NASA Technical Memorandum 58275

Application of Radar for Automotive Collision Avoidance - Phase 1 Final Report

Volume 2: Development Plan and Progress Reports

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National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

NASA Technical Memorandum 58275

Application of Radar for Automotive Collision Avoidance - Phase 1 Final Report
Volume 2: Development Plan and Progress Reports

Edited by

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DISCLAIMER

FOREWORD

This publication was prepared by the Tracking and Communications Division of the NASA Lyndon B. Johnson Space Center (JSC). It fulfills the Interagency Agreement DTNH22-85-X-07163 between the Department of Transportation (DOT) and the National Aeronautics and Space Administration (NASA). The initial or Phase 1 effort covers the period November 1984 through December 1985. Significant tasks undertaken during Phase 1 were the (1) generation of several reports and short studies, (2) design, fabrication, testing, and implementation of a data collection engineering breadboard radar, and (3) analysis of collected data and conclusions and recommendations derived therefrom. The main goal of this program is to fundamentally contribute to the development of a potentially commercial, practical collision avoidance radar for automobiles.

Volume I is the technical report consisting of 13 sections covering all the Phase 1 tasks.

Volume II consists of the development plan submitted to the Department of Transportation during Phase 1 of the NASA/DOT Interagency Agreement DTNH22-85-X-07163 and five progress reports. The progress reports provide additional technical or program management detail to that given in Volume I: Technical Report.

ACKNOWLEDGEMENTS

Special thanks are given to the many individuals who assisted this effort. Several people at the Department of Transportation made this project possible and contributed guidance and assistance, especially Drs. J. Bascunana and K. Brewer.

Thanks to W. Culpepper who, with the help of others at Lockheed Engineering and Management Services Company, handled all the test equipment preparation, data collection, and data analysis which are detailed in sections 9, 10, and 11.

P. Shores organized and managed most of the effort at JSC. His contribution of section 2 is appreciated.

Drs. E. T. Dickerson and C. Hallum from the University of Houston - Clear Lake are recognized for their contributions of sections 4 and 5 as well as their efforts regarding the literature search and collection.

Additionally, H. Nitschke and H. Erwin are recognized for managing and providing final direction necessary for completing this phase of the work.

Appreciation is extended to C. Lichtenberg of NASA-JSC for his radar design and analysis and preparation of most of sections 1, 3, 6, 7, 8, 12, and 13.

D. O'Connell, while with NASA-JSC, provided the early work on the slotted waveguide array antenna and radar accuracy analysis, among other things.

Technical review was provided by Dr. K. Krishen, R. Fenner, A. Feivesen, and Dr. W. Marker of NASA-JSC, and Dr. H. Schaeper of Lockheed - EMSCO.

CONTENTS
VOLUME 2

ACRONYMS/ABBREVIATIONS

AC	alternating current
A/D	analog-to-digital
AGC	automatic gain control
ANSI	American National Standards Institute
B/B	breadboard
CAD	computer-aided-design
CAR	crash avoidance radar
CARDFILE	Crash Avoidance Research Data File
CRT	cathode ray tube
CW	continuous wave
DC	direct current
DMA	direct memory access
DoD	Department of Defense
DOT	Department of Transportation
ERP	effective radiated power
FARS	Fatal Accident Reporting System
FFD	far field distance
FFT	fast Fourier transform
FM	frequency modulated
GFE	Government-furnished equipment
HW	hardware
IF	intermediate frequency
JSC	Johnson Space Center
KRAESP	Kinetic Research Accident Environment Simulation and Projection
LEMSCO	Lockheed Engineering and Management Services Company
LOS	line-of-sight
MSA	midsized automobile
NASA	National Aeronautics and Space Administration
NASS	National Accident Sampling System
NEC	numerical electromagnetics code
NHTSA	National Highway Traffic Safety Administration
OHSA	Occupational Safety and Health Administration

PRF	pulse repetition frequency
PRR	pulse repetition rate
PW	pulse width
RCS	radar cross-section
RCV	receive
RF	radio frequency
RFP	request for proposal
RH	relative humidity
RSS	root sum squared
RSV	research safety vehicle
SAE	Society of Automotive Engineers
SAR	specific absorption rate
S/N	signal-to-noise
SW	software
TBD	to be determined
TLV	threshold limit value
T/R	transmit/receiver
UH-CL	University of Houston-Clear Lake
U.S.	United States
USASI	United States of America Standards Institute
U.S.S.R	Union of Soviet Socialist Republics
VCR	video cassette recorder
VHF	very high frequency
VSWR	voltage standing wave ratio
W/G	waveguide
XMIT	transmit

SECTION 1
DEVELOPMENT PLAN

Paul W. Shores and Kumar Krishen

STATEMENT OF NEED

The cost of automobile accidents in death, personal trauma, and property damage in the United States alone is very high. A recent figure puts this cost in 1982 at more than $80 billion.

The Department of Transportation (DOT) and others believe that a practical crash warning and eventually a crash avoidance system in automobiles could significantly reduce these costs to society.

Radar systems have been examined as one promising means of providing a warning of the imminence of a crash. The National Highway Traffic Safety Administration (NHTSA) of DOT has supported work on radar crash avoidance systems.

In these systems radar is used to detect, track, and warn (through visual and audible means) of objects being approached that represent a potential danger to the radar-carrying vehicle. Because of false alarms and failures to detect only real hazards, DOT believes that the early use of radars will be to provide warnings. These systems will not include automatic braking.

Basic to the use of radar is its ability to detect hazards with small false-to-real hazard detection ratios. For the systems to be practical, they must have the normal commercial attributes of low cost (initial, operational, and maintenance) and long life.

OBJECTIVE

The objectives of this task are to design, develop, and evaluate the performance of a potentially commercial radar system which will provide advanced warning of impending collisions between motor vehicles and traffic hazards. The primary focus of the technology development will be to reduce to the maximum extent possible the number of false alarms while maintaining a system design which may be mass produced inexpensively. This will require the development of a capability to distinguish hazardous objects from a significant clutter background without the utilization of exotic hardware.

APPROACH

The approach will be to

a. Define the 1984 baseline hardware and software data base by performing an in-depth review of previous work and proposed new systems. A comparison matrix of all the systems will be used to evaluate performance, problems, and complexity.

b. Perform analyses of the geometrical relationships of targets relative to the velocity of the radar-equipped automobile to determine the parameters such as angle/angle rate and range/range rate that show the most promise of differentiating between false and real (static and dynamic) hazards. These data will be used for hardware design parameters and processor algorithm development.

c. Design and fabricate an instrumentation system for installation on a test vehicle. The instrumentation system will be installed on a test vehicle and used to collect experimental data under controlled conditions and normal highway driving conditions. The controlled tests will be conducted initially on the 2500-foot paved antenna range at JSC. Other facilities such as the Ellington Air Force taxi way and the DOT automotive test track may be utilized for final system tests. The test data will be analyzed and used as a feedback for optimization of system design.

d. Procure, develop, and test appropriate hardware and software components to provide engineering evaluation of systems performance and the most promising techniques prior to committing to the NASA engineering model (proof of concept) system design. This systems work will include a limited audio/visual warning presentation to the vehicle operator. Candidate systems to be investigated include pulse Doppler, bi-static, stereo, and multiple-beam systems. Computer simulations, systems analysis, and frequency scaling techniques will be used wherever possible. For example, it may be possible to simulate multiple-beam systems using ultrasonic transducers which are much more readily available than developing the microwave multiple-beam systems.

e. Based on results of items a through d, the NASA engineering model will be designed, fabricated, and tested. The results of these tests will be used to identify problem areas and will be incorporated in the final recommendations.

f. Prepare engineering specifications and functional requirements for the recommended approach for the NASA engineering model system.

g. Coordinate and review manufacturing design features with the DOT/NHTSA coordinated research committee for the purpose of evaluating projected estimates of "cost to manufacture."

NASA TECHNOLOGY

The Tracking Systems Section of the Tracking and Communications Division at JSC has been responsible for managing the development of all the major radar systems used on the manned spacecraft missions. In addition to responsibility for the test and qualification of the Shuttle Ku-band radar, the group has been developing, testing, and evaluating many variations of hand-held radar devices for use as range/range rate sensors in applications such as astronaut extravehicular activity, manned maneuvering unit, and small remotely-controlled satellites. The major thrust of this development has been towards the development of a small, lightweight, highly reliable sensor capable of measuring a range of velocities from 0.1 ft/sec to 20 ft/sec and detecting the sense of the velocity (opening or closing). The techniques they have developed for this purpose and the experience of working with rendezvous algorithms are directly applicable to collision warning radars.

This work addresses the sensor and processor operation and the dynamic geometrical relationships involved. It is anticipated that the collision avoidance system will also involve radar signature classification processors operating at high speed. Problems associated with this area might well be solved using the optical signal processing technology which JSC is developing. This technology is based on processing signals in the coherent light domain using a highly versatile device known as a programmable mask. NASA/JSC is presently improving the technology and initiating a program to transfer the technology to the commercial sector.

The appendix is a collection of NASA Tech Briefs of previous work at JSC that are applicable to this program.

TASKS - PHASE I

Study and Analysis

This subtask will begin with a short parametric analysis of previous work to establish the 1984 baseline data base. The following study effort will concentrate on characterization of the environment. Characterization of the environment is the analysis required to determine the equations of relative motion of the various targets within the field-of-view of the radar. Once these equations have been established they will be used to determine the required parameters to be measured and the corresponding measurement accuracy requirements. The results of these studies will be utilized in the overall formulation of the system design concepts.

Hardware Development

Test Vehicle Instrumentation

A panel van will be instrumented with test instruments to collect and record test data from the different configurations of microwave components under actual highway driving conditions. The recorded test data will then be processed in the radar signal processing laboratory and used as test signal inputs to the software processor control algorithms. As a minimum the van will contain a TV camera and video recorder with stereo sound recording capability, any necessary power conversion equipment, and the necessary displays and controls.

Processor Design and Fabrication

An area within the JSC laboratory facilities will be established for the purpose of radar signal data reduction and road test data analysis. This facility will contain standard test equipment of frequency analyzers, time domain analyzers, ancillary equipment, and two general purpose computers with associated peripherals. The computers are presently part of the JSC capital equipment inventory and will be available for use in data analysis and processor software development. If more powerful computations are required an external link will be provided to a VAX 11 system.

Preliminary Design Review*

(Decision point to continue, redirect the effort, or quit)

TASKS - PHASE II

a. Perform detailed design of the NASA engineering model system.

b. Fabricate, test, and debug system at JSC.

c. Perform extensive road testing and data collection using the instrumentated test vehicle from Phase I.

d. Perform data analysis and feedback design improvements to the NASA engineering model for retest.

e. Prepare detailed drawings and performance specs.

MANAGEMENT AND REPORTING

Technical

The study and technical development activities will be the responsibility of the Tracking Techniques Branch/Tracking and Communications Division at JSC. Responsibilities include the following:

a. Management of in-house technical and cost activities at JSC

b. Management of contractor activities

c. Conducting design reviews at critical decision points

d. Preparation and dissemination of design and study reports

e. Preparation and presentation periodic and final oral and written status reports

*Critical design review interface with DOT/NHTSA

Programmatic

The Technology Utilization Office, NASA Headquarters/JSC will have the responsibility for the coordination of activities with the Department of Transportation and other participating Government agencies. The program will be structured with well-defined decision points where the sponsoring agency after reviewing the status may elect to continue or discontinue the project. These decision points should occur at major program milestones to avoid project discontinuities.

ORGANIZATION AND KEY PERSONNEL

The project will be organized as a research team with a principal investigator from the Tracking and Communications Division at JSC. Engineers from the Tracking Techniques Branch will have the responsibility for the design, analysis, and tests. In addition, the team will have access to a group of consultants from the Tracking and Communications Division that have expertise in a multitude of technical areas. The organizational relationships and the names of the primary participants are depicted in block diagram form in figure 1.

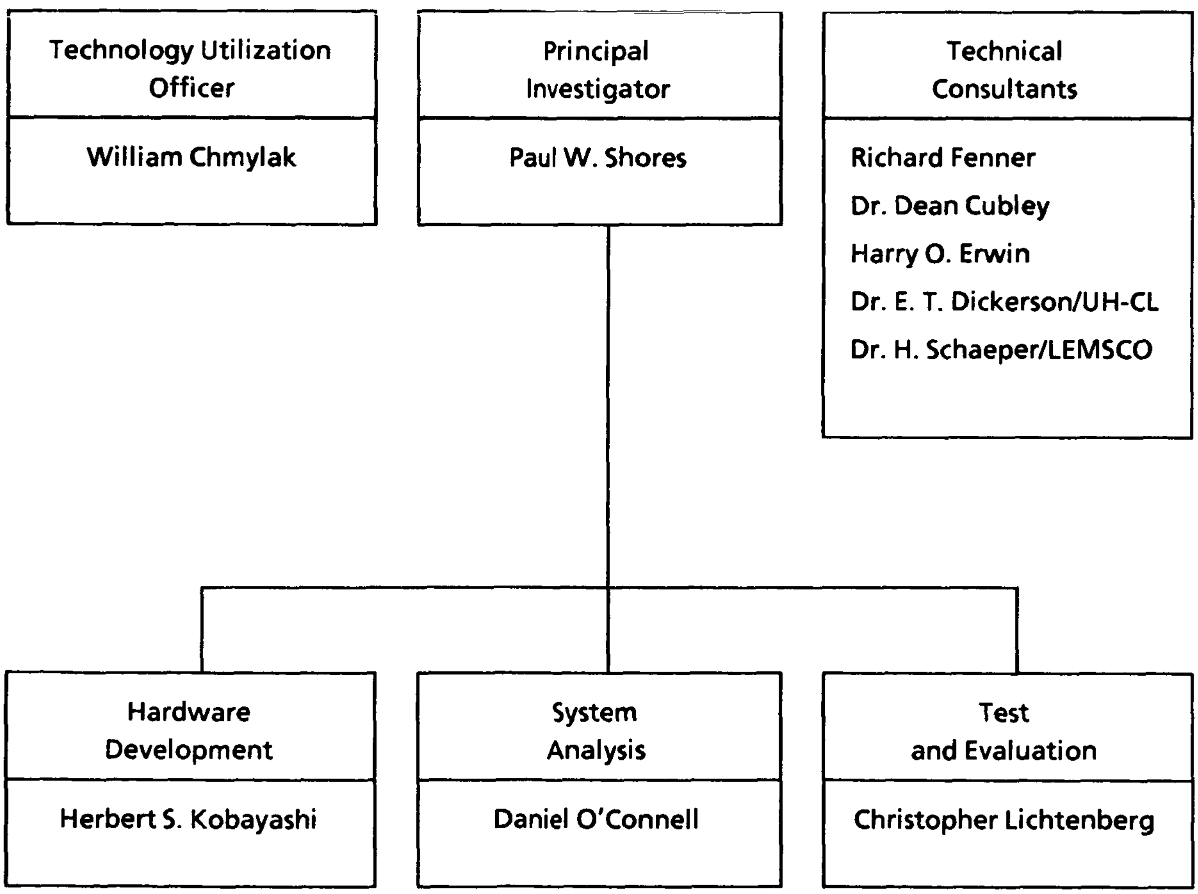

Figure 1.- Organization chart.

NASA/JOHNSON SPACE CENTER

TITLE: APPLICATION OF RADAR FOR AUTOMOTIVE CRASH AVOIDANCE

PROGRAM SCHEDULE

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-------------------------------------------------------------------------------------------------
                     Month----|  2  |  4  |  6  | 8  | 10 |  12| 14 | 16 | 18 | 20 | 22 | 24 |
-------------------------------------------------------------------------------------------------
1. PHASE 1
   -STUDY AND ANALYSIS        |-------------------<> |    |    |    |    |    |    |    |    |
   -HARDWARE FABRICATION      |  -----------------<> |    |    |    |    |    |    |    |    |
   -ROAD TESTS                |     |     | -----------<> |    |    |    |    |    |    |    |
   -FORMULATE DESIGN CONCEPT  |     |     |     |-----------<> |    |    |    |    |    |    |

2. PHASE 2
   -SYSTEM DESIGN             |     |     |     |    |    |    |----<> |    |    |    |    |
   -ELECTRICAL DESIGN         |     |     |     |    |    |    |---------------<> |    |    |
   -MECHANICAL DESIGN         |     |     |     |    |    |    |--------------------<> |    |
   -COMPONENT PROCUREMENT     |     |     |     |    |    |    |---------------<> |    |    |
   -FABRICATE HARDWARE        |     |     |     |    |    |    |    |---------------<>|    |
   -SYSTEM INTEGRATION        |     |     |     |    |    |    |    |    |  ----------<>  |
   -PERFORM ROAD TESTS        |     |     |     |    |    |    |    |    |    |    |  -----<>

3. REPORTING
   -BIMONTHLY PROGRESS REPORTS |    <>    <>    <>   <>   <>   |   <>   <>   <>   <>   <>   |
   -ORAL PROGRESS REPORTS     |     |     <>    |    <>   |   <>    |    |    |    |    |    |
   -PRELIMINARY DESIGN REVIEW |     |     |     |    |   <>    |    |    |    |    |    |    |
   -CRITICAL DESIGN REVIEW    |     |     |     |    |    |    |    |    |    |    |   <>    |
   -FINAL DESIGN REPORT       |     |     |     |    |    |    |    |    |    |    |    |   <>
    AND RECOMENDATIONS
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Title: APPLICATION OF RADAR FOR AUTOMOTIVE CRASH AVOIDANCE

PHASE 1 DETAILED SCHEDULE

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---------------------------------------------------------------------------------------------
                       MONTH----|  1  |  2  |  3  |  4  |  5  |  6  |  7  |  8  |  9  | 10  | 11  | 12 |
---------------------------------------------------------------------------------------------

1.STUDY AND ANALYSIS
   -PARAMETRIC ANALYSIS         |---------<> |     |     |     |     |     |     |     |     |     |    |
   -CHARACTERIZE ENVIRONMENT    |-------------------------<> |     |     |     |     |     |     |    |
   -TEST DATA ANALYSIS          |     |     |     |     |----------<> |     |     |     |     |     |    |
   -FORMULATE DESIGN CONCEPT    |     |     |     |     |     |     -------------<> |     |     |    |

2.HARDWARE DEVELOPMENT &TEST
   -TEST VEHICLE INSTRUMENTATION|---------------------------------------<> |     |     |     |     |    |
   -RADAR DESIGN & FABRICATION  |-----------------------------<> |     |     |     |     |     |    |
   -ROAD TESTS                  |     |     |     |     |  -------------------------<> |     |     |    |
   -PROCESSOR DESIGN FAB.       |--------------------------------------------------<> |     |     |    |

3.DOCUMENTATION
   -PHASE 1 FINAL REPORT        |     |     |     |     |     |     |     |     |     |--------------<>
   -PHASE 2 DEVELOPMENT PLAN    |     |     |     |     |     |     |     |     |     |     -----------<>
     (PRELIMINARY)

4. REPORTING
   -BIMONTHLY PROGRESS REPORTS  |     |    <>     |    <>     |    <>     |    <>     |    <>     |    |
   -ORAL PROGRESS REPORTS       |     |     |     |    <>     |     |     |    <>     |     |     |   <>
   -PRELIMINARY DESIGN REVIEW   |     |     |     |     |     |     |     |     |     |    <>     |    |
   -PHASE 1 FINAL DESIGN REPORT |     |     |     |     |     |     |     |     |     |     |     |   <>
    AND RECOMENDATIONS
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NASA/JOHNSON SPACE CENTER

Title: APPLICATION OF RADAR FOR AUTOMOTIVE CRASH AVOIDANCE

PHASE 2 DETAILED SCHEDULE

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------------------------------------------------------------------------------------------------
                        Month----|  13  |  14  |  15  | 16  | 17  |  18| 19  | 20  | 21  | 22  | 23  | 24
------------------------------------------------------------------------------------------------
1. SYSTEM DEFINITION
   -HARDWARE REQUIREMENTS        |------------<>     |     |     |     |     |     |     |     |     |
   -SOFTWARE REQUIREMENTS        |------------<>     |     |     |     |     |     |     |     |     |

2. ELECTRICAL DESIGN
   -MICROWAVE COMPONENTS         |------------------<>     |     |     |     |     |     |     |     |
   -SIGNAL PROCESSOR             |------------------------<>     |     |     |     |     |     |     |
   -SOFTWARE                     |      |--------------------------<>     |     |     |     |     |

3. MECHANICAL DESIGN
   -MICROWAVE COMPONENTS         |      |      |-------------------------<>     |     |     |     |
   -PROCESSOR PACKAGING          |      |      |-------------------------<>     |     |     |     |
   -DISPLAYS AND CONTROLS        |      |      |     |------------------------<>     |     |     |

4. SYSTEM INTEGRATION AND TEST
   -INTEGRATION                  |      |      |     |     |------------------------<>     |     |
   -LABORATORY TEST              |      |      |     |     |     |     |     |------------<>|     |
   -ROAD TEST                    |      |      |     |     |     |     |     |     |     |     -----------<>

5. REPORTING
   -BIMONTHLY PROGRESS REPORTS   |      |      <>    |     <>    |     <>    |     <>    |     |     |     |
   -ORAL PROGRESS REPORTS        |      |      |     |     <>    |     |     |     <>    |     |     |     |
   -CRITICAL DESIGN REVIEW       |      |      |     |     |     |     |     |     |     |     <>    |     |
   -FINAL DESIGN REPORT          |      |      |     |     |     |     |     |     |     |     |     |     <>
    AND RECOMENDATIONS
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APPLICATION OF RADAR FOR AUTOMOTIVE CRASH AVOIDANCE

PHASE 1 - COST ESTIMATES

Functional Activity	Contractor	Cost
Radar Analytical Support	Univ. Houston	75K
Instrumented Van Design & Fab and Data Processing Support	LEMSCO	95K
Radar Component Procurement	NASA	50K
Computer Maintenance & Support	NASA	20K
Travel:		
6 Trips to Washington, D.C.	$750/Trip	4.5K
5 Trips to vendors	$600/Trip	3K
	TOTAL	247.5K
Civil Service Manpower	16 Man-months	

PHASE 2 - COST ESTIMATES

(These should only be used as guidelines)
(Phase 1 results will influence these numbers)

Procurements	
Microprocessor Development System	40K
Supplies and Materials	20K
Support Contractor	
Manpower and Materials	150K
Travel	5K
Documentation	10K
Computer Maintenance and Support	20K
TOTAL	245K
Civil Service Manpower	15 Man-months

APPENDIX

EXAMPLES OF INNOVATIVE NASA/JSC TECHNOLOGY APPLICABLE TO THIS PROGRAM

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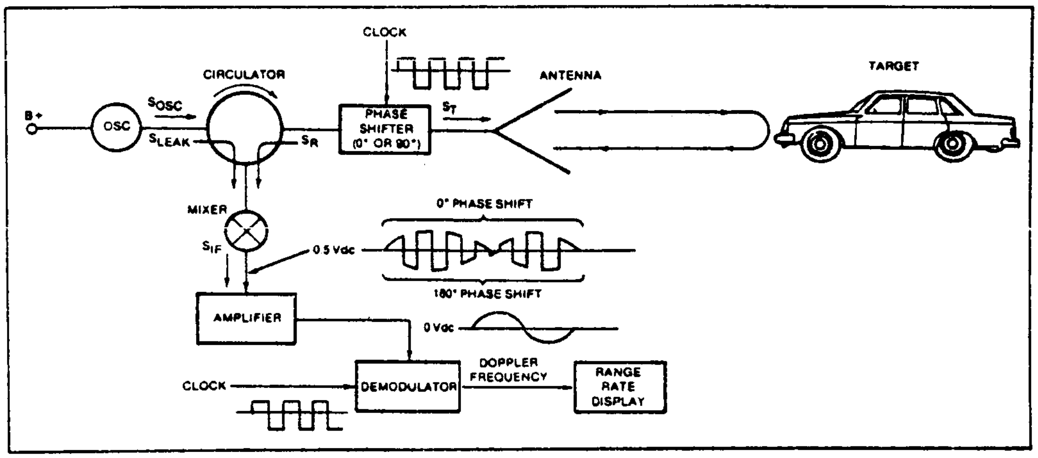
NASA Tech Brief
National Aeronautics and Space Administration

Fall 1982
B82-10135
MSC-18675

Pulsed Phase Shifter Improves Doppler Radar

Periodic phase inversion puts Doppler signal on a carrier for easy amplification and processing.

Lyndon B. Johnson Space Center, Houston, Texas



Periodic 90° Phase Shifting of both the transmitted and received radar signals occurs at a rate that is slow compared to the travel times to and from the moving target but fast compared to the Doppler waveform. The effect is a 180° phase reversal in the detected signal. The reversal rate is fast compared to the Doppler frequency, however, and therefore serves as a carrier for the Doppler signal after mixing. The Doppler signal can therefore be amplified and processed more conveniently than if it were at baseband.

The ability of a microwave Doppler radar to measure the velocity of a slow-moving nearby target is enhanced by a pulsed 90° phase shifter in the radar transmission line between the circulator and the antenna. Because of the phase shifting, the Doppler frequency is detected as modulation on a carrier instead of as a baseband signal. The carrier can be amplified and filtered before demodulation, resulting in a strong, clean demodulated Doppler for measurement and display.

The system is shown schematically in the figure. The oscillator is a Gunn diode, driven by a low-voltage dc source and generating a continuous-wave output at approximately 10 GHz. This microwave signal goes to a circulator, where some leaks to the detection port; most of it emerges from the transmit/receive port, however, and passes through the pulsed phase shifter to the antenna. The phase shifter is driven by a clock signal that periodically delays the phase of the microwave signal by $\pi/2$. The phase-modulated microwaves are then transmitted from the antenna. If they are reflected from a moving target (such as an automobile), the frequency of the reflected signal differs from the transmitted frequency by the Doppler frequency.

The reflected signal received by the antenna is carried back through the phase shifter again, where it undergoes another 90° delay (if the clock signal is still in that phase of its cycle). Thus the reflected wave that finally reaches the circulator has a phase modulation of 180°; the modulation frequency is the clock frequency.

The phase-delayed reflected signal emerges from the detector port of the circulator along with the leakage signal of the (unmodulated) oscillator frequency, and the two are heterodyned in a mixer. The resultant waveform is a carrier at the clock frequency, amplitude-modulated with the Doppler frequency. This signal can be amplified and filtered to reduce the noise component much more easily than a baseband signal of the sort produced by prior Doppler radars, so that the Doppler signal can even be displayed for velocity values as low as zero. Furthermore, the dc signal formed in the mixer is filtered out and therefore does not affect the velocity information.

This work was done by Herbert S. Kobayashi, Paul W. Shores, and Patrick Rozas of **Johnson Space Center.**

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center

For additional information contact the following office: Johnson Space Center, TU Office, Code AT3, Houston, Texas 77058

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NASA Tech Brief

MSC-16170
Winter 1976

Lyndon B. Johnson Space Center, Houston, Texas

Tracking a Phase-Shift-Keyed Signal

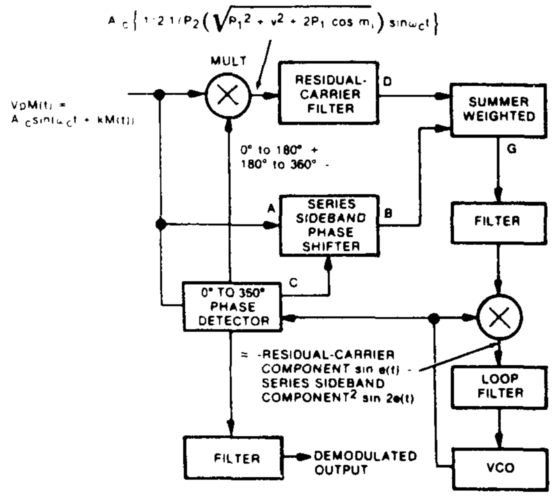
Residual carrier and the converted carrier generated from the demodulated signal and the incoming modulated signal, are summed for a strong tracking signal.

Phase-modulated signals with phase shifts ranging from 0° to 360° may be received and tracked without adjustment using a new phase-locked detector. The detector, implemented in S-band receivers, tracks residual-carrier signals, suppressed-carrier signals, analog modulated signals, QPSK, and NPSK.

The receiver can track both the carrier component and the series sideband component of the expanded input signal, allowing it to receive signals phase modulated from 0° to 360°. The signal is filtered to pass the carrier component at point D in the illustration. The series sideband components are converted to a carrier signal at point B by multiplying the demodulated signal (point C) and the incoming signal at A. The tracking signal is a weighted sum of the residual carrier and the converted series sideband carrier.

In the detector, a phase shifter is used to generate a negative phase shift opposing the detected phase angle. This produces the converted series sideband and component carrier, with the residual-carrier signal and the converted series sideband and component carrier added together to produce the tracking-carrier signal.

Besides being less susceptible to carrier interference (which may degrade tracking), the detector can track on the converted series sideband carrier if the residual carrier drops to zero or is degraded by interference.



The **Phase Lock Loop Detector** tracks a phase-modulated signal from 0° to 360°. To track a signal with many phases, the detector, at point C, detects the phase modulation from 0° to 360°, and the phase shifter, at point A, generates a negative phase shift opposite in angle to the detected phase angle. The result is a stronger tracking signal for the different phase angles, since the tracking signal consists of both residual carrier and converted series sideband carrier component. It is also less susceptible to carrier interference which may degrade tracking.

This work was done by Salvador Villarreal, Stuart D. Lenett, Herbert S. Kobayashi, and James F. Pawlowski of **Johnson Space Center.** *For further information, Circle 28 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page A8]. Refer to MSC-16170.

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NASA Tech Brief

MSC-14840
Summer 1976

National Aeronautics and
Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

Unbalanced Quadriphase Demodulator

A new demodulator for supressed carrier pulse-code-modulated signals represents incoming signals as vectors.

A new demodulator is proposed to process an unbalanced quadri-phase-shift-keyed (QPSK), suppressed-carrier, pulse-code-modulated (PCM) signal. An unbalanced QPSK signal is defined as one in which the four phase positions of the signal are not spaced by 90°. For example, the incoming QPSK signal may be represented as four possible voltage vectors spaced at 26°, -26°, 206°, and -206°, as shown in Figure 1(a). This unbalanced QPSK signal could be generated by adding a 20-percent relative-power PSK signal to a quadrature 80-percent relative-power PSK signal. The QPSK demodulator tracks the incoming signal with the use of two selectable phase-reference signals, I_{gen} and Q_{gen}, making up four phase positions for the reference signals, as shown in Figure 1(b).

The basic demodulator is shown in Figure 2. The two phase positions of I_{gen} and Q_{gen} are necessary to match the four possible incoming vectors. The incoming vector can be determined by a data demodulator which outputs an estimate of the data. When the product of data 1 and data 2 is positive, the incoming vector is V_1 or $-V_1$; so the switch selects position A, shifting the VCO reference +26°. Likewise, when the product is negative, the incoming vector is V_2 or $-V_2$, and position B is selected, giving a -26° phase shift of the VCO reference.

Therefore I_{gen} and Q_{gen} become the in-phase and quadrature reference tracking signals, respectively, whether the input vector is V_1 or V_2. The I and Q signals are then generated by the multiplication of each respective reference signal with the incoming signal. Next the I signal corrects the polarity of the Q signal in the I×Q multiplier, resulting in an error signal for tracking which is proportional only to the phase difference between the incoming signal and the tracking reference-signal phase.

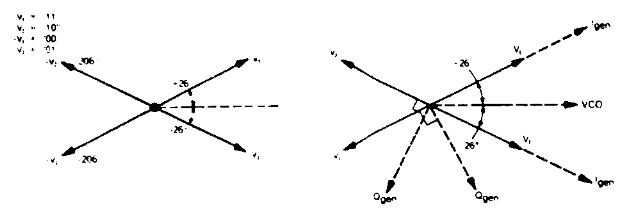

Figure 1. **Voltage Vectors** for an incoming QPSK signal are shown in (a) above. The Vi represent binary data pairs (data 1 and data 2). In (b) the vectors for reference signals at a phase-locked condition are shown.

(continued next page)

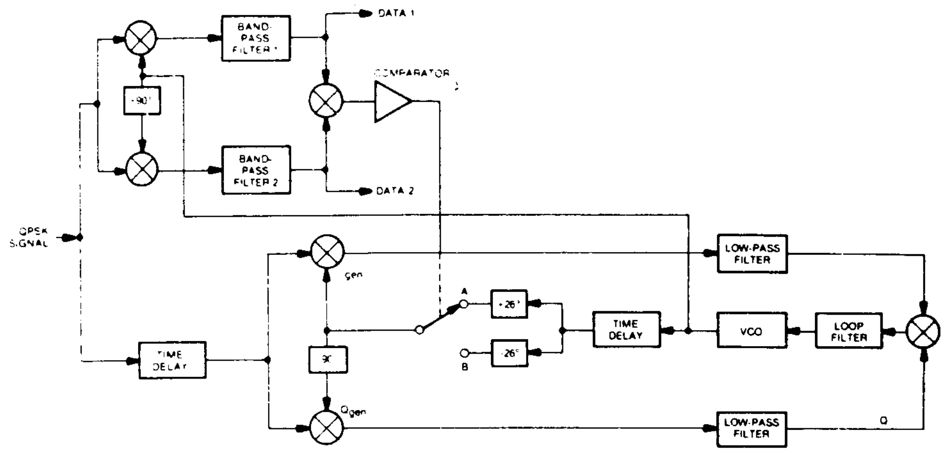

Figure 2. The **Unbalanced Quadriphase** Demodulator will process QPSK pulse-code-modulated signals with a suppressed carrier. Two phase-reference signals I_{gen} and Q_{gen} are used to track incoming signals.

Some important points about this demodulator are as follows:

- If the unbalance ratio of the QPSK signal is changed, then the selectable phase-shift networks should be set to a corresponding amount of phase shift. For example, the demodulator could receive a balanced QPSK signal if the selectable phase shifts are 45° and 45°.
- The tracking performance of the demodulator is not sensitive to voltage-level changes caused by gain and bias variations but only to the accuracy of the phase shifts.
- The difference between the absolute value (square) of the I and Q signals may serve as a lock detection signal for automatic acquisition and as a signal for automatic gain control.
- There are two ambiguities in the data output with an unbalanced QPSK signal. Each data input remains in its respective output form from the demodulator, but each may be of correct polarity or inverted. With a balanced QPSK signal, the data may also change outputs (four ambiguities).

This work was done by Herbert S. Kobayashi and Sydney P. Bradfield, III of **Johnson Space Center.** *For further information, write:*
Technology Utilization Officer
Johnson Space Center
Code AT3
Houston, Texas 77058
Reference: MSC-14840

Inquiries concerning rights for the commercial use of this invention should be addressed to:
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Houston, Texas 77058

SECTION 2
PROGRESS REPORT NO. 1

Paul W. Shores and Kumar Krishen

INTRODUCTION

This document describes the initial efforts by NASA-JSC and its subcontractors to perform the tasks required by the project and serve as a reference for the structure of the program. Since this is the initial report, both administrative and technical efforts which have been undertaken shall be described.

TASK APPORTIONMENT

NASA-JSC Tasks

NASA-JSC shall conduct this effort in collaboration with two subcontractors, Lockheed Engineering and Management Services Company (LEMSCO) and the University of Houston-Clear Lake (UH-CL). NASA-JSC and LEMSCO shall share the responsibility for the hardware development of the breadboard system. UH-CL shall support the effort with a technical study of several aspects of the problem.

NASA-JSC, in addition to overseeing the entire project, shall be specifically responsible for development of the radar front end; that is, the antenna system, the RF signal generation, and the IF circuitry. In addition, NASA shall conduct some internal study efforts on certain selected subjects which shall be described as necessary.

Lockheed Engineering and Management Services Company Tasks

LEMSCO shall be responsible for development of the radar system from the IF portion to the actual system output (warning device). This shall include development of a high speed data sampling technique as well as generation of the system timing. LEMSCO shall also provide laboratory support as required.

University of Houston-Clear Lake Tasks

The study effort being undertaken by UH-CL shall include, but not be limited to, a cost versus performance analysis, estimation of false alarm rates for candidate radar systems, and conceptual analysis and evaluation of proposed hardware.

Joint Participation Tasks

NASA-JSC shall also have the responsibility for development of test procedures and data analysis, with support from either or both of the subcontracts as required.

PROGRESS DURING THIS REPORTING PERIOD

NASA-JSC Task Progress

Experimental System Design

A preliminary radar system design has been selected. The type is to be pulse-Doppler with monopulse angle-tracking capability. Since modifications to the basic radar system may be required at a later date, the design will take into account this possibility. For example, the same front end electronics package may be used to evaluate different antenna types (i.e., a swept-beam system in place of a monopulse). The project leader, Paul Shores, is responsible for overall system design.

Microwave Electronics Design

A design has been drawn up for the radar front end and electronics portion, including selection of both the radar frequency (RF) and intermediate frequencies (IF). Procurement of the hardware necessary to fabricate the circuitry has been initiated. A block diagram of the design, along with a schedule for the development of this portion of the system, is included in appendix D. Chris Lichtenberg has responsibility for this effort.

Antenna Design

An antenna concept is being investigated for this application. The design being considered is a microwave waveguide slotted array antenna. Several prototype antennas have been designed and fabricated for the test purposes. A preliminary version of the document entitled "Slotted Array Antennas for Automotive Crash Avoidance Radar Systems" has been written and is included in appendix A. Dan O'Connell is conducting this effort.

Static Radar Design

A small, side-by-side radar configuration is being fabricated for use in tests of angle measuring capability. When completed, the radar will be fixed in the field and vehicles driven toward it at various angles and the data recorded. Phong Ngo is fabricating the device.

Human Safety Study

Literature survey is in progress to review data on effects of electromagnetic radiation on humans. Both thermal and nonthermal effects are being considered. Analysis of human safety in the proposed electromagnetic environment will be conducted in cooperation with the Satellite Foundation and the University of Texas - M. D. Anderson Hospital researchers. The possibility of providing funds for data compilation to the University of Texas is being actively pursued at this time. Dr. Krishen is leading an effort for this project.

Other Activities

In other activities, the document "Parameteric Accuracies Required of an Automotive Crash Avoidance Radar System" has been completed by Dan O'Connell (and is included); alternative antenna concepts are being investigated by Chris Lichtenberg; development of a radar boresight range at NASA-JSC into an antenna test facility is being conducted. Herb Kobayashi is conducting research into circuit technology which may be applicable to the project.

LEMSCO Task Projects

Laboratory Instrumentation

Lockheed has conducted an investigation into the computer and laboratory support equipment necessary for the development of the data processing and data analysis capabilities. The necessary equipment purchases have been defined and have been initiated. A block diagram of this equipment, along with some cost estimates and a schedule for its procurement, is included in the appendix. Charles E. Coe has the overall responsibility for the Lockheed effort.

Data Processing Design

Plans were initiated to define the engineering tasks required to assemble the development breadboard and the design of the high speed sampling scheme. Personnel from Lockheed's general engineering were invited to assist in the sampling design work. Arrangements were made to have them conduct a review of the suitability of a NASA-supplied circuit board for this purpose as their first assignment. The individual with primary responsibility for the sampling circuit design is William X. Culpepper.

UH-CL

University of Houston-Clear Lake personnel have initiated and completed all paperwork necessary for implementation of the study effort, including a cost breakdown. The statement of work, which defines the specific tasks to be required of the study and the products to be derived thereof, has been completed. A copy is included in appendix E. The purchase request which will award the contract is in work at NASA. Once approved, the actual effort can begin. The study is being scheduled to last 12 months. The responsible person will be Dr. E. T. Dickerson.

EFFORTS IN THE UPCOMING REPORTING PERIOD

NASA-JSC

Efforts will continue in the design, fabrication, and testing of potential antenna systems. Either the radar boresight range will be brought on-line as an antenna test facility or, if it is found to be inadequate, alternatives to antenna testing will be investigated, such as scheduling time in the building 14 anechoic chamber.

Hardware procurements will continue for fabrication of the radar from end circuitry. Fabrication will commence as parts become available.

An investigation will be initiated (and hopefully completed) into the computer algorithm necessary for processing of the measurement data to determine if a target is on a hit/no hit trajectory. A document will be written decribing the results.

The test radar should be completed and data on angle measurement capability will begin to be taken.

The overall parameter selection will be driven by concerns for cost (includes size, weight, and availability of hardware), system accuracy (false alarm rate), resolution, and the weather effects on the overall performance. This trade-off study will be initiated and some partial results documented.

LEMSCO

An evaluation of the Government-furnished equipment (GFE) circuit board for the sampling system should be completed.

Hardware procurement efforts for the data processing support equipment will continue.

UH-CL

Details involved in the contract awarding should be completed so that the study effort may begin in earnest.

SUMMARY

This initial period has seen the administrative groundwork laid for the technical effort to begin in earnest. While some details remain to be ironed out in some areas, the tasks have been defined and apportioned and the technical work begun. Attention devoted to this topic prior to the actual receipt of funds from the Department of Transportation has allowed some progress in the technical area already. The next reporting period should see all the necessary personnel brought fully on-line and the equipment procurement effort well underway.

APPENDIX A

MICROWAVE SLOTTED ARRAY ANTENNAS
FOR AUTOMOTIVE CRASH AVOIDANCE RADAR SYSTEMS

by

Daniel F. O'Connell

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INTRODUCTION

The Department of Transportation has asked NASA-JSC to develop an engineering model of a radar system which would aid automobile drivers in avoiding collisions. Part of this task involves developing an appropriate antenna system, as the antenna is an integral component in any electromagnetic sensing system. Some of the requirements imposed on the antenna design by this particular application are as follows:

a. It should be relatively small and lightweight.
b. It should be mountable in an appropriate place on a vehicle.
c. It should minimize moving parts and avoid complex scanning structures.
d. It must be structurally stable.
e. It should have a low sidelobe level.

Note that no mention was made as to whether the antenna should be scanning or nonscanning, monopulse, phased array or otherwise, as this will depend on the radar system dictates. The characteristics just enumerated, however, apply to any type of antenna to be used in this application.

This report describes one type of antenna being investigated to fulfill these requirements, the microwave slotted array antenna. Emphasis will be not so much on the theory of operation of the device (though this will be touched on as appropriate) as on its suitability to the application and describing the development activities in conjunction with the Collision Avoidance Radar Program.

BACKGROUND

The antenna under consideration is fabricated by creating what is essentially a leaky transmission line - a rectangular hollow metal waveguide with slots milled into its sides. Although there are several methods of orienting and shaping slots to produce radiation, the method chosen thus far has been longitudinal slots in the broad wall of the waveguide, as depicted in figure 1.

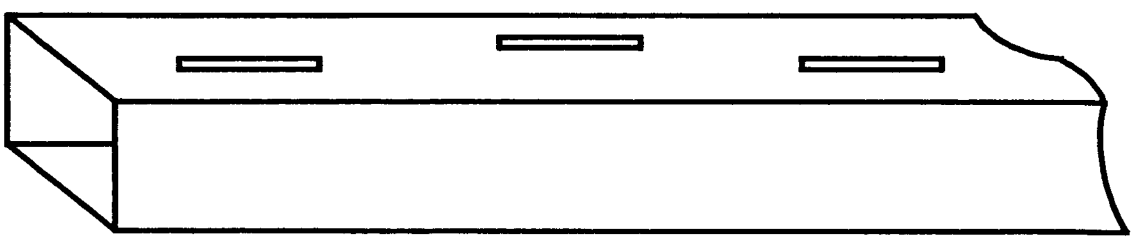


Figure 1.- Longitudinal slots in waveguide broad wall.

The primary reason for this choice is that it is a common method, and hence an adequate amount of literature was available to aid in the design procedure. It also allows for ease of fabrication.

The critical parameters in producing a desired pattern from an array of slots are the number of slots, their center-to-center spacing, the offset of each slot from the center line of the waveguide, and the length of each slot. The width of the slots is not as critical and need be only very thin relative to the wavelength of the radiation. Usually it is made on the order of the thickness of the waveguide wall.

The number of slots in the array determines the 3 db beam width of the resultant radiation pattern. The greater the number of slots, the narrower the beam. For the type of radiation pattern desired, a rule of thumb method, based on experience with measured data, is used to determine how many slots are required for a given beam width with the types of arrays to be discussed here. Starting with the knowledge that a ten slot array will result in a 10° beam width, one may scale linearly to obtain the number of slots for an arbitrary beam width. For example, if one wishes a 4° beam width, which is .4 times narrower than the reference, then 10/4 as many slots are needed, or (10/4×10) = 25 slots. This can be simplified to

$$\frac{100}{\theta\ (\text{degrees})} = \text{number of slots} \tag{1}$$

Theoretical formulations for the beam width of the pattern under discussion exist, but the rule of thumb method is adequate for design purposes.

The center-to-center spacing of the slots is a function of the frequency of radiation being employed and the type of array being constructed. The type of array under discussion here is known as a "broadside" standing wave array, which means it is designated to radiate in a direction perpendicular to the face of the array and no other. This is accomplished by creating a closed cavity of appropriate dimensions (a waveguide with one reflecting end) and launching the proper frequency of radiation. The slots are then positioned over the peaks of the standing wave created. The center-to-center spacing is therefore $\lambda g/2$, where λg, the guide wavelength, is related to the free space wavelength λ_0 by

By

$$\lambda g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{\lambda_0}{2a}\right)^2}} \tag{2}$$

(a is the waveguide broad dimension.)

The offset of a slot from the center line of the broad wall determines how strongly that particular slot will couple energy out to free space. This is a critical parameter in the generation of a given pattern and its determination constitutes the major design effort. Consider the electrical current configuration in the TE_{10} mode of a waveguide:

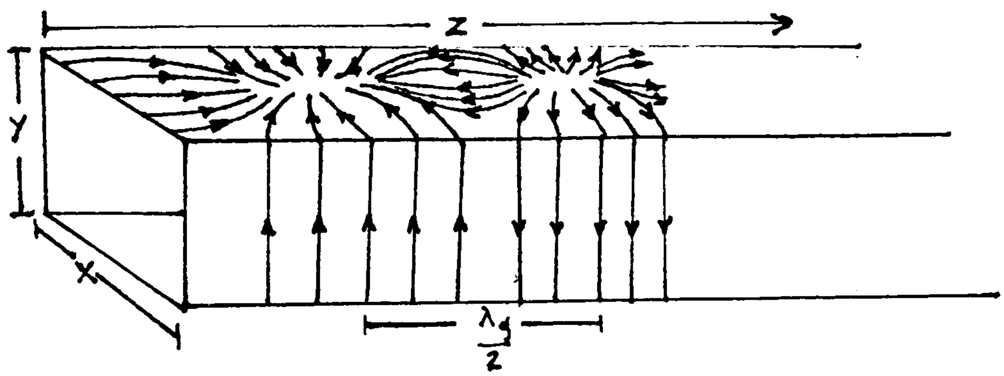


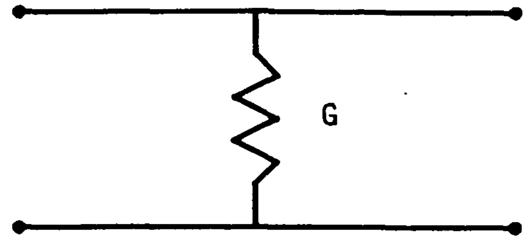
Figure 2.- Current flow in a rectangular waveguide.

The diagram depicts the flow of current inside the waveguide that is created by the propagation of TE_{10} wave down the waveguide. Note that directly along the center line of the broad wall of the waveguide, current flow is essentially zero in the X dimension. The farther off center you measure, the greater is the current flow in this dimension, reaching a maximum at the junction with the sidewall. It is the interruption of this current flow with an aperture that creates the condition necessary for radiation into free space. Thus, a slot cut directly on the center line will be essentially nonradiating. As the slot is moved toward the junction with the sidewall, more and more energy is coupled to free space, reaching a maximum at the junction with the sidewall. The ability of the slot to radiate is represented by the conductance G of the slot. If the slots are fashioned in such a way as to be at resonance (i.e., maximum efficiency), then the relationship between the conductance G of the slot and the offset X may be represented by

$$G = 2.09 \frac{\lambda_g}{\lambda}\left(\frac{d}{b}\right)\cos^2 \frac{\pi}{2}\frac{\lambda}{\lambda_g}\sin^2 \frac{\pi x}{a} \tag{3}$$

where λ_g, λ are as in equation (2)
d is the waveguide broad dimension
b is the waveguide narrow dimension
x is the slot offset from centerline

Equation (3) applies for longitudinal shunt slots only. The longitudinal shunt slot is equivalent to the placement of a shunt resistance in a two wire transmission line. Thus, an equivalent network representation would be



Finally, the length of each of the slots is a function of how far off from center the slot is displaced and is adjusted to produce a condition of resonance. This length may be determined by consulting graphs of measured data (given in the appendix) and then scaling to the appropriate free space wavelength.

DESIGN OF THE DESIRED PATTERN

In the preceding section some of the characteristics of the radiation pattern desired were touched upon, but were never clearly expounded. Let us remedy that situation before proceeding to a discussion of the design procedure. The pattern desired (for the antennas which have been fabricated thus far) is to radiate in a broadside direction, have a beam width which varies for each particular antenna, and have uniform sidelobes of low level. This type of pattern is optimally produced by designing what is referred to as a Dolph - Chebsychev radiation pattern - characterized by a single main beam with uniform sidelobes. The desired feature in the design procedure is to make the physical angular distribution of radiation from the antenna correspond to the shape of the graph of Chebyschev polynomials as they vary in the variable X. Examples of Chebyschev polynomials are given in figure 3.

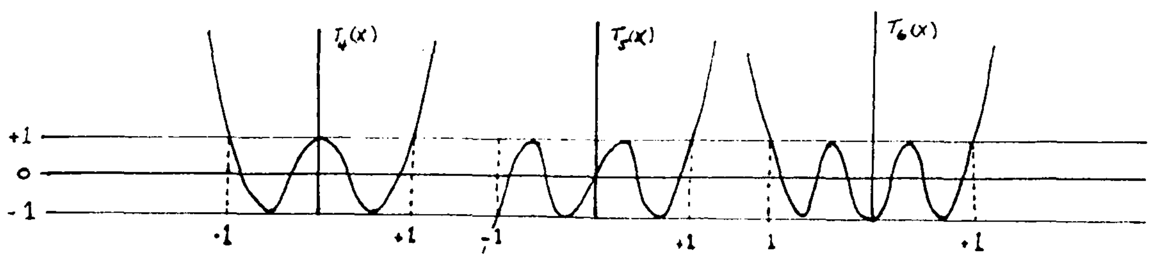


Figure 3.- Chebyschev polynomials examples.

Chebyshev polynomials are solutions of the differential equation

$$\left(1-x^2\right)\frac{d^2T_m}{dx^2} - x\frac{dT_m}{dx} + m^2T_m = 0$$

And take the form

$$T_{2N}(x) = \sum_{n=0}^{N}\left(-1\right)^{N-n}\frac{N}{N+n}\binom{N+n}{2n}\left(2x\right)^{2n} \tag{4}$$

If M is even and

$$T_{2N-1}(x) = \sum_{n=1}^{N}\left(-1\right)^{N-n}\frac{2N-1}{2(N+n-1)}\binom{N+n-1}{2n-1}\left(2x\right)^{2n-1} \tag{5}$$

If M is odd.

They exhibit the property that outside the region x = ±1 they rise (in magnitude) asymptotically and inside the region x = ±1 contain a number of lobes of uniform height, the number depending on the degree of the polynomial. Thus, constructing an appropriate mathematical transformation between the physical angle off boresight θ and the dummy variable x of the polynomials will cause the radiation pattern to exhibit the same desirable properties.

The physical quantity one is solving for in the mathematical manipulations is the normalized conductance value for each of the slots. The required conductance values are then readily translated into values for the offset from centerline for each of the slots. Once the offsets are known the lengths of the slots can be determined. These last two steps are accomplished by applying graphs of measured data and scaling to the appropriate frequency. Once these steps are completed, sufficient information exists to fabricate the array.

The preceding discussion has been a very cursory glance of the design procedure. More complete information may be found in the references.

TEST ANTENNA FABRICATION

The actual test antennas had to be designed with a certain amount of versatility in mind, as the ability to alter certain parameters is an inherent part of most test situations. In the case at hand, the ability to change slot patterns was required, so the waveguide cavities were designed such that three walls were formed by milling a trough into a solid block of aluminum and the fourth wall was formed by a removable top cover plate which is bolted into place by a series of small screws. The slot patterns are then cut into different top cover plates and can be interchanged with one another. A diagram of this configuration is given below.

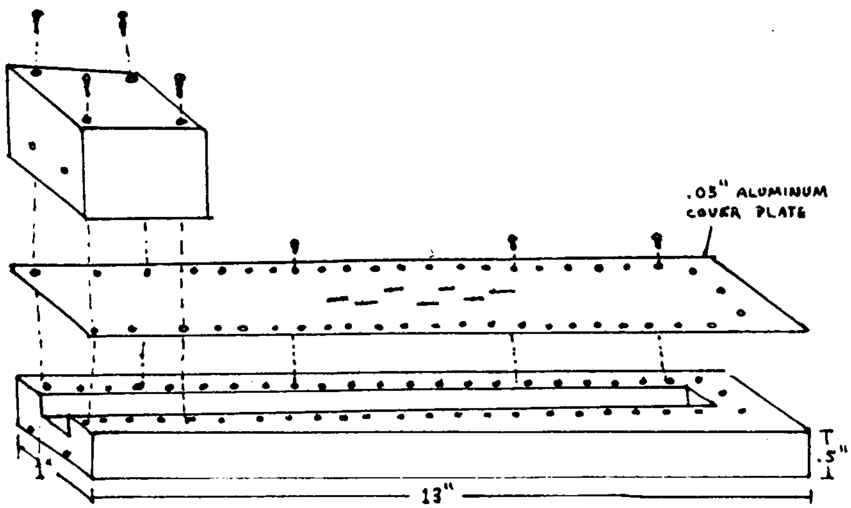


Figure 4.- Test antenna configuration.

The antennas were fabricated by the Technical Services Division at NASA-JSC.

The antennas designed and fabricated to date have been designed to operate at 24.15 GHz, in the K-band region. This is not meant to imply that this frequency is considered optimal for performance of the collision avoidance radar. It was chosen due to the fact that test equipment necessary to investigate the performance of the antennas was available at this frequency, and it is a likely candidate for this type of radar applications.

To date four antennas have been fabricated, three of the "radar box" type just described and one from a section of standard K-band waveguide.

The first antenna was a "proof of procedure" type, constructed in order to verify that the design procedure was being carried out correctly, and that the milled cavity-cover plate configuration would indeed operate properly. The slot pattern was a seven slot array.

The second antenna was designed with the intent of using the box design with a slot pattern that would produce a 4° half-power beam width. It was the first to be constructed with the block end designed to accommodate a standard waveguide flange for RF energy output.

The third antenna was the identical slot pattern from antenna 2, but was modified in its dimensions for standard K-band waveguide and was milled into a section of standard K-band waveguide. (The first two antenna cavities were constructed with customized dimensions in order to conform to parametric ratios found in measured data in the design procedure.) The purpose of this antenna was to test scaling to standard waveguide dimensions.

The fourth antenna is the most complicated. It is a triple cavity monopulse antenna. The central cavity is isolated from the other two and is designed to transmit. The two offset receive cavities bend around and come together to form two output ports, one for the sum channel output and one for the difference channel output. The cavities are all standard K-band waveguide dimensions. Each cavity has an identical slot pattern.

TEST RESULTS AND PERFORMANCE

Antenna patterns were run on antenna number 1 in the building 14 anechoic chamber onsite at NASA-JSC. The beam width of the antenna was less than degree different from that predicted. The gain of the antenna was measured to be approximately 13 db, indicating an efficiency of approximately 62 percent. The maximum efficiency of coupling input RF energy to the antenna (as indicated by measured VSWR) was found to occur at 24.011 GHz. A polar plot of the radiation pattern from this antenna, as well as the others, is included in appendix B of this progress report.

APPENDIX B

ASSESSMENT OF PARAMETRIC ACCURACIES REQUIRED OF AN AUTOMOTIVE COLLISION AVOIDANCE RADAR

by

Daniel F. O'Connell

PURPOSE AND SCOPE

This document presents an examination of the geometry and dynamic environment of traffic situations in order to evaluate the accuracies required of a radar system which would warn of impending collisions. The aim here is to establish generic requirements and not to evaluate particular systems. Each of the parameters measurable by a radar system (range, angle, and their derivatives) are discussed in terms of their possible uses in collision determination. The accuracies required to support these uses are generated. RF effects shall not be treated in this report.

INTRODUCTION AND BACKGROUND

The National Aeronautics and Space Administration, at the request of the Department of Transportation, is conducting a study in the application of radar systems for automotive collision avoidance. Past studies[1] have indicated that an effective system could significantly reduce the property loss and personal tragedy associated with automobile accidents. Several candidate systems have been designed and tested by different organizations,[2] but to date the reduction of false alarm occurrences remains a problem to be solved before a system may be deemed practical.

The designs and breadboards to be generated by this study will be geared toward solving this problem. Prior to developing these designs, the accuracies required of the various parameters it measures must be known, as these have a major impact on the system design. These accuracies may be determined by examining the dynamic environment in which the radar operates and establishing differences in the magnitudes of measured parameters (and the rate they are changing) for collision courses versus noncollision courses. The control algorithm which makes the collision/noncollision decision will be presented in a later report.

PRELIMINARY DEFINITIONS AND ASSUMPTIONS

"Range" and "angle" must be appropriately defined for discussion. These parameters shall be referenced to a vehicle-centered, vehicle-fixed coordinate system. The center of the coordinate system shall be taken to be the location of the radar transmitter if a single antenna system is under discussion and the middle of the front of the vehicle if multiple antennas are used. Unless otherwise stated, the latter location will be assumed. The X-dimension shall lie along the vehicle's velocity vector. Y is then perpendicular to the vehicle's motion.

Range in this system shall then refer to the root sum squared (RSS) distance of the target in question from the origin. Angle shall be defined as the arctangent of the Y-coordinate over the X-coordinate.

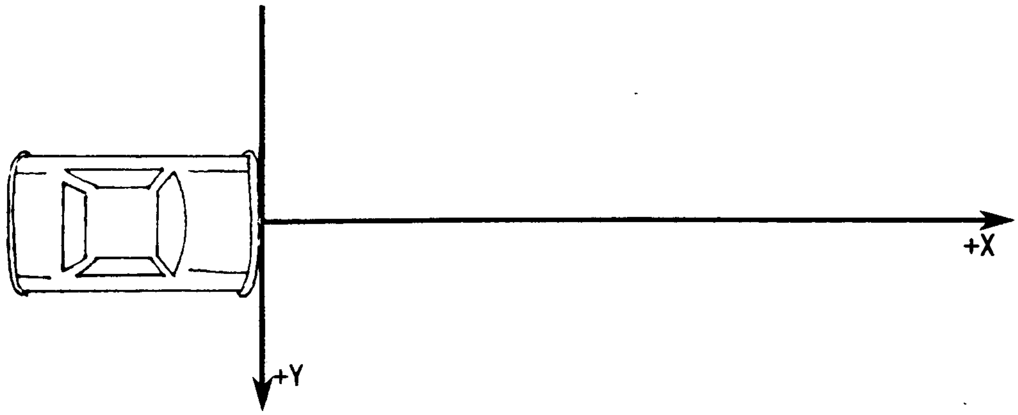


Figure 1.- Vehicle-centered, vehicle-fixed coordinate system.

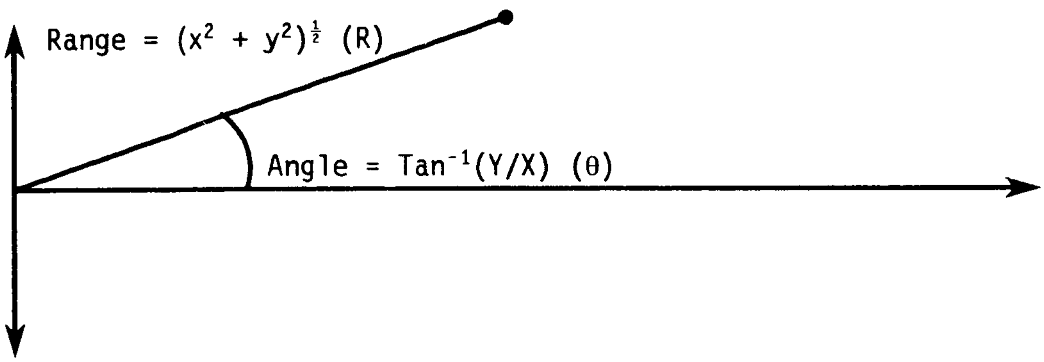
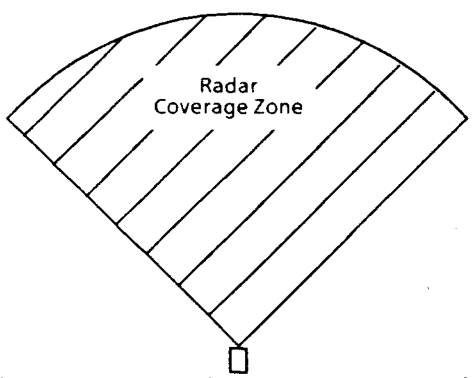


Figure 2.- Range and angle definitions.

Range rate and angle rate are the derivatives of the respective measurements.

The following shall be assumed throughout this report:

- Measurements are made only in the forward direction.
- Radar detection range is 300 feet. Anything farther away is assumed not to be in the radar field-of-view.



(Drawn approximately to scale)

- Angular coverage is ± 45° from direction of travel. Anything outside this region is not in the radar field-of-view.
- The range at which a decision to warn/not warn must be made is variable with the measured range rate.
- Range rate extremes are 176 fps (two cars approaching each other going 60 mph) and 5 fps (3.5 mph, no damage likely).
- Unless otherwise stated, targets are assumed to be idealized points.

ACCURACY DETERMINATION TASK

To generate the accuracy requirements for the proposed system, one must define the tasks the measurements will be required to support. As stated earlier, the primary task of the radar system is to warn of impending collisions, with special emphasis on reducing to the maximum extent possible the false alarm rate.

To accomplish this task, it will be necessary to determine not only if the target's range and velocity are such that the distance to the target is less than the required stopping distance, but also if the course it is on represents a collision trajectory. These two different tasks impose different requirements on the various parameters.

The first task involves establishing a "warning threshold" distance at which to sound an alarm, based on the measured distance and speed of the target. In many systems this task will be the major accuracy driver for the range and range rate measurements. The second task, determination of a collision trajectory, involves monitoring the behavior of the range and angle measurements to predict if the present course is an impending collision. This task will likely be the major driver for angle and angle rate accuracies.

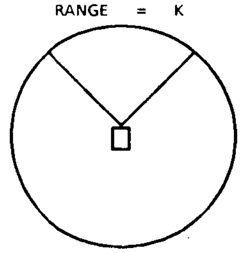
This partioning is true in general, but there are system concepts in which collision prediction is the dominant driver of accuracy requirements for range or range rate, as well as angle. For completeness, these situations will be treated as well.

PARAMETERS

Range and Range Rate

The measured range to a target cannot in and of itself distinguish a collision trajectory from a noncollision trajectory. Range alone merely specifies that the target is somewhere on a circle with the measuring point at its center.

RANGE = K



Of course, we are restricting our measurements to ± 45°, so a range would place the target somewhere on the sector depicted in the diagram.

Since the collision/noncollision decision is not heavily dependent on the range measurement, the accuracy requirements need not be overly strict. The use of the range measurement nominally will be to determine if the range to a target is less than some required threshold, in which case an alarm is to be sounded. For this reason, the range measurement should be at least accurate to the average length of a car. Therefore, a 1σ magnitude of 15 feet is imposed.

It is possible that stricter requirements might need to be imposed for certain systems, however. If range rate is generated by differentiation of range measurements, then range rate accuracy requirements will drive the range accuracy. In this case, σ range is a function of σ range rate given by

$$\sigma_{\text{Range}} = \frac{\sigma_{\text{Range Rate}}}{2}$$

since two range measurements are subtracted to yield a range rate measurement.

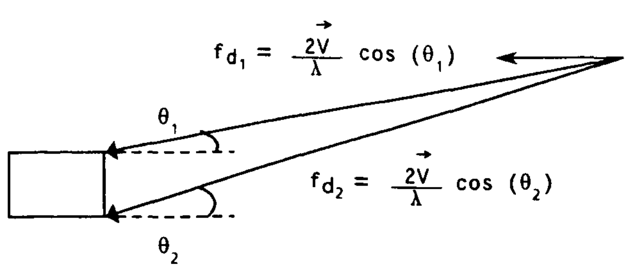
Range rate has an important role in determining the warning threshold, since the distance required for an automobile to come to a stop (the reference for declaring a warning) is proportional to the square of the vehicle's velocity:[3]

$$\text{Distance to stop} = -\frac{v^2}{2\,\mu g}$$

where v = vehicle's speed, μ = coefficient of friction, g = acceleration of gravity.

Through this equation we can relate range rate errors to the error in warning threshold estimate. As with the range measurement, we would want no more error in the threshold than a car length, or 15 feet. Thus, the range rate measurement must be accurate to at least 15 fps, or 3.8 fps, 1 σ.

This is a relatively mild requirement. Range rate has potential uses other than determining warning threshold, however. Some potential system concepts use the difference in range rate measurements taken from two antennas a distance d apart to determine angle to a target, since the spacing D will cause the antennas to see different Doppler frequencies (proportional to range rate) as a function of the target angle. This situation is depicted below.



The effect on accuracy requirements is best described by evaluating a worst case example. Suppose we wish to evaluate the case of approaching an object just off to the side of the car from 300 feet away at a speed of 73.3 fps (50 mph). We will assume d = 5 feet (the typical width of a car). Then the velocity difference between the two antennas will be

$$V\,(\cos(\theta_1) - \cos(\theta_2))$$

$$= 73.3\,(1 - .99986)$$

$$\simeq .01 \text{ fps}$$

.01 fps is a very strict requirement. The worst case described is much stricter than the average case likely to be encountered; however, even as the scenario becomes more realistic, the requirement eases very little, if one wishes to make distinctions at a range of 300 feet. Two cars in opposite lanes (10-foot separation), each travelling 35 mph, would result in a range rate difference of only .05 fps, so an accuracy on the order of hundredths of a fps would still be required.

Angle and Angle Rate

Angle measurements and their behavior are quite necessary to the determination of a collision course. This report will not present the algorithm developed to make this determination, but typical situations will be examined to establish the strictest accuracy requirements.

Angle measurements have long been used on shipboard radar systems to indicate collisions. It is well known that a constant angle combined with a closing range indicates a collision course. This is true for straight line trajectories only, but quite a number of practical cases fall into this category. Any fixed object on or along a straight road section falls into this category. Any normal vehicle traffic along a straight road also falls into this category.

The angle accuracies required to support this determination may be arrived at by examining the change in angle behavior between an object directly in one's path and one just to the side of the vehicle, say 3 feet over. For the collision object, the angle measurement is zero and remains zero all throughout the approach. For the second case, the angle measurement starts at .573° and grows in magnitude, eventually reaching 90° as the car passes the object.

a. Angle = 0 throughout approach   b. Angle varies throughout approach

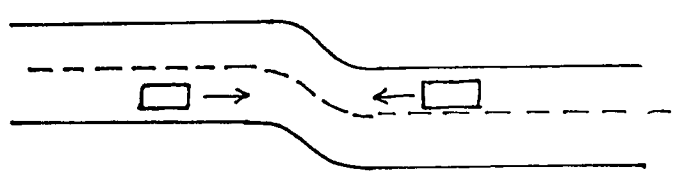
From this case it can be seen that the radar system should be accurate to at least .5°. However, the situation described is the worst case only for straight line trajectories. Many driving situations involve potential collision hazards approaching the radar vehicle along a curved trajectory. From an accuracy standpoint, the worst case would be as slight a curvature as possible, since this would result in the smallest angular changes. For this reason, a computer simulation was run involving a target object beginning at a distance of 500 feet in the opposite lane slowly curving into the radar vehicle's lane. The simulation was run twice, one for a collision case and once for a near miss of several feet. Equal velocities for radar vehicle and target were assumed. At 275 feet (stopping distance for a car going 60 mph under normal conditions), the angle measurements differed by .14°. Thus, to be able to distinguish these cases, accuracies to a tenth of a degree would be required.

It should be noted that at 300 feet, two objects need be separated by only .52 feet to have an angular separation of .1 degrees. Since a car is much wider than .52 feet, the specific point of the target that the radar tracks becomes important. But the phenonmenon is an RF effect to be investigated and really does not influence accuracy requirements.

SUMMARY AND COMMENTS

The arguments presented in this report were designed to arrive at accuracy requirements for a collision avoidance radar system based on an examination of the worst cases of normal driving conditions. The analysis herein is based solely on the geometry of the environment, as this was all that was required to determine the variations in magnitude that the radar parameters undergo.

It should be noted that cases can be envisioned which a radar system most likely could not solve. For instance, the situation depicted below, which is not entirely uncommon at construction sites:



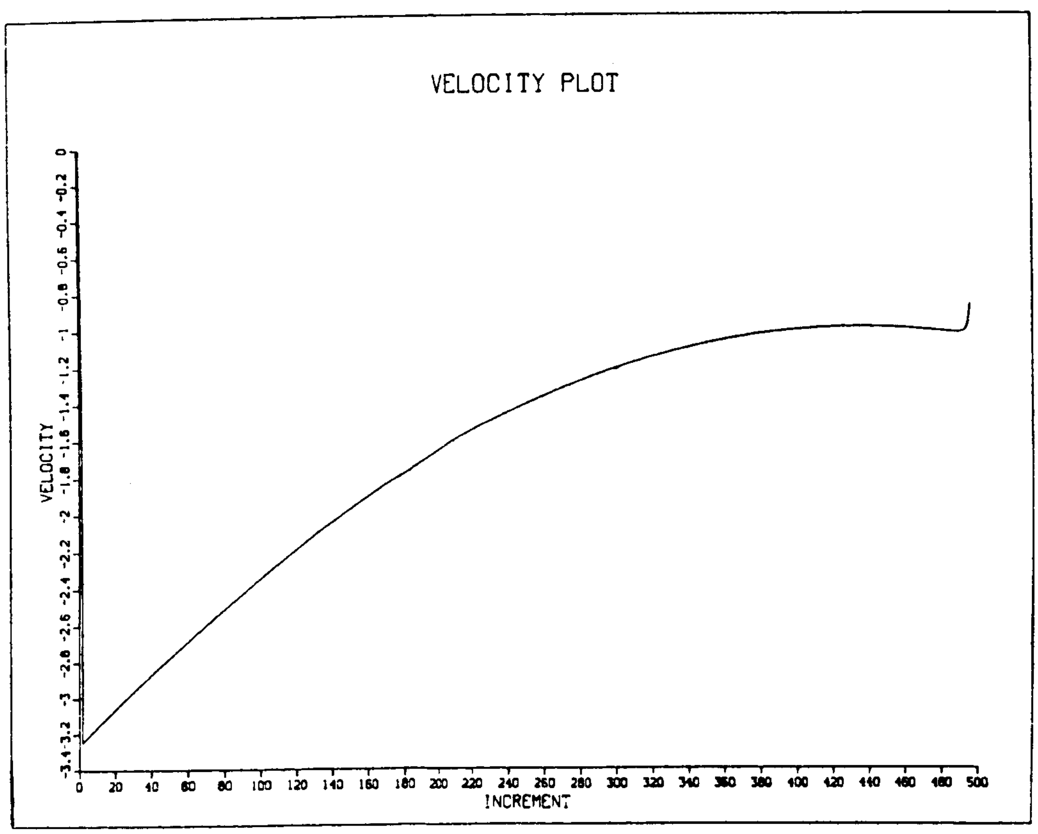
The difficulty here is that the vehicles do indeed follow a direct collision course until the very last moment, and the radar system has no way of knowing in advance that the driver intends to turn away at the last moment. Of course, it could be argued that a warning in this situation is not inappropriate, since a slight amount of driver inattention at the last moment can result in a collision. The point, however, is that situations of this sort are an odd extreme and are not likely to be encountered with any significant frequency. The design of the radar system should be geared towards the practical situations encountered in everyday traffic.

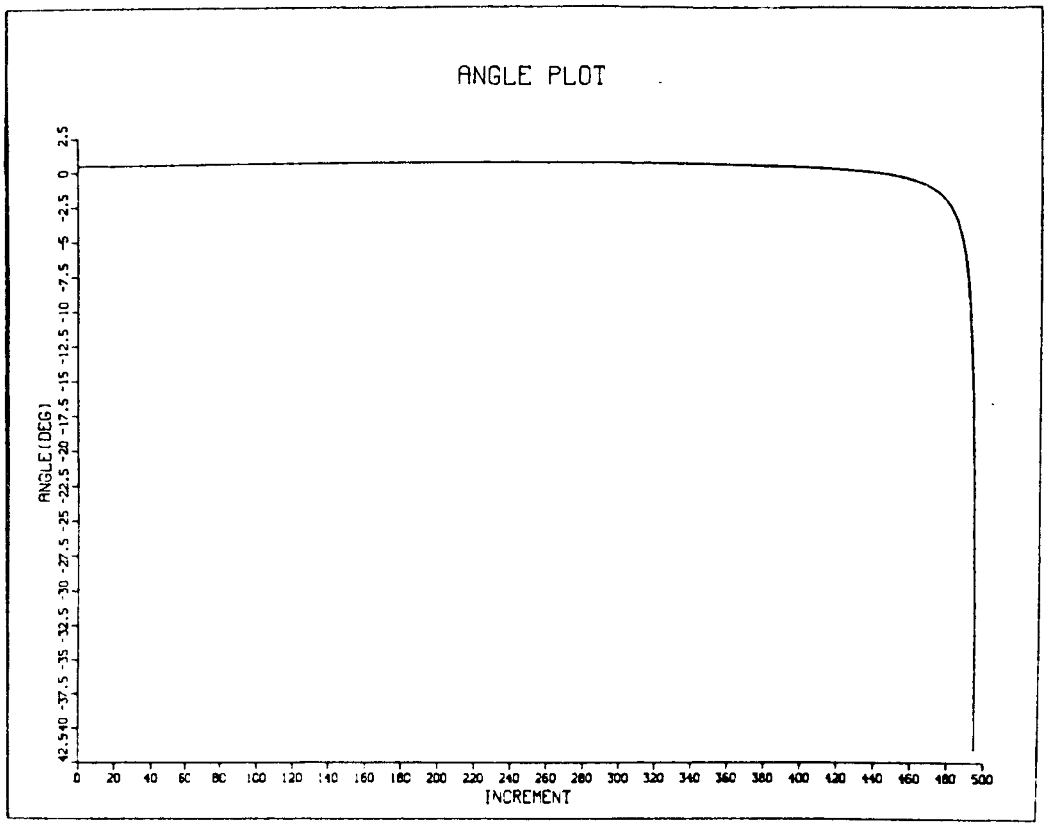
To summarize, if a radar system were designed around the requirements generated by this report, the following would be the accuracies required:

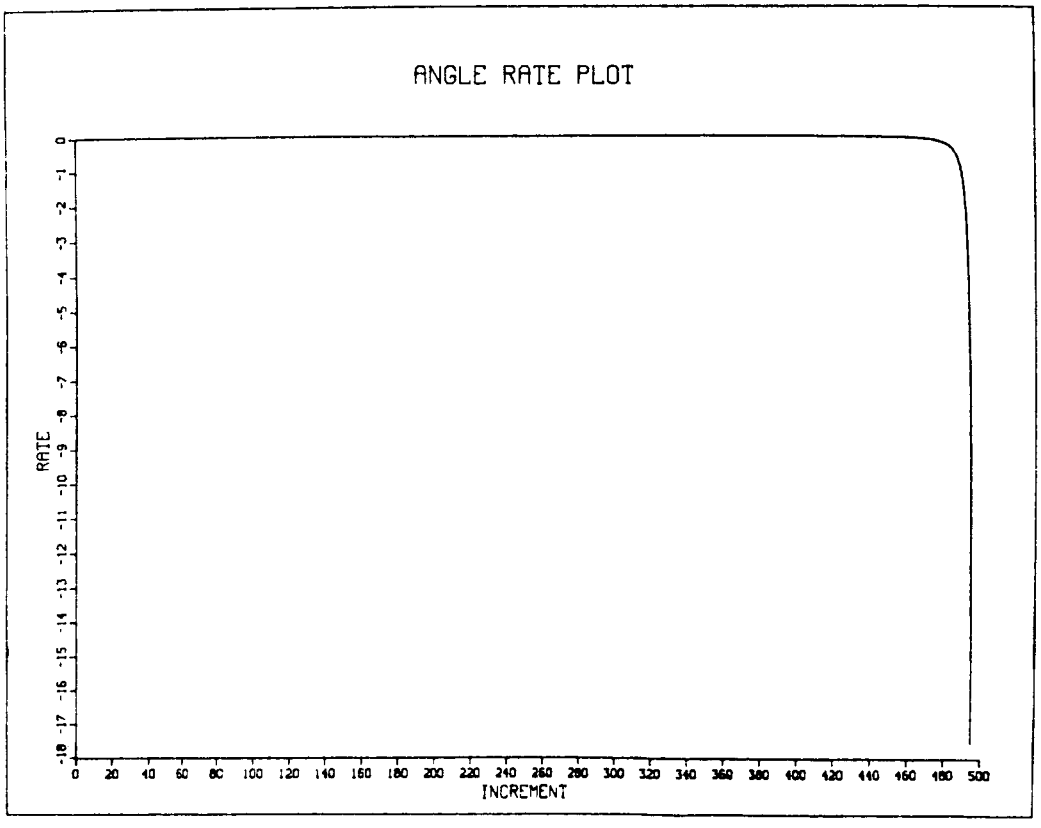
	Worst case error	Best case error
Range	.005 ft	15 ft
Range rate	.01 fps	3.8 fps
Angle	.1°	.1°

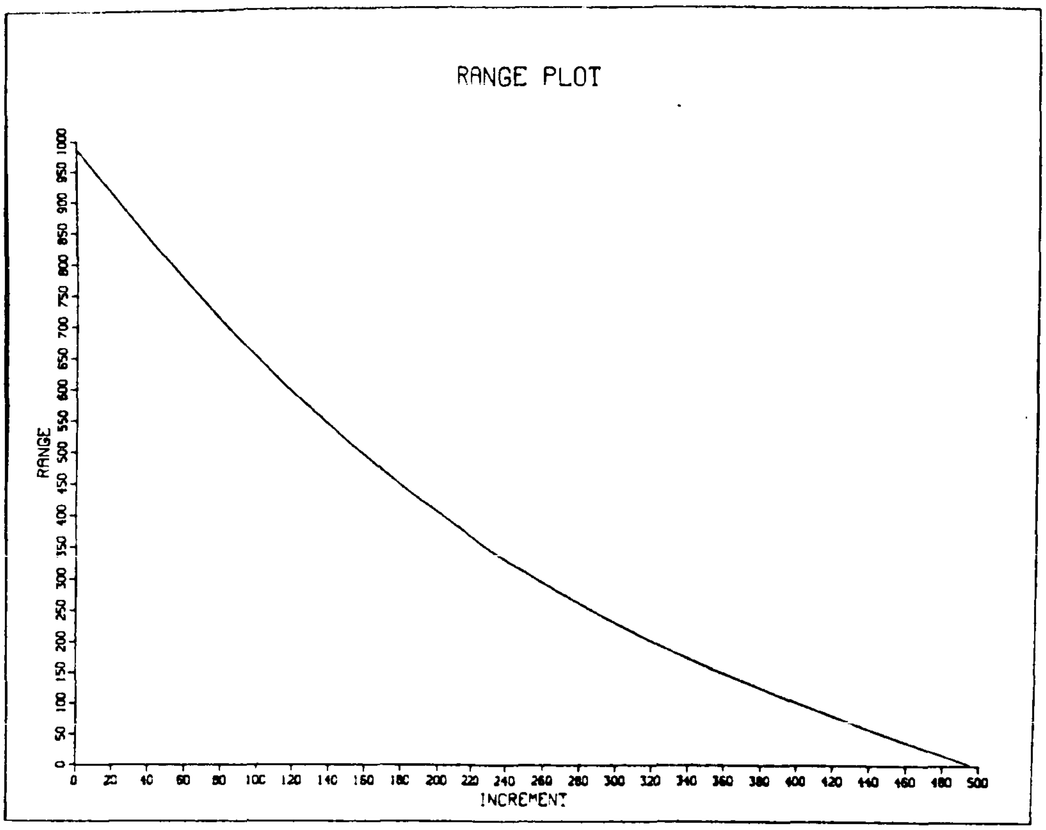
These requirements are intended to be a general guideline, dictated by the geometry of the environment. Actual requirements for a particular system will depend on how that system processes the various parameters.

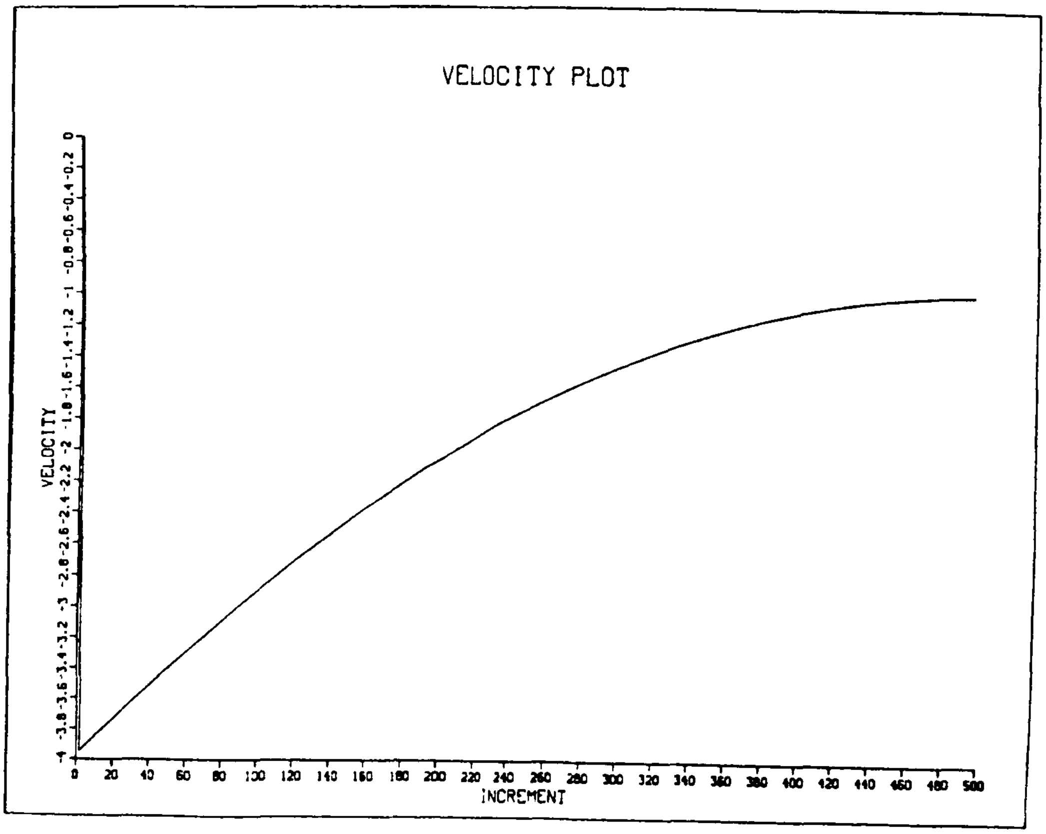
The following plots present the results of the computer simulation referenced in the angle/angle rate section. Two sets of plots are presented, one set for a collision case and one set for a near miss case. On the trajectory plots, the radar vehicle path is indicated by the straight line from X = 0 to X = 500. The target path is depicted by the curved lines.

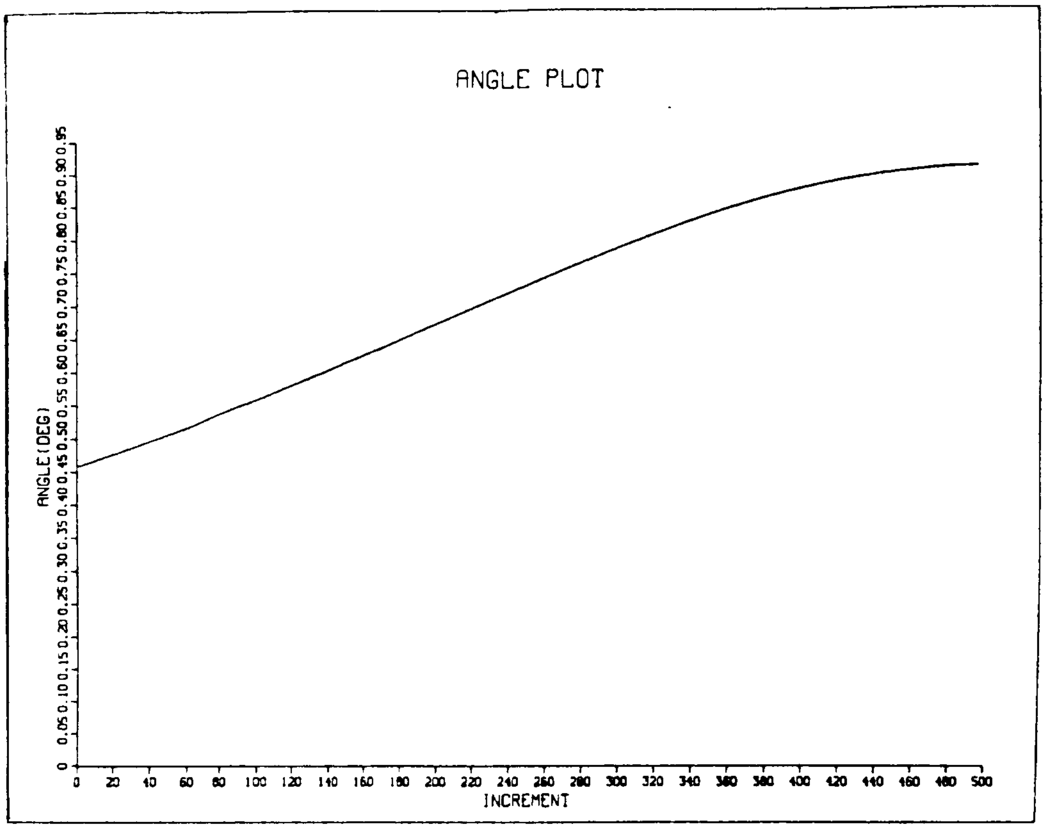


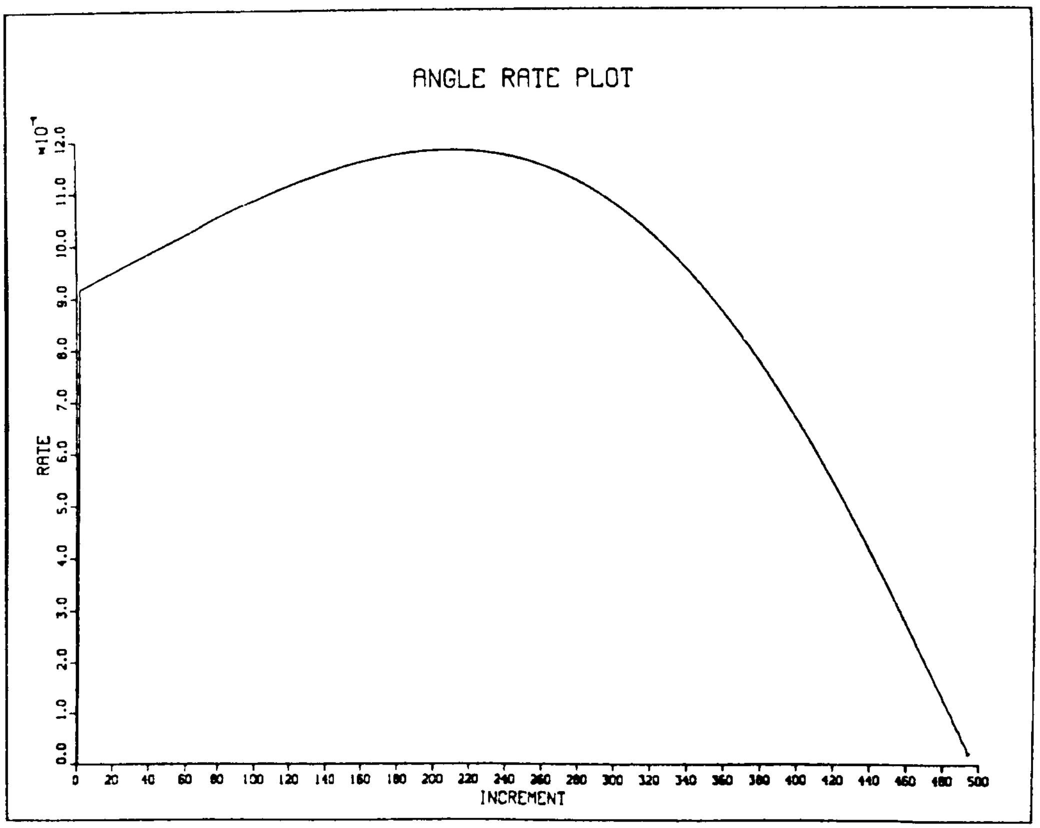

ANGLE PLOT
ANGLE(DEG)
INCREMENT

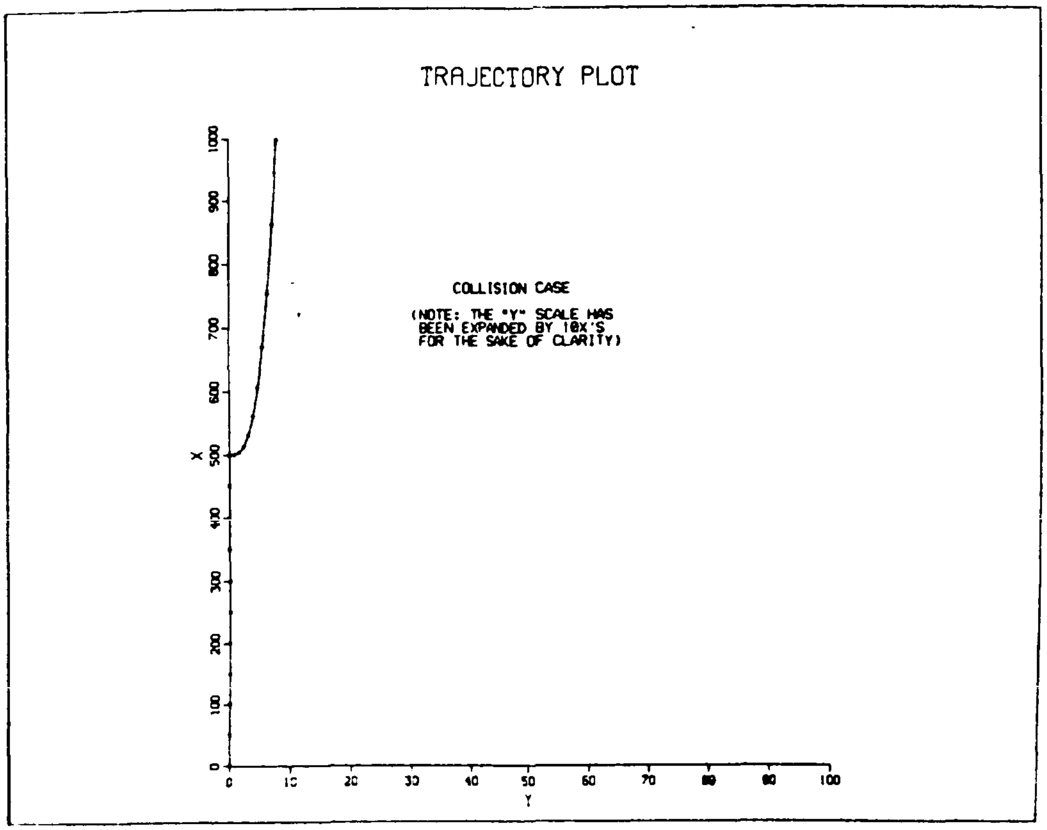

ANGLE RATE PLOT
RATE
INCREMENT


RANGE PLOT
RANGE
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
INCREMENT


VELOCITY PLOT
VELOCITY
-4
-3.8
-3.6
-3.4
-3.2
-3
-2.8
-2.6
-2.4
-2.2
-2
-1.8
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
INCREMENT


ANGLE PLOT
ANGLE(DEG)
0 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500
INCREMENT


ANGLE RATE PLOT
RATE
$\times 10^{-4}$
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500
INCREMENT



REFERENCES

1. "Some Automotive Radar System Considerations," T. D. Jones and D. M. Grimes, Second International Conference on Automotive Electronics, October 1979.

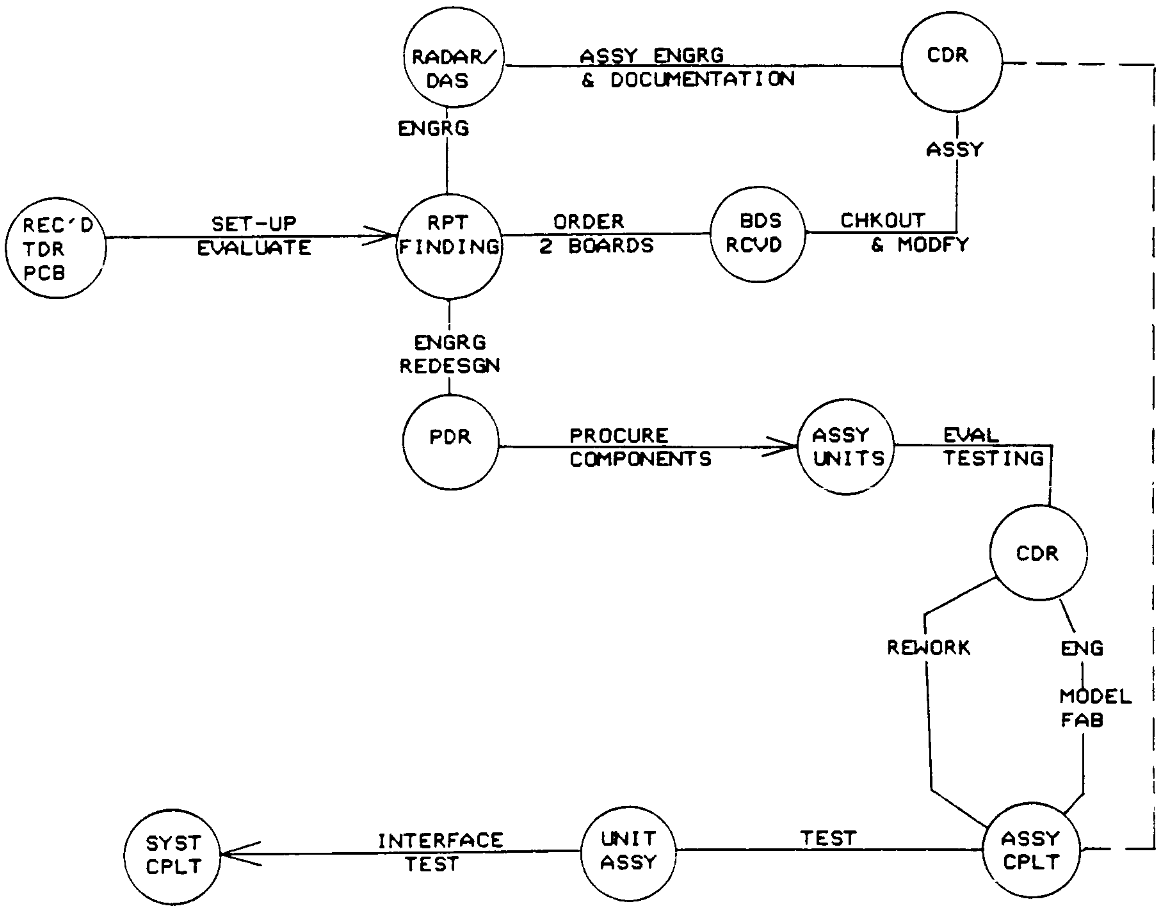
2. "Collision Avoidance System Cost - Benefit Analysis Technical Report," A. V. Kitadilkar, D. Redmond, and V. K. Aushorman, Kinetic Research, September 1981.

3. Fundamentals of Physics, D. Halliday and R. Resnick, Wicoy and Sons, 1970, p. 81.

APPENDIX C

PRELIMINARY PROJECT SCHEDULES

AND FLOW CHART



High Speed Sampling Circuit

A/D Number 85-16-692-01.   Date 01/16/84.   Principal Engineer: J. ALLGAIER

Title: CAR

Operational Activities: ITEM 3 PURCHASE REQUESTS COMPLETED & IN APPROVAL CYCLE.

LEGEND:

=== PLANNED; > SCHEDULED FINISH; >>> RESCHEDULED; /// NO ACTIVITY; +++ WORK IN PROGRESS; C<<==> EARLY COMPL.;
O>>>===>>SLIPPED START DATE; >===>>>> EXTENDED COMPL.DATE; o TASK START DATE; <> EVENT MILESTONE

Month	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Week	1:2:3:4	1:2:3:4	1:2:3:4	1:2:3:4	1:2:3:4	1:2:3:4	1:2:3:4	1:2:3:4	1:2:3:4
1. DESIGN DATA PROCESSOR COMP.	o++++++>COMPLETED								
2. PROCURE COMP EQUIP.		o++VCOMPLETED							
3. EQUIPMENT EXPECTED.				∇					
4. ASSEMBLE COMP. EQPT.				o=======	=====>				
5. INVESTIGATE HDW/SW CAPABILITIES.					o=========	==========	=========>		
6. NASA EQUIP AVAIL.									
7. NASA PROCURED COMP HDW AVAIL.									
8.									
9.									
10.									

A/D Number 85-16-692-02. Date 01/16/84. Principal Engineer: W. CULPEPPER

Title: CAR

Operational Activities: ITEM 1 SSR TO LOCKHEED GENERAL ENGINEERING TO PROVIDE PRELIM RELOCK DIAGRAM, ANALYTICAL APPROACH/DESIGN,HARDWARE SEARCH.

LEGEND:

<1> ORAL REPORT(BIMONTHLY).
<2> WRITTEN REPORT(QUARTERLY).
<3> SYSTEM OPERATIONAL.

```
=== PLANNED; > SCHEDULED FINISH; >>> RESCHEDULED; /// NO ACTIVITY; +++ WORK IN PROGRESS; C<<==> EARLY COMPL.;
O>>>===>>SLIPPED START DATE; >===>>>> EXTENDED COMPL.DATE; o TASK START DATE; <> EVENT MILESTONE
                       Month----|  JAN  |  FEB  |  MAR  |  APR  |  MAY  |  JUN  |  JUL  |  AUG  |  SEP  |
                       Week-----|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|
1.SAMPLING TECHNIQUE DESIGN.    |      o====================================================>   |       |
2.B/B HDW PROCURE.              |       o===================>   |       |       |       |       |       |
3.B/B HDW RECEIVED.             |       |       |       |      ∇|       |       |       |       |       |
4.B/B FABRICATION.              |       |       |     o=======================> |       |       |       |
5.B/B TEST & EVALUATION.        |       |       |       |       |     o=======<3>======================>|
6.INTERNAL PDR.                 |       |       ∇       |       |       |       |       |       |       |
7.DATA REDUCTION S/W DEV.       |       |       |     o================================================>|
8.DECISION CRITERIA DEV.        |       |       |       |       |       |    o=========================>|
9.NASA/DOT REPORTING(REF).      |      <1>      |      <2>      |      <1>      |      <2>      |       |
10.                             |       |       |       |       |       |       |       |       |       |
```

DATE 01/25/85 PRINCIPAL ENGINEER: C.LICHTENBERG

TITLE: CAR

OPERATIONAL ACTIVITIES: MICROWAVE TRANSMIT/RECEIVE ASSEMBLY

LEGEND:

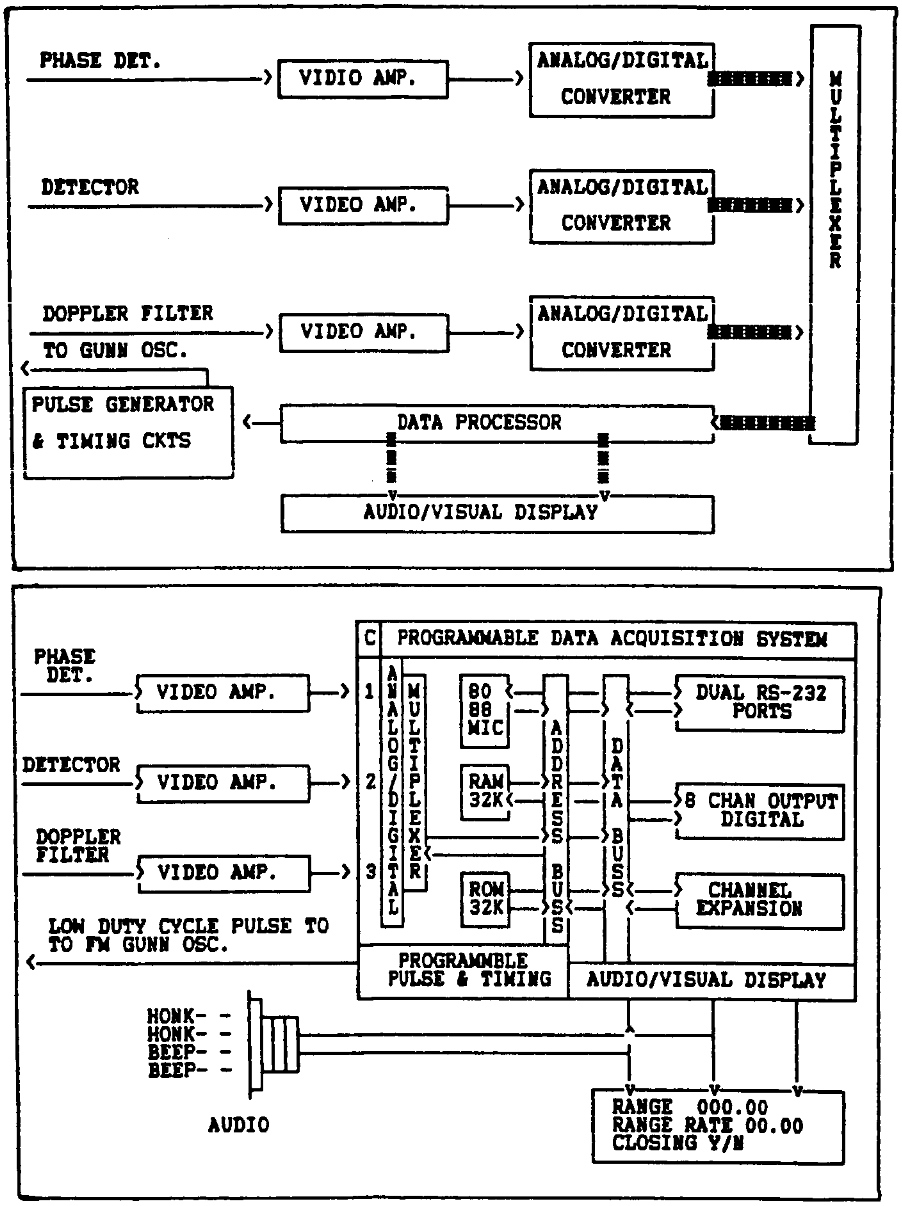
=== PLANNED; > SCHEDULED FINISH; o TASK START DATE; <> EVENT MILESTONE

```
                                              Month----|   DEC   |   JAN   |   FEB   |   MAR   |   APR   |   MAY   |   JUN   |   JUL   |   AUG   |
                                              Week-----|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|
1. DESIGN ANTENNA,RF,AND IF SYSTEM.                     |       |      o================>|       |       |       |       |       |
2. PROCURE COMPONENTS/FABRICATE COMPONENTS.             |       |       |   o========================>  |       |       |       |
3. EQUIPMENT RECEIVED/BUILT.                            |       |       |       |       |       |     < >       |       |       |
4. ASSEMBLE COMPONENTS INTO SYSTEM PLUS PRETEST         |       |       |       |       |  o============>      |       |       |
   COMPONENTS.
5. TEST AND EVALUATE THE SYSTEM.                        |       |       |       |       |       |       |o======>       |       |
6.
7.
```

APPENDIX D

SCHEMATIC REPRESENTATION OF THE MICROWAVE AND DATA PROCESSING EQUIPMENT

LEMSCO PORTION OF COLLISION AVOIDANCE SYSTEM



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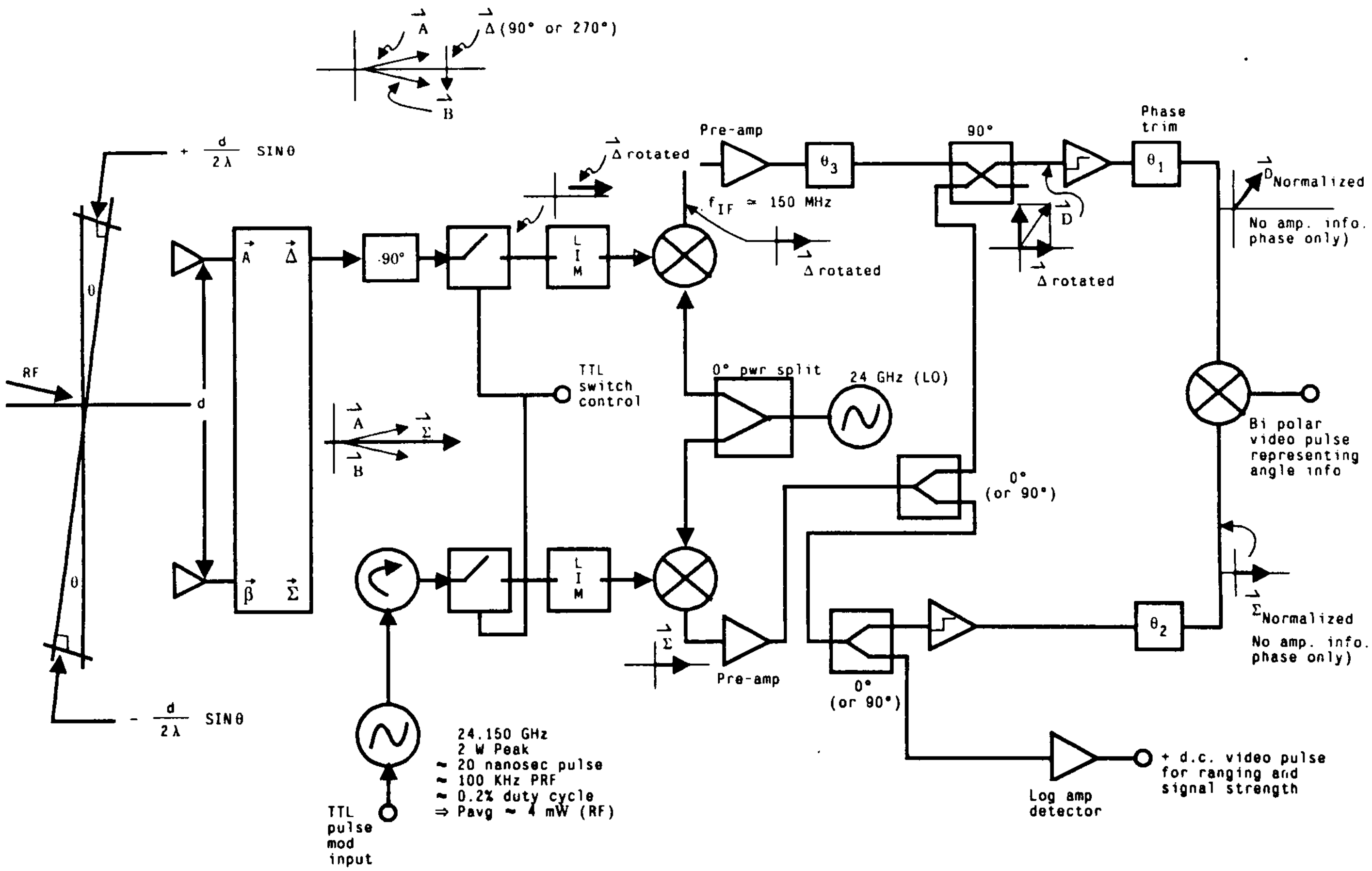


Microwave section block diagram.

APPENDIX E

SUPPLEMENTARY REPORTS

ANTENNA TEST RESULTS

Dan O'Connell

This report may be considered as a supplement to the document, "Microwave Slotted Array Antenna for Automotive Crash Avoidance Systems" supplied in appendix A of Progress Report No. 1.

Tests to determine the radiation pattern and characteristics of the slotted array antenna were performed in the building 14 anechoic chamber during the latter part of April 1985. The antenna was mounted on the positioning pedestal and received a signal from a transmit source located at the apex of the horn of the chamber. The antenna was then rotated in the azimuth and elevation planes and the received signal plotted. By comparing the received signal to that produced by a known reference (standard gain horn) a measure of the gain of the antenna was obtained. This process was repeated at several frequencies, including 22.125, 23.08, and 24.125 GHz. These frequencies were chosen because the VSWR (an indication of power lost due to inefficient coupling) proved to be lowest at these frequencies. The design frequency was 24.125 GHz. The VSWR reading was poor at this frequency, but attempts can be made to tune the antenna to improve this.

Test results showed the antenna to have a 4-degree 3 dB beam width, as designed. Gain of the antenna proved to be about 7 dB. The pattern shape corresponded well to that which was designed for in both the azimuth and elevation planes. The highest sidelobes were 20 dB down from the main lobe in a direction of 50 degrees off axis. The average sidelobe level was about 25 dB down. Plots of the azimuth and elevation are included (figs. 1 and 2).

An additional antenna was tested in the chamber. This was a parabolic dish section which is currently being used in the testing of the ranging capability of the microwave electronics. It has higher gain and thus compensates for the lower power oscillator which must be used at present. It is described further in another report.

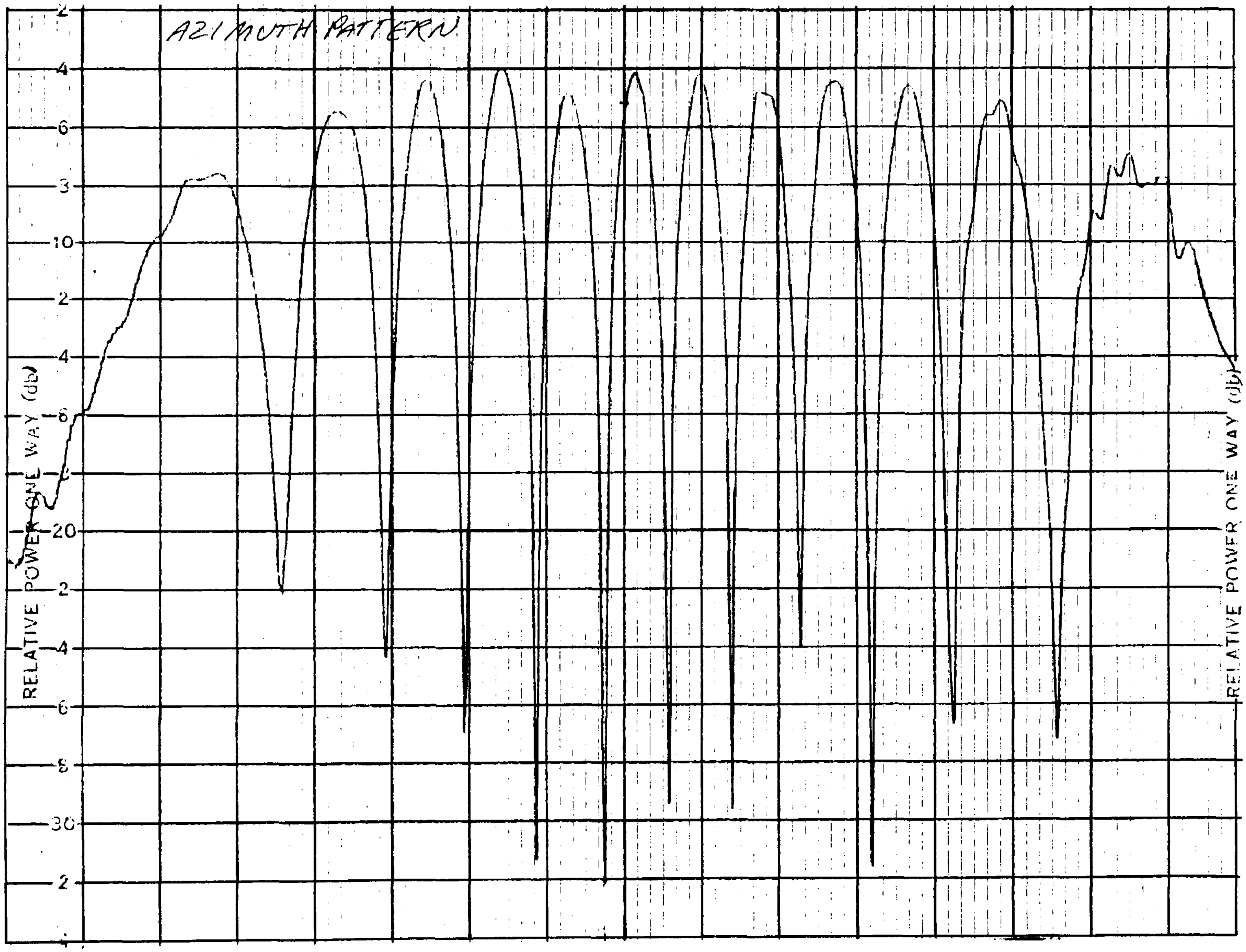


Figure 1.- Azimuth pattern.

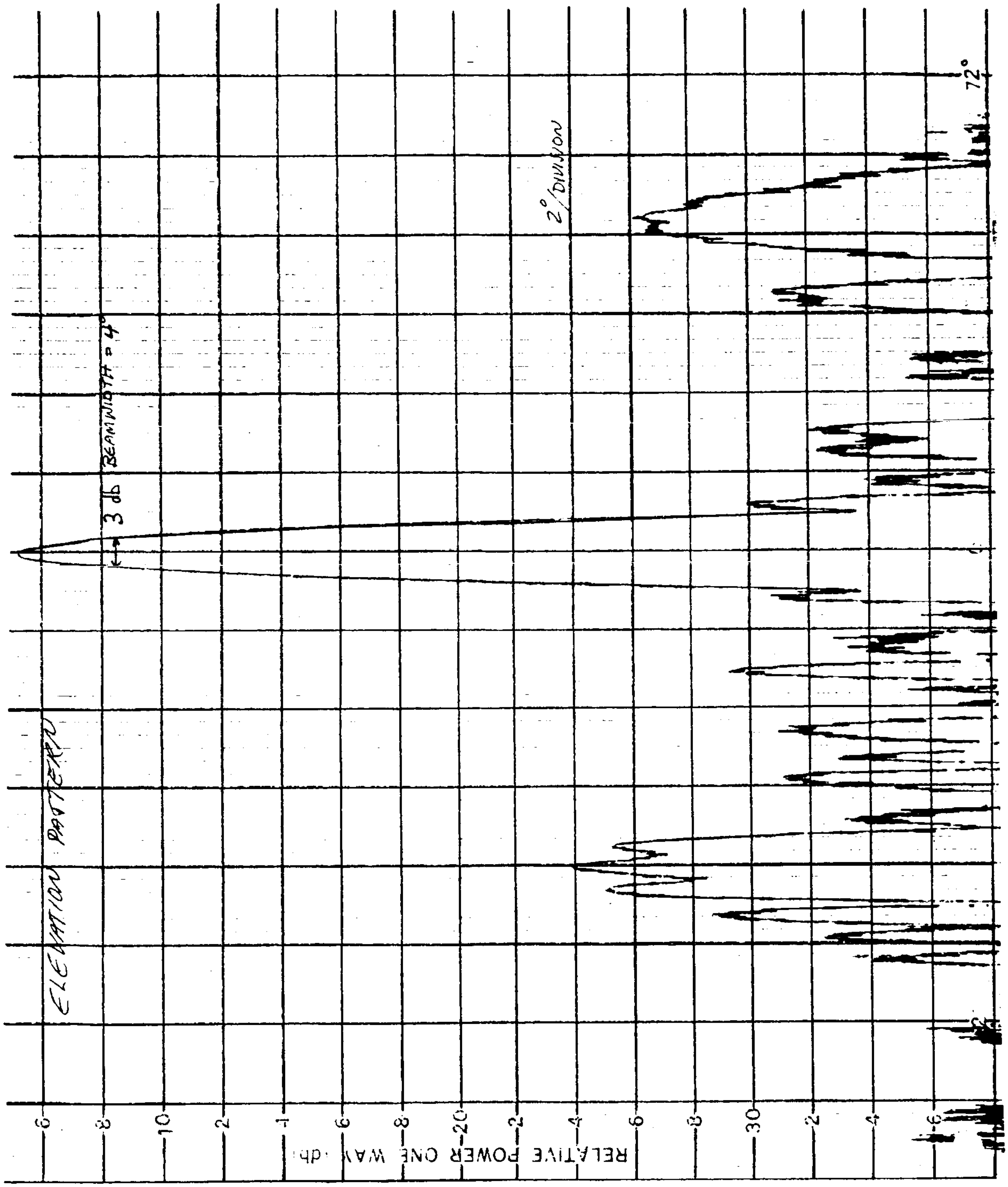


Figure 2.- Elevation pattern.

TEST-BED RADAR/MICROWAVE ASSEMBLY

Christopher L. Lichtenberg

INTRODUCTION

This report describes the design, operation, and construction of a test-bed radar used to evaluate system design concepts, system components, and target reflections as they are pertinent to an automotive crash avoidance radar being developed by NASA-JSC personnel in cooperation with and under contract to the Department of Transportation.

DESIGN OF TEST-BED RADAR

Configuration

The present configuration is a pulse-ranging radar. This conforms basically to the sum channel in monopulse radars, which is the design presently chosen for investigation as a collision avoidance radar. Target reflection amplitude and time delay are the two most useful measurements available from this test-bed radar. Error, or angle track, data are not currently available on this test-bed radar, but will be on the monopulse configuration.

Components Utilized

Currently available components were used to construct this radar. Some of the components are not optimum in that they might not be as powerful, sensitive, wide-band, fast enough, or precise as will be required for the ultimate radar. Nevertheless, the currently used components are useful in evaluating design concepts, component performance, and target effects. Many components are presently being procured. As they become available they will replace others or be integrated into the test-bed radar.

Utilized Component Configuration

Figure 1 shows the overall block diagram of the test-bed radar. The complete detailed test-bed radar is shown in figure 2. A complete list of the included parts is found in the parts list. Similarly, all of the utilized test equipment is listed in the equipment list.

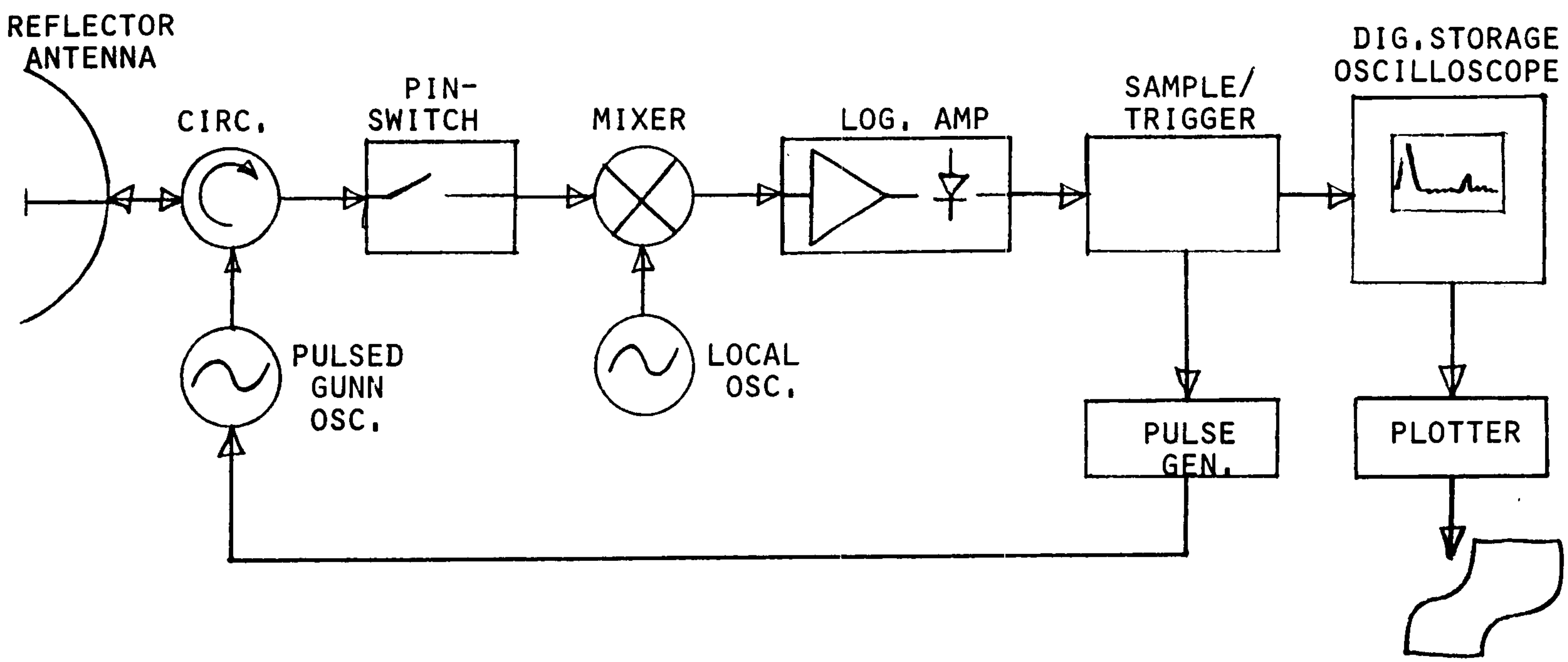


Figure 1.- Pulse-ranging test radar.

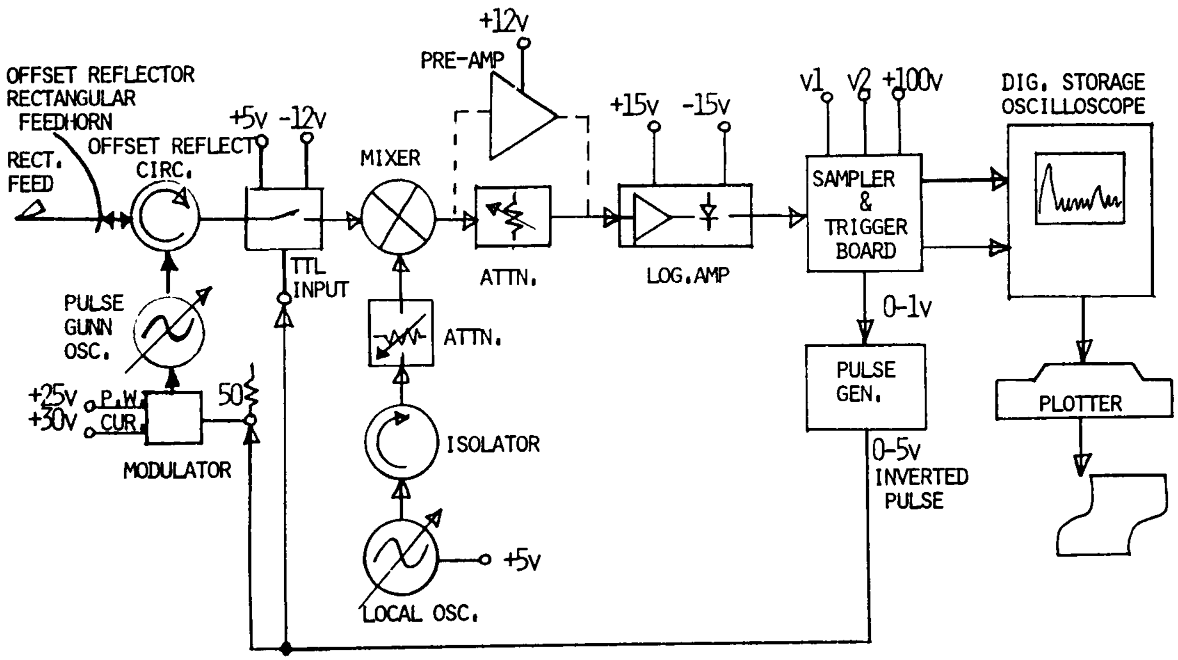


Figure 2.- Test-bed radar detail.

PARTS LIST

Item	Qty.	Description	Manufacturer	Part No.
1	1	Reflector feedhorn	NASA-JSC	-
2	1	Offset reflector (PA-rabolic)	NASA-JSC	-
3	1	Circulator (W/G)	M/A COM	8K679XXX
4	2	W/G-to-W/G section	-	-
5	1	Pulse Gunn oscillator	M/A COM	86794
6	1	Gunn diode modulator	Power Technology	ILC
7	1	50-ohm load	-	-
8	1	W/G P.I.N. switch	Hughes	47970H-2201
9	1	Mixer (co-axial)	Norsal	DBM1-26A
10	1	Co-axial attenuator	Waveline	803
11	1	Isolator (W/G)	E&M Labs	K1113XXX
12	1	Local oscillator (Gunn)	M/A COM	86791
13	1	Pre-amp (VHF)	Avantek	GPD-201
14	1	Log. detecting IF amp	Radar Technology	RTL16040
15	1	Main board ASSY (modified)	Tektronix	TDR1502
16	2	W/G-to-SMA adaptors	Narda	-
17	4	SMA-to-SMA adaptors	Omni-Spectra	-
18	4	BNC co-axial cables	-	-
19	4	BNC-to-SMA adaptors	Omni-Spectra	-

EQUIPMENT LIST

Item	Description	Manufacturer	Model
1	Pulse generator	E and H	122
2	Digital storage oscilloscope (spectrum analyzer)	Hewlett-Packard	8660B
4	Plotter	Hewlett-Packard	7475A
5	Power supplies	Hewlett-Packard	-
6	Power supplies	Kepco	-

RADAR OPERATION

Antenna

An offset parabolic reflector antenna with prime focus feed was built by the task engineer for this test-bed radar. The reflector is basically a 1-foot by 2-foot parabolic section. The reflector is under-illuminated for the purpose of reducing sidelobes. Therefore, the antenna gain and beam width are that expected for an approximately 6-inch by 8-inch parabolic reflector. A specially designed feedhorn is responsible for this characteristic. Figure 3 shows the various important dimensions of the reflector and feedhorn arrangement. The antenna has a nearly symmetrical beam pattern of approximately 5 degrees by 4 degrees at 3 dB points. Antenna patterns are included in figure 4.

Microwave Front-End

Pulses at 24 GHz of about 25 nanoseconds long are generated in the pulse Gunn oscillator. A waveguide circulator directs the transmitter pulses to the antenna which simultaneously sends and receives. After reflection from a target and reception at the antenna, the circulator directs the received pulses through a P.I.N. SPST diode switch which is turned off during the transmit period to protect the IF amplifier from saturation. A co-axial mixer having about 7 dB loss is used in conjunction with a free-running Gunn local oscillator to down-convert the K-band (24 GHz) received pulses to 160 MHz where amplification and then detection occurs.

Intermediate Frequency (IF) Strip

Logarithmic detection is used so that a 70 dB dynamic range can be presented to the sampler in the form of 50 mV to 3 V pulses. Figure 6 shows approximate signal form for target returns. Note that only the sum-channel is used in the present test-bed radar.

Sampler/Trigger Board

This board is used to sample the presently 40 MHz-wide bandwidth IF video output and bandwidth reduce, or time magnify, to about 20 KHz. The operation and circuitry of the board were described in appendix A of Progress Report No. 2 for this project.

Display and Documentation

To obtain qualitative as well as quantitive data about the target returns, a storage oscilloscope and plotter were used. The storage oscilloscope is actually a spectrum analyzer which is capable of functioning as an oscilloscope. Paper documentation is generated by the pen plotter (see fig. 5).

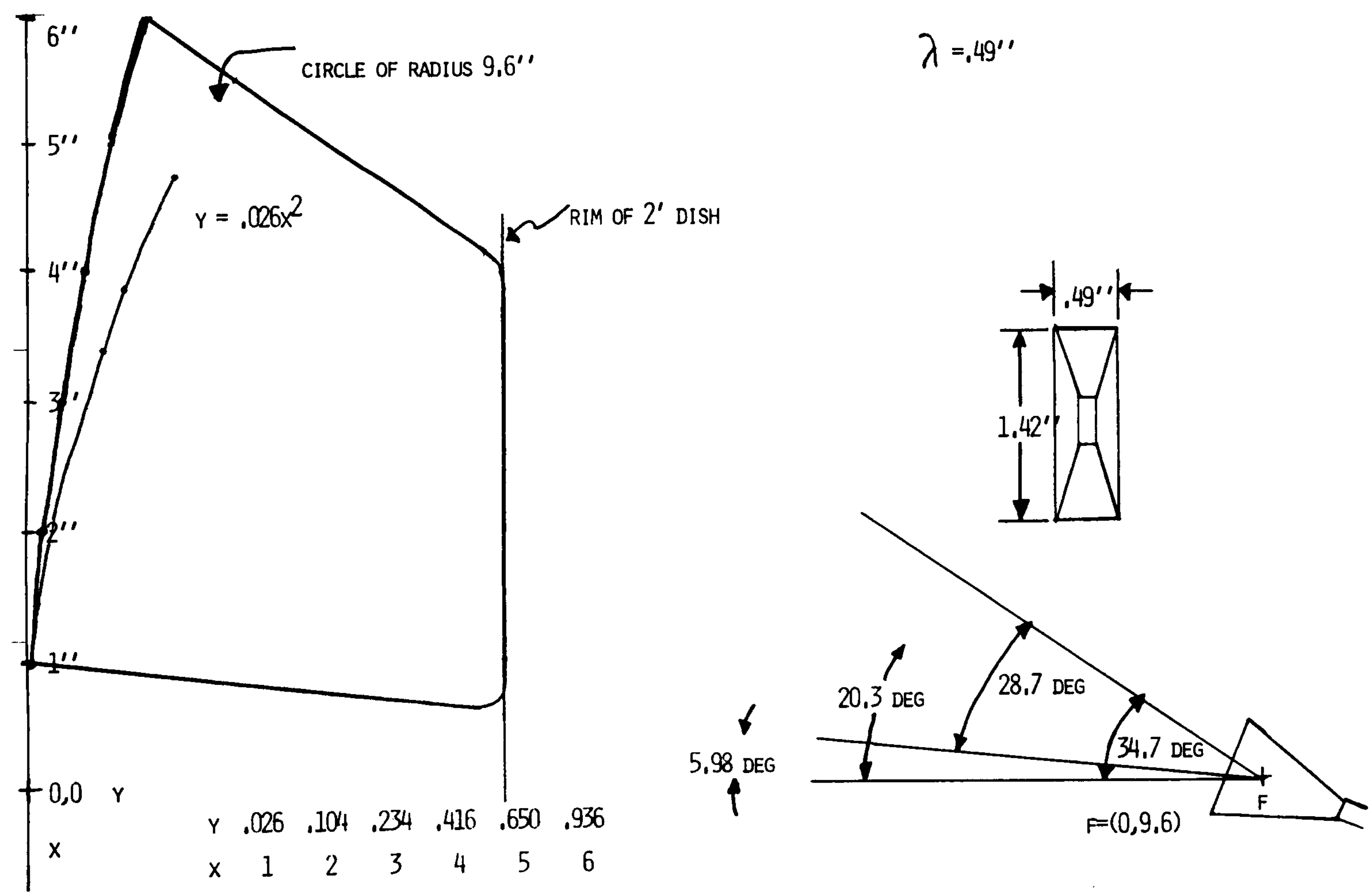


Figure 3.- Reflector and feedhorn arrangement.

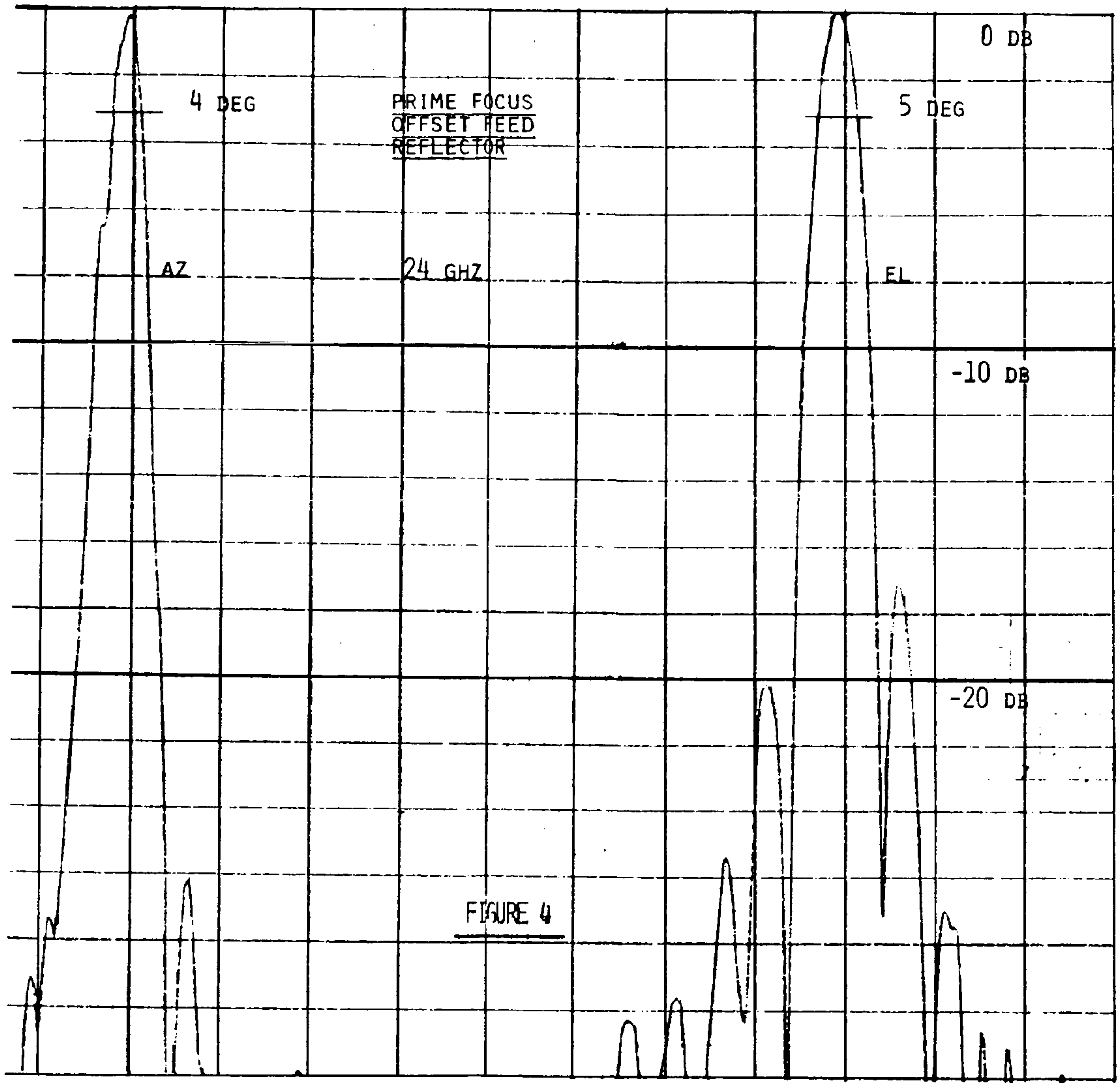


Figure 4.- Antenna patterns.

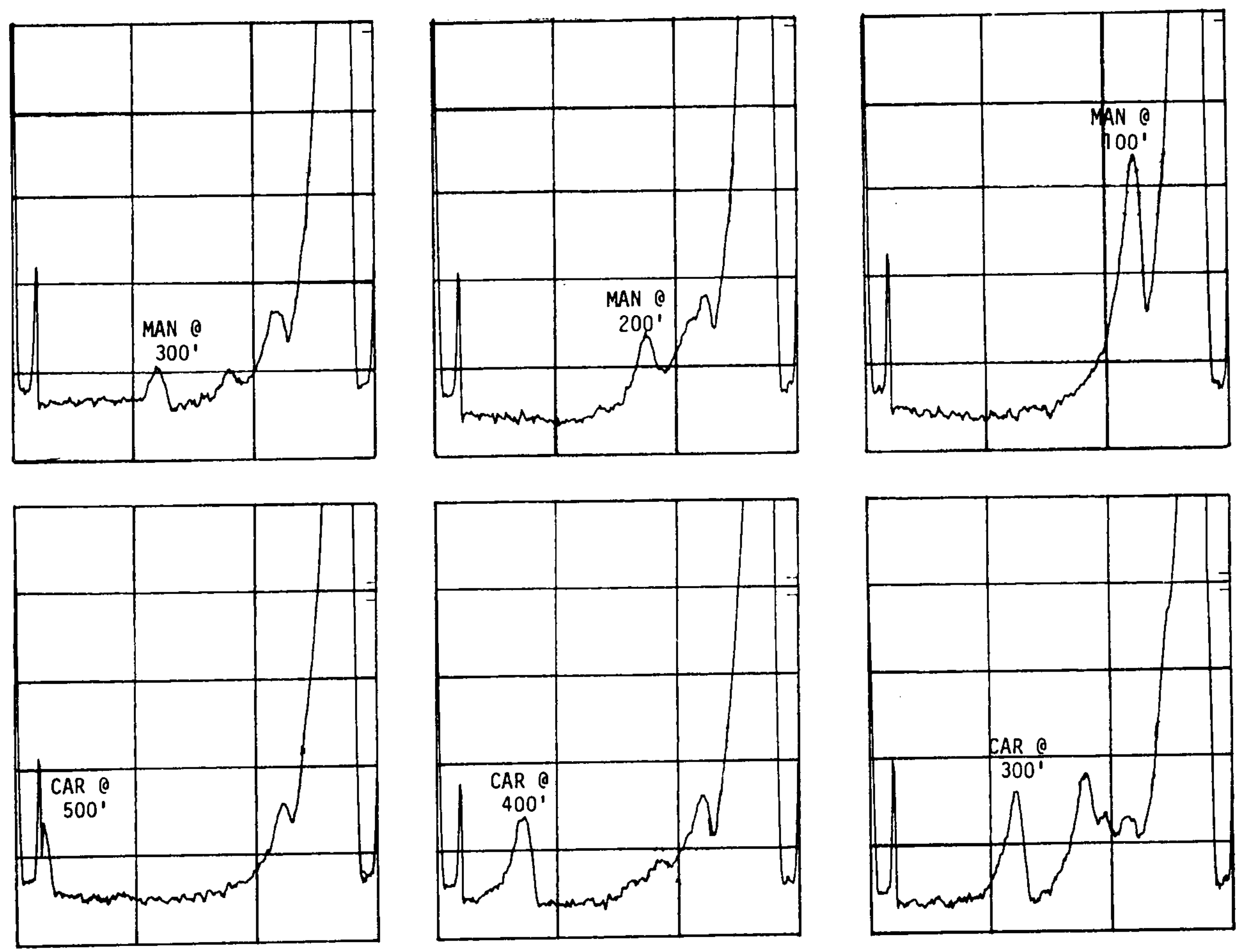
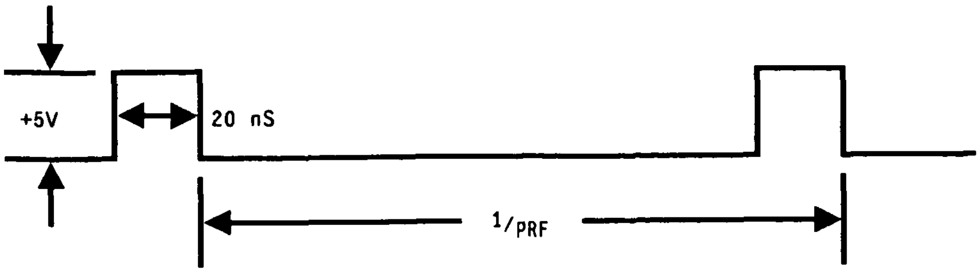


Figure 5.- Pulse-radar output for a man and a car.

VIDEO OUTPUT AND CONTROL SIGNAL INTERFACE
SPECIFICATIONS FOR CAR RADAR

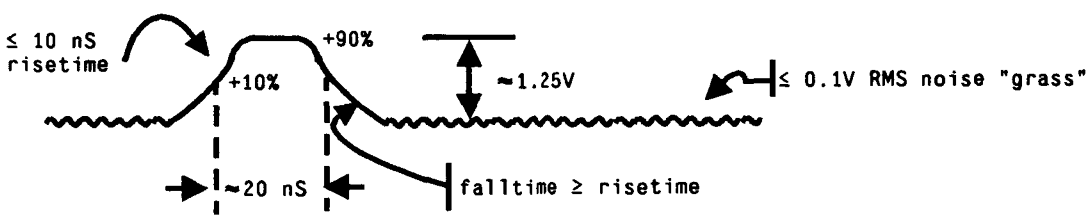
PULSED GUNN OSCILLATOR MODULATOR INPUTS:



(a) Use TTL logic specifications
(b) PRF ≈ 100 KHz (liable to change)

SUM CHANNEL (Σ) (RANGING CHANNEL) VIDEO OUTPUT:

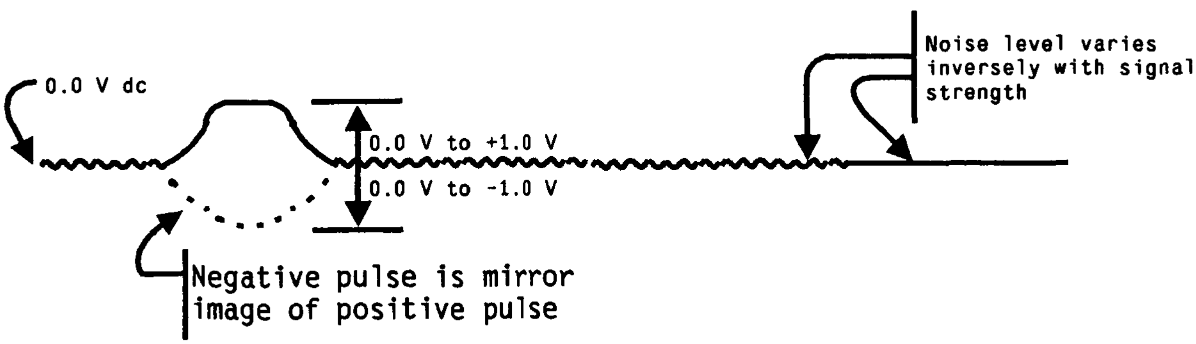
(a) Bi-polar waveform
(b) Pulse width, risetime, and pulse shape same as sum channel



(a) Logarithmic detection is used
(b) Output of video must be connected to 50 ohms

ANGLE ERROR CHANNEL VIDEO OUTPUT:

(a) Bi-polar waveform
(b) Pulse width, risetime, and pulse shape same as sum channel



SUMMARY

A test-bed radar was developed to obtain data in addition to providing a test vehicle for verification and testing of radar concepts, design parameters, as well as individual radar electronic components. Schematic block diagrams, antenna construction and test pattern, target reflection curves, and parts lists are presented from the test-bed radar. This radar is used to support development activities related to a NASA-DOT project to develop an engineering model of an automotive collision avoidance radar.

THE SOFTWARE DEVELOPMENT AND DATA REDUCTION FACILITY

W. X. Culpepper

A laboratory has been activated to support both software development and CAR radar data reduction. The activation phase is complete with the basic hardware elements installed and operating.

The facility is centered about an IBM XT computer with an Intel 8087 mathematical co-processor. Also installed are 640 kbytes of RAM, a color/graphics video interface board, a color monitor, and a Panasonic printer. An analog and digital interface board manufactured by Data Translation, Inc., is also installed.

The DT 2801-A board by Data Translation is crucial in the data reduction of the initial CAR radar system tests. This board will provide the A/D conversion channels to digitize the radar sum and difference channel signals that were recorded on the video recorder. Once digitized, these signals will be mathematically manipulated to support the criteria decisions associated with the avoidance philosophy. Additionally, the test data can be studied to help the synthesis of additional decision criterion. Operation of the DT 2801-A board has been accomplished using vendor-supplied software. This data acquisition subsystem appears to be operational.

A software system called ASYST has been procured from MacMillan Software Company. This software was developed by Adaptable Laboratory Software specifically for use with the IBM processor and includes software routines that support the Data Translation DT 2801-A I/O functions. This software was received the last week of May and has been installed in the IBM XT. Personnel are working through the learning curve phase of this system. First attempts in acquiring data via the A/D converters will occur the first week in June.

In addition to being hardware compatible, the ASYST system offers very powerful scientific programming tools. It is in fact a scientific programming language system. It has built-in capabilities to

1. Acquire data (e.g., via A/D)
2. Produce plots
3. Do statistics
4. Handle complex numbers, vectors, arrays, matrices, and polynomials
5. Calculate eigenvalues and eigenvectors
6. Accomplish least squares approximations
7. Produce Fourier transforms

Speed and ease of use are two important aspects of this package. A 256-point FFT is calculated by the system in less than 1 second. It is expected ASYST will play an important part in the data investigation.

TEST VEHICLE INSTRUMENTATION DESIGN

Fred Beam

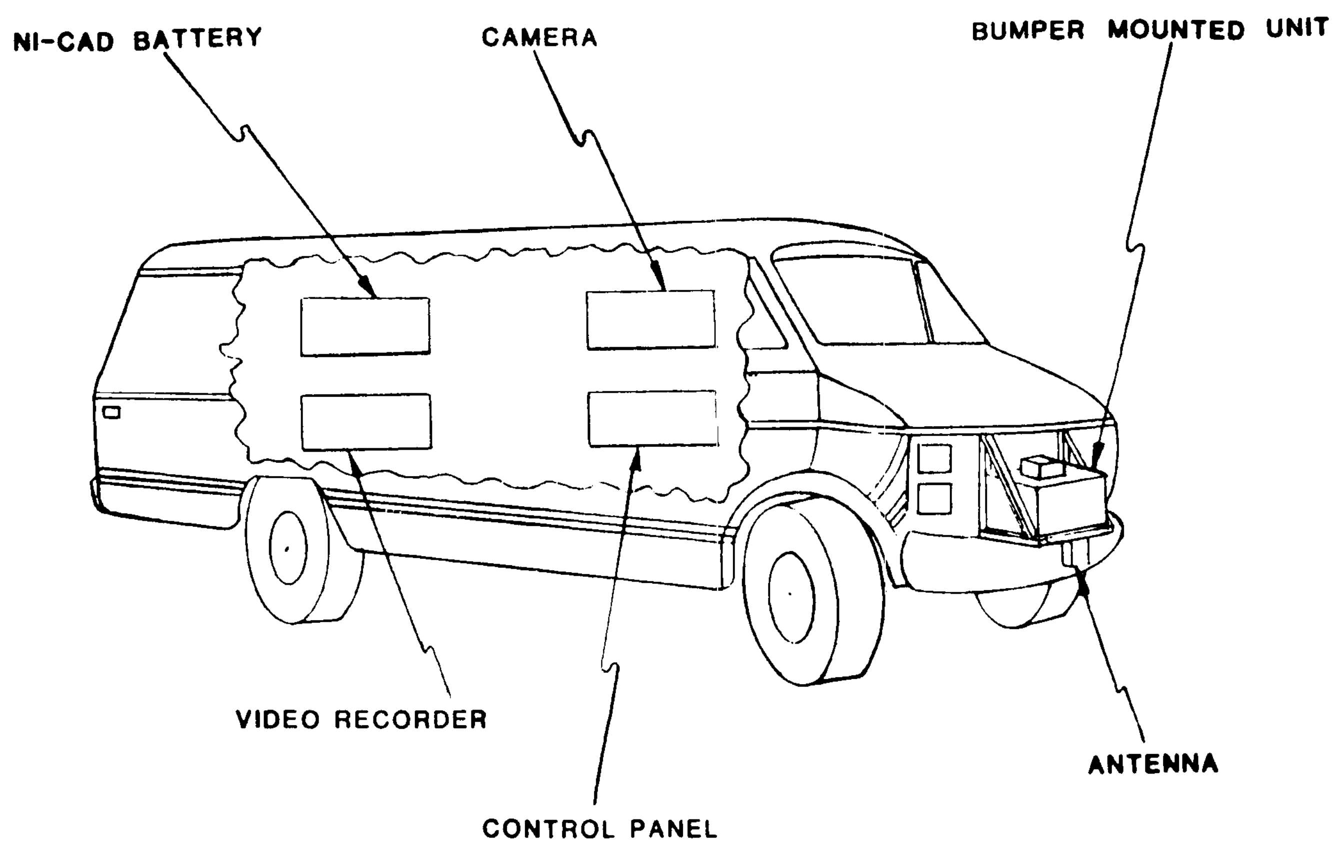
Status Report

Date: May 31, 1985

SSR No. 37548

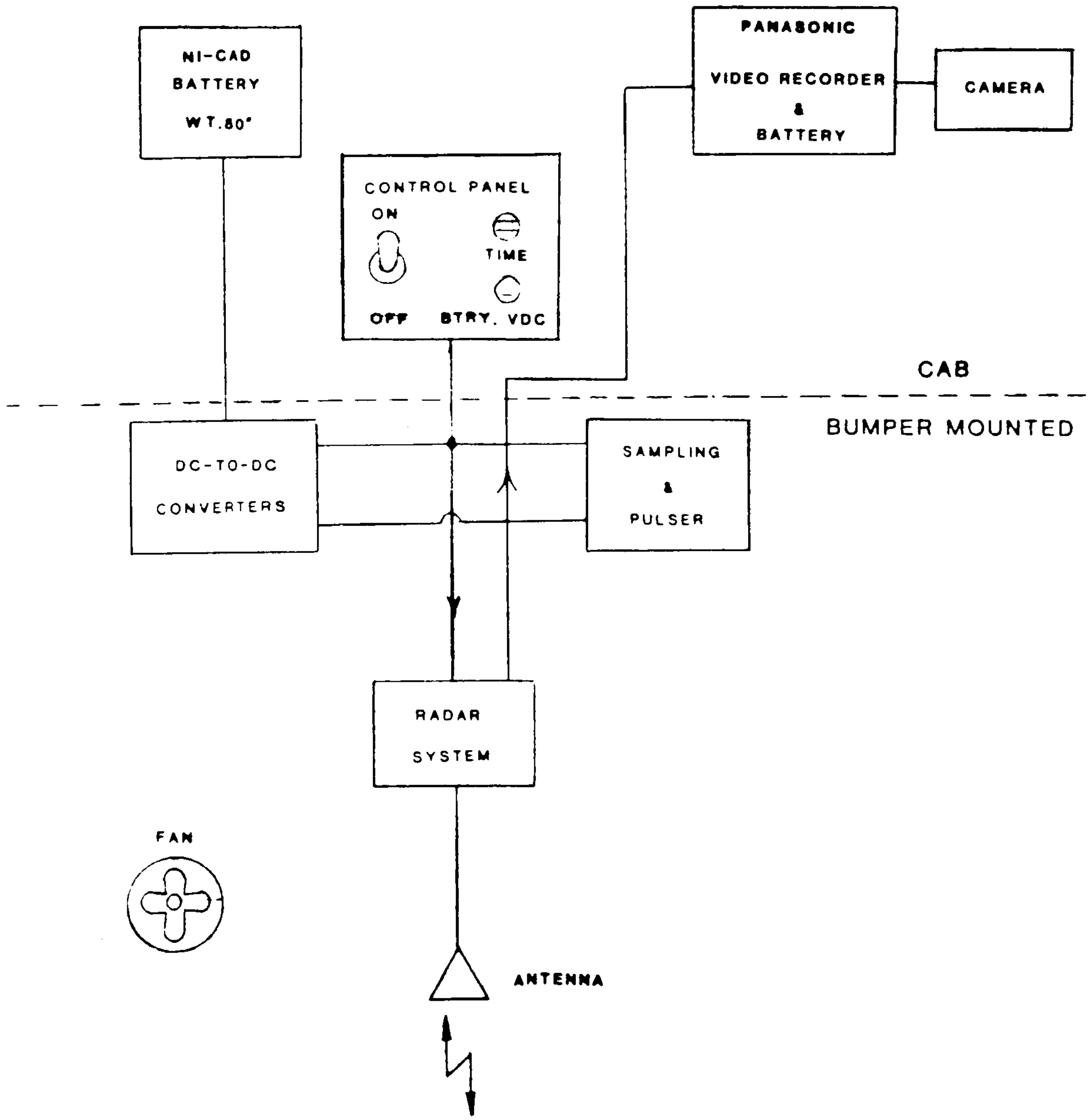
P.W.O. 036-16-692

Task	Remarks
Power Systems	The design and procurement phase of this subsystem has been completed. Assembly will commence when the system is packaged.
Radar	The radar unit's paper design is complete, and a laboratory breadboard is functional. Parts for the vehicle prototype are on order, and we should receive them in 3 to 4 weeks.
Antenna	The design and preliminary testing of the antenna has been completed. The unit is ready for final installation.
Control Panel	Design of the control panel is completed. Parts for the panel have been placed on order. The turnaround time for the needed parts should be short.
Video Recorder	The schematics necessary for modification of the recorder's automatic gain circuits were received from the vendor. After evaluation, the system will be modified to our specifications.
Video Camera	Mounting of the camera will occur during system integration.
Sampling and Pulser Circuits	Two sampling and pulser boards were purchased, modified, and integrated into a dual channel unit. The interface between this unit and the radar unit has been accomplished and preliminary testing completed. Additional range modifications to this unit will be made prior to the final system integration.
Packaging	The prototype packaging for the "CAR" bumper unit has been designed, and implementation is in progress. The structural unit has been designed, and it will be fabricated shortly. Parts being purchased or fabricated include the system cover, radar hold-down brackets, and a system cooling fan.

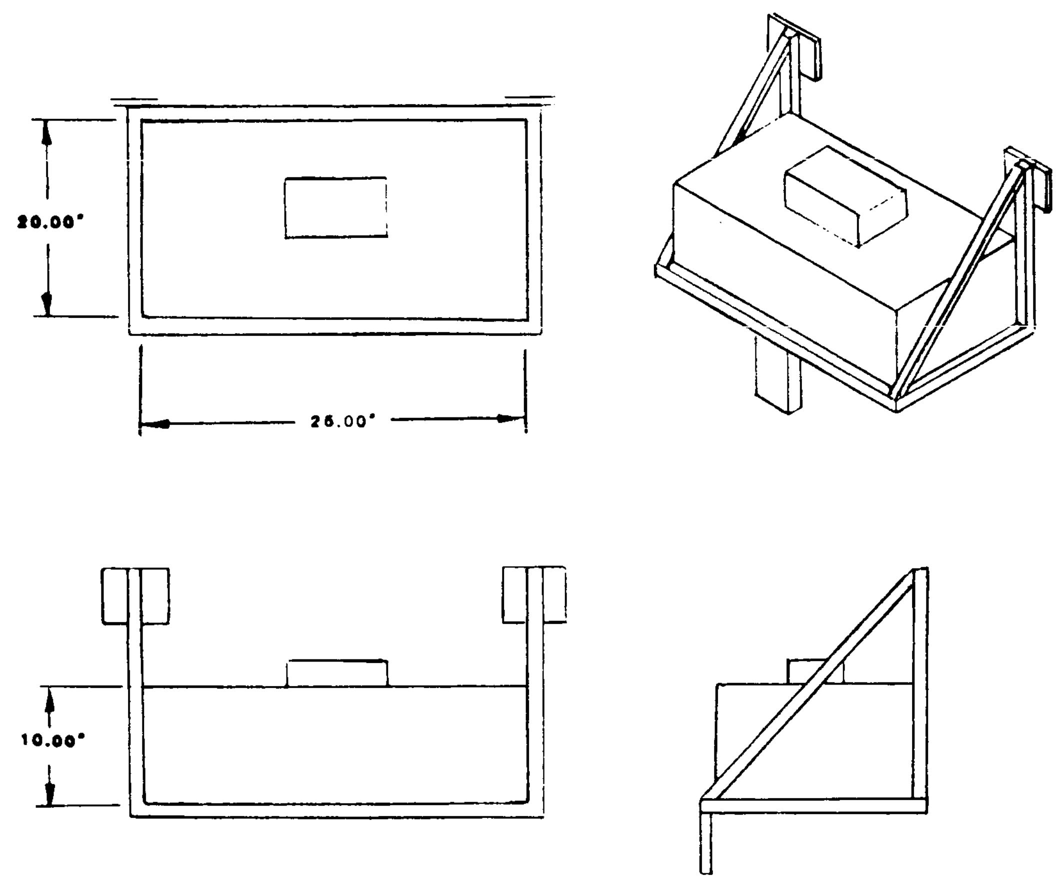


TEST VEHICLE INSTRUMENTATION DESIGN

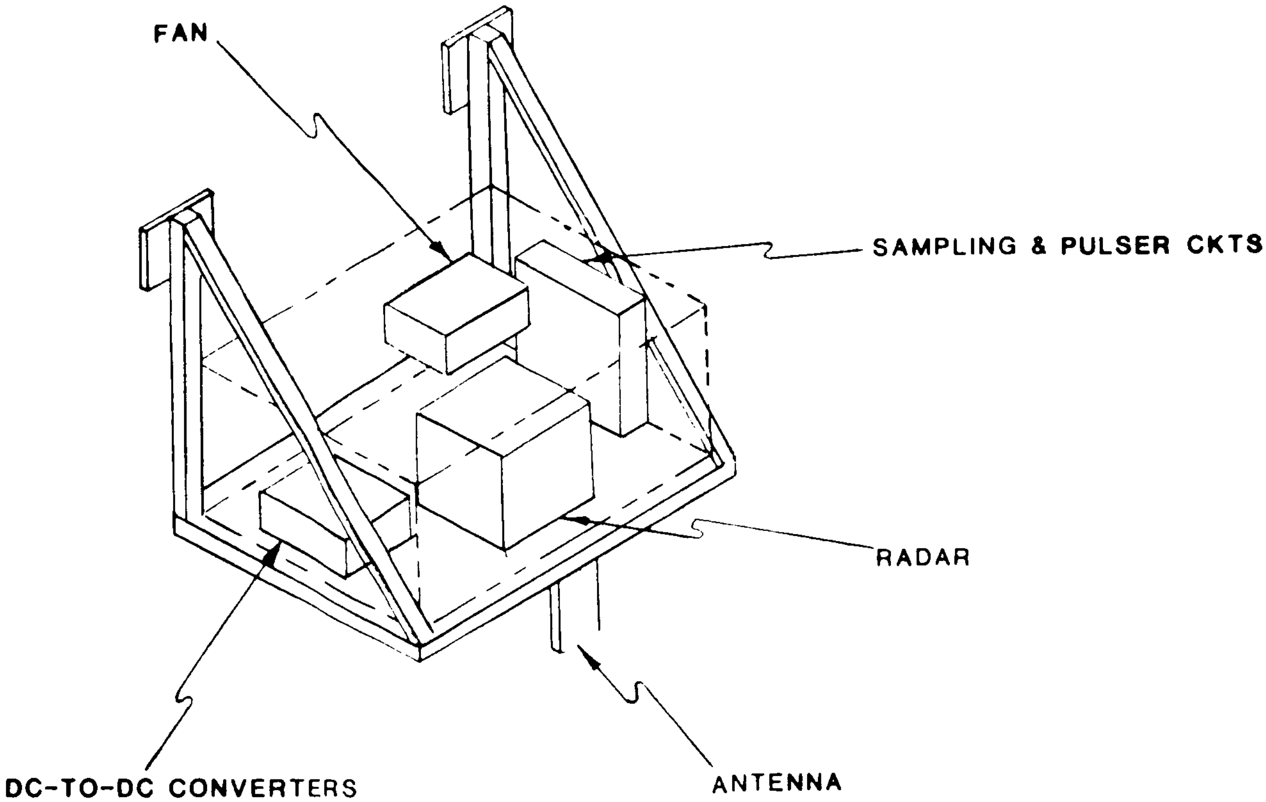
SIMPLIFIED SYSTEM DIAGRAM



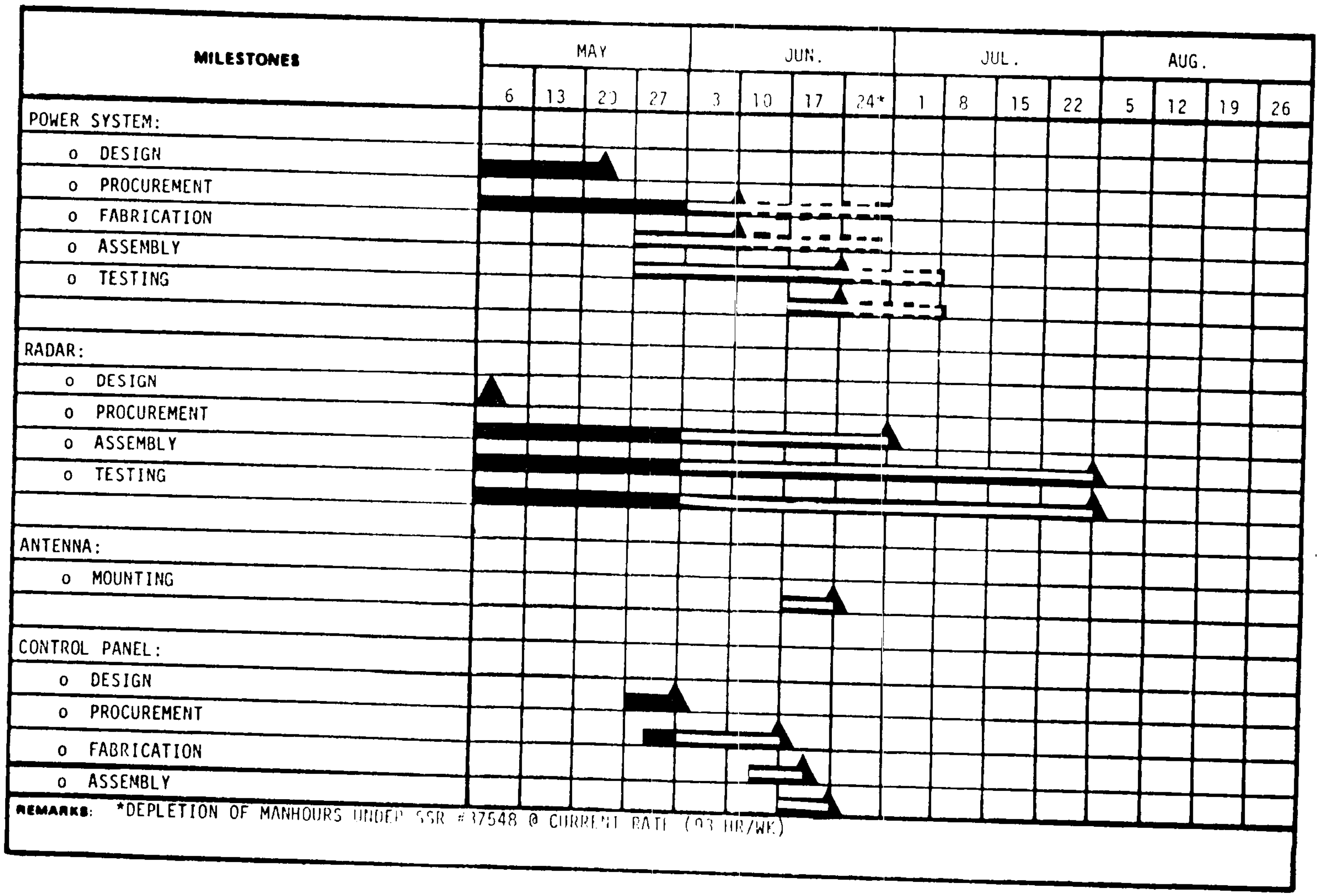
BUMPER UNIT ENCLOSURE



BUMPER UNIT SUBSYSTEM



SCHEDULES



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o PROCUREMENT
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RADAR:
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o PROCUREMENT
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ANTENNA:
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CONTROL PANEL:
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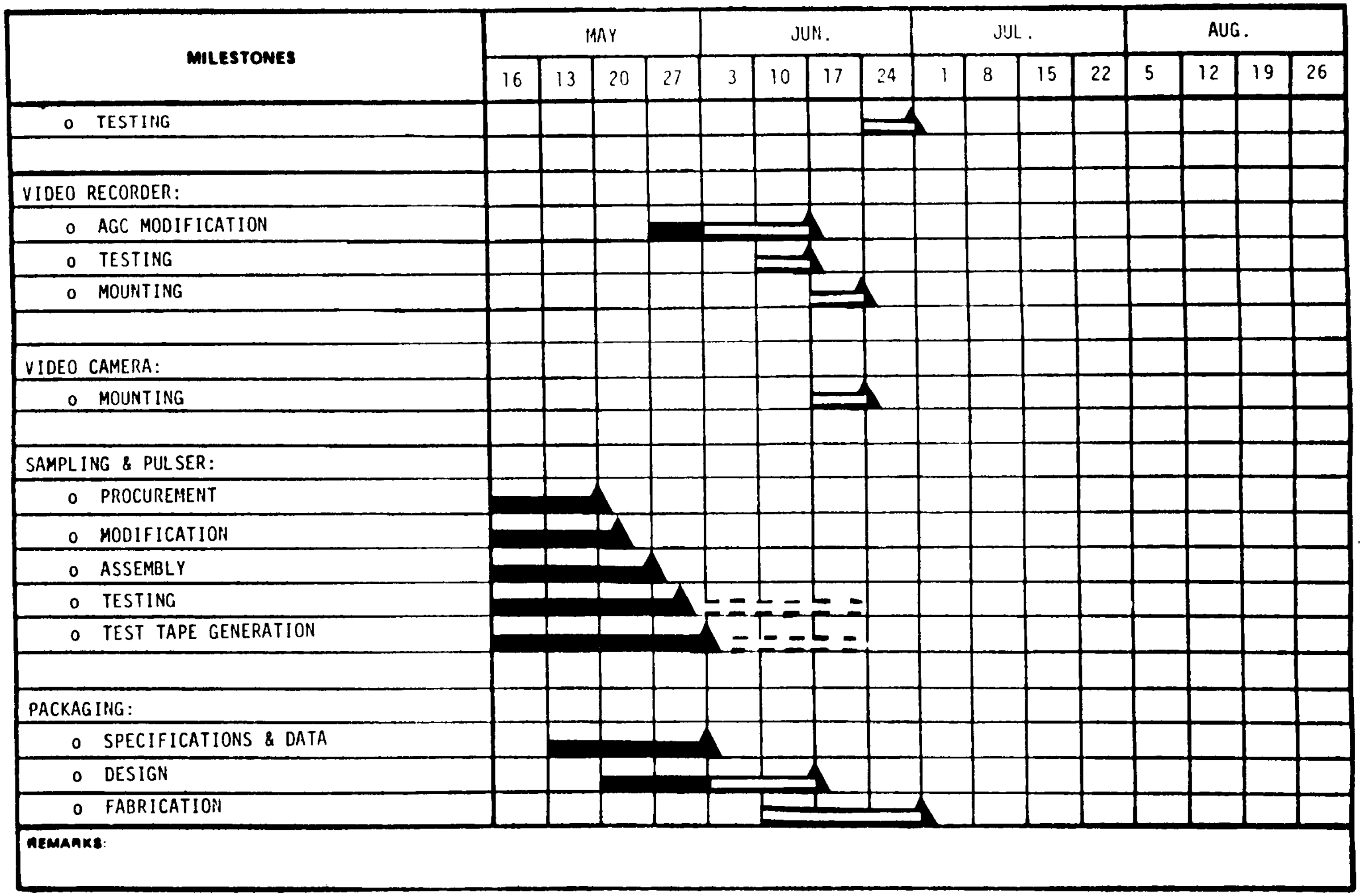
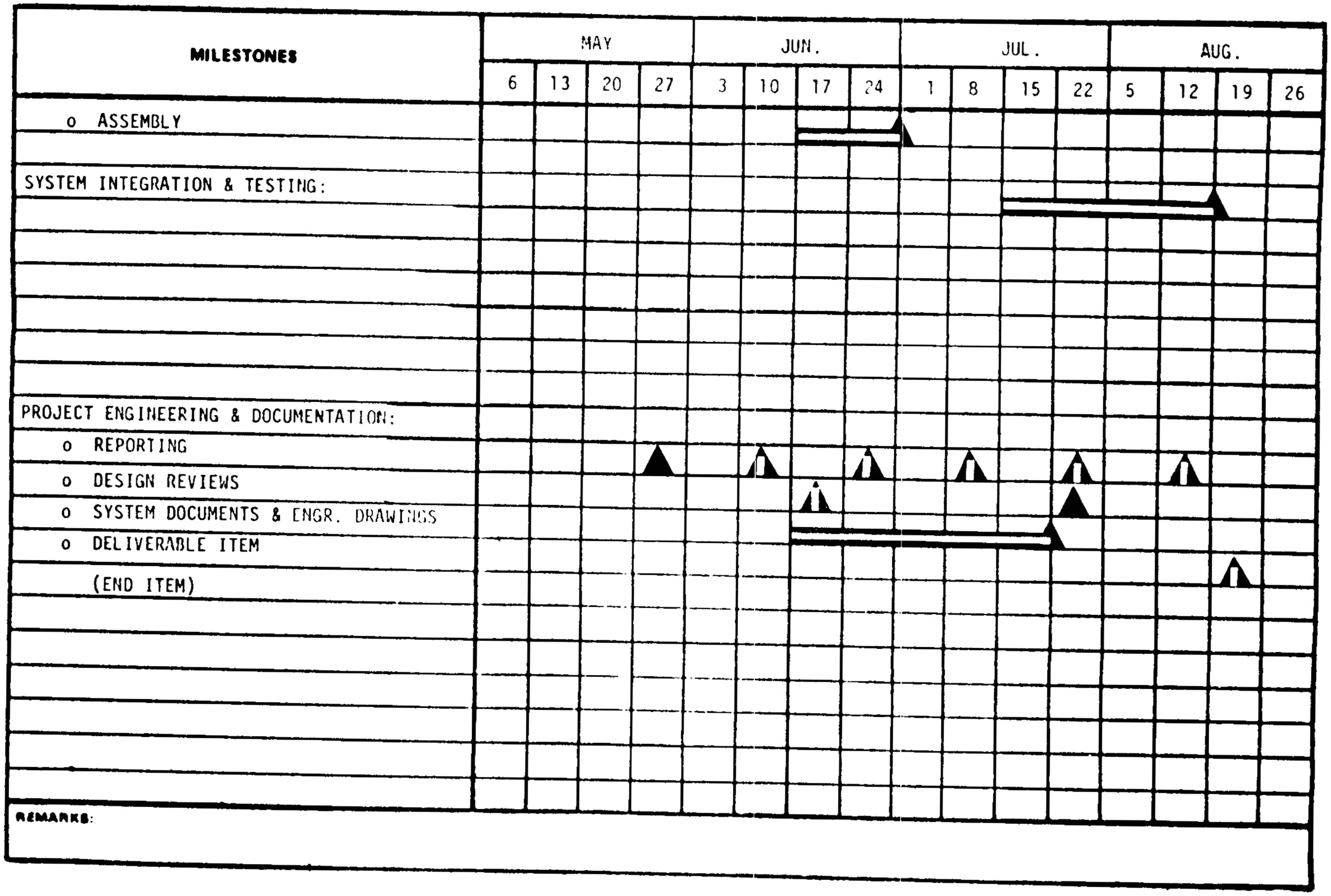
REMARKS: *DEPLETION OF MANHOURS UNDER SSR #37548 @ CURRENT RATE (93 HR/WK)

SCHEDULES - Continued



SCHEDULES - Concluded



RADIATION HAZARDS CONSIDERATIONS

E.T. Dickerson, Ph.D. and
Cecil R. Hallum, Ph.D

University of Houston-Clear Lake

(See Volume 1: Technical Report)

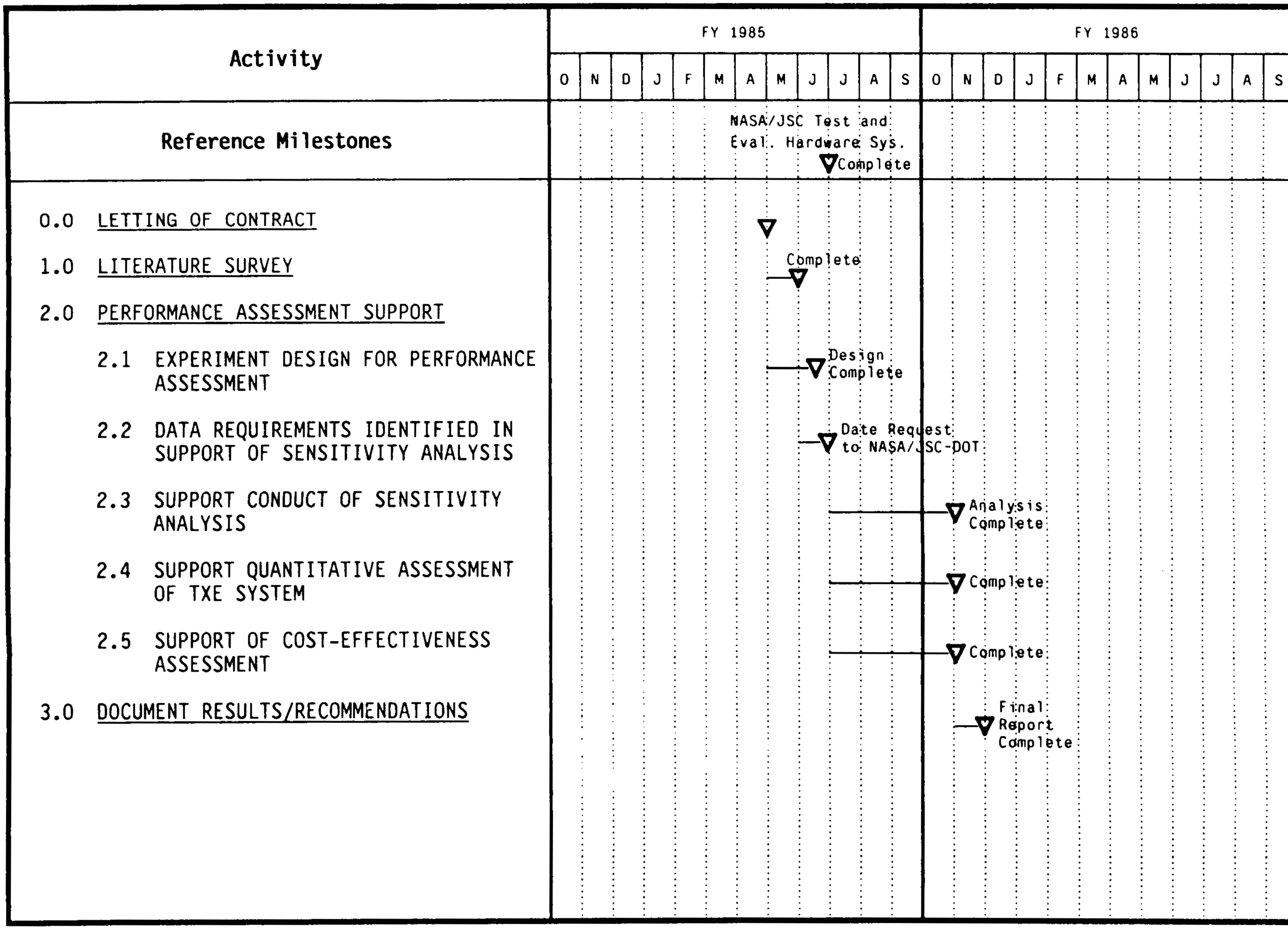
MODELING AND ACCURACY CONSIDERATIONS

E.T. Dickerson, Ph.D. and
Cecil R. Hallum, Ph.D

University of Houston-Clear Lake

(See Volume 1: Technical Report)

UH-CL SCHEDULED SUPPORT ACTIVITIES



STATIC RADAR TEST SETUP

Dan O'Connell

To begin investigating the characteristics of the signals returned from real targets during the automotive radar development phase, a test device was fabricated which will allow some analysis to be done on the effect of phase distortion from vehicle-sized objects on monopulse processing. The device consists of two small horn lens antennas connected to a common source and mounted so that their phase centers are 3 inches apart. Both antennas transmit and receive. The received signal from both the antennas are mixed together producing an output corresponding to the Doppler frequency difference seen by the two antennas. This frequency output ideally will be zero if the target vehicle is approaching from dead ahead and will grow larger as the angle grows larger.

The approach taken with this device was to place it in a fixed position on the antenna range and drive a test vehicle (van) at it from several different approach angles and offset distances. Data were recorded onto the audio channel of the video recording system, as has been done previously.

The purpose of this testing was to make some initial evaluations of the ability of this method to produce angle data which are reliable enough to use in algorithms which will make warn/no warn decisions. The data collected from these tests will soon be analyzed with the data analysis system which has been described elsewhere in this report. A photograph of the device was presented during the first oral presentation in February.

SECTION 3
PROGRESS REPORT NO. 2

Paul W. Shores and Kumar Krishen

INTRODUCTION

This second reporting period has seen the technical effort begun in earnest. Resources have been allocated both to technical development and to the bringing online of test hardware and support equipment which is essential to performing the task. Most of the effort during this reporting period has centered on the latter rather than the former activity. This is a reflection of the fact that certain capabilities in terms of test procedures, data recording, and analysis need to be developed specifically for the unique requirements of this program. Details of these efforts shall be presented herein.

REVIEW OF PREVIOUS ACTION ITEMS

We begin with a review of those items presented in Progress Report No. 1 contained in the section entitled "Efforts In The Upcoming Reporting Period."

NASA-JSC

Item No. 1 referred to efforts being directed at antenna development. It was necessary to expend considerable time and effort in order to repair the malfunctioning receiver system of the radar boresight range; however, these efforts have been successful and the receiver is now operating properly. Preliminary antenna pattern data gathered using standard gain reference horns indicate a problem area in that data are being degraded due to unwanted scattering from nearby objects. This difficulty arises from the fact that the facility is being utilized to perform a type of testing it was not specifically designed for. While the data degradation is at present serious, the problem is not considered to be insurmountable and corrective measures are being implemented. No pattern data on test antennas will be taken until satisfactory results are obtained with the standard references. These efforts are considered crucial because the building 14 anechoic chamber, which is specifically designed to do this type fo testing, will not likely be available for several more weeks due to testing of Shuttle antennas.

Antenna development efforts are continuing. The monopulse microwave slotted array antenna is completed and ready for testing. An alternative concept antenna, based on a section cut from a parabolic reflector, is nearing the completion stage and should be ready for testing soon. The relative performance of the two types of antenna systems may then be compared.

Item No. 2 stated that hardware procurement efforts for the radar front end circuitry would continue, and this has in fact been the case though not all items have yet been received. A brief summary report on this topic is provided in a later section of this report.

Item No. 3 referenced the initiation of the effort to document the potential collision warning computer algorithms. This report has been started, but is not yet completed. The primary reason for postponing completion of this report is to allow time for NASA personnel to access the Department of Transportation (DOT) data base to gain certain sets of parameters from the accident data. These data sets can then be implemented into computer simulations which will test the algorithms' performance in collision prediction and provide quantitative measures against which to judge competing concepts. This quantitative assessment against real accident data will greatly enhance the substance of the report. The appropriate DOT personnel will be contacted very shortly regarding access to the data.

The static radar test setup, item No. 4, has been completed and a preliminary data set has been taken. Problems which have arisen in the processing of this data have hampered any efforts to draw meaningful conclusions, but these are being worked. Also, the system is being enhanced by the addition of a radar front end which operates at 100 GHz. Once the data handling problems have been worked, additional sets of 100 GHz data will be taken and then compared to the original set.

Item No. 5, the tradeoff study, will be included as part of the University of Houston study effort. Delay in the contract awarding has prevented a formal start of this effort.

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The GFE circuit board analysis has been completed and is being modified to perform the functions of the crash avoidance radar. Significant progress has been made in this area.

The sampling system and modulating pulse generator circuits are not self-contained except for an external slow ramp source and power supplies. The modulating and fast ramp circuits are fabricated on two small circuit boards. These have been mounted to the Tektronix sampling board to form one compact unit.

The output of the sampling system was connected to a scope for testing. Coaxial (coax) cables of several lengths were also connected to the sampling system to simulate the radar and target. Each cable, when not terminated in its characteristic impedance, will produce a reflection which simulates a target. Each foot of RG-58 coax represents about 1.5 feet from radar to target. The system has been calibrated to display the generated modulating pulse and reflections up to 1 μ thereafter. This is equivalent to radar targets up to 500 feet.

A more detailed description is included in a later section.

Delivery of several major components of the data processing support equipment is expected within days, as of the writing of this report.

UH-CL

As noted earlier, delays have occurred in the contract awarding process. A major hurdle was recently cleared when the formal request for proposal (RFP) was sent to the contractor. UH-CL has its response prepared to send in. Formal contract awarding should follow shortly after receipt of the response.

Despite these delays UH-CL personnel have begun a more thorough literature search and have acquired several additional reports. They have distributed copies to NASA personnel and are themselves reviewing them.

OTHER ACTIVITIES/NEW STARTS

NASA-JSC

Video recording equipment has been purchased which will allow radar Doppler signal recording along with video data recording of the scene producing the signal. This technique allows time correlation of events in traffic with the signal undergoing analysis. This technique was demonstrated to DOT previously before the actual start of the ARACA Program. It will be used initially to record data with the static test bed radar and later will be utilized in road tests.

Up to now, the system has been used only with continuous wave (CW) sources. Tests are currently underway to determine the frequency response of the system to a pulsed input.

A report has been prepared describing the overall functional requirements of the collision avoidance radar system and is included in this report.

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Preliminary definition and procurement efforts have begun to instrument the test vehicle (Dodge van) with the necessary hardware and power to support road testing. Purchase efforts are underway to obtain the mounting hardware which will support the antenna and electronic assemblies.

EFFORTS IN THE UPCOMING REPORTING PERIOD

There are a number of existing problem areas which will be worked in the upcoming period:

- The radar boresight range will be "cleaned up" in the electromagnetic sense so that antenna testing can proceed.
- The difficulties with the data interfaces from the static test setup will be worked so that some meaningful analysis can be performed.
- The responsiveness of the video recording system to pulse inputs will be determined.

- The computer algorithm report will continue to be worked. Data sets will be gathered from DOT and a computer simulation developed to test algorithm performance.

- Hardware fabrication will continue as components become available.

- Consideration is being given to modifying a surplused positioning system to accommodate mounting an automobile and other similar objects. This would allow the vehicle to be rotated so that radar cross-section measurement can be performed. It is necessary to perform cross-section measurements at some point in the programs.

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- Fabrication of the sampling circuit board will be completed.

- Procurement of the data processing support equipment will be completed and installed in the laboratory.

- Laboratory data analysis equipment will be assembled, and software techniques will be evaluated.

- Instrumentation and modification of the test vehicle should be well underway, if not completed.

UH-CL

- Formal contract awarding should occur during this period so that analysis efforts may get underway.

- Literature research and review shall continue.

- A meeting will be held with NASA personnel to discuss the DOT data base and the needs of UH-CL personnel as to which specific parameters will be required for analysis.

SUMMARY

The first progress report period covered the finalizing of administrative setup and the initiation of technical efforts. During this second reporting period significant effort was concentrated on the bringing on-line of the hardware and necessary test facilities to support the radar development. A number of problems have surfaced, which is to be expected when complicated systems are in their developmental stage. However, nothing is considered insurmountable and proper attention is being focused onto those areas where necessary. It is hoped that beginning with the next progress report a new section covering technical progress and test results can be included, which will become a standard section thereafter.

APPENDIX A

PULSER AND SAMPLING SYSTEM DESCRIPTION

by

Tom D. Lyons
LEMSCO

PULSER AND SAMPLING SYSTEM DESCRIPTION

INTRODUCTION

The function of the pulser is to generate a modulation pulse for the radar transmitter. The pulser controls both the rate and width of the transmitted pulses.

The purpose of the sampling system is to slow-down or time-magnify the received echo signals. These high speed signals would be difficult to record and process at real-time rates.

The heart of the sampling system is a circuit board from a Tektronix type 1502 time domain reflectometer. Due to different requirements, a few of the circuits have been modified or replaced by our own design.

PULSER

The pulser consists of a 250 KHz oscillator, a delay stage, and the modulation pulse shaper. These can be seen in the block diagram of figure 1.

Oscillator

The oscillator is designed around a TLC555 integrated circuit. Its frequency of 250 KHz sets the transmitted pulse interval at 4 microseconds. The clock generator on the Tektronix board will not operate well at this frequency.

Delay

The delay stage ensures the start of the sampling sequence before the leading edge of the transmitted pulse. This will cause the transmitted pulse to appear in the output of the sampling system, along with the echos, for use as a time reference.

There is some delay in the transmitter and receiver circuitry, but it is thought to be an insufficient amount. The delay stage has been designed around another TLC555.

Modulation Pulse Shaper

The shaper provides the transmitter with a fast modulation pulse. Its rise and fall times are 5 nanoseconds or less. A typical width for the pulse is 20 nanoseconds.

The shaper utilizes an NE521 and provides a TTL output. The Tektronix board has a tunnel diode pulse generator. It was not used because it cannot deliver the required TTL output.

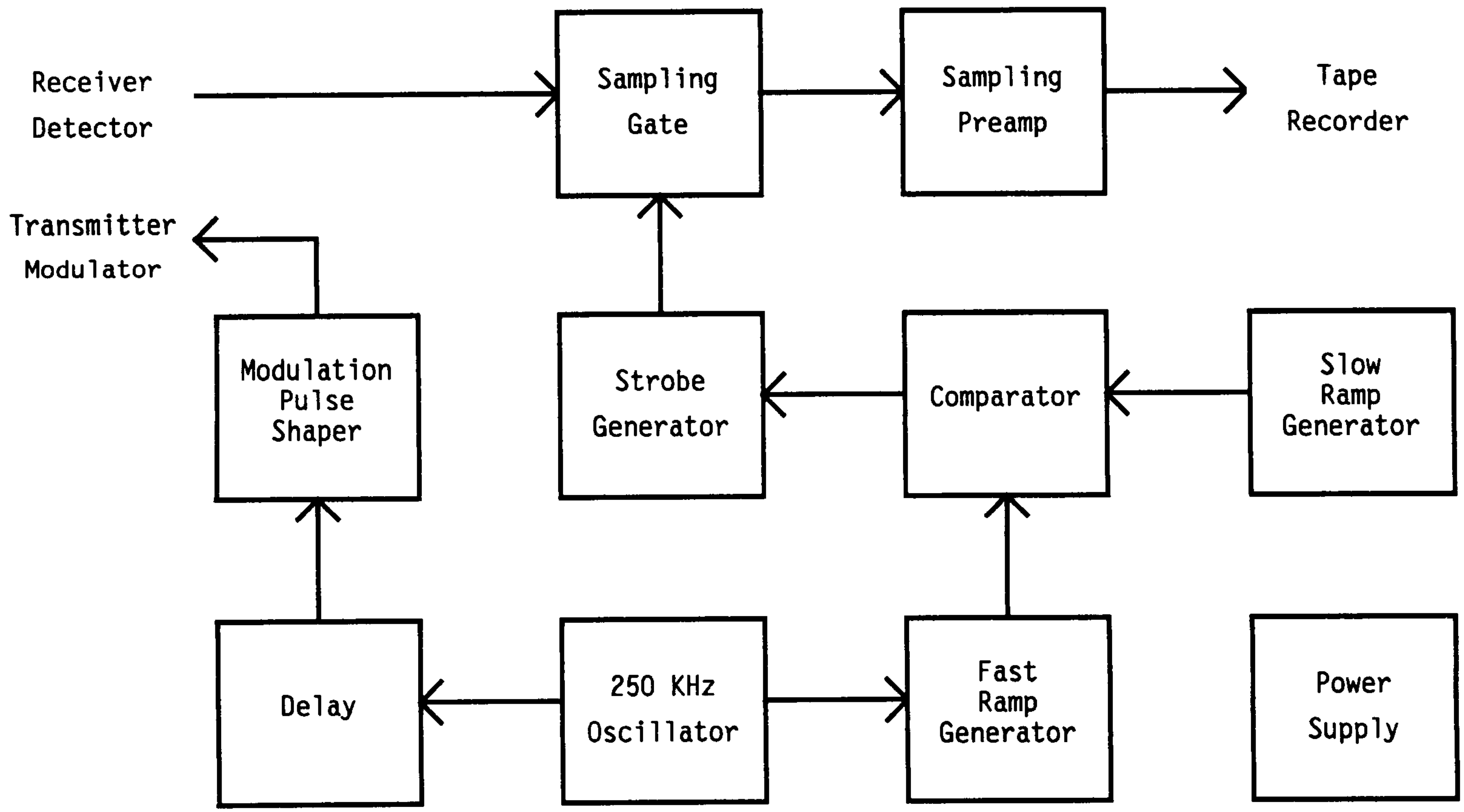

Figure 1.- Block diagram of pulser and sampling system.

SAMPLING SYSTEM

Sampling is the technique used to slow-down or time-magnify the fast incoming pulses of the demodulated signal. The signal contains transmitted pulses and their echos. The transmitted pulses are used as a time reference for the echos.

The sampling system consists of a 250 KHz oscillator, fast ramp generator, slow ramp generator, comparator, strobe generator, sampling gate, and sampling preamplifier. These are shown in the block diagram of figure 1.

Sampling Technique

Basic Characterisitics

The 250 KHz oscillator triggers both the fast ramp generator and the delay stage at the same time (see figure 2). For each transmitted pulse, the fast ramp is triggered one time, and one very narrow sample will be taken of the demodulated signal. Many transmitted pulses and samples are required to reconstruct the signal in the magnified item domain.

To achieve time magnification, it is necessary to take each sample at just the right time, relative to the transmitted pulse. The appropriate time is determined by comparing the outputs of the two ramp generators.

The generators produce ramps that differ greatly in their slopes. In relation to the fast ramp, the slow ramp can be considered as hardly more than a linearly varying dc voltage. Figure 2 shows one cycle of the fast ramp superimposed on the limits of the slow ramp.

The comparator initiates a sample each time the negative slope of the fast ramp crosses the slow ramp.

Sequence of Events

Assume the slow ramp has just begun its sweep. It is at point "B" in figure 2. At point "A", the oscillator triggers the start of the fast ramp. The delay for the modulation is also started at this time. When the fast ramp reaches point "B", the first sample is taken. The fast ramp continues and completes its cycle. When the oscillator triggers the fast ramp again, the slow ramp will have progressed slightly and caused the second sample to be taken between points "B" and "C", but much closer to "B".

The delay ends and a pulse is transmitted each time the fast ramp reaches point "C". Samples are not taken on the positive-going back slope of the fast ramp.

As the slow ramp progresses and the oscillator continues to trigger to fast ramp, consecutive samples are taken. Each sample is taken at a point further down the slope of the fast ramp than the previous sample.

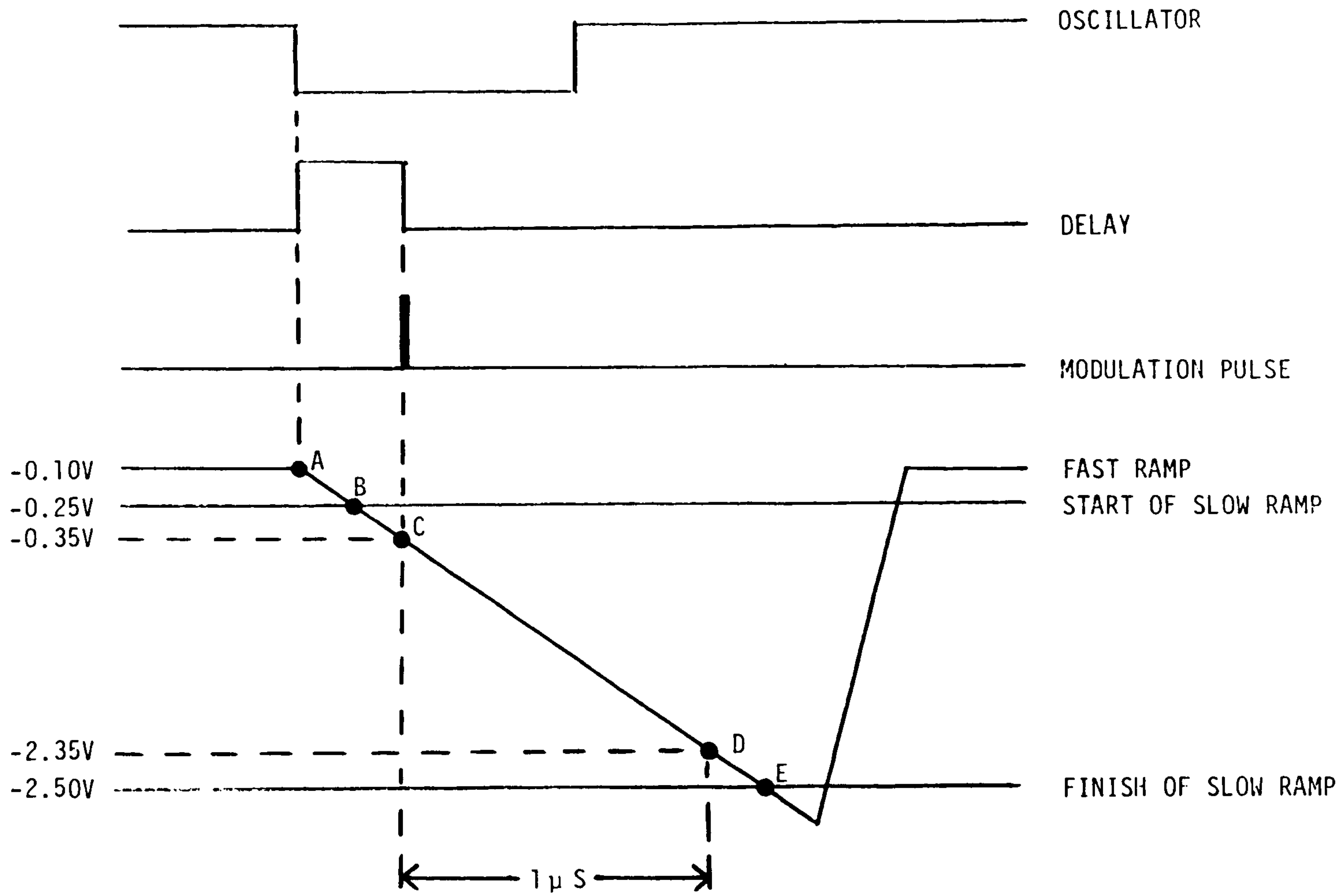

Figure 2.- Timing sequence.

When the slow ramp reaches point "C", the transmitted pulses will be sampled. As the slow ramp progresses beyond "C", the echos of the transmitted pulses will be sampled.

Example

For example, assume the slow ramp is at point "D". The fast ramp will reach point "D" 1 microsecond after a pulse transmission. Therefore, a sample will be taken 1 microsecond after the transmission. The pulse will travel approximately 1000 feet in a microsecond. If an echo is captured in the sample, it would be from a target about 500 feet from the radar (1000 feet roundtrip).

The sweep of the slow ramp ends at point "E". There is no interest in targets much beyond 500 feet.

Additional Characteristics

To avoid problems with the sampling sequence, it is necessary to adjust the ramp altitudes to cause the fast ramp to swing beyond both limits of the slow ramp swing.

Sampling will occur on the positive going-back slope of the slow ramp. These data should be discarded.

The slope of the fast ramp determines the maximum target distance that can be sampled. The slope of the slow ramp determines the time required to reconstruct the sampled signal and its resolution.

The time magnification factor is equal to the ratio of time required for an event to occur after magnification, to the time required for the same event to occur in real time. It is also equal to the ratio of the ramp slopes.

$$MF = \frac{\text{Magnified time}}{\text{Real time}} = \frac{\text{Slope of Fast Ramp}}{\text{Slope of Slow Ramp}}$$

It is possible for an echo to appear at the wrong time. There are 4 microseconds between transmitted pulses. If an echo of a transmitted pulse is not received until after the next transmitted pulse, the target would be more than 2000 feet from the radar. But, it is unlikely that an echo from such a distance would have sufficient strength to be a problem.

CIRCUIT DESCRIPTION

Fast Ramp Generator

The oscillator triggers a ramp width timer designed around 2 TLC555 integrated circuits. The timer output gates a ramp forming stage, which contains a current source, charging capacitor, and discharge circuit. The ramp forming stage is part of the Tektronix circuit board.

Slow Ramp Generator

The design of the slow ramp generator has not been completed. The sweep output of an oscilloscope has supplied the ramp during testing.

Comparator

The Tektronix sampler comparator is used here.

Strobe Generator

The strobe generator consists of a preamplifier, signal-shaping amplifier, avalanche transistor circuit, snap-off diode circuit, and strobe shaping shorted strip lines. These are the Tektronix circuits. Two time constants in the signal-shaping amplifier were changed to allow operation at a 250 KHz pulse rate. The output of the strobe generator drives the sampling gate with a subnanosecond pulse width.

Sampling Gate

The sampling gate takes subnanosecond samples of the demodulated incoming signal. The gate is a dual diode. Time constants in the gate circuit are long enough to hold the sampled voltage until the next sample is taken. The resultant gate output is a series of small steps. The Tektronix sampling gate is used.

Sampling Preamplifier

The sampling preamplifier has a voltage gain of two. A positive feedback network is included to improve the sampling efficiency. The steps in the output of the sampling gate are smoothed by the limited bandwidth of the preamplifier. Tests have shown it has a bandwidth of dc to about 10 KHz. This may need to be increased. The preamplifier output will be recorded on magnetic tape. The Tektronix sampling preamplifier is used.

PRESENT STATUS

The pulser and sampling system circuits that are not part of the original Tektronix board, have been designed and fabricated. Exceptions to this are the slow ramp generator and the power supply. These two functions are being provided by test equipment.

The pulser and fast ramp circuits are fabricated on two small circuit boards. These have been mounted to the Tektronix board to form one unit.

TESTING

Test Conditions

The output of the sampling preamplifier was connected to an oscilloscope for displaying the time magnified signal. Unterminated coax cables of several lengths were connected to the signal input of the sampling gate. Attenuated pulses from the modulation pulse shaper output were fed to the sampling gate signal input. Reflections in the cables provided the echos.

Each foot of RG-58 coax represents about 1.5 feet from radar to target. The sampling system was calibrated to display the modulation pulse and reflections up to 1 microsecond. This is equivalent to targets up to 500 feet.

Test Results

The time magnified signal looked good for magnification factors of 5000 or more. Although, the pulses were somewhat rounded for factors of 1000. It may be necessary to increase the bandwidth of the sampling preamplifier.

APPENDIX B

MICROWAVE ELECTRONICS PRELIMINARY DESIGN

by

C. L. Lichtenberg

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RADAR MICROWAVE ELECTRONICS PRELIMINARY DESIGN

This report describes the preliminary technical design of the microwave radio frequency (RF) components for the proposed crash avoidance radar being developed by NASA-JSC.

Figure 1 shows the proposed design of the major RF through intermediate frequency (IF) components. An approximately 20-nanosecond input pulse to the drive of the Gunn oscillator initiates a 20-nanosecond pulse at 24.150 GHz with a peak power of 2 watts. The circulator directs the RF pulse to the sum channel of the monopulse antenna. Targets in the field-of-view are illuminated and subsequently reflect some of the energy back to the antenna. A sum and delta pulse output are generated by these target reflections.

The target return sum channel output is routed through the circulator transmit/receiver (T/R) switch, and then into the mixer down-convertor. After down-conversion to 400 MHz, the sum channel pulse is split three ways to drive (a) the "D" channel, (b) the angle detector, and (c) the ranging channel.

The ranging channel is composed of a logarithmic detecting amplifier whose output is sampled by digitizing circuits. This sampled output can be processed by the data processing circuitry to determine distance to a target. In addition, the amplitude of the detected pulse gives an indication of return signal strength.

The portion of the sum channel pulse which goes to the angle detector is used as a reference input. The amplitude of the angle detector reference input is maintained at a constant level by a zero phase-shift, limiter amplifier.

A target return also creates a "delta" channel output from the antenna. A characteristic of phase monopulse antennas is that the delta pulse output is either plus 90 degrees or minus 90 degrees in phase when compared to the sum channel pulse output. Additionally, the amplitude of the delta channel, when compared to the amplitude of the sum channel, gives a measure of the angle off of center of a target. The delta pulse is routed through a 90 degree phase-shifter, T/R switch, limiter, and then down-converted to 400 MHz for further processing with a sum channel 400 MHz. A coherent local oscillator is used to simultaneously down-convert the delta channel and sum channel pulses thereby preserving the phase relationship between the pulses. Linear pre-amps are used to amplify the 400 MHz pulses above the noise level. Phase trimmers are employed to compensate for phase disturbances caused by unequal transmission line lengths, etc. Vector addition is performed in the 90-degree hybrid combiner. The "D" vector, or pulse, is created by this vector addition of the delta-channel and sum-channels.

After passing through a limiter amplifier, phase trimmer, and amplitude trimmer, the "D" channel is phase detected with the sum-channel in a phase detector, which here is a common double-balanced mixer. Lowpass filtering is used to reject higher-order products leaving the desired dc pulses which can be utilized to determine the relative direction of a target.

This preliminary design is considered as a starting point for the required radar. The basic system parameter restrictions considered in this preliminary design are as follows:

a. Approximately 10 m^2 radar target cross-section

b. Low average transmitter power

c. Approximately 60 dB dynamic range encountered for various targets from varying distances

d. Pulse length of 20 ns or less for resolving one average car length vehicle

e. Operate on K-band (24 GHz nominally)

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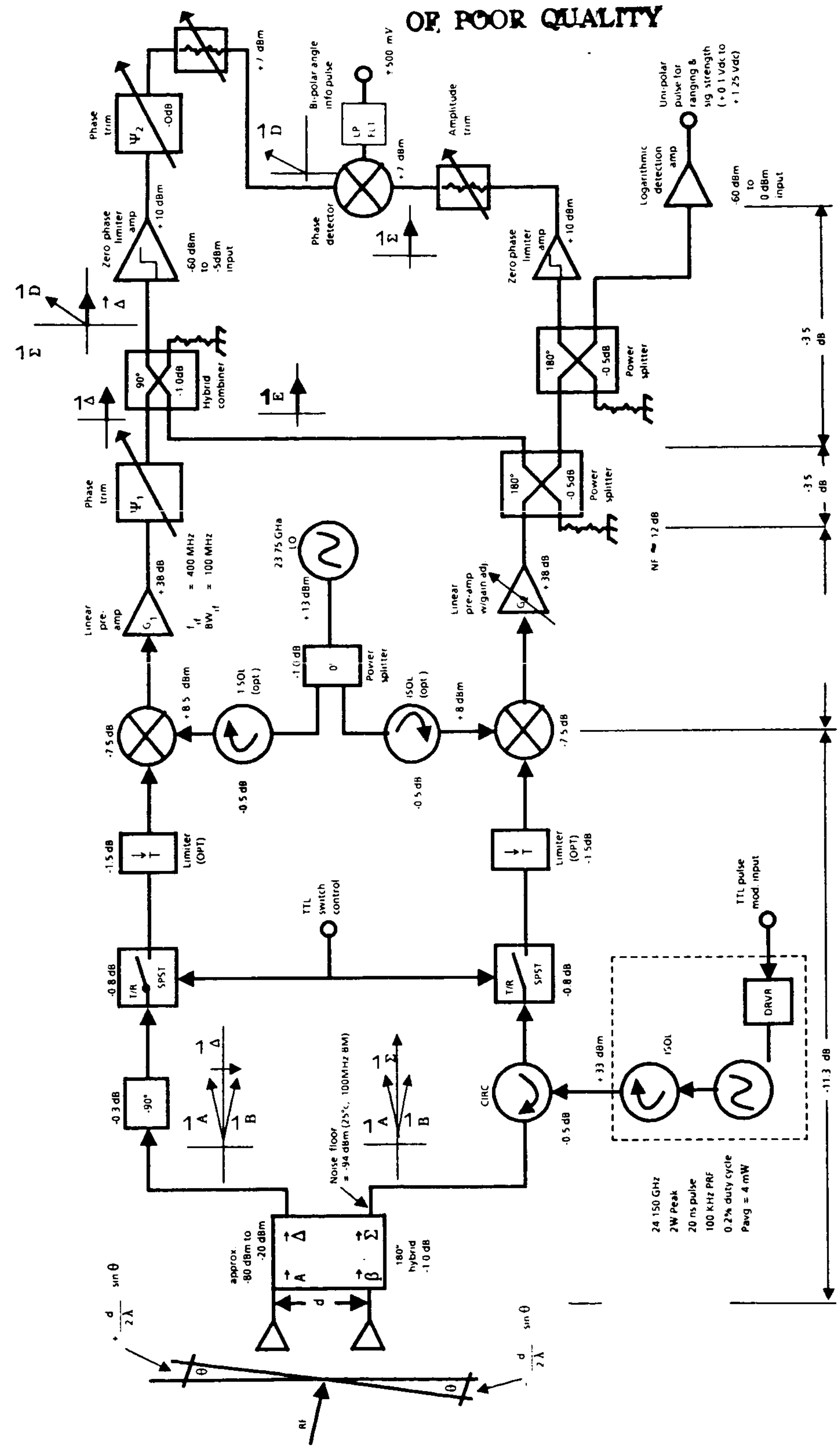

Figure 1.- Microwave block diagram.

C-2

APPENDIX C

PROGRAM SCHEDULES

A/D Number 85-16-692-01.   Date 04/09/85.   Principal Engineer: J. ALLGAIER

Title: CAR

Operational Activities: ITEM 3 PURCHASE REQUESTS COMPLETED & WITH PURCHASER.

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                                   Week-----|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|
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 2.  PROCURE COMP EQUIP.                    |   o++VCOMPLETED       |       |       |       |       |       |       |
 3.  EQUIPMENT EXPECTED.                    |       |       |       |   V   |  < >  |       |       |       |       |
 4.  ASSEMBLE COMP. EQPT.                   |       |       |       o/////////=>>>======>   |       |       |       |
 5.  INVESTIGATE HDW/SW CAPABILITIES.       |       |       |       |       o======================>       |       |
 6.  NASA EQUIP AVAIL.                      |       |       |       |       |       |  < >  |       |       |       |
 7.  NASA PROCURED COMP HDW AVAIL.          |       |       |       |       |       |  < >  |       |       |       |
 8.                                         |       |       |       |       |       |       |       |       |       |
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10.                                         |       |       |       |       |       |       |       |       |       |
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A/D Number 85-16-692-01.   Date 04/09/85.   Principal Engineer: J. ALLGAIER

Title: CAR

Operational Activities: ITEM 3 PURCHASE REQUESTS COMPLETED & WITH PURCHASER.

LEGEND:

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                                  Week-----|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|
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 2.  PROCURE COMP EQUIP.                   |    o++VCOMPLETED      |       |       |       |       |       |       |
 3.  EQUIPMENT EXPECTED.                   |       |       |       |   V   | < >   |       |       |       |       |
 4.  ASSEMBLE COMP. EQPT.                  |       |       |o/////////=>>>======> |       |       |       |       |
 5.  INVESTIGATE HDW/SW CAPABILITIES.      |       |       |       |       o=====================> |       |       |
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 8.                                        |       |       |       |       |       |       |       |       |       |
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A/D Number 85-16-692-02. Date 04/09/85. Principal Engineer: T. LYONS

Title: CAR

Operational Activities: ITEM 1 SSR TO LOCKHEED GENERAL ENGINEERING TO PROVIDE PRELIM RELOCK DIAGRAM, ANALYTICAL APPROACH/DESIGN,HARDWARE SEARCH.

LEGEND:

<1> ORAL REPORT(BIMONTHLY).
<2> WRITTEN REPORT(QUARTERLY).
<3> SYSTEM OPERATIONAL.

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=== PLANNED; > SCHEDULED FINISH; >>> RESCHEDULED; /// NO ACTIVITY; +++ WORK IN PROGRESS; C<<==> EARLY COMPL.;
O>>>===>>SLIPPED START DATE; >===>>>> EXTENDED COMPL.DATE; o TASK START DATE; <> EVENT MILESTONE
                                  Month----|  JAN   |  FEB   |  MAR   |  APR   |  MAY   |  JUN   |  JUL   |  AUG   |  SEP   |
                                  Week-----|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|
1.SAMPLING TECHNIQUE DESIGN.               |      o////////////////==============================>   |        |
2.B/B HDW PROCURE.                         |       o++++++++++++++++===>   |       |       |       |        |
3.B/B HDW RECEIVED(SECOND TDR BOARD).      |       |       |       |     V|       |       |       |        |
4.B/B FABRICATION.                         |       |       |o+++++++====================>  |       |        |
5.B/B TEST & EVALUATION.                   |       |       |       |       |  o========<3>=================>|
6.INTERNAL PDR.                            |       |       V       |       |       |       |       |        |
7.DATA REDUCTION S/W DEV.                  |       |       |       | o=========================================>|
8.DECISION CRITERIA DEV.                   |       |       |       |       |       | o=========================>|
9.NASA/DOT REPORTING(REF).                 |      <1>      |      <2>      |      <1>      |      <2>      |        |
10.                                        |       |       |       |       |       |       |       |       |        |
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DATE 04/09/85   PRINCIPAL ENGINEER: C.LICHTENBERG

TITLE: CAR

OPERATIONAL ACTIVITIES: MICROWAVE TRANSMIT/RECEIVE ASSEMBLY

LEGEND:

o TASK START DATE; <> EVENT MILESTONE

=== PLANNED; > SCHEDULED FINISH;

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                                           Month----| DEC  | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  |
                                           Week-----|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|1:2:3:4|
1.DESIGN ANTENNA,RF,AND IF SYSTEM(INITIAL VERSION).  |       |       o++++++++++++++>|
2.PROCURE COMPONENTS/FABRICATE COMPONENTS.           |       |       |   o++++++++++===================>
3.EQUIPMENT RECEIVED/BUILT.                          |       |       |       |       |       |       |   < >
4.ASSEMBLE COMPONENTS INTO SYSTEM PLUS PRETEST       |       |       |       |       |
  COMPONENTS.                                        |       :       :       :       :  o=====================>
5.TEST AND EVALUATE THE SYSTEM(OR SUBSYSTEMS OF RF   |       |       |       |       |       |
  FRONTEND).                                         |       :       :       :       :       :       o==============>:
6.                                                   |       |       |       |       |       |       |       |       |
7.                                                   |       |       |       |       |       |       |       |       |
8.                                                   |       |       |       |       |       |       |       |       |
9.                                                   |       |       |       |       |       |       |       |       |
10.                                                  |       |       |       |       |       |       |       |       |
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SECTION 4
PROGRESS REPORT NO. 3

Harry O. Erwin and Kumar Krishen

INTRODUCTION

During this past reporting period, significant progress has been made in advancing toward the capability of making test runs with a fully operating data collection system. This "data collection system" consists of a microwave electronics portion, configured as currently envisioned for the collision avoidance radar, the microwave slotted array antenna which has been designed and fabricated for the system, and the data recording equipment and instrumentation which is to be installed in the test vehicle. The test vehicle has been outfitted with a bracket on the front to support the test system, and design efforts for the packaging of the portion of the system which will be mounted onto this bracket are underway. A detailed description of this system, including the test vehicle layout, is included in this report.

Once data collection has begun, test results will be stored on tape to be analyzed in the lab. You will recall from previous reports that data analysis by this method has not yet taken place due to difficulties in interfacing the data tape with the computer being used for analysis. This problem is being circumvented by switching to a different computer for data analysis. The software necessary to complete the interface with the data channel on this system has been received and is currently being reviewed. A rundown on the status of all aspects of the schedules presented in the previous report shall be included in this document.

On the adminstrative side, Paul Shores will no longer be serving as a principal investigator for this progam due to his reassignment to a new organization with Space Station duties. These tasks shall be assumed by Harry Erwin, chief of the Tracking Techniques Branch at NASA-JSC.

REVIEW OF ACTION ITEMS

As with the previous report, those items labeled "Efforts in the Upcoming Reporting Period" from Progress Report No. 2, will be reviewed first.

NASA-JSC

The first task from the last reporting period, the "cleaning up" of the radar boresight range, has proved to be unnecessary, as the testing of the slotted array antenna was able to be performed in the building 14 anechoic chamber during this period. Results of the antenna testing were encouraging and will be presented separately in a later section of this report. Use of the radar boresight range for antenna tests in the future has not been ruled out; however, it is anticipated that further antenna testing will be required. Time will be devoted to this task as deemed necessary.

The second item from the last reporting period referred to the data interface difficulties. As noted in the introduction, this problem is being worked by going to a different computer. LEMSCO was given the task of implementing the new technique. It is anticipated that progress in this area will be reported soon. On a related point, the static radar test set up, which provided the initial set of data to be analyzed in this manner, is described in a later section of this report.

The video recording system mentioned in "Other Activities/New Starts" of the last report requires that some modifications be made to it. The system does respond to pulsed inputs, but the processing circuitry of the system imposes an automatic gain control function onto the received signals, effectively destroying the amplitude information necessary for data analysis. The recorder has been turned over to an audio systems expert from Lockheed who will disable this circuitry, once the necessary electrical schematics have been analyzed.

Detailed work on the computer algorithms for the system has not progressed significantly because no data has yet been received from DOT to be used as input for computer simulations. The computer simulations are being developed, however, and DOT personnel have provided statistics on the frequency of occurrence of various types of accidents which will aid in the selection of specific data sets. Investigators from UH-CL are also beginning to look at this aspect of the problem. They have presented some of their initial efforts in another section of this report.

Completion of the fabrication of the microwave electronics portion of the radar system is still awaiting the arrival of several key components, specifically the pulsed Gunn oscillator (the RF source) and the logarithmic amplifiers. However, the remaining components have been assembled and are being tested using substitute components for those which have not arrived.

The system has already been tested in a range-only mode and the return signals observed on an oscilloscope. This amounts to a partial verification of system operation. Due to delays in the procurement cycle and the long lead-time required for these parts, the amplifiers are not expected to be delivered until November. Substitute of in-house components are being considered to replace them in the interim. The effect on test system performance is being investigated. In addition, the microwave electronics portion has been successfully integrated with the sampling circuitry in the range-only mode and several targets have been observed on the antenna test range. A description of this test and the results from it are presented in this report.

The positioning system referred to in the last item is being refurbished and will be modified to do the type of testing required. The testing involved is the examination of the radar cross-section of typical targets. The pedestal mount acquired will be placed in a hole and fitted with a fixture so that vehicles may be driven onto the mount and then rotated at ground level. This will allow cross-section data to be taken with an accurate representation of ground bounce phenomena. At present there is not any projected completion date.

LEMSCO

Fabrication of the sampling circuitry has been essentially completed. One problem which remains is the presence of excessive noise in one of the two data channels. At present the source of the noise is unknown, but the problem is being worked. As noted earlier, operation of this circuitry in conjunction with the microwave portion has been demonstrated.

Procurement of the data processing equipment has been completed with the recent arrival of the data processing software package. A more detailed description of this system, including the computer and the capabilities of the software system, is included with this report.

The design work for the instrumentation of the test vehicle has been completed and the fabrication work is in progress. The antenna and microwave assemblies will be mounted to brackets on the front of the vehicle, while the data recording equipment and power sources remain inside the vehicle. The van configuration is also described in a separate report.

UH-CL

Contract formalities have finally been completed and the work is now commencing. In addition to the literature search, inputs to this report provided by UH-CL include a preliminary look at the statistical nature of the measurements and its relation to the false alarm problem. An analysis of the electric field intensities likely to be caused by this system and their relation to the radiation safety problem is also included.

TECHNICAL PROGRESS AND TEST RESULTS

Since the last report, sufficient progress has been made in several areas to present some of the results of the work. Toward that end, the following supplemental reports have been included in this report.

- A description of the results of the antenna testing
- A description of the results of the ranging only operation of the microwave electronics with the sampling circuitry
- A description of the data processing system, including a discussion of the capabilities of the signal processing software
- Results of an analysis of the field intensities likely to be produced by this system with regard to the radiation safety issue
- A description of the test vehicle instrumentation design

Other supplemental reports included are a list of reports reviewed by UH-CL, a description of the math modelling effort being initiated, and a description of the static radar test setup mentioned in the previous progress report.

PROBLEM AREAS AND CONCERNS

The major problem area at present is still the procurement of the remaining components for the microwave electronics. The oscillator and the IF amplifiers have not been received. Procurement of the oscillator is proving to be a particular problem, due to the higher-than-usual peak power required. ("Peak" power refers to the energy in the pulse alone, neglecting the interpulse period. Average power is power averaged over all time, and is generally substantially less.) After discussions with vendors, it has been determined that the quickest way to obtain the oscillator is to have the vendor provide NASA personnel with the design for placement of the diode in the cavity and to purchase several of the diodes, fabricating the device in-house. It is hoped that this effort can be finalized within a matter of a couple of weeks.

The IF amplifiers are on order, but they will not be received until November. The substitute amplifiers being used presently are narrower band devices, which means that they do not pass as many frequencies unattenuated as the devices which are on order. The effect on system performance is to "smear" the pulses, degrading the resolution of the system. Consideration is being given to fabricating these devices in-house, if it is determined that sufficient manpower exists and a significant time savings may be realized. In the interim, the present devices will continue to be used.

One other problem area involves the sampling circuit board. The board is a two-channel device, which is required to pick up signals from both the sum and difference channels of the monopulse antenna, from which angle data are derived. One of the channels is not functioning properly due to the presence of excessive noise. Although the source of the noise is unknown at present, this problem is being worked by the responsible LEMSCO personnel and progress is expected soon.

The primary effect of the concerns which have been noted thus far is to delay the operation of the difference channel circuit of the system. Operation of this channel is required in order to obtain angle information, which will in turn be critical to the decision-making algorithms as they are currently envisioned. These difficulties must be rectified before test runs to gather data can commence. If suitable solutions have not been reached in a reasonable amount of time (2 to 3 weeks), then testing will begin in a more limited sense using substitute hardware as necessary.

SCHEDULE UPDATES

Reference is made to appendix C of Progress Report Number 2, "Program Schedules." The tasks described on the first schedule, "item 3 purchase requests", are essentially completed with the exception of line item 5, "investigate hdw/sw capabilities." The software has only recently been received and several weeks need to be allotted to become fully familiar with all its capabilities. However, all the dates indicated on this schedule remain essentially intact.

Similarly, most items on the second schedule remain unchanged. Note though that the "system operational" indication on line 5, "breadboard test and

SECTION 5
PROGRESS REPORT NO. 4

Harry O. Erwin and Harold Nitschke

INTRODUCTION

Reporting period no. 4 is culminating with the completion of the hardware fabrication and the commencement of the acquisition of test data. Some work-arounds have been necessary to accomplish this milestone, but the ability to begin gathering data was considered critical to meeting the original schedule of a major review in November 1985. The most significant workaround is the use of a lower output oscillator than was originally designed for, and this can be easily replaced with the higher power unit when it becomes available in a few weeks.

Performance of the data processing system has been demonstrated with test tapes. A report documenting the details of its configuration and the software development involved with it is included in this report. Also included is a tutorial note on the technique of "time expansion" utilized in the processing and a report from UH-CL on the development of decision logic.

On the administrative side, there are some personnel changes to report. Harold Nitschke shall be taking over as principal investigator and shall be responsible for overseeing the project. Dan O'Connell is leaving NASA for a position in private industry and will no longer be associated with the project.

REVIEW OF ACTION ITEMS

The "Problem Areas and Concerns" section of the last progress report will not be discussed.

NASA-JSC

Significant progress has been made in the hardware development area. The interim IF amplifiers have been received and incorporated into the electronics. The higher-power oscillator is not yet ready and probably will not be for several more weeks, but an interim lower power device is being substituted at present. When the higher power device is ready, it can simply be bolted into place by removing the present one. Hardware fabrication is otherwise complete.

LEMSCO

The noise problem in the sampling circuit board has been corrected and the device operation was verified. A second channel was also prepared. Also, the disabling of the audio automatic gain control (AGC) circuitry in the video recorder, which was necessary to properly record data, has been completed. The recording system is now ready to go. Van instrumentation is nearly complete. Packaging of the radar hardware is complete. The system control box was designed and fabrication has been completed.

TECHNICAL PROGRESS AND TEST RESULTS

At the completion of this reporting period, we now have a fully operating end-to-end data collection system. Some of the hardware is as yet not up to specification, but the basic configuration is now complete. The hardware is in its final configuration and will be mounted onto the test vehicle following the completion of laboratory tests to verify system operation. Preliminary results from these tests indicate that the system is operating nominally. Completion of these tests is expected shortly.

Lockheed personnel have completed development of the data processing software which will convert the data tapes gathered from test runs into a form suitable for performance analysis. Although a modification or two is still planned, the system is ready to be used. An end-to-end system demonstration, from a test run with the vehicle through data reduction and analysis, is expected within 2 weeks.

Following these preliminary checks, a series of test runs will begin and a detailed analysis of system performance and characteristics will commence. These activities should proceed at a pace which will support the major design review planned for November of 1985.

PROBLEM AREAS AND CONCERNS

The chief area of concern at present is the ability of the system to perform with a lower power oscillator than it has been designed for. It may be necessary to restrict the initial testing to targets of unusually large radar cross-sections in order to compensate. However, this situation is only temporary and is not a concern for longer term objectives.

SUMMARY

This preliminary groundwork has now finally been completed and the true business of the program, which is evaluating system performance and the feasibility of automotive radar, will begin. In conjunction with this progress, preparations have been made and plans drawn up for the testing of the vehicle radar safety systems device, the first commercially marketed collision avoidance system. It is hoped that this effort will be added to the contract and timelines can be drawn up. Results of testing will be reported as they become available.

APPENDIX

SUPPLEMENTARY REPORTS

DISCUSSION OF THE TECHNIQUES OF TIME EXPANSION

W. X. Culpepper

The concept of "time expansion" is sometimes difficult to grasp. One good method of achieving understanding of the fundamentals is through the use of a pictorial such as the one attached. This discussion is centered on the concept shown in this figure.

The top waveform on the figure is considered the input to the system. The waveform is repetitive every second and 10 frames or cycles of the waveform are shown in the figure. Time is arbitrarily assigned the value of the zero on the left and runs for 10 seconds. Each cycle of the waveform consists of a pulse 4 units high and approximately 0.15-second duration, followed by a 2.5-unit high pulse of approximately 0.1-second duration. This second pulse occurs roughly 0.5 seconds after the cut-off of the higher amplitude pulse. It is assumed that the input waveform is constant, i.e., the pulses are not moving relative to each other and within the frame.

Assume a sampling system exists that will sample the voltage of the input waveform every 1.1 seconds. Assume the sample width is very small (e.g., 20 nanoseconds) so that a good approximation of the instantaneous voltage of the input waveform is made at each sample. Assume that the last sample value is held until another sample is taken. If this sampling system were applied to the input waveform of the figure, the following would happen.

Assume that the sampling system has been synchronized to the input such that at the arbitrarily assigned time of "zero," the sampling system sees the start of the larger pulse in frame 1. This instantaneous voltage of 4 units is established and held and applied to the output of the system as shown in the output waveform.

Another sample is not taken for 1.1 seconds, or until 0.1 seconds into frame 2. The sample result is again 4 units so that the output remains constant. The third sample is 0.2 seconds into frame 3 and its value is zero. Hence, the output goes to zero. The fourth sample at 0.3 seconds of frame 4; the fifth sample at 0.4 seconds of frame 5; the sixth sample in frame 6 and the seventh sample in frame 7 all yield zero. The output reflects this.

At frame 8, the eighth sample detects the 2.5 unit value of the second pulse within a frame. The output circuit value jumps to 2.5 units and remains there until the ninth sample in frame 9 when zero is detected. The output will go to zero here and remain there through frame 10. At frame 11, the big pulse would again be detected and that would be the beginning of the repeat of the <u>output</u> waveform.

Stop and look at the output waveform in relation to the input waveform. It is approximately the same as the input only it takes 10 seconds to display what the input shows in 1 second. Hence, the output waveform is "time expanded". Here the time expansion factor is 10. In the CAR radar it is thousands.

In comparison of output back to input, the word approximate was used because the replication is not precise. This example waveform was chosen because it is obvious by a little sample-by-sample study where the loss of precision occurs. Taking 100 samples at a rate of one every 1.01 seconds would give a tenfold increase in precision over the example above. However, it will take 100 input waveforms instead of 10 as shown. Also note that the "time expansion" becomes 100 instead of 10 and that one cycle of the output waveform is 100 seconds long. The purpose of applying this technique to the CAR radar system is that it allows a waveform of a relatively high repetition rate to be "slowed down", so to speak, simplifying the processing of the signal.

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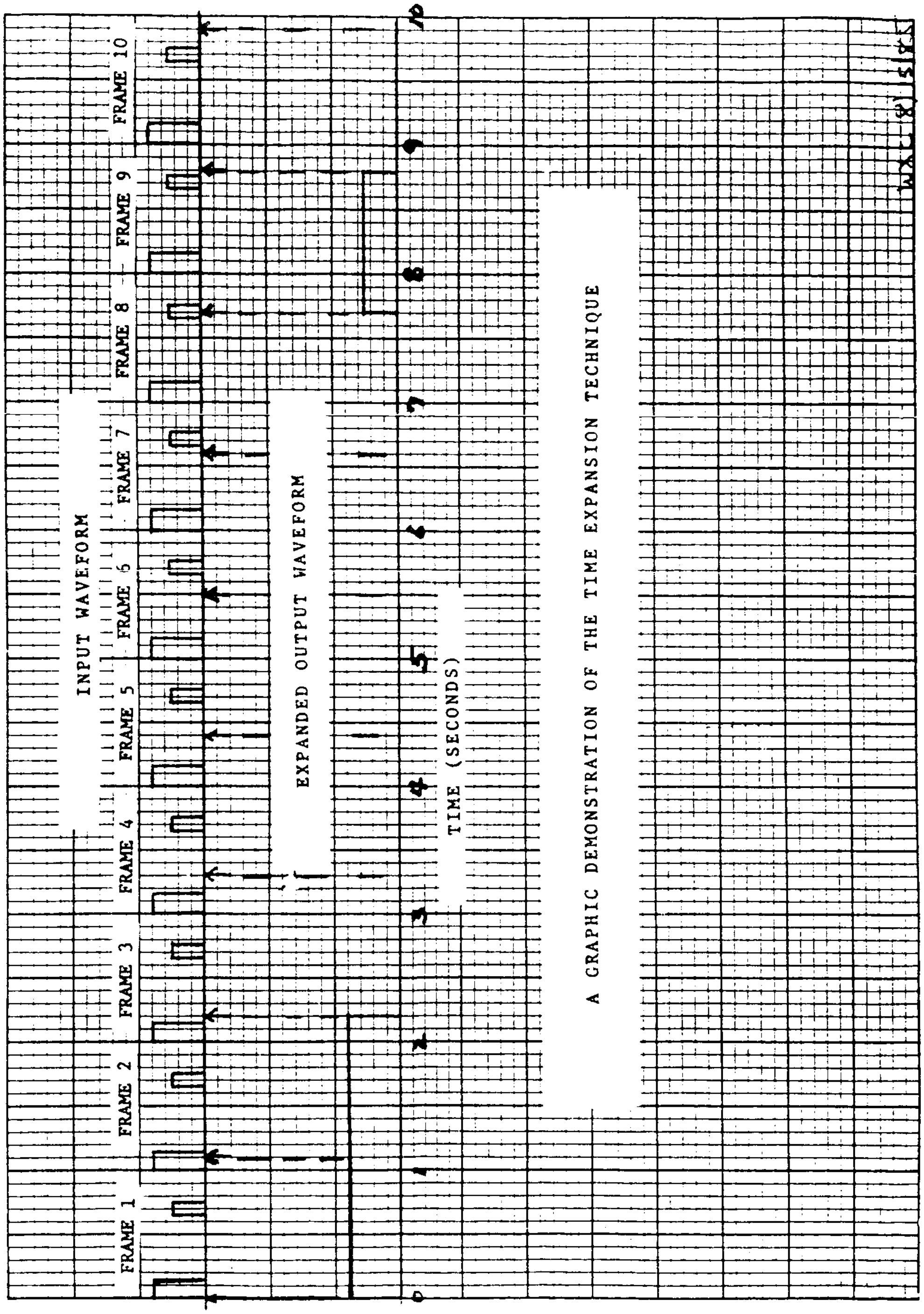


A GRAPHIC DEMONSTRATION OF THE TIME EXPANSION TECHNIQUE

SOFTWARE DEVELOPMENT AND DATA REDUCTION

W. X. Culpepper

The Data Translation DT2801-A data acquisition board was checked using the ASYST software system with the IBM-XT processor. Operation was as advertised for the A/D converter portion of the system. Throughput rates for single channel operation under software control is approximately 600 Hz. Using DMA the rate is approximately 27 kHz as advertised. The CAR data reduction will use the high throughput rate since the conversion time becomes the unit of measure of time delay.

After the completion of the modifications to the AGC of the audio channels of the video recorder, a test tape of transmitted pulse, time delay, and target return was made. Playback of this tape showed the need for signal conditioning and a sync signal locked to the transmitted pulse. This sync will be used to externally trigger the A/D converter.

The test tape also presented the parameters that are covering and constraining the development of the data reduction software. For instance, the range resolution of approximately 9 ft (derived from conversion delay divided by the time expanded value of time per foot of range) dictated the number of samples required from the A/D converter to cover the range interval of the radar. The time expanded radar repetition rate of 22 milliseconds dictated the maximum time to save the data before the next transmitted pulse.

It should be explained that the 9-ft range resolution of the system is based on processing only the range channel, i.e., applying the full speed of the A/D converter to only one channel as opposed to multiplexing the range and angle channel. To operate both channels at once would double the range resolution to roughly 18 feet. It was decided to maintain the higher resolution for now and to accept the penalty of making two passes at a data tape and time correlating the two results.

The first attempt at recovering the data was to digitize an A/D channel (80 samples, 2 bytes each, for each transmitted pulse) in the DMA mode (27 kHz throughput) to the largest memory block possible. Unfortunately, the hardware constraint on DMA input is 16-bit addressing which converts to 64 kbytes of memory or 400 80-sample sets, which at 22 milliseconds per set, translates into 8.8 seconds of real-time data. At best, this would be cumbersome and considering the need to process the tape once for each of the two channels, this method is truly too much of a brute force situation.

The second alternative was to take an 80-sample set and write it to disk file. The ASYST software documentation showed the capability to write to a file the site of which is limited only by disk capacity. This capability proved to be non-existent (ASYST software experts confirmed the documentation error) and because of the computer operating system only a 64-kbyte file can be opened and serviced in real time.

The final choice, and the one being developed now, is to preprocess, in real time, the data such that more than 8.8 seconds worth of tape time is contained in the 64-kbyte limitation. The current software taken in an

80 sample set from the A/D converter, scans the array for any elements that exceed an established threshold. Those elements are then written to memory as a 3-element group; the transmitted pulse number, which A/D converter sample, and the magnitude of the sample. For the single target case, 6 bytes of data are written instead of 160 bytes. This represents a compression factor of roughly 26 which changes 8.8 seconds to almost 4 minutes. This is obviously more reasonable.

This method also simplifies extracting and time correlating the angle data from the second pass of the data tape. On the second pass, the transmitted pulse number will be used to find the appropriate pulse, the converter number will define the element of the converted angle array, and the magnitude of the angle channel can be extracted to be grouped with its time correlated range value. Development of this piece of software will begin in the very near future.

Benchmark tests are being run on the processing requirements to extract the range data. These test results are preliminary and not exhaustive, but the trend seen requires that the 22-millisecond data rate be slowed by a factor between 2 and 4. This change can be accomplished by changing the time magnification factor, the radar repetition, or a combination of both. Some relief may be available by changing from the IBM-XT 6300 processor, since the latter seems to benchmark out at twice the speed as the IBM for this software. There is still some question, however, as to whether the DT 2801-A A/D board will operate properly in the DMA mode with the AT&T processor. All of these questions should be answered in the immediate future and the capability to reduce data should coincide with the first radar test.

REPORT ON THE MODELING AND ACCURACY CONSIDERATIONS

E. T. Dickerson and C. R. Hallum

(Not Included)

SECTION 6
PROGRESS REPORT NO. 5

Harry O. Erwin and Harold Nitschke

INTRODUCTION

Reporting period no. 5 is culminating with improving performance of the hardware and the commencement of the acquisition of test data. Some rework has been necessary to accomplish this milestone, but the ability to begin gathering data was considered critical to completion of Phase I. The most significant rework was to increase the signal-to-noise ratio.

Performance of the data processing system has been demonstrated with test tapes. A report documenting the details of its configuration and the software development involved with it is included in this report.

REVIEW OF ACTION ITEMS

The "Problem Areas and Concerns" section of the last progress report will not be discussed.

NASA-JSC

Significant rework has been made in the hardware development area. The pulse repetition rate was increased and filters added to increase the signal-to-noise ratio. The antenna was replaced with standard gain horns due to excessive reflections from the greater than 180° beam width.

LEMSCO

The radar system was reworked to remove the antenna and install standard gain horns as replacement. Support was provided for filter design and fabrication. The interface board was reworked to accommodate the increased pulse repetition frequency.

UH-CL

The report on "Modeling and Accuracy Considerations" has been under review and corrections to the interim report are being incorporated. The report will be submitted as a separate input in the near future.

TECHNICAL PROGRESS AND TEST RESULTS

At the completion of this reporting period, we now have an end-to-end data collection system. Some of the hardware is not up to specification, but the basic configuration is now complete. The hardware is in configuration and will be mounted onto the test vehicle following the completion of laboratory tests to verify system operation. Preliminary results from these tests indicate that the system is operating nominally.

Lockheed personnel have updated the data processing software which will convert the data tapes gathered from test runs into a form suitable for performance analysis. Although modification is still planned, the system is being used.

Following these preliminary checks, a series of test runs will be conducted and a detailed analysis of system performance and characteristics will be initiated. These activities should proceed at a pace which will support the Phase I review.

PROBLEM AREAS AND CONCERNS

The chief area of concern at present is the ability of the system to perform with a lower power transmitter than it has been designed for. It may be necessary to restrict the initial testing to targets of larger radar cross-sections in order to compensate.

Department of Transportation (DOT) funding for Phase I, except for the University of Houston effort, has been completely used. NASA funds will be used to gather and analyze data and prepare for the Phase I/II review. Changes noted above will delay the Phase I/II review from November to January 1986.

SUMMARY

This preliminary groundwork has been completed and evaluating system performance and the feasibility of automotive radar will begin. Planning and evaluation of objectives for testing a commercial collision avoidance radar are ongoing. Results of testing will be reported as they become available.

APPENDIX

SUPPLEMENTARY REPORTS

TECHNICAL CHARACTERISTICS TEST PLAN

W. X. Culpepper

This short paper describes what is felt to be the initial tests required to be performed when the in-house CAR system is first brought on-line. These tests will define the end-to-end transfer functions and first order limitations of the system. The system in this case includes the RF, time expansion sampling, data acquistions, and data reduction subsystems. Some parameters which will be defined in these tests are the conversion constants necessary to complete the end-to-end data flow.

The preliminary tests are shown in table 1 and show both the transfer functions and the basic dynamic response characteristics needing definition. The results will be the end-to-end capability and response of the system. An important aspect of this test not emphasized in the table is the system ability to detect minimum dynamics, i.e., range rates and angle rates near zero.

Table 2 shows a list of basic situational tests. The criteria of avoiding collisions in all these situations are well known. That is not the purpose here. The purpose here is to establish the ability of this CAR system to reach appropriately to each of these cases. Once this information is gathered and understood, more exotic tests can be formulated. That will be the basis for a test plan for advanced testing.

TABLE 1

PRELIMINARY TESTS

Transfer functions:

Range channel

1. Accuracy
2. Range resolution
3. Extended target response
4. Magnitude vs. cross-section

Angle channel

1. System response (volts/degree)
2. Accuracy
3. Useful angular range
4. Resolution
5. Extended target response

Response to dynamic situations:

1. Range rate

   Zero to 120 mph at zero angle rate

2. Angle rate

   Zero to TBD degree/second at zero range rate

3. Combined range rate and angle rate at TBD values

TABLE 2

BASIC SITUATIONAL TESTS

Roadside

Angle rate response is prime concern

Absolute angle accuracy is secondary concern

Head-On

Maximum range is prime concern

Angle rate response is secondary concern

Follow-After

Range rate response is prime concern

Absolute range is secondary concern

Angular-Collision

Angle rate response is prime concern

Absolute range is secondary concern

SOFTWARE DEVELOPMENT AND DATA REDUCTION FACILITY

W. X. Culpepper

INTRODUCTION

This status report deals with two topics. The first is an overview of major system parameters such as range resolution, data processing rates, etc. This presentation is necessary because of significant changes in the system definition since the last documented status of August 1985. The next section called "System Definition" covers this material.

The second topic of this report discusses the software development effort. Four areas of effort are active at the present time. Two of these four will directly support the initial field tests of the in-house radar system. The other two areas deal with future needs and requirements. This information is in the last section called "Software Development."

SYSTEM DEFINITION

At the present time the CAR radar system is being integrated and checked out prior to actual field testing. Optimization of system parameters, such as the time magnification factor, radar repetition rate, recorded data rates, processing data rates, etc., has occurred repeatedly with give and take between the RF/sampler systems and the data acquisition/reduction system. What has emerged is a system that utilizes the capabilities of the available hardware and software while acknowledging and abiding within their limitations. The purpose of this section is to present this system--at least from a standpoint of system parameters values.

Many changes have occurred since the fourth status report of August 1985. Some of the changes were presented verbally to DOT personnel during their September 1985 visit to NASA-JSC. All changes since August 1985 are included here to maintain continuity in documentation.

The course of action in real-time data acquisition being explored at the conclusion of the August status report centered around a tape data rate of 22 milliseconds, 80 samples/data set, data processing time limits of about 4 minutes, and two data passes per tape--one to extract range and a second for angle. Transmitter pulse counts were necessary both for timing and for correlation of the second pass angle reading to the first pass range reading. Other system parameters included a time magnification factor of 2000 and a range resolution of 9.25 feet. An IBM XT processor was being used.

The main limiting factors with this approach were two. The first and most limiting factor was the two-pass run. Correlation of the second pass of a lengthly tape was too cumbersome and the probability of data skew too high. Second, comparative benchmark tests between the IBM XT and AT&T 6300 showed the IBM to run slower by a factor of two. With the system objective being to acquire multiple targets in real time, the speed of the AT&T became attractive and the IBM system was exchanged for the faster 6300 system. The system that has evolved since August is described in the following paragraphs.

The time magnification factor has been doubled to 4000 which produces a time expanded one-way range propagation delay factor of 8 microseconds/foot. Since the maximum rate of conversions of the A/D converter is 37 microseconds/sample, the best range resolution from the system is 4.625 feet. However, the minimum pulsewidth transmitted by the radar is 20 nanoseconds--meaning a point target will appear to be 10 feet deep in range. Sampling range every 4.625 feet under these conditions yields minimal additional information over sampling every 9.25 feet. Thus the A/D converter system has been programmed to sequentially sample the range channel and then the angle channel. This sampling technique eliminates the two-pass data run and maintains an equivalent 9.25 feet for range resolution.

The remaining system parameters that have been changed since August are the maximum processed range, the effective repetition rate of the system, and the multitarget processing capability. The maximum range processed by the current system is 518 feet as compared to 740 feet in the two-pass system. While the earlier system processed 80 samples of a single channel with 9.25 feet resolution, the current system digitizes 112 samples alternating between range and angle with the same range resolution. This sample set is flexible, but for now is compatible with the current time expanded radar pulse rate. The effective data rate of the radar system has been reduced from one transmitted pulse every 22 milliseconds to one triggerable pulse every 88 milliseconds. While this might appear somewhat arbitrary, it is related to the processor speed and the need to process multiple targets. With the AT&T 6300 processor, four targets can be detected and preprocessed in a time less than 88 milliseconds. For the range-extended targets and general clutter environment expected in the real world, a detection of one to four targets will probably occur very often. Four or more targets (clutter included) will be likely also and because of this the system is trying to handle 20 targets maximum. The software system has been benchmarked such that if an A/D converter output has four or less target detects, the elapsed clock time to process will be 88 milliseconds. If 5 to 13 targets are present, then 76 milliseconds will elapse in the processing cycle. And, if 14 to 20 targets are detected, 224 milliseconds have transpired processing the "busy" environment. While system throughput will suffer, the knowledge of time is preserved and average rates can be calculated.

The portion of the system that cannot be defined here is the angle channel. This determination is the next order of business and the hardware has just reached the level to support the effort. Baseline tests have been defined in an initial test plan which will give a good basic and qualitative understanding of the system performance. The angle channel will be tested to determine difference channel boresight, usable angle coverage, sidelobe response, angular resolution, and angle rate resolution. The pertinent parameters from these tests will be incorporated into the software to properly process the angle data.

SOFTWARE DEVELOPMENT

Four sets of software are currently under development and/or completed in support of the CAR radar effort. These sets are the following:

1. Real-time data acquisition and preprocessing
2. Data conversion and display
3. Simulation and verification
4. Target identification

There will be other software sets needed, but they cannot be developed until these four have been completed and used in the application of processing field data. Lessons learned there will aid in proceeding forward to real-time application software for target avoidance.

The status of each of four above is discussed next.

The real-time data acquisition and preprocessing software is complete. Anticipated changes to this software package center around minor alterations to support operational procedures. This software operates on an 88 millisecond cycle time for conditions of less than five targets with the cycle time increasing as prescribed previously for five or more targets. For each triggering trnasmitted pulse the software compares the preset threshold value to the A/D converter sample values from the 56 range samples. For each range sample that is detected as having exceeded threshold, the transmitted pulse number (relative to the start of the data run), the A/D converter number (range bin relative to the current transmitted pusle), the angle voltage reading and the target voltage reading are written into memory. When the memory is full, the data run is stopped and a permanent disk file is made from the stored data set. That portion of the data tape just processed need not be read again unless there is reason to do so with a different threshold setting. In either case the data written to disk can be manipulated without real-time restrictions.

The second set of software deals with data conversion and display of test data files. A form of this software has been running since early September and was used to access the test data files written to disk by the real-time data acquisition software. This early form also contained routines to plot the file integer data, i.e., range bin number versus pulse number and angle channel integer data versus pulse number. These plots are done on a point plot basis such that to the human mind and eye, target identities and trajectories are immediately assumed. Correlation among range trajectory, angle trajectory, and visual image (target is mailbox, dog, truck, etc.) is all that is required to have a basis for evaluating avoidance criteria--at least to a first level of investigation.

The current plans are to upgrade this software to produce hard copy plots in a finished form on the HP7475A. All conversion factors will be incorporated so that range will be in feet, time in seconds, and angles in degrees. Known bias errors will be corrected in the data sets as applicable. These plots when correlated with the video images of the tests will allow conclusions to be drawn based on the man-in-the-loop intelligence. This will yield results consistent with the initial Phase 1 test plan outlined in the attached memo previously referenced.

The third software set under development is the verification and simulation software. This work started out as a piece of verification software to prove that the data files could be read properly. Very quickly it was realized that this software could also simulate scenarios and present them to the overall CAR software system. Simply put, this software generates an A/D converter output for both range and angle and writes a data file in the format written by the real-time data acquisition software. In reading these files, the data sets appear genuine though they are simulations.

To date this development software has generated single target files and double target files. Several scenarios for each have been produced. Only relative, linear motion has been imparted to the target, although, obviously, this is not the limit. Further work is planned for this area to both predict system response and to evolve and verify hypothesized avoidance criteria.

The fourth area of software development is the target identification package. This software should access the data files, extract and identify individual targets, and produce a history file on each target. Proper target identification includes comparing continuity in range, angle, range rate, and angle rate. A "target memory" of some sort must also be implemented to ensure survival of a target through point dropouts caused by scintillation, making, etc. The logic of this becomes complex. To date the software has progressed to accessing the data files, sorting to events per transmitted pulse, and representing extended targets by their closest interval. These massaged data sets are set up to compare results between the two most recent transmissions. Completion of the effort is extended out into Phase 2 of the program.

BANDPASS FILTERS DESIGN AND CONSTRUCTION REPORT

Christopher L. Lichtenberg

INTRODUCTION

This report describes the design, analysis, construction, and testing of bandpass filters presently used in the collision avoidance radar IF circuitry. These filters are required to (1) reject out-of-band interference caused by other microwave sources adjacent to the radar frequency used in this radar, (2) suppress pulse modulation bleed-thru which exists from dc to 100 MHz, and (3) to set the noise bandwidth presented to the logarithmic-IF (LOG-IF) amplifiers which amplify and detect the target return signals. These filters are installed between the pre-amplifiers and the LOG-IF amplifiers (see fig. 1).

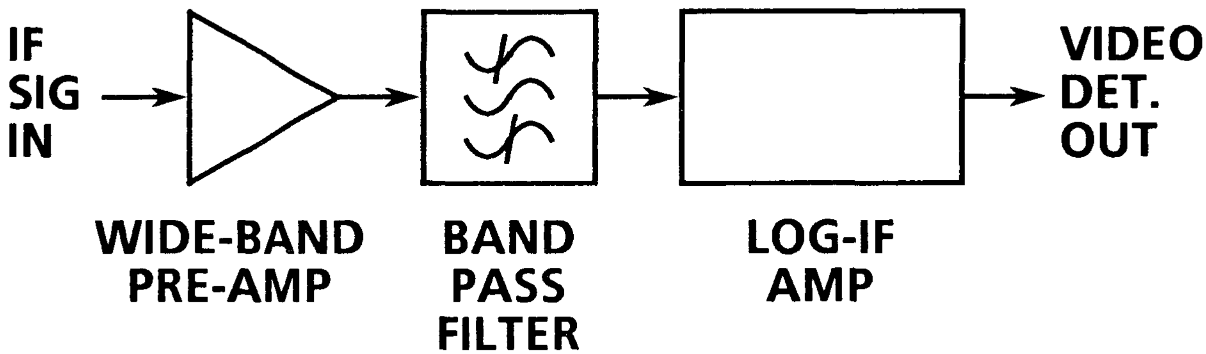


Figure 1.- IF component arrangement.

DESIGN SPECIFICATIONS

The required bandwidth is set by the pulse width (PW) of the transmitter. A pulse width of 20 nanoseconds is used. The best signal-to-noise ratio and least pulse distortion occur when the IF bandwidth is chosen between 1/PW and 2/PW. To achieve low pulse distortion and to allow for oscillator frequency drifting due to temperature changes, 2/PW was chosen as a filter design goal. Because of nonideal filter shape at band edges due to gradual roll-off, the effective detected noise bandwidth will be slightly higher (approximately 2 dB). 100 MHz was chosen as the design goal for filter bandwidth. A filter center frequency of 150 MHz is required by the LOG-IF used. The structure of the filter was chosen as 6-element PI configuration, which represents a compromise between ideal filter response and a structure which is easy to build and align. A Chebyshev 0.1 dB ripple filter design was used. This filter design offers good out-of-band rejection, sharp roll-off, controllable in-band loss, and ease of alignment.

PROCEDURE

First, a Chebyshev lowpass prototype is chosen. Then a transformation is performed which (1) changes the structure from lowpass to bandpass, (2) sets the center frequency and ripple bandwidth, and (3) changes the impedance to 50 ohms. Finally, a filter schematic with component values can be constructed. The above steps are listed in the following section.

DESIGN TABLES

BANDPASS FILTER: 6-ELEMENT CHEBYSHEV

Design Goals

1. Center frequency = 150 MHz
2. Ripple bandwidth = 100 MHz
3. 6 elements = > 6-pole response
4. In-band ripple = 0.1 dB
5. Maximum insertion loss < 1 dB
6. Out-of-band attenuation > 50 dB

Lowpass Prototype Structure

1. 3 elements
2. 0.1 dB ripple
3. Pi-configuration
4. Fc = 1 radian
5. Zin = 1 ohm
6. Clp = 1.0316 F
7. Lls = 1.1474 H

Transformed Values

$L_2 = [(L_{LP})(Z)]/(B)$ - - - - - - - - - - - - EQ. 1

$L_1 = [(B)(Z)]/[(w_0^2)(C_{LP})]$ - - - - - - - - - EQ. 2

$C_2 = (B)/[(w_0^2)(C_{LP})]$ - - - - - - - - - - - EQ. 3

$c_1 = (C_{LP})/[(B)(Z)]$ - - - - - - - - - - - - EQ. 4

Where B = radian bandwidth of transformed filter

w_0 = transformed radian center frequency

Z = desired filter impedance

$B = 6.2832 \times 10^8$ (100 MHz)

Z = 50 ohms

$w_0 = 9.4248 \times 10^8$ (150 MHz)

$w_0^2 = 8.8826 \times 10^{17}$

C_{LP} = 1.0316 Fd

L_{LS} = 1.1474 H

Calculated Values for Transformed Bandpass Filter

L_2 = 91.307 nH

L_1 = 34.285 nH

C_2 = 12.330 pF

C_1 = 32.837 pF

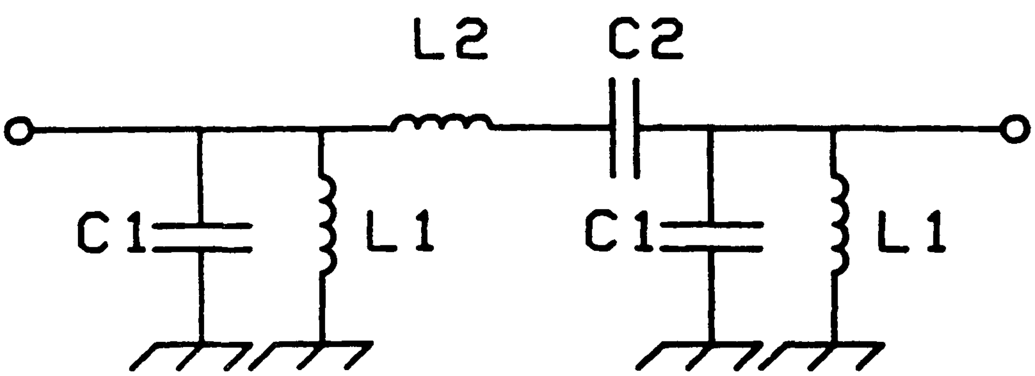


Figure 2.- Filter schematic.

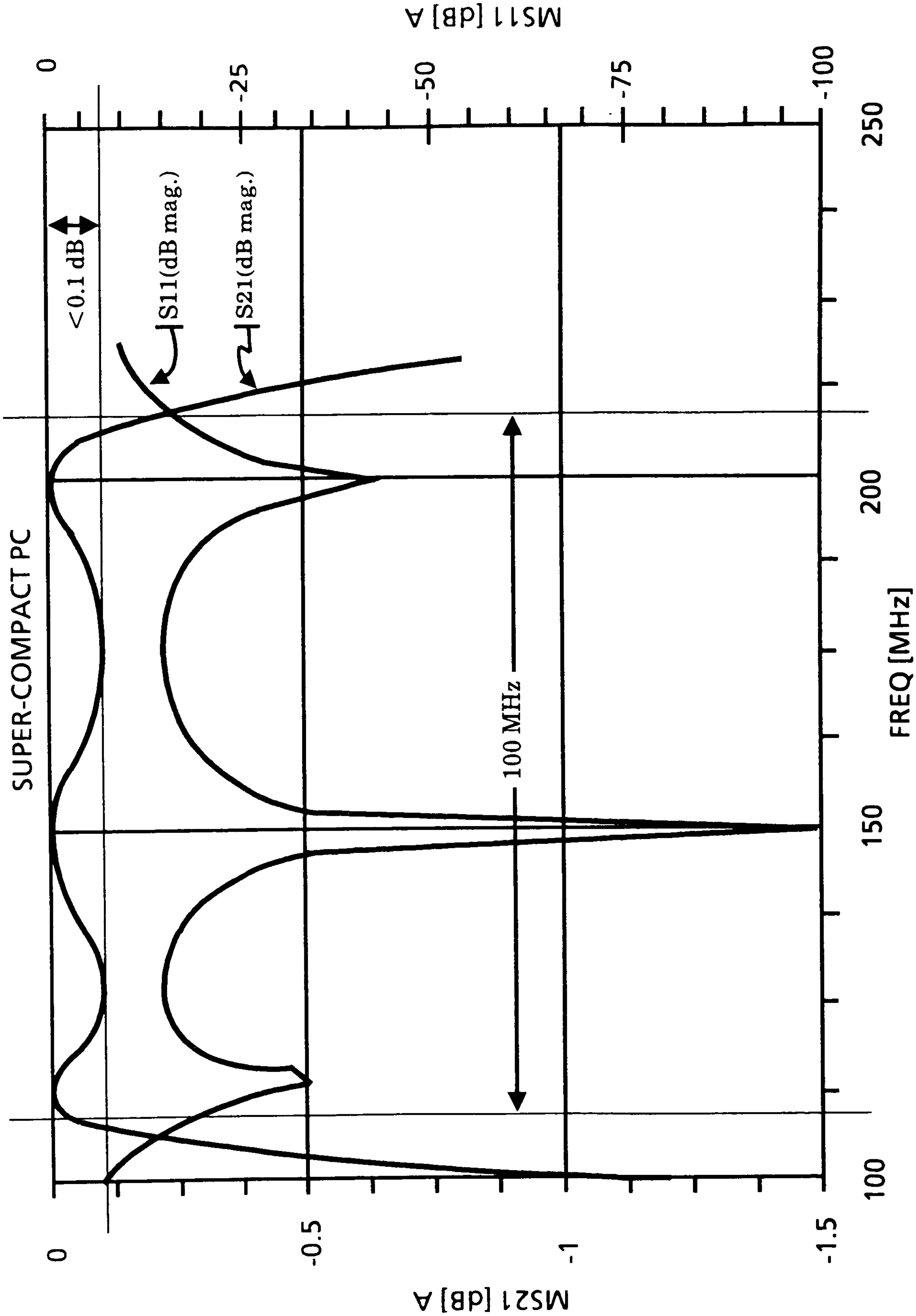
IDEAL (CALCULATED) FILTER RESPONSE

After a candidate filter schematic is generated, it is good modern engineering practice to verify the design by computer analysis. To this end a computer file was written and results of its analysis were plotted. A sophisticated microwave and RF computer-aided design (CAD) program, SUPER COMPACT PC, was used for this analysis. Results verify that correct component values were calculated, and the frequency response plots act as a guide or baseline for comparison with actual measured response of the constructed filters. Results of this analysis show that this filter design meets all of the design goals. Computer file and plots are included at the end of this section.

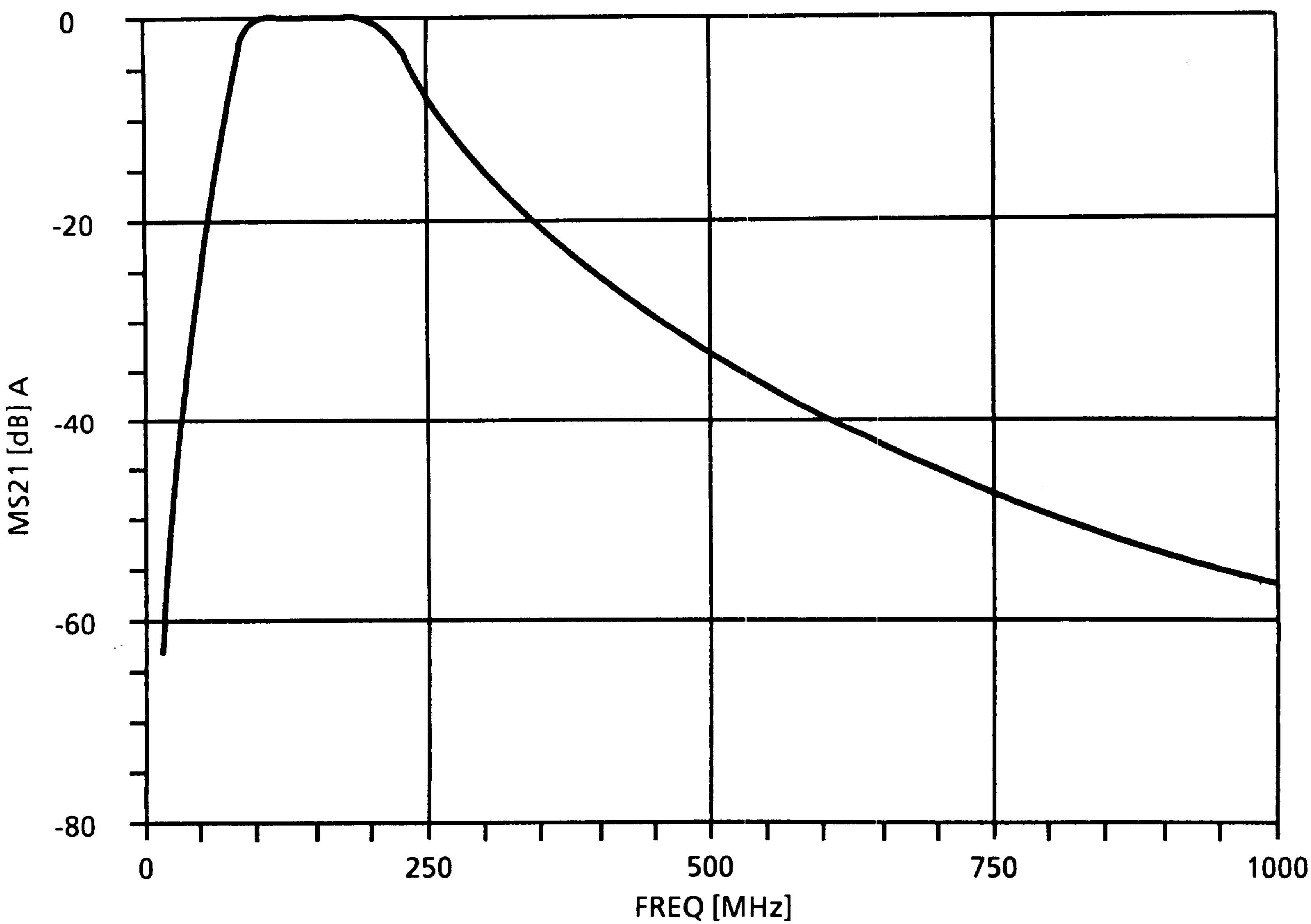
```
SUPER COMPACT PC  10/23/85  10:07:28  File: BPASS3

*CHEBYSHEV BANDPASS FILT., 0.1DB RIP., 100MHZ RIP BW, Fc=150MHZ
* 6-ELEMENT, PI-CONFIGURATION, Z=50 OHM, DESIGNED FROM LOWPASS PROTOTYPE
 LAD
  CAP   1   0 C=32.837PF
  IND   1   0 L=34.285NH
  CAP   1   2 C=12.330PF
  IND   2   3 L=91.307NH
  IND   3   0 L=34.285NH
  CAP   3   0 C=32.837PF
  A: 2POR 1 3
 END
 FREQ
* USE FIRST FREQ'S FOR IN-BAND RESPONSE
   STEP        100MHZ 220MHZ 2MHZ
*  STEP        10MHZ 1000MHZ 10MHZ
 END
 OUT
  PRI A S
 END
```

Computer Analysis Program

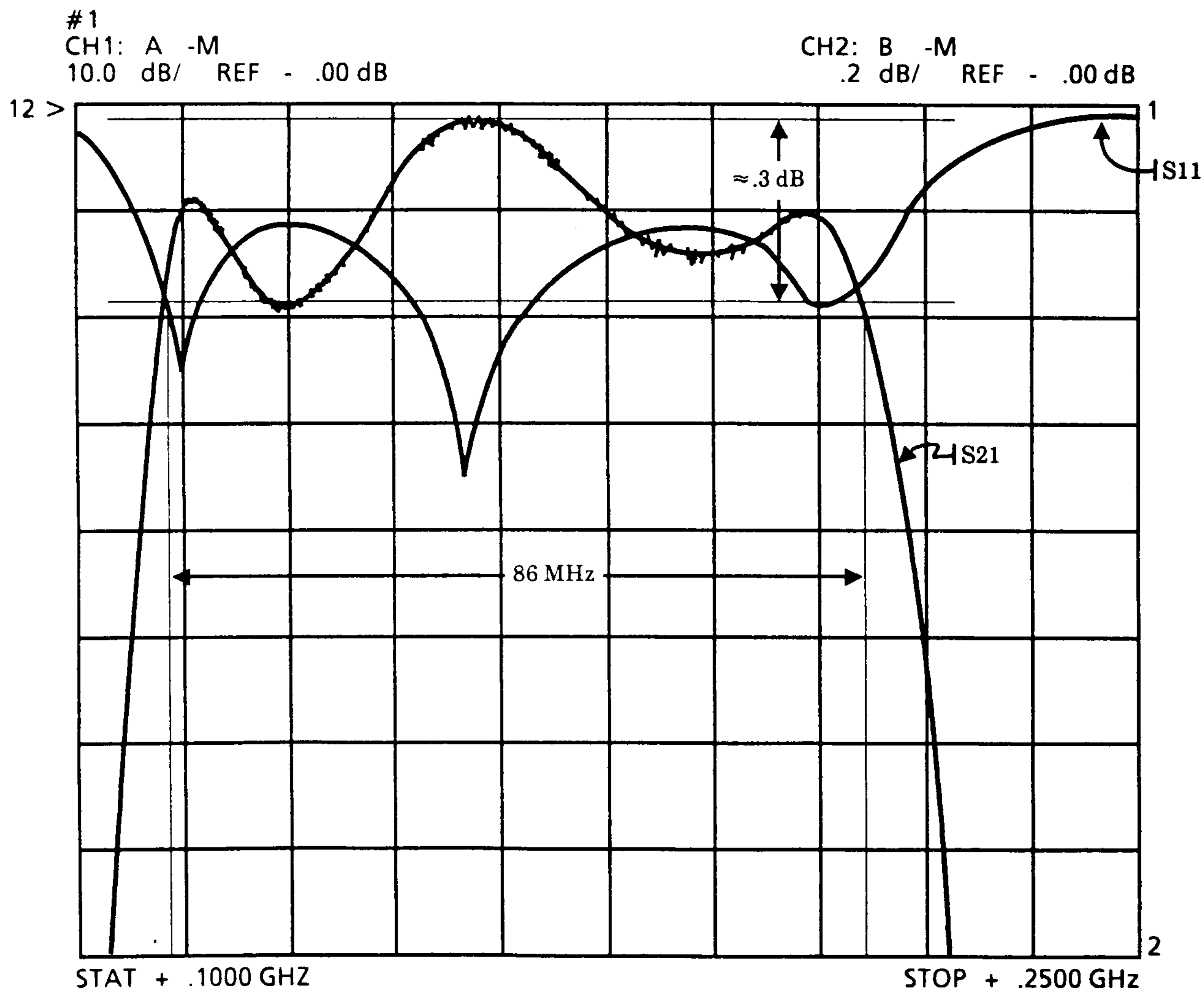

SUPER-COMPACT PC
MS11 [dB] A
0
-25
-50
-75
-100
MS21 [dB] A
0
-0.5
-1
-1.5
FREQ [MHz]
100
150
200
250
< 0.1 dB
S11(dB mag.)
S21(dB mag.)
100 MHz

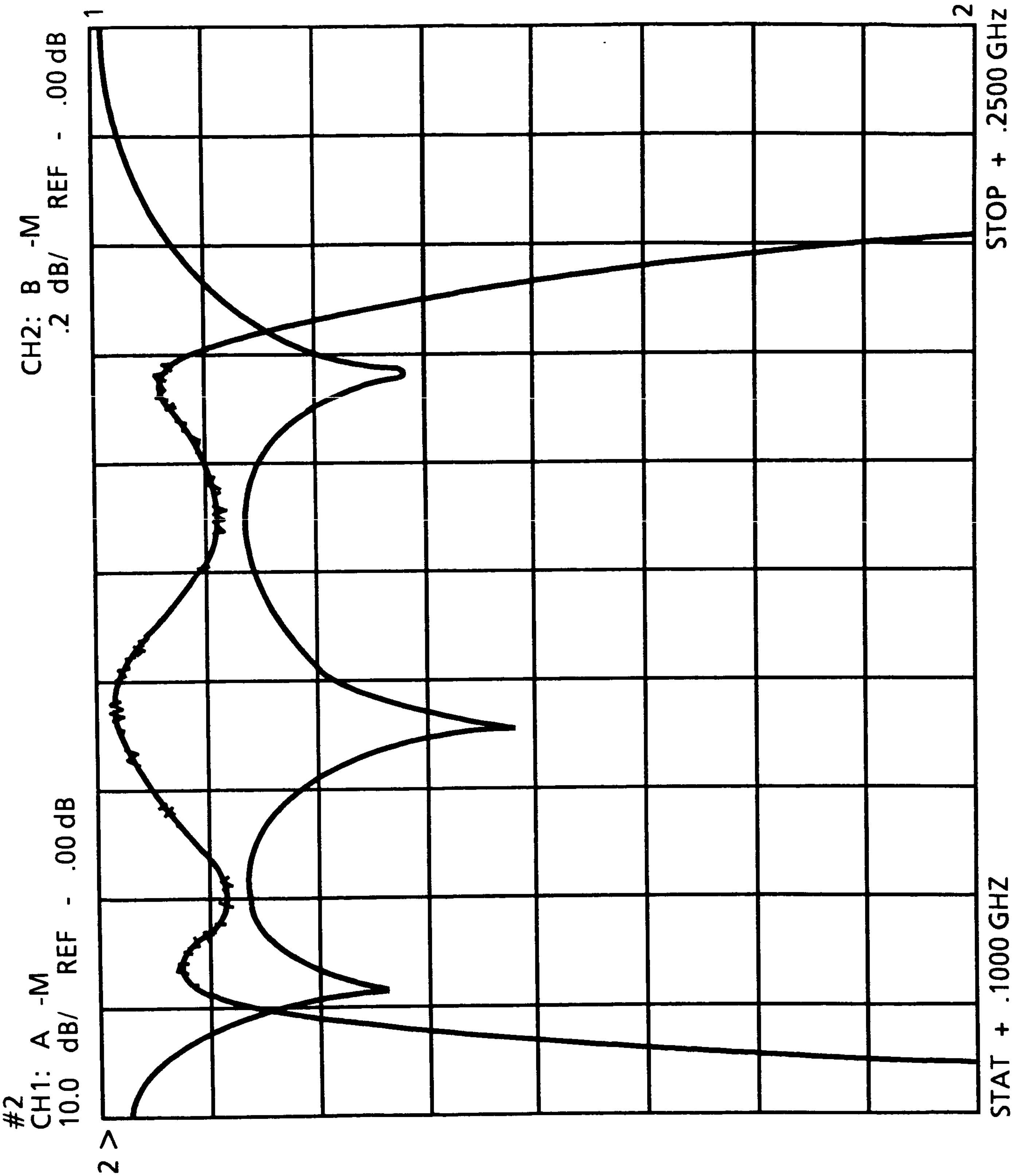
SUPER-COMPACT PC

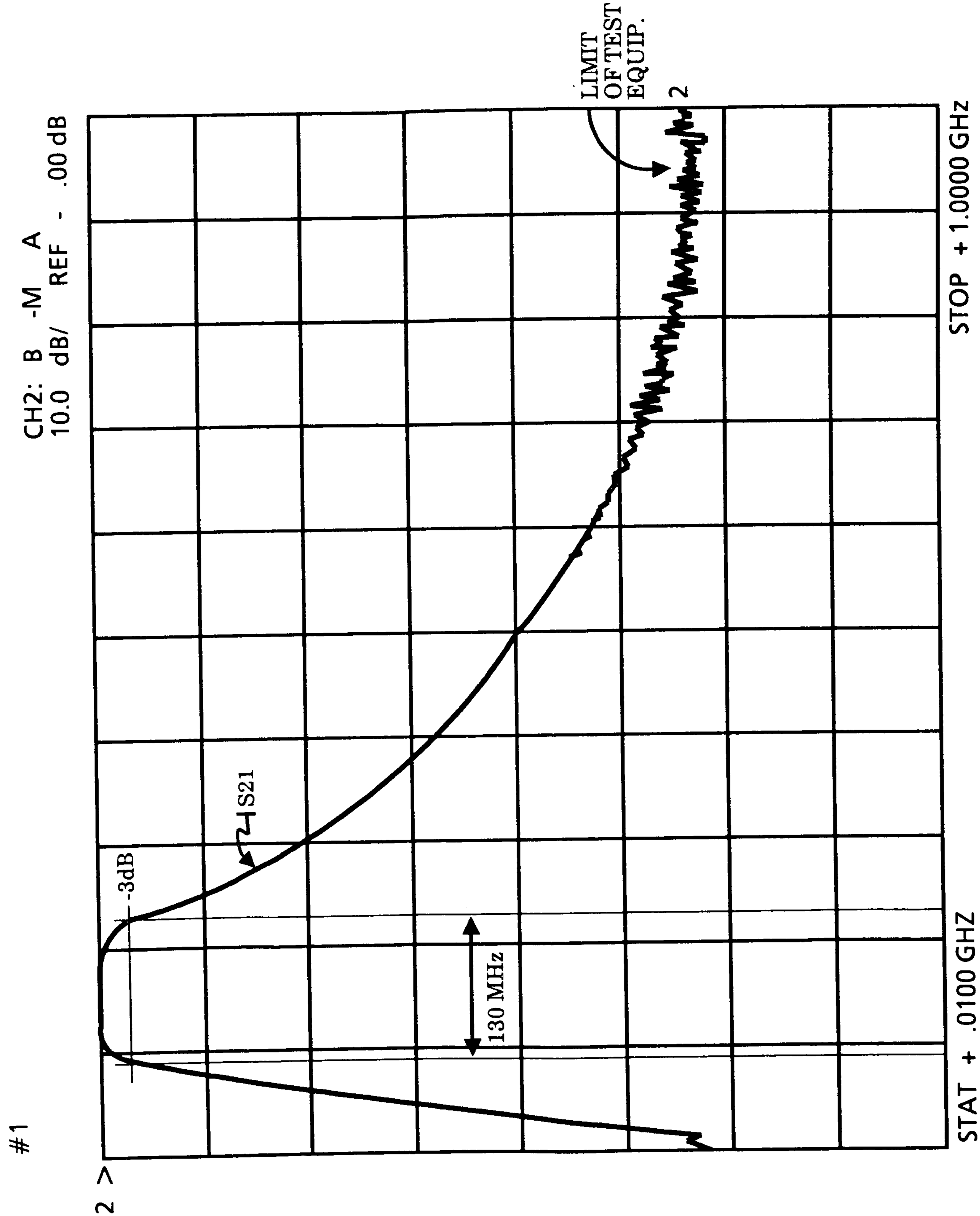


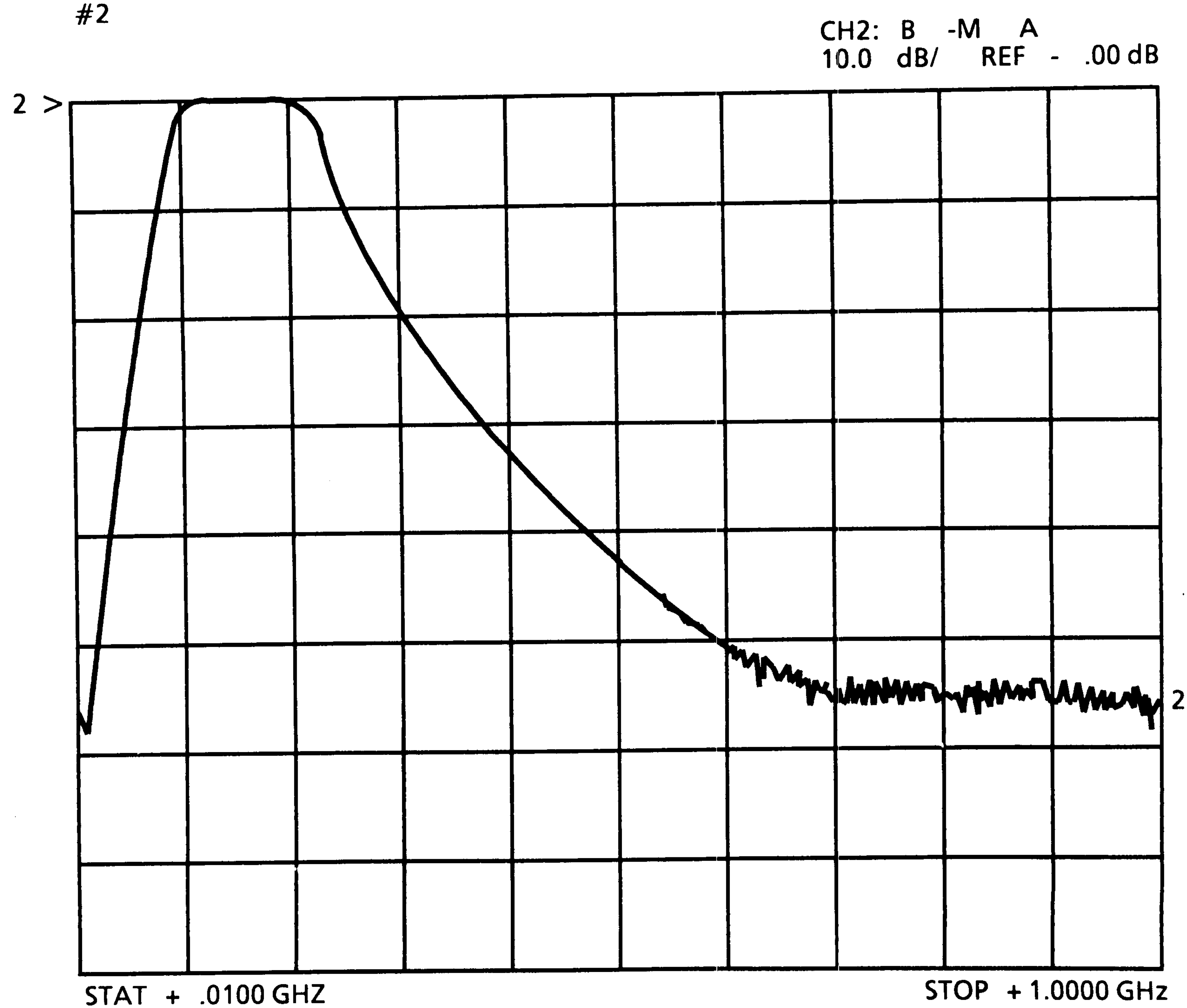
MEASURED RESPONSE

Two filters were constructed, tuned, then tested using a scalar network analyzer. Results of the measurements are plotted and shown at the end of this section. The maximum insertion (in-band) loss was less than 0.5 dB. The ripple bandwidths were on the order of 85 MHz while the 3 dB bandwidths were approximately 130 MHz. Thus, the design goal of 100 MHz is determined to be met adequately. A maximum ripple of approximately 0.3 dB is also allowable for this application. Out-of-band attenuation follows the theoretical values closely. The following plots show return loss (S11) and transmission loss (S21) versus frequency for each of the two filters.




#2
CH1: A -M
10.0 dB/ REF - .00 dB
CH2: B -M
.2 dB/ REF - .00 dB
STAT + .1000 GHZ
STOP + .2500 GHz
12 >
1
2


#1
CH2: B -M A
10.0 dB/ REF - .00 dB
LIMIT
OF TEST
EQUIP.
2
-3dB
S21
130 MHz
2 >
STAT + .0100 GHZ
STOP + 1.0000 GHz


#2
CH2: B -M A
10.0 dB/ REF - .00 dB
2 >
2
STAT + .0100 GHZ
STOP + 1.0000 GHz

CONSTRUCTION

Standard, modern lumped element RF engineering techniques were used to realize these filters. C1 is two chip capacitors soldered in parallel. L1 is a hand-wound inductor of four turns of 18 A.W.G. magnet wire. The diameter is 0.15 inches and the length is 0.15 inches. L2 is also a hand-wound inductor of eight turns of 18 A.W.G. magnet wire measuring 0.25-inches by 0.15-inches diameter. C2 is a commercially available variable capacitor (3 pf to 23 pf). A figure is included at the end of this section showing additional construction details.

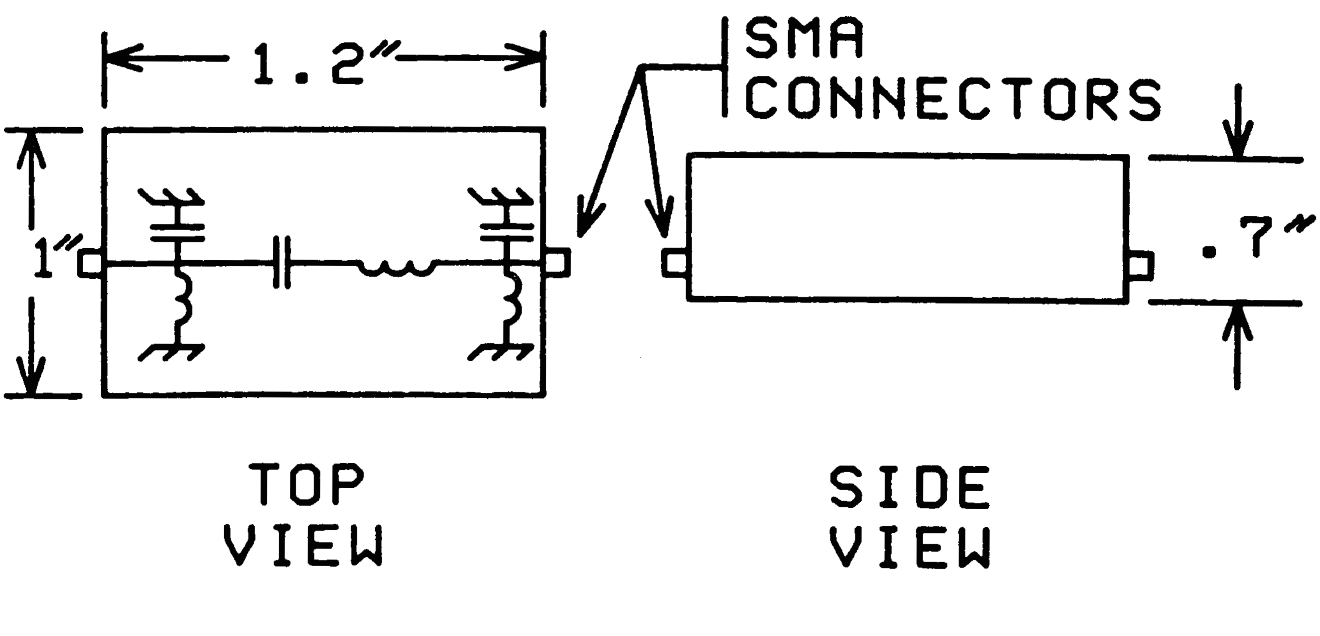


Figure 3.- Filter packaging details.

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15. Supplementary Notes		

16. Abstract

The purpose of this project was to investigate, delineate, develop, and perform tasks related to the development of an automobile collision avoidance radar system. Items within the scope of this 1-year effort were to (1) review previous authors' work in this field; (2) select a suitable radar approach; (3) develop a system design; (4) perform basic analyses and observations pertinent to radar design, performance, and effects; (5) fabricate and collect radar data from a data collection radar; (6) analyze and derive conclusions from the radar data; and (7) make recommendations about the likelihood of success of the investigated radar techniques.

The major finding was that the application of radar to the automobile collision avoidance problem deserves continued research and development even though the specific approach investigated in this effort did not perform adequately in its angle measurement capability. Additional findings were that (1) preliminary performance requirements of a candidate radar system are not unreasonable; (2) a significant number of traffic accidents and/or their severity could possibly be lessened by using a collision avoidance radar system which observes a fairly wide field-of-view ahead of the radar-equipped vehicle (approximately ± 10 degrees or wider; (3) the health radiation hazards of a probable radar design are not significant even when a large number of radar-equipped vehicles are considered; (4) effects of inclement weather on radar operation can be accommodated in most cases by judicious system design; (5) the phase monopulse radar technique as implemented and tested here demonstrated inferior angle measurement performance which warrants the recommendation of investigating alternative radar techniques; and (6) extended target and multipath effects, which presumably distort the amplitude and phase distribution across the antenna aperture, are responsible for the observed inadequate phase monopulse radar performance.

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