# Towards Multiplierless Digital Architectures for Aperture Arrays with 1024 RF Beams: A 32-Beam Building Block at 5.8 GHz

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Aperture arrays with a large number of simultaneous, sharp, and broadband radio-frequency (RF) beams are becoming important in multiple areas, including wireless communications, radar, and imaging. Fully-digital multi-beam beamformers are expensive in terms of both computational (circuit) complexity and power consumption because of the need for a dedicated RF front-end and data converter for each antenna element in the aperture. The digital signal processing (DSP) required for forming multiple RF beams in real-time further increases the computational complexity and power consumption. The two-dimensional (2D) discrete Fourier transform (DFT) is commonly used to generate orthogonal far-field beams from 2D antenna arrays. For example, the matrix of measurements from an $N$-by-$N$ square antenna array aperture can be Fourier transformed to generate $N^2$ orthogonal beams. Fast Fourier transforms (FFTs) allow the DFT to be computed in an efficient way, i.e., using only $O(N \log N)$ multiplicative operations. Nevertheless, for large $N$, parallelized FFT cores still account for most of the chip area and power consumption of a fully-digital multi-beam beamformer. In this talk, we use approximate computing to further reduce these area and power requirements. We propose DFT-like transforms that have a *multiplicative complexity of zero* at a cost of only ~2 dB penalty in the worst-case side-lobe level. By trading side-lobe performance for lower area and power, such approximate DFTs allow considerable savings in the overall size, weight, and power consumption (SWaP) of massively multi-beam digital beamformers. We have validated the proposed approach on a fully-functional 32-element receiver array that operates at 5.8 GHz. The design uses 32 parallel ADCs for sampling the antenna outputs and a multiplierless low-complexity DFT approximation (implemented on a Xilinx FPGA on a ROACH-2 platform) for computing 32 RF beams in real-time. The measured RF beams show a per-beam bandwidth of >120 MHz when all 32 beams are realized in real time, with only marginal (<2 dB) degradation in beam performance compared to a control experiment based on a Cooley-Tukey FFT core. The proposed 32-beam implementation is designed as a sub-system for a 1024-beam aperture array that completely eliminates digital multiplications by using parallelized 32-point approximate DFTs.