GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 6/1/81

Project Title: Small Homing Radar Study

Project No: A-2873

Project Director: Dr. T. G. Farill

Sponsor: Vought Corporation

Effective Termination Date: 5/31/81

Clearance of Accounting Charges: ______

Grant/Contract Closeout Actions Remaining:

- X Final Invoice ~~and Closing Documents~~
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
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Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

31 March 1981

Vought Corporation
P. O. Box 26114
Dallas, TX 75266

Attention: Mr. K. W. Hendricks

Subject: Contract Deliverables - Purchase Order C299702

Dear Mr. Hendricks:

All of the referenced contract deliverables have been provided to Vought Corporation. The items were delivered directly to Mr. Austin Cleveland on or before the required date in order to meet your internal proposal schedule. Copies of the deliverables are attached as a formal submittal to satisfy the contractual agreement.

A) Methodology (Task I) and technical background (Task II) were included in a single document in accordance with Vought's annotated proposal outline and was provided on 5 March 1981 (Attachment 1).

B) Win Strategy (Task III) consisted of a technical discussion held on 27 February 1981 at Vought Corporation in Dallas with T. G. Farill, P. P. Britt of Georgia Tech and Messers Martin, Kuhnel, Carlock, Haislee, Cleveland and Brautigan of Vought in attendance.

C) Related Experience (Task V) was provided on 27 February 1981 (Attachment 2).

In addition, data as requested in your telefax (2-88100/16-136), was provided to Mr. Cleveland on 19 March 1981 (in form and format requested by him) at the conclusion of a two day discussion on the subject matter.

This submittal fulfills all the deliverable requirements of referenced purchase order.

Sincerely,

Trent. G. Farill
Project Director

TGF/vcy

2.1.2 Sensor

2.1.2.1 Introduction

It is proposed that Vought will conduct a rigorous analysis to examine all options for an active radar homing sensor that will provide the guidance accuracy necessary to ensure a high probability of a hit-to-kill of an incoming ICBM re-entry vehicle (RV). Vought proposes to maintain its objectivity in this analytical process by utilizing a non-profit consulting organization to assist in the definition of the sensor requirements, determination of alternative approaches to meet the requirements, and evaluation of concepts solicited from several potential suppliers. The Georgia Institute of Technology/Engineering Experiment Station, with considerable expertise in millimeter wave radar and previous experience in the non-nuclear kill scenario, will perform this critical role. The overall objective of the analysis will be to select a sensor concept, technology, and subcontract for the follow-on proof of principle program (POP) and ultimately for a an operational system as defined by the specifications of the RFQ. It is anticipated that the best combination of missile and sensor technology can be determined for the follow-on POP program by maintaining the conceptual and sensor sub-contractor objectivity during this study phase of the interceptor program. The sensor review, that will be accomplished in the fourth month after contract award, will provide the government with the methodology for and the rationale used in the selection of this combination. The technical proposal for the POP test will include the selected sensor supplier as a team member. Potential suppliers who have agreed to participate in this approach include: (TBD). The remainder of this section discusses the approach that will be used for the sensor selections.

2.1.2.2 Sensor Performance Requirements

The functions to be performed by the sensor and the initial range of values for sensor parameters may be quantified by consideration of the basic system requirements and by extrapolation using standard radar system design considerations. The basic system performance parameters from the SOW may be summarized as follows:

Missile Range:	___	km minimum
	___	km maximum
	___	km degraded performance
Maximum Crossing Angle:	___	degrees
Target RCS:	___	dBsm
Desired CEP:	___	m
Interceptor Velocity:	Mach ___	

Generally, a seeker must perform the following functions: (1) acquire the target either by autonomous search or by the direction of a collateral surveillance sensor, (2) track the target in coordinates appropriate to the guidance law being employed (range and angle, for example) and (3) provide tracking error inputs to the guidance system to guide the missile to the target. The necessity for determining additional target parameters such as range rate (Doppler) or angle rate from the available parameters will depend on the specific radar system implementation. For example, for certain types of radars, CW for example, range is not a necessary parameter. The final choice of radar type to satisfy the system performance specifications will result from the trade studies.

During the initial portion of the interceptor flight, the missile will be flying toward the predicted impact point (determined by data generated by a ground-based acquisiton radar). During this time the target may actually be out of the field-of-view of the seeker. Tracking by the seeker, therefore, need only occur during the final 5-6 time constants of the missile flight. For a missile response time of 50 ms and a net closing velocity of about 15,000 ft/s (~ 4,600 m/s), one time constant corresponds to a distance of about 230 meters. Using a conservative value of 10 time constants for tracking time, the seeker should be designed to provide guidance data when the target is within a range of about 2,300 m.

The size of the basket in which the RV can be located by the associated ground tracking radar will determine the basic range and angular resolution required of the sensor for successful acquisition. A basket length of ___ meters in range implies that the range resolution of the seeker radar should be no less than ____ m. For a similar cross range basket, the angular resolution at a maximum seeker range of 2.3 km is ____. This requires a matching azimuthal resolution for the seeker.

The accuracy of the RV velocity measurement by the acquisition radar is not specified. but assuming a reasonable value of 15 m/s, the required Doppler resolution (at 35 GHz) is no less than 3.5 kHz. To achieve this Doppler resolution the coherent processing time must be no greater than 2.9×10^{-4} seconds (by means of an FFT processor or analog filter, for example). The determination of the required maximum Doppler bandwidth (resolution) will require consideration of a technique for separating the target RV from other RV's, rain clutter, nuclear fireballs and other interference that may occur during the engagement.

The seeker servo bandwidth must be comparable to that of the airframe so as not to limit overall system performance; the specified 50 ms minimum airframe response time corresponds to a bandwidth of 20 Hz.

These preliminary considerations result in a set of sensor performance requirements that must be considered as a baseline for the parameter trade studies (see Table 1). These requirements will be translated to specific radar parameters (pulse width, bandwidth, PRF, etc.) via the usual radar design considerations as the radar design concepts are developed during the course of the study.

TABLE 1. PRELIMINARY SENSOR PERFORMANCE REQUIREMENTS DETERMINED FROM THE SYSTEM REQUIREMENTS

Parameter	Value
Maximum Range	2.3 km
Minimum Range	125 m
Range Resolution	50 m
Angular Resolution	1.25°
Coherent Processing Time	$<$ 0.29 ms
Sensor Bandwidth	$>$ 20 Hz

2.1.2.3 Potential Sensor Subsystem Concepts

A simplified block diagram of a typical radar seeker is shown in Figure 1. The seeker consists of an antenna that senses target-reflected signals, a radar/processor that generates the necessary transmit waveform and processes the received signals to obtain range, range rate, and angle information, as necessary, and an antenna control system that provides tracking signals to the antenna and autopilot inputs. Sensor position data is generally provided by an inertial measurement unit (IMU) on the antenna gimbal or on the

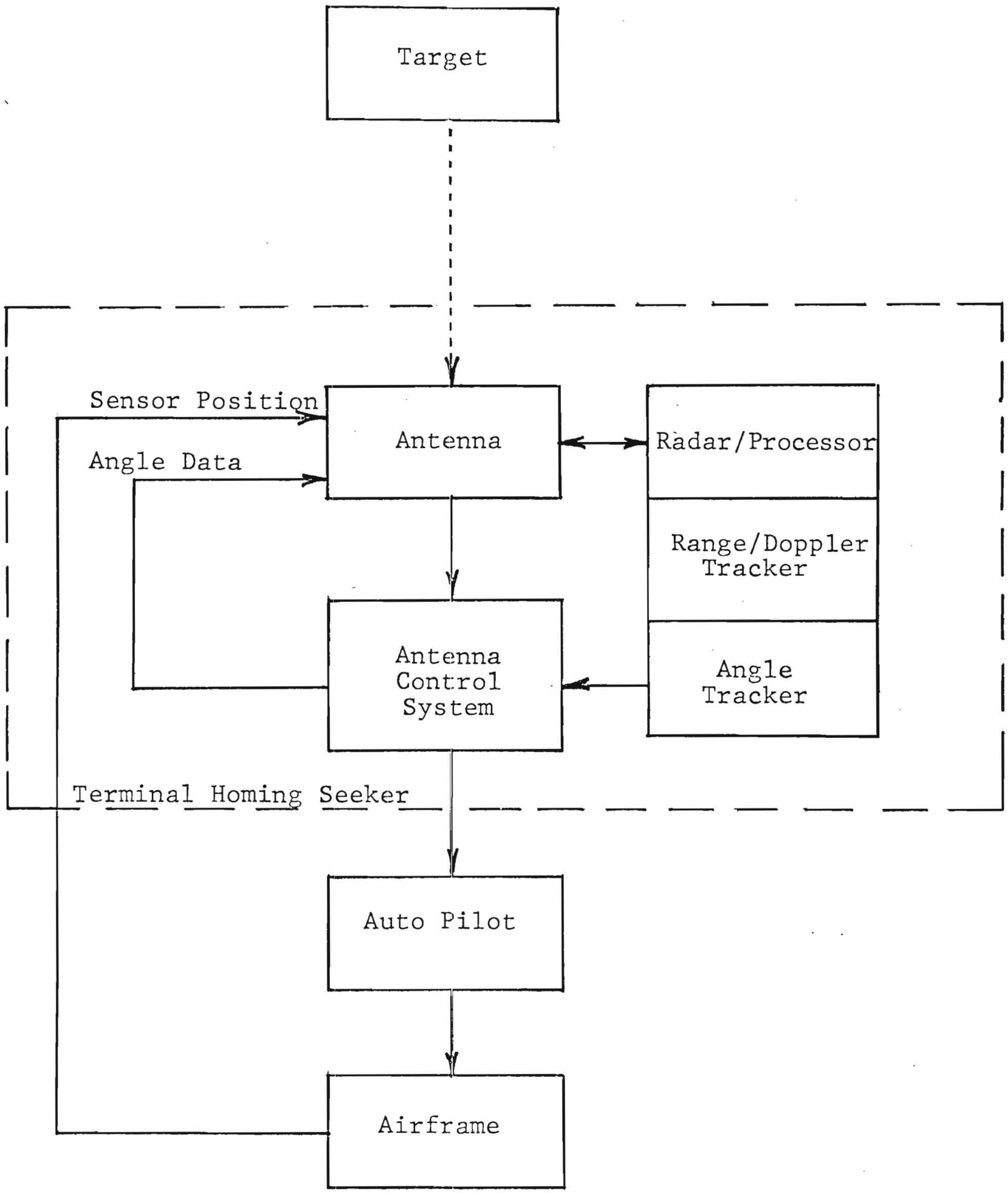


Figure Simplified block diagram of seeker.

airframe. Following acquisition of the target, the seeker normally must automatically track the target in angle (and perhaps range) and provide correcting inputs to the autopilot for missile guidance. Various techniques for implementation of this simplified process (or variations of it) provide several potential concepts that must be examined in detail and evaluated during the sensor trade-off studies. Typical of the concepts that will be included in the studies are those discussed below.

At this time there is not sufficient rationale for selection of either a spinning missile or a non-spinning missile. Such a selection will result from a combination of the airframe trades, the radar sensor study and the integrated interceptor trades. Missile stabilization techniques, combined with the option of a fixed or gimballed antenna, imply that at least five viable candidate configurations of airframe and antenna should be considered:

1. Non-spinning missile with fixed antenna;
2. Non-spinning missile with gimballed antenna;
3. Non-spinning missile with spinning antenna;
4. Spinning missile with fixed antenna;
5. Spinning missile with gimballed antenna.

The sensor parameters to be used in determining the optimum combination for the final seeker configuration include: field of view, RF frequency, tracking technique and resulting error level, radome error effects, transmitter power, Doppler and range resolution, and the processing gain requirement. Input data on concepts will be solicited from appropriate suppliers (with seeker design and development background) for evaluation in determining the optimum configuration. This solicitation will be conducted in parallel with an initial internal (Vought and Georgia Tech) trade study. Seeker solutions proposed by potential subcontractors will be evaluated in light of these analyses.

Several types of antennas have potential application to the problem. These include (1) simple body-fixed antenna, (2) gimballed fixed-beam antenna, (3) mirror scan antenna, (4) focal-pivot parabola,[1] and (5) focal-pivot lens antenna. Frequency or phase-scanning beam arrays are not considered as serious candidates due to schedule risk and anticipated higher cost when compared to dish, lens, or mirror type systems.

[1] "A Focal-Pivot Parabola - A Surprising Millimeter Wave Antenna," P. P. Britt, Proceedings of the 1977 Antenna Applications Symposium, April 1977.

In the scenario for the Small Radar Homing Interceptor, the interceptor launch point is expected to be at or near the targeted impact point of the re-entry vehicle. The resulting maximum crossing angle of the RV is less than ___. Therefore the angle between the interceptor axis and the predicted interceptor/RV impact point will generally be small during the engagement; that is, the lead angle will be essentially zero. Since the sensor field-of-view must provide for the combination of the crossing angle and the angle of attack of the interceptor during maneuvers (the angle of attack will typically be less than $\pm 5^{o}$ for the engagement scenario and type of airframe that will likely be employed), the total required FOV of the interceptor sensor is about ___. For non-crossing intercepts the total required FOV of the interceptor sensor may be only about 10^{o}. For this case a body-fixed seeker antenna offers several advantages. For example, with the maximum antenna size determined by mechanical constraints of the missile, a relatively small FOV requirement and a fixed antenna may allow operation at a lower RF than would be necessary if a narrow beam gimballed antenna were to be employed. A fixed monopulse antenna employing off-boresite track for guidance signal generation is therefore a potential low-cost solution to the non-crossing intercept problem. A significant advantage of a fixed antenna is the absence of a wide band servo loop that is necessary with a gimballed antenna concept. The use of a fixed antenna also greatly simplifies radome boresite and error slope compensation. A more detailed analysis must be performed to verify this concept, but the use of a body-fixed seeker antenna appears feasible.

A gimballed fixed-beam narrow field-of-view antenna is a relatively simple design that can satisfy the basic RV tracking requirements. The concept is more easily adaptable to the non-spinning missile case since the antenna stabilization requirements are more complex when the airframe is spinning. Decoupling of this antenna from missile motion is more difficult.

The mirror scan antenna is a double reflector system employing a rear-fed fixed main reflector and a scanning flat subreflector (or mirror) to produce beam scan. A twist reflector technique is used to prevent the adverse effects of subreflector blockage on beam patterns. This type of antenna is advantageous because (1) it requires no rotary joint, (2) the scanning element (the subreflector) can be very light, and (3) the far-field beam scans over an angle that is twice the subreflector tilt. Maintenance of the beam on target during interceptor maneuvers would require an IMU.

The focal-pivot parabola antenna is a simple concept in which a front-fed dish is gimballed to pivot about its focal point. Similarly this system requires no rotary joints in the RF path. The antenna could be spun up and stabilized before launch. The concept is applicable to both the spinning and non-spinning missiles. The focal-pivot lens antenna is a similar device employing a lens rather than a reflector for beam collimation and has the same advantages as the focal-pivot parabola. In addition it is more easily balanced mechanically so that lateral acceleration does not induce rotation of the antenna.

As noted above, a wide beam monopulse tracking antenna may be profitably employed with a body-fixed antenna concept. A monopulse system is also a good candidate for a narrow beam gimballed or scanned antenna. In the case of a nonspinning missile, dual-plane tracking is required. However, if the the sensor antenna is spinning, a single plane monopulse system may suffice since the tracking plane is rotating with the missile. A spinning dual-plane tracking antenna would provide two looks per spin cycle. For either system it is possible to average out biases and system non-linearities using the rotating reference planes if the missile spins rapidly compared to its response time constant.

In addition to antenna trades, techniques for processing data must be examined. The availability of RV targeting data from a ground sensor may significantly simplify target acquistion by the interceptor seeker. Since the RV position and velocity (range rate) are known to sufficient accuracy to predict an impact basket, the acquisition process for the seeker could consist simply of processing data only from the resolution cell, in position space and velocity space simultaneously, that coincides with the predicted RV parameters. Thus sophisticated search and detection procedures would be unnecessary.

The determination of the appropriate radar wave form (whether pulsed, pulse compressed, FM/CW, or CW, for example) will be made during the parameter trades. General considerations of the waveform and processing options are discussed below.

Because of the small value of target radar cross section (RCS) and the generally low gain of the seeker antenna (due to its limited size), a pulsed radar will typically require relatively high peak power to produce sufficient average power and, therefore, a sufficient signal-to-noise ratio (S/N) for accurate target tracking. Such a high peak power transmitter is disadvantageous because of the requirement for high voltage power supplies and attendant electrical and microwave breakdown problems. A pulse compression system overcomes the high peak power requirement by use of a longer pulse on transmit but the minimum range of the radar is correspondingly limited. Because of the minimum range requirement, sufficient pulse compression may not be available to reduce the peak power significantly. A potential compromise is possible by employing a dual pulse system that uses a coded long pulse for longer ranges and a short pulse (noncompressed) for the short ranges. A continuous wave system is attractive because it has no Doppler ambiguities; however, because there is no range information available, the CW system cannot resolve multiple objects within the antenna beam if their radial velocities are equal. Because of the low probability of such an occurrence, a CW system merits consideration, especially for a low-risk proof-of-principle demonstration. An FM/CW radar would provide range information by means of frequency modulation but suffers from Doppler ambiguities when observing moving targets. If the range/Doppler window for the RV is accurately determined by the ground radar, it may be possible to overcome the ambiguity problems associated with an FM/CW system. Techniques for these approaches will be explored during the study.

2.1.2.4 Parameter Considerations

The seeker subsystem is generally defined to be the combination of a sensor and an antenna control grouping that includes any necessary stabilization. Following lock-on, the autonomous seeker subsystem is expected to track the acquired target and provide input signals to the missile autopilot for guidance and control execution. The choice of parameters involved in seeker specification is dictated by the functional use of the seeker, the performance criteria that must be met, and the desired accuracy and precision of the operating equipment.

The set of radar parameters that will be examined in the proposed study, can be better defined by first considering some general aspects of the RV-Interceptor problem. The incoming RV appears to the seeker radar as a rather complex target composed of individual scattering centers that may be shrouded by an plasma-type wake. Thus, there are a number of independent scatterers, each with an aspect-dependent radar cross section. The composite represents the targets RCS. Associated with the dynamics of the missile trajectories are changes in the relative phase and amplitude of each indiviudal scatterer that lead to a change in the overall integrated radar return signal and to subsequent fluctuations in the apparent target centroid. At millimeter wavelengths and with narrow band signals, these phase changes can occur rapidly for relatively small changes in aspect angle. The use of wideband transmitted signals tends to reduce variation in the return signals by a process of frequency averaging over the pulse bandwidth.

The physical length of the RV trajectory itself leads to errors that arise from several different sources as the RV successively passes from acquisition to intercept. During the early stages of ground radar acquisition when the RV is at a relatively long slant range from the inteceptor base, the errors in state vector determinations are due mainly to thermal noise. As the RV continues to approach the interceptor system, the medium slant range geometry may lead to multipath errors, particularly, for SLBM trajectories as compared to ICBM profiles. Multipath errrors may occur in both range and angle. These errors will mainly affect the acquisition basket size. In the final stages at a converging slant range of 0-8 km, glint errors tend to dominate and become the driving factor in accuracy considerations for the onboard seeker radar system. This regime is of primary importance to the seeker problem addressed here. Although range glint errors are present at all radar ranges, angular glint errors have the greater influence on the end game success of the interceptor missile. If glint does present a serious problem for this scenario, glint reduction techniques such as frequency agility or wideband operation may be necessary.

Besides error sources related to the target, four additional factors that influence a radar's capability to measure AOA of a signal are:

1. Dimensions of the antenna aperture relative to the wavelength of the signal;
2. Aperture illumination functions of the receiver and the transmitter;
3. Ratio of total signal energy received to the receiver noise spectral density;
4. Methods used for scanning and subsequent processing of receiver outputs.

In light of the above considerations and in view of the investigative/technological nature of the proposed study, at least the following set of parameters and techniques will be examined as to trade-offs and their respective influences on the RV-Interceptor problem:

- Operating frequency/wavelength;
- Waveform/sidelobe ratio, PRF and pulsewidth;
- Antenna-size and type, gimballed vs. non-gimballed, beamwidth, gain, FOV, aperture;
- Signal bandwidth/spread spectrum;
- Transmitter power;
- Attenuation losses;
- Accuracy/precision available;
- Relationship between seeker tracking performance (including radome) and PNAV vs. PPNAV or alternative guidance/control laws;
- Signal processing procedures.

This minimum set of "parameters" will be evaluated as to their effect on the RV-Interceptor problem itself and also with regard to effects on the seeker/air frame interface. For example, the system guidance capability can be considered to be a function of the average radar power, the antenna diameter, and the system bandwidth. It can be shown by manipulation of standard radar system formulas that signal-to-noise ratio (S/N) and angular tracking error (ε_θ) are related to the system parameters by

$$S/N \propto P\, D^4/R^4 B$$

and

$$\varepsilon_\theta \propto \sqrt{B}\; R^2 / \sqrt{P}\; D^3 \, ,$$

where P = transmitter average power,

D = antenna diameter,

B = system guidance bandwidth,

R = target range.

Graphs demonstrating these relationships for 35 GHz and 95 GHz and two values of antenna diameter and rain rates are given in Figures __, __, and __. Similar computations and analysis will provide the trades that will allow the determination of the optimal set of radar parameters to satisfy the guidance requirements. There is also an interplay among these parameters that involve the relationship between the missile time constant and the missile diameter, which in turn impacts the physical construction of the seeker unit itself. In addition, there is another trade-off between radar power (the greater the power, the better the accuracy) and the physical size and weight of the radar and supporting units.

A few specific examples of the relationship between the basic sensor requirements developed in paragraph 2.1.2.2 and specific sensor radar parameters are discussed below. For example, if a pulsed radar is used, the maximum range requirement determines the pulse repetition frequency that can be used. The maximum unambiguous range, R_u, is a function of the interpulse period, T, and is given by $R_u = \frac{cT}{2} = \frac{c}{2F_R}$, where F_R is the radar PRF. The PRF should, therefore, not exceed 65 kHz for this scenario.

The range resolution, ΔR, of a pulsed radar is related to the pulsewidth, τ, by $\Delta R = c\tau/2$. Therefore, the range resolution minimum of _____ (to match the system acquisition basket) indicates a pulse width of no less than ____ and a corresponding

Figure 2. S/N and ε_θ versus slant range and rain rate; 4.5 inch antenna at 35 GHz; one watt transmitter power.

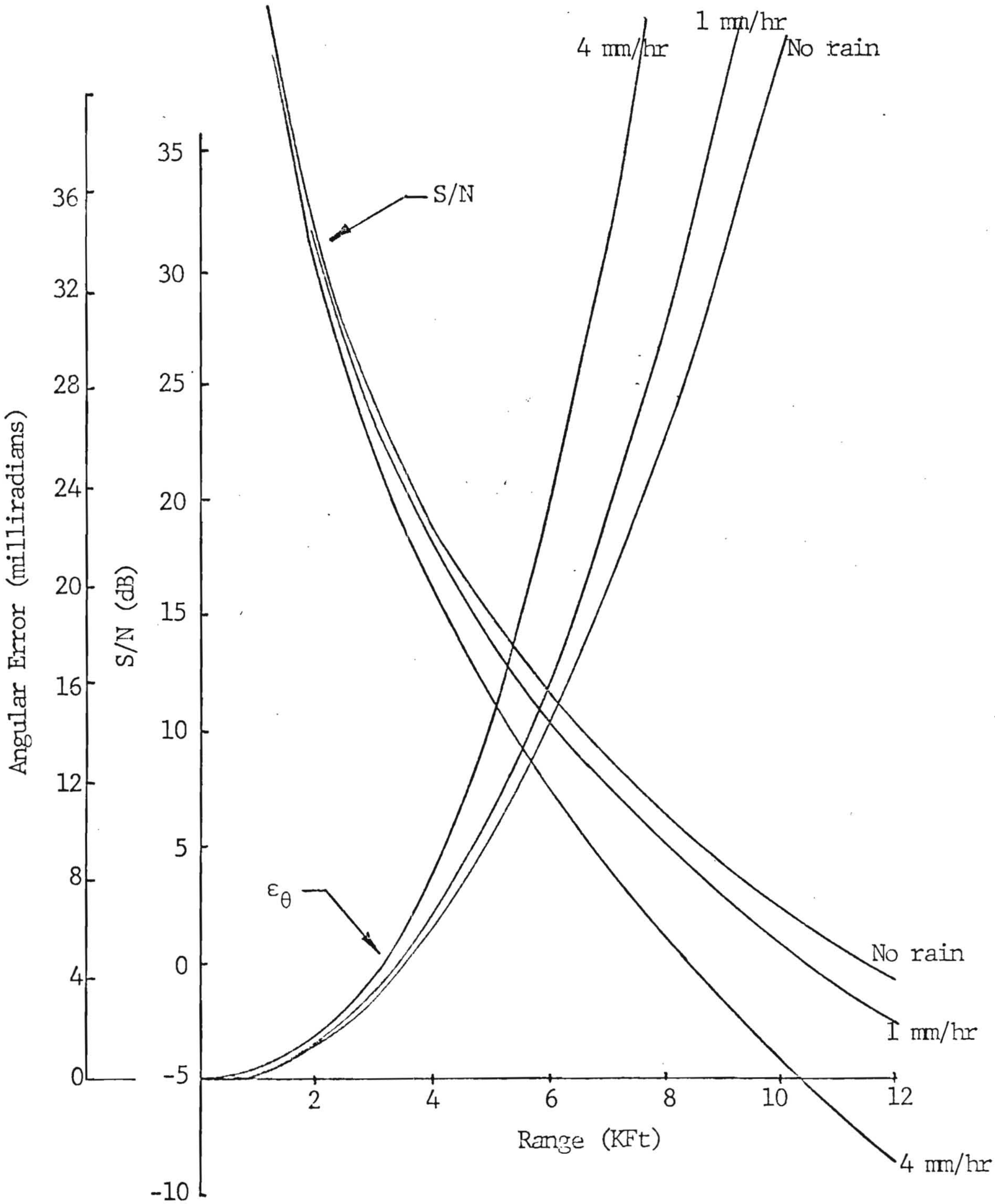


Figure 3. S/N and ε_θ versus slant range and rain rate; 4.5 inch antenna at 95 GHz; one watt transmitter power.

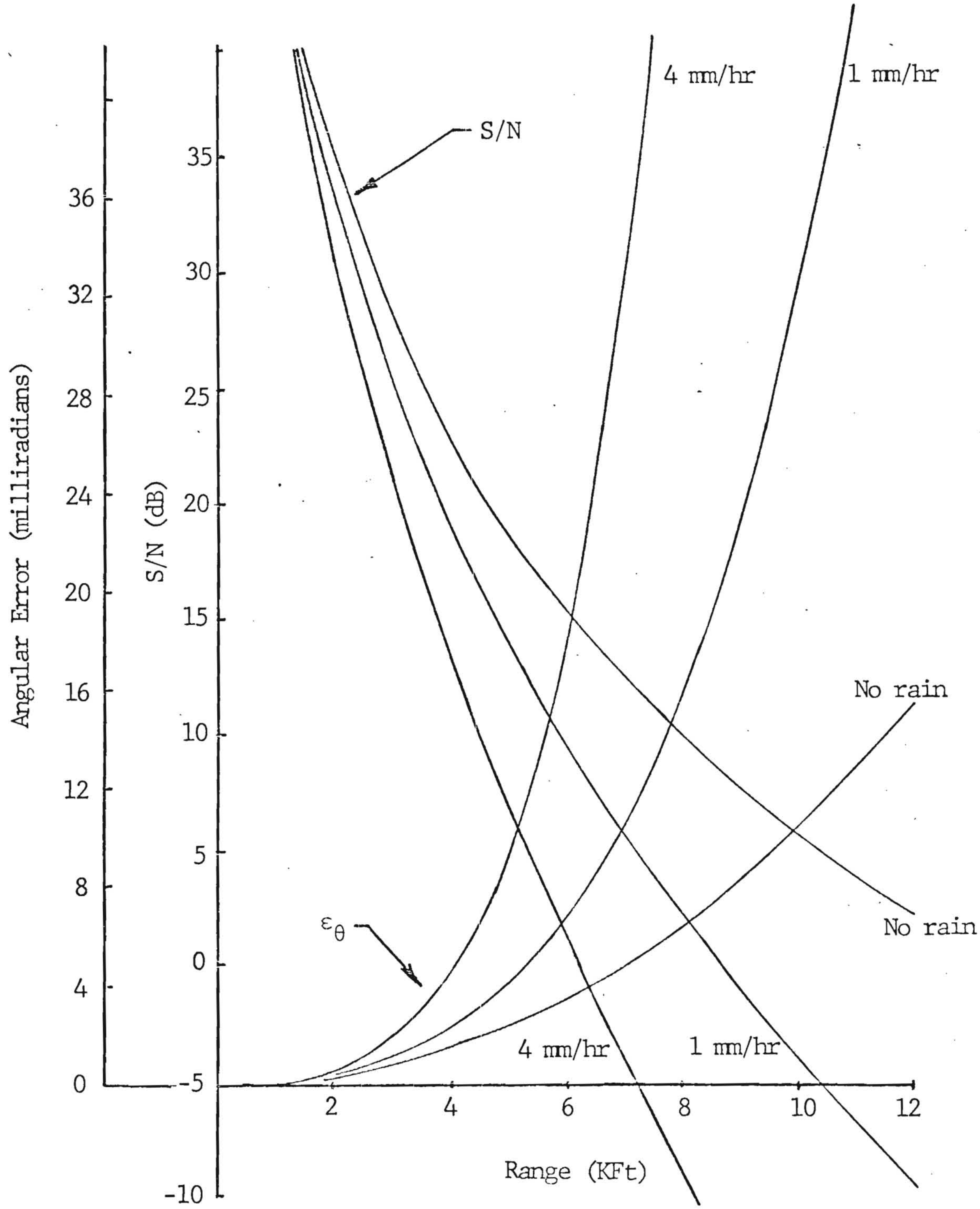


Figure 4. S/N and ε_θ versus slant range and rain rate; 3 inch antenna at 35 GHz; one watt transmitter power.

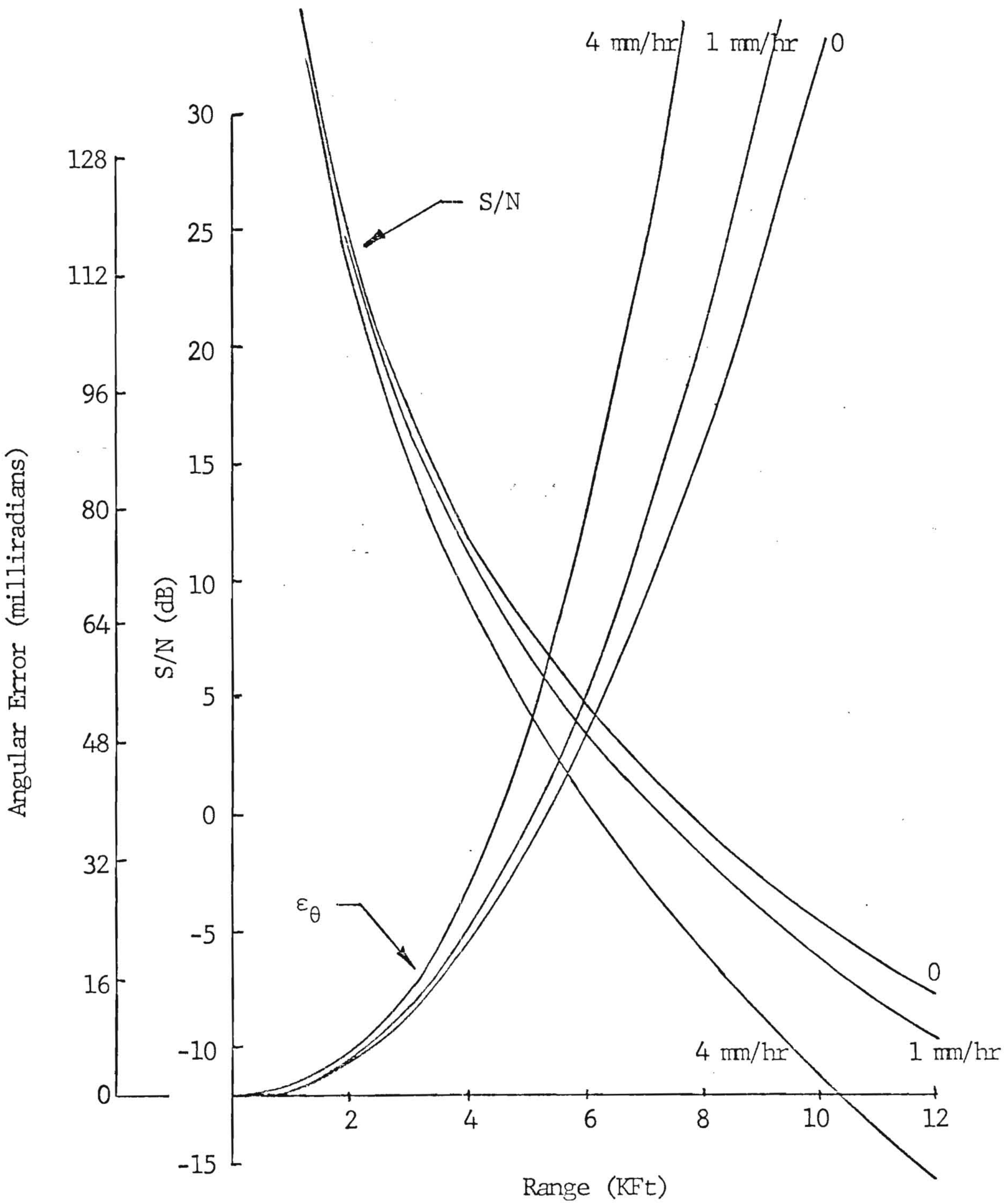
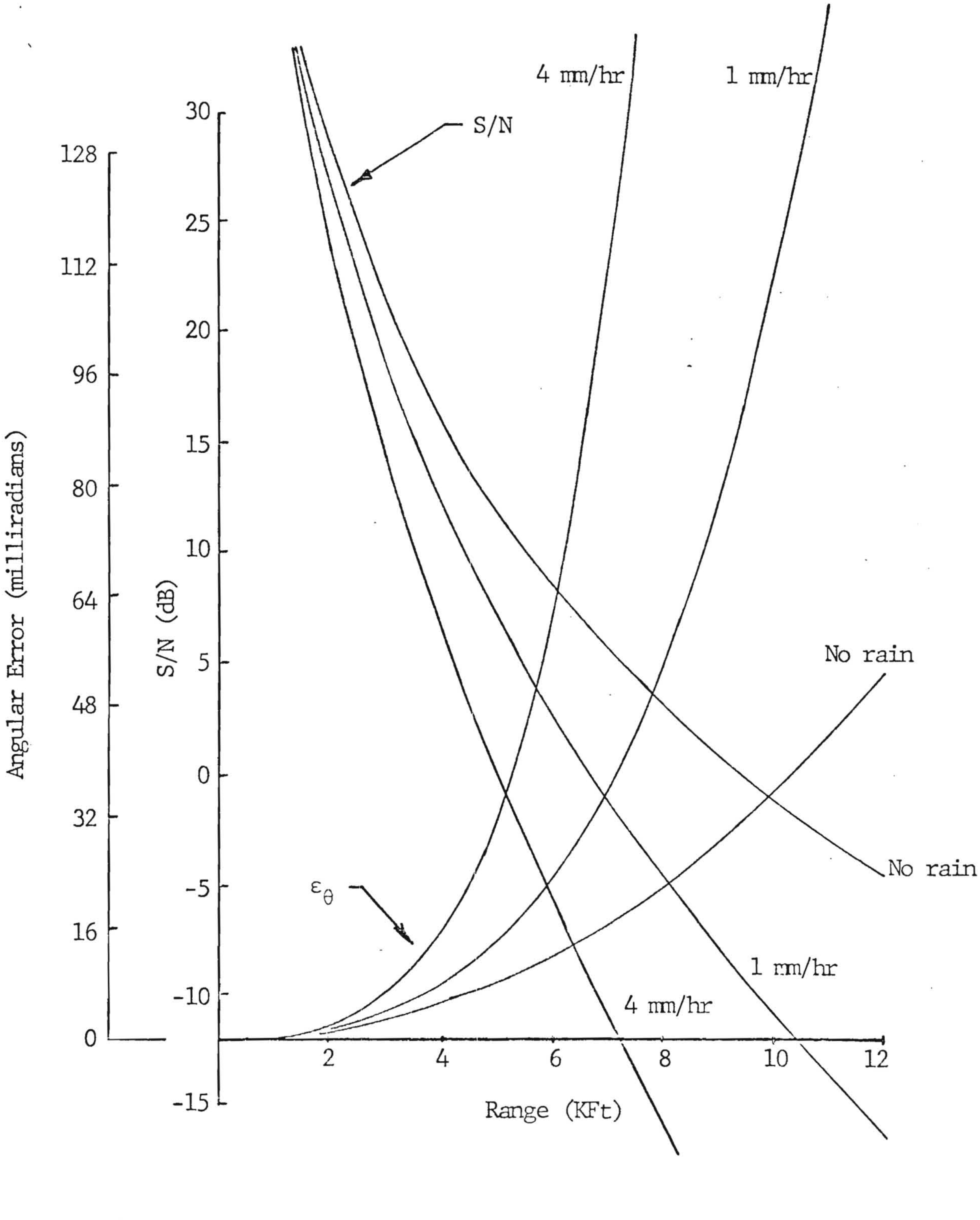


Figure 5. S/N and ε_θ versus slant range and rain rate; 3 inch antenna at 95 GHz; one watt transmitter power.



radar bandwidth of no more than ___ MHz. Consideration of FM/CW bandwidth requirements to achieve the same range resolution would give a comparable result depending on the exact implementation of the frequency modulation.

The angular resolution of the sensor must be on the order of ____ to match the angular acquistion basket of ____ at a maximum sensor range of 2.3 km. For a 4.5 inch aperture diameter this results in an upper limit on the sensor RF of 153 GHz (BW = 73 λ /D).The minimum allowable value of RF will be determined by a combination of requirements that will result from specific radar configuration (antenna gain, clutter and other interference, etc.).

The foregoing considerations are intended to be representative of the types of evaluation necessary in selecting sensor parameters.

2.1.2.5 Critical Issues

Certain issues resulting from considerations presented in the previous sections can have an especially serious effect on the viability of the candidate designs. These critical issues must be evaluated in detail during the study and any proposed seeker designs must properly address these issues to be considered as valid solutions. These issues are:

1. Sensor/Airframe Compatability

The performance of the seeker is of importance only as it functions in an integrated missile system.

a) Effectiveness of Seeker/Airframe Dynamic Decoupling

The primary source of guidance error is expected to be residual error in removing platform motion from the measured line of sight rate which is the dominant term of the missile guidance law. The usual souces of coupling are: antenna gimbal friction and backlash, other servo nonlinearities, uncompensated radome boresight error slope (including polarization effects), and uncompensated antenna off-boresight error slope. It will be necessary to validate all of the hardware and software involved in seeker/airframe dynamic coupling.

b) Accuracy of Seeker Guidance Data

For an adequate probability of intercept the seeker must provide guidance data soon enough in the encounter (> 6 missile time constants from impact) to close out the miss distance. Guidance must continue down to < 1 missile time constant from impact to prevent excessive guidance error accumulation. The sensor angle tracking accuracy (a function of range) needs to be measured (at the guidance bandwidth) from the required acquistion range in to the seeker blind range. Such data can be played though a missile guidance simulation that incorporates a realistic simulation of the missile autopilot, aerodynamics, airframe responses, and relative target motion to predict intercept accuracy.

c) Seeker Packaging

Equally important is the need for the sensor to be packaged in such a manner as to be compatible with the missile dimensions and to operate in the missile environment (shock, vibration, and temperature). Analysis and mock ups are insufficient evidence from which to accept final design of the seeker. Hardware models must be built to meet the packaging requirements and tested under realistically expected conditions.

2. Sensor Performance

The basic capability of the sensor to provide the tracking data at the accuracies required for terminal guidance must be verified. This includes demonstration of such performance parameters as:

a) Sensor output signal to noise vs. target size and range;
b) Angle measurement nonlinearities and biases;
c) Angle, range, and Doppler resolution and ambiguities;
d) Sensor response time and output noise bandwidth;
e) Inherent airframe motion coupling, including effects of radome.

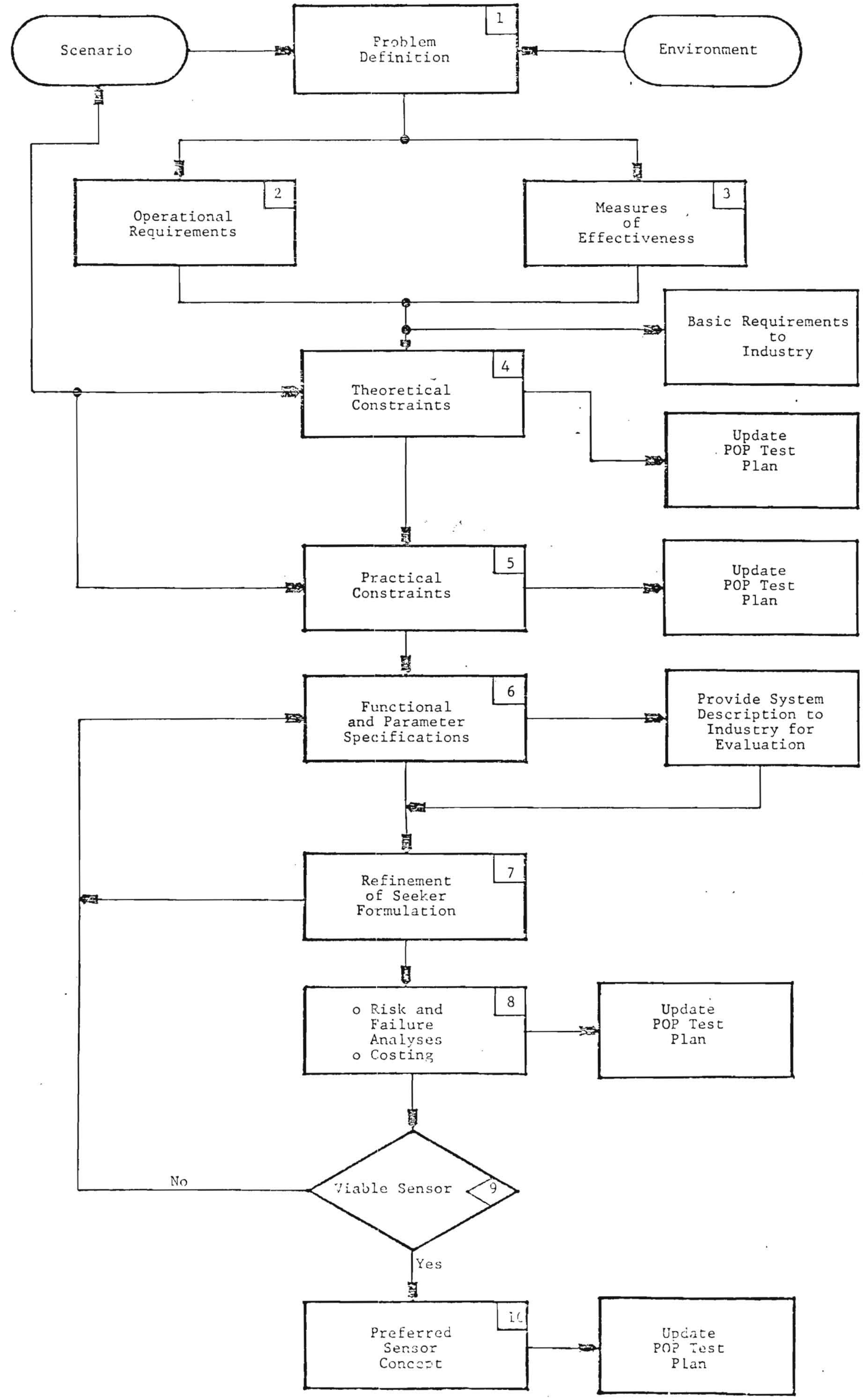
3. Radome Performance

The radome not only affects seeker guidance accuracy but also provides the aerodynamic fairing for the missile and encloses the sensor antenna. The radome design should be verified by calculations and by electrical measurement under temperature extremes representative of those encountered in the expected flight profile. Succeptibility to rain and dust erosion should also be evaluated.

2.1.2.6 Sensor Selection Methodology

This concluding subsection presents in flow chart form (Figure ____) the general approach to be followed in selecting the preferred operational sensor concept. The contemplated use of manual and automated analytical techniques is also indicated in subsequent paragraphs. Each of the "boxes" in the primary activity chain is numbered on the flow chart for reference to the narrative information.

The initial responsive activities begin with Problem Definition (Box #1). These activities involve generating a statement of objectives that recites the operational needs of the user and indicates the extent to which the proposed study will address those user


Scenario
Problem Definition
1
Environment
Operational Requirements
2
Measures of Effectiveness
3
Basic Requirements to Industry
Theoretical Constraints
4
Update POP Test Plan
Practical Constraints
5
Update POP Test Plan
Functional and Parameter Specifications
6
Provide System Description to Industry for Evaluation
Refinement of Seeker Formulation
7
o Risk and Failure Analyses
o Costing
8
Update POP Test Plan
Viable Sensor
9
No
Yes
Preferred Sensor Concept
10
Update POP Test Plan

needs. Distinctions are made between primary objectives (e.g., target kill via kinetic energy in direct collision) and secondary objectives (e.g., maximizing favorable interrupt considerations to decrease the number of missiles required to effect a non-nuclear kill). The overall engagement scenario consideration and environmental aspects are taken as inputs to the Problem Definition activities.

Using the objectives developed in the problem formulation phase, the Operational Requirements are identified (Box #2). These requirements consist of a statement of desired performance and an indication of the limitations thereof. The performance windows are constructed to represent the projected missile/seeker response to the scenario elements in concurrence with the objectives and environmental considerations.

The initial efforts for establishing proof-of-principle demonstration criteria are then made. This activity is called Measure of Effectiveness (Box #3) and is seen to be in parallel with the main developmental efforts in formulating Operational Requirements. Here the issues that will be addressed by the POP test are defined and reasonable limits are prescribed for the demonstration of hit-to-kill probability of an RV. The basic sensor requirements are now provided to Industry for their early consideration and review.

The Theoretical Constraints affecting the envisioned system are formally considered (Box #4) with the beginning of formal analysis and the development of system-level theory and equations. Functional requirements are assessed and subsequently reflected in an updating of the POP. The Practical Constraints that govern system formulation are then examined (Box #5). Losses and error sources are identified, and performance expectations are revised to reflect anticipated limitations. The modifications resulting from this "reasonableness" critique are translated into an upgraded version of the POP test plans.

Functional And Parameter Specifications (Box #6) are prepared at this stage of sensor development. The various error sources previously described are evaluated with regard to their impact on functional performance of the sensor/missile system, and parameters are chosen accordingly. Sensor characteristics are selected to match air frame design and response features. Only active radar seekers will be considered in this preliminary definition of the missile/seeker system. Seeker algorithms and component specification may be included at this point in the methodology of approach. Industry is provided a system description for their evaluation and input.

The Refinement of Seeker Formulation (Box #7) is now required. The evolving seeker concepts and any additional alternative concepts are evaluated using analysis and simulation techniques. System-level considerations are examined in light of overall missile/ seeker/mission interactions and requirements. Particular emphasis is placed on Industry responses regarding the capability and availability of existing or readily modifiable equipment. Efforts will be made to minimize R&D activities in deference to the time constraints for future system deployment. The activities taking place may involve discussions among BMDATC, Vought, Georgia Tech and potential sub-contractors. As indicated on the flow chart, provision is made to re-evaluate the specifications (Box #6) if the refinements are extensive.

At this point in the sensor development cycle a "workable" system has been conceived that must now be examined to ascertain that the system can be implemented executing the mission and POP test program satisfactorily. These Risk and Failure Analyses and Costing activities (Box #8) are used to project system feasibility, particularly as regards the criteria of demonstrability of the POP test program. Major performance and cost drivers are identified along with potential critical path elements in the design and fabrication processes.

The question of Viable Sensor (Box #9) represents an evaluation of whether or not at least one feasible missile/sensor concept has evolved during the sensor development process. This interrogation step incorporates due regard for the inputs of seeker suppliers and ongoing interchanges with Vought. If a satisfactory candidate concept and correlated POP test plan have not emerged, the activity flow recycles back to the specifications (Box #6).

The methodology of sensor concept approach concludes (Box #10) with the enumeration of the Preferred Sensor Concept. The candidate radar sensor subsystem has been projected to meet operational requirements and to perform within the measure of effectiveness prescribed in the updated POP test program. Inputs from various sensor suppliers have been obtained, and Industry is alerted to the forthcoming needs for POP test equipment and for possible development and production of deployable field units.

2.2.2 Sensor Design

2.2.2.1 Introduction

The concept and technology chosen by Vought during the operational system sensor trades will be used as a basis for the selection of a sensor design for the baseline integrated inteceptor that will be proposed for the proof of principle test. Key requirements for this hardware demonstration will be "off-the-shelf" technology and availability of hardware to meet the 24 to 30 month POP schedule. With the overriding goal of demonstrating that the concept of hit-to-kill of an ICBM re-rentry vehicle is feasible, and the constraint of schedule as primary considerations, the critical issues identified during the sensor trades will be examined to determine the critical POP test issues and what approach best answers those test issues. The range of options depends on the results of the trades but could vary from a full-up sensor capable of meeting the operational requirements, to a sensor capable of operating in a restricted scenario, to one in which significant changes or simulations are required due to size, weight, and considerations of current technology. The criteria and methodology for selection of the concept technology, and sensor sub-contractor for the POP phase as well as test issues are discussed below.

2.2.2.2 Preliminary Supplier Selection Criteria

The demonstration of the viability of the selected approach to the Small Radar Homing Interceptor problem via the proof-of-principle hardware will require the selection of a sensor vendor during the study phase who has a viable tactical concept that can be successfully adapted to a POP scenario. At this time there appear to be certain criteria that such a vendor must satisfy to be considered an acceptable source for the POP sensor hardware demonstration model. These criteria, that relate not only to the vendor alone but also to the basic sensor concept and its technology, are described below.

The vendor must have demonstrated general competence in the area of radar techology, and have an extensive background in seeker or related work. Familiarity with concepts specifically related to terminal homing seekers, demonstration of a technology base, flexibility of the organization that would allow successful adaptation to concept changes and cooperation with the Vought/Georgia Tech team during the POP. Growth from the POP to a production system will also be considered.

The basic sensor concept selected must above all demonstrate responsiveness to the RFQ by (1) satisfying of the guidance accuracy specification and (2) by compatibility with the airframe and guidance. Additional critical factors include sensor size and weight, potential for achieving specified performance within the POP time schedule, and the degree of risk in terms of the necessity for new technology development. The tactical system concept must be easily reconfigured to conform to a POP demonstration model and must also possess the capability to grow to a more sophisticated system as necessary.

The technology employed in the concept design for the POP hardware should be restricted to generally available off-the-shelf components but should also satisfy the environmental considerations (shock, vibration, nuclear hardening, etc.). The radome design is a particularly critical area wherein the technology employed will have a strong influence on the long term suitability of the concept particularly relating to radome hardening against heat extremes and rain erosion.

2.2.2.3 Critical Test Issues

Some of the critical issues identified during the sensor trades and the integrated-interceptor trades, will require resolution during the POP program through actual hardware demonstrations, some may be resolved through reasonable simulations, and some may require long term resolution and must be deferred during the POP program by restricted scenarios or test conditions. The baseline configuration sensor design for use during the POP program will be determined after consideration of those critical issues and with the intent of minimizing their effects on the POP. The remaining critical test issues for that baseline design will then be defined and the methods of resolution addressed.

Sensor related issues that are expected to be significant during the POP test are as follows:

1) Sensor decoupling from missile body motion;
2) Sensor and airframe time constant/response compatibility;
3) Radome effects on guidance errors;
4) Sensor and missile size compatibility;
5) Sensor reliability in the vibration and shock environment.

There is also the possibility that critical issues exist for the POP test that would not be issues in a operational system. The use of sensor allocated space for telemetry components and possible interactions of telemetry and radar signals are examples. Test issues of this type will be addressed during the development of POP plan.

The POP plan will be structured in such a manner that each identified critical test issue is resolved at the lowest subsystem level prior to demonstration of a total integrated system. For example, the measurement of output parameters such as range, range rate, angle or angle rate would be measured on a test table to show effects of the platform motion on the sensor output. The effects of radome error compensation could also be demonstrated on such a test set-up. Similar test will be defined for each critical test issue.

2.2.2.4 POP Sensor Selection Methodology

The methodology for selecting a vendor to satisfy the sensor requirements for the POP test program is described in this section. The stated objective of the POP test program is to demonstrate the feasibility of the hit-to-kill capability of a small radar homing missile against an ICBM RV. It is understood that this demonstration can utilize hardware or software in various combinations of actual equipment execution and/or simulation. Thus, the methodology for selecting a sub-contractor must take into account the nature of the POP test. The potential benefit of the POP sensor supplier remaining in the overall missile/seeker program as the supplier of deployable system must be considered.

The methodology described in Section 2.1.2.6 for selecting a basic sensor concept forms the basis for defining the approach to be used to select the supplier for the POP interceptor seeker. In particular, the previous methodology pointed to a "preferred sensor concept" and the generation of a POP test program that reflected the preferred concept. The final POP test plan must contain a baseline seeker design that is fully compatible with the objectives and operational requirements of the missile/sensor mission and that demonstrates the feasibility of an Interceptor/RV engagement. The prepared baseline seeker design will be provided to various seeker suppliers and their responses evaluated as to suitability of manufacture, schedule, and cost. It is anticipated that the interceptor specified for the POP test program will employ the same basic concept that is planned as a operational system.

During this solicitation of bids from Industry, technical information interchanges will take place and the results will be incorporated into the finalized POP test program. As the bids are received and processed, Georgia Tech will continue to assist Vought Corporation in evaluating the proposed sensor activities.

RELATED EXPERIENCE

The Georgia Institute of Technology Engineering Experiment Station (GIT/EES) is a major center for radar research and development. Beginning with radar research in the 1940s and millimeter wave research in the 1950s, GIT/EES has perfected expert capabilities in all areas of radar, including:

RESEARCH - to provide a broad base of fundamental information and to discover new phenomena that may be exploited to expand the existing radar technology base,

DEVELOPMENT - to expand the radar technology base necessary for advanced systems by identifying problems, by determining alternative solutions, and by testing innovative combinations of technological building blocks,

SYSTEM ENGINEERING - to transform operational needs into system performance parameters and preferred system configurations,

STUDIES and ANALYSES - to organize and evaluate data and to make substantive contributions to planning, programming, and decision making.

GIT/EES is nationally known for its expert capabilities in millimeter wave research and development. These capabilities include measurement and analysis to characterize targets and backgrounds, formulation and analysis of concepts for a variety of applications, and development and evaluation of techniques and equipment for specific operational requirements. A summary of our recent millimeter wave contracts is provided in the attached Table. The following project summaries indicate GIT/EES capabilities for developing millimeter wave missile seeker systems.

The concept for contract DASG60-79-C-0125 titled "A Narrow Field of View Terminal Homing Seeker," was developed in response to a NNK guidance problem identified and quantified by BMDATC. The specific definiton of the problem allowed for a simple, but apparently highly effective solution. The concept fully utilizes the capability of the ground radar to perform the target detection acquisition functions so that the missile seeker has only to perform the terminal tracking function. The ground radar provides the relative coordinates of the target, in range, angle, and range rate, with sufficient accuracy that the target is assured of being contained within the range, Doppler, and angle, tracking gates of the seeker. Furthermore, there is

RECENT MILLIMETER WAVE EXPERIENCE

Contract/Sponsor	Dates	Title	Comments
F29601-79-C-0050 Air Force	79-80	Radar Background Signal Reduction Study	Identify materials and techniques to reduce, or eliminate, residual background reflections at 30 MHz to 95 GHz for Radar Target Scatter Facility (RATSCAT)
F19628-78-C-0002 MIT/LL	79-80	MM Wave Transponder	Development MMW transponder for use by MIT/LL in instrumenting terminal homing accuracy of millimeter wave sensor
F08635-79-C-0048 AFATL	79-80	Development of Radiometer Target Models	Develop models for passive cross section of tanks and armored personnel carriers at 95 GHz
F19628-78-C-0002 GE	78-79	Millimeter Sensor Design, Fabrication, Test	Develop 94.5 GHz radar as part of a helicopter-borne radar/radiometric sensor -- a major subsystem of a millimeter terminal homing studies instrumentation sensor
F04704-78-C-0035 Boeing	1979	MX Vertical Shelter Physical Security System Study	Evaluate concepts and radar designs to characterize a point security surveillance system for MX MAP basing
N60921-77-C-A168 NSWC	77-78	Millimeter Radar Sea Return Study	Collection of MMW sea clutter data in literature; computer modeling; planning of measurement exercise
N60921-78-C-A179 NSWC	78-79	Multifrequency Radar Sea Clutter	Sea backscatter measurements at 9.5, 16, 35, and 95 GHz to provide data for assessing low angle tracking of aircraft and missiles near ocean surface
Norden Systems, Inc	1979	Antenna Engineering Assessment	Design antenna/radome (95 GHz) for hypersonic vehicle
N66604-78-M-8220 NUSC	1978	Characterize Electronic Propagation	Assist NUSC in Federated Combat System (FCS) Study in areas of submarine antenna detectability and performance and electromagnetic propagation, from DC to light

Contract/Sponsor	Dates	Title	Comments
Standard Elektric Lorenz	78-79	95 GHz Radar Measurement Program	Measurement of ground clutter (bare ground, bushes, trees) and targets (APC, truck, tank) at low (near zero) depression angle, and battlefield background and attenuation at 95 GHz
DAAG29-78-C-0044 ARO/ERADCOM	78-79	Stationary Target Detection and Discrimination	Measure signatures of tank, jeep, truck, and howitzers at 10 and 95 GHz and develop multi-class target classifier
JUH/APL	1979	MM Wave Signal Experiment	Provide 35 GHz threat simulation for counter-measures evaluation
F08635-78-C-0105 ADTC	78-79	Millimeter-Wave Background Measurements	Measure and analyze background reflectivity and emissivity of clutter and targets in clutter at 35 and 95 GHz to provide data base for Wide Area Antiarmor Munition (WAAM) Program
Martin-Marietta	1978	95 GHz Radar Data Analysis	Analyze 95 GHz radar land clutter for design of signal processing techniques for a ground-to-ground radar with moving armor as the primary target -- STARTLE Program
DAAK40-77-C-0047 MIRADCOM	77-78	Basic and Applied Research Systems Engineering Support	Develop 35 GHz Instrumentation Radar
DNA001-77-C-0269 SRI	78-79	Electromagnetic Scattering and Attenuating Properties of Dust Clouds	Determine 10, 35, 70, and 95 GHz electro-magnetic properties of dust clouds lofted by sur-face or near-surface explosions simulating nuclear detonations
DAAG29-76-D-0100 MIRADCOM via ARO	77-78	Modeling of Targets, Clutter, and Environments for Millimeter Guidance Applications	Assess development of probabilistic models for millimeter (35, 95, 140, and 220 GHz) terminal homing guidance

Contract/Sponsor	Dates	Title	Comments
DAAK40-77-C-0077 MIRADCOM	77-78	Characterization of Coherent Reflectivity from Targets and Background at K_u, K_a, and M-band	Characterize coherent reflectivity to establish a technical data base for development of target acquisition, warning, and recognition sensors
DAAG40-78-C-0158 MIRADCOM	1979	Millimeter Wave Transmitter	Develop 94 GHz transmitter using stabilized EIO
DAAG39-78-C-0044 HDL	1979	Near Millimeter Mobile Measurement Facility	Mobile transmitters and receivers for simultaneous measurements at 94, 140, and 220 GHz.
Army Night Vision Lab (Pending)	1979	A Near Millimeter Wave Radar	Develop 220 GHz radar using a pulsed EIO transmitter phase locked to the receiver LO
F08635-77-C-0114 ADTC	77-78	Adverse Weather Performance Evaluation	Study requirements for a millimeter adverse weather test range for missile seeker development and testing
F08635-76-C-0221 ADTC	76-77	Radar Backscattering at 35 and 95 GHz	Backscatter measurements of snow-covered terrain and wet/dry foliage and active/passive signatures of tanks and armored personnel carriers at 35 and 95 GHz
DAAK40-78-C-0158 MIRADCOM	78-79	Test and Evaluation Laboratory for Millimeter Beamrider Applications	94 GHz coherent transmitter/receiver and 140 GHz incoherent transmitter/receiver using EIO's
DAAG29-78-C-0044 ERADCOM/ARO	79-80	Spectral Analysis of Millimeter Wave Radar Tactical Target Signatures	Analyze 95 GHz coherent signatures of tactical targets; exhibit spectrum differences for NCIFF applications

sufficient information to enable the seeker to control its radar waveform (PRF, pulse length, etc.) to assure that radar clutter (nonmoving target returns) will not degrade the seeker tracking performance. Radar calculations indicate that the transmitter requirements will be minimum (1-10 watts) and the signal processing can be performed without exotic equipment. Analysis has shown that the antenna dynamics involved are well within the capabilities of a hydraulically gimbaled mirror scan antenna. The radome for the seeker may be a more difficult problem but since the flight time is so short (about 2 seconds) the problem should be tractable. The objective of this phase of the program is to "flush out" the concept and provide sufficient analytical evidence to judge the value of pursuing the concept further. The task objectives are system analysis, radome analysis and antenna analysis.

Under Contract F49620-78-C-0121, EES developed validated algorithms in verified ANSI standard FORTRAN IV and implemented these into the Air Force TAC ZINGER computer programs to provide improved estimates of system performance in the presence of multipath and clutter. Several areas were addressed in the study. A survey of existing analytical clutter and multipath models was conducted and the models were then evaluated, which involved using test data for calibration, computer implementation, and investigation of compatibility of clutter and multipath relationships. Data gathered at several Air Force multipath tests were analyzed relative to multipath/clutter models and the TAC ZINGER models. Computer implementations were then produced providing model input dat on climate, terrain, and other factors needed to use the models. Interface modules were developed between clutter/multipath models and the TAC ZINGER models.

Under Contract N00164-78-C-0239, EES was tasked to further develop two missile flyout models for a Soviet-built surface-to-air missile system. These models are part of the TAC ZINGER series of models developed by the Air Force. Both models compute a detailed missile flyout flight path and probability of target kill given inputs of launching site, firing doctrine, target flight path, and target countermeausres. EES will further develop these models to incorporated more ECM simulations and provide a set of models which include additional ECM techniques not currently in the models. In additon, the models will be combined in a larger program in such a manner as to minimize off-line manipulations.

Missile RF systems investigations were conducted under Contract DAAH01-74-C-0743 to perform detailed measurements and related analyses of typical components used in RF seeker systems. Components and subsystems measured included: radome, antennas, gimbal, receiver electronics, angle tracker and doppler tracker. Associated analyses have been made on the angle tracker system including a complete computer of the system. Verification of this model for single targets was conducted in a closed loop simulation in an anechoic chamber. Complex multiple target effects were investigated utilizing laboratory generated signals. Out of band RF susceptibility testing was conducted in an anechoic chamber and certain sensitive frequencies identified. Circuits were investigated in detail stage-by-stage. These included local oscillators, mixers, IF amplifiers, angle demodulation, logic, and gimbal servos.

Under Contracts F08635-76-C-0151 and F08635-76-C-0326, EES developed a Closed Loop Flight Test Simulator for the Armament Development and Test Center (ADTC), Eglin Air Force Base. The facility in which the system is housed is located at the ADTC flight test range and is to be used for real-time missile effectiveness analysis against maneuvering aircraft and various countermeasures techniques. A simulated missile autopilot provides the on-site equipment control and monitor function by use of direct digital control laws. The system provides a highly realistic flight test capability for evaluation of all types of self-protection ECM. This includes conscan countermeasures, Automatic Gain Control countermeasures, and velocity gate countermeasures. The facility also has an excellent capability for evaluation of low speed targets, maneuvering targets, and chaff. The fabrication of a tracking antenna and associated microwave assemblies for this missile seeker involved constructing an antenna assembly and associated RF circuitry physically and electrically equivalent to the seeker antenna and MIL-E-5400 requirements. The software developed for the on-site system provides for control of the system hardware, including a flight table, missile seeker and supporting hardware, RF generation hardware, data recording and display, and communications hardware. This hardware is used during real-time operations and for test and calibration of the equipment in non-real-time. In addition, a remote computer at the main base, a CDC-6600, provides the closed loop simulation algorithms for establishing trajectory data, including relative kinematics, missile dynamics (aerodynamics, engine dynamics, etc.), and target statistics. The CDC-6600 and the on-site computer communicate in real-time via time division multiplex telemetry.

Under Navy Contract N00174-77-C-0099, EES conducted a design study of a Ballistic Antiship Missile (BAM) guidance system. A tradeoff study was conducted to select the best seeker type and the expected seeker performance. A systems design was conducted of the entire guidance system. Trajectory simulations were run to estimate the guidance performance. Rough miss-distance data was computed for a proportional navigation guidance law. The candidate seeker was an active/passive seeker. Passive ranging was used in the passive guidance mode to estimate the range to the target. The passive ranging algorithms were used to estimate both the range and velocity of the target.

A missile guidance and control system simulation program for evaluation of advanced gimballed EM seekers has been developed and applied under Contract F33615-73-C-4070 for the Air Force Avionics Laboratory. The computer program stresses the sensor (and target radiation) characteristics and uses a simplified missile dynamics model. As a result, inclusion of random noise in the sensor model and performance of sensitivity studies can be accomplished with reasonable computer time requirements. Application of the simulation program on the current contract has dealt with low-level signals in a noisy environment. This simulation program has evolved from one developed at EES in 1970 for evaluation of strap-down guidance systems for use with Electro Optical sensors (laser pulse designation).

Under Navy Contracts N60921-76-M-5916 and N60921-77-C-0057, EES conducted terminal guidance law studies of a high lethality antiship missile. Two guidance laws were examined and evaluated using six degree of freedom missile simulations. As part of the study, computer subroutines were developed which modeled the guidance error sources. The seeker error sources were of primary interest. These included the tracking errors from thermal noise, clutter, backscatter, target noise, and multipath. The radar range equation was used to compute the signal-to-noise, the signal-to-clutter, etc., ratios as a function of the range to go. Monte Carlo simulations were run to compute the miss-distance and the terminal orientation of the missile.

Under subcontract to the General Electric Company, technical support was provided in synthesizing a radar system design using the Westinghouse-produced

F-16 Pulse Doppler Radar as a base. The basic objective was to assist General Electric in the preparation of their Divisional Air Defense System (DIVADS) proposal to the U.S. Army. The proposed configuration was evaluated in terms of its suitability for stated mission requirements to identify deficiencies and recommend changes. The basic configuration of the radar system was substantially affected. The configuration eventually proposed represented the results of an evolution in design which appeared reasonably suitable.

Under subcontract to Johns Hopkins University Applied Physics Laboratory (JHU/APL), assistance was provided in performing conceptual design studies of a short-range, self-defense missile system for point defense of naval vessels. Specific design studies were made to define the concepts, configuration, and general specifications for a millimeter-wave, rapid-scan antenna for acquiring (detecting) threat anti-ship missiles and providing target information to the self-defense missile tracking system. The study included a survey of millimeter-wave components, analyses of environmental factors, system calculations, and evaluation of candidate antenna concepts. The component survey assessed the availability of components for operation at 23 GHz and 46 GHz, and the peak power available at several millimeter wave frequencies ranging from 9.3 GHz to 95 GHz. The environmental factors assessed were multipath, atmospheric attenuation, and weather (rain and fog attenuation). Multipath interference patterns were calculated for several combinations of frequency and wave height, and target height above water. A brief study was conducted to specify the requirements of the acquisition antenna. The antenna concepts considered were: frequency scanning by continuous slotted circular waveguide, continuous slotted rectangular waveguide, and disrete slots in rectangular waveguide; electronic phased arrays; multiple beam forming network; Rotman lens, Geodesic Luneberg lens, Rockwell ferrite scanner; and other electromechanical techniques. The antenna concept recommended was a geodesic lens/ring switch feeding a parabolic cylinder pointing vertically and a planar spalsh plate which nods about 45 degrees. The ring switch scan speed (azimuth) would need to be 23 Hz and the plate nodding rate should be 0.67 Hz to be commensurate with the maximum range, one-degree beamwidth, and time on the fastest target. Such an antenna would have a projected aperture of 25 inches by 18.4 inches in azimuth and elevation, respectively.

Under subcontract to the General Electric Company, studies were conducted to assess the radar fire control system requirements for the EW-83 Naval mount and the GAU-8 Gun Systems as a point defense anti-missile system, and to assess General Electric fire control system concepts based on the ULTRA phased array antenna design. The platforms of interest in the study varied from patrol craft to aircraft carriers. Four types of targets were considered: missiles; manned aircraft; major combatants; and small combatants. The study considered on-mount and off-mount antenna concepts and dedicated and semi-dedicated mission requirements. Reaction times and error budgets were also considered. Three special topics considered in the study were projectile cross section enhancement, low angle tracking problems, and aim point criteria. Follow-on work was conducted on GIT/EES Projects A-1952 and A-2050.

GIT/EES is developing an experimental 95 GHz radar using internal funds to enhance its research capabilities in the area of waveform design and evaluation of millimeter wave radars. The radar transmitter uses a 92 GHz phase-locked Impatt source. Two modulation techniques are currently planned: a 3 GHz source that may be pulsed or biphase modulated, and a 0.5 microsecond, 500 MHz FM ramp. The modulation source will be upconverted with the 92 GHz source to derive a single sideband frequency of 95 GHz for the transmitted signal. Receiver processing will consist of down conversion and either FM-CW or correlation-compression processing, as appropriate. The radar will have the capability of providing FM-CW, phase coding, noise modulation, chirp, and conventional pulse waveforms having bandwidths up to 500 MHz.

A flexible, helicopter-borne, 94 GHz radar sensor was developed under subcontract (F12-7F-02674) to the General Electric Company (prime contract F19628-78-C-0002). The 94 GHZ sensor will be a major subsystem of a millimeter terminal homing studies instrumentation sensor that will be used to (1) simulate a wide variety of possible homing seeker designs in real-time operation, (2) develop, validate and compare signal processing techniques applicable to millimeter terminal seekers, (3) experimentally determine the performance of various seeker configurations and/or designs, and (4) collect radar map data for non-real-time use in target acquisition studies. Some of the principal issues to be investigated with the instrumentation sensor are (1) algorithms for target detection, target selection, and false target rejection, (2) the performance of narrow beamwidth systems at short ranges, and (3) angle tracking techniques other than conical scan (CONSCAN) or sequential lobing. The radar uses a pulsed Impatt oscillator whose output level can be computer controlled through a variable attenuator. The transmitter output can be switched between a fan beam antenna and a pencil bean antenna via a computer command. The fan beam antenna will be used to collect data for active radar detection technique development. The pencil beam antenna will also be used for target detection, for comparative detection studies, and for active and passive tracking development. Saliant characteristics of the 94.5 GHz radar sensor include: an acquisition range of 1,000 meters with a minimum output power of 5 watts, a range resolution of 15 meters, a PRF of 5 to 5,000 Hz, a pulse width of 100 to 110 nanoseconds, a 500 MHz linear chirp waveform, a fan beam pattern of 1.0 degree in azimuth and 3 degrees in elevation, and a pencil beam pattern of 1 degree or 3 degrees.

Design criteria for compact 95 GHz transmitters are being developed under subcontract (Delivery Order No. 1468) to Battelle Columbus Laboratories (prime contract DAAG29-76-D-0100). The objective is to develop design criteria for compact 95 GHz transmitters in which the tubes are either extended interaction oscillators (EIO) or magnetrons. GIT/EES is providing guidance for the design of frequency locked EIO and magnetron tubes, operating at 95 GHz, with pulse widths less than 4.0 nanoseconds, a pulse repetition rate of 20 kHz, and peak powers of 1 kW. GIT/EES will provide complete design information for the modulator and the lock-in circuitry as well as on the tubes. Of prime interest is size and weight. Components which contribute most to the size will be singled out and recommendations will be made for size reduction. GIT/EES will also provide design information for developing a 13 kV pulser capable of 4 nanosecond wide pulses, with rise times and fall times of 0.5 nanoseconds, and a pulse repetition rate of 20 kHz, for delivery to a tube capacitance of 30 pF plus estimated stray capacitance. High voltage, wide bandwidth transformers, combined with fast rise time primary pulsers, will be investigated in detail as an approach to the modulator porblem. Problems of interfacing such a pulser to an EIO or magnetron will also be addressed.

A Near Millimeter Mobile Measurements Facility is being developed under Contract DAAG39-78-C-0044 to permit simultaneous measurement of propagation effects and target/terrain characteristics at 94, 140, and 220 GHz. This facility will consist of mobile transmission and receive trailers which will be used to gather data in conjunction with a mobile meteorological facility being developed by the Atmospheric Sciences Laboratory at White Sands, New Mexico. The facility will be computer controlled and have a capability for limited real-time processing and storage and preparation of data for post detection processing. The transmitters are all extended interaction oscillators, and the receivers are heterodyne configurations employing Schottky barrier mixers. The PRFs of all the transmitters will be synchronized so that backscattering data can be obtained from a common range cell.

A valid data base of target characteristics, background and weather characteristics, and battlefield environmental characteristics is being developed under Contract DAAK40-79-D-0028, Delivery Order No. 0013, to provide baseline data to support millimeter wave terminal guidance concept definition. GIT/EES will acquire, analyze and compile millimeter wave characteristic data for the following target types: self-propelled artillery, mobile air defense systems, tanks, armored personnel carriers, and armored reconnaissance vehicles. Emphasis will be given to target aspects as viewed from large depression angles which characterize terminal air-to-ground trajectories. Where measured data does not exist for specified target types, GIT/EES will develop estimates based on extrapolations of data from similar type targets. GIT/EES will acquire available data on cloud cover characteristics in the Central European and Middle-Eastern regions and use this data as a basis for assessing the effects of cloud cover conditions on millimeter wave terminal guidance seekers. The effects of adverse weather, such as fog and rain, will also be evaluated for this application. GIT/EES will also compile and assess all available reflectivity, emissivity, and propagation data relating to millimeter wave terminal guidance operation in battlefield environments, including ground clutter, smoke, dust, and debris.

Under purchase order from Standard Elektrik Lorenz AG of Stuttgart, Germany, Georgia Tech performed a measurements and analysis program involving 95 GHz reflectivity from German military vehicles and tree and ground clutter. The measurements were made using Georgia Tech's dual polarized, polarization agile, 95 GHz instrumentation radar in conjunction with a 7-track FM recorder and various other instruments such as a hardwired correlator and spectrum analyzer. Targets measured included an M-113 personnel carrier, 2-1/2 ton and 5 ton trucks, and an M-109 tank. Clutter cells measured included pine trees and sandy ground, all from relatively low grazing angles. Data analysis include on-site analysis of the probability density functions, autocorrelation functions, and spectra of the targets and clutter for various polarization modes.

A comprehensive data collection and analysis program for the characterization of coherent reflectivity from targets and background at Ku, Ka, and M-band frequencies was sponsored by the U.S. Army Missile Research and Development Command (MIRADCOM) under Contract DAAK40-77-C-0077. The express purpose of this program is to establish a technical data base from which target discrimination, recognition, and identification may be developed for application to target acquisition, warning, and recognition sensors for missile radar seeker systems and for improving the performance of sensor and seeker acquisition and tracking of targets in diverse clutter environments as may occur in land combat operation.

Performance and cost trade-off analyses of several radar surveillance systems/configurations to improve the AN/APS-94F radar system designed for use with the OV-1D (MOHAWK) surveillance system are being conducted under Contract DAAK20-80-C-0016 for the U.S. Army Electronics Research and Development Command (USAERADCOM). The overall objective is to improve the present intelligence gathering capabilities by reducing the time delay between the gathering of intelligence by the OV-1D surveillance system and the presentation of that intelligence in useful form the Corps Commander. The OV-1D MOHAWK radar configuration analyses and definition studies will include detailed analyses of all airborne radar subsystems, including antenna/radome, receiver/transmitter, airborne radar signal processing, and associated electronics. User requirements/performance objectives for the radar system will be determined, candidate radar systems will be defined, performance and cost trade-off analyses will be performed, and technology risks will be asessed. Electronic countermeasures (ECM) vulnerability and electronic counter-countermeasures (ECCM) capabilities of the various candidate systems will be assessed using a validated threat provided by USAERADCOM.

Under Subcontract SCEEE-NAVSEA/79-2 with the Southeastern Center for Electrical Engineering Education (SCEEE), prime contract N00024-78-C-5338, GIT/EES is conducting research on an Intrapulse Polarization Agile Radar (IPAR) concept for achieving compression and correlation. The IPAR concept evolved from previous research that investigated the use of polarization and frequency agility to obtain improved clutter discrimination. That research indicated that polarization agility (pulse-to-pulse), frequency agility, and a phase discriminant could be used to improve clutter discrimination. The IPAR technique retains the clutter rejection capability obtained by using polarization and frequency agility and also offers the potential advantages of anti-multipath, inherent electronic counter-countermeasures (ECCM), stealth, and target discrimination and recognition. Many of these potential advantages are derived partially from the inherent pulse compression nature of IPAR. The pulse compression, auto and cross coherency, beam sharpening and other characteristics of IPAR are being analyzed. The advantages of these characteristics in track and surveillance radars will be assessed. The IPAR concept will be validated in hardware using GIT/EES radar measurement vans and some new hardware that will be fabricated as needed. Discriminats which are detemined to be potentially advantageous will be identified, and a measurement test plan will be prepared. Measurements will be performed commensurate with time and budgetary constraints.

Performance and Cost Analyses of Battlefield Surveillance Moving Target Acquisition Radars were conducted under Contract N00014-75-C-0320. Analyses performed to support design and development of a next generation moving target acquisition radar (MTAR) included (1) review of Army requirements for an MTAR and generation of baseline specifications, (2) development of basic radar cost/performance models and analysis techniques, (3) definition of technical parameters and prediction of cost and performance for seven benchmark, candidate radar concepts, and (4) development and evaluation of several MTAR mechanical configuration concepts. Performance characteristics and required operational capabilities were derived from reviews of numerous documents and discussions with military personnel, and were based on three underlying assumptions: (1) the radar must operate in a highly mobile battlefield scenario in which the enemy will probably have superiority in numbers of equipment and personnel, and perhaps in firepower; (2) modern, sophisticated electronic countermeasures (ECM) techniques will be used against tactical ground-based radars; and (3) operational conditions require rapid target detection, acquisition, and identification, and precise location and tracking of moving targets with an ability to predict future target position. Major operational requirements evaluated included operating range, location accuracy, sector size, target velocity, rain degradation, and weight. A radar performance model was developed and implemented on a CYBER 74 computer to simulate radar system performance and calculate signal-to-noise (S/N) ratio and signal-to-clutter (S/C) ratio to facilitate evaluation of the various MTLR systems and deployment scenarios. The model included parameters for curved earth geometry, effects of shaped antenna patterns, multipath effects, ground clutter return, rain clutter return, and atmospheric attenuation. A cost model, the Radar Equipment Cost Analysis Program (RECAP), was developed for estimating the costs of the candidate MTAR systems. The RECAP includes a series of cost estimating relationships (CERs) that can be exercised either separately or together in an interactive computer program. The model was verified against the actual costs of numerous radar systems and has been used to analyze radar cost data s well as to estimate the costs of the candidate MTARs.

FACILITIES AND EQUIPMENT

SUMMARY

The Georgia Institute of Technology has extensive facilities and equipment devoted to research and development in a wide variety of fields. The Engineering Experiment Station (EES) alone has over 250,000 square feet of floor space devoted to research incorporating a number of major buildings on the Georgia Tech campus and in facilities near Dobbins AFB. The EES facilities include extensively equipped laboratories for research in the electronic, chemical, physical, mechanical, material, and biological sciences, and related branches of engineering. Other campus facilities include the Rich Computer Center and the Price Gilbert Memorial Library.

EES has been a center for microwave and millimeter wave research for over 20 years. A number of specialized facilities have been developed to support these research activities. Specialized facilities for use in millimeter technology programs include the following.

* MMW Measurement Radars
* 95 GHz Radar Measurement Laboratory
* Millimeter Wave Device Development and Test Facility
* Multifrequency Propagation Range
* Michelson Interference Spectrometer -- operates from 40 to 3,000 GHz .

MMW MEASUREMENT RADARS

Georgia Tech has developed a versatile set of MMW instrumentation radars. This includes two 95 GHz radars, a 70 GHz radar, and two 35 GHz radars. One of the 95 GHz radars uses a 1 kW EIO and the other uses a 1 kW magnetron made by English Electric Valve Company. Both radars are dual polarized and can be used with a wide range of antennas. One of the 35 GHz radars is an all solid-state radar using solid-state amplifiers built by Hughes. This radar is fully coherent and can cover a wide range of measurement conditions. The other 35 GHz radar uses a magnetron transmitter and is used for high power measurements. The 70 GHz radar also uses a magnetron transmitter. These radars can generally be configured to provide the measurement matrix of interest to the sponsor. All these radars were designed and built by Georgia Tech.

GIT/EES is developing an experimental 95 GHz radar using internal funds to enhance its research capabilities in the area of waveform design and evaluation of millimeter wave radars. The radar transmitter uses a 92 GHz phase-locked Impatt source. Two modulation techniques are currently planned: a 3 GHz source that may be pulsed or biphase modulated, and a 0.5 microsecond, 500 MHz FM ramp. The modulation source will be upconverted with the 92 GHz source to derive a single sideband frequency of 95 GHz for the transmitted signal. Receiver processing will consist of down conversion and either FM-CW or correlation-compression processing, as appropriate. The radar will have the capability of providing FM-CW, phase coding, noise modulation, chirp, and conventional pulse waveforms having bandwidths up to 500 MHz.

Characteristics of Georgia Tech's 95 GHz instrumentation radars are summarized in the following table.

95 GHz MEASUREMENT LABORATORY

Georgia Tech has set up a 95 GHz measurement laboratory to support its 95 GHz radar development and measurement activities. The primary function of the laboratory is the testing of 95 GHz components and systems and the calibration of 95 GHz radars. The measurement facility includes the capability of making antenna pattern measurements. Included in the facility are a power meter, frequency meter, spectrum analyzer mixer, sweep generator, and various other 95 GHz parts. Many different test configurations can be set up to tailor the facility to the specific test and evaluation requirements.

The 95 GHz measurement facility is set up in a room dedicated to that facility. Access to this room is restricted to assure the integrity of the test set up. The facility is fully owned by Georgia Tech so sponsor approval is not required to obtain use of the equipment.

MILLIMETER WAVE DEVICE DEVELOPMENT AND TEST FACILITY

The Millimeter Wave Device Development and Test Facility has the equipment necessary to fabricate, assemble, and evaluate low-noise Schottky-barrier mixers and detectors of the quasi-optical, stripline, and waveguide types. A precision South Bend lathe, a Bridgport Vertical mill, and a Dumore precision drill press are available for fabricating the hardware components. These tool-room quality precision machines are complemented by Lansing Corporation micrometer stages and a Bausch and Lomb Stereozoom microscope. For soldering and wire-bonding, a miniature Circon Soldering Production Set and a Hughes IL Bonding System are used.

For assembly of millimeter wave devices, three dimensional micromanipulator stages are used. During diode contacting, capacitance of the device is monitored with a Boontoon 75D Capacitance Bridge, and the quality of the diode is checked with a Series 500 Tektronix Curve Tracer. The diode characteristics are measured using a Hewlett Packard power supply and two Hewlett Packard digital volt and ammeters. The assembled devices are then tested and evaluated using a Hughes Millimeter Wave IMPATT Sweeper and an AIL Type 136 Precision Test Receiver, along with Varian Klystron LO's and Signalite Corporation Noise Tubes.

GEORGIA TECH
95 GHZ INSTRUMENTATION RADARS

	EIO	MAGNETRON	SOLID STATE (HI-RES)
Waveform	Freq. Agile Chirped	Fixed Freq Pulse	Coded CW
Power	2 KW, Pk	2-6 KW, Pk	10 mW, Avg
Beamwidth	0.7°, 2.8°	0.7°, 2.8°	Focused -1' at 500'
Range Resolution	7', 25'	7', 25'	Variable -1'
Polarization	Dual H, V Circular	Dual H, V Circular	Dual H, V Circular
Receiver	Dual Coherent NonCoherent	Dual Channel NonCoherent	Dual Channel Coherent/NonCoherent
Application	Reflectivity Propagation Studies	Reflectivity Propagation Studies	Reflectivity Propagation Studies

MULTIFREQUENCY PROPAGATION RANGE

GIT/EES is currently assembling a propagation facility capable of simultaneous measurements at wavelengths from the visible through the microwave region. This facility will contribute to a better understanding of both active and passive military systems that depend strongly on an understanding of atmospheric propagation. The facility will provide a capability for comparative measurements that are extremely important for systems currently operating or being planned in the infrared and millimeter regions.

Propagation experiments for wavelengths throughout the electromagnetic spectrum are currently being initiated. The propagation facility is instrumented with meteorological apparatus to provide this information. Included in the propagation studies will be:

90 GHz propagation link,

183 GHz radiometry,

92 GHz radiometry,

Radiometric studies in the region from 118 GHz to 183 GHz,

300 GHz propagation with 1 watt CSF carcinotron,

890 GHz propagation with an HCN laser,

10.6 micrometer propagation with a CO_2 laser,

1.06 micrometer propagation with a YAG:Nd^{3+} laser,

Argon laser propagation at 0.48 micrometer,
Propagation at 340 GHz and 230 GHz with optically pumped lasers,
Fourier spectroscopy broadband and near-millimeter wave observations.

In addition, a sun tracking radiometric system that has been donated to GIT/EES will provide data at 15 GHz. A short propagation distance of 600 to 1200 feet will be used, and in addition, space on the 17th floor of the C&S Bank has been leased to provide a link distance of 5000 feet. The C&S Bank facility provides a propagation capability to distant points in the north Atlanta area. Propagation to Kennesaw Mountain, where GIT/EES has a facility, is possible for a link of 16 miles.

The meteorological equipment includes four tipping buckets, a distrometer for measurement of rain particle distributions (0.34 to 4 millimeters), optical scattering equipment for fog and aerosol particle measurements (0.3 to 50 micrometer particle sizes), and an instrumented tower (90 feet high) to measure humidity, temperature, and wind. Data taken with any apparatus on this range, although not on a continuous basis, can be made available to interested laboratories.

Georgia Institute of Technology Library

The Georgia Institute of Technology Price Gilbert Memorial Library has developed outstanding collections of scientific and technical publications which are essential to the support of advanced study in scientific and engineering fields. Its holdings number over 763,000 bound volumes, including 11,000 serial titles (representing over 6,150 current journals and 4,900 other serials, such as annual transactions and proceedings of scientific and professional societies in America and abroad). With the addition of 643,000 technical reports and other nonbook materials, library holdings total over 1.6 million items.

The patent collection, the only large one in the Southeast and one of only eighteen in the United States, contains a complete file of all U.S. patents and accompanying drawings issued since May 1946 (over 1.3 million patents). It also has a complete set of the Official Gazette (which gives patent information back to 1872), and other reference literature on U.S. and foreign patents.

In addition to supporting Georgia Institute of Technology's instructional and research programs, the library staff furnishes reference services and research materials to government agencies, industrial corporations, and research institutions, not only in the South, but also in other parts of the nation and in numerous foreign countries.

The library maintains a high degree of cooperation and communication with the Defense Technical Information Center, and frequent use is made of its services. In 1962, the library was designated one of twelve Regional Technical Report Centers. The present collection, comprising reports of the AEC, NASA, DoD, and the National Technical Information Service, totals over 643,000 items. Extensive files of U.S. and foreign standards are also maintained, totaling over 18,000 items.

Since 1964, the library has been a depository for United States government publications distributed by the Government Printing Office; it is also a map depository for numerous Federal and local agencies.

The collection has grown rapidly in recent years, and hence, contains an exceptionally large proportion of material of interest to modern research programs. A special group is responsible for borrowing or obtaining photocopies of materials not available in the library inventory.

Analysis and Design Programs

Various computer programs are available to aid in systems analysis and design. These include: optical system lens design, trajectory and intercept routines, control system evaluation routines, seeker antenna and radome prediction programs, plus other error prediction programs involving range, clutter, scintillation, and glint effects. These programs have been obtained via in-house design, government contract, or from industrial sources.

In addition to computer analysis, EES has an extensive background in the analysis of error sources and minimization of tracking errors in radar angle tracking systems. Effects of polarization agility, frequency agility, amplitude glint correlation, and complex indicated angle processing have been considered for radar angle tracking error reduction. Integral parts of such analysis have been the realistic modeling of targets of interest and the incorporation of such effects as multipath returns and varying target reflectivity with changes in range and aspect.

Two general purpose digital simulations of missile intercept are available. One is a two-dimensional representation while the other is three dimensional. The two-dimensional version has the advantage of requiring less computer time and is adequate to evaluate many effects. Both simulations are sufficiently modular to allow easy variation or replacement of the simulations of the seeker, the control system, or the airframe. The target simulation permits changes in speed, direction and acceleration to be made as needed. These simulations also incorporate pseudo-random noise generating routines that can be used selectively when desired.

Georgia Tech has a six-degree-of-freedom missile simulation which can be modified and used to perform realistic guidance studies of a wide spectrum of missiles. The availability of this simulation means that the sponsoring agency does not have to fund the development of a new missile simulation. In addition, the simulation can be used on programs where funding limitations would normally restrict the analysis to quasilinear models which do not realistically model the missile.

Several software routines are retained as library routines and are available for future work on guidance and control. A digital program exists for the automated design of optimal control systems (linear, quadratic loss) and Kalman filters. Describing function analysis of stability is performed using these computer programs which can also perform plotting of Nyquist and Bode plots. These routines enable rapid analysis of control system stability and are a valuable aid in parameter selection.

Laboratory Computer Facilities

Laboratory programs in target classification, system simulation, design and analysis, data reduction, and modeling, are supported by several major computer systems deciated to Laboratory research in addition to the Institute's CYBER 70/74. Laboratory computer facilities include:

CONTROL DATA CORPORATION (CDC) Model 74-28 CYBER Computer:

- Time-sharing facility
- Two central processing units; 131K, 60-bit words of memory
- Twenty 12-bit word length peripheral processors
- High-speed line printers, tape drivers, disk drives, and plotters

DIGITAL EQUIPMENT CORPORATION (DEC) VAX-11/780:

- 32-bit computer;125K words of MOS memory
- Dual disk drives, 56M byte total capacity
- Eight RS-232 ports, two terminals, high-speed line printer, multi-user system

SYSTEM ENGINEERING LABORATORY (SEL) 32/55:

- 32-bit computer; 125K words of core memory; 80M byte disk drive
- Micro-programmable processor
- Two 1600 bpi tape drives, high-speed line printer
- A/D interface, two terminals, plotting capability
- Secure computer operation

INTERDATA 8/32:

- 32-bit computer; 125K words of memory
- Three CRT terminals, 600 line/minute printer, two 1600 bpi tape drives
- A/D converter, 80M disk drive

DATA GENERAL (DG) Eclipse S130:

- 16-bit computer; 64K words of memory
- Foreground/background mode allows two users
- Two disk drives, two terminals, line printer

DIGITAL EQUIPMENT CORPORATION (DEC) PDP-11/40:

- 64K, 16-bit words of memory, two disk drives, line printer, CRT terminal

DATA GENERAL (DG) NOVA/2:

64K, 16-bit words of memory
Color display, two tape drives, CRT terminal

DIGITAL EQUIPMENT CORPORATION (DEC) PDP-8:

32K, 12-bit words of memory
Remote data reduction facility

Major Software Support Resources

The Laboratory has ready access to an extensive inventory of software support resources as outlined below:

* ELECTRONIC EQUIPMENT COST PREDICTION

Radar Sub-assemblies	Software
Antenna	RDT&E
Data Link	Production
Tracking	Life Cycle

* RADAR PERFORMANCE PREDICTION

Detection	Signal Processing
Tracking	Multistatic/Monostatic
Surveillance	Error Analysis
Antenna Pattern	

* TARGET CHARACTERIZATION (UHF-Near Millimeter)

Coherent/Non-Coherent	EM Scattering
Bistatic/Monostatic	Physical Optics
EM Scattering Theory	Radiometric Temperature
Monte Carlo and Deterministic	

* CLUTTER MODELS (UHF-Near Millimeter)

Sea	Diffuse
Land	Bistatic
Spectral	Monostatic

* PROPAGATION (HF-Millimeter)

Multipath	Spherical Earth
Attenuation	Physical Optics
Ducting	

* RADAR CROSS SECTION REDUCTION

Multilayer Dielectric
Flat Plate
Cylindrical
Free-Space or Metal-Backed
Material Characterization

* TARGET CLASSIFICATION

  Linear Discriminant Analysis
  Statistical Pattern Recognition
  Feature Extraction, Ranking, Selection, and Evaluation
  Algorithm, Training, and Testing
  Piecewise and Fisher Linear Discriminant
  Template-Matching
  Nearest Neighbor and K-NN Prototype
  Perception Criterion Function
  Multiple Class

* ECM/ECCM

  Vulnerability Assessment Models
  Passive Ranging
  Effectiveness Analysis

* MISSILE AND RADAR SIMULATION

  Fly-out Models
  Hardware-in-the-Loop Simulation
  Ballistic Trajectory
  Aerodynamics
  Engagement and End-Game Simulation

* DATA ANALYSIS

  Spectral Analysis
  Statistical Properties
  Amplitude Distributions
  Correlation Properties

Computer Facilities

EES has available a wide range of electronic computing capabilities, including a large scale high speed computer, a number of minicomputers, and several programmable calculators. Associated peripherals include remote access terminals, graphical displays, hard copy plotters, and automated A/D and D/A converters. These capabilities are available through the Office of Computing Services (OCS) and through facilities within and available to EES.

The OCS, since 1955, has operated a variety of central computing systems. Currently, a Control Data Corporation CYBER 70 Model 74-28 is primarily dedicated to the support of education and research, and a Control Data Corporation 6400 is primarily dedicated to administrative support. These independent systems both operate under Network Operating System (NOS) and are coupled through extended core storage.

Software. The NOS Time-Sharing Operation System of software supports a broad variety of programming languages, applications programs, and library subroutines available to both time-sharing, remote batch, and on-site batch users. The OCS staff which maintains this software is constantly alert to implement enhancements or to acquire additions.

Interactive Terminals. In addition to about 100 terminals financed by and located in the various schools and departments, OCS provides a cluster of 10 hard copy and 10 CRT devices for all time-sharing users. These devices are installed in sound controlled carrels conveniently located adjacent to OCS consultants and the necessary documentation.

Plotter. A CALCOMP Model 763 Digital Incremental Plotter provides high quality plots up to 30 inches wide. It is operated off-line from the computer system and has a resolution of 0.0025 inches in both dimensions. Its use is facilitated by a wide variety of library subroutines.

Analog-to-Digital Converter. A Radiation, Inc., Analog-to-Digital Conversion System is also available in an off-line mode. It multiplexes by a programmable scanner, digitizes the samples at a rate up to 50,000 samples per second to an accuracy of 11 bits plus sign, and produces a digital magnetic tape output.

In-House Facilities. For interaction with the central computer facility, EES has access to several remote terminals which connect with the CYBER 70 over dial-up lines. The terminal complement includes both hard copy and CRT display tapes. Two terminals (Tektronix Models 4002 and 4012) with graphics capability are available. Remote operation is enhanced by the capability for storing program and data files on mass storage devices and magnetic tapes. Remote operators can direct print to central facility line printers and graphical output to the Calcomp plotter.

Facility Security Clearance

Georgia Tech is well prepared to conduct classified investigations. EES and the Georgia Tech Research Institute, its contracting agency, have a final TOP SECRET facility clearance granted by DCASR-Atlanta, 14 September 1965, with storage capability of SECRET. All Georgia Tech personnel who require access to classified information hold a SECRET or higher clearance.

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

REEDY, EDWARD K.--Director, Radar and Instrumentation Laboratory
Radar and Instrumentation Laboratory

Education

Ph.D., University of Tennessee	1968
M.S.E.E., University of Tennessee	1964
B.S.E.E., University of Tennessee	1963

Employment History

Georgia Institute of Technology	
Director, Radar & Instrumentation Laboratory	1977-Present
Principal Research Engineer	1978-Present
Chief, Radar Application Division	1975-1977
Head, Systems Technology Branch	1974-1975
Manager, Special Programs Office	1973-1974
Senior Research Engineer	1973-1978
Research Engineer II	1970-1973
U.S. Army Electronics Command, Project Officer	1968-1970
Oak Ridge Associated Universities, Fellow	1966-1968
Bell Telephone Laboratories, Member of Technical Staff	1963
Eastman Kodak, Engineering Trainee	1962

Experience Summary: While at Georgia Tech, has engaged in investigations of ballistic trajectory prediction based on radar-measured data, projectile RCS characterization, radar sky clutter, range instrumentation techniques and ECM vulnerability analysis, signal processing techniques, and target detection in clutter. Has also served as director of projects involving design, development, and fabrication of electro-mechanical scanning antenna systems, investigation of electromagnetic propagation effects on a tracking radar test environment, and analysis of the system requirements for advanced radars. While in the Army with the Army Electronics Command at Fort Monmouth, N.J., participated in a research and development program in radar system design as applicable to Army requirements for a weapon (artillery, mortar, and rocket) locating radar. Developed computer simulation programs for evaluation of new techniques in counter-weapons radar systems and associated data processing. Ancillary investigations into backward extrapolation and analysis of radar measured ballistic data, digital techniques for processing radar signals, and polystation pulse-Doppler and Doppler-only baseline radar systems were performed. At Oak Ridge, performed basic and applied research in the area of very-high-speed digital and pulse circuit theory and design. While with Bell Labs was involved in design, construction, testing, and evaluation of semiconductor-regulated power supply circuits for use both within the Bell system and in the Nike Missile program. At Eastman Kodak, assisted staff electrical engineers in design of electrical power distribution systems, plant lighting networks, and building lighting.

Current Fields of Interest

Radar systems; analysis and synthesis of unconventional radar techniques; operationals analysis; digital signal processing; radar vulnerability to ECM; ECCM; millimeter applications.

Special Honors

Fellow, National Aeronautics and Space Administration
"With Highest Honors" Graduate, University of Tennessee

Major Reports and Publications

1. "Polarimetric Processing Research at Georgia Tech -- Past-to-Present," paper presented at Workshop for Polarimetric Radar Technology, Redstone Arsenal, Alabama, 25 June 1980, coauthor
2. "Millimeter Radar," Chapter in Infrared and Millimeter Waves, Academic Press, New York, N.Y., in preparation, coauthor
3. "Millimeter Wave Radar Technology and Application," Military Electronics and Countermeasures, in preparation
4. "Millimeter Wave Instrumentation Radar Technology--Considerations and Applications," paper presented at the 1979 Military Electronics Exposition, Anaheim, California, 23-25 October 1979
5. "Technical Analysis of Auto-Standoff Jammer System," Final Technical Report, Contract DAAG29-76-D-0100, D01254-1, USAMICOM, Redstone Arsenal, Alabama, September 1979
6. "A Netted Radar for Wide Area Surveillance--LARIAT," paper presented at the 25th Annual Tri-Service Radar Symposium, U.S. Air Force Academy, Colorado Springs, Colorado, 12 September 1979, coauthor
7. "Performance and Cost Analysis of a Command-Guided Ballistic Missile Radar," Final Report, Contract DAAG29-76-D-0100 for USAMIRADCOM, March 1979, coauthor
8. "Preliminary Design Study for a Command Guided Ballistic Missile Radar," Final Report, Contract DAAG29-76-D-0100 for USAMIRADCOM, July 1978, coauthor
9. "Stand-Off Target Acquisition System (SOTAS) Cost Analysis," Final Technical Report, Contract N00014-77-C-0119, May 1978, coauthor
10. "Stationary Target Detection," paper presented at the 23rd Annual Tri-Service Radar Symposium, U.S. Military Academy, West Point, N.Y., 12 July 1977, coauthor
11. "Review of Millimeter Wave Radar Development at Georgia Tech," GIT/EES Internal Technical Report 77-01, May 1977, coauthor
12. "Stationary Target Detection and Classification Studies," Annual Technical Report, Contract N00014-76-C-0961, February 1977
13. "Study of Radar Signature and Augmentation Program Plan," Final Report under Battelle, Columbus, Scientific Services Agreement, DAAG-29-76-D-0100 USAMICOM, September 1976, coauthor
14. "Stationary Target Detection and Classification Studies," Semi-annual Technical Report, Contract N00014-75-C-0320, Mod. P0003, August 1976
15. "Anti-Radiation Missile (ARM) Countermeasures-Operational Considerations for the Artillery and Mortar Locating Radars," SPC Report 253, Contract DNA001-75-C-0032, 31 July 1976, coauthor
16. "Performance and Cost Analysis of Moving Target Location Radars," Technical Report, Contract N00014-75-C-0320, May 1976

Major Reports and Publications (continued):

17. "Indirect Fire Instrumentation Study," Final Technical Report, Contract N00014-75-C-0320, February 1976
18. "HWL Radar System Analysis," Final Technical Report, Contract N00014-75-C-0228, January 1976
19. "Weapons Location Radar, A Historical Overview," invited paper presented to the IEEE AP/MTT Group, Atlanta, Georgia, 2 October 1975
20. "Instrumentation Techniques for Tracking Low-Flying Vehicles," Final Technical Report, Contract DAAD07-75-C-0025, 15 July 1975, coauthor
21. "Performance Tests on the AN/TPQ 31 ( ) Radar," Technical Report, Contract N00014-75-C-0228, Mod. P00001, June 1975
22. "Vulnerability of HOWLS Radars to Electronic Countermeasures," Technical Report No. 3, MIT/LL Subcontract C-891 under Prime Contract F-19628-73-C-002, 30 June 1975
23. "Analysis of AN/TPQ-31 ( ) Radar Performance Test," Final Technical Report, Contract M00027-75-C-0025, May 1975
24. "The HOWLS Radar Sky-Clutter Environment," Technical Report No. 2, MIT/LL Subcontract C-891 under Prime Contract F19628-73-C-0002, 15 April 1975
25. "HWL Radar Studies," Second Annual Technical Report, Contract N00014-67-C-0159-0017, 15 April 1975
26. "Compilation and Analysis of Projectile Radar Cross Section," Technical Report No. 1, MIT/LL Subcontract C-891 under Prime Contract F19628-73-C-0002, 20 February 1975
27. "Evaluation of the Battlefield Vulnerability of Hostile Weapons Location Radars," Final Report, Contract MDA903-74-C-0299, 31 January 1975, coauthor
28. "Electromechanically Scanned Antennas," paper presented at 1974 AOC Technical Symposium, Dayton Ohio, October 1974, coauthor
29. "Millimeter Wave Radars," paper presented at the 1974 IEEE APS-MTT International Microwave Symposium, Atlanta, Georgia, June 1974, coauthor
30. "A Millimeter Radar Concept for Helicopter Applications," Study Paper for Department of the Army, Office of Chief of Research and Development, January 1974, coauthor
31. "HWL Radar Studies," Annual Technical Report, Contract N00014-67-A-0159-0017, 31 October 1973
32. "Microwave Scanning Antenna Studies in Support of Advanced ECHO Range Requirements," Final Engineering Report, Subcontract 271845 on Prime Contract NOW-62-0604-C, 15 June 1973, coauthor
33. "Feasibility Study for Electronic Environmental Laboratory," Final Tecnical Report, Contract F08635-70-C-0102, 15 April 1973
34. "Pedestal Mounted Scanning Antenna," Final Engineering Report, Contract F08635-70-C-0102, 15 December 1972
35. "Pedestal Mounted Scanning Antenna," Acceptance Test Report, Contract F08635-70-C-0102, 15 September 1972
36. "Pedestal Mounted Scanning Antenna, Range Instrumentation, Operation, and Maintenance Manual," Contract F08635-70-C-0102, 15 September 1972, coauthor
37. "Pedestal Mounted Scanning Antenna," Acceptance Test Procedures Report, Contract F08635-70-C-0102, 21 March 1972, coauthor
38. "Investigation of Ballistic Trajectories," Final Report, Contract DAAB07-71-C-0354, February 1972

Major Reports and Publications (continued):

39. "An Offset Paraboloidal Scanning Antenna," Final Report, Contract F08635-69-C-0202, 15 September 1971
40. "An Offset Paraboloidal Scanning Antenna," Range Instrumentation, Operation and Maintenance Manual, Contract F08635-69-C-0202, 31 May 1971, coauthor
41. "An Offset Paraboloidal Scanning Antenna," Preshipment Test Procedures Report on Contract F08635-69-C-0202, 14 August 1970, coauthor
42. "A Complementary Driven Quinary Ring Scalar," Review of Scientific Instruments 41, 860-64 (June 1970)
43. "Sensitivity Analysis of the Ballistic Equation Using a Backward Integration Technique," U.S. Army Electronics Command Technical Report 3318, January 1970
44. "A Complementary Driver with Subnanosecond Rise Time," IEEE Journal of Solid State Circuits SC-4, 293-5 (October 1969)
45. "A Computer-Aided Study of a 600 MHz Decade Scaling System," Oak Ridge National Laboratories TM-22, 14 August 1968
46. "A Study of Three Analog-to-Digital Conversion Techniques," Oak Ridge National Laboratories Scientific Report No. 17, December 1964

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

EAVES, JERRY L.--Associate Director
Radar and Instrumentation Laboratory

Education

M.S.E.E., Georgia Institute of Technology	1964
B.E.E., Georgia Institute of Technology	1960

Employment History

Georgia Institute of Technology	
Associate Director, Radar and Instrumentation Laboratory, EES	1977-Present
Principal Research Engineer	1974-Present
Senior Research Engineer	1968-1974
Research Engineer II	1964-1968
Research Engineer I	1962-1964
Westinghouse Electric Corp., Associate Engineer	1960-1962
U.S. Army, Radar Technician	1954-1956

Experience Summary: Currently serves as Associate Director of the Radar and Instrumentation Laboratory. Has conducted and supervised radar research programs relating to hardware and software simulations, target discrimination, digital signal processing, flight test evaluation, reflectivity signature measurements and analyses, meteorological radar techniques, and mm wave radar techniques. Has directed several research programs concerned with the effects of polarization and frequency agility. Served as project director of research programs to investigate techniques for improving the homing accuracy of antiradiation guidance systems and to investigate backscatter properties of certain radar antenna systems. Supervised measurement and data analysis programs for characterizing backscatter properties of radar antennas. Radar system work at Georgia Tech has included the design and development of several reflectivity measurement and clutter reduction radar systems. Other work at Georgia Tech has involved analytical studies, modeling, model validation tests and test plans, prediction and circuit development related to electromagnetic interference and compatibility. At Westinghouse was engaged in design and test of electronic circuits and systems used in AN/FPS-27 radar.

Current Fields of Interest

Theory and techniques of radar systems; target reflectivity signatures and reflectivity characterization; millimeter radar applications and techniques; radar signal processing; radar clutter reduction; polarimetric radar technology.

Patents

1. "Automatic Gain Balance System for AN/FPS-27 Radar," February 15, 1962, Westinghouse Defense Center patent.
2. "Automatic Slope Adjustment System for AN/FPS-27 Radar," February 20, 1962, Westinghouse Defense Center patent.
3. "A Ground Clutter Reduction Technique for Weather Radars," GIT ROI 560 NC, February 1973.
4. "Intrapulse Polarization Agile Radar System (IPAR)," Disclosure submitted July 8, 1975, U.S. Army MICOM patent, coinventer.

Major Reports and Publications

1. "Target and Environmental Data Base Development for Terminal Guidance Weapons," Final Technical Report on Contract DAAK40-79-D-0028, D.O. No. 0013, November 1980, coauthor
2. "Polarimetric Processing Research at Georgia Tech - Past to Present," Proceedings of Polarimetric Radar Technology Workshop, June 1980, coauthor
3. "Millimeter Wave Instrumentation Radar Technology--Considerations and Applications," Military Electronics Expo '79, October 1979, coauthor
4. "Considerations in the Development of an Early Warning Vessel/Bridge Collision System," Proceedings of the Bridge Engineering Conference, Vol. II, Transportation Research Board, National Academy of Science, 1978, coauthor
5. "Reflectivity Characterization at Millimeter Wave Frequencies," Avionics Section Technical Meeting of the American Defense Preparedness Association, December 1978, coauthor
6. "Radar Detection, Identification and Tracking of SAM Radars: Flight Test Results," Avionics Section Technical Meeting of the American Defense Preparedness Association, December 1978, coauthor
7. "Stationary Targe Detection and Classification Studies," Final Technical Report on Contract No. N00014-76-0961, May 1978, coauthor
8. "Stationary Target Detection and Classification Studies," Second Interim Technical Report on Contract No. N00014-76-C-0961, March 1978, coauthor
9. "Modern Millimeter Wave Instrumentation Radar Development and Research Methodology," EASCON '77, September 1977, coauthor
10. "Stationary Target Discrimination and Classification Studies," Proceedings of the Twenty-Third Tri-Service Radar Symposium, July 1977, coauthor
11. "Stationary Target Detection and Classification Studies," Semiannual Technical Report on Contract N00014-75-G-0320, Mod. P00003, May 1977, coauthor
12. "Flight Evaluation of Stationary Target Indication Techniques," Proceedings of the Twenty-Second Annual Tri-Service Radar Symposium, July 1976
13. "Design Analysis for Implementation of Polarization Agility with Target Indication Techniques," Final Technical Report, June 1976, coauthor

Major Reports and Publications (continued)

14. "Tracking Radar Scan Interrogator (TRASIT)--Phase I Results," Final Technical Report on Contract F33615-74-C-4070, December 1974, coauthor
15. "Investigation of Target Enhancement Techniques," Final Report on Contract F33615-71-C-1612, October 1974, coauthor
16. "Improved Target Discrimination with Polarization Agility and Digital Video Processing," Proceedings of the Twentieth Annual Tri-Service Radar Symposium, July 1974, coauthor
17. "A Study to Determine the Feasibility of Using Remote Sensing Techniques to Prevent Ship Collisions with Selected Draw/Lift Bridges," Final Engineering Report, April 1974, coauthor
18. "A Study of Techniques for the Establishment of a Pilot Electronic Tornado Detection System in Georgia," Final Engineering Report, December 1973, coauthor
19. "An Airborne Investigation of Polarization Diversity for Target Discrimination," Proceedings of the Nineteenth Annual Tri-Service Radar Symposium, July 1973, coauthor
20. "Radar Reflectivity Signatures of Tracking Radar Antennas," Proceedings of the Nineteenth Annual Tri-Service Radar Symposium, July 1973, coauthor
21. "Investigation of Target Enhancement Techniques," Interim Technical Report No. 1 on Contract F33615-71-C-1612, July 1972, coauthor
22. "Special Signal Processing Techniques for Target Enhancement," Final Technical Report on Contract F33615-68-C-1590, April 1971, coauthor
23. "Investigation of Polarization Agility as a Radar Parameter," Proceedings of the Seventeenth Annual Tri-Service Radar Symposium, May 1971, coauthor
24. "Special Signal Processing Techniques for Target Enhancement," Interim Technical Report No. 2 on Contract F33615-68-C-1590, January 1971, coauthor
25. "QRC-495 Radar Measurements," Final Technical Report on Contract F33615-70-C-1186, August 1970, coauthor
26. "QRC-495 Radar Measurements," Interim Technical Report No. 1 on Contract F33615-70-C-1186, March 1970, coauthor
27. "An Investigation of the Characteristics of Tactical Radar Targets," Final Technical Report on Contract No. F33615-69-C-1303, October 1969, coauthor
28. "Roaring Lion Reflectivity Measurement," Special Technical Report No. 2 on Contract No. F33615-69-C-1303, July 1969, coauthor
29. "Investigation of Search Radars as Radar Targets," Special Technical Report No. 1 on Contract No. F33615-69-C-1303, July 1969, coauthor
30. "Radar Measurements of Selected Targets at Ku- and X-Band Frequencies," Special Technical Report No. 1 on Contract F33615-68-C-1590, January 1969, coauthor
31. "Results of an Airborne Radar Test Program," Memorandum Report 2, Contract F33615-67-C-1686, February 1968, coauthor
32. "Investigation of Target Enhancement Techniques," Final Technical Report on Contract F33615-67-C-1686, February 1968, coauthor

Major Reports and Publications (continued)

33. "Investigation of Target Enhancement Techniques," Special Technical Report No. 2 on Contract F33615-67-C-1686, October 1967, coauthor
34. "Radar Reflectivity Measurements with An/APQ-100," Special Technical Report No. 1 on Contract F33615-76-C-1686, September 1967, coauthor
35. "Study of Polarization Techniques for Target Enhancement," Technical Report AFAL-TR-67-102 on Contract AF 33(615)-2593, August 1967, coauthor
36. "A Bibliography of Radar Reflection Characteristics," Volume 7, 8, 9, and 10 on Contract DA 36-039 AMC-03759(E)ARPA Order 672, April 1967, coauthor
37. "Radar Reflectivity of Lewis Scanner Antennas," Special Technical Report No. 3 on Contract AF 33(615)-2593, February 1967, coauthor
38. "Study of Polarization Techniques for Target Enhancement," Special Technical Report No. 2 on Contract AF 33(615)-2593, August 1966, coauthor
39. "Study of Polarization Techniques for Target Enhancement," Special Technical Report No. 1 on Contract AF 33(615)-2593, March 1966, coauthor
40. "Catalogue of Communications Interference Suppression Devices," Supplement No. 3 to Technical Memo X0005-1 on Subcontract X-1 under Contract AF 19(604)-8840, March 1964, coauthor
41. "Environmental Interference Prediction Model Phase II," Technical Memo X0003-25 on Contract AF 19(628)-4154, March 1964, coauthor
42. "A Study of Receiver and Transmitter Non-Linearities," Technical Memo X003-19 on Subcontract X-1 under Contract AF 19(604)-8840, October 1963, coauthor
43. "Preliminary Plans for Phase II of the Georgia Tech Environmental Interference Prediction Model," Technical Memo X003-15 on Subcontract X-1 under Contract AF 19(604)-8840, January 1963, coauthor

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

SCHEER, JAMES A.--Senior Research Engineer
Radar and Instrumentation Laboratory

Education

M.S.E.E., Syracuse University	1973
B.S.E.E., Clarkson College of Technology	1966
Additional Graduate Studies, Georgia Institute of Technology	1976-Present

Employment History

Georgia Institute of Technology	
Chief, Radar Development Division, EES	1979-Present
Chief, Radar Experimental Division	1977-1979
Senior Research Engineer	1975-1977
General Electric Company, Project Engineer	1966-1975

Experience Summary: As chief of Development Division, directs and oversees prototype radar system development, projects involving millimeter wave systems, and computer applications to radar. As Chief of Experimental Division, directed various radar target/clutter reflectivity measurements and analysis programs. Has contributed to the design, development, and evalution of radar signal processors. Has served as project director for development of state-of-the-art millimeter wave instrumentation systems and reflectivity measurements and data analysis for signature characterization. While at General Electric, was Project Engineer/Analog and Digital Circuit Designer, having experience in the field of Attack Radar and Electro-Optical military avionics hardware development. Circuit design areas include A/D and D/A converters, video signal circuits, servo systems (AFC loops), and digital subsystems for digital AMTI and a digital scan converter. Project engineering responsibility was for various projects, including a frequency agile radar digital AMTI and Ka-band radar system flight test program at Nellis Air Force Base, Nevada, and SCANA, Covert Surveillance System, and PAVETACK radar hardware design and development.

Current Fields of Interest

Theory/techniques of radar systems; millimeter wave radar technology; reflectivity signature measurements/analyses; analog/digital circuit techniques.

Registrations

Registered Professional Engineer, New York, Georgia

Patents

1. "Signal Enhancement System for Radar Display," Disclosure submitted December 1975, co-inventor

Major Reports and Publications

1. "Instrumentation Systems for Polarimetric Data Collection," Workshop on Polarimetric Radar Technology, June 25-26, 1980, coauthor
2. "Polarization Related Radar Reflectivity Characteristics from Snow and Targets at 35 GHz," Workshop on Polarimetric Radar Technology, June 25-26, 1980, coauthor
3. "95 GHz Radar Measurement Program," Final Technical Report on P.O. 508050-93-534351-788322938, Project A-2241, May 1980, coauthor
4. "Advanced Millimeter Wave R.F. Technology," Electronic Warfare Technical Meeting, April 1980, coauthor
5. "Reflectivity and Emissivity of Snow and Ground at MM Waves," 1980 International Radar Conference, April 1980, coauthor
6. "Radar Detection and Classification of Buried Non-Metallic Mines," 25th Annual Tri-Service Radar Symposium, September 1979, coauthor
7. "Millimeter Wave Signature Measurements in a Snow Covered Background, Interim Technical Report for Contract F08635-78-C-0105, August 1979, coauthor
8. "Design and Development of Standardized Measurement Unit," Final Report, Contract DAAK40-77-C-0047, GIT Project A1954-060, April 1979, coauthor
9. "Reflectivity and Emissivity Characteristics of Snow, Ice, and Wet Ground at Millimeter Wave Frequencies," Eighth ARPA/Tri-Service Millimeter Wave Conference, April 1979, coauthor
10. "Flight Test Planning Document," Contract F08635-78-C-0105, GIT Project A-2110, April 1979
11. "Reflectivity Characteristics of Clutter and Targets at 35 and 95 GHz," Eighth ARPA/Tri-Service Millimeter Wave Conference, April 1979, coauthor
12. "Reflectivity Characterization at Millimeter Wave Frequencies," ADPA Avionics Section Technical Meeting, November 1978, coauthor
13. "MM-Wave Instrumentation Radar Systems," Microwave Journal, pp. 35-44 (August 1978), coauthor
14. "Test Plan for Millimeter Wave Snowpack and Target Measurements and Characterization," Test Plan, Contract F08635-78-C-0105, GIT Project A2110, February 1978, coauthor
15. "Radar Detection, Discrimination, and Classification of Buried Non-Metallic Mines," Final Technical Report, Contract DAAG53-76-C-0112, GIT Project A-1828, February 1978, coauthor
16. "Test Plan--Characterization of Coherent Reflectivity from Targets and Background at Ku-, Ka- and M-Band Frequencies," Contract DAAK40-77-C-0077, GIT Project A-1981, January 1978, coauthor
17. "Design Concept of Packaging Form for the Standardized Measurement Unit," Interim Technical Report 1, Contract DAAK40-77-C-0047, GIT Project A-1954-060, September 1977, coauthor
18. "Modern Millimeter Wave Instrumentation Radar Development and Research Methodology," EASCON '77, September 1977, coauthor
19. "Review of Millimeter Wave Radar Development at Georgia Tech," Internal Technical Report 77-01, May 1977, coauthor

Major Reports and Publications (continued)

20. "Design of a Ballistic Antiship Missile (BAM) Guidance System," Interim Task Report No. 1, Contract N000174-77-C-0099, GIT Project A-1939, March 1977, coauthor

21. "Spectral Characteristics of Buried Objects," Interim Technical Report No. 1, Contract DAAG53-76-C-0112, GIT Project A-1828, December 1976, coauthor

22. "Power Susceptibility Test Planning for AN/SPG-55B Radar," Planning Report, Contract N00039-75-C-0307, Project A-1725, August 1975, coauthor

23. "High Information Rate Cockpit Display (HIRD)," Technical Proposal for F33615-75-R-5203, General Electric Company, April 1975, coauthor

24. "Study Results for PAVETACK Displays and Controls Program," Technical Report 021755-5292, Contract F33657-74-C-0758, General Electric Company, February 1975, coauthor

25. "Covert Surveillance System for Manned and Unmanned Aircraft," Final Report, contract F33657-74-C-0122, General Electric Company, December 1974, coauthor

26. "Design Considerations for a 5 MHz, 8 Bit Airborne Militarized Analog-to-Digital Converter," Master's Thesis, Syracuse University, May 1973, author

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

BRITT, POPE P.--Senior Research Engineer
Radar and Instrumentation Laboratory

Education

B.S.M.E., University of Alabama	1960
Graduate studies, Syracuse University	1961-1971

Employment History

Georgia Institute of Technology Senior Research Engineer, EES	1978-Present
Martin Marietta Corporation, Senior Staff Engineer	1972-1978
General Electric Company, Project Engineer	1961-1972

Experience Summary: Since joining the staff of EES has served as project director for several millimeter wave radar programs. Has made significant contributions in areas of millimeter wave and radar system development. Has experience in radar and seeker technology, highlighted by new developments in: (1) Antennas - dual frequency (10, 100 GHz) monopulse antenna, dichroic polarization twist mirror scan antenna, focal pivot parabola, polarization twist mirror scan antenna at 95 GHz, MMW/IR sensor, low sidelobe polarization twist cassegrain antenna, dual polarized monopulse printed circuit array, and multimode monopulse feed; (2) Phased Array - low-cost space fed X-band diode array, multifunction Microwave Aperture Study, space fed array for sidelooking radar, zero error 180 degree diode phase shifter, cylindrical transmissive array, and beam scanning and sidelobe control with cylindrical arrays; (3) Radar and Seeker Technology - four channel monopulse sensor for MMW radar and radiometer angle tracking. Design concept for narrow field of view terminal homing seeker. UHF/X-band passive and active seeker, monopulse angle tracking with frequency agile polarization diverse processing, high accuracy seeker for spin stabilized impulsively controlled missile, passive RF cross-over fuze and dip brazed Ku-band microwave assembly.

Current Fields of Interest

Millimeter wave radar; seeker technology development.

Patents

1. "Dual Frequency Antenna System," author, Patent Docket 52-AR-2069 filed with U.S. Patent Office by General Electric Armament Systems Department
2. "A Virtual Pivot Mechanism with Two Degrees of Freedom," Invention Disclosure 76-YC-17, coauthor
3. "Angle Tracking Apparatus for Track Enhancement Obtained by Extraction of Phase Information from the Backscattered Complex RF Field," Invention Disclosure 76-Y-76, coauthor

Patents (continued)

4. "Dual Polarized Printed Circuit Matrix Antenna," Invention Disclosure 76-YC-2, coauthor
5. "Angle Tracking Apparatus Employing Polarization Diverse Wave Forms," Invention Disclosure 76-YC-1, coauthor
6. "Antenna Polarization Menas," Patent Docket 52-AS-935 filed with U.S. Patent Office, author
7. "Antenna Element Including Means for Providing Zero-Error 180 Degree Phase Shift," Patent Docket 52-AS-959 filed with U.S. Patent Office, coauthor

Major Reports and Publications

1. "Spin Stabilized Impulsively Controlled Missile," Phase I Report, OR 15,307 (Martin Marietta Report), October 1978, coauthor
2. "A Focal Pivot Parabola - A Surprising Millimeter Wave Radar Antenna," 1977 Antenna Applications Symposium, University of Illinois
3. "Millimeter Wave Semi-Active Guidance Program," OR 14,790P (Martin Marietta Report), October 1977, coauthor
4. "Polarization-Aided Adverse Weather Seeker (PAWS)," OR-14,171 (Martin Marietta Report), April 1976, coauthor
5. "Millimeter Wave Gimbal Stabilization Analysis," ANA 10140246 (Martin Marietta Report), March 1976, coauthor
6. "Multi-Environment Active RF Seeker (MARFS)," Phase I Final Report, OR 14,049 (Martin Marietta Report), January 1976, coauthor
7. "Sidelooking Radar Phased Array Study," 1110250-2122 (GE Utica Report), November 1972, coauthor
8. "Multifunction Arrays," presented at USAF Antenna Symposium, University of Illinois, October 1972
9. "Cylindrical Phased Arrays--Beam Scanning and Sidelobe Control," presented at NAECON '72, Dayton, Ohio, May 1972, coauthor
10. "Sidelooking Phased Array Study Program," 0522225-2066 (GE, Utica Report), May 1972, coauthor
11. "ULTRA Light Weight Transmissive Array," (GE, Utica IR&D Project Report), January 1972, coauthor
12. "Multifunction Microwave Aperture Study," Vol. I and II, AFAL-TR-71-211, September 1971, coauthor
13. "Multifrequency Conformal Array Study," 0120025-0002 (GE, Utica Report), January 1970, coauthor
14. "Low Sidelobe Antenna Preliminary Technical Results," 1107950-9033 (GE, Utica Report), May 1969, coauthor

Georgia Institute of Technology
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BIOGRAPHICAL SKETCH

ALEXANDER, NEAL T.--Senior Research Engineer
Radar and Instrumentation Laboratory

Education

M.S.E.E., Georgia Institute of Technology	1965
B.E.E., Georgia Institute of Technology	1964

Employment History

Georgia Institute of Technology	
Chief, Microwave Systems Division, EES	1979-1980
Head, Systems and Antennas Branch, EES	1978-1979
Senior Research Engineer	1975-Present
Research Engineer II	1969-1975
Graduate Teaching Assistant	1968-1969
General Dynamics Corp., Aerosystems Engineer	1965-1967

Experience Summary: Currently acts as consultant to various radar system projects, performs system analysis and design and is responsible for internal research in radar ECCM. Has provided microwave analysis and design support to laboratory radar system development programs. Was responsible for analysis and design of two radar antenna systems involving surveillance and tracking antennas employing multiple beams and conical-scan and monopulse tracking techniques. Has performed computer-aided microwave design of a shaped-elevation-beam search antenna, and has participated in the development of a special-purpose radar antenna system involving the design of geodesic lenses and feedhorns and shaping of antenna reflectors. Has designed and performed design studies of several types of organ-pipe scanners, and has participated in design and analysis of Cassegrain twist- transreflector antennas. Has developed computer simulations to study the effects of antenna polarization on radar system performance, and has conducted a design study of scanning techniques for use with cut-paraboloidal reflector antennas. At General Dynamics, participated in design and development of antennas for the electronic countermeasures system for the F-111A aircraft.

Current Fields of Interest

Radar system analysis, design and development; microwave antennas and measurements; electromagnetic scattering and diffraction.

Registrations

Registered Professional Engineer, Georgia

Major Reports and Publications

1. "Technical Support for Projects MUSKETEER OAK and ALMOND," Final Technical Report on Contract MDA904-79-C-0474, September 1979, coauthor
2. "Power/Polarization Analysis," Interim Technical Report on Contract MDA904-78-C-0503, January 1979, coauthor
3. "Feedhorn Evaluation," Final Technical Report on Task 002 of Contract F33657-77-C-0661, December 1978
4. "Air Defense Antennas," Final Technical Report on Contract DAAH01-75-C-1086 and on Task 020 of Contract DAAK40-77-C-0192, November 1978, coauthor
5. "Project MUSKETEER OAK," Final Technical Report on Contract MDA904-78-C-0503, October 1978, coauthor
6. "Low Altitude Tracking Experiments," Final Technical Report on Contract DAAK40-77-C-0192, September 1978, coauthor
7. "CROSSBOW-S Antenna/System Design Study: Task I - Microwave Antenna Technology Assessment," Final Technical Report on Task I of Contract DAAK40-77-C-0101, May 1978
8. "Systems Definition for ADA Simulator," Final Technical Report on Task I of Contract DAAK40-77-C-0025, coauthor
9. "Analysis of Target Tracking Radars," Technical Task Report No. 1 on Contract F33657-76-C-0783, February 1977, coauthor
10. "Surface-to-Air Missile System Analysis," Technical Task Report 1 on Contract F33657-76-C-0783, January 1977, coauthor
11. "ADA Simulator Equipment Design Analysis," Final Technical Report on Contract DAAK40-76-C-0865, December 1976, coauthor
12. "Target Acquisition Experiments Employing a Millimeter Wave Rapid Scan Radar," Final Report on Contract N00014-76-C-0869, Mod P00001, October 1976, coauthor
13. "Stationary Target Detection and Classification Studies," Semiannual Technical Report on Contract N00014-75-C-0320, Mod P00003, August 1976, coauthor
14. "Lightweight Antennas and Components," Final Technical Report on EES Project E-210-905, July 1976, coauthor
15. "Phase Analysis of Cone Scattering Near Base-On," IEEE Transactions on Antennas and Propagation, AP-24, 541-543 (July 1976), coauthor
16. "Performance and Cost Analyses of Battlefield Surveillance Moving Target Acquisition Radars," Interim Technical Report on Contract N00014-75-C-0320, Mod P00001, May 1976, coauthor
17. "Shaped Elevation Beam Antenna," Final Technical Report on Contract N00014-75-C-0574, February 1976, coauthor
18. "Shaped Elevation Beam Antenna," Phase I Technical Report on Contract N00014-75-C-0574, April 1975, coauthor
19. "Analysis of a Fire-Control Radar Antenna System," Final Report on Contract DAAH01-74-C-0683, April 1975, coauthor
20. "Scanning Antenna Reflector Analysis," Final Technical Report on Contract N00019-73-C-0394, September 1974, coauthor
21. "Computer-Aided Analysis of Selected Foreign Radar Antennas," Presented at the 1974 Tri-Service Radar Symposium, July 1974, coauthor

Major Reports and Publications

22. "Computer-Aided Design of Electromechanical Scanning Antennas," Proceedings of the 1974 International IEEE/AP-2 Symposium, June 1974, coauthor
23. "Phase Analysis of Cone Scattering Near Base-on," Proceedings of the 1974 International IEEE/AP-S Symposium, June 1974, coauthor
24. "70-GHz Lightweight Geodesic Lens," Final Technical Report on Subcontract 372113, Prime Contract N00017-72-C-4401, April 1974, coauthor
25. "Methods of Radar Cross-Section Reduction," Final Technical Reporton Contract N00039-72-C-1342, February 1974, coauthor
26. "Scaled Antenna Performance Analysis," Final Technical Report on Contract F08635-73-C-0095, July 1973, coauthor
27. "Radar Backscatter Measurements of Selected Ballistic Projectiles," Final Technical Report on Contract N00014-67-0159-0012, November 1972, coauthor
28. "Investigation of Target Tracking Errors in Monopulse Radars," Final Technical Report on Contract DAAH01-71-C-1192, July 1972, coauthor
29. "Microwave Scanning Antenna Studies in Support of Advanced ECHO Range Requirements, Task IV," Final Engineering Report on Task IV, APL/JHU Subcontract 271845, 31 May 1972, coauthor
30. "Geodesic Luneberg Lens Scanning Antenna," Final Report on Contract DAAG39-69-C-0054, September 1971, coauthor
31. "Semi-Annual Program Technical Status Report," Status Report, APL/JHU Subcontract 271845, 9 August 1971, coauthor
32. "Effects of Polarization Agility on Monopulse Radar Angle Tracking," Final Engineering Report, Vols. I and II, Contract DAAH01-70-C-0535, June 1971, coauthor
33. "Pedestal Mounted Scanning Antennas," Range Instrumentation Design Data Report, Contract F08635-70-C-0102, 12 September 1970, coauthor
34. "Microwave Scanning Antenna Studies in Support of Advanced Echo Range Requirements, Task IIR1, Final Engineering Report on Task IIR1, Subcontract 271845, Prime Contract NO2-62-0604-C, 31 July 1970, coauthor

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

CURRIE, NICHOLAS C.--Chief of Experimental Division
Radar and Instrumentation Laboratory

Education

M.S. in E.E., Georgia Institute of Technology	1973
B.S. in Physics, Georgia Institute of Technology	1967

Employment History

Georgia Institute of Technology	
Chief of Experimental Division, EES	1979-Present
Senior Research Engineer	1977-Present
Research Engineer II	1973-1977
Research Scientist I	1967-1973
Student Assistant	1965-1976
Scientific Atlanta, Inc., Mechanical Assistant	1964
Reigal Paper Corporation, Quality Control Inspector	1963
Scientific Atlanta, Inc., Machinist's Assistant	1961

Experience Summary: Is administratively responsible for operations of Radar Experimental Division. Is directing project to develop automatic computer-based track-while-seen sensor for Triservice BISS/WIDS program. Has wide background of experience in radar research and development work, including directing project to develop "turnkey" data acquisition system for U.S. Air Force Adverse Weather Test range; directing projects involving measuring backscattering properties of foliage, snow, rain, sea clutter, and military vehicles for U.S. Army, Navy, and Air Force; directing projects to evaluate performances of AN/TPQ-312 mortar tracking radar and AN/APS-127 airborne surface, and pulse circuitry in support of radar measurement programs. Was responsible for interface and integration of large experimental radar tracking system with its associated control and data acquisition electronics. Was responsible for development of hardware for computer controlled intertial platform. Participated in measurement programs involving gathering of target signature characteristic bistatic radar properties and performance evaluation of constant false alarm rate (CFAR) processors in a sea clutter environment. As a student assistant, participated in measuring electrical properties of ferrule materials and in compilation of a bibliography on radar reflectively research.

Current Fields of Interest

Radar detection theory; radar signal processing; radar systems design and evaluation; millimeter radar and radimetric measurements; computer modeling of detection performance; computer-based automatic detection systems; program management; data acquisition and analysis.

Major Reports and Publications

1. "Multifrequency Radar Sea Clutter Measurements," Final Technical Report on Contract N60921-78-C-A179, April 1980, coauthor
2. "Advanced Millimeter Wave RF Technology," Digest of the 1980 Electronic Warfare Technical Meeting, White Sands, N.M., April 1980, coauthor
3. "Reflectivity and Emissivity of Snow and Ground at MM Waves," Proceedings of the 1980 International Radar Conference, Washington, D.C., April 1980, coauthor
4. "TDU-ADM Design Document," Technical Report No. 1 on Contract N61339-75-C0122, HR-51, March 1980, coauthor
5. "RCS Measurements of WIDS Targets," Memorandum Report No. 1 on Contract N000612-79-C-8004, HR-13, January 1980, coauthor
6. "Multifrequency Millimeter Radar Sea Clutter Measurements," EASCON 79, Arlington, Va., October 1979, coauthor
7. "Characteristics of Millimeter Radar Backscatter from Wet/Dry Foliage," Proceedings of the 1979 IEEE AP-S International Symposium, Seattle, Wash., June 1979
8. "Multifrequency Millimeter Radar Sea Clutter Measurements," Proceedings of the Eighth ARPA/Triservice Millimeter Wave Conference, Eglin AFB, Florida, April 1979, coauthor
9. "Millimeter Wave Signature Measurements in a Snow-Covered Background," Interim Technical Report on Contract F08635-78-0105, March 1979, coauthor
10. "TDU Prototype Improvement Tests," Memorandum Report No. 1 on Contract N61339-75-C-0122, Delivery Order No. HY-51, February 1979, coauthor
11. "Reflectivity Characterization at Millimeter Wave Frequencies," invited paper published in the Proceedings of the 1978 Avionics Section, Air Armament Division, American Defense Preparedness Association Meeting, Monterey, California, December 1978, coauthor
12. "A BISS/WIDS Sensor for Automatic Waterborne Intrusion Detection," Digest of the Government Microcircuits Applications Conference (GOMAC), Monterey, California, November 1978, coauthor
13. "Environmental Effects on Milllimeter Radar Systems," Proceedings of the Advisory Group for Aerospace Research and Development (AGARD) Conference, Munich, Germany, September 1978, coauthor
14. "MM-Wave Instrumentation Radar Systems," Microwave Journal 21, 8, 35-43, August 1978, coauthor
15. "Millimeter Sea Return Study, Addendum," Addendum to the Interim Technical Report on Contract N60921-77-C-A168, July 1978, coauthor
16. "Millimeter Sea Return Study," Interim Technical Report on Contract N60921-77-C-A168, July 1978, coauthor
17. "TDU Pre-ADM Tests," Technical Report No. 3 on Contract N00024-76-C-7082, May 1978, coauthor
18. "Test Plan for Millimeter Wave Snowpack and Target Measurements and Characterization," Memorandum Report No. 1 on Contract F08635-78-C-0105, March 1978, coauthor
19. "Considerations for an Adjunct TDU Display," Memorandum Report No. 2 on Contract N00024-76-C-7082, December 1977, coauthor
20. "Millimeter Target Signature Measurements," invited paper published in the Proceedings of the Sixth ARPA/Tri Service Millimeter Wave Conference, Harry Diamond Laboratories, Adelphi, Md., November 1977, coauthor
21. "TDU Prototype Test Plan," Memorandum Report No. 1 on Contract N00024-76-C-7082, October 1977, coauthor

Major Reports and Publications (continued)

22. "Radar Backscatter from Land, Sea, Rain, and Snow at Millimeter Wavelengths," Proceedings of the IEE/IEEE RADAR-77 Conference, London, England, October 1977, coauthor
23. "Adverse Weather Test Range Development," Phase I, Final Report on Contract F08635-77-C-0114, October 1977, coauthor
24. "Radar Millimeter Wave Measurements: Volume II, Target Signatures," Report AFATL-TR-77-121, Contract F08635-76-C-0221, October 1977, coauthor
25. "AN/APS-127 Airborne Radar System Evaluation," Final Report on Contract No. 2-70099-6-63919A, Naval Air Development Center, Warminister, Pennsylvania, 30 September 1977, contributor
26. "Modern Millimeter-Wave Instrumentation Radar Development and Research Methodology," EASCON-77 Proceedings, Arlington, Va., September 1977, coauthor
27. "Radar Millimeter Wave Measurements: Volume I, Snow and Vegetation," AFATL-TR-77-92, Contract F08635-77C-0221, July 1977, coauthor
28. "A BISS/WIDS Target Detection Unit for Use Against Waterborne Intruders," invited paper, Technical Seminar on Battlefield Surveillance, Ft. Belvoir, Va., July 1977, contributor
29. "Millimeter Wave Signature Measurements of Military Vehicles," Proceedings of the 23rd Annual Tri-Service Radar Symposium, West Point, N.Y., July 1977, coauthor
30. "TDU Software System Definition Document," Technical Report No. 2 on Contract N00024-76-C-7082, May 1977, coauthor
31. "Review of Millimeter Wave Radar Development at Georgia Tech," Internal Report No. 77-01, May 1977, coauthor
32. "Comparison of Microwave Winter/Summer Foliage Penetration Measurements," Final Report on Task 2 on MIT/LL Purchase Order No. CX-1069, 10 January 1977, coauthor
33. "Millimeter Wave Radar Measurement--Procedures and Equipment," invited paper published in the Proceedings of the Fourth DOD Millimeter Workshop, November 1976, coauthor
34. "Shore Tests on the AN/APS-127 Radar System," Phase I, Final Data Report on Contract N62269-76-C-0232, October 1976, coauthor
35. "Millimeter Backscatter Measurements on Hard Targets," Technical Report No. AFATL-TR-77-53 on Contract F08635-76-C-0221, October 1976, coauthor
36. "Characterization of Snow at Millimeter Wavelengths," Proceedings of the 1976 AP-S International Symposium, 15 October 1976, coauthor
37. "Millimeter Foliage Penetration Measurements," Proceedings of the 1976 AP-S International Symposium, 15 October 1976, coauthor
38. "Backscatter from Ground Vegetation at Frequencies between 10 and 100 GHz," Proceedings of the 1976 IEEE AP-S International Symposium, 12 October 1976, coauthor
39. "Development of an RTDA," Final Technical Report on Contract N000-39-73-C-0676, October 1976, coauthor
40. "Radar Millimeter Backscatter Measurements from Snow," Technical Report No. AFATL-TR-77-4 on Contract F08635-76-C-0221, June 1976, coauthor
41. "Measurement of Radar Backscatter in the Millimeter Wave Region," invited paper published in the Proceedings of the Second DOD Workshop on Millimeter Wave Terminal Guidance Systems, May 1976, coauthor
42. "Radar Foliage Penetration Measurements at Millimeter Wavelengths," Technical Report No. 4 on Contract DAAA25-73-C-0256, December 1975, coauthor

Major Reports and Publications (continued)

43. "Performance Tests on the AN/TPQ-31 ( ) Radar," Technical Report on Contract N00014-75-C-0028, June 1975, coauthor
44. "Design Considerations for the LORCS Head," Technical Report No. 3 on Contract N00039-73-C-0676, Mod. P0005, May 1975, coauthor
45. "Analysis of AN/TPQ-31 ( ) Radar Performance Tests," Final Technical Report on Contract M00027-75-C-0025, May 1975, coauthor
46. "Some Properties of Radar Return from Rain at 9.375, 35, 70, and 95 GHz," Proceedings of the IEEE 1975 International Radar Conference, 22 April 1975, coauthor
47. "Radar Land Clutter Measurements at 9.5, 16, 35, and 95 GHz," Technical Report No. 3 on Contract DAAA25-73-C-0256, 2 April 1975, coauthor
48. "Analysis of Radar Rain Return at Frequencies of 9.375, 35, 70, and 95 GHz," Technical Report No. 2 on Contract DAA25-73-C-0256, 1 February 1975, coauthor
49. "Some Comments on the Characteristics of Radar Sea Clutter," Proceedings of the 1974 IEEE AP-S International Symposium, 10 June 1974, coauthor
50. "OpAmp has 16 Step Digital Gain Control," EDN Design Awards 19, 9, 75-76, 5 May 1974, coauthor
51. "Performance Tests on the APS-119 Radar System," Final Technical Report on Contract DOT-CG-04132, A, 15 February 1974, coauthor
52. "Testing of Radars to Determine Characteristics for Swimmer Defense Program," Preliminary Draft of Final Technical Report on Contract N00024-73-C-5414, January 1974, coauthor
53. "Radar Cross-Section Measurements, Boca Raton, 5-6 September 1973," Memorandum Report No. 1 on Contract N00017-72-C-4401, 25 September 1973, coauthor
54. "An Attitude Sensor for a Precision Phased-Array Antenna," Final Technical Report on Contract N00014-67-A-0159, 0013, 31 May 1973, coauthor
55. "Operation and Maintenance Procedures for a Tracking Antenna System," Operation Manual for Contract ALP/JHU 271845, 15 March 1973, contributor
56. "Pedestal-Mounted Scanning Antenna," Final Engineering Report on Contract F08635-70-C-0102, 15 December 1972, coauthor
57. "Pedestal-Mounted Scanning Antenna System," Range Instrumentation Operation and Maintenance Manual for Contract F0835-70-C-0102, 15 September 1972, contributor
58. "Methods for Comparisons of Clutter Processing Techniques," Technical Report No. 5 on Contract N00024-68-C-1125, February 1971, coauthor
59. "Assistance on Radar Tests," Technical Report No. 1 on Contract N00014-67-A-0159, 004, 29 January 1969, coauthor
60. "Investigations of Techniques for Target Enhancement," Final Report on Contract F33615-76-1685, February 1968, coauthor

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

HAYES, ROBERT D.--Principal Research Engineer
Radar and Instrumentation Laboratory

Education

Ph.D. in E.E., Georgia Institute of Technology	1964
M.S. in E.E., Georgia Institute of Technology	1957
M.S. in Physics, University of Kentucky	1950
B.E.E., University of Kentucky	1948

Employment History

Georgia Institute of Technology	
Principal Research Engineer	1976-Present
Professor of Electrical Engineering	1968-1976
Senior Research Engineer and Associate Head of Radar Branch	1965-1966
Associate Professor of Electrical Engineering	1964-1966
Assistant Professor of Electrical Engineering	1958-1964
Research Engineer I and Research Engineer II	1954-1965
Chung Shan Institute, Taiwan, Guest Lecturer	1975(Summer)
Florida Institute of Technology, Adjunct Professor	1967-1968
Radiation Incorporated, Principal Engineer, Head of Advanced Technology Staff, RF Engineering	1966-1968
Western Electric Company, Field Engineer	1950-1954
University of Kentucky, Student Assistant and Graduate Assistant	1947-1950
U.S. Army Air Corps, Weather Observer	1943-1946

Experience Summary: Serves as Senior Staff Member and Principal Research Engineer within the Radar and Instrumentation Laboratory, as a member of the graduate EE staff, and as consultant to U.S. Army, several commercial companies, and law firms. Served as session chairman and on steering committees of radar symposiums, conferences, and workshops. Teaches courses in microwave techniques, electro-magnetic theory, electronic circuits, and communication systems. Has provided individual technical support for advanced communication and telemetry systems. Designed experiments and performed data analysis of millimeter wave radiometers. Designed a radiometer and measured atmospheric attenuation at millimeter wavelengths. Director of programs concerned with collecting and analyzing data on polarization and statistical properties of radar echoes from natural and man-made targets, and with design, construction, and evaluation of clutter-reduction radars. Developed a 16 GHz multiport rotating microwave switch. Supervised design and construction of the antenna and microwave portions of a multiple-polarized radar. At Radiation Inc., was responsible for in-house research and development programs in RF Engineering Dept. (185 engineers) which covered antennas, receivers, controls, mechanical structures, and product design. At Western Electric Company, taught courses in radar and conducted flight test evaluation of special bomb-navigational radars for the Air Force.

Current Fields of Interest

Microwave development; communication systems; radar systems; radiometers.

Registrations and Special Honors

Institute of Electrical and Electronic Engineers -- Member
Listed in American Men of Science
Listed in Who's Who in American Education, Vol. II
Listed in Who's Who in the South and Southwest, Vol. 10
Sigma Xi--Member, Sigma Pi Sigma--Member, Eta Kappa Nu--Member, IEEE--Member
Referenced:

1. "Atmospheric Transmission Handbook," William I. Thompson, II, Report No. DOT-TSC-NASA-71-6, February 1971
2. "Applications for Millimeter Radars," Dr. L. D. Strom, Systems Planning Corporation, April 1974

Major Reports and Publications

1. "Emissivities of Wet Surfaces at 35 and 95 GHz," Terrain and Sea Scatter Workshop, March 1980
2. "95 GHz Pulsed Radar Returns from Trees," IEEE EASCON '79 Conference Record Vol. 2, October 1979
3. "Reflectivity and Emissivity Characteristics of Snow, Ice and Wet Ground at Millimeter Wave Frequencies," 8th DARPA/Tri-Service MM Wave Conference, April 1979, coauthor
4. "Ground Clutter," Proceedings of the Workshop on Radar Backscatter from Terrain, University of Kansas, RLS TR374-2, January 1979
5. "Sea Clutter," Proceedings of the Workshop on Radar Backscatter from Terrain, University of Kansas, RSL TR374-2, January 1979
6. "MM Wave Reflectivity of Land and Sea," Microwave Journal, April 1978, coauthor
7. Internal U.S. Army Reports/Memos:
   Radar Modeling for Millimeter Wave Applications, MIRADCOM, July 1978
   Sensor for Airborne Missile Weapon, MIRADCOM, August 1977
   Comments on Second Generation Seekers for CLGP, ARMCOM, Jan. 1977
   Comments on Models for Ground and Rain Clutter, MICOM, Feb. 1975
   Some Requirements for Helicopter Fire Control Sensors, SMUFA, 1972
8. "Pulse Millimeter Wave Radar Systems for Target/Height Sensing Fuzes for Gun-Launched Projectiles," ARRADCOM Report ARLCD-78044, June 1978, coauthor
9. "Millimeter Wave Research," presentation to NATO Research Study Group on MM Wave Propagation and Target/Background Signatures, Hanscom AFB, Massachusetts, May 1978
10. "Radar Sea Clutter Studies, VHF to K-Band," Naval Weapons Center, Contract N000123-77-C-1073, January 1978, coauthor
11. "MM Wave Target Signature Measurements," 6th DARPA MM Wave Conference, November 1977, coauthor
12. "Radar Millimeter Backscatter Measurements," Vol. II, Target Signatures, Technical Report on Contract F08635-76-C-0221, July 1977, coauthor

Current Fields of Interest

Microwave development; communication systems; radar systems; radiometers.

Registrations and Special Honors

Institute of Electrical and Electronic Engineers -- Member
Listed in American Men of Science
Listed in Who's Who in American Education, Vol. II
Listed in Who's Who in the South and Southwest, Vol. 10
Sigma Xi--Member, Sigma Pi Sigma--Member, Eta Kappa Nu--Member, IEEE--Member
Referenced:

1. "Atmospheric Transmission Handbook," William I. Thompson, II, Report No. DOT-TSC-NASA-71-6, February 1971
2. "Applications for Millimeter Radars," Dr. L. D. Strom, Systems Planning Corporation, April 1974

Major Reports and Publications

1. "Emissivities of Wet Surfaces at 35 and 95 GHz," Terrain and Sea Scatter Workshop, March 1980
2. "95 GHz Pulsed Radar Returns from Trees," IEEE EASCON '79 Conference Record Vol. 2, October 1979
3. "Reflectivity and Emissivity Characteristics of Snow, Ice and Wet Ground at Millimeter Wave Frequencies," 8th DARPA/Tri-Service MM Wave Conference, April 1979, coauthor
4. "Ground Clutter," Proceedings of the Workshop on Radar Backscatter from Terrain, University of Kansas, RLS TR374-2, January 1979
5. "Sea Clutter," Proceedings of the Workshop on Radar Backscatter from Terrain, University of Kansas, RSL TR374-2, January 1979
6. "MM Wave Reflectivity of Land and Sea," Microwave Journal, April 1978, coauthor
7. Internal U.S. Army Reports/Memos:
   Radar Modeling for Millimeter Wave Applications, MIRADCOM, July 1978
   Sensor for Airborne Missile Weapon, MIRADCOM, August 1977
   Comments on Second Generation Seekers for CLGP, ARMCOM, Jan. 1977
   Comments on Models for Ground and Rain Clutter, MICOM, Feb. 1975
   Some Requirements for Helicopter Fire Control Sensors, SMUFA, 1972
8. "Pulse Millimeter Wave Radar Systems for Target/Height Sensing Fuzes for Gun-Launched Projectiles," ARRADCOM Report ARLCD-78044, June 1978, coauthor
9. "Millimeter Wave Research," presentation to NATO Research Study Group on MM Wave Propagation and Target/Background Signatures, Hanscom AFB, Massachusetts, May 1978
10. "Radar Sea Clutter Studies, VHF to K-Band," Naval Weapons Center, Contract N000123-77-C-1073, January 1978, coauthor
11. "MM Wave Target Signature Measurements," 6th DARPA MM Wave Conference, November 1977, coauthor
12. "Radar Millimeter Backscatter Measurements," Vol. II, Target Signatures, Technical Report on Contract F08635-76-C-0221, July 1977, coauthor

Major Reports and Publications (continued)

13. "Radar Millimeter Backscatter Measurements," Vol. I, Snow and Vegetation, Technical Report on Contract F08635-76-C-0221, July 1977, coauthor
14. "Data Requirements for the Millimeter Seeker Problems," Fourth DoD Millimeter Workshop, November 1976, coauthor
15. "Performance and Cost Analysis of Battlefield Surveillance Moving Target Acquisition Radars," Technical Report on Contract N00014-75-C-0320, 1976, coauthor
16. "Fluctuations in Radar Backscatter from Rain and Trees," DARPA/Tri-Service MM Wave Workshop, NELC, San Diego, November 1976
17. "Backscatter from Ground Vegetation at Frequencies Between 10 and 100 GHz," AP-S International Symposium, 1976, coauthor
18. "Instrumentation Techniques for Tracking Low-Flying Vehicles," Final Report on Contract DAAD07-75-C-0025, 15 July 1975, coauthor
19. "Some Properties of Radar Return from Rain at 9.37, 35, 70, and 95 GHz," IEEE International Radar Conference, April 1975, coauthor
20. "Radar Land Clutter Measurements at Frequencies of 9.5, 16, 35 and 95 GHz," Technical Report on Contract DAA25-73-C-0256, 2 April 1975, coauthor
21. "Analysis of Radar Rain Return at Frequencies of 9.375, 35, 70, and 95 GHz," Technical Report on Contract DAAA25-73-C-0256, February 1975, coauthor
22. "Land Clutter Characteristics for Computer Modeling of Fire Control Radar Systems," Technical Report No. 1 on Contract DAA25-73-C-0256, May 1973, coauthor
23. "A Study of Factors Basic to the Development of Millimeter Wave Radiometric Terminal Tracking," prepared for Harry Diamond Laboratories, March 1972
24. "Salt Systems Studies and Simulation," prepared for Lockheed-Georgia Company, January 1972, coauthor
25. "A Technique for Radar Detection of Small Targets in Sea Clutter," Record of the Twelfth Annual Radar Symposium, University of Michigan, June 1966, coauthor
26. "Study of Polarized Techniques for Target Enhancement," Special Technical Report on Contract AF 33(615)-2593, March 1966, coauthor
27. "Some Statistical Properties of Radar Returns from the Sea," Technical Report on Contract N62269-2408, November 1965, coauthor; also published in the Record of the Twelfth Annual Radar Symposium, University of Michigan, June 1966
28. "Total Vertical Atmospheric Attenuation Measured from 40 to 140 GHz," Boulder MM Wave and Far Infrared Conference, August 1965
29. "Study of Elements for an Experimental Radar," Final Report on Contract N62269-2408, April 1965, coauthor
30. "Total Atmospheric Attenuation at Millimeter Wavelengths," Ph.D. Thesis, Georgia Institute of Technology, June 1964
31. "Polarization Characteristics of Sea Targets," Final Report on Contract NObsr-89149, August 1963, coauthor

Major Reports and Publications (continued)

32. "A Clutter Reduction Radar," Record of the Ninth Annual Radar Symposium, University of Michigan, June 1963, coauthor
33. "Anti-Clutter Radar," Quarterly Reports on Contract DA 36-039 SC-78268, April 1959 - July 1962, Technical and Final Reports, October 1962, coauthor
34. "Some Polarization Properties of Targets at X-Band," Record of Radar Return Symposium, University of New Mexico, 1959, coauthor
35. "An X-Band Polarization Measurements Progam," Record of the Third Annual Radar Symposium, University of Michigan, May 1957, coauthor
36. "Study of Polarization Characteristics of Radar Targets," Technical and Final Reports on Contract DA 36-039 SC-64713, September 1956 - October 1958, coauthor
37. "Modification Kit for the Two Beam 16,000 Mc Modified Luneberg Lens Scanning System," Technical Report on Contract DA 36-039-SC-42707, September 1955, coauthor
38. "Polarization Characteristics of Radar Targets," Final Technical Report on Contract DA 36-039-SC-56761, March 1955, coauthor

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

BOMAR, LUCIEN C.--Research Engineer II
Radar and Instrumentation Laboratory

Education

B.E.E., Georgia Institute of Technology	1969
Post graduate course work, Georgia Tech	1977-Present

Employment History

Georgia Institute of Technology	
Research Engineer II, EES	1976-Present
Sperry Microwave Electronics	
Senior Engineer	1974-1976
Engineer	1971-1974
Associate Engineer	1969-1971
Southern National Gas Company	
Engineering Assistant	1968-1969
Draftsman	1966-1968

Experience Summary: Has been project director of data acquisition and analysis program to evaluate radar target detection algorithms at Ka- and M-bands, project director for the fabrication of 35 GHz solid state radar, and participated in development of 95 GHz tracking radar. Has been involved in measurement and analysis of radar signatures of ground-based tactical targets and backscatter from land and sea clutter at millimeter frequencies. Has been involved in design, development, and testing of airborne radiometric and radar seekers for terminal guidance applications. While at Sperry, had project responsibility for system design and development of prototype 94 GHz FM-CW microwave radiometric seeker to be evaluated by the Army as candidate missile guidance senor. Project responsibility also included captive flight testing and data analysis for 35 GHz Microwave Radiometric Seeker Subsystem (MRSS) in both tower and airborne tests. In addition has been responsible for conducting test programs to evaluate millimeter wave applications for direction finding and use as RPV data links. Also participated in Army-funded design study to define system concepts and requirements leading to development of the MRSS. Developed novel ranging techniques applicable to FM-CW radar as well as adaptive target derived automatic gain control technique for use in airborne FM-CW seeker. Responsibility has included development of overall seeker control system and specifically design of two-axis gimbal control for two microwave seeker systems. In addition, has had design responsibility for servo controls of two high-speed scanning antenna systems developed for millimeter applications.

Current Fields of Interest

Radar systems design and evaluation; millimeter radar and radiometric measurements; millimeter radar and radiometric applications for fire control and terminal guidance; automatic control systems.

Patents

1. "Adaptive Gain Control for Radiometric Target Tracking System," Patent No. 4,115,776 (September 1978), co-inventor
2. "FM-CW Range Bin Techniques," Disclosure submitted 4/5/76, co-inventor

Major Reports and Publications

1. "Instrumentation Systems for Polarimetric Data Collection," Proceedings of the Polarimetric Radar Technology Workshop, June 1980, coauthor
2. "Polarimetric Characteristics of Clutter and Targets at 356 Hz," Proceedings of the Polarimetric Radar Technology Workshop, June 1980, coauthor
3. "Final Technical Report--Characterization of Coherent Reflectivity from Targets and Background at Ku-, Ku and 956 Hz Frequencies," Contract DAAK40-T1-C-0077, February 1980, coauthor
4. "Evaluation of Target Detection Characteristics at 35 GHz," Proceedings of Eighth ARPA/Tri-Service Millimeter Wave Conference, April 1979, coauthor
5. "Interim Report for Characterization of Coherent Reflectivity from Targets and Background at Ku-, Ka- and M-Band Frequencies," Interim Report No. 1, Contract DAAK40-77-C-0077, January 1979, coauthor
6. "Test Plan for the Characterization of Coherent Reflectivity from Targets and Background at Ku, Ka and M-Band Frequencies," Memorandum Report No. 2, Contract DAAK40-77-C-0077, August 1978, coauthor
7. "Millimeter Wave Reflectivity of Land and Sea," Invited Paper, Microwave Journal, August, 1978, coauthor
8. "Data Examination and Interpretation Efforts," Final Technical Report on Subcontract 60043, April 1978, coauthor
9. "Test Plan for the Characterization of Coherent Reflectivity from Targets and Background at Ku, Ka, and M-Band Frequencies," Memorandum Report No. 1 on Contract DAAK40-77-C-0077, January 1978, coauthor
10. "Radar Millimeter Wave Measurements: Volume II, Target Signatures," October 1977, Report AFATL-TR-77-121, Contract F08635-76-C-0221, coauthor
11. "Millimeter Backscattering Measurements on Hard Targets," Technical Report 2 on Contract F08635-76-C-0221, October 1976, coauthor
12. "FM-CW Millimeter Sensor Target-Background Measurements," Final Report on Contract DAAH01-74-C-0682, August 1975, author
13. "FM-CW Range Bin Investigation," Technical Note, Sperry Microwave Electronics, June 1975, Report SJ-SP-242-0148, coauthor
14. "Adverse Weather Attenuation Measurements," Final Report on Contract F33615-74-C-1236, Report AFAL-TR-74-316, December 1974, author
15. "Microwave Radiometric Seeker Subsystem (MRSS)," Final Report on Contract DAAD05-72-C-0448, April 1974, coauthor

Major Reports and Publications (continued)

16. "Millimeter Wave Conical Scan Tracker Flight Test," Technical Report on Contract DAAD05-72-C-0448, July 1963, author
17. "Daytron Tower Test Documentation," Technical Report, Volume 2 on Contract F33615-72-C-2066, coauthor
18. "Model K-510 Radiometric Tracker Development and Testing," Technical Manual on Contract F33615-72-C-2066, coauthor
19. "Radiometric Scanning Antenna System," Operations Manual on Contract DAAD05-70-C-0057, July 1970, coauthor

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

FARILL, TRENT G.--Senior Research Engineer
Radar and Instrumentation Laboratory

Education

Program Management Course, Defense System Management College	1977
U.S. Army Command and General Staff College	1973
M.S.E.E., Georgia Institute of Technology	1968
B.E.E., Georgia Institute of Technology	1958

Employment History

Georgia Institute of Technology	
Senior Research Engineer	1980-Present
System Planning Corporation	
Program Manager	1979-1980
Research Staff	1978-1979
U.S. Army	1958-1978
Electronics Research and Development Command	
Special Assistant and Executive Officer to Commander	1976-1978
Materiel Development and Readiness Command	
Project Officer for Test Equipment	1975-1976
Hewlett Packard Company, Training with Industry	1974-1975
Army Aviation School, Avionics Requirements Officer	1972-1973
General Support Group, Vietnam	
Avionics Maintenance Officer	1971-1972
Army Avionics Laboratory, Technical Plans Officer	1968-1971
Radio Research Unit, Vietnam, Operations Officer	1967-1968
Aviation, Air Defense and Signal Assignments	1958-1967
Georgia Power Company, Co-Op Student	1953-1958

Experience Summary: Is a member of the Senior Staff of the Radar and Instrumentation Laboratory participating in radar system studies and project direction. While at System Planning Corporation, participated in various studies and program management support related to intelligence, surveillance, target acquisition, and electronic warfare. Managed analyses concerning the Remotely Piloted Vehicle under development by the U.S. Army. RPV studies included survivability assessments and survivability enhancement planning; evaluation of opportunities for international cooperation, the determination and evaluation of program acceleration alternatives; and the examination of mission enhancement techniques, such as multiple air vehicle control. At the U.S. Army Electronics Research and Development Command, analyzed organizational alternatives and performed other study efforts for the establishment of the Army's Command responsible for the development of its intelligence, surveillance, electronic warfare, night vision, and target acquisition materiel. Initiated the implementation planning for the reorganization into the selected organizational structure; and after completion of the reorganization phase, initiated the command level system engineering

Experience Summary (continued):

effort. Participated in the source selection process for two major system contracts. At the U.S. Army Materiel Development and Readiness Command, planned, organized, and managed various aspects of the Army's test equipment programs from the initiation of development efforts through the development of logistic support and standardization procedures. As a Training-with-Industry-Officer at Hewlett-Packard, participated in on-going company projects in the areas of customer support, quality assurance, and production planning. As the U.S. Army Aviations School's project officer for avionics materiel development, was responsible for analyzing aviation missions to determine the Army's avionics requirement. Areas of interest were communications, navigation, and landing systems. As an Avionics Staff Officer, directed the General Support Avionics Maintenance effort for the entire Vietman area during the reduction in forces phase of the conflict. Identified and solved problems in the area of interservice support and efficient locations of critical maintenance support capabilities. As an Avionics Maintenance Unit Commander, provided avionics general support maintenance for several airmobile units in the northern portion of South Vietnam. In the Avionics Laboratory, performed duties increasing in responsibility from project engineer on high frequency radio development and static dissipation from helicopters to the executive officer of the Laboratory. Held various positions with other Signal, Air Defense, Intelligence, and Aviation Units, as well as the Aviation School as a flight instructor.

Current Fields of Interest

Radar systems; battlefield identification, friend-or-foe; surveillance and target acquisition; physical security.

Major Reports and Publications

1. "A-10 All Weather Targeting System Concept Study," Final Report on Contract P.O. #SC37733, January 1981, coauthor
2. "SOTAS -- RPV/Copperhead -- MLRS Interface," Technical Report ERADCOM 2942-15, April 1980, coauthor
3. "Issues Identification for U.S. Army RPV Program," SPC Report 560, January 1980, coauthor
4. "Control of Multiple Remotely Piloted Vehicles (RPV)," SPC Report 535, December 1979, coauthor
5. "U.S. Army RPV Rationalization, Standardization, and Interoperation (RSI) Program," SPC Report 437, May 1979
6. "Commercial Electronic Test Equipment: Army Standard?" Study Project Report, DSMC, November 1977
7. "Interrelationship, Design-to-Cost, and Prototyping," Research Report, USCGSC, April 1974

Georgia Institute of Technology
Engineering Experiment Station

BIOGRAPHICAL SKETCH

LUNSFORD, GARY H.--Senior Research Scientist
Radar and Instrumentation Laboratory

Education

Ph.D. in Physics, Math Minor, Georgia Institute of Technology	1972
M.S. in Physics, Math Minor, University of Illinois	1964
B.S. in Physics, Math Minor, Duke University	1962
Additional Graduate Work:	
Atmospheric and Space Sciences, University of California, Berkeley	1965-1966
Physics, University of Illinois, Urbana	1964-1965

Employment History

Georgia Institute of Technology	
Senior Research Scientist	1978-Present
Teaching & Research Assistantships/Fellowships	1968-1972
IBM Corporation	
Scientist/Engineer	1972-1978
Systems Analyst	1967-1968
University of Illinois, Digital Computer Laboratory	
Graduate Research Assistant	1962-1965
Summer Student Employment	1961-1965
Frisco Railroad, Industrial Engineering Department	1964
Brookhaven National Laboratory, Applied Mathematics Department	1963
IBM Corporation	1961,1962,1965

Experience Summary: At Georgia Tech, engaged in studies relating to cruise-missile vulnerability, satellite vulnerability, and the effects of illuminated chaff on threat system radars. Wrote an algorithm for signal discrimination for an automatic direction-finding radar system; organized and performed technical editing on missile-flyout descriptive material used in software training courses. Participated in studies for system's integration of hardware and software for munitions-testing facility. Developed computer simulation of two-platform, radar location algorithm used for surveillance and error determinations. Directed project that dealt with assessing F-15 automatic avionics test equipment. Served as technical staff assistant to senior-level manager in IBM Development Laboratory, which involved identifying areas requiring tecnical assistance, formulating department charters, allocating manpower resources, and representing manager's interests in meetings. Also conducted programming tests and performance-analysis activities in Shared Logic Systems area. Worked in identifying and quantifying anticipated market areas for future product development. Assessed vehicle guidance requirements and generated mathematical test cases to analyze system performance of space shuttle during orbital and re-entry phases of flight. Adapted an existing flight

Experience Summary (continued): simulation model for use in parametric sensitivity studies with various re-entry algorithms. Conducted guidance studies for Sprint missile in ABM system on-site at Bell Labs and became familiar with battle-space scenarios, missile data processing, and data filtering algorithms. Developed simulation characterization of ABM tactical software for a multi-processing system. Served as technical editor/reviewer for journal articles written by members of Systems Engineering Department. Participated in defining areas of new business activities and major follow-on tasks. Taught 40-hour class in Celestial Mechanics to senior technical personnel. Completed two IBM management training classes. Conducted Ph.D. thesis research on stability of harmonic oscillator systems experiencing a small, non-linear perturbation. Developed a series of computer programs for modeling these physical systems and performing sensitivity studies. Taught several undergraduate physics courses. Pursued post-master's courses in astronomy and astro-physics at Berkeley and became familiar with experimental instrumentation techniques used in high-altitude rocket probes. Developed a series of mission analysis computer programs that simulated the flight of the Saturn launch vehicle from lift-off to orbital insertion and simultaneously time-optimized various mission parameters. Wrote User's Guides and Technical Operations Manuals for these programs and made technical contribuions to study proposals that utilized these simulation models. Developed computer programs that optimized component usage in circuit design via Boolean algebraic techniques. Served as analyst/consultant in various applied mathematics projects. Devised algorithms for computer pattern recognition of digitized bubble chamber data; studied properties of Ising spin-flip lattice using a computer simulation model. Developed a computer program that optimized train loading/scheduling, and conducted sensitivity studies on various loading configurations.

Current Fields of Interest

Modeling and analysis activities in applied mathematics; trajectory analysis and orbital mechanics; vehicle mission-planning considerations; threat scenarios, electronic warfare activities, and war-game responses; multi-processing and real-time computer performance operating characteristics; assessment of new technical business areas.

Major Reports and Publications

1 "Final Technical Report, F-15 AIS Troubleshooting/Fault Isolation Analysis," Contract No. F01600-79-D0146, September 1980, for Air Force Logistics Management Center, Gunter Air Force Station, Alabama, principal author

2 "Final Report on EES/GIT Project A-2170-150," Contract No. F33615-77-C-1253, August 1980, for Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio, coauthor

3. "Two Platform Emitter-Location System," presented by a coauthor at 1980 Western Region Electronic Warfare Technical Meeting, White Sands Missile Range, New Mexico, April 1980, and published in Conference Proceedings; principal author of paper

4. "Integrated Hardware/Software Technology Plan," Contract No. F30602-78-C-0120, October 1979, for A. F. RADC, Griffiss AFB, New York, coauthor

5. "Chaff vs. Monopulse System Study," Interim Report, Contract No. F33657-79-C-0148, July 1979, coauthor

Major Reports and Publications

6. "Performance Summary Memo-System-6," published by IBM Office Products Division, August 1978
7. "Data Bank Retrieval System Program," published by IBM Office Products Division, April 1977
8. "An Assessment of the Effects of Guidance Delays due to Software Structure upon GN&C System Performance," contract report for NASA published by IBM Federal Systems Division, February 1975
9. "Multiprocessor Performance Analysis," presented at 1974 National Computer Conference, Chicago, Illinois, May 1974, and published in Conference Proceedings, coauthor
10. "Delta Clock Settings for TOS Tasks-Summary Report," contract report for Bell Telephone Laboratories, published by IBM Federal Systems Division, February 1974, coauthor
11. "On Board Mission Planning for Orbital Maneuvers," presented in orbit-to-orbit session of the XXIV International Astronautical Congress, Baku, USSR, October 1973, and published in Conference Proceedings, coauthor
12. "Multiprocessor Performance Study-Summary Report," contract report for Bell Telephone Laboratories published by IBM Federal Systems Division, July 1973, coauthor
13. "On the Stability of Periodic Orbits for Nonlinear Oscillator Systems in Regions Exhibiting Stochastic Behavior," Series of Selected Papers in Physics-Computer Experiments, Physical Society of Japan, 1973, coauthor
14. "On the Stability of Periodic Orbits for Nonlinear Oscillator Systems in Regions Exhibiting Stochastic Behavior," Journal of Mathematical Physics, 13, No. 5 (May 1972), coauthor
15. Stochastic Behavior of Resonant, Nearly Linear Oscillator Systems for Arbitrarily Small Non-Linear Coupling, Ph.D. Thesis, Georgia Institute of Technology, December 1971
16. "Stochastic Behavior of Resonant Nearly Linear Oscillator Systems in the Limit of Zero Nonlinear Coupling," Physical Review A, 1, No. 1 (January 1970), coauthor
17. "Mission Analysis Computer Program Series, Technical Description of OPGUIDE II Computer Program," IBM Federal Systems Division No. 68-K04-0003, July 1968
18. "OPGUIDE II - Accuracy and Performance Assessment," IBM Federal Systems Division No. K04-II-68, June 1968,
19. "Mission Analysis Computer Program Series, OPGUIDE II," IBM Federal Systems Division No. 68-K04-0001, February 1968, coauthor