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NRL Report 6476

Copy No.

Results of Acceleration and Velocity Processing of HF Radar Signals from Missile Launches

Part 1 - Observations of ETR Tests 2949, 6075, and 3635

[Unclassified Title]

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Radar Division

October 10, 1966

NAVAL RESEARCH LABORATORY
Washington, D.C.

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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 Polaris 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 2949 (A2 Polaris), 6075 (A3 Polaris) and 3635 (A3 Polaris).

PROBLEM STATUS

This is the first in a series of reports 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 19, 1966.

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

Part 1 - Observations of ETR Tests 2949, 6075, and 3635
[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 and 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 compressed target spectrum to effect primarily a coherent integration over the number of samples (1800) 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 low (or high) amplitude 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 echos under any conditions, large accelerating targets are prevented from spreading and masking other target echos, 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 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 was 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. The 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 three Polaris missiles launched down the Eastern Test Range (ETR) will be presented. In each case a radar pulse recurrence frequency of 90 cps, a pulse width of about 700 μsec, 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 of the three missiles 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 missile trajectory intersect at a 90-degree angle about 140 sec after launch. This means that the radar is not required to handle the full range of accelerations which will be necessary when the radar is located near or in the plane of the missile trajectory. The acceleration and velocity processor design, however, is capable of handling the full extent of acceleration required for an in-plane location.

Test 2949 — A2 Polaris Launch

Results of processing the return echo of this missile launch through the acceleration and velocity signal processor are shown on Fig. 1.

Radial velocity is displayed along the ordinate axis and time along the abscissa. With a pulse recurrence frequency (prf) of 90 cps and a radar operating frequency of 15.595 Mc/s radial velocity becomes ambiguous above 855 knots. The lower photographic strip gives the results of processing for targets of deceleration (apparent velocity reduction) while the upper strip shows the results of processing for targets of acceleration (increasing velocity).

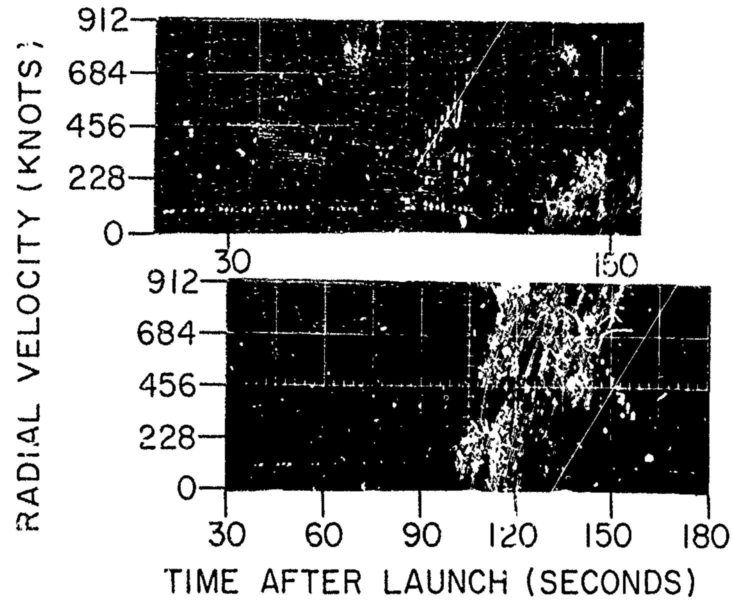

Fig. 1 - Velocity-time profile of ETR Test 2949 (A2 Polaris launch). Lower profile is for decelerating targets; upper profile for accelerating targets.

In order to confirm the identity of the return target echos, a radial velocity-time profile of this test launch was calculated from ETR postflight data and plotted on Fig. 2. Calculated velocity is shown, first, for combined first and second stages with burning first stage, and then after first-stage burnout for second stage alone through burnout and beyond. It will be noted that the radial velocity passes through zero at the time (about 140 sec) when the ray path and missile trajectory pass through a 90-degree configuration. The expected profile of the spent first stage is also shown (dashed curve) along with staging events and times.

Actual data points were taken from the discrete tracks of Fig. 1 and also plotted on Fig. 2. It is evident that one of the tracks coincides with the calculated curve. A second track closely paralleling the first track appears at the time of re-entry body (REB) separation. It is assumed that these two targets arise from the second stage and the re-entry

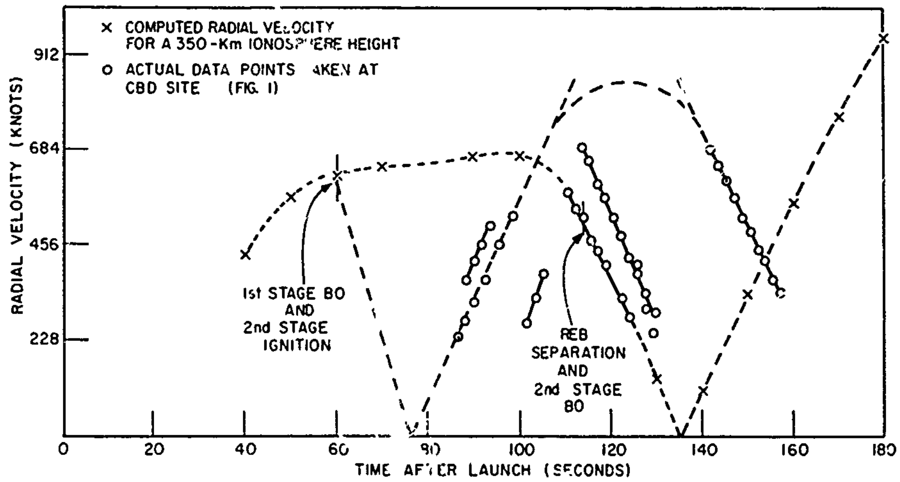

Fig. 2 - Calculated velocity-time profile of ETR Test 2949 from ETR postflight information as compared with actual radar data points transcribed from Fig. 1

body. The remaining two most prominent tracks agree with portions of the expected profile of the spent first stage.

A threshold circuit was employed at the output of the acceleration and velocity 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 the photographs of Fig. 1 shows the light noise background produced by the above choice of level. Of course, other false alarm rates may be selected.

The baseline visible in the photographs is not desired or intended and may be eliminated by processor readjustment.

Test 6075 — A3 Polaris Launch

Figure 3 shows the results of processing the return echo of ETR launch 6075 with a pulse repetition rate of 90 cps and a radar operating frequency of 18.070 Mc/s. These parameters cause a radial velocity ambiguity above 750 knots.

The upper photographic strip from a live run shows the results of processing for targets of deceleration. The lower left-hand strip shows the results (from a tape recording rerun) of processing for accelerating targets. The lower right-hand strip is a duplicate of the upper strip except that it is processed from a rerun of the tape recorder and that the time scale has been extended to include a later time record of the missile return signal.

Figure 4 shows a plot of the calculated radial velocity-time profile of this missile compared with the actual data points obtained with the radar. One target track is seen to coincide with a section of the calculated curve. From the time of coincidence it is assumed that this return echo is from the second stage. Shortly after REB separation, three new targets are seen to appear, each having slopes slightly different from the

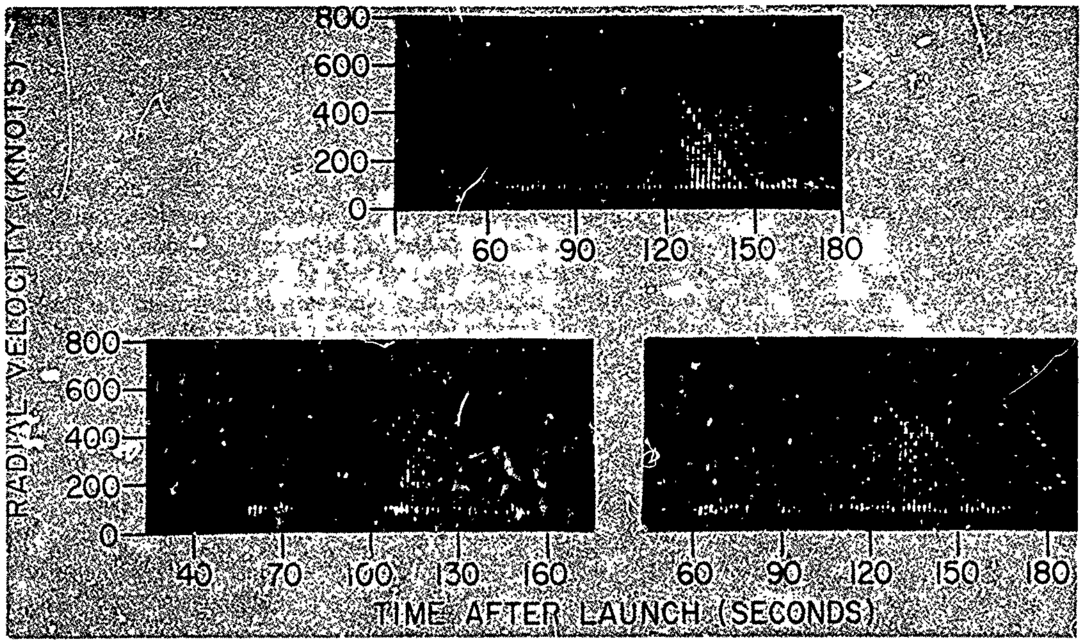

Fig. 3 - Velocity-time profile of ETR Test 6075 (A3 Polaris launch). Upper profile is for decelerating targets; lower profiles are tape recording reruns. Lower left profile shows accelerating targets; lower right is time-extended duplicate of upper profile.

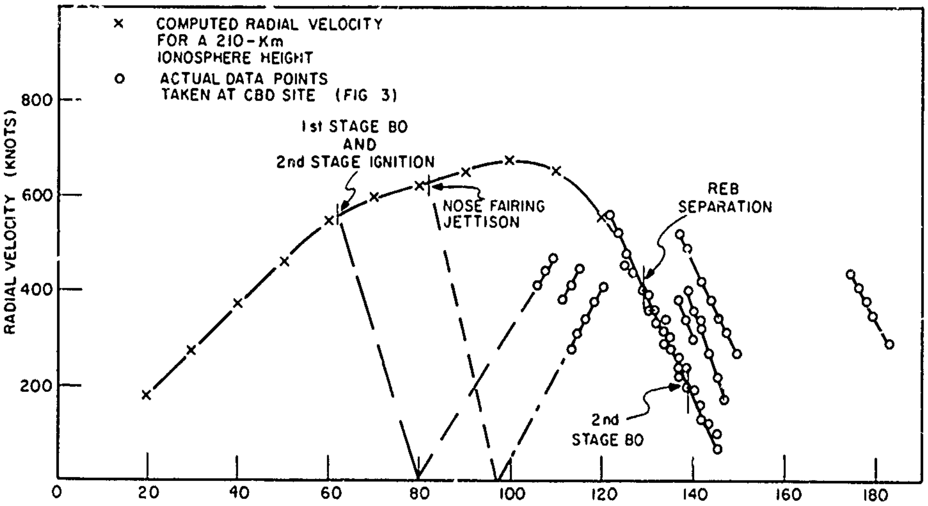

Fig. 4 - Calculated velocity-time profile of ETR Test 6075 from ETR postflight information as compared with actual radar data points transcribed from Fig. 3

second-stage echo. Other target tracks are also present which may be due to the spent first stage and a jettisoned nose fairing.

Test 3635 — A3 Polaris Launch

A radar operating frequency of 19.270 Mc/s and a pulse recurrence rate of 90 cps were employed for ETR Test 3635. Results shown on the upper two photographic strips of Fig. 5 are for 12 continuous acceleration channels set for high acceleration, with the left-hand strip displaying accelerating targets and the right-hand strip decelerating targets. Processing for 12 contiguous medium acceleration channels is shown on the lower strips, the right-hand strip being, as above, for decelerating targets and the left-hand strip for accelerating targets.

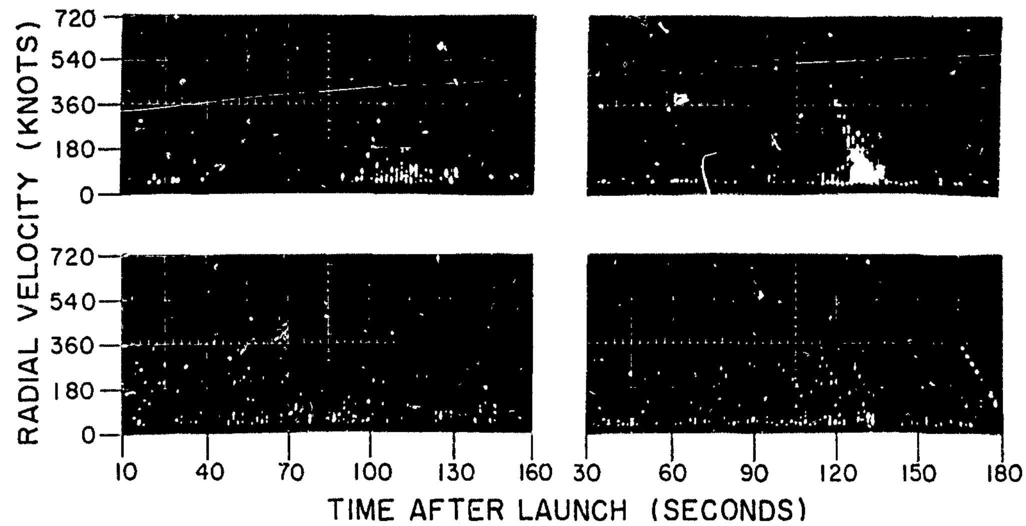

Fig. 5 - Velocity-time profile of ETR Test 3635 (A3 Polaris launch). Upper profiles show high accelerations; lower profiles show medium accelerations. Left-hand profiles are for accelerating targets; right-hand are for decelerating targets.

Postfight data were not available for this test. Hence, the velocity-time profile of the missile could not be calculated or plotted on Fig. 6. However, most of the actual radar data points are plotted, and the similarity between the target tracks of this test and the two previous tests is evident. Again it is believed that a clear second-stage echo is shown. Also, the additional echos are very probably due to the spent first stage and the jettisoned nose fairing.

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

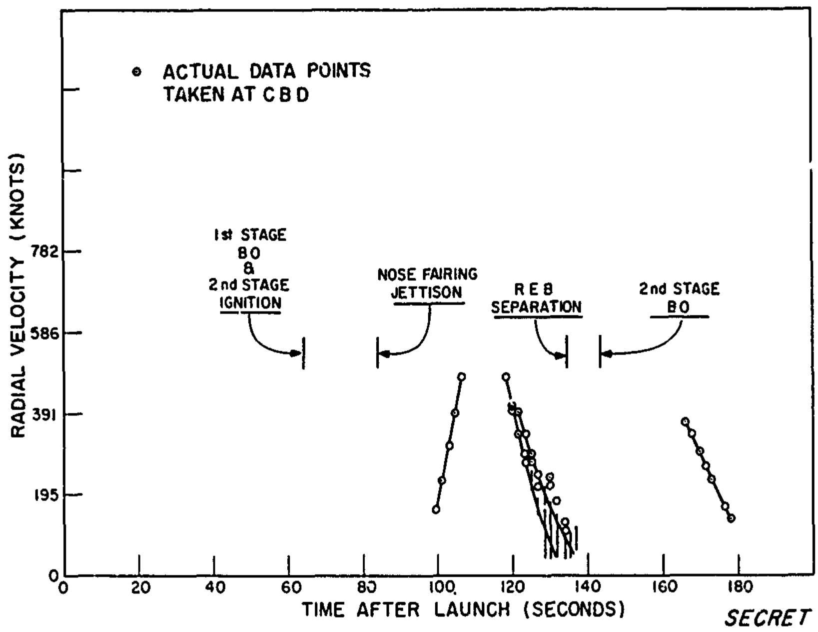

Fig. 6 - Velocity-time profile of ETR Test 3635 from radar data points transcribed from Fig. 5

effects, 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.

In all three tests the signal skip range was such that the missiles were not illuminated until 90 to 100 sec after launch. This means that there was no chance of seeing earlier target echos, which would have been highly desirable.

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) separation of missile and aircraft targets; and (c) information facilitating separation and identification of multiple targets.

Figure 7 illustrates the minimum number of display formats that are required to adequately present the above information. The choice between zero acceleration or non-zero acceleration will determine whether missiles or aircraft are presented on a display. The dual parameter displays (involving parameters other than time) allow associating the various parameters with a particular target. In order to minimize the number of displays, separate approach and recede target displays are not provided, but the determination of target direction may be made by normally operating the displays from a sum signal processing channel. Then, determination of approach or recede would be made by briefly switching all displays to either an approach or a recede signal processing channel.

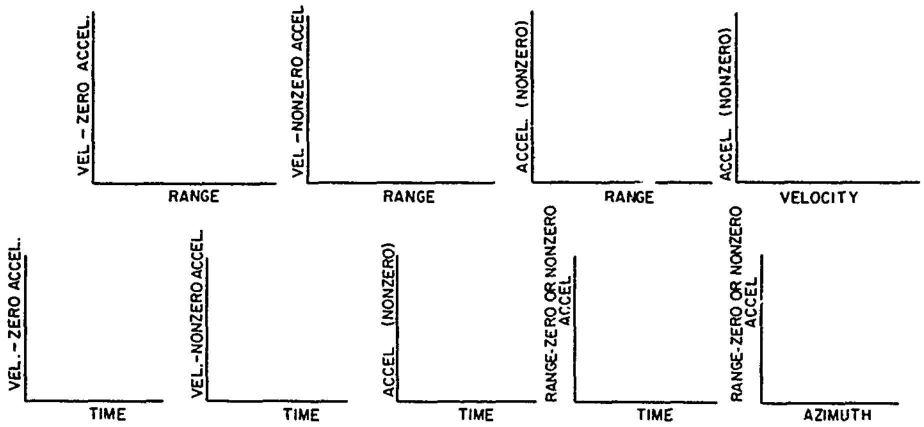

Fig. 7 - Minimum number of display formats required to present most of the target information available at the acceleration and velocity signal processor

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. Examples of amplitude display formats are indicated on Fig. 8.

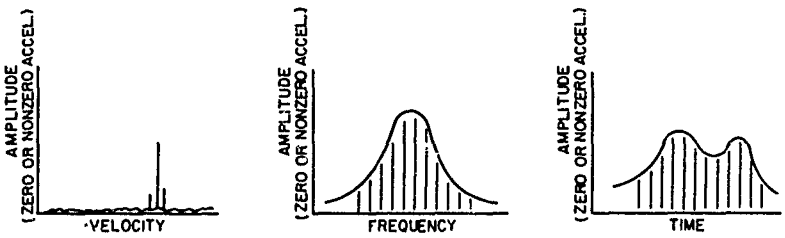

Fig. 8 - Display formats useful to present the target amplitude information available at the acceleration and velocity signal processor

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. Return echo tracks of Polaris missile second stages, spent first stages, and nose fairings are shown for a one-hop ionospheric propagation path.

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

3. The resolution and SNR of accelerating targets were improved.

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

5. 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.

6. 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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Target tracks of high definition are shown for the second stages, spent first stages, and nose fairings of ETR tests 2949 (A2 Polaris), 6075 (A3 Polaris) and 3635 (A3 Polaris).

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To: Larry Downing, DTIC

From: Darlene DeMarr, Code 5596.3

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Thank you,

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