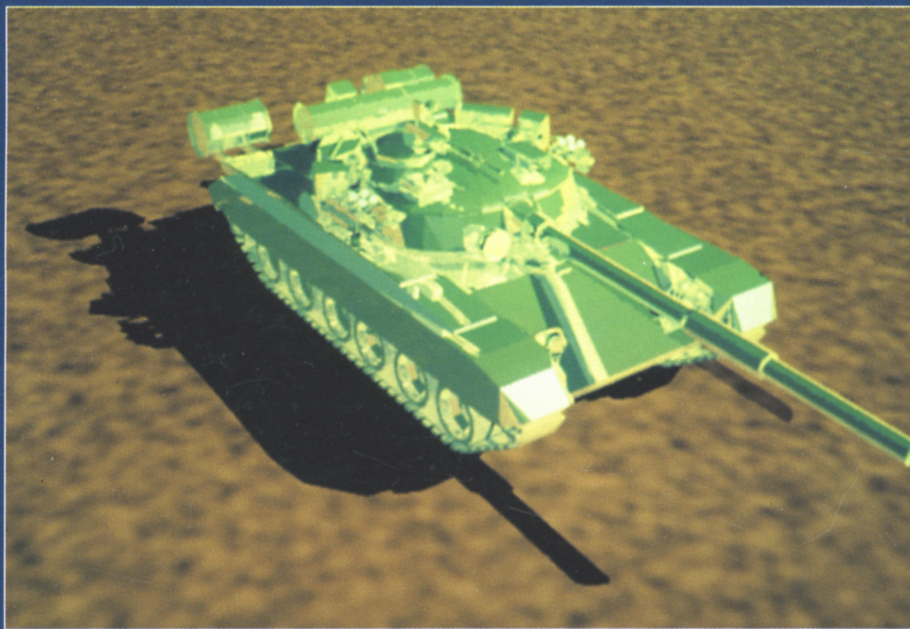


# Radar Research and Development



From the Theoretical . . .



To the Practical

*Georgia Tech*  
RESEARCH INSTITUTE

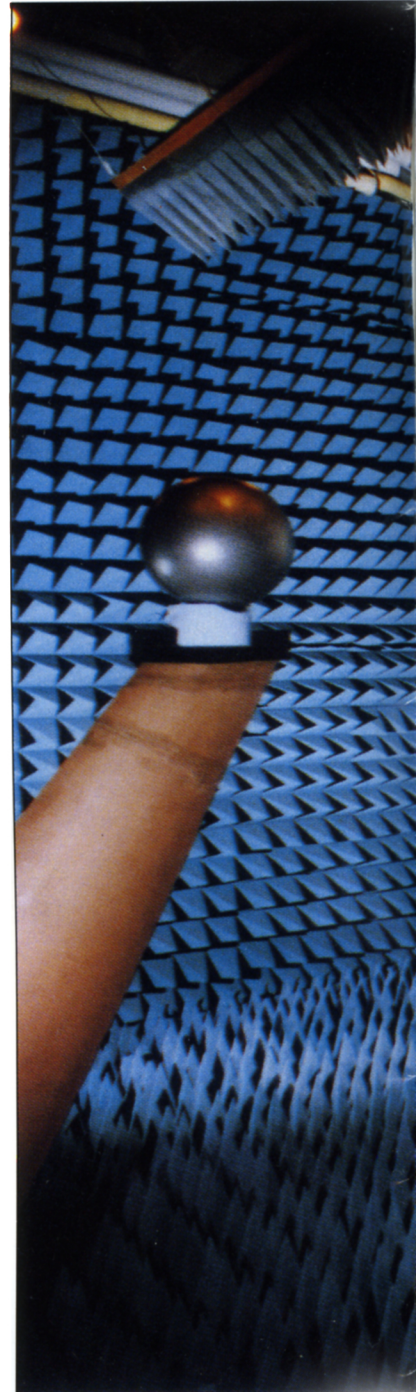


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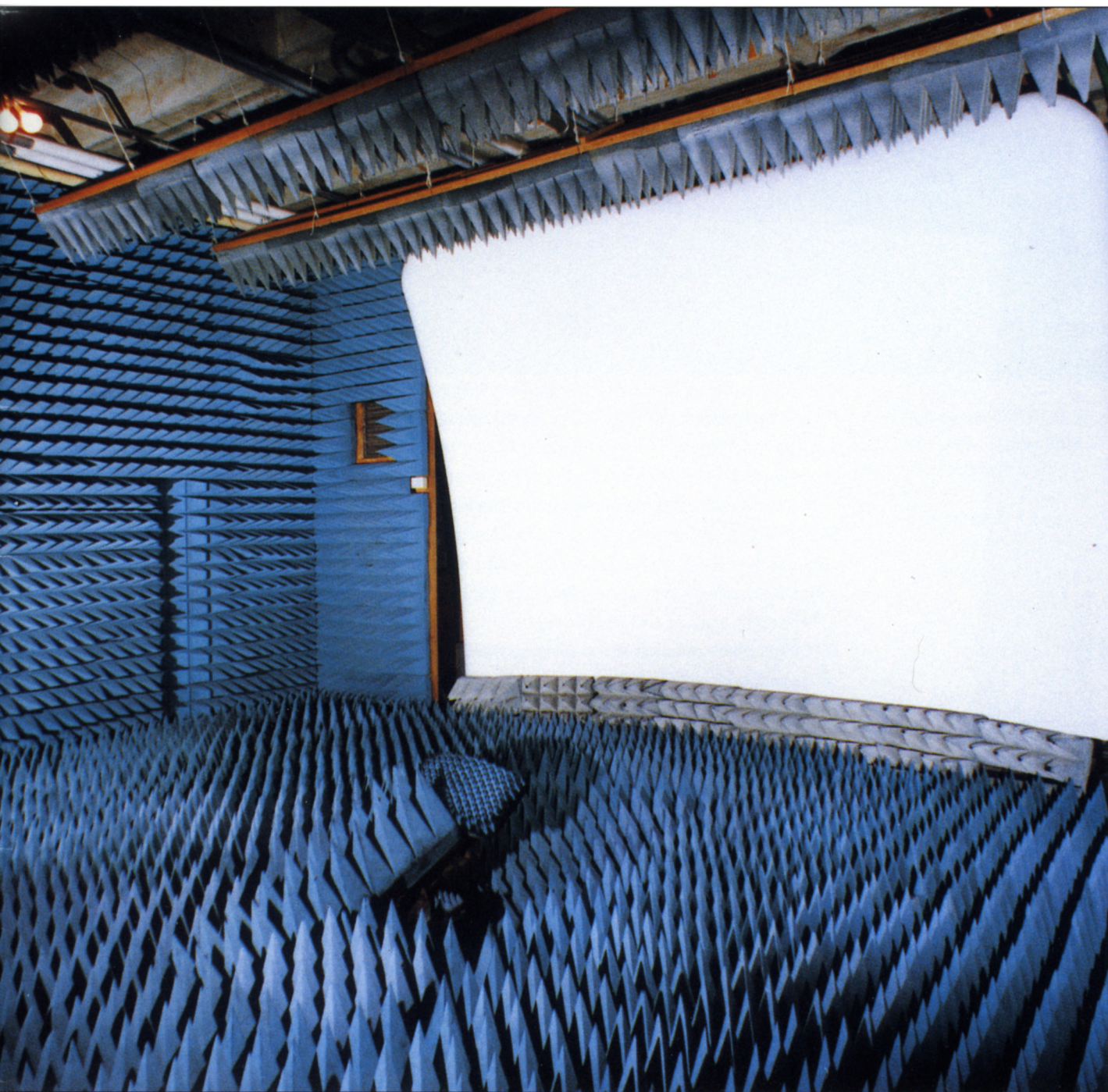
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**On the Cover:** GTRI researchers have pioneered many developments in radar and antenna technology over the past several decades. Shown are several radars used in a multi-frequency sea target measurement program conducted by GTRI. The tank image is an optical representation of an M-1 tank generated with GTRI's MAX 3-D geometric data base editor.

*GTRI researchers use this indoor compact range to perform a variety of measurements of antenna and radar cross section patterns.*









## Introduction

*GTRI has achieved an international reputation for research and development in the radar field.*

The Georgia Tech Research Institute (GTRI) is one of the country's largest university-based centers for applied engineering research and development. GTRI serves outside sponsors on a non-profit basis and operates as an integral part of the Georgia Institute of Technology. Approximately three-quarters of GTRI's external research sponsorship is provided by Department of Defense (DoD) agencies; however, it ranks among the top five American universities in its level of support from business and industry. Last year, GTRI's research volume exceeded \$100 million.

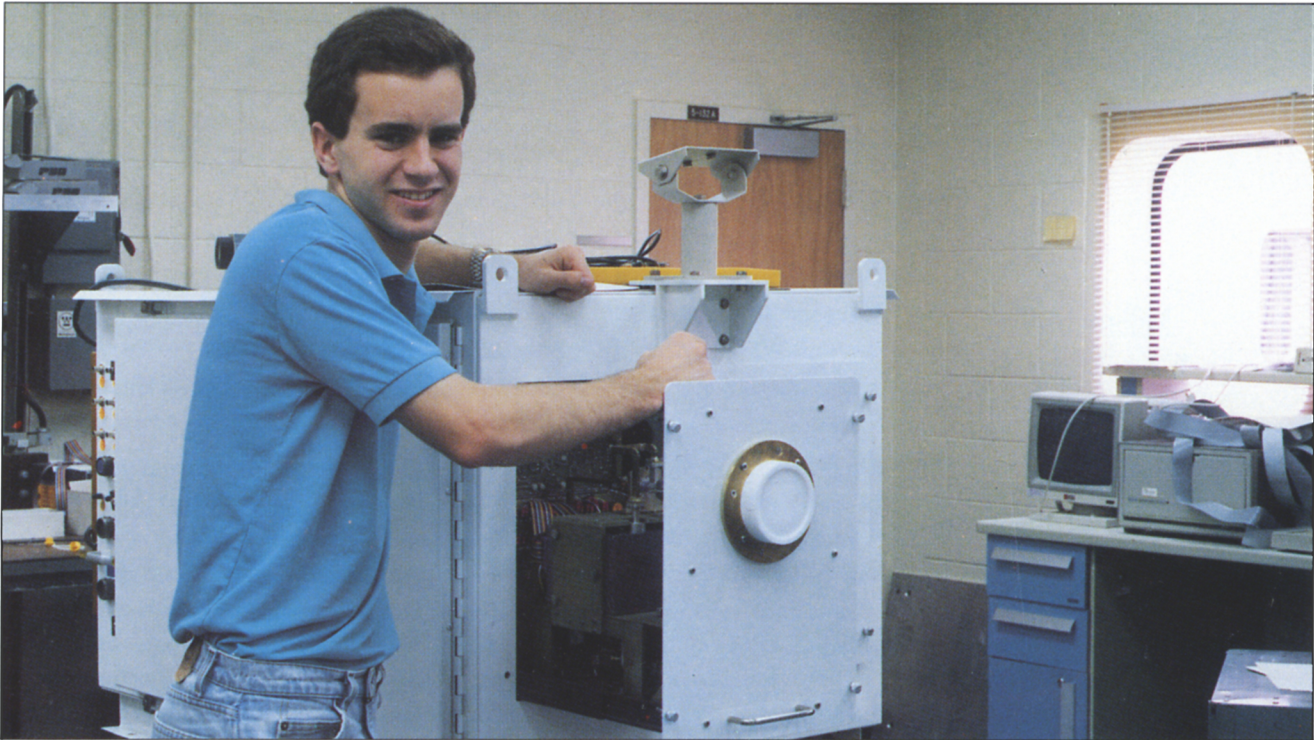
GTRI has a staff of approximately 1,400 employees, of whom around 650 are full-time professionals in various engineering and scientific disciplines. The Research Institute consists of 20 laboratories, which pursue focused technical missions but work collaboratively on broad program initiatives. These laboratories also work with colleagues from Georgia Tech academic departments through Tech's 34 research centers. These centers include the U.S. Army Institute for Research in Management Informations, Communications, and Computer Sciences (AIRMICS) and the Center of Excellence in Rotary Wing Aircraft Technology (CERWAT).

GTRI has achieved a national reputation for research and development in the radar field. Areas of technical expertise include radar cross section (RCS) measurements, millimeter-wave (MMW) radar technology, radar system development, threat simulators, and physical security applications. Integrated into this radar expertise are extensive capabilities in electronic warfare and electro-optics.

GTRI's radar research spans sensor/system design and evaluation, measurement of propagation phenomenology, characterization of target signatures, definition of clutter backscatter characteristics, development of signal processing algorithms, and modeling and simulation of systems. Program highlights include the following:

- GTRI has many years of experience in the analysis and design of special-purpose and one-of-a-kind radars. In support of these projects, several unique computer simulation tools have been developed for the design of both reflector antennas and phased arrays.
- GTRI engineers have performed state-of-the-art antenna measurements all over the world and have contributed significantly to the theory and technique of antenna measurement. Examples include the invention and development of the compact antenna range, construction of the first operational planar-surface near-field measurement system, and development of the theory of cylindrical-surface near-field measurements.
- GTRI researchers have designed and built specialized microwave antennas for many years, including complex antennas and support structures. GTRI has fielded a number of systems that are still operational at various military installations.
- In the millimeter-wave region, GTRI engineers have developed numerous antennas,





including a narrow-beam, rapid-scan antenna for one of the first operational millimeter-wave radars in the country.

- For more than 30 years, GTRI investigators have defined the reflectivity characteristics of target and clutter. They have performed radar cross section measurements on virtually every type of target and terrain. GTRI researchers have also studied the effect of the environment on electromagnetic propagation.

In addition to conducting research in specific areas, GTRI personnel support government and industrial programs by:

- Serving on technical panels, source selection boards, and Blue Teams such as the CROSSBOW S panel, the SADARM, WAM, MTAS, and Longbow Blue Teams, and the X-ROD Multipath panel;
- Participating in system design reviews and system/concept demonstration field tests;
- Serving on major government and societal panels such as the Tri-Service Radar Symposium paper selection committee, the IEEE AESS Board of Governors, and the IEEE International Radar Conference papers selection committee; and
- Conducting numerous technical short courses designed to keep participants up-to-date on the many rapidly changing technologies associated with radar.

GTRI staff members routinely publish in the technical literature, including technical reports, symposia, and referred journals. In addition, several staff members have authored textbooks on various radar specialties.

GTRI engineers are able to efficiently respond to varied requests, ranging from quick-reaction, short-term studies requiring low levels of effort to major developments involving complete operational electronic systems designed from the ground up. This booklet describes some of the many radar-related activities conducted at GTRI.

*This dual-band (35/95 GHz) millimeter-wave instrumentation radar was developed by GTRI for the U.S. Army White Sands Missile Range.*



## Radar Systems

### Millimeter-Wave Radar

GTRI has performed research in the millimeter-wave (MMW) spectral region since the early 1950s, achieving an international reputation for its expertise in MMW radar and other MMW sensor systems. Currently, GTRI exhibits this expertise in the areas of:

- MMW sensor design and evaluation;
- MMW measurements of targets, clutter, and related radar propagation phenomenology; and
- MMW instrumentation radars designed to collect specific calibrated measurement data needed for use in radar and signal processing designs.

Senior members of the GTRI research staff have actively served on committees and panels for the U.S. Government, assisting in technology and system assessments related to high-technology developments. These activities have included:

- Serving on a panel for the Deputy Undersecretary of Defense for Research and Development to determine critical needs for Department of Defense (DoD) investment in the area of Automatic Target Detection and Identification.
- Serving on a "Blue Team" of industry experts for the U.S. Army Sense And Destroy Armor (SADARM) Program Office at Picatinny Arsenal to review the full-scale development efforts of the two contractors, Alliant Systems and Aerojet. The team continues to

*GTRI researchers developed HIPCOR, the first high-power, coherent radar system operating at 95 GHz. This research tool has been used for studying target, clutter, and millimeter-wave propagation data.*





work with the Army and the contractors to correct deficiencies and to improve system performance.

- Organizing a “Blue Team” of industry experts for the U.S. Army Wide Area Mine (WAM) Program Office at Picatinny Arsenal to evaluate the WAM contractor’s full-scale development design. The primary goals of the Blue Team were to uncover any major problem areas early in the development effort so that costly problems would not be discovered near the end of the development phase. GTRI personnel also supported the Blue Team activities for the Kinetic Energy Weapons (KEW) program.

GTRI personnel conduct 12 radar-related short courses each year. Tailored courses are also presented at sponsor facilities on a continuing basis. For example, GTRI worked with Picatinny Arsenal to develop a special training course on Smart Munition Technology for its engineers and scientists. The course was conducted on a one-week-per-month basis for 15 months and is being considered as an ongoing core curriculum for the arsenal’s professional staff who are working on programs related to smart munitions. The five major parts of the course covered basic radar, advanced radar, MMW systems, infrared systems, and smart munition technology. Emphasis was given to “hands-on” instruction including problem sessions, design seminars, and laboratory demonstrations.

**G**TRI researchers have developed quality radar systems over a frequency range of 1 GHz to 220 GHz. The development of radar hardware at GTRI is supported by extensive facilities and equipment. These include:

- A complete high-power transmitter modulator facility for development of transmitters utilizing magnetrons, traveling-wave tubes, extended-interaction oscillators, extended-interaction amplifiers, and other tube types.
- A complete microwave/MMW development and test facility for breadboarding and testing radar subsystems.
- A Hewlett-Packard 9000-based RF and digital simulator for modeling both analog and digital performance including PC-board layout.
- Minicomputer-based Unix workstations for developing system software.
- A rooftop test facility for evaluating final radar system performance.
- Antenna range for testing microwave and millimeter wave antennas.
- Model shop and full machine shop facilities.

The following summaries describe the wide variety of radar hardware experience at GTRI.

■ **High Resolution Imaging Radars** Under the Synthetic Vision program, GTRI supported the Federal Aviation Administration (FAA) and the U.S. Air Force in the development of a visual landing aid for use in poor visibility conditions. This program, jointly funded by the FAA and Wright Laboratories, uses a real-aperture MMW radar to map the scene along an aircraft’s glide slope and display it on a head-up display for the pilot. This research also includes analysis of the effects of hardware limitations on the performance of Doppler Beam Sharpening (DBS) in MMW air-to-ground seekers.

In related work, basic theory for Synthetic Aperture Radar (SAR) processing from nonconventional flight trajectories and for turntable Inverse Synthetic Aperture Radar (ISAR) processing has been developed. In a recent internally funded project, GTRI investi-

## Radar Hardware Experience



*The development of radar hardware at GTRI is supported by extensive facilities and equipment.*

gated the application of a novel signal processor architecture—based on vector quantization coding concepts—to SAR and ISAR processing. A new high-resolution imaging technique known as Fast Constrained Iterative Deconvolution (FCID) provides a means of improving azimuth resolution in inexpensive noncoherent sensors which cannot support SAR and DBS imaging.

■ **High Range Resolution** A Microwave Reflectometer Instrumentation Sensor (MRIS) was designed for NASA-Langley to characterize the plasma boundary layer which forms around reentering spacecraft. The instrumentation radar operates at frequencies of 20, 44, 95, and 140 GHz with sufficient bandwidth to allow range measurement accuracies of better than one centimeter.

■ **Airborne Systems** The Airborne Radar Measurement System (ARMS), an airborne 95 GHz radar cross section (RCS) measurement system, is being developed by GTRI for the 3246th Test Wing at Eglin AFB, Florida. The system will be solid state with a 1 GHz bandwidth and will be used to collect RCS signature data of tactical targets from an airborne platform.

■ **Polarimetric Systems** GTRI built a dual-band 35/95 GHz instrumentation radar for the U.S. Army (WSMR/ARMTE). The solid-state instrumentation radar system will ultimately provide the ability to perform full polarization matrix RCS measurements with a bandwidth of 800 MHz (approximately 0.75 foot resolution) and a peak power of 5 W. The system will be used by the Army to validate the RCS signatures of full-scale target models of foreign and domestic military vehicles.

■ **Tracking Radar Systems** A monopulse tracking antenna capability was recently designed for the 95 GHz High Power Coherent Radar (HIPCOR) previously developed for the Army by GTRI. The modifications provide three-channel monopulse angle tracking, a range tracking gate, and a real-time moving target indicator (MTI) processor. The modified system will be used to perform radar low-angle tracking and multipath experiments for rod-type projectiles related to the Advanced Kinetic Energy Missile (ADKEM) program.

■ **Phased Array Systems** For the past several years, GTRI has had an ongoing program, sponsored by Crossbow and internal research funds, to investigate polarization characteristics of phased-array radars. Specifically, the radars of interest include advanced threat radars and U.S. simulations of those radars. The objective of the Crossbow-funded efforts has been to determine the effect of phased-array configuration design on the susceptibility of the radars to cross-polarization countermeasures. This information can then be used to establish guidelines on the required simulator array fidelity for various test scenarios.

■ **Ground Penetration Radar** Externally funded R&D projects conducted at GTRI in the area of ground-penetrating radar (GPR) have included initial research in the use of GPR for locating underground pipelines and utilities and for developing land-mine detection techniques. As a result of these efforts, GTRI has acquired a strong background in the development and evaluation of GPR equipment, in the signal processing and enhancement of GPR signatures, and in the understanding of the earth's electromagnetic properties that affect the performance of these systems.

■ **Police Radar** GTRI has worked closely with the U.S. Department of Transportation to assist in training police operators in the proper use of police radar. GTRI personnel have served on the National Highway Traffic Safety Administration's expert review panel



on police radars tasked with reviewing radar training material disseminated by that agency.

■ **Weather Radar** GTRI has supported the NASA Langley Research Center in investigating dangerous changes in wind speed and direction (known as wind shear) and the hazards they present to aviation. GTRI was part of a multi-contractor team which reviewed NASA test plans and evaluated proposed signal processor designs for a real-time airborne wind shear radar detection and warning system. GTRI is under contract to assemble and program two real-time digital signal processing and display computers for use in the flight test of an airborne wind shear radar detection and warning system. In addition to the radar signal processor development, GTRI also examined novel millimeter-wave radiometry techniques for use as possible wind shear detectors.

■ **Ultra Wideband (UWB) Radar** UWB radar uses a large bandwidth signal (i.e., larger than 25 percent of the carrier frequency) and offers the potential for improved clutter suppression and range profiling, and greater foliage, earth, and water penetration. GTRI has been involved in research related to this type of radar since 1983, including investigations of target characteristics, combined waveform and antenna design for ambiguity control, and overall system architecture and performance estimates. UWB radar systems have been studied by GTRI for air defense applications through the development and assessment of point designs, analysis of foreign technology development efforts, and support of UWB radar clutter data collection.

*GTRI modified an AN/MPS-36 tracking radar for the White Sands Missile Range. The tracking performance was significantly improved by converting to a three-channel monopulse system with low noise preamplifiers.*





■ **Fire Control Radar** The U.S. Army Strategic Defense Command is currently being supported in the development of large phased-array acquisition and fire control radar systems for strategic and theater missile defense applications. GTRI supports the Ground Based Radar Project Office through assistance in the development of the antenna, transmitter, receiver, and signal processor for a family of wideband phased-array radar systems. GTRI has developed sophisticated analytical and modeling techniques to address the interaction of phased-array measurement error with system-level fire control performance. The development of alignment and calibration techniques to facilitate dynamic sensor/seeker registration has been one area of emphasis.

GTRI is actively involved in U.S. efforts to develop fire control radars for theater missile defense as well as strategic defense. This work emphasizes the development of robust registration techniques to support hit-to-kill interceptors in a countermeasures environment. The capabilities of these radars have been assessed in support of strategic test range and space surveillance missions. GTRI also supports the Kinetic Energy Weapons directorate in the development of precision tracking radars to provide hypervelocity weapon fire control. These efforts are concerned with advancing the state of the art in resolution and accuracy achievable with phased array radar systems. GTRI research has also supported PAVE PAWS and other ballistic missile surveillance radar systems.

■ **Airborne Radar** The F-15 program is being supported by GTRI through several projects at Warner Robins AFB. In one project, the obsolescence of the APG-63 radar of the F-15C/D was investigated from two standpoints: spare parts availability and the ability to counter the latest threats. Memory boards are being redesigned by GTRI to use avail-

*GTRI has supported development of the Marine Air Traffic Control and Landing System (MATCALS) for more than 15 years.*





able parts as an interim solution, and specifications are being prepared for the long term solution—a major upgrade program. A trade-off assessment of approaches to support the reprogrammable avionics in the F-15E was also performed. Two specifications were generated: one for the APG-70 radar Avionics Integration Support Facility and one for the remainder of the avionics. This task required a thorough understanding of the avionics integration approach; in particular, the interfacing of the central computer to the avionics via MIL-STD-1553 and other buses.

■ **Antenna Arrays** Array polarization computer models have been developed, array polarization predictions have been completed for two specific arrays of interest, and the relative susceptibilities of these two array radars (and a third for which measured data were available) to cross-polarization countermeasures has been determined. The GTRI array polarization model accounts for the polarization effects from all major components of the array. The array configurations include one which is the assessed configuration of most land- and ship-based advanced threat radars and one which can be used in U.S. simulators.

■ **Bistatic Radar** Over the years, bistatic radar has been proposed as one method of solving the Anti-Radiation Missile (ARM) threat and as a means of detecting low-observable targets. A major issue for bistatic radar is the degree of coherency required between transmitter and receiver to achieve range correlation and adequate Doppler processing. While systems have been built that demonstrate the feasibility of cooperative bistatic radar, the degree of coherency needed for a noncooperative bistatic radar is still unknown. Bistatic radar clutter is also not understood well enough to define dynamic range requirements for the bistatic radar application.

To assess these basic bistatic radar issues, GTRI developed a bistatic/digital beamforming test bed array using approximately \$500,000 of internal funding. The eight-element antenna array is configured in two rows of eight microstrip dipole elements with element pairs summed to provide a narrow elevation beam. A ninth receiver channel, using a horn antenna, is dedicated to receiving pulses from the noncooperative transmitter. The signal from each of the eight element pairs is downconverted, digitized, and stored in a computer. Beamforming and range correlation are performed in the computer as post-measurement processing. Aircraft data are processed using range correlation and beamforming algorithms developed by GTRI to bistatically detect and locate targets of interest. Truth data, available from local FAA radars, will be compared with the data processing results. As part of this research, GTRI developed calibration algorithms that more precisely locate targets in angle.

A similar 8x8 64-element digital beamforming (DBF) array was also designed for the U.S. Army. Under two separate contracts, GTRI designed the array, the receiver interfaces, and the digital signal processing hardware. A simulation of the array was developed to analyze the impact of quantization effects on beamforming performance in the presence of phase noise.

■ **Aircraft Landing Systems** The Space and Naval Warfare (SPAWAR) Systems Command has been supported for more than 15 years by GTRI in the acquisition of the Marine Air Traffic Control and Landing System (MATCALS). During this time, GTRI has been actively involved in analysis, specification, and testing of the MATCALS radar systems, including the Air Traffic Control Subsystem (ATCS), the Precision Approach Radar Sub-

*To better assess  
bistatic radar issues,  
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forming test bed array.*



*GTRI personnel have extensive experience in the design, development, and fabrication of full-scale threat simulators.*

system (PARS), and the Secondary Surveillance Radar (SSR) system.

The Precision Approach Radar Subsystem (AN/TPN-22) was the first active radar component of MATCALs to be acquired by SPAWAR, and GTRI was actively involved in the testing and analysis of this system. Prior to selection of a specific radar system, GTRI performed several extensive analyses of available landing systems. After the AN/TPN-22 radar system was selected as the PARS, GTRI continued to support SPAWAR in the acquisition of the system. GTRI created a sophisticated computer simulation for analysis of tracking radar performance, which included modeling of the radar's unusual "edge tracking" technique. GTRI performed a series of field tests on the effect of multipath interference on the AN/TPN-22 in the vicinity of touchdown. These tests utilized a unique target radar cross section enhancer designed and built at GTRI.

At the same time, GTRI began supporting SPAWAR in the acquisition of the Airport Surveillance Radar (ASR) portion of the ATC Subsystem. As a preliminary step in the ASR acquisition, GTRI analyzed and compared the performance of all domestically available off-the-shelf ASR systems, including the AN/ASR-7, AN/ASR-8, AN/TPS-44, AN/TPS-59, and AN/TPS-65 systems. Detection performance predictions of these systems were produced using a GTRI-developed computer simulation. GTRI assisted SPAWAR in generating a set of technical specifications for the acquisition of the ASR subsystem, specifically the generation of analytical models for land and rain clutter. Once the ASR Request for Proposal was released, GTRI continued to provide technical support to SPAWAR, contributing to the proposal evaluations and then to the preliminary and critical design reviews of the system selected, the AN/TPS-73. GTRI continues to support the development of this radar system through the developmental test and evaluation (DT&E) process.

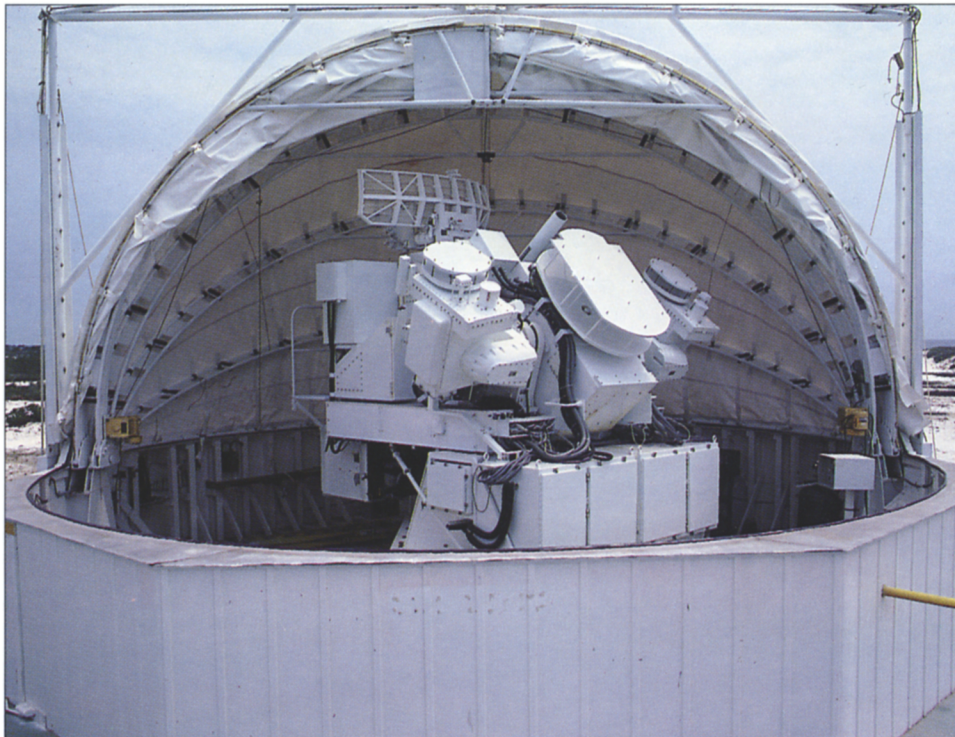
■ **Radar Simulator Systems** GTRI personnel have extensive experience in foreign material exploitation (FME) through the design, development, and fabrication of full-scale threat simulators. Threat simulator design begins with analysis of available information from open literature searches and intelligence sources. Knowledge of electronics systems

### Radar Antenna Simulations

*GTRI has built radar antenna simulations for the threats listed below.*

Long-Range	Acquisition	Target and Missile Track	Command	Seeker
Flat Face	Flap Wheel	Fan Song E-Mod	Land Roll	Guideline Missile
Head Net C	Land Roll	Flap Wheel	Low Blow	
	Pop Group	Land Roll	Peel Group	
	Straight Flush	Low Blow		
		Pat Hand		
		Peel Group		
		Pop Group		
		Straight Flush		





Top Photo: *GTRI researchers built the XM-04 “work-alike/look-alike” radar simulator.*  
Bottom Photo: *The Simulated Air Defense System VIII (SADS VIII) radar simulator was developed by GTRI for the U.S. Air Force.*

from the particular country and postulation of features based on experienced engineering is then factored into the simulator design. Threat simulators developed at GTRI have ranged from replications of the RF portion of the threat (radar transmitter and associated antenna) to complete systems having the same electrical and electronic parameters as the actual threat and conforming to the external visual characteristics.



For the U.S. Air Force, GTRI researchers developed the Simulated Air Defense System VIII (SADS VIII). This simulator is a surface-to-air missile system threat simulator consisting of target acquisition and tracking radars, missile capture and tracking radars, RF target and missile simulators, and command guidance subsystems. Typical of modern simulators, SADS VIII includes embedded computer systems to provide improved radar system control, built-in test capabilities, and recording of critical operational mission data. GTRI has also built “work-alike/look-alike” simulators, such as the XM-04 and the XM-08, for the U.S. Army.

■ **Physical Security/Intrusion Detection** GTRI has been involved in physical security and border integrity control for many years, specifically in the areas of analysis, sensor development, and testing. In one program, GTRI assisted the U.S. Customs Bureau in the technical evaluation of competitive proposals from industry bidders on an upgrade for the Customs Service Aerostat Radar. This upgrade involved the evaluation of certain deployment considerations and system hardware modifications for border surveillance.

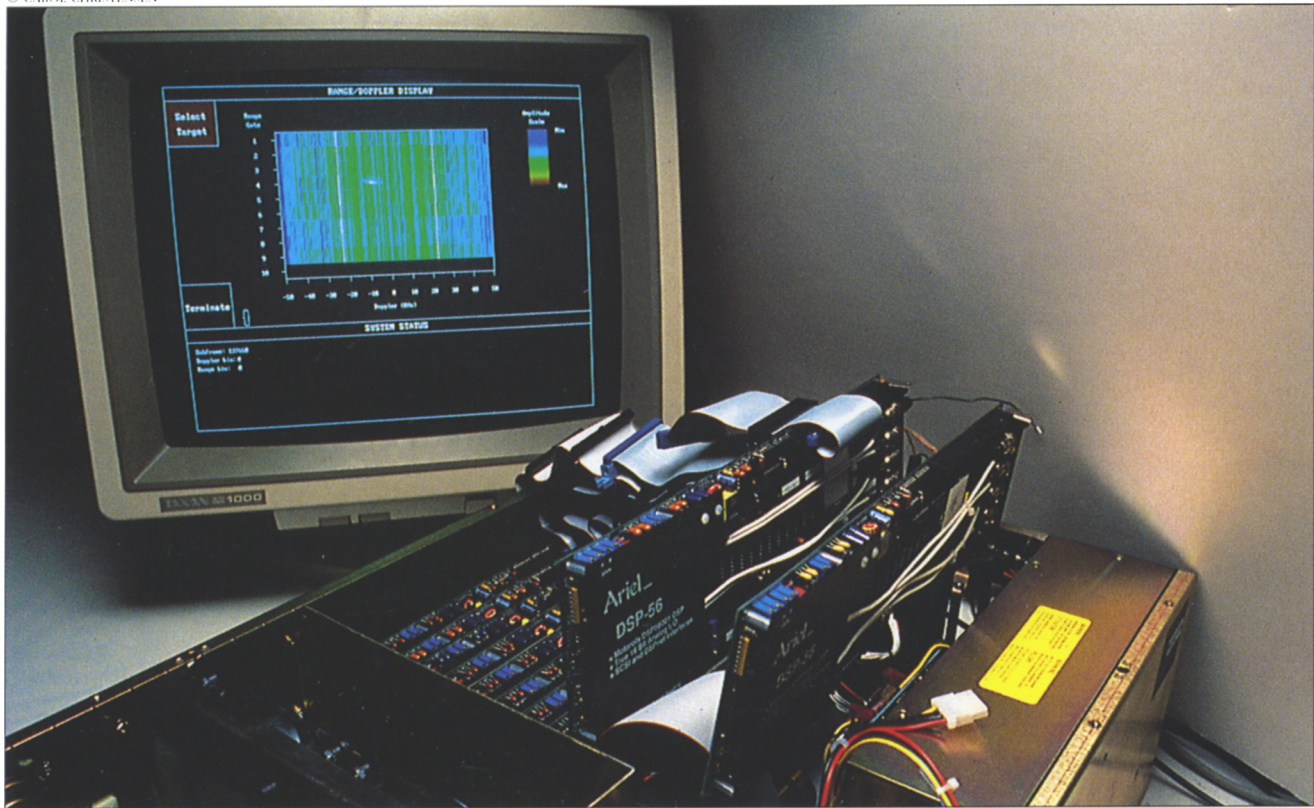
GTRI also provided technical support to the Naval Ocean Systems Center (NOSC), Kailua, Hawaii, in the development of an automated radar surveillance system for the Waterside Security System (WSS). Support to NOSC included the generation of a specification for the automatic target extractor and tracker called the Local Radar Track Processor (LRTP), assistance in acceptance tests of an LRTP unit developed by Folsom Research, Inc., making recommendations for LRTP upgrades to Folsom Research, and preparing a

*GTRI helped the U.S. Customs Bureau evaluate components used in an aerostat radar for border surveillance.*





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"B" specification for the entire WSS Radar Element including the LRTP, radar, and peripherals. The WSS will contain multiple radars, sonars, and imaging sensors netted together into a single highly automated C<sup>3</sup>D (command, control, communications, and display) system for the detection of potential terrorist threats to Navy assets.

In related work, a netted radar base surveillance system was developed for the U.S. Air Force Space and Missile System Organization (SAMSO). This Long-range Area Radar for Intrusion-detection And Tracking (LARIAT) security system included signal processing algorithms that controlled radars in the net and automatically alerted the operator when a target track was detected within the surveillance area. The system was successfully demonstrated with two radars and was conceptually expandable to 10 radars. The netted surveillance system provided automatic tracking and analysis of both radar returns (skin-returns) and beacon returns (from radar beacon responders used for selected security forces).

*A real-time Generic Doppler Processor developed at GTRI simulates all types of Doppler processing methods in a single hardware configuration.*

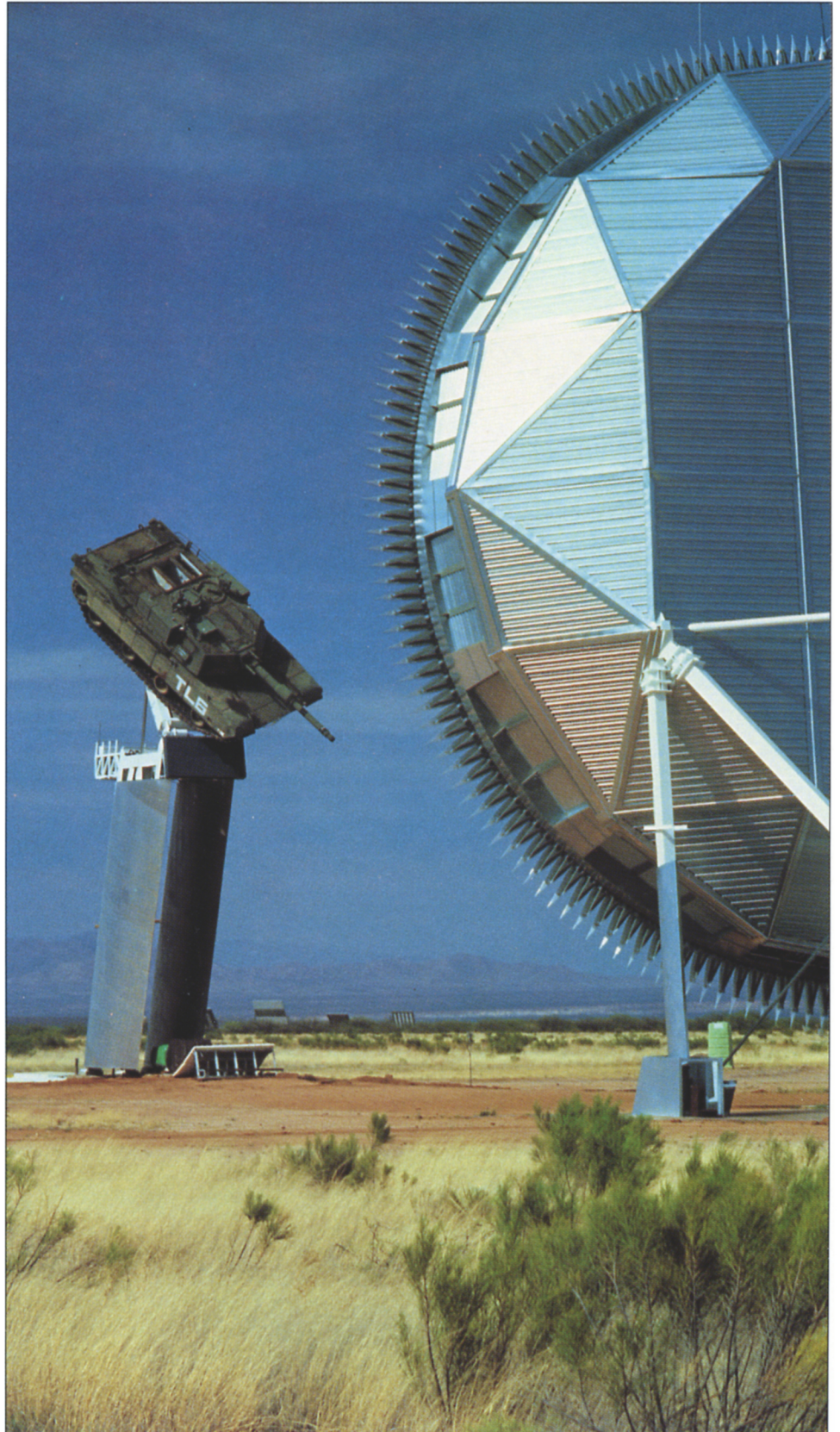
GTRI's work in antenna design, analysis, and development has a long history dating back to World War II. GTRI personnel are widely recognized for their innovative work in the areas of geodesic lenses, compact range technology, near-field probing and antenna diagnostics, and reflector and phased-array antenna technology.

Recently, GTRI engineers completed delivery, installation, and initial testing of one of the world's largest compact ranges. Built for the U.S. Army Electronic Proving Ground at Fort Huachuca, Arizona, the range will allow testing of microwave and millimeter-wave

## Special Subsystems and Components



*GTRI's work in antenna design, analysis, and development dates back to World War II.*



*GTRI engineers recently designed and built one of the world's largest compact ranges at Fort Huachuca, Arizona.*



antennas mounted on full-size aircraft, tanks, and other vehicles. The system includes an offset-fed parabolic reflector 75 feet in diameter, a novel positioner capable of supporting up to 70 tons, a set of five feed horns to cover frequencies from 6 to 40 GHz, and complete instrumentation.

■ **High Power Transmitters** GTRI's extensive experience in the development of high power radar transmitters includes very high pulsed-power magnetron transmitters and coherent systems employing klystron amplifiers, traveling wave tube amplifiers, and crossed-field amplifiers. Frequency coverage spans the low microwave frequencies up to the upper millimeter-wave (MMW) frequencies. For example, systems operating at frequencies up to 220 GHz have been developed using extended interaction klystrons. GTRI expertise includes high voltage power supply and modulator design as well as high-power microwave circuit design.

GTRI has also conducted investigations of potential applications for MMW sources with peak powers on the order of a gigawatt. This power level is representative of MMW devices such as the free electron laser and the cyclotron auto-resonance maser under development at the Lawrence Livermore National Laboratory. GTRI investigations included reviewing technical requirements, investigating potential uses, and performing trade-off evaluations of system parameters.

■ **Generic Doppler Processor** For particular radar applications, system designers need to know which type of Doppler processing is best before committing to a final processor approach. By using a Generic Doppler Processor that implements a selected processing method through programmable Digital Signal Processing (DSP) modules, processor architects can easily evaluate many different approaches and scenarios. The real-time Generic Doppler Processor developed at GTRI allows easy assessment of the interaction of any desired signal (including ECM signals) with most of the popular Doppler processing methods. The processor uses an industrial-grade desktop computer configuration with a separate DSP card for each range gate. The processor permits rapid changes of Doppler processing specifications such as Doppler bandwidth and center frequency, windowing, number of bits of quantization, and the output display type and format. Users can select among Fast Fourier Transform, analog filter bank, and correlator-type filter methods.

■ **Quasi-Optic Techniques** As the operating frequencies of experimental radar systems increase, the methods of implementation must change from conventional radar practices of lower frequency systems. GTRI researchers have explored the use of quasi-optical signal processing techniques for high-frequency radar applications. For example, a 225 GHz pulsed coherent radar developed at GTRI includes in the design a quasi-optical circular polarization duplexer with an antireflection-coated sapphire quarter-wave plate and polarizing metal wire grid array to separate the transmit and receive signals. Both the antenna and the duplexer were fabricated with quasi-optical components to minimize losses normally associated with waveguides used at this frequency.

*GTRI researchers have explored the use of quasi-optical signal processing techniques for high-frequency radar application.*



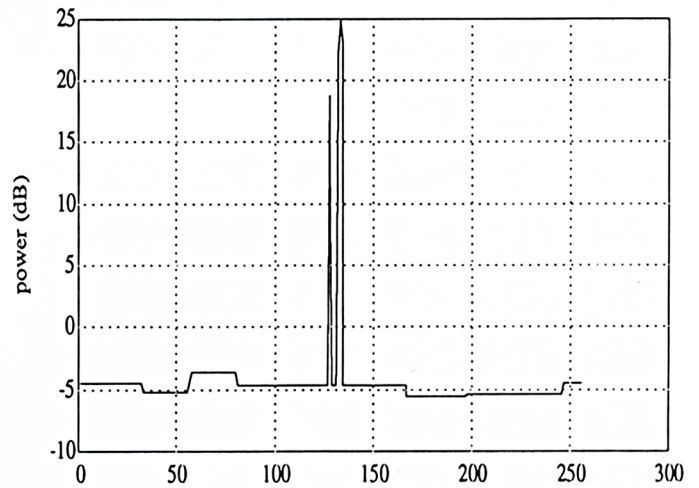
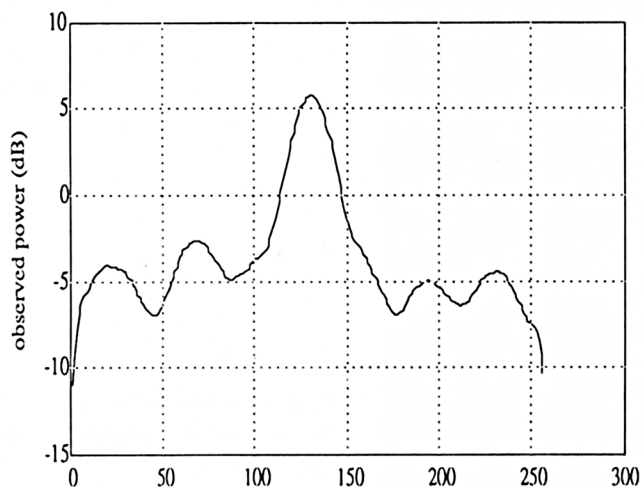
## Radar Vulnerability Assessment

GTRI has an extensive background in assessing a radar system's ability to effectively operate and survive in a hostile electronic warfare (EW) environment. GTRI has been deeply involved with Army systems developed over the past 20 years and is familiar with systems currently in development, including Improved FIREFINDER, Forward Area Air Defense System (FAADS), Joint Surveillance Target Attack Radar System (JSTARS), MEDFLI, GUARDRAIL, TEAMPACK, LABCOM Cooperative programs, and Strategic Defense Initiative (SDI) systems.

GTRI is also familiar with a wide variety of U.S. and foreign Intelligence and Electronic Warfare (IEW) and Reconnaissance, Surveillance, and Target Acquisition (RSTA) systems, including the AN/PPS-5, the AN/PPS-15, the AN/TPS-25, and the AN/TPS-58. GTRI has performed extensive analyses of threat radar system vulnerability to ECM. Under contract with the Air Force, GTRI has developed a systematic methodology for identifying detailed vulnerabilities of radars.

*The figure on the left shows a simulation of two closely spaced point targets (unresolved) in ground clutter as sensed by a millimeter-wave radar. After super-resolution processing (right), the two targets can be resolved.*

The Vulnerability Assessment Laboratory is being supported by GTRI in its mission to provide independent assessments of the vulnerability of U.S. Army and foreign weapons and electronic communications systems to hostile electronic warfare. GTRI is also assisting hardware developers in formulating ECCM requirements, in developing ECCM technology, and in providing ECCM hardening recommendations throughout the life cycle of electronic communications systems. Systems being supported include the Forward Area Air Defense System - Ground Based Sensor (FAADS-GBS) and the Battalion Targeting System (BTS). Implicit in these activities is strong communication among the ECM, ECCM, radar, and threat communities. Under contract with the Air Force, GTRI has developed a system-





atic methodology for identifying detailed vulnerabilities of radars.

■ **Low Probability of Intercept (LPI)** GTRI's Intra-pulse Polarization Agile Radar (IPAR) concept has been implemented in two X-band instrumentation radar systems. The prototype was used to collect a comprehensive set of data characterizing calibrated reflectors in a variety of physical environments. In addition, IPAR returns were collected from man-made targets and sea clutter. The wideband modulation process utilized in the IPAR system induced rapid decorrelation of the clutter signal without degrading the target signal.

As a result of the prototype's success, an advanced version of the IPAR system was developed. This AIPAR system employs VHSIC technology and state-of-the-art, high-speed correlators to achieve polarization modulation rates of up to 100 MHz, corresponding to compressed pulses as short as 10 ns. As with the prototype, wideband noise modulation of the carrier is used to enhance the system's LPI capabilities.

The IPAR system transmits a pulse that is encoded by polarization modulation on a subpulse basis. The coding is utilized to compress the received return signal. This technique differs from conventional pulse encoding on a carrier-phase basis. With the IPAR technique, coding is based on the relative phase between horizontal and vertical polarization components of the transmitted pulse. Consequently, the IPAR process can be implemented with a wide variety of RF waveforms. Since the code information is contained in the relative phase between horizontal and vertical polarization components, the RF carrier's absolute phase and frequency are unimportant. It is thus possible to modulate the RF carrier for other purposes. For example, frequency agility can be employed to achieve clutter decorrelation without affecting the transmitted code. In addition, it is possible to

*GTRI has performed extensive analyses of threat radar system vulnerability to electronic countermeasures.*



*GTRI researchers use the ECM Vulnerability Assessment Data Encyclopedia (EVADE) to retrieve specific ECM/ECCM test results.*



*GTRI is a leader in developing a novel approach for improving the angular resolution of a scanning radar.*

modulate the RF carrier with random phase noise, thus spreading the transmitted spectrum and reducing the detectability of coded information.

■ **ECM/ECCM** The Air Force Wright Laboratories, with GTRI's participation, has established at its Avionics Directorate a center for airborne radar electronic counter-countermeasures (ECCM). This jointly operated center provides a focal point in research efforts to assess the vulnerability of radar systems to electronic countermeasures (ECM), develop hardware implementations of ECCM techniques, and investigate the effectiveness of advanced ECCM concepts. In support of this center, GTRI has participated in a series of research programs to:

- Analytically evaluate candidate ECCM technique performance via modeling and computer simulation.
- Create a pulsed Doppler laboratory for implementing ECCM techniques in both hardware and software.
- Provide an electromagnetic test facility at its Cobb County location that includes a 1400-foot antenna range, a 100-ton capacity turntable, and radar systems with frequencies between 1 and 100 GHz.
- Develop an Air Force standard ECM and ECCM data base.
- Determine the vulnerability of a radar system to a set of ECM techniques.
- Provide a quick response evaluation capability to the Air Force in ECCM technology.

■ **Digital Beamforming** In support of a bistatic radar research program, digital beamforming concepts have been developed using GTRI internal funds. Time-tagged data were stored in core memory of a minicomputer for off-line processing to determine the target azimuth and for pulse correlation to determine bistatic range. Innovative array calibration techniques that use the eigenstructure of the data to achieve enhanced resolution were shown to improve resolution performance. Superresolution algorithms were developed to perform in real time on large arrays, and research was performed to understand sidelobe degradation in conformal arrays.

■ **Superresolution** GTRI is a leader in investigating and developing a novel approach for improving the angular resolution of a scanning radar. This method, known as Fast Constrained Iterative Deconvolution (FCID), already is in use in such fields as radio astronomy, spectroscopy, and image processing. It is being adapted to the needs of small millimeter-wave seekers and noncoherent radars, for which conventional synthetic aperture techniques are impractical. FCID also has applications in the Synthetic Vision landing aid program and to radiometers and infrared sensors.



*This gray-scale representation of a modeled Inverse Synthetic Aperture Radar (ISAR) image of an F-15 jet aircraft is used in the development of multi-attribute target identification techniques.*



## Radar Signal Processing

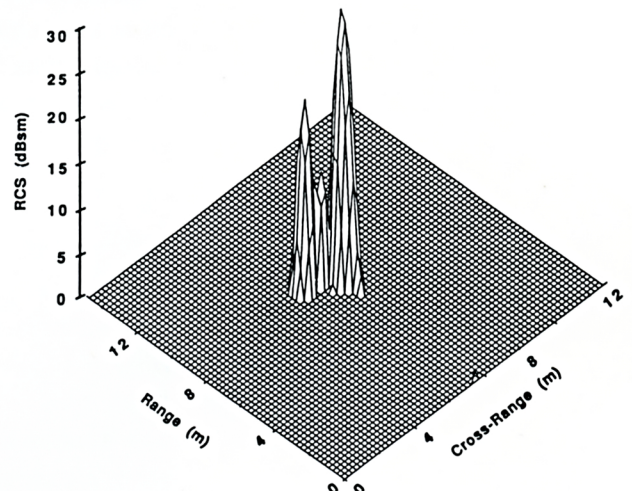
Radar signal processing investigations conducted at GTRI range from consulting for government or industry on the development of new analytical techniques to testing signal processing concepts in hardware implementations. Some recent programs include the following:

■ **ISAR Imaging** GTRI has extensive experience with Inverse Synthetic Aperture Radar (ISAR) imaging, including data collection, advanced image formation algorithms, and image data compression. Much of this experience has been gained in programs concerned with characterizing the radar cross section of various vehicles, either at GTRI's own Electromagnetic Test Facility or on radar ranges at various sponsor facilities. GTRI's radar signature modeling software includes an ISAR image prediction capability which has also been used to develop computer-based tabletop tools for training naval radar operators in ISAR image interpretation.

■ **Use of Fractals in Stationary Target Detection** GTRI has applied a new technique involving fractal geometry to the problem of stationary target identification. In this technique, target and clutter radar signatures are replaced by equivalent fractals through an interpolation technique. The fractal dimension (a measure of orderliness of a given geometry) is then computed and used to sort manmade targets and clutter.

■ **Multi-Attribute Identification of Fixed-Wing Aircraft** Using techniques developed for Non-Cooperative Target Recognition (NCTR), GTRI has been developing similar NCTR techniques for multispectral identification of fixed-wing aircraft under the Multi-Attribute Identification and Analysis (MAIDA) program with the U.S. Air Force.

■ **Real-Time Wind Shear Radar Detector** Under a program for NASA, GTRI participated in a multi-contractor team which evaluated signal processor designs for a real-time airborne wind shear radar detection and warning system. Algorithms and computer processor capacity were reviewed, and architecture was developed for in-flight use.



*This three dimensional plot shows an Inverse Synthetic Aperture Radar (ISAR) image of three corner reflectors.*



## Radar Phenomenology

**R**adar phenomenology involves the study of a number of physical systems affecting the transmission of radar energy between the radar system and the target, target reflection characterization, and the clutter backscatter environment. GTRI is actively involved in measurements of radar phenomena, analysis and modeling of measured data, and simulations of the systems involved.

### Propagation

**G**TRI has conducted research and measurements of radar propagation phenomena for a number of years to characterize conditions affecting propagation such as attenuation, backscatter, atmospheric turbulence, and multipath. Recent investigations have addressed the characterization of the fluctuations of MMW signals propagating through inclement weather and turbulence-induced scintillation effects.

For example, GTRI is supporting NASA-Langley in the design, development, and deployment of an instrumentation radar to characterize the plasma boundary layer which forms around reentering spacecraft. The system, to be deployed in a small craft from a future shuttle mission, will measure the distance to the point of highest reflection in the boundary layer. The instrumentation radar operates at frequencies of 20, 44, 95, and 140 GHz with sufficient bandwidth to allow range measurement accuracies of better than one centimeter.

### Measurement of Target and Clutter Characteristics

**T**he GTRI radar labs have a number of facilities to support phenomenology characterization work, including:

- **Electromagnetic Test Facility** — The EMTF consists of a 1400-foot antenna range and 150-foot look-down turntable range (the turntable can support tactical targets weighing up to 60 tons).
- **Rooftop laboratory** — Radar test facility with full view of EMTF towers for propagation experiments.
- **Instrumentation radars** — Covering the frequency range of 5-140 GHz.
- **Data acquisition and analysis facility (DAAS)** — Minicomputer-based radar digital DAAS with magnetic tape and optical disk storage.
- **Data analysis workstations** — Sun Sparc workstations operating under Unix with full analysis software capabilities.
- **Radar test van** — 40-foot electronics van equipped with generator, heat/AC, kitchen facilities, and modular rooms for computer and radar equipment.

GTRI's measurement radar systems range from 5 to 140 GHz. In addition to the lower frequency measurement systems at 5, 10, and 16 GHz, MMW instrumentation radars are



also available, including noncoherent radars at 35, 95, and 140 GHz and coherent radars at 35 and 95 GHz. All but the 35 GHz noncoherent radar contain a programmable pulse repetition frequency, range delay timing, and video sampling circuits. The two coherent radars also have computer interfaces which allow automatic control of frequency, polarization, and range gate position. All GTRI radars have manually adjustable precision RF attenuators for calibration, and most have interchangeable antennas for selecting beamwidth. The 95 and 140 GHz noncoherent radars use separate antennas for transmit and receive, thus maximizing sensitivity, while the other radars have antenna multiplexers.

The GTRI radar labs also have extensive digital data collection and analysis facilities for collecting real-time coherent radar data, and Sun workstations that provide extensive data analysis and RCS prediction capabilities. A number of instrumentation radar vans are available for supporting tests at remote sites.

■ **Experience and Capabilities** GTRI has extensive experience in performing RCS measurement programs involving characterization of both targets and clutter. Recent experience has included work in the following areas:

- 2-D and 3-D high-resolution, coherent RCS measurements of military vehicles.
- Full polarization measurements and processing.
- Clutter and propagation measurements (ground, sea, snow, and atmospheric).
- RCS test design and calibration validation.
- Doppler measurements.

In recent years, GTRI has made numerous contributions to the smart munition community by measuring high-quality, high-resolution, polarimetric backscatter data for many foreign threat vehicles. These data are being used to perform detection analyses, to develop target recognition algorithms, and to evaluate the effects of countermeasures on system performance.

*GTRI's measurement radar systems operate in the 5 to 140 GHz range.*

### GTRI Clutter Measurement Programs

Description	Sponsor	Year
MMW Rain Reflectivity . . . . .	US Army Frankford Arsenal	1974
MMW Foliage Backscatter . . . . .	US Army Frankford Arsenal	1975
MMW Snow Backscatter . . . . .	US Air Force Armament Lab	1976
MMW High Angle Foliage . . . . .	US Air Force Armament Lab	1976
MMW Foliage Penetration . . . . .	MIT/LL	1977
MMW Sea Reflectivity . . . . .	US Navy, NSWC Dahlgren	1978
Misers Bluff Explosive Cloud . . . . .	DOE via SRI	1978
MMW Snow Backscatter & Emissivity . . . . .	US Air Force Armament Lab	1978
MMW Airborne European Terrain (TABILS 11)	US Air Force Armament Lab	1981
MMW Sea Ice Backscatter . . . . .	Canadian Government	1983
SNOWMAN Desert Backscatter . . . . .	US Army MICOM	1983
SNOWMAN Snow Tower Backscatter . . . . .	US Army MICOM	1984
SNOWMAN Snow Airborne Backscatter . . . . .	US Army MICOM	1984
FAADS - Forward Heavy Backscatter . . . . .	US Army MIA	1988
Aerostat Clutter Measurements . . . . .	US Air Force Rome Labs	1991



GTRI's influence in the MMW community has led to widespread adoption of the Massachusetts Institute of Technology/Lincoln Labs Pulse Doppler Modulation calibration technique. As a result, data produced by different organizations now compare much more closely. GTRI and its sponsors in the RCS signature community are prepared to rapidly provide high-quality signature data on new threat vehicles as they become available for testing.

## Modeling and Analysis

GTRI employs numerous computer models for the purpose of modeling radar performance, target backscatter characteristics, aircraft/radar engagements, and ECCM techniques. For over 20 years, GTRI has been involved in modeling the radar cross section of complex targets and in the design and evaluation of signature control techniques to be applied to those targets. Efforts have involved vehicles as diverse as ships, tanks, fixed and rotary wing aircraft, and missiles.

■ **Radar Cross Section (RCS) Modeling** RCS modeling is accomplished using a GTRI-developed software package containing two major computer programs. A surface modeler and data base editor called MAX is used to input and manipulate target geometry. An RCS prediction program called TRACK is used to calculate radar cross section and predict radar detection and tracking performance. All of the software is written in the C programming language and is designed to run on engineering workstations in a Unix environment.

MAX is used to describe the target geometry in terms of a collection of surface primitives. Available primitives include flat polygonal plates, cone frusta (for which cones and cylinders are limiting cases), ellipsoids, edges, interacting flat plates (e.g., dihedrals and

### GTRI Target Measurement Programs

Description	Sponsor	Year
MMW Military Vehicles . . . . .	US Air Force Armament Lab	1977
LCAC RCS Measurements . . . . .	US Navy NCSC	1980
RCS of Marine Amphibious Landing System (MARS) . . . . .	US Navy NCSC	1982
RCS of Waterborne Intrusion Targets . . . . .	US Navy NCSC	1982
HAWFCAR Target Measurements (MMW) . . . .	US Army via Westinghouse	1983
SNOWMAN Target Measurements . . . . .	US Army MICOM	1984
Chicken Little I (MMW & IR) . . . . .	Joint Program Office	1984
Rains Effects on Tank Signature . . . . .	US Army MICOM	1985
Special Target Measurements (MMW) . . . . .	Joint Program Office	1986
Rotary-Wing Target Doppler Measurements . .	US Army MICOM	1990
Chicken Little II (MMW) . . . . .	Joint Program Office	1991



Model	Description
INTERCEPT	Fighter/target engagement model. Five fire control system configurations modeled.
MERGE	Surveillance and Tracking Radar simulation which produces detection capability predictions and tracking error estimates.
SAMURAI	Simulation and modeling of specific targets for radar analysis investigations. Detailed complex scatter representation.
LAMP	Low angle multipath and clutter model using monopulse radar.
GAISER	Generic airborne interceptor search radar. Simulates encounter between an airborne sector search radar employing sidelobe blanking and a single target utilizing ECM equipment.
ILLCH	Illuminated Chaff Model. Program used to evaluate the effectiveness of Chaff as a jamming agent against a threat system radar.
PHASED ARRAY ANALYSIS	Model for computing the far-field patterns and analyzing the tracking accuracies of phased-array antenna.
GEM	General Effectiveness Model. Used to analyze the effectiveness of manual and automated EW systems on EW/GCI radars, tracking guidance radars associated with surface-to-air missile, air-to-air missile, anti-aircraft artillery systems.
MAX	Geometric Data Base Editor. Hierarchical data base graphics editor used to create, display and modify computer models of 3-D objects.
TRACK	Radar cross-section and radar tracking computer simulation. Open loop missile fly-in with monopulse tracking radar.
TERRAIN COUNTER-MEASURES MODEL	Simulates detection performance of MMW seekers in various target and terrain background scenarios.
AECM	Airborne Electronic Countermeasures Model. Simulates a modern, airborne pulse Doppler monopulse radar in an EW environment.
AIM-7F	Models the performance of the AIM 7F Sparrow missile.
AIM-7M	Models the performance of the AIM 7M Sparrow missile.
RADAR	Computes complex radar return using multiple stationary receiver elements in an EW environment.
HELIO-SIM	Simulation of airborne rotary wing aircraft for radar performance studies. Detailed dynamic elements represented for accurate Doppler signature, computes complex I/Q return.

*GTRI employs numerous computer models to model radar performance, target backscatter characteristics, aircraft/radar engagements, and ECCM techniques.*





Above: GTRI researchers use a computer model of the F-15 jet aircraft for predicting radar cross section.

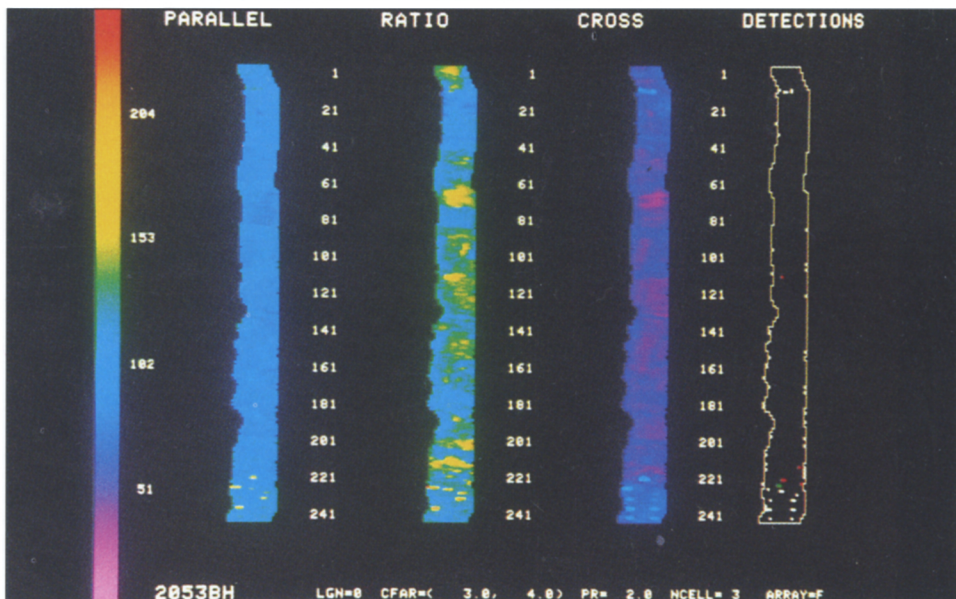
Below right: In this graphic display of GTRI's SEEKER program output, the first and third columns are maps of the parallel-polarization and cross-polarization reflectivity data used as input to the simulation. A ratio of these two channels is displayed in the second column. Signal processor output appears in the fourth column: white dots are detections, the green dot is a missed detection, and red dots are false alarms.

trihedrals), and top hats (interacting cylinders and flat plates). Recently, a general doubly curved surface—the Hermite patch—was added to allow the efficient description of blended bodies. MAX data files, which describe the target geometry, are generally constructed from drawings, pictures, or models. Work is underway to allow MAX to utilize the most common IGES (Initial Graphics Exchange Specification) data output formats used by many computer aided design packages. MAX utilizes a hierarchical tree structure to describe the target, and all scatterers are uniquely named, thus allowing easier identification of major scattering centers for diagnostic purposes.

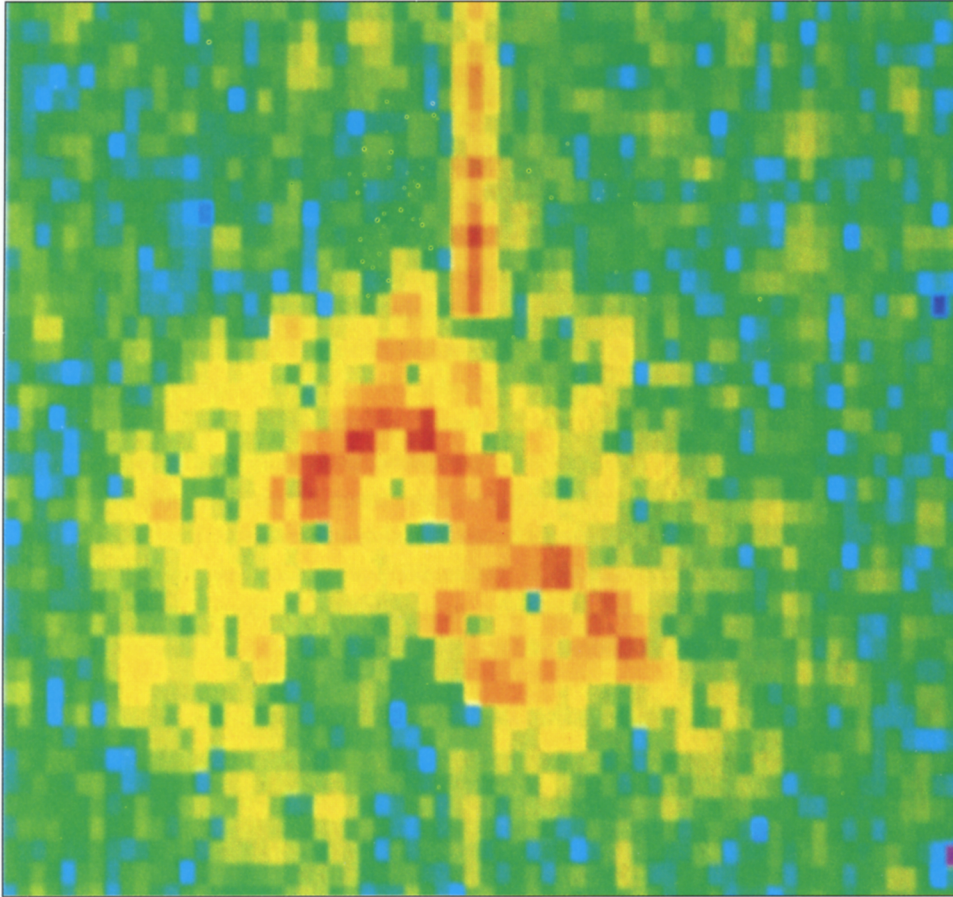
The two major methods of signature control are shaping and the use of radar absorbing materials (RAM). The flexibility of target manipulation provided by MAX allows changes in the target configurations to be easily made so that the effects of shaping on the signature can be explored. ISAR images or high range resolution plots may be used to locate major scattering centers. Each scatterer is also accompanied by a material file which describes its reflectivity properties. Material file look-up tables can be created to provide RAM attenuation factors as a function of material type, frequency, polarization, and incidence angle.

The TRACK code is based on a combination of physical optics and the method of equivalent currents, and calculates the RCS as the phasor sum of the returns from all of the visible individual primitives. TRACK is fully bistatic and has been used to predict scattering at all bistatic angles—including forward scatter—as well as the more common monostatic backscatter case.

TRACK has several features not typically found in RCS codes. For example, the effect of specular multipath from the earth's surface on RCS and on monopulse tracking error can be calculated. Also, full polarization scattering matrix data are available in a single prediction. And last, the RCS code is integrated into a program which allows radar detection performance and radar tracking to be simulated. Data output can be post-processed in a number of different formats, including SAR and ISAR images, high range resolution plots, and conventional polar and rectangular RCS plots.







*High-resolution millimeter-wave measurements have been taken at GTRI to create pulse-compressed Inverse Synthetic Aperture Radar (ISAR) images. The one shown in the large photograph at left is of the Volkswagen convertible seen in the photograph below. (Radar was located at the top of the photo.)*



RCS validation efforts have been successfully carried out for ship, armored vehicle, helicopter, and missile targets using radar data generated by GTRI and other organizations. Tracking error validation has also been performed using data for ships and tanks. These validation efforts have resulted in a good understanding of the strengths and weaknesses of the code and an appreciation for the problems to which this software package may be usefully applied.

GTRI has developed missile simulations which include software-only and hardware-in-the-loop capabilities. These simulations serve to evaluate the effectiveness of missile guidance, kill probabilities, and ECCM capabilities. They include both batch and real-time capabilities.

Software-only simulations are useful in exploring many missile flights for statistical results and in examining many scenarios. The hardware-in-the-loop simulators achieve the highest degree of realism short of an actual missile flight. These simulators are useful in the proof-of-principle testing necessary before actual flight testing.

Both types of simulation produce large quantities of data which must be calibrated and analyzed in order to produce high-quality information. The advent of powerful personal computers has provided sophisticated analysis capabilities heretofore available only with large and costly mainframe computers.

## Simulation



■ **SEEKER Simulation** GTRI's SEEKER program simulates the detection performance of a generic millimeter-wave radar seeker signal processor against ground vehicles. Using parallel-polarization and cross-polarization channel reflectivity data as input, the program determines detections, missed detections, and false alarms.

■ **HAWK Missile Simulation** For almost a decade, GTRI has been responsible for the design, maintenance, and upgrade of the Army HAWK missile simulation. This simulation has been used extensively for test planning of RF simulation systems, testing future hardware modifications, and planning White Sands missile firings. GTRI was responsible for modeling the HAWK receiver logic (including monopulse signal processing), a complex antenna pattern, and the front receiver speedgate model so that the simulation could be used in a multitarget environment.

The U.S. Army Missile Command has also been supported by GTRI in the simulation and analysis of existing and projected future ground radars used by the HAWK air defense system. These high fidelity simulations (for the High Power Illuminator, the Continuous Wave Acquisition Radar, and the Pulse Acquisition Radar) were used to predict radar performance in the presence of specific ECM threats. GTRI also used these simulations, and simulations of the tactical software algorithms, to predict the effectiveness of planned radar upgrades and to process operational radar data.

## Target/Clutter Data Acquisition and Analysis Capabilities

GTRI has developed significant data acquisition and analysis capabilities over the years to support radar testing and hardware development efforts. GTRI digital data acquisition analysis capabilities include the following:

- Data Acquisition and Analysis System (DAAS) based on a Masscomp minicomputer capable of collecting 16 channels of data, providing real-time display of amplitude data and quick-look analysis capabilities such as calibration plots, statistics, and Fast Fourier Transform (FFT) plots, and performing extensive off-line analysis including 2-D high-resolution Inverse Synthetic Aperture Radar (ISAR) plots.



- Macintosh-based data analysis system for performing ISAR image processing. The system includes a 9-track tape drive, color display, and laser printer.
- PC-based transportable data acquisition and analysis system for collecting up to four channels of radar data and performing basic statistical functions such as density and cumulative distributions, means, medians, standard deviations, and FFTs.
- Unix Sun-based workstations for sophisticated data analysis and processing.

In recent work, GTRI has been developing the Multispectral Target Signature Measurement/Data Acquisition and Analysis System (MSTM/DAAS) for the Chicken Little Joint Project Office. GTRI researchers modified GTRI-owned instrumentation systems to provide for full polarization matrix, coherent, RCS data collection with an equivalent bandwidth of 2 GHz (0.25 foot range resolution). GTRI is also developing an automated data acquisition system with high data rates and the ability to perform a wide variety of analyses ranging from system calibration (including polarization distortion matrix and I/Q correction) to statistical analysis (such as mean, median, amplitude distribution, and Fourier transforms), to two-dimensional, high-resolution ISAR plots of target images. The MSTM/DAAS will be utilized to obtain high-quality RCS signature data of special foreign and domestic targets of military interest.

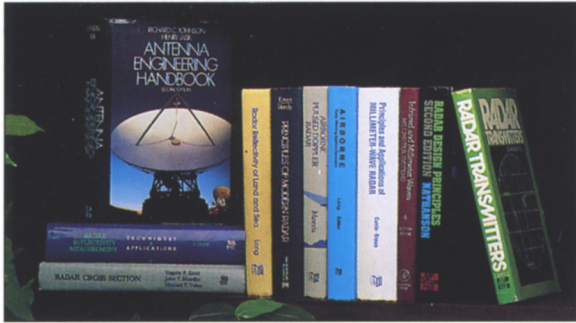
GTRI has assisted sponsors in planning, conducting, and evaluating test programs for many years. This work has included airborne programs for the Coast Guard and Navy, ground measurement programs for the Army and Air Force, and indoor/outdoor test chamber programs for both government and industry. GTRI has acted as a consultant to the Patriot Office on a series of RCS measurements by defining test objectives, helping to locate suitable facilities, developing a test plan, monitoring the measurements, and helping to evaluate results. GTRI has also assisted in the design of radar measurement facilities for a variety of customers, including Eglin AFB, Picatinny Arsenal, and the U.S. Army MICOM.

### RCS Test Range Design and Test Methodology



*GTRI has supported the HAWK air defense system for more than a decade.*





## GTRI Radar Training Programs

*GTRI researchers have authored a number of textbooks covering various radar specialties.*

The Georgia Institute of Technology offers a number of technical short courses and conferences through the Georgia Tech Continuing Education Department designed to keep engineers and other professionals up-to-date on the latest developments in a variety of fields. The short courses are staffed by senior personnel from both GTRI and the academic schools. Courses specifically related to the field of radar include:

- Advances in Millimeter-Wave Applications
- Coherent Radar Performance Estimation
- Principles of Pulse Doppler Radar: High, Medium, and Low PRF
- Radar Cross Section Reduction
- Elements of Phased-Array Radar System Design
- Principles of Modern Radar
- Polarimetric Radar Technology
- Fundamentals of Electronic Defense
- Radar Signal Processing: Theory, Technology, and Applications
- Radar Reflectivity Measurement: Techniques and Applications
- Antenna Engineering
- Principles and Applications of Millimeter-Wave Radar
- Electronic Counter-Countermeasures

### Recent Radar Books by GTRI Staff

Title	Author	Publisher	Year
<i>Radar Transmitters</i>	G.W. Ewell	McGraw-Hill Book Co.	1981
<i>Infrared and Millimeter Waves: Volume 4, Millimeter Systems</i>	K.J. Button/J.C. Wiltse	Academic House	1981
<i>Radar Reflectivity of Land and Sea</i>	M.W. Long	Artech House	1983
<i>Antenna Engineering Handbook</i>	R.C. Johnson/H. Jasik	McGraw-Hill Book Co.	1984
<i>Radar Cross Section</i>	E.F. Knott/J.S. Shaeffer/M.T. Tuley	Artech House	1985
<i>Principles of Modern Radar</i>	J.L. Eaves/E.K. Reedy (eds.)	Van Nostrand-Reinhold	1987
<i>Principles and Applications of Millimeter Wave Radar</i>	N.C. Currie/C.E. Brown (eds.)	Artech House	1987
<i>Airborne Pulse Doppler Radar</i>	G.V. Morris	Artech House	1988
<i>Radar Reflectivity Measurements: Techniques and Applications</i>	N.C. Currie (ed.)	Artech House	1989
<i>Radar Design Principles, 2nd Edition</i>	F.E. Nathanson	McGraw-Hill Book Co.	1991
<i>Airborne Early Warning System Concepts</i>	M.W. Long	Artech House	1992

## Research Facilities

Over the past several decades, the Georgia Tech Research Institute has developed extensive facilities to support high-quality radar research. These facilities include the following:

- Radar warning receiver laboratory
- Electronic defense research laboratory
- 100-dB dynamic range phase noise measurement system
- Two far-field antenna ranges
- Two planar near-field antenna ranges
- Secure compact range
- RCS turntable/range
- Model shop
- Secure computer facility (TEMPEST)
- Materials characterization laboratory
- Laser/electro-optics laboratory
- Two instrumented wind tunnels
- Sensitive Compartmented Information Facility (SCIF)
- Five high-bay assembly areas
- Transmitter development laboratory
- Millimeter-wave laboratory
- Digital RF Memory laboratory
- Heavy machine shop
- Numerous instrumentation vans



*GTRI's Electromagnetic Test Facility, located at the university's Cobb County Research Complex near Dobbins Air Force Base, includes this source tower and radar cross section turntable.*

*For further information concerning GTRI's radar research, please call or write:*

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