forming technique is applied to a smaller number of units (analogue beam formed sub-arrays) provides a significant saving in both the amount of digital signal processing and the number of physical connections between the RF front end and digital beam former. This allows mitigating extremely tight space constraints in the E-band (71-86 GHz). A small scale E-band phased antenna array has been developed for an experimental verification of the hybrid beam forming concepts. Analogue beam forming (ABF) of this array using 6-bit phase shifters and attenuators at IF has been reported earlier in [3]. In this paper, we report the test results of an E-band prototype that implements a digitally beam-formed (DBF) phased antenna array.

System Demonstrator and DBF Results

A small prototype developed for experimental verification of the adaptive beam forming is shown in Fig. 1.

- The main functional block of the prototype is a four-channel receive RF module (Fig. 1c) integrated with a linear end-fire Quasi-Yagi antenna array [4]. Array element spacing was 2 mm (or 0.48 wavelengths at the carrier frequency) to suppress appearance of grating lobes for scanning angles up to ± 42 degrees.
- For digital beam forming (DBF), each of the IF analogue signals was digitised by the Analogue-to-Digital (A/D) converters using two EV8AQ160 A/D devices used in dual channel mode at 2 Gsps sampling and two Xilinx V5SX95T FPGA's (Fig. 1b). The samples are captured on the FPGA internal memory and uploaded to a PC for processing.

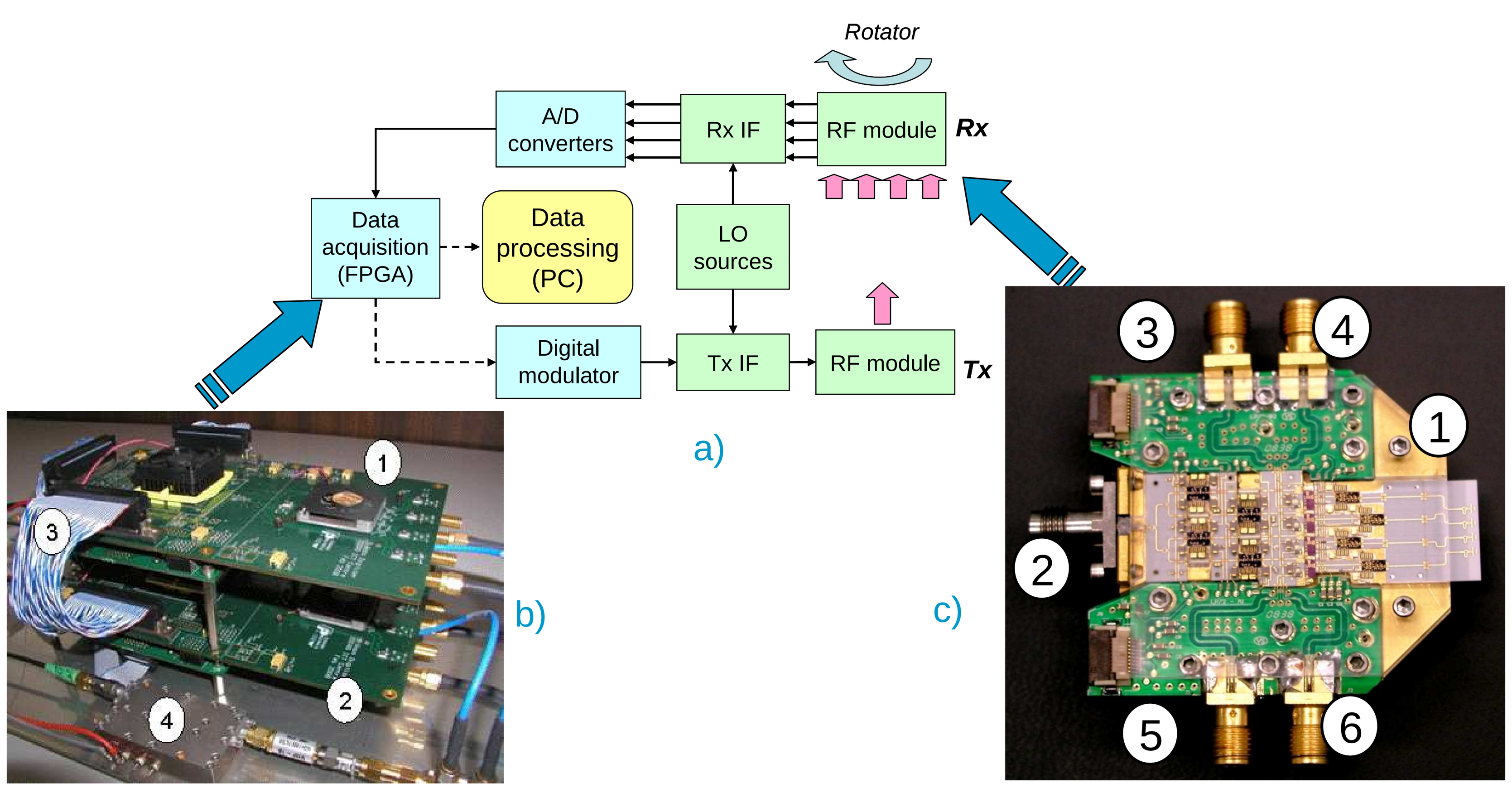

Figure 1: **a)** System block diagram; **b)** Photograph of the digitizer module assembly where 1 and 2 are two identical digitizers, 3 is interconnect cable and 4 is a sampling oscillator; **c)** Photograph of the RF module assembly where: 1 is the antenna array; 2 is the LO input; 3-6 are IF outputs.

- A wideband frequency-domain DBF algorithm [5] was used in the experiment. Its structure is shown in Fig. 2a.
- The transmitted digital signal was generated using OFDM modulation (128 subcarriers in 0.5 GHz bandwidth). To facilitate synchronization and channel estimation, a preamble composed of 5 predefined OFDM symbols is pre-pended before the pseudo-random QPSK data sequence. The analogue baseband signal was centred at 1.5 GHz using a second Nyquist response of a return-to-zero D/A.
- The signal sequence received at each element was synchronised using the preamble and converted into the frequency domain by FFT followed by calibration. After calibration, the frequency domain signals were weighted with coefficients for each of the incident angle at which a beam is to be formed.
- The weighted signals are finally summed up and converted into the time-domain by Inverse FFT (IFFT) to obtain the beam formed output signal.
- Experiments were conducted to verify validity of obtained phase and magnitude weights. Computed DBF array radiation patterns were very close to those measured for the ABF array as shown in Fig. 2.

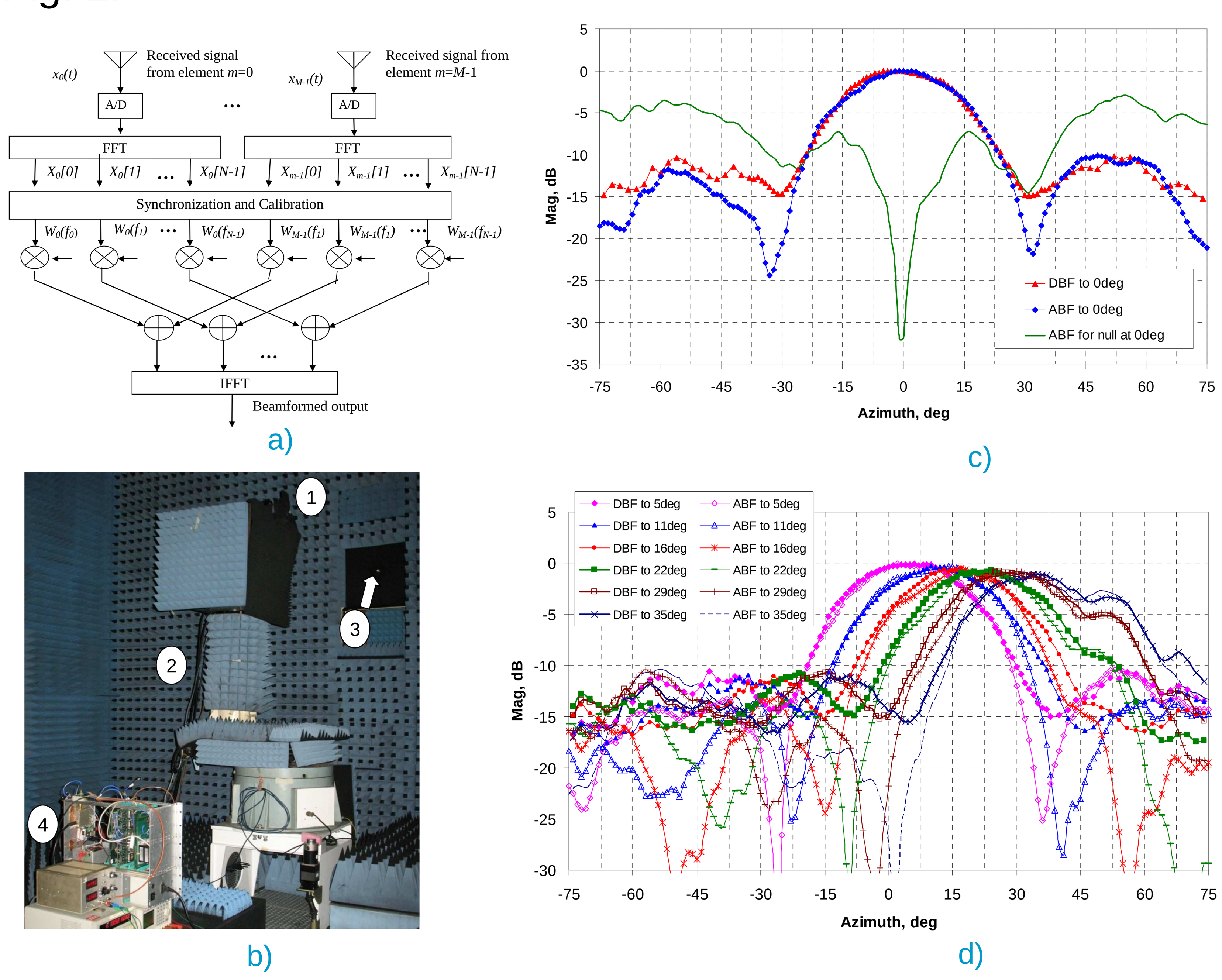

Figure 2: **a)** Structure of the DBF; **b)** System test setup in the 12m far field anechoic chamber where 1 is the receive array RF module, 2 is the rotator and 3 is the transmit antenna aperture, 4 are the modulator, IF module, digitiser & power supplies; **c)** Measured E-plane co-polar DBF and ABF array patterns at 0° azimuth; **d)** Measured E-plane co-polar DBF and ABF array radiation patterns for a selection of positive azimuth angles.

Conclusion

A steerable E-band receive array demonstrator has been tested using a wideband frequency-domain DBF algorithm. Obtained DBF array patterns were very close to those measured for ABF array. Beam steering accuracy of 1° has been achieve d for steering angles within ± 40°. Demonstrated wideband adaptive digital beam forming along with validated phase-only ABF at IF can be used for hybrid beam forming of larger arrays. To our knowledge, this work represents the first experimental results on the digitally beam formed antenna array in the E-band.

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Acknowledgements

The authors wish to thank Andrew Weily and Nasiha Nikolic for the antenna array elements design, Alex Grancea for the IF circuits design, Jayasri Joseph for the data capture VHDL, Mei Shen for integration of the receive array prototype, John Bunton and Y. Jay Guo for valuable discussions of adaptive beam forming algorithms.

Further information

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