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SEATRACKS: A 35GHZ MONOPULSE TRACKING RADAR.(U)
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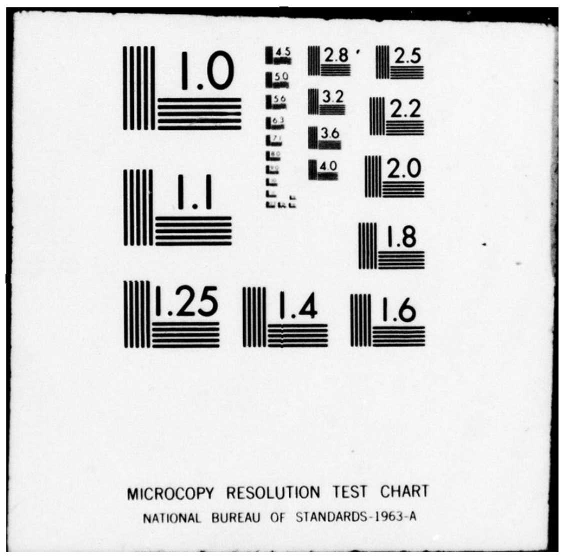
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SEATRACKS: A 35 GHz MONOPULSE TRACKING RADAR

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ELECTRONICS SYSTEMS DEPARTMENT

10 MARCH 1978

NAVAL SURFACE WEAPONS CENTER

Dahlgren, Virginia 22448 • Silver Spring, Maryland 20910

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NSWC/WOL/TR-78-30

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): SEATRACKS: A 35GHz MONOPULSE TRACKING RADAR.

5. TYPE OF REPORT & PERIOD COVERED: Interim Rept.

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s):

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8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS:

Naval Surface Weapons Center
White Oak, Silver Spring, MD 20910

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62766N; CF61-112; ZF61-112-001; 9F02AM

11. CONTROLLING OFFICE NAME AND ADDRESS:

12. REPORT DATE: 10 March 1978

13. NUMBER OF PAGES: 40

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 43p.

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

Approved for public release, distribution unlimited

F61112

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): ZF61112001

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Radar
Monopulse
Tracking Radar

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This report describes the development and theoretical analysis of a 35GHz Monopulse Tracking Radar. Some notes on the rationale behind the program are followed by an explanation of monopulse and the specifications and block diagrams of the SEATRACKS system. The operation of the radar is described by giving the details of each subsystem (i.e., receiver, transmitter, range tracker, etc.). The system performance analysis is described

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and an outline of system test plans is given in the appendix to the report.

SUMMARY

This report described the development and theoretical analysis of a 35GHz Monopulse Tracking Radar.

Some notes on the rationale behind the program are followed by an explanation of monopulse and the specifications and block diagrams of the SEATRACKS system.

The operation of the radar is described by giving the details of each subsystem (i.e., Receiver, Transmitter, Range Tracker, etc.).

The system performance analysis is described. This includes:

1. Prediction of maximum detection range performance using the Blake model in a clear environment, clutter environment, and in the presence of multipath. Predictions of signal level as a function of range due to clutter and multipath interference.

2. The effects of gain and phase mismatch for the sum and difference channels of the millimeter wave monopulse receiver and how this relates to building practical hardware.

3. Monopulse Angle and Range Tracking accuracies as a function of thermal noise, multipath, and the servomechanism response.

4. The performance improvement of a frequency agile system.

5. ECCM performance of a millimeter wave radar.

6. The determination of a system transfer function.

An outline of system test plans is given in an appendix to the report.

By direction

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ILLUSTRATIONS

SEATRACKS
A 35GHZ MONOPULSE TRACKING RADAR

INTRODUCTION

As part of the Center's FY'77 IED program (Radar Engineering Branch, F-46) has undertaken the development of a mobile 35GHz monopulse tracking radar called SEATRACKS (Small Elevation Angle TRACKing and Surveillance). SEATRACKS is being built not so much to accumulate data as an end in itself, but rather to demonstrate the feasibility of millimeter wave radar as a solution to specific Navy operational requirements (Figure 1) and to determine the necessary system trade offs in making this type of radar an operational reality. This report describes the radar, the theoretical analysis of the system, and the future plans. (It should be noted that additional details of the performance analysis, such as the tracking error, will be published in separate reports.)

MONOPULSE

Monopulse derives its name from the fact that directional information is obtained from a single radar pulse. Beam switching or mechanical scanning is not necessary for direction information, although both may be used in a monopulse radar system to keep the target within the beam width of the receiving antenna. Since a monopulse system provides directional information from a single pulse, it requires a minimum of two channels to obtain azimuth data. At least one more channel is needed to provide elevation information simultaneously.

Information obtained from monopulse systems is in the form of difference-to-sum ratios. This normalization eliminates those components of fading and scintillation resulting from time dependent sampling of quadrature components of angle information. Two basic types of systems are commonly used -- phase or amplitude. A combination of both is possible. The type of system is designated by the antenna configuration employed rather than by the processing

AREA	POSSIBLE APPLICATIONS	RATIONALE
• FIRE CONTROL	• SHORT RANGE WEAPONS	• SUPERIOR CLUTTER AND MULTIPATH PERFORMANCE • SMALL SIZE
• NAVIGATION	• OBJECT AVOIDANCE FOR HIGH PERFORMANCE SHIPS	• SHORT RANGE DETECTION OF SMALL FLOATING OBJECTS
• SURVEILLANCE	• LOW ELEVATION DETECTION OF SEA TARGETS	• NARROW BEAMWIDTH • SUPERIOR CLUTTER AND MULTIPATH PERFORMANCE • DENY STANDOFF JAMMING

Figure 1. Seatracks Applications

SPECIFICATIONS

PARAMETER	VALUE
TRANSMITTER TYPE	COAXIAL MAGNETRON
OPERATING FREQUENCY	35 GHz
PEAK TRANSMITTING POWER	100 KW
PULSEWIDTH	0.1, 0.5, 1.0μ SEC
PRF	5.5, 1.1, 0.55 KPPS
AVERAGE POWER	55 WATTS
ANTENNA GAIN	43 db
BEAMWIDTH	1°
POLARIZATION	VERT., HORZ., CIRCULAR
IF FREQUENCY	60 MHz
IF BANDWIDTH	15 MHz
FRONT END	WAVEGUIDE (WR-28)

Figure 2. Basic Design Specifications

information obtained after it has been received by the antenna. Phase information received at the antenna can be readily converted to amplitude information or vice versa (Reference 1).

SPECIFICATIONS AND FEATURES

Figure 2 gives some of the basic design specifications of the system. Availability of state of the art hardware plus system performance requirements drove the selection of these parameters. In addition to an AFC and instantaneous AGC, the system features matched receive channels for maximum dynamic stability, test injection ports in the RF and a high degree of mobility and maintain ability. The entire radar and its control system is shown mounted on the pedestal shown in Figure 3 and instrument rack shown in Figure 4.

BLOCK DIAGRAMS

Figure 5 shows the basic block diagram of the Monopulse Tracking Radar. Note that this block diagram also shows the sources for the various subsystems which are being integrated at White Oak. Figure 6 shows the front end of the radar. Figure 7 shows the video processor which is being designed and built at White Oak.

ANTENNA AND COMPARATOR

The antenna is a two-foot diameter cassegrain reflector with a four-horn monopulse feed (Figures 8 and 9). Polarization is linear vertical with capability built in to change to linear horizontal or circular. Peak gain of the sum channel is 43 dBi with a 1.0° 3 dB beamwidth sidelobes are-18 dB nominal. Phase shifters are incorporated into the comparator and tuned to equalize the electrical length of all three channels. The insertion loss of any one channel is 0.75 dB maximum. Power handling capability of the antenna/comparator is 100 kw peak, 60 watts average.

35GHz TRANSMITTER SYSTEM

The heart of the transmitter system is 100 kw peak Varian SFD 319 coaxial magnetron (Figure 9). The tube operates at a maximum duty cycle of 0.00055 to provide 55 watts average power. The solid state modulator provides selectable PRF's of 5.5, 1.1, and 0.55 KHz with pulse widths of 0.1, 0.5, and 1.0 microseconds respectively. A power reduction network allows reduction of power by 10, 20, 30, or 40 dB and a 40 dB coupler on the output provides power to the AFC network. The modulator control panel is mounted remotely. The system is pressurized with Sulfahexafluoride (SF_6).

1. "A Monopulse System Using the MIF 8394 as a Subsystem Component," Varian Application Engineering Bulletin AEB-101, Dec 1972.

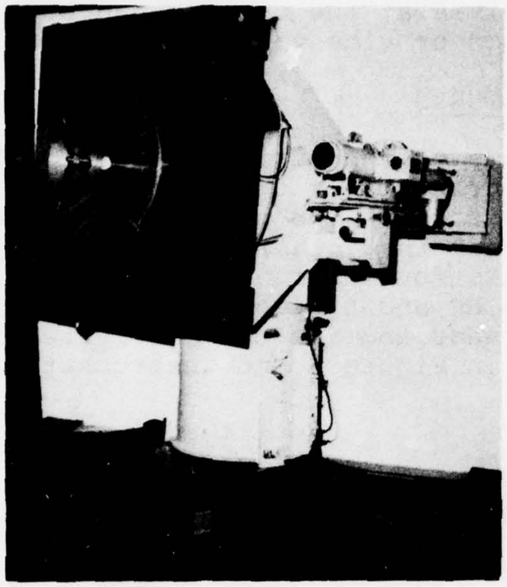

Figure 3. Tracking Pedestal

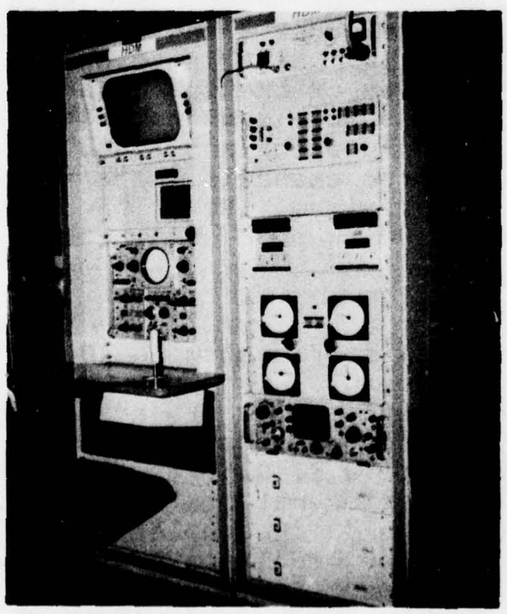

Figure 4. Instrument Rack Which Will Include
All Controls, Displays and Power Supplies

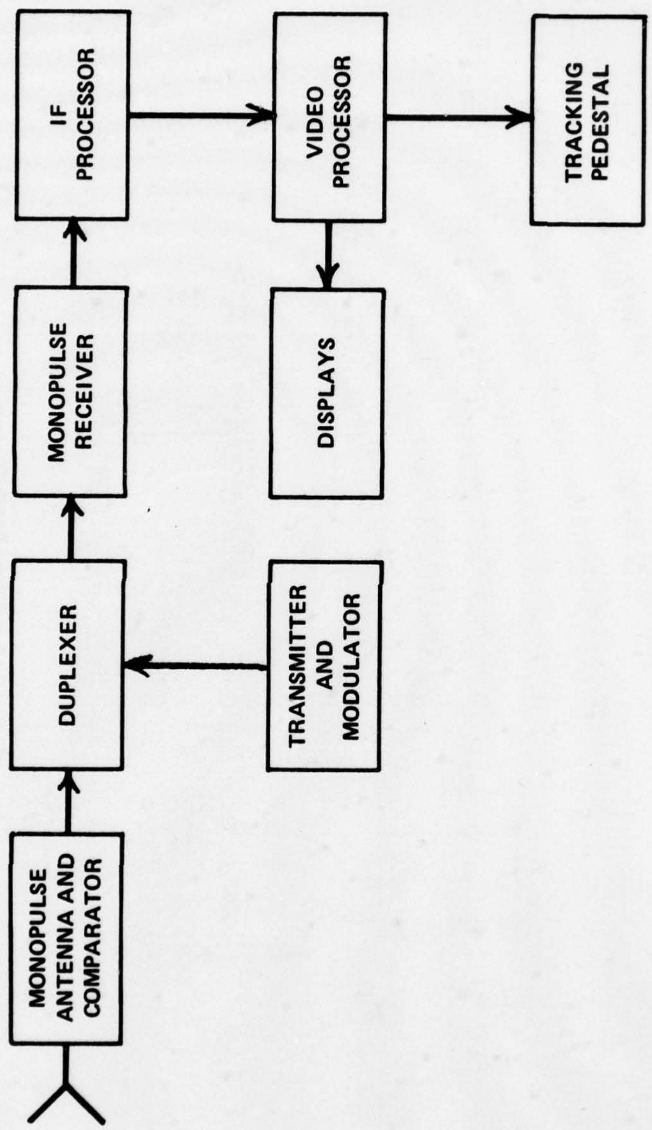

Figure 5. Basic Block Diagram of a Monopulse Tracking Radar

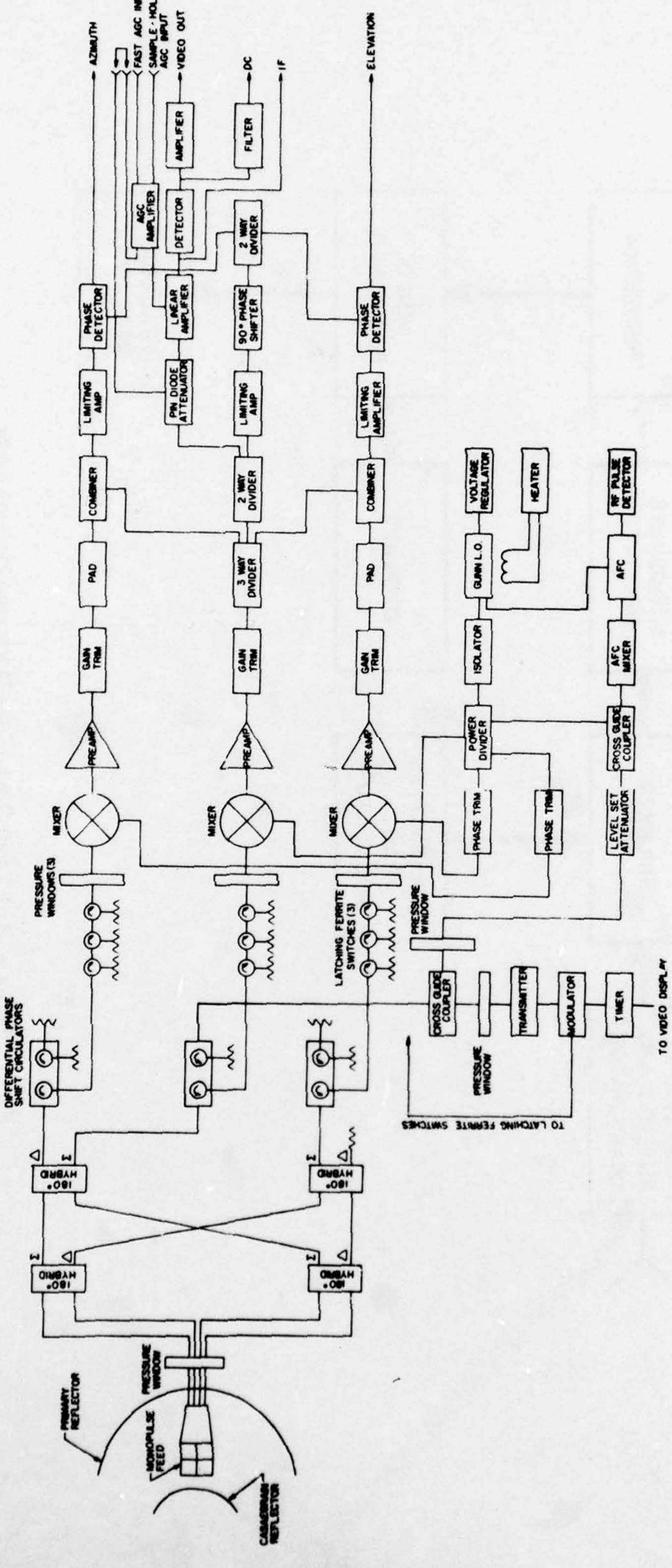

Figure 6. Front-End Block Diagram

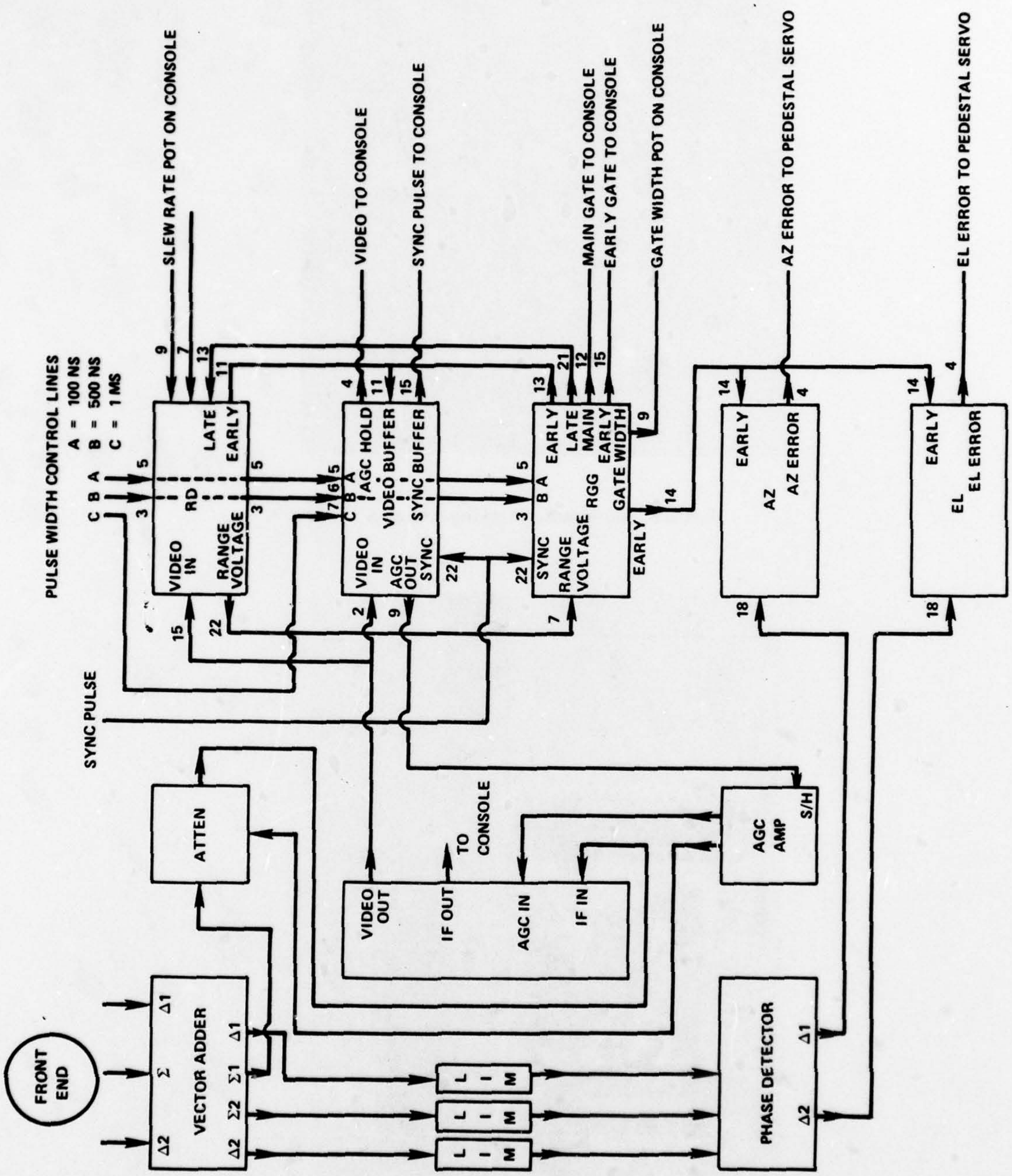

Figure 7. Video Processor Block Diagram

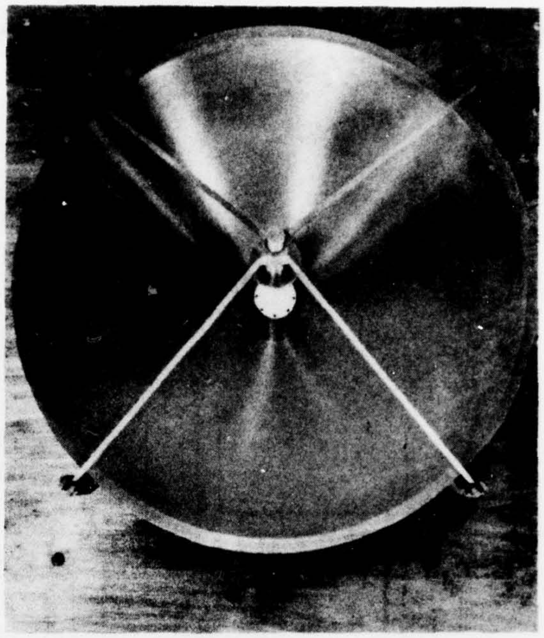

Figure 8. Monopulse Tracking Antenna

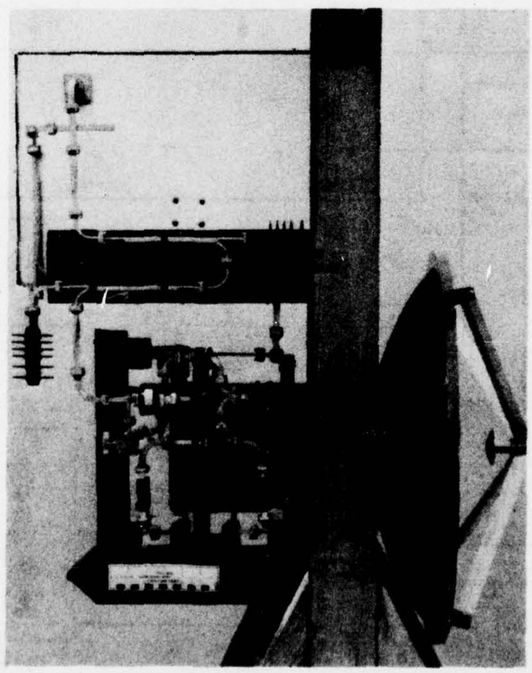

Figure 9. Completed RF Front-End Showing Monopulse Antenna, Receiver, and Transmitter

DUPLEXER

The duplexer (Figure 10) consists of three latching ferrite switches per channel and one differential phase shift circulator per channel. Although, from a circuit protection standpoint, the differential phase shift circulators are unnecessary in the different channels, they will provide better channel to channel dynamic phase tracking. A voltage sensing interlock device on the terminals of the latching switches prevents the modulator from being triggered until the latching switches are in the high attenuation state. A "main bang" sensor coupled with fixed delays (different for each pulse width) returns the switches to the low attenuation states. Total receiver isolation during the transmit pulse is 80 dB.

THREE-CHANNEL MONOPULSE RECEIVER

Each channel of the monopulse receiver (Figures 9 and 11) consists of a balanced mixer/preamp with a 5.1 dB noise figure and 6 dB conversion loss. The 1 dB compression point is +3 dB and the dynamic range is approximately 65 dB with a total RF to IF gain of 32 dB. The local oscillator is a Gunn Oscillator with 50 mw of output power. Phase trimming is done at the L.O. arms of the difference channels to adjust the relative phase of the IF difference signals with respect to the IF sum signal. Pin-diode attenuators provide gain trim in all three channels.

AFC

The AFC circuit consists of a gated discriminator followed by an integrator and amplifier. The AFC voltage is directly applied to the varactor tuning diode inside the L.O. source. The AFC circuit acts independently of the IF strip. As a result, the IF frequency of the AFC mixer can be chosen to be different from 60 MHz to allow for a combined worst-case drift of the magnetron and Gunn L.O. higher than 60 MHz. The AFC error signal is maintained at all times by means of a sample-and-hold circuit even in the absence of target return.

SIGNAL PROCESSING

Processing of the return signal can be broken into 4 sections: the first mixer; the three channel IF processor; the video circuits; and the AGC loop.

IF PROCESSOR

A Varian MIF 8394 Monopulse IF subsystem as modified by NSWC, accepts the outputs of the 3 mixer/pre-amps (Σ, Δ_E, and Δ_{AZ}) and puts out a DC error signal for both Azimuth and Elevation and also puts out a linearly amplified sum channel video. Simplicity and reliability are built into the IF system by using insensitive passive components to convert the amplitude/phase information, from the three input channels, into phase only information. This

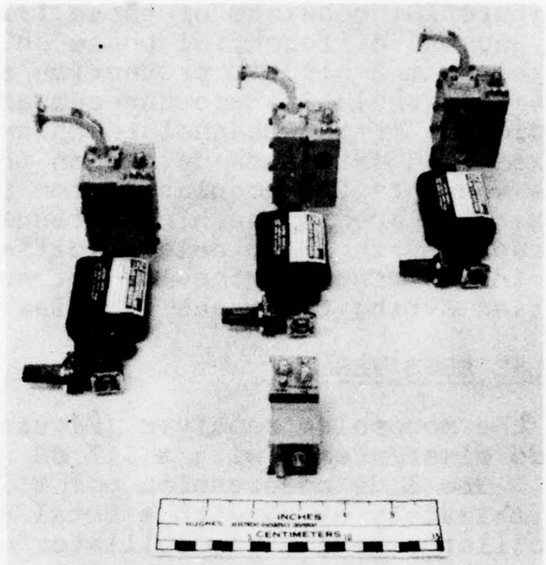

Figure 10. Duplexer Components

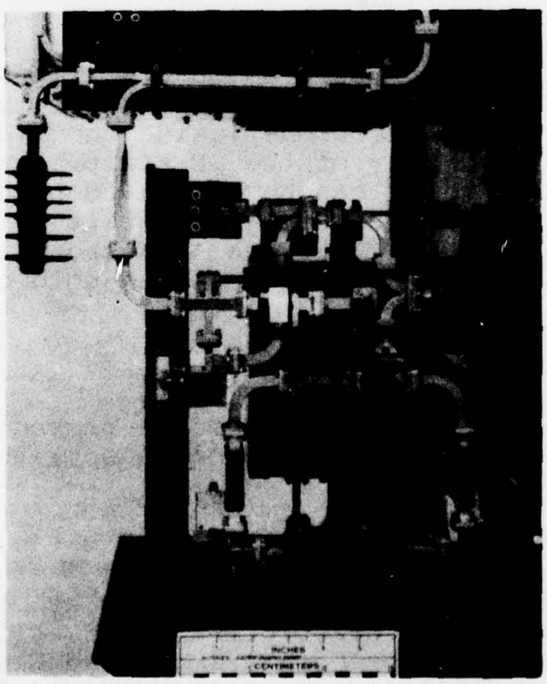

Figure 11. Monopulse Receiver

conversion makes the processing hardware far simpler. Instead of building and maintaining three amplifier channels which track both in phase and in amplitude, only phase tracking is necessary. Hence, three limiting amplifiers are used to determine the angle tracking information. Only the sum channel requires a linear amplifier since the display and ranging circuitry make use of a linear input/output relationship. With only one linear amplifier, the AGC system becomes very inexpensive and reliable to produce.

VIDEO PROCESSOR

The video processing can be separated into 4 subsystems: the range tracker; the angle processing; the AGC system; synchronizer; and the displays. An inexpensive MOS-FET input op amp is utilized throughout the video processor to reduce the number of different piece parts needed for system support. The Range Discriminator (RD) makes use of the extremely low input bias current of the MOS input op amp in the early and late gate integrators as well as in the range control voltage integrator. The circuit configuration of the integrator which generates the range control voltage allows the leakage resistance of the integration capacitor to be completely cancelled. To date, drift rates at the lowest PRF (500 HZ) are equivalent to approximately 1/2 inch between pulses. New, ultra fast D MOS FET analog gates and gate drivers have been employed in the RD which greatly simplify the circuit complexity. And critical matching of saturation characteristics of switching transistors has been completely eliminated by the use of the V-MOS FET in the range gate generator (RGG).

Each of these subsystems incorporates recent technological advances in integrated circuit and solid state devices technology to attain high performance levels while simultaneously reducing the system size and complexity, thus retaining high reliability and high serviceability.

RANGE TRACKER

Tracking a target in range is accomplished using the standard "split gate tracker" technique. Two "gates", an early gate, and a late gate, are timed from the transmitted pulse, such that the end of the early gate and the beginning of the late gate are exactly at the center of the return pulse from a target.

The "Range Discriminator" (RD) board produces a voltage (V_R) which is proportional to the range of the target. After each return signal from the target, the RD updates the range control voltage (V_R) and thus tracks the target. It updates the range control voltage by integrating the video over the time that the early gate is on, and subtracting the two results. The difference, an error voltage, being either positive or negative depending on whether the target has moved toward the radar or away from it. The range control voltage is derived by integrating this error voltage in a very stable integrator. A manual override is incorporated so that the range control voltage can be slewed up or down to any desired range by the radar operator. Inputs from two transmitter control lines (A and B) are used to match the integration time of the early and late gate integrators to the selected pulse width of the radar. The early and late gates used by the Range Discriminator board are produced in the "Range Gate Generator" (RGG) circuit board.

It is the responsibility of the RGG to establish a fixed time between the transmit pulse and the early and late gate output pulses, to vary that time interval as a function of the range control voltage, to generate an early gate pulse and a late gate pulse with exactly the same width, to vary those pulse widths both continuously and in steps to follow the transmitted pulse width, and to generate a pulse for the digital range display. A sync pulse generated in the transmitter is used to start the timing between when the transmit pulse leaves to when the early and late gate pulses occur. While a range control voltage between -5 volts and +5 volts results in gating pulses at ranges of 1000 feet to 50 miles. The width of the gating pulses can be continously varied with a simple DC gate width control voltage. Plus, the transmitter pulse width control lines (A & B) automatically program the proper gate widths into the RGG. During all of these pulse width changes, the difference between the width of the early gate pulse and the width of the late gate pulse remains unmeasurable (less than lns). The use of analog devices, V-MOS FET switches, and Shotkey digital logic, has resulted in pulse to pulse jitter of less than 10 nans seconds yet the entire RGG fits on one circuit board.

AGC SYSTEM

The automatic gain control of the radar is derived from two sets of attenuators. The first is a PIN diode array manufactured by Anzac. This attenuator is immediately ahead of the linear amplifier within the IF. This allows signals of up to +20 dBm input at the input to the IF amplifier without saturation of the linear amplifier. A second PIN diode attenuator is contained inside the Varian linear amplifier. Together they provide a constant output level over a 100 dB dynamic range. Control of the attenuators have been made seperable so that sensitivity time control (STC) could easily be added. Further flexibility has been built in by designing the AGC loop to operate in manual, range gated or instantaneous AGC modes.

ANGLE PROCESSING

Each angle channel must take the low level error signal pulse from the IF processor and use the information to steer the antenna pedestal so as to track the target. This is accomplished by using the early gate pulse to drive an extremely fast sample hold circuit to sample the IF output error signals. In order to accommodate possible fixed delay variations between the Varian linear and limiting amplifiers, tapped delay lines are built into each angle channel. The sample hold output is adjusted in gain and connected to the Scientific Atlanta pedestal servo control loop.

DISPLAYS

An "A" scope is used to look at the radar return signals. Provisions for a "PPI" scope and "B" scope are included for video display while the radar is in a scan mode. The Range gate generator produces a pulse whose width is equal to the time it takes for the transmitted pulse to travel to the target and back. This pulse of variable width will be measured and displayed digitally by using standard, off the shelf, digital interrogated circuits. Not only will the digital display provide fast and accurate range information to the operator, it will also allow direct connection to digital processing equipment. The target is also displayed on a closed circuit T.V. Both wide angle and Telephoto lenses are available on the pedestal mounted camera.

TRACKING PEDESTAL

The entire radar, which weighs about 400 lbs., is mounted on a Scientific-Atlanta 3100 series tracking pedestal. This unit is capable of slew rates of up to 30^{o}/sec and slew accelerations of $30^{o}/sec^{2}$. It can travel ± 370 in azimuth and -5^{o} to $+185^{o}$ in elevation. A sector scan device automatically scans the pedestal up to $\pm 20^{o}$ in azimuth and elevation.

SYSTEM PERFORMANCE ANALYSIS

A comprehensive performance analysis is being conducted to provide a theoretical data base for the follow-on test program and to assist in identifying problem areas in the application of millimeter wave techniques to Navy radars. Specifically, the following areas are being investigated:

1. Prediction of maximum detection range performance using the Blake model in a clear environment, clutter environment, and in the presence of multipath. Predictions of signal level as a function of range due to clutter and multipath interference.

2. The effects of gain and phase mismatch for the sum and difference channels of the millimeter wave monopulse receiver and how this relates to building practical hardware.

3. Monopulse Angle and Range Tracking accuracies as a function of thermal noise, multipath, and the servomechanism response.

4. The performance improvement of a frequency agile system.

5. ECCM performance of a millimeter wave radar.

6. The determination of a system transfer function.

DETECTION RANGE CALCULATION

The detection ranges for the monopulse radar were calculated using several methods. One method calculates the detection range of the radar in "quasi-free" space. The calculated range is based on the assumption of free-space wave propagation modified only by the effects of the normal atmosphere, including molecular absorption losses and normal refraction, but not including absorption by rain or other precipitation, abnormal refractive effects, or multipath interferences.

Using this assumption, the law of variation of power density of the transmitted wave at range R along any ray path is:

$$P(R) = \frac{P_t G_t}{4\pi r^2} \int_0^R e^{-d(r)}\, dr$$

where P_t is the transmitter power, G_t is the transmitter antenna gain, and d(r) is the attenuation constant of the atmosphere at distance r from the radar. This constant includes refractive losses as well as absorptive losses. Refractive losses are the lens effect loss, and absorption losses are those due to oxygen and water vapor absorption. The detection range was calculated for this method using the standard radar parameters of Figure 12 and the statistics of detection criteria, Pd = 0.9 and $P_{fa} = 1 \times 10^{-6}$. An additional required input is the target size and its fluctuation characteristics. Results for a one square meter non-fluctuating target and a one square meter Swerling Case 1 are presented in Figure 13.

A second detection range calculation method includes the additional effects of multipath and the vertical plane radiation pattern of the radar antenna. The output is in the form of a range-height-angle profile of the vertical plane radar coverage. Figure 14 is an example of this vertical plane radar coverage for two selected radar parameter combinations in Figure 13.

The third detection range calculation provides a plot of the return signal vs. range for a target approaching the radar at a constant altitude. This method also takes into account sea-reflection, multipath, interference, and is the only one of the three methods that includes the effects of clutter. This technique is particularly suited for the case of a low altitude target for which the information contained from the second method (vertical plane coverage) is inadequate. When the plotted signal is above a certain threshold, as indicated on the graph by different lines or curves for different conditions, the target is detectable. The threshold is determined by the minimum detectable signal, clutter, and any ECM environment. A sample performance curve is included in Figure 15. It should be noted that it has been found necessary to perform certain modifications to the Blake models to obtain the correct results at 35GHz. The atmospheric attenuation used in this simulation is considered to be optimistic. Recent references have

PULSE POWER, Kw	100.0
PULSE LENGTH, μSEC	SEE TABLE BELOW
PRF, Hz	" " "
BANDWIDTH CORRECTION FACTOR, C_B, dB	" " "
NUMBER OF PULSES INTEGRATED, n	" " "
DUTY CYCLE	.00055
TRANSMIT ANTENNA GAIN, dB	43.0
RECEIVE ANTENNA GAIN, dB	43.0
FREQUENCY, MHz	35,000
RECEIVER NOISE FIGURE, dB	8.0
ANTENNA OHMIC LOSS, dB	1.5
TRANSMIT TRANSMISSION LINE LOSS, dB	1.5
RECEIVE TRANSMISSION LINE LOSS, dB	3.0
SCANNING ANTENNA PATTERN LOSS, dB	1.6
HORIZONTAL BEAMWIDTH, DEGREES	1.0
VERTICAL BEAMWIDTH, DEGREES	1.0
SIDE LOBE LEVEL, dB	18.0
ANTENNA POLARIZATION	VERTICAL

PRF (Hz)	PULSEWIDTH (μSEC)	NUMBER OF PULSES n	C_B (dB)
5.5×10^3	0.1	110	+2.03
1.1×10^3	0.5	23	+3.29
$.55 \times 10^3$	1.0	11	+6.03

Figure 12. Millimeter Wave Radar System Parameters.

PULSEWIDTH (μSEC) PRF (Hz) NUMBER OF PULSE(N)	ANTENNA TILT ANGLE (DEG)	TARGET ANGLE (DEG)	NON-FLUCTUATING ONE SQUARE METER TARGET			SWERLING CASE 1 FOR ONE SQUARE METER TARGET		
			DETECTION RANGE (N.MI.)	TROPO LOSS (dB)	S/N (dB)	DETECTION RANGE (N.MI.)	TROPO LOSS (dB)	S/N (dB)
1	0	~0	13.8	5.26	-1.5	9.2	3.57	7.0
2	0	~0	14.8	5.91	2.76	10.2	4.10	11.1
3	0	~0	13.5	6.14	4.97	9.3	4.27	13.2
1	0.5	0.5	13.9	5.14	-1.5	9.3	3.49	7.0
2	0.5	0.5	14.9	5.73	2.76	10.3	4.01	11.1
3	0.5	0.5	13.6	5.96	4.97	9.3	4.17	13.2
1	1.0	1.0	14.0	4.96	-1.5	9.4	3.43	7.0
2	1.0	1.0	15.1	5.55	2.76	10.2	3.89	11.1
3	1.0	1.0	13.8	5.75	4.97	9.4	4.06	13.2
1	3.0	3.0	14.6	4.38	-1.5	9.6	3.13	7.0
2	3.0	3.0	15.9	4.83	2.76	10.6	3.52	11.1
3	3.0	3.0	14.5	4.96	4.97	9.6	3.65	13.2

PULSEWIDTH (μSEC) PRF (Hz) NUMBER OF PULSE (N)	CODE NUMBER
0.1 5.5×10^3 110	1
0.5 1.1×10^3 23	2
1.0 $.55 \times 10^3$ 11	3

Figure 13. Detection Range Performance In Clear Air

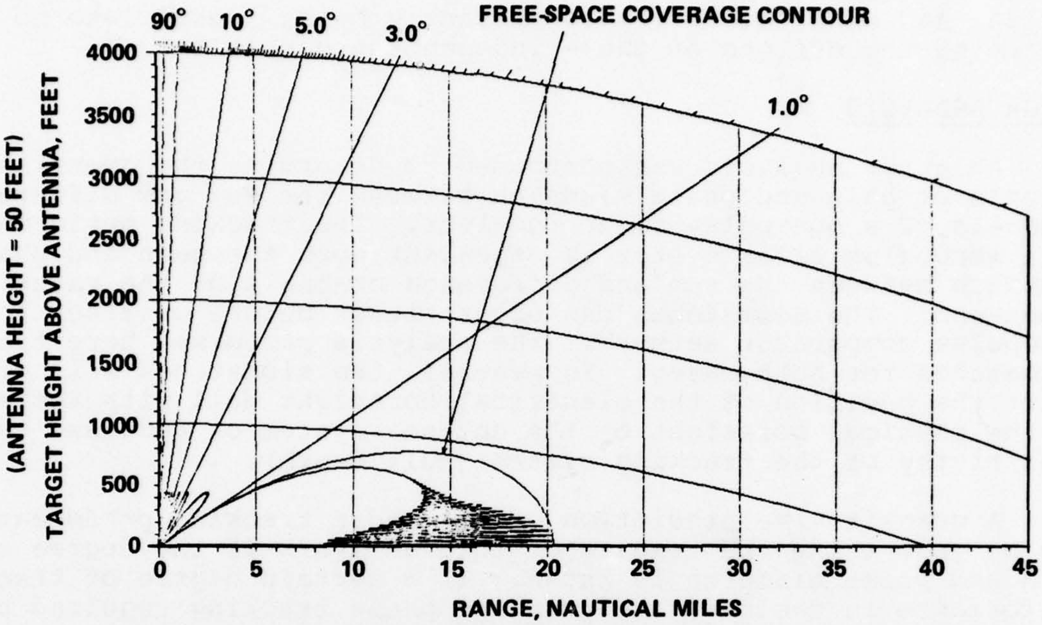

FIGURE 14 Lobe Plot

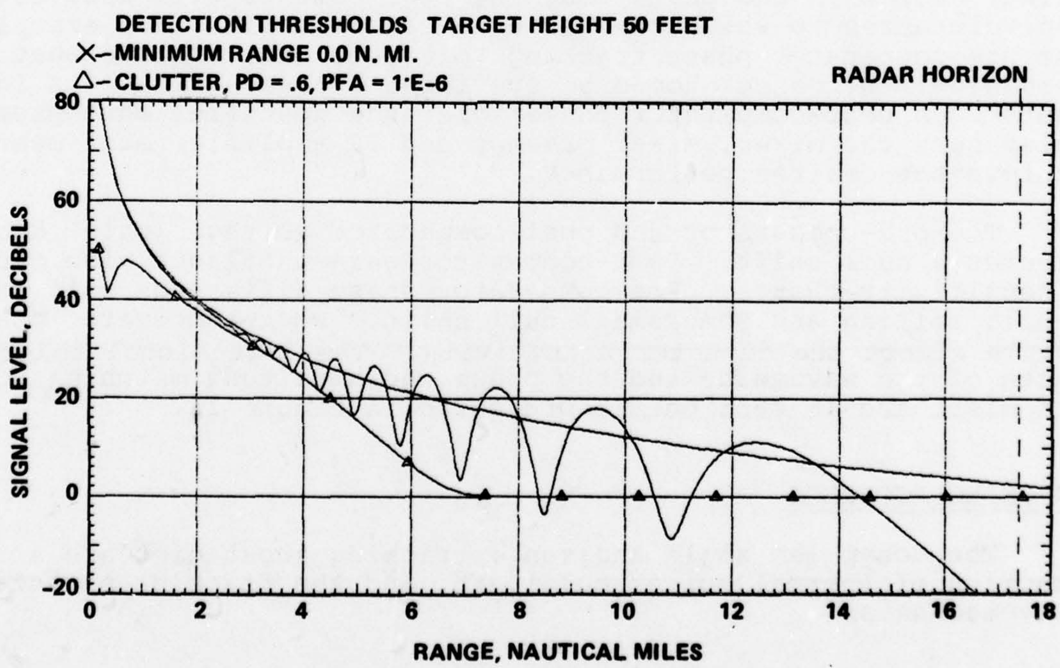

Figure 15 Signal-Level Vs. Range 35 GHz

cited attenuation numbers that are more than this. Work is being directed at incorporating the more recent atmospheric attenuation numbers into the Blake program. In addition, the measured data for sea clutter at 35GHz at low grazing angles is sparse. The Blake method for determining sea clutter at different sea states, grazing angles, and wind velocities is presently being looked into to determine the effects of these independent variables.

ERROR ANALYSIS

An error analysis was performed to determine the quantitative effects of gain and phase mismatch between the sum and difference channels of a monopulse radar receiver. The tracking performance of a monopulse radar system is dependent upon the gain and phase mismatch between the sum and difference channels of the radar front-end. The mismatches can occur either before or after the monopulse comparator network. The analysis performed here treats mismatches for both cases. In general, the mismatches will either shift the position of the electrical boresight null with respect to the physical boresight of the antenna system or decrease the sensitivity of the tracking system (null depth).

A quantitative prediction of the radar tracking performance can be made using the results of this analysis if the degree of gain and phase mismatch is known. If a certain degree of tracking performance is desired, the gain and phase tracking required can be determined for post-comparator and pre-comparator gain and phase shift. The gain and phase tracking requirements will also establish the tolerances to which the hardware can be built. For example, the pre-comparator phase tracking tolerance will dictate what mechanical tolerance should be specified for waveguide runs in the system. A post-comparator phase tolerance specifies what phase tolerances the mixer, mixer preamp, and IF amplifier must meet to achieve the desired performance.

The pre-comparator and post-comparator voltage (gain) unbalance creates a null shift. Post-comparator gain unbalance also causes a sensitivity change. Pre-comparator phase difference will cause a null filling and some small null shift. Post-comparator phase shifts affect the detector sensitivity. The dimensional tolerances of the waveguide and the phase and amplitude matching for the mixer and IF section are presented in Figure 16.

TRACKING ACCURACY

The monopulse angle and range tracking accuracies are a function of thermal noise, multipath, and the tracking pedestal servomechanism.

– PRE–COMPARATOR (ANTENNA/COMPARATOR) GAIN MISMATCH.

EFFECT: CAUSES A SHIFT IN THE BORESIGHT AXIS.

TOLERANCE REQUIRED	ERROR (MRAD)
1 dB GAIN MISMATCH	1
3 dB GAIN MISMATCH	2

– PRE–COMPARATOR (ANTENNA/COMPARATOR) PHASE MISMATCH.

EFFECT: CAUSES NULL FILLING AND SOME SMALL NULL SHIFT OF THE ANTENNA RADIATION DIFFERENCE PATTERN. IT DETERMINES THE NULL DEPTH. IT ALSO CAUSES A SMALL NULL SHIFT DEPENDENT ON POST-COMPARATOR PHASE SHIFT.

PHASE TOLERANCE REQUIRED	MECHANICAL TOLERANCE	REQUIRED NULL DEPTH
3.6 DEGREES	0.034 INCHES	30 dB

– POST–COMPARATOR GAIN IMBALANCE.

EFFECT: CAUSES A NEGLIGIBLE NULL SHIFT (LESS THAN 0.1 MRAD). IT ALSO CAUSES A SENSITIVITY CHANGE IN THE RECEIVER ERROR CURVE.

TOLERANCE/CONDITION	ERROR	SLOPE CHANGE
3 dB GAIN MISMATCH $\|\Sigma\|>\|\Delta\|$	35%	DECREASE
3 dB GAIN MISMATCH $\|\Delta\|>\|\Sigma\|$	20%	INCREASE

– POST–COMPARATOR PHASE IMBALANCE.

EFFECT: CAUSES A SENSITIVITY CHANGE IN THE RECEIVER ERROR CURVE. IT ALSO CAUSES A SMALL NULL SHIFT DEPENDENT ON PRE-COMPARATOR PHASE SHIFT.

PHASE TOLERANCE REQUIRED	ERROR	SLOPE CHANGE
Σ LEADS Δ BY 15° (+15°)	8%	DECREASE
Σ LAGS Δ BY 15° (-15°)	5%	INCREASE

Figure 16. Error Analysis Results

Using the radar system parameters of the 35GHz monopulse radar curves of the angle and range tracking accuracies have been plotted as a function of signal to noise ratio (Figures 17 through 20). The effects of multipath are also shown for the angle and range tracking case as a function of elevation angle in Figures 21 and 22. The tracking pedestal servo-system error is composed of a 0.05 degree peak static error and a 0.05 degree peak backlash error.

FREQUENCY AGILITY

Using the appropriate parameters of the 35GHz monopulse radar, a minimum frequency agile bandwidth was calculated based on References 2 through 8. This bandwidth will be necessary to produce the requisite performance and to achieve a 6-8dB increase in S/N ratio. A minimum bandwidth of approximately 200 MHz appears adequate.

ECCM

The ECCM benefits of millimeter wave radar are due to the inherently narrow beamwidth possible with physically small apertures. Another benefit stems from the state of the art in millimeter wave generation and amplification. Very high-power transmitters and amplifiers are not readily available and expendable jammers are not yet a reality at 35GHz. Using postulated jammer characteristics whose numerical values are based on current state of the art hardware, the analysis was performed to determine the effective detection performance in the presence of a stand-off jammer and a self-screening jammer. The stand-off jammer (SOJ) will not be a problem, since by conventional SOJ procedures, the jammer would be well

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2. Beasley, E. W., and Ward, H. R., "A Quantitative Analysis of Sea Clutter Decorrelation with Frequency Agility," IEEE Trans. on A.E.S., May 1968.

3. Birkemeier, W. P., and Wallace, N. D., "Radar Tracking Accuracy Improvement by Means of Pulse to Pulse Frequency Modulation," IEEE Trans. on Comm. and Electronics, Jan 1968.

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7. "On the Improvement of Detection Range Using Frequency Agile Techniques," Boeing Report D6-6835, 1964.

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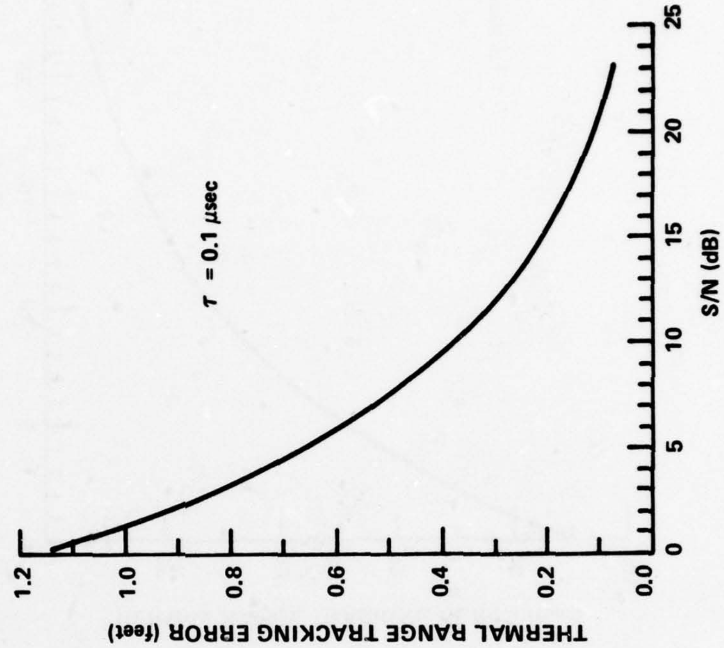


Figure 18. RMS Thermal Range Tracking Error Vs. S/N

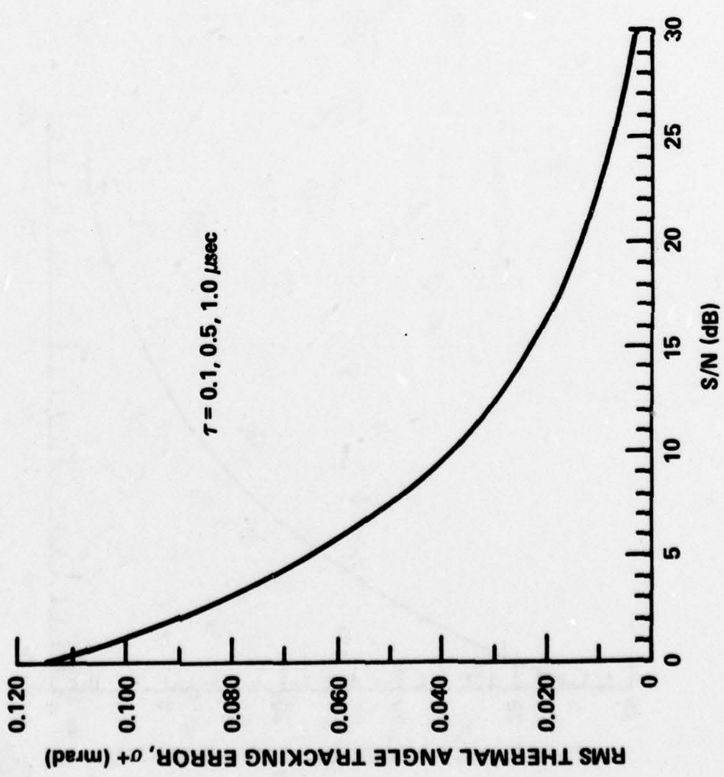


Figure 17. Thermal Angle Tracking Error Vs. Signal to Noise Ratio

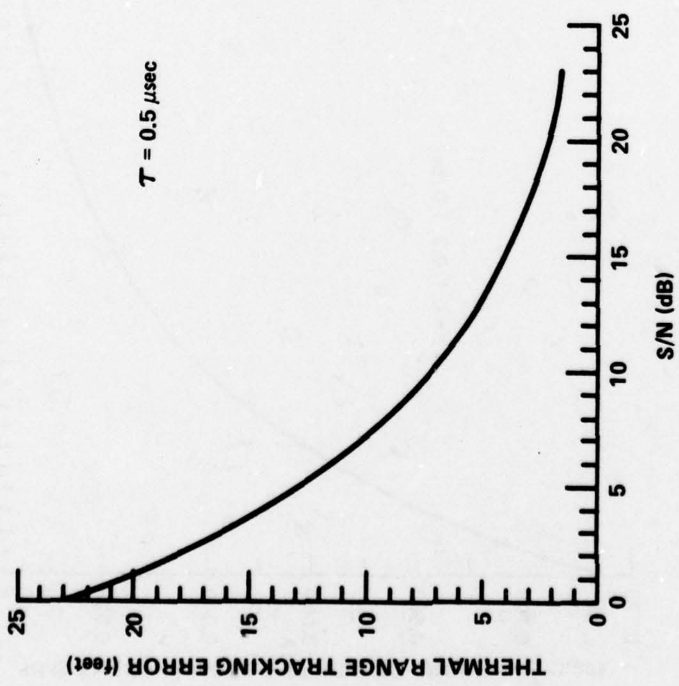


Figure 19. RMS Thermal Range Tracking Error Vs. S/N

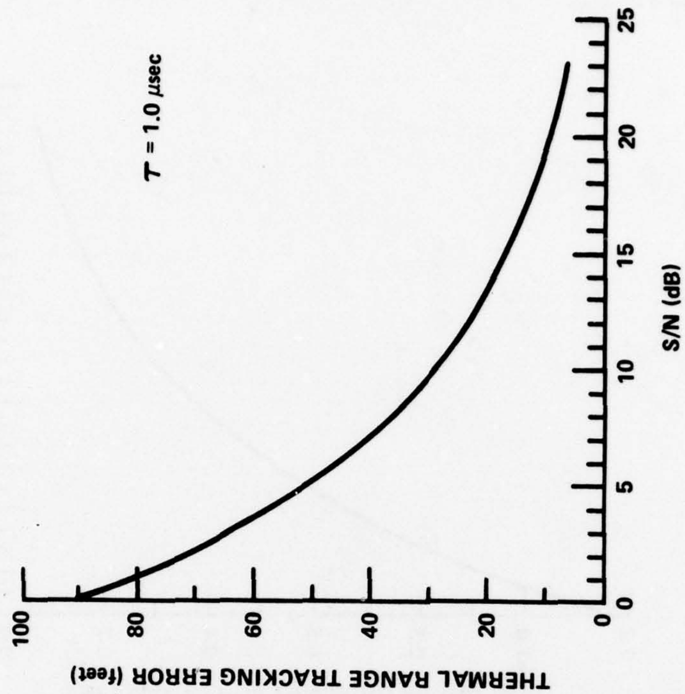
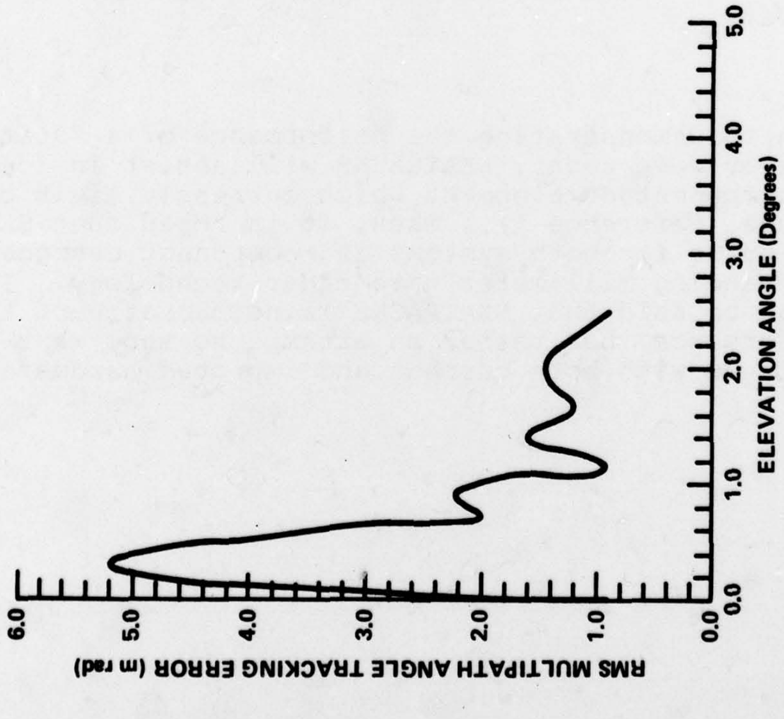


Figure 20. RMS Thermal Range Tracking Error Vs. S/N



*Assumes a reflection coefficient (e = 1), worst case. Actually 0.2 would be closer to the actual number for most sea states.

Figure 21. Multipath Angle Tracking Error Vs. Target Elevation Angle*

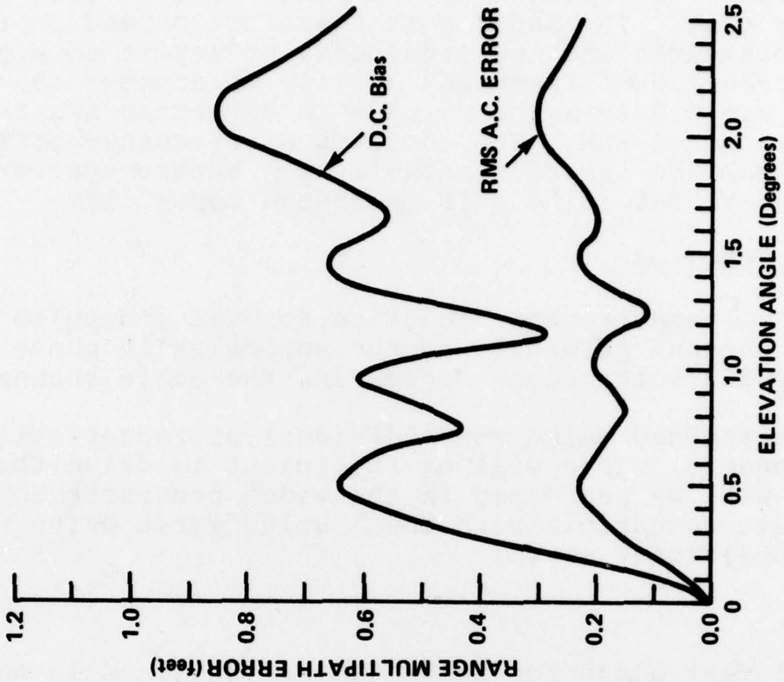


Figure 22. Range Multipath Error Vs. Target Elevation Angle

beyond the millimeter wave radar maximum detection range in a tactical situation. The self-screening jammer (SSJ) case, however, is a problem because the self-screening range is much less than a mile for worst case. The radar must therefore depend on its narrow antenna beamwidth and low sidelobes, or resort to a more sophisticated technique of frequency agility to counter the SSJ. Further studies are presently being made to determine system performance in the presence of ECM. The addition of frequency agility to the system will enhance the ECCM capability. Future system studies will be performed to determine this increased capability.

SYSTEM TRANSFER FUNCTION

The system voltage transfer function for the monopulse radar system from the antenna terminals to the monopulse IF phase comparator output is 0.263 volts/space degree for the angle channels.

This was determined using the individual characteristics of the system components. This will be sufficient to drive the pedestal. Scaling will be performed in the video processor to make this voltage drive compatible with the 1 volt/degree drive required by the antenna positioner servo.

TEST PLAN

The initial test plans for SEATRACKS are outlined in Appendix 1. These include subsystem checkout and integration, and stationary target measurements. In addition, plans are being developed for moving target tests.

CONCLUSIONS

In addition to demonstrating the performance of a "state-of-the-art" millimeter wave radar, SEATRACKS will assist in identifying those areas of component development which currently limit overall system performance (Reference 1). Thus, it is hoped that SEATRACKS will serve as a guide for both systems and component designers interested in advancing millimeter wave radar technology. In summation, it can be said that SEATRACKS is not an attempt to analyze theoretical performance, but rather an attempt to show what a real world system will do with both current and improved hardware.

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Appendix 1

TEST PLAN OUTLINE

A. SUB-SYSTEM CHECKOUT

Prior to turn-on of entire system, the following sub-system checks shall be completed.

1. TEST FOR PROPER OPERATION OF ANTENNA/MONOPULSE COMPARATOR ASSEMBLY.

a. Antenna radiation pattern check.

b. Antenna impedance measurement.

c. Adjust monopulse comparator phase trimmers for zero degrees at the three output ports at fo with signal at input port.

d. Measure phase vs. frequency out of comparator output ports.

2. TEST FOR PROPER OPERATION OF DIFFERENTIAL PHASE SHIFT CIRCULATORS AND LATCHING FERRITE CIRCULATORS.

a. Measure isolation port to port on differential phase shift circulators.

b. Measure isolation and switching times on latching ferrite circulator.

3. TEST FOR PROPER OPERATION OF RECEIVER RF/IF SECTION.

a. Measure dynamic range of mixers (this will also give an idea of power handling capability).

b. Set gain trim on all three channels for equal outputs just before MIF inputs with a signal input to one quadrant of comparator.

c. Connect antenna, receiver and MIF together. Set LO phase trim of receiver for maximum MIF azimuth and elevation error outputs on boresight at fo.

4. TEST FOR PROPER OPERATION OF VIDEO PROCESSOR.

a. Range gate generator operation and trigger timing.

b. Angle channel zero offset and gain adjust.

c. Angle channel performance.

5. TEST FOR PROPER OPERATION OF PRF/PULSEWIDTH GENERATOR AND TRIGGER LOGIC.

a. Check timing in each PRF mode of operation to assure main bang will not enter receiver. (Measure trigger to latching ferrites and latching ferrite delay.)

6. TRANSMITTER CHECKOUT.

a. Measure detected RF output for each pulse.

b. Measure delay between trigger pulse input and detected RF output.

c. Monitor current pulse.

d. Based on all previous measurements in the sub-system checkout procedure, determine if latching ferrites perform as intended in protecting receiver mixers.

7. *TEST ANTENNA PEDESTAL STABILITY WITH TRACKING SIGNALS FROM* VIDEO PROCESSOR (FULL RADAR WEIGHT).

B. SYSTEM CHECKOUT.

1. SYSTEM ASSEMBLY.

a. Assemble all radar sub-system components on pedestal. Transmitter will be limited to 10 watts peak output power level with power reduction network.

2. MIXER INSPECTION.

a. After power up of transmitter/receiver system together, check for mixer damage.

3. MANUAL RADAR LOCK-ON WITHOUT PEDESTAL.

a. Using a fixed target (balloon towing a corner reflector), manually acquire and lock-on the receiver. Tracking pedestal will be in the manual control mode and not affected by the video processor error signals.

4. VIDEO PROCESSOR AZ AND EL ERROR SIGNAL CHECK.

a. Measure video processor AZ and EL error signals to determine if sense and amplitude are correct.

b. A transit or boresight scope will be used for an angle reference. Correct sense and/or amplitude with inverters and gain adjustments in video processor.

5. PEDESTAL CONTROL BY RADAR.

a. Switch pedestal to auto track mode to transfer control from a manual position control to a radar control mode.

b. Check radar video processor operation and correct any problems.

C. STATIC TRACKING PERFORMANCE OVER LAND USING AN ELEVATED TARGET.

1. RADAR TRACKING AND RANGE MEASUREMENT TEST.

a. Using the same target as in B, balloon and corner reflector, acquire and lock-on target manually, then switch pedestal to auto-track mode such that the radar steers the pedestal.

b. Compare radar measured range with actual measured range.

c. Check tenacity of range track by moving target in and out in range.

d. Check tenacity of angle track by moving target in angle.

e. Determine receiver dynamic operating range for this target to assure proper AGC operation. Manually adjust AGC control if required.

2. SCAN MODE DETECTION TEST.

a. Break receiver lock-on and place radar pedestal in a slow scan mode/auto track. The scan area will include the target.

b. Determine the ability of the radar to detect the target in a scan mode by manually adjusting the range gate control as antenna scans. Stop scan when A-scope presentation shows target in range gate. Verify target track by moving target. Observe S/N on A-scope.

3. EFFECT ON TRACKING PERFORMANCE IN THE PRESENCE OF A SECOND TARGET.

a. Launch a second balloon/corner reflector identical to the first target.

b. Observe radar tracking behavior as second balloon is moved in angle and/or range in close proximity about first target.

c. Observe S/N on A-scope during this test.

4. ERROR VERSUS ANGLE CURVES FOR THE RADAR (S-CURVES).

a. Re-acquire and lock-on single sphere or balloon target.

b. Disconnect AZ and EL error signals from pedestal and measure both S-curves as pedestal is manually slewed approximately ± 1 degree about boresight first in azimuth and then in elevation.

c. Use a transit to measure angle if greater accuracy than obtainable with pedestal readout is desired.

d. An idea of the dynamic operating range of the receiver for this target should be obtained to verify receiver linearity for this curve.

5. CROSS-SECTION MEASUREMENT.

a. Using a calibrated reference sphere suspended high in the air (RCS range), measure the radar cross-section of the reference with the radar.

b. Measure the radar cross-section of the corner-reflector target towed by the balloon.

6. STEADY-STATE TRACKING ERROR. (Long-term average tracking error)

a. Reduce the tracking bandwidth of the system to 0.1 Hertz.

b. Boresight the radar on the sphere target (or corner reflector) at a fixed height above ground. The transit will also be set up here on the target and boresighted.

c. Lower the sphere slowly and the radar will appear to track the target, but with a slight error, because it may not be pointing directly at the sphere center (particularly if the sphere is near ground). The transit will measure the tracking bias.

d. The angle correction needed to center the telescope on the sphere is the tracking bias.

e. As the sphere is lowered, the apparent tracking point of the radar moves away from the sphere center. The deviation is the tracking bias; it is the lower bound of the tracking error for a long time constant. A plot of the bias error as a function of sphere height could be made for a low hanging sphere. This would be the multipath error over ground.

7. DYNAMIC TRACKING ERROR.

a. The procedure above in (6) for steady-state tracking error could be repeated with a wider tracking bandwidth. The boresight error will need to be averaged by a human operator. Magnetic tape could also be used to measure the data for later analysis (Power spectral density, probability distribution, mean, variance, etc.).

D. STATIC AND DYNAMIC PERFORMANCE OVER SEA AT LOW ELEVATION ANGLES

1. STATIC TRACKING ERROR. (This test will be an attempt to isolate and measure the magnitude of the multipath error for a low angle target over water.)

a. With the tracking bandwidth reduced to 0.1 Hz., the steady state tracking error will be measured.

b. Boresight the radar on a sphere suspended about 15 feet above the water surface. This is the test set-up located at the end of a pier overlooking water (described in the test site description). A transit will also be boresighted on the sphere at the same time.

c. As the sphere is slowly lowered, the radar may still indicate an electrical boresight, but may not be actually pointed at the sphere center. This can be measured and verified with the transit. The angle correction needed to center the telescope on the sphere was measured as the tracking bias.

d. As the sphere is lowered, the apparent tracking point of the radar moves away from the center of the sphere. This deviation is the tracking bias. If the filtering time constant is long, the tracking bias is the lower bound of the tracking error.

e. As the sphere gets closer to the water, the target image also moves closer to the water and the bias error will increase and then decrease as the sphere gets very close to the water surface. A plot of the bias error as a function of the sphere height is a measure of the multipath error.

2. DYNAMIC TRACKING ERROR OVER WATER.

a. Dynamic tracking error is measured using the same technique as in (1) above except that the tracking bandwidth is increased.

b. It will be necessary to measure boresight error by an averaging process (performed by a human operator) due to the wider bandwidth response.

c. Error signals could be recorded on magnetic tape for later analysis (power spectral density, probability distribution, mean, variance, etc.).

E. RADAR CROSS-SECTION MEASUREMENTS.

1. CALIBRATION OF RADAR.

a. Using a calibrated reference sphere suspended over the water, calibrate the sum channel return signal for radar cross-section measurements.

b. Measure the radar cross-section of the sea at various grazing angles by recording the sum channel return signal. Stable tracking of a patch area via accurate range and angle tracking is required to measure radar cross-section.

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