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RESEARCH OPPORTUNITIES IN ELECTRONICS

Panel on Research Opportunities
in Electronics
Naval Studies Board
Commission on Physical Sciences,
Mathematics, and Resources
National Research Council (U.S.).

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PREFACE

The Electronics Division of the Office of Naval Research (ONR) is charged with the responsibility for research addressing the needs of the Navy and Marine Corps for (a) higher speed information and signal processing, (b) improved reliability and maintainability of electronic systems, (c) operation in natural and manmade hostile environments, (d) improved security and communication systems resistant to jamming and interception, (e) expanded exploitation of the complete electromagnetic spectrum, and (f) improved systems design, control, and analysis.

The Naval Studies Board was requested to establish a panel to identify research opportunities for the ONR in electronics. This panel would advise on long-range research opportunities appropriate to the mission of the ONR and would provide a source of input from the scientific community as the ONR formulates plans for electronics research in both its core program and special-focus initiatives. The panel would also explore the broad role of electronics in the Navy's missions, including its role at in-house laboratories, such as the Naval Research Laboratory (NRL). Clearly, identifying new electronics research opportunities could fundamentally affect the Navy's ability to meet the needs enumerated above.

The panel was extensively briefed by ONR senior management and electronics program managers at its initial meeting on June 30, 1987, regarding the ONR's current research program and plans. In executive session following that briefing, the panel prepared a report to assist the ONR in a timely way rather than making a detailed, long-term study. The current programmatic organization into solid state electronics, systems and communications theory, electromagnetics, and space science was taken as an appropriate structure for considering opportunities for expanded and new research thrusts. The panel first considered what conditions in the scientific and technological environment during the next 10-20 years could lead to new electronios opportunities. The panel then identified basic research directions that could be undertaken to provide focus to these potential breakthroughs. This report presents the panel's consensus concerning research areas that merit significant support by the ONR because of their substantial relevance to Navy missions. It is our hope that the report will enable the ONR electronics program managers to consider the panel's suggestions now in making plans for the coming fiscal years and augmenting their current, successful, strong basic research program.

Robert S. Bauer
Chairman, Panel on ONR Research
Opportunities in Electronics

PANEL ON RESEARCH OPPORTUNITIES IN ELECTRONICS

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SUMMARY

The Office of Naval Research (ONR) has been instrumental in fostering the scientific and technological base of the nation for over 40 years. This tradition of identifying promising opportunities and providing sustained funding for basic research is a consistent record of singular import to the nation that has allowed promise in electronics to be achieved. In reviewing the current programs in electronics, the panel finds that exciting, world-class research is being supported, especially in the area of greatest emphasis: solid state electronics. Without compromising this success, selective funding increases are recommended for systems research.

In this study, we suggest that an opportunity exists to augment the current work by establishing more cross-disciplinary efforts. For example, this is an ideal time to profit from joint efforts among materials, characterization, theoretical modeling and simulations, and device areas. Without advanced components, systems capabilities will have limited functionality. The performance of an electronic system is ultimately limited by the performance of the devices that it is composed of. Slight differences in performance can be critical to the success or failure of a military mission. The ONR Solid State Electronics Program is central to providing the Navy with the highest performance electronic systems. The current ONR program is innovative, concentrating on the right issues, and well-managed. However, we believe that if additional funds were available, the ONR would be better able to ensure that Navy needs in command, control, and communications (C^3) and electronic warfare (EW) are successfully met. Some areas for emphasis with new funding include: (a) innovative devices that couple effectively with the materials research program; (b) the use of high-performance, inexpensive computing in the fabrication of devices; (c) nanofabrication techniques; (d) devices with characteristic dimensions of <100 nm; and (e) basic science of heteroepitaxy and homoepitaxy to provide the technology base suppport for the development of modern electronics, electro-optics, and sensors.

Developments in complexity of electronic devices have come at a cost. The increased capital investments and maintenance costs are well-documented in the manufacture of state-of-the-art electronic devices. Research in the area has suffered the same increase in overall cost. A serious research program in each of these areas will require a few capital equipment items that cost more than $0.5M apiece. Purchase and maintenance of the equipment and the associated research efforts are changing dramatically the cost of research in these areas of electronics. For this reason, funding increases beyond the standard rate of increase will be required in the future to take advantage of the leverage these areas could provide to our modern Navy. There are many who believe the opportunities in solid state electronics today are as great as in the early 1960s when integrated circuits were first invented.

We recognize important Navy needs for scientific research in regions of power/frequency space where solid state electronics cannot provide required characteristics: for example, gyrotrons and ubitrons, as well as more traditional slow wave devices such as TWT and CFTs. A modest investment in vacuum electronics should be part of the Navy's electronics portfolio.

The pervasive role of networks and communication systems suggests fruitful topics for additional investment in order to deal in an orderly way with the ever-increasing complexity and inherent unreliability of future systems. Although the area has recently had a substantial infusion of SDIO/IST funds, and although it is also partly covered by efforts in the mathematics and computer sciences programs, it is so relevant to Navy needs that additional funding of the core program base would appear to be extremely important. The high quality of the small program currently existing in this area must be commended, but efforts to bring more researchers into the area without reducing the exploding opportunities in solid state electronics will be essential for significant progress. We suggest algorithms for distributed architectures and networks as a major topic that is both forward looking and at the same time related naturally to the existing efforts in the ONR. The panel identifies new opportunities for enhanced activity in electromagnetics and space science in an effort to add to the rather limited ONR-supported efforts in these fields. These opportunities include: (a) advanced systems and techniques for using electromagnetic radiation to detect ocean conditions and the presence of surface and subsurface vessels, and (b) study of the feasibility of modifying ionospheric conditions using high-powered sources of high-frequency electromagnetic radiation.

The ONR support of some basic electronics research in industrial laboratories has been instrumental in encouraging advances in this field throughout the years. Therefore, we urge the ONR to continue such support and to maintain close awareness of developments in electronics research in industry, being alert to opportunities for cooperative efforts in areas of mutual interest.

INTRODUCTION

FUTURE SCIENTIFIC AND TECHNICAL ENVIRONMENT

Electronics is the underpinning for the functioning of society in the Twenty-first Century. In particular, electronics forms the backbone on which all future Navy thrusts depend: space-based systems, global command-control-communications networks, weapons sophistication, increased automation of platforms, and electronic warfare. These needs will be met depending on the effects of evolving trends in the general scientific and technical environment. As examples:

- Research will become increasingly interdisciplinary, from the impact of biological understanding of neural networks to the coupling of system performance with an understanding of material and device properties.
- Technologies will be combined for enhanced functionality, from the merging of analog and digital functions to achieving compatibility among presently incompatible electronics materials combinations.
- Three-dimensional devices will be fabricated with lateral modification on a nanometer scale, which will allow very small, high-performance structures with couplings, thereby beginning a new era of unwired arrays of nonstandard transistor structures.
- Advanced sensors will be developed for monitoring such diverse physical phenomena as ocean currents, atmospheric changes, and semiconductor materials growth.
- Systems will deal with massively parallel data from sensor and global communications networks.
- Need will increase for understanding the fundamentals affecting reliable manufacture of quantum devices. We will move beyond "green thumb" electronics fabrication to computer control of processing, growth environment, and defect incorporation based on theoretical simulations.
- There will be widespread availability of ultrahigh-performance computing.
- It will be possible to controllably modify the ionosphere with active plasmas in a way that fundamentally affects communications.
- Systems problems will shift from implementation to the design and organization for such complex functions as command, control, and communications.
- Robustness of systems will be achieved through distribution of system functionality.
- Memory requirements will increasingly shift to massive, nonvolatile storage.
- Systems will need to deal with integration of information that is massive, incomplete, conflicting, ambiguous, and wrong. This will be true for applications ranging from battle management to electronic process control.

- High-temperature superconductors will provide devices with new functionality.
- Monolithic integration of structures of materials that are incompatible today will allow optimized component functionality well beyond the individual element capabilities available today. Focus on devices will lead to combination of materials, solid state physics, and processing research for single chips having such parts as a HgCdTe sensor, with a GaAlAs light source controlled by VLSI Si integrated digital circuits.

One of the major themes that emerges in considering the impact of these trends is the importance of having more interdisciplinary and cross-disciplinary efforts within and among fields, as well as potential new topics for investigation. This theme is reflected in the organization and topics of the panel's report, as follows:

SOLID STATE ELECTRONICS

- Innovative Device Focus, for combining materials, structures, and fabrication research.
- Effective Utilization of Computing Power, for merging advanced characterization techniques with simulation and modeling to achieve process control.
- Better Understanding of Manufacturing and Reliability Issues.
- Advances in Sensors and Signal Processing.

SYSTEMS AND COMMUNICATIONS THEORY

- Algorithms, Networks, and Architectures, for high-speed processing.
- Unreliable Links in Distribution.
- Massively Parallel Systems, including neural networks.
- Theory and Processing in Large Adaptive Systems.

ELECTROMAGNETICS

- Innovative Integrated Antenna Elements.
- Electromagnetic Remote Sensing.

SPACE SCIENCES

- Modification of the Ionosphere.

In addition to cross-disciplinary cooperative efforts, the panel notes that much of the pioneering basic research in electronics occurs in industrial research centers. The ONR, whenever possible, should continue to fund foundation research efforts in industrial research laboratories. We urge ONR program managers and members of their research staffs to maintain interaction with their colleagues in industry in order to remain aware of new developments and emphases in industrial research. The Navy should continue to be alert to opportunities for cooperation with industry on research of mutual interest.

We recognize important Navy needs for scientific research in regions of power/frequency space where solid state electronics cannot provide required characteristics, as for example, gyrotrons and ubitrons, as well as more traditional slow wave devices such as TWT and CFTs. Although there was no specific expertise on the panel to address this area, we believe that a modest investment in vacuum electronics should be part of the Navy's electronics portfolio.

No attempt is made to be exhaustive in this exposition. Rather, we attempt to identify some of the most exciting current programs and suggest areas for coordination, changing emphases over time, and new initiatives. The ability to realize the potential of the broad range of electronic applications is limited by the solidity of the basic scientific foundation in a very fundamental way. We have attempted to identify critical thrusts for making major advances in electronics research.

SOLID STATE ELECTRONICS

INTRODUCTION

Solid state electronics has been the foundation of the technological revolutions that have taken place since World War II in information processing, computation, communication, control, and other fields. Modern naval defense systems depend heavily on high-performance solid state electronics. It is critically important that naval research policy promote the advancement of research in solid state electronics and sensors. The current program of the ONR in this area is broad, well-directed, and basically sound. However, it is clear that over the next two decades there will be major changes in the structure of microelectronic devices and the systems based on them. Specifically, devices will continue to shrink in size, and the transistor will very likely give way to fundamentally new devices based on quantum mechanical effects. Advanced sensor arrays and devices to convert the output of electronic systems to physical actions will lead to systems whose complexity and capabilities are not dreamed of even today. We therefore urge the ONR to fill the vacancy that currently exists in the solid state electronics area with an outstanding individual who has a broad interest in the area of device research.

One of the significant problems in solid state electronics research is the rapidly increasing cost of equipment and facilities. Two decades ago research could be done in normal laboratory space with low-cost homemade equipment. Today, research is carried out in cleanrooms with equipment that costs orders of magnitude more. An individual investigator must have access to millions of dollars worth of equipment and facilities in order to participate in solid state electronics research. Equipment replacement costs are proportionately high. Future budgets for solid state electronics research should reflect the rapidly increasing cost of equipment purchase, operation, and replacement.

NOVEL DEVICES AND SYSTEMS

Integrated circuits, whether in Si or III-Vs, are based on transistors interconnected by means of metallic or semiconducting wiring. As devices decrease in size below 1 micron, more and more of the circuit area is taken up by wiring. This "wiring crisis," together with problems that arise as the minimum feature size of transistors approaches 100 nm, has led many experts to predict that totally new devices, based on quantum mechanical effects and local coupling (i.e., nonwired), will replace the transistor and wired-up integrated circuit. No one has any idea at present what such devices will look like or how systems based on them will operate. We only anticipate that devices will be small and systems will be quite different from what we have learned to deal with in today's technology. Hence, it is important for the ONR to pursue a basic research program aimed at promoting this envisioned fundamental change in solid state electronics. Most of the

ONR research over the last several years on artificially structured materials and quantum-well devices has been focused in this direction. We wish to encourage this trend and suggest some opportunities for high impact.

As we approach the turn of the century, the direct link between electrical material properties and electrical performance of the solid state device must be established as an integral part of proposed research efforts. The role of defects and their influence on device electrical characteristics must be emphasized to understand reliability and fabrication.

MATERIALS

The ONR research program in electronics is one of the premier programs in the country on electronic materials. The well-managed innovative nature of this program has made it the source of many of the major developments in this field over the years. The current efforts are very much in keeping with this tradition and are required to secure the technology base of U.S. electronics, both private and military. Hence, we feel that the new efforts we are proposing should be additional to those currently funded.

In the future, we anticipate that heterostructures between materials of both similar and dissimilar substances are going to be the key to electronics in the 1990s and beyond. Epitaxial layers involving group IVs, as well as III-Vs and II-VIs, will be important. Although the ONR already has very substantial efforts in this area of research, we feel that particular emphasis should be placed on a few key areas where major progress can be obtained because of a confluence of new developments.

The arrival of inexpensive, high-performance computing is going to make it possible to use realistic models of materials fabrication in the simulation of device formation. Soon it will be possible to add Cray levels of computing to a crystal puller, MBE machine, MOCVD reactor, or reactive ion etcher for roughly 10 percent of the cost of the system. Hence, it will be feasible to use computers in a realistic process control mode with very complex, sophisticated equipment for device growth and processing. The production of new, very complex heteroepitaxial devices will require exceedingly precise control over materials preparation and fabrication. Structures in which uniformity of fabrication over wafers whose characteristic dimensions are inches must be maintained to levels measured in angstroms; this will require control of fabrication to one part in 10^8. These levels of control are going to require the construction of computer-based models that will allow the development of fabrication engines with a very high level of control. We feel that the ONR should begin to initiate programs aimed at this very exciting and essential direction of development.

The ruggedness and compactness of modern electronics are based on the fabrication of microchips that contain large numbers of electronic elements. To date, these microchips have been based on a single semiconductor material--Si for most chips, and GaAs for a few chips. Yet some of the advanced concepts in electronics require the integration of the high-speed or optoelectronic properties of III-V semiconductors with the complex circuits that can be fabricated in Si, coupled with the detector or display properties of II-VI semiconductors. It is possible to conceive of the use of heteroepitaxy to fabricate chips with a number of different semiconductors, each performing the function it does best. We believe that such structures will be very important to the Navy.

A major feature of these new heteroepitaxial systems is the existence of large lattice mismatch between the layers in the structures. The development of techniques for controlling the defects that may be introduced by such a procedure will be important to the successful development of a heteroepitaxial technology. Hence, we think that the ONR should have a major research program to understand and control the fundamental characteristics of electronic materials that affect device performance. This can be accomplished by focusing more effort on the device behavior of novel structures.

MICROFABRICATION

Future generations of solid state electronic devices and systems will require advances in microfabrication (lithography, etching, and additive processes) as well as in materials. Especially is this true for quantum-effect devices that involve sub-100-nm linewidth structures. Although electron-beam lithography techniques have demonstrated sub-100-nm patterning, this method is extremely slow and produces coherent structures over very small fields. For example, to cover a 1-cm diameter area with a dense array of 50-nm features requires a writing time in an electron-beam system of the order of one year! Achieving a linewidth control of 10 percent at 50-nm linewidths is highly problematic, yet such control may be required. For 50-nm linewidths, the writing field of electron-beam systems is only about 100 microns in diameter. Larger fields require a step and repeat procedure. Electron-beam lithography is adequate for certain first order research demonstrations but inadequate for Navy needs beyond that point. Metrology in the sub-100-nm domain is crude or nonexistent.

Replication techniques such as x-ray lithography, masked-ion-beam lithography, and perhaps x-ray projection are capable of producing sub-1-nm features with short exposure times, but much further research needs to be done to make such techniques useful for both research and the development of the next generation of microelectronic devices and systems.

Electron-beam lithography systems are extremely expensive facilities, as are the synchrotrons being contemplated for x-ray lithography. Unless lower cost approaches are developed, research on microelectronic devices and systems will be beyond the means of the vast majority of university researchers. Such research cannot be done by occasional visits to major facilities that have such equipment.

Beyond lithography, techniques of etching and additive patterning require extensive research to achieve the precision, accuracy, and linewidth control required by the next generation of microelectronics. Perhaps entirely new approaches to making microstructures need investigation.

In summary, the ONR should not overlook the opportunity for supporting research on the microfabrication techniques required to take us into the next generation of microelectronics in the sub-100-nm domain.

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SYSTEMS, COMMUNICATION, AND SIGNAL PROCESSING

The importance of secure, high-speed communications, signal processing, and image processing capabilities to the Navy, and in fact all the Services, hardly needs elaboration. Recent news items, for example, about how increasingly quiet Soviet submarines have become, make amply clear the significance of rapid and sophisticated methods for the extraction of information from very weak signals in uncertain and nonstationary environments, and its rapid dissemination to a wide network of users. Moreover, the continued success of the ONR's longstanding and notable efforts in the solid state area make the needs for corresponding signal processing efforts even more acute. Without prior attention to the appropriate application, the potential capabilities of very-high-density submicron devices may never be usable.

The ONR's electronics program in the area of systems, communications, and signal processing is an important, but still small, fraction of its core research budget. Although the area has recently had a substantial infusion of SDIO/IST funds, and although it is also partly covered by efforts in the mathematics and computer science programs, it is so relevant to Navy needs that additional funding of the core program base would appear to be extremely important. The high quality of the small program currently existing in this area must be commended, but efforts to bring more researchers into the area without reducing the exploding opportunities in solid state electronics will be essential for significant progress.

Of the several directions for systems, communications, and signal processing that could be recommended, perhaps the most exciting are those at the boundaries of several disciplines. We recommend algorithms for distributed architectures and networks as a major topic that is both forward-looking and at the same time related naturally to the existing efforts in the ONR. This area is divided into four subtopics:

- Algorithms and architectures.
- Sensor array processing and high-resolution spectral analysis.
- Distributed algorithms for network control.
- Neural nets.

These are described in greater detail in this section, but first some general remarks may be useful.

There are many fundamental issues concerning the design of algorithms for signal processing, sensor processing, pattern recognition, control, and other functions when those algorithms must operate in a distributed environment. In some examples, such as neural networks and parallel processing, one uses distributed signal processing elements to enhance the computational power and speed of the system, whereas in other examples, such as network control and distributed sensor systems, the geographical separation of the nodes forces the system to be distributed. In both types of examples, however, the design of the communication between the processing elements is at least as important as the processing done by the individual elements. In both types of examples, the distributed nature of the system both permits the opportunity for robust operation in the presence of failures and also provides the challenge of understanding how to construct distributed algorithms that can adapt to failures. Finally, there is also the common problem of how to scale such algorithms with the number of nodes or processing elements. These general questions appear implicity in all the four promising research areas discussed in the following sections.

ALGORITHMS AND ARCHITECTURES

A look at current activity in the very large scale integration (VLSI) area will show a substantial effort in more sophisticated digital signal processing (DSP) systems. However, most of this activity is microprocessor-based, albeit on ever-newer and more powerful units, and therefore subject to certain fundamental limits on the maximum processing speed. For example, microprocessor-based systems for decoding convolutional codes are currently in the 10-20 Mbits/sec range, and more than doubling this rate appears to be difficult to achieve, whereas applications demand rates of several Gbits/sec. New computing structures are clearly necessary. One possibility is the use of general purpose parallel computing machines such as the hypercube, the connection machine, the BBN butterfly processor, the SAXPY-1M, and the GE WARP systolic processors. However, if we look a few years (5 to 10) ahead, it is conceivable that advances in technology and in computer-aided design (CAD) will allow us to build cheaper and faster special purpose solutions for different classes of signal processing applications. The warm reception accorded ZORAN's very simple move in this direction through the introduction of dedicated vector multipliers and adders is an indication of how welcome more customized solutions could be. More evidence accumulates every day (see the August 6, 1987, issue of <u>Electronics</u>).

There has been considerable progress already in the direction of special purpose arrays with work on systolic arrays, wavefront processors, regular iterative arrays, and the like, and, in fact, some of this work has been sponsored by the Contract Research Department (CRD) Electronics Division already (under the USER-VLSI program) and by the CRD Computer Science and Mathematics Divisions. However, these efforts are winding down, perhaps just at the time when increased effort toward longer-term issues behind the original support is most needed.

It will become important to move toward the development of a <u>theoretical</u> base for the design of classes of special purpose computing arrays as opposed to the rather ad hoc methods used so far for the <u>invention</u> of systolic arrays (and some generalizations thereof). Bridges also need to be developed to related work in computer science on compiler theory and on the development of methodologies for high-level programming languages, both of which have some surprising (at least initially) similarities to problems encountered in the studies motivated by signal processing. Moreover, such research has to be closely linked with the study of methods of fault modeling, test generation, error detection and correction, fault recovery, and fault-tolerant design.

SENSOR ARRAY PROCESSING AND HIGH-RESOLUTION SPECTRAL ANALYSIS

Fast and accurate algorithms for detecting and resolving narrow band signals in noise, while also determining their angles of arrival, are clearly of great interest to the Navy. Although the current ONR program has a few excellent investigators in this field, there is an opportunity here for bringing in several other researchers from related areas in signal processing, numerical analysis, and processor array design, and for useful collaborative efforts with researchers at several naval laboratories, especially Naval Ocean Systems Center (NOSC), Naval Undersea Systems Center (NUSC), Naval Research Laboratory (NRL), and Naval Ocean Research and Development Activity (NORDA).

There has been striking progress in recent years in direction of arrival (DOA) algorithms such as MUSIC, root-MUSIC, and recently ESPRIT. Some useful solutions to the longstanding problems of combating coherent interference (as in multipath or smart jamming) have been developed. However, there is a need for further examination of sensitivities to model uncertainties, robustness in numerical calculations, and the development of special purpose architectures of various types (e.g., bus-connected processors with local memory, systolic arrays, or connection machines). Interaction with naval laboratories will also enable some trials with real data, an important guide in such highly theoretical areas. One might mention that such tests have recently been made with ESPRIT on the analysis of very flexible robot arms with encouraging results. There are still several open questions in the area of spectral analysis, which is not surprising considering the very wide range of problems and applications in this field.

DISTRIBUTED ALGORITHMS FOR NETWORK CONTROL

Communication networks, whether for data, voice, or both, inherently require distributed control. The required distributed control algorithms range from link access protocols to routing and flow control algorithms to transport and higher layer protocols. Research and development on conventional networks has been well funded by the government and by industry over the past 20 years and has led to a mature and recognized research field. This research, and the corresponding technology, is based on a clear separation between communication theory (and technology) and network theory (and technology).

The Navy (and more generally the Department of Defense) has a critical need for survivable communication networks, that is, networks that maintain a minimally acceptable level of throughput under a wide variety of highly stressed conditions. Often these networks must operate in a multiaccess environment and must operate in the presence of rapidly varying propagation conditions. There are many approaches to such survivable networks, including spread spectrum, clustering, multicast flooding, contention resolution, and various combinations of these.

Research on survivable networks must integrate the communication and network aspects of the problem, as opposed to the conventional network approach of separating these aspects. The ONR is currently funding excellent work in this area, but the size of the program is very small considering its importance. The NRL is also doing excellent work here, but on a limited scale. A significant expansion of basic research on the underlying problems of survivable networks should be of highest priority. At present there is not even a conceptual basis for contrasting the various approaches to these networks. Thus, along with the need for expanded exploration of particular approaches, there is a great need for basic research to provide a cohesive framework for the integration of comunication with network control. Given the number of supposedly survivable networks currently being built, and given the primitive state of understanding of this area, the need for more basic research is particularly pressing.

NEURAL SYSTEMS

Significant advances are being made by neural scientists in the understanding of biological neural networks, and basic mathematical models are beginning to evolve. Scientists and engineers have even begun to implement VLSI circuits based on these models to study the behavior of these circuits in relation to the behavior of the human brain. At present, these models are significantly lacking in their ability to model the human brain, but a breakthrough in this area would constitute a major scientific discovery comparable to or even greater in magnitude than the discoveries that led to the development of the digital computer. The development of neural network models combined with the ability to implement massively parallel systems in VLSI technology could lead to new forms of computation in which pattern recognition and feature extraction with imperfect information become more nearly feasible computationally and more reliable.

With the rapid advances currently taking place in VLSI circuit technology and the neural sciences, the Navy could reap substantial benefits through the funding of interdisciplinary research projects between the electronics and biological sciences communities. Thus, we are pleased that the Electronics Division of the CRD has proposed an Accelerated Research Initiative (ARI) research program in this area in FY 1989 to: (a) promote a transfer of information between the two communities, (b) develop mathematical models and algorithms for neural networks in order to gain a deeper understanding of their behavior, and (c) implement these models in VLSI circuit technology and study their behavior. In the future, implementation of these algorithms in opto-electronic systems could be feasible. We also applaud the preliminary work at the NRL in this area. However, caution is advised. This is an extremely high-risk area in which it is difficult to make judgments about the quality of the research. Furthermore, major breakthroughs in the short term may not be forthcoming.

The goal of this research should be to develop new forms of algorithms and computation for information and signal processing. A bird and a plane both fly, but they are not identical structures. Similarly, a VLSI circuit may never be identical to the human brain, but this research could lead to a better understanding of the functional processes of the brain, and thus to a realization of some of these functions in electronic systems.

ELECTROMAGNETICS

The electromagnetics program of the ONR has supported basic electromagnetics research in radiation, propagation, and scattering that is highly relevant to the development of Navy radar, communication, and remote sensing systems. Because the electronic devices and circuits that comprise these systems are rapidly changing, there continue to be urgent requirements to solve new and challenging electromagnetic problems. We, therefore, encourage the ONR to continue supporting basic research in electromagnetics. We also recommend that the ONR increase its support of research in the areas of advanced sensor devices and systems for remote sensing, and the electromagnetic analysis and modeling of monolithic integrated circuits.

ADVANCED SENSOR DEVICES AND SYSTEMS FOR REMOTE SENSING

Radar and radiometer systems show great promise for remotely sensing oceanic and atmospheric parameters that are critical to naval operations. Microwave instruments on the SEASAT satellite launched by the National Aeronautics and Space Administration (NASA) in 1977 demonstrated that synoptic measurements of ocean wave heights, surface winds, and sea-ice coverage can be achieved. The Navy has not been able to fully exploit these early successes owing to the unavailability of suitable satellite platforms. Nevertheless, the Navy has placed sensors on the GEOSAT satellites and is currently planning the N-ROSS experiments to further advance remote sensing techniques.

The ONR has supported research that is relevant to the Navy's remote sensing objectives: research programs that study rough (ocean) surface scattering of electromagnetic waves and the microwave emissivity of the ocean that may have payoff in detecting ship wakes. These studies and others that are suggested below should provide important information that will enhance the Navy's remote sensing efforts.

Background: The electromagnetic sensing systems for N-ROSS and remote sensing satellites launched by other agencies represent modest technological advances over SEASAT systems. However, the Navy's ability to remotely sense the ocean environment should be greatly enhanced by recent and future technological advances in devices, signal processing, and algorithm development. For example, the rapid improvement of microwave, millimeter wave, and infrared components should have major impact on the sensitivity, accuracy, and reliability of advanced sensor systems. Similarly, improvements in computers and signal processing techniques permit the real-time analysis of data and opportunities for adaptive systems that focus surveillance on specific areas or objects such as ships. Finally, increased understanding of electromagnetic propagation and scattering should enhance modeling efforts and the development of useful algorithms that are necessary for extracting oceanic and atmospheric information from sensor data.

Objectives: We recommend that the ONR support basic research on advanced concepts for remote sensing instruments. We also encourage the ONR to increase its support of basic electromagnetic studies useful to the development of remote sensing algorithms that can be used to determine environmental parameters such as, for example, wind speed and direction, water vapor and precipitation, ocean currents (both surface and deep ocean), and sea ice. This support should be provided cooperatively with other ONR programs that have responsibility for programs in oceanography and atmospheric sciences. Participation in such programs by the electronics groups, however, should be limited to only those cases where it is clear that innovative electronic components or systems concepts are being attempted. At present, few oceanographers and atmospheric physicists know the possibilities that are presented by modern electronic technology. Traditionally, they have been more interested in the "science" of their own disciplines and have provided little support for the development of innovative prototype sensors. Cooperative efforts with the electronics program should accelerate the use of modern device technology and systems concepts in measuring the ocean environment.

Research Programs: Examples of high risk areas that the electronics program might consider include the following:

- Approaches to improve spatial resolution of targets by passive radiometer systems.
- Development of low-loss planar antenna arrays for radiometer applications.
- Theoretical studies on the imaging of ocean surfaces by synthetic aperture radars (SARs).
- Use of thinned arrays for space applications.
- Effects of surface currents on radiative emissibility and normalized radar cross-sections.
- Multifrequency doppler radars to measure ocean surface currents.
- Novel millimeter wave sensors to measure atmospheric water vapor.

ELECTROMAGNETIC ANALYSIS AND MODELING INTEGRATED CIRCUITS

As radar, communication, and computing systems process data at higher speeds and operate at higher frequencies and wider bandwidths, the Navy must be concerned with the performance limits placed on integrated circuits by electromagnetic propagation, scattering, and radiation. Circuit designers of high-speed digital and microwave and millimeter wave analog circuits are increasingly confronted by electromagnetics problems that hamper the design and operation of circuits. Therefore, there is a growing need to develop electromagnetic models of devices that can be used in CAD.

Background: For many years the ONR has supported a number of high-quality research efforts that have provided valuable insights into obtaining electromagnetic solutions relevant to the Navy's interests.

Basic theoretical studies have greatly enhanced the ability to analyze and compute radiative properties of antennas and the scattering characteristics of radar targets. Recently, ONR support has included the study of electromagnetic phenomena in modern integrated circuits. The electromagnetic interactions in high-speed integrated circuits, pulse transmission in planar structures, and the coupling between integrated microstrip transmission lines are examples of new ONR-supported studies. We recommend that additional research support be provided in this area that is aimed at placing radiating elements on monolithic integrated circuits.

Objectives: Antennas are important components in radar and communication systems. In the past, antenna design could be accomplished quite independently of the circuit and system designs. The advent of monolithic integrated circuits, however, suggests that radiating elements might be integrated into the monolithic structure at millimeter wavelengths. This approach minimizes long transmission paths, which will improve the noise performance of the system. For this approach to succeed, a number of important technical issues must be resolved. For example, viable device models must be created owing to the increased role that CAD software will play in the design and fabrication process; new and innovative architectures are needed to efficiently utilize the chip real estate; new electronic components such as phase shifters must be created; and the propagation, coupling, and radiative properties of millimeter waves must be understood for the monolithic circuit.

We encourage the electronics program to support basic research that addresses the above issues and those related to the eventual implementation of monolithic millimeter wavelength technology. The advantages that this technology presents for compact radar and communication systems indicate that the payoff will be great in the future.

The analysis and modeling of monolithic integrated circuits require that researchers must be well-versed in both solid state electronics and electromagnetics. Consequently, we encourage the electronics program's support of an interdisciplinary research program in which the principal investigators are closely coupled to integrated circuit design and fabrication. Recent advances in optoelectronic devices and superconductivity present new opportunities for research support by the ONR in the following two areas.

Optical Control of Microwave Devices: Recently, there has been considerable work done on the development of new devices for use in monolithic optical integrated circuits. To date, optical integrated circuits and monolithic microwave integrated circuits have generally been considered to be two separate fields of research. However, the fact that the same materials, such as GaAs, can be effectively used to produce both optical and microwave devices suggests that the two fields may merge to produce optical microwave monolithic integrated circuits. These require strong backgrounds in both electromagnetics and solid state areas. There have been successful techniques for optical controls of microwave signals, including optical modulation and switching, optical phase shifters, or optical generation and detection of microwave signals. Since the conventional microwave waveguides and phase shifters are usually bulky, the use of optical components will reduce size and weight problems. The optical system may also be immune from electromagnetic interference. Thus the research in the optical control of microwave devices, including the monolithic optoelectronic integrated circuits, should be very important for future electronic systems.

Superconducting Antennas and Integrated Circuits: The recent discovery of high-temperature superconducting materials has revived interest in the research on microwave integrated circuits and antennas using superconducting materials, which was under intensive investigation in the late 1960s. The major reason is that superconductors will reduce the conducting loss significantly in the propagation structures such as transmission lines and antennas, thus enhancing the responsivity or the signal-to-noise ratio. The possibility of high-temperature superconductors may not only eliminate the necessity of cooling systems but also significantly improve the performance of the microwave antenna system. However, more work is necessary to evaluate the overall performance of a superconducting microwave integrated circuit with antennas.

SPACE SCIENCES

The space sciences program at the ONR has had a long and distinguished history, some of which laid the foundations for the field prior to launch of the first artificial satellites. It is evident from the FY 1986 report that a baseline research program continues to support important research in this area, which is becoming more significant to the Navy's mission as many essential assets are located in near-earth space and must operate under a variety of environmental conditions, both natural and manmade.

Evidence has accumulated in recent years, however, that active modification of the near-earth space environment is likely to assume a very important role, both as a means of enhancing and controlling communications and of interfering with similar activities by potential adversaries. There exists, therefore, a need to pursue a program of experimental and simulation studies that will provide basic understanding of the plasma physical processes operating in the near-earth environment. Such understanding will then lead to potential operational systems in the next decade and beyond.

SECOND GENERATION IONOSPHERIC MODIFICATION FACILITY

Backgound: Over the past two decades, ground-based ionospheric heating facilities utilizing powerful HF transmitters have been developed in the United States, the Soviet Union, and Europe. These facilities, with effective radiated powers of 50-400 MW, have produced a variety of interesting and potentially useful effects resulting from the interaction of intense HF radio waves with the ionosphere. Among these are direct ionospheric generation of ultralow frequency (ULF), extremely low frequency (ELF), and very low frequency (VLF) waves, formation of ionospheric structures, and direct heating of the ionospheric plasma. In addition, it has been demonstrated that intense radio wave signals stimulate plasma instability processes in the ionosphere. •A direct consequence of this stimulation is strong absorption of the incident radio frequency energy.

Although the ONR funded work in this area through the HIPAS facility, the power generated was not adequate to achieve significant effects. With the conclusion of the HIPAS program, it is necessary to consider a second-generation facility that could be used as a research tool into the early 1990s and could well have important operational utility in that time frame. The principal objective would be to develop a high-power, ground-based, ionospheric heating facility for communications and surveillance.

Relevance to Navy Requirements: The wide-ranging effects induced by ground-based heaters lead to considerations of (a) the potential applications that these facilities might have in the fields of communications and surveillance, and (b) the form that advanced second-generation heating facilities might have. Calculations have indicated that more powerful heating installations should be capable of producing enhanced ionization layers in the ionosphere. These layers would be capable of supporting controllable long-range communication links and over-the-horizon (OTH) radar coverage. Other researchers have demonstrated that more powerful ionospheric heaters would be capable of direct generation of strong VLF and ELF signals within the ionosphere. These low-frequency signals could also be utilized for communication purposes. Finally, an advanced ionospheric heating facility could produce controllable perturbations of the ionosphere. These perturbations could be imposed along the path of satellite-to-ground and ground-to-ground communication systems to test their operational capabilities under disturbed conditions.

Research Program: An advanced ionospheric heating facility would need to have an effective radiated power ranging from 1-2 gigawatts to produce the anticipated effects. This is approximately an order of magnitude greater than the power capabilities of existing U.S. heating facilities; furthermore, an advanced facility would need frequency ability within the HF band, and it would need beam steering so that the heated ionospheric volume might be formed in an overhead or oblique direction. The contemplated facility could utilize a large two-dimensional phased array of medium powered (1-10 kW) solid state transmitters and cross-polarized log periodic antennas.

APPENDIX A

Naval Studies Board
Electronics Panel
National Academy of Sciences
Washington, D.C.

June 30 - July 1, 1987

Agenda

Tuesday, June 30 - NAS 280

0830-0900	INTRODUCTION
	Drs. Kostoff/Moss, ONR
0900-0930	OVERVIEW - SEM
	Dr. Borsuk, CRP
0930-1040	ELECTRONICS
	Dr. Borsuk, NRL
1040-1150	ELECTRONICS
	Dr. Davis, CRP
1150-1230	ELECTRONICS
	Dr. Whiting, ARP
1230-1300	Open Discussion
1300-1400	Lunch
1400-1430	Open Discussion
1430-1800	Executive Session
1800	Adjourn

Wednesday, July 1 - JH 451

0830-1200	Executive Session
1200-1300	Lunch
1300-1800	Executive Session
1800	Adjourn