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ADAPTIVE INTERFERENCE TECHNIQUES FOR MOBILE ANTENNAS

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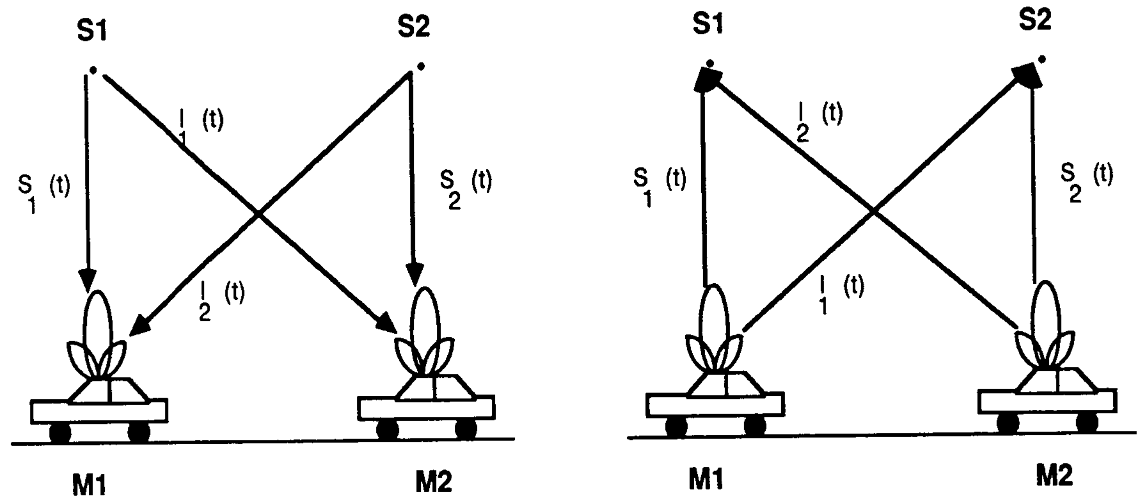
ABSTRACT

This paper describes the results of a study which has been performed to investigate effective, low cost adaptive signal processing techniques for suppressing mutual satellite interference that can arise in a mobile satellite (MSAT) communication system. The study has focussed on the use of adaptive sidelobe cancelling as a method to overcome undesired interference caused by a multiplicity of satellite transmissions within the field of view of the ground station. Results are presented which show that the conventional sidelobe canceller produces undesired reduction of the useful signal. This effect is due to the presence of the useful component in the reference antenna element. An alternative structure, the generalized sidelobe canceller (GSC), has been proposed which overcomes this difficulty. The GSC requires one additional multiplying unit (fixed) and one additional summing junction. It is concluded that the GSC provides an effective means for suppressing mutual satellite interference. A preliminary investigation of possible implementations of the GSC has been conducted. It was found that at most 8 bits would be required to implement the GSC processor under conditions in which the desired signal-to-interference ratio is 25 dB.

MSAT COMMUNICATION SYSTEM

For typical operational scenarios involving two or more satellites, mutual satellite interference (MSI) can degrade the performance of an MSAT communication system. In the situation where nearby satellite transmissions cannot be sufficiently isolated from each other (spatially or in frequency), some form of interference suppression must be incorporated at the various receiver/transmitter sites to mitigate the effects of MSI. Furthermore, since the relative geometry between the various transmitter and receiver terminals is constantly changing, the interference suppression techniques must be adaptive in order to provide robust performance over a range of system geometries. The basic geometry of interest is depicted in Figure 1.

Two MSI scenarios are shown corresponding to interference received by ground stations (on receive) and by the satellites (on transmit). Satellite transponders are indicated by (**S1**, **S2**) while $S_1(t)$ and $S_2(t)$ indicate the desired signal components and $I_1(t)$ and $I_2(t)$ denote MSI components.



a. Mutual interference on receive   b. Mutual interference on transmit

Fig.1. Mutual satellite interference between mobile users (**M1**, **M2**) and proximate satellite transponders

Observe that at the earth terminal, desired signals cannot be spatially distinguished from this interference due to the fact that both components enter through the mainlobe of the fixed-earth terminal antenna pattern.

ADAPTIVE ARRAYS

The spatial techniques studied are based on adaptive sidelobe cancelling (SLC). The array is assumed to be narrowband, which is a valid approximation for MSAT applications. The SLC approach utilizes an auxilliary antenna element, termed the reference antenna element, which is subtracted from the primary receiving antenna after appropriate weighting. The basic configuration is illustrated in Figure 2.

In this system, adaptation consists of adjusting the weight $W(n)$ such that the output power $|y|^2$ is minimized. Given that the interference component in the primary input is highly correlated with the reference input, then the minimization of output power accomplishes interference cancellation (Widrow, 1975). One simple adaptive method for minimizing $|y|^2$ is the LMS algorithm (Widrow, 1975). This algorithm ensures that the minimum possible output power level is obtained for the overall system.

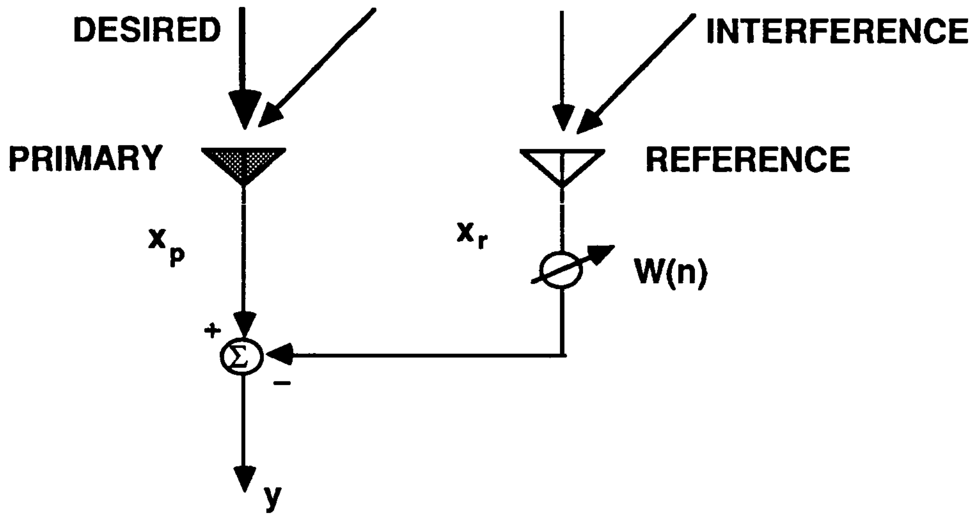


Figure 2. Basic MSAT adaptive SLC architecture.

If there is an appreciable amount of desired signal in the reference channel input, this method will lead to significant signal cancellation at the output. Effective interference cancellation is achieved only when the ratio of interference to desired signal is substantially larger in the reference antenna output than it is in the primary. Although this is the case for the nominal system, significant amounts of desired signal cancellation can nevertheless be expected to occur in MSAT geometries.

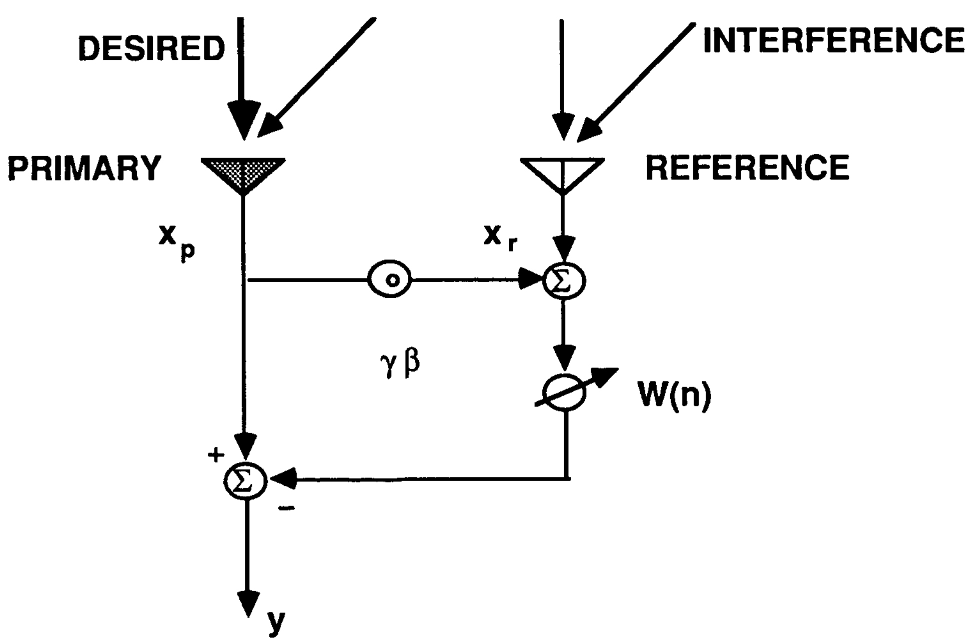


Figure 3. Generalized sidelobe canceller configuration.

The Generalized Sidelobe Canceller (GSLC) method of adaptive beamforming (Buckley, 1986) offers an approach which overcomes the signal cancellation effects observed with the basic SLC. The GSLC method utilizes the fact that *a priori* information is available regarding the anticipated gain differences between the desired signal component in the primary and in the reference beam outputs. This information would normally be available from the antenna patterns and is employed to combine the output from the two antennas *prior to the adaptive weight*, as shown in Figure 3.

The multiplier term $\gamma \beta$ between primary and reference is the gain required to equalize the difference in magnitude observed for the desired response at the primary and reference antenna outputs. The constant γ represents the polarization difference and β is the array gain term.

SIGNAL CANCELLATION EFFECTS

A numerical example was generated using a simple single interference model and the signal-to-interference power ratio (SIR) at the SLC output was computed. The example employed corresponded to a typical MSAT application in which a 19 element primary array pointed toward the desired signal was assumed. At the output terminals of this antenna, the undesired interference term is approximately 15dB below that of the desired response due to the antenna gain. A single-element reference antenna was assumed such that the gain difference β between the desired signal observed at the outputs of the primary and secondary antennas was 13dB.

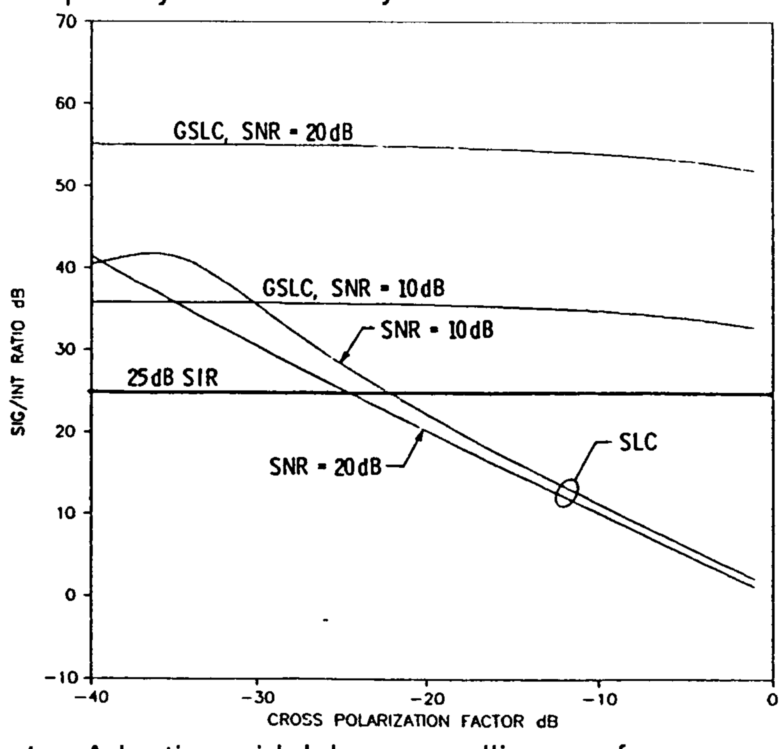


Fig. 4. Adaptive sidelobe cancelling performance curves.

Figure 4 illustrates the results as a function of the magnitude of the cross-polarization gain factor, $|\gamma|$ (with the phase of γ set at 0°), for a typical MSAT geometry. Two curves (marked SLC) are presented corresponding to two different values of signal-to-noise ratio (SNR): σ_s^2 / σ_n^2 = 10 dB and 20 dB. As is seen, the output SIR decreases as the cross-polarization isolation decreases due to signal cancellation. Note also that over almost the entire range of $|\gamma|$, somewhat better SLC performance is obtained at the smaller SNR values. This is a consequence of the desired signal component which is present in the reference channel. In fact, a more detailed examination of the closed form expression for SIR reveals that there exist optimal SNR values for which the output SIR is maximized.

In analogy with the SLC performance analysis calculations, the SIR at the GSLC output has been computed as a function of the magnitude of the cross-polarization factor, $|\gamma|$ (again with the phase of γ set at 0°). Two curves (marked GSLC) are presented in Figure 4 corresponding to SNR = 10 dB and 20 dB. In contrast to the SLC performance curves, the GSLC output SIR remains nearly constant as a function of the cross-polarization isolation.

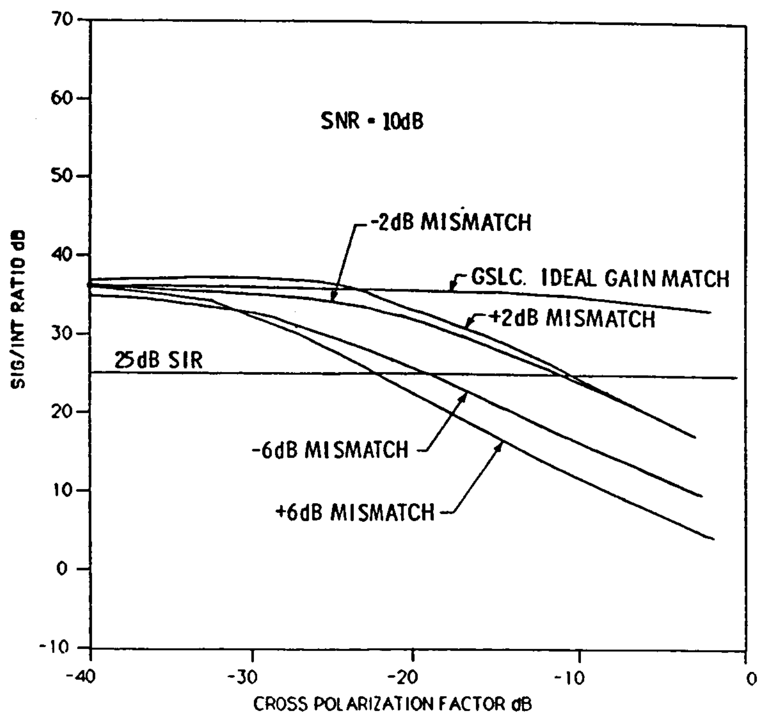


Fig. 5. Effects of gain mismatch on GSLC performance.

To further understand the performance of the simplified GSLC when the magnitude of the gain constant, $|\gamma \beta|$, is not known precisely, GSLC performance curves are presented in Figure 5 corresponding to different values of gain mismatch. As is seen, at a mismatch of ± 2 dB, 25 dB output SIR is available at the nominal 10 dB cross-polarization isolation level.

Comparing the SLC performance curves in Figure 4 with the GSLC curves in Figure 5 reveals that the GSLC operating with a ± 6 dB gain mismatch still outperforms the SLC near the nominal 10 dB cross-polarization isolation level. This demonstrates the superior performance of the GSLC in preventing signal cancellation.

DIGITAL PRECISION REQUIREMENTS

An important consideration in the design and implementation of digital adaptive sidelobe cancellers is the digital precision (bitwidth) required to represent the different variables in the weight update algorithm. The required precision is intimately related to the adaptive step size, μ, utilized in updating the adaptive weight, W(n). In particular, it has been shown (Gitlin) that the required bitwidth, B, for updating the LMS algorithm must satisfy the inequality:

$$2^{-B} < 2\, \mathrm{MIS}\, |y|_{RMS} / |x'|_{RMS} ,$$

where $|y|_{RMS}$ and $|x'|_{RMS}$ denote the root-mean-square (RMS) voltage levels of the GSLC output and augmented reference input, respectively, and MIS is termed the LMS algorithm misadjustment level (Widrow). For typical implementations, $|y|_{RMS}$ and $|x'|_{RMS}$ will be comparable (i.e., due to AGC limiting prior to digitization) and thus it is sufficient that 2^{-B} satisfy $2^{-B} < 2$ MIS. Therefore, the determination of a minimum bitwidth requirement is equivalent to specifying a maximum tolerable misadjustment level, MIS. As a particularly stressing example, if the output signal-to-interference ratio is assumed to be the desired 25 dB and a fixed-weight, residual white noise level 30 dB below the desired signal in the GSLC output is assumed, then a value of MIS = .002 or less will ensure that the total output noise level for the adaptive system will not exceed 25 dB below the desired signal level in the adaptive GSLC output, i.e., an increase of no more than 5 dB over the ideal, fixed-weight GSLC case. This value for MIS corresponds to requiring at least B = 8 bits. This will most likely represent a worst-case bitwidth specification for digitally implementing the adaptive GSLC.

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