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Semi-Annual Status Report No. 130

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1 January through 30 June 1976

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Prepared by

Information Systems Laboratory
Digital Systems Laboratory
Integrated Circuits Laboratory
Solid-State Electronics Laboratory
Radioscience Laboratory
Institute for Plasma Research

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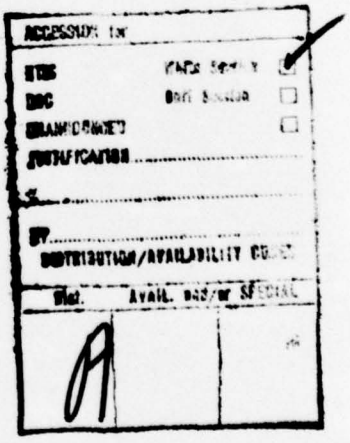

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1. Steps in the dielectric isolation process 24

I. INFORMATION SYSTEMS

A. Project 6151. PATTERN RECOGNITION

Principal Investigator: T. M. Cover
Staff: R. King, A. El Gamal, C. P. Tan, W. Rogers, K. Jarrett, J. van Campenhout, P. Algoet

1. Objective

The purpose of this project is to investigate problems of information processing and pattern recognition.

2. Current Status of Work

a. Measurement Selection (T. Cover, J. van Campenhout)

Suppose one is given a collection of observations $X_1, X_2, \ldots, X_n$ and wishes to make some inference concerning an underlying state of nature θ. Corresponding to every subset S of observations is a resulting minimal Bayes probability of error $P(S)$. We have demonstrated that virtually any ordering of $P(S)$ as a function of the 2^n subsets $S \subseteq \{X_1, X_2, \ldots, X_n\}$ is possible. As a result, it can be shown that no nonexhaustive measurement-selection procedure exists for finding the best k-element subset of measurements. This work will be presented at the Third Annual International Conference on Pattern Recognition, November 1976, and will be submitted for publication in the IEEE Transactions on Systems, Man, and Cybernetics.

b. Kolmogorov Complexity and Shannon Entropy (T. Cover, C. Leung)

Shannon defines entropy as a certain functional of the probability distribution of a given random variable. He also invests this concept with operational significance in terms of data compression. Kolmogorov, Chaitin, and others have defined an algorithmic complexity measure as the length of the shortest computer description of the outcome of the random variable. We have demonstrated that these definitions are essentially the same when the algorithmic problem is placed in a probabilistic framework.

c. Estimating the Entropy of English (T. Cover, R. King)

Shannon proposed a guessing game for the estimation of the entropy of English. It can be shown, however, that the entropy estimates obtained by Shannon do not converge to the true entropy unless the underlying stochastic process is degenerate. An asymptotically consistent gambling estimate is proposed. Experiments indicate that the entropy of English is approximately 1.3 bits per symbol, thereby suggesting an achievable data compression on English text of three to one.

d. Broadcast Channels (T. Cover, A. El Gamal, K. Jarrett)

An attempt is being made to determine the capacity region of networks of gaussian channels.

e. Algorithmic Complexity and Universal Probability Measures (A. Shenhar)

The concept of Kolmogorov complexity has been extended to functions on topological spaces. This work will have particular application to pattern recognition, in which a consistent theory of complexity as a function of the degree of resolution of the image is required.

f. Fast Data Compression (R. Pasco)

A thesis has just been completed demonstrating that data-compression algorithms achieving the Shannon limit for sources with complicated stochastic structure can be achieved in only two single-precision multiplications per bit encoded and two single-precision operations per bit decoded. As a result, speeds well over 1000 bits/sec can be achieved in encoding and decoding.

g. A Question on the Prediction of Ergodic Processes (T. Cover)

In the past, we have proposed the question of how the entropy and conditional distributions of ergodic processes can be estimated in real time. This problem has been solved by D. Bailey in his Ph.D. dissertation in which it was shown that

- the entropy of binary ergodic processes can be consistently estimated
- given the past, the conditional distribution of the next symbol cannot, in general, be asymptotically consistently estimated except in Cesaro mean
- given the past, the conditional distribution of a specific symbol X_0 extending to minus infinity can be estimated consistently
- hypothesis tests exist that yield asymptotically zero probability of error in distinguishing whether the underlying ergodic process is independent

h. Feedback Capacity of Degraded Broadcast Channels
(A. El Gamal)

It has been demonstrated that feedback does not enlarge the capacity region of the discrete memoryless degraded broadcast channel. This work has been submitted to IEEE Transactions on Information Theory. Attempts have been made to determine the capacity region of interference channels and to prove the optimality of the achievable region for the multiple-access channel with feedback proposed by Cover and Leung.

B. Project 6240. OPTIMAL CODES WITH VARIABLE WEIGHT SYMBOLS

Principal Investigator: J. T. Gill
Staff: N. Cot

1. Objective

The objectives of this project are to determine procedures for producing optimal uniquely decipherable codes, using symbols of unequal costs, and to study the properties of the corresponding codes.

2. Current Status of Work

We have demonstrated that variable-length coding schemes have potential applications in such fields as

- game theory, where they are associated with the determination of optimal gambling strategies
- data allocation in storage and data retrieval [1], where their application is based on the relationship between double-chained trees and variable-length codes (a file can be organized as a double-chained tree wherein keys correspond to variable-length code words)

An optimal tree (or code) corresponds to a minimal average search time. Given the simplest possible search strategy, determination of the optimal tree is a specific problem of variable-length encoding where the cost composition [2] is $1,2,\ldots,r$. More complex strategies of information retrieval correspond to different cost compositions $(a_1, a_2,\ldots,a_r)$. They occur, for example,

- when the storage is not homogeneous or when some capacity constraints are introduced
- given practical implementations of trees

Because of these considerations, we are investigating a precise analysis of the algorithms aimed at constructing optimal codes and their computation complexity; some of the results obtained appear in Ref. 3. We are also investigating the properties of the resulting optimal trees. Our method develops a very efficient framework to explore the configuration of these trees and their weighted path lengths.

References

1. L. Stanfel, "Optimal Trees for a Class of Information Retrieval Problems," Info. Stor. Retr., 9, 1973, pp. 43-59.
2. N. Cot, "A Linear-Time Ordering Procedure with Applications to Variable-Length Encoding," Eighth Annual Princeton Conference on Information Sciences and Systems, 1974.
3. N. Cot, "The Complexity of the Variable-Length Encoding Problem," Sixth Southeastern Conference on Combinatorics, Graph Theory, and Computing, 1975.

C. Project 6302. PROBLEMS IN CONTROL

Principal Investigator: G. F. Franklin
Staff: G. Aral

1. Objective

This study is concerned with design problems in automatic control systems, especially when model uncertainty is present.

2. Current Status of Work

Research has continued on this project during the past reporting period. The staff member most heavily involved in the research work, however, has not yet returned from Turkey. A detailed report will be included in the next Semi-Annual Status Report.

D. Project 6418. FUNDAMENTAL LIMITATIONS IN IMAGE DEBLURRING AND CODED-APERTURE IMAGING

Principal Investigator: J. W. Goodman
Staff: A. Dias

1. Objective

The objective of this project is to determine the fundamental limitations on the restorability of images recorded in a photon-limited environment. Applications to the restoration of atmospherically degraded images, motion-blurred images, and images recorded by coded-aperture systems are of concern.

2. Current Status of Work

This project was terminated on 1 April 1976 because of the availability of other funding for support of the work on photon-limited image restoration.

The possible use of homomorphic filtering for restoration of atmospherically degraded images formed with coherent light was theoretically investigated before the project was terminated. The results indicated that the procedure was not very practical and, therefore, it was not further pursued.

E. Project 6503. DATA COMPRESSION TECHNIQUES AND APPLICATIONS

Principal Investigator: R. M. Gray
Staff: Y. Linde, J. Dunham

1. Objective

Research conducted under this project is directed toward the development of a theory of data compression and implementable compression algorithms.

2. Current Status of Work

The basic theory of trellis codes for data compression has now been developed and is scheduled for publication. A new result obtained is the demonstration that the design of good trellis codes is equivalent to the design of a good simulator for a given random process by nonlinear filtering of white noise. The initial stages of a simulation capability have been completed for testing trellis and sliding-block codes for data-compression discrete sources. The goal is to determine the properties of good codes so that a method of computer-aided design can be developed.

Optimal quantization of reflection coefficients in LPC speech-compression systems (done in conjunction with an ARPA project at Speech Communications Research Laboratory in Santa Barbara) has been completed, with experimental data reinforcing the theory. All existing schemes were compared and contrasted and it was found that, if single-symbol quantization is described, all systems perform equally well and, as a result, "optimal" systems are not worth the complexity. Performance of LPC speech compression will improve only when the memory in the reflection coefficients is utilized (by predictive quantization, predictive comparison, or trellis-coding techniques). Research along these lines is now being initiated.

As an offshoot of the speech work, a new derivation of the properties of asymptotically optimal quantizers has been developed that involves a simple application of standard inequalities from information theory and no generalized Lagrange techniques. The proofs are greatly simplified and the results are stronger.

In collaboration with L. D. Davisson (working with NASA support), we have developed a new random-process model for radiometer and video data that matches both the marginal and Markov nature of the observed data. The model is a Wiener process between two reflecting barriers and has a uniform marginal density; however, it is a Markov process with gaussian-like properties. Second-order properties such as power spectral density were analytically obtained, and the performance of PCM, DPCM, and predictive comparison data-compression techniques were analyzed for both video and high-resolution radiometer data. Experiments agreed well with the theory.

Both the speech work and the video-compression project are examples in which simple techniques from information theory obtained new results on practical systems that correlated well with experimental and simulation data.

F. Project 6601. INFORMATION THEORY AND INFORMATION PROCESSING

Principal Investigator: M. E. Hellman
Staff: S. K. Leung, L. Pinto de Carvalho, E. Verriest

1. Objective

The objective of this project is to investigate the relationships between information theory, information processing, and complexity theory.

2. Current Status of Work

Additional results have been obtained for multiuser communication networks [1]. In related work, we have established that any rate 1 convolutional encoder of a given constraint length ν has the same steady-state properties when used as a scrambler for the binary wiretap channel. In steady-state, the wiretapper's uncertainty over any ν consecutive bits of the source output is complete (he knows no more than before listening on the wiretap channel).

We have derived upper bounds on the decoding effort of a convolutional source code and are attempting to extend these bounds to codes that appear to be simpler to decode.

Reference

1. S. K. Leung, "Multiuser and Wiretap Channels Including Feedback," TR No. 6603-2, Stanford Electronics Laboratories, Stanford University, Stanford, Calif., July 1976.

G. Project 6701. ADAPTIVE FILTERING

Principal Investigator: B. Widrow
Staff: C. Williams, M. Larimore, J. Treichler

1. Objective

The objective of this project is to study the effectiveness of various adaptive techniques in communication systems. Interest has focused on adaptively computed direct-channel models in systems where doppler effects, multipath, and additive noise are present. Other work is concerned with the application of adaptive techniques to detect spectral lines in noise.

2. Current Status of Work

Direct-channel models can be used to partially unravel the multipath effects in spread-spectrum communication systems. The reaction of the direct model to doppler has been simulated and analyzed, and its performance has been related to the signal-to-noise ratio, convergence rate of the model, channel-impulse response, and doppler rate. The study has revealed that the dynamics inherent in the adaptive process can track some degree of doppler shift. We are led to believe that doppler effects can be greatly mitigated by combining an adaptively computed direct model with a nonlinear synchronization adjustment.

The behavior of an adaptive filter is highly dependent on the structure of its input. The presence of additive noise uncorrelated with the signal can influence both the evolution of the filter impulse response and its ultimate converged form. It is sometimes desirable to ignore the noise component of the input and use only the signal component for adaptation. An adaptive algorithm is being developed and analyzed that takes advantage of the uncorrelated nature of the noise by adjusting the filter in such a way that, at convergence, its form is

independent of the noise structure. Such a filter can be applied to adaptive noise canceling and to communication-channel modeling in the presence of noise.

There are many situations in which the detection of a narrowband signal of unknown frequency in a noisy environment is desired. An adaptive-filter configuration, called the adaptive line enhancer, can accomplish this detection over a wide range of signal-to-noise ratios and in nonwhite-noise environments. The line enhancer bridges the gap between real-time autoregressive modeling of the source ("maximum entropy" approach) and correlation techniques. It also promises higher dynamic-range tolerance when dealing with several narrowband inputs of widely different powers, and it can generate accurate frequency estimates of the input signal.

H. Project 6851. IMAGING OF GAMMA-RAY DISTRIBUTIONS

Principal Investigator: A. Macovski
Staff: A. L. Steinbach, D. Rosenfeld

1. Objective

The objectives of this work are to study the fundamental characteristics of a gamma-ray source distribution and to derive optimal methods for imaging such distributions. Because refractive effects do not exist at these energies, various attenuative masking structures are being investigated with respect to efficiency, resolution, depth delineation, and signal-to-noise ratio.

2. Current Status of Work

A computer program has been designed and implemented to plot the complete spatial distribution obtained by encoding and decoding, using a one-dimensional zone-plate configuration. From this plot, lateral and axial resolution can be determined and background or "clutter" which can restrict the dynamic range can be evaluated. The resultant responses are a strong function of the zone-plate design. This design is represented by the radial function that determines the position of opaque and transparent zones. As a result of both the computer plots and analytical

techniques, zone-plate functions are being obtained that provide optimal performance in various measures, such as in the lateral and depth dimensions.

Several computer studies have been made on the modulated aperture system where an array of pinholes are temporally modulated by orthogonal functions. Selection of the functions (or codes) is strongly object-dependent. The classic cases of a point source and an infinite source were analyzed. The point source exhibits its maximum signal-to-noise ratio where all but one aperture is open at any time, and the optimal code for the infinite source has one aperture open at a time. It was demonstrated that varying the code to provide more open apertures increases the performance of point sources much more rapidly than it degrades the performance of infinite sources. Optimal codes were designed for square planar sources of specific dimensions relative to the imaging mask. The reconstructed image was plotted, indicating the signal-to-noise ratio as a function of position. Studies are under way to obtain an optimal code based on initial measurements rather than a priori knowledge.

I. Project 7050. STUDIES IN STATISTICAL SYSTEM THEORY

Principal Investigators: T. Kailath, M. Morf
Staff: J. Dobbins, B. Levy, S. Y. Kung,
G. Verghese, A. Vieira

1. Objective

The purpose of this project is to study basic problems in statistical system theory.

2. Current Status of Work

a. Multichannel Maximum Entropy (M. Morf, A. Vieira, T. Kailath)

The single-channel maximum-entropy method (MEM) has been studied by Burg and applied with success to the spectral analysis of time series. We have extended the MEM to address the multichannel problem. Similar to the scalar case, we have characterized the covariance

function in terms of a matrix generalization of the square-root normalized "reflection coefficients" (or "partial autocorrelations"--PARCOR as known in the statistical literature). The singular values of these matrix coefficients have singular values in magnitude (≤ 1). We have found estimates of these coefficients that are guaranteed to have this property which, in turn, guarantees that the corresponding estimates of the covariance will be positive definite and that the prediction filter will be minimum-phase.

b. Ladder Structure for Least-Squares Estimation (M. Morf, A. Vieira, T. Kailath)

In the linear prediction method of signal analysis, ladder structures for predictive coding have been devised by Itakura and Saito, Wakita, and others. These structures must calculate the "reflection coefficients," which can be only approximated for real data. Morf, Dickinson, and Kailath (1975) had developed recursive algorithms for solving the underlying least-squares problem in the prediction analysis. The new algorithms can be made equivalent to either one of the classical methods, namely those using Atal's equations (also known as the "covariance method") obtained by defining errors entirely within the data or to those using the Yule-Walker (or "autocorrelation method") equations where zeros are added before and after the data.

Through the new algorithms, we have developed a ladder structure for the prediction errors. The PARCOR coefficients are now calculated recursively to minimize a squared-error criterion. Similar recursive formulas [using $O(N^2)$ instead of the standard $O(N^3)$ operations] have also been developed for the covariance method, and the corresponding ladder structure is being investigated.

c. Stochastic Interpretations of New Square-Root Algorithms (T. Kailath, M. Morf, J. Dobbins)

Recasting the Kalman filtering and related smoothing algorithms in square-root form greatly improves their numerical conditioning. For the smoothing problem, however, several different algorithms exist and their interrelationships have not been clearly understood.

Using an approach that views the square-root arrays as arrays of cross-correlations between the random variables of interest and sets obtained from them by orthonormalization, we have placed most of the known algorithms into a comprehensive framework and have developed some new algorithms.

We are also working to extend computationally fast filtering algorithms to the smoothing problem and to remove some restrictions on the type of problem to which the fast algorithm can be applied. We intend to investigate whether the square-root approach can be combined with certain results from scattering theory that, recently, have proved fruitful in linear least-squares estimation.

d. A Generalized Resultant Matrix for Polynomial Matrices
(T. Kailath, S. Kung, M. Morf)

The description of transfer functions by matrix fractions is now well-known. As a result, a right matrix fraction description (RMFD) of a transfer function $H(s)$ is $H(s) = N(s)D^{-1}(s)$, where $N(s)$ and $D(s)$ are polynomial matrices. If the only right common factors of $N(s)$ and $D(s)$ are unimodular (polynomial matrices with constant determinants and polynomial inverses), then $N(s)$ and $D(s)$ are termed "right coprime" and the MFD is irreducible. The determinantal degree of the denominator matrix of every irreducible MFD of $H(s)$ is the same and is equal to the order n_{min} of a minimal (controllable and observable) state-space realization of $H(s)$. It is of interest, therefore, to develop efficient methods to determine an irreducible MFD.

One method for obtaining an irreducible MFD is to find and remove the greatest common right divisor (gcrd) of $\{N,D\}$. We have constructed a generalized resultant matrix that tests the coprimeness of $\{N,D\}$ and leads to a simple algorithm for calculating their gcrd.

We have also developed another approach that produces a fast and numerically advantageous algorithm. This algorithm can be used for finding the canonical minimal state-space realization from a given transfer matrix and for solving the "minimal design" problems.

e. New Results on 2-D Systems Theory, 2-D Polynomial Matrices, Factorization, and Coprimeness (M. Morf, B. Levy, S. Kung)

In recent years, linear system theory has been applied intensively to estimation and control. At the same time, image processing has attracted increasing interest, and attempts have been made to extend the techniques of systems theory to multidimensional problems either from a polynomial (input-output) or state-space (internal) point of view. Our first results are centered around polynomial descriptions of systems. The concept of minimality relating to state space requires the theory of coprimeness of 2-D polynomial matrices. For this purpose, we have extended the existing 1-D results obtained from gcrd (greatest common right divisor) extraction, Sylvester resultants, and matrix fraction descriptions (MFD) to the 2-D matrices. We have also obtained results that appear to be unique for multidimensional problems, such as the existence and uniqueness of "primitive factorizations" in addition to general factorizations.

f. State-Space Models for 2-D Systems Controllability, Observability, and Minimality-Realization and Implementation (M. Morf, S. Y. Kung, T. Kailath, B. Levy)

We have analyzed state-space models for 2-D systems from both the algebraic point of view of Nerode equivalence and from the standpoint of hardware implementation of 2-D transfer functions. A major difference between 1-D and 2-D systems is that, in the 2-D case, a global state and a local state can be introduced. We prove also that the local state can be decomposed into a vertical and horizontal state that can be propagated horizontally and vertically by first-order difference equations.

We have also compared the different state-space models proposed by previous authors, using what we consider to be correct definitions of state controllability and observability and their relationship to the minimality of 2-D systems. In addition, we have achieved new implementations of 2-D transfer functions through a minimal number of dynamic elements.

II. DIGITAL SYSTEMS

A. Project 6961. LSI MULTIPROCESSORS

Principal Investigators: M. J. Flynn, J. F. Wakerly
Staff: R. Cutler, D. Davies, R. Lee, L. Widdoes

1. Objective

The purpose of this study is to advance multiprocessor architectures suitable for implementation by large-scale integration (LSI) components such as microprocessors.

2. Current Status of Work

a. Minerva--A Multimicroprocessor Network (L. Widdoes)

There has been no change in project status since the last report. Construction and debugging are still under way. The structure and goals of the system have been published in the literature.

b. Microprocessor Reliability Improvement by Triplication (D. Davies, J. Wakerly)

The work on triplicated microprocessors has been completed and reported. An offshoot of this research is "Synchronization of Redundant Processes."

c. Synchronization of Redundant Processes (D. Davies, J. Wakerly)

Classical studies of reliability improvement, using massive redundancy such as triplication, have assigned synchronous operation; that is, all three copies of the system must be synchronized to a common clock. A common clock, however, introduces the possibility of a single failure bringing down the entire system. In addition, triplication cannot be applied in the traditional manner to the clock itself because it is inherently an asynchronous rather than synchronous circuit.

The problem extends far beyond the "micro" level of clock circuits. For example, there are software schemes for replicating entire

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programs and matching program outputs. If one program can execute at a different speed than the others, a synchronization problem exists.

This problem is being studied. We have demonstrated that it is impossible to synchronize three redundant processes reliably if one is faulty unless one can bound the minimum and maximum computation time of the nonfaulty processes. Work is continuing on characterizing the bounds and specifying arbitration procedures.

d. Design of a Self-Checking Minicomputer Based on LSI (J. Wakerly, R. Cutler)

The data paths for a self-checking processor have been designed. The data paths use a 4-bit slice architecture implemented with conventional MSI but with LSI implementation in mind. The MSI bit-slice has been constructed and tested, and control-unit design and microprogramming are under way.

e. Efficiency of Overhead Instructions (R. Lee, M. Flynn)

The design of new instruction sets and processor architectures should reflect a clearer understanding of the role of "overhead instructions" (such as program-sequence control and memory-reference instructions) in the overall efficiency of the machine organization.

The first step was a study of program-sequence control (or "branch") instructions. A proposed model of the program-control structure led to some interesting results. One application of the model resulted in the reduction of the overhead (space and time) caused by branch instructions, including the elimination of unconditional branch instructions. A more efficient internal representation of the program was also proposed.

Another application led to a general prefetch policy to accurately anticipate future instruction references, thereby reducing the overhead caused by memory references for instruction fetches and eliminating the need for backup in pipelined machines and machines with simple sequential "look-ahead" units.

A third application considered one aspect of program behavior (program entropy) and, in particular, the program's "control

uncertainty." Especially relevent to the design of instruction sets was a consequence of the definition of "control uncertainty" that enabled us to compare the speedup of program execution caused by increasing the "branch potential" of the branch instructions in the instruction set. This speedup was found to be proportional to $\log_2$ (branch potential). Under certain general assumptions of space and time, the optimal branch potential of an instruction set, with respect to the space-time product, was also determined.

f. Bounds for Maximal Parallelism (R. Lee, M. Flynn)

This is a theoretical study of the performance limits of a single program running on a large number of multiprocessors. It is known that multiprocessor efficiency is limited by program behavior.

By applying the concept of a program's "control uncertainty," certain hypotheses were proposed for the minimum expected execution time of a given invariant program and the maximal parallelism (or overlapping of execution) beyond which negligible speed improvements may be observed.

B. Project 7151. COMPUTER PERFORMANCE

Principal Investigator: E. J. McCluskey
Staff: D. J. Rossetti, F. W. Terman

1. Objective

The objective of this study is to gather and use data concerning computer-systems performance to gain new insight into computer architecture and operating-system design.

2. Current Status of Work

A set of trace programs has been developed to obtain data on computer performance. These programs provide data on operating-system and user performance for IBM Systems 360 and 370 computers. The trace programs are unique in their ability to gather data on such system functions as supervisor calls and input/output operations and also in their

capability to collect real in addition to virtual addresses. The trace data are being used for a number of purposes, including validation of models of computer systems, evaluation of new computer architectures, and studies of the effects of program modularity, interfaces, and primitive operations on system performance.

The same techniques can also be applied to the measurement of small-scale processors (specifically, microprocessors) to obtain a more detailed understanding of their resulting architectural issues. The basic characteristics of microprocessors can be analyzed (with respect to usability, cost, and performance) through a study based on the measurement of actual systems. The empirical results will provide the framework in which the fundamentals of microprocessor architectures can be understood.

a. Trace Facility (D. J. Rossetti)

A general trace facility has been implemented that traces the instruction-level operation of the IBM System 370 running with the OS/VS2 operating system. Parts of the operating system were modified dynamically so that the trace program can gain control at the signal from a special hardware attachment, called the Trace Ace, developed specifically for this project. Once in control, the trace program records the execution of up to 4000 consecutive instructions, beginning with the instruction following the hardware signal. The information gathered is transferred to an external storage medium, such as tape or disk. After tracing the instructions, the trace facility remains dormant until the next signal from the Trace Ace. The trace sample is limited to 4000 instructions so as to limit the main storage buffer space to a reasonable size and to avoid excessive domination of processor time caused by tracing overhead.

The Trace Ace is a variable-rate periodic timer that provides the external stimulus required to obtain the trace data. Through a simple hardware modification, the timer signal closes a switch and causes an interrupt. The interrupt is recognized by the trace program, which begins the operation. The Trace Ace then resets for the next time signal or tick. The interval between ticks (one second to a few minutes) is determined by a setting on the Trace Ace.

The tracing system has been demonstrated to be stable, and it has been used to create trace tapes of the execution of representative jobs. Examples of the application of the trace data are

- opcode frequency counts
- costs of different supervisor functions
- use of supervisor functions
- distribution of execution cycles among supervisor and various user tasks

A technical report entitled, "The Design and Implementation of an Operating System Tracer" is being prepared for publication. It describes the unique aspects of the tracer, provides some examples of its use, and recommends further applications of both the data and the technique.

b. Memory Interleaving (F. W. Terman)

A model of interleaved memory systems for IBM Systems 360 and 370 architecture has been investigated by means of a trace-driven simulation. This model extends the one developed by Burnett and Coffman [1] to include variable-length instructions and operands and multiple word transfers per memory access.

Memory requests for the simulation are obtained from two sets of instruction-by-instruction trace records. The first set, produced by the program TRACE/360 written by Terman, traces the problem state component of typical scientific programs running on the IBM 360/370. The second set, produced by the program STRAP/370 written by Rossetti, traces samples of the total activity of the CPU, including supervisor state in addition to problem state.

The theoretical predictions of Burnett and Coffman were found to fit well with the simulation results obtained for the fetching of instructions. For the transfer of operands to and from memory, however, the simulation results show only one-half the increase in the memory bandwidth predicted by the Burnett-Coffman analysis. This indicates

that data references on the IBM 360/370 are not random in the way assumed by Burnett and Coffman.

This investigation of memory interleaving is being extended to include the effects of interference between the channels and the CPU and between multiple CPUs. Future investigations will include the reduction in realizable memory bandwidth as a result of the interdependencies between operands and instructions and the increase in memory bandwidth possible when memory requests are reordered.

Reference

1. G. J. Burnett and E. G. Coffman, Jr., "A Study of Interleaved Memory Systems," Proc. AFIPS Spring Joint Computer Conf., 36, AFIPS Press, Montvale, New Jersey, 1970, pp. 467-474.

C. Project 7181. THE 2000 TERMINAL COMPUTING SYSTEM

Principal Investigator: V. Cerf
Staff: W. Warren

1. Objective

The purpose of this project is to investigate the possibilities, requirements, capabilities, limitations, and advantages of a computing system serving a very large number of users. Computer and communication networks linking potential users over a large geographic area make possible a computing system with an active user population of several thousands. Functional, rather than general-purpose, multiprocessing may make such a system possible. Such a system could realize a number of economies of scale and specialization and could provide reliability through modularity and redundancy. We propose to investigate the fundamental architectural requirements, limitations, functional organization, and specialization of these systems, the software requirements in a network environment, and the functional characteristics of the user interface (both hardware and software).

2. Present Status of Work

In our investigation of system architectures feasible for use in a 2000 terminal computing system, we have arrived at a distributed

network of fully interconnected microprocessors. The microprocessors will be individually allocated to the functional tasks of terminal-I/O modules, common memory modules, and the general-processing modules. Each module will contain local memory, processing power, and a communication interface to provide, via microwatt radio, a complete interconnection network [1]. This interface will handle module-module packet communications protocol, using the carrier sense multiple-access technique developed for the ALOHA system [2,3].

One feature will be the fast response time seen by the terminal users. Each terminal connected to the system will have its own dedicated terminal-I/O module attending to line control, formatting, and echoing [4]. Another significant feature would be the potential for hardware reliability, implicit when multiple copies of each hardware structure exist. With appropriately designed software, such a system would be able to cope with the complete failure of one or more hardware modules, resulting in only a minor degradation of response time. This type of reliability will be obtained through the same methods and techniques used by Pluribus [5]--duplication of hardware, isolation between independent hardware modules, and a software system that performs self-consistency checking and recovery.

During this last reporting period, we have investigated the problems of recovering error-free information when a faulty hardware module is detected. If an error is detected at some point during the processing of a task, it may be necessary to amputate the faulty module, reconfigure the hardware environment, and rerun the task that failed. The state of the system (including data structures that became invalid) must be restored to a previously consistent state so that the task can be run again.

A system architecture was investigated that would permit systematic recovery after the occurrence of an error and the restoration of erroneous data. Algorithms were developed to perform state restoration, thereby minimizing the recovery overhead cost and the total expected task-execution time. The model used for these algorithms provides for recovery of the program state, revoking of erroneous outputs, and restoration of external data structures.

Further areas of research will extend these recovery techniques to handle those problems that may occur during the concurrent asynchronous interactions between the multiple hardware modules and to the organization of the operating system required to provide this fail-soft reliability.

References

1. R. Okano, "Preliminary Design Considerations for a Multi-Microprocessor System," University of Hawaii, 1974.

2. N. Abramson, "The Aloha System," AFIPS Proceedings, 37, Fall 1970.

3. L. Kleinrock, "Random Access Techniques for Data Transmission over Packet-Switched Radio Channels," National Computer Conference, 1975 Proc.

4. P. C. Heckel and B. W. Lampson, "A Terminal-Oriented Communication System," BCC-500, Sep 1975.

5. S. M. Ornstein, W. R. Crowther, M. F. Kraley, R. D. Bressler, A. Michel, and F. E. Heart, "Pluribus - A Reliable Multiprocessor," National Computer Conference, 1975 Proc.

III. INTEGRATED CIRCUITS

A. Project 4606. PRECISION CHEMICAL MACHINING OF SINGLE-CRYSTAL SILICON

Principal Investigator: J. B. Angell
Staff: S. Terry, P. Barth

1. Objective

This project was established to perfect techniques for fabricating thin films of single-crystal silicon (5 μ or less), using chemical preferential etching. This work has resulted in a new dielectric isolation technique for silicon that has several advantages over other isolation techniques. The new method allows greater device density than does junction isolation in bulk silicon and maintains a functional advantage over silicon-on-sapphire by providing both MOS and bipolar capabilities.

2. Current Status of Work

The processing sequence now in use to obtain dielectrically isolated devices is described below.

On a silicon wafer heavily doped with arsenic ($3 \times 10^{19}/cm^3$), a 5 μ epitaxial layer is grown by the two-step epitaxial technique that minimizes autodoping and produces a sharp transition from heavy to light doping (Fig. 1a). A thermal oxide is grown on this epitaxial layer, and a layer is deposited as a "handle" for later processing.

The wafer is chemically etched in a preferential etch (1HF: $3HNO_3$:$8CH_3COOH$) that removes the heavily doped starting substrate but leaves 4 μ of the lightly doped epi layer (Fig. 1b). The exposed surface is then oxidized.

A masked etch with KOH establishes islands of silicon that will later become active devices (Fig. 1c). The oxide, used as the KOH etch mask, is stripped from the surface, and another oxide is grown to insulate the entire surface, including the sloping walls of the islands.

A masking step defines the contact holes, and a 1 μ poly-Si layer is deposited. Another masking step defines a pattern in this thin

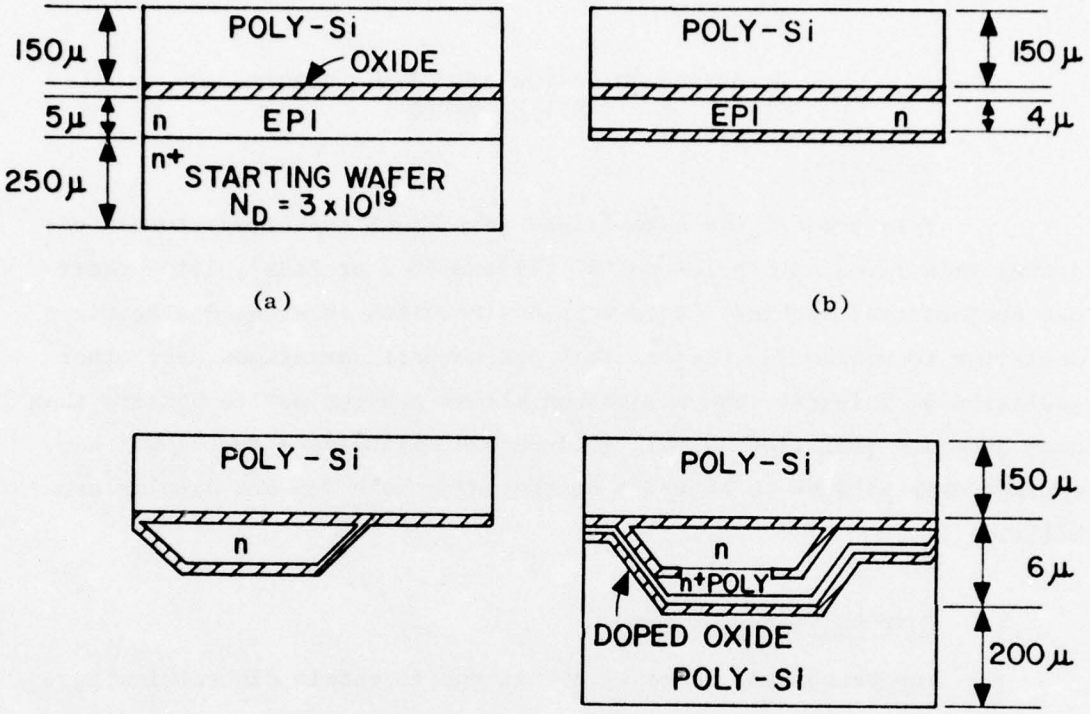

Fig. 1. STEPS IN THE DIELECTRIC ISOLATION PROCESS.

layer (Fig. 1d). An oxide, heavily doped with arsenic, is next deposited over the entire surface and is "capped" by a layer of undoped oxide. A thick (200 μ) layer of poly-Si is then deposited at 1180°C as a supporting substrate for the end structure. During this step, the As-doped oxide acts as a diffusion source that lowers the resistivity of the thin poly-Si layer.

The original 150 μ layer of poly-Si is etched away, exposing the original epitaxial surface (Fig. 1e). Three more photomasking steps (the base diffusion need not be a masked diffusion) suffice to form the bipolar transistor structure by standard predeposition and drive-in steps followed by contact hole definition and aluminum deposition and etching.

This three poly-Si layer (tri-poly) process has the following advantages over competing technologies.

- Complete dielectric isolation eliminates most of the parasitics associated with bulk silicon devices.
- A buried conducting layer of poly-Si effectively provides three levels (aluminum, base diffusion, and poly-Si) of crossover and interconnection, plus low-resistance contacts to NPN transistor collectors.
- Device geometries are smaller than those available in the Fairchild ISOPLANAR process and are in combination with partial self-alignment features similar to those of the ISOPLANAR and ISOPLANAR II processes without the long oxidation times required by both of these processes.
- Any mechanical lapping operation, which would decrease control of thickness and reduce yield, is not necessary. With preferential etching rather than mechanical lapping, thickness is controllable to ±1 μ.
- Lifetime and mobility are comparable to those in bulk silicon and permit the formulation of both bipolar and MOS devices, as opposed to silicon-on-sapphire where only MOS devices are possible. In addition, the high mobility leads to shorter transit time in MOS tri-poly devices than in SOS devices.

B. Project 5012. IC PROCESS DESIGN AND COMPUTER MULTILAYER SEMICONDUCTOR DEVICE ANALYSIS

Principal Investigator: R. W. Dutton
Staff: M. Rodoni, D. B. Estreich

1. Objectives

Computer methods were developed to predict impurity profiles after processing, and physical parameters related to impurity diffusion were calculated.

Improved models will be developed for the prediction and simulation of multilayer semiconductor device behavior based on layout and device processing history.

2. Current Status of Work

a. IC Process Design (M. Rodoni)

This segment of Project 5012 is complete. Work will continue, however, on distributed-device modeling.

b. Device Modeling (D. B. Estreich)

During this past reporting period, the following major accomplishments have been realized:

- development and application of an extended integrated injection logic (I^2L) macromodel which now includes all current-dependent transport parameters [1,2]
- fabrication of special complementary MOS (CMOS) latch-up test structures to allow separation of the relevant transport parameters associated with p-n-p-n paths

The I^2L macromodel and CMOS latch-up work are a continuation of the work described in the last Status Report.

An I^2L macromodel, previously developed [1], modeled the lateral interactions between adjacent I^2L gates and within the gate itself; however, this version was limited to computer simulation of I^2L at low-current operating levels. An extended I^2L macromodel [2] models the complete current dependence of the current gains of both the multiple

n-p-n and lateral (injector) p-n-p transistors within the gate. The key element in the correct modeling of the current gains is the inclusion of the base resistance with the proper partitioning. It is important to be able to model the high current falloff characteristics of the n-p-n current gains because this factor has proven to be the major limitation in the fan-out of I^2L.

Recent work has been involved with the identification and analysis of latch-up paths within CMOS integrated circuits and related merged structures. Experimental results suggested that a one-dimensional analysis was not adequate for accurate latch-up modeling. Further testing with specially fabricated latch-up test structures has not only reaffirmed this statement but has indicated that, in many cases, the parasitic lateral p-n-p transistor participating in CMOS latch-up is a "field aided" structure. This field-aiding feature can greatly enhance the current gain of the p-n-p, thereby making some CMOS layouts more susceptible to latch-up. Three specific areas are being emphasized:

- behavior and modeling of the field-aided lateral p-n-p transistor
- development of electrical measurement techniques necessary for both static and dynamic nondestructive testing of latch-up susceptibility and parameter extraction
- methods for analyzing the lateral spreading resistance in CMOS structures, which will allow the necessary forward-bias conditions to occur for regeneration

References

1. D. B. Estreich, R. W. Dutton, and B. W. Wong, "An Integrated Injection Logic (I^2L) Macromodel Including Current Redistribution Effects," IEEE J. Solid-State Circuits, SC-11, Oct 1976.

2. D. B. Estreich and R. W. Dutton, "Integrated Injection Logic (I^2L) Modeling," to be presented at the 10th Annual Asilomar Conference on Circuits, Systems, and Computers, Pacific Grove, Calif., Nov 1976.

IV. SOLID STATE

A. Project 4730. PROTON-ENHANCED ANNEALING OF SUPERCONDUCTORS

Principal Investigator: J. F. Gibbons
Staff: J. R. Anderson

1. Objective

The purpose of this research is to determine whether the proton-enhanced annealing process can be used to cause an amorphous-to-crystalline phase transition in A-15 superconductors such as Nb_3Sn.

2. Current Status of Work

Superconducting alloys such as Nb_3S_n are advantageously evaporated onto sapphire substrates held at temperatures in the range of 380°C. At this temperature, the stoichiometry of the evaporated film is retained; however, the film is amorphous and requires annealing at elevated temperatures (650° to 750°C) to promote a transformation to the A-15 crystal phase. The phase transformation is important because the material exhibits a critical temperature of only 5° to 7°K as evaporated whereas, in the A-15 phase, the material can have a critical temperature as high as 17°K.

Normally, the annealing that is necessary to promote the amorphous-to-crystalline phase transition is accomplished at 700° to 750°C where the differential evaporation of Sn from the film is high enough to destroy the stoichiometry achieved during film preparation. To circumvent this problem, proton-enhanced annealing was used in an attempt to cause amorphous layers of Nb_3Sn to crystallize into the A-15 crystal structure at low (~600°C) temperatures. Films with superconducting critical temperatures of 7°K were heated to 600°C and then were bombarded with a 100 na/cm^2 proton beam at an energy of 100 keV for 1/2 hr. The result was an increase in T_c from 7° to 14°K. An increase in the substrate temperature to 650°C during bombardment resulted in a final T_c of 16°K. This is essentially equal to (but not better than) the highest values of T_c that have been obtained by conventional thermal annealing cycles.

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B. Project 5244. STUDIES OF HIGH-TRANSITION SUPERCONDUCTORS SUCH AS V_3Si AND Nb_3Sn AND DEPTH PROFILING OF $Al_xGa_{1-x}As$-GaAs HETEROJUNCTIONS

Principal Investigator: W. E. Spicer
Staff: I. Lindau, J. Miller, C. M. Garner

1. Objectives

This project is involved in two separate areas of research. The first is to explore the electronic structures of type-II (hard) superconducting alloys, particularly the structure of Nb_3Sn to determine such parameters as valence bandwidth which is important to the theoretical models of superconductors.

The second is to study the chemical interface between $Al_xGa_{1-x}As$ and GaAs in this heterojunction system, particularly the chemical width of the junction and surface morphology of the interface for various aluminum concentrations ($0.3 \leq x \leq 0.85$) grown by several techniques.

2. Current Status of Work

a. High-Transition Superconductors (I. Lindau, J. Miller)

Samples of pure Nb sputter deposited on a sapphire surface were supplied and prepared by Bell Laboratories and sealed in helium-billed glass ampules for transport. The samples were studied by ultraviolet photoemission spectroscopy, and argon-ion milling was used to remove surface contamination. The samples yielded results that were indicative of a contaminated metal surface, indicating the necessity for in situ preparation.

New equipment made available for this work now allows us to perform high-temperature heating, argon-ion milling, Auger electron spectroscopy, and photoelectron spectroscopy in the same chamber. A Nb single crystal has been studied and, coupled with Auger electron spectroscopy, has indicated that carbon, nitrogen, and oxygen are the principal contaminants.

The current activity is directed toward the removal of these contaminants from the Nb surface. After preparing a clean surface, the formation of Nb_3Sn will be attempted. The Sn will be evaporated onto the clean Nb surface in situ and subsequently will be diffused into the

Nb. This will result in Nb_3Sn crystallites forming at the surface. The sample, still in ultrahigh vacuum, may then be characterized through ultraviolet photoemission spectroscopy with the analyzer available in this chamber.

b. Depth Profiling (C. M. Garner)

Samples grown by liquid phase epitaxy with $x = 0.43$ were prepared and studied through depth profiling (ion milling with Auger electron spectroscopy). It was found that the interface width of the samples varied from 170 to 250 Å, with three of six samples exhibiting a width of 170 Å. In addition, samples with $x \approx 0.8$ have been found to have a chemical junction width of $\approx 200 \pm 50$ Å.

Current activities are directed toward studying the morphology of the interface to determine the roughness of the interface and examining the chemical environment of the Al, Ga, and As in the interface region with the Auger peaks. We plan to study these interfaces grown by molecular beam epitaxy at a lower temperature and analyze the differences between the interfaces resulting from the different growth technique.

V. RADIOSCIENCE

A. Project 3476. DEVELOPMENT OF AN AUDIO-TRACKING FILTER/ANALYZER

Principal Investigator: R. A. Helliwell
Staff: E. Paschal

1. Objective

Variable frequency narrowband VLF signals in the magnetosphere are difficult to analyze. At present, we record VLF signals at field stations and process the recordings at Stanford, using a spectrum analyzer to generate photographic spectral records. It is difficult, however, to determine the amplitude of individual signals in the filmed spectra. One solution is to use a frequency-tracking filter that can follow the changing frequency of an individual signal and separate it from other signals present in the tape-recorded data so that its amplitude as a function of time can be measured. The purpose of this project is to develop such a filter, capable of tracking signals over the range from 50 Hz to 30 kHz. The filter will have selectable bandwidths from 10 Hz to 1 kHz wide and will be capable of tracking signals that change frequency at rates up to 20 kHz/sec.

2. Current Status of Work

The design of the system is approximately 90 percent complete, and the construction is 70 percent finished. We estimate that another two man-months will be required to complete the project. Because the project leader (E. Paschal) will be working in the Antarctic from October 1976 until March 1977, the project should be finished sometime in May 1977.

The tracking filter uses a local oscillator and mixer to translate the input-signal spectrum into the passband of an IF filter with a center frequency of 100 kHz. The output of the filter is then fed to a frequency discriminator whose output controls the LO frequency to cause the system to follow the input-signal component as it changes frequency. The tracking filter system can be divided into two parts--the IF filter and discriminator assembly and the local oscillator and track-control assembly.

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a. IF Filter and Discriminator Assembly

The IF filter uses conventional analog techniques to filter the input signal; actually, several filter elements are used in series. The input signal at 100 kHz is run through a three-pole Butterworth filter with a bandwidth of 3 kHz and is then mixed with a 70 kHz tone. The 30 kHz difference spectrum is then filtered with another three-pole filter with a 1 kHz bandwidth, and the output is translated down to 10 kHz. This process is repeated with successive filters with bandwidths of 300, 100, and 30 Hz and finally with a 10 Hz bandwidth filter centered at 300 Hz. System bandwidths of 10, 30, 100, 300 Hz, and 1 kHz are obtained by selecting the output of the appropriate filter. Each filter has a matching discriminator, and the output of the selected discriminator is used to control the local oscillator. The IF filters and discriminators employ temperature-compensated L-C resonators.

This multiple-conversion approach makes it possible to build a variable bandwidth filter with a given (input) frequency without resorting to crystal resonators which would be required if all the filtering were to be done at 100 kHz. The spurious response to out-of-band signals should also be less than with a crystal filter. The IF filter and discriminator assembly are nearly one-half completed.

b. Local Oscillator and Track Control

This part of the system uses all digital circuits and has been the most interesting segment of the design. To track a signal, the local oscillator is set to such a frequency that the signal, when it appears, will be translated into the passband of the IF filter. The LO frequency runs from 100 to 130 kHz. It is necessary to set the initial frequency of the LO with sufficient accuracy so that the translated signal is within the passband of the IF filter; with a filter bandwidth of 10 Hz, this means that the oscillator must be set within ± 5 Hz of the correct frequency. Because such accuracy at a frequency of 100 kHz was deemed beyond the ability of an analog oscillator, a digital frequency synthesizer has been designed for the LO.

The synthesizer uses a novel form of direct digital synthesis. Its output is a square wave at a frequency from 100 to 130 kHz. The jitter in the square wave is approximately 3 nsec rms and, as a result, spurious synthesizer signals are at least 60 dB below the fundamental. (A spurious LO signal appears in the system as a spurious filter response and must be kept as small as possible.) The synthesizer can be controlled in 1 Hz steps and has an accuracy of 0.1 Hz. CMOS logic is used, and the synthesizer consumes approximately 5 W of power. Its design is apparently new and may be patented.

Using a digital frequency synthesizer for the local oscillator also simplifies the frequency and tracking-control circuits. The initial frequency-set and the frequency and slew-rate-limit circuits are all digital. The construction of the local oscillator and track-control circuits is approximately 95 percent complete.

B. Projects 3606 and 4504. MEASUREMENTS OF METEOROLOGICAL PARAMETERS IN THE LOWER TROPOSPHERE

Principal Investigators: A. M. Peterson, V. R. Eshleman, A. T. Waterman, Jr., M. Frankel

Staff: N. Bhatnager, S. J. Wernecke, R. W. Lee, R. D. Fleming

1. Objective

The objective of this research is the investigation of atmospheric parameters and phenomena in the lower troposphere, based on two different but complementary techniques--radio acoustic sounding (RASS) and radio propagation in the S- and K-bands. The goals of each method are as follows.

a. RASS (Project 3606)

- **Measuring real-time vertical temperature profiles over a 1 km (or greater) range, using both RASS and conventional techniques.**
- **Obtaining temperature profiles over extended periods of time and through varying meteorological conditions.**

- Monitoring atmospheric phenomena continuously (with sampling periods of less than 5 min).

- Extending the lower bound on the RASS measurement range from ~400 to $\leq$100 m.

b. Tropospheric Radio Propagation (Project 4504)

- Probing the structure of winds and turbulence in the lower troposphere under various conditions of atmospheric stability and instability.

- Measurement of wind velocity in the common volume of a transhorizon troposcatter propagation path through doppler techniques.

2. Current Status of Work

a. RASS (Project 3606)

During the past six months, our research has been directed toward analytically evaluating the performance of a RASS terminal in a nonideal environment. This analysis has been motivated by the fact that all previous work examined the RASS in a static environment (one characterized by no winds or turbulence). The current study relaxes these unrealistic environmental constraints and considers a model wherein atmospheric turbulence, winds, and the RASS acoustic frequency are all variables. The only assumption made is that the EM wave is not affected by stochastic perturbations of the atmosphere.

The principal topic being considered is the coherency of a vertically propagating acoustic wave. This coherency, in and between wavefronts of the acoustic pulse, is being investigated through a perturbation-theoretic method and Feyman's diagramatic technique. The results will be used to evaluate the strength of the electromagnetic signal scattered from the acoustic pulse train.

Preliminary results indicate that the performance of the RASS, which operates at an acoustic frequency of 85 Hz, is not affected by atmospheric turbulence over ranges on the order of several kilometers. It was found, however, that mean horizontal winds shift the focus of the reflected electromagnetic energy from its origin, resulting in a decrease

in the received signal level when a monostatic RF system is used. For a bistatic radar configuration with space-diversified receiving antennas, the shifting of the acoustic pulse makes possible the remote measurement of the horizontal wind component.

An additional outcome of the above analysis is a correction factor that allows us to temperature profile down to 100 m. Past experiments with the RASS indicated that a system limitation was its inability to measure temperatures at heights (h) of $0 \leq h \leq 400$ m. This problem was the result of the bistatic radar configuration being used which introduces large uncertainties in the temperature data at low altitudes. By applying the correction factor to data within the $100 \text{ m} \leq h \leq 400$ m range, however, we have found very good agreement (for $h \geq 100$ m) between RASS temperature measurements and data obtained by conventional techniques.

During the next reporting period, we plan to experimentally verify our theoretical results and to extend our analysis to RASS systems operating at higher acoustic frequencies.

b. Tropospheric Radio Propagation (Project 4504)

As outlined in the last Status Report, the wind-measuring technique is to involve the simultaneous reception of 3-GHz CW signals on each of two narrow beams from a transmitter located 100 miles away (beyond line-of-sight). The two beams are aimed on either side of the great-circle bearing toward the transmitter by small amounts (1° or less). If there is a wind component transverse to the path in the region of the common volume, it is anticipated that the signal received on one beam will be doppler shifted to higher frequencies and the signal on the other to lower frequencies. The magnitude of the doppler difference should be proportional to transverse-wind velocity. The two beams will be formed during the data-reduction procedures because the receiving antenna is a sampling array that measures and stores on digital tape the amplitudes and phases of the signal as received on 12 individual antennas. To obtain high resolution in azimuth, the antennas are arranged in a horizontal linear array.

The linear array to be used is an array of 12 4-ft parabolic dishes mounted on a 70-ft tower. The tower had been used in previous experiments in a vertical position. For the current work, it was necessary to move the tower from a vertical to a horizontal position. In addition to other equipment preparation, this move consumed many of the available funds. As a result, there has been only a modest amount of activity during the last six-month period. Most of the equipment, however, has been checked out and is in satisfactory operating condition. We expect to resume activity during the coming months.

VI. PLASMA PHYSICS AND QUANTUM ELECTRONICS

A. Project 1328. VERY LONG DELAYED RADIO ECHOES

Principal Investigator: F. W. Crawford
Staff: R. J. Vidmar, T. L. Savarino

1. Objective

There is evidence indicating that radio signals can occasionally be returned from the ionosphere with delays of the order of tens of seconds, rather than the few milliseconds corresponding to direct reflection. The objective of this project is to develop a theoretical explanation of this phenomenon.

2. Current Status of Work

Earlier theoretical studies [1] have suggested the following plausible mechanism for long-delayed echoes. When an ordinary wave from the transmitter reaches its reflection point, near the peak of the F-layer, it is partially converted into a longitudinal plasma wave. This wave is amplified by energetic electrons precipitating down Earth's magnetic field lines, and propagates with very low group velocity ($\approx$1 km/sec) over a distance of several kilometers. The longitudinal plasma wave is partially converted into a transverse electromagnetic wave as it propagates down the ionospheric electron-density gradient, and this wave propagates to the receiver.

The work performed during the reporting period was directed towards an understanding of the process by which the amplified longitudinal plasma wave is coupled to a transverse electromagnetic wave which can propagate out of the ionosphere. Specifically, the coupling into an ordinary wave has been studied in the region $\omega \approx \omega_p$, near the ordinary wave reflection point. Coupling between these wave modes is assumed to occur as a result of Earth's magnetic field, and an inhomogeneity in the ambient electron density. Even with a simple model of this amplified longitudinal wave, significant coupling into the ordinary wave is predicted, confirming preliminary estimates made in the last reporting period. The next step will be to develop a model of the mechanism that

couples energy into longitudinal waves from the electromagnetic waves produced by the ground transmitter.

Reference

1. D. M. Sears, "Long Delayed Echoes," Stanford University Institute for Plasma Research Report No. 584, Stanford University, Stanford, Calif., Nov 1974.

B. Hansen Laboratories. TWO-PHOTON RESONANTLY PUMPED IR UP-CONVERTERS

Principal Investigators: S. E. Harris, J. F. Young
Staff: E. A. Stappaerts, J. H. Newton

1. Objective

The goals of this project are the development and extension of efficient IR up-conversion techniques in metal vapors, particularly image up-conversion.

2. Current Status of Work

During this period, we have demonstrated the up-conversion of 2.9 μm IR images to 4550 Å in Cs vapor. A power conversion efficiency of 20 percent with over 1000 resolvable spots was achieved using a pump power of only 8 kW. The pumping laser, Nd:lanthanum berylate, has a natural two-photon coincidence with the Cs $6s^2S$-$7s^2S$ transition, resulting in a simple practical system with a number of potential applications. Other attractive features include scalability to large apertures and collection angles and the ability to withstand high-incident power densities without damage. Additional details of this work are described in Ref. 1.

The design optimization of this type of image up-converter was calculated and is also described in Ref. 1. Based on that work, we are planning and constructing a new experiment to provide ~10^4 resolvable spots and to determine experimentally the optimal running parameters. This device will require the solution of a number of serious technical problems.

Reference

1. E. A. Stappaerts, "Infrared Image Up-Conversion in Alkali Metal Vapors," G. L. Report No. 2569, Edward L. Ginzton Laboratory, Stanford University, Stanford, California.

Appendix A

OUTSIDE PUBLICATIONS

1. Papers Presented at Meetings

Information Systems

Cover, T. and R. King, "A Convergent Gambling Estimate of the Entropy of English," IEEE International Symp. on Information Theory, Ronneby, Sweden, Jun 1976.

Goodman, J. W. and J. F. Belsher, "Fundamental Limitations in Linear Invariant Restoration of Atmospherically Degraded Images," presented at the Society of Photo-Optical Instrumentation Engineers, Washington, D.C., 22-23 Mar 1976; also to appear in the Proc. of the SPIE.

Gray, R. and M. B. Pursley, "Continuous Time Source Coding Theory," IEEE International Symp. on Information Theory, Ronneby, Sweden, Jun 1976.

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Appendix B

ABSTRACTS OF REPORTS PUBLISHED DURING THIS PERIOD

This appendix is a compilation of abstracts of reports issued by the Stanford Electronics Laboratories (SEL).

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A FREQUENCY-TRACKING
DIRECTION FINDER FOR
WHISTLERS AND OTHER VERY
LOW FREQUENCY SIGNALS
by Mark Keith Leavitt

Nonr N00014-67-A-0112-0012
NSF Grant DES-07707
NSF Off. of Polar Programs
Grant GV-41369X
TR No. 3456-2
December 1975

ABSTRACT

Whistlers and related very low frequency radio signals are guided in ducts of enhanced or reduced ionization along the geomagnetic lines of force of the earth's magnetosphere. The signals convey information about the distribution of particles in the plasma through which they have propagated and about the occurrence of wave-particle interactions in the magnetosphere. Direction-finding on such signals will aid in locating the ducts and measuring their temporal drifts, thus making an important contribution to studies of magnetospheric convection.

The signals, although narrowband in nature, exhibit wide frequency excursions in the 1 to 10 kilohertz range. An innovative technique is presented for tracking these frequency excursions in real time to produce a filtered, quasimonochromatic version of the signal. The voltages induced by the incident wave on two orthogonal loop antennas and a vertical monopole antenna are processed by this method. The filtered signals are then cross-multiplied in a manner analogous to a Poynting vector calculation to obtain a continuous indication of the wave direction of arrival.

The design, construction, and laboratory testing of a prototype instrument are described. Field testing of the instrument was performed at Stanford, California, and Roberval, Quebec, Canada. Operating at fixed frequencies, the direction-finder produced accurate results on VLF transmissions in the 10 to 20 kilohertz range from NAA, NPG, GBR, and the Omega stations. Well defined bearing indications were also obtained for spherics at frequencies in the 1 to 10 kilohertz region. Successful frequency-tracking and direction-finding were demonstrated for a wide variety of whistler-mode signals, including whistlers, chorus, and discrete emissions. The technique was also successfully applied to emissions in the 2 to 7 kilohertz range stimulated by the VLF transmitter at Siple Station, Antarctica.

Direction of arrival indications on whistlers were consistent with the duct positions predicted by frequency profile analysis. Evidence

was also presented of temporal changes in the direction of arrival of signals which may be an indication of duct drifts.

This instrument provides, for the first time, a continuous, immediately readable record of the direction of arrival of whistler-mode signals. It could also be applied to the automatic acquisition of whistler-mode signals and measurement of their amplitude and frequency variations.

ION IMPLANTATION IN
CADMIUM TELLURIDE
by John Condon Bean

NSF Grant GH 31999
TR No. 4733-3
January 1976

ABSTRACT

The effects of ion implantation doping in CdTe have been investigated using the complementary tools of transmission electron microscopy (TEM) and electrical evaluation. Modification of an acid jet thinning technique has allowed CdTe samples to be reduced to the 1000 Å thickness required for TEM. The technique has permitted the first comprehensive analysis of the submicron size defect structure of CdTe. TEM data may be summarized as follows: 1) defect species have been cataloged and their concentrations correlated with infra-red absorbtion properties; 2) it was found that long cadmium vapor anneals could sharply reduce dislocation densities and promote the dissolution of tellurium precipitates; 3) it was shown that heavy ion irradiation produces 50 Å diameter dislocation loops in CdTe. Upon annealing, mean loop size grew while concentrations decreased. The annealed loops were identified as ⟨111⟩ orientation vacancy loops. It was shown that if loops were assumed to consist of a deleted cadmium plane that the observed dissolution would imply substantial liberation of electrically active acceptor defects.

Electrical measurements were used to investigate the doping effects of a number of ions. Earlier arsenic implantation work was expanded upon, effects of implantation and anneal temperatures investigated, and krypton damage and heated control samples added. It was found that both arsenic and krypton produced acceptor-like doping for post-irradiation anneals between 400 and 600°C. It was suggested that experimental data could be explained by the radiation-induced formation of electrically active defects rather than by substitutional impurity doping. The results of cadmium and tellurium implantation experiments supported such an explanation. A doping model was proposed involving the liberation of cadmium vacancy acceptors from radiation induced loops. The model explained the results of experiments in this and other laboratories. The possibility of cadmium vacancy formation also suggested the use of a column I dopant which, unlike arsenic, should naturally fill a cadmium vacancy site. Implantation with the column IA element cesium produced acceptor doping. The electrical activity did not exhibit the reverse anneal seen in earlier experiments and strong doping occurred.

This study concludes with a brief investigation of ion implantation's use in CdTe device applications. P-N junction formation was demonstrated for both arsenic and cesium implantations. Despite similarities in dark I-V characteristics, it was shown that cesium implanted diodes display superior current collection capability when exposed to simulated solar illumination. TEM data suggested that the superiority could be due to the higher anneal temperature permitted by cesium doping. Device proposals incorporating thin CdTe layers suggested ion implantation experiments in epitaxial films. A CSVT epitaxial growth apparatus was built and film quality investigated with the scanning electron microscope. Finally, single crystal films were implanted with both arsenic and cesium ions. Both the ions produced p-type doping, and under suitable annealing conditions cesium implantation resulted in high mobilities and carrier concentrations equivalent to ion doses.

ABSTRACT

In the first part of this paper the basic differences between the classical (placement, routing) and the topological approach to solving the circuit layout problem are outlined.

After a brief survey of some existing mathematical models for the problem, an improved model is suggested. This model is based on the concept of partially oriented graph and contains more topological information than earlier models.

This reduces the need for special constraints on the graph embedding algorithm. The models also allow pin and gate assignment in function of the layout, under certain conditions.

ULTRASONIC DOPPLER
MEASUREMENT OF RENAL
ARTERY BLOOD FLOW
by William R. Freund
and James D. Meindl

Progress Report to NASA
Grant NGR-05-020-615
TR No. 4962-2
1 Mar 1974 - 31 Aug 1975

ABSTRACT

This progress report summarizes research completed during the past three semi-annual periods, March 1, 1974 through August 31, 1975. This work provides an extensive evaluation of the practical and theoretical limitations encountered in the use of totally implantable CW Doppler flowmeters. Theoretical analyses, computer models, in-vitro and in-vivo calibration studies describe the sources and magnitudes of potential errors in the measurement of blood flow through both the renal artery, and larger vessels in the circulatory system. The evaluation of new flowmeter/transducer systems and their use in physiological investigations is reported.

A CMOS IMPLANTABLE AUDITORY PROSTHESIS USING INTEGRATED CIRCUITS TECHNOLOGY
by Tushar R. Gheewala

NIH Grant NS-10532-04
Contract N01-N-NS-5-2306
TR No. 5306-1
March 1976

ABSTRACT

This report describes an implantable auditory prosthesis which is designed to stimulate the auditory nerves of sensory deaf people in an effort to produce a sensation of sound. The prosthesis is made up of two components; one external to the body which receives the sound, processes it and generates appropriate stimulation patterns. The other component is implanted in the mastoid cavity and delivers electrical stimulations to neural electrodes according to the instructions received from the external electronics.

Presently it is believed that a single stimulation channel has a limited bandwidth of about 300 Hz. This demands multiple stimulation channels (15-20) each with a bandpass bandwidth of 300 Hz. The central frequency of each bandpass channel is determined by the location of the electrode with respect to the cochlea or the auditory nerve bundle.

To avoid any wires running across the skin which may cause infections, the power and stimulation information are transcutaneously delivered to the implantable electronics. A high Q inductively coupled radio frequency link is used to deliver power at a high efficiency. A second, low Q, ultrasonic link comprised of a transmitter and a receiver piezoelectric crystal is used for information transmission. The separation of power and data link results in high power transfer efficiency, wide signal bandwidth, low cross talk and excellent misalignment tolerance.

The information is digitally coded using a novel extended missing pulse code which exhibits low noise, ease of implementation and protection against excess or erroneous stimulations. A novel charge redistribution digital-to-analog converter and demultiplexer circuit is described which maps a single channel of digitally coded information on to multiple analog outputs. This circuit exhibits compactness and low power consumption - both very essential for the implantable electronics. A model for the accumulative error of the charge redistribution digital-to-analog converter is presented.

Complementary Metal-Oxide-Semiconductor (CMOS) logic is utilized throughout for low power dissipation, custom CMOS integrated circuits

are developed at the Stanford Integrated Circuits Laboratory which make possible the fabrication of an auditory prosthesis with a large number of output channels.

HIGH VOLTAGE DOUBLE
DIFFUSED MOS TRANSISTORS
FOR INTEGRATED CIRCUITS
by Michael Donald Pocha

NIH PHS Grant
5-PO1-GM-17940
NSF Grant NSF
ENG-74-12151
TR No. 4956-1
March 1976

ABSTRACT

Monolithic silicon integrated circuits, including double diffused MOS (DMOS) switching devices with a breakdown voltage in excess of 200 volts and the capability of conducting 3 to 5 Megahertz signals with peak currents greater than 0.25 Amps, have been fabricated for use in a unique, high resolution, real time, three dimensional, ultrasonic imaging system (ULISYS) for medical diagnosis. This dissertation presents an experimental and theoretical study of the DMOS structure, examining the electrical parameters of importance in high voltage switching applications, relating these electrical parameters to processing, structural, and material parameters and discussing the optimization of device structure and processing to obtain desired electrical behavior.

Initially, the important electrical parameters are established to be threshold voltage, breakdown voltage, on resistance, current handling capacity, and parasitic capacitances from drain-to-substrate and drain-to-source. These electrical parameters are examined in detail and related to device structure and processing. The effects of variations in processing on the controllability of threshold voltage are studied. Minimum structural requirements such as oxide thickness, epitaxial layer thickness, spacing between diffusions, and channel length for a 200 volt breakdown are considered. A new device model suitable for computer aided design has been developed that accurately predicts the current-voltage behavior over a wide range of operating conditions. This model takes into account several second order effects such as scattering limited velocity saturation, mobility reduction due to the gate electric field, and resistance of the drift region.

In addition to the main purpose--the study of the monolithic high voltage DMOS device--this thesis also includes descriptions of the structure and characteristics of a number of compatible devices which can be fabricated on the same chip as DMOS devices. These compatible devices include conventional MOS transistors, pnp and npn bipolar transistors, diodes, several resistor structures, and both MOS and junction

capacitors. Also presented, is a discussion of a typical high voltage circuit application--the level shifting circuit used in the ULISYS system. This discussion presents some of the constraints and problems that are peculiar to the design of high voltage integrated circuits. Primary among these considerations, is power dissipation. Alternate level shifting circuits to reduce power dissipation are discussed. Finally, a description of the fabrication technology is presented with emphasis on problems and constraints peculiar to the high voltage DMOS structure.

METHODS FOR THE COMPUTATION
OF A SPEECH ANALYSIS FILTER
PARAMETERS AND FOR THE
EXTRACTION OF THE PITCH
PERIOD OF A SPEECH SIGNAL
by Jean-Pierre Lelarge

Principally NASA
Grant NGL 05-020-014
In part by NASA-Ames
NCAR-745-420
TR No. 3208-4
December 1975

ABSTRACT

This is an expose of several experiments on speech waveforms using a ladder-form digital filter. The purpose of the experiments was to try and gain a better understanding of the nature of speech and to study, in a detailed manner, the performance of the ladder-form filter in the breaking down of the speech waveform into its basic characteristics. Only a few characteristics were inspected here, and the experiments carried out are only a small subset of the set of experiments that should be performed on speech waveforms using the ladder-form digital filter.

Chapter 1 gives the reader a general background in the speech analysis and synthesis techniques and theories. A speech synthesis model and two similar ways of looking at the ladder-form digital filter (which we shall hereafter refer to as LFDF) are presented. A glottal excitation period extraction technique will also be presented. Chapter 2 comparatively analyzes two various ways of computing the LFDF coefficients and proposes techniques that will enable a processor to compute these coefficients in real-time. Several solutions with various degrees of efficiency are thus presented. Chapter 3 shows the experimental results, backing up the propositions made in Chapter 2. Chapter 4 discusses a tentative way of extracting the glottal excitation (pitch) period information. The appendices contain the computer outputs related to the experiments.

I wish at this point to express my sincere appreciation to those who have helped realize this paper: Dr. Alan Peterson for his support, suggestions, and advice; Drs. A. Despain and M. Sites for their ideas and suggestions; Mr. John Burg for providing me information about his deconvolution filters techniques; Mr. M. J. Narasimha, my officemate, for frequent, sometimes daily, discussions of speech analysis and synthesis related problems; all others who had some participation, whatever it was, in this effort.

THE RESPONSE OF THE
IONOSPHERE TO THE
INJECTION OF CHEMICALLY
REACTIVE VAPORS
by Paul Alan Bernhardt

NASA Grant NGR 05-020-001
and Contract NAS 8-31769
TR No. 17
May 1976

ABSTRACT

An opening in the ionosphere may be created by the release of reactive chemicals that promote ion-electron recombination. The following sequence of events is initiated by a gas release. As the gas expands, it is rapidly cooled. If the temperature of the vapor falls below the saturated vapor temperature, some of the gas condenses. During the day, the condensate is re-vaporized by sunlight, but at night the condensed molecules remain as clusters that do not effectively interact chemically with the ionospheric plasma.

When the vapor becomes sufficiently tenuous, it is reheated by collisions with the ambient atmosphere and its flow is then governed by diffusive expansion. As the injected gas becomes well mixed with the plasma, a "hole" is created by chemical processes. In the case of diatomic hydrogen release, depression of the electron concentrations is governed by the charge exchange reaction between oxygen ions and the hydrogen, a reaction that produces positive hydroxyl ions. This latter ion rapidly reacts with the electron gas to produce excited oxygen and hydrogen atoms. Enhanced airglow emissions will result from the transition of the excited atoms to lower energy states.

Owing to the ion depletion, the remaining electrons are no longer effectively cooled by Coulomb collisions and the electron temperature in the depleted region rises sharply causing a thermal expansion of the plasma and a further reduction in the local plasma concentration. Replenishment of the plasma in the depleted region takes place in part by plasma flow from the protonosphere. Such a flow produces a tube of reduced plasma that extends into the magnetosphere and, for cases of extreme depletion, may extend into the conjugate ionosphere.

Flights of space vehicles, such as the Space Shuttle, into the ionosphere may permit the controlled depletion of the F2-layer by the injection of selected gases. Estimation of the optimum modification experiment is based on calculations of temporal and spatial characteristics of the ionospheric hole for various types and amounts of injected gas. Criteria for judging candidate gases include the amount of ionospheric plasma

depleted per unit mass of released gas, the chemical reaction rates, and the resistance to photodissociation during the day and to condensation during the night. Based on these criteria, H_2 is recommended for gas release experiments. Water vapor and carbon dioxide are acceptable for daytime releases, but lose efficiency at night due to condensation.

The amount of gas released partially determines the size and duration of the depletion. The release of 100 kg of diatomic hydrogen into the ionosphere produces an F-layer depletion lasting over 2 hours.

Measurements of the temporal variation in the spatial structure of the ionospheric hole may provide information about the dynamic processes that maintain the ionosphere. These processes include chemical dissociation, diffusion, and photoionization.

Artificially produced ionospheric holes may significantly affect radiowave propagation. During the early period of chemical modification, the hole may act as a lens that focuses or bends VHF or HF radio waves. In the later period, a few percent plasma density depression may extend over the entire geomagnetic field line. Such field-aligned irregularities may guide HF and VLF radio waves for interhemispheric propagation.

MINI-MSINC - A MINICOMPUTER SIMULATOR FOR MOS CIRCUITS WITH MODULAR BUILT-IN MODEL

by T. K. Young and
R. W. Dutton

Grant NSF ENG-74-12151
and H-P Corp. Grant
TR No. 5013-1
March 1976

ABSTRACT

This paper describes MINI-MSINC, a minicomputer simulator for MOS integrated nonlinear circuits. MINI-MSINC runs on an HP2100-Series minicomputer with 32K words of memory and simulates the nonlinear DC and transient responses of MOS transistor circuits. A test circuit of 26 transistors with 150 timepoints was simulated in 10 minutes. A modular-model program feature facilitates the alteration and replacement of semiconductor device models. Models other than MOS transistors can be implemented within the constraint of four external and two internal nodes. The structure of MINI-MSINC, the second-order MOS transistor model implemented in MINI-MSINC and a bootstrap circuit application are described.

A VERIFIED SPECIFICATION
OF A HIERARCHICAL
OPERATING SYSTEM
by Ashok R. Saxena

TR No. 107
January 1976

ABSTRACT

This thesis discusses the design, specification, and verification of computer operating systems. The operating system problem considered, the many-process problem, is the design of an operating system that can support a large number of concurrent processes. This design problem is a vehicle to investigate the use of a design methodology, the hierarchical levels of abstraction methodology; the use of structured programming techniques in the specification of the system; and the development of techniques for the verification of concurrent programs, particularly operating system programs.

A solution to the many-process problem is obtained and it is shown that the hierarchical levels of abstraction methodology simplifies the conception of the solution and helps avoid potential deadlocks in the system. A PASCAL specification of the four levels of the system is given demonstrating the usefulness of structured programming techniques for specifying operating system programs. A detailed description of the development of the simple memory manager, a complex and large segment of the system, is given to show the use of step-wise refinement for improving the efficiency of the program and as an aid in understanding its final specification. The specifications for the first two levels: simple scheduler and simple memory manager, are formally verified. The notion of exclusive access of a resource has been formalized and used in the verification of concurrent program. Sufficient conditions for verifying the absence of deadlocks in a system of monitors are also developed.

MINICOMPUTER CALCULATION
OF THE DC OPERATING POINT
OF BIPOLAR CIRCUITS
by J. Payne Freret
and R. W. Dutton

NSF Grant NSF ENG-74-12151
Hewlett-Packard Co. Grant
TR No. 5015-1
May 1976

ABSTRACT

Attempts to use large-computer circuit analysis programs on minicomputers generally result in poor or unacceptable performance due to single precision roundoff errors in the minicomputer. This paper identifies three sources of minicomputer roundoff errors and demonstrates algorithmic improvements which virtually eliminate these errors. One of these improvements is a new approach to Newton-Raphson iteration which is shown to be extremely effective. A minicomputer program incorporating the algorithmic improvements has been used to simulate ten integrated circuits, including a 741 operational amplifier. The results compare favorably with those of a popular, large-computer circuit analysis program, SPICE.

DETERMINATION OF THERMOSPHERIC QUANTITIES FROM IONOSPHERIC RADIO OBSERVATIONS USING NUMERICAL SIMULATION

by Dimitri Alexander Antoniadis

NASA Grant
NGR 05-020-001
TR No. 18
August 1976

ABSTRACT

Ground based radio-wave probing of the ionosphere is a well established method of upper atmospheric investigation. Among the prominent techniques used at present are incoherent scattering, vertical incidence sounding and transionospheric radio-wave propagation from space vehicles. The scope of the present work is the development of methods for processing data obtained by these techniques to estimate upper atmospheric quantities that cannot be directly obtained from the available data. More specifically, in the first part of this work a new numerical simulation method, based on theoretical thermospheric modeling is developed. The method is used with incoherent scatter data to determine diurnal vertical profiles of wind and corresponding pressure gradients for a day in each of the four seasons. In the second part of this work, a new numerical ionospheric simulation method is developed. The method is used to determine time dependent vertical plasma drifts (induced by neutral winds and/or by electric fields), and exospheric neutral temperatures from electron content, and peak electron concentration (N_{max}) data. Results are presented for a typical equinox day at the East and West Coasts of the U.S.A. The results are in good agreement with incoherent scatter measurements taken during the same day. In addition it is demonstrated that neutral winds can also be obtained using only electron content and N_{max} data, by coupling the thermospheric to the ionospheric simulation. Results thus obtained, are in agreement with results derived independently from incoherent scatter data.

The general conclusion from this research is that the present state of the art in ionospheric and thermospheric modeling permits the extension of radio-wave probing measurements to the study of upper atmosphere dynamics. The analysis of such data is made practical by the numerical techniques developed here. Particularly, in the case of ionospheric simulation, the simplicity of obtaining the required data coupled with the efficiency of data analysis provides an attractive new method for obtaining quantities previously observable only through incoherent scatter measurements.

THE METHOD OF SYMBOLIC
ABBREVIATED EQUATIONS
AND ITS APPLICATION TO
NON-ISOCHRONOUS OSCILLATORS
by Vyacheslav M. Bogachev

May 1976

ABSTRACT

The method of symbolic "abbreviated" equations suggested by S. I. Evtyanov, is finding increasing acceptance in EE circles. This method applies to schemes, generating almost harmonic oscillations, both single-frequency and multi-frequencies. The increasing popularity is explained, on one hand, by its simplicity and its applicability to concrete engineering problems, and, on the other hand, by allowing users to obtain the general equations of oscillators and, thereby to analyze their general properties. This paper illustrates all these advantages of the method. It presents a cross-section of examples of concrete problem solutions. We also obtain and discuss at some length the general oscillatory equations (abbreviated and characteristic). This is done for non-isochronous oscillators, containing arbitrary frequency selective systems and auto-bias circuits. A regular approach, given herein, to derive higher order approximations opens new perspectives for the method.

The paper is devoted to students, engineers and scientists interested in the theory as well as in the applications of oscillators.

DESIGN, FABRICATION AND
TESTING OF SILICON, MOLYBDENUM
AND TUNGSTEN MICROELECTRODE
ARRAYS FOR BIOSTIMULATION
by H. Dean Mercer

NSF Grant NS-10532-04
Contract N01-N-NS-5-2306
TR No. 5306-2
May 1976

ABSTRACT

The development of an auditory cochlear prosthesis for the profoundly deaf has been a major project at several medical research centers. Such a prosthesis requires microelectrodes to stimulate directly the auditory nerve with various frequencies and intensities of electrical signals. This dissertation describes the design, fabrication and testing of multi-electrode arrays that are physiologically compatible with the human auditory system: strong to avoid breakage during implantation; as thin as possible (50 μ) to give minimum insult to the nerve tissue; electrically insulated to avoid stimulation at inappropriate sites; resistant to electrolysis so that a human implant will last a minimum of five years.

The initial microprobes were constructed on silicon substrates using integrated circuit technology. Each double-sided probe consists of two sets of eight gold or platinum leads sandwiched between two insulating silicon dioxide layers. Planar photolithographic techniques are used to open stimulation sites of predetermined surface areas and interelectrode spacings. An anisotropic silicon etch procedure has been developed that allows one to etch any two dimensional probe pattern wanted and any probe thickness needed.

This dissertation further describes the fabrication of probes on molybdenum and tungsten substrates. An initial substrate preparation and cleaning procedure has been developed. The deposition and densification of silicon dioxide insulating layers on the molybdenum and tungsten substrates and over the platinum electrode leads is described. The isotropic molybdenum and tungsten etches used limit the maximum thickness of a probe to one half the width of the bottom surface of the probe.

Various experiments have been conducted using these metallic microprobes. Results of electrical characterization and initial lifetime studies are presented. However, the most challenging experiments involved the in vivo testing of the microprobes. Several auditory and electrical experiments were set up and programmed for automatic control by a PDP 8 computer. These studies included measuring the response seen by a cat's auditory system to acoustical "clicks" (100 μsec pulses) and tone bursts

(10 msec pulses of frequencies varying from 500 Hz and 8000 Hz). Further, the response of the inferior colliculus to direct electrical stimulation of the auditory nerve was determined. Representative tracings of these experiments are included as well as data interpretation correlating the responses of the electrical and acoustical stimulation studies. Finally, the threshold value for electrical stimulations was 0.23 $\mu C/cm^2$ - a factor of 10 less than previous microelectrode arrays. This indicates the inherent reduction of tissue damage possible with the microthin, planar, electrode arrays described in this paper.

SPATIALLY-FILTERED
LIDAR VELOCITY PROBES
A FEASIBILITY STUDY
by R. W. Lee

NOAA
DOT03-6-022-35170
Report 4511
July 1976

ABSTRACT

A feasibility study has been conducted to assess the utility of the application of spatial-filter techniques to pulsed laser probes for wind velocity measurement. Electronic and incoherent optical techniques are used to filter in space the response of the lidar system at each range of interest; three orthogonal alignments of the filter can be used, one parallel and two transverse to the laser beam, allowing measurement of the total wind vector. The motion of naturally-occurring aerosol inhomogeneities through the spatial filter results in modulation of the backscattered signal, the frequency of which indicates the magnitude of the appropriate velocity component. Operation of such a system at 1-km range appears possible, with the magnitude of aerosol inhomogeneity being the major unknown. The technique offers good range resolution, simultaneous measurement at many ranges without mechanical scanning, and modest data processing requirements.

ANALYSIS OF DUAL-FREQUENCY OBSERVATIONS OF INTERPLANETARY SCINTILLATIONS TAKEN BY THE PIONEER 9 SPACECRAFT
by Horen Chang

NSF Grant DES 75-00493
NASA Grant NGR 05-020-407
TR No. 3552-1
May 1976

ABSTRACT

Interplanetary scintillation data collected at Stanford during the period 1968-1973 are reported. These data were acquired by sending 50 and 423 MHz signals from Stanford to the sun-orbiting Pioneer 9 spacecraft and then telemetering results back to the earth. For the first time, the integrated electron contents along the propagation path were also simultaneously measured. The closest distance of the propagation path to the sun ranged from 0.1 to 1 A.U. Unlike noisy natural sources such as quasars or pulsars which were used in most previous experiments, our ground transmitter served as a constant-magnitude, monochromatic, point source of observation. As a result, our data are free from some inherent ambiguities contained in the majority of the previous data.

Experimental apparatus and procedures of data reduction are described in considerable detail. The so-called thin-screen diffraction model is reviewed and applied to interpret our observations, leading to several interesting and useful results. The spatial power spectrum of interplanetary inhomogeneities is found to follow a power-law variation; the mean and standard deviation of the power-law exponent are estimated to be 3.5 ± 0.13 and 0.3, respectively. This result agrees with in situ spacecraft measurements near 1 A.U. In addition, the magnitude of the temporal spectrum of electron-density fluctuations deduced from our scintillation data is also consistent with in situ measurements. Based upon the form of the observed scintillation spectra, the existence of a gaussian micro-structure in the interplanetary medium, as suggested by many other authors, is precluded. Occasionally the Fresnel structures in the scintillation spectra are observed. Eight solar wind velocities inferred from eight such structures lie between 400 and 500 km/sec.

The radial dependence of the correlation length of intensity fluctuations is shown to be compatible with the power law model of exponent 3.5. The radial dependence of the scintillation index indicates that the root-mean-square electron-density fluctuation in the solar wind is inversely proportional to the square of the heliocentric distance from the sun. The wavelength dependence of the correlation length and that of the scintillation index, nevertheless, remain unexplained.

The study of the cross-correlation between the integrated electron content and the scintillation index reveals that not only these two parameters but also their deviations from means are approximately linearly related. This suggests that scintillation observations may be employed as an efficient means for monitoring both the density and density enhancements in the regions too near the sun to be accessible to direct measurements.

In cases of very strong scintillations, the form of the observed scintillation spectra becomes exponential, and the occurrence of these exponential spectra may be caused by the very strong wave scattering phenomenon rather than genuine changes of the turbulence spectrum forms.

ANALYSIS OF SHORTS
USING THE CHANNEL
CHARACTERISTICS OF
FIELD-EFFECT TRANSISTORS
by Albert S. Wang

May 1976

ABSTRACT

The phenomenon of enhanced diffusion along a single dislocation in silicon was investigated. The study employed a technique of treating the "shorts" between emitter and collector of a bipolar transistor as the channel region of a junction field-effect transistor (FET) so that an analysis of the short could be carried out by using the channel characteristics of the FET. Some shorts observed in commercial microwave transistors exhibited properties suitable for the analysis and the influence of these shorts on the DC characteristics of the devices were carefully illustrated.

The study covered different domains of operation in order to establish the dimensions of the shorts. For example, a domain called double pinch-off, where both the source and the drain are biased beyond pinch-off, which bears a great resemblance to the sub-threshold region of operation of a metal-oxide-silicon FET, was analyzed. A saddle point model of the electric field distribution in the domain was then developed to describe the behavior of both long and short channel effects.

By further adapting the theory of enhanced phosphorus diffusion along the dislocation, to establish the doping profile of the channel, the operation of the FET in the linear domain was examined. Based on a set of electrical measurements, the identity of the shorts was established. This identity cannot be determined otherwise because of the small 200 Å (radius) geometry. The results confirm the theory of enhanced diffusion along a single dislocation and the nature of its structure.

ABSTRACT

This study is concerned with the analysis of the performance of various buffer organizations in a two-level demand paged memory system using a Cache.

Chapter I describes the buffer organizations analyzed here, namely the Fully Associative buffer, the Direct Mapping buffer, the Set Associative buffer and the Sector buffer. It also discusses the use of the limiting page fault rate as the performance indicator and the use of the independent Reference Model to describe program behavior. The chapter concludes by summarizing the results obtained in the study.

In the second chapter, we show how to compute the fault rates of the Direct Mapping buffer, the Set Associative buffer and the Sector buffer, using King's results for the Fully Associative buffer where appropriate.

In Chapter III, we compare the performance of the Sector buffer and its Equivalent Fully Associative buffer. Next, we prove that all the buffers perform equally well under the replacement strategies FIFO and Random replacement. The performance of the Direct Mapping buffer is sensitive to the mapping used. We discuss how this mapping constraint can be used to advantage and show that with certain types of mappings, the Direct Mapping buffer can yield a performance comparable to that of the Fully Associative LRU cache.

Chapter IV discusses the role played by distribution-free results in the analysis of performance. Here we derive distribution-free upper bounds on the fault rates of the Direct Mapping buffer, the Set Associative LRU cache, the Sector buffer and the Fully Associative FIFO cache. The bounds for the Direct Mapping buffer are close enough to the actual fault rates to be considered as approximations to the latter. Their use is illustrated.

In the next chapter, we study techniques which can be used to take advantage of the mapping scheme for the DM buffer. The problem addressed is to arrive at a mapping strategy, given a reference string, which will yield low fault rates. We show that the frequencies of references obtained from the string can be used as a reliable basis for such a mapping. We also consider how the optimal page replacement strategy (MIN)

PREPARATION AND PROPERTIES
OF GROWN JUNCTION GaAs
SOLAR CELLS
by Lawrence Chin-Chiu Shen

NSF Grant GH-34549
TR No. 5124-2
June 1976

ABSTRACT

In this work, $p(Al_xGa_{1-x}As)$-$p(GaAs)$-$n^+(GaAs)$ solar cells with grown p-n junctions are fabricated and investigated. Minority-carrier diffusion lengths in Ge-doped liquid phase epitaxial (LPE) GaAs layers are evaluated by using scanning electron microscope (SEM) beam-induced current techniques.

The starting material for the solar cell is a Te-doped boat-grown n-type GaAs substrate. A p(GaAs) layer followed by a $p(Al_xGa_{1-x}As)$ layer, both doped with Ge, were grown onto the substrate successively by using a horizontal LPE growth system. The grown samples were subsequently processed into cleaved or mesa cells. The p-n junction of the cell was identified from the peak of the beam-induced current trace, which was superimposed on the secondary emission image of the cleaved edge of the cell. The results show that the p-n junction is coincident with the substrate-grown layer interface, indicating that no apparent impurity cross diffusion had occurred during the growth period. With a slow cooling rate of 0.2°C/min, the thickness of the grown layers can be controlled within ± 0.1 μm of the desired value. This technique provides good control of the position of the p-n junction which is a principal parameter for highly efficient $p(Al_xGa_{1-x}As)$-$p(GaAs)$-$n^+(GaAs)$ solar cells. It also provides precise control of the carrier concentrations in the grown layers.

A series of LPE p(GaAs:Ge) layers with different doping levels was grown on n^+(GaAs:Te) substrates and processed into cleaved diodes. SEM beam-induced current techniques were used for determining the minority-carrier diffusion lengths in the grown layers. Our results show that as the carrier concentration increases from 10^{16} to 10^{18} cm^{-3}, the electron diffusion length slowly decreases from 8 to 5 μm. In LPE p(GaAs:Ge) with a doping density of 1.3×10^{18} cm^{-3}, an electron diffusion length of 5.1 μm was obtained. In a boat-grown p(GaAs:Zn) substrate with a carrier concentration of 2×10^{18} cm^{-3}, the electron diffusion length was found to be 1.55 μm. These diffusion length results show that Ge is superior to Zn as a p-type dopant.

Several completed cells were tested under bright sunlight. The cell areas ranged from 0.1 to 0.45 cm^2. For a power input of about 90 mW cm^{-2},

can be used for this purpose. Finally we discuss the limitations of these strategies.

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NSF Grant GH-34549
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Several completed cells were tested under bright sunlight. The cell areas ranged from 0.1 to 0.45 cm^2. For a power input of about 90 mW cm^{-2},

which was measured by a calibrated Si solar cell, the typical open circuit voltage was 0.87 to 0.90 V, short circuit current was 15 to 20 mA cm^{-2}, and the fill factor varied from 0.70 to 0.75. Power conversion efficiencies ranging from 10 to 15 percent were obtained.

After further reduction in the series resistance and the reverse saturation current, together with optimization of the cell parameters, conversion efficiencies in the range of 15 to 20 percent can be expected. This study indicates that grown junction GaAs solar cells have several technical advantages and are practical to construct.

A ROLLBACK INTERVAL FOR
NETWORKS WITH AN IMPERFECT
SELF-CHECKING PROPERTY
by John J. Shedletsky

NSF Grant GJ-40286
TR No. 96
December 1975

ABSTRACT

Dynamic self-checking is a technique used in computers to detect a fault quickly before extensive data contamination caused by the fault can occur. When the self-checking properties of the computer circuits are not perfect, as in the case with self-testing only and partially self-checking circuits, the recovery procedure may be required to roll back program execution to a point prior to the first undetected data error caused by the detected fault.

This paper presents a method by which the rollback distance required to achieve a given probability of successful data restoration may be calculated. To facilitate this method, operational interpretations are given to familiar network properties such as the self-testing, secureness, and self-checking properties.

An arithmetic and logic unit with imperfect self-checking capability is analyzed to determine the minimum required rollback distance for the recovery procedure.

ADAPTIVE RANDOM
TEST GENERATION
by Kenneth P. Parker

NSF Grant GJ-40286
and Hewlett-Packard Co.
TR No. 109
May 1976

ABSTRACT

Various approaches to the problem of generating a set of fault detection tests for digital circuitry can be broadly categorized as deterministic or random. Deterministic test generation is inapplicable or prohibitively complex for many circuits. Random test generation is applicable to a wide variety of circuits. Though random test generation is inherently inexpensive, it becomes progressively inefficient when attempting to detect more deeply embedded faults. Recently it has been noted that random test generation efficiency is related to the statistical nature of the input source. This paper describes a method for increasing the efficiency of random test generation by adaptively controlling the source statistics. Several examples are given. The random test generation process is modelled with a Markov chain. With this model, insight is gained into the nature of random test generation, and the advantages of adaptive control are illustrated. Finally, factors governing the success of adaptive random test generation are explored, and further research suggested.

THE ERROR LATENCY
OF A COMBINATORIAL
DIGITAL CIRCUIT
by John J. Shedletsky

IBM Graduate Fellowship
NSF Grant GJ-40286
TR No. 103
December 1975

ABSTRACT

In a digital circuit there is typically a delay between the occurrence of a fault and the first error in the output. This delay is the error latency of the fault. A method to probabilistically predict the error latency of a fault is given. A simple technique establishes a bound on the error latency of a fault for a given circuit.

The error latency behavior of a circuit susceptible to one of many possible faults must be described by an "average" of the latent effects of each fault. This "averaged" measure is the circuit error latency. Methods to approximate the circuit error latency are given.

It is shown for a very general case that the circuit error latency is relatively small compared to a typical functional lifetime of the circuit. The implications of this for life expectancy calculations are discussed.

EMMY/360 FUNCTIONAL
CHARACTERISTICS
by Walter A. Wallach

Army Research Office-Durham
Grant DAAG-29-76-G-0001
TR No. 114
June 1976

ABSTRACT

An emulation of the IBM System/360 architecture is presented - the EMMY/360. Problem state code which executes correctly on an IBM 360 will also execute correctly on the EMMY/360. Code producing execution exceptions will, in most cases, produce the same results on the two systems. Certain exceptions occurring on IBM 360 cannot occur on the EMMY/360, such as address specification exceptions for main store operands, and certain precise interrupts on IBM 360 will be imprecise on the EMMY/360, such as address exceptions. The EMMY/360 supports the Standard 360 instruction set with single precision floating point. The 360 input/output structure is not supported; I/O on the EMMY system is done by Function Call instruction, rather than channel program and Start-Test I/O.

AN "ALMOST-EXACT"
SOLUTION TO THE N-
PROCESSOR, M-MEMORY
BANDWIDTH PROBLEM
by B. Ramakrishna Rau

ERDA Contract
E(04-3)326 PA 39
TR No. 117
SU-326-P.39-12
June 1976

ABSTRACT

A closed-form expression is derived for the memory bandwidth obtained when N processors are permitted to generate requests to M memory modules. Use of generating functions is made, in a rather unusual fashion, to obtain this expression. The one approximation involved is shown to result in only a very small error--and that, too, only for small values of M and N. This expression, which is asymptotically exact, is shown to be more accurate than existing closed form approximations. Lastly, a family of asymptotically exact solutions are presented which are easier to evaluate than is the first one. Although these expressions are less accurate than the previously derived closed-form solution, they are, nevertheless, better than existing solutions. This family of solutions is shown to include a couple of existing solutions.

THE STANFORD EMULATION LABORATORY
by Michael J. Flynn,
Lee W. Hoevel, and
Charles J. Neuhauser

ERDA Contract
AT(04-3) 326 PA 39
TR No. 118
SU-326-P.39-11
June 1976

ABSTRACT

The Stanford Emulation Laboratory is designed to support general research in the area of emulation. Central to the laboratory is a universal host machine, the EMMY, which has been designed specifically to be an unbiased, yet efficient host for a wide range of target machine architectures. Microstore in the EMMY is dynamically microprogrammable and thus is used as the primary data storage resource of the emulator. Other laboratory equipment includes a reconfigurable main memory system and an independent control processor to monitor emulation experiments. Laboratory software, including two microassemblers, is briefly described.

Three laboratory applications are described: (1) A conventional target machine emulation (a system 360), (2) 'microscopic' examination of emulated target machine I-streams, and (3) Direct execution of a high level language (Fortran II).

MULTI-USER AND
WIRETAP CHANNELS
INCLUDING FEEDBACK
by S. K. Leung-
Yan-Cheong

NSF Grants
GK-33250 and ENG-10173
USAFOSR F44620-73-C-0065
TR No. 6603-2
July 1976

ABSTRACT

The concept of the wiretap channel was first proposed by Wyner. He considered the case in which data is to be transmitted reliably over a discrete memoryless main channel to a legitimate receiver. The wiretapper views the output of the main channel through another discrete memoryless channel. It is assumed that the wiretapper knows the code being used and his only handicap is the additional noise in his signal. The problem is to maximize the transmission rate R to the legitimate receiver and the equivocation d of the wiretapper.

In this dissertation, the additive white Gaussian noise wiretap channel is introduced and the set of all achievable (R,d) pairs is determined explicitly through the use of certain special properties of the Gaussian channel. Some useful characterizations of a special class of wiretap channels are also explored.

A model of the wiretap channel with feedback is proposed. It turns out that with the introduction of feedback, even when the main channel is inferior to the wiretapper's channel, it is still possible to reliably communicate with the legitimate receiver in complete secrecy. The binary erasure wiretap channel with feedback is examined and inner and outer bounds on the achievable (R,d) region are given.

Finally, a scheme for enlarging the capacity region of multiple-access channels using feedback is analyzed. It is shown that conditions under which an enlargement is possible are fairly weak, indicating that feedback can almost always increase the capacity region.

ABSTRACT

This report summarizes the research carried out in the Digital Systems Laboratory at Stanford University during the period August 1975 through July 1976.

Research investigations were concentrated into the following major areas: Computer Performance; Computer Reliability Studies, including fault-tolerant computing, evaluation of dual-computer configurations, and implementation of reliable software systems; Computer Architecture, including organization of computer systems, feasibility of real-time emulation, and directly executed languages; Design Automation of Digital Systems; Computer Networks, including network interconnection protocols, the 2000 terminal computing system, and packet-switched network technology/cost studies; LSI Multiprocessors; Compiler Implementation; and Parallel Computer Systems.

LOWEST-ORDER AVERAGE
EFFECT OF TURBULENCE ON
ATMOSPHERIC PROFILES DERIVED
FROM RADIO OCCULTATION
by Von R. Eshleman and
Bjarne S. Haugstad

ABSTRACT

Turbulence in planetary atmospheres and ionospheres causes changes in angles of refraction of radio waves used in occultation experiments. Atmospheric temperature and pressure profiles, and ionospheric electron concentration profiles, derived from radio occultation measurements of Doppler frequency contain errors due to such angular offsets. The lowest-order average errors are derived from a simple determination of the radio-wave phase advance caused by the addition of uniform turbulence to an initially homogeneous medium. It is concluded that the average profile errors are small and that precise Doppler frequency measurements at two or more wavelengths could be used to help determine characteristics of the turbulence, and accuracy limits and possible correction terms for the profiles. However, a more detailed study of both frequency and intensity characteristics in radio and optical occultation measurements of turbulent planetary atmospheres and ionospheres is required to realize the full potential of such measurements.

ULTRASONIC DOPPLER
MEASUREMENT OF RENAL
ARTERY BLOOD FLOW
by William R. Freund,
William L. Beaver,
and James D. Meindl

Annual Report to NASA
for 9/1/75-7/31/76
Grant NGR-05-020-615
TR No. 4962-3
August 1976

ABSTRACT

This Annual Report summarizes research completed during the past eleven months--September 1, 1975 through July 31, 1976. During this period, studies were made of (1) blood flow redistribution during lower body negative pressure (LBNP), (2) the profile of blood flow across the mitral annulus of the heart (both perpendicular and parallel to the commissures), (3) testing and evaluation of a number of pulsed Doppler systems, (4) acute calibration of perivascular Doppler transducers, (5) redesign of the mitral flow transducers to improve reliability and ease of construction, and (6) a frequency offset generator designed for use in distinguishing forward and reverse components of blood flow by producing frequencies above and below the offset frequency. Finally methodology has been developed and initial results have been obtained from a computer analysis of time-varying Doppler spectra.

STATE RESTORATION
AMONG COMMUNICAT-
ING PROCESSES
by David L. Russell

NSF Grant GJ41644
USAFOSR Grant
F44620-75-C-0082
Computer Science
Program of USC
STAN-CS-76-563

ABSTRACT

In systems of asynchronous processes using messagelists with SEND-RECEIVE primitives for inter-process communication recovery primitives are defined to perform state restoration: MARK saves a particular point in the execution of the program; RESTORE resets the system state to an earlier point (saved by MARK); and PURGE discards redundant information when it is no longer needed for possible state restoration.

Errors may be propagated through the system, requiring state restoration also to be propagated. Different types of propagation of state restoration are identified. Data structures and procedures are proposed that implement the recovery primitives.

In ill-structured systems the domino effect can occur, resulting in a catastrophic avalanche of backup activity and causing many messagelist operations to be undone. Sufficient conditions are developed for a system to be domino-free. Explicit bounds on the amount of unnecessary restoration are determined for certain classes of systems, including producer-consumer systems, k-producer systems (cyclic systems of k producers and k messagelists), and MRS systems (where the sequence of recovery primitives is described by the regular expression (MARK;RECEIVE*; SEND*)*).

PRINCIPLES OF SELF-
CHECKING PROCESSOR
DESIGN AND AN EXAMPLE
by John F. Wakerly

JSEP N00014-75-C-0601
NSF Grant GK-43322
TR No. 115
December 1975

ABSTRACT

A self-checking processor has redundant hardware to insure that no likely failure can cause undetected errors and all likely failures are detected in normal operation. We show how error-detecting codes and self-checking circuits can be used to achieve these properties in a microprogrammed processor. The choice of error-detecting codes and the placement of checkers to monitor coded data paths are discussed. The use of codes to detect errors in arithmetic and logic operations and microprogram control units is described. An example processor design is given and some observations on the diagnosis and repair of such a processor are made. From the example design it appears that somewhat less than 50% overall redundancy is required to guarantee the detection of all failures that affect a single medium- or large-scale integration circuit package.

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The progress of research under each of the locally established project numbers for this contract is summarized.

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