Improving the Performance of Array Receivers by Exploiting the Basic Physics of Spacetime

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Aperture arrays assume a dedicated receiver per element in order to exploit the maximum degrees of freedom in a fully-digital beamformer. Each frequency down-converted (i.e. base-band) analog signal is subsequently digitized using a dedicated ADC resulting in a digital version of the incident array signal. Digitization in both space- and time-domains requires satisfaction of the Nyquist sampling theorem, which in turn, requires i) equally-spaced antenna elements to be placed at intervals not exceeding half-wavelength of the highest frequency of interest, and ii) the sampling clock to be at least twice the bandwidth of the down-converted signal. Such straightforward application of the Nyquist sampling theorem to both spatial and temporal dimensions leads to a sampled signal that aliases on a periodic square grid, where each copy of the spectrum is uniquely located within the Nyquist Square. However, this sampling scheme does not take into account the physics of propagation pertaining to far-field plane-waves, which have spectral energies confined to conic regions, which are essentially spatio-temporal representations of the Light Cone (Special Theory of Relativity). In fact, the Light Cone ensures that 50% of the Nyquist Square is empty for linear arrays, and more than 50% is empty for square/rectangular arrays. The spatio-temporal frequency-domain is highly-sparse due to the physics of wave propagation. We explore the concept of spatio-temporal spectral sparsity in detail, while considering the basic physics of wave-propagation, and propose theoretical approaches to receiver design that embrace such sparsity in creative ways. The proposed approaches allow both LNAs and ADCs to be designed to have new multi-port behaviors while taking sparsity into account. Specifically, new multi-port algorithms based on the theory of delta-sigma data converters are applied to both LNAs and ADCs to improve performance metrics such as noise figure and distortion (for LNAs) and effective number of bits (ENOB) (for ADCs) for the particular situation where they are used for arrays. The exploitation of spatio-temporal sparsity based on the Special Theory of Relativity is shown to allow the shaping of noise from array receiver electronics to regions where no propagating waves exist in nature (so-called "Elsewhere") thereby potentially allowing better linearity, lower noise, and higher ENOB for array processing applications. Simulation results for a multi-port LNA and a multi-port ADC for use in aperture arrays will be provided, together with a discussion of the relevant trade-offs that must be made to exploit the said space-time frequency domain sparsity properties arising from physics.

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