Phys. Rev. **70**, 232 - 233 (1946)
[Issue 3-4 - August 1946]

Properties of Radar Echoes from Shell Splashes

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July 31, 1946

BACK scattering from spray drops has frequently been proposed as the explanation of phenomenon of sea echo on microwave radar. Although many of the characteristics of the echo are in accord with this hypothesis, measurements on the frequency dependence are in violent disagreement with the theoretical prediction.[1] It has been suggested that the study of the echo from a target known to contain spray, such as the splash thrown up by a shell striking water, might provide further information on the matter.

Through the cooperation of the Army authorities at Ft. Wright, Fishers Island, New York, measurements have been made on echoes from splashes, set up by inert 90-mm anti-aircraft shells fired at ranges up to 8000 yd. from the gun, corresponding to distances up to 6800 yd. from the radars. Accurate measurements of the location, dimensions, and duration of each splash were obtained from motion pictures taken with a cine-theodolite. The radar systems used were three experimental truckborne sets developed by the Propagation Group, Radiation Laboratory, Massachusetts Institute of Technology, operating on wave-lengths of 9.2, 3.2, and 1.25 cm, respectively. The outputs from any two of the systems could be presented on two special high intensity A-scopes which were simultaneously photographed by a high speed camera,[2] providing a record of each successive sweep. The pulse recurrence frequency, about 200 c.p.s., was crystal controlled and furnished an accurate time scale. The absolute power of the received echo on each sweep could be determined by reference to a pulse from a signal generator injected into the system at a known r-f level and displayed on the scopes. (The dynamic characteristics of the receiver were determined by separate calibration with a signal generator.)

The outstanding features common to all the echoes measured are most strikingly shown in the comparison between the 9.2 and 1.25-cm records with horizontal polarization. On both wave-lengths the echo fluctuated violently because of interference effects, there being little correlation between successive pulses. In order to exhibit the general rise and decay of the echo, the fluctuations were smoothed somewhat by averaging over successive intervals of 0.12 sec. From the constants of the system, and assuming perfect reflection from a flat sea, the apparent radar cross section of the splash was then calculated for each time interval and for both wave-lengths. (The error of the absolute calibration is estimated at not more than 2 db on 9.2 cm or 4 db on 1.25 cm.) The two lower curves of Fig. 1 are plots of the cross sections so calculated as time from the start of the splash. A similar plot of the ratio of the two cross sections, in db, is shown by the top curve. The proper interpretation of these curves depends on some of the characteristics of the splash. Despite the flat trajectory (all the shells ricocheted) the splash was almost entirely vertical. Initially the splash rose rapidly in height, attaining 80 percent of its 50 ft. maximum by the end of 0.5 sec. Thereafter its dimensions changed only slowly, but the original column of water rapidly disintegrated into spray. The motion pictures clearly show that this pillar of spray, though progressively thinning in density, retained almost its maximum height up to the very end. Most of the time, therefore, the splash covered many of the interference lobes, even at the longer wave-length. The separate parts of the initial column of water should scatter coherently. From the magnitude of the cross sections and the

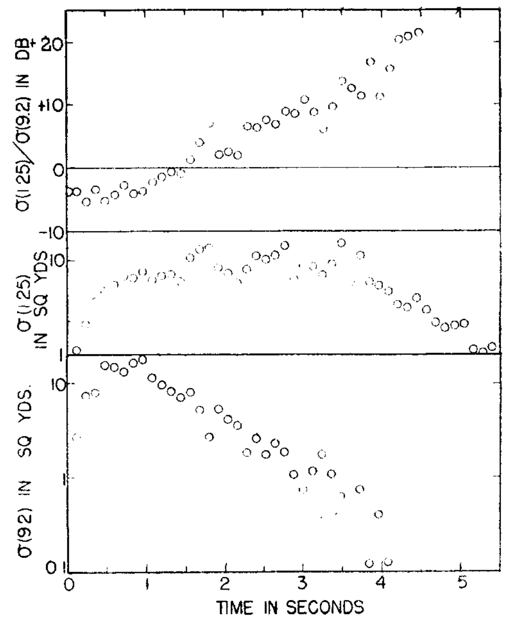

FIG. 1. The lowest curve is a plot of the radar cross section of a typical shell splash on **9.2** cm as a function of time. The corresponding plot at a wave-length of 1.**25** cm is shown in the middle curve, while the ratio of the two cross sections is plotted in the top curve.

geometry it is clear that the main back-scattered beam misses the radar which receives only the side lobes, which at constant angle increase in intensity with increasing wave-lengths. The echo is therefore stronger on 9.2 cm at the start, but as the splash changes into spray and the scattering becomes incoherent, the balance swings to the shorter wave-length. Even after the splash has reached its maximum height, the echo on 1.25 cm is still increasing and attains its peak long after the 9.2-cm echo has started to decay. Toward the end, when the spray has become finely divided, the 1.25-cm echo is still appreciable when the echo on 9.2 cm has completely disappeared. The ratio of the cross sections ideally should approach the +35 db figure predicted for very small drops by the Rayleigh λ^{-4} law. The maximum value measured is much lower (about +20 db) probably because of the drops not being sufficiently small. It is still much greater than the ratio observed for sea echo, +8 db, confirming the conclusion that sea echo cannot arise from the small drops of spray.

It is a pleasure to acknowledge the aid and cooperation of the personnel of the Mt. Prospect Field Station, Radiation Laboratory, M.I.T., and of the members of the Propagation Group, especially Miss Margaret Harwood who performed most of the tedious film analysis.

* The work reported on was performed while at the Radiation Laboratory, M. I. T.

[1] Herbert Goldstein, Phys. Rev. **69**, 695A (1946), and paper in preparation.

[2] The photographic techniques have been described by H. Goldstein and P. D. Bales, Rev. Sci. Inst. **17**, 89 (1946).