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Electromagnetic Field Measurements at 60 Hz in the Sea Near Montauk Point, NY, and New London, CT

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Abstract—The 60-Hz electromagnetic fields in the Atlantic Ocean off Montauk Point, NY, and from Block Island Sound to the harbor in New London, CT, have been measured to determine the levels of interference to extremely low frequency (ELF)接收器。Such data are needed to specify how close to the coastline an ELF receiver can come before 60-Hz external interference will degrade system performance. The data indicate that degradation to the ELF receiver from 60-Hz external interference will not occur offshore, but may occur within the confines of New London Harbor.

I. INTRODUCTION

In the open ocean, electromagnetic interference to extremely low frequency (ELF) reception is typically dominated by atmospheric noise. In most circumstances, the 60-Hz external interference is negligible compared with the level of naturally occurring atmospherics, assuming that such 60-Hz interference is not caused by the receiving platform. However, the ELF receiver must also operate in coastline areas, where many strong sources may contribute to 60-Hz external interference (i.e., in land stations near industrial complexes or on ships operating in or near harbor approaches). A knowledge of the interference levels in these areas would be useful for determining how close to the coastline an ELF receiver can come before 60-Hz interference will degrade system performance. This communication summarizes measurements of the 60-Hz field in the Atlantic Ocean off the coast of Montauk Point, NY, and from Block Island Sound to the harbor in New London, CT.

II. DESCRIPTION OF THE EXPERIMENT

Measurements of the electromagnetic fields associated with power-line frequencies were made at several locations in the Atlantic Ocean offshore Montauk Point and from Block Island Sound to the New London Harbor. Open ocean data were taken in approximately 9.3-km (5-nmi) increments as far out as 55 km (30 nmi) southeast of Montauk Point. Block Island Sound data were taken at various locations but primarily in the vicinity of Cerberus Shoal. Additional data were taken in the navigational channel from Race Rock near Fishers Island, NY, to the State Pier in the harbor at New London, CT. Fig. 1 shows the location of the primary measurement sites in the Atlantic Ocean and in Block Island Sound.

A 10-m (32.8-ft) electrode-pair antenna and a triaxial loop antenna were used to measure the electromagnetic interference in the ELF band. The electrode-pair antenna is a figure eight, with maximum induced voltage occurring when the antenna is aligned with the maximum E-field; that is, this antenna receives the component of the E-field parallel to its orientation. Thus the electrode pair was used to measure the horizontal E-field just below the air/sea interface and the vertical loops were used to measure the horizontal H-field above the interface.

The 60-Hz generating equipment belonging to the measurement platform had to be shut down when measurements were made with the triaxial loop antenna. Since this procedure was inconvenient for the ship operators, only a few measurements were made with this antenna. The majority of the data were collected with the 10-m (32.8-ft) electrode-pair antenna, which was towed 100 m (328.1 ft) behind the measurement platform. In this position, the antenna was not influenced by the 60-Hz field of the research vessel.

All of the antennas were used with the standard test equipment shown in Fig. 2. The measurement systems were atmospheric noise limited over the band of interest; this meant that the antenna and low-noise preamplifier were able to discern atmospheric noise in the 40-100-Hz range. For the vertical loops, this sensitivity was $-140$ dB re $1\, \text{A m}^{-1}\, \text{Hz}^{-1/2}$ and, for the horizontal electrode pair, it was $-180$ dB re $1\, \text{V m}^{-1}\, \text{Hz}^{-1/2}$.

III. RESULTS

A. Atlantic Ocean Off Montauk Point

At each measurement site in the Atlantic Ocean off Montauk Point, the maximum and minimum $E$-field was measured with the electrode-pair antenna. In general, the maximum field occurred at approximately $70^\circ$ true bearing and the minimum at $160^\circ$ true bearing. Here the minimum is defined as the direction from which a signal cannot be discerned from atmospheric noise. Fig. 3 shows the approximate direction of the maximum and minimum horizontal $E$-field at each meas-
Strength in that area is proportional to \( l/r_{1/3} \), implying an 8-dB attenuation every time the distance is doubled. This result is surprising, because for distant point sources, a \((l/r)^{1/2}\) dependence and, more importantly, a maximum in the normal direction are expected. One explanation is that the fields of several power lines combine to produce this effect. Bannister [2] has shown that for a grid of \( n \) equally spaced power lines, the combined effect within 18.5-92.6 km (10-50-nmi) broadside of the array will be a maximum induced field that is parallel to the array of power lines. For example, a grid of three power lines spaced 11.2 km (6 nmi) apart yields a fall off of 8.4 dB in the 25-50-km (13.5-27-nmi) range, broadside to the array.

Fig. 4 shows the approximate east-to-west routing of high tension power transmission lines in Connecticut and Rhode Island. The direction of these transmission lines in association with the distance data in Table I suggests a causal relationship. When the line of measurement is reflected back toward the coastline, the power grid forms an approximate three-line array with a 19.7-km (10.6-nmi) separation between each line. If the long-line approximation is used, a -7-dB attenuation in the range of 37.0-74.1 km (20-40 nmi) from the array would be expected. However, additional data are required to support this hypothesis.

### Block Island Sound and New London Harbor

A measurement of the total horizontal \( H \)-field at 60 Hz above the sea surface at Cerberus Shoal (approximately 9.5 km (5.1 nmi) from Race Rock and 18.5 km (10.0 nmi) from the Connecticut shore line) indicates that the field strength in that area is \(-109.4 \pm 3 \text{ dB re } 1 \text{ A/m}\). The corresponding horizontal \( E \)-field at the sea surface is \(-144 \pm 3 \text{ dB re } 1 \text{ V/m}\). However, the \( E \)-field no longer exhibits the pattern observed off Montauk Point—that is, the direction of the maximum \( E \)-field is no longer parallel to the coastline. Thus at this range from shore, many strong sources are combining to distort the \( E \)-field.

**Table I**

<table>
<thead>
<tr>
<th>Site</th>
<th>Distance From First Power Line in km (nmi)</th>
<th>Maximum E-Field Strength in dB re 1V/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>37.0 (20)</td>
<td>-140</td>
</tr>
<tr>
<td>2</td>
<td>46.3 (25)</td>
<td>-142</td>
</tr>
<tr>
<td>3</td>
<td>55.6 (30)</td>
<td>-145</td>
</tr>
<tr>
<td>4</td>
<td>64.8 (35)</td>
<td>-146</td>
</tr>
<tr>
<td>5</td>
<td>74.1 (40)</td>
<td>-148</td>
</tr>
<tr>
<td>6</td>
<td>83.3 (45)</td>
<td>-155</td>
</tr>
<tr>
<td>7</td>
<td>92.6 (50)</td>
<td>-156</td>
</tr>
</tbody>
</table>

**Table II**

<table>
<thead>
<tr>
<th>Site</th>
<th>Distance From State Pier in km (nmi)</th>
<th>E-Field Strength in dB re 1V/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.11 (3.3)</td>
<td>-140</td>
</tr>
<tr>
<td>2</td>
<td>5.56 (3.0)</td>
<td>-135</td>
</tr>
<tr>
<td>3</td>
<td>4.44 (2.4)</td>
<td>-125</td>
</tr>
<tr>
<td>4</td>
<td>3.89 (2.1)</td>
<td>-118</td>
</tr>
<tr>
<td>5</td>
<td>3.52 (1.9)</td>
<td>-116</td>
</tr>
<tr>
<td>6</td>
<td>3.33 (1.8)</td>
<td>-108</td>
</tr>
<tr>
<td>7</td>
<td>2.22 (1.2)</td>
<td>-102</td>
</tr>
<tr>
<td>8</td>
<td>1.85 (1.0)</td>
<td>-95</td>
</tr>
<tr>
<td>9</td>
<td>1.67 (0.9)</td>
<td>-92</td>
</tr>
<tr>
<td>10</td>
<td>1.48 (0.8)</td>
<td>-90</td>
</tr>
</tbody>
</table>
grid. No attempt was made to correlate these data with their local sources.

IV. DISCUSSION OF RESULTS

The specification for the propagation validation system (PVS) ELF receiver requires it to operate with less than 0.5-dB degradation in signal-to-noise ratio (SNR) for a maximum 60-Hz interference-to-signal ratio of 60 dB [3]. The average ELF signal strength in this area from the Wisconsin Test Facility antenna is -144 dB re 1 A/m [4], which corresponds to an average horizontal E-field strength of -182 dB re 1 V/m for a 4-S/m ocean. Thus, the ELF receiver could be expected to operate here with 0.5 dB or less degradation in SNR if the 60-Hz interference in the sea were not more than -122 dB re 1 V/m. The data (Table II) show that the receiver could operate with less than 0.5-dB degradation in SNR up to approximately 4.4 km (2.4 nmi) from the State Pier in New London Harbor.

V. CONCLUSIONS

It appears that the ELF receiver can tolerate the 60-Hz external interference levels that have been observed in the Atlantic Ocean off Montauk Point and in Block Island Sound. The data show that the receiver could be expected to operate with 0.5-dB degradation or less in SNR as long as the receiving platform remains outside the confines of New London Harbor. If the measured 60-Hz interference levels are typical, then the ELF receiver should operate with less than 0.5-dB degradation in SNR in most coastal areas of the continental United States. However, the expected level of degradation will depend upon the SNR and the signal-to-interference ratio at the area under consideration.

REFERENCES


Spaceborne Long Vertical Wire as a Self-Powered ULF/ELF Radiator

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Abstract—In December 1987, on the occasion of the first demonstration flight of the shuttle-borne Tethered Satellite System (T.S.S.), NASA will deploy in orbit a 20-km vertical conducting wire (electrodynamic tether) and will test, among other things, the wire’s ability to function as a generator of dc electric power, through the $\mathbf{v} \times \mathbf{B}$ mechanism of interaction, as well as its capability to operate as a self-powered radiator of ultralow-frequency extremely low frequency waves (ULF/ELF), through such mechanisms as the Alfvén Wings. The wire’s ability to generate dc electric power up to the 100 kW level has been investigated by several authors and it is now considered to be a reasonable expectation. Concerning the wire’s ability to radiate ULF/ELF waves, rigorous analytical evidence still has to be worked out. The expectation at this time is that this vertical radiator may be able to inject from above into the earth–ionosphere transmission line about 10 W at night and 10$^{-1}$ W by day. Thus in the “hot spot” on the earth’s surface, directly underneath (in a magneto-conjugate sense) the orbiting system, signal-to-noise ratios of practical interest may be achievable against natural micropulsation noise. The tether’s ability to excite from above long-range propagation modes in the earth–ionosphere transmission line still has to be verified analytically. It is expected that by 1987–1989, comprehensively analytical and experimental evidence will be available to the ULF/ELF community, so that conclusions may be drawn as to the feasibility of strategic communications using orbiting wires. The advantage of the spaceborne placement for the ULF/ELF radiator, compared with the traditional ground-based placement, may be the avoidance of the potential environmental threat posed by the conventional siting.

Experiments are presently under preparation to conduct, in 3 to 4 years from now, orbital tests on the electrodynamic interactions between long vertical wires, deployed from NASA Shuttle Orbiters, and the magneto-ionic medium of the earth ionosphere, in which they are embedded. A first demonstration flight of the Tethered Satellite System (T.S.S.), as this shuttle facility is now called, is scheduled for December 1987, and consists of the upward deployment from the shuttle of a 20 km conducting wire.

One of the electrodynamic interactions that will be tested is the generation, at the expense of the shuttle’s orbital energy, of dc electric power. The levels of generated power are expected to be substantial, when the orbital inclination, as presently planned for the initial flights of the T.S.S., is low enough to exclude polar and near-polar regions. That the electrodynamic tether can function as a dc power plant, can be recognized by reasoning as follows.

An observer who is at rest in the ionosphere sees an electric field established along the electrodynamic tether by virtue of the $\mathbf{v} \times \mathbf{B} \cdot \mathbf{L}$ mechanism (where $\mathbf{v}$ is the tether’s orbital velocity, $\mathbf{B}$ the Earth’s magnetic field and $\mathbf{L}$ the tether length). Because the tether is an insulated metal wire terminated with two electrodes (or equivalent devices) that are in good contact with the ionospheric plasma, this observer at rest in the ionosphere sees a difference of potential applied between the two end terminations of the tether system. For an observer who sits on the orbiting tether, there is a current that flows in the wire, and this is a dc current. In fact, the magneto-ionic medium (superimposition of the ionosphere and of the geomagnetic field) in which the long tether is orbiting, can be modeled as an array of nearly parallel transmission lines, with the transmission line’s two wires represented by the highly conducting lines of force of the geomagnetic field, one of which passes through the upper termination of the tether, and the other through the lower termination. These lines of force represent a “harpichord-like” structure, where the strings are the transmission lines illustrated above. The long wire (func-