A SYSTEM FOR PERFORMING ULTRA HIGH RESOLUTION BACKSCATTER MEASUREMENTS OF SPLASHES

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ABSTRACT

A novel laboratory measurement system is described. The apparatus combines ultra high resolution radar techniques and split screen video photography in order to capture the microwave scattering effects of small scale transient features. One example presented is a time history of the backscatter at 9.0 GHz caused by the splash of a water drop on a water surface.

INTRODUCTION

An understanding of the basic radar scattering mechanisms at the sea surface is useful for both remote sensing and target detection applications. Unfortunately, deterministic laboratory measurements of microwave backscatter from transient features such as ripples or splashes are hampered by experimental difficulties. Problems are generally encountered in containment of the illuminating microwave source, measurement response time and isolation and calibration of the test region. Typical c.w. systems must guard against multiple reflections (1) while high resolution f.m. systems experience difficulty in achieving close range, fast response operation due to bandwidth limitations on transmit modulation and receiver filtering (2).

This paper describes a laboratory measurement system which utilizes off-the-shelf hardware and which combines time domain techniques and video photography in order to gauge the microwave backscatter caused by the physical formation of individual surface features. The system presents experimental advantages in general ease of use and the identification of causative events.

EXPERIMENTAL SYSTEM

The initial experimental requirement was for a scatterometer, operating at a nominal center frequency of 9.0 GHz, which could perform backscatter measurements of laboratory produced raindrop splashes in a small (91 x 61 x 20 cm) water filled basin. The dimensions of the experiment dictated an effective range resolution of less than 15 cm with the capability to gate out reflections from external equipment. High speed photographic studies (3) have shown that a splash can evolve through many different physical stages whose lifetimes are of the order of 20 ms; even though the overall splash may exist for a period in excess of 0.4 seconds. Measurements of such transient features therefore required a system with a fast response time and the means to record the complete backscatter time history of the evolving splash formation. The system configured to solve these requirements utilizes both ultra short pulses and split screen video photography. The primary equipments are a standard time domain reflectometer (TDR) set up with a sampling oscilloscope mainframe, pulse generator and sampling head (TEK models 7904-7512, S-52, and S-6), several wideband (8 to 12 GHz) microwave amplifiers, separate transmit and receive horns, a diode detector, a storage oscilloscope, and two TV video cameras with a split screen combiner and recorder.

As outlined in the diagram of the experimental setup shown in Fig. 1, the 45 ps. rise time voltage pulses (see Fig. 2) of the TDR pulse generator are used to directly drive a wideband microwave transmit amplifier. The amplifier selectively filters and amplifies frequency components of the input voltage step thus producing the 0.5 ns duration voltage waveform shown in Fig. 3. This short burst of microwave signal is then fed to a pyramidal transmit horn which illuminates the surface of a salt water filled test basin at a nominal range of 1.5 meters. Reflections from the test basin are received by a separate horn, amplified by another wideband microwave amplifier and then fed either directly or via a diode detector to the sampling head of the TDR unit. (The sampling head accommodates signals from DC to 12 GHz which can then be displayed via equivalent time sampling on the oscilloscope.) The effective bandwidth and resolution achieved by the complete transmit/receive system are illustrated by the time sampled return signals from several string suspended test targets shown in Fig. 4. Note that the envelope of the transmit pulse of Fig. 3 is slightly broadened by the transmit/receive horns and receive amplifier. The cleanly displayed r.f. voltage waveforms of Figs. 3 and 4 show that the transmit frequency components are locked in phase synchronization with the initial TDR voltage step and the timing of the sampling head. The sampled and held voltage output of the TDR sampling head is also displayed on an external storage oscilloscope. In this manner, reflections from any range resolved surface segment

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(corresponding to the 0.5 ns transmit pulse duration and the 14.3 degree cross range beamwidths of the collimated horns) can be sampled by adjusting the external range delay of the TDR unit. At a range of 1.5 m the resolved surface segment is approximately 7.5 x 38 cm. A time history of the microwave backscatter from a stationary transient feature at a given range is formed by time sweeping the storage oscilloscope while sampling the detected power. Finally, the formations of both the storage oscilloscope trace and the physical surface features in the test basin are simultaneously recorded with two T.V. cameras and combined in a split frame format for time synchronization. The nominal transmit/sampling period of the system is 16 μs, thus allowing unambiguous modulation response approaching 30 kHz. The accompanying T.V. video system produces integrated images over each 17 ms frame interval.

In addition to backscatter amplitude, the system can also be used to measure the velocity of small features by simply observing the backscatter time history of the r.f. voltage rather than the detected power. For a fixed range sample point, the return from a moving target will show multiple cycles of the r.f. voltage. Target velocity may be gauged by measuring the amount of time, T_S, recorded in the stored time history between consecutive voltage peaks. Since the 9.0 GHz r.f. voltage exhibits a nominal peak-to-peak spacing T = 111 ps, the velocity may be calculated via the relation: $v = cT/2Ts$, where c is the speed of light in m/s. Figure 5 shows several return voltage histories for a string suspended test target which was swung as a pendulum through the fixed range sample point. This example illustrates target velocities of 2.8 and 0.32 m/s.

EXPERIMENTAL MEASUREMENTS

An example of the type of data taken with this measurement system is illustrated in the series of split screen video frames shown in Fig. 6. This series shows the development of the backscatter from a single water drop splashing on the salt water surface. System polarization for this sequence was vertical transmit and receive as controlled by the horn orientations. The top portion of each successive frame contains an updated time history from the storage oscilloscope of the backscatter power which was received in the time up to and including the physical stage of the splash shown in the bottom portion of each frame. Other measurements were taken with horizontal polarization on a similar splash and time histories comparing the responses for both polarizations are shown in Fig. 7. The time of occurrence of the "crown" and "stalk" phases of the splash process are indicated by the arrows. Note the differences in the responses and the relatively short lifetimes of these stages of the evolving splash formation.

As with any surface reflection process, the effects of classical interference (4) must be considered when evaluating the splash measurements. Figure 8 compares theoretical field strengths patterns at 8, 9, and 10 GHz for a grazing angle of 15° and assumed vertical and horizontal salt water reflection parameters of 0.35 magnitude, 40° phase and 0.93 magnitude, 182° phase (5). Even though a wide instantaneous bandwidth tends to fill in the nulls and reduce the peaks, this type of lobing pattern provides a partial explanation for the differing polarization responses to the splash formations.

Vertical polarization was also used to measure the velocity of the outwardly spreading circular waves moving from the splash center. Figure 9 shows examples of r.f. voltage time histories of the backscatter from the waves as they moved through a range sample point which was offset from the center of the splash. The velocity calculated from the single wave time history of Fig. 9 was 0.21 m/s. (This value was corroborated by a series of high speed photos of the splash.) The nonsinousoidal time history of Fig. 9 illustrates the waveform obtained when the sampled r.f. voltage consists of the returns from two separate waves in the same range resolved surface segment.

CONCLUSION

The deterministic measurements performed by this system have provided some interesting insights into the effects of rain splash on backscatter from the sea surface. The experimental setup has proven to be very "user friendly" in the sense that stray reflections occurring outside the test basin can be gated out. A combination of stable transmit signals, ultra high resolution and split screen video photography has also facilitated the measurement of very short lived transient features.

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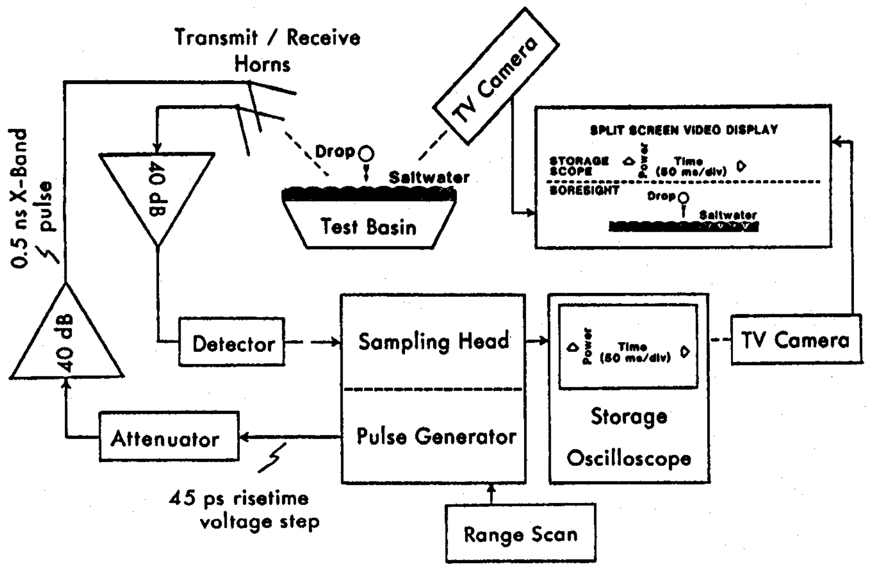

Fig. 1 - Diagram of experimental system

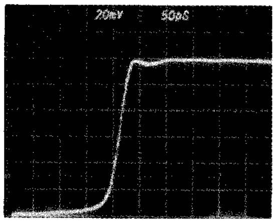

Fig. 2 - Voltage input to transmit amplifier
(hor. scale 50 ps/div)

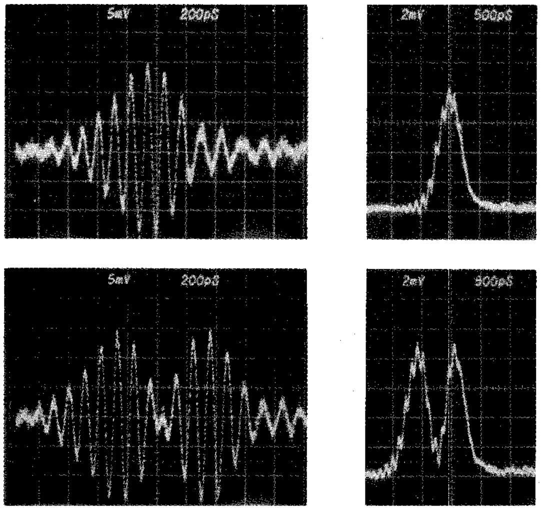

Fig. 4 - Return signals from 6 mm dia. spheres
Top: single Bottom: two spaced 9 cm
Lft: r.f., .2 ns/div Rt: power .5 ns/div

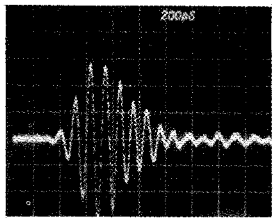

Fig. 3 - Voltage output from transmit amplifier
(hor. scale 200 ps/div)

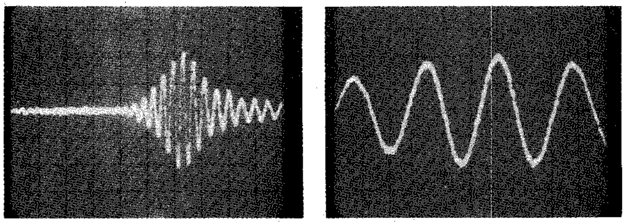

Fig. 5 - Velocity measurement of moving sphere
(hor. scale 20 ms/div)
Left: 2.8 m/s Right: 0.32 m/s

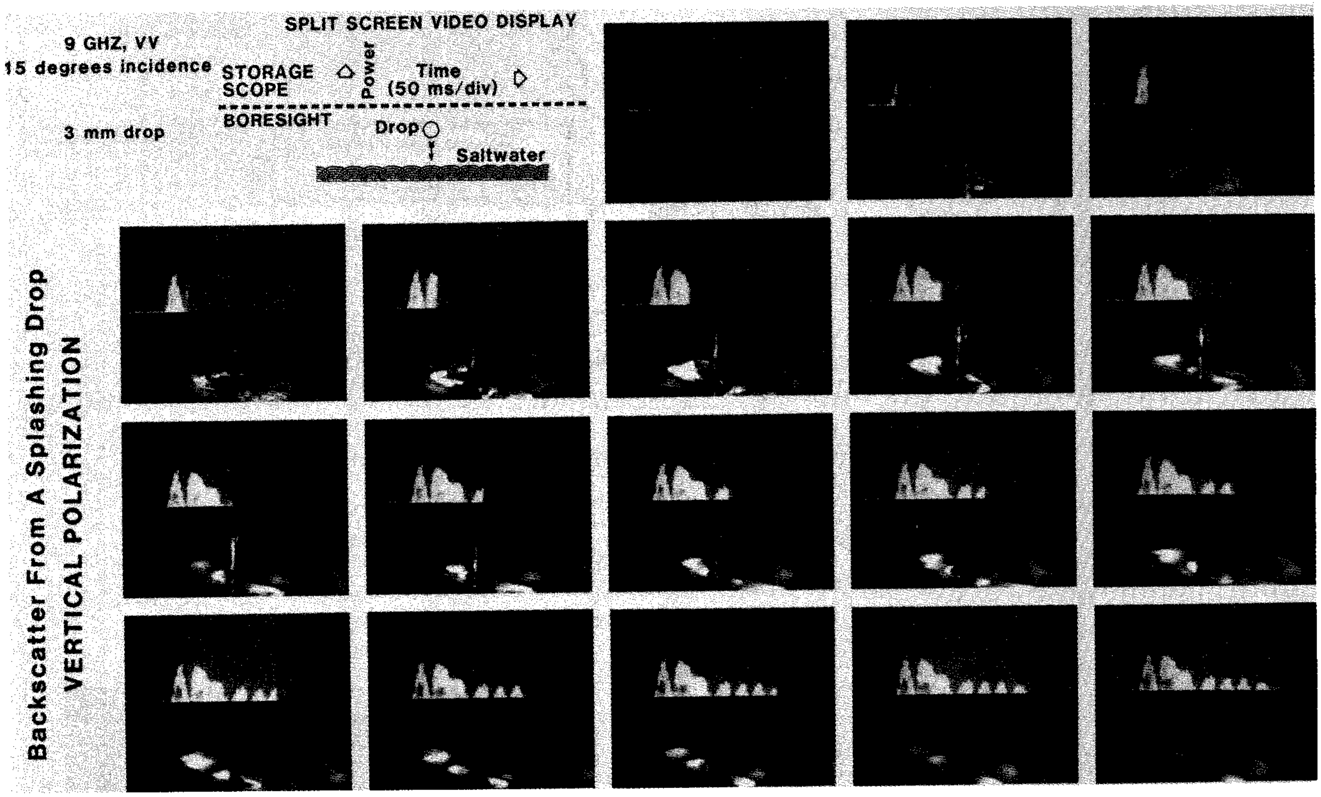

Fig. 6 - Consecutive split screen video frames showing backscatter from a splashing drop. Time interval per video frame is 17 ms.

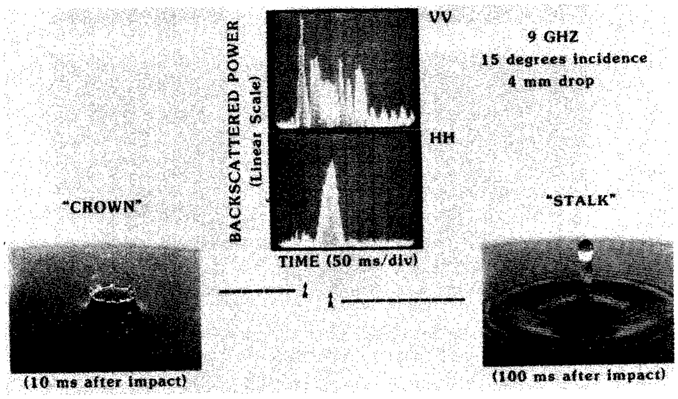

Fig. 7 - Backscatter history of a splashing drop for vertical & horizontal polarizations

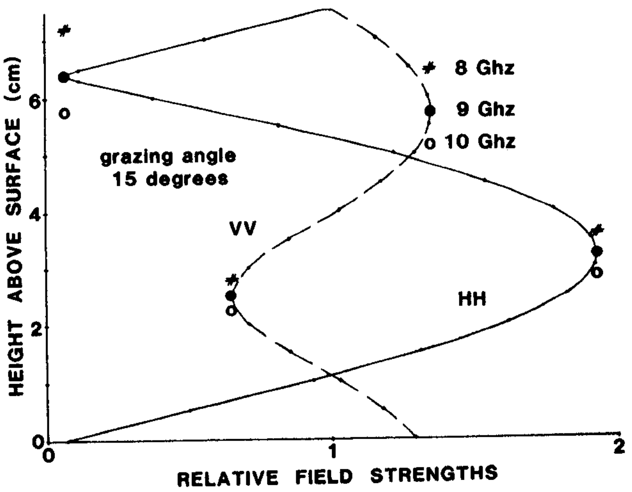

Fig. 8 - Calculated interference patterns above a smooth salt water surface (field amplitude relative to free space)

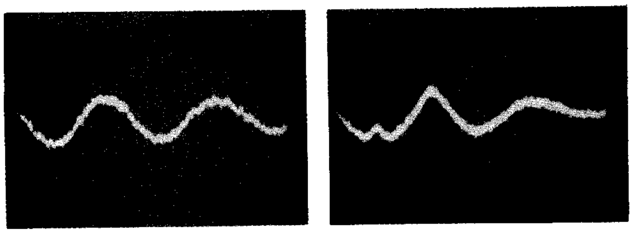

Fig. 9 - Velocity measurement of circular waves (hor. scale 20 ms/div)
Lft: 1 wave, 0.21 m/s Right: 2 waves