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Some Electromagnetic Considerations for a Sea-Water-Based Platform for Electromagnetic Sensors

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Abstract

Two general approaches to platforms for electromagnetic sensors on a sea-water surface are discussed. One approach utilizes a conducting sheet in electrical contact with the sea water to give a well-defined ground plane. The other approach is to make the platform have insignificant effect on the field distributions. Each approach has its own advantages and limitations for electromagnetic measurements, and each may be desirable in different circumstances.

I. Introduction

Measurements of the nuclear electromagnetic pulse (EMP) on the ocean surface require some sort of platform to position the electromagnetic sensors and, in some cases, sensors for related physical quantities such as the nuclear radiation. In addition, some of the sensors may need protection from adverse features of the ocean environment. The platform is a significant part of the problem of electromagnetic field measurements on the ocean surface. It can distort the electromagnetic fields in its vicinity, thereby introducing errors in the field measurements, i.e., the field distribution in the vicinity of the platform may be significantly different from the field distribution which would have existed at the same position in the absence of the platform. One might prefer the platform to either not significantly distort the field components of interest or distort these field components in a simple way which can be easily understood so that the field measurements can be related to what the fields would have been in the absence of the platform. In some cases platform distortion may be desirable. For example, one may not be interested in the fields at the water surface, but in the fields which would be there if the water surface were removed. Such might be the case if one were trying to measure the electromagnetic fields, in a high-frequency electromagnetic pulse, propagating to the surface from a high-altitude nuclear detonation. In such a case a controlled platform distortion may be preferable to the distortion due to the ocean surface.

There are two interesting cases to consider for the sensor platform on the ocean surface. First, the air conductivity may be insignificant, as for measurements associated with high altitude and intermediate altitude detonations or for far-field measurements for near surface detonations. In a second case, the air conductivity may be significant as for close-in measurements for near surface detonations. The field-distortion problems may be somewhat different in these two cases. As an example one might think of extensively using electrical insulators for the platform to prevent shorting out the electric fields. In some cases, however, for significant air conductivity such insulators may still significantly distort the electric field distribution.[1]

There are various mechanical problems associated with the design of a sensor platform on the ocean surface relating to stability, drag, ocean spray, water waves, etc. These problems can be quite significant but are not of primary concern to us in this note. In this note we consider some of the electromagnetic problems involved in designing a platform for electromagnetic sensors at the ocean surface. We consider two concepts for the electromagnetic design of such a platform. The first concept entails a platform made with good conductors to form a local

1. Lt Carl E. Baum, EMP Measurement Note III, Low Frequency Electric Field Distortion in the Vicinity of the WEBS Catamaran, May 1966.

ground plane in good electrical contact with the sea water. In the second concept a platform is made electromagnetically "invisible", leaving the local sea water surface intact, or in some cases using insulators on the water surface. Each of these concepts has advantages and disadvantages as a sensor platform. Different approaches may be desirable for different applications.

II. Local-Ground-Plane Platform

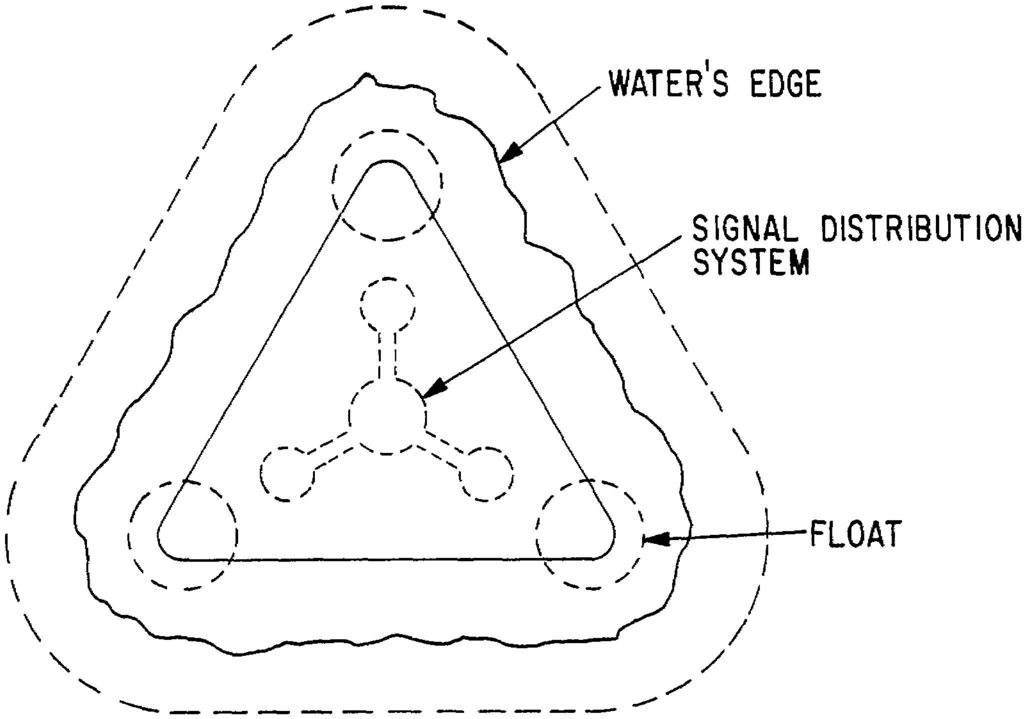
Consider a sensor platform consisting of a conducting sheet (or screen) which is held a small distance (relative to the horizontal dimensions of the sheet) above the water. As illustrated in figure 1, the conducting sheet is sloped around the edge so as to gradually enter and make electrical contact with the sea water. This conducting sheet makes a flat, well-defined electromagnetic boundary, constraining the electric field to be perpendicular to it and the magnetic field to be parallel to it. The conducting sheet may be included in the sensor designs as an image plane.

Sea water is a good conductor ($\sigma \simeq 4$ mhos/m) and has a large relative dielectric constant ($\varepsilon/\varepsilon_o \simeq 80$). The relaxation time ($\varepsilon/\sigma$) thus is about .2 ns. A plane wave in nonconducting air reflects off a sea-water surface as if it were a perfect conductor for characteristic times in the pulse greater than several relaxation times-about one ns. Such required times can be longer for the part of the incident wave polarized with the magnetic field parallel to the sea-water surface, if the angle of incidence of the wave is such that the wave is propagating nearly parallel to the surface.[2] Sea water is then a good reflector for a plane wave. Perhaps the conducting platform can be considered to be an extension of the sea-water surface, only with a better geometry (flat because of no short-wavelength water waves). This type of platform might be useful for measurements of electromagnetic fields in cases without significant air conductivity.

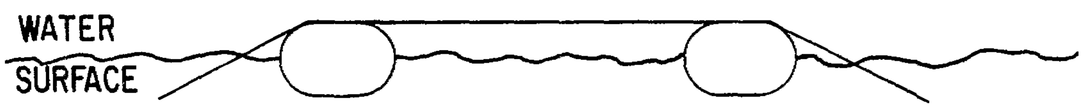
There is some difficulty with this type of platform regarding field distortion. Consider the field distribution in the vicinity of the platform for frequencies with wavelengths much larger than the characteristic platform dimensions. (The air conductivity is presumed negligible.) Idealize the water surface as a flat surface so that the electric field distribution is as indicated in figure 2A. The electric field is perpendicular to both the conducting sheet and the sea-water surface. If the height, h, of the conducting sheet off the water surface is much less than the characteristic horizontal dimension, w, of that part of the sheet protruding above the water surface, then the electric field distortion over the conducting sheet should be small.

The magnetic-field distortion is somewhat different. Considering the conducting sheet as a perfect conductor, the magnetic field does not penetrate it. However, the magnetic field does penetrate the sea water to some extent. For convenience consider a step function magnetic field of amplitude, B_o, at

2. Capt Carl E. Baum, EMP Theoretical Note XXV, The Reflection of Pulsed Waves From the Surface of a Conducting Dielectric, Feb. 1967.

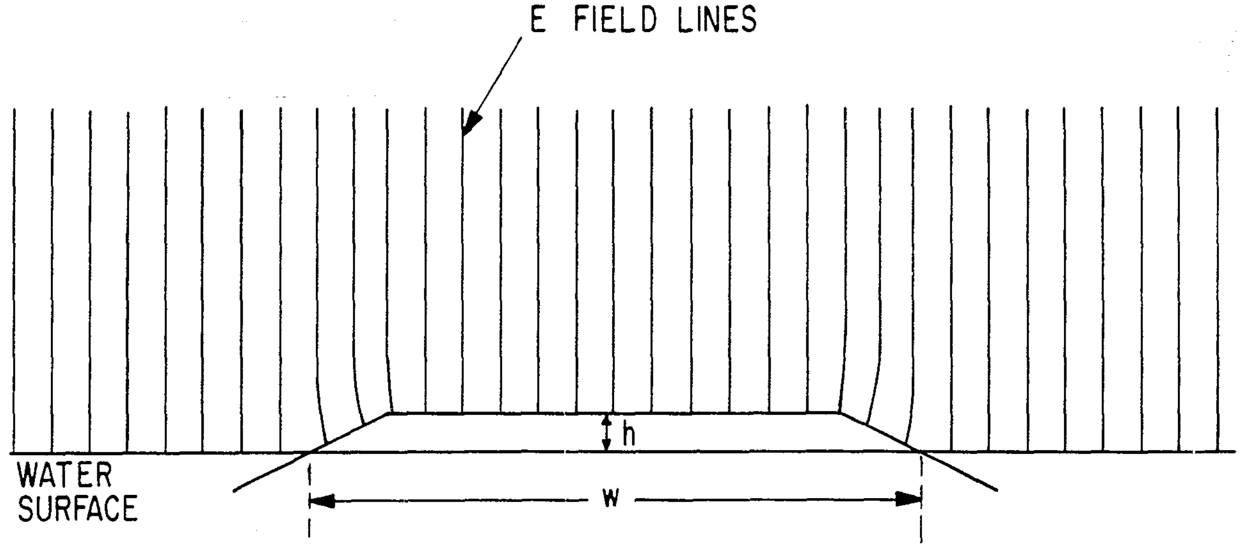


A. TOP VIEW

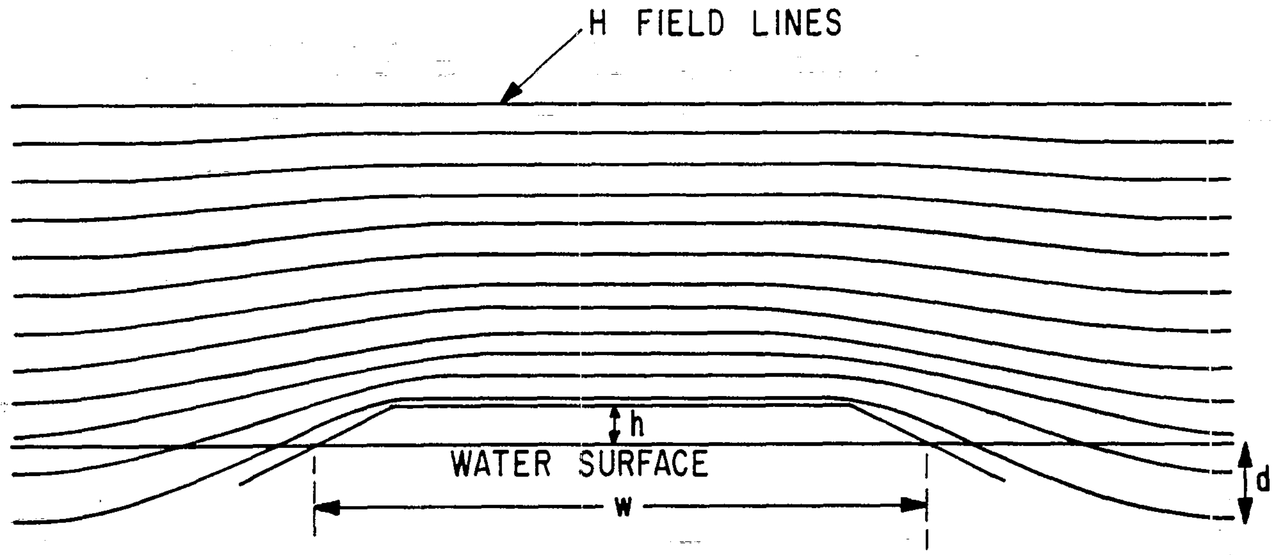


B. CROSS SECTION VIEW

FIGURE 1. LOCAL-GROUND-PLANE PLATFORM.



A. ELECTRIC FIELD DISTORTION



B. MAGNETIC FIELD DISTORTION

FIGURE 2. ELECTROMAGNETIC FIELD DISTORTION BY LOCAL GROUND PLANE.

the sea water surface. The Laplace transform of the magnetic field in the water, neglecting displacement currents is then

$$\tilde{B} = \frac{B_o}{s} e^{\sqrt{s\mu_o \sigma}\, z} \qquad (1)$$

where z (negative) gives the distance of the position of interest from the surface and s is the Laplace transform variable (transform taken over time), and a tilde, ∿, over a quantity indicates the Laplace transform of the quantity.[3] Integrating over negative z gives a quantity,

$$\tilde{\phi} = \int_{-\infty}^{o} \tilde{B} dz = \left. \frac{B_o e^{\sqrt{s\mu_o\sigma}\, z}}{s\sqrt{s\mu_o \sigma}} \right|_{-\infty}^{o} = \frac{B_o}{s^{3/2}\sqrt{\mu_o \sigma}} \qquad (2)$$

or in the time domain

$$\phi = \int_{-\infty}^{o} B dz = B_o \sqrt{\frac{4}{\pi}\frac{t}{\mu_o \sigma}} \qquad (3)$$

This defines an effective depth of magnetic field penetration into the water as,

$$d = \frac{\phi}{B_o} = \sqrt{\frac{4}{\pi}\frac{t}{\mu_o \sigma}} \qquad (4)$$

where t is time and the sea water has permeability, μ_o, and conductivity, σ. If the magnetic field is prevented to a significant extent from penetrating underneath the conducting sheet because of the good electrical contact of the sheet with the sea water, then the magnetic field can be increased on top of the conducting sheet as illustrated in figure 2B. For insignificant distortion one needs $(d+h) \ll w$. As an example, however, for t = 1 μs then d ≃ 1m, requiring a rather large w. This criterion that $(d+h) \ll w$ is harder to meet for longer and longer times. Of course, the magnetic field eventually penetrates through the water, around the conducting sheet to beneath the conducting sheet, relieving the distortion to some extent.

3. All units are rationalized MKSA.

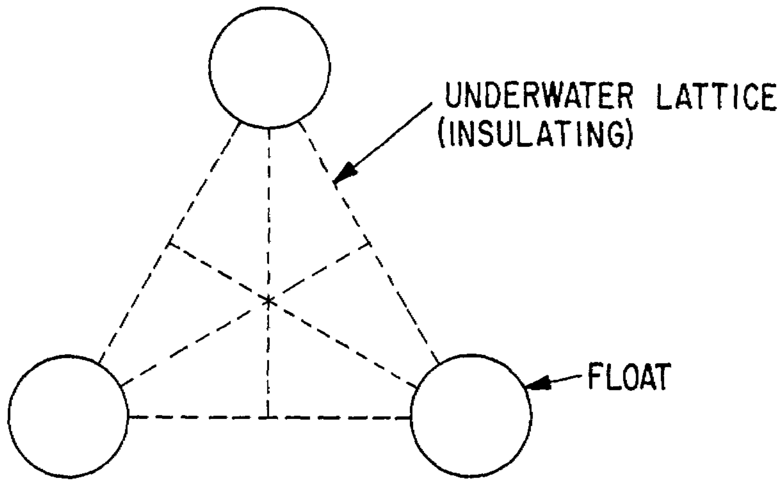
There may then be significant magnetic field distortion associated with the local-ground-plane sensor platform, but relatively less electric field distortion. For sufficiently high frequencies the magnetic field penetration into the water is not significant and this type of sensor platform may be applicable for such a measurement.

There are other advantages to this local-ground-plane approach. The conducting sheet covers up sensor cables, orientation systems, etc., which might distort the electromagnetic fields, to some extent, in the vicinity of the various electromagnetic sensors. One might even construct a shielded, water-tight signal distribution system underneath the conducting plane. Also one might try to design the platform to keep water away from the central part of the top side of the platform, where the sensors are located. This could be important for high impedance devices such as E field dipoles which might be shorted out by the conducting sea water. As with other platform designs, consideration should be given to the effects of wave motion, spray, etc., regarding their effects on sensor response. For some sensors such effects may have to be significantly suppressed or sufficiently calm sea conditions will have to prevail.

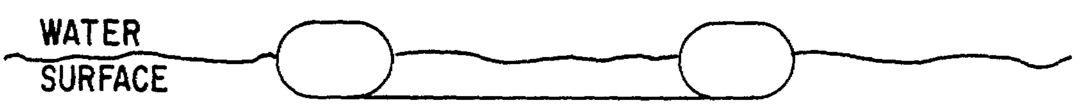
Note that this ground-plane approach applies best to the case of insignificant air conductivity. In the highly conducting source region for a near surface burst, the electric field component parallel to the water surface can be significant if the air conductivity approaches the sea water conductivity. The conducting platform would then distort this tangential E field, and, through the nonlinear air conductivity, the vertical E field would be distorted as well. Likewise the high frequency components of the tangential B field would be distorted because of the changed local air conductivity and the increased conductivity of the nearby lower medium. If the air conductivity is significant, but does not approach the sea water conductivity, then the platform would not be shorting a significant electric field component. However, there may be problems associated with boundary-layer or plasma-sheath effects at the interface of the conducting air and the conducting platform. The local-ground-plane approach may possibly apply in some cases if the air conductivity is not too high; it applies, at least for the vertical electric field in the air, for cases with insignificant air conductivity.

III. "Invisible" Platform

Now consider a sensor platform which is designed to leave the sea-water surface essentially undisturbed and has an insulating structure which is mostly subsurface and which does not significantly interrupt the current flow in the water. Such a platform might be like that illustrated in figure 3, consisting of floats and an underwater lattice to which sensors, orientation systems, etc., can be attached. This type of approach has an advantage that some sensors, if appropriate, can be placed under, as well as at, or above the water surface. It has a disadvantage in that sensor cables, orientation systems, etc., are not "hidden" beneath a conducting ground plane. These items will then have to be designed and located so as to achieve an acceptably small field distortion. This type of approach to a sensor platform does not have the magnetic field distortion problem associated with the magnetic field penetration into the sea water (as the local-ground-plane platform may have) because there is no conducting plane to locally inhibit this penetration.



A. TOP VIEW



B. CROSS SECTION VIEW

FIGURE 3. "INVISIBLE" PLATFORM.

For the case of insignificant air conductivity the "invisible" platform might also include an insulating sheet on the water surface to smooth the surface and make it better defined. Such an insulating sheet might help protect some of the sensors from the salt water environment. However, additional features may be needed to prevent the salt water and spray from coming over the insulating sheet and affecting the performance of some of the sensors.

If the air conductivity is significant such an insulating sheet would distort the vertical conduction current density and thereby the electromagnetic fields as well. Thus, the natural sea-water surface should be in contact with the conducting air. For such a platform the rough, moving sea-water surface may be a significant problem. Perhaps the water surface can be stabilized to some degree by the use of insulating baffles which are arranged so that they do not significantly distort the current density in either the air or the water.

If the air conductivity approaches the sea-water conductivity other problems enter into the design of the sensor platform. In particular, the sensor cables and other items below the water surface can distort the fields both below and above the surface. This may require layout of the sensor positions to minimize such problems. If the fields are not distorted below the water surface, then the fields can also be measured there. In some cases this may be desirable because the sensors can be at least partially shielded from the nuclear radiation. For example, some electromagnetic sensors, such as $\dot{B}$ loops, can be designed to work in a high conductivity environment.[4] Since the magnetic field is continuous across the air-water boundary, a measurement can be made either just above or just below the surface.

The "invisible" platform may represent a more difficult design problem than the local-ground-plane platform. The "invisible" platform may be necessary, however, to avoid distortion of the electromagnetic fields for cases of significant air conductivity, i.e., in the source region for a near-surface nuclear detonation. An "invisible" platform may also be preferable to a local-ground-plane platform in some cases for use with insignificant air conductivity. An example might be for magnetic field measurements when interference of the sea water with the sensor may possibly be avoided in the sensor design.

IV. Summary

There are at least two general concepts for a platform for electromagnetic sensors at a sea-water surface. The first concept is the local-ground-plane platform in which a conducting sheet in electrical contact with the water is used to establish a well-defined conducting ground plane. Such a platform may be advantageous for electric field measurements for cases of negligible air conductivity. In such cases it may also have

4. Capt Carl E. Baum, Sensor and Simulation Note XXX, The Single-Gap Cylindrical Loop in Non-Conducting and Conducting Media, Jan. 1967.

some application for magnetic field measurements. The second concept is the "invisible" platform in which the platform is made of insulators arranged so as not to disturb the electromagnetic field distribution. Such an approach can avoid significant platform field distortion even at very high air conductivity levels, in the source region for a near-surface nuclear detonation. For cases of insignificant air conductivity an insulating sheet may be used to control the water surface motion and still be "invisible". An "invisible" platform may be desirable in some cases for magnetic field measurements, even at insignificant air conductivity levels, to avoid magnetic field distortion.

It should be noted that there are numerous mechanical problems associated with such platforms for electromagnetic sensors, including drag, stability, water waves and spray, etc. However, in designing such a platform, the various electromagnetic problems should be kept foremost in mind. It may turn out that a rather calm sea surface is necessary for proper performance of the sensor platform. It would be desirable to measure the characteristics of such platforms, both electromagnetic and mechanical, under various sea conditions, in order to know the response of a platform and to improve its design.

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