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NRL Report 6485
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# Results of Acceleration and Velocity Processing of HF Radar Signals From Missile Launches

## Part 2 - Observations of ETR Tests 0169 and 3670

[Unclassified Title]

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*Radar Division*

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CONTENTS

## ABSTRACT
[Secret]

The acceleration and velocity signal processor developed at the Naval Research Laboratory was employed with the hf transmitter and receiving equipment located at the Chesapeake Bay Division site to observe missiles launched along the Eastern Test Range.

The spectral compression and coherent integration techniques utilized in processing the return radar echoes resulted in improved resolution and signal-to-noise ratio, and provided target acceleration as a parameter, along with velocity and range.

Target tracks of high definition are shown for the second stages, spent first stages, and nose fairings of ETR tests 0169 (Saturn) and 3670 (A3 Polaris).

## PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

## AUTHORIZATION

NRL Problem R02-42
Project MIPR(30-602) 64-3412

Manuscript submitted August 22, 1966.

# RESULTS OF ACCELERATION AND VELOCITY PROCESSING OF HF RADAR SIGNALS FROM MISSILE LAUNCHES

Part 2 - Observations of ETR Tests 0169 and 3670
[Unclassified Title]

## INTRODUCTION

The acceleration and velocity signal processor was proposed (1) and developed (2-5) at NRL. Its purpose is to provide near-optimum signal-to-noise enhancement, as well as near-optimum velocity and acceleration resolution for accelerating (missile) targets as well as constant-velocity (aircraft) targets, through employment of a spectral compression technique with coherent integration. This is accomplished by acceleration matching (1) the change in the accelerating target doppler frequency occurring over the memory storage period in order to achieve a compression of the spread target spectrum. The benefits of this operation are an improvement of the signal-to-noise ratio (SNR), an improvement in velocity resolution, and the acquisition of target acceleration as a parameter (velocity and range are also obtained). Signal processing of the target echo is completed by performing a matched filter operation on the spectrally compressed target spectrum to effect primarily a coherent integration over the number of samples (either 1800 or 3600) stored in the memory and a corresponding improvement in SNR.

The ultimate purpose of the acceleration and velocity processor proposal and development is the creation of a radar with at least the following capabilities:

1. One which will extract the largest possible quantity of information from each of many targets in real time without off line signal processing. The number of parameters and their resolutions are made as high as possible. The parameters are acceleration, acceleration-rate (if desired), velocity, range, azimuth, amplitude, plus-minus acceleration, and recede-approach velocity.

2. One which will achieve the highest possible signal processing gain through the use of coherent and incoherent integration and near-ideal signal matching processes, enabling over-the-horizon (OTH) detection of even small component parts of missiles.

3. One which requires the least complex automatic detection equipment because of the high-quality signal processor output.

4. One capable of separating and processing accelerating, constant-velocity, or zero-velocity target signals of all amplitudes (including very low and very large) in a manner to prevent any type of signal from masking or reducing the radar sensitivity for either of the other types, or a like type. For example, the large backscatter clutter is prevented from masking low-level echoes under any conditions, large accelerating targets are prevented from spreading and masking other target echoes, and accelerating targets which are displaced only 1 or 2 sec in time may also be separated.

5. One with the widest possible signal dynamic range in order to minimize the undesirable effects of high-level interference or jamming.

6. One designed to process all resolution cells of all parameters, to process all target types, and to process multiple targets without compromises or tradeoffs which would otherwise result in the loss of information or the inability to acquire certain information.

7. One possessing a high order of functional efficiency through multipurpose design, simplified circuitry, real-time data acquisition, and the absence of the need for off line signal processing. The functional efficiency will aid in minimizing the cost of acquiring the wealth of information existing in all the range-azimuth cells which an operational radar will need to cover.

The results obtained with the present limited acceleration and velocity processor and the proposals and ideas for improvements in (a) the acceleration and velocity processor, (b) the memory, and (c) the data processor indicate that the above ultimate goals may be fully achieved. All of the most important principles required to achieve the above goals have been verified with the present limited acceleration and velocity signal processor.

The present limited acceleration and velocity signal processor is in use with the hf transmitter and receiving equipment installed at the Chesapeake Bay Division (CBD) site.

Earlier results (6,7) of missile observations obtained with the present acceleration and velocity processor were directed toward proving principles and did not utilize or demonstrate the full capability of even the limited system; only one of the 12 acceleration gate channels was used and none of the data were displayed as a function of time. In the acquisition of the data, to be described, advantage was taken of utilizing all of the available capabilities in order to more completely demonstrate the full extent of the capabilities of acceleration and velocity signal processing. It should be noted, however, that the processor is limited to 12 acceleration analysis channels (limited funding permitted development of only 12 acceleration channels), whereas a full system was desired with 100 or more channels (acceleration bins).

The 12-channel or partial system is capable of analyzing any 12 acceleration bins and all the velocity and the range bins for targets in either real time or from continuous prerecorded magnetic tape recorder playback at the real-time rate. Other acceleration bins must be analyzed on subsequent reruns of the tape. It should be emphasized that a full acceleration and velocity signal processing system will have no such limitation and that all acceleration, velocity, and range bins may be analyzed in real time.

## RESULTS

Data obtained from two missiles (a Polaris A3, Test No. 3670, and a Saturn, Test No. 0169) launched down the Eastern Test Range (ETR) will be presented. In the case of the Polaris launch a radar pulse recurrence frequency (prf) of 90 cps, a pulse width of about 700 $\mu$sec, a transmitter average power of 100 KW, and a rotatable antenna having a free-space one-way antenna gain of about 13 db were used. Illumination was via a one-hop F-layer ionospheric propagation path.

Because of the geometrical locations of the radar at the CBD site and the ETR, the propagation path and the Polaris missile trajectory intersect at a 90-degree angle about 140 sec after launch, as will be noted on Fig. 3.

In the case of the Saturn, a prf of 180 pps and a pulse width of about 340 μsec were employed with line-of-sight illumination. The other above parameters were unchanged.

Although several operating procedures are possible for the limited system, the figures which follow were obtained by setting the 12 acceleration gates as a fan of 12 consecutive accelerations and photographing the combined analyzer output as the input was fed either in real time from the receiver (via the storage drum) or at the real-time rate from a magnetic tape recorder which had previously recorded the receiver output. Several readouts, each with a different acceleration fan, are generally required for a complete analysis.

Test 0169 — Saturn Launch

Figure 1 presents the radial velocity versus time after launch for a Saturn, ETR Test 0169, observed in this case by direct look at an operating frequency of 22.6 Mc/s and a prf of 180 cps. The input was obtained from magnetic tape at the real-time rate. The top view shows the processed output for a fan of positive accelerations, the center view for a fan of negative accelerations, and the bottom view also for negative accelerations but with a readjustment of the system to discriminate against the diffuse signal and also for a later time period and half the velocity extent.

Several well-defined target tracks are shown. These are the spent first stage, the powered second stage, and a near-range aircraft. The fan of accelerations has been split in order to show both first and second stages on the same readout. Most of the acceleration gates are centered about the high value of the burning second stage, with just enough set at low value to show the spent first stage. No zero slope (constant velocity) or very low value acceleration slopes were used in this readout.

The top view shows the early positive readout of the burning second stage, commencing with the onset of target illumination. Foldover of the doppler frequency occurs when the doppler reaches one-half the prf and is equivalent to a radial velocity of approximately 1000 knots. A continuation beyond foldover distinctly appears on the center view as the steeper of the early tracks. On this same view a very long track of the spent first stage may be seen. It is obscured for an interval by the diffuse signal, but a further system capability permits adjustment to display that track without the diffuse signal interference, as shown in the bottom view for the lower half of the doppler extent. The last track in the bottom view is the near-range aircraft shown only for an interval of time where a turn produced a radial acceleration that happened to match an acceleration gate. Other tracks that are shown are believed to be related to the missile but are not positively identified.

The target tracks of Fig. 1 are replotted on Fig. 2 to compare them with values calculated from postflight data obtained for both the spent first stage and the powered second stage. Although exact agreement is not obtained, the assumptions used in the calculations are considered to have caused the difference, and the identification of the tracks appear reasonable. A ray-path-type diagram is shown in the lower view, but this merely shows the straight line rays for elevation angles of 0 and 3 degrees to aid in estimating the onset of target illumination

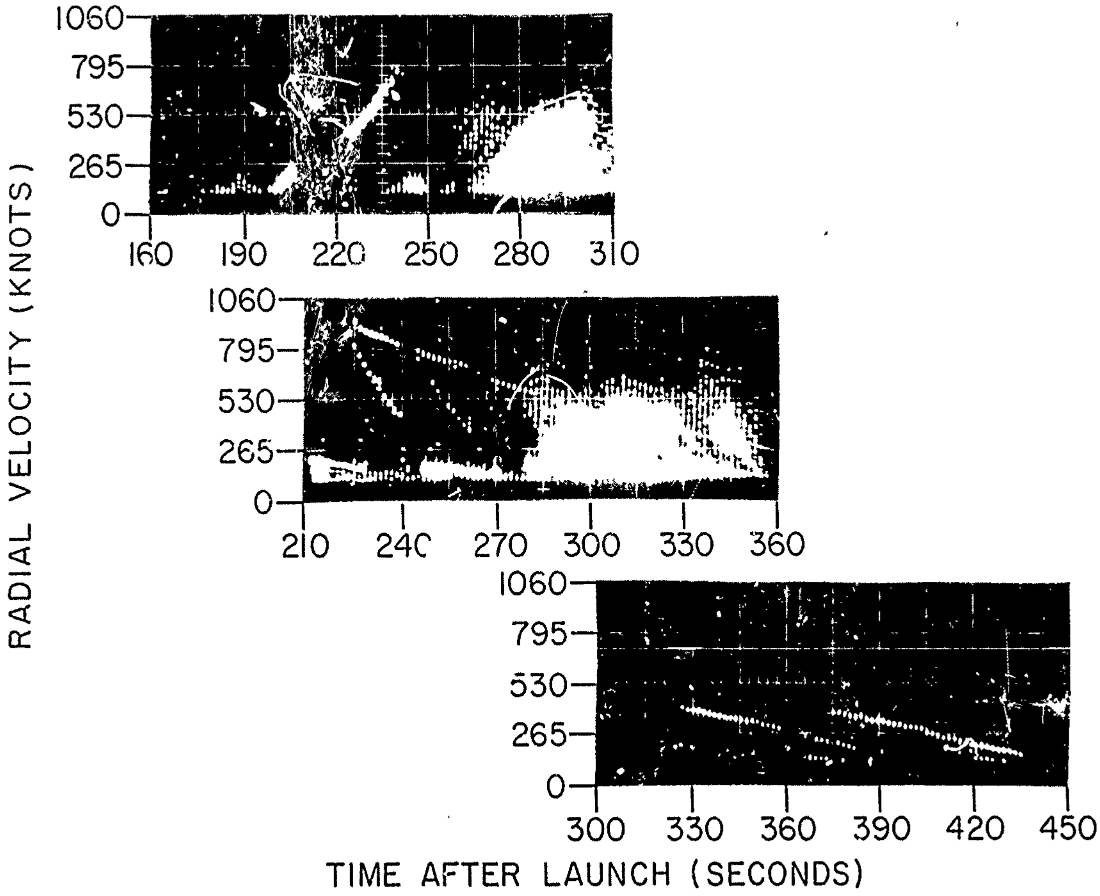


Fig. 1 - Velocity-time profile of ETR Test 0169 (Saturn launch). Upper profile is for accelerating targets; middle profile is for decelerating targets; bottom profile is an extension of middle profile to later times and for half the velocity interval. The ability of the system to separate discrete targets from diffuse echoes is demonstrated in the bottom profile.

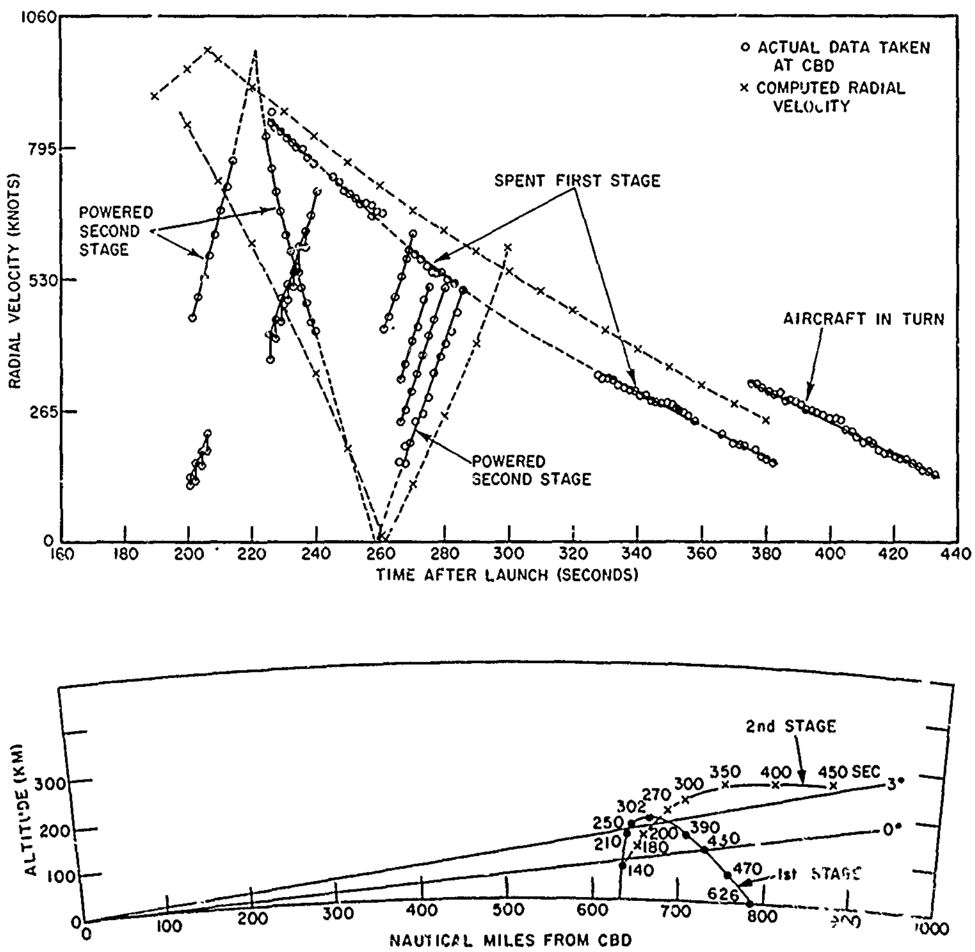


Fig. 2 - (top) Calculated velocity-time profiles of ETR Test 0169 from ETR postflight information compared with actual radar data points transcribed from Fig. 1; (Bottom) ray path diagram applicable to ETR Test 0169. Numbers on target trajectories in the bottom figure indicate the time after launch (in seconds).

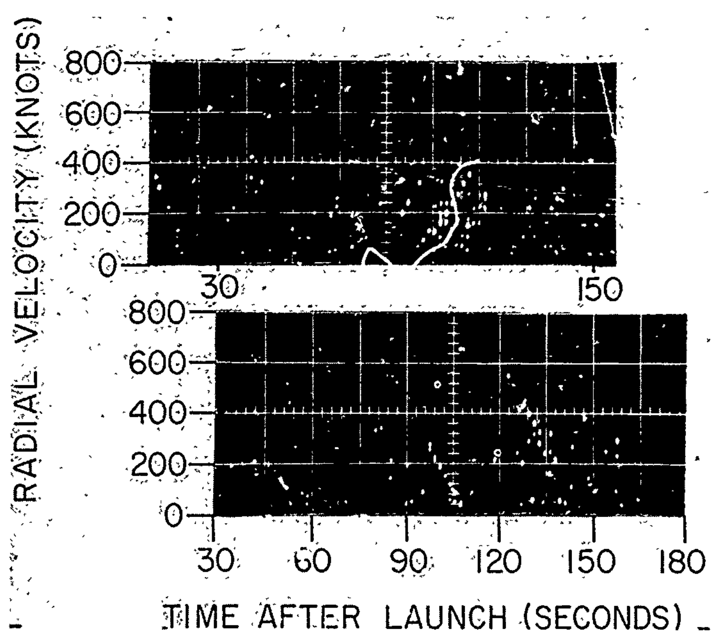


Fig. 3 - Velocity-time profiles of ETR Test 3670 (A3 Polaris launch). Upper profile is for accelerating targets; bottom profile is for decelerating targets.

Test 3670 — A3 Polaris Launch

Figure 3 shows the result obtained for ETR Test 3670, a Polaris A3 launch which was illuminated via the ionosphere. Input was obtained from the tape recorder. The carrier frequency was 18.036 Mc/s and the prf was 90 cps. Several tracks may be seen. The negative track beginning at about 128 sec is identified as the powered second stage. Those appearing earlier are believed to be related to the first stage and the nose fairing jettison.

The tracks are replotted in Fig. 4. The computed velocity-time characteristic based on ETR postflight data is shown to confirm the identity of the return echoes and to indicate the unusual shape of the curve due to the geometry of the observation site with respect to the missile trajectory. The trajectory of many missiles launched from ETR intersect the illuminating radar ray path at right angles at some point during the period of powered flight. The radar observed velocity (in the direction of the ray path) is zero at the right-angle condition, as illustrated at 142 sec. The velocity-time curve prior to that point indicates an approaching target and is also typical of many ETR missile launches as observed from the CBD site.

Actual data points were taken from the discrete tracks of Fig. 3 and plotted on Fig. 4. One of the tracks coincides with the computed curve and is assumed to be the burning second stage. The remaining tracks coincide with portions of the expected profile of the spent first stage and the nose fairing.

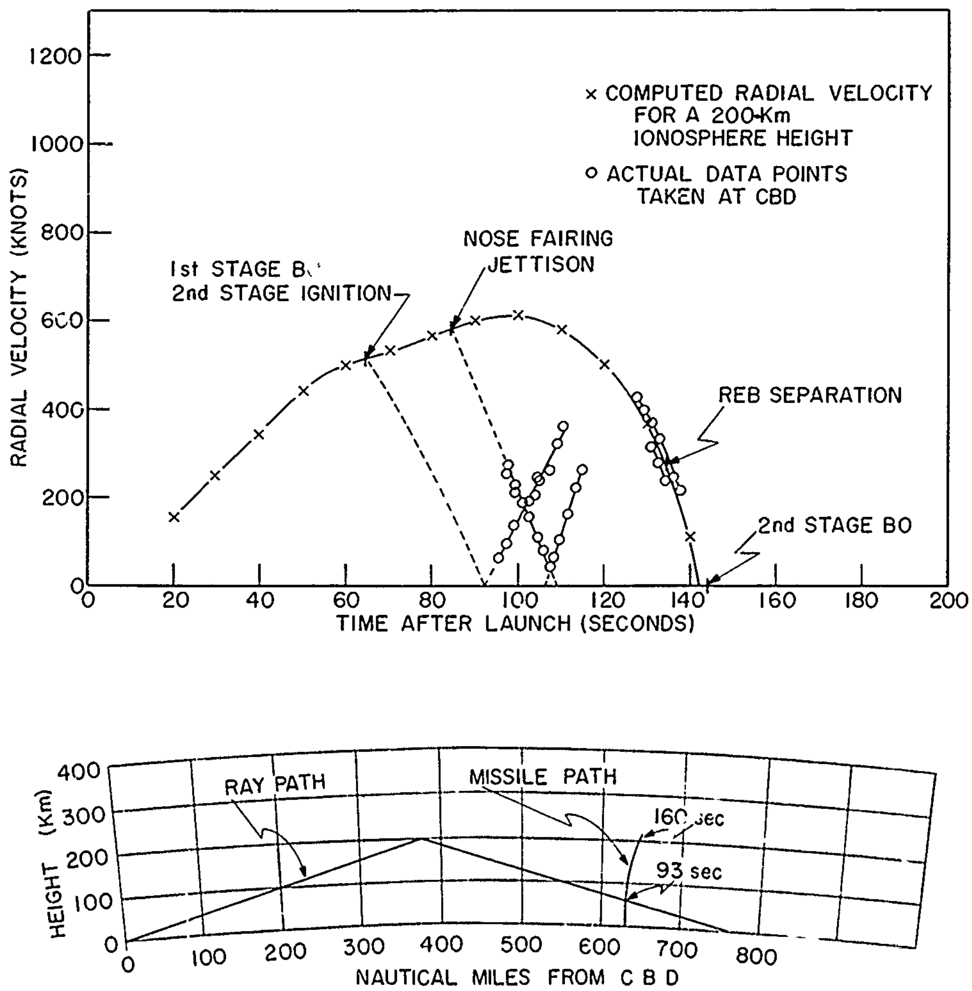


Fig. 4 - (top) Calculated velocity-time profiles of ETR Test 3670 from ETR postflight information compared with actual radar data points transcribed from Fig. 3; (bottom) signal ray path applicable to ETR Test 3670. Times shown on missile path in bottom figure indicate the time after launch.

A ray plot is also included in Fig. 4 for Test 3670. The radar skip range ray is shown, which means that the missile was not illuminated until about 90 sec after launch. Thus, there was no chance of seeing earlier echoes, which would have been highly desirable.

A threshold circuit was employed at the output of the acceleration and velocity signal processor. This circuit was adjusted for an output SNR such that, in the absence of a signal, noise peaks caused a few triggering events per minute. Reference to Fig. 3 shows the light noise background produced by the above choice of level. Of course other levels may also be selected.

## COMMENTS

The background in the photographic strips is relatively free of other signals because the velocity-time characteristics of only those signals having finite accelerations (zero acceleration and the first few of the lowest acceleration bins have been excluded) are displayed in the photographs. Constant-velocity targets, such as aircraft, most meteor effects, diffuse signals, and most interference will not appear but instead may be separated. because of the discriminating capability afforded by the acceleration parameter, and placed on another display of velocity-time for zero - and low-acceleration targets.

The acceleration and velocity signal processor also provides other information which has not been presented here. Acceleration and range information on all targets is available. Azimuth information may also be obtained from a complete two-channel acceleration and velocity processor, as may the approach-recede character of velocity.

The following information is available and should be presented to an operator in a useful and meaningful manner: (a) acceleration, deceleration, velocity, approach or recede, range, azimuth, and time; (b) missile and aircraft targets separated and independently displayed; and (c) information facilitating separation and identification of multiple targets.

Additional information, primarily of interest for research purposes, is also available in the form of target amplitude. Individual targets may be gated out and spectrum analyzed. Other studies of the amplitude versus the various parameters may also be accomplished.

The Naval Research Laboratory's recent experience and findings with acceleration and velocity signal processing and display is being prepared for publication in a forthcoming report. This experience has also suggested methods of improving processor capability, methods of simplifying and reducing the electronics, methods of increasing reliability, improvements in the storage memory, etc., which will also be included. This work, of course, has the goal of creating a radar with the broad capabilities previously mentioned. An earlier report covering recommended improvements has been published (8).

## SUMMARY

1. Discrete return echo tracks of a Saturn missile second stage, first stage, and other component parts are shown.

A diffuse return signal from the F-layer height is also shown, which may be separated from the discrete tracks.

2. Discrete return echo tracks of a Polaris missile second stage, spent first stage, and nose fairing are shown for a one-hop ionospheric propagation path.

3. A wide range of accelerations were readily matched, thus providing the acceleration parameter.

4. The resolution and SNR of accelerating targets were improved by the addition of acceleration procession. Even small missile parts were detected.

5. Missile (accelerating) targets were presented as well-defined tracks which were separated from constant-velocity (aircraft) targets, most meteor effects, diffuse signals, and interference; this resulted in a relatively clear display background.

6. High velocity resolution and high acceleration resolution are provided for either small or large amplitude returns from accelerating targets.

7. Accelerating targets may be separated from constant-velocity targets and viewed on separate displays. This allows separation of most aircraft and meteors from the missile displays, but still retains the information on a constant-velocity display. This separation is similar to the method where fixed and low-velocity targets (including backscatter) are separated from the velocity display.

8. Well-defined target velocity vs time tracks are provided, even in the presence of large diffuse signals and meteors, and can be displayed separately from the diffuse signals and meteors.

9. The partial acceleration and velocity signal processor is a valuable research tool to further the study of improved processing methods and to aid in studies of target and ionospheric characteristics.

10. Experience with the acceleration and velocity signal processor, data handling, and display system has lead to proposals for improvements in all of these items, as well as a proposal for a new type of memory, which form the bases for an hf radar with extensive capabilities.

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13. ABSTRACT [Secret]

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**From:** Darlene DeMarr, Code 5596.3

**Date:** 9/17/2007

**Subject:** Change in Classification & Distribution Statement

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Thank you,

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