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MULTI-BEAM ADAPTIVE BEAMFORMING USING A C-BAND RECEIVER ARRAY AND A FREQUENCY-DOMAIN DIGITAL BEAMFORMER

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This paper introduces a novel architecture of a multi-beam adaptive beamformer for SDMA (space division multiple access) applications. Combined with a 5.8 GHz eight-element RF front-end, digital beamforming performance using the proposed frequency-domain multi-beam beamformer is demonstrated in post processing. The DOA estimation based on the ESPRIT algorithm and simultaneous dual-beam forming results validate highly efficient multi-beam forming with high-quality interference suppressions.

1. Introduction

Digital beamforming can provide a high flexibility using advanced adaptive algorithms and accurate main-beam and null steering by mathematically operating the beamforming networks [1]. However, for multi-beam synthesis, separate beamforming networks are commonly required [2]. Frequency division multiple access (FDMA) is often used for efficient multi-channel wireless communications. We utilize this efficient multiplexing concept for the weighting vector application in the beamforming network. The new architecture allows only one beamforming network for multi-beam synthesis and can reduce the number of computations for vector weighting multiplication. Multiple weighting coefficients are modulated onto different carriers in quadrature amplitude modulation (QAM) format. Since each tone includes amplitude and phase information of each weighting coefficient, multiple weighting coefficients can be simultaneously applied in a single vector multiplication process. This reduces the number of operation units in multi-beam scenarios. After the vector multiplication and summation, efficient adaptive filtering techniques can be used for a bandpass filtering function to select an intended channel, when the proposed beamforming network is combined with the traditional FDMA system. Thus, multi-beam forming in the proposed scheme can provide highly flexible and efficient multi-channel systems. Moreover, the FDMA in the beamformer level can increase the frequency reuse for multi-beam applications since a single RF frequency can be shared in a spatial domain. In this paper, we propose a multi-beam adaptive array architecture using frequency domain digital beamforming for SDMA applications.

2. RF front-end and multi-beam frequency-domain digital beamformer

Fig. 1 shows a 5.8 GHz RF front-end, consisting of an 8-element quasi-Yagi array [3], a standard RF-IF down-converter, and an IF amplifier stage. The down-converter is made of RF low noise amplifiers (LNAs) with 34.5 dB gain, and passive RF mixers. After the down-conversion, the IF signals are further amplified at the variable gain amplifiers (VGAs) with up to 25 dB gain. These IF amplifiers are also used to calibrate gain errors among eight elements. The lowpass filters (LPFs) limits the IF bandwidth at 30 MHz. The IF signals are sampled by an eight-channel digital oscilloscope with a 200 MHz sample rate.

Fig. 2 shows the block diagram of the IF digital beamformer with simultaneous dual-beam forming capability. The digital beamformer consists of a beamforming network and a weighting computation block. In a weighting computation block, the circuit phase errors of the RF front-end are first calibrated using the calibration factors by receiving RF signals from broadside direction and detecting each phase from the Fourier transform. Based on the calibrated IF signals, the DOA estimation is carried out by the ESPRIT algorithm [4] and the Sample Matrix Inversion (SMI) algorithm [5] subsequently calculates the weighting coefficients to form two independent beams.

The weighting coefficients are modulated as two-tone weightings onto 100 and 300 MHz carriers by a quadrature amplitude modulator (QAM) block. Each tone includes amplitude and phase information of a weighting coefficient at each channel. Thus the applications of multiple weighting coefficients are simultaneously conducted using a single multiplication process at each element in the frequency domain. This efficient multiple weighting process is in a way similar to the frequency division multiplexing used in wireless communication. Thus, the number of vector multiplication process can be reduced from (M×N) to (M+N), for M-beam synthesis in a case of an N-element linear array. After the weighting vector multiplication, each bandpass filter (BPF) selects a desired channel. The IF signals in the respective channels are recovered through demodulation by multiplying the corresponding carriers and filtering out unwanted harmonics. These functions are carried out by MATLAB code used for offline digital beamforming.

3. DOA estimation and multi-beam beamforming results

Fig. 3 shows the direction-of-arrival (DOA) estimation error in terms of the incident angle. A single unmodulated transmitter source located in a far field is used for this experiment. The experiment is carried out in the open space of a laboratory room. The down-converted IF signals at the RF front-end are sampled by an eight-channel digital oscilloscope and are transferred to the personal computer through the GP-IB interface. The DOA estimation is carried out by the ESPRIT algorithm. The DOA estimation error is less than three degrees from –50 to 50 degree incident angle. The scan range is limited by the directive pattern of the antenna element. Thus, four systems can cover the whole azimuth range.

Fig. 4 shows the off-line two-beam beamforming results from the frequency-domain digital beamformer outputs. Two RF source signals, placed at different locations in a far field, are transmitted at the same power. The position of a source 1 is moved from 0 degree to +10 degree, while a source 2 is fixed at –20 degree. The sampled IF signals are sampled at the digital oscilloscope and the offline two-beam beamforming using the proposed frequency-domain digital beamformer is carried out. In Fig. 4 (a), the signal bearings detected by the ESPRIT algorithm are –1.2 degree for channel 1 and –19.0 degree for channel 2, respectively. In Fig. 4 (b), the corresponding bearings are –9.4 degree for channel 1 and –18.7 degree, respectively. For both cases, the interference suppression of more than 20 dB is accomplished using the proposed digital beamformer.

4. Conclusion

A multi-beam adaptive array architecture using the frequency domain digital beamformer is proposed. The offline demonstration of DOA finding and dual-beam forming is carried out using a 5.8 GHz RF front-end. This architecture can be used for the cost-effective multi-beam SDMA applications.

Acknowledgements

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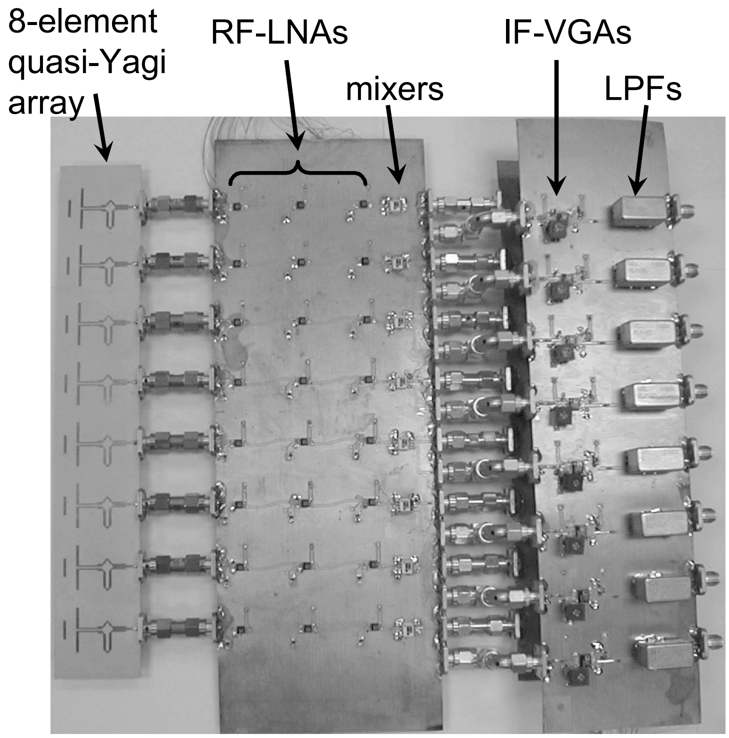


Fig. 1. RF front-end.

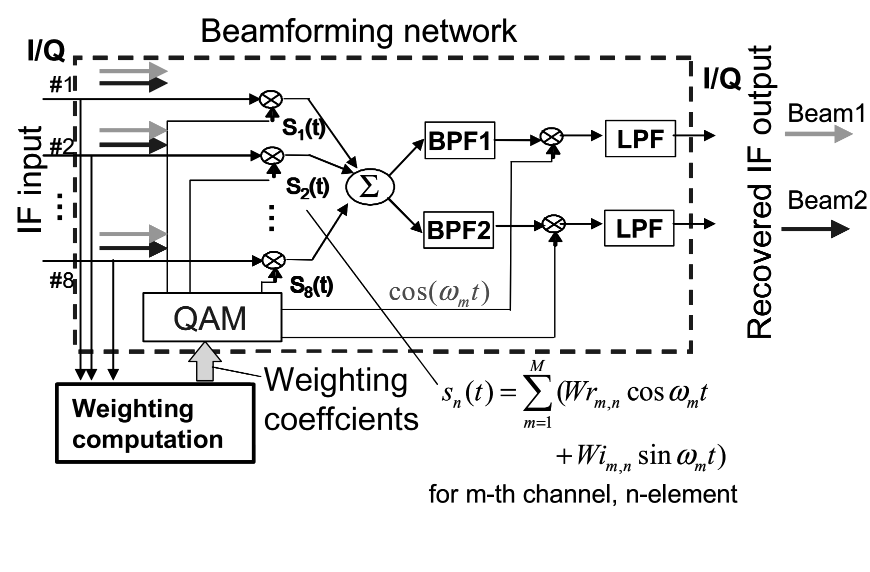


Fig. 2. Proposed frequency-domain multi-beam beamformer block diagram for two-beam formation.

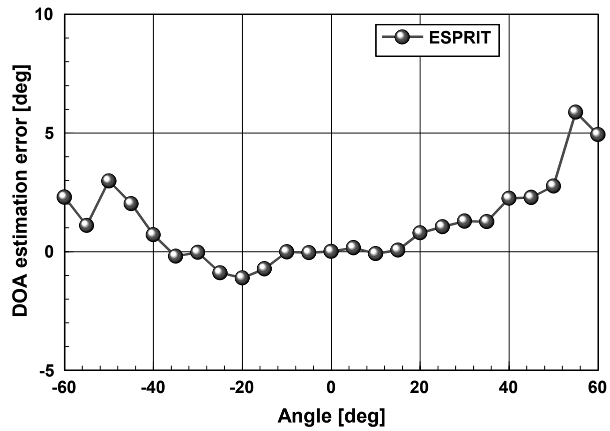
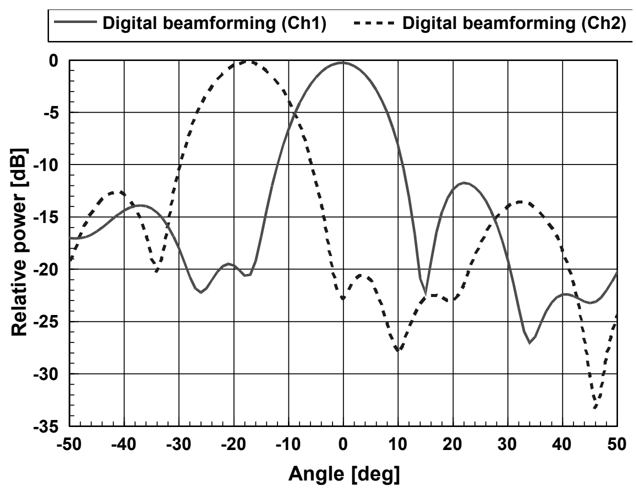
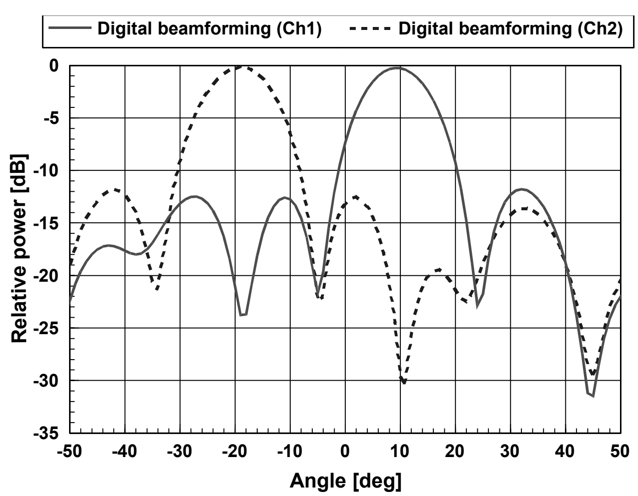


Fig. 3. The DOA estimation error under a single RF signal detection.



(a) Source locations; Tx1: 0 deg, Tx2: -20 deg.



(b) Source locations; Tx1: +10 deg, Tx2: -20 deg.

Fig. 4. Two-beam digital beamforming results for SDMA demonstration.