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ELECTRONICS ENGINEERING RESEARCH
Final Report FY 1979

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Table of Contents

	Page
Executive Summary	1
FY79 Project Summaries	5
1. Gallium Arsenide Integrated Circuits	5
2. Thin-Film Neutron Detector	16
3. Image Processing	27
4. Geophysical Applications	37
5. Decision Support Systems	41
6. Wave Theory Applications	44
7. Software Tools	46
FY80 Program	48
New Projects for 1980	51
8. Estimation and Identification Algorithms	51
9. Three-Dimensional Modeling of Particles and Fields	54

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Executive Summary

Accomplishments in Electronics Engineering Research (EER) during FY79 spanned a broad range of technologies, from high-speed microelectronics to digital image enhancement; from underground probing with electromagnetic waves to detecting neutrons with a small solid-state device; and from computer systems to aid engineers, to software tools to aid programmers. This report describes the overall EER program and its objectives, summarizes progress made in FY79, and outlines plans for FY80.

The Electronics Engineering Research Program is devoted to developing state-of-the-art electronics capabilities in support of long-term Laboratory needs. Because it receives its funding from the Nuclear Explosives Program (NEP), Engineering Research particularly focuses on anticipating and meeting weapons program objectives.

EER focuses its limited funds (on the order of a dozen FTE's and a million dollars annually) on those NEP needs that would not otherwise be satisfied in a timely or cost-effective fashion. These funds produce major impacts by providing crucial funding of new initiatives. This seed-money is complemented by technology-base development and maintenance from Department Burden and Overhead, and support from Reimbursable and Programmatic sources. (These interrelationships are illustrated in Fig. 1.)

This report summarizes the FY79 achievements of the EER program. It also includes a brief review of its current procedural organization.

The EER Program is presently divided into six major thrust areas as outlined below; also listed are the seven FY79 projects (with resources given in FTE's in parentheses):

Fig. 1. Role of EE Research in Stimulating Initiatives.

EER Thrust Areas

● Diagnostic Systems/Microelectronics

1. Gallium Arsenide Integrated Circuits (2.6)
2. Solid-State Neutron Detector (1.5)

● Signal Processing/Control

3. Image Processing (3.0)

● Remote Sensing/Geophysical Probing

4. Geophysical Applications (1.5)

● Modeling and Simulation

5. Decision Support Systems (1.3)
6. Wave Theory Applications (1.5)

● Pulsed Power Systems

No FY79 major effort

● Computer Systems

7. Software Tools (.5)

The total resources used in FY79 amounted to 11.9 people (FfE's) and 1.094M\$ total cost. An FfE level of 12.4 had been allocated, but had to be reduced in the face of higher-than-anticipated manpower costs and escalated expenses.

Following are very brief descriptions of each of the seven projects. Somewhat more detailed descriptions follow in the body of the report.

The concluding section describes the FY80 program, beginning with an outline of the new review procedures initiated during FY79, proceeding with a summary of the FY80 program, and ending with project outlines for the two new projects which are being introduced.

14

1. Gallium Arsenide Integrated Circuits

In our modern solid-state laboratory in the past we have routinely used silicon substrates to produce custom large-scale integrated circuits (IC's). Examples of circuits and devices that have been developed include high-speed charge-coupled devices (CCD's) for sampling fast transient signals (transient digitizers), various custom IC's for specialized control applications, and radiation detectors.

The objective of this project is to develop a gallium arsenide technology to complement the silicon-based one; gallium arsenide promises attractive increases in the speed of circuits for high-speed transient recording. Ultimately, we hope to use this technology to help produce transient digitizers which will operate clocking rates at least in the 1-2 gigahertz range, faster than anything currently available.

During the past year, we decided that the IC technology would be based solely on field effect transistors (FET's), and we focused on developing capabilities for fabricating gallium arsenide devices based on this technology. Progress this year included achievements in ion implantation and annealing and in upgrading our photolithography (obtaining 0.8 μm gates).

We have also produced a test IC consisting of 75 metal semiconductor field-effect transistors (MESFETs), as well as two types of laser-activated switches.

As a design tool we began the development of a 2-D numerical code for predicting the behavior of MESFETs.

The major activities for FY 80 will be 1) the fabrication issues of photomask preparation, ohmic contacts, and anodic oxidation; and 2) (with increasing emphasis) circuit design and device modeling and characterization.

2. Thin-Film Neutron Detector (TFND)

The basic goal of this project is to develop fast-response solid-state neutron detectors with large active areas, yet relatively small volumes. To achieve this objective, we are investigating mechanisms in thin-film electronic structures that permit efficient detection of heavy, energetic ions. Potential applications include personnel neutron dosimeters with real-time response.

There were several advances in processing and testing in FY79, but the major result was successful operation of 1mm^2 active-area devices in air rather than in a vacuum. This was in part made possible by use of an ultra-thin, uniform aluminum top films deposited in the EERU magnetron sputtering system. Operations in air will greatly facilitate completion of a small test-module system including bias and control circuitry for neutron-response testing in FY80.

The next step is to demonstrate neutron detection with a lab prototype, a small array of 1mm^2 active-area breakdown detectors, with a U-235 radiator at the Hazards Control Neutron Calibration Facility. If the results are promising, a Np-237 film will be sought because this material's neutron conversion spectrum closely mimics the body's energy-dependent damage profile.

The ultimate objective will be the development of a large active area (2cm^2 or more) TFND. The principal research question here will be whether unpredicted area-dependent effects will arise to hinder performance.

3. Image Processing

In the past, we developed a digital image processing and display system which was interfaced with LLNL's Octopus computer system. FY79 activity focussed on improving this capability in two major directions:

- Radiographic Image Processing. We implemented new techniques for image enhancement and restoration that can be applied to various LLNL programmatic needs.

In FY79 we studied, implemented, and documented a variety of new image processing algorithms.

- On-line Image Processing. We investigated image processing in a minicomputer/array processor (AP) environment. This project focussed on maximizing the efficiency of the image-processing hardware system, consisting of a PDP 11/70 minicomputer, a floating point systems array processor, and a COMPTAL image display system.

The mini/AP combination permits an operator to enhance and restore images at the speeds of very large computers (e.g., the 7600), but at much less cost and with an interactivity which is unattainable with large machines.

In FY79 we proved out the system concept and developed an effective interactive facility, with many algorithms implemented.

As a result of these research and development activities, the Image Processing Research Facility (IPRF) continues to experience a strong programmatic demand for its capabilities. In addition to the facility development and the programmatic applications, we continued to produce documentation consisting of reports and papers in the technical literature.

In FY80, we plan to continue to develop useful algorithms, implement them, and make them part of our capability. In addition, we will add and integrate more hardware into the system and continue to extend the application of our techniques to real image processing problems at LLNL.

4. Geophysical Applications

This effort is devoted to improving technologies for remotely sensing underground features and determining geological characteristics. The work integrates fundamental physical modeling (EM/seismic/electrical and geophysical phenomena), instrumentation systems, algorithm development, and signal processing. These united efforts are solving traditionally difficult problems in remote sensing, with applications including coal gasification, nuclear waste site evaluations, and strategic defense problems in detection of underground activity and structures.

During 1979 we performed a variety of tasks in pursuit of these overall objectives. These tasks included:

- 1) The analysis of a potential field about an electrically excited sphere buried in the ground, with potential application to locating buried grout balls,
- 2) Reviewed and selected remoted probing techniques for defining discrete fractures,
- 3) Made propagation measurements in the Piledriver complex at NTS,

- 4) Assembled an automated core sample "impedance camera." This camera will provide the data to be interpreted using the computerized program described in previous work. The camera has been built but not debugged.

In FY80, a program is planned to provide support for brief studies to assess possibly useful technology areas. If such a study shows a particular technology area to be especially attractive in terms of its overall utility, then a prototype system via simulation or actual hardware would be evaluated for use in demonstrating the procedure to interested users. Further development of demonstrated systems would be left to funding provided by these interested users.

5. Decision Support Systems

The overall objective of this work is to develop computer tools for aiding engineers and decision makers in complex modeling, design and decision tasks. This is in support of a wide-range of current program activities, including research on the safeguarding of nuclear materials, analysis of nuclear waste disposal sites, research on R&D decision making, and the design and evaluation of tactical military engagement games. This work should also be of assistance in other applications, including nuclear weapons safety, on-line support system for responding to nuclear terrorist acts/threats, and management of complex Lab/DOE, R&D projects.

The basic objective of this project is to advance the state-of-the-art in computer-based decision support tools and to develop a useful integrated system. The immediate goal is to implement several practical interactive tools on an LSI-11 computer. At this time, we have focussed on two codes to achieve maximum impact on improving the effectiveness of our analysts: 1) an algebraic-modeling code and 2) a decision-tree code. An implementation for

our algebraic modeling system has been worked out based on data-flow concepts used in code-optimizing computers. A decision tree analysis program has also been designed. Parts of this code have been implemented and checked out on the LSI-11.

In addition, we have supported research on the STOP algorithm, a new method for computing exact probabilities in complex systems. The STOP (Superfast Method To Obtain Probabilities) algorithm has been coded and run on sample problems; it appears (from analysis as well as numerical experience) to be significantly faster than anything currently available. It has a number of potential applications to the analysis of the reliability of complex systems (including nuclear weapons safety, reactor safety and availability, waste repository analysis, and nuclear safeguards).

In FY80, we will complete the theoretical and empirical investigation of STOP. Because the potential applications of STOP there is a good opportunity for programmatic support once we demonstrate that the concept is sound. Following this work, we will complete the decision tree analysis program and continue work on the algebraic model building system.

6. Wave Theory Applications

These funds were used to react quickly to LLNL needs and to look at new methods for EM and Acoustic modeling. Further, the funds provided seed-money for short feasibility studies and demonstrations.

Among the subjects treated in FY79 were early efforts in particle beam weapons, rail guns, cave-in location, and hardening issues. Also during the past year the studies of high field compression were completed and an initial linac design was performed.

In the particle beam weapons area, the EM effects of these beams were investigated briefly. An outgrowth of this work was a brief experimental study of whether emissions from housed accelerators can be detected and used for identification.

Feasibility studies and initial designs for the rail gun were funded. The rail gun, a mechanism for magnetically propelling projectiles to hyper-velocities, has potential application to various high impact studies, equation-of-state studies, and inertial fusion.

Work in FY80 will be devoted to a new project, "Three-Dimensional Computer Modeling of Particles and Fields." (See Section 8.)

7. Software Tools

The objective of this small project was to support computer systems research activities by developing "software tools." Such tools are the software analogs of hardware tools--they help one to more effectively develop, debug and maintain a software end-product. With general-purpose software tools available, specific software can be developed with greater efficiency.

Common software tools include text editors, compilers, and debugging packages. Most current computer systems include at least primitive versions of each of these. The principal effort on this project was the adaptation of a structured FORTRAN preprocessor, originally developed at SLAC, called MURTRAN. The purpose of this type of tool is to allow a programmer to write a code which is more structured than normal FORTRAN and therefore more readable. This makes the code easier to debug and easier to maintain.

In the next section, we present more detailed summaries of the work performed under each of the seven projects listed above. Plans are also outlined for those five projects which will continue in FY80.

The concluding section describes the FY80 program, beginning with an outline of the new review procedures initiated during FY79, proceeding with a summary of the FY80 program, and ending with project outlines for the two new projects which are being introduced.

Project Summaries, FY79

1. Gallium Arsenide Integrated Circuits (2.6 FTE's)

Principal Investigator: A. Blum

Participating Personnel: L. Jelsma, K. Mayeda, S. Swierkowski

1.A Objectives

A modern solid state laboratory exists for the fabrication and testing of custom large scale integrated circuits (IC's) and other solid state and electron devices. In the past, silicon substrates have been used routinely for the integrated circuit work. Examples of circuits and devices that have been developed include high-speed charge coupled devices (CCD's) for sampling fast transient signals (transient digitizers) various custom IC's for specialized control applications, and radiation detectors.

Gallium Arsenide is a newer IC substrate material which promises very attractive increases in the speed of circuits for high-speed transient recording. Ultimately, we hope to use this technology to help produce transient digitizers which will operate at least in the 1-2 gigahertz range, faster than anything currently available. Our general objectives are to:

- Develop a capability for supplying high-speed gallium arsenide (GaAs) integrated circuits.
- Develop designs which maximally exploit the use of reported industrial GaAs technology.
- Work with the experimental programs to find applications for our circuit capability.

During the past year, we have translated these general objective statements into concrete action steps:

- The IC technology will be based solely on field effect transistors (FET's).
- A demonstration IC is vital if we are going to attract program interest. We will produce a demonstration IC selected from among three candidates:
 - a. Pulse amplifier
 - b. Optical (or radiation) detector
 - c. Clock signal generator for use on CCD's (charge-coupled devices)
- We will respond to NESD and Y-Division interest in GaAs laser-activated, high-voltage switches.

For the longer term, we may broaden our objectives to include the growth of our own material. This would give us the fabrication flexibility that we would need if certain physical effects (such as hetero-junctions, permeable bases, and very-high-speed layered structures) are to be exploited.

During the year covered by this report, our attentions were focused on developing our capabilities with respect to the specific fabrication techniques that the IC's listed above would require. Undoubtedly, as we get more involved in the IC design process we will define some additional fabrication requirements.

1.8 Progress

As is the case for any integrated circuit, a number of in-house processing skills must be demonstrated at an acceptable level of reproducibility before IC processing begins. The principal process which was not in-hand to some degree and which was crucial to IC fabrication was the formation of N-type layers by ion implantation and annealing and the measurement of results by van der Pauw methods. This has now been demonstrated. The results are very consistent and generally show converted fractions and mobilities in-line with others reported (the reported values span a significant range).

The other technology issues were matters of up-grading already demonstrated processes to enhance either consistency or performance. We made significant improvements in our photolithography. These include:

- A technique for reducing the photoresist layer thickening that occurs at the chip periphery has been devised. While time consuming and introducing some chance of scratching the GaAs surfaces, the technique does work.
- We have brought a new high resolution mask aligner into operation. The alignment of photomasks to the visible features of prior layers is now limited only by the photomask quality.
- We are now using oxygen plasmas to de-scum and strip photoresist. This process reduces ragged edges on 1 micrometer sized features.

As an example of the significance of these processing refinements note the 0.8 micrometer long gate shown in Fig. 2.

Figure 2. 0.8 micrometer gate MESFETs illustrating the improvements in our photolithography.

Figure 3. A 75 MESFET array with transistors of varying gate widths.

During the year, we encountered a severe problem with delivery on photomasks with 1.0 micrometer features. Our order was delivered nine months late. By devoting some small fraction of our engineering effort to working with Technical Photography (LLNL) we have been able to produce servicable masks with similarly sized features and less than one month turn-around time.

These improvements in our photolithography brings us to the point at which we can undertake the fabrication of small scale integrated circuits.

We will need to electrically characterize our metal semiconductor field-effect transistors (MESFET's) and be able to predict the effects of minor dimensional changes before we can begin IC design. We adopted a three way attack on this problem. First we have constructed an array of test MESFET's and measured their low frequency parameters. The chip is described in detail in the "Product" section. The information derived from these tests, while limited, is being used for our first IC designs.

The other two approaches to the problem are 1-D and 2-D numerical calculations. These efforts have served to broaden our understanding of the MESFET behavior but have not yet produced any results of their own.

The 2-D numerical method is defined and a considerable amount of code has been written with the objective of obtaining working code early in 1980.

In order to identify small scale demonstration IC's that are of potential interest to the programs, we have had informal discussions with individuals in NESD and are starting discussions with FTSD. One application which has been suggested concerns the waveform generating and driving circuits that support the CCD function. Raising the speed of these would strengthen the CCD effort and start an evolutionary shift to GaAs CCD's.

Not all the fabrication issues have been laid to rest. Both Schottky barrier and ohmic contacts are workable but less than fully satisfactory. In the future we will need a more durable metalization scheme, probably requiring electron beam evaporation. The observed breakdown voltages on our sample MESFET's, while comparable to the values reported in journals, are not adequate for driving off chip with either the voltage swings that the program people have suggested or for the CCD drive requirement. Some combination of recessed gate technology and heavily implanted contact areas will be required. Finally, we do not have any information about the high frequency behavior of our devices, and although we do not anticipate any problems, there is some risk. We expect to resolve the most critical of these issues during the coming year while at the same time developing demonstration IC's.

1.0 Products

During FY79 we fabricated: the 75 MESFET array shown in Fig. 3; two types of laser activated switches, one of which is shown in Fig. 4; and we did some initial design work on a clock signal generator for use on CCD's.

The MESFET array was intended to demonstrate our fabrication capabilities with particular emphasis on i) ion implantation and annealing, and ii) fine-line lithography. Two series of chips, each at a variety of implant levels, calibrated the implant process. The second chip series also tested both variations in the surface preparation prior to deposition of the Schottky barriers and the effects of plasma de-scum. The characteristics of the MESFET's were approximately as expected and generally consistent both between similar chips and among MESFET's on the same chip. Fig. 3 shows a chip from the first of the two series. The second series showed improved feature sharpness, perhaps due to the use of plasma de-scum. Fig. 5 shows the output

Figure 4. A laser activated GaAs switch mounted in a 50 ohm strip line configuration on a pyrex dielectric.

Figure 5. Output characteristics of an ion implanted GaAs MESFET with a 1.5×40 micrometer gate.

characteristics of a 1.5 x 40 micrometer gate MESFET. The devices are adequate for low voltage and digital applications. At drain-source voltages above five volts we observe greatly increased looping, possibly due to the injection of carriers into the substrate. We are preparing a MESFET array chip using a modified fabrication to allow operation at higher voltages. There was some nonuniformity in the I-V characteristics of the Schottky-barrier gates. This was attributed either to the surface treatment prior to gate evaporation or to a lack of cleanliness during the evaporation. Because these MESFET's showed usable characteristics and a moderate yield we will attempt to resolve the remaining problems concurrently with the testing of IC's.

Both Y-Division and NESD requested laser activated switches. We provided preliminary samples to both but neither group has been able to free up the time required for testing. This illustrates one key problem that impairs our ability to interest the programs in our work. They are often unable to justify the packaging and evaluation of LLNL devices until the program management is confident that the devices will work. Perhaps we should broaden our mission to include more of the electronic system.

During FY79 it was pointed out that GaAs circuits might alleviate the speed limitations that the CCD's are subjected to by their supporting electronics. Accordingly, we have done some preliminary design on a clock signal generator.

The MESFET test chips were intended to and have provided device parameter for the design work. The test chip fabrication and the circuit design were closely coupled.

At most of the processing steps it is essential to have a clean surface with a consistent surface chemistry. Toward this end we have modified our cleaning chemistry and fabricated hardware to minimize chip handling. The consistency of our implantation and annealing experiments suggests that the GaAs chips are effectively clean of trace contaminants such as copper.

Contamination by the pump oil vapor and residual gases present in a vacuum system during the evaporation of metallic ohmic contacts or Schottky barrier gates can lead to inconsistent pinchoff voltages and high source resistances. We have started, but not yet completed, the modification of an existing vacuum system as a first step toward improving this situation.

1.D FY80 Plans

Some of the remaining fabrication short-comings will be addressed with the objective of bringing them up to a level of quality and consistency necessary to supply circuits to programmatic and ERD needs.

If we project our progress for the balance of this present year optimistically, the major device technology issues during the next year will be photomask preparation, ohmic contacts and anodic oxidation. Since the mask preparation problem affects all the microelectronic work in ERD, other interested parties (mainly Dino Ciarlo) will be assisting A. Blum on this problem.

Steve Swierkowski and a technician will evaluate ohmic contact problems.

The major line of effort will shift toward circuit design and device characterization. Here it is expected that some designs will get a major input effort from the eventual users. S. Swierkowski will be more heavily concerned with the device modeling and characterization and A. Blum will be more concerned with the circuit design. K. Mayeda will focus on the fabrication issues.

The specific circuit work which is expected from these efforts includes:

- Study and test of MESFET optical detectors. Central in this effort is numerical studies for device modeling based on the 2-D code under development.
- Fabrication and testing of the CCD clock signal generator.
- Design of high speed pulse amplifiers.

Improvements in our circuit test methods will be required by the anticipated high speeds. The implementation of this supporting technology will be a major facet of the year's effort.

During this period we must concern ourselves with interactions with the programs and outside funding sources. We can approach these end users with a convincing argument when we have our first reasonably complex working circuits as demonstrations of our capability when packaged as a part of a working system rather than just a chip and scope photo.

2. Thin-Film Neutron Detector (1.5 FTE's)

Principal Investigator: O. E. Miller

Participating Personnel: K. E. Vindelov

2.A Objectives

The basic goal of this project is to develop fast-response solid-state neutron detectors with large active areas, yet relatively small volumes. To achieve this objective, we are investigating mechanisms in thin-film electronic structures that control efficient detection of heavy, energetic ions. Based on information from this research and existing data on generation of heavy ions by neutron fluxes incident on fissile radiator films of Th-232, U-235, Np-237 or U-238, initial thin-film neutron detectors (TFND) are being designed on the neutron fissile-foil conversion-to-ions principle.

A current specific objective is to configure some of the experimental thin-film devices used for this research as laboratory-prototype neutron detectors of modest areas ($0.1-1 \text{ cm}^2$) on which actual neutron flux experiments are to be conducted during FY80. A longer range goal of the project is to determine material and metal-dielectric interface combinations that would allow neutron conversion to ions of sufficient energy loss rates ("stopping power") by recoil processes in nonradioactive materials.

Potential applications which are of significant interest to DOE and LLNL include:

- Fast-response detection of neutrons, particularly for cases in which there is:
 - Low volume for instrumentation.
 - High background of alphas or other light particles.
 - High gamma or X-ray environment.
- Neutron dosimetry, with portable or wearable monitors:
 - Continually updated dose monitor with no-delay readout.
 - Real-time rate or threshold monitor alarm.
 - "REM-meter": Spectral response to match body neutron-damage sensitivity.
- Detection of heavy ions in nuclear chemistry or physics experiments with fluxes of lighter ions or gammas and X-rays.
- Nanosecond timing experiments with neutrons or heavy ions, in confined spaces or high background radiation.
- Laser-pulse subnanosecond switch trigger.

2.8 Progress

In 1976, Klein, Solomon and Tommasino reported on the first thin-film detector of heavy ions, as developed at the Technion Institute. The detecting element was a thin-film capacitor whose dielectric and at least one electrode were both less than 1000 Å (4×10^{-6} in.) thick. The key results and observations of Klein et al., were:

- As with a spark chamber, a bias voltage slightly less than needed to cause a spontaneous spark breakdown was applied between the two capacitor electrodes.
- An induced breakdown was triggered by the passage through the dielectric film of an energetic, heavy ion.
- Breakdowns, induced or spontaneous, did not leave the capacitor short circuited if the insulating film and its interfaces are nearly ideal in terms of defects, composition and contacts.
- Nonshorting breakdowns caused damage holes only a few micrometers in diameter in the very thin electrode, about two orders of magnitude smaller than typical etched holes in plastic film track detectors, so that over 10^6 ions/cm² could be counted.
- In theory, any metal-insulator-metal (MIM) or -semiconductor (MIS or MOS) thin-film structure could act as a breakdown detector, but only small area silicon-based MOS capacitors showed good heavy-ion detection properties.

In spite of promising data that included testing with Cf-252 fission-fragment sources, the efforts at the Technion were brief and exploratory. Only a few thin-film capacitors were fabricated in a limited microelectronics facility. There was insufficient opportunity or people to do any device characterization beyond the source-response data taken.

By the onset of FY79 at LLNL we had demonstrated detection of Cf-252 fission fragments, with definite discrimination from spontaneous ("dark") events. Subsequently, complementary funding was secured from EER and Hazards Control, Special Projects Division, to pursue the development of an LLNL TFND.

The operating principle of LLNL's TFND is illustrated in Fig. 6. Its performance depends upon stimulation of minute, partially destructive arcs in metal-oxide-semiconductor (MOS) thin-film structures. This operation leads to several key research questions:

1. Which existing theories, if any, of insulator charge transport adequately model the nonshorting breakdown conduction in our MOS capacitor-detector structures?
2. What experimental methodologies will provide data on induced and spontaneous breakdown mechanisms without being significantly intrusive?
3. How do data from more conventional nonbreakdown MOS-device test procedures, such as capacitance vs. bias voltage characteristics, relate to TFND- regime breakdown behavior?
4. What physical factors of the MOS structures,, such as capacitor geometry, processing modifications, ambient storage, electric-field stress history and exposure to low energy X-rays and electrons most significantly affect breakdown operation, both initially and after thousands of breakdown events?

Fig. 6. TFND Operating Principles.

5. Even with excellent initial MOS breakdown characteristics, what are the mechanisms or, at least, operating conditions which allow minimal degradation over the lifetime of the MOS capacitor-detector?
6. With the desirability of using nonfissile radiator foils for neutron dosimetry, what limits the use of lighter ions, perhaps recoil particles, to induce breakdowns?

2.C Products

During FY79 we made advances on questions above. These results are outlined below. Literature reviews and direct contacts with C. Osburn, N. Klein and P. Solomon of the Oxides Studies group at IBM Research, Yorktown Heights, lead us to favor field emission with hot electron ionization and recombination as the best theoretical mechanisms description, but the highly nonlinear and extreme electric-field stress conditions mitigate against predictive modeling of a specific thin-film electronic structure's behavior. Rather, existing theories seem to aid qualitative interpretations of research data.

On the issue of lighter-ions detectability, experimental work by Donichkin et al., in Leningrad indicates some critical factors, as insulator-film material and ion-incidence angle, that LLNL is well prepared to explore. One of the authors (D. Miller) and R. Griffith reviewed the Donichkin paper, submitted for publication in Nuclear Track Detection during FY79.

Besides the research on specific breakdown phenomena associated with our test MOS structures, progress was made to develop rudimentary circuitry and system integration to be able to get neutron-response data in FY80.

In response to interest by many groups, a large number of presentations were made in FY79. The primarily oral reports about the ongoing TFND research allowed bilateral communications that gave impetus and direction to our work.

There were several advances in processing and testing, but the one result that could be called a "breakthrough" was operation of devices on a particular wafer (#45p) in air rather than vacuum. This was in part made possible by use of an ultrathin, uniform aluminum top film deposited in the EERD magnetron sputtering system. Development of an optimized bias network also contributed, along with insulator-film processing modifications. Operations in air will greatly facilitate completion of a small test-module system using "45p" for neutron-response testing in FY80.

Moreover, initial data on 45p at the end of FY79 indicates very uniform spark distribution patterns, as shown in Figs. 7-10. Fig. 7 is an optical micrograph (approximately 100x) of an MOS capacitor-detector before any breakdown events occurred. Figs. 8 and 9 show 45p capacitors that have detected several hundred fission fragments. The events caused the small dots apparent in the white rectangle that is the active 1 mm^2 area; the larger black spots in Figs. 8 and 9 are images of dust. Note also the scratches made by our test probes. For comparison, Fig. 10 shows the breakdown pattern typical of many of our earlier FY79 devices. (The white streaks are photo defects.) The nonuniformity of the size and distribution of breakdown tracks, especially clustering, leads to early failures, principally by excess leakage through the insulator film.

Additional operation in air tends to extend the number of breakdown events that can be recorded per area, probably by spark-enhanced oxidation that reduces leakage paths. Testing which is continuing in FY80 indicates over 10^6 ions/cm² have been detected.

Figure 7. MOS capacitor-detector before breakdown events.

Figure 8. 45p capacitor after detecting several hundred fission fragments.

Figure 9. 45p capacitor after detecting several hundred fission fragments.

Figure 10. Breakdown pattern typical of early '79 devices.

Table 1 shows how the LLNL TFND research effort has resulted in data that compares very favorably with results reported from a significantly larger effort in the USSR on thin-film heavy-ion breakdown counters. The Soviet work was extensive but focused on the counting system aspects of one configuration, rather than the research questions about the breakdown detection approach.

2.0 FY80 Plans

The next crucial step is to demonstrate neutron detection with a lab prototype, a small array of 1mm^2 active-area MOS breakdown detectors, with a U-235 radiator at the Hazards Control Neutron Calibration Facility. If the results are promising, a Np-237 film should be sought because this material's neutron conversion spectrum closely mimics the body's damage profile.

However, effective use of Np-237 depends upon development of a large active area (2cm^2 or more) TFND. The research question is: Do area-dependent effects exist that hinder or preclude effective large area breakdown-events detection? Tommasino suggested in 1977 based on early data that the field strength that can sustained varies inversely and logarithmically with the capacitor area. This, however, was inconclusive and perhaps processing-dependent.

Preliminary design of $10\text{-}12\text{mm}^2$ MOS breakdown capacitors done in FY79 includes more reliable means of interfacing with experiment diagnostics. Although earlier thought to be required only for array development, this physical consideration was found to be necessary to have a better chance of getting more consistent research data.

Successful operation of large area TFND in FY80 would generate interest relating to significant DOE problems, listed above in Section 2.A.

Research Team	Year	Oxide Thickness (Å)	Operating Voltage (V)	Spontaneous Breakdown (V;MV/CM)	Max. Counts Detectable/cm ²
Tommasino, Klein and Solomon (Israel)	1975 1977	1150 380	62 28	75 (6.5) 35 (9.2)	6 x 10 ⁵
Donichkin, Eismont and Smirnov (USSR)	1978	1400	82	100 (7)	10 ⁴
Miller/Vindelov* (LLNL/EERD)	1979	450	32	40 (9)	10 ⁶

*(Device #39p with magnetron-sputtered Al top layer)

Table 1. Comparison of LLNL/ERD thin-film fission-fragment detectors with others

Finally, it may be of interest to point out that our pursuit of TFND R&D depends on a unique combination of highly developed processing and analysis capabilities. Other labs, such as IBM, Yorktown Heights, have advanced silicon MOS expertise but no impetus and inadequate facilities for neutron and heavy ion effects research that could lead to compact yet large area detectors. Moreover, semiconductor device labs elsewhere typically focus on particular material technologies oriented toward high mass-production devices. We have developed expertise in a wide-range of thin-film materials and devices that allows much more research flexibility to address problems unique to TFND.

On the other hand, when the above research questions related to large area TFND have been sufficiently explored by LLNL to generate a design "prescription," then small semiconductor "custom houses" should be considered for field prototypes and limited production, with interaction with other DOE/LLNL user groups for specialized TFND applications.

3. Image Processing (3.0 FTE's)

Principle Investigator: R. E. Twogood

Participating personnel: G. Clark, D. Goodman, C. Journeay, J. McClellan,
G. Myers, G. Poe, J. Sherman, and R. Sherwood

3.A Objectives

Previous efforts developed a digital image processing and display system which was interfaced with LLNL's Octopus computer system. Current activity focussed on improving this capability in two major directions:

- Radiographic Image Processing is a fundamental part of a long-term commitment to develop a powerful set of image processing capabilities that can be applied to various LLNL programmatic needs. In FY79, emphasis was placed on implementing new techniques for image enhancement and image restoration. This project focuses on the development, test, and implementation of image processing algorithms.
- On-line Image Processing is an investigation of 2-D digital signal processing in a minicomputer/array processor (AP) environment. The objectives of this work are to 1) improve the interactivity of our image processing facility, 2) increase our image processing capabilities, and 3) gain an understanding of the application of array processors to computational problems. This project focuses on maximizing the efficiency of the image-processing hardware system, consisting of a PDP 11/70 minicomputer, a floating point systems array processor, and a COMPTAL image display system.

The mini/AP combination permits an operator to enhance and restore images at the speeds of very large computers (e.g., the 7600), but at much less cost and with an interactivity which is unattainable with large machines.

As a result of the research and development activities funded by the Engineering Research budget, the Image Processing Research Facility (IPRF) continues to experience a strong demand for its capabilities. Among the LLNL programs that have utilized our facility for image processing applications during FY79 are B-Program and NDE (radiographic enhancement), Y-Program (laser diagnostics), Hazards Control (ultrasonic imaging), L-Division (potential CT&F applications and Pinex image enhancement), Z-Division (intelligence), W-Division (cable inspection), ERD (geotomography), and others.

3.B Progress

During FY79 we performed the following tasks in support of the "Radiographic Image Enhancement" project:

- Attempted an analytic modeling of the image formation process.
- Implemented several well-known image restoration schemes (including inverse, Wiener, and maximum entropy).
- Completed our testing and documentation [1] of the "contrast-stretching" algorithm.
- Implemented several 2-D adaptive filtering and restoration procedures.

- Actively investigated a 1-D block adaptive filtering technique (a spin-off of our 2-D adaptive filtering work)--this developed into a Ph.D. dissertation topic with expected completion (funded by other sources) during FY80.
- Developed homomorphic image processing capability (using the array processor and the 11/70) and tested for one radiograph of interest.
- Implemented the extended "alpha-root" algorithm using the software package IMG on the 11/70 and array processor.
- Made a preliminary study of potential methods for a space-variant motion blurring problem of B-Division (this work will be funded by B-Division during FY80).

We performed the following tasks in support of the "On-Line Image Processing" project:

- Integrated the AP into a fully operational image processing facility.
- Learned to use the associated AP software tools (debug, simulator, linker, etc.), and also implemented some of our own software in both "vector function chainer" syntax and in the array processor assembly language (APAL).
- Wrote routines to directly transfer data between the AP and the host's disks, bypassing the host computer--this capability may prove to significantly enhance the applicability of our minicomputer/AP architecture to computational problems of applied science.

- Wrote subroutines on the 11/70 to utilize the "trailers" in our image files and to process families of files (rather than single files).
- Began the process of developing a large collection of useful image processing software routines to run on the array processor. Software developed during FY79 includes:
 - 2-D FFT of externally-stored data (and inverse FFT)
 - histogram
 - histogram equalization
 - alpha-root
 - convolution
 - convolution via DFT
 - add, subtract, multiply, divide images
 - add, subtract, multiply, divide images by constants
 - contrast stretch
 - median window filter
 - log, exponentiate, absolute value, scale, raise to a power
 - compute statistics of image (min, max, mean, variance)
- Incorporated the above modules into a software package we call "IMG" which also utilizes previously developed routines on the PDP 11/70 and the array processor.
- Published an article describing the current image processing facility configuration and capabilities in the April 1979 issue of E&T Review [2].

- Continued our characterization of digital signal processing algorithms and how they mesh with our system architecture, including the effect of direct disk-AP transfers [4], [11].
- Continued to publish the results of our investigation (supported in part by NSF) of fundamental issues of 2 digital signal processing [3], [6], [7], [10].

3.C Products and Publications

The major "product" that has resulted from our FY79 ER effort is, of course, the large collection of image processing capabilities described above. These capabilities consist primarily of image enhancement methods, image restoration techniques, and general purpose image processing algorithms.

Approximately 1.5 additional FTE's of applications work (most from LLNL programs) was performed during FY79 as a direct consequence of our image processing capabilities. In addition, we are involved in a significant amount of "technology transfer" activities. These include software transfer and providing consultation to other users both within LLNL and outside). Recipients of such software and/or services during FY79 included Y-Program, Z-Division, Computations, Sandia Corp., LASL, Lockheed, Ford Aerospace, APL, Floating Point Systems, JPL, MIT, and many others.

We have also continued to publish a substantial amount in the technical literature. The following list of publication/presentations for FY79 includes journal and conference papers, in addition to internal reports and seminars. Because of these activities, we continue to be recognized as a major center of image processing research and we are able to attract outstanding research engineers to LLNL.

Publications in Image Processing

- [1] G. K. Myers and R. E. Twogood, "An Algorithm for Enhancing Low-Contrast Details in Digital Images," UCID 18015, November 1978.
- [2] R. E. Twogood, "Digital Image Processing at LLNL," Energy and Technology Review, April 1979.
- [3] R. E. Twogood and M. P. Ekstrom, "Why Filter Recursively in Two Dimensions?," Proc. 1979 IEEE International Conf. on Acoustics, Speech, and Signal Processing, Washington, DC, April 1979, pp. 20-23.
- [4] R. E. Twogood, "Array Processor Implementation of 2-D Digital Filters," Proc. of the 1979 IEEE International Conference on Circuits and Systems, Tokyo, Japan, July 17-19, 1979.
- [5] S. K. Mitra, K. Mondal, and R. E. Twogood, "Design and Implementation of Half-Plane Two-Dimensional Digital Filters," Proc. 1979 IEEE International Colloquium on Circuits and Systems, July 1979.
- [6] M. P. Ekstrom, R. E. Twogood, and J. W. Woods, "Two-Dimensional Recursive Filter Design: A Spectral Factorization Approach," accepted for publication in IEEE Trans. Acoustics, Speech, and Signal Processing.
- [7] J. M. Goodman, "Quadrantal Symmetry Conditions for Nonsymmetric Half-Plane Filters," UCRL 82443, March 1979.

Presentations Made Describing FY'79 ER Image Processing Research

- [8] R. E. Twogood, "Image Processing Activities at Lawrence Livermore Laboratory," presented as an invited guest seminar at the Jet Propulsion Laboratory Pasadena, CA, February 7, 1979.
- [9] R. E. Twogood, "Digital Image Processing at the Lawrence Livermore Laboratory, guest seminar at the University of California, Santa Barbara, May 29, 1979.
- [10] R. E. Twogood, "Recursive Filters Designed by Spectral Factorization," presented at the IEEE First ASSP Workshop on Two-Dimensional Digital Signal Processing, Berkeley, CA, October 3-4, 1979.
- [11] R. E. Twogood, "Array Processor Implementation of Image Processing Algorithms," presented at the IEEE First ASSP Workshop on Two-Dimensional Digital Signal Processing, Berkeley, CA, October 3-4, 1979.

3.D FY80 Plans

FY80 plans break down into two parts:

- I. Enhancement and Restoration Procedures for Digital Images (P.I.'s
R. E. Twogood/G. K. Myers).

II. Interactive Image Processing in a Minicomputer/Array Processor Environment.

Specific plans follow:

- I. The following nonlinear image enhancement algorithms will be implemented on either the CDC 7600 or the PDP 11/70 with array processor. In each case, the performance of the algorithm will be tested on actual images, and the results of interest will be documented in either internal reports or conference papers.
 1. Noise cheating -- This is a nonlinear method of noise suppression that does not blur the edges of objects in the image as much as conventional filtering techniques.
 2. Brightness and contrast scaling -- This work will parallel that done by Gilkes and Curlander in each of their master theses done at MIT. An image is enhanced by locally scaling the brightness and contrast in some optimal manner. The optimization criteria will make use of overshoot at edges and other such artifacts which enhance one's perception of image quality.
 3. Alpha-rooting -- We will finish documenting and testing our modified alpha-root procedure, which involves an image-dependent windowed filtering that approximates the alpha-root procedure while avoiding the spatial aliasing of that procedure.

4. Linear restoration schemes -- We will complete our testing and comparisons of several linear deconvolution techniques implemented during FY79, including inverse filtering, Wiener filtering, and power spectrum equalization.

The obvious short-term goal of this research effort is to implement and test a variety of algorithms for the enhancement and restoration of digital images. Most of the above algorithms have been used to some degree by other researchers in the field, and hence appear to have potential application to our problems here at LLNL.

In terms of long-range goals, we perceive two ways in which this research is justified. The first goal is the continued development of a powerful collection of image processing algorithms that allow the user tremendous flexibility in the processing options available to her/him. We have already partially fulfilled this goal in the past two or three years of effort in this general area, where most of the emphasis has been on implementation of the most useful fundamental image processing algorithms (such as transforms, statistical operations, simple numerical tasks, format changing, geometric manipulation, and some nonlinear operators). Our continued work in this area will insure that we maintain our reputation as a leading center of image processing research and capabilities.

The second goal is the application of the techniques developed to real image processing problems at LLNL. With the support of this engineering research funding, we anticipate a continued growth in the number of LLNL programs which approach our Division for assistance in solving their image processing problems.

III. The following hardware will be integrated into the image processing laboratory:

1. Tablet -- This device will provide a very interactive method of specifying a number of image processing tasks to be initiated by the user. A significant amount of software development will probably be needed here, but we are assuming that "overhead" funds will be available for some of this.
2. Image digitizer -- Again, some software development will be required, but not a large amount.
3. Hardcopy unit -- Should only require simple testing.
4. Other hardware -- For example, probable purchase is a new image display system.

With regard to the array processor, the following tasks will be performed:

5. Many more image processing algorithms will be implemented using the AP, including contrast-stretching, median window filtering, image registration, and a number of algorithms to be implemented under the "Enhancement and Restoration Procedures for Digital Images" Engineering Research effort.
6. Characterizations of image processing algorithms in the mini/AP environment will be made. We will investigate and document such considerations as memory needs, processing throughput, CPU vs. I/O trade-offs, effects of device-device transfers, etc.

7. Other appropriate uses for the array processor may be investigated, including standard signal processing algorithms and/or numerical problems in computational physics.

4. Geophysical Applications (1.5 FTE's)

Principal Investigator: R. J. Lytle

Participating Personnel: C. Conception, K. A. Dines, N. Gilson, and
J. T. Okada

This effort is devoted to improving technologies for remotely sensing underground features and determining geological characteristics. Electromagnetic and acoustic subsurface probing techniques are being developed for detecting and locating fracture and void zones, tunnels, and coal burnfront location. The work integrates fundamental physical modeling (EM/seismic/electrical and geophysical phenomena), instrumentation systems, algorithm development, and signal processing. These integrated activities are proving successful in solving traditionally difficult problems in remote sensing, with applications including coal gasification, oil shale retorting, nuclear waste site and nuclear test site evaluations, and strategic defense problems in detection of underground activity and structures.

4.8 Progress and Products

During FY79 we performed the following tasks in the course of this project:

- Analyzed the potential field about an electrically excited sphere buried in the ground [1]. The results provide a theoretical method for interpreting experimental data for electrically excited conductors such as grout. Using such a procedure, the location and extent of grout balls could be determined, either from ground or borehole measurements.

- Reviewed and selected usable remote probing techniques for defining discrete fractures in the geophysical environment.
- Acquired computerized program management techniques.
- Derived basic equations for determining fetal position using multiple electrodes.
- Performed basic research on core sample data collection and interpretation.
- Improved gravity field interpretations.
- Carried out basic studies on
 - impedance plethysmography
 - electromagnetic measurements of temperatures
- Made propagation measurements in the Piledriver complex at NTS.
- Assembled an automated core sample "impedance camera." This camera will provide the data to be interpreted using the computerized program described in the work of Dines and Lytle. The camera has been built but not debugged. The concept has been included in the multidisciplinary proposal submitted to the Division of Basic Energy Sciences concerning Underground Imaging. If this proposal is funded, the remainder of the work will be performed under this sponsorship. When operational, this camera will provide a

requested, needed, high resolution capability for monitoring what is going on in geophysical scale models. The intended uses are broad and include weapons, nuclear waste disposal, and fundamental research programs. The development of the camera and interpretation of its data was the major segment of FY79 research effort.

One outgrowth of this and associated work is that R. J. Lytle was appointed to serve on the Rock Mechanics Research Requirements Panel concerned with Fracture Mapping. This panel has been assembled by the National Academy of Sciences and Engineering and is defining the research needs for U.S. Technology.

A basic outgrowth of this project is a vigorous and varied program of activity over a broad range of geophysical applications.

Publications in Geophysical Applications

- [1] R. J. Lytle, J. T. Okada, and C. Concepcion, "The Potential Field Around Subsurface, Electrically Excited Conductor," UCRL-83191, August 24, 1979, to appear in IEEE Trans. on Geoscience Electronics.

4.C FY80 Plans

A program is planned which provides the guaranteed long-term support required to assess possibly useful technology areas. If such a study shows a particular technology area to be especially attractive in terms of its overall utility, then a prototype system (mathematical or instrumentation) would be developed for use in demonstration of the procedure to its interested users. Further development of demonstrated systems would be left to funding provided by these interested users.

At this time, the particular tasks deemed worthy of possible study include: 1) how to adequately, but succinctly, mathematically describe bore-hole-to-surface wave propagation with anomalies present, 2) assessing the validity of using acoustic emission and the remnant "memory" of rock to its

prior stress state for designing an in situ stress instrument, 3) identifying, conceiving, and implementing remedies for effectively coupling seismic energy from sources in boreholes into the host medium, 4) evaluating SQUIDS which show merit for differential (gradient) measurements of magnetic field, permitting development of an especially sensitive metal detector usable for on-site-inspection for metal artifacts, 5) using the Prony method on accelerometer measurements results for mechanically shock-excited rocks elevated on an air cushion. This may be one way of determining the Q of rocks for the low frequencies used in seismic studies. This data is nonexistent now.

Broadly speaking, the first two months will be used to make a relative ranking of probable tasks. This necessitates working in all areas to identify problems and detailed costs. The most fruitful first task could thus be identified. The major effort would then shift to pursuing this project through (if feasible) to a prototype system. Funding of further development would then be sought. The next task effort would then begin and follow the same development route.

5. Decision Support Systems (1.3 FTE's)

Principal Investigator: W. F. Rousseau

Participating Personnel: G. C. Corynen, R. L. Palasek

5.A Objective

The overall objective of this work is to develop computer tools for aiding engineers and decision makers in the performance of complex modeling, design, and decision tasks. This is in broad support of a wide-range of current program activities, including research on the safeguarding of nuclear materials (involving assessment of system vulnerabilities as well as the development of a methodology for regulating and designing safeguard systems), analysis of nuclear waste disposal sites, the development of a national energy supply model for policy analysis, review of energy storage systems for powering vehicles, detailed modeling of batteries and electric vehicle systems, research on R&D decision making, and the design and evaluation of tactical military engagement games. This work should also be of assistance in other applications, including nuclear weapons safety, on-line support system for responding to nuclear terrorist acts/threats, and management of complex Lab/DOE, R&D projects.

The basic objective of this project is to advance the state-of-the-art in computer-based decision support tools and to develop a useful integrated system. The immediate goal is to implement several practical interactive tools on an LSI-11 computer. At this time, we have focussed on two codes to achieve maximum impact on improving the effectiveness of our analysts: i) an algebraic-modeling code and ii) a decision-tree code. The first tools will aid an analyst in structuring models, simulating them, and performing sensitivity analysis. The decision tree code will greatly facilitate the development of decision-tree models, a fundamental model structure for a large

and important class of probabilistic systems. It will also permit automatic sensitivity analysis and the solution of large decision tree problems which would be infeasible without the code.

5.8 Progress/Products

We reviewed the literature on computer-based decision support and decision analysis tools. The concept for our algebraic modeling system has been developed [1], and an implementation approach has been worked out by R. Palasek based on data-flow concepts used in code-optimizing computers. A decision tree analysis program has also been designed (by Rousseau and Palasek) which is similar to the SRI CFREE code but more powerful. Parts of this code have been implemented and checked out on the LSI-11.

In addition, we have supported research by G. C. Corynen on the STOP algorithm, a new method for computing exact probabilities in complex systems. The STOP (Superfast Method To Obtain Probabilities) algorithm has been coded and run on sample problems; it appears (from analysis as well as numerical experience) to be significantly faster than anything currently available. As a result of its speed, precision, and its ability to treat probabilistic events with complex interdependencies, it has a number of potential applications to the analysis of the reliability of complex systems (including nuclear weapons safety, reactor safety and availability, waste repository analysis, and nuclear safeguards).

5.C Plans

We expect to defer work on the algebraic modeling and tree analysis codes in order to complete the theoretical and empirical investigation of STOP. Because the potential applications of STOP there is a good opportunity for programmatic support once we demonstrate that the concept is sound. Following this work, we will complete the decision tree analysis program and continue work on the algebraic model building system.

References

- [1] Miller, A. C., An Algebraic Modeling System, UCRL-15074.

6. Wave Theory Applications (1.5 FTE's)

Principal Investigator: A. J. Poggio

Participating Personnel: R. M. Bevensee, T. J. Burgess, R. Hawke

6.A Objectives

The short to intermediate term goals for these funds were to react quickly to LLNL needs and to look at new methods for EM and Acoustic modeling. Further, the funds provided seed-money for short feasibility studies and for the preparation of proposals.

6.B Progress/Products

The Wave Theory Applications funds permitted quick reactions to changing technological requirements and to rapidly developing opportunities. Among the subjects treated in this area were early efforts in particle beam weapons, rail guns, cave-in location, hardening issues, LLNL and outside support (helping others use our tools), and prospective funding search. Also during the past year the studies of high field compression were completed and an initial linac design was performed.

In the particle beam weapons area, the EM effects of these beams were investigated briefly for a proposal. This study was aimed at determining the effects on systems as the fields due to propagating beams which can be substantial and can serve as an EMP kill mechanism. An outgrowth of this work was a brief experimental study of whether emissions from housed accelerators can be detected and used for identification.

The Rail Gun is a mechanism for magnetically propelling projectiles to hypervelocities for various high impact studies, equation-of-state studies, and inertial fusion.

Feasibility studies and initial designs for the Rail Gun were funded under this project. Funding is being sought from DARPA.

6.C Plans

Work in this area in FY80 will be specifically devoted to a new project, "Three-Dimensional Computer Modeling of Particles and Fields." (See Section 9 below.)

7. Software Tools (0.5 FTE's)

Principal Investigator: L. Hatfield

Participating Personnel: R. Sherwood

7.A Objectives

Computer systems research currently includes both hardware and software projects in such areas as computer-aided design, computer networking and multiprocessor systems design.

Recent work ranges from development of an interactive graphics design system on a minicomputer to participation in the design of a new large scale computer, from logic design to operating system.

The objective of this small project was to support these computer systems research activities by developing "software tools." Such tools are the software analogs of hardware tools--they help one to more effectively develop, debug and maintain a software end-product. With general purpose software tools available, specific software can be developed with greater efficiency. Because current costs of a typical computer system are 80% software (including software maintenance over the lifetime of the system) and only 20% hardware, significant savings can be achieved by relatively modest investments in software tools.

7.B Progress/Products/Plans

Common software tools include text editors, compilers, and debugging packages. Most current computer systems include at least primitive versions of each of these. The principal effort on this project was the adaptation of a structured FORTRAN preprocessor, originally developed at SLAC, called

MORTRAN. The purpose of this type of tool is to allow a programmer to write a code which is more structured than normal FORTRAN and therefore more readable. This makes the code easier to debug and easier to maintain.

Other types of tools, e.g., program logic analyzers, library maintenance systems and cross-reference generators, would also be desirable to develop and will be pursued in the future as time and funding permits.

FY80 Program

New Selection Process

During FY79 a new proposal review and selection process was developed and applied to the FY80 program. In previous years the process had been relatively informal: brief proposals were submitted to the Engineering Research Division Leaders and Associates; on the basis of their review and their perception of Department, Laboratory, and NEP needs, a proposed program was developed and submitted to the Associate Director of Engineering for approval.

While preserving the main lines of responsibility and authority, in FY79 the procedure was made more formal and public; and broad Department advice was sought for assistance in ranking proposals. The process involved the following steps:

1. Open Proposal Submission - June

Proposals were solicited from members of ERD. Sixteen written proposals were submitted.

2. First-Cut Review and Elimination - July/August

On the basis of a review of the written proposals, three proposals were eliminated by the ERD Division Leader and Deputy.

3. EE Department Review - August

The remaining 13 proposals were presented orally by the Principal Investigators in an all-day review. Attending as reviewers were the EE Department Head and Deputy, EE Division Leaders and/or Deputies, and a representative from Mechanical Engineering Research.

Reviewers submitted written evaluations and/or numerical rankings of projects. Selection criteria were listed as:

NEP Impact

Potential contributions (medium and long-term) to the Nuclear Explosives Program. Will NEP need this capability? Will the capability be available to NEP from other sources?

(Other) L³ Impact

Potential for the development of new skills and tools relevant to other LLNL and DOE programs. Will this work lead to self-supporting capabilities? Does it build on or complement existing ERD capabilities?

Research Impact

Potential research content. Will the project produce results which are not only technically sound but are also new and of interest to a technical peer-group?

Alternate Support Availability

Are other sources of support available for this project?

Investigator's Capability

Capability of proposed and available staff for executing the projected work in the proposed time. Are the expertise, level of experience and time all adequate to accomplish the objectives?

Proposal Technical Soundness

Are the proposal and the work plan technically sound?

Reviewers were asked to rate each proposal by a score of from 0 (worst) to 10 (best) on each of these six dimensions of performance. Their evaluations were then melded together and used by the ERD Leaders to help put together a final program.

While numerical aggregations of project scores were developed, they were considered advisory only and were not made public. The funding decisions were broadly consistent with these rankings (and the verbal evaluations of reviewers), but it was believed important not to become rigidly bound to a mechanical ranking system.

4. ERD Synthesis - September

The final program was reviewed with EE Division Leaders and presented to the Associate Director for Engineering.

5. Final Program Selection - October

In response to a reduction in FY80 support (due to overall Laboratory reduction in Engineering Research funds), the program was finally revised to consist of eight projects in four major thrust areas. Support level will be 11 people (FTE's) and 1.077 \$M total cost. Table 2 describes the overall FY80 program.

Following Table 2 are outlines of the two projects which are being initiated in FY80.

New Projects for FY80

8. Estimation and Identification Algorithms: Development and Implementation

(2.0 FTE)

Principal Investigators: J. V. Candy, D. R. Dunn, D. L. Lager

Participating Personnel: S. Azevedo, D. Gavel, M. Portnoff

Consultants: D. Siljak, D. Dudley

8.A Objectives

Throughout the EE Department and the Laboratory, programs acquire data and wish to process it to extract the maximum information content. The overall objective of this project is to provide computer-based, signal processing tools for this purpose.

More specifically, this project will address two issues:

- Algorithm development. We will develop Kalman filter-based estimation/identification algorithms for large-scale dynamic systems (e.g., with 40 or more states).
- Computer implementation. We will develop and implement fundamental signal processing algorithms for minicomputer systems.

These two combined tasks provide significant potential for both long and short-term impact. The implementation of signal processing algorithms on a minicomputer will immediately serve a number of ERD and Department users interested in processing data. Relevant programs range from Weapons (who have previously benefited from the PARET parameter estimation algorithm) to Nuclear Systems Safety (Seismic and Safeguards) to the (CTBT) Seismic Monitoring Program.

The other effort involves the development of effective model-based estimation/identification algorithms for large-scale dynamic systems. Originally perfected and proved out on the systems encountered in aerospace applications, Kalman filter techniques now appear ready for adapting to a broad range of Laboratory problems, including those mentioned above. In addition, underground energy and nuclear waste management systems are also potential targets: they all may be described by large partial differential equation models which are susceptible to this kind of analysis; and this development will provide such programs with a more sensitive tool for the analysis of data than they currently possess.

8.8 Plans

The basic approach to satisfy the first objective will be to implement an existing simulation consisting of a large number of differential or difference equations (typically derived from a partial differential equation model) and to develop a state estimation algorithm in stages to solve the large scale estimation problem. Each stage will utilize a more detailed dynamic model consisting of more and more differential equations. Motivated by a weapons related large scale estimation problem, special techniques will be developed to increase algorithm computational capability (speed and size). Initially, a linear system will be investigated, since results are more promising, and eventually the nonlinear estimation problem will be considered time permitting. A parallel effort will follow in developing an off-line identification algorithm, since the estimator will be part of the overall identifier. In summary, the approach to the large scale estimation identification problem will be to: (1) develop a large scale system data base (simulators) using existing LLNL codes; (2) modify/implement our existing estimation algorithm to

handle large numbers of differential or difference equations starting with a linear estimation problem; and (3) in parallel develop an estimator-based identification algorithm.

The approach to satisfy the second objective will be to develop some general purpose signal processing algorithms on the PDP-11/70 system and purchase some packages to enhance processing capability. Again a linear state/parameter estimator algorithm will be developed with inherent small machine problems (roundoff, limited memory) in mind.

8.C Anticipated Products

1. State/parameter estimation algorithms for large scale dynamic systems.
2. Signal processing algorithms including state/parameter estimators for minicomputer use.

9. Three-Dimensional Computer Modeling of Particles and Fields (1.0 FTE)

principal Investigators: H. S. Cabayan and G. J. Burke

9.A Objectives

The objective of this effort is to develop the capability to solve self-consistently three-dimensional, time-varying problems involving Maxwellian fields and charged particles. This will be achieved with a user-oriented, versatile computer code.

Many problems in analysis or design are characterized by Maxwellian fields and charged particles that interact. The fields are physically modeled by two well-known partial differential equations in space and time that involve quantities such as currents and electric and magnetic fields. The trajectories of the charged particles are physically described by the two relativistic Lorentz equations. Hence, the fields and particles can be modeled by four coupled differential equations in space and time that are nonlinear and can be inhomogenous. Of course, proper boundary conditions have to be defined before any solution is attempted.

We propose to develop a user-oriented flexible computer code to solve this problem. The solution will be performed in the three space dimensions and time. A finite difference scheme will be used to model the two field equations, and an efficient external boundary-handling capability will be added that will provide appropriate boundary and radiation conditions. The trajectories of the charged particles will be followed in space and time by updating the Lorentz and field equations simultaneously. The code will be written so that only its field portion is used if free particles are not present in the problem.

A survey of the presently used field and particle codes in the EE Department has shown that they are inadequate and often very limited. Usually, a quasi-static approximation is made and the problem is solved in two-dimensions. These approximations introduce large uncertainties and make present code predictions unreliable. For field problems only, ERU in the past had developed sophisticated integral equation techniques to solve three-dimensional problems in the time domain. These techniques, however, cannot handle inhomogenous problems and as presently implemented do not include particle interaction physics.

User-oriented field and field-particle codes would find applications in many programs:

- Nuclear Test Program instrumentation design
- New linear accelerator design
- Particle beam effects
- Protection for high energy systems in Lab energy programs (e.g., Y and MFE)
- Weapons effects on electronics

9.B Plans/Products

The project is broken down into the following series of tasks:

Task 1: Survey existing codes in the field-particle interaction area used throughout the country. Complement this with a survey effort of the numerical modeling literature. Decide on exact details of the modeling.

- Task 2: Survey field-particle code needs in EE and LLNL and compile a list of desired parameters and their ranges. Use this to further scope Task 1.
- Task 3: Develop the field package first with approximate boundary conditions. Validate with tests at the LLNL Transient Range or with integral equation codes.
- Task 4: Implement exact boundary conditions in code. Validate.
- Task 5: Implement the particle pushing capability to the code. Validate with existing experimental data.
- Task 6: Apply the package to several problems identified under Task 2.
- Task 7: Document code and write user's manual. Provide means for the transfer of the capability to other groups and divisions at LLNL.