NPS-52Hs72062

NAVAL POSTGRADUATE SCHOOL

Monterey, California

MULTIPLE-TARGET CW FM RADAR

David B. HOISINGTON

June 1972

Technical Report for Period July 1971 - June 1972

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral Isham Linder
Superintendent

Jack R. Borsting
Provost

The work reported herein was supported by the Naval Postgraduate School.

This report was prepared by:

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS-52Hs72062	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MULTIPLE-TARGET CW FM RADAR		5. TYPE OF REPORT & PERIOD COVERED Technical Report July 1971 - June 1972
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) David B. HOISINGTON		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA Code 52Hs		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, CA Code 52Hs		12. REPORT DATE 15 June 1972
		13. NUMBER OF PAGES 6
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

RADAR
CW radar

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Development of a multiple-target CW FM radar is described. This type of radar has advantages over pulse radars particularly in portable, battery operated applications.

MULTIPLE-TARGET CW FM RADAR

David B. Hoisington
Naval Postgraduate School
Monterey, California

Abstract

Development of a multiple-target CW FM radar is described. This type of radar has advantages over pulse radars particularly in portable, battery operated applications.

INTRODUCTION

Although multiple-target CW FM radars have been suggested [1], little application of FM radar in this mode of operation seems to have been made. Recent advances in solid-state technology have made available devices that would permit the construction of a multiple-target FM radar that would be completely solid state except for the cathode-ray tube indicator, and perhaps even a solid-state replacement for the cathode-ray tube will be available within a few years.

The most obvious application for a radar of this type would be in situations where light weight, low power consumption, and high reliability are of paramount importance. Light weight indicates operation at 9 GHz or higher to obtain narrow antenna beam width with reasonable antenna size. It will be shown that doppler frequency shifts can be of acceptable magnitude at 9 GHz for surface targets. Powers in the order of 1 watt can be obtained at 9 GHz from solid-state devices, and this is adequate for many applications. An experimental program has been initiated to demonstrate the feasibility of such a radar suitable for use on small vessels down to the size of motor whale boats.

THEORY OF OPERATION

If the transmitted frequency of a CW radar is swept linearly with time as shown in Figure 1a, the received echos from fixed targets will have a similar pattern, but will be delayed in time by 2 R/c where R is the target range, and c is the velocity of propagation. If now the echo frequency is heterodyned with the transmitted signal to obtain the beat frequency, f_b, then

$$f_b = \frac{2R}{c}\frac{df}{dt} = \frac{2R\Delta f}{cT} \qquad (1)$$

where Δf is the transmitter frequency excursion and T is the sweep period. Figure 1-b shows that during the initial portion of the transmitter sweep, echos are still being received from the previous sweep, hence the beat frequency is higher than given by (1). After a time ΛT corresponding to targets at maximum range the difference frequencies associated with all targets are as given by (1). The receiver is gated off during the initial interval to prevent the passage of the incorrect frequencies. It is convenient to make the duty cycle, $(1 - \Lambda)$, equal to 1/2 so that the receiver is gated on for a time τ equal to one half of the sweep period, T.

Figure 2 shows the beat frequency spectrum due to a single sweep and a single target. The spectrum is continuous and has a (sin x)/x envelope.

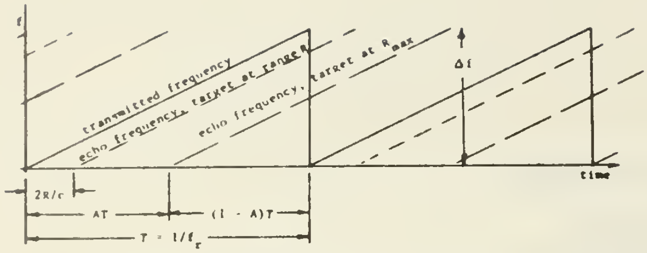

Figure 1-a Radio frequencies vs. time

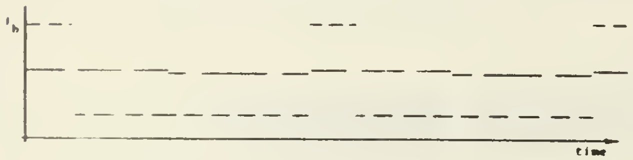

Figure 1-b Beat frequencies vs. time

To separate targets at different ranges one or more filters may be used. The ideal filter for maximum output signal-to-noise ratio would be matched to the spectrum. As a practical matter the filter may be matched as nearly as possible to the central lobe of the spectrum. The filter 6dB (half amplitude) bandwidth is, then, $1.2/\tau$ or $2.4/T$. This filter has rise and decay times approximately equal to τ, hence the signal due to one target decays during the receiver dead time clearing the filter to accept another target during the succeeding on time.

Figure 3 is a simplified block diagram of the complete system. Received echos are converted to an intermediate frequency for good noise performance and convenience in filtering. The carrier oscillator is linearly swept over the frequency band Δf. A portion of this signal is mixed with the output of the IF oscillator at the frequency $(f_i - f_b)$. A bandpass filter passes the sum frequency $(f_t + f_i - f_b)$, to the receiver mixer. The other input to this mixer is from the receiving antenna. The received signal at frequency $(f_t - f_b)$ is mixed to form a signal at the IF frequency, f_i. The IF filter with 6dB bandwidth $f_f = 1.2/\tau$ passes this signal to the gated amplifier, detector and indicator.

By slowly varying the frequency of the IF oscillator from f_i to $(f_i - 2R_{max}\Delta f/cT)$, incoming signals from each range interval from zero to

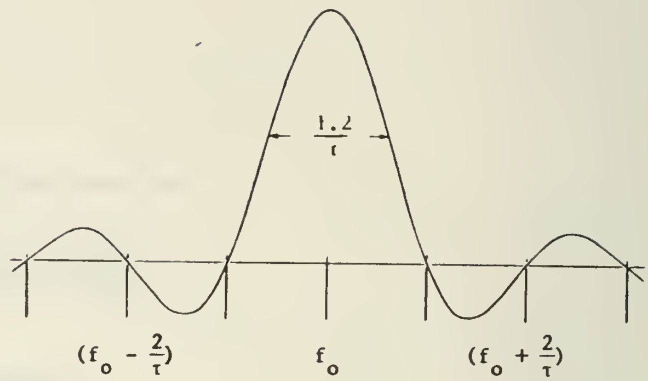

Figure 2. Beat-frequency spectrum due to a single sweep and a single target.

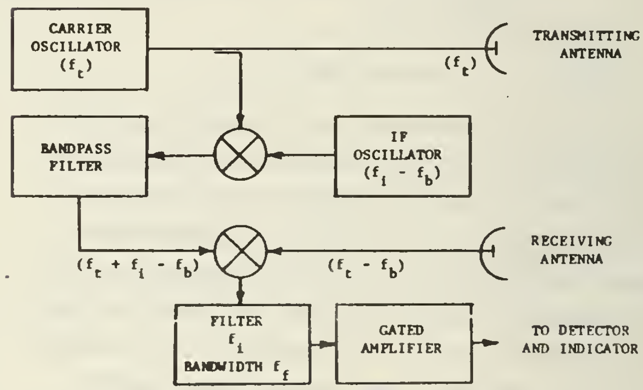

Figure 3. System block diagram

maximum range are successively converted to the frequency f_i and are thus separated to yield target range information. The oscilloscope PPI display is deflected radially in synchronism with the IF oscillator frequency sweep, and deflected in azimuth synchronously with the antenna sweep.

The range discrimination of the systems can be determined from equation (1). Targets of equal strength can be separately detected if their beat frequencies are separated by f_f. It follows then the range discrimination, δR, is given by

$$\delta R = \frac{cTf_f}{2\Delta f} = \frac{1.2c}{\Delta f} \qquad (2)$$

Now for $\tau\Delta f >> 1$ it can be shown that the width of the transmitted spectrum at half amplitude is Δf[2]. It is not surprising that for equal bandwidth, the range discrimination of the CW FM radar is the same as that of the pulse radar.

The radar shown in Figure 3 has the advantage of simplicity, but information rate is limited since only one range interval can be examined at a time. Information rate could be increased by using a multiplicity of filters. It is significant to determine the time required to search all range and azimuth bins. Assume that the maximum range of interest is N times the range discrimination. If successive range intervals examined are separated by δR, and 1/T range are intervals examined per second, then the time required to sweep from 0 to maximum range, t_s, is

$$t_s = NT \tag{3}$$

If the antenna is rotated one beam width, θ_B, in time t_s, then the search time required to rotate the antenna through 360° is

$$t_a = \frac{360NT}{\theta_B} \tag{4}$$

where θ_B is in degrees. For example, if N is 200, T is 400 μsec, and θ_B is 3°, then t_a is 9.6 seconds. This time is increased if N is increased, or if, as is desirable, some overlap is permitted between successive range intervals examined. The search time decreases if a sector less than 360° is scanned.

The doppler shift due to target motion is $2v_r f_o/c$ where v_r is the radial component of velocity. If v_r is 20 yards/sec, representing a very fast surface target, and f_o is 9 GHz, the doppler shift is 1100 hertz. Typically f_f would be in the order of 5000 hertz for a marine navigation radar, so this doppler shift represents a range error less than one fourth of the range discrimination, an entirely acceptable error.

COMPARISON WITH PULSE RADAR

Equation (2) shows for equal transmitted bandwidths, CW FM and pulse radars have virtually the same range discrimination. In the pulse radar the receiver must have a bandwidth comparable to the transmitted bandwidth. The CW FM radar, on the other hand, has an IF bandwidth equal to f_f, a small fraction of the transmitted bandwidth. Required gain can therefore be obtained with a relatively small number of stages. Moreover, the range discrimination may be changed simply by changing Δf, the transmitter frequency deviation. To change range discrimination of a pulse radar, one generally changes pulse width, receiver bandwidth, and the pulse repetition frequency.

It can be shown that for equal useful average powers transmitted, target illumination times, equal receiver noise figures, antenna gains, integration efficiences, integration times, and optimized bandwidths, pulse and CW FM radars have the same maximum range on a given target. Here the CW FM radar has a 3dB disadvantage if the receiver duty cycle is 50 percent. Additional loss of up to 3dB may occur if the echo spectrum is not centered in the IF filter. The pulse radar, on the other hand, has a 7dB loss when in a typical case 25 pulses from a given target are integrated by means of a cathode-ray tube. Typically, then, the range performance of a CW FM radar equals that of a comparable pulse radar when the average transmitted powers are the same.

The pulse radar transmits high peak power in short pulses to obtain a given average power. High voltages are therefore required in the relatively complicated modulator. In the CW FM transmitter the power is constant, and only relatively low voltages are required in the transmitter. Solid state oscillators now available can furnish the power required for a moderate (10 mile) range marine navigational radar while operating from the storage battery voltages available on most small craft. A high degree of modulation linearity is required in the CW FM transmitter, but the required linearity is not necessarily hard to obtain [3].

Pulse radars do not suffer from any range ambiguity provided echos are not received from targets at a time greater than the pulse repetition period. CW FM radars may have a range ambiguity problem when weak target returns are received at ranges somewhat smaller or larger than the return from a very strong target. Figure 2 shows the IF spectrum of a given target. If the IF filter is at a frequency $2/\tau$ higher than the center of this spectrum in an effort to locate a target at a range differing by $2c/\Delta f$, the filter will respond to the side bands of the strong-target spectrum. The filter output in this case will be in the order of 26 dB less than if the strong target return were centered in the filter, but this spurious response could make it difficult to detect the return from a navigational buoy with a relatively large object such as a ship nearby. This range ambiguity can be reduced, for example, by shaping the IF spectrum of targets to reduce the amplitude of the side bands. This could be accomplished by modulating the receiver gain before the IF filter with a smooth weighting function rather than by employing square-wave gating as has been assumed. Further work needs to be done in this area.

EXPERIMENTAL PROGRAM

As the first step in demonstrating the feasibility of a solid-state CW FM radar, a hybrid unit was constructed from laboratory components. The basic system block diagram was as indicated in Figure 3. Operation was at a frequency of about 9 GHz with a power output of 2 watts. The transmitter frequency deviation could be set at any value up to 12 MHz. The receiver intermediate frequency was 30 MHz, and the IF filter was a linear phase (Gaussian) filter with a 6 dB bandwidth of 5.1 kHz. Receiver noise figure was 13.8 dB. Circular parabolic reflectors with a 3 degree beam width were used for both transmitting and receiving antennas. These antennas could not conveniently be scanned, so a type A (amplitude vs range) presentation was used.

Figure 4 shows a typical display obtained with the antenna oriented as shown in Figure 5. Figure 6 shows a high resolution display obtained with the antenna oriented as shown in Figure 7. Note that objects separated by 40 yards are completely resolved. This display was obtained with a Δf of 12 MHz for a theoretical range resolution from equation (2) of 33 yards.

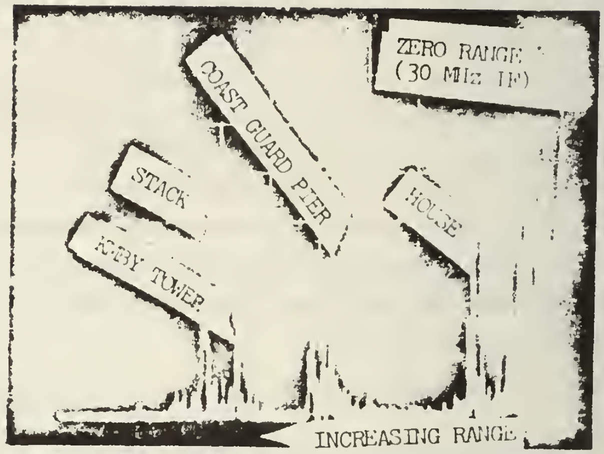

Figure 4. Long-range display

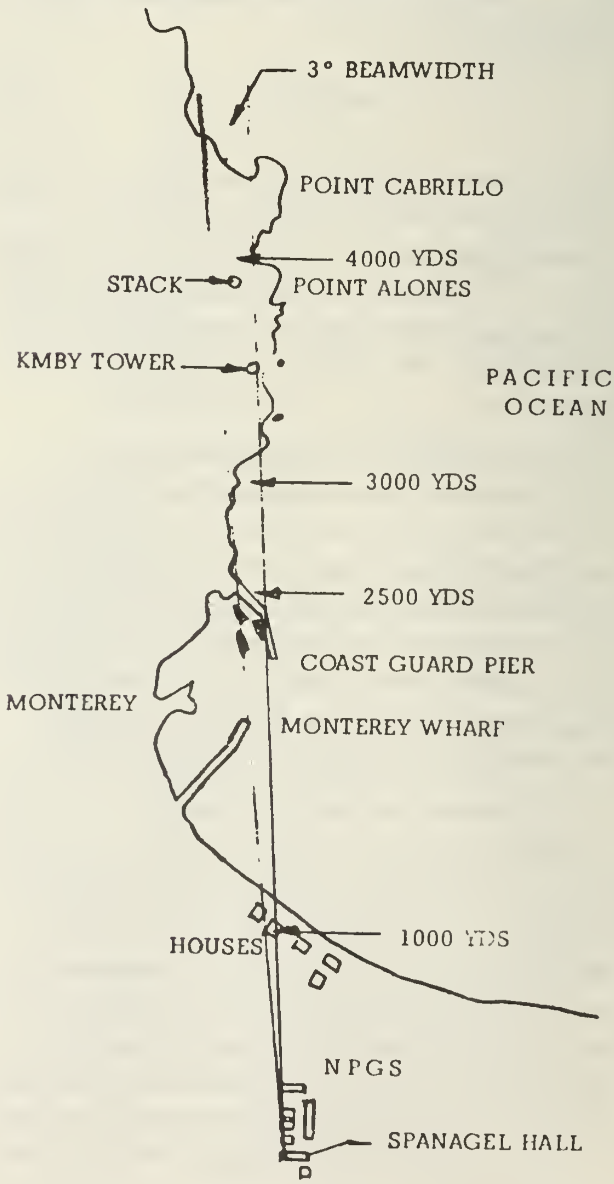

Figure 5. Radar field of view (long-range)

Figure 6. Short-range display of campus

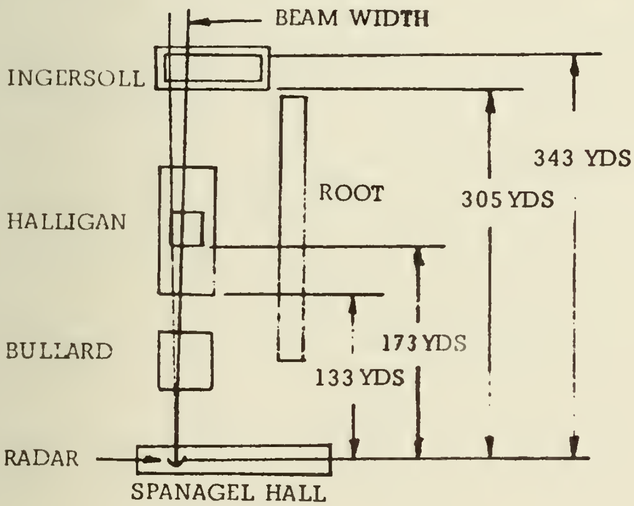

Figure 7. Radar field of view (short-range)

CONCLUSIONS

The feasibility of a CW FM radar with a range resolution of about 30 yards has been demonstrated. It remains to be shown that such a radar can be built with all solid-state components in a small, lightweight package. Development of the necessary solid-state circuitry is proceeding as time and limited funding permit.

ACKNOWLEDGMENT

Appreciation is expressed to Lieutenant Ronald P. Lewis, USN, who performed much of the experimental work reported in this paper as part of the requirements for a Master of Science thesis.

REFERENCES

1. Luck, D. G. C., FM Radar, McGraw-Hill Book Company, Inc., New York, 1949
2. Berkowitz, R. S., Modern Radar, P. 225, John Wiley & Sons, Inc., New York, 1965.
3. Lewis, R. P., A Developmental CW FM Multi-Target Radar, M.S. Thesis, Naval Postgraduate School, Monterey, California, 1971.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, VA 22314	12
2.	Library, Code 0212 Naval Postgraduate School Monterey, CA 93940	2
3.	Dean of Research Code 023 Naval Postgraduate School Monterey, CA 93940	1
4.	Professor David B. Hoisington Electrical Engineering Dept. Code 52 Naval Postgraduate School Monterey, CA 93940	10

The FM-CW radar system uses a differential detection method for removing any signals from background objects and uses a tunable FIR filtering in signal processing for detecting multiple targets. The differential detection method enables the correct detection of both the distance and small displacement at the same timeâ€¦ CONTINUE READING. View PDF. Save to Library. Create Alert. Cite. Monterey, California. Multiple-target CW fm radar â™¦. David B. HOISINGTON. June 1972. Technical Report^ for Period July 1971 - June 1972. Approved for public release; distribution unlimited. FEDDOCS. D 208.1 4/2: NPS-52HS72062.Â Multiple-target CW fm radar. 5. type of report & period covered. Technical Report July 1971 - June 1972. 6. performing org. Report number. 7. AUTHORCs; B. contract or grant numbercs