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EXPERIMENT ON A THREE-BEAM ADAPTIVE ARRAY FOR EHF FREQUENCY-HOPPED SIGNALS USING A FAST ALGORITHM

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For Department of Communications

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1.INTRODUCTION:

In a previous series of Contracts[1,2,3] experimental studies of a two-beam adaptive array for EHF frequency hopped signals were made and theoretical studies of fast algorithms for such arrays were conducted. From these studies multi-beam adaptive arrays was chosen for further study because of its large nulling bandwidth and low susceptibility to out-of coverage-area interference in comparison with phased arrays[4]. The maximum signal to jammer plus noise ratio (SJNR) criterion was chosen because of its superior performance in preventing the degradation of user signals in the presence of nearby jammers[5]. For frequency hopped signals the user signals can be separated from the majority of the jammer signals by using the frequency hopping sequence, hence measures of their power can be obtained without undue difficulty. A new fast algorithm using a modified conjugate gradient approach[6] was found to be a very efficient way to implement anti-jamming arrays based on the maximum SJNR criterion. An early algorithm to implement the maximum SJNR criterion is the Maximin algorithm of Bahkru and Torrieri[7], which is later refined to include an anticipative approach to compensate for broad band nulling in phased arrays[8,9].

The present investigation is a continuation of the previous studies, the main objectives being to refine and to simplify the new algorithm introduced before, and to implement the algorithm on an experimental array for real time evaluation of anti jamming performance. For more realistic experimental investigations a three-beam adaptive array is to be used. In the present Phase D study, the three-beam adaptive array is designed, required commercial components are acquired, and special components are either developed and fabricated or are being developed. Assembling of the setup is yet to begin. A processor to implement beam control has been acquired. The processor is based on the AT&T 32 bit floating point digital signal processor chip DSP32 using an IBM AT type personal computer as a host. A software package AJSIM is being developed for the execution and evaluation of real time beam control using different versions of the modified conjugate gradient algorithm as well as other algorithms for comparison. In addition, because the experiment is on a three-beam array while real systems would invariably make use of more elements, a simulation package is to be included so that multi-beam systems of more elements and different user-jammer scenarios can be simulated for evaluation. Further analysis of the maximum SJNR was performed with a view to reduce the computational burden with limited success. Finally, in a Supplement to the Reportract, a method of acquiring and tracking an incoming laser beam in a coherent laser communications link is proposed. The work is to fulfill an Amendment to the Contract.

2. A MULTI-BEAM ADAPTIVE ARRAY FOR FREQUENCY-HOPPED SIGNALS:

A simple block diagram of the adaptive multi-beam array for frequency hopping signals is given in Fig.1. The RF signal received by each beam of the array is first down converted to a broad band IF using a fixed local oscillator. The signal is then further down converted to a dehopped IF using a frequency synthesizer synchronized with the hopping sequence of the user signals. A narrow band pass filter is used to extract the user signal. Two band rejection filters on each side of the desired frequency band is used to extract the jamming and noise signals which do not follow the hopping sequence. The bandwidth of the band rejection filters is chosen to receive sufficient jammer power yet with bandwidth not too large to degrade the nulling performance immediately in the vicinity of the user signals. The same set of weights W are than applied to the user signals X and the jammer signals Z.The covariance matrices of the two signals are then evaluated in a beam control processor and optimum weights Wopt derived to maximize the SJNR. An alternative implementation is to insert the weights before the separation of the user and jammer signals by filters.

3. THE EXPERIMENTAL THREE-BEAM ADAPTIVE ARRAY

The adaptive multi-beam array for frequency-hopped signals described above is being implemented experimentally in a three-beam adaptive array. It is an extension of the two-beam array used in previous studies. The system is based on frequency hopping user signals and CW jamming. At the present time it is not easy to implement noise jammers due to the lack of simple low cost EHF noise sources of adequate power. The first IF is a broad-band IF with fixed local oscillator frequency. The second IF hops with the user signal in producing a narrow band IF. For simplicity the adaptive weights are implemented at the broad-band IF. The details of the circuits associated with each beam of the array are the same as the previous two-element array[2,3], hence, will not be repeated here. To improve the dynamic range of the array, new narrow band IF amplifiers and logarithmic amplifiers were developed. A third dual mode horn following the previous design was fabricated. A three way power divider to split the common local oscillator to the three mixers is under development. For control of the experiment the ancient first generation IBM PC was replaced by a new AT clone for enhanced performance. It is expected that the array will be completedwithin the next quarter. The array will be interfaced to the Beam Control Processor to be described in Section 4.

4. THE BEAM CONTROL PROCESSOR AND THE SOFTWARE PACKAGE AJSIM:

The beam control processor in the experimental 3-element array is implemented using a digital signal processing chip the AT&T DSP32. The chip operates in 32 bit single precision floating point arithmetic and is capable of performing 12.5 million floating point operations per second. (A new version of the chip, the DSP32C, has twice the operational speed.) The processor is on a board installed inside a host computer of the IBM AT type personal computer. To program and operate the processor an interactive software package AJSIM is being developed. The package, based on a graphics interface, is designed for flexibility and ease of operations. In addition to perform real time processing, the package can also perform simulation of larger arrays.

In the real time mode the processor will input data from the three-element experimental array, controls the weights of the array, and records the resulting signal to jammer plus noise ratio performance. Flexibility in control algorithm is maintained by selection of an algorithm from a library. The dynamic nulling performance is measured and stored for display on command. Parameters in the algorithms can be adjusted for fine tuning of performance.

In the simulation mode the system supplies simulated user signals, jammer signals and noise to the DSP32 control processor and the user signal and jammer signal outputs are derived from the derived weights. The performance of the simulated system is then evaluated. The details of the simulator is given below.

Array Configuration:

3,7,19 element multi- beam array in a hexagonal lattice

Beam size:

The element spacing in terms of element beam width can be adjusted

Criterion:

- Maximum SJNR

Algorithms:

- LMS
- LMS with variable step size;
- Conjugate gradient
- Modified conjugate gradient
- Anticipative modified conjugate gradient
- Direct matrix inversion
- Maximin

User Signal: Fast frequency hopping. Jammer signal: Partial tone, noise or others. Number of users and jammers: total number number of elements. The user graphics interface consists of:

- Mode selection
- If simulation
    - Scenario builder
    - Array configuration selection
- Selection of algorithm
- Adjustment of parameters
- Display of convergence in SJNR
- Display of convergence of element coefficients
- Print and plot data
- Save and retrieve from file

The program is being written using the objective programming language C++. The use of an objective language allows the ease of expansion and maintenance of the software. It is expected that the package will facilitate both the planned experimental study of anti-jamming arrays and the prediction of future systems in various user jammer scenarios.

5. LINEARIZED MAXIMUM SIGNAL TO JAMMER PLUS NOISE ALGORITHMS:

The fast convergent modified conjugate gradient algorithm for maximizing the signal to jammer plus noise ratio (SJNR) in an anti-jamming array introduced in the last Report[3] requires considerable computational effort in evaluating the step size. An attempt is made to approximate the algorithm by a linear one based on the gradient of the SJNR with partial success. The Maximin algorithm of Bakhru & Torrieri[7] is also based on the gradient of the SJNR. In each iteration the powers of both the user signals and the jammer plus noise are measured and used to obtain the derive the new weights. To this end the algorithm is nonlinear. A simple modification is to assume the user signals are of known power and P_s is set to some fraction of it, for example 10-20%, and replace the jammer plus noise power by the noise power alone P_n. In this way the algorithm becomes the usual LMS algorithm with convergence depending on a step size parameter. The SJNR as given by

$$W^h R_{xx} W / W^h R_{zz} W \quad (1)$$

where R_{XX} and R_{ZZ} are the covariance matrices of the user signals and the jammer plus noise respectively, and h denotes the conjugate transpose. The estimated gradient vector at iteration k is proportional to[3]

$$[R_{xxk} - l_k R_{zzk}] W_k \quad (2)$$

where l_k is the SJNR for step k. On replacing the l_k by the constant P_s/P_n, the weights W_{k+1} for the next step can be derived from

$$W_{k+1} = W_k + u \, [R_{xxk} W_k / P_s - R_{zzk} W_k / P_n] \quad (3)$$

Although the algorithm converges for an individual jammer, the required step size u is found to be very dependent on the jammer power. Fig.3 shows the performance of algorithm (3) as a function of the iteration number for a user signal SNR of 20db, a single jammer of JNR 50db using a step size of 10^{-9}. The antenna is a 7-beam array with the locations of the signals sources shown in Fig.2a. Fig.4 shows the performance for the same user jammer scenario except that the jammer power is reduced to JNR = 10 db, however, in this case a step size of 10^{-5} is required. The achieved SJNR in both cases is 63db. Fig.5 shows the performance when both jammers are present and a step size of 10^{-9} is used. The locations of the sources is changed to that of Fig.2b. The strong jammer is reduced to the level of the weak jammer and the resulting SJNR is no greater than 10db because the step size is too small for the weaker jammer. One method of equalizing the jammer powers is to insert a limiter in the jammer signal path Z so that the maximum output is say 5 to 10db above the weakest jammer to be nulled. Fig.6 shows the performance of such a limiter with 35db limit. The two jammer levels are 50db and 30db respectively. The step size used is 10^{-7}. A final SJNR of 39db is achieved. Although the above algorithm is very easy to implement, its advantage over the modified conjugate gradient algorithm is not clear. A final evaluation will be performed using the AJSIM package.

6. FURTHER WORK:

The present Phase D Report is essentially an interim Report. Most of the work were initiated but not completed. In the next Phase E, the main objective would be to evaluate the performance and limitations of the various beam control algorithms introduced both experimentally and in simulation.

SUPPLEMENT:

PROPOSAL FOR A HETERODYNE SPATIAL TRACKING OPTICAL RECEIVER FOR SATELLITE TO SATELLITE COMMUNICATION

Laser communications link is an attractive means of communication between low orbit satellites and geostationary satellites. The optical system of such a link generally have very small transmit and receive beamwidths. Spatial pointing, acquisition and tracking must achieve an accuracy of about one tenth of the beamwidth for proper operation of the link. The following is a proposal for a heterodyne spatial tracking optical receiver using a Fabry-Perot interferometer as an angle discriminator. Although direct detection tracking system are frequently investigated, heterodyne receivers are more immune to background radiation and have higher-sensitivity10. The proposal is based on preliminary analysis and simulation. However, because of the incomplete nature of the work, details will not be included in this Report.

Fig.7 shows the proposed heterodyne receiver. The main objective is to steer the local oscillator beam as close to the signal beam in direction as possible. The wavefronts of the two beams will then be parallel within the detector area and maximum heterodyne efficiency will be achieved. The laser local oscillator beam is first steered by an electro-optical device. It is then combined with the signal and then split into two arms, the main signal arm and another arm feeding an angle discriminator. A Fabry-Perot Interferometer has the characteristics that its phase shift is dependent on the angle of incidence. This means it converts spatial angular difference into temporal phase difference. Thus it can be used as an angle discriminator. A possible way of using this angle discriminator to detect the angle difference between the local oscillator beam and the signal beam is to measure the phase difference between the IF output of the two arms as shown in Fig.7. The phase difference is used to drive a phase lock loop through the beam steering device.

Preliminary analysis and simulation show the system functions as expected. However, much work remains to be done to delineate the limitations and potentials of the system.

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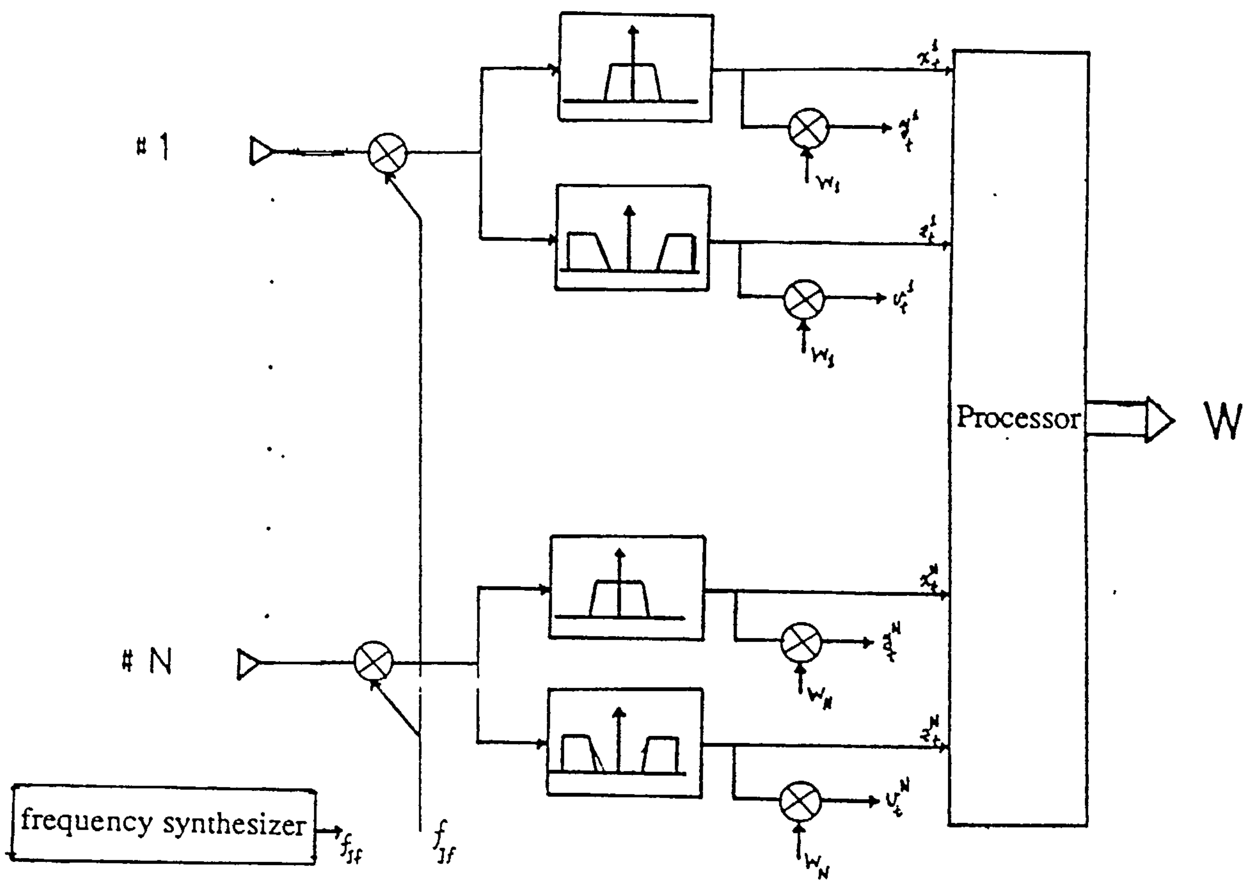
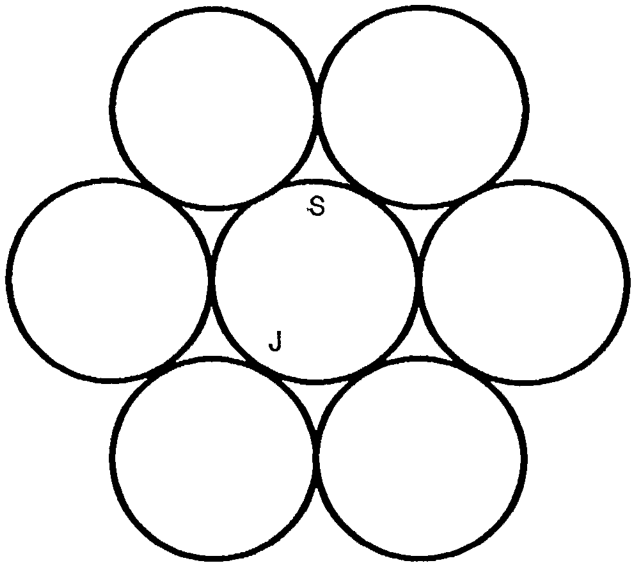


Fig. 1 Block diagram of max SJNR adaptive array



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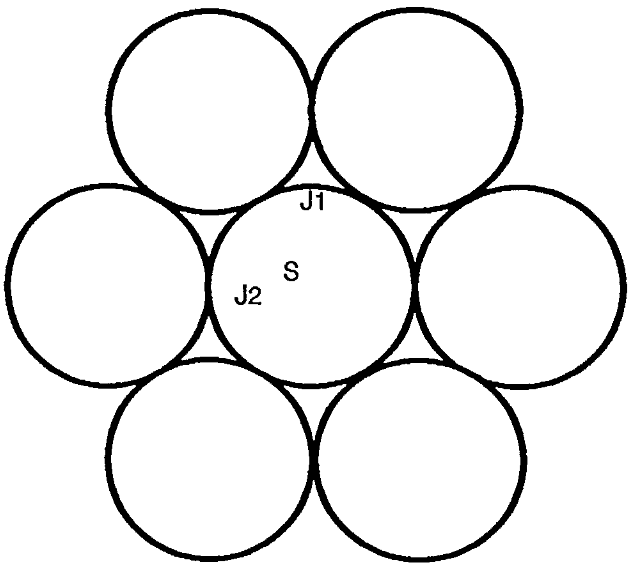

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FIG. 2 ARRAY BEAMS & USER JAMMER SCENARIOS
S = USER, J = JAMMER

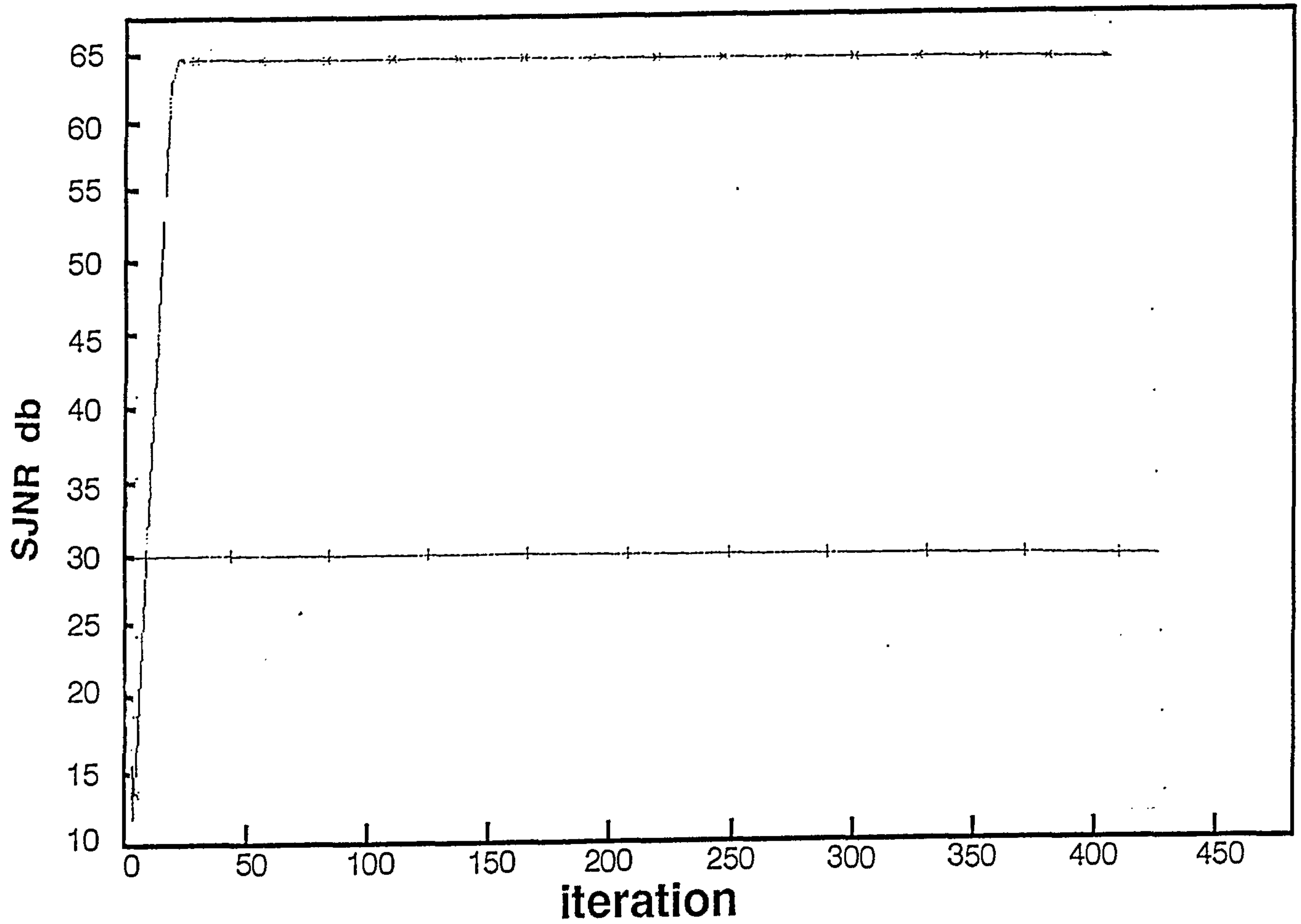

Fig. 3 SNR = 20 db, JNR = 50 db, u = 10e-9

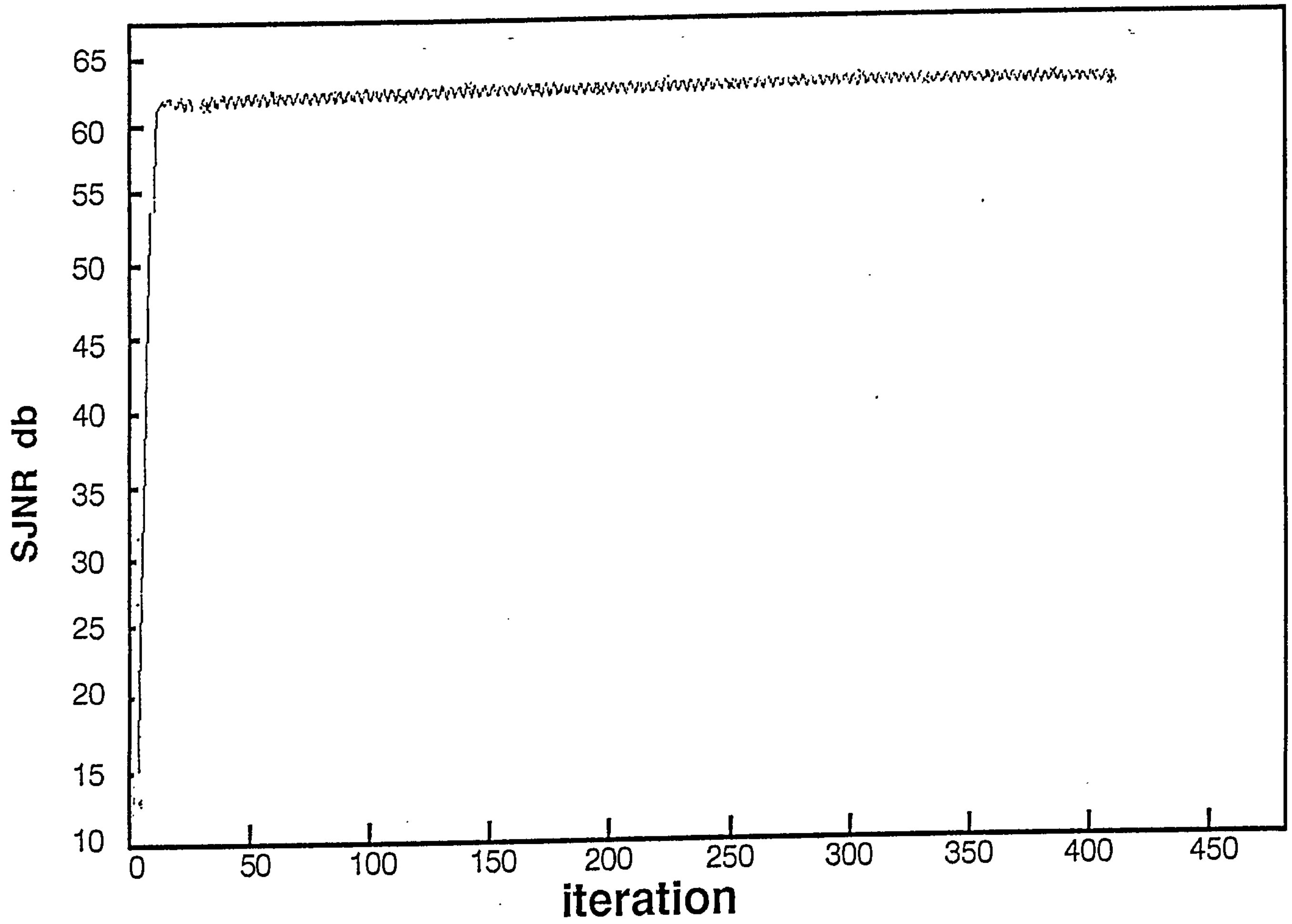

Fig. 4 SNR = 20 db, JNR = 10 db , u = 10e-5

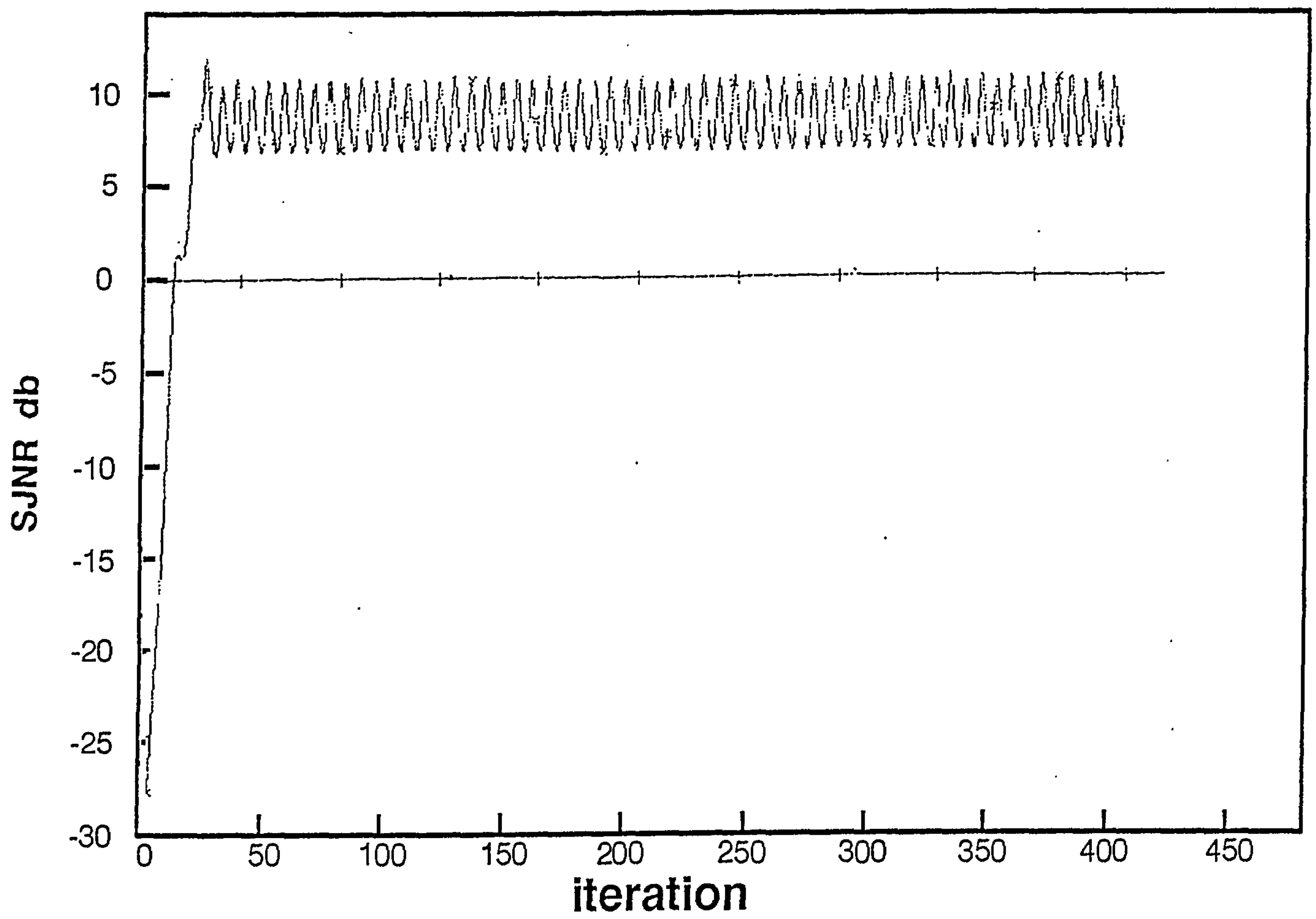

Fig. 5 SNR = 10 db, JNR1 = 50 db, JNR2 = 10 db, u = 10e-9

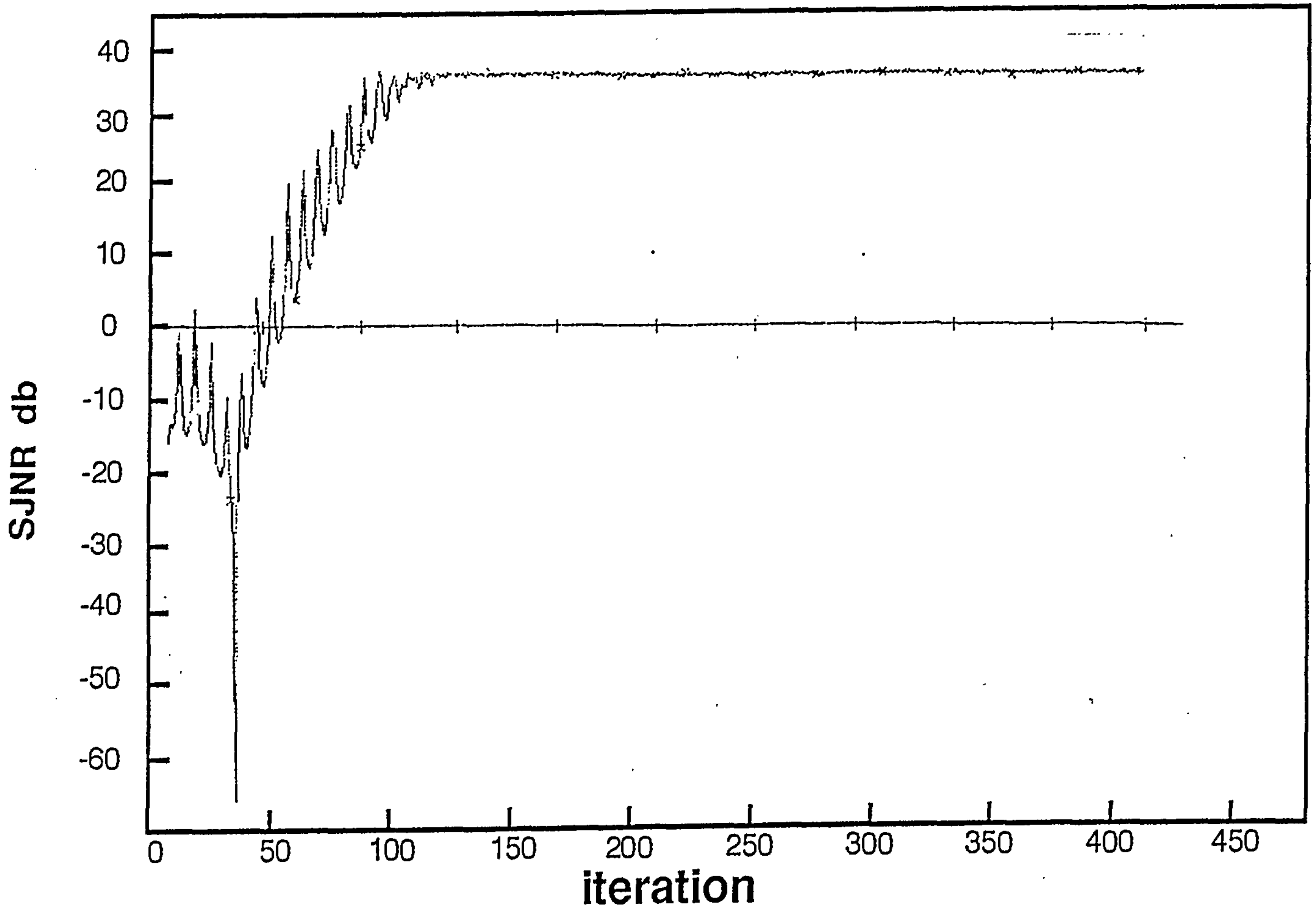

Fig. 6 SNR = 10 db, JNR1 = 50 db, JNR2 = 30 db,

u = 10e-7, limiter

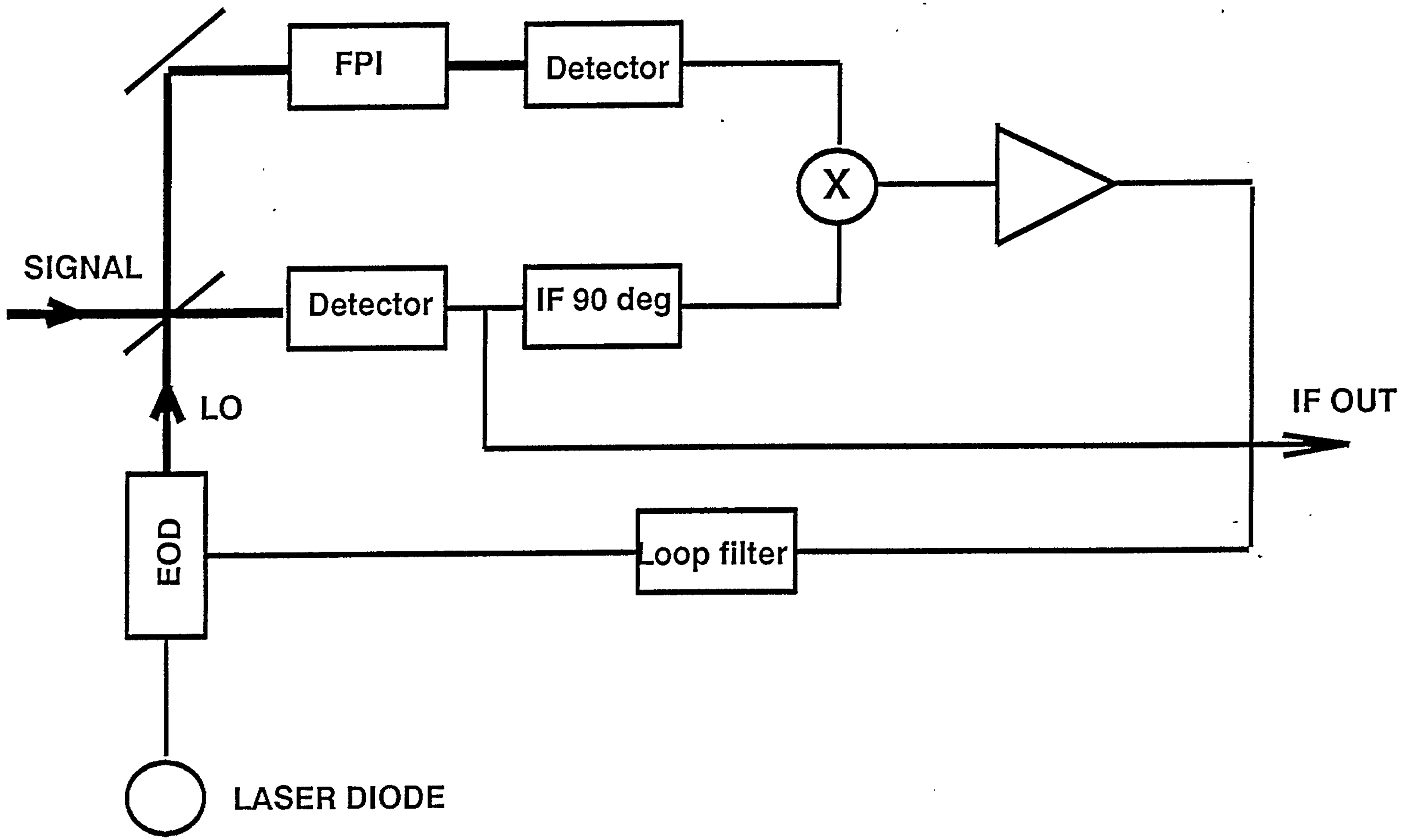

Fig. 7 Heterodyne Spatial Tracking Optical Receiver

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A three-beam 43 Ghz adaptive antenna and a beam control processor is under development. An interactive software package for the operation of the array, capable of applying different control algorithms is being written. In addition, the package will support simulation of multibeam arrays of many elements under various user-jammer scenarios. An attempt to linearize the fast convergent modified conjugate gradient algorithm for beam control was conducted, and simulation results included.

As a supplement to the contract, a method of acquisition and tracking of a coherent optical receiver for space optical communications is proposed.

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Adaptive antenna, frequency-hopping, anti-jamming ratio, experimental, fast algorithm.