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A STUDY OF RADAR ANTI-CLUTTER DEVICES

FOR NAVAL USE

BY
I. H. Page

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Radio Division - Search Radar Section

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by

I.H. Page

Approved by

R.C. Guthrie
Head, Search Radar Section

Dr. A. Hoyt Taylor
Superintendent, Radio Division

A.H. Van Keuren, Rear Admiral, USN
Director, Naval Research Laboratory

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Abstract

The anti-clutter problem resolves itself mainly into the detection of rapidly moving targets in the presence of a large number of stationary or slowly moving targets. This is particularly so for air-search radars as used aboard U.S. Naval vessels.

Improved resolution in the radar equipment is a help against clutter but does not completely solve the aircraft detection problem.

Non-coherent pulse doppler may have special applications where it is desired to detect moving targets among clutter but for general search applications it is not considered a complete answer.

Coherent pulse doppler gives a method of detecting radial movement of any target and a number of indicating devices of varying degrees of complexity are available. A storage-cancellation method using a mercury supersonic delay line and associated circuits for cancelling from pulse to pulse has been developed in the laboratory (Radiation Laboratory) and appears to be a relatively complete answer for air-search if applied to a radar with the correct radio frequency and pulse repetition rate. The advantage of a storage-cancellation scheme of doppler presentation using delay lines or storage tubes is that no appreciable scanning speed is lost. This is vitally important for shipboard air-search radars. By modifying one or more of the Navy standard air-search radars it should be possible to develop a moving target indicator using delay line cancellation which would be useful against targets with a radial velocity above 70 miles per hour. All types of clutter would be greatly attenuated.

The consensus of opinion in U.S. laboratories is that a coherent pulse doppler system can detect moving targets as much as 20 to 30 db below the clutter level if sufficient precautions are taken to keep hum levels, pulse amplitude jitter, repetition jitter and frequency jitter to a low value.

Experimental systems at Radiation Laboratory at 10 cm, at Camp Evans Signal Laboratory at 100 Mc, and at Naval Research Laboratory at 700 and 950 Mc indicate the practicability of pulse doppler radar and give evidence that some existing radar systems can be converted without excessive difficulty.

It is not believed that c-w doppler, FM doppler, or frame storage methods of detecting moving targets are applicable to Navy air-search radar problems.

Table of Contents

1. INTRODUCTION.

1-1. The primary requirements of radar in naval warfare are the detection of moving targets and the furnishing of fire-control data to the computer. Ground clutter, Window, sea clutter and cloud clutter tend to obscure or confuse moving targets such as aircraft or ships and reduce the possibility of detection or of furnishing accurate fire control data by conventional radar systems,

1-2. Many devices or methods have been proposed for reducing the masking effect of clutter (hereafter all forms of fixed or slowly moving targets will be designated clutter) and some of them have been developed to the practical stage.

1-3. New radar systems, or attachments to and modifications of existing radar systems are being developed which make use, in one way or another, of the movement of the target as a means of discriminating against fixed targets. It will be the attempt of this report to evaluate the various devices with respect to their use in naval radar, with particular emphasis on the air-search problem.

1-4. The work on this problem was authorized by reference (a). Other references pertinent to the problem are listed in references (b) through (t).

2. HIGH RESOLUTION RADARS.

2-1. For surface search, target designation and fire control a high resolution microwave radar gives improved operation against desired targets in the presence of clutter because it traces a cleaner and more well defined map of the area, reducing the regions affected by the clutter and improving the probability of obtaining a "look-through" in gaps within the clutter.

2-2. Clutter-cutting circuits such as video differentiation and fast acting a.v.c. give most improvement with low resolution systems because their main function is to improve the apparent resolution of the system.

2-3. Although high resolution reduces the infected area on a PPI screen it is still possible to confuse an operator with a cluttered screen, making the detection of moving targets analogous to "finding a needle in a haystack". It is of considerable advantage, therefore, to furnish with even high resolution systems an aid to detection of moving targets which makes possible quick and positive detection and identification. The devices and methods considered in this report are of such a nature and even the highest resolution radar system could use some device to improve its anti-clutter operation.

2-4. For detection of surface targets with a shipboard radar it is felt that high resolution plus sensitivity-time control (which is a means for reducing receiver sensitivity for strong close-in echoes) is the best approach. Addition of IAVC and video differentiation may give some additional improvement.

3. C-W AND MODULATED C-W DOPPLER RADAR.

3-1. C-W Doppler.

3-1-1. C-W doppler is the simplest method of detecting a moving target. The c-w signal radiated by the transmitter is reflected from the target and is picked up by a receiver along with some of the transmitted signal. If the target is moving a frequency shift due to Doppler's Principle takes place so that the received signal at the receiver is different from the transmitted signal. In the simplest receiver system a coherent detector will produce the difference frequency between the transmitted and received signal which may be amplified by an audio amplifier to give an aural indication of the presence of the moving target.

3-1-2. Interesting experiments have been performed with c-w doppler systems to determine their value for detection of movements of men or vehicles, and for specialized applications of this type it may be of some value. See reference (j) and (o).

3-1-3. The only advantage of c-w doppler is its simplicity. It has the serious disadvantages for general radar use that it can give true rate information only when just one target is in the beam and it cannot give range information.

3-2. AM and FM Doppler.

3-2-1. In order to determine range of a target using a c-w radar, modulation must be applied.

3-2-2. This has been accomplished in various ways; some of the methods using sine wave amplitude modulation, square wave (chopped cw) and sine wave frequency modulation. When modulation is put on the c-w signal it is possible to get a range indication by comparing phase between the modulation on the reflected signal and on the transmitted signal. This can be done in a number of ways but in most methods confusion results if more than one target is present in the beam. In addition modulating the cw makes the system sensitive to stationary targets so that the advantage of moving target indication only is sometimes lost.

3-3. Armstrong FM Doppler Radar System.

3-3-1. Major Armstrong's FM Doppler Radar System is of considerable interest and, although it is not felt to be the answer to the shipboard radar clutter problem it warrants a brief description because it may be a valuable ground radar system for use in mountainous terrain.

3-3-2. The Armstrong FM radar utilizes double FM, both the carrier and the modulation being frequency modulated. The carrier is modulated about ± 200 kc by a sine wave swept at a low rate between 10 kc and 500 cycles per second. After the transmitter puts out one sine wave cycle it is turned off for a period equal to the length of the modulation cycle. The receiver is frequency modulated over the same ± 200 kc sweep as the transmitter and in phase with it, but is not keyed so that an echo at the correct range determined by the length of the modulation cycle will be in tune with the receiver, but signals at any other range will not be in tune. This is analagous to a pulse radar which has a range "gate" automatically swept across the range at a low rate.

3-3-3. Five indicating scopes are used in combination with selective filters to indicate whether a target is stationary, moving away, or moving toward the radar. This can be accomplished because the doppler shift on the echo gives slightly increased or slightly decreased frequency if it is moving toward or away from the observer. The receiver is so heterodyned that a stationary target gives a 200 cycle per second output signal. Therefore a target moving toward the observer gives an output greater than 200 cycles and a target moving away gives an output frequency less than 200 cycles per second.

3-3-4. The most interesting indicator is a "PPI" type with deflection modulation on the radial traces. The radial deflection is in synchronism with the FM modulation on the transmitter so that the center of the tube corresponds to about 95 miles (minimum range) or 10 kc modulation and the outer extremity of the tube corresponds to 186 miles or 500 cycle modulation (maximum range). This indicator shows moving targets only and if a target is moving away it deflects on one side of the trace and if moving in it deflects on the other side.

3-3-5. The advantages claimed for this system are: (1) its reduced vulnerability to jamming because the receiver is narrow band (1 kc) and is frequency modulated in synchronism with the transmitter; (2) high performance with low peak power, again due to the narrow receiver bandwidth and resulting high sensitivity; (3) moving target indication only if desired, reducing the vulnerability to clutter.

3-3-6. The disadvantages of the system are obvious: (1) slow rate of scan (again comparable to a pulse radar with swept range gate); (2) high degree of complexity; (3) a probable vulnerability to jamming because of the narrow band over which it is frequency modulated and because of the low peak power; (4) difficulty of obtaining resolution comparable to a pulse radar. These difficulties could be greatly reduced if the frequency and the frequency deviation were increased by a large factor. By doing this, however, the complexity and the stability problem would be greatly increased.

3-3-7. Information available indicates that the Armstrong FM radar is comparable in normal performance to the SCR-270 radar. For ground operation in mountainous country it should be useful for detection of aircraft among large permanent echoes. In its present state it is doubtful that it can compare with a higher frequency coherent-pulse doppler radar in overall performance because of its low resolution and slow scanning rate.

4. PULSE DOPPLER.

4-1. Non-Coherent Pulse Doppler.

4-1-1. Non-coherent pulse doppler consists of utilizing the doppler beats between the moving target and clutter at the same range to give a moving target indication. It can be applied to existing radars with various degrees of success depending on stability and hum level in the system as well as the radio frequency and pulse repetition rate.

4-1-2. Many methods of indication are possible, including all those which are used with coherent pulse doppler. The most widely used is an aural indication, obtained by gating in range, passing the gated echo through pulse lengthener circuits and a filter to remove repetition rate components and low frequency hum, jitter and clutter components. If the doppler frequency is less than half the pulse repetition rate of the radar the true doppler frequency is heard. If it is greater than that, the difference frequency between the doppler and the repetition rate will be heard. To remove a maximum of clutter and to prevent having velocity "holes" or speeds at which there will be no response the repetition rate should be greater than the highest doppler frequency it is desired to detect. If true rate information is wanted the repetition rate should be greater than twice the highest doppler frequency. Plate 1 shows the response characteristics of a gated and filtered pulse doppler system.

4-1-3. The non-coherent pulse doppler method has been tested at the Naval Research Laboratory on the Mark 4 and Mark 12 fire control radars with good success, making possible the tracking of airplanes through window and through ground clutter when they could not be tracked on the "A" scope. The main disadvantages of the non-coherent pulse doppler is that it indicates moving targets only in the presence of clutter. This does not seem a serious disadvantage at first glance but when it is realized that extra operators and extra equipments might be required for searching in the clutter it puts a serious limitation on shipboard use. In addition when using aural indication and the required range gate the scanning speed is low. The main application of this type of system is probably to fire control radar.

4-1-4. The frequency versus pulse rate requirements of non-coherent pulse doppler is such that most air-search radars in the fleet today are not satisfactory for this purpose. The minimum pulse rate for 200 Mc radars should be above 300 pulses per second, 400 Mc above 600, 600 Mc above 900, 1200 Mc above 1800, and 3000 Mc above 4500 pulses per second for satisfactory detection of targets moving at velocities up to 400 m.p.h. For actual radial rate determination the above repetition rates would have to be doubled.

4-1-5. In order to obtain a satisfactory scanning rate for PPI operation it appears that delay line or storage tube cancellation is required. Since most existing radars would have to be modified to increase pulse rate and stability and a new receiver and indicator added, the addition of a coherent oscillator to obtain moving target information outside cluttered areas is probably a small part of the total work involved and is well worth the cost.

4-2. Coherent-Pulse Doppler.

4-2-1. By adding a coherent c-w oscillator locked in phase with the transmitted pulse, movement of a target can be quickly determined by detecting frequency difference between the returning echo and the c-w reference signal. This frequency difference will show up as a low frequency amplitude modulation on the envelope of the echo pulses after they pass through a coherent detector. Any method of indicating the variation of amplitude of the moving target echo can be used. A range gate and aural indication can be used as with non-coherent pulse doppler. A visual indicator can be used which will show the modulation envelope of the gated pulses. An intensity modulated scope with vertical scan at a low frequency rate will show fixed targets as uniform lines and moving targets as striated lines. An expanded "A" scope will show a moving target as a filled-in echo and a fixed target as a stationary undulation in the base line. Although these methods can be used all of them have the failing that extreme operator concentration is required (because clutter is not removed) and scanning rate is low.

4-2-2. What is desired for search radar is a normal PPI indication at normal scanning speed so that moving target indication is available instantly without confusion. At the present time only one method of indication even approximately gives this solution. That is the storage-cancellation method which stores video pulses for one period of the repetition rate and mixes them out of phase with the pulses coming in on the next sweep. The difference signal is then amplified and applied to a normal PPI indicator. The storage-cancellation method has been developed in Great Britain and at Radiation Laboratory making use of a supersonic liquid filled delay line to store pulses (as a video modulation on a carrier of about 10 Mc) for one period of the repetition rate and then subtracting the delayed pulses from the non-delayed pulses to remove stationary targets from the output indication. The mercury delay cell in use by Radiation Laboratory appears to be practical for service operation and attempts at Naval Research Laboratory to get long delays in a small space by "folding" the delay line back and forth several times have met with success. A "folded" delay line can be made quite small and permits practical physical sizes for delays up to at least 1600 microseconds and probably up to 3200 microseconds if desired. It is therefore felt that the delay line problem is no longer a deterent to the use of the storage-cancellation method of moving target indication, designated "MTI" by Radiation Laboratory.

4-2-3. Iconoscope type of storage tubes are being developed which show promise of having sufficient resolution for moving target indicator systems and it is possible that within a reasonable time this principle can be used to supplant the delay line cancellation method. Information now available indicates that a resolution of about .2% in area or 14% linearly can be obtained in the latest storage tubes developed by RCA. This shows promise but still does not match the resolution available in a liquid delay line unless a very small range sector is examined at one time. The real advantage of the storage tube lies in the relative circuit simplicity since the job of storage and cancellation all takes place within the tube. This eliminates the need for critical balancing circuits and accurate keying circuits required in delay line cancellation methods.

4-2-4. A discussion of the radio frequency-pulse repetition rate requirements of a delay line cancellation system of moving target indicator is in order to show the modifications required in converting a present radar system for such operation. Since the prime purpose of a moving target indicator is to remove clutter and to show moving targets we must select a range of velocities to which the system will be sensitive and at the same time make the system as insensitive as possible to stationary and slowly moving clutter. The shipboard problem is somewhat more complicated because the ship may be moving with speeds up to perhaps 35 knots and this velocity may be added to any low velocity movements of the clutter. It immediately becomes apparent (see Plate 2) that the higher the velocity chosen to be accepted the more complete will be elimination of slowly moving clutter. In this type of operation there will be a sine wave response curve of amplitude difference between adjacent pulses versus target radial velocity. The response curve will go through zero at zero miles per hour, be maximum at a velocity giving the doppler frequency on the echo equal to one half the repetition rate and will go through zero again at the velocity equivalent to the repetition rate. This curve will repeat itself, going through zero at each harmonic of the repetition rate. It has been stated that the velocity "holes" or points of zero response are not serious because they may be very narrow if a high r-f frequency and low repetition rate is used. This is not believed to be the fact, however, because clutter is not stationary. This means that slowly moving targets such as window, sea clutter and cloud clutter, in order to be eliminated will require a low frequency cutoff in the indicating device at an appreciable velocity. The velocity gaps present at the repetition rate will then be double the width in miles per hour of the minimum velocity of response. Assuming a reasonable figure of a minimum attenuation of 6 db at 35 knots to reduce the indication from clutter to a low value, it is apparent that the velocity holes around the repetition rate and its harmonics will be ± 35 giving 70 knot intervals between the 6 db response points. The obvious answer appears to be to make the repetition rate high enough to make the velocity hole above the highest radial velocity to be detected. This will automatically reduce the sensitivity to slowly moving targets and clutter. However, since a useful range scale is needed on the radar to reduce interference from "second time around" echoes, to keep duty cycles within limit, and to accommodate standard range scales built into shipboard indicators a maximum repetition rate limitation is imposed. For air-search radars it is felt that the maximum tolerable repetition rate is in the neighborhood of 600 pulses per second. To keep the first null well above 400 m.p.h. we are limited to a radio frequency of about 400 Mc or less. At 400 Mc and 600 p.p.s. the velocity of the null will be

$$V = \frac{f_d c}{2 f_o} = 500 \text{ miles per hour}$$

where f_d = doppler frequency present on echo, c = velocity of radio waves and f_o = radio frequency. Maximum moving target echo response will be at 250 m.p.h. with the 3 db down points at 125 and 375 m.p.h. and the 6 db down points at 83 and 417 miles per hour. This range of velocities should very nicely take care of airplane targets and at the same time should give a very useful reduction in all types of clutter. To maintain the same velocity range as above, radars operating on the following frequencies would need repetition rates as listed:

Radar Frequency	Repetition Rate p.p.s.
200 Mc	300
400 Mc	600
600 Mc	900
1200 Mc	1800
3000 Mc	4500
10000 Mc	15000

For satisfactory clutter elimination consistent with maintaining good sensitivity to aircraft targets it is felt that the above relationship between radio frequency and pulse repetition rate should be approximately maintained in a delay line cancellation type of moving target indicator. An example of how various radars with 600 p.p.s. pulse rate would respond to radial velocities from zero to maximum aircraft speeds is shown in Plate 2. Two things are evident from Plate 2 as radio frequency relative to repetition rate is increased: (1) less clutter is eliminated; (2) velocity holes are introduced which may be quite serious. It is therefore strongly felt that for air-search M.T.I., maximum effort should be placed on 200 or 400 Mc radar systems, using a 300 or 600 p.p.s. repetition rate on 200 Mc and 600 p.p.s. repetition rate on 400 Mc. Existing systems can probably be adapted with a minimum amount of delay.

4-2-5. The use of a double pulse MTI system in which pulses are sent out in pairs spaced by the delay time of the delay cell with the direct second pulse subtracted from the delayed first pulse and the resultant displayed on the indicator would give a method by which radars above 400 Mc could operate at low average duty cycles. MTI operation would result, in such a system, over the first part of the range scale (determined by the delay time) and normal operation would be obtained at ranges beyond. On an "S" band double pulse MTI the delay time should be about 220 microseconds for optimum aircraft detection versus clutter elimination and MTI operation would result over the first 20 miles or so of range. For operation with a 600 p.p.s. indicator the spacing between pairs of pulses would be 1667 microseconds. Any reasonable amount of "jitter bug" operation could be accomplished by jittering the spacing between pairs of pulses without disturbing the delay-line cancellation operation of MTI.

4-2-6. The problem of detecting low velocity targets such as ships or submarines is more difficult than the detection of aircraft because the range of doppler frequencies which are to be detected are very close to expected doppler frequencies on the clutter. Remembering that the shipboard problem is being considered in this report the problems multiply. The ship is moving with respect to both the clutter and to the targets. The only advantage is that the ship targets are likely to be larger than the clutter. This makes one believe that such palliatives as high resolution and sensitivity-time control may be the best answer. Gated doppler systems with aural or visual indicators should offer real advantages over delay line cancellation methods for this type of operation because sharp high pass filters plus the additional discrimination of the ear and the eye can be used. This may be a very useful field for "S", "X" or "K" band doppler systems. It is most desirable for Radiation Laboratory to make field tests of an "S" band MTI radar aboard ship to determine what the clutter reducing properties are under shipboard conditions particularly in operating against ship targets.

5. FRAME STORAGE SYSTEMS.

5-1. The British have done considerable work with storage systems which store the picture from one complete PPI scan to the next on long persistent tubes (such as skiatrons) and superimpose the images through an optical system with shutters showing first one picture and then the other. Moving targets, being displaced a small amount between scans will "flicker" and will thus stand out from fixed echoes. (See reference e).

5-2. A similar presentation with better performance using photographic storage, rapid development and alternate projection gives a more sensitive "flicker" indication but appears quite messy for shipboard use.

6. CONCLUSIONS AND RECOMMENDATIONS.

6-1. High resolution radar systems are of considerable value in operating through clutter and must be depended on in the immediate future. They may always be the best anti-clutter method for operation against surface targets.

6-2. Development work should be immediately initiated on moving target type of indication for one or more of the standard Navy air-search radars. The SC-SK and SR types of systems are in quantity production and while they would require rather extensive modification to increase repetition frequency, shorten pulse and remove hum and jitter in the systems to a sufficiently low value it could undoubtedly be accomplished. The SR-1 at 400 Mc and 600 p.p.s. appears to have optimum characteristics for a delay line cancellation system giving a velocity range of about 100 to 400 m.p.h. without velocity gaps. It is therefore recommended that immediate conversion of the SR, SC-SK and/or SR-1 to MTI operation be attempted. It is also recommended that the Navy request shipboard tests of microwave MTI systems such as have been developed at Radiation Laboratory which would demonstrate their anti-clutter properties under typical naval conditions. It is reasonable to expect that MTI could be incorporated in existing fire control radars such as the Mark 4 and Mark 12 and microwave systems without disturbing their present indicator set-up and thus permit normal solution of aircraft tracking problems in the presence of clutter.

6-3. Frame storage systems, C-W Doppler and FM Doppler are not recommended for shipboard use as an answer to the air-search through clutter problem.

6-4. Non-coherent pulse doppler has value as a stop-gap palliative to low resolution systems which have a sufficiently high pulse rate. The Mark 4 system is an example where/relatively simple device can give considerable aid to tracking through clutter. In addition, gated doppler systems may be of value for determining range rate on a moving target.

7. ACKNOWLEDGMENTS.

7-1. Acknowledgment of the cooperation and help in gathering the information included in this survey is extended to Mr. J.B. Trevor, Jr. of the Fire Control Section of the Naval Research Laboratory; Mr. R.S. O'Brien of Radio Research Laboratory; Dr. J.L. Lawson, Dr. R.A. McConnell, and Dr. P.R. Bell and their associates at Radiation Laboratory; Mr. E.K. Stodola and his associates at C.E.S.L.; and to Lt. R.K. Guthrie of Section 920 of the Bureau of Ships.

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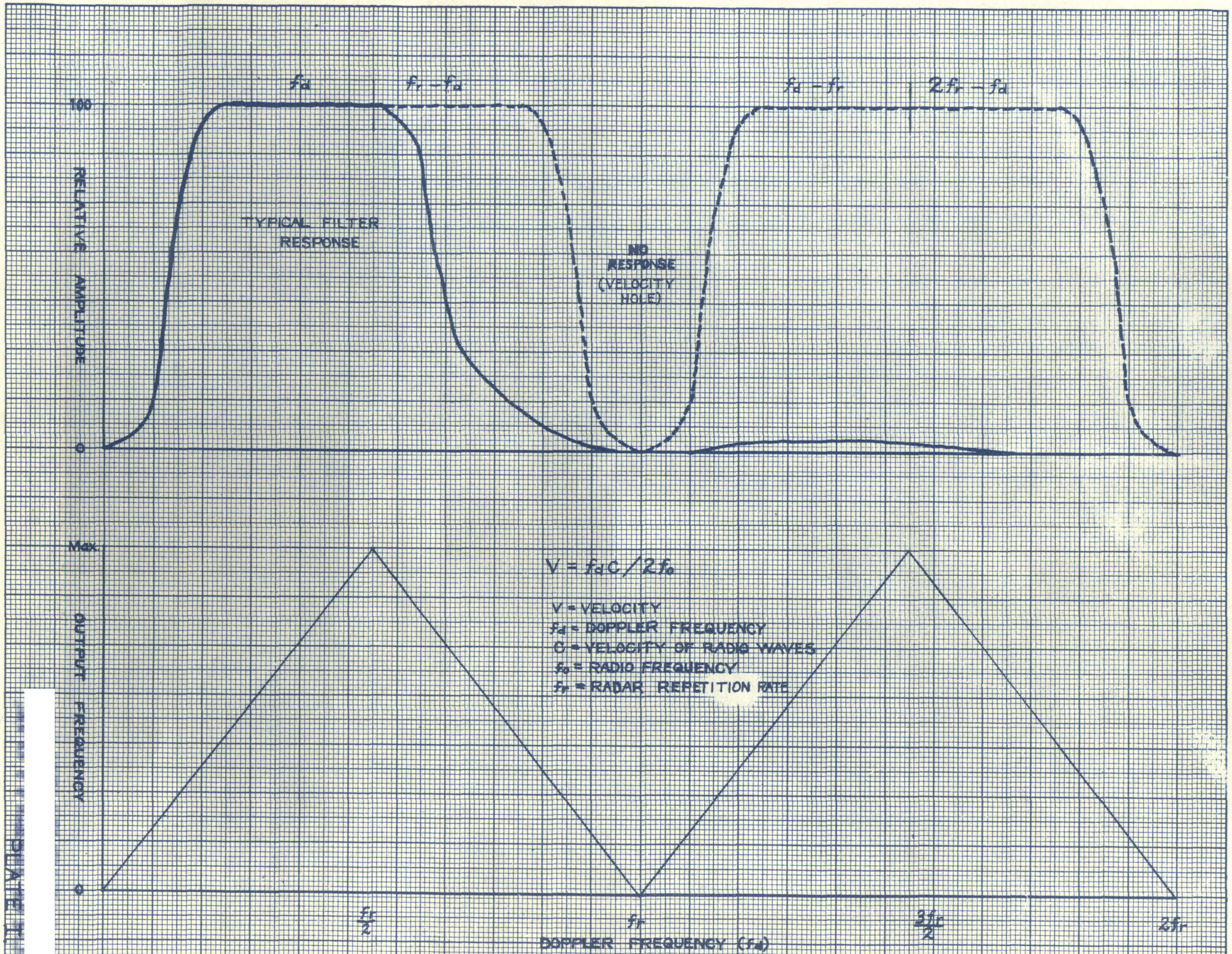
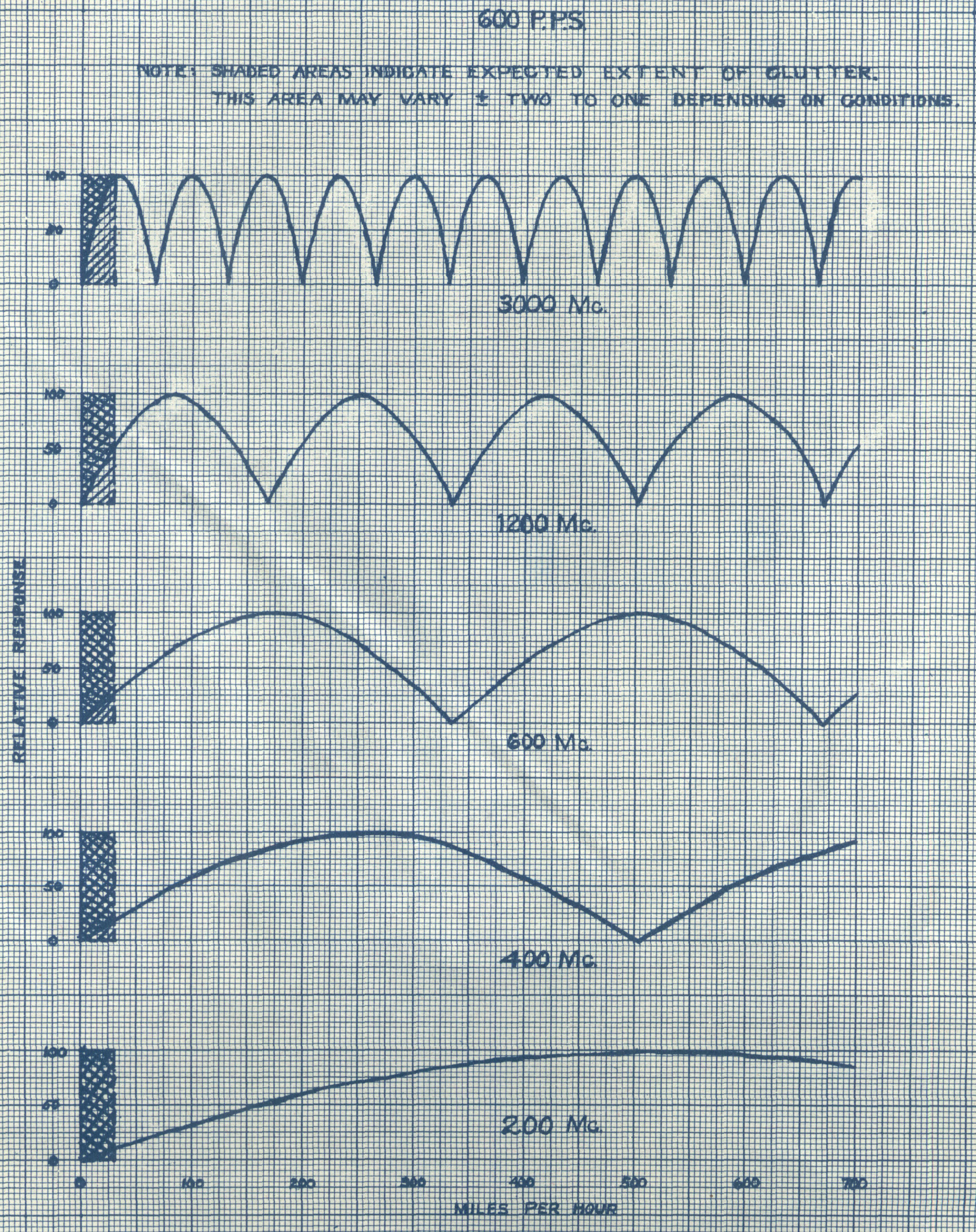


PLATE I.

CHARACTERISTICS OF GATED AND FILTERED PULSE DOPPLER SYSTEM



M.T.I. RESPONSE

PLATE

Table 1

Brief Comparison of Anti-Clutter Methods

Method	Rate of Scan	In Clutter	In Gaps*	Range Info.	No. of Targets Simultaneously	Remarks
High Resolution	Normal 5 rpm	No	Yes	Yes	Normal PPI	Mk 8, SG-3, and others
Coherent Pulse Doppler MTI Presentation	Normal 5 rpm	Yes	Yes	Yes	Normal PPI	Laboratory systems developed at Radiation Laboratory and in Great Britain.
Coherent Pulse Doppler Striated Pulse Presentation	¼ rpm Hoped by CESL on 270 system	Yes	Yes	Yes	All targets on one bearing. PPI not feasible.	CESL Adaptation of 270 System. Requires Pulse Rate many times higher than MTI.
Coherent Pulse Doppler Gated System	1/100 of Normal for 1% resolution	Yes	Yes	Yes	1 Target PPI not feasible.	Used on one of the displays on the CESL adaptation of the 270.
Non-Coherent Pulse Doppler Gated Systems	1/100 of Normal for 1% resolution.	Yes	No	Yes	I Target PPI not feasible.	NRL has tested it on the Mk 4, Mk 8 and Mk 12.
CW Doppler	-----	Yes	Yes	No	One moving target to get rate information.	Sperry has developed an "X" band system.
Armstrong's FM Doppler	¼ rpm	Yes	Yes	Yes	Slow PPI picture possible.	Maj. Armstrong has a system in operation on 100 Mc. May be useful for ground installations.

*Gaps in Clutter.

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1 Chief of Division 14, NDRC, Empire State Building, New York, New York.
2 Navy Liaison Officer, Radiation Laboratory, MIT, Cambridge, Mass.
1 Chief of Division 15, NDRC, 1 River Road, Schenectady, New York.
1 Navy Liaison Officer, Radio Research Laboratory, Harvard University, 16 Divinity Ave., Cambridge, Mass.
1 General Headquarters SWPA, Office of the Chief Signal Officer, Section 22, A.P.O. 500, San Francisco, California.