IMPACT SCORING RADARS

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INTRODUCTION

Training operations which involve live firing of guns or rockets, dropping of bombs or mines, etc., are costly. The trainee will obtain maximum benefit from the exercise if results are available immediately so that he can correct his mistakes while they are fresh in his mind. Special-purpose radars offer the possibility of instrumenting gunnery and bombing ranges so that impact positions are located quickly with reasonable accuracy; the accuracy can be improved later, if desired, by additional data processing. The radar and associated instrumentation could have a large data-handling capability so that range utilization would be high. Another important use of such radars could be in development and testing of ordnance.

Rapid-scan, high-resolution radars offer the opportunity to observe short-lived events at short to intermediate ranges. Accurate location information can be provided through the proper choice of radar parameters. A B-scope or PPI radar display provides scoring capability over an extended area. Scan rates of 1 to 100 scans per second give a data rate high enough that many events spaced closely in time can be separated (and even associated with individual training activities). Accuracies of a few feet to tens of feet are possible over areas which are thousands of feet in dimension and located up to a few miles away.

A radar can locate the surface impact position of a projectile (shell, bullet, bomb, mortar, rocket, mine, etc.) by detecting either: (1) the projectile itself in the air just prior to impact, or (2) the surface effect during or just after impact. Although detection of the projectile is feasible under some circumstances, and may even be preferable for certain applications, the radar cross-section usually is large only for certain aspects and may be very low for others. This paper is concerned primarily with the detection of impact effects such as water splashes which provide a reasonably consistent target of sufficient cross-section and lifetime (up to tens of square meters for one to ten seconds) for reliable detection at useful ranges.

The detection and location of splashes by means of radar were investigated as early as 1943. Both the United States and Great Britain developed X-band (wavelength of about 3.2 cm) splash-spotting radars for use by the Coast Artillery. The U.S. radar was the AN/MPG-1 which scanned a 10° sector 16 times per second, and the British radar was the C.A. No. 1 Mk IV which scanned a 6° sector 4 times per second. Both of these radars had narrow horizontal beamwidths, relatively short pulse lengths, and high PRF's.

These early systems had some desirable characteristics for splash spotting, such as moderately high resolution and rapid scan rates, but they were limited in utility by their narrow scan sectors and low transmitter power.

SPLASH SPOTTING SYSTEMS

The first work at Georgia Tech involving radar splash spotting was initiated in July 1947 for the Bureau of Ordnance; it was a program to develop a radar system capable of rapidly determining the errors in naval gunfire aimed at a towed target. After studies with the AN/TPQ-2 mortar location radar [1], an experimental K-band (1.25 cm) radar called the FEAR (for Firing Error Analysis Radar) was constructed and evaluated [2].

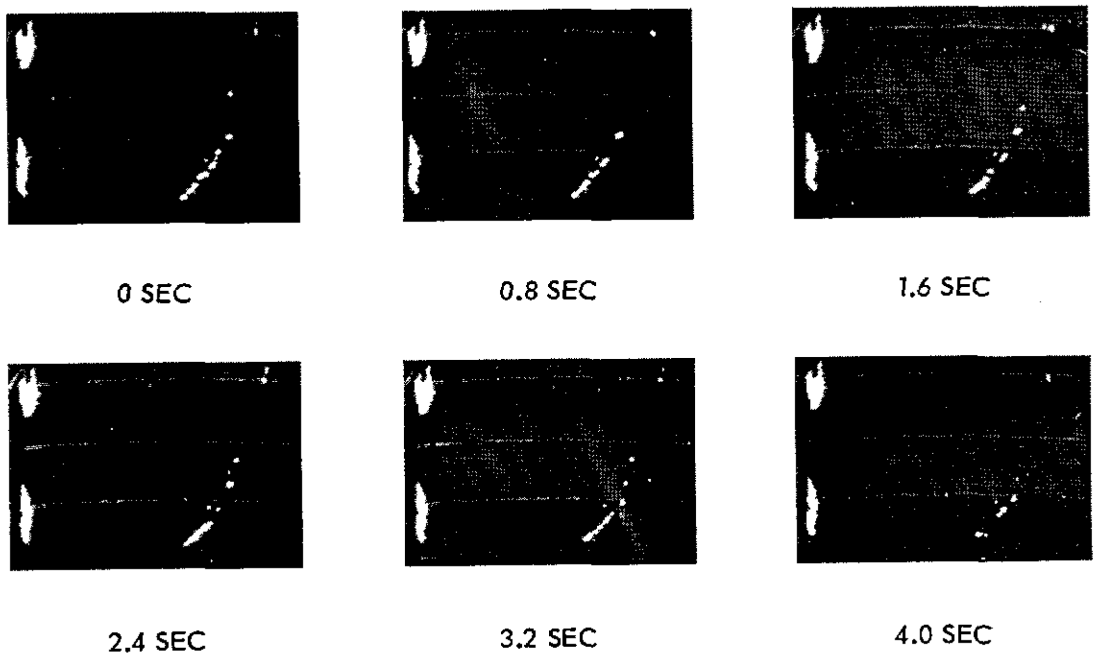
Additional work in splash spotting began in 1951 with a program for the Bureau of Ships to develop a radar capable of rapidly locating splaces produced by air-laid mines in harbor and coastal waters. Several of the illustrations in this paper are the results of studies made with the FEAR [3] during that program.

The FEAR had a fan beam (0.65° azimuth and 3.5° elevation) which scanned a 95° sector 10 times a second. The pulse length was 0.125 micro-second and the peak power was 18 kilowatts.

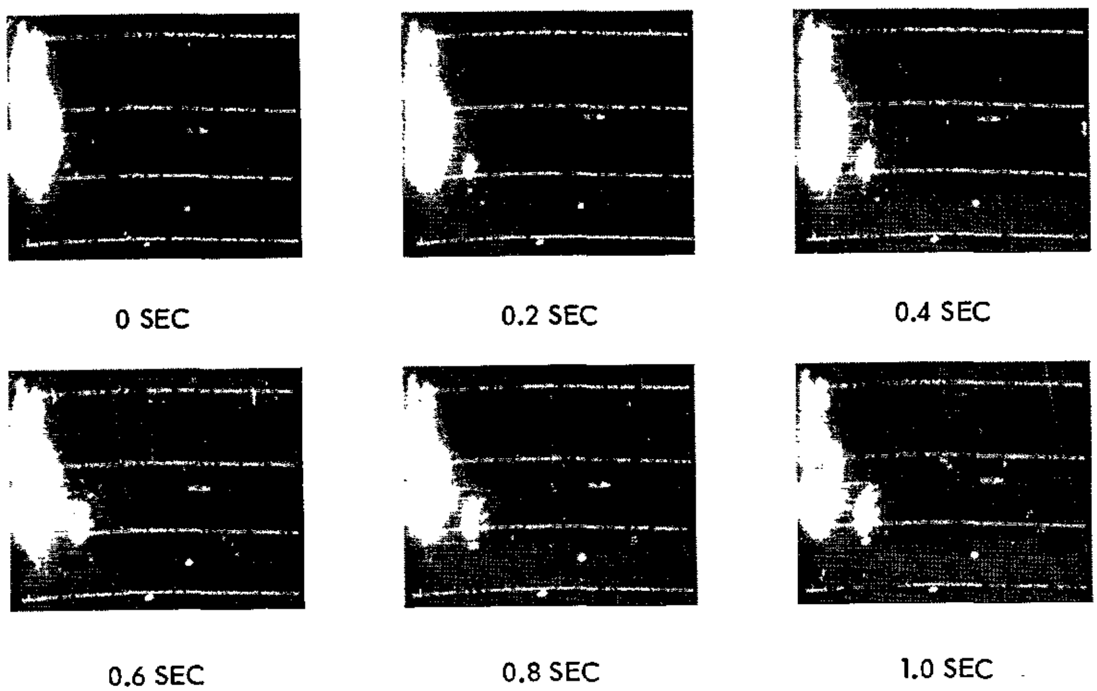
Maximum range capabilities of the above radars were not investigated directly, but numerous observations made on actual splashes of various types indicated good range performance. Generally reliable detections out to ranges of over 10,000 yards were made by the FEAR with antenna heights of 25 and 50 feet.

Figure 1 (a) shows a pattern of splashes from projectiles fired by a 40-mm machine gun with impacts at ranges of 2000 to 2500 yards from the FEAR radar. It is likely that the line of splashes (curved because of the B-scope presentation of the radar) results from ricochets along the water. Note the excellent detection and resolution of these small splashes at the short ranges. Scoring of small-caliber training ammunition, therefore, should be feasible.

Figure 1 (b) shows the beginning of a sequence depicting a time-fuzed 5-inch projectile exploding over water. The air burst occurred about 1600 yards from the radar and 1000 yards from the firing battery at the left in the region of saturated land return. These photographs demonstrate the growth pattern of dispersing fragments in such a burst, the quarter-moon pattern shows the forward asymmetry of the fragment trajectories; individual splashes of large fragments are seen to be resolved around the edges of the main splash area. This and previous examples [2] indicate the possibility of determining two-dimensional fragmentation patterns of projectiles or missiles by observing above-water bursts with a moderate-resolution, rapid-scan radar.



(a) Line of 40-mm Projectiles Ricocheting at 2000 to 2500 Yards.



(b) Beginning of Pattern from Fragments of 5-inch Air Burst.

Figure 1 Splashes from 40-mm Machine Gun and 5-inch Projectile Bursting in Air over Water.

Dispersed impacts from 5-inch area-saturation rockets fired at a rate of 45 rounds per minute have been observed at ranges of 12,000 to 13,000 yards. Almost all of the 150 individual impacts were located with the rapid-scan radar—a feat which would have been very difficult to achieve by other means.

ACCURACY OF SPLASH LOCATION

High accuracy was obtained with the above splash spotting radars by using known reference targets in the displayed field of view and by scaling photographs of the radarscope to determine the difference in range (ΔR) and the difference in azimuth (ΔA) between the reference target and the splash. As would be expected, the size of the region displayed affects the accuracy of the impact locations.

Film measurements were then made with a micrometer slide comparator with a least count of 1 micron. Local scale factor (yards or degrees per micron) was determined from a marker grid of 1000-yard range marks and 10° azimuth marks. The azimuth displayed was 85°, and the range displayed could be selected as 1, 2, or 5 nautical miles. The table below summarizes location results on 283 observations of shell and mine splashes under widely varying conditions of impact angle, radar range, etc. Radar locations were compared with optical triangulation locations determined by phototheodolities or manual theodolities ("rake" instruments); most of the optical triangles had sides shorter than 5 yards.

		Range Error		Azimuth Error	
Sweep Length	Number Splashes	Mean	Standard Deviation	Mean	Standard Deviation
2,000 yds	93	-5.2 yds	4.7 yds	+0.037 deg	0.102 deg
4,000	159	-4.4	7.8	+0.020	0.102
10,000	31	-10.2	13.8	+0.032	0.088

Significant improvements in accuracy over the above results could be obtained by approximately matching the radar cross-section of the reference target (or targets) to that of the splashes. Higher radar resolution could be used to improve accuracy where long-range detection was not a requirement. Also, displays and grid markers could be optimized to any given impact area where high accuracy was required, and effects of most system non-linearities could be removed in data processing. Recording could be done by photography or, if desired, video tape could be used under some circumstances. Accuracies of a few feet to a few tens of feet appear reasonable at ranges up to a few miles.

In addition to the accurate data reduction described above, tests also were made on real-time estimates made from the B-scope by the radar operator, and on quick-look estimates made from the film records without measurement. Using the standard marker grid of 1000 yards by 10°, the radar operator had mean errors of about 30 yards in range and 0.3° in azimuth with standard deviations of about 80 yards and 1°, respectively. Quick-look film locations showed mean errors of about 10 yards in range and 0.06° in azimuth with standard deviations of approximately 35 yards and 0.4°, respectively.

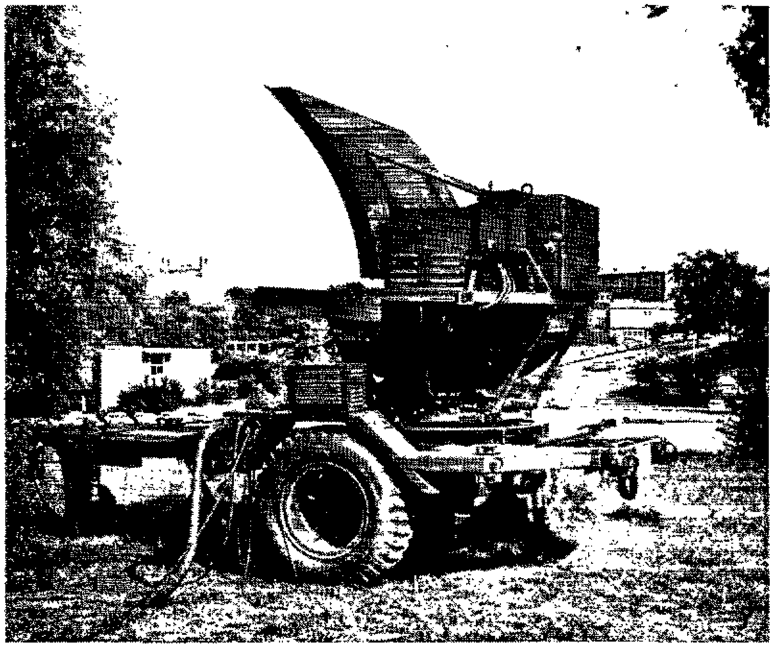
In order to improve the capability for real-time locations, a storage tube could be used to retain the display of a transitory splash target (including any detections of the projectile in the air) so that an operator would have more time to estimate splash location or even use cursors or a light pen for direct readout of coordinates. A marker grid with closer spacings also could be used without confusion if the displayed region was reasonably small and visual interpolation were to be used.

EXPERIMENTAL SURVEILLANCE SYSTEMS

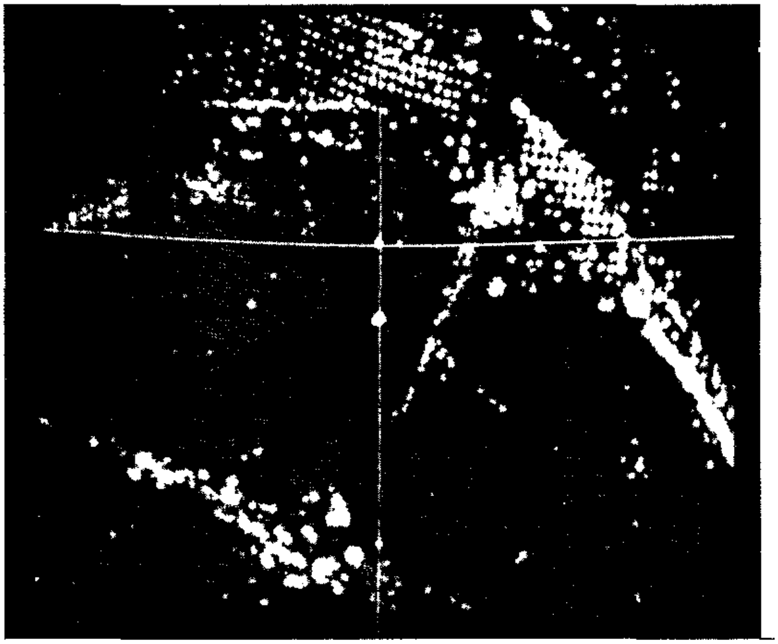
Some of the experimental surveillance systems which have been designed and constructed by Georgia Tech also have capabilities as impact scoring radars. One such system is the AN/MPS-29 ground surveillance radar which was developed for the Army Signal Corps [5]. The antenna is a geodesic Luneberg lens scanner with a parabolic-cylinder reflector as illustrated in figure 2 (a). The AN/MPS-29 operates at a wavelength of 4.3 millimeters; it scans a slightly fanned beam (0.2° azimuth and 0.3° elevation, shaped to -4° elevation) across a 30° sector 20 times a second. The pulse length is 50 nanoseconds, and the peak power is 15 kilowatts.

The rapid-scan, high-resolution features of the AN/MPS-29 are desirable in an impact scoring radar. Figure 2 (b) is a photograph of the B-scope display showing the return from a point-contact mortar burst at the intersection of the azimuth and range cursors; the range to the mortar burst was 2700 meters. Note that the resolution was sufficient to display the returns from individual trees in an orchard beyond the test range. This system has also been used to detect artillery shell bursts [6].

A smaller 4.3-millimeter rapid-scan surveillance system was recently designed, fabricated, and given preliminary testing before delivery to Harry Diamond Laboratories [7]. A photograph of the two-foot geodesic Luneberg lens scanner and reflectors is shown in figure 3. This antenna scans a fan beam (0.5° azimuth and 3° elevation) across a 45° sector at rates up to 70 times a second. Pulse lengths of 15, 30, and 45 nanoseconds are available; the peak power is 500 watts. Although this system was not used to demonstrate impact detection and location, the basic



(a) Antenna Pedestal Showing Geodesic Lens Scanner.



(b) Ground Burst of Mortar at 2700 Meters.

Figure 2. AN/MPS-29 Equipment and Example of Burst Detection.

capabilities—rapid scan and high resolution—for these functions do exist. The small size of the antenna may be noted by comparison with its 35-inch diameter movable mounting ring.

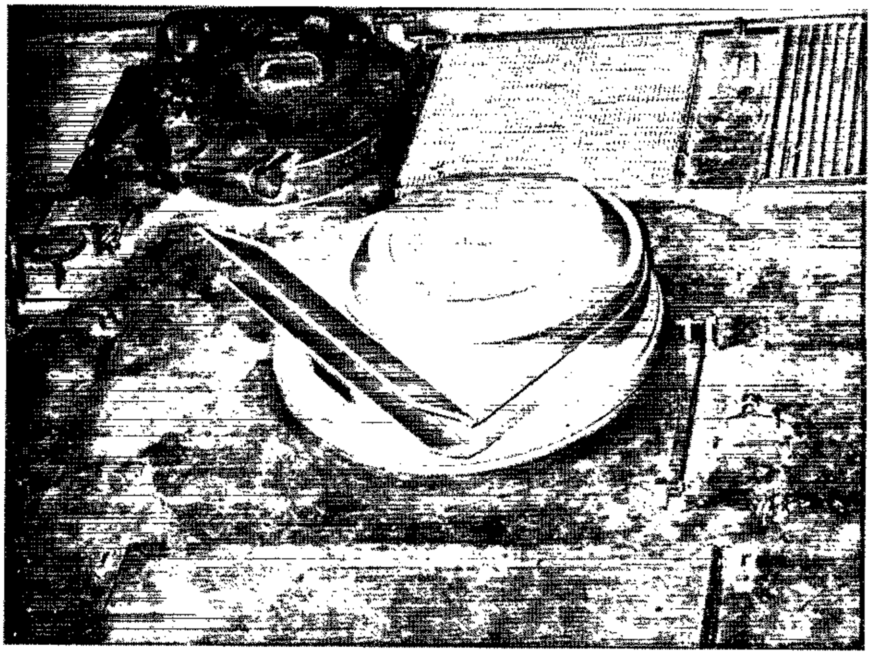


Figure 3. A 4.3-Millimeter Geodesic Lens Scanning Antenna.

CONCLUDING REMARKS

It is important to note that modern techniques in electromechanical scanning antennas offer the promise of relatively simple and reliable radar systems that can provide real-time scoring of the impacts of weapons used for training exercises. The selection of parameters for a particular impact scoring radar depends upon many factors—such as type of projectile, characteristics of impact (water splash, land burst, etc.), and geometrical layout of the impact area as viewed from the radar. Fortunately, however, techniques already exist for solving a wide variety of scoring problems.

Impacts can be located with an accuracy and precision approaching that of optical methods if moderate equipment complexity and analytical data reduction are allowable. Alternatively, special display procedures can result in good approximate location information immediately, and this feature appears attractive for training applications.

Among possible applications of impact scoring radars are the following: location of projectile impacts or explosions, location of nosecone impacts, determination of the general or specific impact positions of multiple projectiles from single-fire and rapid-fire weapons (such as machine guns or area-saturation rockets), and determination of the fragmentation patterns of bursting projectiles. Other potential applications include voice-vectoring small boats or land parties; this feature would be useful for placing targets or underwater objects, or for recovering projectiles for additional post-impact studies during ordnance development or testing.

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