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RANGE AMBIGUITY REDUCTION IN THE MADRE RADAR

PART II - INITIAL SYSTEM EVALUATION

(UNCLASSIFIED TITLE)

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RADAR DIVISION

January 1964

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DEPARTMENT OF THE NAVY · OFFICE OF NAVAL RESEARCH

U. S. NAVAL RESEARCH LABORATORY
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ABSTRACT
(Secret)

The Madre radar, a coherent MTI radar which utilizes ionospheric reflection of high-power HF waves to extend its range beyond the horizon, has been proven reliable in the detection of aircraft targets at ranges as great as 2000 nautical miles and launch-phase ballistic missiles from the Atlantic and Pacific Missile Ranges.

A method has been devised by which range ambiguity in the Madre radar may be reduced without the degradation of echo doppler coherence which would result from a simple interpulse frequency-switching scheme. A series of double-sideband pulses, with sidebands separated by different amounts from a common suppressed carrier, is transmitted cyclically. Evaluation of the double-sideband frequency-stepping exciter and receiver system in a study of meteor ionization echoes and local aircraft targets is reported.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem R02-17
ARPA 160-60

RANGE AMBIGUITY REDUCTION
IN THE MADRE RADAR

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INTRODUCTION

The Madre high frequency (HF) surveillance research radar has been developed by the Naval Research Laboratory as a part of an investigation into cross-correlation signal processing techniques applied to long-range, over-the-horizon detection of aircraft and missile targets. A full description of the Madre radar appears in earlier reports (Refs. 1-3); parameters of interest in the ensuing discussion are presented in Table I.

TABLE I

Parameters of the Madre Radar

Frequency band	13 to 27 Mc/s
Peak power	4.6 Mw
Average power	100 kw
Pulse repetition frequency (prf)	180 pulses per second (pps)

A cross-correlation process has been developed which, with the aid of a rotating magnetic drum for storage of 20 seconds of target range and doppler information, has been applied with extremely high reliability to the detection of launch-phase SLBM vehicles at altitudes below 100 km from the Atlantic Missile Range and to the detection and tracking of aircraft targets at distances up to 2000 nautical miles. The Madre facility has also been utilized frequently in tracking aircraft targets beyond 2500 nautical miles in range and in detecting launch-phase ICBM vehicles from the Pacific Missile Range. A high degree of flexibility has been built into the Madre radar as is demonstrated by its ready adaptability to such diversified applications as studies of high-altitude nuclear explosion effects upon the ionosphere (Refs. 4 & 5) radar echoes from the moon (Ref. 6), and ionospheric effects associated with a solar eclipse (Ref. 7).

The 180 pps repetition frequency of the Madre facility permits the determination of unambiguous velocity information for targets traveling as rapidly as 1015 knots at the high frequency limit of the Madre radar and for proportionately faster targets at lower frequencies. The prf of 180 pps sets a limit of 455 nautical miles on unambiguous range, however, and this circumstance presents considerable difficulty in studying targets at ranges of 2000 to 3000 nautical miles. The 5 to 7 superimposed range intervals from which a target at these extreme ranges must be extracted contain saturating meteor returns and strong local targets as well as closer over-the-horizon targets.

A method has been devised which multiplies the unambiguous range of the Madre system without degrading the echo coherence upon which the cross-correlation process depends and which would be seriously degraded if a simple frequency-stepping technique were used. Doppler coherence is preserved in this method by stepping in frequency such that all echo dopplers are referred to a single effective carrier reference. A set of 3 double-sideband signals, separated from a common suppressed center frequency by differing amounts, is transmitted cyclically. Echoes are subjected to extensive filtering and product-detection to extract from each of them doppler information corresponding to the suppressed carrier. This information may be processed with the aid of the same cross-correlation technique which has been used previously with the Madre facility and will yield range information which is unambiguous to 1365 nautical miles and doppler information which is unambiguous to 508 knots at the high-frequency end of the Madre spectrum (this division of unambiguous velocity sensitivity by a factor of two is a result of the product detection process and was accepted because the present drum is limited to a maximum pulse repetition frequency of 180 pps; it could be eliminated by employing a 360-pps repetition frequency and 6-step frequency-shifting cycle). A more complete exposition of the coherent frequency-stepping technique is presented in references 8 through 11.

DEVELOPMENT

An exciter system has been developed which generates 3 sets of double-sideband signals separated by 10 kc, 20 kc, and 30 kc, respectively, from a suppressed center reference frequency. Figure 1 is an illustration of the pulse sequence which the exciter produces, showing from left to right double-sideband pulses with sidebands displaced by 10 kc, 20 kc, and 30 kc from the suppressed center frequency (f_c). Figure 2 is a spectrum analysis of the double-sideband pulse sequence. A cosine-squared pulse shape has been chosen to minimize spectrum side-lobes, and it may be seen from Fig. 2 that spurious components are depressed by more than 25 db below the sideband peaks. Although the frequency crossover between adjacent sidebands is only 20 db below each band center in Fig. 2, adjustment of the pulse length may be exploited to alter this crossover point as desired.

Figures 3 and 4 are block diagrams of the frequency-stepping exciter and receiver systems. Outputs from the 510 kc, 520 kc, and 530 kc oscillators at the extreme left of Fig. 3 are arranged in 3 sequences by the sequential modulators. One of these sequences is presented to a balanced mixer which creates the double-sideband signal sequence for transmission, and each of the three sequential modulator outputs is presented to a separate receiver for use as a local oscillator. Each receiver is then sensitive to echoes from one of three different 455 nautical-mile range intervals. Received echoes are subjected to two mixing operations, product detection, and a comb-filtering operation which removes ground-backscatter energy within a few cycles per second of the center frequency and prf-associated sidebands. The resulting signal is then ready for further processing with the aid of the Madre drum and scanning doppler filter.

Figures 5 and 6 are front and back views, respectively, of the frequency-stepping exciter and receiver systems. The rack on the left in Fig. 5 (whose reverse is on the right in Fig. 6) contains the receiver, product detector, and power supplies for the entire system. The rack on the right in Fig. 5 (whose reverse is on the left in Fig. 6) contains the exciter equipment. The comb filters are not shown.

EVALUATION

Preliminary testing of the frequency-stepping system has been completed, and a limited series of operational evaluation tests has been conducted. The Madre high-power amplifier and antenna systems have been found to be readily compatible with the frequency-stepping exciter despite the rather wide spectrum of the exciter's signal (in excess of 65 kc at the 3 db points), and the transmitter has been operated at 4.6 Mw peak power throughout the frequency range from 13.5 Mc/s to 21.3 Mc/s with only minor antenna tuning difficulties. No degradation in transmitter performance has been detected.

Figure 7(a) is an oscilloscope photograph made at the receiver 100-kc intermediate frequency (i.f.) of ground-backscatter echoes detected with the Madre frequency-stepping exciter and receiver. Figure 7(b) is a similar photograph of ground-backscatter echoes detected a few minutes earlier with the normal Madre exciter and receiver. The only noticeable degradation of the signal in Fig. 7(a) compared to that in Fig. 7(b) is a generally higher level of noise received throughout the trace of Fig. 7(a). This slight degradation, an effective multiplication of noise power by a factor of four, is a consequence of the four times wider receiver bandwidth necessary in the frequency-stepping receiver to accommodate the 65 k.c. wide frequency-stepping signal spectrum.

For the purpose of facilitating the adjustments necessary in applying the frequency-stepping receiver and analysis systems to the study of actual radar targets, a series of observations has been conducted upon meteor ionization trails and local aircraft targets. Figure 8 is a photograph of the frequency-stepping receiver 100 k.c. i.f. signal displayed above the product-detector output trace and showing the effects of a meteor echo. Although the 100 k.c. i.f. trace is filled with echoes, chiefly low-level ground backscatter, the product-detector output is seen to reflect quite strongly the effects of the meteor echo (circled). This discrimination in the product-detector against low-level backscatter echoes is partially a result of their low doppler shifts compared to the meteor echo and is caused by a high-pass filter in the product-detector output. Further discrimination against these backscatter echoes is a result of photographic integration in Fig. 8 which emphasizes the discrete meteor echo in the product-detector trace at the expense of the diffuse backscatter signal.

Figures 9(a), 9(b), and 9(c) are photographs of the frequency-stepping receiver 100 k.c. i.f. signal displayed below a product-detector output trace for each pair of symmetrically-displaced sidebands. A local target echo appears at the left in each illustration. The local target echo gives rise to a product-detector output signal which is apparent in each illustration, although in Fig. 9(b) it is somewhat obscured by interference. This interference is incoherent with respect to the double-sideband transmitted signal, and hence would be strongly suppressed in later data-processing stages.

A study of local aircraft targets was conducted with the aid of the Madre data-processing system, and several targets were tracked for periods up to a half hour. Figures 10(a) through 10(g) are Madre display photographs of a target which was tracked for 32 minutes with the use of the frequency-stepping exciter and receiver. A single pair of sidebands was transmitted during the tracking period; stepping in frequency was not attempted. Range runs from left to right and is indicated in nautical miles along the bottom of each photograph. The vertical coordinate is target doppler shift, although in the series of photographs shown no absolute calibration was made, and hence the left vertical scale indicates only relative doppler shift. The circled trace in each photograph represents the target echo; its progress in range through approximately 80 nautical miles and decrease in doppler shift through approximately five cycles per second (corresponding to a decrease in velocity of 75 knots) may be followed without difficulty.

CONCLUSIONS AND FUTURE PLANS

The Madre frequency-stepping exciter has been tested and found to satisfy the requirements of spectral distribution, pulse shape, sideband amplitude stability and power level necessary for it to be used satisfactorily with the existing Madre high power amplifier and antenna systems. Preliminary evaluation of the Madre frequency-stepping receiver system in studying echoes from ground-backscatter, meteors and local aircraft targets indicates that the double-sideband-suppressed-carrier (DSSC) technique may be used satisfactorily in combination with the crosscorrelation signal-processing method which forms the basis upon which the Madre program is built.

Evaluation of the Madre frequency-stepping exciter and receiver in DSSC studies of over-the-horizon targets will begin after the existent Madre delay-line comb filter network is modified to make it compatible with the DSSC system. It is expected that the necessary comb filter modifications will be accomplished by February, 1964, and that evaluation of the DSSC system in over-the-horizon tracking may commence at that time. The initial objectives of the frequency-stepping study should be achieved by June, 1964, and further study into random-stepping and other anti-countermeasures techniques may then be essayed.

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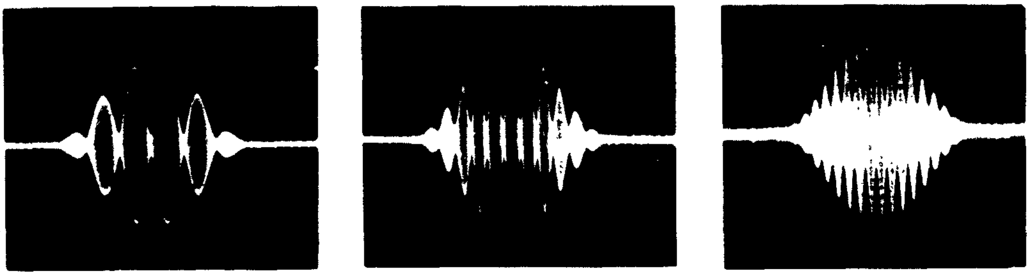


fc ± 10kc fc ± 20kc fc ± 30kc

Fig. 1 - Double-sideband pulse sequence produced by Madre frequency-stepping exciter

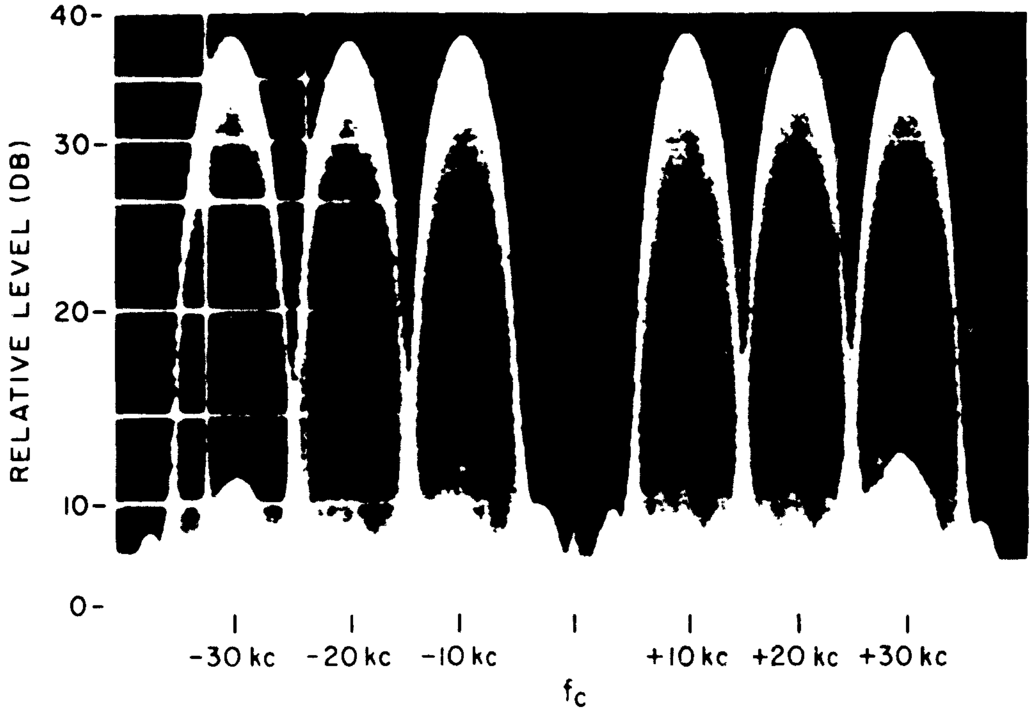


Fig. 2 - Spectrum analysis of double-sideband pulse sequence illustrated in Fig. 1

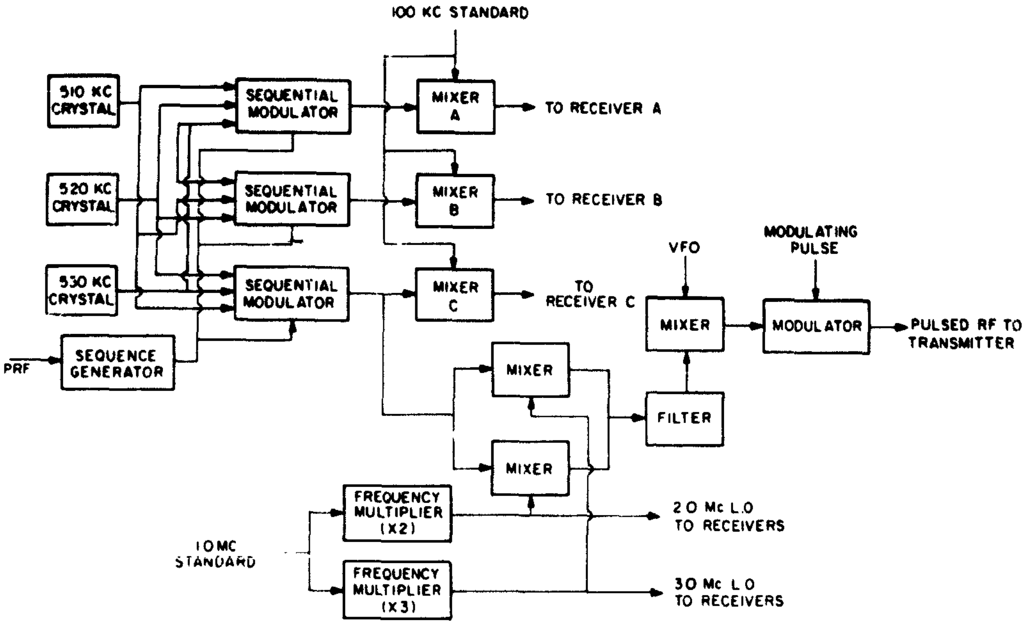


Fig. 3 - Block diagram of Madre frequency-stepping exciter system

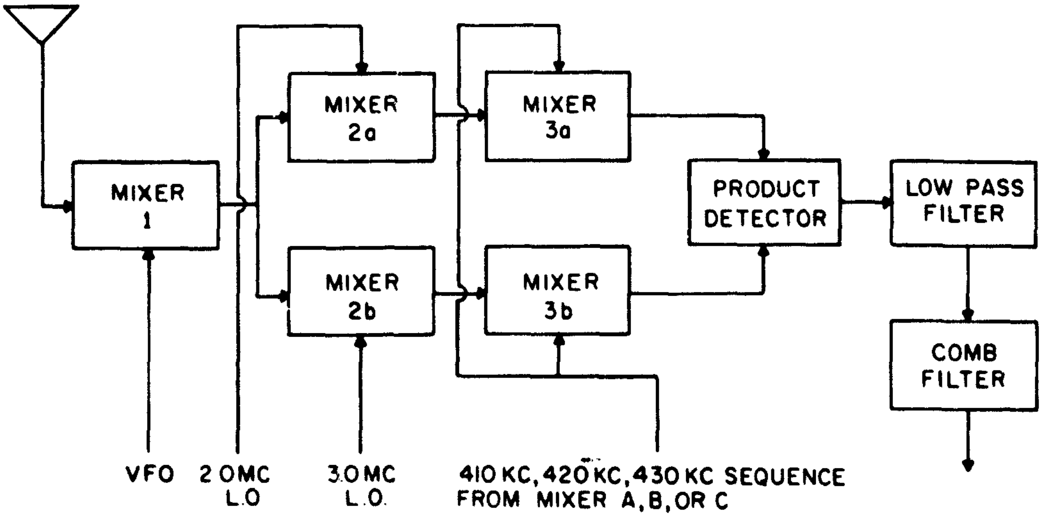


Fig. 4 - Block diagram of Madre frequency-stepping receiver system

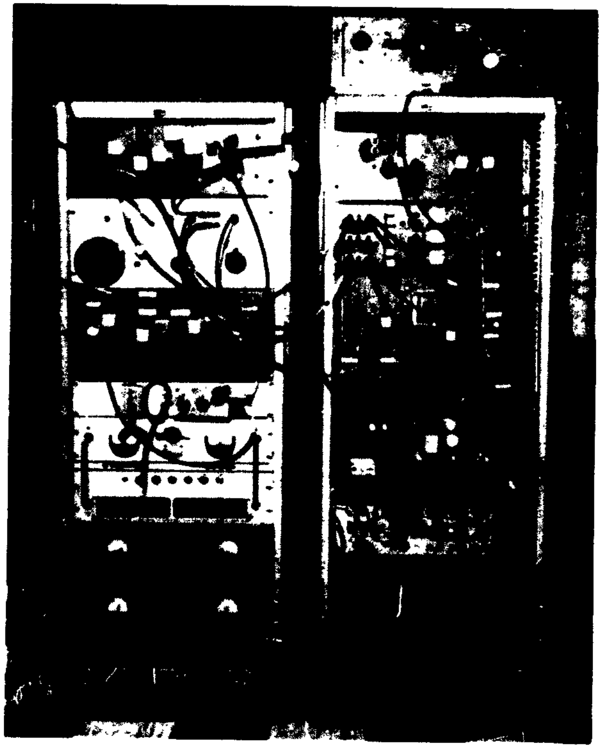


Fig. 5 - Front view of Madre frequency-stepping exciter system (right) and receiver system (left)

Fig. 6 - Back view of Madre frequency-stepping exciter system (left) and receiver system (right)

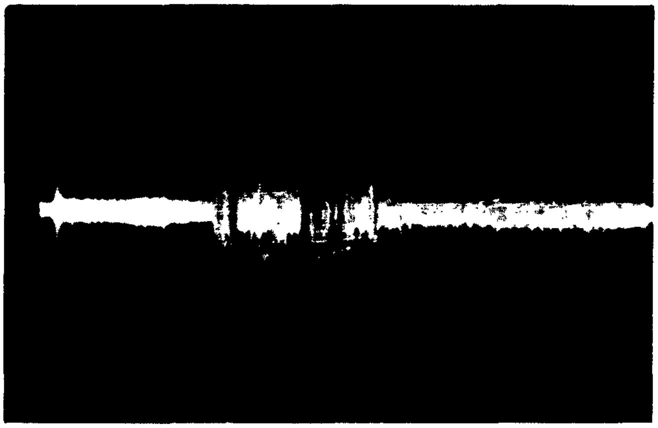


Fig. 7(a) - Oscilloscope photograph at 100 k.c. i.f. of ground-backscatter echoes detected with Madre frequency-stepping system

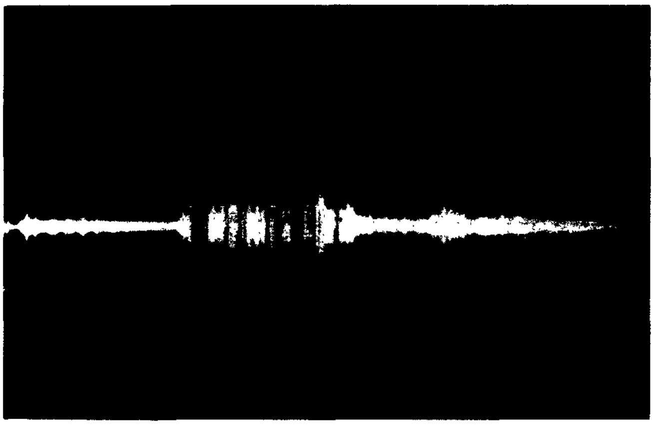


Fig. 7(b) - Oscilloscope photograph at 100 k.c. i.f. of ground-backscatter echoes detected with normal Madre facility

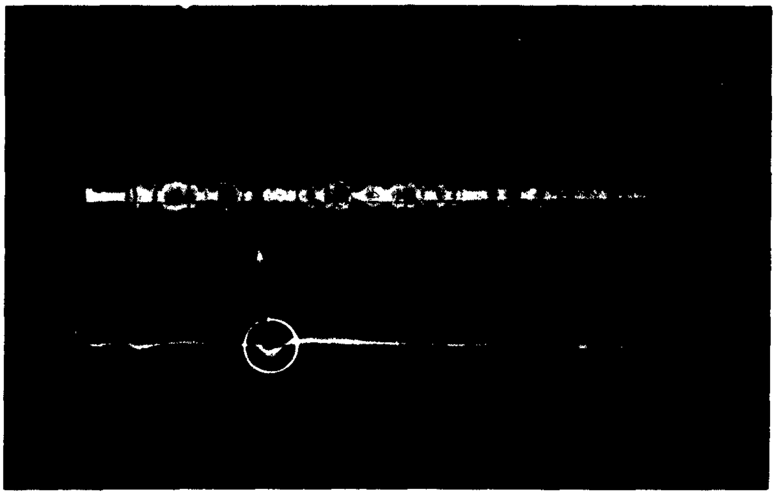
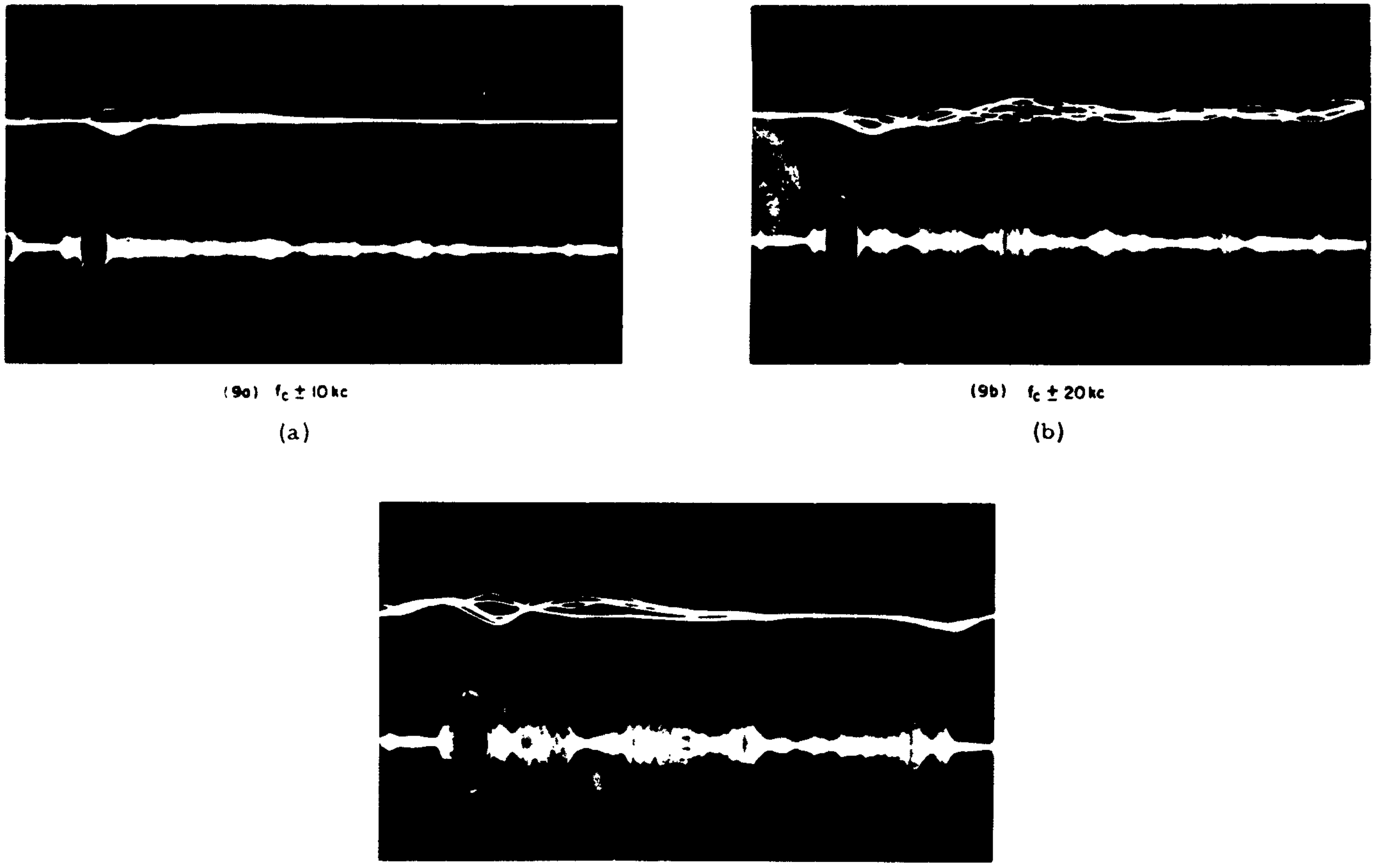


Fig. 8 - Oscilloscope photograph of Madre frequency-stepping receiver signal at 100 k.c. i.f. (above) and product-detector (below) showing effect of meteor echo



(9a) $f_c \pm 10$kc

(a)

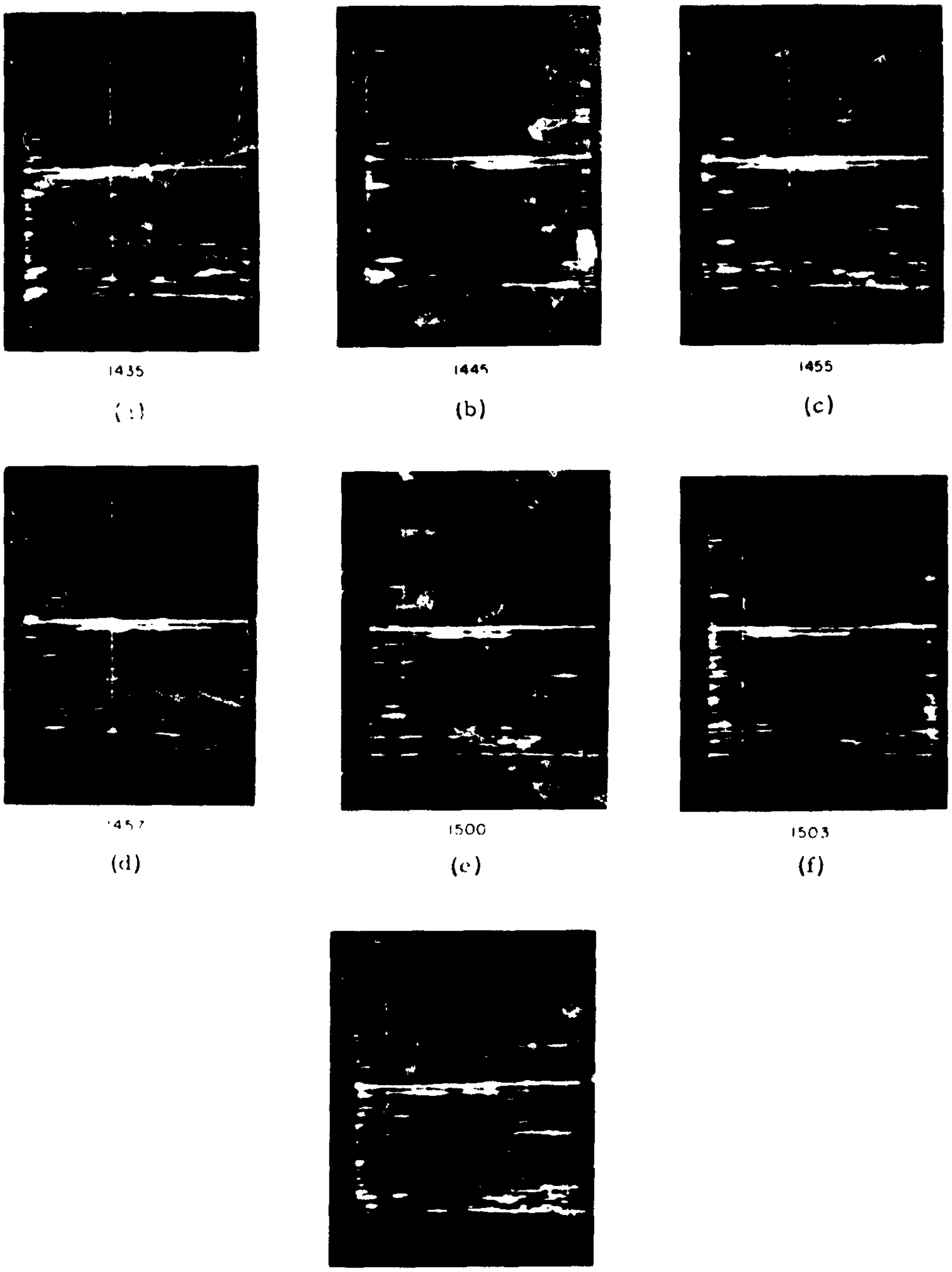
(9b) $f_c \pm 20$kc

(b)

(9c) $f_c \pm 30$kc

(c)

Fig. 9 - Oscilloscope photographs of Madre frequency-stepping receiver signal at 100 k.c. i.f. (below) and product-detector (above) for each double-sideband signal showing effect of local aircraft target



1435
(a)

1445
(b)

1455
(c)

1457
(d)

1500
(e)

1503
(f)

1507
(g)

Fig. 10 - Velocity versus range display photographs of local aircraft target tracked with Madre frequency-stepping system using double-sideband technique (Eastern Standard Time indicated below each frame)

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