Meetings

Electromagnetics of the Sea

Recent advances in electromagnetic wave interactions with the sea were examined at a North Atlantic Treaty Organization Conference in Paris from 22 to 26 June 1970. The conference was divided into two distinct parts. The first part, designated Radio, included discussions of electromagnetic phenomena at all radio frequencies, from extremely low to ultrahigh. The second part, designated Optics, included discussions of all electromagnetic phenomena in the infrared and visible wavelength ranges.

In general, the technical contributions at the meeting were oriented toward fundamental analytical studies and understanding, rather than engineering feasibilities and systems aspects. This emphasis was appropriate in view of the nature of the subject and the previous state of knowledge. There were few physical oceanographers present, so the hoped-for interactions between oceanographers and radio physicists were not possible. Nevertheless, the discussions were useful and stimulating, even though the participants were mostly radio engineers and physicists.

The opening paper, "ELF Propagation" by J. Galejs, was a summary of the present state of knowledge of ionospheric propagation at extremely low frequencies. This was relevant, since in any long-distance communication between submerged terminals, the energy path by necessity must involve propagation via ionospheric reflections. He reviewed the fundamental formulations for earth-ionosphere propagation which are available in the literature. This material served as a suitable backdrop for subsequent papers where the ionospheric propagation mechanisms were considered to be understood. Galejs also considered the nature of the atmospheric radio noise, and he pointed out that the major sources of natural radiation in the ELF range are lightning discharges. These sources can be used to investigate the attenuation characteristics of the propagation channel.

The complexities of nighttime propagation in the earth-ionosphere wave guide were stressed by Galejs. It turns out that the F layer is important in determining the attenuation rate in addition to the well-known dependence on the D- and E-layer profiles. It was curious that, in spite of these complications, average isotropic models give results which are in fair accord with observations.

In the same paper, Galejs introduced the topic of the influence of sea roughness on the ELF field received at depth. The departures from the simple exponential law were attributed to the influence of the bottom surface, while the fluctuations of the signal were related to the surface characteristics in the vicinity of the submerged receiving antenna.

In the following paper entitled "Propagation of EM Waves across Land/Sea Boundaries," J. R. Wait considered the general problem of surface wave propagation across a coastline. A new exact solution for the idealized two-dimensional model was used to discuss the problem in a general context. For example, it was shown that the often-used assumption that reflection from coastlines could be neglected did have some justification. It was emphasized that exact solutions for simplified situations have a great value in establishing the validity of the approximate formulations of more complicated (that is, realistic) situations. In the discussion it was pointed out that the results have a relevance to prediction of errors in phase navigation systems over inhomogeneous land and sea paths.

The final paper in the morning session was entitled "Propagation of Acoustic or Electromagnetic Waves in an Inhomogeneous Sea-type Medium with Rough Frontiers" and was coauthored by M. F. Verheghe and A. Wirgin (Institut d'Optique, Paris). Wirgin presented a comprehensive theory for wave propagation in stratified media with wrinkled interfaces between the layers. A rather involved perturbation analysis was used which appears to converge if the surface slopes and undulations (for example, wave heights) were small. Also the physical-optics approximation was used to allow for the interactions between the layers. Apparently the lengthy analysis was used in studies of thin film optics, and the authors apparently considered the possible relevance to the ocean only quite recently. During the subsequent discussion, it was discovered that Wirgin's technique may have a definite application to the more realistic sea-wave HF backscatter problem, but further examination of the matter is needed. Wait also wondered if the implications of "Rayleigh's hypothesis" in problems of this kind should not be explored. However, Wirgin felt that the use of nonrigorous wave functions were justified for gently rippled surfaces.

The session on antenna problems was begun by R. Gabillard who gave a review on "Radiation of EM Sources Placed in Absorbing Media," coauthored by P. Degauque and J. R. Wait. The paper contained a critical summary of past work including an annotated bibliography which contains over 400 references. Some of these are early papers on electrical prospecting which apparently have been overlooked by most present-day workers. The principal part of the review contained an outline of dipole radiation theory for both homogeneous and stratified absorbing media. Numerous graphs are included for convenience of application to field calculations in seawater. Considerable attention was given to situations where displacement currents play a role. Also, the importance of accounting for the insulation in antenna power calculation was stressed. Hopefully, the French version of this review paper prepared by Gabillard and Degauque will serve as a useful guide to future investigators in the radio aspects of electromagnetic waves in the sea.

Unfortunately, the second paper by Gabillard, Degauque, and Fontaine was not given. This work would have dealt with communication between submerged antennas via a path through the crystalline basement below the sea bottom. This important topic was not discussed at all during the conference. Also, many other significant accomplishments of Gabillard's group at Lille were not given adequate exposure at the meeting.

Two papers by Bouix followed in this session. The first one dealt with the formal theory of integral equations in determining current distributions on finite length antennas in homogeneous media. The second paper was concerned with the influence of a reflecting surface on the field of a dipole in an otherwise homogeneous media. The paper seemed rather classical, but it may provide analytical insight.

The final paper in this session, by G. Franceshetti, dealt with "The Influence of Excitation Gap on Antenna Performance." The main point of the paper was to establish the validity of quasi-state formulations in low-frequency antenna radiation in conducting media. On the basis of the oral presentation, it appeared that the actual analysis was only carried out for spherically shaped antennas with azimuthal gaps. As expected on intuitive grounds, the static results are valid provided the antenna dimensions are reasonably small compared with the skin depth in the conductor. In principle, the results can be generalized to other geometries, but much additional work needs to be done. The experimental work described was carried out in a scaled model tank. In the discussions, Wait emphasized the importance of accounting for induced polarization effects of metal-electrolyte interfaces. This can be particularly troublesome at audio frequencies.

The session on transmission was supposed to have been initiated by a paper entitled "Transmission of Radio-correlated Low Audio and Sub-audio Frequency Signals through Sea Water." The paper, with five authors, was withdrawn for unknown reasons by the sponsor (U.S. Army, Fort Monmouth). The abstract indicated that transmission experiments between shore and boat were carried out at a distance up to 1.6 nautical miles. Apparently, correlation of radio and conduction current signals was to be undertaken with a view to improved range coverage.

"Surface Wave Propagation from VLF Arrays in Polar Seas" was the title of a paper given by A. W. Biggs. This paper dealt mainly with mixed-path effects for ground-wave propagation over high-latitude terrain which is highly inhomogeneous. The semi-empirical formulation of Millington was used to estimate the gross nature of the expected field variation of coastlines between sea and arctic land. Surface wave effects in polar ice, and all the complicating factors such as brine content, pore volume, and surface rough-

ness, were also considered. The design of antenna arrays using up to five elements was described. The paper indicated that many unusual and perplexing effects could be expected.

The final paper in the session, presented by R. Lindquist, was entitled "Some Results in Connection with a Search for Maximum Underwater LF/VLF Coverage." This paper described a simple method to determine fields in seawater (in the seas around Sweden) from a fixed VLF station on land. The distribution of salinity and the coastline geometry was considered in the analysis. The final results displayed the frequency and range dependence for a wide variety of cases. No new analytical approaches were needed, but the author demonstrated a deep understanding of the problem and a capability to adapt known methods to the problem at hand.

The session on VLF/ELF electronic noise contained a group of four papers on naturally occurring signals in the ELF range. One, by H. L. Konig, dealt with the mechanical and electrical design of magnetic and electric dipole receiving antennas. The results should be of considerable value to experimenters and many practical hints in the construction and operation were generously supplied. The second paper, by G. Mattern, dealt with a rather qualitative discussion of VLF radio noise during a sea voyage between Germany and Ecuador. The noise was recorded with a 500-hz to 5-khz bandpass receiver using, apparently, a vertical whip antenna. It was concluded that, for below 40°N latitude, the principal contribution to the noise was lightning discharges in African and South American storms. The third paper, by E. Selzer, dealt in a very general fashion with the problems of doing EM noise studies at great depths in the ocean and in freshwater lakes. Many intriguing aspects, such as hydromagnetic propagation and ocean bottom noise, were briefly mentioned.

The fourth paper on noise, by E. F. Soderberg and M. Finkle, was a successful attempt to correlate measured ELF noise fields at the surface and beneath the sea. The experimental results were consistent with a straightforward theoretical calculation using a plane-wave and homogeneous half-space model.

The session on HF/VHF backscatter was probably the highlight of the whole conference. The contributors represented the leading workers in the field, and the audience was in a position to appreciate the impact of the results. Again, however, the lack of participa-

tion from physical oceanographers was noticed.

It was very fitting that the first paper was given by D. D. Crombie who, in 1955, had first identified Bragg-type resonant backscatter as the principal mechanism in determining the reflected ground-wave HF signal from a rough sea. Crombie's paper (coauthored by J. M. Watts and W. H. Beery), dealt with the spectral characteristics of the Doppler-shifted backscattered signal. He attributed differences from the "simple theory" to four factors: (i) nonlinear interaction between the waves causing the coherent backscatter and the rest of the sea spectrum; (ii) changes in phase velocities depending on wave amplitude (that is, Stokes effect); (iii) drifts duced by the wind; and (iv) tidal drifts.

An important contribution to this session was a theoretical analysis by D. E. Barrick who used a boundary perturbation treatment for interaction of an electromagnetic ground wave and the rough sea surface. The results provided a quantitative estimate of the effective ground-wave attenuation for an HF ground wave on a rough sea. Also included in his analysis was the special case of backscatter, and here his results were consistent with earlier calculations of others.

A third paper in this backscatter session was given by W. H. Shonfeld, who considered a semi-empirical analysis of microwave backscatter (that is, clutter) from the sea. Parameters such as range, wind, wave height, and antenna height were considered.

A rather controversial paper was given by R. K. Moore on the use of radar to determine oceanic winds (up to 50 knots). He suggested that the scattering coefficient at centimetric wavelengths is a well-determined function of wind speed and, with the use of satellites, this should open up a new field in oceanography. During the discussion, however, it was pointed out mainly by J. W. Wright (Naval Research Laboratories) that, for high wind speeds, the situation is very complicated. Thus wind speeds may not be deduced easily from such microwave data.

In his paper "Doppler Spectra in Microwave Scattering from Wind Waves," J. W. Wright used a laboratory wind-wave tank and obtained Doppler spectra on vertical polarization at X-band (3.2 cm) and K-band (1.25 cm) for depression angles between 15° and 80° and wind speeds between 2.25 and 8 m/sec. By Fourier-analyzing optical

data, he was able to obtain two-dimensional slope spectra of the wind waves. He concludes that microwave scattering from low-speed wind waves (in a short fetch tank) can be satisfactorily accounted for by low-order Bragg scattering. Wright conjectured that the Doppler bandwith is a kind of inverse lifetime for the Bragg resonant wind wave. This suggestion, attributed to Crombie, means that the currently accepted views by oceanographers on wind waves are incomplete at best. There was no rebuttal from any physical oceanographer in the audience!

An unscheduled but useful presentation was given by L. Wetzel on the signal characteristics received beneath a rough ocean. He compared several different models proposed on earlier occasions.

A round-table discussion on the Radio papers was held. An edited account of this is being prepared by A. W. Biggs. It served as a useful mechanism to extend the discussions which followed each of the papers above. Unfortunately, the format of the round-table session was not conducive to informal discussion. It may be better in future meetings of this kind to dispense with "round-table" discussions and instead allow more time for discussion after each paper.

This meeting, organized by the Electromagnetic-Wave Propagation Panel of the Advisory Group for Aerospace Research and Development (AGARD), was held at the Centre National de la Recherche Scientifique in Paris. The program chairman was P. Halley from Saclay, and the cochairman was T. Hodara (Tetra Tech, Inc., Pasadena, California). The EM Wave Propagation Panel is under the chairmanship of K. Davies (Environmental Science Services Administration, Boulder, Colorado), and the executive officer is C. R. Smith (U.S. Navy, AGARD staff, Paris).

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Oral-Facial Sensory and Motor Mechanisms

The U.S.–Japan Cooperative Science Program has fostered an exchange of scientific information through joint seminars on subjects under intensive investigation in both countries. Neurobiological research on sensory and