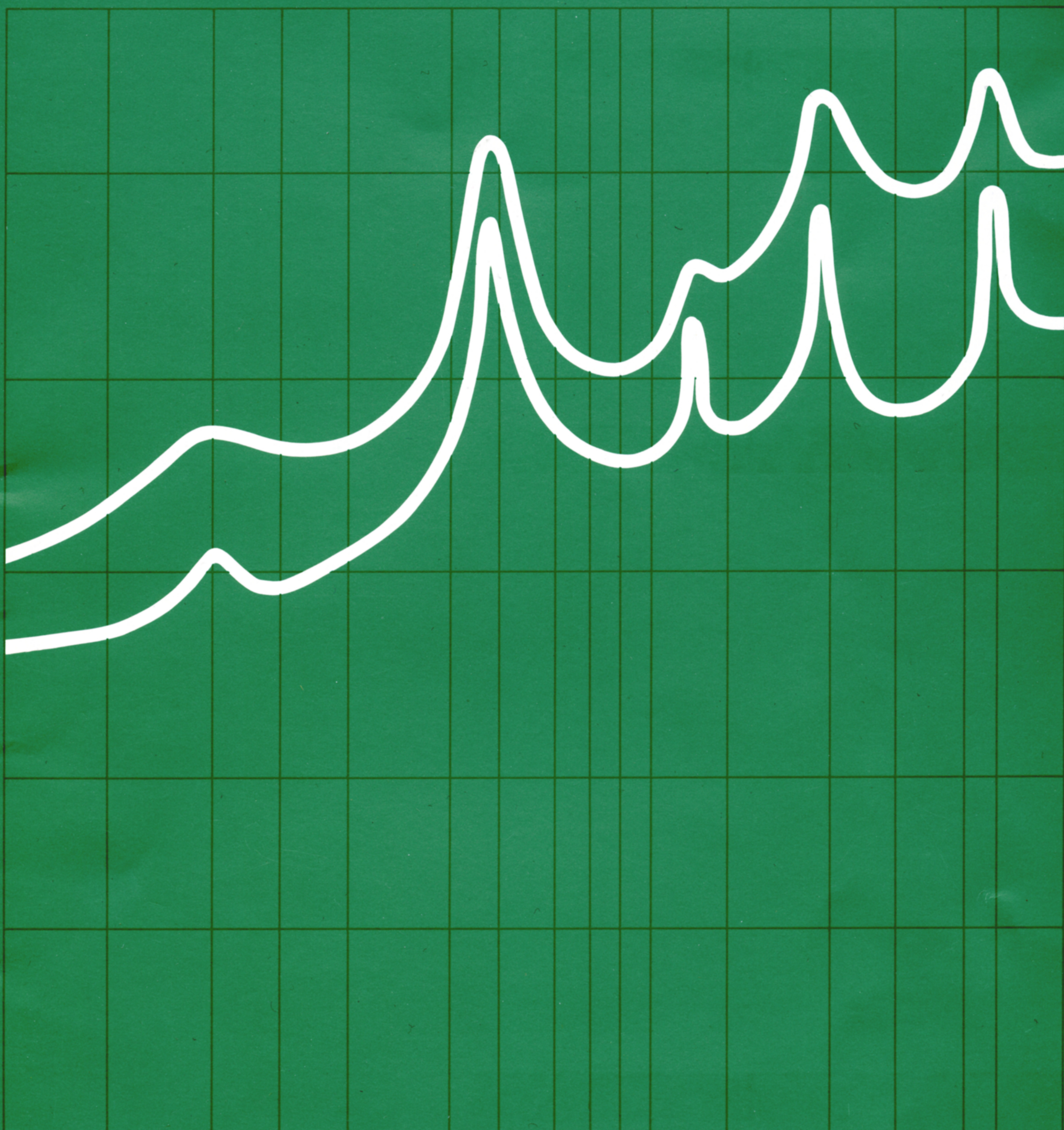


MILLIMETER WAVES

GEORGIA TECH RESEARCH INSTITUTE/GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia

CONTENTS

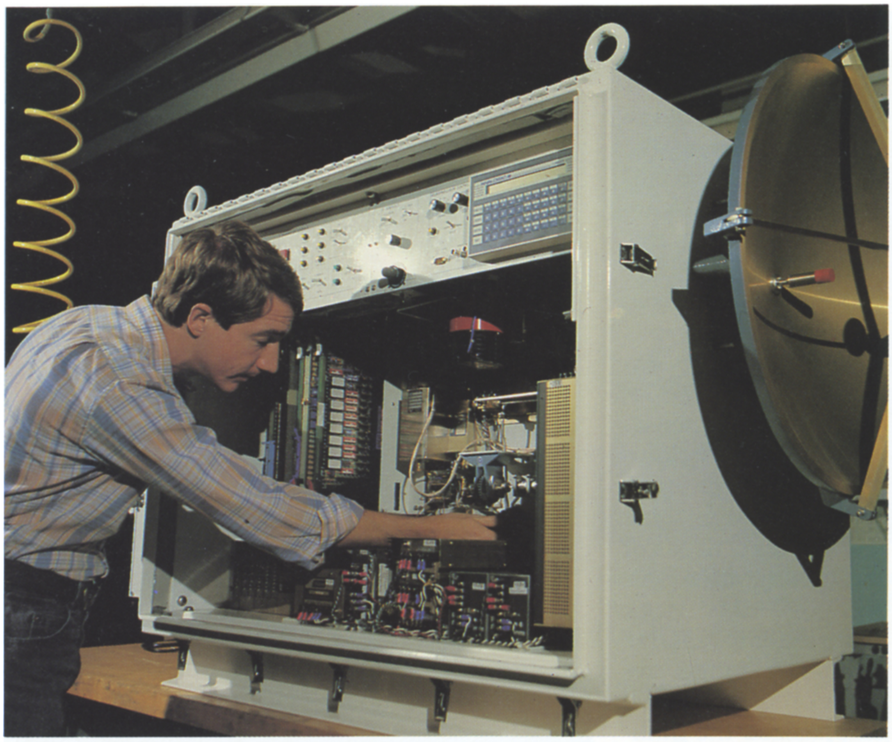
On the cover is an artist's rendering of the millimeter-wave atmospheric absorption coefficient.

INTRODUCTION

Today, millimeter-wave applications include radar communications, imaging radiometry for remote sensing, missile guidance, radio direction finding, electronic countermeasures, and biomedical studies. In most cases, these uses are a result of some unique characteristic of the millimeter-wave region, such as the availability of large frequency bandwidth, narrow antenna beams and high gain from antennas of small size, or the selective absorption of certain atmospheric gases, such as water vapor or oxygen, which permit passive remote meteorological sounding or covert communications.

For the past 25 years, the Georgia Tech Research Institute (GTRI) has made contributions to basic and applied research of the millimeter-wave spectrum. GTRI offers its sponsors a full range of R&D capabilities for work in phenomenology, systems development, studies, the development of components and technology, measurements programs, and materials development.

This broad base of expertise is becoming increasingly important. Thanks to ground-breaking research in recent years, the Department of Defense is developing its first large millimeter-wave systems. They will be useful for applications where there is a need for secure communications, substantial information content in a single transmission, accurate imaging of scenes, and relatively small component sizes.



GTRI researchers have developed the HIPCOR, a high-power, coherent radar system operating at 95 GHz. It is serving as a research tool for studying target, clutter and millimeter-wave propagation data.

Component costs are still high, and research is needed to make millimeter-wave systems more affordable.

Though the value of millimeter-wave technology is widely recognized, few R&D institutions are capable of designing and developing systems to meet custom-tailored needs. Moreover, the cost of components is still high, and research is needed to make millimeter systems more affordable.

GTRI is helping to remove these obstacles through one of the nation's most comprehensive millimeter-wave programs. We invite you to examine our capabilities more thoroughly in the pages that follow.

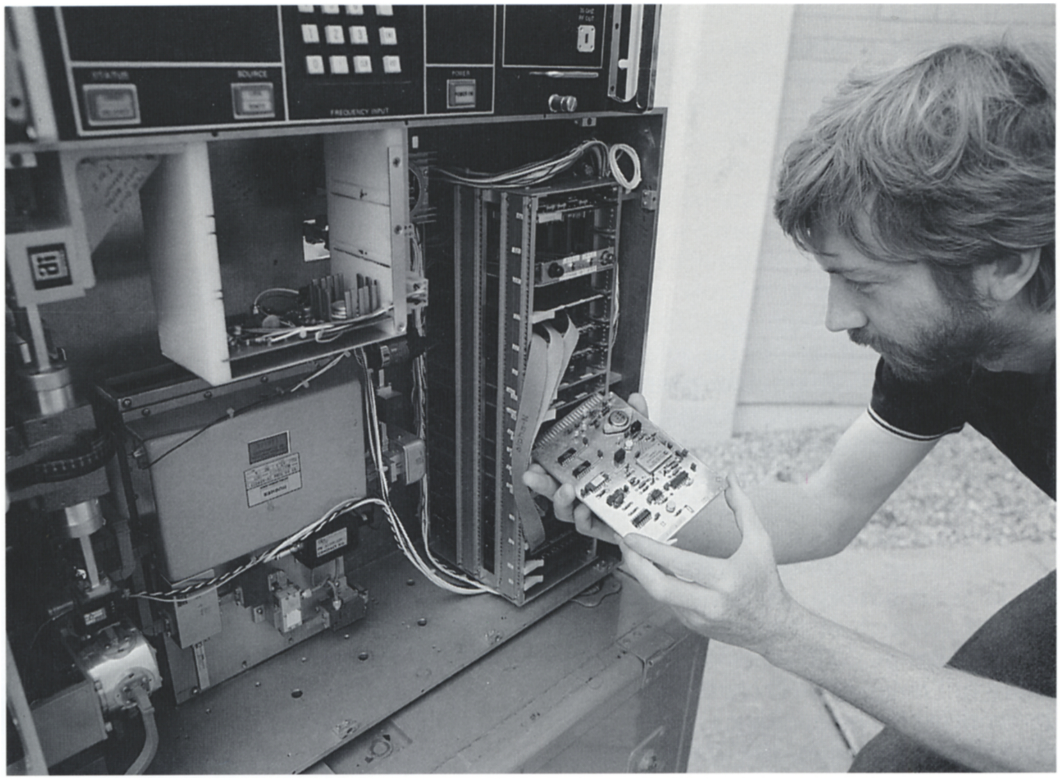
Donald J. Grace

Dr. Donald J. Grace
Director

James C. Wiltse

Dr. James C. Wiltse
Associate Director

Radar



The Georgia Tech Research Institute built its first millimeter-wave radar in the 1950s and today has broad experience throughout this region of the spectrum. GTRI engineers have developed numerous millimeter-wave radars to support Department of Defense-sponsored research, inhouse research programs at Georgia Tech, and the R&D needs of foreign organizations. Although this work spans the 35 to 225 GHz frequency range, recent programs have emphasized the millimeter-wave transmission windows centered at 35, 95, 140 and 225 GHz.

In the course of this research, GTRI engineers have advanced the state of the art significantly in mixers, solid-state receivers, transmitters (including extended-interaction oscillator and traveling-wave tube types), quasi-optical duplexers, frequency control, and phase stabilization. The development of these technologies is vital, since the cost, availability and durability of millimeter-wave equipment must be improved before millimeter-wave systems can be more widely used in diverse applications.

Significant accomplishments in the radar field include the development of:

• A high-power, coherent 95 GHz radar known as HIPCOR that incorporates the most advanced transmitter and receiver technology available;
• A coherent 225 GHz radar that is capable of detecting targets at ranges of 3.5 kilometers with an antenna aperture of only 15 centimeters (six inches);
• A coherent 95 GHz transmitter/receiver system and a noncoherent 140 GHz transmitter/receiver system that are designed to test millimeter-wave beamrider guidance concepts;
• A 35 GHz solid-state radar that evaluates missile-seeker concepts using coherent frequency-agility and pulse-agility techniques;
• Polarimetric processing; and
• A millimeter-wave multiband instrumentation radar system (MIRS) capable of collecting wideband (1 GHz), coherent polarimetric data at 35 and 95 GHz with a common IF/data acquisition system.

Further information is available from Mr. Ted Lane, (404) 421-7682, or Mr. James Scheer, (404) 421-7689.

This 35 GHz high-resolution, full-polarization-matrix instrumentation radar developed at GTRI collects reflectivity data on clutter and military targets.

Radar research at GTRI focuses on the transmission windows that are centered at 35, 95, 140 and 225 GHz.

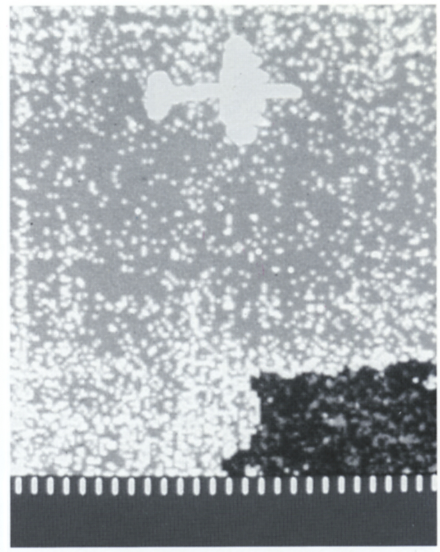
Radiometry/Imaging

GTRI's research in millimeter-wave radiometry and imaging involves system development and implementation as well as a variety of measurement programs. Researchers have provided new information on the effects of atmospheric precipitation and water vapor on millimeter-wave propagation. They also have developed decision-making algorithms for determining whether a millimeter-wave radiometer has detected a hidden target or signaled a false alarm.

In one notable effort, GTRI researchers are developing an Advanced Microwave Precipitation Radiometer that will operate in the 10.7 to 85.5 GHz spectral range on future airborne measurements for NASA. Beginning in mid-1990, the instrument will fly onboard the ER-2 research aircraft at an altitude of 20 kilometers, measuring the scattering and emission signals of precipitation and providing information on the intensity of storms. The instrument also will be used onboard the ER-2 in data flights and will be used during underflights of the aircraft with the Special Sensor Microwave/Imager (SSM/I) spaceborne instrument. This radiometer will be the only airborne sensor with capabilities to image at the identical millimeter wavelengths as the Special Sensor Microwave/ Imager and at altitudes high enough for use in precipitation studies.

In another significant project, researchers used a set of walk-through demonstrations to test the ability of a passive imaging millimeter-wave sensor to detect concealed weapons at an airport security station. The system included a real-time data processor using GTRI-developed algorithms for weapon detection versus false-alarm indication.

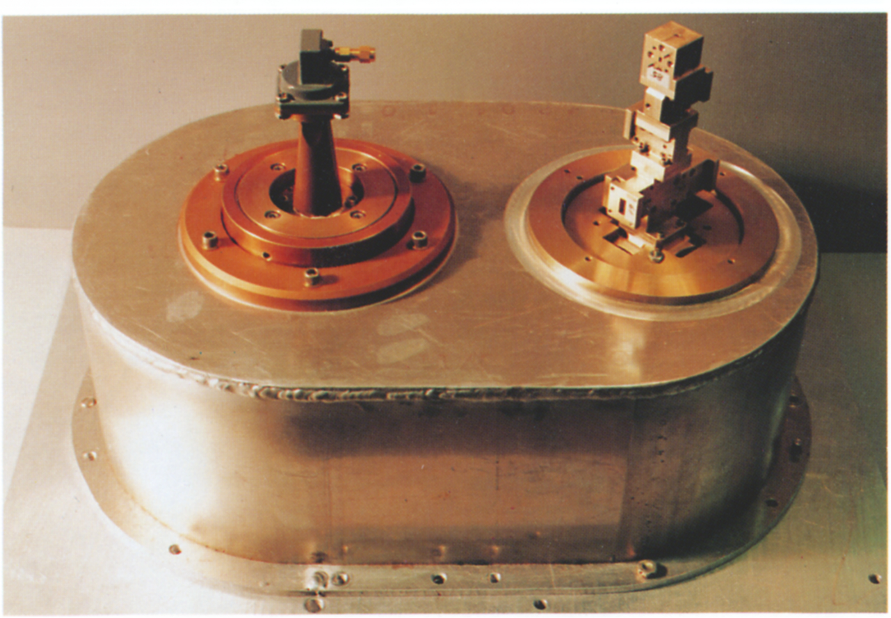
Work continues at GTRI on an Army program for the development, fabrication and testing of a 340 GHz active imaging radiometer. This system uses a phase-locked carcinotron transmitter and a f/4 subharmonic mixer as part of the superheterodyne receiver. The system will be packaged and delivered to the Department of Defense sponsor for field measurements.



This 140 GHz aircraft image was taken by the Navy with a 140/220 GHz radiometer developed at GTRI.

In an internally sponsored project, researchers are developing a cooled (liquid helium) sensor that will operate initially at 94 GHz with eventual use over the entire W-band. The cooled sensor will become the low-noise front end for an internally developed scanning radiometer. The instrument's cooled mixer and first-stage infrared amplifier will provide the improved receiver sensitivity necessary to perform accurate atmospheric measurements (of such phenomena as atmospheric ozone), high-resolution target imaging, and enhanced imaging for improved target detection.

Further information is available from Mr. Joe Galliano, (404) 894-3503.



Shown here is the antenna of Georgia Tech's Advanced Microwave Precipitation Radiometer, a system which operates in the 10 to 85.5 GHz frequency range. When mounted on a NASA research aircraft, the radiometer will provide information on the intensity of storms.

Communications

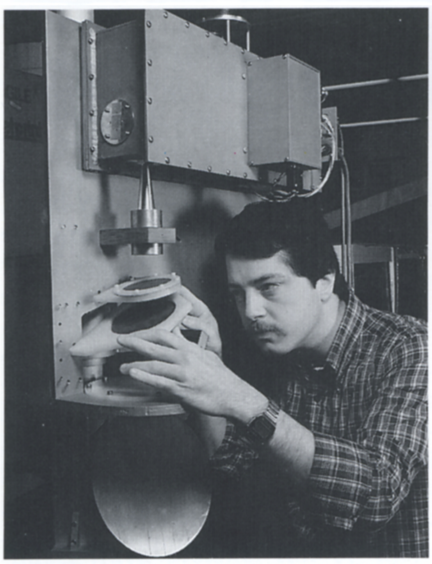
Millimeter-wave technology offers special promise for the field of communications. Among the benefits available are large-message band width, solutions to spectral crowding, and more secure communications. GTRI researchers have shown that bandwidths similar to those attained in current state-of-the-art optical fiber systems are possible at these frequencies. Their experience in communications research at the lower frequencies has prepared them to offer extensive assistance in developing these new applications. They also have been involved in the design and analysis of various millimeter-wave communications systems.

This research has concerned satellite communications systems for NASA and the MILSTAR (Military Strategic and Tactical Relay) program. The latter program, sometimes termed the EHF (extremely-high-frequency) MILSATCOM, involves the use of a wide-band, secure, ground-satellite system. Other activities have included the investigation of air-to-air communications systems as well as point-to-point terrestrial radios. Electromagnetic compatibility considerations for millimeter-wave hardware also have been studied.

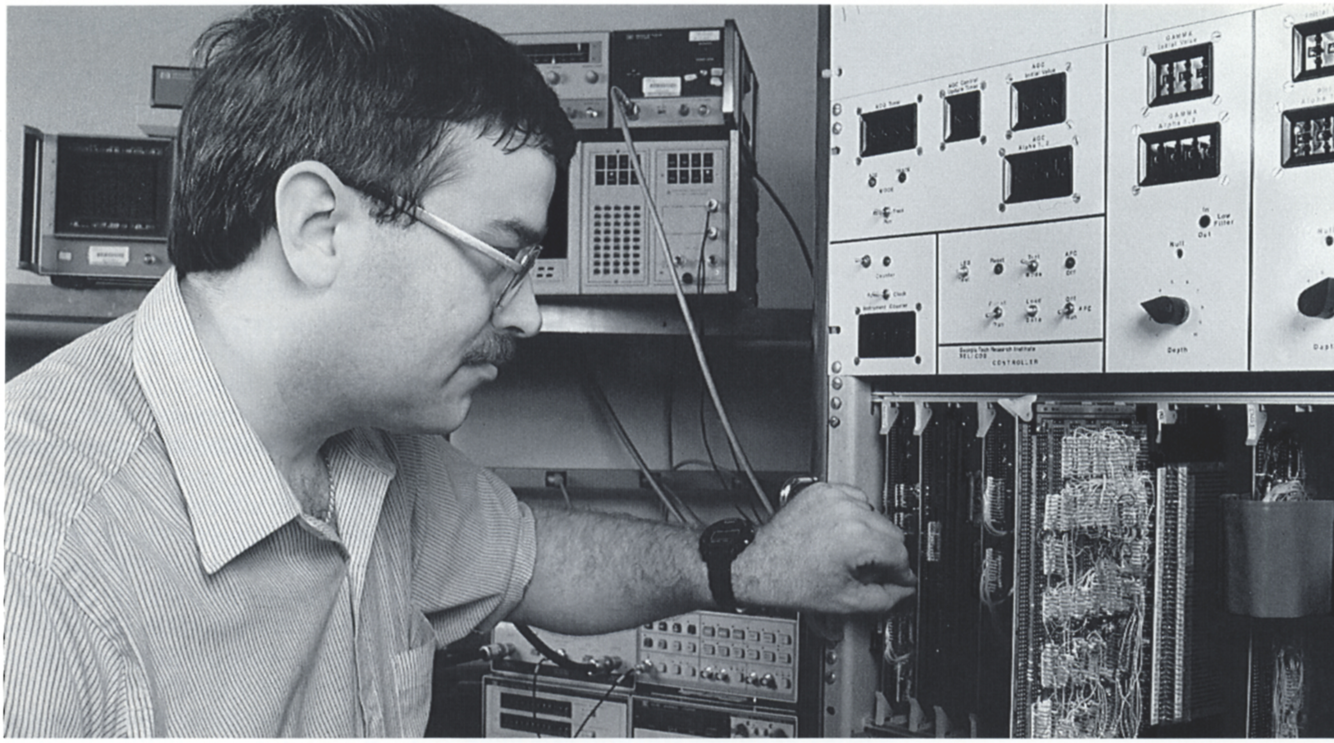
Engineers at GTRI have coupled these design and analysis activities with propagation models that reflect the unique aspects of extremely-high-frequency communications. In particular, they have implemented propagation models that account for atmospheric absorption losses as a function of altitude and weather conditions. These models are applicable to air-to-air communication systems as well as to terrestrial point-to-point cases. In addition, engineers have used statistics on worldwide rainfall to build models that account for rain-induced losses. Finally, an effort is underway to supplement these propagation analysis capabilities with a model that accounts for extremely-high-frequency ducting on over-water propagation paths.

Other communications programs involve systems evaluation, development of test procedures, and design of receiving systems.

Further information is available from Mr. Richard Moss, (404) 894-3544.



Above, GTRI researchers have developed a tactical millimeter-wave direction-finding system. At right, communications specialists have shown that bandwidths similar to those attained in current state-of-the-art optical fiber systems are possible at millimeter-wave frequencies.



GTRI engineers developed and field-tested a prototype receiver system for measuring radar polarization. It can be modified easily to measure multiple radars in the microwave and millimeter-wave bands.

Electronic Countermeasures

GTRI researchers work actively in the development, upgrade and redesign of electronic countermeasures systems for use at millimeter-wave frequencies.

In one recent program, engineers evaluated an intercept and direction-finding antenna/ receiver for a specific airborne platform. This analysis led GTRI personnel to propose an upgrade that was subsequently designed, developed, tested and delivered.

Another effort involved the design of a high-power, computer-controlled, dual-band transmitter. The 35/95 GHz system enables Army personnel to define the susceptibility and vulnerability of U.S. missile and electronic/communication systems to electronic warfare techniques in the millimeter-wave spectrum.

In another program, GTRI researchers furnished and operated two millimeter-wave radars that were used at the White Sands Missile Range in support of electronic countermeasures chaff measurements.

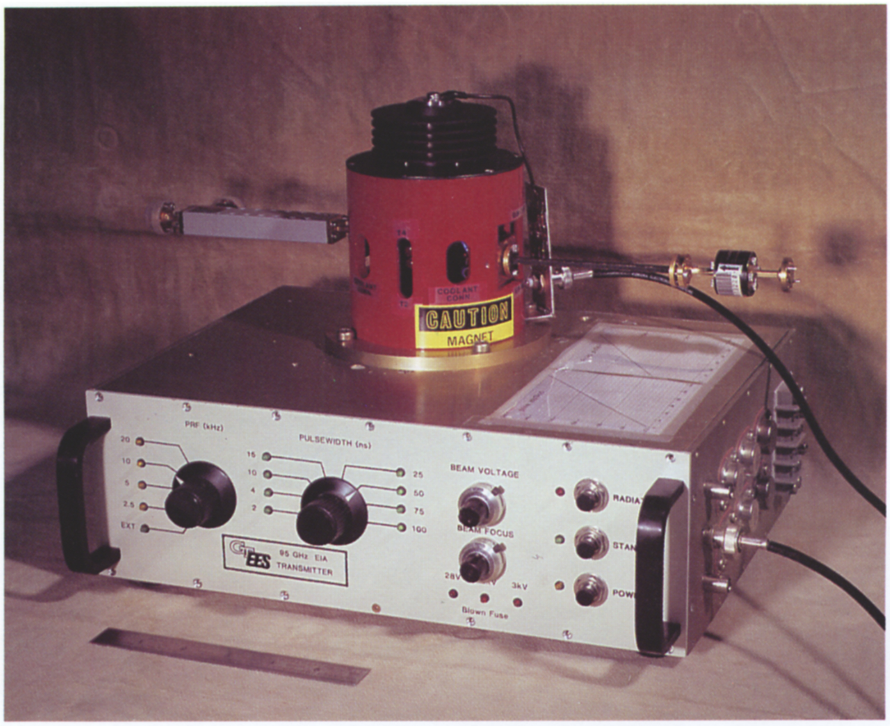
A current effort seeks to prove that a Ka-band switched-beam array can improve upon inertia-free antenna scan. Engineers working in this project also will study a Ka-band down converter upgrade.

In another program, engineers are designing an antenna controller and processor to support the development of improved millimeter-wave intercept systems. The antenna controller/processor will be designed so that it can interface with the extremely-high-frequency switched-beam array under development. The switched-beam array and controller/ processor will use scan and receive modes not available in presently installed systems.

Further information is available from Mr. Harry Andrews, (404) 894-7219, or Mr. William E. Sears III, (404) 894-3592.

GTRI researchers designed a high-power transmitter to define missile susceptibility to disruption in the millimeter region.

TECHNOLOGY



This 95 GHz extended-interaction-amplifier transmitter was developed by GTRI engineers for the U.S. Army

Transmitters

GTRI engineers have made important advancements in the area of high-power millimeter-wave transmitter technology over the past several years. Criteria have been established for reliable design and development of compact 95 GHz transmitters with pulse widths as short as 1.0 nanosecond when operating at a pulse repetition rate of 20 kHz and a peak power of 1 kW. GTRI engineers routinely provide guidance for the design of transmitters employing extended interaction klystron amplifiers (EIKAs), extended interaction oscillators (EIOs), and traveling wave tubes (TWTs).

One of the first high-power coherent transmitters to operate in the 95 GHz frequency region using a TWT amplifier was recently designed and developed. It will be integrated into an advanced air-to-surface pod-mounted avionics radar to support a target acquisition and terrain following/avoidance feasibility demonstration for the Air Force.

A modulator and power supply for a gridded EIKA is being produced. It will emphasize small size and low weight, two key requirements for a variety of military radar systems. Narrow pulse modulators enhance the ability of millimeter-wave systems to resolve detail.

The Research Institute's capabilities in transmitter technology also have been enhanced by the successful extension of X-band multichip power combining techniques to the 40 GHz range. In this R&D program, 40 GHz IMPATT diodes were combined in series on diamond with 82 percent efficiency.

Further information is available from Dr. George W. Ewell, (404) 894-3532, or Mr. T.V. Wallace, (404) 421-7567.

Quasi-Optical Components

High-frequency waveguide components are subject to substantial losses. For this reason, emitters often transmit through free space, where diffraction largely determines beam characteristics. Thus, the term "quasi-optical" applies to the associated components and techniques.

GTRI is recognized for leadership in the design and fabrication of interference filters, interference diplexers, polarizers and polarization duplexers, millimeter-wave lenses and zone plates, horn feeds, and attenuators. In a recent investigation, the millimeter-wave characteristics of the phase-correcting Fresnel zone plate, a planar device with lens-like properties, were determined for use in focusing, imaging and frequency-filtering applications.

To support these developments, the Research Institute has excellent photo-lithography facilities for grid polarizers and mesh-beam splitter fabrication. Georgia Tech also maintains high-quality machining facilities including copy-turning lathes for processes such as aspheric lens surface turning.

Recently, a seven-inch diameter sapphire quarter-wave plate was built at Georgia Tech that produces circular polarization at 225 GHz. Grid polarizers have been fabricated with excellent performance up to about 2 THz and horn-lens combinations that offer nearly ideal Gaussian beam profiles for beam transmission. GTRI researchers have built beam waveguides for propagation of millimeter waves with Gaussian profiles that operate at 94 GHz and over the range from 58 to 115 GHz.

Further information is available from Dr. Robert McMillan, (404) 894-3503.

Using pulsed and CW modes, GTRI has phase- or injection-locked a variety of solid-state and tube-type millimeter wave sources.

Frequency Control Devices

Researchers at GTRI have been able to phase- and/or injection-lock, in both pulsed and CW modes, a wide variety of solid-state and tube-type millimeter-wave sources. These include klystrons, Gunn oscillators, extended interaction oscillators, and an oroton (a quasi-optical millimeter-wave tube).

Phase-lock systems have been built that can lock klystron sources at frequencies up to 175 GHz and both pulsed- and cw-extended interaction oscillator sources up to 230 GHz. A microprocessor-controlled frequency synthesizer that uses a backward-wave oscillator to cover the 40 to 60 GHz waveguide band has been built and tested, and plans are for this capability to be extended to the 110-170 GHz band when a source becomes available. These phase-lock systems are extremely reliable and operate unattended for long periods.

GTRI engineers recently designed circuitry for phase-locking a 340 GHz carcinotron that will be used for millimeter-wave imaging experiments. A base of experience also is in place for the locking of solid-state sources such as Gunn oscillators and in developing systems with frequency agility. The latter technology allows significant improvement in target detection.

Further information is available from Dr. Robert McMillan, (404) 894-3503.

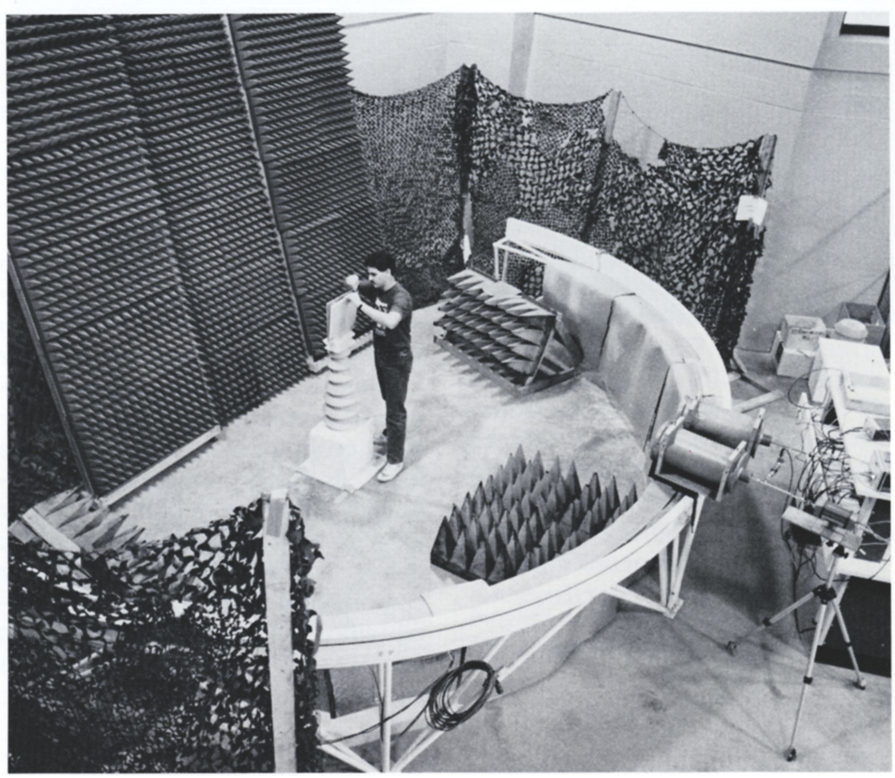
Evaluation of Materials

A variety of techniques is available for characterizing semiconductor materials and devices to determine their electrical, structural and optical properties. The Research Institute's emphasis is on optical techniques that provide rapid analyses and avoid problems caused by ohmic contacts.

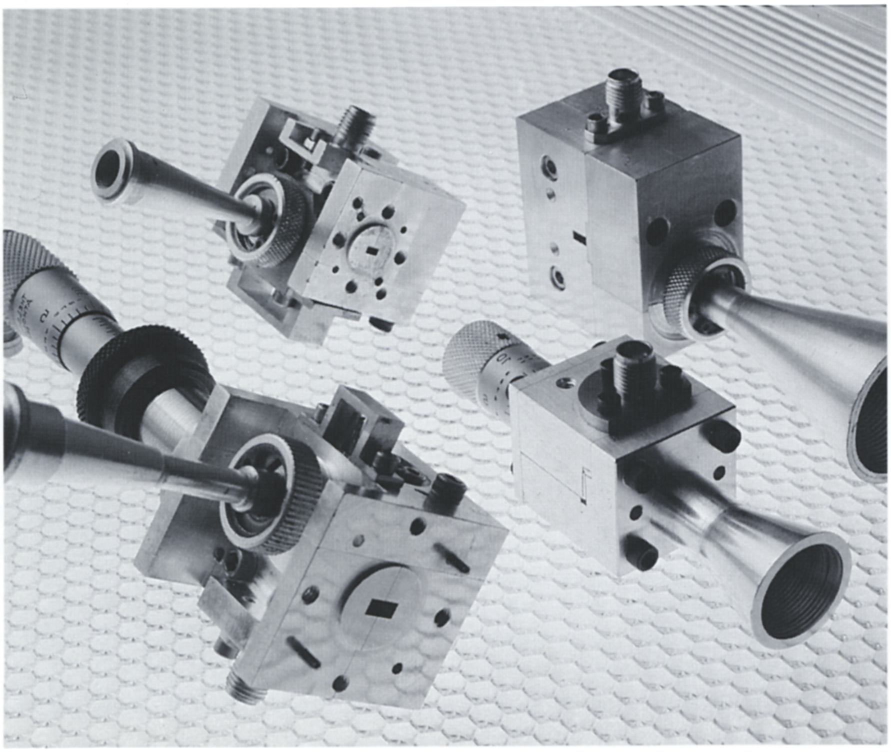
Researchers at GTRI make materials evaluations with equipment such as transmission electron microscopes, scanning electron microscopes, and X-ray topography cameras. They also use an energy dispersive X-ray unit, reflection electron diffraction unit, electron probe microanalyzer, X-ray spectrograph, single- and double-crystal X-ray diffractometer, optical interferometer, step profiler, automated Hall measurement assembly, deep-level transient spectroscopy assembly, capacitance-voltage profiler, and visible-infrared spectroscopic facility.

GTRI researchers have developed and implemented extensive capabilities in microwave and millimeter-wave characterization of materials. Through these methods, complex permittivity (dielectric constant and loss factor) and compiex permeability can be determined for frequencies from 0.1 to 110 GHz at temperatures as high as 2400°C (4250° F). A variety of techniques that make use of a reflectometer, open resonator, perturbative cavity, and free-space focused beam allow the researcher to determine a range of material parameters from windows to absorbers.

Further information is available from Dr. Tom Wells, (404) 894-3550.



This horizontal reflectivity arch at GTRI is allowing engineers to perform measurements in the 2 to 60 GHz frequency range.



Researchers at GTRI have developed subharmonic mixer and receiver components with excellent sensitivity, ruggedness, wide bandwidth, and economical operation.

Mixers/Receiver Components

A team of GTRI engineers has built up a special competence for development of all types of superheterodyne receivers in the 90 to 340 GHz range. Its highly effective subharmonic mixer designs are especially notable achievements. These mixers work in conjunction with low frequency 45 to 85 GHz solid-state Gunn oscillators. They contain back-to-back Schottky barrier diodes and quartz stripline matching networks. These designs use solid-state oscillators that operate at either one half or one quarter of the desired local oscillator frequency. Receivers built with these mixers have proved rugged and reliable in extensive flight and ground field testing due in large measure to their all-solid-state design.

Normally, signals come into mixers through horns and waveguide sections, but engineers at the Research Institute are investigating another technique for signal entry: quasi-optical coupling to diodes. Another R&D program seeks to integrate the local oscillator, intermediate frequency amplifier section, and planar antenna feeds into the subharmonic mixer. Integration of millimeter components is increasingly important since miniaturization has become one of the principal growth areas in millimeter-wave research.

Further information is available from Mr. Joe Galliano, (404) 894-3503.

Radomes

GTRI is a world leader in the development of radomes, the structures that protect radar antennas and act as windows for electromagnetic energy. As the velocities of missiles have increased, researchers have needed to develop higher temperature materials for use as radomes. GTRI first considered slip-cast fused silica as a radome material in the late 1950s. Since then, engineers here have fabricated a wide range of radomes, including a nine-inch radome for millimeter-wave frequencies.

For the past 10 years, GTRI also has provided engineering program support to the Army for the millimeter-wave radome phase of its advanced interceptor program. Programs at the Research Institute benefit from multidisciplinary capabilities in electromagnetic theory, aerodynamics, and structural and thermal analysis. In addition, researchers have access to a high-temperature solar test facility, precision-grinding tools and unique radome-firing furnaces.

Further information is available from Dr. John Handley, (404) 894-3650.

GTRI engineers have developed all types of superheterodyne receivers in the 90 to 340 GHz range.

Lasers

GTRI engineers have constructed a number of near-millimeter or submillimeter lasers pumped by CO_2 lasers, the most powerful pumped by a seven joule TEA laser in support of a near-millimeter-wave transmitter/receiver system.

Laser transitions have been obtained at 20 frequencies by use of only four gases in the near-millimeter cell. A peak output power of 25 kilowatts was generated in a newly discovered line near 600 GHz. GTRI engineers also have built CW-type lasers with outputs of a few milliwatts, which have application in spectroscopy, materials evaluation, and atmospheric propagation studies.

Further information is available from Dr. Robert McMillan, (404) 894-3503.

Researchers use this Fabry-Perot interferometer to characterize materials at high millimeter-wave frequencies.

Metrology

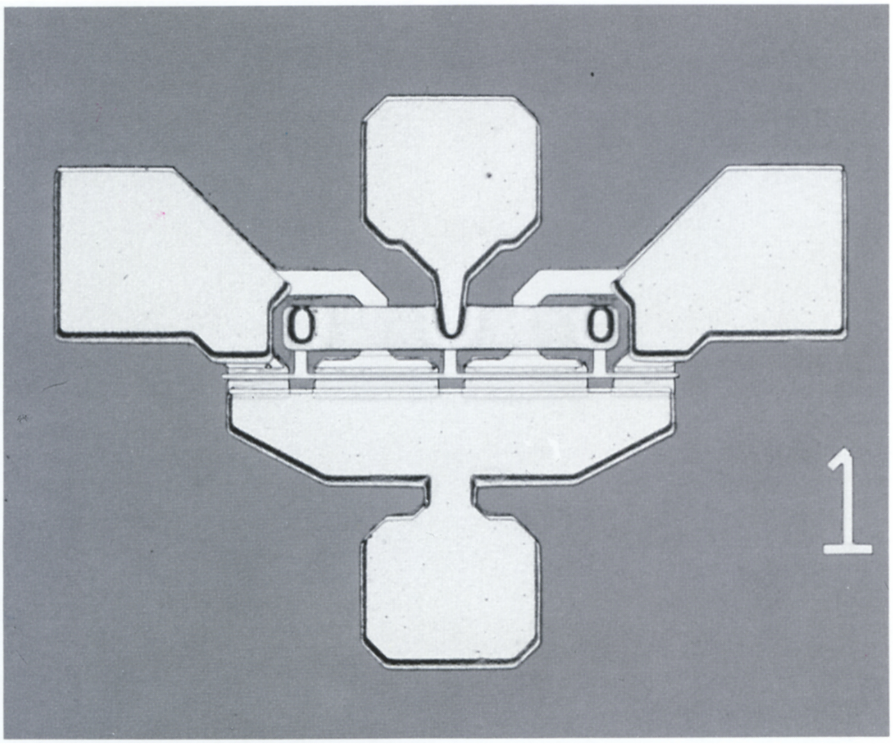
A unique amplitude-and-phase reflectometer at Georgia Tech accommodates a wide range of millimeter components testing needs. This first-of-a-kind network analyzer can make two or four port measurements up to 160 GHz. It is completely computer-controlled and can automatically calibrate out errors inherent to the system.

The Research Institute also has developed device reflectometers, and one such instrument under construction for the 40 to 60 GHz range will incorporate a synthesizer that allows engineers to quickly scan this part of the spectrum. This reflectometer has heterodyne receivers that make ultra-low power measurements possible. The equipment will be used to measure reflections from biological materials.

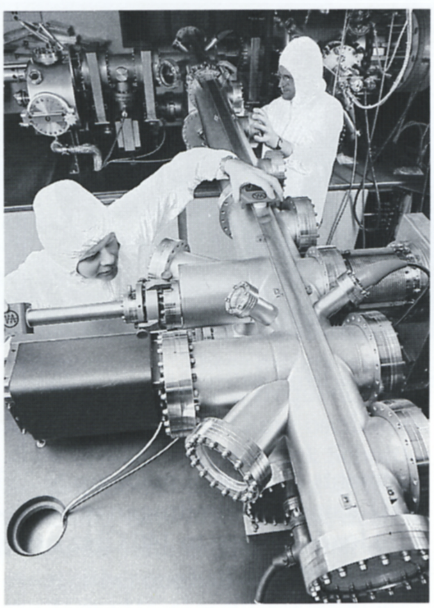
As frequency increases, waveguide component performance falls off, and it becomes difficult to make equipment with the high standards needed in metrology. Alternative measurement systems based on optical or quasi-optical techniques are under investigation, and a revolutionary quasi-optical instrument for measuring waveguide component reflectivity from 90 to 340 GHz has been developed.

GTRI maintains excellent facilities for testing receivers throughout the millimeter-wave spectrum and frequently helps industry in assessing equipment. Noise figure measurements have been made up to 225 GHz using liquid nitrogen temperature loads and up to 140 GHz using noise tubes.

Further information is available from Dr. Robert McMillan, (404) 894-3503.



Advanced processing techniques have been developed to facilitate integration of discrete devices into microwave and millimeter-wave integrated circuits.



Top of page, GTRI researchers used selective doping to produce these GaAs/AlGaAs heterostructure transistors. They are useful as low-noise amplifiers in millimeter-wave applications. Directly above, GTRI maintains several molecular beam epitaxy systems.

Solid-State Devices/Circuits

The device and circuit fabrication program at GTRI has far-reaching goals, both in the development of unique fabrication technologies for sub-micron semiconductor devices and in the development of superconducting, optoelectronic and vacuum integrated circuits. This program, therefore, is capable of fully exploiting the advanced material structures grown by molecular and chemical beam epitaxy. Techniques are being developed for the fabrication of high-speed, high electron mobility transistors, with gate length features between 0.5-0.1 μm, for operation at frequencies up to 60 GHz.

High-performance gallium arsenide (GaAs) based mixer diodes are being fabricated for use as sources and detectors at very high frequencies, 100-240 GHz. These devices require the use of high reliability refractory Schottky barrier metal systems deposited by electron beam evaporation. Low capacitance point contact devices have been developed for applications requiring semi-automated assembly.

Resonant-tunneling devices are being fabricated with material grown by MBE. Mesa isolation is employed to electrically separate the devices. Highly selective etches have been discovered that permit novel device fabrication on these materials, which have layer thicknesses on the order of 50 angstroms.

Other advanced processing techniques have been developed to facilitate integration of these discrete devices into microwave and millimeter-wave integrated circuits. For low loss, crossover (air bridge) interconnections have been developed to permit two levels of circuit metallization with minimum parasitic capacitance. Dry processing techniques such as reactive ion etching, planar plasma etching, and plasma enhanced chemical vapor deposition are also being developed to support microwave and millimeter-wave device and circuit research, and also to fabricate unique structures for investigating optical-microwave interactions.

Further information is available from Dr. Christopher J. Summers, (404) 894-3420.

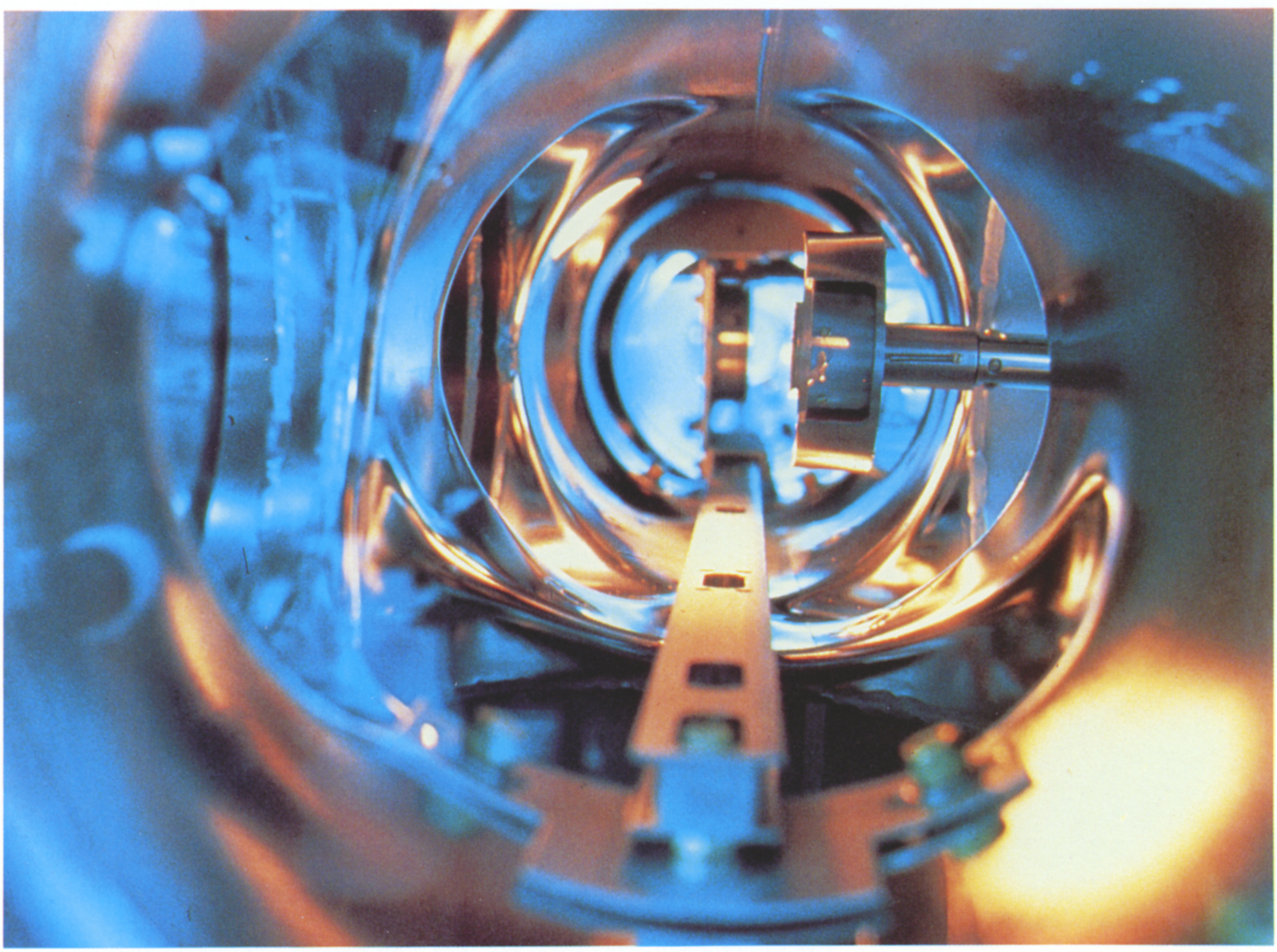
Molecular Beam Epitaxy

GTRI has extensive expertise in the chemical and molecular beam epitaxial (CBE and MBE) growth of advanced material structures in the III-V and II-VI semiconducting material systems. Material structures such as atomically abrupt heterojunctions, multiple quantum-well and superlattice structures, and modulation-doped semiconductors are grown for a wide variety of millimeter-wave, optoelectronic, ultra-violet, visible, and infrared devices using two Varian Gen II MBE systems as well as specially designed systems.

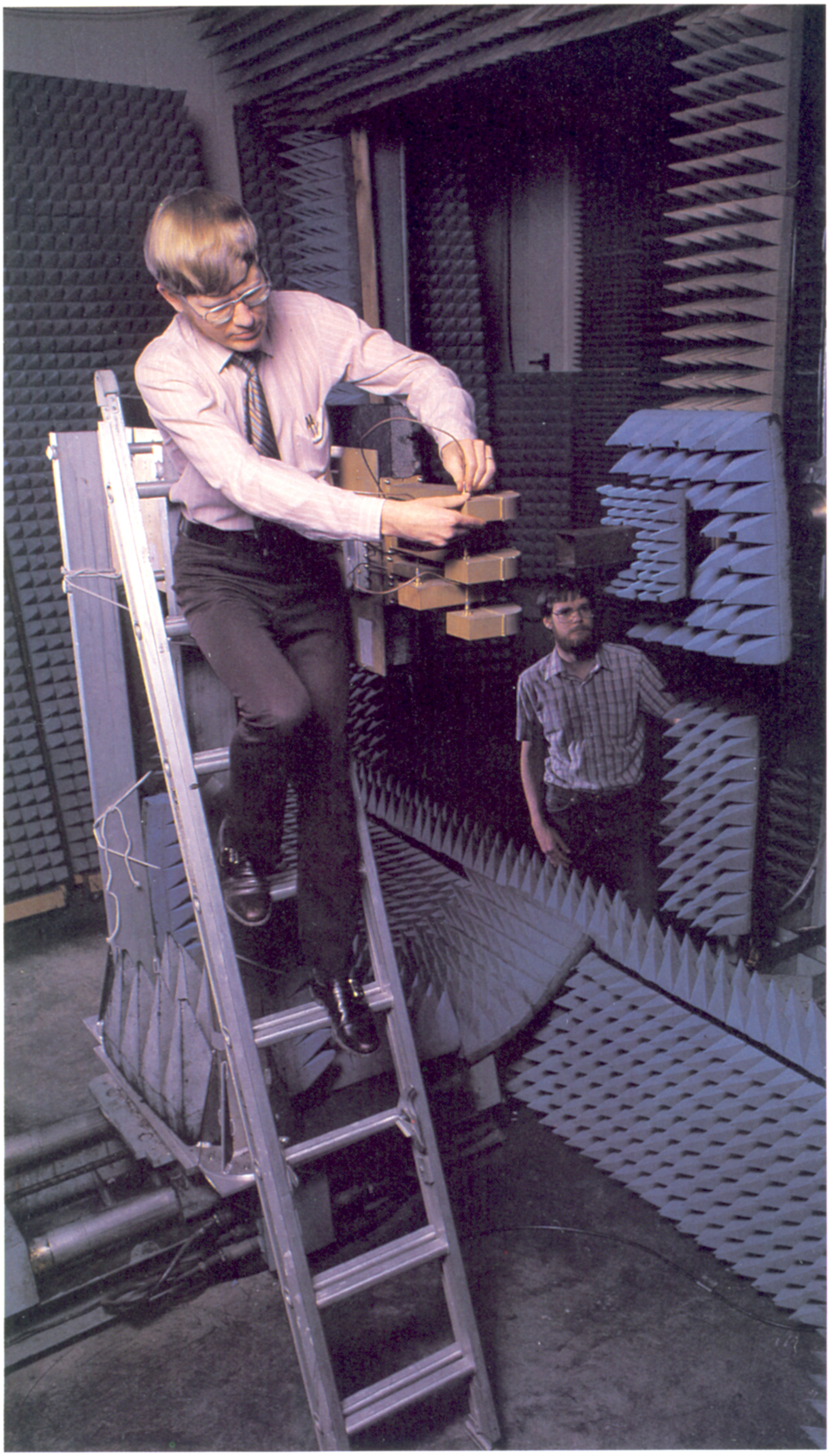
For millimeter-wave devices, current research is focused on the development of new growth techniques such as growth interruption, low-temperature growth and ramping, delta doping, and migration enhanced epitaxy in the AlGaAs, AlInAs and InGaAs systems. These techniques are being investigated for improving the performance of high-electron-mobility transistors in order to obtain high-frequency (20-60 GHz), high-efficiency, and high-power devices. An important part of this work has been the use of quantum-well doping in the AlGaAs/GaAs MODFET structures and the extension of these techniques to pseudomorphic AlInAs/InGaAs structures.

Additionally, high-performance single and multiple quantum well resonant tunneling devices have been grown in the AlGaAs/GaAs system for very-high-frequency (100-500 GHz) applications. Extensions of this technology are in progress for a variety of three terminal hot-electron resonantly tunneling transistors. Novel multiple quantum-well and optical waveguide device structures also are being grown to study the potential of optical control of microwave circuits and systems.

Further information is available from Dr. Christopher J. Summers, (404) 894-3420.



GTRI researchers use molecular beam epitaxy to grow a variety of advanced microelectronic materials.



This near-field antenna measurement range accommodates a variety of traveling-wave array measurements, including an analysis of the effects of combat on different antenna types.

GTRI maintains its own antenna ranges with state-of-the-art equipment for frequency testing.

Antennas

GTRI researchers have extensive experience in the analysis, design, fabrication and testing of millimeter-wave antennas for use at frequencies up to 2 THz. Notable accomplishments in this research area include development of:

- Low-loss, rapid-scan antennas with a high degree of ruggedness;
- A narrow-beam, rapid-scan antenna for one of the first operational millimeter-wave radars in the U.S.;
- Over-moded structures and quasi-optical techniques for low-loss antennas;
- Lightweight antennas;
- A 70-foot compact range with a 50-foot quiet zone;
- Broad-band, millimeter-wave radomes; and
- Corrugated feedhorns to improve illumination efficiency with low-spillover losses.

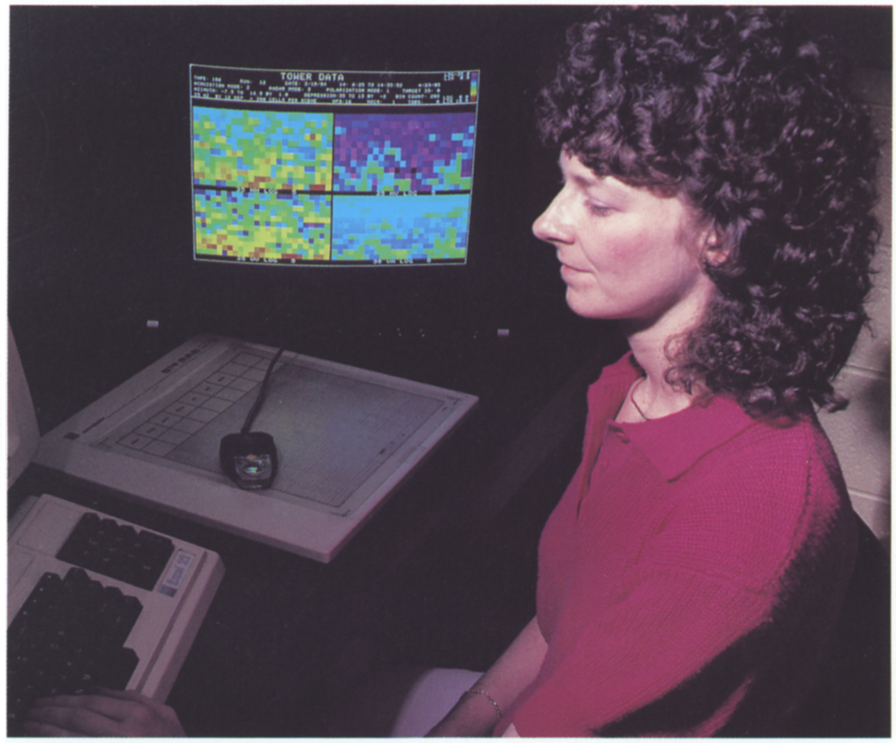
GTRI has built parabolic reflectors, Cassegrain systems, and geodesic and Luneburg lenses, as well as line-source, pillbox, horn, twist/trans reflector, Fresnel zone plate, and conventional lens antennas. They have been used for radars, radiometers and communication systems.

GTRI maintains its own antenna ranges with state-of-the-art equipment for millimeter-wave frequency testing.

Further information is available from Dr. Milton Cram, (404) 894-2548 or Mr. William Cooke, (404) 421-3151.

MEASUREMENTS

Clutter Characterization

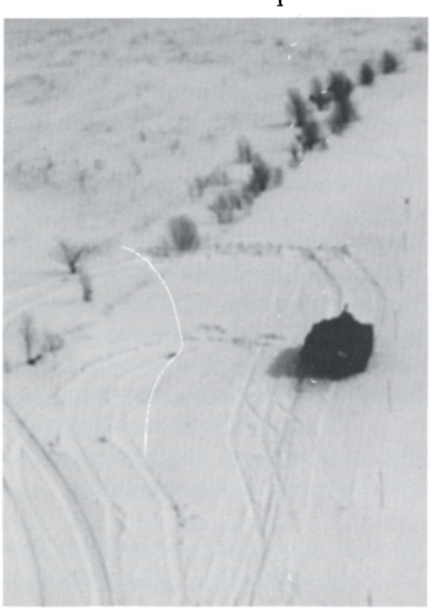


In the millimeter-wave region, electronic signatures are less predictable than those found at lower frequencies. For this reason, target and clutter characterization are essential for reliable millimeter-wave applications. GTRI is a national leader in measurement programs of this kind. Engineers at Georgia Tech have been performing millimeter-wave clutter characterization measurements since 1953. More recently, these measurement programs have involved diverse backgrounds, including falling rain, snow-covered ground, desert, foliage and sea return.

Under Project Snowman for the Army, GTRI engineers made 35 and 95 GHz measurements of desert terrain from an airborne platform and snow-covered ground from air and tower platforms. The tower measurements produced frequency-agile, full-polarization-matrix data that were collected as "maps" generated by raster-scanning over an angular sector of snow-covered terrain.

GTRI researchers also have been involved in measuring the backscatter and transmission properties of foliage. One experiment measured the radar cross section per unit area of deciduous trees for low-depression angles (2-12 degrees) over the frequency range of 9 to 95 GHz. Another series of tests determined the propagation properties through foliage for signals in the 9 to 95 GHz range. Finally, 35 and 95 GHz measurements of deciduous trees were made to determine the radar cross section per unit area in the plateau angular regime (15-45 degrees).

Under a project for the U.S. Air Force, GTRI worked with another organization to collect airborne 35 and 95 GHz measurements on both continental United States and Central European terrains. The "maps" resulting from the measurements were calibrated and inserted into the Eglin AFB Target and Background Instrumentation Library System.



Project Snowman provided a wealth of millimeter-wave data for characterizing snow-covered terrain. At left, GTRI engineers made on-site measurements of tanks on snowy terrain. Top of page, these measurements were used to produce frequency-agile, full-polarization-matrix data.

Sea backscatter measurements are another area of expertise at GTRI. In one program for the Navy, engineers compiled sea backscatter data with simultaneous recording of parallel- and cross-polarization signal components of 9.5, 16, 35 and 95 GHz for various sea states, wind/wave-look directions and depression angles less than 10 degrees.

GTRI participated in the joint Air Force/Army "Chicken Little" program that involved high-resolution simultaneous millimeter-wave and infrared measurements of tactical vehicles. The data have been used for developing target-classification and identification algorithms.

To support similar projects, GTRI has developed an on-site "look down" RCS range that has been used to measure military and civilian targets.

Further information is available from Mr. Nicolas Currie, (404) 421-7681, or Mr. Wayne Cassaday, (404) 421-7743.

Atmospheric Effects

Extensive studies of atmospheric effects at Georgia Tech have created a valuable data base for modeling the effects of clear and precipitating weather on millimeter-wave systems.

In one particular program of note, engineers at GTRI assisted the U.S. Army in defining the weather conditions in which a multiple-launch rocket system can operate effectively.

Radar backscatter measurements on falling rain were performed in conjunction with the U.S. Army's Ballistic Research Laboratories over the 10 to 95 GHz frequency range.

GTRI researchers also have employed near-millimeter optically pumped lasers in collaboration with Emory University to measure absorption coefficients and refractive indices of water vapor and liquid water. In addition, they are developing rapid-scanning Fourier transform spectrometers for studies of atmospheric transmission and emission in the 90 to 1800 GHz range. Through another program, evidence will be sought to assess controversial anomalies in atmospheric transmission as they relate to high humidity.

GTRI researchers recently completed a ground-breaking research effort designed to measure the effects of atmospheric turbulence on the propagation of millimeter-wave radiation. Over a two-year period, experiments were conducted over a wide range of millimeter-wave frequencies of interest, extending from 116 to 230 GHz, and phenomena that might cause some degradation of systems performance were quantified over this range. Measurements were performed under a variety of weather conditions. This work is the most comprehensive and fully instrumented measurement effort yet made to understand the complex effects of atmospheric turbulence on millimeter-wave propagation.

Many of the measurement efforts undertaken are distilled into new propagation model programs. GTRI engineers routinely predict millimeter-wave propagation characteristics as an integral part of concept evaluation and design studies.

GTRI researchers made a ground-breaking study of millimeter-wave propagation in turbulent atmospheres. Measurements were taken on location at Flatville, Illinois.

Further information is available from Dr. Robert McMillan, (404) 894-3503.

Spectroscopy

Spectroscopy offers a powerful tool for detecting obscure microscopic organisms and atmospheric molecules. GTRI maintains some of the highest frequency millimeter-wave equipment available for this research.

GTRI engineers have used near-millimeter lasers pumped by CO_2 lasers to perform definitive spectroscopic research on liquid water in collaboration with Emory University.

Fourier spectroscopy is another technique that GTRI researchers have employed recently to characterize biological materials. The instrumentation allowed the spectrum to be scanned over a wide band of frequencies (from 180 to 1000 GHz). This capability also gave engineers a comprehensive technique for locating atmospheric processes that affect millimeter-wave propagation.

In the past, GTRI researchers have used microwave frequencies to look for highly resonant, non-thermal interactions with biological materials. They are ready to extend this research to the millimeter spectrum. A recent example of Georgia Tech's expertise in this area is the use of a Fabry-Perot interferometer to measure the absorption of biological materials in freon at 94 GHz.

The spectroscopic measurement capability of GTRI is being greatly enhanced by the acquisition of a family of millimeter-wave backward-wave oscillators covering the frequency range from 26.5 to 170 GHz in full waveguide bands. These sources will be designed into full waveguide band frequency synthesizers that provide phase-locked stability and sweep-while-locked performance over this entire frequency region.

GTRI researchers are also building an FM laser spectrometer that operates at CO_2 wavelengths.

Further information is available from Dr. Robert McMillan, (404) 894-3503.

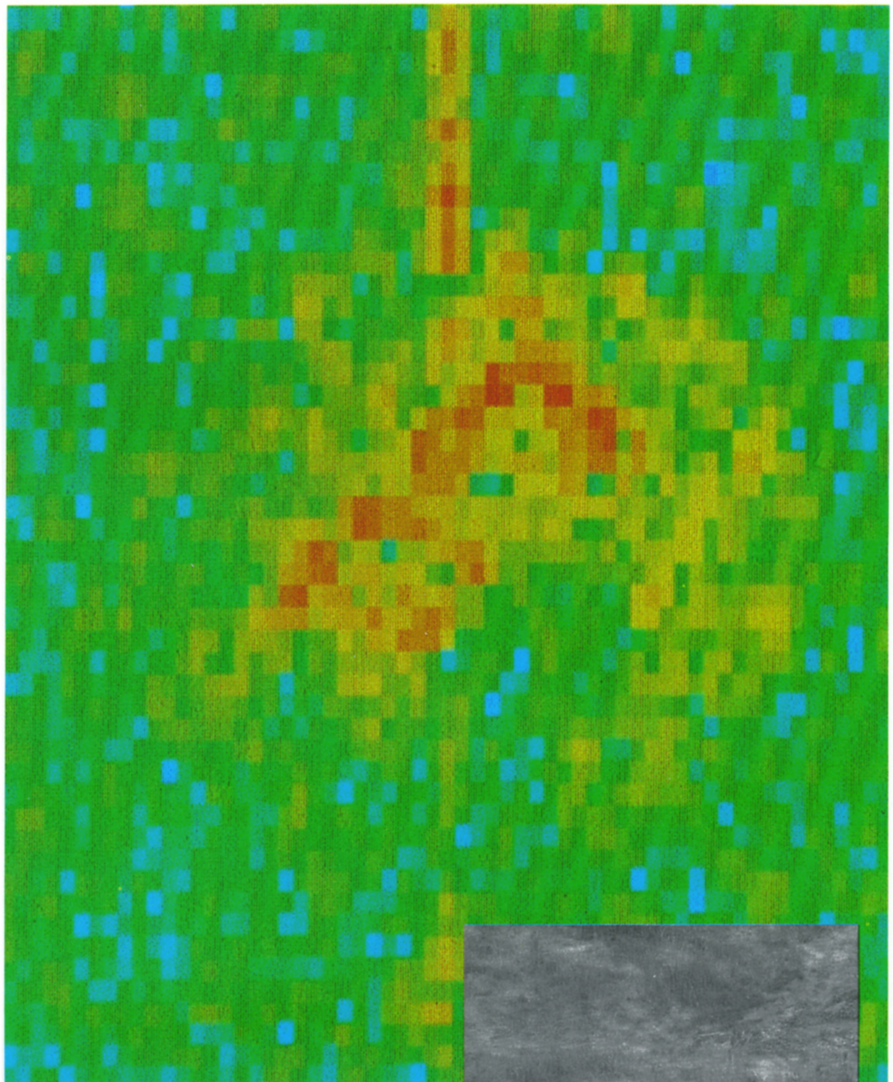
Target Characterization

Engineers at GTRI have performed extensive target characterization research with active or passive systems for nearly 40 years. One recent project involved airborne radar measurements of civilian and military targets at 35 and 95 GHz for the Wide Area Anti-Armor Munitions (WAAM) program. Another set of measurements made at 35 GHz at Eglin AFB's C-52A tower concerned several military and civilian targets. Through this effort, researchers collected coherent, frequency-agile, full-polarimetric data in support of the Helicopter Adverse Weather Fire Control and Acquisition Radar (HAWFCAR) program.

Georgia Tech researchers also participated in the U.S. Army's Snowman project, making 35 and 95 GHz measurements of military vehicles on a turntable from a tower platform. Tower measurements included full-polarization matrix and frequency agility at 35 and 95 GHz for various domestic and foreign military vehicles. The data from this measurement program are being inserted into the Air Force's Target and Background Information Library Systems (TABILS).

Researchers participated in the Army's Snowman project, making 35 and 95 GHz measurements of military vehicles on a turntable from a tower.

Also, GTRI is participating in a joint Air Force-Army program that calls for simultaneous millimeter-wave and infrared images showing various aspects of the targets.



For many years, engineers at Tech have been actively involved in the identification and classification of stationary targets. They have processed and analyzed data from HAWFCAR and Snowman, then developed automatic classification algorithms to recognize specific targets or classes of targets. These data sets include 35 and 95 GHz full-polarization-matrix data that are processed to obtain the Mueller Matrix coefficients.

Further information is available from Mr. Wayne Cassady, (404) 421-7743, or Mr. Ted Lane, (404) 421-7682.

High-resolution millimeter-wave measurements have been taken at GTRI to create pulse-compressed ISAR images. The one shown in the large photograph above is of the Volkswagen convertible seen in the inset photograph.

ANALYSIS

Studies

Millimeter-wave technology is still in the developmental stages, and applications often call for extensive research and large financial investments. Government agencies and industries routinely ask GTRI engineers to make studies of millimeter-wave questions involving considerations such as design parameters, technology assessment, trade-off analysis, cost-benefit analysis, and threat weapon system evaluation.

Recent studies in the high-frequency range of the millimeter spectrum have focused on topics such as rocket-plume detection at near-millimeter-wavelengths; quasi-optical front-ends for meteorological applications; satellite-borne target or threat-sensing feasibility; and millimeter-wave missile-seeking. In addition, GTRI researchers have been major participants in an Army millimeter-wave technology base study.

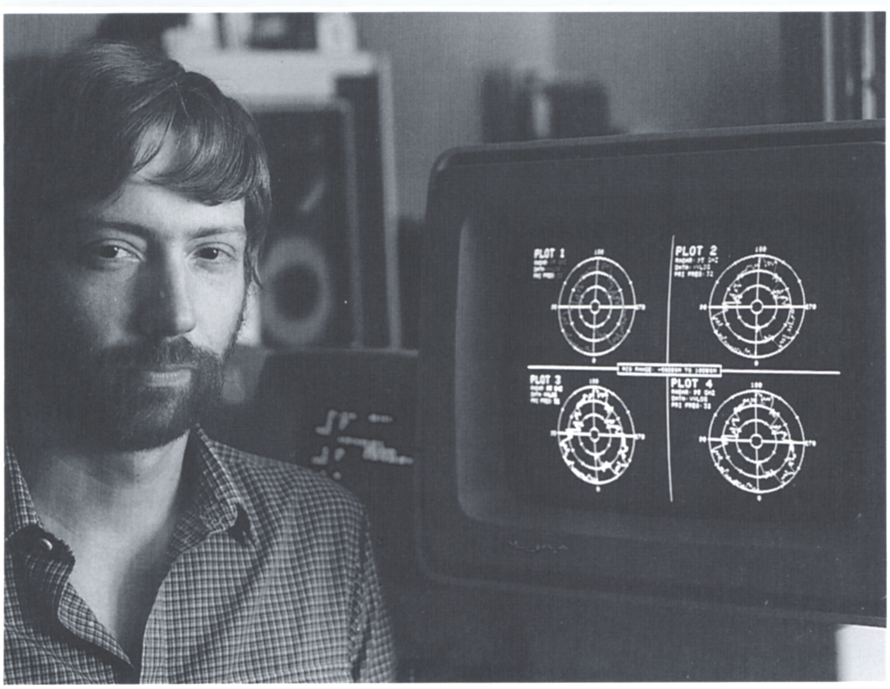
Recent studies in the radar applications area have focused on subjects such as a 95 GHz system for a surveillance drone; a dual-frequency upgrade that facilitates short-range radar cross section measurements; and non-nuclear-kill terminal guidance studies for ballistic missile defense.

GTRI researchers established preliminary design requirements for a dual-mode millimeter-wave/infrared seeker for terminally guided submissiles applicable to indirect fire systems for land combat. Studies also have been performed to develop specifications and design parameters for millimeter-wave radar test ranges. Engineers conducted a design study of a millimeter-wave adverse-weather test range for Eglin AFB and for an indoor test range that measures target models at Boeing Company. A similar study of a 95 GHz measurement system was undertaken for McDonnell Aircraft Company's Grey Butte Outdoor Range. Another study was performed to upgrade the Electronic Warfare Anechoic Chamber at the Avionics Laboratory.

GTRI has a number of the nation's leading specialists in electronic countermeasures and other electronic defense areas, and much of their work involves studies. These programs rely heavily on many computer models.

One recent project undertook a detailed assessment of the effectiveness of coherent electronic countermeasures techniques against millimeter-wave monopulse target tracking radars and was able to identify those features that are unique to the millimeter environment. Other notable programs have involved the design of a millimeter-wave direction-finding system and the evaluation of a millimeter-wave upgrade to an existing Army jamming system.

Numerous millimeter-wave studies are conducted at Georgia Tech. For preliminary information, contact Dr. James C. Wiltse, (404) 894-3494.



GTRI researchers conducted one of the most comprehensive efforts yet made to collect reflectivity data on snow at millimeter-wave frequencies.

Electromagnetic Compatibility

As millimeter-wave systems become more common, chances increase that they will encounter interference problems. GTRI engineers have performed basic studies to enhance the electromagnetic compatibility of systems operating at the millimeter-wave bands. On an Army contract, techniques were identified for characterizing the interference potential of millimeter-wave systems. Another research program comprehensively documented the similarities and differences between millimeter and lower frequency signals, identified primary areas of concern, and formulated recommendations to lessen the likelihood of interference in future millimeter-wave systems.

Further information is available from Mr. Hugh Denny, (404) 894-3535.

Tech has developed diffuse-scattering algorithms to model millimeter-wave radar backscatter.

Target Modeling

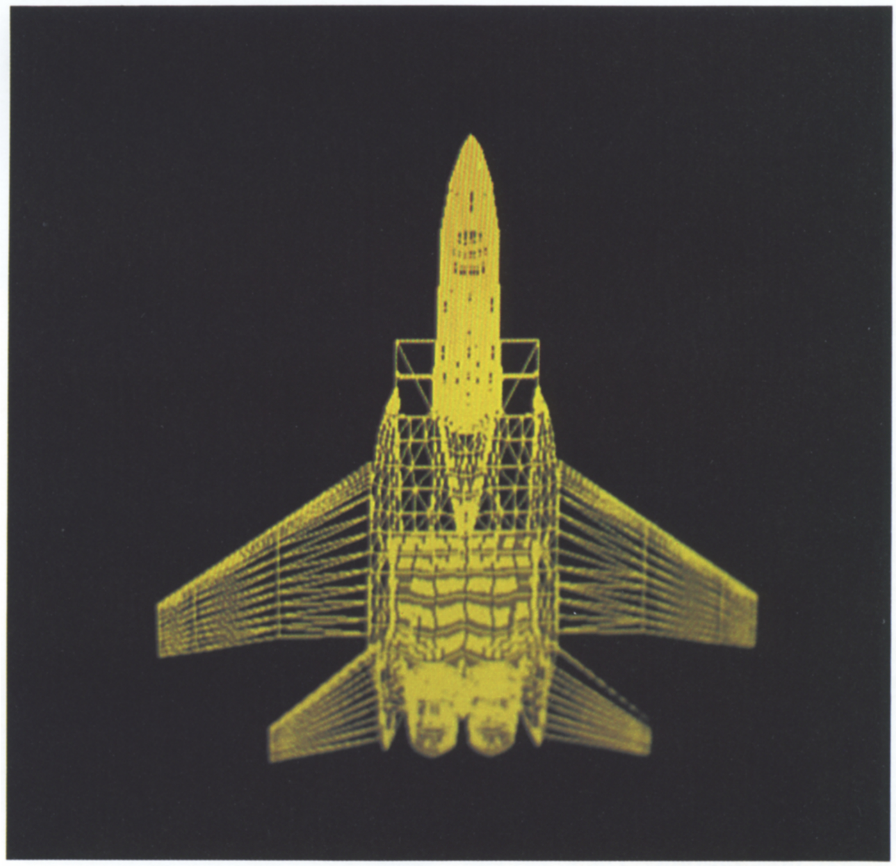
GTRI engineers have developed models to predict radar backscatter from complex targets such as ships, tanks and other ground vehicles, and aircraft. An important consideration in extending these models from microwave to millimeter-wavelengths is the diffuse scatter from realistically rough surfaces.

The surfaces of a tank, for example, might be considered "smooth" in terms of fractions of a wavelength for microwave radars, and the backscatter at those wavelengths is well represented by the specular return predicted from physical optics solutions for smooth surfaces. At millimeter-wave frequencies, however, the return from the surfaces of a "real" tank is scattered diffusely, and the classical specular scattering theories no longer hold.

Georgia Tech has developed diffuse-scattering algorithms to model millimeter-wave radar backscatter, in which the amount of energy scattered diffusely depends on the rms surface roughness and the solid angle over which the energy is scattered diffusely depends on the rms surface slope.

These realistic computer models of millimeter-wave backscatter from complex targets have been used in larger simulations to model the effects of glint on millimeter-wave seekers and to predict target-tracking and missile-impact points for millimeter-wave radar guided missiles and smart munitions. The models have been validated by comparison with measured data and can thus be used to extend measured data to other scenarios.

Further information is available from Ms. Margaret M. Horst, (404) 894-3578.



Above, GTRI researchers developed a computer model of the F-15 jet aircraft.

Airborne

GTRI maintains two Convair airplanes that are ideal airborne test platforms for millimeter-wave R&D programs. These Airborne Electronics Laboratories are equipped for measurements and data collection, system integration tests, technique evaluation, and equipment analysis.

The two Convairs (a C-131B and a T-29B) are twin-engined, cargo type, pressurized aircraft sufficiently large to provide laboratory environments, yet small enough for relatively economical operation. Each plane has a large belly radome, and the T-29 has a large nose radome. The C-131 can carry equipment pods under the wings or fuselage, has a large cargo door, and has two optical glass windows suitable for photographic mapping.

The airborne laboratories have shown exceptional reliability thus far: through 10 years of use, only two in more than 500 missions were cancelled.

Further information is available from Mr. Harry W. Andrews, (404) 894-7219.

Tech's airborne labs have shown exceptional reliability: through 10 years of use, only two in more than 500 missions were cancelled.

Top of page, GTRI maintains two airplanes that are useful in millimeter-wave research. Above, this mobile laboratory is used for electronic countermeasures at remote locations.

Mobile

GTRI maintains instrumentation radar systems for tasks such as basic radar reflectivity collection, radar system simulation, and evaluation of new radar techniques. The radars cover most frequency bands from 1 to 140 GHz and are designed to allow maximum flexibility of self-contained mobile radar vans and can be mounted in aircraft or sea tower facilities. Radar field measurements have been conducted in many locations, including West Germany.

A recently developed Mobile Data Acquisition/Reduction Facility provides computer workstation control of data acquisition, conversion, and recording as well as color display, hard-copy graphics, ISAR imagery, and a wide range of statistical data analysis and calibration routines. This facility allows data to be recorded under computer control and provides an in-field analysis capability.

A Multiband Instrumentation Radar System (MIRS) is under development that will provide for two RF heads at different bands with a common IF/data acquisition and control system. Initially, 35 GHz and 95 GHz IF heads are being constructed, although other heads at higher and lower frequencies are contemplated. The system is coherent, fully polarimetric, and has a 1 GHz bandwidth on a pulse-to-pulse basis. A computer workstation-based data acquisition and analysis system allows real-time data calibration and near-real-time data analysis including two dimensional ISAR images. The system can be easily mounted on ranges, towers, or instrumentation on fixed wing aircraft.

A mobile electronics laboratory at Georgia Tech provides an environment for electronic countermeasures field measurements and evaluations. The van is completely self-supporting, easily transportable, and can be situated at remote locations where physical facilities and electrical power are not readily available. Fifteen kilowatts of 60 Hz power are available from an internally mounted generator. A rigid-roof platform facilitates the use of a large variety of antennas.

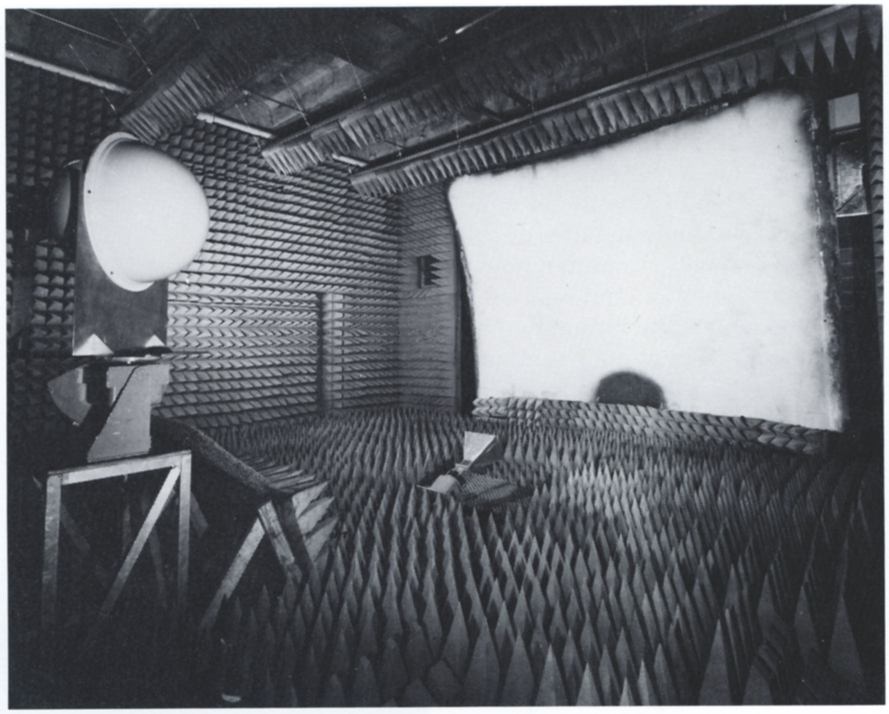
In addition, engineers have developed a Transportable Electronic Defense Support System (TEDSS) that can receive and process signals up to 40 GHz.

TEDSS is an automated data-acquisition system designed specifically for the acquisition and storage of contiguous-pulse waveforms generated by military and civilian radar systems. The TEDSS instrumentation is housed within rugged environmental containers to facilitate field deployment of the data-acquisition system for both ground-based and airborne collection platforms. TEDSS is comprised of a Microtel general-purpose microwave receiver, appropriate IF and demodulated signal outputs, and a high-speed LeCroy waveform digitizer. All instruments are controlled by a portable computer system using an IEEE-488 bus structure for instrument communication.

TEDSS is configured for the acquisition and storage of intrapulse signatures from domestic radar systems. For the specific collection of intrapulse signatures, GTRI utilizes TEDSS to acquire data intercepts that consist of a contiguous-pulse train of data captured at one radar emitter frequency. Intrapulse characteristics, represented by AM video, FM video, and 21.4 MHz IF data, are acquired and digitized by TEDSS for storage on nine-track magnetic tape.

GTRI's Electromagnetic Test Facility includes this 90-foot source tower along with a heavy-duty target turntable and a 64-foot receive tower. The facility is well-equipped for high quality antenna and radar cross section measurements. This and other laboratory facilities are discussed on page 20 of this booklet.

Laboratories



This completely automated compact indoor antenna range produces plane wave illumination of test antennas and scatterers.

The frontier of millimeter-wave technology is being extended at several GTRI facilities. These include:

- Antenna measurement facilities. GTRI operates three elevated outdoor antenna ranges, a compact reflectivity range, a cylindrical indoor near-field and antenna test range, several anechoic chambers, and a millimeter-wave test laboratory with facilities for measurements from 35 to 220 GHz. One of the outdoor antenna ranges is capable of handling large antenna systems over a long baseline. It features a rigid 90-foot tower and turntable that make it possible for measurements to be performed on millimeter-wave targets as large as tanks. This range also includes a roof-top facility for radar measurements;
- A microelectronics facility that provides equipment to support research in materials, circuits and devices associated with millimeter semiconductor and microelectronics technology. Engineers at this facility completely process semiconductor devices through epitaxial-layer growth, lithography, etching, mounting, packaging and evaluation;
- A spectroscopy and technology facility that accommodates studies of devices, harmonic generation, and frequency control as necessary parts of spectroscopic apparatus and millimeter-wave techniques in general;
- A molecular sciences facility where engineers collect data for computer modeling studies of the complex chemical composition of atmospheric and combustion systems. The facility is equipped with lasers for thermal chemical kinetics research;
- A rooftop laboratory which is well-instrumented with meteorological probes for propagation measurements over ranges from 200 to 600 meters. These probes include hygrometers, thermometers, an aerosol spectrometer, distrometers, barometers and wind-speed and direction indicators. Engineers can use some of these instruments on a meteorological tower near one of the propagation sites. At this facility, transmitters such as klystrons, carcinotrons, pumped lasers and broadband sources can be deployed. Receivers available for research include superheterodyne receivers and Fourier transform spectrometers with liquid helium-cooled detectors;

One of GTRI's outdoor antenna ranges can handle large antenna systems over a long baseline.

- Electronic defense facilities, such as an electromagnetic measurements laboratory, Georgia Tech clutter reduction radar, electro-optical/infrared laboratory, automated near-field measurement facility, remote sensing analysis facility, microprocessor design laboratory, and electromagnetically quiet test site;
- A laser measurements facility that is equipped for programs involving spectroscopy, tests of the optical properties of materials, and optical components development;
- A variety of computer facilities, including Georgia Tech's CDC Cyber 180/990, Cyber 180/855, two DEC VAX 6210s a VAX 11/750, several MicroVAX-2s, and numerous microcomputers. Many computer models are maintained to assist in defense electronics programs; and
- Machine shop facilities to meet many component and system fabrication needs, including numerically controlled milling.

These facilities are located in several areas. For preliminary information, contact Dr. James C. Wiltse, (404) 894-3494.

DIRECTORY

Six of the seven laboratories at the Georgia Tech Research Institute have millimeter-wave-related activities. Listed below are areas of interest and a point of contact at each laboratory.

LABORATORIES

Electromagnetics Laboratory
Mr. Devon G. Crowe, Director
(404) 894-3500
Phenomenology, Radiometric Systems, Active Systems, Components and Technology, Metrology, Instrumentation and Measurement, Electronic Materials, Studies, Antennas, Frequency Control, Phase Control, Optical Control

Electronics and Computer Systems Laboratory
Mr. Fred L. Cain, Director
(404) 894-3542
Electronic Direction Finding, Metrology, Electromagnetic Compatibility, Communications Systems, Evaluation of Materials, Camouflage, Antennas

Energy and Materials Sciences Laboratory
Dr. Daniel J. O'Neil, Acting Director
(404) 894-3530
Radome Materials, Fabrication and Evaluation of Radomes, Anti-Reflection Materials, Radar-Absorbing Materials, Materials Characterization

Radar and Instrumentation Laboratory
Dr. Edward K. Reedy, Director
(404) 421-7035
Phenomenology, Radar Systems and Studies, Transmitter Techniques, Frequency Control, Measurements, Modeling

Systems Engineering Laboratory
Mr. Robert P. Zimmer, Director
(404) 894-3519
Electronic Countermeasures, ECM Modeling and Analysis, Radar Warning Receivers, Signal Intelligence

Systems and Techniques Laboratory
Dr. Charles K. Watt, Director
(404) 421-7010
Antenna Technology, Threat Systems

For more general or administrative information, the appropriate contact is the director of the Georgia Tech Research Institute or the associate director most closely associated with the millimeter-wave activities listed above.

GTRI ADMINISTRATION

Dr. Donald J. Grace
GTRI Director
(404) 894-3400

Dr. James C. Wiltse
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(404) 894-3494

This booklet was produced by Georgia Tech's
Research Communications Office.

GTRI

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Georgia Tech is a unit of the University System of Georgia
3K/August 1989/$8,108