A 2x2 12 GS/s Sampled Beam-Forming Receiver

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***Abstract*—This paper presents a 12 GS/s sampling-based beam-forming receiver architecture for a 2x2 antenna-array. Utilizing sample-based RF-channel summation approach eliminates all wave-length dependencies by summing up all phase-aligned input signal samples. Isolating front-end- and back-end-buffers are realized as push-pull pairs simultaneously increasing bandwidth and linearity. Bootstrapped and body-driven track-and-hold-slices sample delay-correct the input waveforms. After summation of all inputs, a total beam-forming gain of 8.9 dB is achieved. The linear front-end SFDR and SNDR is >69 dBc and >56 dB respectively. Only a total of 30 mW per antenna is drawn from a triple -0.4/0.9/1.7 V supply.**

I. Introduction

Future wireless communication requires data-rates in the double-digit GBit/s domain to handle future applications. Therefore, key design goals are to increase both the bandwidth and the spectral efficiency, which can be done with a phased-array ideally increasing the SNR by 3 dB with each doubling of the antenna count. Thus, phase-shifters or true-time delays are required to steer the beam to different locations. Moving the sampler from the ADC towards the antenna and directly sample the RF signal with a certain delay introduces a true time delay. The summation of the inputs can be done in the charge domain to save power and area.

II. Circuit Design and Simulation Results

Figure 1a depicts the proposed 12 GS/s beam-forming 2x2 sampler utilizing sample-based beam-forming with a charge-based summation [1]. The RF-front-end (FE) is not part of this work and includes the $\lambda/2$ arranged 2x2 antenna array designed for a 4 GHz carrier frequency and the LNA/VGA. An ideal voltage array gain of 12 dB can be achieved if the steering angle and incoming angle are well matched. The time delay between the antenna 1 1 and the other antennas inside the array depends on the angles of the incident wave and the spacing and can be calculated by:

$$\Delta T_{\mathrm{mn}}(\Theta, \phi) = \frac{(m-1)\lambda \sin(\Theta)\cos(\phi)}{2v_0} + \frac{(n-1)\lambda \sin(\Theta)\sin(\phi)}{2v_0}, \quad (1)$$

where m and n are the indices of the antennas. The input signals $\mathrm{RF}_{\mathrm{IN},1-4}$ are sampled with respect to the delay. Thus, sample-based beam-forming can be done by increasing or decreasing the hold time of the sample, depending on the incoming angles Θ and ϕ, resulting in a true time-delay. It can be seen by eq. 1 that a maximum time delay of $\sqrt{2}\lambda/(2v_0) \approx 177$ ps for the worst case $\Theta = 90°$ and $\phi = 45°$ is required. The sampling network is four times time-interleaved (TI) to relax the timing providing the required 177 ps delay. $\overline{\Phi_{15}}$ introduces the summing phase where all held signals are added in the

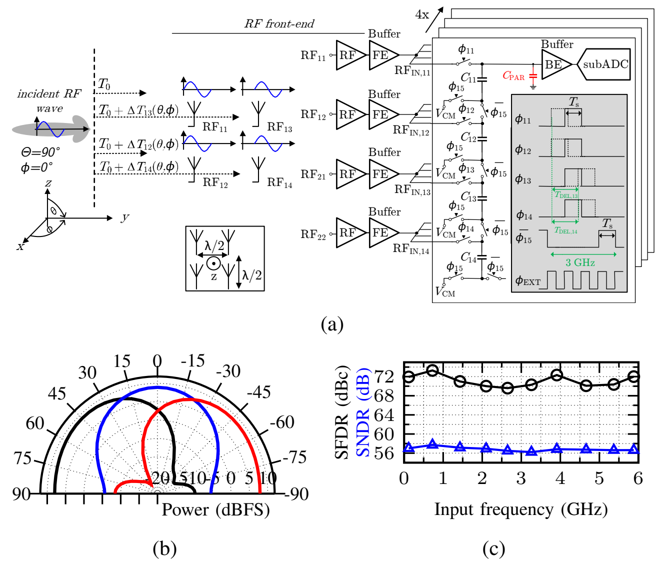

Fig. 1. (a) Proposed beam-forming receiver, (b) receiver gain as a function of the steering angle Θ_0 and $\Phi_0 = 45°$, and (c) SFDR and SNDR across f_{IN}.

charge domain by adding the capacitors in series. The BE-buffer drives the sub-ADCs, modeled as a 300 fF capacitor. The pseudo-differential push-pull source-follower FE-buffer drives four TI track-and-hold (TaH) slices while only one TaH slice is active at a time due to serialized operation. The FE-buffer is designed to have a 5 Ω output impedance to provide a high bandwidth and suppress kickback effects. The TaH slices sample at Φ_{11-14} and Φ_{15} the output of the FE-buffer. All sample switches are bootstrapped with a tracking time of only 70 ps to have enough margin for the delay for a correct summing. The summing phase is introduced by $\overline{\Phi_{15}}$, which is non-overlapping to Φ_{15}. Transmission gates connect all TaH slices from one TI lane for the charge-based summation. The added and held input is handed over to the BE-buffer. In order to have a high summing gain, the parasitic capacitance at the input of the BE-buffer has to be as small as possible to minimize charge sharing effects. Furthermore, the swing is of importance since it is ideally four times the input swing due to the summing. Thus, a downscaled version of the FE-buffer with cascodes is used allowing a higher swing. As a result, Fig. 1b depicts the summing gain at the output of the BE-buffer as a function of the steering angle Θ_0 and the angle of the incoming wave Θ. A total summing gain in the steering direction of 8.9 dB is achieved. An input frequency sweep with $\Phi_0 = 45°$, and $\Theta_0 = 0°$ is shown in Fig. 1c resulting in an SFDR above 69 dBc and an SNDR beyond 56 dB up to 6 GHz.

Reference:

[1] E. Wittenhagen, et al., "A TI 12 GS/s Sampled Beam-Forming Receiver for a 2 × 2 Antenna-Array with 69 dBc SFDR", 2022 ICECS