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LOSSY MEDIA PROPAGATION AT 50 kHz

Kenneth Murphy
Kurt Ikrath

July 1971

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US ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

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LOSSY MEDIA PROPAGATION AT 50 kHz

Introduction

A research program has been carried on for the purpose of investigating new methods and instrumentation for use in the exploitation of man-made and natural structures for communication. The program was directed principally to the development of magnetic couplers and antennas for exciting electrical currents and fields in the natural structures, such as rivers or beaches, and in man-made structures, such as buried pipes, railroad tracks, water towers, telephone lines or power lines.

Signal Propagation Mode

The theoretical concept relied upon as the basis for this work is the existence of analogies between elastic and electromagnetic waves. Elastic-wave propagation along the boundaries of media with different elastic properties (velocities of propagation) is characterized by the existence of several wave modes. One of these modes involves the propagation of part of the energy emanating from a source in the low-velocity medium along the boundary with the high-velocity medium. This mode is sometimes referred to as the lateral wave mode. Analogous with the elastic case, an electromagnetic source embedded in the low-velocity medium will have part of its energy transformed at the boundary of the high-velocity medium into a lateral wave mode. In both the elastic-wave and the electromagnetic-wave case, propagation of the lateral wave modes requires that most of the energy of the wave is ducted on the high-velocity side of the interface. The attenuation of this type of interface wave is lowest when the low-velocity medium is extremely lossy (provided that the high-velocity medium has very little or no loss).

In the present applications, we are concerned with situations where the "primary medium" is the lossy one. Theoretically, it can be shown that interface wave modes correspond to particular terms in the series expansion for the fields as a function of distance from the source. Residue terms which are contributed by poles in the integrand of the Bessel Hankel integral transforms for the field correspond to the normal modes of surface waves. The surface waves decay with negative odd half powers ($r^{-\frac{1}{2}}$, etc.) Branch-cut terms are contributed by integration around branch cuts of the multivolume integrand in the complex spatial frequency domain, and correspond to the lateral wave mode. The former decay with odd negative half powers of the distance from the source. These latter terms decay in proportion to the negative second power of the distance. Thus, compared to the inverse distance attenuation law for the geometrical spreading of the wave in unbounded homogeneous space, the interface wave modes introduce a negative half and three half power law and an inverse square attenuation versus distance law, if the media are lossless. If the low velocity medium is lossy, the algebraic decay of the $r^{-\frac{1}{2}}$ and $r^{-3/2}$ residue expansion terms are enhanced by an additional exponential decay factor.

For communications over short distances in terms of numbers of free space wavelengths, the r^{-2} branch-cut terms are more significant than all other terms in the series expansion for the field including the r^{-3} term, which, in the electrical case, represents the induction field in the immediate vicinity of the dipole source. In the case of elastic waves which are excited at the interface, one can show* that the amplitudes of the r^{-2} terms are significantly larger than the amplitudes of the other terms, with the exception of the r^{-3} terms for the displacement amplitudes of the elastic medium. Thus, at distances intermediate between the wave excitation region and the far zone, as in the transition region, the r^{-2} branch-cut term dominates the overall attenuation versus distance law. By virtue of the previously mentioned elastic electromagnetic analogy, a similar behavior should be expected in the case of electromagnetic waves. For communication purposes, the r^{-2} decay of signals is certainly more advantageous than the strong exponential decay which is unavoidable in the case of propagation through lossy media.

Thus, efforts have been expended to exploit the wave mode corresponding to the branch-cut term for communications on long wavelengths where transmitter and receiver are embedded or under the surface of lossy media. The exploitation hinges on the implementation of a practical method of exciting these wave modes efficiently.

Design of Magnetic Antennas

The word "antenna" is used rather loosely to describe the function of the device by which the signal is inserted into a propagation medium. It must be emphasized that a magnetic antenna is intrinsically not a good radiator. The magnetic action is as a transformer which, in our application, is somewhat similar to an inverted Tesla transformer. A high-impedance primary is connected to the lumped source while the low-impedance secondary is made up by the water and soil media. The problem consists in finding a coupling method by which the current induced into the medium is maximized for both the given electrical characteristics of the medium and the source.

The type of antenna (Figure 1) chosen to be used for propagation tests was made from carbonyl-iron loaded silicon rubber. A long, one-centimeter thick and one-meter wide, sheet of homogeneous distribution was formed by repeated extrusion methods. A mylar sheet was placed on the finished rubber sheet which was then rolled together with the mylar on a plastic rod; this forms the core of essentially a large solenoid. This design method makes it possible to construct mylar-laminated magnetic cores of large cross-section and of any desired shape.

Experiments

All experiments were conducted in the wetlands estuary of the Shrewsbury River, New Jersey (Figure 2). The experiments consisted of observing and

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* Maurice Ewing, Wenceslas Sardetsky, and Frank Press, Elastic Waves in Layered Media, (McGraw-Hill Book Company, Inc., New York, 1951).

measuring the fields and currents as well as the electrical potentials produced by magnetic induction of the brackish water environment. Special emphasis was made to obtain data on the decay of nominal 50 kHz signals as a function, 1) distance from the antenna, and 2) the height and orientation in and above the water of the transmitter antenna and receiver probe. Measurements were made with the transmitter antenna oriented vertically and horizontally, perpendicular and parallel to the shore line. Signals were received and recorded along various courses: perpendicular and parallel to the shore, at depths down to 3 feet and heights up to 8 feet above the water surface. A test range was staked out in shallow water to measure magnetic field strength (Figs. 3 and 4) versus distance and azimuth angle, and to obtain "radiation patterns" (Figs. 5 and 6.) Electric field strength versus distance was also measured (Fig. 7.) In all cases, reception of signals were confirmed by reporting on-off state of transmission back to the transmitter party by means of radio or flag signals.

Discussion of Test Results

1. Communications Range (New Jersey Test Area)

A communications range of up to 300 meters was achieved using a single ferrite loopstick as a receiver pickup. Using a HP 203A Wave Analyzer as a detector, the signal-plus-noise-to-noise voltage ratio ($\frac{S+N}{N}$) at 300 meters was still 6 to 10. The flux density measured directly at the end of the antenna does not exceed 320 gauss. This appears to be a saturation value corresponding to about 30 watts drive power. At a 15 watt drive power level, the flux density is only 10% lower.

2. Signal Decay

The most striking proof that the desired effect has been achieved is seen by the inverse square distance dependence of the signal amplitude (Figs. 3 and 4) measured on the staked out test range in the Shrewsbury River. Further evidence of this follows from the observation that the received signals are strongest in a zone extending from about 1 foot below the water surface to roughly 3 feet above the water surface, with a maximum just 1 to 2 inches below the water surface. It was also significant that signals received on land in the air were stronger when the transmitter antenna was submerged under water, than when the antenna was in the air above the water.

These tests tend to confirm the role of the sea water currents as secondary radiators. There is a distance zone where the orientation of the pickup probe for maximum signal changes from a longitudinal alignment, with respect to the transmitter, to a perpendicular alignment. This effect is most pronounced when the transmitter is horizontal and parallel to the shore, and submerged in about 2 feet of sea water. With these conditions, the maximum signal is received 100 meters along the shore with the pickup probe oriented parallel to the shore and collinear with respect to the transmitter. As one approaches the transmitter, the orientation of the probe, required for maximum signal reception, changes towards perpendicular alignment to the shore and to the transmitter antenna. This effect is tentatively attributed to the influence of the land-sea water boundary on the field and currents. The optimum orientation of the transmitter antenna for communications across and through water is horizontal and perpendicular to the shore line, with the receiver pickup probe oriented essentially radially towards the transmitter location. This is consistent with the radiation patterns obtained on the staked-out range in the Shrewsbury River estuary.

Conclusions

Experimental evidence obtained so far confirms the validity of the concept used to exploit the material properties and the topography of land, water, and air media, not only as propagation media, but also as means to produce secondary current distributions and fields which tend to excite wave modes which are ducted along the interface of the various earth media.

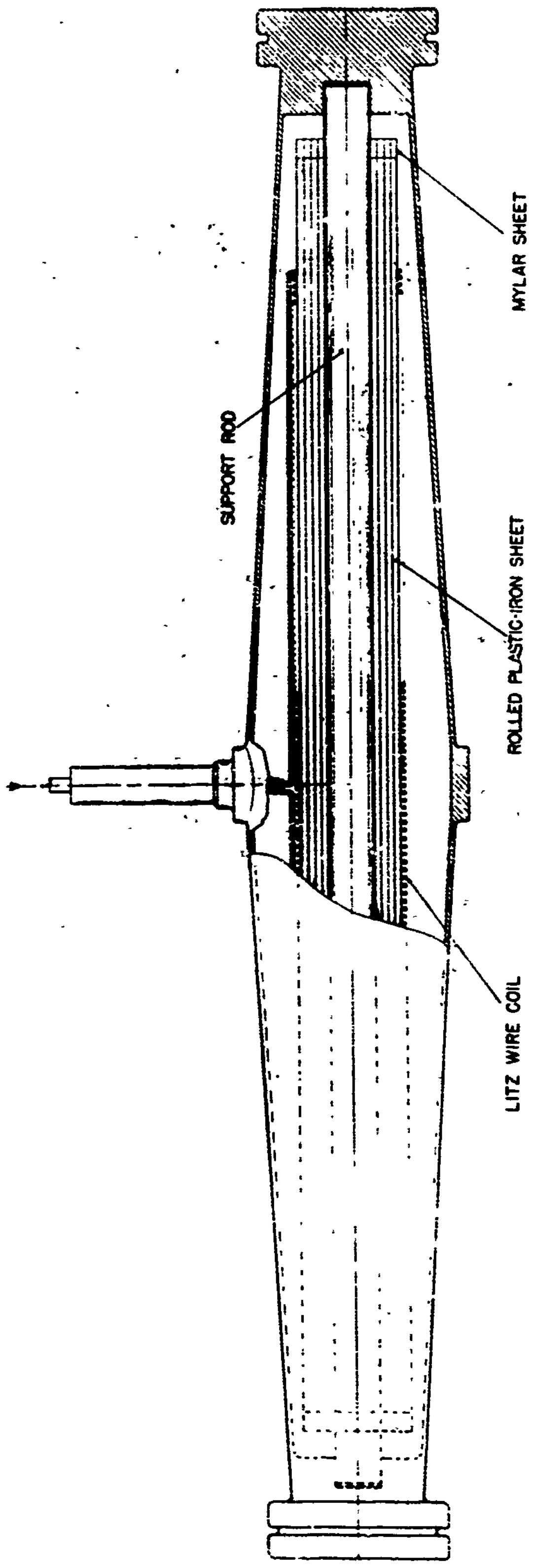
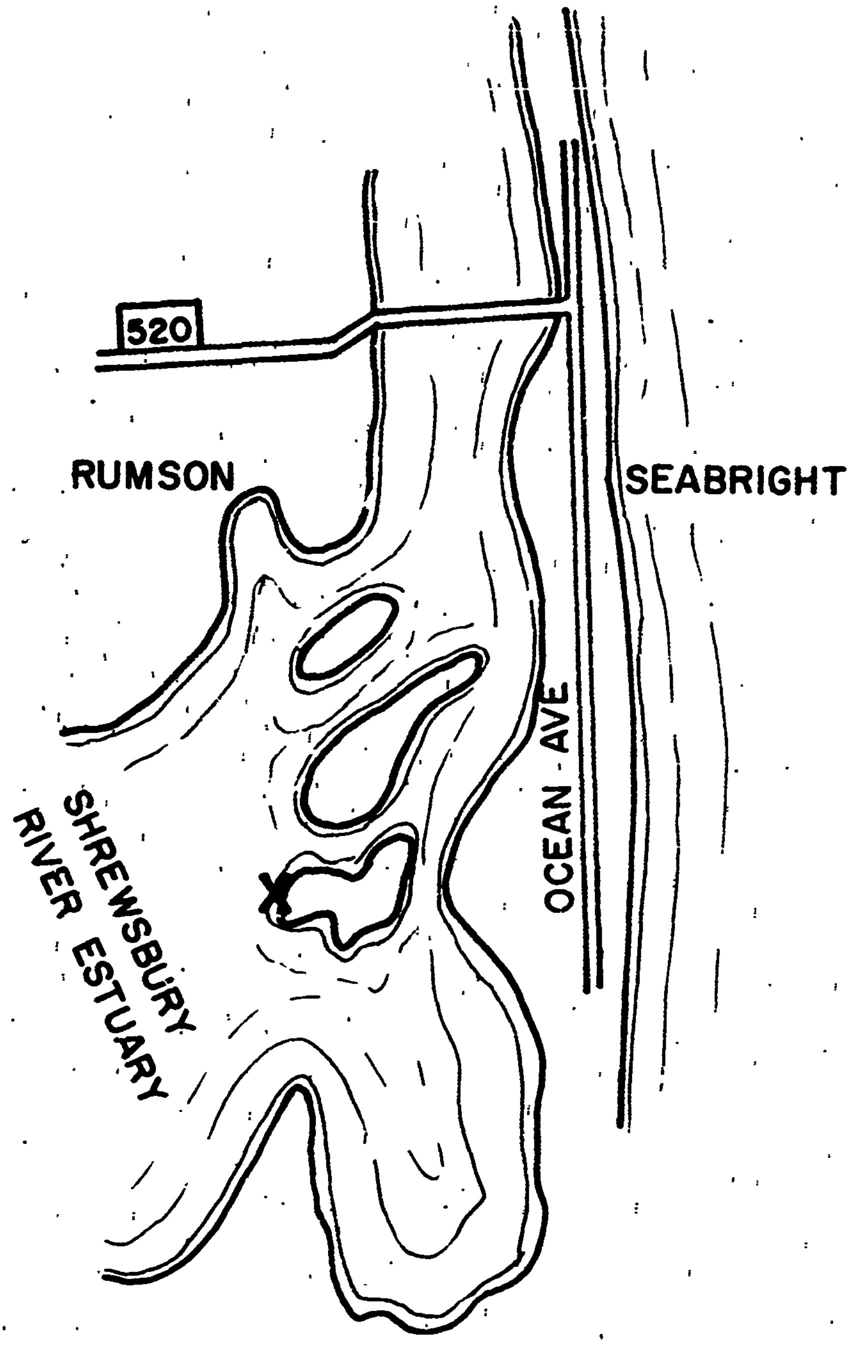


FIGURE 1.   MAGNETIC SHEET ANTENNA



X - XMTR LOCATION

FIGURE 2. SHREWSBURY RIVER, NEW JERSEY

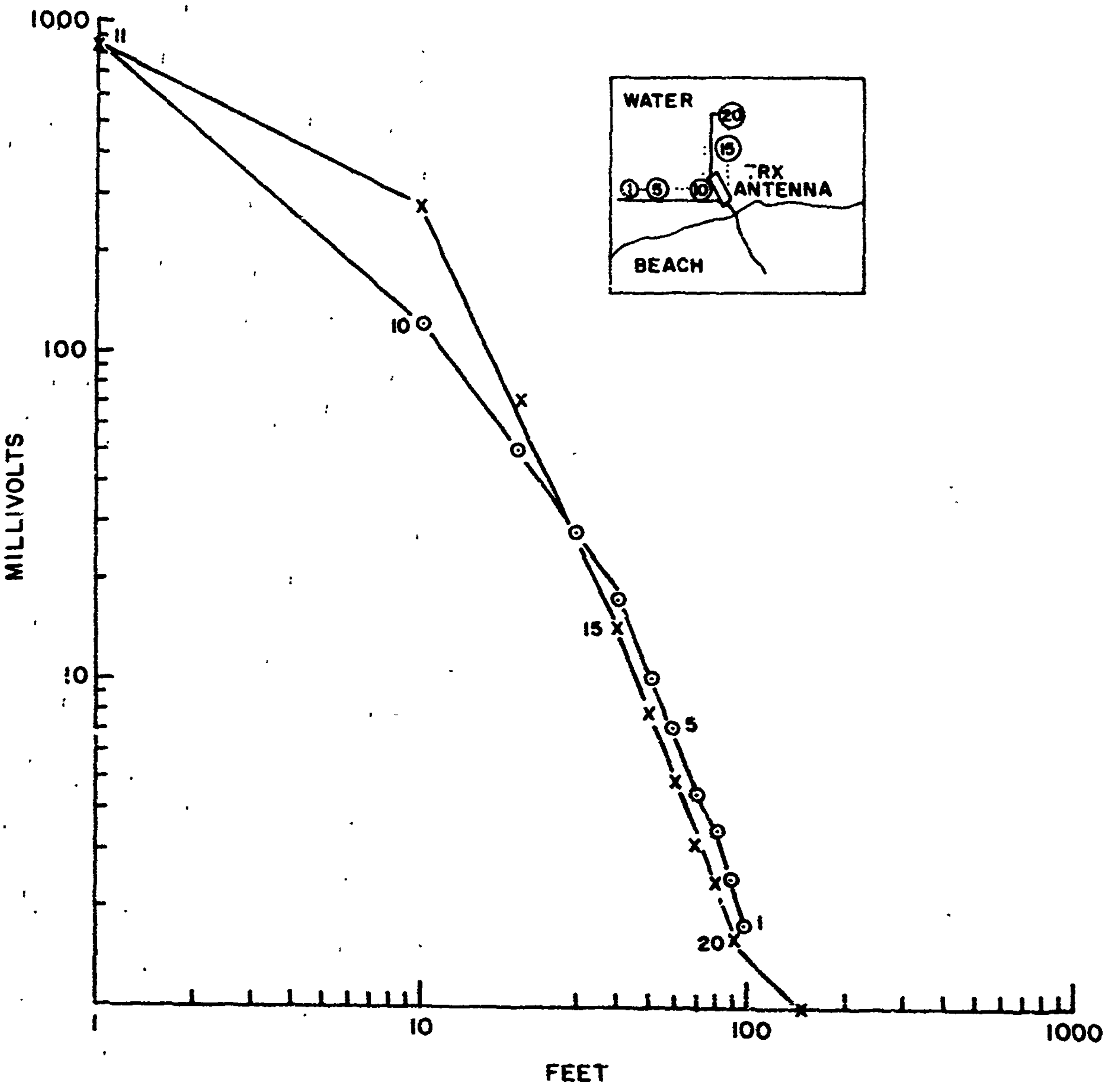


FIGURE 3. MAGNETIC FIELD STRENGTH (ANTENNA ORIENTATION 1)

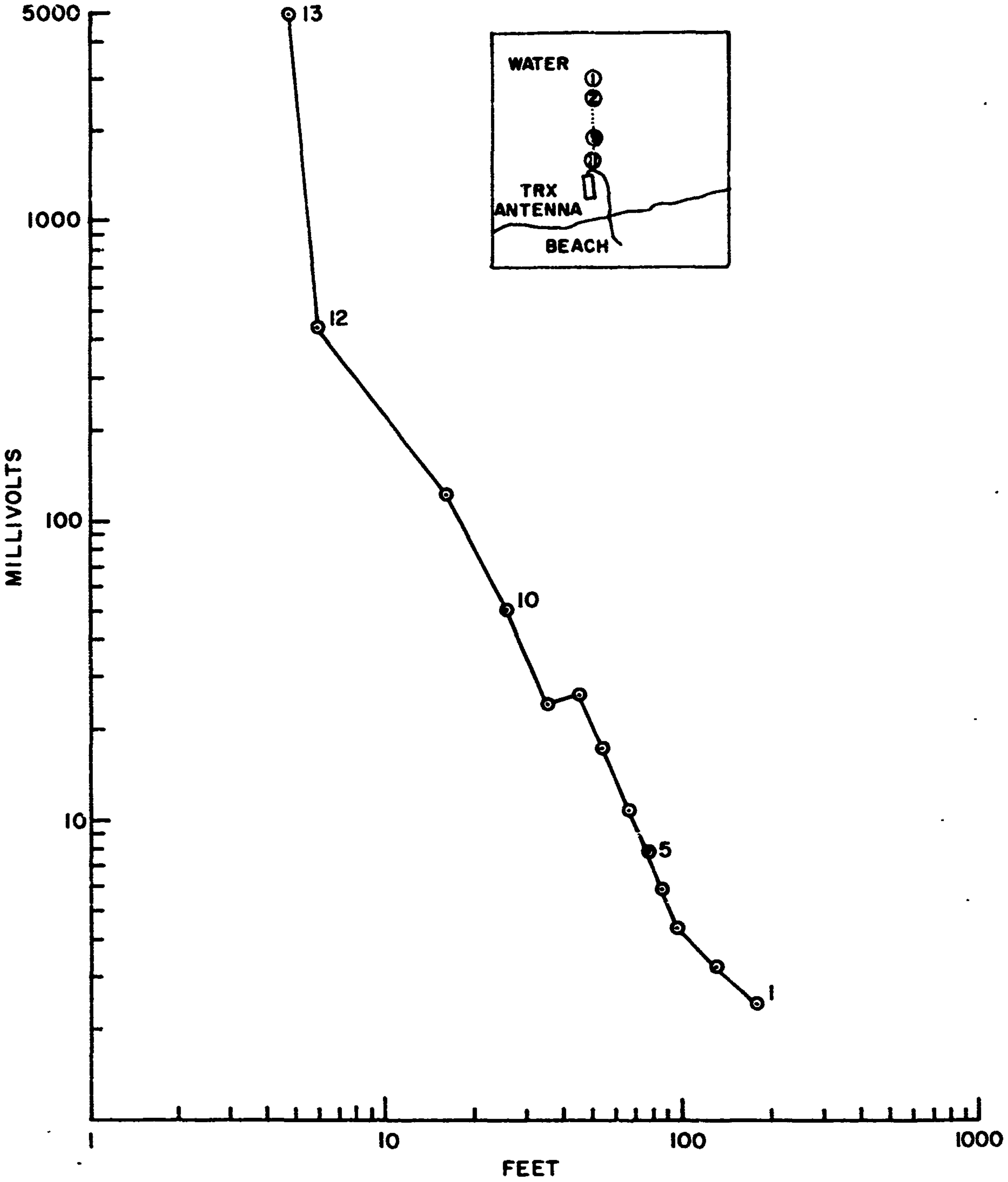


FIGURE 4. MAGNETIC FIELD STRENGTH (ANTENNA ORIENTATION 2)

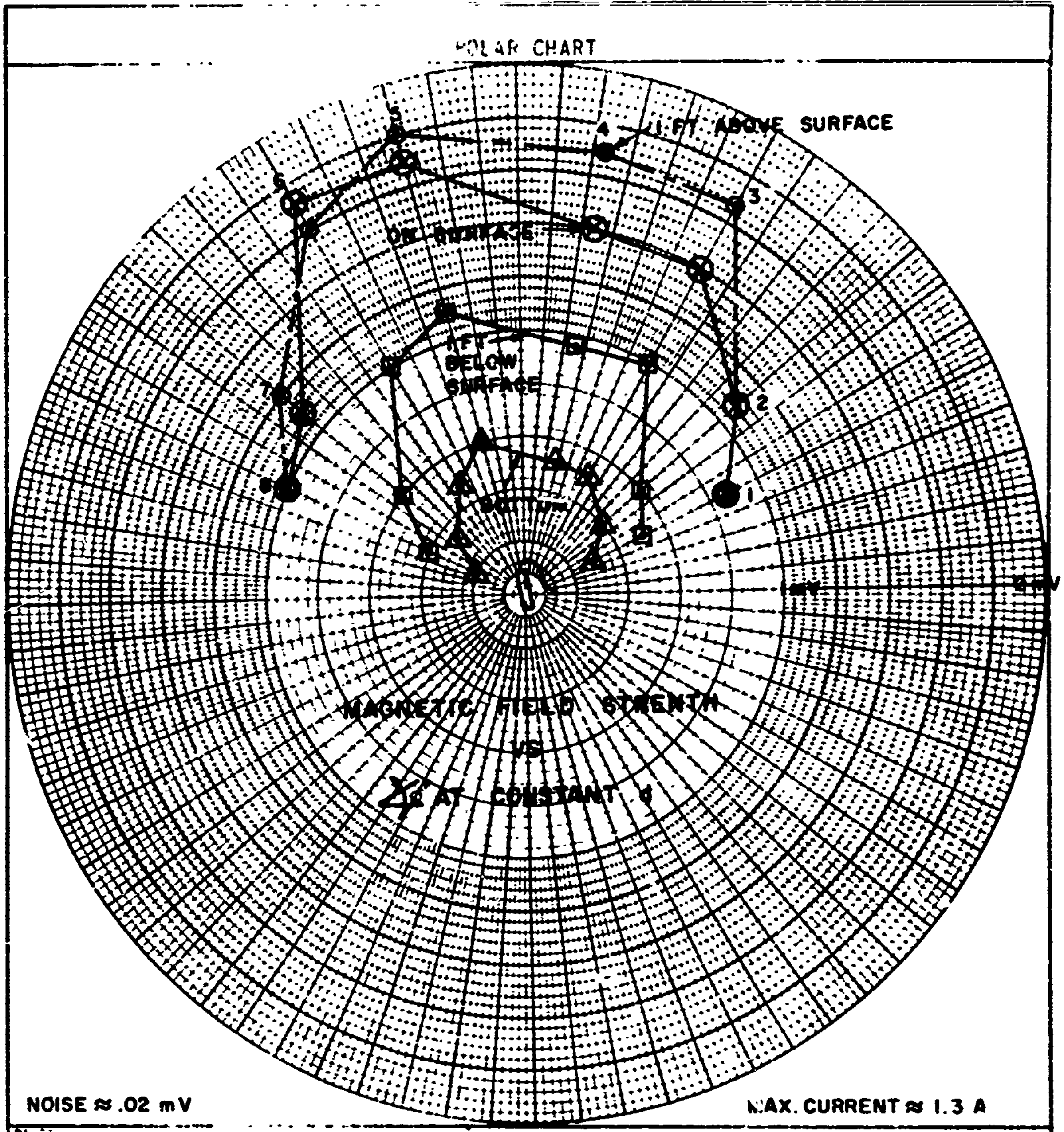


FIGURE 5. RADIATION PATTERN (ANTENNA ORIENTATION 1)

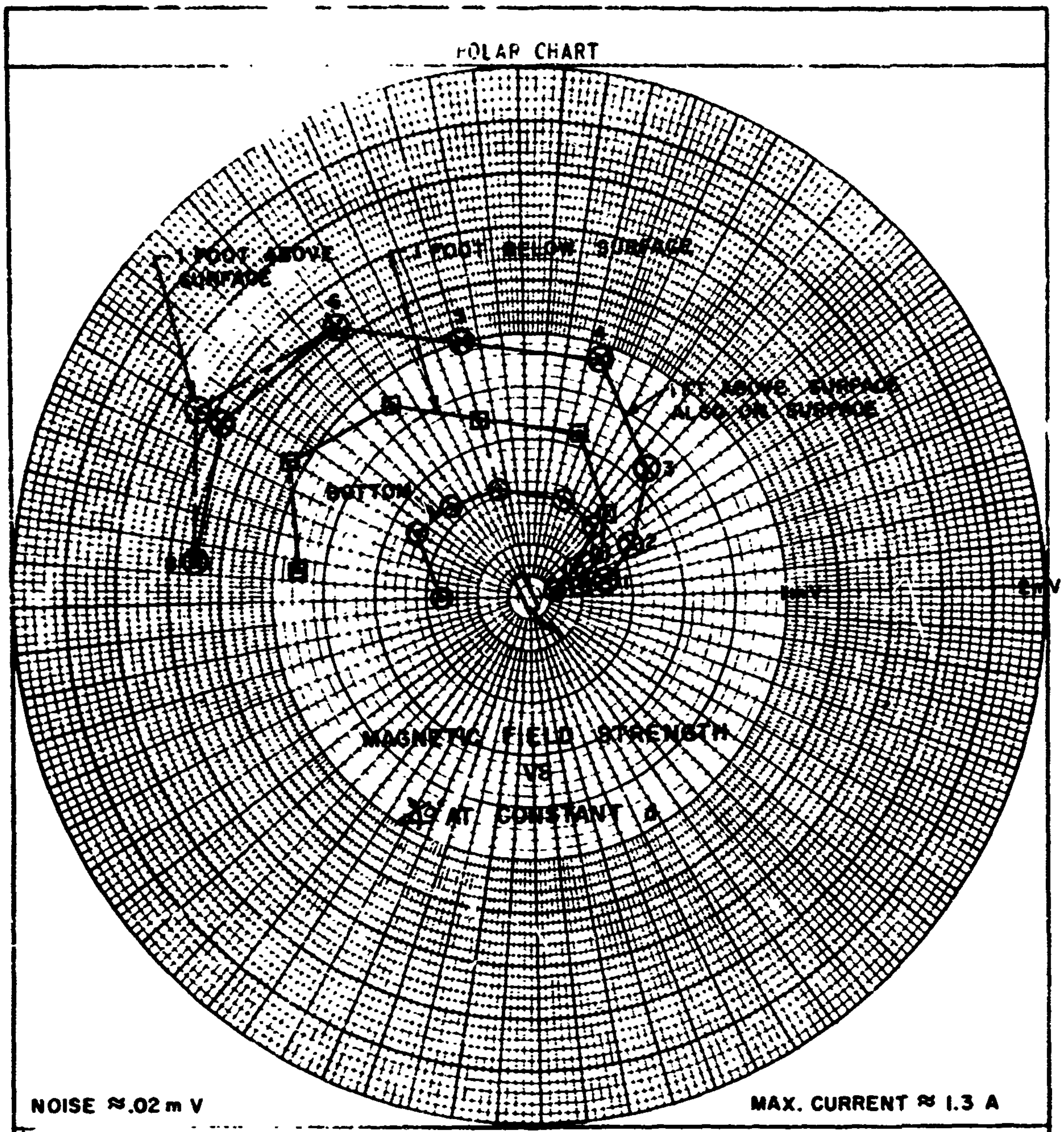


FIGURE 6. RADIATION PATTERN (ANTENNA ORIENTATION 2)

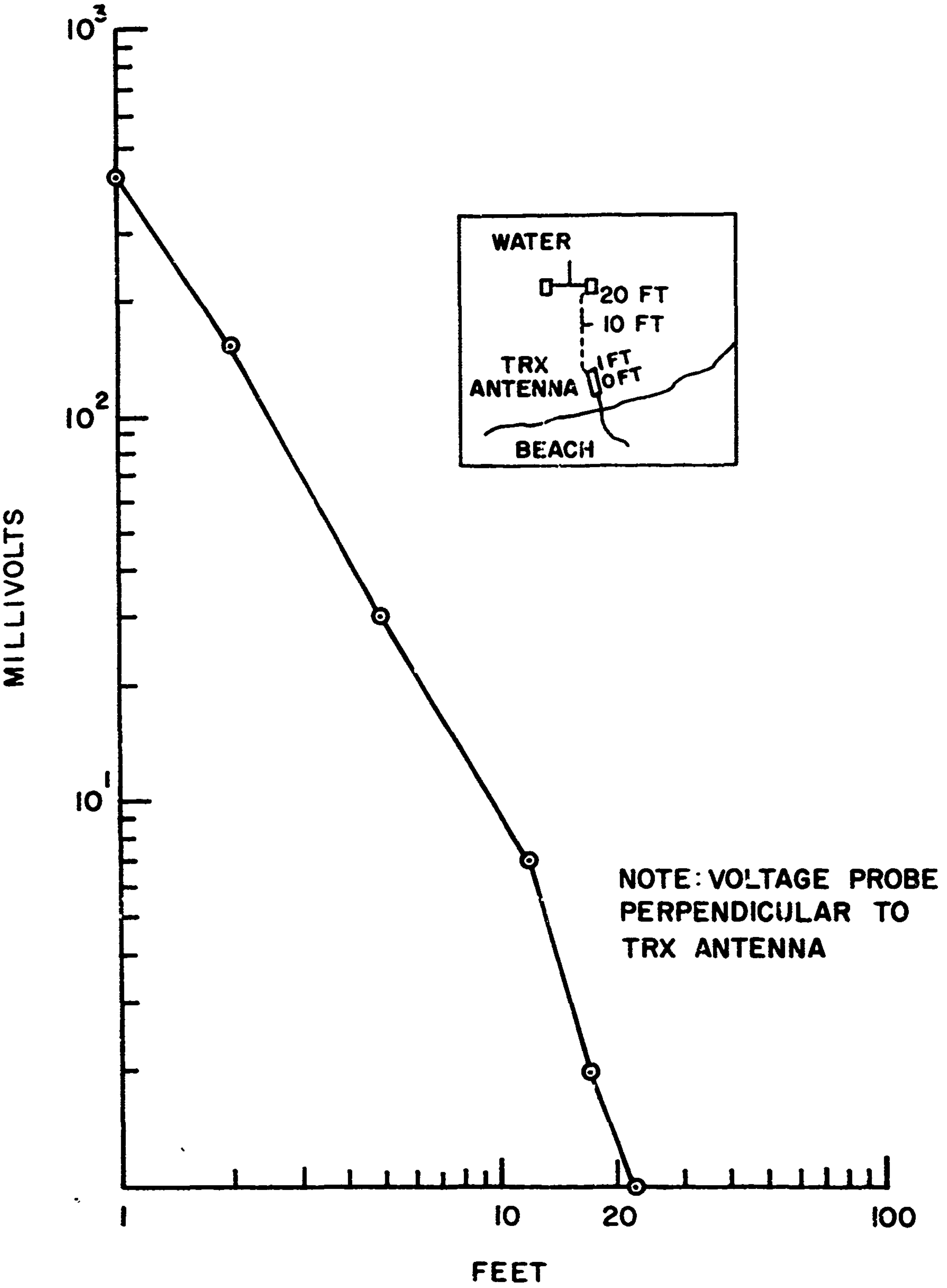


FIGURE 7. ELECTRIC FIELD STRENGTH