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

PHASE-E

by

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PHASE–E FINAL REPORT

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INTRODUCTION

The main objective in this contract is the development of a three beam experimental adaptive jammer–nulling multi–beam array for frequency hopped signals in the EHF frequency band. It is based on an existing two beam experimental array developed under a 1986-88 Contract [Yen, 1987,1988,1989]. The array is configured as a vehicle to investigate the performance of different interference nulling algorithms experimentally. Among these algorithms is the efficient modified conjugate gradient method developed previously. The algorithm was detailed in a PhD dissertation [Amin, 1988], partially supported by the previous contract . The new array consists of an antenna and radio frequency or RF package, a two stage intermediate frequency or IF package, a coherence matrix measurement section, a real–time beam–control processor and a host computer to supervise, control and collect data for the experiments. The IF system makes use of two IF channels to separate in–band dehopped signals from out–of–band interferences in a frequency hopped system. To support the computing burden required in the nulling algorithms a real–time– processor based on a Digital Signal Processing chip, the AT&T DSP32 is used. To control the exeriments a software package named AJSIM is being developed. AJSIM makes use of a Graphical User Interface (GUI) for flexibility and ease of operations. Since the three element experimental array is too small to reflect future real operational arrays, simulation capabilities for larger arrays are included in the software. The antenna–RF and the IF packages are near completion. The host computer, an IBM AT compatible has been acquired. A processor board using this DSP chip for use with the host has also been acquired and the interface to the host implemented. The GUI in the software package AJSIM is near completion. It programmed using the objective language C++. The codes for implementing nulling algorithms and integration off the above into an experimental system are yet to be carried out. The following describes the detailed results and what remains to be done beyond the present contract.

A second objective is the development of a new angle discriminator for spatial–tracking in heterodyne space laser communication systems. A novel angle of arrival discriminator using a Fabry–Perot Interferometer was proposed in the previous contract. Detailed performance analysis of the device is completed. An experiment to evaluate the performance of the angle discriminator is performed. A complete description of the angle discriminator is contained in a Ph.D. dissertation to be presented [Fung, 1990], partially supported by the Contract.

THE THREE–BEAM EXPERIMENTAL ARRAY

The experimental 3–element multi–beam–array is an upgrade of the 2–element array developed in a series of previous contracts. The array is installed in a test range which supports a single user source and a single jammer source. The positions of the user and the jammer are adjustable with respect to the fixed beams of the experimental array. The centre frequency of the system is 44 Ghz. Briefly, the array consists of three feed horns distributed in a triangle, each of which is connected to its own RF circuit as shown in Fig 1. The RF signal from each element is first down converted to a broad band first IF using a local oscillator common to the entire array. The bandwidth of the broad band IF is 500 Mhz which covers the entire user hopping frequency band. This signal is then amplified and split into in–phase and quadrature–phase or I and Q channels using a 90^0 hybrid. Each channel is further split up into two, one of which is amplitude controlled before summing to obtain the broad band output for interference cancelling. Each of the broad–band IF channels from a single array element as well as the weighted sum array output are then down converted to a second IF, using a local oscillator hopping in synchronism with the user signal, to obtain a dehopped IF. In each channel a narrow band filter of bandwidth about 150 khz is then used to extract the user signals. Signals from interfering jammers not capable of following the user frequency hopping will fall outside the narrow user band most of the time, and therefore can be collected by means of filters at the second IF rejecting the dehopped user frequency band. The rejection bandwidth of this filter is 1 Mhz, centred at the same frequency as the narrow band filter. The complex correlation functions S_iY of the signal components of each array element S_i and the weighted output signal Y from the in–band channels and the correlation functions J_iZ of the jammer components of each array element and the weighted output jammer from the out–band channels are then separately measured using balanced mixers as multipliers. Based on these correlation functions, an appropriate algorithm is introduced to adjust the complex weights of the three elements to adaptively maximize certain criterion to reduce the interference of the jammers by means of a real–time–processor. The main purpose of the experimental array is to evaluate the nulling performance of different algorithms.

The RF portion of the three-beam array is completed. This included a 3–way local oscillator power divider which is unavailable commercially and need be developed. Since the system is to incorporate phase control in each element, no attempt was made to equalize RF path lengths between the array elements and the down converters. Similarly, no attempt was made to equalize the local oscillator phase of the individual down converters. In the broad-band IF section the I and Q channel splitter and the associated amplitude controllers for each array element are implemented. The amplitudes or the complex weights can be adjusted manually for set up or, by the host computer using digital to analog converters, for adaptive interference nulling. A set of six down converters driven by a common dehopping local oscillator then converts the six channels down to the second IF band. The dehopping local oscillator, which is also to be controlled by the host computer, is not yet implemented. An external adjustable oscillator is currently used for testing purposes. Narrow band band–pass filters for extraction of the dehopped in–band user signal channels are completed. Because of their narrow bandwidth, ceramic filters are used. Two combiners are used to sum the outputs of the three I channels and the three Q channels to derive the complex output of the array. One 3–complex correlator bank for coherence matrix measurements is completed. The correlator outputs are multiplexed to an analog to digital converter and the digital data transferred to the host computer for implementation of a nulling algorithm. In the implementation of the complicated IF circuitry, care was exercised to buffer all passive components with low gain amplifiers to reduce feed throughs and other deleterious signal impairments.

A small number of components of the array are unfinished at present. The band rejection filter for extraction of the jammers is being developed. Another 3–complex correlator bank for the out–band channels is to be fabricated. Since the currently the system makes use of a single EHF source, means of time sharing of the source between user and jammer in a meaningful manner is being investigated; otherwise a second EHF source must be acquired. When these items are implemented, the hardware of the array would be complete.

THE BEAM CONTROL REAL TIME PROCESSOR

Since a large amount of computations are required to implement beam control algorithms, a high speed processor using a 32 bit floating point DSP chip, the DSP32, and an IBM AT type host computer were acquired. This processor will take the coherence matrices measured by the experimental array and perform an algorithm, selected from a collection of possible candidates, to derive coefficients to weight the different array elements for jammer nulling. Since most algorithms are iterative in nature, updates of the element weighting coefficients are derived at each step, which are then applied to the array and another iteration begins. The algorithm would converge at a certain rate to some final signal to jammer ratio representing the effectiveness of the jammer nulling performance of the algorithm and the array. The speed of convergence depends on the algorithm and on the computing burden on the real–time–processor. The status of the important parameters during the nulling process will be monitored and transferred to the host computer for performance analysis, display and data logging.

The interface software between the DSP32 processor board and the host computer is implemented. Data transfer software between the host and the processor is also completed. Estimates of execution time of some sample computations required by selective algorithms to be used are made. Since the computing burden depends pronouncedly on the algorithm, it is yet unclear whether the floating point arithmetic of the processor is sufficiently fast to allow implementation of the most time consuming algorithms. Coding of beam control algorithms using the DSP processor assembly language is initiated. The development software for the DSP32 chip is found to be easy to use and perform well. The processor will also perform computations for simulations under the software package AJSIM using simulated signals to generate the coherence matrices for larger arrays. The DSP codes will be developed first in the simulation environment because of flexibility. The same codes will then be applied to the experimental array. At present the software for the real–time–processor is in an early stage of development.

THE AJSIM SOFTWARE PACKAGE

The AJSIM is for the control, data collection and display of experiment performed on the 3–beam array operating using different algorithms, as well as for simulation of the operation of larger arrays under different user–jammer scenarios and using different algorithms; all under user control. It consists of a mouse oriented Graphics User Interface (GUI), a set of DSP32 programs for down loading to the DSP processor to perform the selected jammer nulling algorithm, and a module for displaying and storing the data from the DSP processor for both experiments and simulations. The GUI is written in an objective programming language C++. It is chosen because of the ease in program maintenance. The compiler used is from the Zortech Corporation. Considerable thought and trials are being given to the organization, the functions, the visualization of system variables during operation, the options and the look and feel of the interface. The aim is towards a simple to use package yet provide enough options in operation and in depth monitoring of system dynamical behaviour at the user's disposal.

In the Experiment mode, the user can select one of the supported algorithms, set the parameters such as the step size and initial element weights, initiate a run and monitor the coherence matrices, the element weights and the signal and jammer powers, selected on user demand, as the adaptive process is underway. All the parameters and the monitor data during a run will be stored in a file for analysis. In the Simulation mode, the user selects the array configuration, the antenna element beam shape and the user–jammer scenario. From the above information, coherence matrices simulating a real array are synthesized continuously to replace the measured values obtained from the experimental array. The synthesized coherence matrices will be processed and monitored by the real–time–processor in exactly the same manner as in the Experiment mode. The array configurations available for simulation are 3, 7 or 19 element multi–beam arrays with beams arranged in a hexagonal lattice. The spacing between the elements can be set. A few commonly used beam shapes of different side lobe structures are available for simulation. The configuration setup scenario screen will show the selected beam configuration as well the element pattern selected. The program user next sets the scenario for simulation by assigning users, CW jammers and noise jammers according to their signal or jammer to noise ratio and their positions in the scenario space. When this is done one can proceed to setup and run an experiment just as in the Experimental mode.

At the present time the GUI is near completion. Details of selection and display of monitoring data is yet to be decided before implementation. Down loading of simple test programs to the DSP processor and up loading of results to the host computer has been successfully carried out. The DSP codes for the major nulling algorithms, the integration with the host AJSIM program and with the hardware and the DSP processor are yet to be implemented. Finally, the software need be debugged to ensure reliable operation. During the development of the GUI, the program crashes frequently until a compiler bug was discovered after a lengthy period.

SYSTEM PLANNING AND INTEGRATION

To provide a test bed for a wide variety of approaches to beam control, many options for operation and monitoring of the experiment will be provided in the real–time–processor under software control by the host computer. To begin with the integration time for data gathering will be selectable. Preweighting of the correlator data can be inserted to account for the different sensitivities of the analog correlators. A number of promising algorithms such as the LMS, the conjugate gradient, the modified conjugate gradient as well as matrix inversion will be provided for experimental studies. Simple means of implementing new algorithms will also be a desirable feature. Acquisition of various performance measures necessary for evaluation of the algorithm during the adaptive phase will be included. Monitoring key variables under operation would assist in better understanding of the adaptive process. Means of calibration of constituent components would also be useful. Most of these tasks require careful planning and integration between the experimental array, the real–time processor, the host computer and the software. The integration of the experimental array, the beam control processor, and the AJSIM software package is in currently at an early state. Much work remains to be done.

A NOVEL ANGLE DISCRIMINATOR FOR SPATIAL TRACKING IN LASER COMMUNICATIONS

A spatial tracking optical receiver for space borne laser communications was proposed. The main feature of the proposal is to use a Fabry–Perot interferometer as a precision angle discriminator. A description of the proposal was given in a previous report [Yen, 1989]. For high sensitivity heterodyne laser communications reception, the local oscillator and the signal beams must fall on a common area of the photodetector. A typical spatial tracking system consists of a steering mirror, an angular discriminator, an angular error detector and a steering loop controller. Fig.2 shows a traditional system using a quadrant detector for angular discrimination. The quadrant detector however operates on the difference of total beam power falling on the detectors, a process of low sensitivity. The new angular discriminator makes use of a Fabry-Perot resonator as shown in Fig.3 . The received signal beam combines with a LO beam and then split into two paths. In one path the two beams are coherently detected by using a photodetector. The IF signal obtained provides a reference signal for phase comparison with the signal obtained in the second path. By inserting a Fabry-Perot interferometer in the second path, an optical phase delay between the signal and the LO beams dependent on the angle of incidence of the two beams is introduced. Ideally, the profile of the angular discriminator should be linear in its designed range of operation. A photodetector on the second path obtains an IF signal whose phase, compared with the IF signal of the first path, contains information on the difference in angle between the signal and the LO beams. Thus, the angular error can be estimated by measuring the phase shift between the two IF signals. This signal is then used to steer the mirror for alignment of the signal beam and the LO beam. Since the operation makes use of high sensitivity heterodyne detection of signals, the proposed system is superior to the quadrant detector.

An experiment to verify the performance of the Fabry-Perot Interferometer as an angular discriminator and to delineate its potentials and limitations has been carried out. The experimental setup is shown in Fig.4. For simplicity, a single photodetector is used and each path consists of one beam only. A beam generated by a He Ne laser is incident on an acousto-optic modulator. The modulator is driven by an IF oscillator at 140 Mhz. An unmodulated beam emerging from the modulator along the same direction of the incident beam serves as the reference beam. A modulated beam emerging at the Bragg angle serves as the signal beam. A Fabry-Perot resonator is inserted in the signal beam. The angle of incidence on the interferometer is adjusted by rotating the interferometer on a motorized rotary stage. The two beams are combined and detected by a photodetector to obtain a 140Mhz IF. Phase shift of the signal beam relative to the reference beam is obtained by measuring the phase shift of the 140 Mhz IF and the IF oscillator. A series of measurements were taken, a typical result is shown in Fig.5. It is seen that the experimental discriminator operates in a range of $\pm 0.25^0$ producing an IF phase shift of 120^0. The experiment was conducted using facilities of the Ontario Laser and Lightwave Research Centre at the University of Toronto.

A complete description of the proposed angle discriminator for acquisition and tracking of heterodyne type laser communication links is prepared. It is contained in a Ph.D. dissertation to be presented [Fung 1990].

CONCLUSIONS AND FURTHER INVESTIGATIONS

The main objective of developing a complete experimental three–beam adaptive array system is well underway. The major work remains to be done is in software implementation. Both the AJSIM host computer Graphics User Interface software and the DSP32 signal processing codes for the real–time–processor need be completed. Consideration for inclusion of experiments on noise jamming need be investigated. Inclusion of multiple apertures in simulation should also be considered. When these are finished, a series of experiments and simulations to evaluate various arrays and nulling algorithms will be undertaken. The investigation on a new angle detector for spatial tracking in heterodyne laser space communications is completed.

REFERENCES

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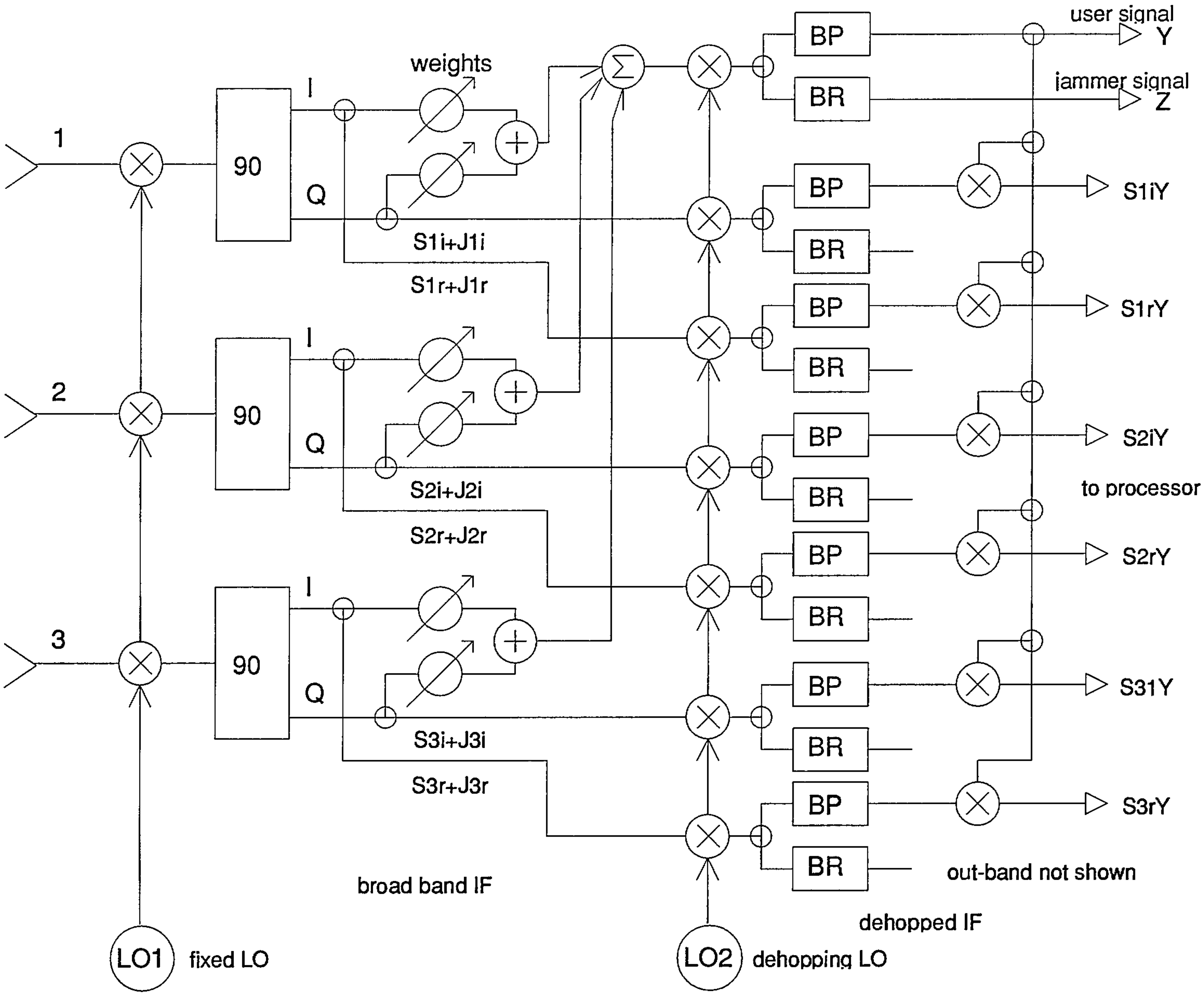

Fig.1 Block Diagram of the Experimental Array

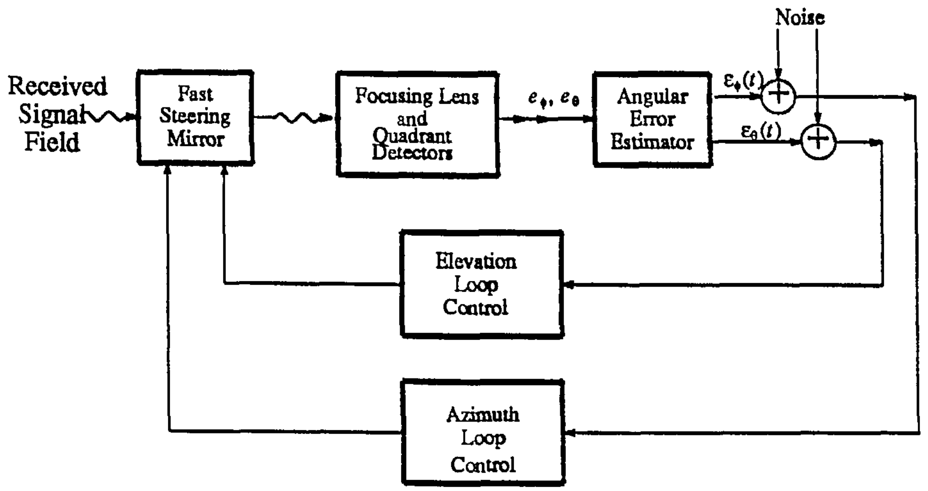

Fig.2 A Typical Spatial Tracking System

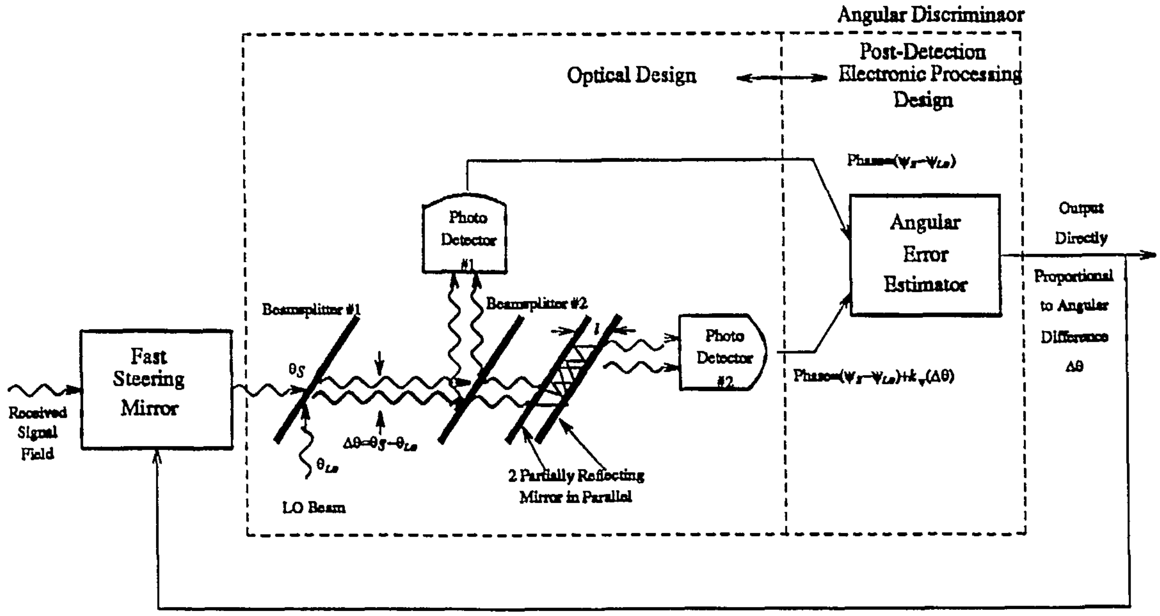

Fig.3 The Novel Spatial Tracking System

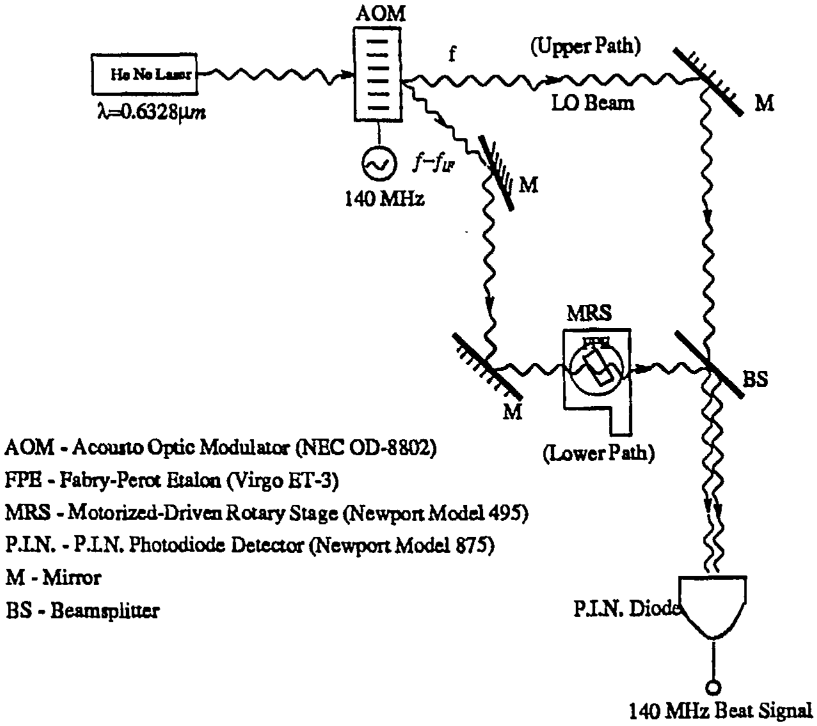

Fig.4 The Experimental Setup

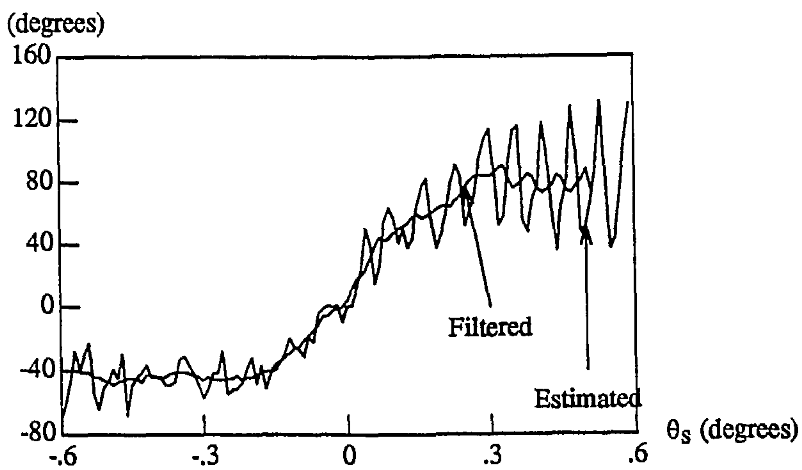

Fig.5 Measured Phase Response of FPI

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An experimental three–beam adaptive array at 43 Ghz, initiated under a previous Contract, is near completion. The array is configured as a vehicle to investigate the performance of different interference nulling algorithms experimentally. It has two IF channels to separate in–band dehopped signals from out–of–band interferences in a frequency hopped system. A real–time–processor based on a digital signal processing chip, the AT&T DSP32 is used to perform beam control algorithms. A software package AJSIM based on a Graphical User Interface (GUI) is being developed for the control, data collection and display of the experiments. The package also supports simulation of larger arrays under different user–jammer scenarios using different algorithms.

A secondary objective is the investigation of a new angle detector for spatial tracking in heterodyne laser space communications. The angle discriminator makes use of a Fabry–Perot interfereometer to convert angular displacement into phase shift of an IF signal. An experiment was conducted to verify the new discriminator.

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Adaptive antenna, frequency–hopping, anti–jamming, experiment, laser communications, spatial tracking.