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COMMUNICATION APPLICATION OF ADAPTIVE ARRAYS

R. T. Compton, Jr.

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The Ohio State University

**ElectroScience Laboratory**

Department of Electrical Engineering  
Columbus, Ohio 43212

Final Report 710929-5

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<p>▲ This report describes progress under Naval Air Systems Command Contract N00019-78-C-0131 during the final quarterly period. Research on the use of adaptive arrays in conventional communication systems is summarized.</p>			

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## INTRODUCTION

This report summarizes work done under NASC Contract N00019-78-C-0131 during the final (fourth) quarterly period. There are four areas of work under this contract. The first is a continuation of experimental work started under the previous contract on the use of adaptive arrays with AM and FM signals. The second and third areas involve research on the problem of frequency acquisition in adaptive arrays and on the use of analog phase modulation for desired signal tagging. The last area involves the preparation of a monograph of adaptive arrays. (By mutual agreement of NASC and OSU personnel, this last area of work has been deferred until the follow-on contract.)

## PROGRESS

During the final quarter, work has been done in three areas as described below:

### (1) Studies on Frequency and Code Acquisition

Studies on frequency and code acquisition techniques for use with adaptive arrays have been continued. Previously the use of a power inversion array with a dithered loop gain had been studied. With power inversion, loop gain dithering is necessary because there is no way of knowing the optimum loop gain setting a priori, since the interference environment is unknown. However, loop gain slewing increases the time required for frequency or code acquisition, because the acquisition circuitry behind the array cannot lockup until the loop gain reaches the right value.

For this reason, during the current quarter, we have studied an alternative method of achieving a favorable output signal-to-interference-plus-noise ratio (SINR) for frequency acquisition. The method is based

on a power maximization algorithm developed during an earlier NASC contract<sup>1</sup>. The algorithm as described in Reference 1 is used for maximizing array gain. However, the same algorithm can also be used to minimize array output power, by reversing the sign of the feedback loop gain. In this form, the array behavior is similar to a power inversion array, but has several advantages.

The feedback loop for maximizing or minimizing array output power is shown in Figure 1. In this figure  $x_i(t)$  is the signal from one of the two quadrature channels behind each element of the array. The behavior of this loop is controlled by the loop gain  $K$ . If  $K > 0$  the loop will yield weights that maximize array output power, whereas if  $K < 0$ , the loop will minimize array output power. The magnitude of  $K$ , in either case, affects only the speed of response of the loop, not the final result.

This loop can be used in a two-element array, on which a desired signal and interference are incident, to obtain a suitable SINR at the array output. If the interference power is larger than the desired signal power, a negative value of  $K$  yields a good output SINR. If the desired signal is stronger, a positive value of  $K$  is needed.

Figure 2 shows a typical result that is obtained. The figure shows the array output SINR as a function of the input desired signal-to-noise ratio (SNR). In this example it is assumed that the input interference-to-noise ratio (INR) is +40 dB; also, the desired signal arrives from broadside and the interference from  $50^\circ$  off broadside. The output SINR is shown for several values of interference bandwidth  $B_i$ . (The interference is assumed to have a flat spectral density over a bandwidth  $\Delta\omega$ .  $B_i$  is the fractional bandwidth, defined as  $\Delta\omega/\omega_0$ , where  $\omega_0$  is the center frequency of the signals.) In the region where  $\text{SNR} < 40$  dB, it is assumed that  $K < 0$ . For  $\text{SNR} > 40$  dB, it is assumed  $K > 0$ . A

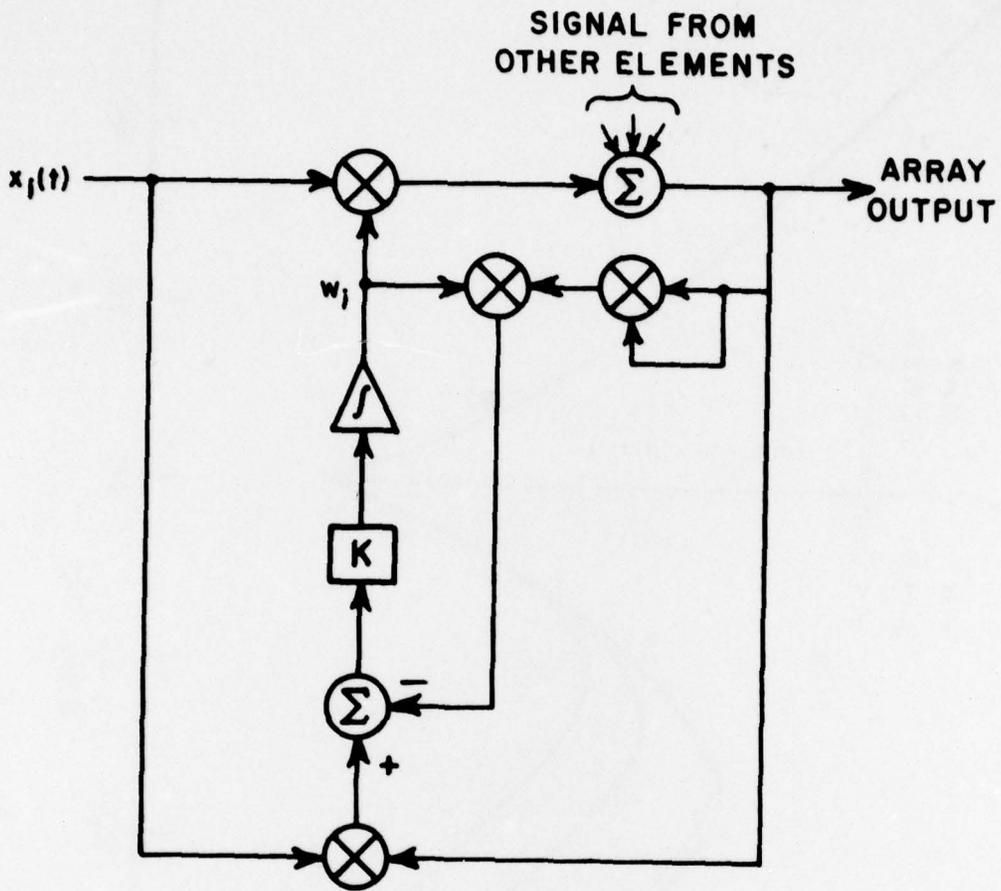


Figure 1. Gain maximizing loop.

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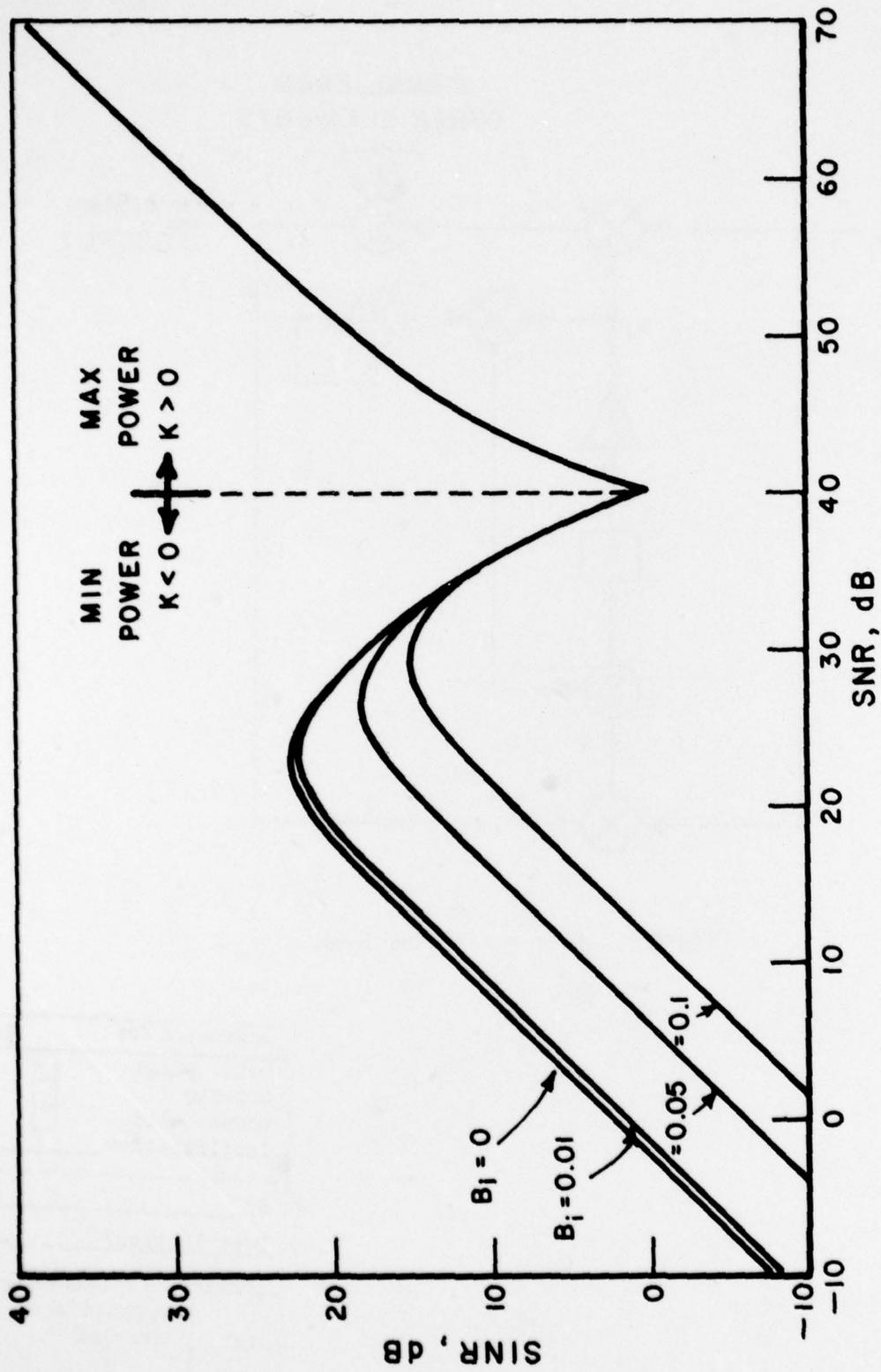


Figure 2. Output SINR vs. SNR.

system using this concept would start by attempting to acquire desired signal with  $K > 0$ . If lockup is not achieved, indicating that interference is present, the sign of  $K$  would be changed and lockup would be reattempted.

By operating first with  $K > 0$  and then with  $K < 0$ , a useable SINR will exist at the array output in almost all situations. (The only difficulty arises when the desired and interference powers are nearly equal. However, this difficulty also exists, to a greater extent, with power inversion.)

Studies on this technique indicate that it has certain advantages over the power inversion array for signal acquisition with unknown interference. These advantages are:

- (a) There is no need to slew the loop gain. Only two values of loop gain need to be tried ( $K > 0$  or  $K < 0$ ) to obtain lockup.
- (b) This technique has better performance than a power inversion array when the desired signal and the interference are nearly equal in power.
- (c) There is less variation in desired signal attenuation with this technique than with power inversion.

## (2) FSK Signals and Adaptive Arrays

Studies on the use of adaptive arrays with FSK signals are being continued. The FSK signal is assumed to be a binary Markov source. A one-bit prediction of the bit stream is derived from the received bits to obtain a reference signal. Simulations of this technique show that enough reference signal correlation is developed to be effective

against a single frequency CW jammer as long as the reference signal frequencies match those of the desired signal. With the Markov transition probabilities biased so a change in bit is more likely than no change, the array nulls CW interference.

Currently we are studying the more difficult problem of acquiring the desired signal frequency behind the array for use in constructing the reference signal. This problem is complicated by the fact that FSK is usually transmitted incoherently from bit to bit, since there is little advantage to coherent detection in FSK. One technique we are studying is a bootstrap loop that passes only one of the two FSK frequencies at a time. The one-bit predictor is used to decide which frequency will be passed. This approach is effective against CW interference, but not against an interfering signal with two CW tones, one in each FSK channel. To null this more complicated interference, we are studying a modified FSK detector that sets the reference signal to zero when both FSK channels contain a strong signal at the same time. This procedure causes the array to null the 2-frequency interference until it is small enough that the FSK detector can operate in a conventional manner.

### (3) Studies on Dynamic Range

Studies have continued on the performance of the modified LMS feedback loop, whose purpose is to increase dynamic range in the adaptive array. Extensive computer simulations of loop transients have been done to verify theoretical results and to determine the effect of various parameters on the loop performance. Currently, the simulations are being used to explore the relationship between the time duration of the averaging operation in the loop and the loop time constant. Also, we are studying the steady-state weight variance to determine how it is affected by input thermal noise power, interference power, and loop gain constants.

For all of the work to date, the averaging operation in the loop has been defined as a finite time average. This type of averaging is expedient for analytical purposes, but is somewhat inconvenient to implement in a hardware design. For this reason we are currently beginning simulations of a modified loop that uses a decaying RC-circuit type of averaging. This work will be continued under the follow-on contract.

#### PAPERS

Under this contract, two papers have been submitted for publication.

These are:

- (1) R. T. Compton, Jr., "The Power Inversion Adaptive Array - Concept and Performance," submitted to IEEE Transactions on Aerospace and Electronic Systems.
- (2) R. T. Compton, Jr., "An Improved Feedback Loop for Adaptive Arrays," submitted to Proceedings of the IEEE.

#### REFERENCES

1. H. H. Al-Khatib and R. T. Compton, Jr., "A Gain Optimizing Algorithm for Adaptive Arrays," IEEE Transactions, AP-26, 2 (March 1978), 228.