CHAPTER VII
SENSORS, ELECTRONICS, AND BATTLESPACE ENVIRONMENT

A. INTRODUCTION

1. Definition and Scope

The Sensors, Electronics, and Battlespace Environment (SEBE) program area addresses technology for the sensors, electronics, and battlespace environment in 14 subareas (Figure VII–1). The sensor technology developed here has broad application to warfighting needs including strategic and tactical surveillance as well as identification and targeting of land, sea, air, and space threats under all conditions. In addition, SEBE encompasses the research and development, design, fabrication, and testing of electronic materials; digital, analog, microwave, optoelectronic, and vacuum devices and circuits; and electronic modules, assemblies, and subsystems. Finally, SEBE provides for the study, characterization, prediction, modeling, and simulation of the terrestrial, ocean, lower atmosphere, and space/upper atmosphere environments to understand their impact on personnel, platforms, sensors, and systems; enable the development of tactics and doctrine to exploit that understanding; and optimize the design of new systems.

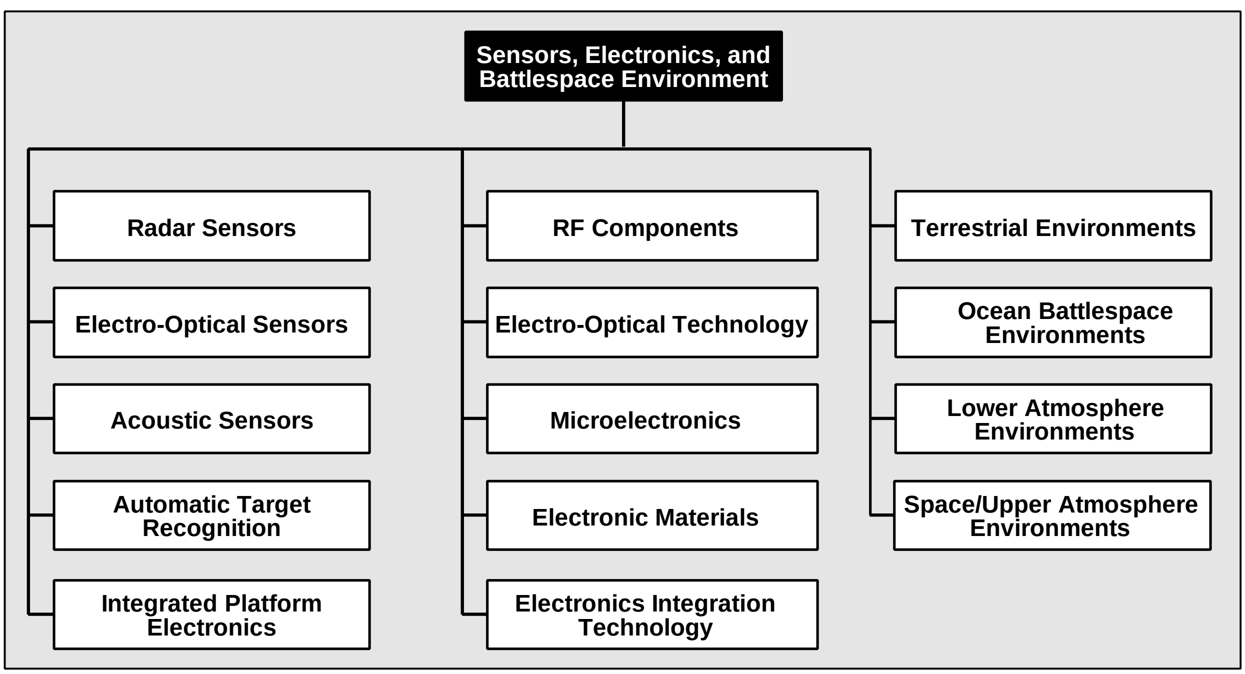

Figure VII–1. Planning Structure: Sensors, Electronics, and Battlespace Environment Technology Area

In the material that follows only *some* of the key objectives of the science and technology (S&T) programs in SEBE are explicitly described. Funds not reflected in Defense Technology Objectives (DTOs) also address many other objectives just as important to DoD in the areas of SEBE. In addition, most of the demonstrations described in this chapter were enabled by earlier S&T efforts. For example, compact high-power RF transmitters were enabled by the development of the microwave power module (MPM), which is two and one-half times more powerful, ten times smaller, and one-third as costly as current technology. In turn, the MPM was possible only because of the DoD-supported efforts in gallium arsenide (GaAs) materials development and monolithic microwave integrated circuits (MMIC) technology. Similarly, the S&T foundations for future technology demonstrations are being laid by the current S&T programs.

2. Strategic Goals

The vision for this area is to provide the military with perfect situation awareness of the expanded battlefield in all environments. This will enable the warfighters to assess the scope and intent of the enemy and develop superior tactics for achieving whatever political or military goal is selected. Investment in this area ensures that the United States will continue to maintain the warfighting edge through all weather, day/night surveillance, precision targeting, and damage assessment; detection and tracking of difficult targets such as cruise missiles, antiship missiles, ballistic missiles, mines, and submarines; and positive target identification. In addition, this must be accomplished at an affordable cost in a diminished production base.

Examples of specific goals include 90% probability of detection of time-critical targets that are camouflaged or concealed by foliage; a threefold increase in infrared (IR) detector focal plane array (FPA) sensitivity at 50% weight and cost reduction; 50% resolution improvement for thermal imaging systems; improved night/adverse-weather pilotage; orders of magnitude increased bandwidth for control and processing RF communications and surveillance providing seamless sensor-to-shooter capability; high-power switches operating at greater than 100 volts and at current densities exceeding 1,000 amps/cm^3; 16 times improvement in over-the-horizon detection of sea-skimming cruise missiles; 100% improvement in submarine periscope detection through the application of advanced analog-to-digital converter technology; 75% reduction in design time and cost for system integration using “virtual” prototyping; improved forecast capability for small-scale currents and waves in the littoral coastal area; and 95% improvement in global command, control, communications, and intelligence (C^3I) specification by fusing ground and space data. These developments provide technologies crucial to meeting the Joint Warfighting Capability Objectives (JWCOs).

3. Acquisition/Warfighting Needs

SEBE technologies provide the foundation for the critical “eyes, ears, and brains” of nearly all decisionmaking systems, tactical and strategic weapons systems, and intelligence collection and processing. They are the key to force multiplication (the ability of a minimal number of U.S. personnel and platforms to defeat a much larger enemy force), and their continued advancement is critical to the avoidance of technological surprise on the battlefield by enabling comprehensive intelligence gathering and achieving total situational awareness over the extended battlespace. Essential for the development and operation of DoD’s information-gathering capabilities is the complete understanding of the environment in which these sensors operate and the impact of that environment on the operation of the sensors. With this knowledge, U.S. forces will be able to optimize their sensors and tactics to use the entire battlespace and its environment.

Consequently, the SEBE subareas address key requirements identified in the Joint Warfighting Science and Technology Plan (JWSTP). As Table VII–1 shows, these technologies are particularly critical to the needs and capabilities associated with Information Superiority, Precision Force, Combat Identification, and Joint Theater Missile Defense.

Table VII-1. Connectivity of JWCOs to Sensors, Electronics, and Battlespace Environment Technology Area

	Joint Warfighter Capability Objectives										
SEBE Subarea	Information Superiority	Precision Force	Combat Identification	Joint Theater Missile Defense	Military Operations in Urbanized Terrain	Joint Readiness & Logistics and Sustainment of Strategic Systems	Force Projection/Dominant Maneuver	Electronic Warfare	C/B Warfare Defense & Protection and Counter Weapons of Mass Destruction	Combating Terrorism	Protection of Space Assets
Radar Sensors	●	●	●	●	○	○	⊗	⊗	⊗	●	⊗
EO Sensors	●	●	●	●	●	○	●	○	⊗	●	⊗
Acoustic Sensors	●	●	●	●	⊗	○	●		⊗	●	
Automatic Target Recognition	●	●	●	⊗	⊗		⊗		⊗	●	⊗
Integrated Platform Electronics	●	●	⊗	○		●	○	●			○
RF Components	●	⊗	●	●	⊗	⊗	●	●			⊗
EO Technology	●	●	●	●	⊗		⊗	⊗	○	⊗	⊗
Microelectronics	●	●	●	●	⊗		●	●	●	⊗	⊗
Electronic Materials	●	●	●	●	⊗		●	●	○		○
Electronics Integration Technology	●	●		●	●		○	●	○		⊗
Terrestrial Environment	●	●	○	⊗	●	●	⊗	○	○	⊗	
Ocean Battlespace Environment	●	●	●	●	⊗	●	●		⊗	○	
Lower Atmosphere Environment	●	●	○	●	●	●	○	○	●	⊗	○
Space/Upper Atmosphere Environment	●	●	●	●	⊗	●	⊗		⊗	○	●

● Strong Support ⊗ Moderate Support ○ Marginal support

In addition, SEBE technology accomplishments contribute to developments in other defense technology areas. For example, the results of a number of these activities enhance the operability of the Chemical/Biological (CB) Defense and the Nuclear Technology DTOs: Joint Warning and Reporting Network (CB.02), Laser Standoff Chemical Detection Technology (CB.07), and Hard Target Defeat (NT.03) efforts. SEBE results also find application in the Consistent Battlespace Understanding (DTO IS.01) work performed within the Information Systems Technology area. The Ground and Sea Vehicle area's Future Scout and Cavalry System (DTO GV.01) utilizes sensor suites that could be enhanced, directly or indirectly, by the results of SEBE development efforts.

B. DEFENSE TECHNOLOGY OBJECTIVES

Radar Sensors

SE.03 Advanced Radar Processing From Airborne Platforms
SE.05 Automatic Radar Periscope Detection and Discrimination
SE.58 Lookdown Bistatic Technology
SE.73 E-Scanned Antenna for Airborne Surveillance, Warning, and Control ATD
SE.75 Multimode Airborne Radar

Electro-Optical Sensors

SE.06 Multifunction Electro-Optical Sensors and Signal Processing
SE.09 Multiwavelength, Multifunction Laser
SE.59 Low-Light-Level Imaging Sensors

Acoustic Sensors

SE.13 Lightweight, Broadband, Variable-Depth Sonar
SE.14 Multistatic Active Antisubmarine Warfare
SE.15 Affordable High-Performance Towed Arrays
SE.60 Underwater Acoustic Communications
SE.69 Autonomous Distributed Sensors

Automatic Target Recognition

SE.19 Affordable ATR via Rapid Design, Evaluation, and Simulation
SE.20 ATR for Reconnaissance and Surveillance
SE.61 Multiphenomenology Sensor Fusion for ATR and Tracking
SE.62 LADAR ATR for Conventional Weapons

Integrated Platform Electronics

SE.24 Common Radio Frequency Digital Modules
SE.72 Advanced Multifunction RF System

RF Components

SE.27 Microwave SiC High-Power Amplifiers
SE.28 Low-Power Radio Frequency Electronics
SE.29 Design Technology for Radio Frequency Front Ends
SE.63 Digital Beamforming Antenna Technology
SE.64 Millimeter-Wave Gyro-Amplifiers
SE.70 Integrated Compact Electronic Sensors and Components
SE.71 Advanced Multifunction RF System Components

Electro-Optical Technology

SE.33 Advanced Focal Plane Array Technology
SE.35 Optical Processing and Interconnects
SE.36 Photonics for Control and Processing of RF Signals
SE.65 Long-Wavelength and Multispectral, Large-Area, Staring Focal Plane Arrays

Microelectronics

SE.37 High-Density, Radiation-Resistant Microelectronics
SE.38 Microelectromechanical Systems
SE.57 Analog-to-Digital Converter

Electronic Materials

SE.39 Wide-Bandgap Electronic Materials Technology

Electronics Integration Technology

SE.43 Energy Conversion/Power Generation
SE.44 Power Control and Distribution
SE.66 Packaging and Interconnect for Multiple Technologies

Terrestrial Environments

SE.67 Hyperspectral Applications Technology
SE.68 Rapid Mapping Technology

Ocean Battlespace Environments

SE.45 Forecast of Littoral Currents and Waves
SE.47 Autonomous Ocean Sampling Network: Mapping of Ocean Fields

Lower Atmosphere Environments

SE.52 Weather/Atmospheric Impacts on Sensor Systems
SE.53 On-Scene Weather Sensing and Prediction Capability

Space/Upper Atmosphere Environments

SE.55 Space Radiation Mitigation for Satellite Operations
SE.56 Satellite Infrared Surveillance Systems Backgrounds

C. TECHNOLOGY DESCRIPTIONS

1. Radar Sensors

a. *Warfighter Needs*

Radar sensor programs directly support JWSTP's areas of Information Superiority, Precision Force, Combat Identification, Joint Theater Missile Defense, Combating Terrorism, Military Operations in Urbanized Terrain, and Force Projection/Dominant Maneuver by offering "near-perfect," real-time knowledge of the enemy on a global basis. Important objectives include heightened ability (20-dB improvement) to detect low radar cross section (RCS) targets using surface-based and airborne wide area surveillance sensors; breakthrough capabilities to detect and classify foliage-concealed, time-critical targets as well as underground targets; development of affordable hardware (<$200,000/copy) to provide decisive target acquisition and fire control capabilities for armored vehicles, and an increase in radar instantaneous bandwidth (to 1 GHz and beyond) to achieve improved target classification, identification, and tracking.

Service requirements for radar are moving beyond detection to target classification, which is now driving radar performance to high-resolution, precisely registered n–dimensional measurement capability. Because cost reduction is an important aspect of all new DoD systems, significant use of commercial-off-the-shelf (COTS) equipment and novel electronically scanned antenna designs are being pursued. The UHF/L–band array technology is targeted for transition to upgrades to the Navy E–2C and to the Air Force E–3 radars. The associated space-time adaptive processing algorithms will have application to all airborne radars where nulling of clutter and jamming is required. The low-frequency ultra wideband (UWB) radar and the concealed target detection algorithm programs lead to required capabilities in battlefield surveillance from platforms such as unmanned aerial vehicles (UAVs). The high-frequency (HF) surface wave and UWB technology is planned for transition to improve/upgrade the Navy's surface fleet surveillance and over-the-horizon (OTH) targeting capabilities.

b. *Overview*

(1) Goals and Timeframes. The radar sensor can provide capability for all-weather, long-range detection, location, and recognition capability of significant military targets. However, continued technology development is required to meet the evolving needs of the warfighter. The goals of the radar program are listed in Table VII–2. Meeting these goals depends on advances in automatic target recognition (ATR) (Section C4), RF components (C6), microelectronics (C8), electronic materials (C9), and electronics integration (C10) as well as understanding the battlespace environments (C11–C14).

Table VII–2. Radar Sensors Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Demonstrate antenna performance, beam steering control, and circular array space time adaptive processing at PMFR during TBM and cruise missile exercises.
FY00	20-dB improvement in clutter cancellation. 10X improvement in resolution. Demonstrate detection, location and identification of targets moving at 4 km/hr to 60 km/hr.
FY02	Complete ATD at Mountain Top radar test facility in Hawaii.
FY05	Counter 1,000-fold reduction in RCS. 75% cost reduction of radars.

(2) Major Technical Challenges. The alignment of radar DTOs with the JWSTP is accomplished by defining key challenges. The DTOs are then defined by the specific near-term and long-term goals and milestones associated with each challenge. Three key radar sensor challenges are affordability, enhanced detection and discrimination of low-RCS targets in difficult environments (clutter, noise, and countercamouflage, concealment, and deception (CC&D)), and enhanced resolution and quality imaging.

Affordability. The major technical challenge is to improve the capability of radar sensors while significantly improving affordability, especially in an environment of declining quantities of weapon system platform integration opportunities, thus reducing the sensor production base. Specific examples of this challenge include utilization of COTS and MMIC and development of digital receivers and low-cost electronically scanned arrays (ESAs). By making radars more affordable, the warfighter will reap the benefits of the acquisition of larger numbers of more capable systems previously unavailable to his budget. This will have a pronounced effect on future radar systems, especially for UAVs, helicopters, and tanks. The long-term goal for this challenge is a 75% reduction in the production cost of radars.

Enhanced Detection/Discrimination of Low-RCS Targets in Difficult Environments. The major technical challenge is to improve the detection and track of advanced targets in severe clutter and interference (intentional and nonintentional environments). Specific research areas include foliage and ground penetration using low-frequency radar OTH detection of low-altitude cruise missiles using HF surface waves; detection of targets in severe clutter from moving platforms using space-time adaptive processing and offboard sources; improved target tracking using advanced algorithms (e.g., knowledge-based techniques, multiple hypothesis testing); and detection of stationary targets using real and synthetic aperture radar (SAR) techniques. Long-term goals are a 20-dB improvement in clutter cancellation, countering a 1,000-fold reduction in RCS, and detection of targets in foliage, under ground, and in buildings with a 90% probability of detection (P_d). This capability will deliver to the warfighter superior knowledge of the battlespace in any environment.

Enhanced Resolution and Quality Imaging. The major technical challenge is to improve the capability to produce fine, high-quality, one- and two-dimensional displays of airborne, ground, and sea targets of interest. A major research area is the detection of a periscope in high sea clutter. Other research areas include image-while-scan inverse SAR (ISAR) using super-resolution techniques and multipath mitigation using very wide bandwidths to develop enhanced, low-angle tracking for fire control solutions. A long-term goal is an order-of-magnitude improvement in resolution using more capable signal processors, algorithms, and advanced waveform generation techniques. This capability will provide the warfighter with enhanced detection and recognition of targets of interest.

(3) Related Federal and Private Sector Efforts. Advanced radar sensors are primarily developed for government applications. Data from airborne space-based efforts are relevant to NASA and NOAA research efforts in weather detection, global change, atmospheric remote sensing, astronomy/astrophysics, and orbital debris tracking, along with numerous private sector spacecraft programs. Surface and airborne radar technology is useful to the Department of Transportation, local and federal law enforcement agencies, the medical community, and multiple organizations for humanitarian purposes (e.g., search and rescue, buried mine and tunnel detection).

c. *S&T Investment Strategy*

Overcoming the technical challenges defined in Section C1b(2) requires an investment strategy that will achieve the required long-term goals. To achieve the affordability goal of a 75% reduction in production costs of radar by FY05, use of COTS and MMIC technology must be coupled with the development of digital receivers and low-cost ESA antennas. To achieve the enhanced detection and discrimination of low-cost RCS targets in difficult environments, technology efforts must result in a 20-dB improvement in clutter cancellation, countering a 1,000-fold reduction in RCS, and the detection of targets in foliage, under ground, and in buildings with a probability of detection of 90%. Research efforts will focus on low-frequency radars for foliage and ground penetration. Research efforts will apply advanced algorithms to enhance target tracking. Real and SAR technologies will be applied to overcome the challenges of detecting stationary targets in clutter. To solve the difficult problem of detecting targets in severe clutter from moving platforms, space-time adaptive processing (STAP) techniques will be applied. Significant improvements in image resolution requires technology investment that incorporates more robust signal processors, algorithms, and advanced waveform generation techniques.

(1) Technology Demonstrations. None.

(2) Technology Development. *Advanced Radar Processing From Airborne Platforms* (DTO SE.03). This technology development focuses on detection of targets in severe clutter from moving platforms using STAP and offboard sources, improved target tracking using advanced algorithms, and detection of stationary targets using real and SAR techniques.

Automatic Radar Periscope Detection and Discrimination (DTO SE.05). This technology development will demonstrate the advanced radar technology necessary for surface ship and airborne radars to automatically detect exposed periscopes in the presence of sea clutter and small targets and debris found in the littoral environment. This DTO has been extended to address the Navy technical demonstration in FY99 and FY00.

Lookdown Bistatic Technology (DTO SE.58). This technology objective develops and demonstrates passive (bistatic) airborne/spaceborne lookdown surveillance and target identification technologies, and transitions them to operational assets such as UAVs, to reconnaissance assets such as Rivet Joint, and to mission enhancements for the Airborne Warning and Control System (AWACS). Bistatic imaging capabilities such as bistatic SAR technologies and adaptive interference cancellation techniques known as bistatic STAP will also be developed.

E-Scanned Antenna for Airborne Surveillance, Warning, and Control ATD (DTO SE.73). This technology develops electronically scanned surveillance antennas with embedded 360-degree identification, friend or foe (IFF) for airborne surveillance platforms, and provides a roto-dome-configured (form, fit, and function with existing aircraft) antenna that is fully scanned electronically in azimuth and providing high-rate volume surveillance with rapid revisit scanning for track-while-scan operations. The E-scanned antenna will also provide 20% weight savings and increase affordability.

Multimode Airborne Radar (DTO SE.75). This technology develops techniques for detection, location, imaging, and exploitation of moving tactical targets in the littoral environment using ultra-high resolution SAR with clutter cancellation moving target indicator and moving target imaging using an integrated Global Positioning System/Inertial Navigation System (GPS/INS).

(3) Basic Research. The basic research in new wide-bandgap semiconductors, such as SiC and Group V nitrides, promises the potential for extremely high-power, high-efficiency amplifiers that could significantly reduce size, weight, volume, and power requirements of radars thereby enabling more powerful air-based radar systems. Progress in high-temperature superconductors offers the potential for ultrastable oscillators, channelized filters with extremely sharp cutoffs, and 20-bit, high-speed analog-to-digital (A/D) converters to enable radars with required dynamic range to handle the high environmental clutter of the littorals. Finally, a recent breakthrough in research offers, for the first time, the capability to perform real-time, true nonlinear filtering for target tracking.

2. Electro-Optical Sensors

a. *Warfighter Needs*

Fielding of superior EO sensors will provide force multiplication in (1) Information Superiority—addressed through high-quality, long-range imaging and nonimaging data from sensors digitally interfaced into the C^4I infrastructure; (2) Precision Force—addressed through (a) high-resolution multisensor systems for target acquisition and fire control, guided munitions, and aided target processing to drive battle tempo, (b) high-resolution, distributed sensors for large fields of view/regard, and (c) inexpensive ground vehicle day/night imagers; (3) Joint Theater Missile Defense—addressed through long-range passive IR search and track; (4) Combat Identification—addressed through multifunction and multisensor concepts; and (5) Military Operations in Urbanized Terrain—addressed through land and littoral unattended, robotic, and individual soldier multispectral sensors. Transition opportunities exist for all future military and commercial space systems. Aircraft applications include F–14, F–15, F–16, F–18, F–22, JSF, E2C, C–130, C–141, V–22, AH–64, SH–60, Comanche, Kiowa Warrior, and the AC–130 gunship. Surface applications include, M1 Main Battle Tank and subsequent improvements, M2/M3 Bradley Fighting Vehicle, Future Scout Cavalry System, Landing Assault Vehicle upgrades, Advanced Amphibious Assault Vehicle, Future Scout Vehicle, TOW Missile System, and underwater mine reconnaissance sensors.

b. *Overview*

(1) Goals and Timeframes. The broad goals (shown in Table VII–3) are to provide affordable sensors that enable U.S. forces to maintain a decisive warfighting edge in performing tactical target detection, identification, acquisition, engagement, mobility missions, and battle damage observation. These goals will also provide superior warfighter capabilities in the detection, discrimination, and tracking of theater ballistic missiles. All goals are based on improving current performance, while paying particular attention to life-cycle ownership cost. Meeting these goals depends on advances in EO technology (Section C7), microelectronics (C8), electronics integration technology (C10), and electronic materials (C9) as well as understanding the battlespace environments (C11, C13, and C14).

Table VII–3. Electro-Optical Sensors Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Demonstrate air-air and air-ground target ID at extended ranges (20 nmi).
FY00	Assess high-resolution concept demonstrator with 2,000 x 2,000 elements, 90-deg wide FOV, low-power IR imaging sensor.
FY01	Demonstrate hyperspectral smart sensing.
FY02	Complete testing of multispectral detection and ID for deep-hide targets (P_d > 90%/P_{fa} < 0.01/km^2).

(2) Major Technical Challenges. The major technical challenges are to improve the capability of EO sensors and to reduce their size, weight, and power requirements while maintaining affordability. Specific challenges include (1) active (laser-based) sensors—providing robust multifunctionality while maintaining compact size and low-power requirements compatible with existing weapon system platform constraints, and providing compact, efficient laser sources with substantial average powers at multiple wavelengths while accommodating eye-safe operation; (2)

individual soldier systems—development of lightweight, affordable system-integrated optics; and (3) through the multisensor systems—use of shared or distributed aperture systems in order to control size that will improve drag characteristics and reduce cost, implementation of alternate sensing modes (e.g., polarization) to extract more scene information and reduction of the dependence on spatial resolution, and signal processing to enable multifunction sensing and fusion of multiple sensors.

(3) Related Federal and Private Sector Efforts. Advanced EO sensors are primarily developed for government applications. Data from space-based efforts are relevant to, and to be coordinated with, NASA and NOAA research efforts in global change, atmospheric remote sensing, astronomy/astrophysics, and orbital debris tracking, along with numerous private sector spacecraft programs. Surface and airborne tactical technology are coordinated with the Department of Transportation (night driving, ship navigation), FAA (aircraft runway navigation and pilotage), local and federal law enforcement agencies (surveillance, physical security), the medical community (diagnostics, human vision aids), and multiple humanitarian organizations (search and rescue, buried mine detection). Industrial applications of thermal imaging technology involving calibrated measurement of temperatures are also leveraged.

c. *S&T Investment Strategy*

National investments are made to address warfighting needs and to maintain the U.S. force warfighting margin. Particular emphasis is paid to affordability, which is critical in an environment of lower weapon system quantities. Investment in multifunction sensors is also pursued where more than one battlefield capability can be provided through a single system, precluding the need for multiple systems. Key thrusts are in five areas.

Passive EO Sensors. Passive (nonemitting) long-range sensing with high sensitivity and resolution of tactical and strategic targets are being pursued. These are configured to operate either individually or as part of multisensor/multispectral systems. This thrust area supports JWSTP DTOs D.03, E.02, G.11, H.02, H.07, and J.04.

Active EO Sensors. Technologies are being developed to enable system capabilities for solid-state, eye-safe lasers for long-range precision track and target identification. Multifunction lasers to address multiple platform and operating functions (including ranging, designation, and micro-Doppler, visible, and IR countermeasures) are emphasized. This thrust area supports JWSTP DTOs C.02, C.04, and I.02.

Multifunction Sensor Suites. Development of multifunction sensor suites capitalizes on the synergism of individual sensors operating together (to include shared aperture) to allow greater range performance and reduction of target false alarms. This includes agile sensors, multimode FPAs, and multispectral sensors. In addition, this operating mode compensates for the shortcoming of individual sensors due to weather and battlefield obscurants. This thrust area supports JWSTP DTOs B.06, D.03, G.11, H.02, and H.07.

Signal Processing. Signal processing maximizes the performance potential of modern EO sensors through efficient high-speed processing of signals. This allows for alternative modes of operations, affording real-time panoramic battlespace awareness. This thrust area supports JWSTP DTO D.03.

Modeling and Simulation. Performance and simulation modeling of sensors, targets, and scenes will allow technology assessment, training, and doctrine development through virtual prototyping as a part of the hardware development process. This thrust area supports JWSTP DTOs A.06 and A.07.

There are three areas of technology focus.

EO Sensor Fusion and Targeting. This is directed at enhancing targeting capability in an expanded battlespace with improved precision for direct fire, indirect fire, precision-guided weapons, bomb damage assessment, and enhanced location and identification of a wider variety of targets. It capitalizes on the fusion of EO and allied sensors, incorporating advanced FPAs, ATR, multifunction lasers, radars, and C^4I to sharply increase the target acquisition and target identification range, target location accuracy, multiple target tracking capability, and target servicing rates.

Target Signature Measurement, Modeling, and Management. This is directed at acquiring and predicting the EO signatures of adversarial and friendly ground and air targets in support of tactical analyses, developing and evaluating aided target recognizer algorithms, simulations employing virtual prototypes for warfighting tactical assessment, and training in a manner that reduces the overall need for field and flight data acquisition and testing. This will also demonstrate technologies that enable development of signature management and detection systems that deny acquisition of friendly force assets by threat sensors.

Integrated Sensor Modeling and Simulation. Efforts include advancing the state of the art in synergistic modeling and prototyping capabilities to permit end-to-end predictive modeling and hardware tradeoff for performance evaluation of new technologies in a virtual environment. Techniques will include high-resolution synthetic image generation and presentation on tactically relevant displays, distributed operational simulations interfaced with virtual prototyping and stereo lithographic facilities, interactive multimedia for readily accessible training, and digital signal interface format for evaluation of human observer performance with and without aided target recognition processors and algorithms.

(1) Technology Demonstrations. None.

(2) Technical Developments. Key technical developments will result in capabilities for improved precision targeting, passive theater missile defense (TMD), laser functions, and signal processing.

Multiwavelength, Multifunction Laser (DTO SE.09). This effort develops laser sources and systems for multifunction applications. The approach is to use a single laser source embedded in a system to accomplish multiple functions (e.g., rangefinding, designation, identification), thus enhancing affordability and platform size capability. Multiwavelength output of 0.26–12 μm will be demonstrated allowing eye-safe operating modes for more robust training and for minimizing personnel injury. Horizontal technology integration approaches will be investigated across multiple system platforms.

Multifunction EO Sensors and Signal Processing (DTO SE.06). This effort advances development in signal processing and multidimensional target detection, discrimination, and tracking for shipboard, ground vehicle, and airborne applications. This effort will develop IR search-and-track approaches for TMD, cruise missile and aircraft detection for ships, air defense from on-the-move ground platforms and fixed-wing antiair, and TMD. TMD ranges are beyond 500 km and cruise missile detection at 13 nmi. Advanced thermal sensors and digital signal processing technology will be employed, with multiple service capitalization on common components and subsystems.

Low-Light-Level Imaging Sensors (DTO SE.59). This technology demonstrates solid-state visible and near IR and short-wavelength IR sensors for a broad range of night vision applications, including pilotage and navigation, weapon sights, missiles guidance, surveillance, and targeting.

(3) Basic Research. Basic research capitalized on in this area includes physics, target acquisition (advanced IR focal plane research and image science); physics, radiation (blue-green lasers); electronics, solid-state and optical electronics (uncooled IR detectors, wide-gap semiconductors, nonlinear optical materials); and electronics, information electronics (IR target recognition and image analysis, sensor fusion, and digital signal processing).

3. Acoustic Sensors

a. *Warfighter Needs*

Joint warfighting capabilities in the areas of Information Superiority, Combat Identification, Joint Readiness and Logistics, and Force Projection/Dominant Maneuver are particularly dependent on acoustic, magnetic, and seismic sensor technology. These sensors provide reliable undersea and terrestrial surveillance against threat targets. Such surveillance is required to achieve and maintain battlespace dominance to enable timely execution of joint/combined operations in support of national security objectives. Undersea acoustic sensor efforts are unique and critical to the Navy.

This subarea develops surveillance, communications, and environmental science technologies that use acoustics and magnetics to detect, classify, track, and localize quiet threat targets in all operating environments, across all missions, and with all platforms. Acoustic sensors are the primary sensors of choice to detect threat submarines operating below periscope depth. However, the increasingly quieter nuclear threat and the diesel-on-battery threat limit traditional passive narrowband processing, yielding shorter detection ranges. This demands higher array gain (by using more sensors) and adaptive signal processing to counter these quieting trends. It also requires increased emphasis on use of active sonars to counter this threat.

The operational shift to the littorals presents a more difficult undersea environment for sensor operation. The littoral region exhibits increased clutter from biologics, commercial shipping, and background ambient noise. This results in higher false alarm rates and greater weapons expenditures. To counter the environmental effects, fusion of data from acoustic and magnetic sensors with other nonacoustic sensors is finding increased emphasis. Effective multisensor data fusion offers more robust detection and classification performance and a greater range of adaptability. Development of sensors that automatically adapt to optimize themselves to existing environmental conditions is receiving increased emphasis. Larger array apertures require emphasis on affordability if such systems are ever to be fielded.

Navy applications include undersea surveillance in both open ocean and in highly variable, cluttered, shallow-water areas. The sensors may be hull-mounted, towed, and deployed on a variety of platforms, including surface ships, submarines, fixed-wing aircraft, and helicopters. Army and Marine Corps applications encompass shore area and battlefield surveillance used to detect and classify ground and air targets. Acoustic sensors can be produced at low cost and employed in large numbers on the battlefield. These systems are mounted on both stationary and mobile platforms. They are also used to detect mines at short ranges.

b. *Overview*

(1) Goals and Timeframes. The worldwide proliferation of modern, quiet, diesel-electric submarines requires increased emphasis on the use of active sonar and full-spectrum passive processing and cooperative engagement technologies utilizing robust undersea acoustic communications technologies. Improved classification for existing active sonar systems and robust acoustic submarine-ship acoustic communications at speed and depth are short-term (<5 years) goals. Within 10 years, high-gain passive systems and active sonar systems that can adapt to the highly variable littoral environment and accurately classify targets in high-clutter environments with reduced false alarm rates are required. Modern Army battlefield acoustic systems have demonstrated the capability to detect, classify, and identify ground targets at ranges in excess of 1 km and helicopters beyond 5 km with meter-sized sensor arrays, while netted arrays of sensors have been used to track and locate battalion-sized armor movements over tens of square kilometers in non-line-of-sight conditions.

Far-term improvements will extend these capabilities to tactical ranges. Significant goals are shown in Table VII–4. Advances for meeting these goals depend on progress in EO technology (Section C7), understanding the ocean battlespace environments (C12), and acoustic and magnetic materials.

System development to achieve the above goals requires a balanced investment in both signal processing and sensor designs. Improved sensor systems providing increased array gain, aperture, sensitivity, source level, and bandwidth will not be fully optimized without corresponding improvements in signal processing techniques. Accordingly, many projects in this subarea emphasize both sensor and signal processing technology development.

(2) Major Technical Challenges. In general, the major technical challenges are to provide:

- Highly effective undersea warfare (USW) shallow-water antisubmarine warfare (ASW) that can adapt to the environment, including high-resolution environmental modeling and measurement, and incorporating “through the sensor” environmental characterization.
- Low-cost options for USW systems (affordability).
- Improved tactical decision aids through the use of near-real-time simulation coupled with more capable sensing and modeling of the tactical environment.

Table VII–4. Acoustic Sensors Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Transition signal processing algorithms to the helicopter-dipping sonar system, improving active classification in shallow water. Test multistatic ASW sources and algorithms at sea. Demonstrate ability to track large vehicle formations with real-time tracking and identification.
FY00	Demonstrate broadband time-bandwidth product signals of 10,000. Demonstrate 5X increase in active source bandwidth. Test environmentally adaptable volumetric passive arrays that can provide near real-time aperture flexibility. Demonstrate a ¼ aperture array on a single fiber for the Affordable Array Technology ATD. Demonstrate an autonomous offboard source (OBS) at sea. Demonstrate an acoustic communications packet message transmission success rate = 90% at mid frequencies, range@ 2.4 kbps = 20–67 nmi; at high frequencies, range @10 kbps = 2.2–3.2 nmi; 100% real-time processing in 80% of environments; and multinet connectivity for underwater acoustic communications.
FY01	At-sea demonstration of LBVDS. Demonstrate 90% P_d at 7–10-nmi range and a one-per-day false alarm rate. Complete final OBS design that will lead to a 15–20-dB improvement over existing passive systems; increase detection ranges by 3X; increase area coverage by 10X. Demonstrate automated array hose and chassis assembly with cost reduction of 50–75%.
FY02	Demonstrate optical slip rings and engineering sensors for optical arrays. Demonstrate underwater acoustic communications capability with environmental and tactical adaptation. Demonstrate deployable, distributed array with real-time magnetic classification.
FY03	Demonstrate active and passive in-buoy signal processing algorithms at sea.
FY05	Demonstrate optical array technology providing a further 2X reduction (overall, 10X relative to FY95) in towed array acquisition costs and programmable apertures. Demonstrate data-linked, autonomous-distributed, deployed sensor systems. Demonstrate 10X area coverage using integrated all-sensor fusing.

Specific technical challenges include (1) active sonar detection techniques for targets in clutter caused by nontarget geologic features, biologic and manmade objects on the bottom, and reverberation from surface, bottom, and volume interactions (e.g., CST–5 sea trial data show "routine" deep-water performance hampered by 2 to 12 false tracks per hour; in shallow water, performance impeded by more than 300 false tracks per hour); (2) passive sonar—algorithms capable of detecting quiet targets in the midst of interference from local and distant shipping; (3) passive and active sensors—compact, high-power, lower and broader frequency active acoustic sources and larger aperture receiving arrays in affordable applications on a diverse range of platforms; and (4) acoustic communication algorithms capable of utilizing a priori and in situ environmental data to estimate channel response accurately enough to optimize the choice of modulation and signal processing process.

(3) Related Federal and Private Sector Efforts. COTS plays a significant and growing role in this subarea. Examples include telecommunication technology; fiber optics with associated laser, coupler, and splitter technology; polyvinylidene fluoride materials; and computationally intensive hardware.

c. *S&T Investment Strategy*

The investment strategy for acoustic sensors is focused in two technology areas.

Sensor Signal Processing Technology. Efforts are aimed at developing active waveform designs, improving signal processing and displays to reduce clutter and false alarm rates encountered in cluttered environments, investigating bistatic and multistatic detection schemes, providing algorithms and data fusion techniques that increase P_d with reduced false alarms, and demonstrating long-range ground and air target detection and identification at low cost. Resolving closely spaced targets or target-like objects is addressed by improving array bearing accuracy and beamforming. Other techniques include passive processing, which exploits the complete spectrum of target-emitted signals, platform noise suppression, and ambient (e.g., wind) noise discrimination. Sensor signal processing technology has three major thrusts:

- Active algorithms and techniques, which include active acoustic techniques for (1) detecting and classifying echoes reflecting off small, quiet submarines in the difficult littoral environment; and (2) connecting surface combatants and submarines with a robust acoustic communications link. Major challenges for active detection and classification include operations in reverberation-limited environments, high clutter and false target rates, and low-/no-Doppler targets that provide few target motion clues. The major challenge for development of a robust acoustic communications capability is adapting the signals to specific environments to ensure reliable, high-data rate communications while minimizing the probability of interception and detection.
- Passive algorithms and techniques, which include algorithm development for detection, classification, and localization of a variety of sea, land, and air targets using that target's emitted signals. This subarea includes passive acoustic and magnetic techniques for ASW, and air acoustics, magnetic, and seismic techniques for battlefield target detection.
- Data fusion and interoperability, which include raw sensor data fusion and coherent inter-sensor processing; techniques for cooperative engagement of multiple platforms for target detection, classification, and localization; and tactical data fusion for improved undersea and battlefield awareness.

Active/Passive Sensor Technology. Active efforts will develop innovative, high-power transducers using new high-energy density transduction materials (e.g., the electrostrictive lead magnesium niobate, the magnetostrictive Terfenol–D). Active array element interactions will be modeled to aid in providing affordable, compact sources with minimal ship impact that can be towed at the optimum depth determined by the environmental conditions and the target's depth. Deployed or offboard sensors and distributed systems are needed to provide alerts and cueing to tactical platforms. Efforts include the development of affordable, lightweight, extended bandwidth optical sensors, velocity sensors, micromachined sensors (e.g., microelectromechanical systems (MEMS)), and rugged, soldier-mounted acoustic sensors for long-range and early warning threat detection. Sensor noise models and noise mechanism insights are required to optimize aperture designs.

Active/passive sensor technology is divided into three major thrusts: acoustic/seismic transduction includes technologies for development of individual sensors or sources both for active and passive acoustics and for passive seismic applications. Magnetic/nonacoustic sensors include technologies for development of individual sensors for magnetic and other nonacoustic applications, such as wake detection sensors. System development, integration, and test include efforts that incorporate the individual sensor developments from the previous two thrusts to develop platform-specific sensor systems for the detection/classification/localization of targets. This subarea includes testing in the operational environment for data collection, system testing, and concept demonstration, with the goal of gaining support for transition of such technologies to higher funding category programs.

(1) Technology Demonstrations. *Lightweight, Broadband, Variable-Depth Sonar* (DTO SE.13). The LBVDS will combine advances in high-energy density transduction materials and in broad frequency bandwidth waveform generation and signal processing in a 1- to 6-kHz sonar system that provides a shallow-water-environment USW capability to naval surface ship platforms. Real-time clutter rejection, reverberation suppression, target highlighting, and classification will be evaluated through sea tests of the broadband waveforms. A compact, towable source projector and receive array with manageable ship design and operational impact will be developed and used as the testbed. The LBVDS payoff will be an estimated 20-dB improvement in detection and classification, more rapid localization, and a false alarm goal of less than one per hour against quiet, slow submarines and mines in shallow water. The technology is targeted for transition to DD–21.

Multistatic Active ASW (DTO SE.14). This DTO develops and demonstrates a multistatic ASW capability, which incorporates an advanced acoustic source for use of surface ships, submarines, aircraft, and deployed distributed sensors. The majority of the DTO addresses the long-endurance, low-frequency active source (LELFAS) that starts in FY99 and will develop and demonstrate a leave-behind active source with a 30-day life that is commandable using underwater acoustic communications technology. The LELFAS will be packaged in a half-length MK48 torpedo-sized unit, capable of deployment from a submarine, surface ship, or maritime patrol aircraft. The LELFAS source frequencies will be designed to be compatible with existing sensors in order to provide a multistatic ASW capability.

Affordable High-Performance Towed Arrays (DTO SE.15). This DTO develops, delivers, and operationally tests an improved towed array for tactical submarines and surface ships. The Affordable Array Technology ATD is an integral portion of this DTO and is scheduled to start in FY98. This ATD will demonstrate a new approach for constructing all-optical towed arrays with potential for greater than 90% reduction in per-channel cost and inherent versatility for use over a very wide acoustic bandwidth.

Underwater Acoustic Communications (DTO SE.60). This DTO develops and demonstrates a reliable, high-data-rate, underwater acoustic communications capability for tactical use among submarines, surface ships, unmanned undersea vehicles, and other platforms. The associated ATD will provide an order-of-magnitude improvement in underwater acoustic communication data rates—from 2 to 20 kbps—allowing a greatly expanded communications capability for submarines at speed and depth.

Autonomous Distributed Sensors (DTO SE.69). This DTO develops and demonstrates a capability to detect, track, classify, and report battlefield and undersea threats with distributed, unmanned sensors using a variety of acoustic and magnetic threat emissions. These low-cost, battery-powered, networked sensor fields will greatly extend the situational awareness of the warfighter. They will be primarily passive receivers of emitted energy and as such are relatively clandestine and applicable to prehostility surveillance and battlespace preparation. (This DTO complements work in the Unattended Ground Sensors ACTD (DTO A.24), which is focused on continuous surveillance of choke points to permit target identification and cueing and improved reporting of local weather conditions.)

(2) Technology Development. System development to achieve the goals outlined above requires a balanced investment in both signal processing and sensor designs. Improved sensor systems providing increased array gain, aperture, sensitivity, source level, and bandwidth will not be fully optimized without corresponding improvements in signal processing techniques. Accordingly, many projects in this subarea emphasize both sensor and signal processing technology development.

(3) Basic Research. This subarea is interdisciplinary, drawing on efforts in materials, mathematical, computer, information, cognitive, neural, surveillance, and battlespace environmental sciences. Environmental effects play a major role in sensor performance, and insight into the environmental complexities offers a means to develop adaptable systems.

4. Automatic Target Recognition

a. *Warfighter Needs*

ATR addresses the following JWCOs: (1) Information Superiority—ATR gives real-time identification of an adversary from high-bandwidth sensors (providing sufficient knowledge to neutralize the enemy) and yields enormous data compression for transmission on battlefield datalinks; (2) Precision Force—ATR's real-time identification of forces over a wide area compresses the C^4I timeline for responsive sensor-to-shooter operations and enables timely reacquisition of the target for a strike platform; (3) Combat Identification—ATR gives beyond-visual-range identification to launch missiles at long range, enabling lethal enemy engagement, reduced fratricide, and ownship survival; (4) Joint Theater Missile Defense—ATR enables finding ground-based missile launchers in a timely manner consistent with elusive adversary operations, discriminating between reentry vehicles (RVs) and decoys during reentry, and discriminating between cruise missiles and slow-moving, low-flying confusers; (5) Military Operations in Urbanized Terrain—ATR enables finding targets in cluttered urban environments to precisely identify targets allowing precision weapon employment resulting in minimal collateral damage; (6) Joint Readiness and Logistics—ATR synthetic scene generation and modeling provides capabilities for enhanced simulation and training; (7) Force Projection/Dominant Maneuver—ATR technology enables rapid detection of mines; and (8) Combating Terrorism—ATR aids in timely bomb damage assessment. ATR is needed both for intelligence, surveillance, and reconnaissance and for weapon-delivery systems. Transitions are planned for Joint Surveillance Target Attack Radar System (JSTARS), P–3, S–3, U–2R, Tier 2, Tier 2+, Tier 3–, F–14, F–15, F–16, F–18, F–22, Apache, Comanche, AWACS, Abrams, Bradley, MSX, THAAD, Destroyer, CG–47, DDG–51, DDG–993, and DD–963.

b. *Overview*

The ATR subarea is related to battlespace environments and sensors of this DTAP. Knowledge of battlespace environments can facilitate ATR evaluation and utility studies. Sensors and ATR are tightly intertwined as sensors provide the data for ATR development, and ATR is a key objective of sensor design. The ATR subarea also leverages computing technologies reported in the Information Systems Technology area (Chapter III) and the ATR work reported in the Weapons area (Chapter X).

(1) Goals and Timeframes. The ATR program goals are grouped into two categories: those organized by target class (land, sea, air) driven by the need to improve ATR performance, and those that are general ATR goals driven by the need to reduce both acquisition and life-cycle costs. The goals and timelines for ATR are shown in Table VII–5.

Table VII–5. Automatic Target Recognition Subarea Goals and Timeframes

Fiscal Year	Goals
FY99	Ground targets—open targets/standard configuration Airborne targets—10 target types Surface targets—100 large combatant ship classes Reentry vehicles—discriminate debris Target insertion—2 months for classification, 6 months for ID[a]
FY02	Ground targets standard configuration—up to 30% target obscuration; 150X search area Airborne targets—35 target classes Surface targets—small craft; 20 classes Reentry vehicles—discriminate crude decoys Target insertion—24 weeks for target classification, 6 weeks for target ID[a] Affordability—2X–4X reduction in development time, 2X reduction in software costs, 10X reduction in hardware costs
FY07	Ground targets—multiple target configurations including articulation, light CC&D; 1,000X search area Airborne targets—100 target classes Surface targets—small craft; 100 classes Reentry vehicles—discriminate sophisticated decoys Target insertion—48 hours for target ID[a] Affordability—6X–10X reduction in development time, 6X reduction in software costs

[a]Varies significantly depending on whether target is captured or denied, target complexity, sensor, and recognition approach.

(2) Major Technical Challenges. The major technical challenge for ATR is contending with the combinatorial explosion of target signature variations caused by permutations of target configuration (e.g., stores, articulation, manufacturing, wear and tear), target/sensor acquisition parameters (e.g., aspect, depression, squint angles), target phenomenology (e.g., cavity responses, glints, IR thermal behavior), and target–clutter interaction (e.g., foliage masking, camouflage). ATR systems must maintain low false alarm rates in the face of varying and complex backgrounds, and they must operate in real time. Another extremely important challenge for ATR is the evaluation and prediction of ATR field performance given the practical limitation that data sets cannot represent the extreme variability of the real world. The ability to rapidly insert new targets and to train algorithms on the fly in the field to support flexible and sustained employment of ATR is an important challenge. A key technical challenge is the development of affordable ATR solutions that employ an open architecture. This will provide capability growth via expandable hardware and software insertion.

(3) Related Federal and Private Sector Efforts. Image processing technologies are used in medical imaging, law enforcement, automated manufacturing, transportation sensing, remote sensing, environmental sensing, robotics, and multimedia. Commercial computer technologies are leveraged as well.

c. *S&T Investment Strategy*

Technology is divided into four areas. Note that high-performance computing is a key enabler for each technical area. Also note that the Moving and Stationary Target Acquisition and Recognition (MSTAR) technology development is advancing the state of the art in all four areas.

Algorithm developments address the key technical challenge—combinatorial complexity of ATR. Approaches include the development of both data-driven and model-based approaches using single and multiple radar and EO sensors. Developments include multidisciplinary technologies utilizing advances in signal processing, decision and estimation theory, artificial intelligence (AI), operations research, and computer science. Key programs include MSTAR, image understanding program, imaging ATR, and multisensor fusion.

Affordability developments leverage open architecture initiatives and design tools. Algorithm tools focus on a common environment to reduce ATR development and evaluation cost and improve algorithm performance via shared and distributed algorithm design, reuse of software, and decoupling of software development from real-time, high-performance computer (HPC) architectures. The key program activity is integrating the development of Khoros and the image understanding environment as the ATR standard. The hardware component of affordability is addressed by leveraging commercially developed multichip modules to design and demonstrate a family of affordable, miniaturized, high-density, high-performance image and digital signal processors. These efforts use HPC processors and design tools developed by rapid prototyping of application-specific signal processors to meet cost and performance objectives.

Database development, including signature modeling and scene synthesis efforts, is the backbone of ATR progress. Databases support the development and evaluation of ATR algorithms for single and multisensor EO and radar systems. Signature modeling is critical to rapid target insertion capability and provides a cost-effective complement to measured data to evaluating multispectral ATR. Synthetic data also provide a practical means of exploring complex multi-sensor ATR design spaces. Scene synthesis efforts uniquely provide high-fidelity models for distributed, interactive simulations to assess the warfighting payoff of new technologies such as ATR, including performance of postulated advanced sensor systems against future conventional and low-observable (LO) threats. Key developments include Electronic Terrain Board, Xpatch, and Creation.

Scientific evaluation promotes accelerated and orderly ATR development by providing statistically significant performance feedback that pinpoints algorithm deficiencies to developers and provides valid field performance data to the respective service users for use in transition decisions. Scientific evaluation includes the development of performance estimation and bounding theories to guide ATR development. Strong ATR predictive theories will provide developers the tools to focus efforts at the knee of the curve in the highly complex ATR design space.

Standard metrics and evaluation procedures are jointly developed as part of the efforts of the ATR Working Group. Collaboratively developed evaluation methodologies and shared data sets enable direct comparison of algorithms and processors among developers across the services and development agencies.

(1) Technology Demonstrations. *Semiautomated Imagery Processing ACTD* (JWSTP Information Superiority DTO A.09). This technology demonstration develops template-based ATR coupled with terrain and force structure analysis, object-level change detection, image/map registration, human–computer interface, and interactive target recognition. Model-supported exploitation technology developed by the RADIUS program will be integrated and applied to site monitoring. ATR-aided data compression technology developed by the Clipping Service program will be used to reduce datalink requirements. The final demonstration delivers software modules integrated into imagery exploitation migration systems. Key imagery platforms include Tier 3 and U–2R.

Reentry Vehicle Discrimination Technology Demonstrations. These efforts develop discrimination algorithms to separate RVs from debris and sophisticated decoys using radar and EO sensors. Collection and analysis of missile flight data are used to validate signature models and develop and evaluate discrimination algorithms.

Advanced Air and Surface Target Identification ATD (JWSTP Combat Identification DTO C.04). The objective of this DTO is to develop radar signal processing algorithms that provide reliable identification of noncooperative maneuvering aircraft at all target/sensor aspect angles from long standoff ranges. The technology approach is to develop algorithms to continually adapt radar's ID processing to target dynamics and mission demands on the radar system by fusing multiple radar/RF modes—electronic support measure (ESM), radar signal modulation, and high-resolution radar—and by performing advanced ISAR imaging techniques via an adaptive range Doppler imaging process. Potential technology insertion platforms include F/A–18, F–14, F–15, F–16, F–22, and AWACS.

(2) Technology Development. *Affordable ATR via Rapid Design, Evaluation, and Simulation* (DTO SE.19). The objective of this DTO is to reduce the cost and development time for ATR systems including single and multisensor ATRs for land and air targets. Technology advancements will be made in the areas of high-fidelity, real-time synthetic signature and scene simulation; image and performance evaluation metrics, standards, facilities, and tools; large, high-quality, ground-truthed, multi-sensor databases; algorithm development tools and environments; integrated design environments; and high-performance computing. Standardized methodologies and databases will be integrated with industry and academia via the ATR Working Group.

ATR for Reconnaissance and Surveillance (DTO SE.20). The objective of this DTO is to develop the capability to automatically recognize targets using high-range-resolution radar and ISAR for moving targets and high-resolution SAR for stationary targets. Advances in high-resolution imaging for both stationary and moving targets and advances in hybrid ATR algorithms using elements of both template and model-based approaches will be developed. This advanced imagery exploitation capability will be demonstrated using imagery from a number of reconnaissance/surveillance platforms to meet service-specific exploitation needs. Demonstrations are planned for JSTARS, U–2R, Predator, S–3, and P–3.

Multiphenomenology Sensor Fusion for ATR and Tracking (DTO SE.61). This DTO will provide multisensor fusion algorithms for ATR of land targets for multiple warfighter platform applications. It emphasizes cross-phenomenology fusion algorithm development.

LADAR ATR for Conventional Weapons (DTO SE.62). The objective of this DTO is to provide laser radar (LADAR) ATR capabilities in all mission areas of conventional guided weapons including the span of applications related to missiles, bombs, submunitions, and projectiles. It develops algorithmic methodologies necessary to detect, classify, recognize, identify, and characterize targets that are appropriate for conventional weapon scenarios.

(3) Basic Research. ATR is a key focus for the 6.1 community. Basic research investment in ATR subarea technologies is estimated at $11 million. Important research themes include multiresolution processing, fusion, advanced and nonlinear signal processing, computational electromagnetics, algebraic invariance, AI and knowledge-based systems, advanced imaging techniques and inverse processing, and distributed and parallel computing. Recent key initiatives include the reduced signature target recognition effort focused on advanced algorithm and computational electromagnetic research; the Federated Lab effort focused on research partnerships between university, industry, and service labs; the signal processing and AI program; the single-sensor ATR program; and the Center for Imaging Science and the sensor processing program.

5. Integrated Platform Electronics

a. *Warfighter Needs*

Integrated platform electronics (IPE) addresses the system technologies of the platforms with the focus on affordability and multimission capability. Using a COTS-based open system architecture with resource sharing attains these capabilities. This permits platform reconfiguration and cost-effective upgrades to legacy systems enhancing the capability of the warfighter. In addition, embedding multifunction antennas in the structure of the platform, managing the RF functions, and providing enhanced situational awareness not only improve performance but also increase survivability. The fusion of information also improves the targeting capability while reducing operator workload. Government and weapon system contractors concur, using F–22 and RAH–66 as baselines, that by FY05 procurement, support, and development costs will be reduced by 25% and aircraft attrition rates by 10%, while mission-capable rate will be improved by 30%, first-pass kill by 50% for fixed-wing attack aircraft, and nap-of-the Earth engagements by 20% for rotary-wing aircraft. The technologies developed under this subarea can be applied to air, space, ship, and ground platforms. Military use of commercial technology, tools, and standards will enhance transition opportunities. Joint warfighting S&T being supported by this subarea include Precision Force, Combat Identification, Joint Theater Missile Defense, Electronic Warfare, and Information Superiority.

b. *Overview*

IPE develops and demonstrates open system technologies that facilitate the physical and functional integration of emerging technologies on and across air (manned and uninhabited), ship, and ground platforms. It addresses both legacy and future platforms. Emphasis is placed on the system-level aspects of the architecture particularly the integration of on/offboard sensors with other platform functions. The efforts in this area draw on the output of the technology developed in radar sensors (Section C1), EO sensors (C2), RF components (C6), microelectronics (C8), and electronics integration technology (C10). In addition, IPE is closely linked to the Information Systems Technology and Human Systems DTAPs. IPE technology advancements include wide-band integrated apertures and array elements, high-speed networks and protocols, integrated processors including reusable software, and resource management development.

(1) Goals and Timeframes. Table VII–6 shows the goals and timeframes for the IPE subarea.

Table VII–6. Integrated Platform Electronics Subarea Goals and Timeframes

Fiscal Year	Goal
FY00	Deliver LO Advanced Demonstration Model Smart Skin Array, reducing detectability by 25%. Flight test of optical backplane, reducing costs by 30% and improving reliability by 15%. Complete development of Advanced Multifunction RF System (AMRFS) high-band transmitter, signal processing, and resource manager subsystems. SH–60R EW and radio receiver flight demonstration (Advanced Common Electronic Modules), reducing weight by 20% and costs by 25%.
FY03	Flight demonstration of Sub Carrier Multiplexing, improving performance by 20X. Demonstrate AMRFS integrated over 1–5 GHz with dynamically reallocateable subapertures with at least one beam per transmit subaperture with an instantaneous bandwidth of 500 MHz.
FY05	Demonstrate AMRFS high-band (digital synthesis) transmitter, high-band receiver (digital receiver beamforming) in at-sea tests, reducing the number of antennas threefold. Demonstrate machine intelligence algorithms to assess situation and formulate response in real time, reducing pilot workload by 35% and serving as an enabler technology for UCAV.

(2) Major Technical Challenges. Significant new approaches are needed for the avionics system hardware and software, particularly considering the affordability and multimission goals. Cost reductions are included in the R&D phase as well as the operations and maintenance (O&M) support costs. This is particularly important in that 80% of life-cycle costs are determined by end-of-design development phase. Obsolete parts and software rehosting are critical logistics problems that require multiple innovative approaches. Engineering and manufacturing development time must be shortened and operational lifetime extended to be compatible with this era of fast technology turnover. Designs must be transparent to rapid, frequent technology upgrades using commercial components. Wide-bandwidth, high-dynamic-range-sensor components that can be time shared to support multiple functions are needed. Low-cost COTS hardware and software components with plug-and-play capabilities and that can be packaged to survive the military environment must be supported architecturally using open-system architectures based on commercial endeavors. Development of reliable, super high-density connectors and fiber optic components to implement high-bandwidth networks must be developed, matured, and inserted into systems. Incremental upgrades to legacy software and mechanisms to allow existing software to coexist with new software without extensive revalidation are critical to cost reduction and the use of COTS components. Major advancements are required in multilevel secure data manipulation, system-level sensor management, and fusion, which are keystones to the future of situation awareness and improved crew productivity with reduced crew size—perhaps the mantra for UAVs and unmanned combat air vehicles (UCAVs). Another technical challenge is to look across all military platforms to see if common solutions can be attained in order to achieve economies of scale.

(3) Related Federal and Private Sector Efforts. The Boeing 777 and Airbus best represent commercial aircraft avionics. However, these platforms do not possess nor require the avionics offensive and defensive functions that are the core capabilities of military attack platforms. However, numerous technology advancements in the commercial sector, roughly characterized by COTS, indeed impact the lower level function required to implement the military-unique offensive and defensive functions. These include processors and fiber optics networks. These will be fully exploited primarily to address affordability.

c. *S&T Investment Strategy*

Sensors, decision aids, and weapons must be integrated in a manner such that the warfighter can understand situation awareness, mission plan, and contingencies; and such that the systems can be affordably, physically, and functionally integrated onto the platform. IPE develops the technologies and tools to accomplish this, including electronic system architecture (fault tolerance, standards and interfaces, interconnects, modeling and simulation), resource and information technology (shared resource management), integrated multifunctional/multifrequency apertures, and electronic signal and data processing (packaging, power management, cooling, modularity/commonality). The payoffs cited in Section C5a will be achieved through IPE technology developments and demonstrations that, in turn, will be integrated into higher level simulations and demonstrations using laboratory testbeds.

(1) Technology Demonstrations. *Common RF Digital Modules* (DTO SE.24). This DTO will develop a family of state-of-the-art modular, multifunction, reconfigurable digital receiver modules capable of performing any mission function spanning the RF spectrum of 50 MHz to 45 GHz. These digital receiver modules consist of RF acquisition and digital processing modules. This DTO is focused on application to the SH–60 helicopter. Flight tests are scheduled for FY00.

Advanced Multifunction RF System (DTO SE.72) AMRFS demonstrates a simultaneous multibeam, multifunction (radar, electronic warfare, and communication) RF system by integrating these functions in a common, broad RF band into a common pair of apertures using an open architecture configuration to permit cost-effective technology and functional upgrades.

(2) Technology Development. There are a number of technology efforts ongoing in this subarea. These include high-speed optical networks that are protocol independent, portable distributed operating systems, fusion of on/offboard data including 3D perspective scene with integrated mission and threat data, legacy software reuse, and development of broadband RF components. These technologies serve as enablers for the DTO demonstrations delineated above.

(3) Basic Research. A revolutionary approach to fusion algorithms is required of the mathematics research areas. Machine-intelligence algorithms that can learn and perform temporal and spatial reasoning to automatically determine importance, relevancy, and timeliness of information are needed. Basic research in the area of high-speed devices that will allow movement of the A/D interface toward the sensor can revolutionize the implementation architecture of avionics functions. Broadband RF components that are affordable will help achieve multifunction platforms.

6. RF Components

a. *Warfighter Needs*

The successful pursuit of national objectives requires the continued superiority of our military-essential RF electronics. The widening variety of military missions challenges these systems to be increasingly broad banded, flexible, timely, and precise on their application. The RF components' sub-thrust is meeting this modernization challenge by developing affordable electronics technology for information dominance and improved dexterity in national strategy and response actions.

Radar remains DoD's primary all-weather sensor to provide capabilities such as surveillance, situation awareness, self- and area defense, targeting, terminal guidance, and battle damage assessment. In addition, a major complement to the hardkill capability of weapons is the softkill afforded by electronic warfare (EW) systems that can potentially handle a much larger attack force than hardkill weapons. Finally, the glue that holds all these capabilities together to form an effective warfighting force is the communications networks. These three areas rely heavily on and are enabled by RF technology, which represents the key to force multiplication (the ability of a minimal number of U.S. platforms and personnel to defeat a much larger enemy force) and the avoidance of technological surprise on the battlefield. The following JWCOs are supported: Information Superiority, Precision Force, Combat Identification, Electronic Warfare, Joint Theater Missile Defense, Military Operations in Urbanized Terrain, Force Projection/Dominant Maneuver, and Joint Readiness and Logistics.

The availability of affordable, manufacturable RF electronic components that satisfy the performance, weight, size, interoperability, cooling, and maintainability requirements of military systems is vital for sustaining the competitive edge of U.S. forces over their adversaries. These warfighting capabilities require reductions in size, weight, volume, power consumption, and costs while increasing bandwidth and efficiency. Advanced high-performance and affordable RF solid-state, vacuum electronic, frequency control, and antenna technologies are currently being transitioned into a broad range of military systems, including the F–15/ALQ–135, LANTIRN, AMRAAM, MILSTAR, GEN–X, GBR, GPS, Longbow, Patriot, SADARM, F–22 radar, Predator, and EW arrays with planned transitions to DD–21, CV–77/CV(X), CEC, and CSA.

b. *Overview*

(1) Goals and Timeframes. The RF components thrust involves the technology required to generate, control, radiate, receive, and process VHF, UHF, microwave, and millimeter-wave signals. The technologies under development are applicable to solid-state and vacuum electronic devices, low-noise signal and frequency control components, MPMs, MMICs, transmit/receive (T/R) modules, advanced packaging and interconnect technology, digital receivers and transmitters, waveform generators, antennas, and multifunction electronically steered arrays. The five technology thrusts that compose the RF component subarea are solid-state electronics, vacuum electronics, signal and frequency control, antenna support, and multichip assemblies. The results of these efforts enable many of the goals in radar sensors (Section C1); Weapons—ordnance (Chapter X); Electronic Warfare—threat warning, self-protection, and mission support (JWSTP Chapter X); Information Systems Technology—seamless communications (Chapter III); and

Space Platforms—space vehicles (Chapter VIII). The timeframes of the goals of the RF components area is presented in Table VII–7.

Table VII–7. RF Components Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Demonstrate low-noise, ultra-stable frequency source with 5X improvement in acceleration sensitivity for improved slow target detection. Complete advanced algorithms for STAP and failure correction on receive-only testbed; finalize lightweight subarray design; complete miniaturization of brassboard T/R module; complete tradeoff study for full system demonstrations. Demonstrate W-band CC–TWT, 1-kW peak, 10% duty, and 3-GHz bandwidth. Demonstrate W-band gyro-klystron, 100-kW peak, 10% duty, and 600-MHz bandwidth. Demonstrate 1–5-GHz, low-parasitic SIT power amplifier.
FY00	Demonstrate miniature digital receivers for multifunction radar, communications, and EW RF sensors. Achieve efficient, full digital beamforming capability on T/R. Demonstrate the feasibility of a miniature, low-power atomic clock. Demonstrate W-band gyro-klystron, 100-kW peak, 10% duty, and 1.5-GHz bandwidth. Demonstrate a 4–20-GHz GaN power amplifier.
FY01	Demonstrate W-band CC–TWT, 1-kW peak, 10% duty, high PRF, and 3-GHz bandwidth. Complete algorithms for STAP; test failure correction on receive-only system. Demonstrate a DDS using low parasitic HBT technology whose output signal can be set to any frequency between 1 and 5 GHz and capable of 500-MHz modulation. Demonstrate a 10-bit, 4-GHz sampling InP HBT-based A/D converter. Demonstrate multibeam performance with a Ka-band Rotman lens. Demonstrate a 1–18-GHz GaN MPM driver.
FY02	Develop advanced RF, optical, and digital components for fully integrated, multifunction radar, EW, and communications compact sensors. Demonstrate GaN high-power, efficiency microwave amplifiers at $\geq$10 GHz. Achieve two orders of magnitude reduction in frequency control oscillator acceleration sensitivity. Demonstrate W-band gyro-TWT, 100-kW peak, 10% duty, and 3-GHz bandwidth. Demonstrate W-band gyro-amplifier, 100-kW peak, 10% duty, high PRF, 600-MHz and 3-GHz bandwidths.
FY03	Demonstrate dynamically programmable front ends for multifunction systems with 10-MHz to 2-GHz bandwidth and 16 bits of corresponding resolution.

(2) Major Technical Challenges. A particularly challenging technical obstacle confronting military systems is in producing affordable solid-state and vacuum power amplifiers for broadband microwave and millimeter-wave applications that simultaneously achieve high output power, high efficiency, small volume, and acceptable linearity. Specifically, amplifiers meeting these objectives must have instantaneous bandwidths extending over frequency ranges from 0.1 to 5 GHz, 1 to 18 GHz, 4 to 20 GHz, 18 to 40 GHz, 40 to 75 GHz, 75 to 110 GHz, and 110 to 140 GHz at costs ranging from one-fifth to one-tenth that which can be achieved using present design approaches and manufacturing capabilities. Another technical challenge is the achievement of two orders of magnitude improvement in frequency clock stability where size is critical and where stress due to shock and vibration are factors. A third major technical challenge is to develop RF solid-state components that reliably operate at junction temperatures greater than 300^{o}C. Such components are needed for compact sensors that operate in extreme military environments. Another technical challenge is to develop highly integrated, low-power consumption RF electronics for advanced RF and digital applications. This includes devices, integrated circuits (ICs), and high-density multichip assemblies. Specific needs are for a family of miniature digital receivers for use in radar and EW sensors. In the antenna area, the several challenges are to develop reconfigurable, adaptive beamforming for affordable compact and shallow-depth, phased-array antennas used in C^4I and radar applications, and to develop wideband phased-array architectures for space-based radar antennas. A final technical challenge is to develop lightweight, low-power-consumption, radiation-tolerant T/R modules for space-based sensors.

(3) Related Federal and Private Sector Efforts. Related efforts include metrology work with DOC/NIST, miniature atomic clock development with NIST, optoelectronic oscillator R&D with JPL/NASA, and joint programs with NASA in solid-state and vacuum electronics.

c. *S&T Investment Strategy*

Four major thrusts are being undertaken to address the deficiencies noted in Section C6b(2).

Solid-State RF Electronics. A generic technical obstacle associated with the front end of military systems is producing affordable and compact solid-state RF electronics with adequate sensitivity, bandwidth, and dynamic range for use in the frequency range extending from 0.1 to 140 GHz. One specific challenge is achieving high output power, high efficiency, and small volume with acceptable dynamic range, linearity, and low-power consumption. Similarly, there is need for increasingly capable and affordable small signal and low-noise components and for integrated circuits for amplification and signal processing at the higher frequencies and over broader bandwidths; compact multifunction down-converters and related receiver components, at costs ranging from one-fifth to one-tenth that which can be achieved using present design approaches and manufacturing capabilities; and advanced devices that operate in severe environments (e.g., high temperatures). The following projects are focusing on these deficiencies:

- Leverage development of novel semiconductor materials, device structures, and circuit designs to realize enabling RF electronics including 10–100-watt, low-cost, solid-state RF power sources and wide bandgap devices operating at temperatures above 250°C for single-function and multifunction system applications.
- Development of advanced design tools and high dynamic range, power, and multifunction processes to realize significant across-the-board cost reductions in design, fabrication, assembly, and testing.
- Continued effort at the interchip level to develop improved, more compact packaging and interconnect technology, and at the intrachip level to increase the level of RF integrated circuit integration.

Vacuum Electronics. This thrust involves the development of vacuum electronic devices and related components and materials technologies to meet DoD system insertion needs. The impact of this thrust is new capabilities, improved performance, increased survivability, and greater affordability of military electronic systems. These objectives will be achieved by exploiting scientific advances and technological opportunities and by channeling industrial activities into areas of importance to the national defense. The major challenge is finding ways to achieve higher power output, efficiency, and linearity over broad bandwidths extending from 1 to 18 GHz, 18 to 40 GHz, 40 to 75 GHz, 75 to 110 GHz, and 110 to 140 GHz at a cost that is 2X to 10X lower than can be achieved using present design approaches and manufacturing capabilities. The effort includes (1) integrating a solid-state driver with a vacuum power booster to produce compact power sources, (2) modeling and simulation, extending from electromagnetic simulations to final product design and manufacturing, (3) high-performance millimeter-wave devices exploiting fast- and slow-wave technologies, (4) advanced emitter technology, investigating new ways for improvement in electron emitters, and (5) supporting technologies (e.g., improved magnetics, materials technology).

Signal and Frequency Control. The objectives of this thrust are to develop ultrastable, low-noise frequency sources, digital synthesizers, and clocks for radar, communications, navigation, and IFF systems. Such development will provide higher time and frequency accuracy with lower power consumption, ultra high stability in small volume and in severe environments, and lower noise close to the carrier, especially in vibrating environments. Examples of these improvements include:

- Two orders of magnitude reduction in vibration sensitivity of oscillators, stable oscillators, and microresonator filters in a size comparable to MMIC chips.
- High-accuracy clocks that are 10X smaller and 10X lower power consumption with 10X higher accuracy.
- New piezoelectric materials.
- Microcomputer-compensated, low-power clocks.
- Novel miniaturized resonators for highly integrated microwave circuit applications.
- Microresonators for ultra high stability.
- Miniaturized atomic frequency standards using optical pumping techniques.
- Microresonator arrays for uncooled IR and biological and chemical sensors.

Antenna Support Technology. This thrust involves the development of supporting and enabling technology for low-cost shared aperture, multiple function antennas, advanced T/R functionality, digital beamforming capabilities, and conformal and reconfigurable agile arrays. Of particular importance is the development of wideband techniques for large space-based arrays. This technology includes an overlapped subarray architecture and a new means for the calibration of large arrays. A second topic of importance is the reconfiguring of apertures to perform multiple functions and provide failure correction, including the development of analytical tools to provide adaptive and deterministic control of conformal array antennas. Advanced monolithic integrated components and multichip assembly technology will be employed to increase phased-array reliability and reduce cost. This effort leverages related electronic integration technology to achieve multiple interconnected components within advanced, thin, lightweight packages for reliable low-cost operation at SHF and EHF. Development of agile beamforming for space-based arrays and conformal arrays represents major advances in DoD system capabilities.

(1) Technology Demonstrations. None.

(2) Technology Development. *Microwave SiC High-Power Amplifiers* (DTO SE.27). The primary objective is to develop compact, lightweight, highly efficient L- through X-band microwave, solid-state transmitter building blocks from wide bandgap materials (e.g., advanced SiC-based, field-effect transistors; static induction transistors (SITs)) that meet output power, power density, efficiency, linearity, operating voltage, and temperature to provide size, reliability, and life-cycle cost advantages over competing Si- and GaAs-based, solid-state amplifiers and tube-based RF transmitter systems. This DTO supports JWSTP Information Superiority DTO A.02, Robust/Tactical/Mobile/Networking.

Low-Power RF Electronics (DTO SE.28). Affordable, low-power consumption RF electronics are being developed for military manportable communications and for airborne/space platforms that are volume and weight starved. This effort addresses development of devices and technology for miniature, low-power consumption digital receivers, embedded passive filters, and digital waveform generators. This DTO supports JWSTP Information Superiority DTOs A.02, Robust/Tactical/Mobile Networking, and A.13, Satellite C^3I/Navigation Signals Propagation Technology; and Military Operations in Urbanized Terrain DTO E.01, Small-Unit Operations Technology Demonstration.

Design Technology for RF Front Ends (DTO SE.29). Work focuses on providing enhancements by leading computer-aided engineering (CAE) tool suppliers with tight coupling to the microwave and millimeter-wave industry and establishing processes to ensure that end-user requirements are addressed. The resulting capabilities will become part of the commercial product lines of the leading CAE suppliers and will, therefore, be sustained after the microwave and analog front-end technology (MAFET) program ends. As above, this DTO supports DTOs A.02, A.13, and E.01.

Digital Beamforming Antenna Technology (DTO SE.63). The objective is to build and test critical subsystems and components of digital beamforming array antenna systems with the ultimate goal of solving key deficiencies in existing Air Force and Navy radar systems. Component technology from MAFET, other DARPA programs, existing DTOs (i.e., SE.57, SE.29, and IS.33) will be integrated. Present radar capabilities for detection and tracking of multiple targets in the presence of interference (clutter, jamming, etc.) are inadequate against the LO technology of the future. This capability is offered with a digital beamforming receive array. For the receive-only system, the challenge is of advanced algorithms for STAP of multiple beams with jammer, platform, and terrain clutter suppression and with array failure correction; and of design and development of lightweight subarrays for mobile platforms. For a multifunction system, T/R modules are needed for digital beamforming functionality.

Millimeter-Wave Gyro-Amplifiers (DTO.SE.64). The primary objective is the development of efficient, high-power, high-gain, wide-bandwidth amplifiers; the associated RF driving sources; high-power components; and design tools for defense applications above 30 GHz. The millimeter-wave (MMW) amplifier technology is intended to support current and future high-performance radar and communication systems.

Integrated Compact Electronic Sensors and Components (DTO SE.70). The objective is to develop the electronic component and integration technologies for the next generation of lightweight, compact sensor systems required in military space, air, and ground applications. The focus of this DTO is on two key technology areas: the miniaturization and integration of sensor devices and components, and the networking and data fusion of multidomain sensors arrays. Device technologies include on-chip/off-chip integration of RF, IR, acoustic, seismic, magnetic, MEMS, low-power RF, and digital electronics. These technologies will enable the demonstration of extremely efficient, rugged, low-power, fused, and internetted sensor technologies capable of reliable, remote, unattended operation in the required military environment.

Advanced Multifunction RF System Components (DTO SE.71). This DTO will develop the electronic component technologies to realize advanced multifunctional RF systems, such as surveillance, illumination, weapon control, EW, radar, communications, and IFF for operation over the 1- to 44-GHz frequency range. The investment is focused in four military-essential components areas of development: wide-bandwidth, high-efficiency power amplifiers; direct digital synthesis (DDS) components; high-speed A/D converters; and photonic and digital beamforming. The subject DTO leverages off other existing DTOs (e.g., SE.29, SE.57, SE.36, and SE.39). An anticipated life cycle cost savings of $100 million per ship for 21st century surface combatant ships will accrue from significantly reduced parts count, logistics, operations, maintenance, and upgrades. Size and weight reductions of 30% to 75%, required for sensor systems on future aerospace vehicles, will be realized. Developing affordable multifunction K-band arrays will provide increased lethality, accuracy, and all-weather operations.

(3) Basic Research. Basic research in the RF component technology area is directed toward the synthesis of advanced semiconductor, superconductor, ceramic, piezoelectric, ferroelectric, ferromagnetic, and ferrite materials; the development of affordable processing sequences for them; and the realization of accurate predictive modeling and simulation algorithms and techniques. The successful completion of research tasks in these areas will enable development of high-performance, reliable, low-cost structures for RF devices and components used in DoD systems. Basic research efforts provide technology options for device and component designers and fabricators that may lead to the realization of improved or entirely new classes of devices and components. Specific device and component-related goals that motivate these efforts are achievement of improved device performance (e.g., higher frequency, higher temperature operation, higher efficiency, lower noise, reduced complexity, ability to support small feature sizes), lower cost, higher yield, improved predictability of properties, and greater reliability. Basic research in the antenna area includes the use of neural networks and other approximate algorithms for control of arrays with failed elements, subarraying techniques, and advanced algorithms for conformal arrays and wideband space antennas.

7. Electro-Optical Technology

a. *Warfighter Needs*

The detection, precise location, specific identification, and tracking of targets and an accurate battlefield damage assessment are key elements of the JWCOs of Information Superiority, Precision Force, Combat Identification, Joint Theater Missile Defense, Military Operations in Urbanized Terrain, Electronic Warfare, and Counter Weapons of Mass Destruction. EO offers advanced technology solutions to the problems of high-resolution target location and identification, nighttime surveillance, and high-capacity data storage and processing. In addition, electro-optics is the basic technology of displays, which are crucial to all man-in-the-loop systems. The continued development of high-performance, man-in-the-loop, and autonomous systems using advanced EO technology will substantially advance global surveillance and communications; all-weather, day/night, camouflage-resistant precision strike missions against fixed and mobile targets; advanced antisubmarine warfare capabilities; and space and sea control systems.

b. ***Overview***

(1) Goals and Timeframes. High-performance sensors, displays, and data storage and processing will be required to meet future warfighter needs. Photonics will provide high-capacity, rapid-access data storage; distortionless wideband analog fiber optic communications for sensor, emitter, and antenna remoting; ultra high speed data processing for real-time analysis of signals intelligence (SIGINT) and electronic intelligence (ELINT) data; and new approaches to steering and control of microwave beams. Display technology will address the problems of developing high-definition, helmet-mounted displays for the individual soldier and the aircraft pilot. A short-term goal is to demonstrate the capability of the active matrix electroluminescent display (AMEL) to operate with analog inputs for low power and compatibility with existing signal sources. Reductions in required display luminance and decreases in associated power consumption and heat-loading in see-through helmet-mounted display (HMD) designs will be addressed by developing active ambient illumination modulators. Cost reductions in infrared focal plane arrays (IRFPAs) will be sought through uncooled sensor technology and by improvements in the functionality of cooled IRFPA technology. New applications will be addressed through development of multispectral sensors. Laser technology will attempt to lower the cost per watt of semiconductor lasers, develop long-lived blue laser diodes, and demonstrate eye-safe tunable monomode optical fiber lasers. Specific goals are listed in Table VII–8. Long-term (FY01–FY05) goals include integration of IRFPA and ATR functions, 3D stereoscopic displays, and

Table VII–8. Electro-Optical Subarea Goals and Timeframes

Fiscal Year	Goals
FY99	Demonstrate miniature, low-power 640 x 480 display for HMD and weapon-sight application. Demonstrate parallel optical interconnects to 2.5 Gbytes/s. Demonstrate 1–100-GHz optical RF frequency synthesizer for EW, ELINT and ECM. Demonstrate 0.05 NEDT uncooled FPA with 30-μm pixels. Demonstrate eye-safe (1.5–1.6 μm) 3-W monomode fiber laser. Demonstrate 300 K CW operation of an optically pumped Type II quantum well laser. Demonstrate 80 K CW operation with 350-mW output of a Type II quantum well laser.
FY00	Demonstrate miniature low-power 1024 x 1024 monochrome displays for HMD applications. Demonstrate 1–100-GHz channelizer for ELINT/SIGINT. Demonstrate full-color, high-resolution (>1,000 lines) "smart" display. Demonstrate radiation hardened 256 x 256 MCT FPAs with cutoff above 13 μm. Demonstrate 200 K CW operation of an interband cascade (electrically pumped) laser. Demonstrate 100 K CW operation with >100-mW output of an interband cascade laser.
FY01	Demonstrate 1024 x 1024 dual-band LWIR MCT sensor array. Demonstrate a photonic beamformer for GPS antijam. Demonstrate medium- and high-resolution plastic displays using all-organic materials.
FY02	Demonstrate large-format (1024 x 1024) space LWIR QUIP FPA. Demonstrate 10-megapixel head-down tactical crewstation.

monolithic opto-electronic integration leading to 2D optical "smart" pixel arrays for high-speed parallel processors. The subarea includes four prior-year DTOs and has participation in a new DTO submission in FY99, SE.71, Advanced Multifunction RF System Components, for the development of electronic and photonic component technologies for A/D conversion and optical beamforming.

(2) Major Technical Challenges. Key challenges in the laser diode array area include extending the range of available wavelengths in the mid-/long-wavelength infrared (MWIR/LWIR) bands and reducing size, weight, power consumption, and cost. A cost target of $1 per peak watt is sought. In focal plane arrays, the key short-term challenges are in improving sensitivity and reducing cost through functionally improved and new uncooled sensor technology. Longer term, multispectral-cooled FPAs will address the problem of detecting dim and camouflaged targets automatically in ground clutter.

The enormous potential of photonics technology for high-speed data transmission and processing is being exploited for peculiarly military applications. The key technical challenges are in (1) extending the capability of optical recording and data storage to provide increased capacity and faster retrieval to allow processing of SIGINT and ELINT data in real time, using the vast bandwidth of optical waveguides for microwave transition on optical fiber, which allows sensor remoting in satellite communications (SATCOM) and electronic countermeasure (ECM) applications; and (2) developing high-speed, 2D parallel processors for a range of applications including antijammer beam-null steering. Fiber optic sensors are needed for hydrophones and strain sensing in composites and pose challenges in components, sensor array fabrication, multiplexing, and signal processing. The key challenge in displays for military applications is the development of the HMD, where low-power consumption, low weight, and high resolution are the principal requirements. Long-term needs are focused on a full-color, high-resolution display with integrated drive electronics.

(3) Related Federal and Private Sector Efforts. There are significant commercial activities in flat-panel displays, optical recording, and fiber optics for telecommunications and local broadband services. Additionally, federal laboratories have addressed the development of fiber optic subsystems for specialized tasks such as nuclear test instrumentation. The DoD-funded efforts leverage commercial technology wherever possible, supplemented by R&D of the technology and components needed for military applications. A typical example of this approach in the photonics area is leveraging commercial optical fiber technology combined with government-sponsored development of the advanced laser sources and detectors needed for military requirements for high-speed analog communications.

c. *S&T Investment Strategy*

The EO technology subarea is organized in four major thrusts.

Compact Solid-State Lasers. The goals are to meet future laser requirements for infrared countermeasures against IR-guided missiles; design multifunction lasers for ranging, designation, IFF, and laser radar functions; and develop electrically driven, high-energy lasers for sensor and platform destruction, which will require lasers well beyond the extrapolated state of the art of flashlamp-pumped or diode-pumped solid-state lasers. Each application area has implicit wavelength requirements that generally reduce performance of current lasers by factors of three or more. Also, laser packaging for field use has been a long and expensive process. This thrust is aimed at developing the essential elements of laser technologies that offer the potential of order-of-magnitude or greater performance improvements with intrinsic advantages in wavelength control and packaging. Specific needs for this technology are referenced in the JWCOs of Electronic Warfare and Military Operations in Urbanized Terrain (for laser ranging). This thrust also addresses MOUT needs for laser illuminators and target designators not explicitly referenced.

Two technologies recommend themselves as having the potential of substantial improvements in performance. For the lower power missions, direct laser diode operation at the wavelengths of interest in the visible through the MWIR bands now appears possible. For higher power applications, the use of arrays of fiber lasers appears to be an attractive candidate. This thrust is aimed either at validating the promise of these technologies or of finding even more attractive systems. The emphasis is on demonstrating device performance characteristics of an acceptable nature in power and lifetime, demonstrating the power scaling of the technology, and deriving system concepts for stressing missions.

Focal Plane Arrays. The FPA thrust focuses on the development of military-unique EO devices and components for optical sensing and the integration of this technology into sensor systems. The broad objective is to provide faster, more accurate detection and targeting capabilities combined with the benefits of low weight and low power. Specific objectives include:

- Large, staring, cooled IR arrays for multispectral detection.
- Uncooled arrays with improved sensitivity and resolution and, combined with low-light-level imaging, increased reliability through the employment of staring technology.
- Sophisticated and advanced growth techniques for monolithic integration of smart silicon processors and ultraviolet (UV) through very long wavelength IR detector arrays.
- Arrays with active and passive sensing capability for LO target detection and identification.
- More affordability and reproducibility of FPAs.

These objectives are obtained by integrating multispectral/hyperspectral FPAs with smart readout ICs, innovative micro-optics, and adaptive micro-/nano-electronics into tactical Dewars. The more distant goals involve UV through MMW smart temporal and multispectral sensing with processing that emulates human vision. The results of this thrust will provide the warfighter with increased situational awareness, enhanced defense suppression, increased detection and identification of LO targets, and improved precision weapon delivery for increased lethality and survivability. Needs for IRFPA technology are extensively documented in the JWSTP under the following JWCOs: Information Superiority (multispectral smart surface sensors); Combat Identification (IRFPA, advanced IR sensors); Joint Theater Missile Defense (large-format, high-uniformity LWIR FPAs, high-sensitivity multispectral IR sensors); and Force Projection/Dominant Maneuver (multispectral/hyperspectral imaging). There are obvious needs for IRFPA imagers under MOUT that are not referenced explicitly in JWCO goals.

Displays. This thrust addresses an extremely wide range of system requirements. At one extreme, there is the miniature, low-power, low-weight, flat-panel devices for head-mounted cockpit and individual soldier applications. State-of-the-art optics (diffractive, aspherics, hybrids, etc.), sensors (charged coupled device (CCD), intensified CCD), and flat-panel displays (AMEL, AMLCD, AMOLED, FED, FLCD, VRD, etc.) will be investigated and selected for future helmet-mounted, high-resolution display and sensor systems. Parallel investigations into active ambient modulators will reduce luminance and power requirements for miniature displays used in see-through HMD system designs. Concurrent development of sensor readouts and display driver electronic architectures will be used to optimize power and bandwidth. In the longer term, all solid-state sensor and display systems with digital input/output imagery and symbology will be developed to integrate the individual soldiers and aviators into the digital battlefield. At the other extreme of this thrust are large, high-definition, direct-view flat panel and projection color displays for use by battlefield commanders for multimode C^3 information and battle briefing. The DoD goal of maintaining informational superiority and situational dominance requires a continual closing of the 1,000X gap between presently fielded crew interfaces (1 megapixel) and the human visual system capacity (1 gigapixel). More advanced technical investigations address 3D image presentation for applications where depth perception is a critical requirement for understanding the information presented. High-fidelity (20:20 Snellan acuity) projectors require 5,120 x 4,096 pixels compared to the 1,600 x 1,200 pixels now available.

Photonics. Photonics technology uses light for the transmission and processing of information and offers the potential advantages over conventional electronics of vastly enhanced data throughput and information capacity. From the military viewpoint, photonics provides both enhancements in existing systems, some of which are already close to being available in the inventory, and entirely new applications in areas such as high-speed processing, communications, surveillance antenna and receiver systems, ATR, EW, SIGINT systems, and high-speed communications networks that are well beyond the capability of conventional electronics. These enhancements are necessary in order to achieve future requirements for enhanced system performance within the size, weight, power consumption, and volume constraints imposed by military platforms.

This photonics area is organized into two thrusts: optical processing and interconnects, and RF photonics. Work previously reported here on optical memory is now reported in the Information Systems Technology area. The work previously reported here on fiber optic sensors has transitioned to operational systems. The work previously reported here on high-speed communications networks technology has been terminated. The photonics area includes the development of devices and subsystems to demonstrate and quantify military system impact. This work is funded by the services, DARPA, and BMDO. This area includes two prior DTOs (SE.35 and SE.36) and a new DTO (SE.71) to develop a variety of optical components such as optical beamforming and high-speed A/D converters.

There are numerous explicit references to photonics technology needs in the JWSTP and other needs that are implicitly addressed by emerging photonics technology, for example in ATR and tracking. The relevant JWCOs are Information Superiority (small volume/weight, very high speed capacity processors, ATR, wideband communications and interconnectivity, secure GPS); Precision Force (Enhanced Fiber-Optic Guided Sensor system, multisensor ATR); Combat Identification (secure datalinks); Joint Theater Missile Defense (high-speed optical datalinks, high-capacity computer interface, target discrimination algorithms); MOUT (high-bandwidth datalinks, ATR, lightweight optoelectronics); Joint Readiness and Logistics (secure, high-rate, high-bandwidth communications); Force Projection/Dominant Maneuver (joint (combined) multisensor fusion, information fusion); Electronic Warfare (wideband datalinking); Chemical/Biological Warfare Defense and Protection and Counter Weapons of Mass Destruction (embedded monitors, miniaturization technology, ATR); and Combating Terrorism (fiber optic waveguides, multisensor fusion, multisensor ATR, high-bandwidth datalinks).

(1) Technology Demonstrations. The photonics thrust includes a number of ATDs. Three Air Force ATDs have been approved: Analog RF and Millimeter-Wave Optical Signal Distribution (AF/AIA, FY04), Optical Control of Phased Arrays for Multimode Communications (AF/C4A, FY99), and Integrated C^3I Optical Processor (AF/ACC, FY01). The Navy has one ongoing and two recently completed fiber optics ATDs: Advanced ECM Transmitter for Ship Self-Defense (N/PEO/SC, FY96–98), Precision Strike Navigator (N/ONR, FY96–98), and Multifunction Electromagnetic Radiating System (N/NSPAWAR, PMW176 & SEA03K2, FY97–99). In addition, the Navy has two new ATDs that rely on fiber optic development: High-Band Multifunction Receive System (N/ONR, PEO/SC, FY99-01) and High-Power Microwave ATD (N/ONR, FY99–01). In the FPA thrust, the Army has a single ATD: Multifunction Staring Sensor Suite.

(2) Technology Development. *Advanced Focal Plane Array Technology* (DTO SE.33). This DTO includes both cooled and uncooled arrays. The cooled technology focuses on dual-band and multispectral sensing for detecting dim and camouflaged targets in background clutter. The uncooled technology development aims for improved sensitivity and resolution while maintaining low cost, weight, and power consumption. The integration of IR and low-light-level FPA imaging in a single package will improve nighttime rifle sight effectiveness and allow the development of low-cost missile seekers.

Optical Processing and Interconnects (DTO SE.35). This DTO will develop radically new optical interconnect technologies that provide terabit-per-second throughput between chips, boards, and processors. The goal is to achieve tera-operations-per-second processing in a massively parallel opto-electronic processor that is small in size and low in power consumption. High-speed signal processing is driven by the operational realities of increasing jammer densities against C^4I assets, LO target surveillance, and the requirement to manage large intelligence databases. Performance limits of conventional electronic approaches to air and ground surveillance are stressed by LO threats, sophisticated ECMs, increased target densities, and complexity of the modern battlefield, all of which make high-processing speeds essential. Hybrid or all-optical techniques provide solutions to the processing bottleneck at reasonable levels of cost, power consumption, and volume.

Photonics for Control and Processing of RF Signals (DTO SE.36). This DTO exploits the huge bandwidth of monomode optical fiber to replace bulky, lossy, narrowband, and dispersive RF cable and waveguide. Optical fiber delay lines provide unprecedented bandwidth, which suggests their use as true time-delay elements in a microwave-phased array. Further, high-quality optical sources allow the novel implementation of RF systems on optical carriers with their attendant reduction in size (e.g., RF filters, channelizers, up/down converters). These applications are being developed. Multigigahertz analog fiber optic interconnects are being developed for high-fidelity remoting of antennas over kilometer distances. Full-scale, optically controlled phased arrays for SATCOM applications are planned for FY00. A major aspect of these efforts is the development of components such as MMW modulators, detectors, and semiconductor laser optical sources.

Long-Wavelength and Multispectral, Large-Area, Staring Focal Plane Arrays (DTO SE.65). This DTO will develop long-wavelength and multispectral, large-area, staring IRFPAs for ground and space applications. Mercury-cadmium-telluride (HgCdTe) FPAs as large as 2,048 x 2,048 for terrestrial applications and radiation-hardened versions as large as 256 x 256 for use in space will be built. The terrestrial FPAs will have an operating temperature of 120 K or higher and will have flexibility to change frame rates from 30 Hz to 480 Hz. These FPAs will also have an integrated laser receiver to provide functions such as target profiling.

(3) Basic Research. Research is an important component of the EO effort where much of the technology is emerging. Key basic research is being done in electronic and optical materials. The extensive work on GaN for blue lasers is a good example. Many photonics applications are component limited; consequently, there are significant research efforts for development of devices and components including guided-wave modulators; semiconductor lasers, switches, and spatial light modulators; and smart pixel arrays. In addition, research is being directed toward new nonlinear optical materials and techniques. The long-term goal of research in this area is monolithic integration of optics and electronics. A multidisciplinary university research initiative for liquid crystal and liquid crystal polymers is underway (FY96–01) to improve materials needed for advanced displays, laser eye protection, and optical communications devices.

8. Microelectronics

a. *Warfighter Needs*

The warfighter has become critically dependent on the ability of systems to process, store, and transmit information to achieve force multiplication through remote and distributed awareness and control. Key military equipment (e.g., sensor packages, satellites, manportable communications equipment) must meet stringent military requirements as described in *Joint Vision 2010* (e.g., radiation and high-temperature environments, extended operating lifetimes, lower weight, high performance) to achieve force multiplication throughout the range of potential warfighter environments. A crucial factor affecting DoD’s ability to provide superior capabilities to the warfighter is the cost of electronic systems, which depends directly on the producibility, quality, and cost of microelectronics devices, circuits, and fabrication technologies. The challenge facing DoD is to formulate an investment strategy that leverages the more than $150 billion commercial microelectronics market while still maintaining technology leads in low-volume areas that are key to military applications.

Over the short term (1–2 years), electronic systems enabled by microelectronics should double the capability for processing information in the battlespace, while reducing cost, power consumption, and weight by a factor of two. In the mid term (3–5 years), it is expected that microelectronics will enable a doubling of sensing resolution, range, or speed; reduce power consumption by a factor of 10; and reduce weight by a factor of 10. In the long term (6–10 years), microelectronics innovations should provide an order-of-magnitude improvement in the range of sensing capabilities, while decreasing cost, power consumption, and weight by more than a factor of 100.

The technologies for signal conversion and processing, low-power, radiation-resistant microelectronics, and MEMS all have the potential to significantly increase the capabilities of weapon platforms and information systems and simultaneously decrease their size, weight, cost, and assembly complexity. The dramatic rate of microelectronics technology innovation has also created the need to ensure that the warfighter has access to current state-of-the-art microelectronics to sustain superiority. Toward that end, the rapid transition of new technology to the industrial base and insertion of new (possibly commercial) technologies into military systems will continue to play an increasingly important role in meeting future warfighter needs.

b. ***Overview***

The microelectronics technology is geared toward meeting very unique military requirements through the exploitation of pivotal technologies based on a range of electronic materials (e.g., Si and its compounds, SiGe and SiC; GaAs; other III–V compounds) and novel processes for new device structures (i.e., MEMS and radiation-resistant components) and circuit applications (i.e., A/D converters and inertial measurement systems). Military use of these technologies, associated with deep submicron, 100-nmi feature sizes, will enable order-of-magnitude advances in sensors; low-power systems; and complex, radiation-resistant, integrated electronic functions (for signal conversion, processing, amplification, and MEMS sensing). These are to be implemented with advanced design architecture. This will allow handling of 10–1,000 times more data at several hundred times higher throughput through parallelism, functional density, architecture innovation, and device speed and by covering a broad spectral range from dc to several tens of gigahertz.

(1) Goals and Timeframes. The United States must maintain its military superiority in an era of rapidly changing microelectronics technology. This superiority is based on (1) force multiplication through advanced microelectronics (technology and component applications) with a minimum number of platforms and personnel, and (2) actively avoiding technological surprises in future combat scenarios. In this context, the microelectronics subarea develops device, circuit, and fabrication technologies to realize digital, analog, and mixed-signal integrated circuits that are needed for introduction in a timely and planned fashion into weapon systems ensuring superiority over our adversaries. Specific goals are shown in Table VII–9.

(2) Major Technical Challenges. The warfighter's needs and projected threats are translated into technology goals aimed at removing the bottlenecks and barriers to the affordable and efficient collection and processing of information. As the commercial microelectronics market has experienced explosive growth, industry has focused increasingly on large commercial markets and less on critical military characteristics (e.g., radiation hardness, multigigahertz operation, MEMS capability). It is now even more important that DoD surmount the following technical challenges: (1) developing affordable process, design, and layout of microelectronics to enable them to survive in the unique radiation environments required by DoD systems; (2) applying electronic design automation tools in conjunction with high-volume commercial processes to close the gap between radiation-resistant and commercial devices; (3) reducing piece-part costs to provide new generations of radiation-hardened ICs at an affordable cost that provide the warfighter with survivable state-of-the-art electronic systems; (4) model and simulate mixed analog and digital circuits with greater bandwidths at multigigahertz clock rates; and (5) reduce MEMS fabrication complexity to lower the cost of fabricating MEMS products.

Table VII–9. Microelectronics Subarea Goals and Timeframes

Fiscal Year	Goal
FY 99	Develop a 4- to 5-bit, 10-Gsps A/D converter in CMOS/SOS (associated with subnanosecond RF memories for EW). Demonstrate 256-kb nonvolatile memory; develop mixed-signal sensor processor that incorporates next-generation packaging concepts; develop ultra low power, 12-bit A/D converter; demonstrate how commercial automated electronic design tools can be adapted to meet rad-hard electronics requirements. Demonstrate a BiFET transceiver chip set in DRFM/DIFM brassboard.
FY00	Demonstrate a 4- to 5-bit, 20-GHz A/D converter (employs interleaving in CMOS/SOS). Demonstrate a 16-bit, 60-MHz instantaneous bandwidth A/D converter. Demonstrate a 16- to 18-bit, 2–100 Ksps, 1-mW A/D converter in CMOS/SOS. Demonstrate a rad-hard, 4-Mb SRAM with 16X density improvement and 2X improvement in speed; space qualify high-speed device manufacturing technology. Transfer BiFET IC technology to pilot production.
FY01	Develop highly integrated, nanometer-feature-size, MEMS-based microsystems that integrate sensors, processing circuits, and I/O (actuators, displays) produced by affordable, flexible fabrication techniques. Develop deep-submicron, radiation-resistant microelectronics fabrication technology for microelectronics components. Qualify submicron 4-Mb memories, single-chip 32-bit data processor, and 3,000-k gate array; demonstrate a high-gate-count (~400,000), rad-hard, field-programmable gate array; develop a scaleable, open-system space computer architecture. Develop a detailed model of aircraft flight under control of multiple (>10,000) distributed and embedded MEMS sensors, actuators, and processing elements.
FY02	Demonstrate space qualifiable data processor node for scaleable space computer (e.g., rad-hard, PowerPC-like device with performance greater than 200 mips).
FY03	Demonstrate a rad-hard, 16-Mb SRAM with 64X density improvement and 4X improvement in speed.
FY05	Develop and demonstrate space-qualified rad-hard system-on-a-chip with 0.18-µm CMOS mixed signal technology with 100X and 10X density and speed improvement, respectively.

(3) Related Federal and Private Sector Efforts. External programs (including support contracts) account for approximately 85% of the current government S&T investment in this subarea. Specific efforts include:

- Consortia (Microelectronic Advanced Research Corporation and SRC) created in academia to implement an industrial investment plan specifically in the microelectronics area. However, much of their focus has been on the technology needed for high-volume (e.g., interconnects for gigascale integration), state-of-the-art products (e.g., memories, processors) rather than on the specialized products required by the military.
- Radiation-hardened electronics are critical for the multibillion dollar commercial and civilian space industry. Commercial space-system firms have no interest in producing radiation-hardened microelectronics.
- Radiation-hard efforts are conducted by DOE and NASA. The DTRA enabling technology efforts are coordinated with the Sandia (DOE) and the Goddard and JPL (NASA) radiation-hard microelectronics programs.
- MEMS activities at various organizations, including Sandia National Laboratories, Lawrence Livermore National Laboratories, and U.C.–Berkeley.

c. ***S&T Investment Strategy***

The microelectronics technology subarea applies a range of electronic materials technologies (e.g., Si and its compounds, GaAs, other III–V compounds) to develop advanced devices and circuits that support a number of key DoD applications. These advanced devices and circuits are either not available from industry or require performance superior to those available from industry. The components and subsystems that depend on advanced technologies are critical to communications (e.g., satellites); radar (e.g., digital warning receivers and ATR devices); ECM and jammers; avionics systems; command and control; intelligence, surveillance, and reconnaissance (ISR) UAVs; digitized battlefield; ASW, antisurface-ship warfare, and mine detection; and smart munitions. Emphasis is given to potential nuclear threats. Many of the radiation-hard products developed have broader applicability—enabling technologies provide protection against both weapon-induced and natural radiation hazards that might be encountered by commercial space systems. Components and subsystems include:

- D/A and A/D converters supporting faster, cheaper, and more accurate processing for sensing, surveillance, and communications.
- DDS devices for low-probability-of-intercept communications and C4I.
- High-temperature and high-power SiC devices and circuits for sensing and performance.
- Deep-submicron, radiation-hardened silicon bulk and silicon-on-insulator (SOI) microelectronics that withstand natural and nuclear radiation.
- MEMS devices enabling very tightly controlled automatic manufacturing and orders-of-magnitude improvement in the performance and density of mechanical systems.

Microelectronics technology supports all 11 JWCOs. In particular, microelectronics provides critical support to six of the JWCOs: Information Superiority, Precision Force, Joint Theater Missile Defense, Force Projection/Dominant Maneuver, Electronic Warfare, and Chemical/Biological Warfare Defense and Protection. The microelectronics subarea comprises thrusts in three areas: advanced manufacturing, expanded performance processes, devices and circuits and MEMS.

(1) Technology Demonstrations. None.

(2) Technology Development. *Analog-to-Digital Converter* (DTO SE.57). Novel Si and III–V devices are being developed from materials such as SiGe, SiC, TFSOS, GaAs, and GaN. These novel devices will be used to achieve low-power SOI circuits and high-performance circuits and applications (e.g., high temperatures, high-speed data and signal processing, wide bandwidths, high-speed/low-power A/D and D/A converters). In the long term, substantial operations enhancements will eliminate intermediate-frequency conversions, allowing the placement of the A/D converters at the sensor (or antenna) for the immediate processing of the analog signal into a digitized format. System enhancements will be realized in (1) radar for target detection in high-clutter environments; (2) deployable sensor systems and SIGINT for unattended, remotely controlled applications; and (3) surveillance (HF direction finding) EW and ESM for real-time computation of direction/time of arrival to changing emitters, channels, and environments requiring high-performance components. Specific efforts include:

- Complementary metal oxide semiconductor/silicon-on-silicon (CMOS/SOS) technology development (funded by the Navy).
- High-speed GaAs and InP heterojunction bipolar transistor (HBT) development (funded by DARPA).
- Flexible, high-performance A/D converter development analyzing the tradeoff between speed and resolution (funded jointly by DARPA, Navy, and Air Force).

This DTO strongly supports two JWCOs: Joint Theater Missile Defense (D.03, Discriminating Interceptor Technology Program) and Force Projection/Dominant Maneuver (G.12, Lightweight Airborne Multispectral Countermine Detection System).

High-Density, Radiation-Resistant Microelectronics (DTO SE.37). Fabrication capabilities are being developed to produce high-performance, extremely dense, radiation-resistant microelectronics that are key to continued U.S. domination of battlefield surveillance, intelligence, and communications as well as joint TMD. Investment is focused on leveraging commercial advances in the fabrication of microelectronics to produce key military components with performance and density close to commercial devices. Space applications, which presently dominate requirements for radiation-resistant microelectronics, need to operate reliably after exposure to natural and nuclear radiation (e.g., total dose 300 krad, dose rate upset thresholds 10^8 rad/s, single-event-upset thresholds 40 $MeVcm^2/mg$). Specific efforts include:

- Deep submicron, radiation-hard bulk CMOS and SOI process and memory development (funded by DTRA).
- Radiation-hard processor and memory development (funded by the Air Force).
- Radiation-hard nonvolatile memory and analog circuit development (funded by BMDO).

During FY98, a submicron, radiation-hard microelectronics fabrication process was successfully developed that enabled a 4-Mb SRAM and 32-bit data processor to be developed. This DTO provides strategic systems (Minuteman,Trident, BMDO National Missile Defense interceptor systems) and satellites (Milstar, advanced EHF, UHF Follow-On, GPS–IFF, Space-Based Infrared System (SBIRS)–High, SBIRS–Low) with timely access to key microelectronic technologies. The technologies developed also provide significant reductions in weight, size, and power while simultaneously increasing performance.

This DTO strongly supports two JWCOs: Information Superiority (DTO A.13, Satellite C^3I/Navigation Signals Propagation Technology); and Joint Theater Missile Defense (D.05, Advanced Space Surveillance).

Microelectromechanical Systems (DTO SE.38). Reliable, repeatable, MEMS-specific fabrication techniques are being developed. These techniques will be fed into developing MEMS devices and circuits that integrate sensing, actuation, computation, communication, and control components. Specifically, DARPA (in conjunction with the Army and Air Force) is funding the establishment of a MEMS fabrication infrastructure, physical science work to understand individual MEMS devices, and MEMS applications (e.g., an inertial measurement system). This

DTO strongly supports the Information Superiority JWCO DTO A.10, High-Altitude Endurance UAV ACTD.

(3) Basic Research. The DoD basic research (6.1) investment in microelectronics is concerned with developing novel processes, devices, and circuits using innovative materials and physical mechanisms. Over the past 20 years, several large programs have been planned and executed jointly. Most notably, a joint venture on the physics of compound semiconductor interfaces was a highly successful defense-wide approach to setting national goals for surface and interface electronics. This effort continues to broadly impact on infrared detectors essential for operations under realistic battlefield conditions; wide-bandgap semiconductors critical for RF applications and high-power shipboard switching devices; and optical computing devices that provide major weight and size reductions in aircraft signal processors. Another highly successful joint venture was the Ultra Small Electronics Research program, the precursor for the National Technology Roadmap for Semiconductors developed by the U.S. Semiconductor Industry Association.

9. Electronic Materials

a. *Warfighter Needs*

Warfighters are increasingly exploiting electronic systems to achieve force multiplication. The performance and price of components in these systems depend directly on the reproducibility, quality, and cost of electronic materials synthesis and processing. Electronic materials science also is the enabling technology for electronic and EO devices, whose payoffs include higher maintainability, lighter weight, smaller volume per function, higher data rate processing, and higher frequency/bandwidth operation—characteristics essential for establishing military dominance in areas such as avionics, radar, C^4I, guidance, target identification, surveillance, and navigation. For example, development of III–V semiconductor substrate and films/nanostructures will make more compact radars and higher frequency and data rate communication systems possible in the mid term (3–5 years). In the mid and long terms, materials for IRFPAs will make possible modules capable of broader band detection, multiple color response, and room temperature operation; materials for mid-wave semiconductor lasers will allow reduction in size and weight of heat-seeking missile countermeasure systems; wide-bandgap semiconductors will make electronics available that operates at 300–500°C (e.g., near engine components) as well as compact UV laser systems for full-color display applications and high-density optical data storage. Because electronic materials technologies are inherently dual use, DoD programs will benefit civilian electrotechnology, whose enhanced capabilities will benefit military technologies in time.

b. *Overview*

(1) Goals and Timeframes. The electronic materials subarea develops materials, fabrication processes, and device structures that are not supported commercially; are necessary for developing RF, microelectronics, and EO devices and components; and combine affordability with high performance for use in DoD systems. Major goals are listed in Table VII–10.

Table VII–10. Electronic Materials Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Demonstrate a commercially viable SiC epitaxy process that yields materials properties (defect density, control of dopants) that exceed substrate quality. Evaluate approaches and downselect. Demonstrate a means to synthesize 1 in or greater diameter substrates lattice matched to GaN.
FY00	Demonstrate quality of materials growth and processing with power device structures of <10% performance variation across wafer. Downselect GaN substrate approaches. Demonstrate effective doping of high aluminum alloy ratio AlGaN material.
FY01	Transfer to manufacturing 3-in diameter substrate wafers of 4H SiC with doping concentration variation <10% and micropipe density less than 5/cm^2 across the entire wafer.

(2) Major Technical Challenges. Most electronic materials efforts are linked by the need to reduce the concentration of deleterious defects; to control material composition (including intentional, judicious introduction of impurities), structure, and morphology in order to tailor properties; and to develop fabrication and characterization methods that result in high-quality materials at affordable prices. Additional challenges depend on specific materials and the maturity of the technology. The near-term challenge for high-temperature semiconductors (HTS) and HTS materials, both of which are at early stages of development, is to produce material having properties suitable for demonstration devices and small-scale components. Substrates that match the lattice constants and thermal expansion coefficients of III–N films are especially needed. For the more nearly mature GaAs- and InP-based materials, challenges include fabrication of larger diameter substrates having lower defect densities, higher uniformity, and lower cost; further control and exploitation of the relationships among growth environments and resulting properties—particularly controlling heterostructure interfaces such as InGaAs/InP or AlSb/InAs/GaSb; and minimizing the strain induced by lattice mismatches between constituents of the heterojunctions. Key technical challenges for IR detector materials are the achievement of greater uniformity, and more precise process control; and, for heterostructure detectors, control of interfaces and strain.

(3) Related Federal and Private Sector Efforts. AT&T, Hewlett-Packard, Texas Instruments, Raytheon, Lincoln Labs, Hughes, and several universities have important III–V epitaxy programs. NIST works with AFRL/ERX and /ELD to characterize wafers manufactured by contractors in the Title III GaAs substrate program. M/A–COM, Litton-Airtron, and AXT market GaAs substrates; Crystacomm and AXT produce InP substrates. (No company, however, conducts significant internally funded R&D.) Hewlett-Packard, APA Optics, ATMI, and some universities conduct important III–N work. Cree, Northrop-Grumman, Litton-Airtron, ATMI, Sterling Semiconductor, and North Carolina State University fabricate SiC. NASA, NIST, LANL, Sandia, ANL, Lincoln Labs, AT&T, IBM, Westinghouse, Conductus, Superconductor Technologies, Dupont, and several universities have important HTS programs.

c. *S&T Investment Strategy*

The electronic materials subarea is directed toward the development of new materials and the improvement of existing materials intended for device applications. Device/component performance and reduced cost are the benchmarks of success. This subarea encompasses substrate development, epitaxial growth, dopant incorporation and control, control of interface abruptness and quality, bandgap engineering, and development of materials/device interfaces and structures. Materials development supports device development thrusts by providing quick turnaround of materials growth and characterization, the ability to tailor growth and processing techniques to optimize parameters, and the development of processing materials and techniques. Classes of interest include semiconductor, superconductor, ferro/ferrimagnetic, ferroelectric, and nonlinear optical materials.

(1) Technology Demonstrations. The electronic materials subarea is primarily an enabling technology. Upon optimization of materials and processes, the growth or processing technology is transitioned to device development projects and to industry for scale-up or commercialization. Thus, electronic materials technologies are "demonstrated" by successful transitions into the device/component community. For example, the electronic materials work being performed on wide bandgap semiconductors will allow the goals of DTO SE.71, Advanced Multifunction RF System Components, to be achieved.

(2) Technology Development. By targeting high-leverage technologies, notably materials technologies that have diverse electronic and electro-optic applications, this subarea anticipates the needs of the DoD electron device and component communities. Key areas of investment are summarized below.

Wide-Bandgap Electronic Materials Technology (DTO SE.39). The focus is on growth of large-area SiC substrates for high-power RF and high-temperature electronics; on use of (Al,Ga,In)N materials for these electronic applications; on producing and detecting green, blue, and UV light; and on creating field-emitting arrays. The III–N efforts include growth of lattice and thermally matched substrates (e.g., ZnO and Li aluminate as well as high-risk, high-payoff efforts to grow GaN as a substrate including both hydride vapor phase epitaxy and lateral epitaxial overgrowth) and also of films and heterostructures by organo-metallic chemical vapor deposition (OMCVD) and molecular beam epitaxy (MBE) techniques.

Intermediate bandgap III–V semiconductors efforts include development of advanced InP substrates; III–V films, heterostructures, and nanostructures grown on GaAs and InP substrates by OMCVD and MBE; and SiGe heterostructures for RF HBTs. GaAs-based materials development is being pursued because GaAs still dominates microwave electronics and because certain GaAs-based ternary alloys have been identified as candidates for high-speed applications. InP-based materials and InAs/GaSb/AlSb heterostructures are being developed for very high frequency/high data rate applications (300-GHz transistors are possible) and for possible displacement of GaAs in high-power or low-noise microwave applications. InP-based materials are, moreover, the mainstay of optoelectronics for telecommunications. Thus, they are being developed for optically implemented control functions (e.g., of radar antenna remoting and true time delay control of phased-array antennas) as well as for communications applications and opto-electric integrated circuits.

IR detector materials are being developed for applications that include IRFPAs for surveillance and night/all-weather operations. Films and structures based on InAs/GaSb superlattices (capable of detecting wavelengths >12 µm) and SiGe (for Schottky barrier devices) are being developed in pursuit of these goals. Work in the high-temperature superconductivity area emphasizes development of $YBa_2Cu_3O_7$ films and structures whose near-zero electrical resistance can be exploited to create extraordinarily narrowband filters and compact high-frequency, high-bandwidth antennas. Also under development are materials for mid-IR optical amplifiers and oscillators (e.g., for frequency-agile lasers), lasers, optical computing/storage, target identification, free-space optical interconnects, and optical data storage.

Patterning efforts include lithographic resists by self-assembled monolayers for creating device features <0.25 µm and proximal probe methods for nanoscale device patterning. Processing and equipment efforts, synergistically linked to semiconductor film/nanostructure deposition work described above, emphasize development and technology transfer of promising process technologies. Examples include the Desorption Mass Spectrometry feedback and the Linear Motion Oven for improving MBE yield; use of Sb surfactant, In pre-deposition, and flashoff in GaAs/InGaAs MBE growth; development and applications of a conical sputter source; and development and characterization of an OMCVD close-spaced reactor.

(3) Basic Research. Basic research opens up fruitful new areas of exploratory development. Consistent with electronic materials' character as an enabling technology, many 6.2 efforts are strongly coupled to basic research tasks. Basic research is employed to create the knowledge base undergirding the exploratory development efforts; exploratory development efforts help direct basic research along high-impact paths, and may also generate specific technologies that enhance research work. Specific basic research material efforts that will enable key technology development are atomic control of structures, investigation of new concepts for growth and patterning of nanoscale device structures, and materials tailored for multiple spectrum sensors and sources. Continued investigation of fundamental properties of wide-bandgap materials feeds directly into materials and device technology.

10. Electronics Integration Technology

a. *Warfighter Needs*

Many of the JWSTP areas require significant advancements in affordable high-performance electronics technology, a major challenge given the relatively small volume of specialized military parts needed compared to commercial production volumes. Specifically, miniaturized, power-efficient, reliable, high-performance circuitry is needed for Information Superiority, Precision Force, Joint Theater Ballistic Missile Defense, and Electronic Warfare. Today, the cost, performance, size, weight, power consumption, testability, reliability, and maintainability parameters of military systems must all be dealt with on an integrated basis.

b. *Overview*

The electronics integration technology (EIT) thrust is critical to all electronic equipment as it affects the performance, reliability, affordability, power generation, conditioning, and distribution for virtually every type of system, both military and commercial. The thrust includes:

- Integrated, distributed, and collaborative design environment technology; and modeling and simulation technology for computationally based acquisition of electronic systems.
- Test, reliability, and quality assurance tools, methods, and standards aimed at enabling comprehensive synthesis, design, and diagnostics from the individual transistor to the assembled multiboard system. (Due to funding cuts in the Air Force, work in

this sub-subarea has been virtually eliminated with only "pilot-light" efforts remaining in the other services.)

- Packaging and interconnect technologies for mixed-signal assemblies containing analog, digital, microwave, millimeter wave, and optoelectronic devices in conjunction with MEMS devices that will preserve device performance throughout an electronic system while increasing reliability and reducing size, weight, volume, and cost. DARPA's recent decision to change the emphasis of their packaging efforts toward supporting more specific application and demonstration programs has significantly reduced the technology development efforts in the packaging and interconnect sub-subarea. This will directly impact the realization of further integration of analog, digital, EO, and MEMS devices.
- Energy conversion and power generation, including advanced batteries and chargers, fuel cells, engine-driven generators, thermophotovoltaics, capacitors, and other direct-energy conversion technologies for manportable C^4I, soldier systems, communications equipment, sensors, combat service support applications, lightweight tactical operations centers, tactical power systems, and emergency power. A key new thrust is in integrated power management in order to combine these power sources with the most intelligent use of power to decrease weight and increase energy usage efficiency.
- Power control and distribution including power electronic building blocks (PEBBs), which will revolutionize the way electric power is produced, distributed, and used for land, air, and underwater vehicle propulsion; tactical power systems; electric weapons and vehicles; emergency power; silent power generation; smart munitions; manportable C^4I; and soldier systems.

(1) Goals and Timeframes. DoD efforts in this area particularly address the long-term thrusts for maintaining the "technology edge"; for reducing the size, weight, and power; and for improving the testability, affordability, and quality of electronics. Major goals are listed in Table VII–11. The impact of the thrusts in this area is pervasive through many of the technologies described in the DTAPs.

(2) Major Technical Challenges. The major challenges of designing the systems on silicon and the system of systems that are being demanded by our warfighters are to reduce the high cost of system design, the lengthy design times, and the pervasive occurrence of redesigns and overruns. This requires researching and developing technology and methodology solutions to alleviate the root causes of these problems. These include developing solutions for (1) managing the extremely high complexity of DoD electronic systems' design; (2) modeling and simulating hardware and software at the system level to provide a high level "virtual prototype" that can be shown to the warfighter before detailed design begins; (3) modeling, simulating, and verifying prior to manufacturing the RF components and the digital processing parts of the system; (4) lowering the time, cost, and errors associated with the analog/RF portion of the design through automated synthesis; (5) enabling geographically dispersed groups of specialists to collaborate on a given design; and (6) enabling the system developer to specify the requirements for and

Table VII–11. Electronics Integration Technology Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Integrate hardware description language simulation tools into a cooperative enterprise environment for collaborative, geographically distributed engineering. Demonstrate a prototype system for automatically synthesizing analog circuits from a hardware description language specification. A 10X improvement over manual method. Achieve 1-month MCM design cycle with 80–90% recurring cost reduction. (Typically 6 months to 1 month; $150,000 to $30,000.) Demonstrate a 50% increase in packaging density by using integrated passive components. Increase primary battery energy by 40% using $Li/Mn0_2$.
FY01	Turn over for standardization a system-level modeling and simulation language that also includes object-oriented coding capability for managing very complex designs. Demonstrate a hardware-description-language-based integrated design environment for analog and mixed signal systems on silicon. Turn over for standardization a system-level design language/representation for capturing, checking, tracing, and verifying a system's specifications and constraints. Develop GHz rate MCMs for affordable, mixed analog/digital subsystems. Demonstrate high-energy battery for soldier system: 1/2 size battery for SOF. Demonstrate digitally controlled vehicular power at 10% of the cost of current practice. Demonstrate a 10X increase in power density and 3X–5X in reliability and switching speed for PEBBs (typically on-card 5–10 W/in^3 to 50–100 W/in^3).
FY03	Develop the capability to simulate circuits in both the time domain and the frequency domain to allow both digital and RF circuits to be simulated together using a common hardware description language. Demonstrate 1–10-kW field power source: thin, conformal battery for soldier system.

constraints on the system in a concise formal manner (i.e., computer checkable for consistency and completeness and not use hundreds of pages of ambiguous English text) that are independent of whether they will be implemented in analog/digital or hardware/software technology.

By addressing these challenges, developers will support—via circuit and systems engineering tools and collaborative enterprise environments—what quality experts have been telling us to do for years to avoid project failures and overruns: Obtain complete, unambiguous, and traceable requirements and specifications; get the user involved early; use multidisciplinary teams; assure each designer is cognizant of the requirements and interfaces for the piece being designed and its effect on the rest of the system; use smaller, more manageable pieces and configuration control; and use the right tools for the job.

The next generation of multichip module (MCM) technologies must be developed for high-speed, mixed-signal circuits and increased levels of integration including MEMS devices and buried components in an effort to achieve additional sensor/signal processor miniaturization for the individual warfighter, satellites, autonomous vehicles, and ATR processors. New rechargeable batteries based on lithium-ion anodes and new types of nickel-based systems, combined with portable and mobile smart chargers, should significantly reduce training costs in C^4I applications and provide backup systems in future warfighting operations. Efficient electrocatalysts, and ultimately convenient fuel processing techniques, are key to 400-Wh/kg fuel cells where silent, portable power generation is required. Diesel-fueled mobile electromechanical systems are and will be the prime source of power generation in sizes about 2 kW. Improvements are required to reduce weight, improve efficiency, and reduce signatures. In addition, PEBB power quality (<3% total harmonic distortion), power density (50 kW/ft^3), and quiet operation must be achieved based on:

- Advanced engineering tools and methods.
- Interim products such as high-power MOS-controlled thyristors (MCTs) for megawatts rectification.
- High-efficiency (85%–90%), high-density (>200 W/in^3) power converters for control, sensor, and device electronics from the prime power to the multiple low-voltage-regulated load outputs, immune to the harsh electromagnetic interference (PEBB environment).
- Use of existing manufacturing infrastructure within the U.S. industrial capability in order to ensure commercial viability of the PEBB products.

The next generation Surface Combatant of the 21st century (SC–21) requires technology insertion of PEBBs to ensure affordability of future “force multiplier” weapon systems.

(3) Related Federal and Private Sector Efforts. Related to the design efforts are the visions expressed in the technology roadmaps developed by the Silicon Integration Initiative, a consortium of many of the key players in the government, Electronic Design Automation, and Semiconductor Industry Association communities. More detailed requirements for much of our research comes from the Electronic Design Automation Industry Council Project Technical Advisory Board and the Institute of Electrical and Electronics Engineers (IEEE) Design Automation Standards Committee’s Working Groups. There is also a close relationship with the large commercial electronic design automation industry. In order to complete the link to the warfighter, our research must be both a significant enhancement to and complementary to the capabilities currently offered commercially. This is because the design automation industry must want to pick up the new technology and offer it to the DoD information and weapon system developers. The commercialization of our R&D by industry must be done before there is a return on investment to DoD. The information obtained from other federal laboratories and DoD system developers plays a critical part in developing and evaluating electronic design technologies. Related electronic module/subsystem and packaging efforts include MCM development at Sandia National Laboratory and consortium efforts at the Microelectronics and Computer Technology Corporation and the Semiconductor Research Corporation. The IEEE Computer Society has established a study group under the Design Automation Technical Committee to begin standardization of fault model and simulation techniques and methodologies.

c. *S&T Investment Strategy*

The EIT subarea is directed at the exploitation of modern electronics to provide a competitive battlefield edge by investing in the development of an integrated design environment closely coupled to high-reliability technologies, advanced packaging and interconnect technologies for mixed signal assemblies, improved power generation and sources, and distributed power architectures. The technology efforts, developments, and demonstrations are designed using a strategy that capitalizes on U.S. industrial capabilities, with the overall objective of meeting present and future military system and subsystem cost and performance objectives. As a result of the long life cycle of military systems and reduced DoD budgets, this technology addresses both new and fielded systems. In the area of electronic design, concurrent strategies are being developed to (1) enhance the ability to deal with more complex designs; (2) automate analog design to a level comparable to digital design; (3) capture the requirements and specifications data needed in a form that lends itself to automated checking, automated design, and easy system enhancement; (4) simulate more of the pieces of the system working together and at higher levels of abstraction; and (5) allow for larger, multiorganizational teams to work together more effectively. The impact on DoD systems will be affordable, maintainable, and upgradable electronic systems with reduced redesigns and overruns.

In the areas of dependability, performance, and affordability, the strategy is aimed at achieving an order-of-magnitude increase in mean time between maintenance action, a tenfold reduction in unnecessary maintenance actions, and a 4X decrease in support cost. Design tools and built-in test methodologies are being produced that incorporate reliability technology at the earliest stages of system development. Efficient diagnostic methodologies to enable fault detection and isolation at the component, board, and system levels will be developed. These tools will be utilized by DoD and the commercial industrial base in the design, development, production, and maintenance of cost-effective, dependable systems that meet customer needs. The reliability activity has been deactivated by the Air Force with only a limited focused effort remaining by the Army and Navy in the area of GaAs microwave and millimeter-wave reliability and GaN and SiC technologies.

The growing need for increased functionality in mobile military systems requires the integration of mixed-mode digital, analog, microwave, millimeter-wave, electro-optical, and MEMS components. The strategy is to work closely with industry to develop low-volume access to high-volume commercial fabrication lines and to employ higher integration at both the chip and the packaging levels in an effort to preserve on-chip speeds within a factor of two throughout the subsystem. Advanced packaging approaches include using MCMs, 3D interconnect techniques, and chip-level protective coatings to eliminate expensive hermetic enclosures. These concepts will be applied to mixed-mode assemblies to permit the affordable, reliable assembly of various analog and digital device technologies on a common substrate along with opto-electronic and MEMS components**.** Even though commercial products are becoming more sophisticated, many military sensor and signal processing assemblies are required to operate over a wider temperature range and meet more stringent size, weight, and power requirements than are achievable by using COTS components and packaging approaches.

Significant military capabilities such as smart weapons, secure wireless communications, covert tags, individual soldier computers, navigation aides, and tactical information assistants will be enabled using affordable MCM capabilities. The strategy of the efforts in the areas of energy conversion and power generation is aimed at lightening the soldier’s burden by providing smaller, lightweight, environmentally compatible power sources with high-power and energy densities. This will include demonstration of superior low-cost primary and rechargeable batteries and other silent portable power sources as well as logistically acceptable sources of mobile tactical power such as generators, fuel cells, solar power converters, and other advanced energy conversion devices.

Finally, the strategy of the distributed power and control efforts is to develop standard power components or building blocks and an architecture that will provide high-quality, responsive power conversion at the point of load. This is the objective of the PEBB program. The

PEBB program is striving to revolutionize the way electric power is produced, distributed, and used. It will demonstrate a 10X improvement over the next 5 years (versus the 7X improvement that has occurred over the last 40 years), where improvement is the product of power density, switching speed, reliability, and cost. This effort will provide a system solution— low total harmonic distortion and quiet operation for shipboard systems—that replaces complex one-of-a-kind power electronic circuits with a single architecture that brings added value to the services in the form of reduced size, weight, and performance. For the DD–21, the projected improvements in power density afforded by PEBB will be 50 kW/ft^3 at a cost of $0.05/watt as compared to the present 36 kW/ft^3 at $3.00/watt.

(1) Technology Demonstrations. None.

(2) Technology Development. The technology efforts within the EIT subarea are viewed as critical to the affordability and performance of all new and currently fielded electronic equipment. These efforts are concerned with breakthroughs in CAE methods and tools, dependability and performance technology, advanced mixed-signal MCM technology, energy conversion and power generation technologies, and power control and distribution advancements including PEBBs for a more highly distributed power architecture. Over the past few years, DARPA has provided the majority of the funding for the technology developments in the EIT subarea; however, last year DARPA changed the emphasis of their packaging program. The focus of their future packaging work will be more application driven and will be included as a subset of the application development effort as opposed to being a standalone technology development effort. The conclusion of DARPA's packaging technology efforts and the services' programs last year are reported under DTO SE.66, Packaging and Interconnect for Multiple Technologies.

Design Technology for RF Front Ends (DTO SE.29). Although DTO SE.29 is not grouped under the EIT subarea, the design work included in the EIT subarea directly supports this DTO. Tools and processes are being developed for the rapid and efficient design of MMIC, multichip assemblies, and mixed-signal electronic subsystems. The overall goals are to drive down the cost of RF component and multichip module assembly development, enhance system portability, upgrade reliability, and reduce life-cycle costs. These goals will be accomplished with improved virtual prototyping, reduced design cycle time, improved tool integration, and behavioral modeling.

Energy Conversion/Power Generation (DTO SE.43). This DTO will demonstrate improved lightweight, low-cost, environmentally compatible power sources with high-power and -energy densities as well as provide the initial thrust in a the new area of integrated power management. This is aimed at combining the most effective power source with intelligent usage in order to reduce weight, improve efficiency, and reduce signatures. The goal is to decrease the weight of batteries by up to 50%, develop a 50-W portable fuel cell system, design a lightweight 5-kW diesel-powered engine–generator set that weighs about one-half (350 lb) of the present system, and develop initial versions of diesel-powered thermophotovoltaic power generators. These efforts will improve the deployability, tactical mobility, and effectiveness of a CONUS-based fighting force.

Power Control and Distribution (DTO SE.44). This DTO addresses advanced military platforms that are becoming "all electric" or "more electric" systems. To meet the challenging objectives in the generation, conversion, and distribution of electric power requires minimizing the cost, weight, and volume/size of power electronics, while maximizing performance (the product of current density, standoff/blocking voltage, and turnoff time or switching frequency). The approach will improve power device efficiency, circuit topologies, and thermal techniques and will develop a family of common power components. These advanced systems anticipate improvements of 10X in power density and 3X–5X in the reliability and switching speed for PEBBs over present conversion and distribution systems technology. The power control and distribution envelope must encompass commonality, performance (i.e., power density), affordability, maintainability, and dual-use applicability for efficient use of resources. This DTO will develop the technologies to revolutionize, through the use of PEBBs, the way electric power is produced, stored, distributed, and used. By using the U.S. industrial infrastructure for volume manufacturing, the projected cost reduction for both military and commercial applications will be achieved.

Packaging and Interconnect for Multiple Technologies (DTO SE.66) This DTO includes some of the work that was originally reported under DTO SE.24, Common RF Digital Modules, in the integrated platform subarea. Work included under DTO SE.66 addresses development of fabrication, protection, and assembly processes required for integrating digital, analog, microwave, and millimeter-wave signals into a single format. To realize the performance improvements at the subsystem level, advanced packaging approaches must be employed, including mixed-signal MCMs, chip-scale packaging, chip-on-board, and 3D interconnect techniques permitting extremely high-bandwidth operation.

Technologies being developed under the various sub-subareas of the EIT subarea also support the new cross-cutting DTO titled Integrated Compact Electronic Sensors and Components (DTO SE.70).

(3) Basic Research. Computer-aided, engineering-oriented research at the Computer Engineering Research Consortium of Ohio and within other universities ranges from individual "niche" tool development to unified environments for end-to-end electronic system development. Much research is currently being conducted in digital signal processor design systems, algorithms, architectures, and software systems. CAE tools for low-power electronic systems are also in research and development at the University of California, Berkley. Research is also being conducted to provide very high energy density portable power sources. Technologies being researched include zinc-air batteries and advanced hydrogen-based fuel cell architectures that use polymer-exchange membrane systems and new hydrogen storage mechanisms at locations such as the International Fuel Cell Corporation.

11. Terrestrial Environments

a. *Warfighter Needs*

The warfighter requires high-resolution geospatial information, terrain visualization technologies, and knowledge of climatic effects that collectively provide a relevant common picture of the battlespace to dominate maneuver, execute precision strike, protect the force, and win the information war. Battlespace domination will be achieved through all-weather, air–land–sea continuous operations based on superior knowledge of the terrain, weather impacts (on both friendly and enemy capabilities), and enhanced all-weather, day/night sensor performance. By providing terrain visualization capabilities, including physics-based environmental effects, commanders will be able to train as they intend to fight, execute mission planning and rehearsal within realistic constraints, and ultimately conduct superior military operations.

b. ***Overview***

The terrestrial environments (TE) subarea emphasizes characterization and modeling of the physical phenomena, processes, interactions, and effects associated with terrain and its surface/subsurface features at scales of interest to ground combat forces.

(1) Goals and Timeframes. The TE goals and timeframes are shown in Table VII–12.

(2) Major Technical Challenges. The major technical challenges include:

- Modeling the interaction among air, snow, frozen ground, and unfrozen soil layers to predict seismic and acoustic wave propagation.
- Developing a physics-based capability for predicting and visualizing the performance of multimode sensing systems over weather-affected complex terrain and land features.
- Using knowledge-based systems, inferencing techniques, and geostatistical interpolation to identify and attribute terrain features, both natural and manmade, within the enemy's decision cycle.
- Developing a total force positioning and navigational capability for the Army that is all weather, day/night, resistant to jamming, and operable in areas where GPS may not work such as buildings, canyons, and a triple canopy jungle.
- Achieving joint interoperability through the promulgation of standard, reusable, verified, and validated mapping, charting, and geodesy software.
- Generating dynamic, physics-based terrain and environments in near real time for distributed modeling and simulation, mission planning, and rehearsal.
- Exploiting and disseminating multiple scene/multiple sensor imagery and derived terrain and target information using high-speed digital networks.

(3) Related Federal and Private Sector Efforts. Other investment in TE research is relatively low because of the focus on warfighting needs.

c. ***S&T Investment Strategy***

Providing improved knowledge of the terrestrial environments encompasses varied requirements. The winter environment presents a severe challenge to not only the performance of materiel, but also its operability. Snow and frozen ground dramatically alter the propagation of acoustic and seismic energy. The infrared and millimeter wavelength signatures of terrain features change markedly with freezing and thawing. Icing may significantly change aircraft performance and impact communications capability. The ability to quantify and model these processes and their effects is essential to system design, test and evaluation, mission planning, and wargaming. Developmental efforts in the topographic sciences concentrate (1) on remote sensing, spectral characterization and analysis, rapid geospatial data generation, point positioning,

Table VII–12. Terrestrial Environments Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Demonstrate an integrated, dynamic IR/MMW/mechanical wave terrestrial background scene generation capability for synthetic environments. Develop image perspective transformation technology for use with imagery to rapidly evaluate sub-10-meter resolution terrain data and position reality. Demonstrate virtual-reality-based battlefield environments that place the soldier in an environment with replicated actual terrain and climate, creating a highly detailed realistic setting for training and mission planning/rehearsal. Create hyperspectral system capable of continuous day/night and poor visibility operations. Develop/test initial automated feature extraction capability for spectral imagery (roads, buildings, vegetation, and soils) and SAR, providing an additional 15% improvement in feature detail and 5% decrease in data extraction time. Incorporate automated feature extraction techniques from spectral, SAR, and electro-optical sources (roads, bridges, buildings, vegetation, and soils) into the DSPW, providing an additional 15% improvement in feature detail and 10% decrease in data extraction time. Develop/test initial automated feature attribution capability for roads, bridges, buildings, vegetation, and soils, based on terrain-reasoning software, providing an additional 15% improvement in feature detail and 10% decrease in data extraction time. Demonstrate initial automated feature extraction and attribution capability on the DSPW, providing an additional 15% increase in feature detail and 10% in data extraction time.
FY04	Demonstrate spatially distributed, physics-based, 3D ground state and weather effects in future distributed simulations. Develop multiscale/multiproduct geospatial data generation software capable of generating large integrated terrain databases at multiple levels of detail. Model IR/MMW winter background dynamics for predicting the performance of sensor systems over winter-impacted terrain. Model processes that affect seismic and acoustic signal characteristics in snow and frozen ground. Achieve realistic 3D visualization of winter ground state and weather effects on sensors. Increase operational capability in icing situations through avoidance or impact mitigation. Characterize performance and durability of advanced materials (composites) subjected to winter environments. Quantify impacts of winter environments on combat engineer activities for realistic training simulations.
FY09	Demonstrate knowledge-based systems for predicting the performance of multimode sensing systems (IR and MMW) over winter-impacted terrain. Demonstrate automated feature extraction and attribution capability. Develop virtual-reality-based battlefield environments capabilities that place the soldier in an environment with replicated actual terrain and climate, creating a highly detailed realistic setting for training and mission planning/rehearsal. Demonstrate spatially distributed, physics-based 3D ground state and weather effects in future distributed simulations. Develop multiscale, multiproduct geospatial data generation software capable of generating large integrated terrain databases at multiple levels of detail. Demonstrate knowledge-based systems for predicting the performance of multimode sensing systems (IR and MMW) over winter-impacted terrain. Develop automated feature extraction and attribution capability.

land navigation, surveying, environmental analysis; and (2) on the effects on tactical operations; interoperability of mapping, charting, and geodesy software; exploitation and dissemination of geospatial data; battlefield visualization; and distributed interactive modeling and simulation.

The TE subarea includes cold regions and topography. Research emphasizes techniques for the rapid generation of high-resolution geospatial information; improved capabilities for receiving, interpreting, and disseminating topographic imagery/data; and characterization and modeling of physical phenomena, processes, interactions, and effects associated with terrain and its surface or subsurface energy response at scales and frequencies of interest to ground combat forces. Accurate physics-based models provide realistic portrayals of the environments for combat simulations while also enhancing the all-weather performance of targeting and surveillance sensors. These technologies, along with improved positioning/navigation capabilities and digital communications, collectively enhance the warfighters' ability to dominate the battlespace through rapid exploitation of geospatial data and battlefield visualization. The terrestrial environments area will more fully exploit the data from radars (Section C1) and EO sensors (C2) and the planning and rehearsal of military missions. Research in the TE subarea supports the Rapid Battlefield Visualization ACTD and the MOUT ACTD and contributes to the development of the Synthetic Theater of War.

(1) Technology Demonstrations. *Rapid Terrain Visualization ACTD* (JWSTP Information Superiority DTO A.06). The RTV ACTD will demonstrate the technologies and infrastructure necessary to meet the Army requirement for rapid generation of digital topographic data to support emerging crisis or contingencies. These data sets will allow soldiers to "see" the roads, trees, hills, and waterways and visualize complex battlefield situations before the fight. They will enable commanders and their staffs to more effectively plan and rehearse missions, evaluate courses of action, and maintain situational awareness using 2D and dynamic 3D displays.

(2) Technology Development. TE emphasizes characterization and the modeling of the physical phenomena, processes, interactions, and effects associated with terrain and its surface/subsurface features at scales of interest to ground combat forces. Developments will significantly impact military operations by providing decisionmakers with superior and accurate information about the terrestrial environments in a timely manner. Technologies in this subarea provide the capability to generate, process, analyze, manage, and disseminate TE information for dominant maneuver and information superiority and will provide greater realism in winter terrain visualization, increased reliability of surveillance and targeting by sensors, more accurate predictions of icing impacts on aviation and communications, and improved knowledge of advanced materials' suitability for Army materiel under all weather conditions. Technology developments in the TE subarea will interact with the RTV ACTD (above).

Hyperspectral Applications Technology (DTO SE.67). The objective of this DTO is to develop and demonstrate hyperspectral imaging technology from air and space platforms for two promising domains of defense applications: (1) battlespace environment characterization of both the terrestrial and the littoral ocean environments, and (2) tactical target detection, characterization, and identification.

Rapid Mapping Technology (DTO SE.68). The objective of this DTO is to provide the capability to rapidly extract and properly attribute features of importance to the warfighter, with focus on the high-resolution-feature data requirement. Integrated, automated, geospatial feature generation and attribution software will be developed. Feature data will be generated and attributed from a variety of disparate sources. The software ensures that multi-imagery formats, varying scale, spatial and thematic accuracy, temporal data, and high-resolution and -density data are integrated.

(3) Basic Research. The requirement for terrestrial environments research stems from the impact that the terrain and the environment have on virtually all aspects of military ground activity. The modern power projection military force must be able to perform at full capability throughout the world, in operational theaters that may range from equatorial to polar latitudes, and in terrain that may vary from coastal beach and lowlands to deserts and mountains. In the 21st century, detailed information will be required regarding terrain conditions along with a sophisticated capability for terrain information collection, processing, analysis, visualization, and dissemination. There is an important need for an improved ability to understand terrain and utilize terrain information for military operations in order to lessen the impacts of terrain and environmental conditions, particularly in areas of climatic extremes. Research in this area comprises both field studies and laboratory research related to the acquisition, analysis, interpretation, and modeling of information about terrain and terrain behavior under different climatic conditions. Research on terrain characteristics, dynamics, and effects is aimed at enhancing the current capability to interpret and utilize remotely sensed elevation and feature information at a variety of scales.

12. Ocean Battlespace Environments

a. *Warfighter Needs*

The warfighter needs an affordable, reliable operational capability in all environments and the ability to foresee environmental changes that may affect his capabilities. The variable ocean environment greatly affects warfighter operations, such as movement of equipment and supplies over the beach, torpedo targeting, or aircraft carrier operations; it also affects the performance of the sensors and systems used by the warfighter. Knowledge of this environment and its impact on the various sensors available to the warfighter is critical to the choice of sensor(s), ability to gain knowledge of the tactical battlespace, and effective delivery of weapons. Knowledge of the ocean battlespace environment is important to the JWSTP areas of Information Superiority, Precision Force, Combat Identification, Force Projection/Dominant Maneuver, Joint Theater Missile Defense, and Joint Readiness and Logistics and Sustainment of Strategic Systems. These needs translate to the requirements for understanding processes and phenomenology; measurements and mapping; nowcasts and forecasts of ocean variability; and translation of environmental effects to their impacts on sensors, platforms, structures, and operations. The products in this subarea are designed to increase the warfighter's knowledge of his battlespace environment. The goal is to unclutter his tactical picture, provide him tools to decide on tactics, and give him an advantage over his opponent through exploitation of environmental variability. A recent major thrust area is "environmental adaptability," meaning systems and tactics that exploit real-time environmental conditions with minimal hands-on activity.

b. *Overview*

(1) Goals and Timeframes. Anticipated conflicts encompassing the ocean battlespace environment involve increasing emphasis on mine, special, and amphibious warfare in addition to continuing concerns with antisubmarine warfare. Thus, emphasis is increasing on the coastal, shallow, and semi-enclosed sea areas where the ability to predict and simulate the spatial and temporal variability of the environment is a formidable challenge. The fundamental goal is sufficient understanding of the environment's effects on weapons, tactics, and operations, coupled with affordable technologies to observe, describe, and predict those effects. A complementary underlying goal is to encourage and aid the design and use of naval systems that are able to exploit environmental variability to military advantage. Anticipated goals are reflected in Table VII–13. Advances in understanding the ocean environment are critical for the design of new acoustic, optical, and electromagnetic sensors; signal analysis; and command and control.

Table VII–13. Ocean Battlespace Environments Subarea Goals and Timeframes

Fiscal Year	Goal
FY01	First range-dependent, on-scene, adaptive-weapon, frequency-acoustic propagation model. 3D turbulence model for localized sediment scour in real time. 1/8 degree North Pacific Oceanographic Prediction System.
FY06	Remote in situ autonomous coastal sensing system. Autonomous sea floor mapping system. Full-spectrum noise model for ASW and mine countermeasure frequency bands.

(2) Major Technical Challenges. Past efforts have been predicated on the construction of databases supplemented by limited onsite information and have been aided by large-scale predictive models driven by large-scale observational programs. As the warfighter's needs move from the open sea to the littoral, the battlespace shrinks in size but expands in complexity and rapidity of change. To respond, the S&T community related to the ocean battlespace environment continues to develop models for forecasts and to move toward the use of models as tools to interpolate and extrapolate sparse observations. The goal is to extract maximal information from available and disparate observations. The challenges are:

- Very high resolution current, wave, surf, and tidal forecasting models coupled to atmospheric models for support of operations in shallow water.
- Measurements and models of physical and biological processes that impact acoustic, optical, and electromagnetic propagation at surveillance and weapons frequencies.
- Models of fluid-sediment interaction relevant to mine burial.
- Specialized sensing systems for ocean processes in shallow water.
- Remote sea floor mapping capabilities.
- Models of the ocean environmental effects on acoustics, optics, and electromagnetics such that environmentally adaptive signal processing can be developed (in cooperation with acoustic and other programs) to enhance clutter rejection and improve target detection.
- Joint service efforts with warfare system developers to quantify the impact of environmental characteristics on warfare systems and operations.

(3) Related Federal and Private Sector Efforts. With the exception of coastal engineering, industry investments are small. Federal S&T is this area has been supported for many years by

NOAA, NSF, USGS, MMS, NASA, and DOE; none of these non-DoD programs are aimed at warfighter requirements, especially if those requirements involve non-U.S. waters.

c. *S&T Investment Strategy*

Successful battlespace environment products only occasionally result in formal, large-scale acquisition programs. Many, however, result in a small number of software applications resident on just one or only a few DoD computers (e.g., a super computer at the Fleet Numerical Meteorology and Oceanography Center). Thus, the S&T transition and investment strategies have evolved to respond to the specific needs of a few specific customers. Issues such as affordability are not always critical since the major costs are, for example, in the first (and sometimes *only*) copy of some ocean forecasting software. Affordability mainly applies in the acquisition of ocean data through measurement and monitoring and the consequent construction of databases. As computing power moves from a few central sites to an on-scene distributed system, however, affordability rises in importance.

The ocean battlespace environment covers the domain from the bottom of the ocean to and including its surface and from deep water to the beach, including the waves breaking on the beach and the consequent modifications of the beach. The range of scales covered extends from fully global, transoceanic scales (10,000 km) down to the scale at which small eddies erode the bottom and bury mines (<1 m), and extends further to the scales of turbulence and of particulate and biological matter that scatter high-frequency sound and limit optical transmission in the water. This is at least 10 orders of magnitude in spatial scales, accompanied by at least 8 orders of magnitude in temporal scales; thus, this is the fundamental 4D observational and numerical computing problem that drives the costs and technological difficulties of the area.

Seven distinct program elements (two in 6.1, the rest in 6.2 and higher) support the efforts, supplemented by partial funding from, and cooperative efforts with, many other program elements. The programs in this area include the scientific disciplines of oceanography, ocean geophysics and geology, hydrodynamic and sediment processes, and environmental aspects of ocean acoustics, which are linked to the *Basic Research Plan*. The ocean battlespace environments are divided into four technology thrusts for addressing warfighter requirements: models and forecasts, sensors and data, small-scale ocean processes and applications, and cooperative (performance and funding) efforts with other programs.

Ocean Models and Forecasts. This thrust covers global to littoral scales (about 1 km), with primary emphasis on support of undersea warfare, secondary emphasis on amphibious and strike warfare, and joint logistics over the shore. Developments in this thrust will primarily support the following JWSTP areas: Information Superiority, Joint Readiness and Logistics and Sustainment of Strategic Systems, Force Projection/Dominant Maneuver, Precision Force, Joint Theater Missile Defense, and Combat Identification. The primary technology topics are:

- Global models for regional boundary conditions.
- Regional models for littoral boundary conditions.
- Littoral models supporting ASW and other coastal operations.
- Relocatable, nested models.
- Wave models for shallow and coastal waters.
- Onboard models using real-time data.

Sensors and Data. This thrust covers all scales and warfare areas, but concentrates on regional and smaller scales at which traditional instrumentation is less effective. It focuses on deployable, affordable measurements and monitoring for real-time input to on-scene models and environmental characterizations. Also included are concerns with the movement of data between locations, the design and construction of databases, and data fusion. These topics are usually pursued jointly with other programs. Developments in this thrust will primarily support efforts in the following JWSTP areas: Information Superiority, Force Projection/Dominant Maneuver, and Combat Identification. The primary technology areas are:

- Use of organic fleet sensors.
- Adaptive/conditional sampling.
- Autonomous networks.
- Expendable and remote observational techniques.

Small-Scale Oceanography. This thrust covers littoral scales down to 1 meter and smaller, with primary emphasis on support of mine warfare and secondary emphasis on amphibious warfare (AMW) and ASW. Developments in this thrust will primarily be relevant to the Force Projection/Dominant Maneuver and Precision Force areas of the JWSTP. The primary technology topics are:

- Measurement, monitoring, and analysis of all significant natural phenomena related to acoustic, optical, and electromagnetic detection/classification of mines.
- Integration of real-time, small-scale data with historical data sets.
- Understanding of effects of the small-scale environment on systems and operations.
- Prediction of changes in the small-scale environment.

Cooperative Programs. This thrust covers all ocean scales but concentrates on the ASW and mine warfare (MIW) areas; consequently, developments under this thrust will primarily serve the following JWSTP areas: Information Superiority, Force Projection/Dominant Maneuver, and Combat Identification. Due to the necessity for the various DTAP areas and subareas to work together, not just coordinate, the ocean battlespace environment has designated a major thrust specifically to work with other DTAP subareas. This is equivalent to interprogram-element cooperation in the performance of activities. The general objectives are to identify, for all warfare areas, the most critical environmental factors to be dealt with and to provide that critical information when, and in the form, needed with the overriding long-term objective to more rapidly transition products and methodologies to partnering program elements.

(1) Technology Demonstrations. There are no specific ocean battlespace environment technology demonstrations at the present time. However, S&T developed under this subarea was used in the now-completed DTO G.04, Joint Countermine ACTD, involving the Navy, Marine Corps, and Army, and is being used in SE.60, Underwater Acoustic Communications, involving only the Navy. In general, S&T developed in this subarea establishes the basic environmental understanding upon which many system developments and tactics rely.

(2) Technology Development. *Forecast of Littoral Currents and Waves* (DTO SE.45). This program aims to improve forecast capability for the small-scale currents and waves in the littoral coastal areas. The accurate characterization and forecast of the surf, coastal ocean currents, and waves are important to contingency planning, operational planning, and execution of a number of joint warfighter operations in the littoral environment. This program will establish capabilities important to the Information Superiority and Joint Readiness and Logistics and Sustainment of Strategic Systems areas of the JWSTP.

Autonomous Ocean Sampling Network: Mapping of Ocean Fields (DTO SE.47). Using an autonomous underwater vehicle (AUV), real-time ocean and bathymetric data that are necessary for MIW, AMW, and ASW operations will be acquired. Of great significance is the ability of AUVs to conduct ocean sampling in a covert manner, especially in those littoral operations where military interest must remain concealed but where environmental data are necessary prior to the operation. Capabilities established here will be of special relevance to the Force Projection/Dominant Maneuver and Information Superiority areas of the JWSTP.

The ocean environments are inherently international. Most observational systems, databases, and numerical models span national boundaries, and even limited-scale local and regional activities have their analogs in other locations and must take into account their surroundings. All the major nations have ocean S&T technology activities, and significant cooperation takes place in the basic research arena, with some very useful cooperation in the applied research related to coastal oceanography. Were it not for these international coastal activities, the current U.S. capability in surface wave forecasting, for example, would be quite poor and would not come close to meeting today's requirements, much less tomorrow's. Many of our coastal circulation, wave, and sediment movement models are developed in close cooperation with the Dutch, the Germans, and the British. International coordination of international work in the ocean battlespace environments comes through both scientific bodies (such as the International Association for the Physical Sciences of the Ocean, and the Scientific Committee on Oceanic Research) and governmental bodies (such as the Intergovernmental Oceanographic Commission of UNESCO). The SACLANT Undersea Research Centre in La Spezia, Italy, acts as a very useful focal point for activities in ocean acoustics, and the International Field Offices (in London and Tokyo) of the Office of Naval Research provide considerable coordination and aid.

(3) Basic Research. Numerous basic research programs in both the Navy and the Army are in direct support of these technology efforts. Notably, the Army's efforts in surface wave prediction have critical application to the Navy and Marine Corps. The Navy programs in the areas of physical oceanography, remote sensing, coastal dynamics, geology and geophysics, oceanic biology, underwater acoustics, and the associated observations, databases, and models are key to enabling the development of the modeling and measuring techniques discussed above. Examples of research programs today that may provide the critical underpinning for tomorrow's applications include topics in nonlinear systems and chaos theory, aerosols, nested models for tactical scale predictions, multisensor data assimilation, and nonrandom distributions of biological sources of optical scattering.

13. Lower Atmosphere Environments

a. *Warfighter Needs*

The nature of conflict has evolved to highly localized, intense but short-lived battles involving the use of high-tech weaponry. This, in turn, has shifted the focus of lower atmosphere environments support to the warfighter. This shift emphasizes the need for battlespace awareness products in greater detail—spatially and temporally—than were ever required in the strategically driven cold war. The increasing use of weapons, intelligence, and surveillance systems operating at EO and microwave frequencies places greater dependence on information on the radiative and physical characteristics of the lower atmosphere.

As a result, the warfighter needs knowledge of the lower atmosphere environment, its dynamics, and its impact on sensor and weapon systems. Therefore, lower atmosphere environment emphasis is on specifying and forecasting atmospheric conditions such as temperature, pressure, rainfall, humidity, wind direction and velocity, cloud cover, acoustic and electromagnetic transmissions, and visibility—all of which directly affect the warfighter’s ability to see and operate ships, aircraft, ground vehicles, and most weapons and surveillance systems. This drives the need for weather sensing, analysis, prediction, and tailored application approaches that represent more completely the physical processes unfolding in the Earth’s measurable atmosphere. Achieving this requirement demands a capability to continuously observe or monitor the battlespace in 3D using remote and in situ sensors operating on space, ground, and air (manned and unmanned) platforms. The changing role of U.S. forces toward a reactive force available for deployment to small-scale conflicts anywhere on the globe requires that this monitoring capability be available around the world on extremely short notice.

As was demonstrated in Operation Desert Storm, weather was the major cause of aborted strike missions, causing 40% of ordnance to be unused over targets and greatly compromising battle damage assessment. Increased knowledge, quality, and timeframe of forecasts are needed to ensure that operations occur successfully, with reduced casualties and decreased costs, in system development and asset utilization. A unique DoD need is provision of operational support in data-sparse and data-denied areas. Emphasis must be placed on the development of tailored weather decision aids and on the simulation of weather elements in support of system acquisition, training, and wargaming.

b. *Overview*

(1) Goals and Timeframes. Lower atmosphere environment emphasis is to provide tactical-scale atmospheric specifications and forecasts on a global basis; develop the real-time tools to assess the environment and its effects on system performance and operations; and develop the techniques of atmospheric measurement, analysis, and prediction with seamless, global, continuous coverage. The application of these technologies in the natural environment will result in measurement, monitoring, and prediction systems that will be truly full spectrum, providing the real-time capability to support air, land, and sea operations across the battlespace. Better understanding of the lower atmosphere and its dynamics is critical to radar (Section C1), EO sensors (C2), ATR (C4), electro-optics technology (C7), and command and control for mission planning. The goals of this area are shown in Table VII–14.

(2) Major Technical Challenges. A multisensor/multiscale approach is required in order to provide localized, on-scene weather information at tactical-scale spatial resolution. Data assimilation, fusion, quality control, and interpretation techniques for new sensor systems and “through the sensor” data need to be incorporated. Models must be physically complete in order to account for the complex interactions within the air–sea–land system (including aerosols, clouds, ice, waves, and biosphere). The primary technical barrier to comprehensive tactical

Table VII–14. Lower Atmosphere Environments Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	Demonstrate software prototype of night vision goggles with performance capable of 75% prediction accuracy. Deliver automated weather analysis system for shipboard and battlefield applications, reducing forecast time by 5X.
FY01	Assimilate all-source data, including satellite radiance and aerosols, into on-scene prediction systems. Transition tactical targeting EO simulator to AF Mission Planning System, introducing the capability to specify detailed scenes based on spectral response of the weapon system.
FY04	Demonstrate interoperability of verified/validated Unified Battlescale Weather and Battlescale Atmospheric Effects Models for Force XXI situation awareness, mission planning, and training. Transition through-the-sensor refractivity observation techniques.

decision aids (TDAs) is expanding computer codes to fully account for the environment and its interaction with system performance via physically based models that execute efficiently on transportable computers.

(3) Related Federal and Private Sector Efforts. NSF, NOAA, NASA, and FAA participate in lower atmosphere environment S&T. Their efforts are coordinated with those of DoD through the Office of the Federal Coordinator for Meteorology. There is a clear distinction between the work described here that focuses on battlespace applications and the R&D in the broader civilian meteorological community. There is only a very small industrial base in this area.

c. *S&T Investment Strategy*

The long-term goal of this subarea is to evolve a worldwide theater-level battlespace weather awareness system that can be activated on short notice anytime warfighter requirements dictate.

In executing the lower atmosphere environments subarea, focus is maintained on joint service weather requirements and capabilities. The challenges are to provide current battlespace weather information (natural and manmade) on a global basis, predict battlespace weather information out to 2 weeks, and provide tailored TDAs for all weather-sensitive systems. Meeting these challenges will require the development of revolutionary new on-scene and remote sensors; data acquisition, data integration, and quality control systems; battlescale analysis and prediction capability; and AI technology for atmospheric product management. Specifically, DTO SE.52 is providing technology support (weather impact decision aids) to JWSTP Information Superiority DTO A.07, Battlefield Awareness and Data Dissemination ACTD.

Technology advances in all constituent areas of atmospheric science and target signatures are required to achieve the lower atmosphere environment goals. Key thrusts include new ways to observe and predict atmospheric parameters on theater space and time scales, data fusion techniques, improved knowledge of boundary layer physics and explicit cloud processes leading to improved numerical weather prediction models, and tailored application methods in support of specific weapon systems. The focus in this program is on atmospheric measurements, prediction, simulation, and development of system-specific, tailored weather decision aids.

(1) Technology Demonstrations. None.

(2) Technology Development. *Weather/Atmospheric Impacts on Sensor Systems* (DTO SE.52). The objectives of this program are to develop and validate models and algorithms that use atmospheric measurements or forecasts to define the impact of the environment on specific combat systems and operations. A common requirement of combat systems is knowledge of the propagation of electromagnetic energy at the required wavelengths (visible to microwave regions) with substantially increased spectral resolutions to support emerging hyperspectral and ultraspectral systems.

On-Scene Weather Sensing and Prediction Capability (DTO SE.53). The objectives of this program are to develop local, regional, and global atmospheric sensing and prediction systems that describe and forecast battlespace environment parameters to support the increased use of sophisticated environment-sensitive battlespace surveillance, communications, and weaponry assets for mission planning; ship, aircraft, and ground vehicles movement; logistics; and strategic and tactical operations.

(3) Basic Research. Advances in basic research critical to the technology developments in this subarea are detailed in Section 3.8 of the *Basic Research Plan.* It is directed toward understanding the basic physical processes relevant to extended forecasting models for:

- Directly diagnosing critical meteorological parameters for battle regions (cloud ceilings, bases, and tops; precipitation intensities; visibility; icing; and turbulence).
- Developing improved algorithms to exploit new satellite multispectral sounders and imagers for cloud, water vapor, and temperature retrieval providing greater vertical resolution than currently available.
- Developing microphysical models to characterize cloud, aerosol, and low-level moisture properties that impact DoD systems and operations.
- Understanding the turbulent nature of the atmosphere over water, littoral regions, and complex land surfaces.
- Understanding of how energy is exchanged between the surface of the Earth and the lowest layers of the atmosphere, with particular emphasis on the evolution of cloud systems and the marine atmospheric boundary layer.

14. Space/Upper Atmosphere Environments

a. *Warfighter Needs*

Information superiority relative to the space/upper atmosphere environment is required in order to maintain control of the “high ground” during all levels of engagement. Inadequate knowledge of the space environment, in which and through which DoD must operate, jeopardizes the safety and effectiveness of warfighting units. At the same time, the possibility that the enemy is using electronic warfare places a high demand on DoD systems to distinguish hostile actions from naturally occurring events and to respond accordingly. The increased specification, mitigation, and exploitation techniques associated with the space/upper atmosphere environment subarea goals will be major contributors to Information Superiority, Joint Theater Missile Defense, Electronic Warfare technology, and Protection of Space Assets areas.

The key objectives are to provide the warfighter with superior knowledge, tactics, and capabilities. Recognized communications deficiencies in warfighter engagements in Panama, Bosnia, and the Persian Gulf have identified the need for improved C^3I battlespace specifications. Requirements for C^3I specifications are now an integral part of the concept of operations for GPS and AFSATCOM. Improved filter specifications and clutter-suppression algorithms are needed to optimize the performance of military satellite surveillance systems, specifically the SBIRS. Overall, the increased military dependence on space operations makes it imperative that DoD space systems function reliably irrespective of natural space environment disturbances. The approaching solar maximum 2000–2001 may lead to significant adverse operational impacts unless precautionary measures are undertaken. The objectives of the space/upper atmosphere environment subarea, once satisfied, will provide the warfighter with superior capabilities to assess and exploit the space and upper atmosphere environments.

b. ***Overview***

Because DoD is committed to using space assets in the future for such important mission areas as communication, navigation, and surveillance, it is necessary to accumulate a detailed knowledge of the space environments and how these impact the performance of typical DoD systems that must operate there in continuous, reliable service. Many measurements have been made of the space environment; however, few measurements are available to DoD on a real-time continuous basis. The impulsive, dynamic, often disruptive nature of the space environments must be measured in a standardized, disciplined manner that parallels weather measurements made in our lower atmosphere by meteorological services throughout the world. The long-term goal of this subarea is to operationally deploy a series of validated space environmental models that will provide DoD with accurate, reliable predictions by FY07.

(1) Goals and Timeframes. The technologies developed within this subarea are directed toward specifying and exploiting those space and upper atmosphere environmental conditions that limit the effectiveness of military systems. The goals and timelines (Table VII–15) have been specified within existing fiscal constraints to demonstrate that warfighter information superiority in this subarea results in dominant warfighting capabilities. Understanding the steady-state

Table VII–15. Space/Upper Atmosphere Environments Subarea Goals and Timeframes

Fiscal Year	Goal
FY99	75% improvement in localized communications connectivity specification for the Mid East region. 25% improvement in IR sensor accuracy for atmospheric, cloud, and terrain backgrounds. 100% decrease (elimination) of spacecraft charging hazards using charge control techniques.
FY01	80% improvement in prediction accuracy of C^3 outages using space-based sensor system. 50% improvement in target–image reconstruction using clutter suppression techniques. 25% decrease in technology insertion time for new space power systems.
FY03	95% improvement in global C^3I specification by fusing ground and space data. 80% improvement in radar target geolocation and target–image reconstruction. 95% increase in satellite anomaly prediction and space environmental mitigation.

conditions and the dynamics of the space and upper atmosphere environment are critical for the design and operation of DoD space systems, military communication networks, and IR target signatures/surveillance imaging.

(2) Major Technical Challenges. The theoretical foundations of the space and upper atmosphere environments have steadily progressed since the mid 1970s due to the availability of scientific data from DoD, civil, and foreign sources. For example, we know that space disturbances that adversely affect military operations in and through space are caused by environmental effects such as ionospheric density fluctuations, atmospheric composition variations, and space charged-particle radiation. However, the availability of in-space monitors of the near-Earth space environment is limited, and we are required to use "space weather data" that happen to be available rather than measurements of the specific space effect that we know to be the causative force. As a result, realistic predictions of the space environment are essentially nonexistent, and warfighter support is limited to using predictions based on statistics or climatology.

Current efforts must be geared to obtaining the necessary space environmental measurements on a continuous and timely basis and to incorporate these measurements into real-time assimilation models based on first principles. Improved forecast capability will be achieved through the development of coupled basic physics models of the solar, space, and upper atmosphere environments and on better knowledge of spacecraft–environmental interactions. Specific technology development areas include advanced space environmental modeling and monitoring, atmospheric transmission and IR background phenomenology, and dynamic models of vehicle interactions with space plasmas.

(3) Related Federal and Private Sector Efforts. NASA, NOAA, and NSF are involved with DoD in a strategy to achieve, within the next 10 years, a system to provide timely, accurate, and reliable space environment observations, specifications, and forecasts. Included in this strategy is support to the space/upper atmosphere environment for specifying, predicting, and mitigating the adverse space environmental effects on military space systems. The National Space Weather Program operates under the auspices of the Office of the Federal Coordinator for Meteorological Services and Supporting Research. Agency roles and missions specify that DoD is responsible for developing and transitioning first-principles models of the near-Earth space environment for operational utility.

c. *S&T Investment Strategy*

Three major thrusts are focused on assessing space environmentals impacts on DoD operations: ionospheric effects, optical effects, and space effects. The first thrust has within it a technology demonstration having the near-term goal of validating the approach and providing a residual operational capability, as described in the JWSTP Information Superiority DTO A.13, Satellite C^3I/Navigation Signals Propagation Technology.

The second and third thrusts are more appropriately considered as technology developments and have within them several near-term goals that are captured within DTOs SE.55 and SE.56 technologies. Overall investment in these areas include demonstrations of space and atmospheric environmental models and of space environmental sensors. These investments will provide DoD with unparalleled capabilities to specify and predict space environmental impacts on warfighting systems. Specifically, DTO SE.56 is providing technology support (IR background characterization) to JWSTP Joint Theater Missile Defense DTO D.05, Advanced Space Surveillance; and DTO SE.55 provides identification and warning of natural space anomalies support to several JWSTP DTOs that rely upon an uninterupted flow of information from operational spacecraft, such as Information Superiority DTO A.13. Furthermore, these investments benefit DoD in areas such as improved radar target geolocation and target detection and tracking for Advanced Radar Processing From Airborne Platforms (DTO SE.03), interpreting signals and images important to ATR for Reconnaissance and Surveillance (DTO SE.20), and Multifunction EO Sensors and Signal Processing (DTO SE.06).

(1) Technology Demonstrations. None.

(2) Technology Development. Technology advances in the following constituent areas are required to fully achieve the goals of the space/upper atmosphere environmental programs.

Satellite IR Surveillance Systems Backgrounds (DTO SE.56). Technology developments within this DTO are for developing scene-depiction modeling and simulation tools that correctly specify spatial structure in atmospheric, cloud, and terrain radiance backgrounds. Currently, these technology developments are focused to support space-based surveillance and threat warning systems such as SBIRS.

Space Radiation Mitigation for Satellite Operations (DTO SE.55). Technology developments under this DTO are to establish the causal relationship between the space radiation environment and (1) satellite anomalies, (2) space-systems degradation, and (3) systems failure; develop techniques and instrumentation that mitigate the adverse effects of space radiation; and enable warning capabilities for potentially deleterious satellite operations. Currently, these technologies are focused to support all space-based military systems.

(3) Basic Research. As noted in Subsection 14b(2) above, the major challenges for the space/upper atmosphere environments subarea are the lack of an adequate number of spaceborne instruments measuring and reporting in real time the various space environmental effects that are known to cause problems to DoD operations and a unified theoretical foundation for developing predictive models of the near-Earth space environment. The fundamental knowledge for understanding how the energy flows from the Sun, through the magnetosphere, into the ionosphere and upper atmosphere is incomplete and must be obtained before truly accurate and timely predictions of the space effects on DoD assets can be possible. It is this energy flow within the space and upper atmosphere environment that manifests itself in increased ionospheric disturbances on military communications and navigation, large variations in atmospheric densities that affect IR optical transmissivity, and enhanced space-charged particle fluxes that affect satellite operations. The basic research programs must provide this fundamental understanding.