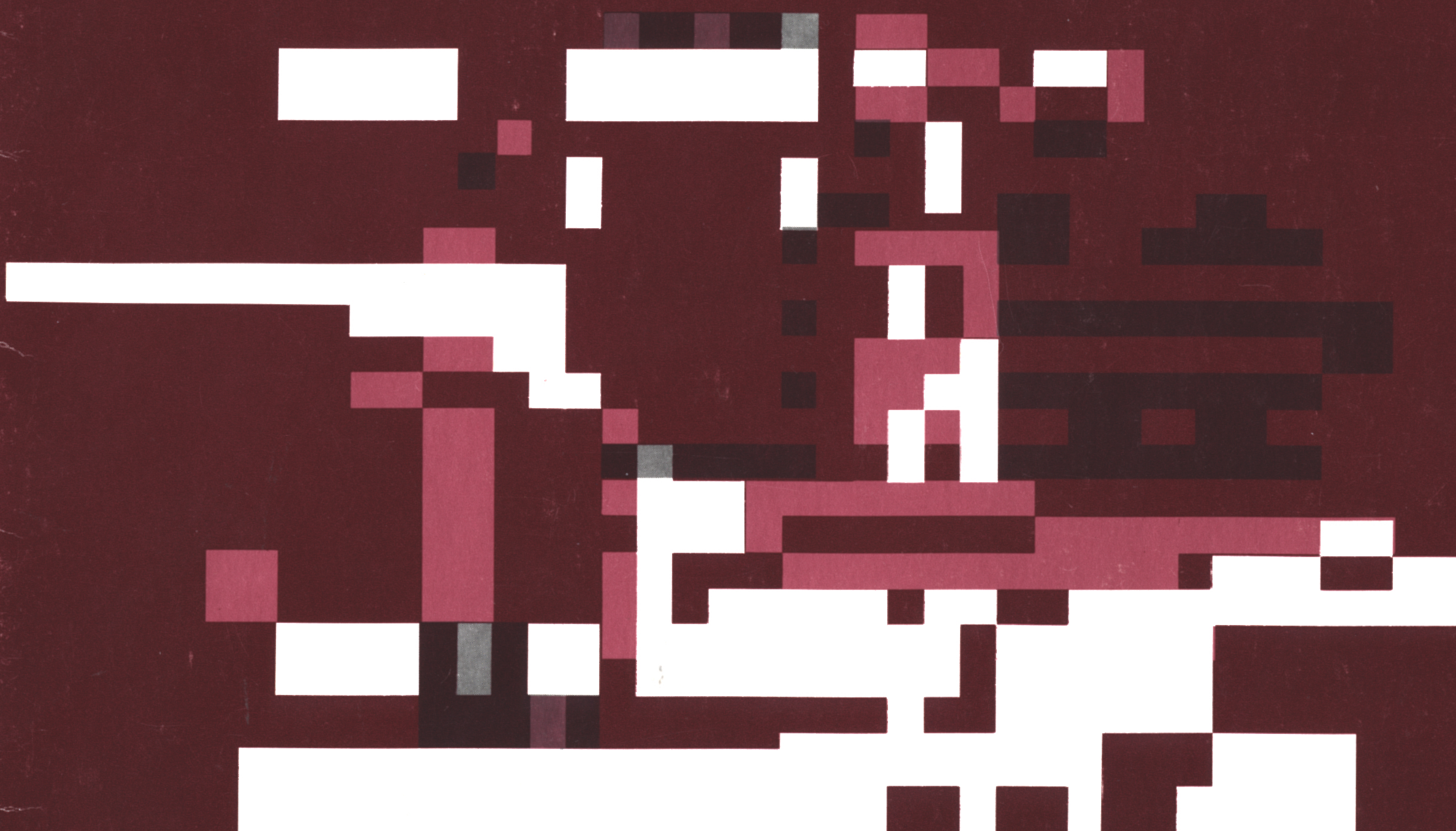
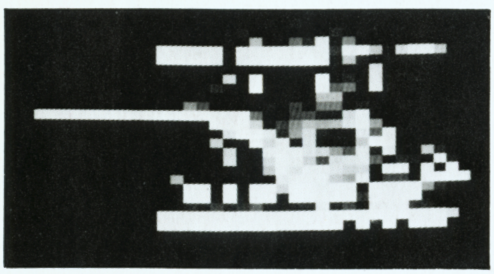
RADAR AND INSTRUMENTATION LABORATORY



ENGINEERING EXPERIMENT STATION/GEORGIA INSTITUTE OF TECHNOLOGY
the University System of Georgia

PLEASE NOTE

The Engineering Experiment Station has changed its name to the Georgia Tech Research Institute.



Researchers in the Radar and Instrumentation Laboratory can simulate predicted radar images of military vehicles like the tank depicted on this booklet's cover.

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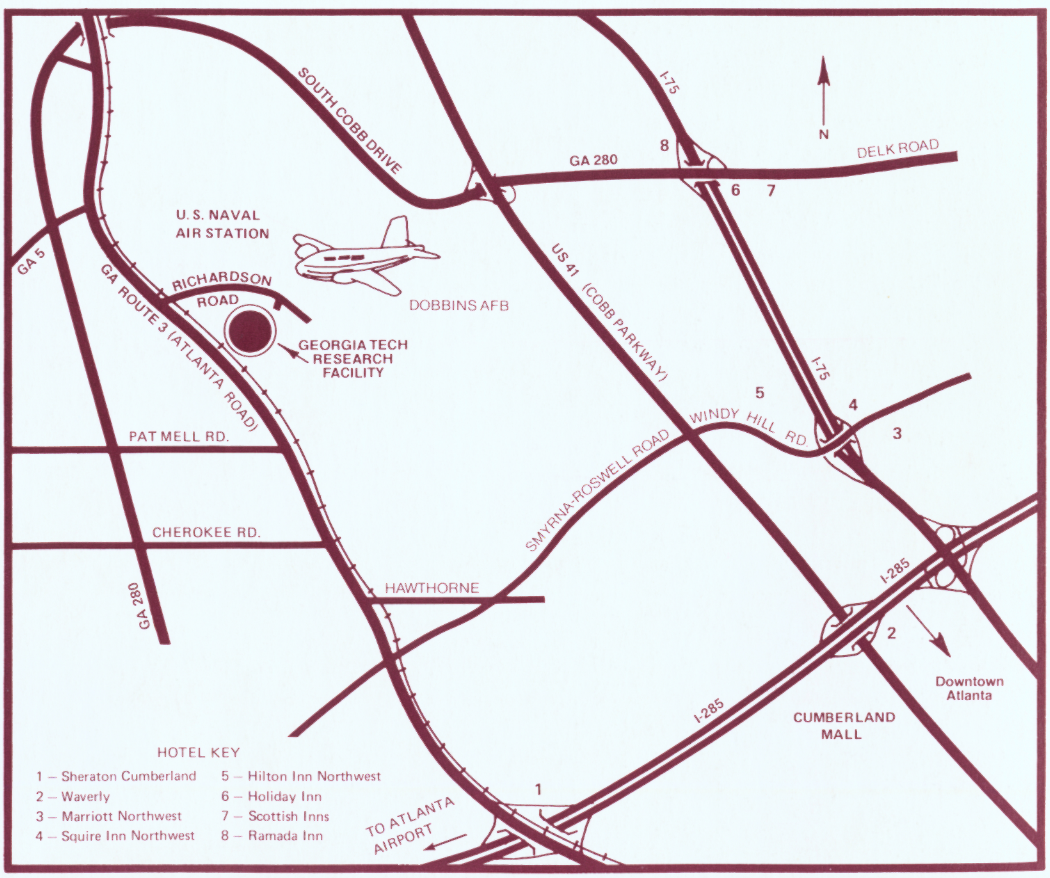
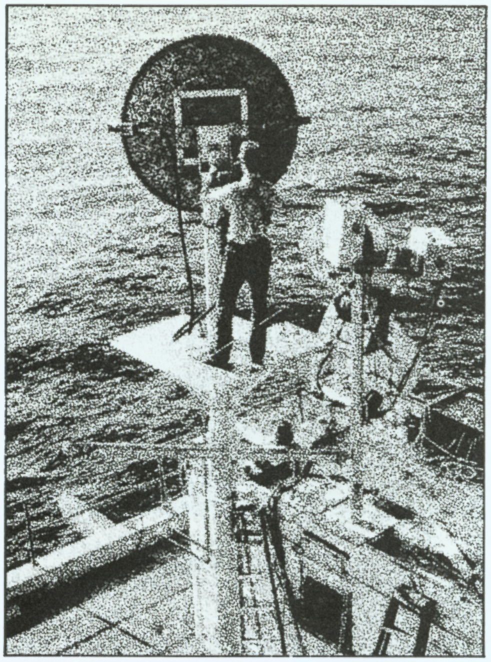




RAIL
THE DIVERSE RADAR LABORATORY

The Radar and Instrumentation Laboratory (RAIL) was formed in March of 1977 as an outgrowth of the extensive radar experience at Georgia Tech's Engineering Experiment Station (EES). Since then, the laboratory has continued as a part of the Station while expanding rapidly to meet the technology challenges of the 1980's.

RAIL capabilities span the following areas:

- Research — to provide a broad base of fundamental information and to discover new phenomena that may be exploited to expand the existing radar technology base.
- Development — to extend the radar technology base necessary for advanced systems by identifying problems, determining alternative solutions and testing innovative combinations of technological building blocks.
- System engineering — to transform operational needs into system performance parameters and preferred system configurations.
- Studies and analyses — to acquire, organize and evaluate data and to make substantive contributions to planning, programming and decision-making.

People are the primary resource of RAIL. The laboratory staff of full-time professionals is well-balanced in terms of education and experience. RAIL's immediate staff is complemented by professionals from other laboratories within the Station and the teaching faculty of Georgia Tech to provide expertise in most fields of science and engineering.

An extensive array of equipment, computers and laboratory facilities is available to RAIL researchers for conducting experiments, automated analysis and design, and developing and demonstrating advanced system feasibility.

RAIL is organized into five working units. The Instrumentation and Measurements Division is primarily responsible for experimental investigations to measure microwave and millimeter wave characteristics of tactical targets and their environments, analysis and evaluation of experimental data, and synthesis and development of advanced instrumentation equipment. The Analysis Division is engaged in synthesizing signal processing techniques that exploit identifiable radar signature characteristics to enhance target discrimination and classification, system level development and analysis, fiber optic applications, and laser radar research.

Radar system engineering and prototype development with emphasis on terminal guidance and millimeter technology and applications are the responsibility of the Development Division. The Modeling and Simulation Division investigates electromagnetic wave propagation phenomena and formulates techniques to exploit these phenomena, develops detailed electromagnetic scattering models, and investigates signature modification technology and radar cross section reduction. Finally, the Special Projects Office provides RAIL with the specialized administrative capability to organize and manage large diverse research projects which require support from all divisions.

Ground-based, portable, airborne, missile seeker, and shipborne radar systems for government and industry are the focal points of research performed by RAIL. A staff of professionals located on the Georgia Tech campus and the nearby Cobb County Research Facility is actively involved in the study, analysis, design, development and evaluation of multipurpose radar systems.

For many years, Georgia Tech operated a permanent radar field site at Boca Raton, Florida, for the U.S. Navy. In recent years, mobile and semipermanent sites have been used more extensively within the United States and abroad. Field operations have been conducted at St. Croix, Virgin Islands; Molokai, Hawaii; Baffin Island, Canada; and Graffenwohr, Germany.

Georgia Tech's capabilities in radar research and development have grown substantially over the past 25 years, and RAIL has been an integral part of that development. RAIL projects sponsored by the Department of Defense, other federal agencies and private industry have resulted in significant contributions in radar systems and technology in a host of radar-related fields.

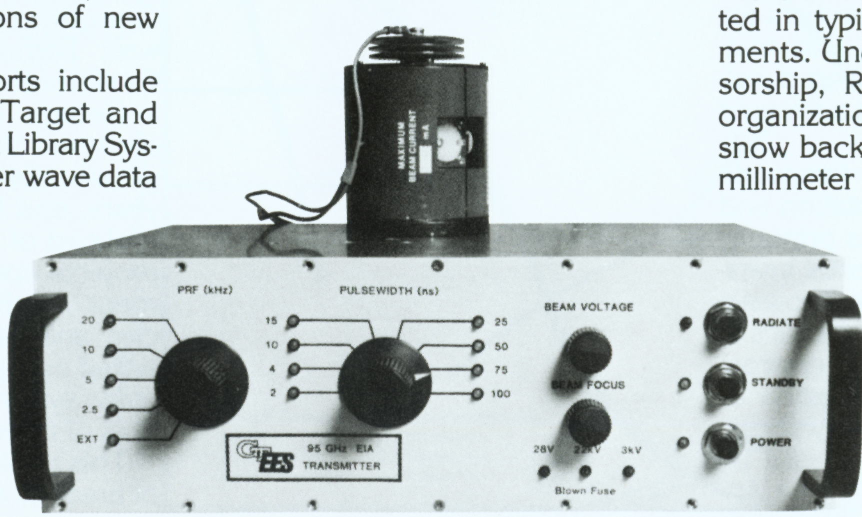
This booklet highlights a number of areas of achievement.

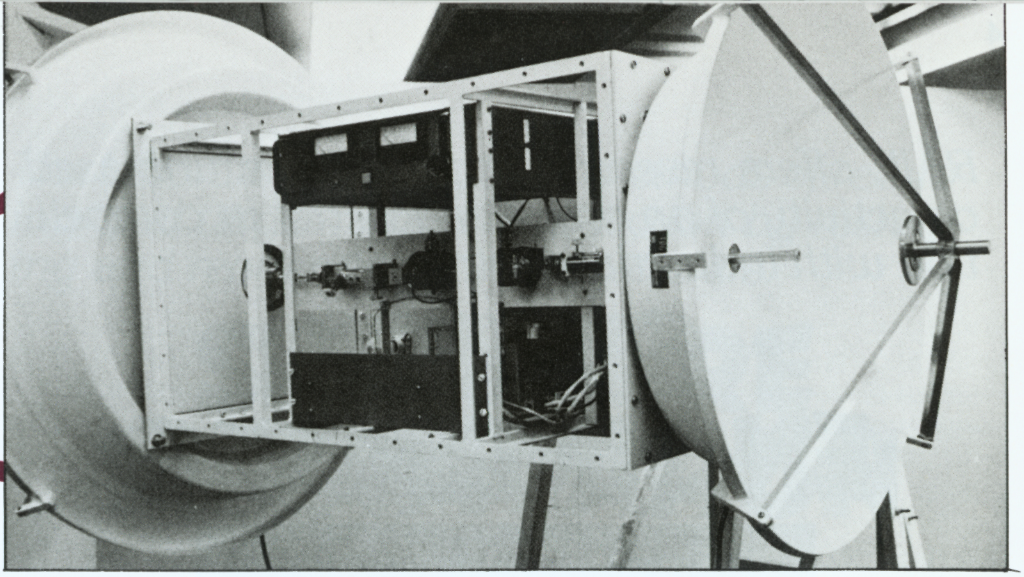
MILLIMETER WAVE TECHNOLOGY

Advances in component technology have supported a rapid increase in millimeter wave research for military applications over the past decade. Continued development of this region of the electromagnetic spectrum is now a high priority for the Department of Defense. Through sponsored and inhouse research activities, RAIL has established a full spectrum development capability ranging from 35 to 220 GHz. Current programs span all research phases of millimeter wave R&D, including systems analysis, signature characterization, modeling and simulation, hardware development and fabrication, and feasibility demonstrations of new concepts.

System analysis efforts include use of the Air Force Target and Background Information Library System (TABILS) millimeter wave data base to identify terrain features that a tank commander should exploit to minimize the probability of detection and successful attack by enemy millimeter wave precision guided munitions. Under contract to Standard Elektrik Lorenz in West Germany, RAIL analyzed the applicability of millimeter wave technology to remotely piloted vehicles (RPVs). RAIL also has analyzed the effectiveness and efficiency of using a millimeter wave "interrogator" and a variety of "reply" techniques in a cooperative Battlefield Identification Friend or Foe (BIFF) system to identify a friendly target.

RAIL has extensive experience in measuring and modeling millimeter wave target signatures for characterization/exploitation, particularly for air-to-surface sensor applications. One important area of capability is characterization of various types of millimeter wave ground clutter. One of the most severe clutter types is frozen snow, which can exhibit wide variation in backscatter characteristics. A single patch of snow/ice could include adjacent areas of extremely high and very low backscatter at the same time; these factors make stationary target detection and classification even more difficult than normally expected in typical high clutter environments. Under U.S. Air Force sponsorship, RAIL was the first R&D organization to document such snow backscatter characteristics at millimeter wave frequencies. This





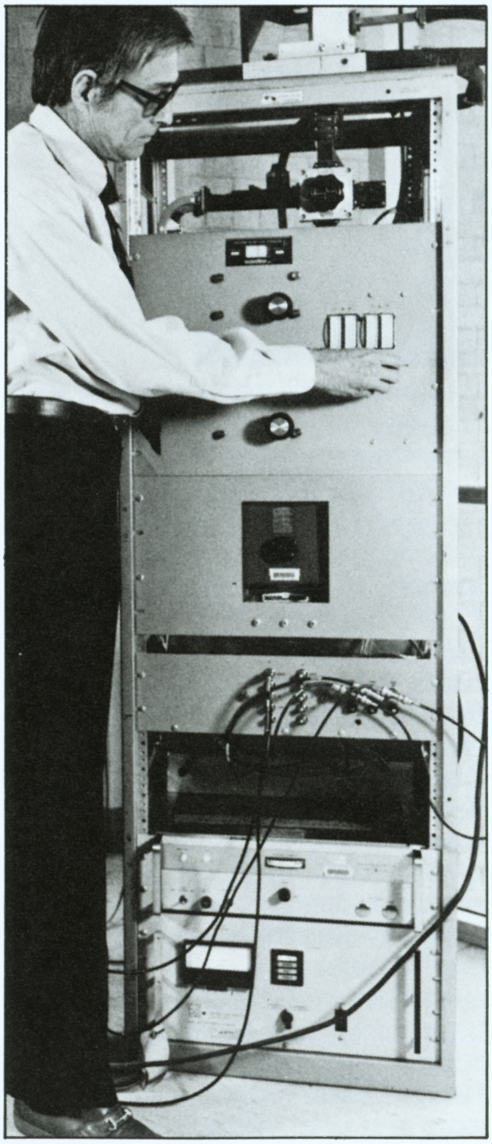
program has resulted in a much better understanding of the techniques which can be utilized to detect stationary targets in a snow-covered background.

Radar signature exploitation programs have stressed both frequency and polarization agility as either individual or complementary means for enhancing the distinctive characteristics of various types of stationary targets. For moving targets, the unique Doppler characteristics of various vehicles also have been exploited for target classification purposes.

RAIL has made important advances in transmitter technology over the past several years. Solid state sources, klystrons and travelling wave tubes have been used in transmitter designs for various radar and electronic countermeasure hardware development programs. Expertise in the design and development of millimeter wave transmitters employing extended interaction amplifiers (EIAs) and extended interaction oscillators (EIOs) has gained national recognition for RAIL. As an example, criteria have been established for reliable design and development of compact 95 GHz transmitters with pulse widths as short as a few nanoseconds when operating at a pulse repetition frequency of 20 kHz and a peak power in excess of 1 kW.

RAIL developed one of the first high power 95 GHz transmitters for advanced attack aircraft. This unit was integrated into an airborne pod configuration in support of the Aeronautical Systems Division's Tactical Avionics for Low Level Navigation and Strike (TALONS) program. Under study is the utility of millimeter wave radars for various adverse weather avionics applications such as terrain avoidance and following, ground mapping, and target acquisition and tracking.

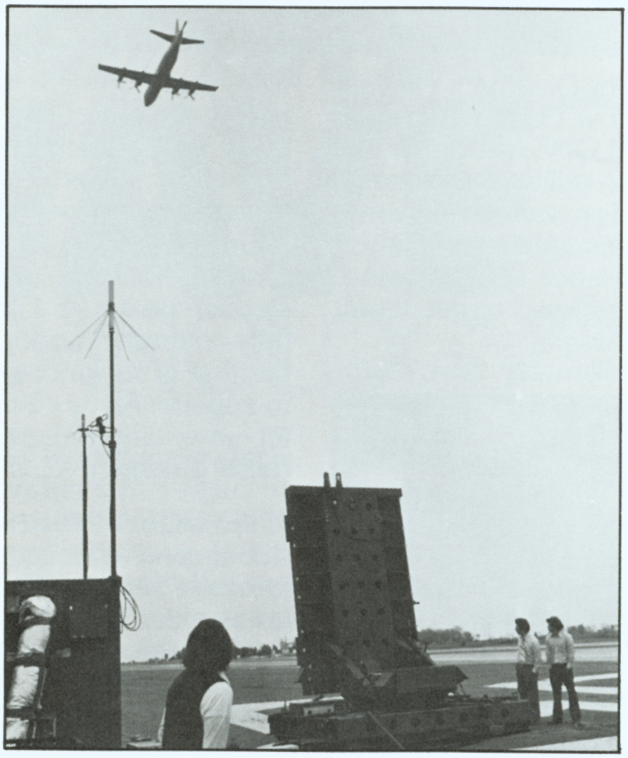
Although millimeter wave hardware development programs primarily have focused on radar systems and associated instrumentation at 35, 95 and 220 GHz, RAIL recently developed a 140 GHz instrumentation radar for signature characterization/exploitation. A state-of-the-art 95 GHz high-power, fully-coherent monopulse radar — the first of its kind — is being built to support Army advanced millimeter wave target acquisition and terminal guidance R&D.

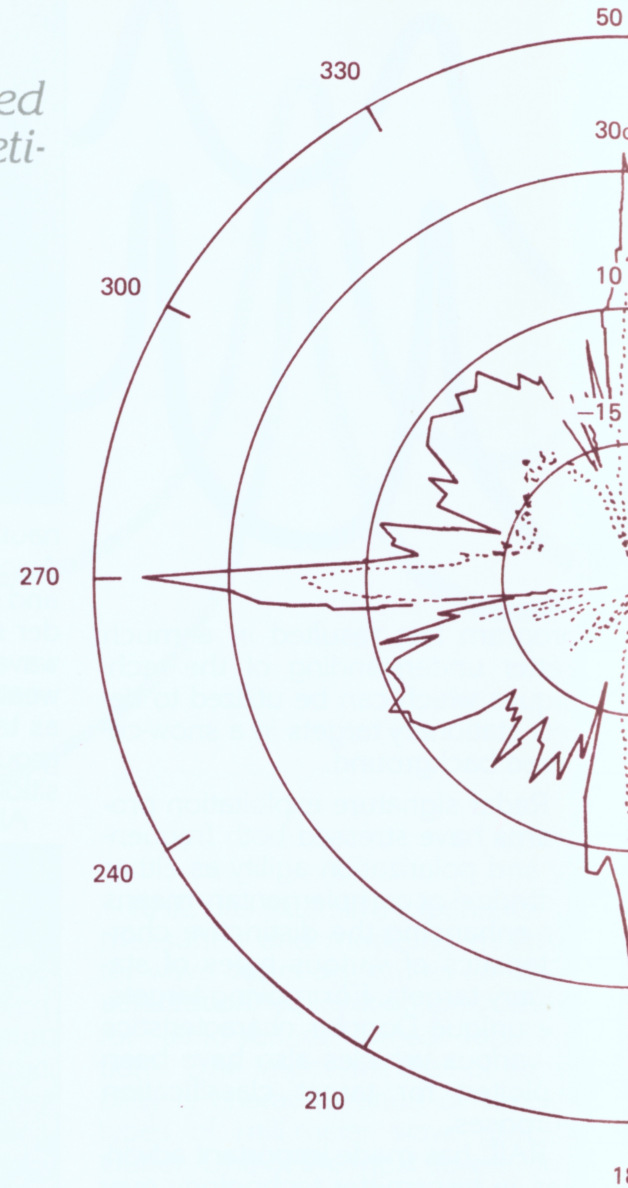


PHOTOGRAPHS: (Page 2) RAIL developed this totally self-contained short pulse 95 GHz radar transmitter, capable of producing a two nanosecond pulse of 1kW peak power at 95 GHz. (Page 3) Below: RAIL currently is researching the applicability of Intrapulse Polarization Agile Radar (IPAR) techniques for target discrimination, classification and identification at millimeter wavelengths. Shown here is the RAIL X-band IPAR prototype which was used to initially demonstrate this unique polarization modulation concept. Above: RAIL designed this dual-band millimeter wave illuminator to support Air Force evaluation of airborne millimeter wave electronic warfare receivers.

RAIL offers research sponsors the unbiased objectivity of an organization not in competition with industrial contractors.

SYSTEM ENGINEERING





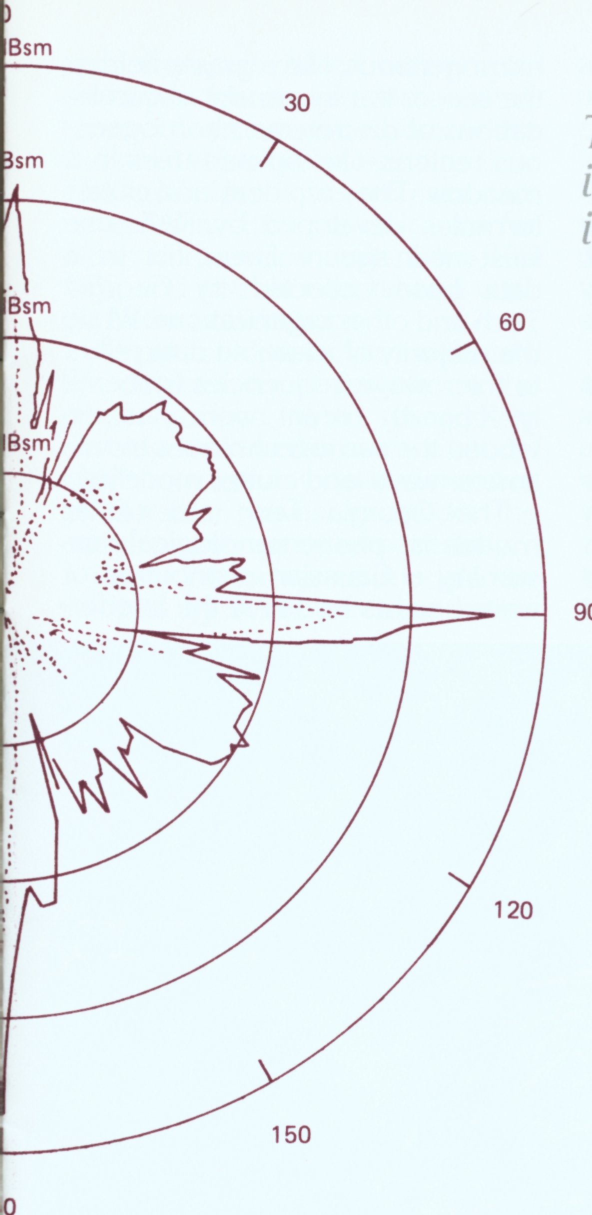
The conceptual design of a radar system is dictated by its mission requirements: target detection/tracking performance, environmental conditions, geometry considerations, and target types. Georgia Tech has developed various computational tools to quantify radar system performance as a function of these separate parameters, including a detection range and tracking accuracy program called MERGE.

RAIL analyzed a lower cost variant of the Sergeant York weapons system for detecting fixed wing and rotary wing aircraft for General Electric. A candidate domestic radar system was identified, and the detection performance of a suitably modified system was calculated for a variety of radar, environment, geometry, and target parameters. Performance limitations were thereby determined, permitting an iterative process of radar system modifications to meet mission operational requirements.

The laboratory conducted performance and cost-benefit analyses of several new radar system configurations designed to improve the AN/APS-94F of the OV-1B (Mohawk) surveillance system. The Mohawk currently has a fixed, side-looking airborne radar (SLAR), but can be modified to scan electronically, considerably reducing flying time and increasing information return.

RAIL defined the capabilities of several radar units of the Marine Air Traffic Control and Landing System (MATCALS) which will be used to control air traffic at expeditionary air bases. MATCALS incorporates an Airport Surveillance Radar (ASR), Radar Beacon System, and Precision Approach Radar (PAR). RAIL personnel analyzed radar and beacon requirements for MATCALS and participated in tests at the Patuxent River Naval Air Station in Maryland.

PHOTOGRAPHS: (Left) RAIL helped to define capabilities of radars in the Marine Air Traffic Control and Landing System (MATCALS). (Center) An example of the predicted radar cross section reduction of a target by shaping and use of radar absorbent material (RAM). (Right) RAIL engineers compare predicted signatures with measured data for model validation.



The laboratory has studied methods of reducing total target radar cross section by reshaping and reorienting major scatterers.

SIGNATURE MODIFICATION

Development of increasingly sophisticated hostile detection systems that threaten the effectiveness of U.S. military systems has focused attention on methods of increasing the survivability of U.S. military equipment by reducing its detectability.

Target signature models and computer programs that model the reflectivity of multi-layered flat plates and cylinders have been combined for cost-effective evaluation of RCS reduction (RCSR) techniques. Expensive prototype construction is reserved for the most promising RCSR configurations. A recently developed multilayer radome provides a very low RCS at design frequencies, while passing the operating frequencies with little loss.

More complex targets such as aircraft and ships are represented as collections of basic target elements, and thus the dominant sources of target echo can be isolated. Methods of reducing total target RCS by reshaping or reorienting major scatterers or by covering them with radar absorbent material (RAM) have been investigated. Other research areas concentrate on the determination of material properties of RAM samples using admittance tunnel and compact range measurement facilities. The Georgia Tech admittance tunnel is capable of measuring the sheet admittance, or equivalently the sheet impedance, of a variety of materials. A thin sheet of the material is placed over an aperture in the tunnel and illuminated by a plane wave travelling down the tunnel toward the aperture. The phase and amplitude of the reflected wave are recorded using a CW reflectometer while a metal shorting plate moves away from the aperture on the outside of the tunnel. The material properties can then be computed using a variety of methods.

The compact range is capable of making far field RCS measurements on targets four feet and smaller from S-band to Ku-band. A parabolic reflector provides a plane wave. A CW reflectometer nulls the background signal and records the target RCS. The range may be used to measure the RCS of standard and low cross section designs, scale models, radar absorbent material (RAM), and for some material property measurements.

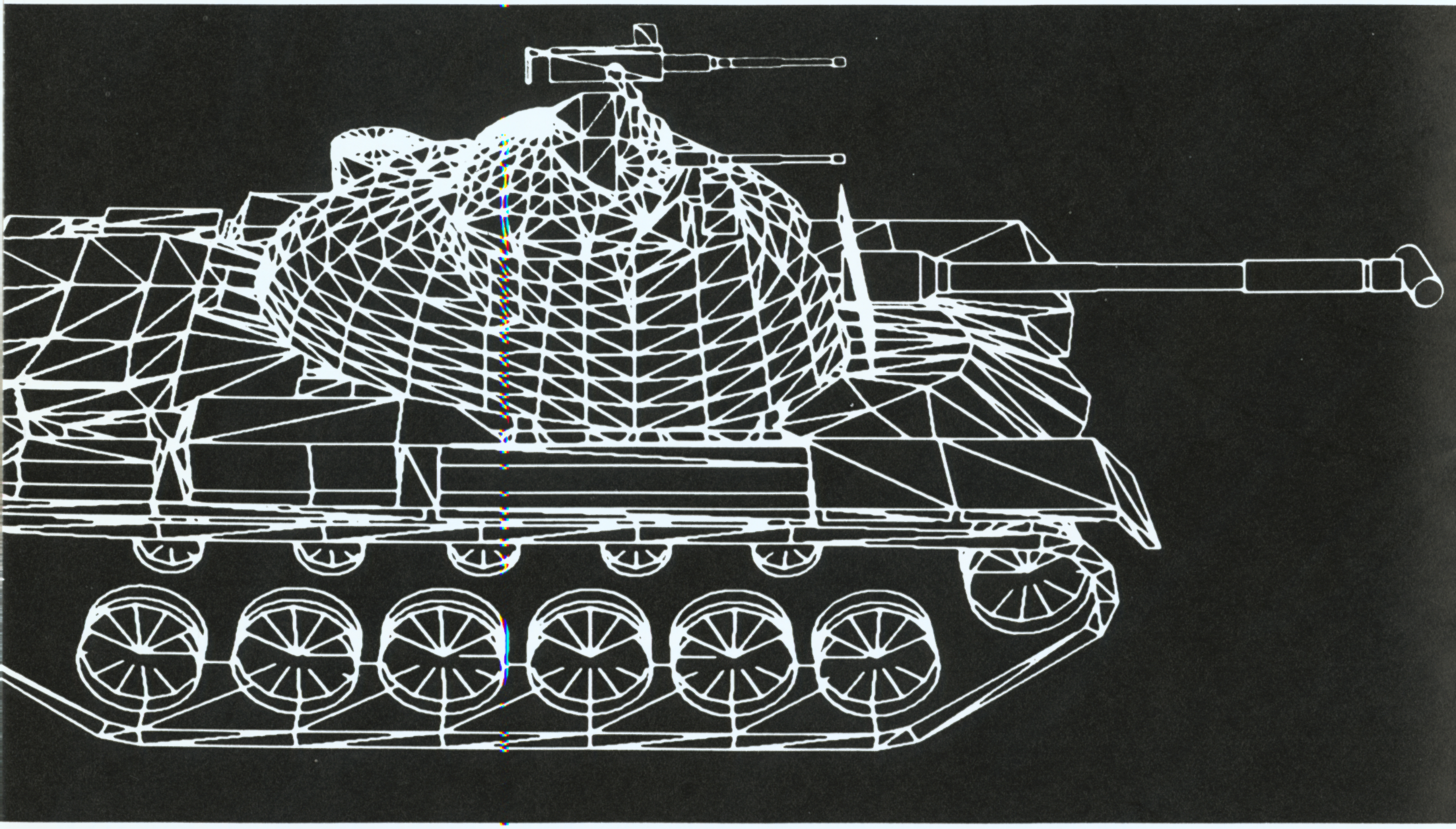
The RCS of several military land vehicles with and without RCSR camouflage nets was recently measured for the U.S. Army MERADCOM to evaluate the effectiveness of such nets.

RAIL contributes substantially to the study of electromagnetic propagation phenomena. A thorough knowledge of propagation theory and a broad experimental background have allowed RAIL engineers to develop computer models relevant to all stages of radar system design and evaluation.

Detailed models have been developed for predicting target and clutter reflectivity characteristics. Extended targets are represented by finite element models composed of simple geometric shapes (flat plates, cone frusta, ellipsoids, dihedrals, and trihedrals). The shapes are defined so that relatively simple exact or asymptotic solutions to the physical optics integral can be formulated for each individual scatterer. The physical theory of diffraction (PTD) is employed to find the backscatter from straight edges in a near field formulation. Total target radar cross section (RCS) is then found as the phasor sum of the individual scatterer contributions. Curved earth effects, specular and diffuse multipath, and target motion are included in the models.

Radar targets such as tanks or ships are not viewed by a radar in isolation; they are seen in a given environment or background. The background may be extensive and homogeneous, like a grassy field or the sea, or it may consist of combinations of discrete and homogeneous regions, like isolated trees in a meadow. The empirical land clutter formulas developed by RAIL use least-mean-square linear fits to a data base collected by Georgia Tech and other organizations. While the majority of available data refers to microwave frequencies (generally X-band), recent work has extended the same techniques to millimeter wave land clutter modeling.

The Georgia Tech sea clutter model is phenomenological, assuming a Gaussian distribution of wave heights to derive the interfer-



MODELING & SIMULATION

ence term, combined with empirical dependencies of sea backscatter on other sea state parameters like wind velocity and sea direction. The model predicts mean sea clutter cross section per unit area for radar frequencies from 1 to 100 GHz, and both horizontal and vertical linear polarizations.

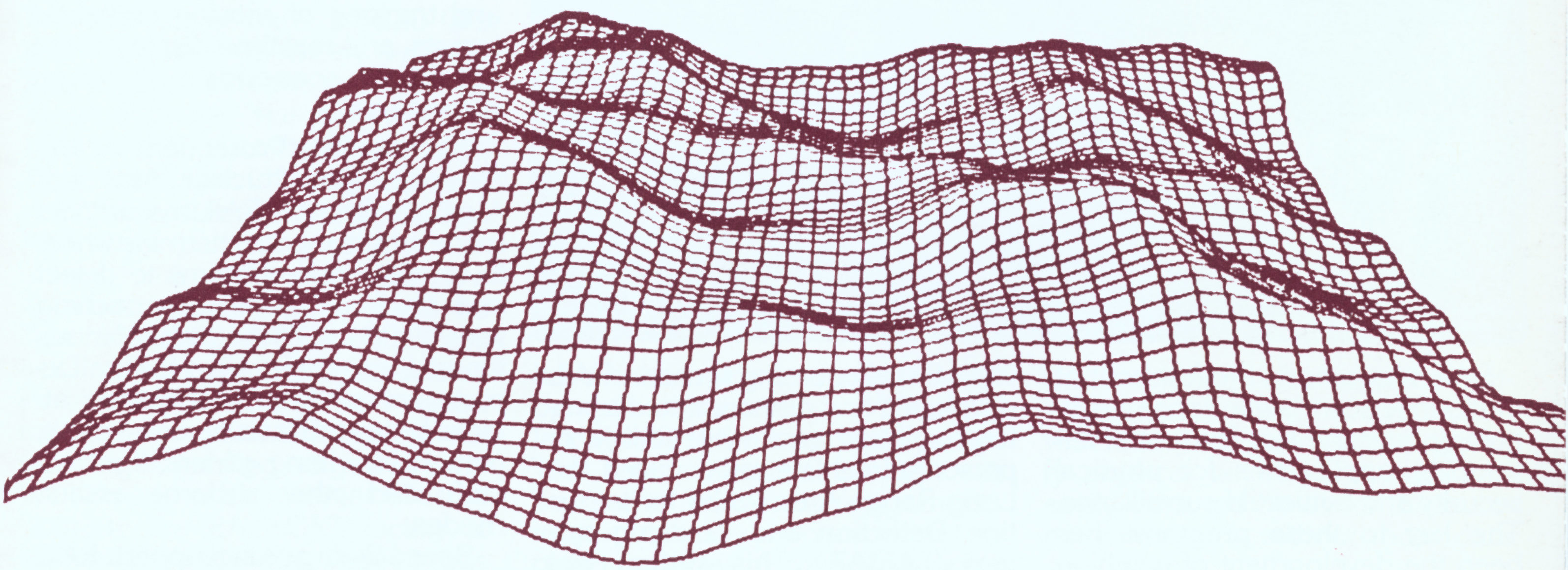
As part of a project to investigate the detectability of targets on the ocean surface, RAIL researchers developed an ocean surface model which can use any desired number of Gerstner waves to model the ocean as accurately as necessary.

Radar performance models developed by RAIL are used extensively in radar system analyses. The probability of detecting a target against a given background is calculated using the target and clutter models to provide input to search radar signal processor and display models. Sophisticated, state-of-the-art clutter rejection radar systems with automatic detectors, as well as more conventional radar systems with human operators, have been modeled.

Other models for tracking radars simulate track errors from surface and volume clutter, multipath, glint, and servo system lag, allowing the prediction of total engagement contours. In combination with missile fly-out models, the track error models predict aimpoint wander during terminal guidance, and provide impact point distributions for extended targets.

RAIL uses models of tracking radars and missile engagement scenarios to generate detection contour and engagement plots for targets with known radar cross section, velocity, and altitude.

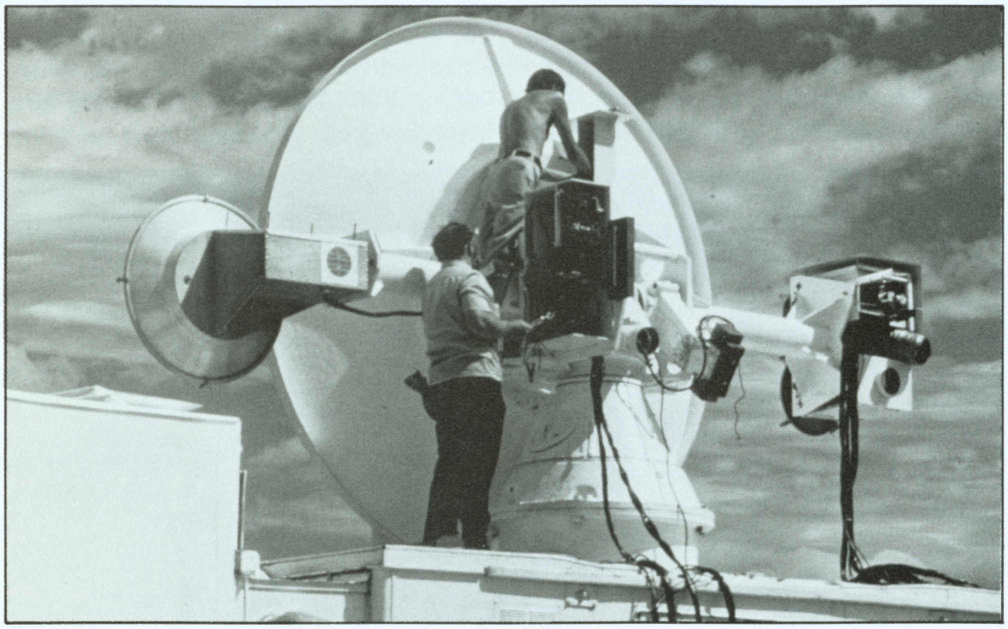
A very complex closed loop missile simulation system was designed, fabricated, delivered, and verified at Eglin AFB. This four-year project involved engineers with expertise in missile flight dynamics, simulation hardware/software design, electromagnetic propagation phenomena, microwave component design, real-time simulation design, seeker system characterization, and advanced computer technology. For another missile simulator, RAIL developed simulation software in a top-down structured design per MIL STD 483. The Environmental and Radar Operation Simulator (EROS) developed by RAIL combines a general purpose computer, special purpose digital hardware and analog hardware to produce synthetic backscatter. Battlefield clutter is synthesized by an array of digital filters that allow user selection of amplitude distributions, spatial distributions and spectra. The targets are simulated by combining recorded backscatter with user-defined maneuvers.



PHOTOGRAPHS: (Left) RAIL generates a variety of models of tanks, ships and aircraft for studies of reflectivity characteristics. (Right) The laboratory developed this three-dimensional surface model of a six-component ocean wave.

The laboratory has built instrumentation radars which take radar reflectivity measurements in the 1 to 220 GHz region of the spectrum.

SURVEILLANCE & TRACKING



RAIL has been in the forefront of track-while-scan surveillance technology over the last few years, developing applications for physical security and battlefield surveillance. The key to these programs has been the development of two high speed digital pipeline microprocessors for real time radar data processing. One processor contains the American Micro Devices (AMD) 2900 series bit slice micrologic with the salient characteristics of 16 bit words, 5MHz clock rates, and microprogrammability. The second processor was developed using silicon on sapphire (SOS) technology to provide the salient characteristics of high speed and low power consumption.

Notable recent accomplishments in this technology include:

MX missile support. RAIL recently completed a multiyear program demonstrating hardware which would provide physical security in several of the MX missile siting scenarios. In support of the original MX vertical shelter basing scenario, RAIL developed and demonstrated a prototype netted track-while-scan antipersonnel/vehicle radar called the Long Range Area Radar for Intrusion Detection and Tracking system (LARIAT). This system was capable of netting up to 10 radars, each with a 10 km radius detection zone, into a single display capable of automatic detection and tracking of walking men and ground vehicles.

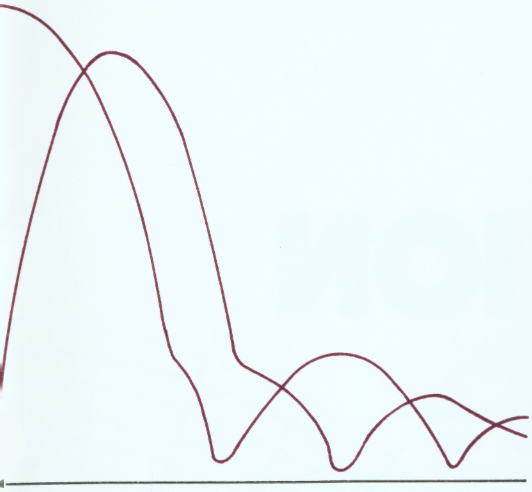
Waterborne Intrusion Detection Segment (WIDS) support. RAIL developed an advanced development model of a low-cost track-while-scan surveillance radar system which detects waterborne targets. The system is capable of automatic detection and tracking of targets and the application of certain alarm criteria to determine potential physical security threats.

Anti-Armor Surveillance and Target Acquisition Radar (ASTAR). RAIL developed an advanced development model of a track-while-scan, battlefield surveillance radar system installed in an armored personnel carrier. ASTAR features a telescoping mast-mounted, low sidelobe antenna, automatic acquisition and tracking of moving battlefield targets, and real time display of the battlefield scenarios and target parameters.

Nuclear Site Protection. At the Savannah River Nuclear Plant near Augusta, Georgia, RAIL researchers made air surveys to determine where to locate sensor systems to detect and track air traffic approaching sensitive areas of the plant. Various threat scenarios studied for the Department of Energy included attacks by terrorists using helicopters, parachutes, hang gliders, light aircraft, and other airborne assault modes.

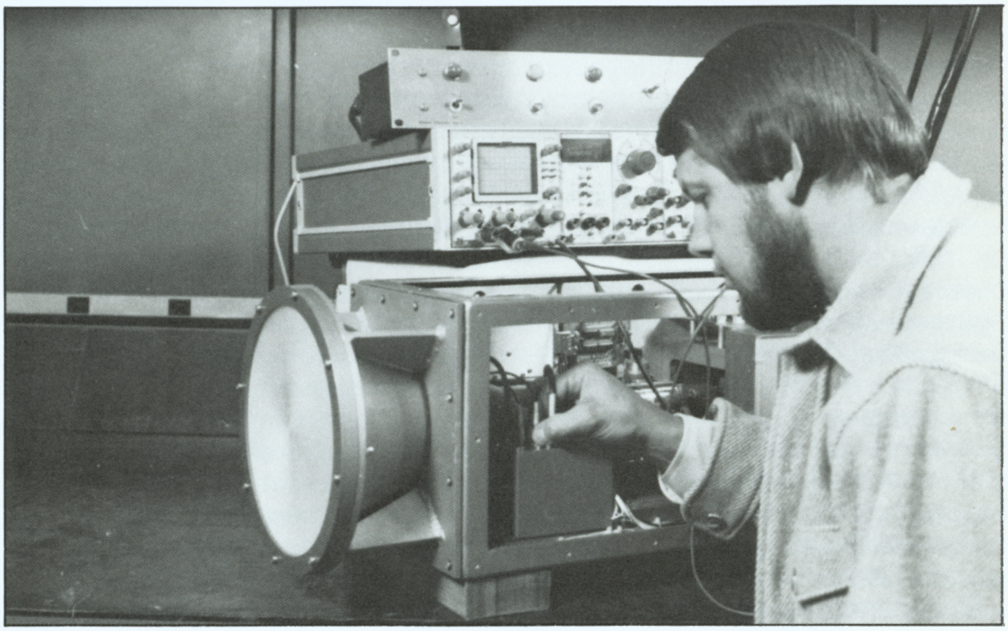
Speed timing radar support. RAIL has prepared a video tape for the Department of Transportation that will ensure more effective use of highway safety speed timing radar. Preliminary studies were conducted with equipment commonly used throughout the state to detect speeding motorists. A large margin for error due to vehicle monitoring practices is being reduced by conducting video training courses for law enforcement officers.

PHOTOGRAPH: (Left) Researchers collected data on reflectivity and attenuation with this radar during a nuclear blast simulation.



RAIL has developed track-while-scan technology for detecting walking men and ground vehicles in several MX missile siting scenarios.

INSTRUMENTATION TECHNOLOGY



RAIL has worked for many years to develop instrumentation which supports diverse technological areas. These include:

Instrumentation radars. RAIL has built systems which measure radar reflectivity over the 1 to 220 GHz frequency regime. Recent accomplishments include the development of an airborne, scanning 35 GHz radar and a helicopter mounted 95 GHz monopulse tracking radar.

RCS measurement range design. RAIL has performed study programs for industry and U.S. government agencies to upgrade far field radar cross section (RCS) ranges. In recent programs conducted for industry, RAIL engineers added millimeter wave measurement capabilities to existing ranges. In addition, Phase I of a multi-year effort to upgrade the RATSCAT facility at Holloman AFB, New Mexico was completed.

Compact and Model Range Facilities. RAIL participated in developing the Georgia Tech "compact range" and frequently uses the range for research. This range is capable of low cost measurements of the RCS of targets up to four feet in length, with minimum RCS values of -40 dBsm over frequency ranges of 2 to 18 GHz. Another model RCS range is under development which will be able to handle targets up to 10 feet in length and 1,000 pounds in weight over the frequency range of 5 to 95 GHz.

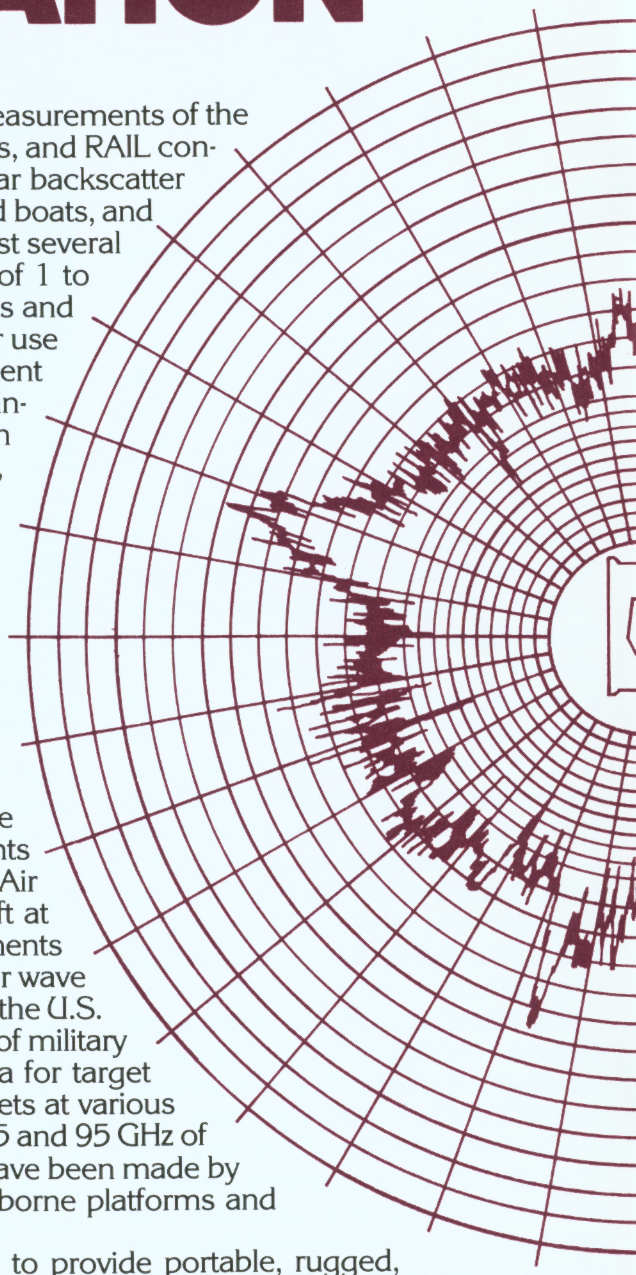
Battlefield Instrumentation. RAIL has supported the Army in developing instrumentation for war games. Propagation measurements for grazing and near grazing conditions have been made to support development of the Army's Microwave Intervisibility Measurement System. This instrumentation concept will be used in simulated engagements to automatically monitor when two player vehicles (ground-to-ground and ground-to-air) are in a line-of-sight condition and capable of weapon system engagement.

Fiber-optic technology. RAIL operates a fiber optic laboratory with full facilities for performing signal processing and electro-optic interface experiments using clock rates up to 1 GHz. Research programs have included development of a wide bandwidth delay line for a radar warning receiver, a fiber optic correlator for signal processing applications and a fiber optic strain sensor interferometer.

Miscellaneous instrumentation capabilities. RAIL has made remote measurements of low and high speed events through photographic recordings. Both 16-mm and 35-mm movie and instrumentation cameras may be used in conjunction with radar measurements to quantify physical target parameters not easily obtained by direct measurement methods without radar data corruption.

PHOTOGRAPHS: (Top Center) The sum and difference patterns for a monopulse tracking antenna. (Right) Final adjustments are made on an advanced high power short pulse 95 GHz prototype radar designed to gather unique research data from an airborne test platform.

TARGET CHARACTERIZATION



Georgia Tech's Engineering Experiment Station has performed measurements of the reflectivity characteristics of targets and clutter for more than 30 years, and RAIL continues to build on this rich legacy of measurement activities. The radar backscatter of land, rain, snow, dust and debris, military ground vehicles, ships and boats, and aircraft have all been subjects for study by RAIL personnel over the last several years. Instrumentation radars operating over the frequency ranges of 1 to 140 GHz, as well as two Mobile Data Acquisition/Reduction Facilities and several mobile instrumentation vans, are maintained and operated for use on reflectivity characterization programs. These radar measurement capabilities include dual polarization, frequency agility, coherent inphase and quadrature receivers, polarization agility, pulse compression using either frequency or polarization (Intrapulse Polarization Agility, IPAR) waveforms, and monopulse and conical scan angle measurements.

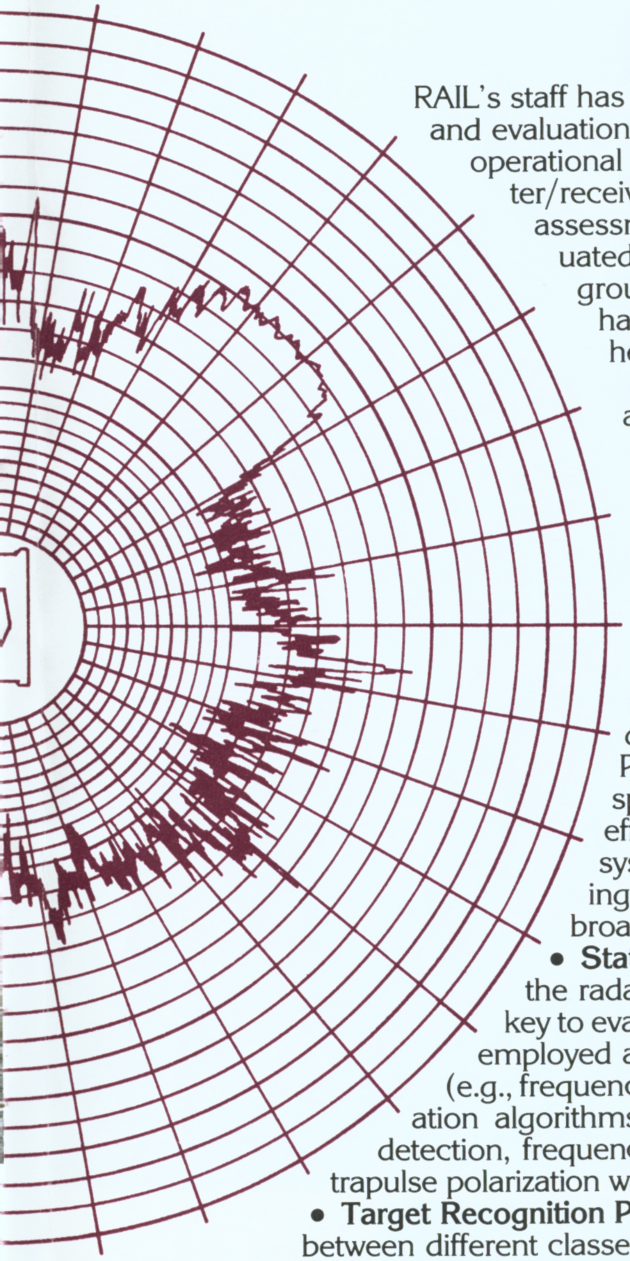
Analysis facilities provide average values, amplitude densities and cumulative distribution functions, frequency spectra, correlation functions, calibrated radar maps, polar plots, and range and crossrange profiles of targets. Facilities also exist for large analysis programs such as the U.S. Air Force's TABILS millimeter wave data base.

Recent measurement programs at RAIL have involved diverse areas of study. Engineers in the laboratory have obtained measurements of sea backscatter over the frequency range of 9 to 95 GHz, taking into account depression angle, polarization and wind/wave height/direction. Another research program resulted in measurements of the radar cross section of several Navy surface effect vehicles. The Air Force sponsored research to measure the "echo sources" of aircraft at millimeter wave frequencies. The laboratory performed measurements and analyses of high value targets and terrain signatures at millimeter wave frequencies to provide data for the Eglin AFB TABILS data base. For the U.S. Army, RAIL has conducted millimeter wave measurement programs of military vehicles which included full polarization matrix, high resolution data for target rotations on a turntable and coherent measurements of moving targets at various angles. Another program for the Army produced measurements at 35 and 95 GHz of desert terrain reflectivity from an airborne platform. Measurements have been made by RAIL engineers of snow reflectivity at 35 and 95 GHz from both airborne platforms and tower-based measurement systems.

The RAIL measurement facilities are constantly being upgraded to provide portable, rugged, flexible measurement radar systems and in-the-field analysis facilities. Many of the systems also incorporate state-of-the-art processing capabilities such as wideband frequency agility, polarization agility, and pulse compression using pulse-to-pulse coherent frequency agility or intrapulse polarization agility. The in-the-field analysis capabilities provided by the Mobile Data Acquisition/Reduction Facilities ensure the quality and usefulness of the data being collected.

Monopulse and conical scan instrumentation radar facilities currently under development will provide the means for measuring target glint and low angle tracking errors at radar frequencies up to 140 GHz.

TARGET DETECTION



RAIL's staff has several decades of experience in radar system performance analysis and evaluation. The performance of radar systems has been evaluated for various operational scenarios, with attention focused on antenna/radome and transmitter/receiver sub-systems, radar platform considerations, technology risk assessments, and cost/performance trade-off analyses. Radar systems evaluated have ranged from airborne surveillance and tracking systems to ground-based target acquisition radars. Signal processors considered have included simple non-coherent, analog, MTI processors, and coherent, fully-digital, airborne pulse-Doppler processors.

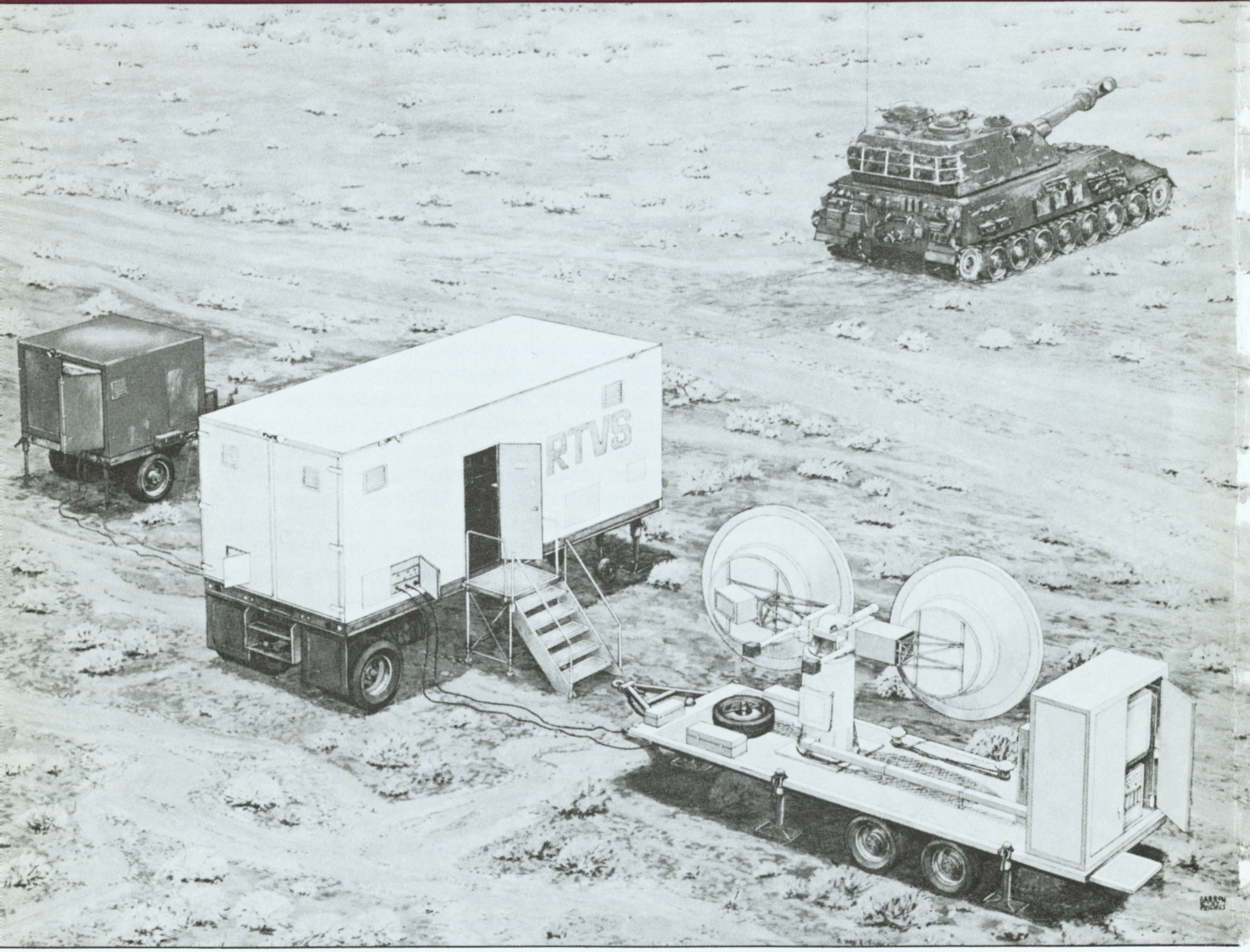
The key radar subsystem in performance/trade-off studies is invariably the radar signal processor. In many instances, the processing strategy and method of implementation chosen are the determining factors in the selection of the radar system.

As a result of these programs, RAIL has expertise in evaluating all types of radar signal processors. A sampling of the type of signal processors evaluated and the methodology employed includes:

- **Moving Target Indication (MTI) and Pulse-Doppler (PD) Processors.** These processors enable the radar system to discriminate between moving targets and stationary clutter. MTI processors include range-gated-filters and delay-line-cancellers. PD processors include digital Doppler filters and fast-Fourier-transform (FFT) processing. Performance evaluation involved the consideration of clutter power spectral density, filter frequency response, and motion compensation effects for coherent systems, non-coherent effects for clutter-referenced systems, signal processing losses (filter straddle, filter mismatch, weighting, etc.), improvement factors and degradation factors (clutter spectral broadening and system instabilities).
- **Stationary Target Indication (STI) Processors.** These processors enable the radar system to discriminate between stationary targets and clutter. The key to evaluating these processors is the target/clutter discrimination algorithm employed and the requirements the algorithm places on the radar system itself (e.g., frequency agility and/or polarization agility). RAIL has studied many discrimination algorithms/techniques including dynamic threshold gating, pseudo-coherent detection, frequency induced amplitude oscillations, polarization ratio discriminant, intrapulse polarization waveform coding, and Mueller (Stokes) matrix algorithms.
- **Target Recognition Processors.** These processors enable the radar system to discriminate between different classes of targets, such as a truck and a tank. The key to evaluating these processors is the target-recognition algorithm employed and its impact on the radar system itself (e.g., large bandwidth requirements). RAIL has evaluated several target recognition algorithms, including high range resolution profiles/pattern recognition and Mueller (Stokes) matrix algorithms.
- **Tracking Radar Processors.** These processors enable the radar to maintain a track on a given target (or targets) while either in a search-light or scanning mode. Evaluation considerations include tracking mechanism (conical scan, monopulse, or track-while-scan), tracking error considerations (glint, signal-to-noise ratio), and tracking update algorithms for a track-while-scan system.

DRAWING: A polar plot of the radar cross section of a target vehicle.

RADAR



SYSTEM DEVELOPMENT

RAIL's radar system development capabilities have evolved over the past 25 years to a point unequaled by any other academic or non-profit institution. RAIL has conceived, designed, fabricated, integrated, and tested radar and radar-related systems for the Department of Defense, other federal agencies, and private industry. Ground-based, airborne, and shipborne systems have been developed.

A signal processing subsystem of a continuous wave multi-frequency ranging and velocimeter radar with conical scan tracking was developed for White Sands Missile Range. The radar system transmits three different frequencies for detection and ranging of airborne targets. The signal processing subsystem performs a 2048-point complex fast Fourier transform (FFT) on each signal, selects a target based on predetermined target selection criteria, and extracts phase, amplitude, and velocity data from the target returns.

The Intrapulse Polarization Agile Radar (IPAR) system transmits a pulse that is encoded by polarization modulation on a subpulse basis. The coding is utilized to effect pulse compression of the received echo pulse. This method differs from more conventional approaches of pulse compression encoding on carrier phase or frequency because the coding is contained in the *relative* phase between the horizontal and vertical polarization components of the transmit pulse. As a consequence of this novel approach, IPAR exhibits many unique characteristics including the ability to be implemented with a variety of RF waveforms and an intrinsic potential for discriminating stationary targets from surrounding clutter.

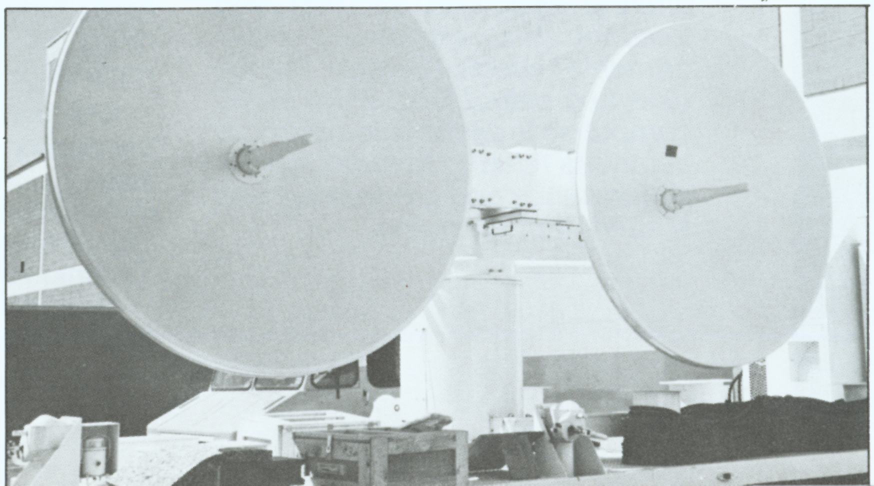
The current IPAR concept has been implemented in an X-band radar developed by RAIL. A high speed digital processor implemented in TTL and ECL technology allows binary codes up to 32 bits in length to be generated at bit rates up to 100 MHz and processed in real time. The system has been used in a comprehensive data collection program to investigate and quantify IPAR's properties for various applications.

RAIL developed a coherent repeater for use in verifying the correct operation of a given class of target acquisition and track radars.

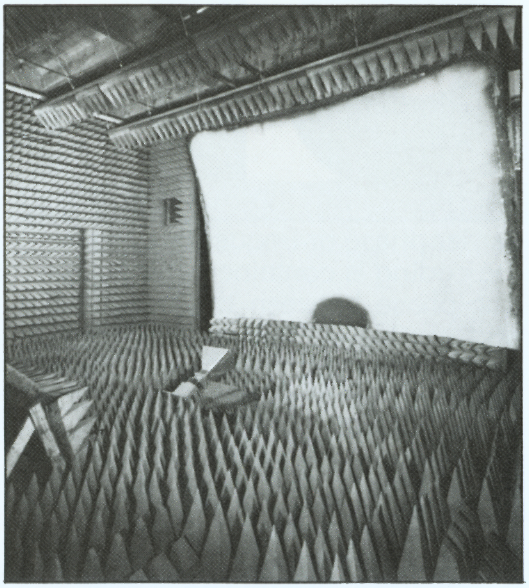
The repeater has six modes of operation and is designed to operate over a 4 to 8 GHz range of frequencies. It provides a coherent extended target echo or coherent point-target echo simulating ranges of either 15 or 30 km, simulates a target at either 15 or 30 km with one of three simulated velocities superimposed on the coherent return pulse, and tests the radar's coherent Doppler tracking response to a moving target traveling a simulated radial path between 10 and 40 km at one of three velocities.

System anomalies which occasionally cause the AN/MPS-36 radar to spiral off the target were investigated for White Sands Missile Range. These anomalies were determined to be a result of cross-polarization signal coupling in the antenna feedhorn structure. Based on this study, RAIL was funded to modify the AN/MPS-36 radar to eliminate the cross-coupling.

PHOTOGRAPHS: (Above left and below right) RAIL was a key member of a team which developed a prototype U.S. Army Real Time Velocimeter System (RTVS) for use as a transportable CW instrumentation radar system. (Below left) RAIL engineers have adapted radar techniques initially developed for military non-metallic mine detection to two civilian applications. One version of this radar can readily locate underground pipes and another detects voids beneath pavement that would later result in breakdown of the pavement surface.



FACILITIES



PHOTOGRAPHS: (Above) RAIL has access to a compact reflectivity range at Georgia Tech whose 12 x 16 foot parabolic section provides a large plane wave area. This range requires less space than a conventional outdoor range while offering improved security and freedom from extraneous environmental effects. (Below) The lab uses two netted DEC VAX 11/780 computers to perform complex calculations relating to radar system performance and electromagnetic scattering phenomena.

RAIL has developed a number of instrumentation radar systems for tasks such as basic radar reflectivity data collection, radar system simulation, and new radar techniques evaluation. The systems cover most radar bands from 1 to 140 GHz, are designed to allow maximum flexibility of configurations, and are instrumented to permit accurate measurements to be made.

RAIL researchers have use of two elevated outdoor antenna ranges, a compact reflectivity range, a cylindrical indoor near-field and antenna test range, and a millimeter wave test laboratory with facilities for measurements from 35 to 220 GHz. Laboratory facilities for high power transmitter development include high voltage power supplies, high voltage/current probes, and test equipment. RAIL also maintains model shop facilities for prototype fabrication and has access to the Georgia Tech machine shop with full metalworking capabilities.

RAIL engineers have ready access to a number of computer facilities, including: a Gould SEL 32/77 which is secured for classified processing and capable of real time simulation; three DEC VAX 11/780's; a number of Data General Eclipses and Novas; and a CYBER 70/74 mainframe computer on the Georgia Tech campus. Computer models and software support programs are available to support a wide range of research activities.

RAIL recently developed a Mobile Data Acquisition/Reduction Facility which provides minicomputer control of data acquisition, conversion and recording, color display and hard copy graphics, and a wide range of statistical data analysis routines.

RAIL staff members conduct short courses on these radar-related subjects:

Reflectivity of Land and Sea
High Power Radar Transmitters
Techniques of Radar Reflectivity Measurement
Radar Cross Section Reduction

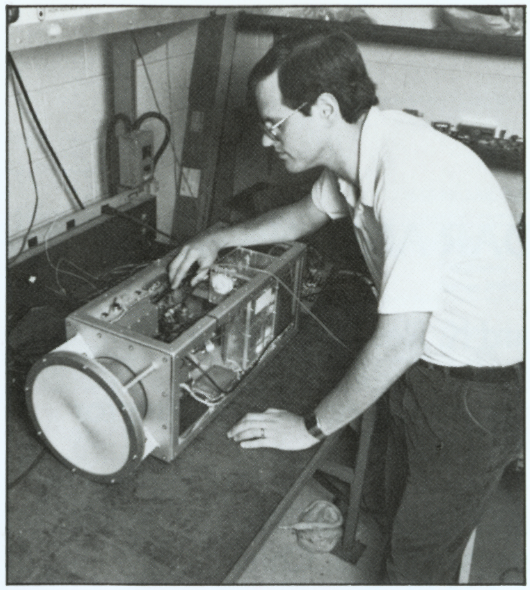
RESOURCES

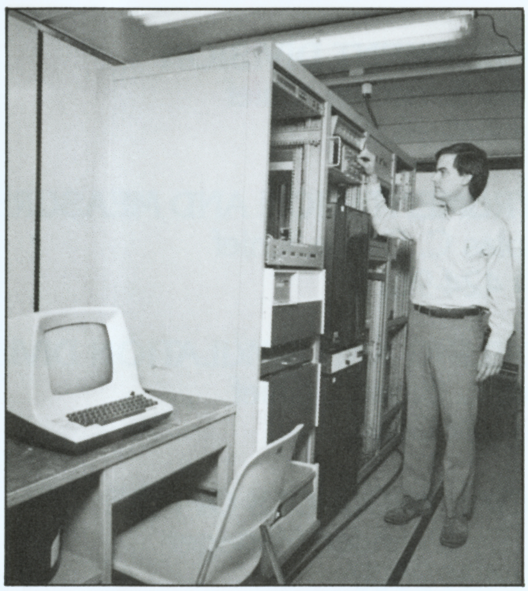
Modeling and Simulation of Land Combat
Computer Modeling of Electromagnetic Signatures
Principles of Modern Radar

Radar measurement capabilities include:

Frequency	Capability
UHF	RF sources (+10 dBm), Logarithmic Receiver
L-Band	1 kW Non-Coherent, Logarithmic Receiver; 1kW Coherent, Linear I/Q Receiver
C-Band	1 W Non-Coherent, Logarithmic Receiver; 10 W Coherent, Linear I/Q Receiver
X-Band	50 kW Non-Coherent, Dual Polarized, Logarithmic Receiver; 1 kW Coherent, Logarithmic Amplitude, Linear I/Q Receiver, Full Polarization Matrix
Ku Band	50 kW Non-coherent, Dual Polarized, Logarithmic Receiver
Ka Band	20 kW Non-Coherent, Dual Polarized, Logarithmic Receiver; 3 W Coherent, Logarithmic Amplitude, Linear I/Q Receiver, Pulse Compressed to 1 ft. Resolution, Full Polarization Matrix.
95 GHz	1 kW Non-Coherent, Logarithmic Receiver; 1 kW Coherent*, Linear I/Q Receiver, Pulse Compressed to 2 ft. Resolution
140 GHz	150 W Non-Coherent*, Logarithmic Amplitude, Conical Scan, Linear Quadrature Error Signals.
10 μm	55 W (average) CW or Pulsed Coherent Laser Radar*, Dual-plane Scanning, HgCd Te Detector

*Under Development





PHOTOGRAPHS: (Above) RAIL employs a variety of instrumentation radars covering most radar bands from 1 to 140 GHz for research purposes. (Below) Another important RAIL research tool is this Mobile Data Acquisition/Reduction Facility.

DIRECTORY

RADAR AND INSTRUMENTATION LABORATORY

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EMENT DIVISION

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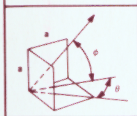
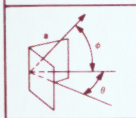
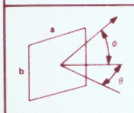
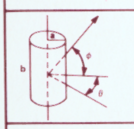
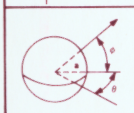
Radar and Instrumentation Laboratory
Georgia Institute of Technology

TECHNICAL DATA

Hierarchy of scattering shapes

Geometry	Type	Freq. Dep.	Size Dep.	Formula	Remarks
	Square trihedral corner retro-reflector	F^2	L^4	Maximum $\sigma = \frac{12\pi a^4}{\lambda^2}$	Strongest return; high RCS due to triple reflection
	Right dihedral corner reflector	F^2	L^4	Maximum $\sigma = \frac{8\pi a^2 b^2}{\lambda^2}$	Second strongest; high RCS due to double reflection, tapers off gradually from the maximum with changing θ and sharply with changing ϕ.
	Flat plate	F^2	L^4	Maximum $\sigma = \frac{4\pi a^2 b^2}{\lambda^2}$ Normal Incidence	Third strongest; high RCS due to direct reflection, drops off sharply as incidence changes from normal.
	Cylinder	F^1	L^3	Maximum $\sigma = \frac{2\pi a b^2}{\lambda}$ Normal Incidence	Prevalent cause of strong, broad RCS over varying azimuth (θ), drops off sharply as elevation (ϕ) changes from normal. Can combine with flat plate to form tophat corner reflector.
	Sphere	F^0	L^2	Maximum $\sigma = \pi a^2$ Normal Incidence	Prevalent cause of strong, broad RCS over varying azimuth and elevation angles.

RADAR AND ECM LETTER BANDS FOR FREQUENCY

STANDARD RADAR BANDS*	Frequency Range (MHz)	ELECTRONIC COUNTERMEASURES BANDS** Band Designation	Frequency Range (MHz)
HF	3 - 30	Alpha	0 - 250
VHF	30 - 300	Bravo	250 - 500
		Charlie	500 - 1000
UHF	300 - 1000	Delta	1000 - 2000
		Echo	2000 - 3000
L	1000 - 2000	Foxtrot	3000 - 4000
S	2000 - 4000	Golf	4000 - 6000
		Hotel	6000 - 8000
C	4000 - 8000	India	8000 - 10,000
X	8000 - 12,000	Juliet	10,000 - 20,000
K_u	12,000 - 18,000	Kilo	20,000 - 40,000
		Lima	40,000 - 60,000
K	18,000 - 27,000	Mike	60,000 - 100,000
K_a	27,000 - 40,000		
Millimeter	40,000 - 300,000		

*From IEEE Standard 521 - 1976, 30 November 1976.
**From AFR 55 - 44 (AR105 - 86, OPNAVINST 3430.9B, MCO 3430.1), 27 October 1964.

JAMMER-TO-SIGNAL RATIO

$$J/S = \left(\frac{4\pi}{\sigma(SPG)}\right)\left(\frac{P_J}{P_T}\right)\left(\frac{G_J G_{RJ}}{G^2{}_{RT}}\right)\left(\frac{B_R}{B_J}\right)\left(\frac{R_T{}^4}{R_J{}^2}\right)$$

Where

σ = Target Cross Section (Meters^2)
SPG = Radar Signal Processing Gain
P_J = Jammer Power (Watts)
P_T = Radar Transmitter Power (Watts)
G_J = Jammer Antenna Gain (Direction of Radar)
G_{RJ} = Radar Antenna Gain (Direction of Jammer)
G_{RT} = Radar Antenna Gain (Direction of Target)
B_R = Receiver Bandwidth of Radar (MHz)
B_J = Jammer Noise Bandwidth (MHz)
R_T = Range to Target (Meters)
R_J = Range to Jammer (Meters)

PARABOLOIDAL ANTENNA CHARACTERISTICS

3dB Beamwidth = $\frac{72.8\lambda}{D}$ (degrees)

Where
λ = Wavelength
D = Reflector diameter

[Aperture distribution of the form $1-\rho^2$ where ρ is normalized radius]

First null position = $\frac{180}{\pi}\sin^{-1}\left(\frac{1.63\lambda}{D}\right)$ degrees

First sidelobe maximum position = $\frac{180}{\pi}\sin^{-1}\left(\frac{2.07\lambda}{D}\right)$ degrees

Gain = $10\log\left[E\left(\frac{\pi D}{\lambda}\right)^2\right]$ dB

Where
E = aperture efficiency

MAXIMUM DETECTION RANGE
(Signal-to-Noise Ratio = Unity)

$$R_{MAX} = \left[\frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 KTBF_N L}\right]^{1/4} \text{ Meters}$$

Where

K = Boltzmann's Constant
T = Temperature
B = Receiver Bandwidth
L = Signal Losses
F_N = System Noise Figure = $\frac{[S/N] \text{ Input}}{[S/N] \text{ Output}}$

$4570/4M/11-83
Produced by Georgia Tech
Research Communications Office