IMPLEMENTATION OF A DIGITAL BEAMFORMING ANTENNA FOR MOBILE SATELLITE COMMUNICATIONS UTILIZING MULTI-DIGITAL SIGNAL PROCESSORS

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1. INTRODUCTION

Over the past decade, digital beamforming(DBF) techniques have been utilized and developed mainly in the field of radar systems[1]-[2]. Recently, the DBF antenna has attracted a lot of attention for mobile antenna application in satellite communications[3]. DBF, together with modulation and/or demodulation, is becoming a key technique in developing a mobile antenna with advanced functions such as antenna pattern calibration, correction, and radio interference suppression. Moreover, efficient and realtime DBF is essential for beam control of both transmitting and receiving array antennas, as beam scanning for satellite tracking is required in high-quality communications.

In this paper, efficient DBF techniques for transmitting and receiving are presented, and a realtime DBF operation based on these techniques is tested experimentally utilizing multi-digital signal processors(DSPs) as core processors. Beam scanning characteristics of a planar array antenna utilizing DSPs are also tested experimentally.

2. SIGNAL PROCESSING TECHNIQUE FOR TRANSMITTING

The basic block diagram of a digital beamformer for transmitting is shown in Fig. 1, where digital PSK modulation is assumed. The shaded sections ⓐ, ⓑ, and ⓒ in Fig. 1 indicate the position proposed for the phase-shifter. In this configuration, phase-shift operation can be achieved using the following three typical methods;

Method Ⅰ: conduct a phase-shift operation right after the baseband signal generation, which corresponds to placing the phase-shifter at sectionⓐ,
Method Ⅱ: conduct a phase-shift operation right after the low-pass filtering, which corresponds to placing the phase-shifter at sectionⓑ,
Method Ⅲ: conduct a phase-shift operation of the quadrature LO signals, which corresponds to placing the phase-shifter at sectionⓒ,

where an antenna beam is assumed to be fixed to a known direction, the phase data for beamforming is known for each phase-shifter, and the LO signal is generated through referring to the data in the processor memory table.

In method Ⅰ, an operation number proportional to the symbol rate f_b is required, whereas an operation number proportional to sample rate f_s is required in methods Ⅱ and Ⅲ. Since the symbol and sample rates are related by $4 \times f_b \leqq f_s$, a lower operation number is required in method Ⅰ. In method Ⅲ, phase-shift operation can be achieved by direct reference to the phase-shifted LO signal data in the table, where the table data is calculated according to the desired phase-shift accuracy. However, this method is less efficient in memory usage as a large amount of memory is generally required for the table.

The configuration of the transmitting DBF antenna implemented using multi-DSPs is shown in Fig. 2. The core DSP employed in the DSP board is the AT&T DSP32C[4]. In this configuration, the Tx data are transmitted from the Tx Proc unit to the DBF/Mod unit through P-I/O within one symbol time. In each DBF/Mod unit, after receiving Tx data and transmitting it to the next DBF/Mod, signal processing for the two channels is conducted using the program based on the method Ⅰ. These successive operations are conducted in all DBF /Mod units using pipelined processing.

3. SIGNAL PROCESSING TECHNIQUE FOR RECEIVING

The block diagram of a digital beamformer for receiving is shown in Fig. 3, where digital PSK demodulation is assumed. Since precise carrier and data-clock references have to be established in demodulation, reference signal recovery at a high carrier-to-noise ratio is required. In this configuration, baseband I and Q signals are generated from incoming signals using quasi-coherent demodulation with the fixed LO signals. The carrier and data-clock are estimated and recovered after adjusting the amplitude and phase of the baseband signals and summing up I- and Q- signals, respectively[3]. This technique can provide flexible beamforming, as no feedback loops are included between beamforming and demodulation processing. This indicates that the processor configuration can be simplified.

The configuration of the receiving DBF antenna implemented using multi-DSPs is shown in Fig. 4. In DBF units, the IF signal converted from the incoming RF signal is sampled synchronously with the timing clock, and then processed for beamforming as shown in Fig. 3. The I- and Q- signals generated are summed up respectively using pipelined processing. In demodulation, the baseband signals with carrier frequency offset are corrected utilizing the FFT technique in Demod#1 and 2, and then data clock estimation and data decision are conducted in Demod#3[5].

4. BEAMFORMING EXPERIMENT

The modulation waveforms after beamforming for transmitting, which were obtained at the analog LPF output ports, are shown in Fig. 5. In this experiment, a planar array rectangularly arranged with half-wavelength element spacing is assumed, and its beam is assumed to be directed to $\theta=30°$ and $\phi=0°$. As shown in Fig. 5, D/A outputs are acquired synchronously with timing clock, and the desired waveforms with a phase-difference of $\pi/2$ radians are obtained.

The measured beam scanning characteristics of the 8-element planar array utilizing the multi-DSPs for both transmitting and receiving are shown in Fig. 6. Theoretical patterns are also plotted for comparison. In the experiment, the antenna array whose elements were arranged rectangularly in 2×4 with half-wavelength spacing and excited for right-hand circular polarization was used, and continuous waves without modulation signals at 1.54GHz were transmitted or received as RF signals. Calibration of the whole system except for antenna array was conducted in the digital section. As shown in Fig. 6, beam scanning characteristics close to theoretical ones are obtained for both the transmitting and receiving array, and precise beam control is achieved utilizing the DSPs.

5. CONCLUSIONS

In this paper, highly efficient DBF techniques for transmitting and receiving array antenna in communication use have been presented and tested experimentally. For transmitting DBF, it has been shown that the technique that conducts phase-shift operation right after baseband signal generation is most effective in processing efficiency. The realtime DBF operation at a baseband of 16kbps symbol rate has been successfully demonstrated utilizing multi-DSPs for both transmitting and receiving. The precise beam control of a planar array has been also demonstrated at 1.54GHz. This result shows the feasibility of actual DBF antennas for mobile satellite communications.

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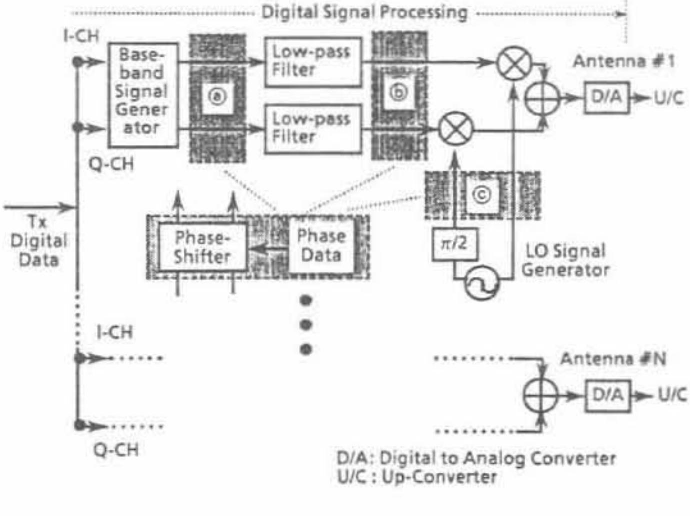


Fig. 1 Basic block diagram of a transmitting DBF processor.

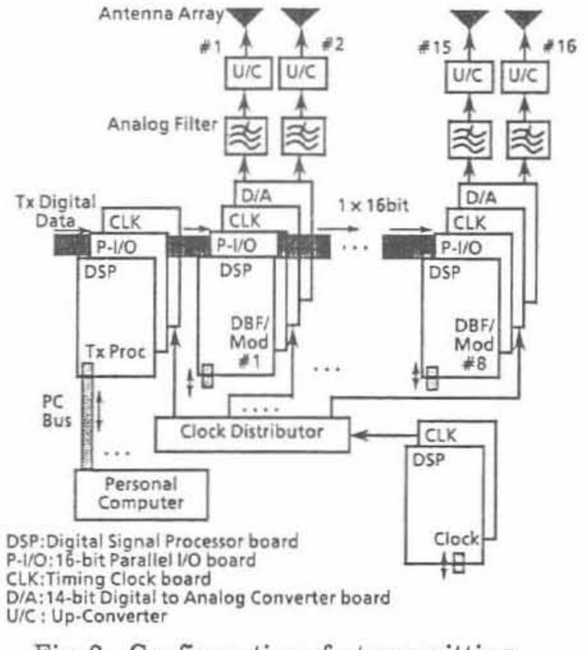


Fig. 2 Configuration of a transmitting DBF antenna.

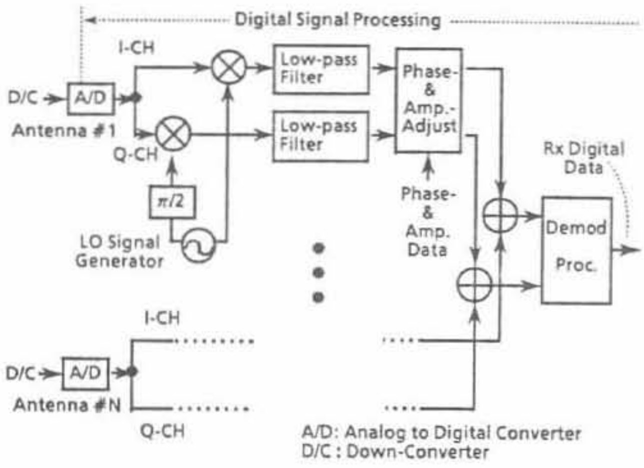


Fig. 3 Block diagram of a receiving DBF processor.

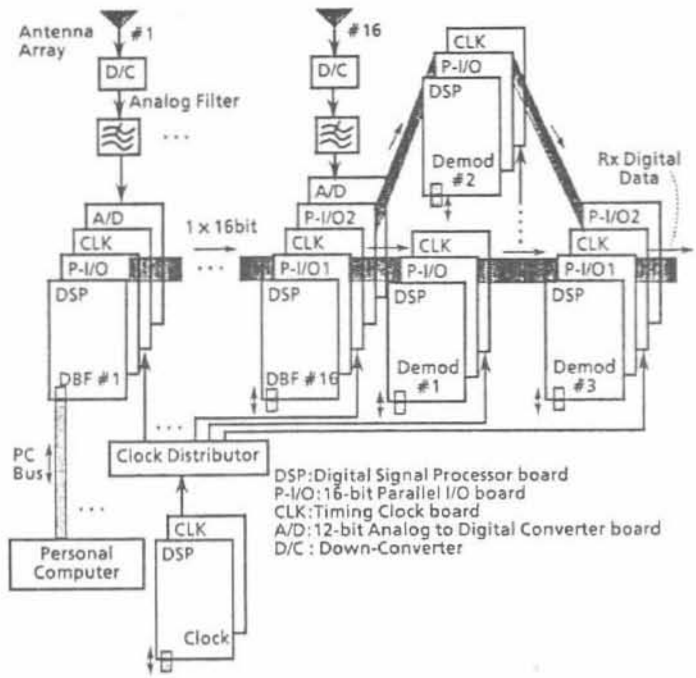


Fig. 4 Configuration of a receiving DBF antenna.

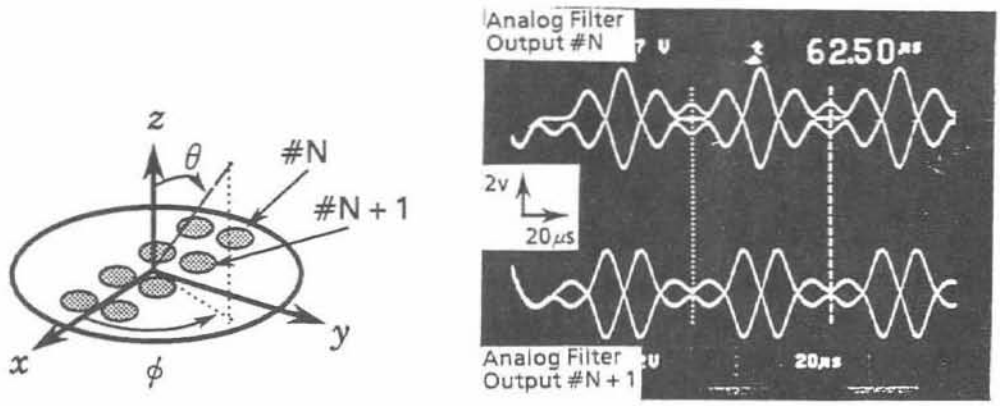
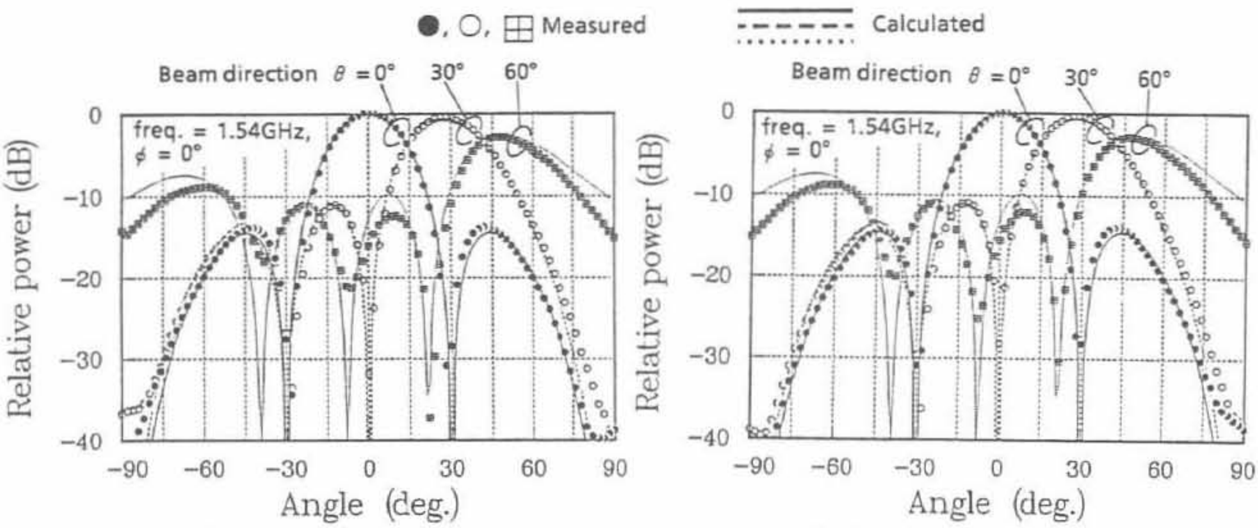


Fig. 5 Modulation waveform after beamforming.
(Modulation : BPSK, Bit rate : 16kbps, Tx data : PN sequence
Timing clock freq. : 128kHz LO signal freq. : 32kHz)



(a) Transmitting array (b) Receiving array

Fig. 6 Beam scanning characteristics of a 8-element planar array.