G. Stamm 7310

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NRL Memorandum Report 1170

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PROPAGATION OF LIGHT PULSES THROUGH WATER

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G. L. Stamm, R. A. Langel, and C. M. Whitfield, Jr.

OPTICS DIVISION

[redacted]

29 March 1961

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U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
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From: Commanding Officer, Naval Research Laboratory
To: U. S. Department of Justice, Assistant Attorney General
Civil Division, Commercial Litigation Branch

Subj: CHARLES E. PFUND V. UNITED STATES, COURT OF FEDERAL CLAIMS NOS. 276-87C AND 592-88C

Ref: (a) DOJ ltr 154-276-87/154-592-88 of 5 Jun 95

Encl: (1) NRL Memorandum Reports cover pages

1. Per reference (a), we have reviewed all the reports in the 5 June 1995 letter from Mr. Hunger and Mr. DiPietro.

2. The material contained in enclosure (1) describes measurements made relating to optical communication with submarines. The instruments and hardware used in the measurements is quite out of date and not in use currently. For example, the electronic circuits described employ vacuum tubes rather than solid state devices.

3. The measurements results do not reveal any operational details, but rather are descriptive of the instrument capabilities, the optical properties of water, and some atmospheric phenomenology.

4. None of the information contained in these reports requires any further protection.

5. In our opinion, every report itemized in reference (a) can be downgraded to UNCLASSIFIED and assigned a distribution statement A: Approved for public release; distribution unlimited.

CHARLES ROGERS
By direction

[redacted]

NRL Memorandum Report 1170

PROPAGATION OF LIGHT PULSES THROUGH WATER

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G. L. Stamm, R. A. Langel, and C. M. Whitfield, Jr.

29 March 1961

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ABSTRACT

Measurements have been made of the slant ranges over which light pulses were transmitted from a submerged submarine to an aircraft off the coast of Key West Florida. These experiments were performed as part of an investigation of the use of light for identification and communication between submerged submarines and aircraft.

At night during a full moon, slant ranges of 15 and 14 miles were measured when the receiver was at altitudes of 5000 and 2500 feet, respectively, and when the light source was 50 feet below the sea surface. Even with the light at a depth of 100 feet, light pulses could be detected at a slant distance of about 11 miles from an altitude of 2500 feet. These data were gathered using a submergible transmitter which emits high-intensity one-microsecond flashes of light in an 11-degree beam. A very sensitive photoelectric receiver detected the light pulses during ambient illumination from a full moon when the pulses could not be seen by eye.

PROBLEM STATUS

This is an interim report on results from recent field work. Work on this problem is continuing.

AUTHORIZATION

NRL Problem 73N03-02
RN No. RF-006-05-41-4401

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PROPAGATION OF LIGHT PULSES THROUGH WATER
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INTRODUCTION

Since water is relatively transparent to visible light it is possible to transmit light signals from a submerged submarine to an aircraft. Experiments performed as part of Project STARFISH (1, 2) have been in progress at the Naval Research Laboratory to show the feasibility and limitations of pulsed light for such purposes as submarine identification and communication. During recent experiments in the Key West area (28 Feb. and 2 Mar. 1961), submarine-to-aircraft signaling ranges were measured for various submarine depths and aircraft altitudes. Typical slant ranges on a clear night with a full moon were 15 miles with the light source 50 feet beneath the sea surface and the receiver at 5000 feet altitude and 4 miles for a light source depth of 150 feet. At most depths the best ranges were obtained with the light beam inclined 60 degrees from the vertical and pointed toward the aircraft. At the greatest depth of 150 feet, ranges were almost independent of beam angle. Once submerged, the light was seldom visible to the eye. During daylight, light pulse detection was impossible both electronically and visually.

EQUIPMENT

Light Pulse Transmitter

The light pulse transmitter is described in detail in another report (1); its submarine-mounted housing was a modification of a previous model (3). Light pulses are emitted by discharging two 0.05-μf capacitors through a straight-gap flashtube mounted in a reflector 9 inches in diameter. Control of the flashing rate is effected by electronically triggering a thyratron in the discharge circuit. The flashtube, reflector, high-voltage charging and discharge circuits, trigger circuit, and high-voltage power supply are all mounted in a 200-pound steel cylinder which can be submerged to a maximum depth of 150 feet. In one end of the cylinder is a 9-3/4-inch window through which the light beam is emitted. The axis of the beam is continuously adjustable in elevation from vertical to an angle of 60 degrees. The beam width is 11 degrees.

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Upon discharge of 4 watt-seconds of energy through the flashtube, a pulsed light beam is emitted with the following characteristics:

Maximum peak radiant intensity (330 to 680 mμ) - 1.1×10^5 watts/ster
Maximum peak luminous intensity - 1.0×10^7 candelas
Flash duration - 1 μsec
Maximum flashing rate - 5 flashes/sec
Wavelength of maximum intensity - 435 mμ
Beam width - 11 degrees
Power requirement for pulsed light beam - 300 watts at 115 volts, 60 cps

Light Pulse Receiver

Weak light pulses are converted into electronic pulses which subsequently undergo amplification, detection, and display. Electronic bandwidth is optimized for the detection of the one-microsecond light pulses emitted by the transmitter. Both visual and aural displays of the received light pulses are possible.

Radiation falls on four phototubes having a total sensitive flat area of 8.8 sq. in. No optical collecting system is used; therefore light pulses can be detected from any direction in a hemisphere. To correspond with the maximum spectral intensity of the transmitter, the maximum spectral response of the receiver is at 440 mμ, where ocean water has high transmittance. Table 1 shows the minimum peak luminous flux at the receiver of a light pulse which can be detected at various ambient light levels. The ambient illuminances are typical of those found at night.

TABLE 1

Minimum Detectable Signal in Typical Night Backgrounds

Ambient Illuminance (μlumen/cm^2)	Night time Condition	Minimum Detectable Peak Flux (μlumen)
21.5	Full moon	29
2.15	Quarter moon	9
0.086	Starlight, no moon	2

[redacted]

The lowest peak flux from a light pulse which can be detected in complete darkness is 0.65 microlumen.

The receiver (4) was designed to be operated at low levels of illumination such as prevail at sea at night. It operates from a 60-cps 115-volt source and consumes 250 watts.

SIGNALING RANGES

To conduct signaling experiments, the transmitter was mounted on the forward deck of the submarine USS BLENNY(SS324) so that it could be pointed out over the bow of the ship. In this position the transmitter was 28 feet above the keel of the submarine. With the receiver mounted under a Naval Research Laboratory R5D aircraft, straight-line runs were made from a point over the submarine out to the limit of light pulse detection. Data were gathered during a 12-hour flight starting on the night of 28 February 1961 and a 6-hour flight on the night of 2 March 1961 at latitude 24° N, longitude 82° W, approximately 30 miles southwest of Key West, Florida.

On both nights the conditions were good for carrying out the experiments. Lights in Key West were visible at a distance of approximately 15 miles. Scattered clouds were encountered at an altitude of 2500 feet on the night of 28 February and at 7000 feet on the night of 2 March. During the entire period a full moon illuminated the sea surface, which was in a state 2. In this area of the Gulf Stream the water is 1800 to 2400 feet deep.

Slant ranges during the first night were measured with the aircraft at an altitude of 1000 feet and the transmitter tilted at angles of 0, 20, 40, and 60 degrees from the vertical. Figure 1 shows the measured slant ranges for various transmitter depths and transmitter angles. Ranges for zero transmitter depth were measured with the submarine surfaced. The greatest ranges when the light source was submerged were achieved when the transmitter was tilted at 60 degrees; at this angle the ranges varied from 10.3 miles at a depth of 25 feet to 4.2 miles at a depth of 150 feet. At the greatest depth, 150 feet, the ranges were 3 to 4 miles at all transmitter angles.

During the second night the transmitter was kept fixed at 60 degrees, and the transmitter depth and aircraft altitude were varied. Data for aircraft altitudes of 2500 feet and 5000 feet are shown in Fig. 2. The curve for 1000 feet was repeated from Fig. 1. Increased detection ranges were achieved at the higher altitudes. At a transmitter depth of 50 feet the range was 15 miles with the aircraft at 5000 feet and 14 miles with the aircraft at 2500 feet. Even at a depth of 100 feet the range was almost 11 miles at the 2500-foot altitude.

The ranges presented in Figs. 1 and 2 are probably not the maximum possible under the stated conditions because of the difficulty encountered by the aircraft pilots in locating the submarine and properly executing a run to measure the range. This is especially true of the greater depths and explains to a large extent irregularities in the curves.

Once submerged, the light was difficult to see. At the greater depths it was seldom visible except for the situation when the light was beamed straight up and the aircraft was directly over the beam. At most times when the light was visible, it was so weak that an observer had to know where to look in order to see it. The ranges over which the light could be seen are much shorter than those measured electronically. This is a result of the extremely short duration and high peak intensity of the light pulse, the eye being sensitive to the integral of the product of the duration and intensity and the electronic receiver responding to peak intensity only.

Attempts were made to detect the light pulse electronically and visually in daylight on the afternoon of 2 March, but without success. The sunlit sea was too bright for satisfactory operation of the receiver, even when a narrow-band optical interference filter was placed over it.

During the morning twilight of 1 March an effort was made to measure ranges as the ambient illumination increased. However, the light level changed so rapidly in relation to the time of a range measurement that no accurate data could be gathered. As daylight approached, it was not long before the unfiltered daylight radiation saturated the receiver.

CONCLUSIONS

Optical slant signaling ranges from a submerged submarine to an aircraft may be affected by a number of factors such as water clarity, light source depth, angle at which light is emitted, atmosphere clarity, ambient sunlight, and altitude of the receiver. The results from experiments reported herein provide a basis on which to determine how some of these factors affect signaling ranges.

Increased[redacted]ing ranges have been realized by operating the light source close to the surface, by tilting the light bea[redacted] the vertical, and by locating the receiver at high altitudes. For light emitted at large angles (40 to 60 degrees) from the vertical a large initial decrease in signaling range occurs as the light source is submerged below the surface. Once below[redacted]urface[redacted]e decrease is more gradual as depth is increased. For light emitted upward at small angles (0 to 20 degrees), no drastic reduction is noticeable upon submergence of the light source; in fact, ranges were reduced only slightly from approximately 5 miles to 3 miles as the[redacted]t source[redacted]ken from the surface down to 150 feet. Regardless of the angle at which light is emitted, range curves (Fig. 1) converge to about 4 miles at depths of 125 and 150 feet.

All results reported herein w[redacted]ights[redacted] was illuminated by a full moon. On a moonless night the receiver sensitivity could be increased by a factor of 15, thereby making it possible to detect weaker light pulses at longer ranges. Also, longer ranges can be attained by increasing the light intensity in a properly designed transmitter.

FUTURE WORK

The present transmitter can be submerged to only 150 feet and can be tilted to a maximum angle of 60 degrees. In view of these limitations, further investigations of submarine-to-aircraft signaling would require the construction of a new transmitter. Furthermore, an optical IFF system would require signaling from an aircraft to a submarine, and no such experiments have been initiated. A watertight optically transparent housing for the receiver would be required if aircraft-to-submarine experiments are to be performed. The desirability of taking these steps depends strongly on operational need and will be the subject of discussion with naval offices concerned.

[redacted]

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[redacted]

FIGURE CAPTIONS

Fig. 1 - Variation of maximum signaling slant range with transmitter depth and angle.

Fig. 2 - Variation of maximum signaling slant range with transmitter depth and aircraft altitude.

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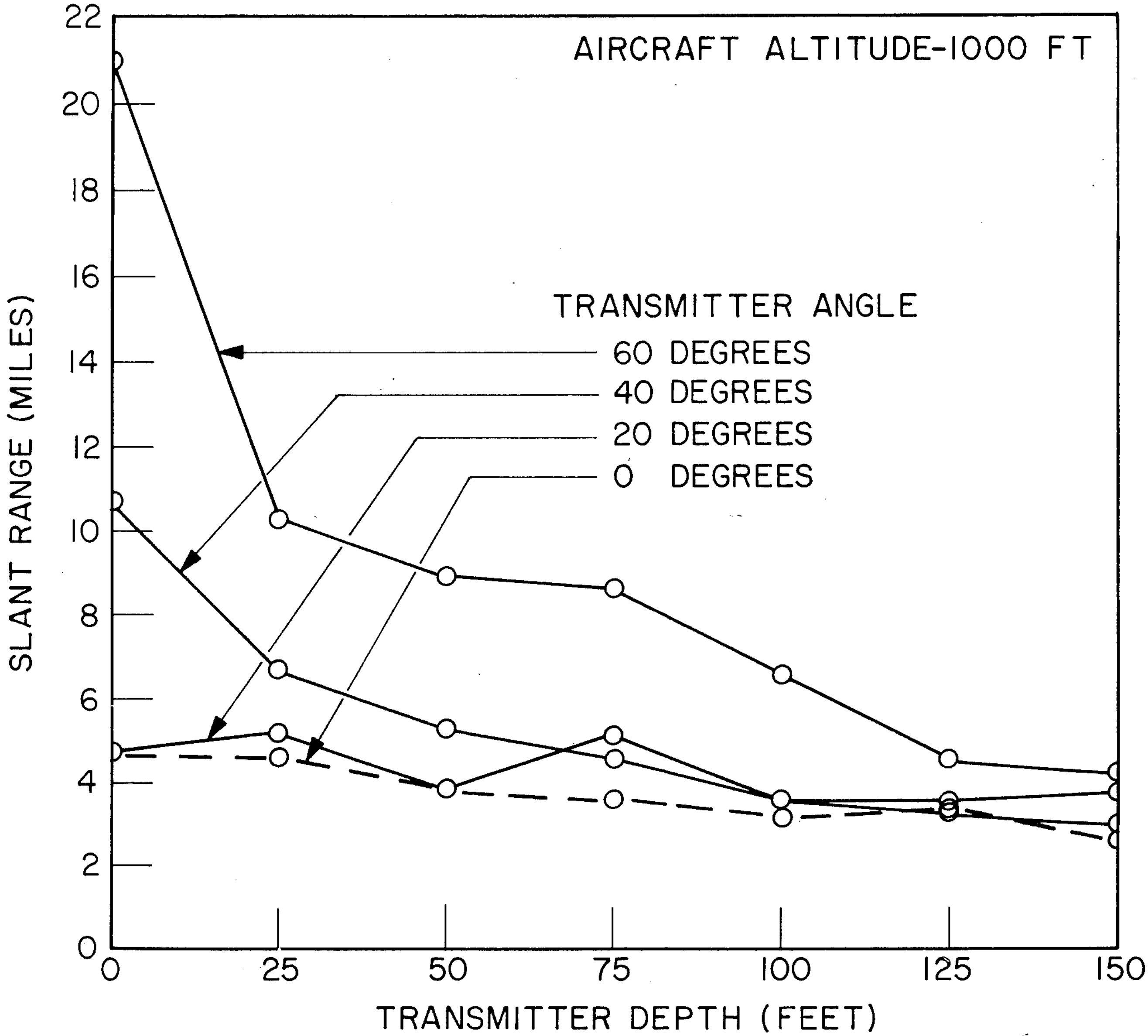

Figure 1 - Variation of maximum signaling slant range with transmitter depth and angle

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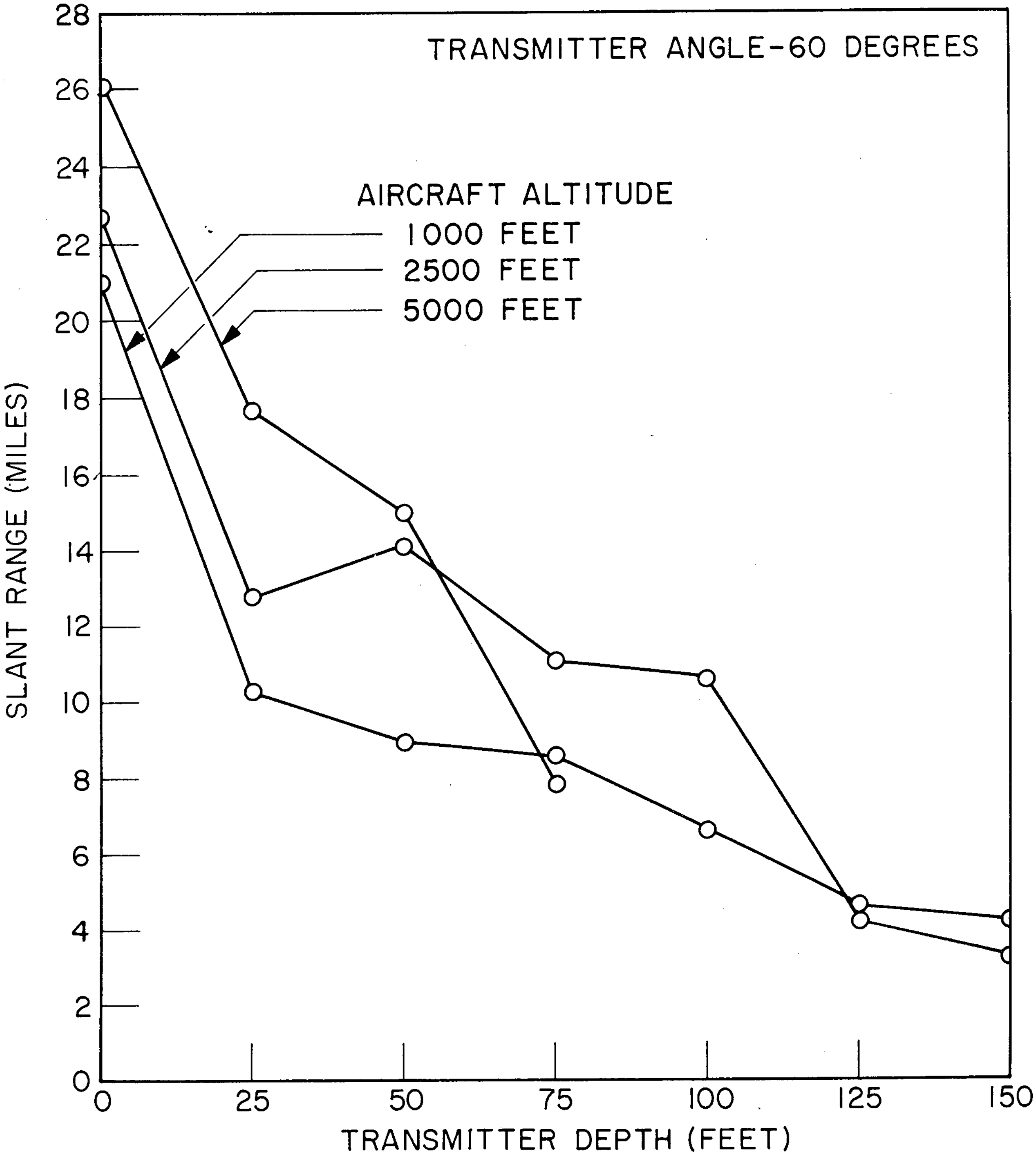

Figure 2 - Variation of maximum signaling slant range with transmitter depth and aircraft altitude

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