Selective-Sampling Receivers for Mitigating a Single Dominant Interferer

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1. Introduction

In this paper, we describe a novel narrowband 2-sensor antenna array processor that offers a low-complexity implementation, responds rapidly to changes in the signal environment, and offers performance similar to optimal beam-space processors for the case of a single interferer.

Many adaptive antenna algorithms require calculation of the sampled array correlation matrix, **R**. A bank of correlators is required to compute **R** from the complex signals received at each element. The optimal weights are then given by

$$\hat{\mathbf{w}} = \mathbf{R}^{-1}\mathbf{S_0} \qquad (1)$$

where $\mathbf{S_0}$ represents the steering vector in the direction of the desired source [1], typically near boresight. If the correlation matrix or an estimate thereof is not available, weights can be adjusted adaptively using information derived from the array signals and outputs. The selective-sampling receiver requires neither the computation of **R** nor adaptive weight optimization to achieve near-optimal interference suppression for a single interferer.

In the following section, we will show how the topology of the selective-sampling receiver relates to a generalized sidelobe canceller (GSC) and explain how the selective-sampling operation removes the need for adaptive weight adjustment when a single dominant interferer is present. In Section 3, we present simulation results that benchmark the output signal-to-interference-plus-noise ratio (SINR) for a selective-sampling receiver versus an optimal beam-space processor.

2. Selective-Sampling Receiver

The generalized sidelobe canceller is a beam-space processor that uses presteering delays to track a desired signal source [1][2]. For the classical 2-sensor GSC shown in Fig. 1, the weights $\mathbf{v} = [v_1 \quad v_2]^T = [1/2 \quad 1/2]^T$ form the main beam, the blocking matrix **B** is given as $\mathbf{B} = [1/2 \quad -1/2]^T$, and the weight w_1 is typically found adaptively. If the array correlation matrix **R** is known, the optimal value of w_1 can be computed as

$$w_{1,opt} = \left(\mathbf{B}^H\mathbf{R}\mathbf{B}\right)^{-1}\mathbf{B}^H\mathbf{R}\mathbf{v}. \qquad (2)$$

The final operation of the GSC involves subtracting off the estimate of the interferer component in the main beam.

The selective-sampling receiver incorporates the same presteering capability and quiescent pattern beamformer as the GSC. The function of the blocking matrix from the GSC is also replicated in the selective-sampling receiver; this can be implemented along with the quiescent pattern beamformer using a Σ-Δ beamforming network (a 180° hybrid). To maximize the output SINR, the GSC must apply the correct magnitude and phase weights to the auxiliary beam prior to subtracting it from the main beam. This is where the selective-sampling receiver diverges from the GSC: instead of subtracting an

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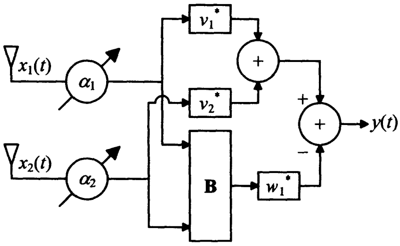

Fig. 1. Two-element generalized sidelobe canceller.

estimate of the interference, the selective-sampling receiver attempts to sample the main beam signal when the interference component within it passes through a zero crossing [3]. This requires knowledge of the correct phase of $w_{1,opt}$, but allows its magnitude to remain unknown.

Consider a two-sensor array consisting of an isotropic element at the origin and another on the x axis at $x = \lambda_o/2$, where λ_o is the free-space wavelength at bandcenter for the narrowband signal of interest. The angle of incidence is measured from the x axis. After presteering, the desired signal is effectively at boresight ($\theta = 90°$) and the interferer impinges from some unknown angle θ_i. For the noiseless case, the geometry dictates that the GSC needs to select the weight w_1 such that

$$w_1^* = \frac{1 + e^{j\pi \cdot \cos\theta_i}}{1 - e^{j\pi \cdot \cos\theta_i}} = j\frac{\sin(\pi \cdot \cos\theta_i)}{1 - \cos(\pi \cdot \cos\theta_i)}. \tag{3}$$

Note that regardless of the value of θ_i, the phase of the complex-valued w_1 is ±90° for this noiseless case. This value for w_1 is not optimal for the GSC when noise is present. For example, as $\theta_i \to 90°$, $w_1 \to \infty$ causing the auxiliary beam noise to be amplified tremendously prior to the output summation operation. Still, the ±90° phase offset between the main- and auxiliary-beam *interferer components* revealed by (3) holds even when noise is present at significant levels. This result is important in understanding how the selective-sampling receiver works.

For a narrowband signal centered at f_o, the interferer's zero-crossings will occur at intervals of ~$1/2f_o$ seconds. The selective-sampling receiver takes advantage of the fact that the interferer component in the main beam is always leading or lagging the interferer component in the auxiliary beam by 90°. By delaying either the main beam signal or the auxiliary beam signal by 90°, we can align the zero crossings of the interferer components in the two signals. The interferer is then suppressed by sampling the main-beam signal during the zero crossings of its interferer component. As shown in Fig. 2, the selective-sampling operation is achieved using zero-crossing detectors and sample-hold circuits.

If the main-beam output is taken as the in-phase signal, delaying this signal by 90° will produce its quadrature component. To preserve all signal information, it is necessary to selectively sample both the in-phase and quadrature components of the main beam output. The selectively sampled signals are next passed through low-pass filters to remove harmonic content introduced by the sampling operation. The cutoff frequency for these filters should be around $1.5f_o$.

The instantaneous frequency of the narrowband interferer varies from slightly above to slightly below f_o, implying that sampling rate is nonuniform and at ~$2f_o$ since there are two zero crossings per cycle. For a narrowband system, the information bandwidth is

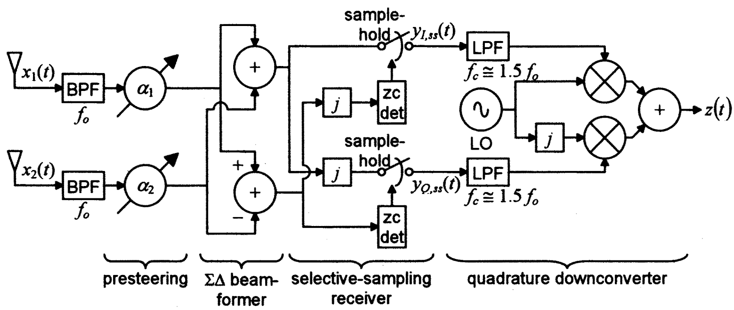

Fig. 2. Selective-sampling receiver equivalent to the two-element GSC.

much less than f_o. After quadrature downconversion to a lower intermediate frequency or to baseband, it is apparent that the effective sampling rate is well beyond the Nyquist rate and all signal information has been retained. Although the receiver shown in Fig. 2 includes a free-running local oscillator, carrier recovery can be achieved by applying a standard phase-locked synchronization loop to $y_{I,ss}(t)$ after it has been low-pass filtered. It is important to note that carrier recovery is optional, however, and that the performance of the selective-sampling receiver is completely independent of this operation.

It is critical to maintain isolation between the Σ and Δ channel outputs of the Σ-Δ beamformer in the analog implementation of the selective-sampling receiver. If we assume a complex coupling coefficient C between the Σ and Δ channel outputs and a presteering-adjusted interferer angle of arrival θ_i, the ratio of the phasor quantities that represent the main- and auxiliary-beam interferer contributions is

$$\frac{\Sigma(\theta_i)}{\Delta(\theta_i)} = \frac{1 + e^{j\pi\cdot\cos\theta_i} + C\left(1 - e^{j\pi\cdot\cos\theta_i}\right)}{1 - e^{j\pi\cdot\cos\theta_i} + C\left(1 + e^{j\pi\cdot\cos\theta_i}\right)} \tag{4}$$

As $|C| \to 1$, the phase relationship between the interferer components in the main and auxiliary beams strays from its ideal value of ±90°, varying as θ_i changes. This effect degrades the ability of the selective-sampling receiver to sample the main-beam signal during the zero crossings of its interferer component, reducing the output SINR.

3. Output SINR Performance

The interference-suppression performance of any array-based receiver can be judged based upon how well it optimizes the output SINR for a given set of conditions. We describe the relationship between a desired signal source, the noise environment, and a single directional interferer using an input SNR, an input SIR, and a swept angle of arrival for the interferer. Although the selective-sampling receiver has a presteering capability, for the sake of clarity we maintain the desired signal's angle of arrival at 90° (from broadside) in the analyses that follow.

To benchmark the performance of the selective-sampling receiver, we modeled the receiver shown in Fig. 2 and compared its output SINR to that of the ideal 2-sensor GSC with an optimal weight. The plots (a) through (c) shown in Fig. 3 compare the output SINR of the ideal GSC, the ideal selective-sampling receiver, a selective-sampling receiver with a Σ-Δ beamformer isolation of 40 dB, and a conventional beamformer with two equal weights. Three comparisons are shown under three different combinations of input SNR and input SIR. In each case, the ideal selective-sampling receiver very nearly approaches the SINR achieved by the ideal GSC with optimal weights. Also, the nonideality of the Σ-Δ beamformer only degrades the selective-sampling receiver's suppression capability slightly. The plot in (d) shows how the output SINR of the selective-sampling receiver degrades as the Σ-Δ beamformer isolation is reduced.

The selective-sampling receiver reacts quickly to changes in the angle of arrival and power level of the dominant interferer since it avoids the transients associated with adaptive processing. When the interferer power is not sufficiently above the noise floor, the selective-sampling receiver cannot accurately identify the zero crossings of the interferer and it instead samples randomly, approaching the SINR of the conventional array. In the limit, the performance of the optimal beam-space processor also approaches that of the conventional array, though. The selective-sampling receiver also performs poorly when multiple interferers of similar magnitude are incident from widely varied angles of arrival. However, for applications requiring a low-complexity solution to the problem of mitigating the effects of a single dominant interferer, the selective-sampling receiver offers an excellent alternative to existing adaptive array antennas.

4. References

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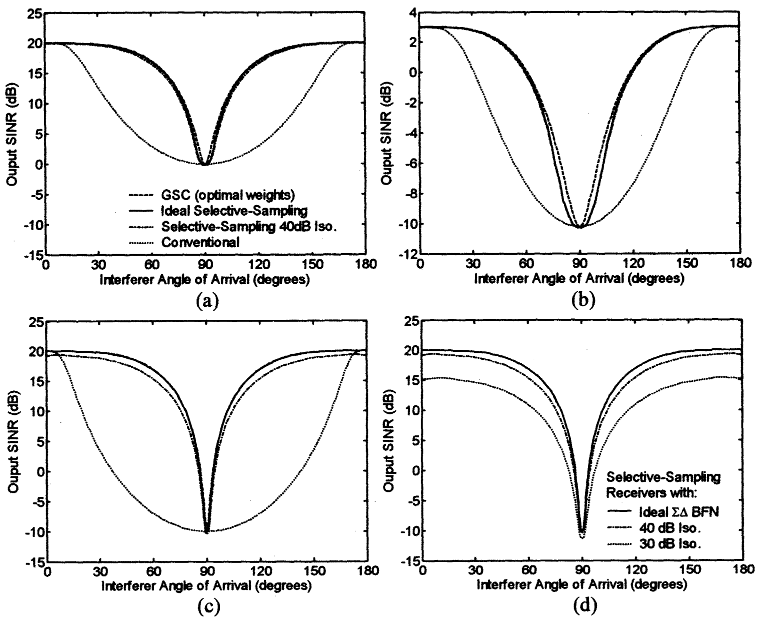

Fig. 3. Output SINR versus the angle of arrival of a single interferer for a 2-element, half-wave-spaced array with (a) SNR_{in} = 17 dB, SIR_{in} = 0 dB, (b) SNR_{in} = 0 dB, SIR_{in} = −10 dB, and (c) and (d) SNR_{in} = 17 dB, SIR_{in} = −10 dB. The desired source is incident from boresight (90°). Plots (a) through (c) share the legend shown in (a).