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MTI (MOVING TARGET INDICTORS) TRACKING OF A REENTRY VEHICLE IN STRONG ATTACHED WAKE

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Riverside Research Institute

Prepared for:

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MTI TRACKING OF A REENTRY VEHICLE IN STRONG ATTACHED WAKE

By

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Prepared for

Commanding General
White Sands Missile Range
New Mexico
88002

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AUTHORIZATION

This report describes research performed at Riverside Research Institute and was prepared by M. Arm and I. Weissman.

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Approved by:

N B Marple

N. B. Marple
Director,
Radar Division

I. INTRODUCTION

This memorandum presents data, obtained by the AMRAD radar at the White Sands Missile Range, which demonstrate the utility of MTI clutter cancellation techniques for improving the tracking of reentry vehicles in the presence of strong wake echoes.

If unsuppressed, wake returns within the tracking gate of a BMD radar could degrade the quality of metric data or even steal the RV track, with consequent detrimental effects on the designation, discrimination and intercept functions. MTI (moving target indicator) waveforms and processing techniques provide an efficient means of wake suppression by cancellation of echo Doppler components differing from that of the RV. Other methods for eliminating or reducing the effects of wake exist, including use of wideband tracking pulses, coherent burst waveforms, or tracking using a long up-chirp pulse, and these approaches may be advantageous under various conditions. However, MTI has the advantages of not requiring particularly large pulse bandwidths, of not having a long waveform duration more prone to ambiguous range echo interference, and of not being wasteful of radar energy resources (as may be the case with a long pulse).

As described in Ref. 1, MTI processing can be used to suppress either the body echo or the wake echo within the same range resolution cell. An application in which the wake echoes are canceled in data processing in order to permit measurement of RV cross sections in strong wake is discussed in Ref. 2. The data presented here are intended to demonstrate the performance of a range tracker, using a real-time 3-pulse canceler, which has recently been implemented in the AMRAD radar. Section II, which follows, briefly describes the principle and the expected performance using MTI processing. Section III discusses the AMRAD data obtained during the RANT-01 flight and analyzes the performance of the MTI tracker.

II. THEORY

The improvement of tracking performance in wake clutter is accomplished by pulse cancellation techniques similar to those commonly employed in MTI radar. Several coherent pulses are transmitted, as indicated in Fig. 1a. Upon reception, the signals are processed by forming a weighted complex summation of the echoes corresponding to the individual pulses, thereby synthesizing, in effect, a Doppler filter. Cancellation can, for example, be achieved at a particular Doppler velocity by forming the summation of echo voltages $E_1, E_2 \ldots, E_m$ for m equally-spaced pulses (of spacing T_s) as follows:

$$E_x = k_1 E_1 + k_2 E_2 \epsilon^{-i\Psi} + \ldots + k_m E_m \epsilon^{-i(m-1)\Psi} \tag{1}$$

where, for achieving a null at the Doppler velocity, V_{null}, the phase weighting $\Psi = 4\pi V_{null} T_s / \lambda$ is used (for radar wavelength λ), and the amplitude weights are chosen to satisfy the condition $\sum_{j=1}^{m} k_j = 0$. The residual value of E_x then corresponds to the uncanceled components. The Doppler separation between peak and null of the filter characteristics is equal to $\lambda/(4T_s)$ so that, at L-Band, spacings of between 8 and 12 μsec would be typical under ICBM conditions in order to suppress the low-velocity wake components. As indicated

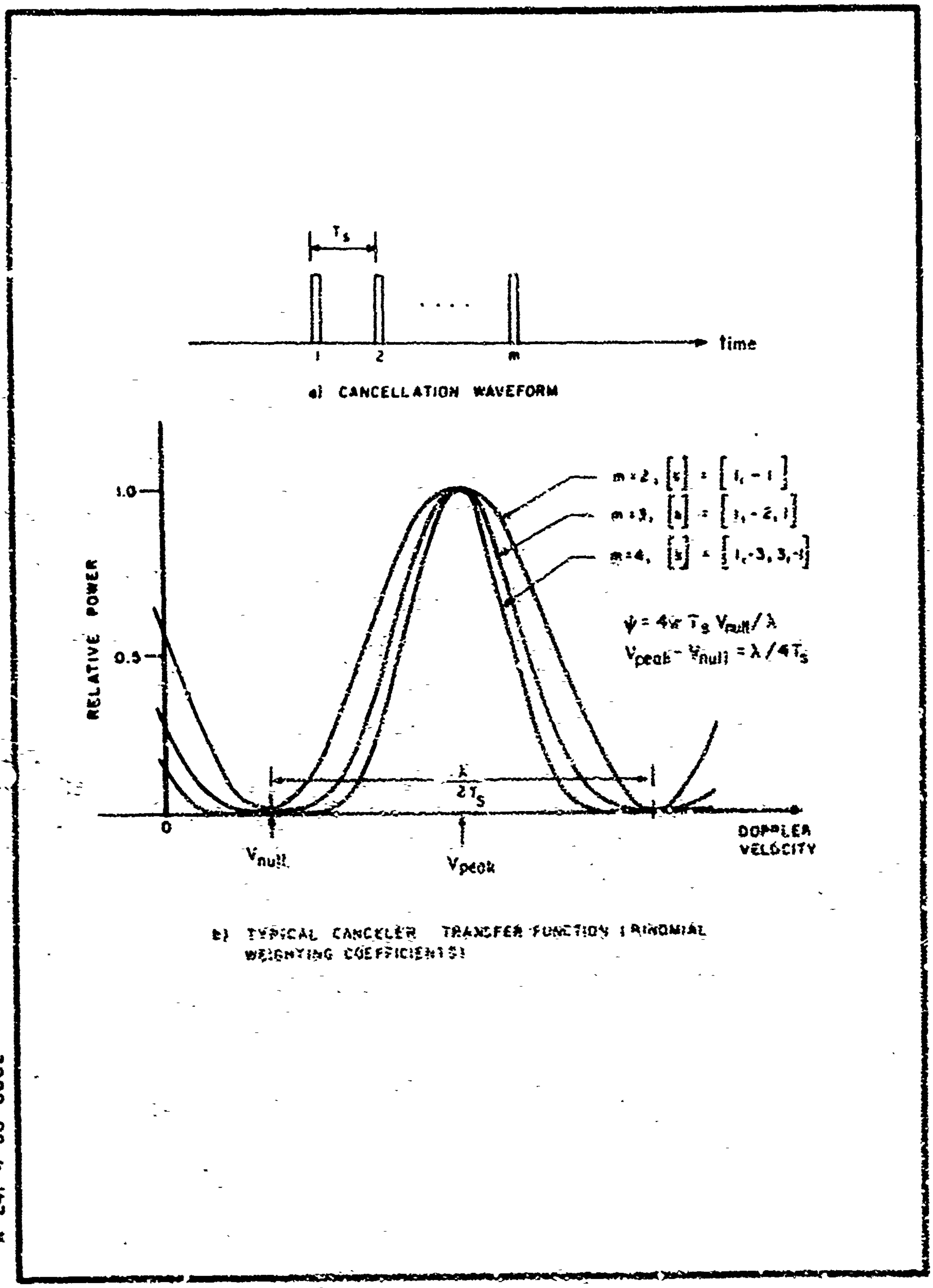

FIG. 1 BASIC WAVEFORM AND CHARACTERISTICS

in Fig. 1b, the use of a simple two-pulse canceler ($k_1 = 1$, $k_2 = -1$) results in a relatively sharp null in the Doppler filter characteristic. For suppressing clutter echoes characterized by a large Doppler spread a broader wake rejection characteristic may be required, such as that obtained by the three-pulse or four-pulse canceler. (For the cases shown, a binomial sequence of weighting coefficients was assigned; in general, more optimum filters can be synthesized, depending on the clutter echo spectra, by other combinations of weights or by nonuniform pulse spacings.)

Figure 2 gives the degree of wake RCS suppression (power cancellation ratio, R) achievable as a function of the fractional wake r.m.s. Doppler spread, $\sigma V/V_B$, for m = 2-, 3-, and 4-pulse cancelers, and for different amounts of misaligment between the null Doppler and the true mean wake Doppler. It is seen that for an r.m.s. wake Doppler spread as large as 10 percent of the body Doppler velocity, a 4-pulse canceler can achieve more than 35 dB of wake suppression for cases where the mean wake Doppler has been accurately predicted. This suppression figure is not severely degraded even for a mean wake Doppler which is unknown to the extent of 10 percent of the body velocity. These calculations were based on the assumption of a Gaussian wake Doppler spectrum; actual spectra having different characteristics, especially out on their tails, can substantially alter these results.

Note that, in practice, the actual achievable wake suppression could be limited by quantization coarseness in analog-to-digital conversion (if a digital tracker is used), by instabilities in the radar, or by spurious amplitude or phase modulation.

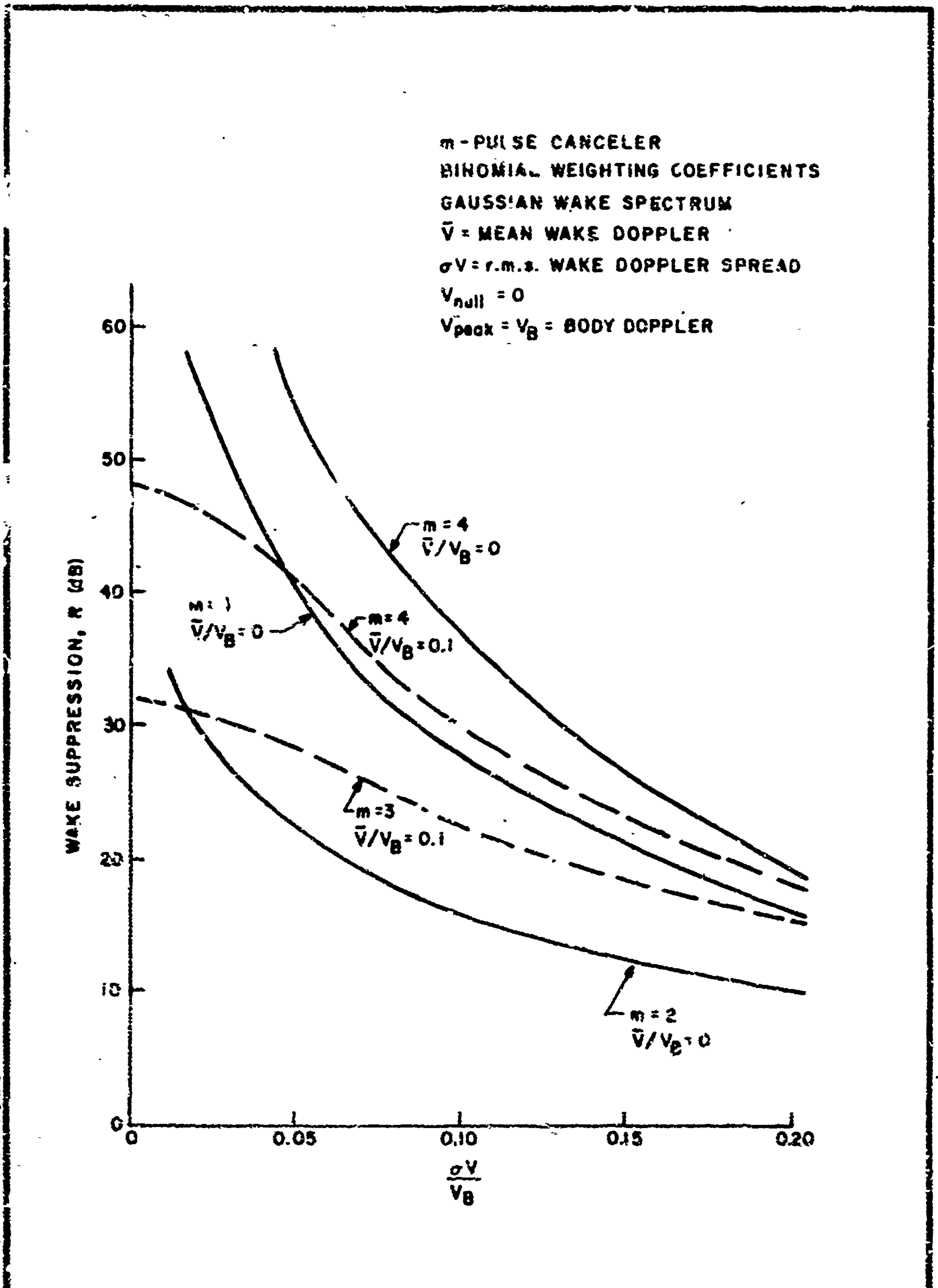

FIG. 2 ACHIEVABLE WAKE SUPPRESSION

By tracking on the canceler output signal rather than on the raw pulse echoes, both range and angle tracking can be improved. In most situations of interest in a terminal defense geometry, the wake would introduce a negligible amount of angle-tracking scintillation (glint) relative to the noise-determined monopulse error signals. However, the presence of uncanceled wake in the tracking range cell can in fact limit the range tracking precision, as will be illustrated. When wake cancellation waveforms are employed, the r.m.s. range tracking jitter for a steady (nonfluctuating) reentry body cross section can be expressed as

$$S.D.(r) = \frac{K}{B} \sqrt{\frac{\sigma_n + (\sigma_w/R)}{\sigma_b}}$$

where σ_b, σ_n, and σ_w are the RCS values corresponding to the body, integrated receiver noise, and wake clutter within the body range resolution cell, respectively, B is the bandwidth of the tracking pulse and K depends on the tracker characteristics (including the tracking loop dynamics and smoothing, tracking PRF, leading edge threshold criteria, and detailed tracking pulse shape). This expression is only valid for sufficiently large ratios of body to random-echo signals (σ_b/σ_n, $R\sigma_b/\sigma_w \gtrsim 1$). Also, if significantly large body RCS fluctuations are present the tracking quality can be affected. These latter effects, as well as the effects of receiver noise, are not reduced by the cancellation process. (Techniques are available for coping with the effects of body RCS fluctuations.)

III. RESULTS

The results presented here were obtained from data collected on the RANT-01 payload (Athena 137) flown on 12 January 1973 at the White Sands Missile Range, which was the first flight test for which the AMRAD MTI tracker was operational.* In order to assess the effectiveness of the MTI technique two independent range trackers were used at AMRAD to simultaneously track the payload during reentry. The principal tracker employed a single pulse (3 μsec compressed to 0.1 μsec). The MTI tracker, which operated on the output of a cancellation circuit, used 3 pulses, each 0.1 μsec wide, with a fixed spacing of 10.5 μsec. Binominal amplitude weighting coefficients (1,-2, 1) with no phase weighting ($\psi = 0$) were employed for this test. Thus the transfer function null was at zero Doppler and, since the AMRAD frequency is 1300 MHz, the peak occurred at a Doppler velocity of 5.5 km/sec.

A block diagram of the three-pulse cancellation circuit employed is shown in Fig. 3. (A conventional analog design approach which would adequately demonstrate the tracking technique was selected.) The first loop provides the amplitude weighting while the second loop provides the proper delay (and phase) to form a null at the desired wake Doppler frequency. Two power dividers (PD_1 and PD_2) and one gate (G_1) perform the amplitude weighting function with coefficients $k_1 = 1$, $k_2 = -2$, $k_3 = 1$. Cable (ϕ_c) cut to the proper length is used to maintain proper phase between the gated and ungated signal paths. The second pulse of the received triplet is gated on by G_1 as shown in the timing diagram. Power divider PD_2 drives the cancellation loop which introduces a 10.5 μsec delay and a loop gain of two. (The exact delay is adjusted by the proper length of cable ϕ_1.) The output of the cancellation circuit feeds the MTI range tracker which is gated on with the third pulse. In practice, this circuit achieved a cancellation ratio (R') of about 30 dB.

* The RANT-01 target was flown under the sponsorship of the U.S. Air Force, SAMSO. AMRAD data are presented in Ref. 3.

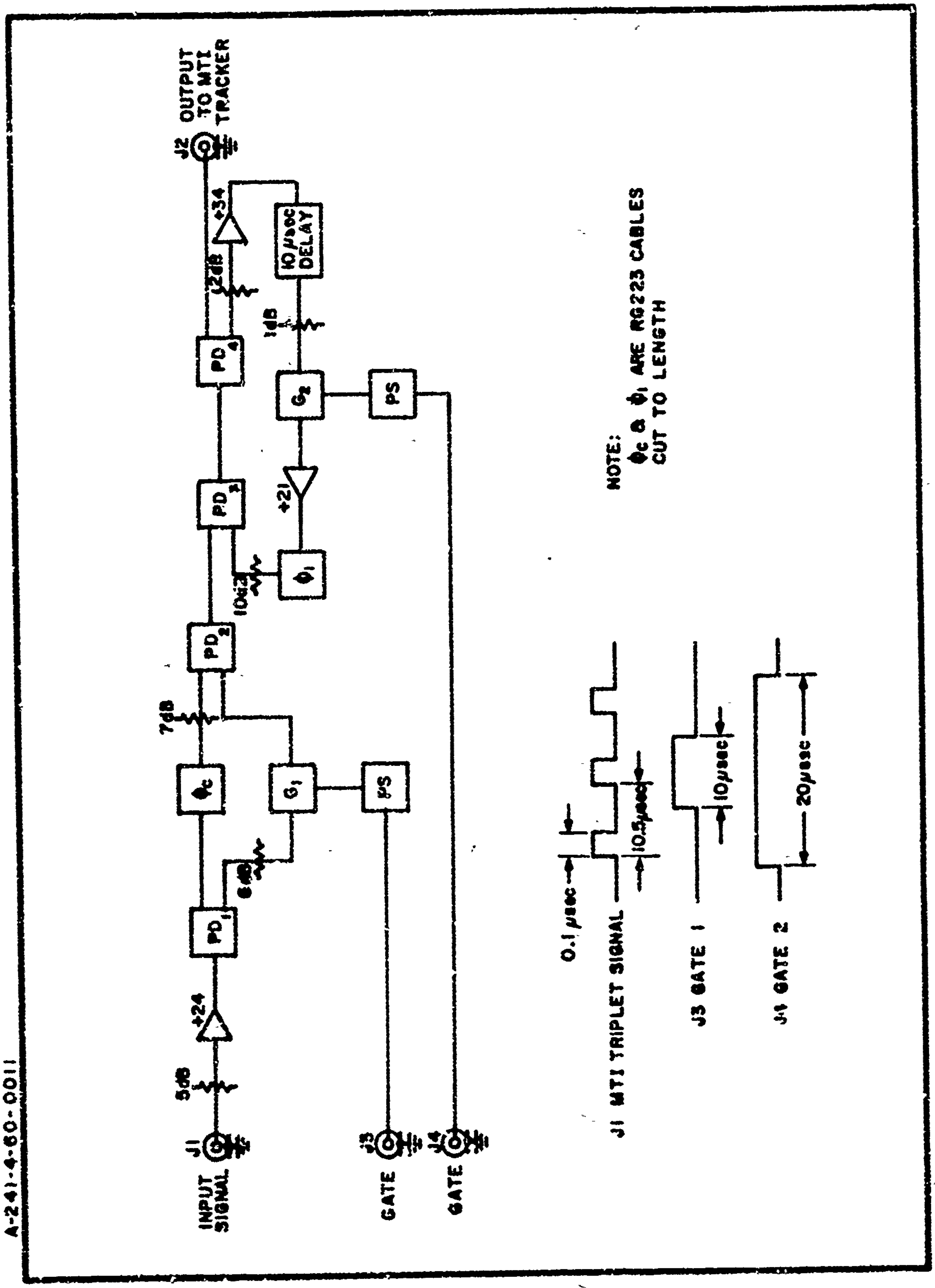

FIG.3 3-PULSE ANALOG CANCELLATION CIRCUIT EMPLOYED AT AMRAD

Both trackers operated in a leading edge mode at a waveform repetition rate of 50 Hz; the trackers were identical in all other respects, including the tracking loop time constant (approximately 0.1 sec).

No attempt was made to incorporate an MTI waveform for wake suppression in the AMRAD angle tracker, which uses a 1.2-μsec uncompressed pulse. For the RANT-01 flight, the slant range at maximum waking was approximately 125 km and the radar aspect angle was 20 deg. Thus, the angle subtended by the wake within the angle tracking range cell was at most 0.5 mrad, which is not significantly greater than the single-pulse angle tracking jitter due to noise alone. (In fact, the wake had no discernible effect upon the angle tracking quality for this test.[3])

Fig. 4 shows the range vs. time history and the range tracking residuals obtained during data processing for both the MTI and single-pulse trackers over the interval (313 to 32 sec) for which comparisons are meaningful. The residuals correspond to the tracking fluctuations about a 2-sec running polynomial fit to the range vs. time history. Fig. 5 shows the reentry body and wake RCS in the body range cell, the wake mean Doppler and Doppler spread in the body range cell at various times,* and the suppressed wake echo RCS calculated on the basis of both the ideal cancellation ratio (as determined by the wake Doppler moments) and the actual cancellation ratio (29 dB) measured for the circuit employed. For reference purposes, the equivalent RCS σ_n corresponding to the receiver noise is also shown.

The effects of wake upon the single-pulse range tracking can be observed in Fig. 4, particularly when strong attached

* The body RCS and wake RCS and Doppler measurements were obtained by burst waveform Doppler processing.

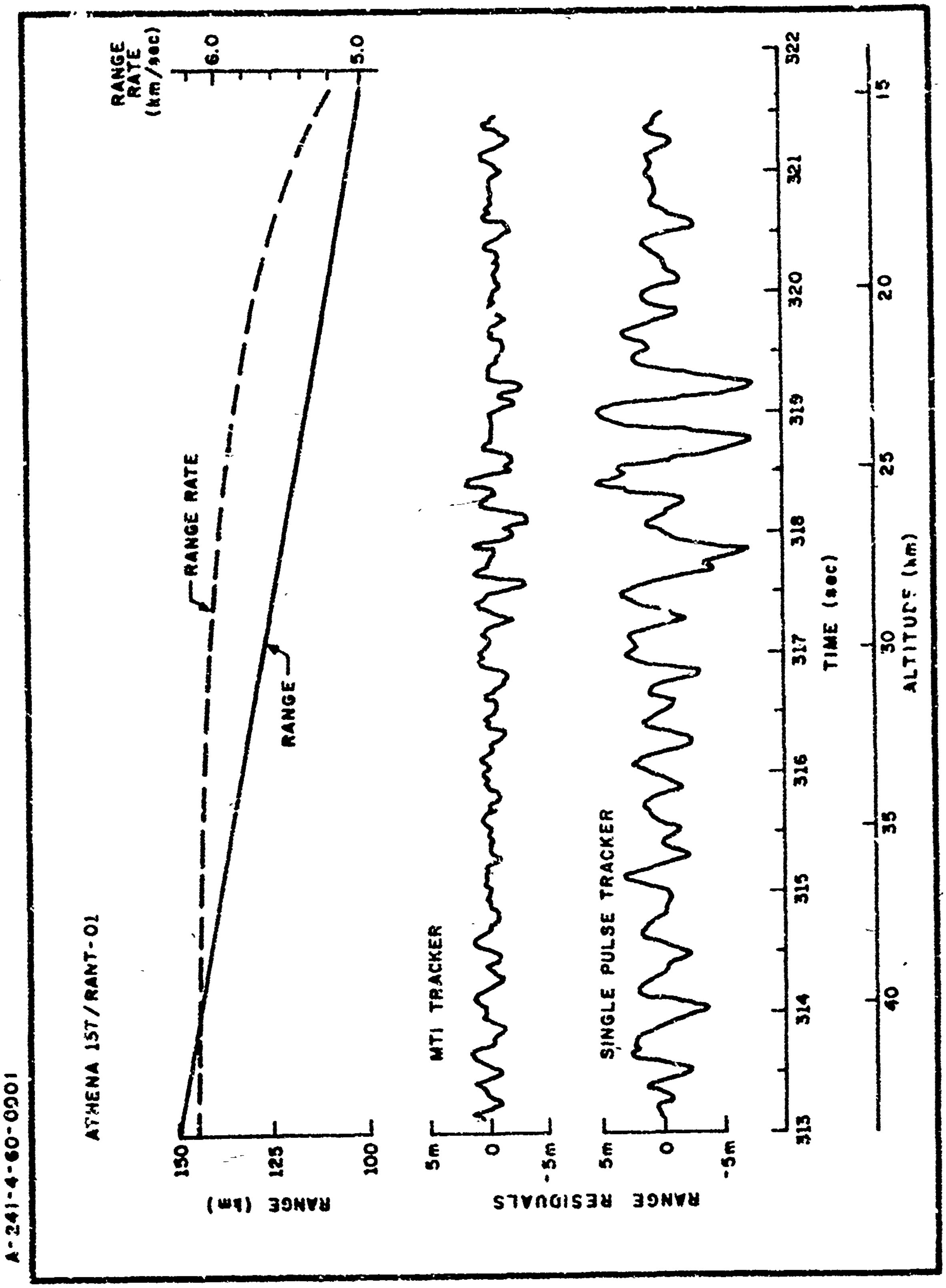

FIG.4 AMRAD RANGE TRACKING DATA

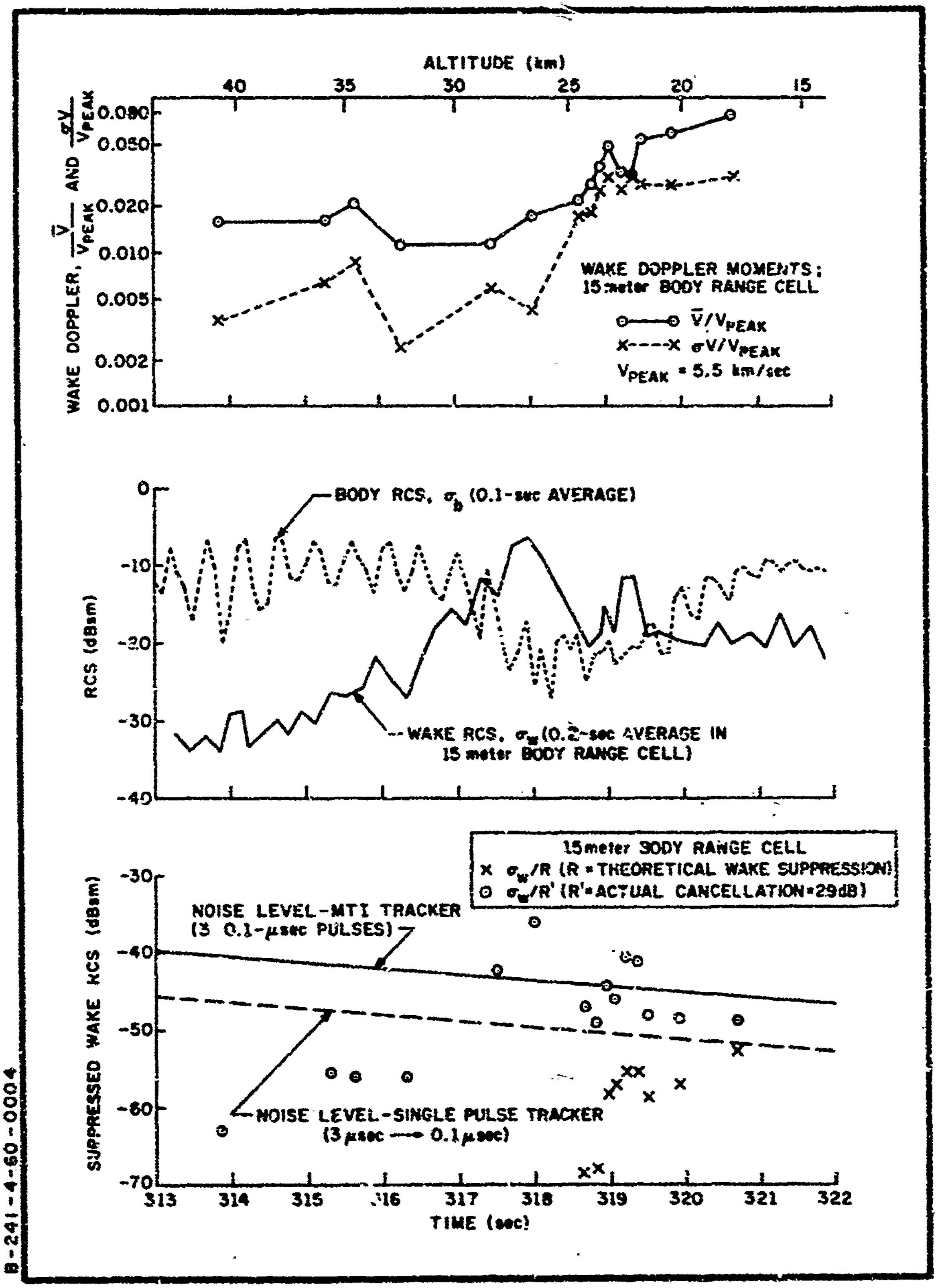

FIG. 5 AMRAD DATA RELEVANT TO MTI TRACKER PERFORMANCE FOR RAN⁻-O1 FLIGHT

wake is present (317.5 to 319.5 sec). During the entire interval the wake RCS exceeds the noise level and therefore contributes more to the tracking jitter. For the MTI tracker, the wake echo is suppressed to levels where it is negligible compared to the receiver noise, except in the interval 317.5 to 319.5 sec when it somewhat exceeds the noise (see Fig. 5). This is consistent with slight increase in MTI tracker jitter during this latter interval. In any case, note the general improvement in tracking performance obtained with the MTI tracker.

More striking examples of the tracking improvement using MTI techniques have been obtained for more recent WSMR flights, for which the data are classified. Those interested in these recent data are invited to contact M. Arm at the AMRAD site for further details.

ACKNOWLEDGMENT

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REFERENCES

1. Weissman, I., "Low-Altitude Discrimination Waveforms (U)," in Proceedings of the 1971 Low-Altitude Workshop, published by Riverside Research Institute, 4, 5 March 1971, Secret/RD.

2. Edelson, W., "A Cancellation Technique for Processing Radar Reentry Measurements (U)," Riverside Research Institute Report TM-45/186-4-10, 1 January 1973, Secret/RD.

3. "Preliminary AMRAD Data Report, Athena Flight No. 137 (H005J/RANT-01)," Riverside Research Institute Report PADR-25/241-4-10, 9 February 1973, Unclassified.

4. Weissman, I. and Grieco, D., "A Low-Altitude Discrimination Waveform Employing Frequency Agility (U)," Riverside Research Institute, Technical Memorandum TM-33/077-4-00, 30 June 1970, Secret.