# ELF Communication from radar facility into Sea water

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*Abstract* **ELF refers to the band of radio frequencies from 3 to 30 Hz. It was used by the US Navy to communicate with submerged submarines. Because of the electrical conductivity of salt water, submarines are shielded from most electromagnetic communications. Signals in the ELF frequency range, however, can penetrate much more deeply. The low transmission rate of ELF communications limits their use as communications channels. ELF wave is attenuated by the boundary condition at sea surface and antenna's length is proportional to transmitter power**

## I. Introduction

Low frequency is highly recommended in deep sea communication. A high electrical conductivity of sea water, signals are attenuated rapidly as they propagate downward through it. In effect, the sea water hide the submarine from detection but simultaneously preventing it from communicating with the outside world through normal radio transmissions .

As ELF has long wave length it is very hard to generate because wavelength is proportional to transmitter antenna. There are two large site to transmitter the ELF wave to each Ocean in the world in Wisconsin and Michigan.

Generally communication is reserched in free space, but the way that ELF should go through is not free space but layered media that is seawater. Actually the earth is sphere but its radius is very big then it can be thought palanarly layered media. When the ELF penetrate into the sea water it is solved with Boundary condition. There are reflection and ELF begin to attenuate as it propagate in sea water. Because of its long length ELF has big skin depth. A parameter about the ELF communication in Sea water can show a signal to noise ration with antenna length.

## II. ELF Characteristics and transmitter facility

ELF is defined wave which frequency is 30-300hz but 76hz. ELF wave is used by US Navy for submarine communication. In this case Wave length can be found that light velocity per 76. It is given 3,940Km. By Nyquist rate we must take the sample with 2 times to modulation frequency, we must make the 1820Km sampling waves length that is very difficult to make and it has narrow range ELF has low data rate.

ELF has enough skin depth but there are difficulties associated with the use of ELF for communication purpose. First difficulty is generating the ELF wave. The physical size of antenna is inversely proportional to the frequency( $\lambda \propto$ 1/Freqency). For example, an antenna useful for cellular telephone frequencies, need only be several inches long to be completely effective but at ELF a reasonably efficient antenna must be quite large. So the ELF system, which became operational in 1989, uses two transmitting antennas, one in Wisconsin and one in Michigan. The two sites must operate simultaneously to meet world wide converge requirements[Fig.1] Each antenna looks like a power line, mounted on wooden ples. The Wisconsin antenna consists of two lnes[Fig.2], each about 14miles long. The Michigan antenna uses three lines, two about 14 miles long. The Michigan antenna uses three lones, two about 14 miles long and one about 28 miles long. Each site has a transmitter building near the antenna. The transmitter facility in Michigan uses about six acres of land and the one in Wisconsin about two acres.

## Ⅲ. Boundary condition in surface of sea water

The conductivity in seawater is proportional to salinity. Thus the deeper the water, the less the temperature of water, the salinity is increase. Then we assume that the depth of water is related with the conductivity and other conditions are constant. Then, the deeper we go into the water the salinity is increase and conductivity is increase too. As result, high conductivity by depth of water EM waves propagation is more easier. But the sea is lossy media and skin depth is related to length of wave not the conductivity of media, we need more wave length to communicate in deep sea water.

$$E_i = yE_o \exp(-j\beta_1 z)\, e^{-\alpha z} \text{...(1)}$$

Eq-(1) is the equation of the Plane EM wave to lossy media and characteristic permittivity is $\varepsilon_c = \varepsilon_o - j\frac{\sigma}{\omega}$ ($\sigma = 4$, $\varepsilon_c = 81$, $f = 76Hz$), wave number is $k = \omega\sqrt{\mu\varepsilon} \approx \sqrt{\pi f \mu\sigma}(1-j) = \beta - j\alpha$, impedence is $\eta = \sqrt{\frac{\mu}{\varepsilon_c}} \approx \sqrt{\frac{\pi f \mu}{\sigma}} = \frac{\alpha}{\sigma}(1+j)$, skin depth is $\delta = \frac{1}{\alpha} = \frac{1}{\beta} = \frac{\lambda}{2\pi}$. The wave length $\lambda$ is only related to skin depth and as time past, EM wave is attenuated.

At the boundary of sea water EM wave, at the air its equation is

$$E_i = yE_o \exp(-j\beta_1 z)\text{...(2)} \qquad H_i = -x\frac{E_o}{\eta}\exp(-j\beta_1 z)\text{....(3)},$$

Then the penetrated wave into the sea water is

$$E_t = yE_t \exp(-j\beta_2 z)\text{...(4)} \qquad H_t = -x\frac{E_t}{\eta}\exp(-j\beta_2 z)\text{....(5)}.$$

The power of ELF can be represente

$$P_{av} = \frac{1}{2}\mathrm{Re}[E \times H^*] = z\frac{E_o^2}{2\eta_2}\,|\tau|^2\text{...(6)}$$

As deeper the sea water, $\beta_2$ increase by $\varepsilon_c = n\varepsilon$ then the power of wave is increase. Salinity is related to $E_o$.

## Ⅳ. Parameter for elf communication in sea water

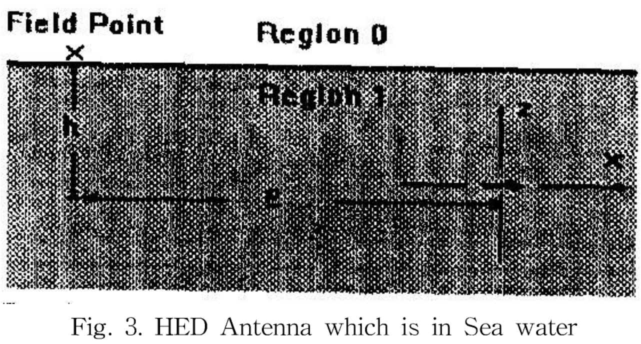


Fig. 3. HED Antenna which is in Sea water

In [Fig 3] a region 0 is free space and region 1 is sea water which has permittivity 81 and conductivity 4[S/m] No matter where the transmitter antenna is, all Elctro magnetic is satisfy the Maxwell equation and the boundary condition. When the anttena is in seawater with depth h, the equation is

$$E_{0Z}(\rho) = \frac{iIL_H}{4\pi\varepsilon_o}\int_0^\infty dk_\rho k_\rho^2 T_{10}^{TM} J_1(k_\rho \rho) e^{ik_{1z}h}\cos\phi\text{...(7)}$$

$$E_\rho(\rho) = -\frac{IL_H}{4\pi\varepsilon_o}\int_0^\infty dk_\rho k_\rho k_{0z} T_{10}^{TM} J_1'(k_\rho \rho) e^{ik_{1z}h}\cos\phi - \frac{IL_H\omega\mu_o}{4\pi}\frac{1}{\rho}\int_0^\infty dk_\rho \frac{1}{k_{1z}} T_{10}^{TE} J_1(k_\rho \rho) e^{ik_{1z}h}\cos\phi$$
...(8)

$$E_{\phi}(\rho)=\frac{IL_H}{4\pi\varepsilon_o}\frac{1}{\rho}\int_0^{\infty}dk_{\rho}k_{0z}T_{10}^{TM}J_1(k_{\rho}\rho)e^{ik_{1z}h}\sin\phi+\frac{IL_H\omega\mu_o}{4\pi}\int_0^{\infty}dk_{\rho}\frac{k_{\rho}}{k_{1z}}T_{10}^{TE}J_1'(k_{\rho}\rho)e^{ik_{1z}h}\sin\phi...(9)$$

$$T_{10}^{TM}=\frac{2\varepsilon_1 k_{0z}}{\varepsilon_1 k_{0z}-\varepsilon_0 k_{1z}}...(10-1),\quad T_{10}^{TE}=\frac{2k_{0z}}{k_{0z}-k_{1z}}...(10-2),\quad J_1'(k_{\rho}\rho)=\frac{dJ_1(k_{\rho}\rho)}{d(k_{\rho}\rho)}...(10-3)$$

(10-1) and (10-2) is the penetrate coefficient.

When a length of antenna is Lv, the open voltage Voc is

$$V_{OC}=-\frac{1}{I_0}\int_0^{L_V}I(Z)E_z(z)dz...(11).$$

But ELF's wave length is much bigger than antenna's length then Voc is apparently $V_{OC}\cong-\frac{L_V}{I_0}E_z(z)...(12)$ And the transmitted power is exract from the equation.

$$P_r=\frac{|V_{OC}|^2}{4R}\quad...(13)$$

From the Equation (7), (12), (13), transmitted power is proportional to receiver antenna length's square. [Fig.4] shows the ampletude change with HED antenna in sea water. [Fig. 5] is the transmitted power when dipole moment is 10Am, f=76Hz, water depth is 50M and receiver antenna length is 40M.

## V. Conclusion

In this work, we investigated characteristics of ELF wave. From the characteristics ELF wave need huge generator. ELF is kind of EM wave and the sea water has the conductivity by salinity. As the ELF wave penetrate into the sea water it shows us a plane wave's lossy media propagation. But the ELF wave has big number then its skin depth is much bigger. As the point of antenna big wave length effect to antenna's current I(z) then equation is apparently same with Eq(13). From this Equation the re0ceiver antenna length's is proportional to transmitted power.

## References


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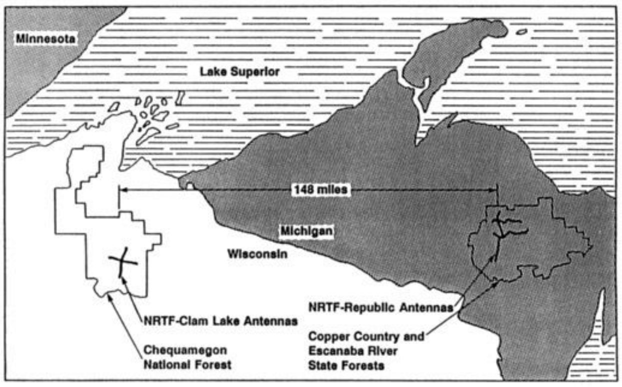


Fig. 1. ELF communication facility in Wisconsin and Michigan

**View of a typical Clam Lake ELF antenna**

Fig. 2. Clam lake in Winsconsin ELF antenna

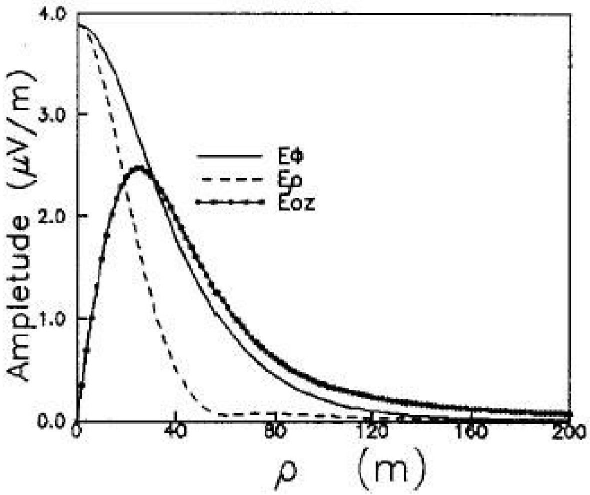


Fig.4 shows the ampletude change with HED antenna in sea water.

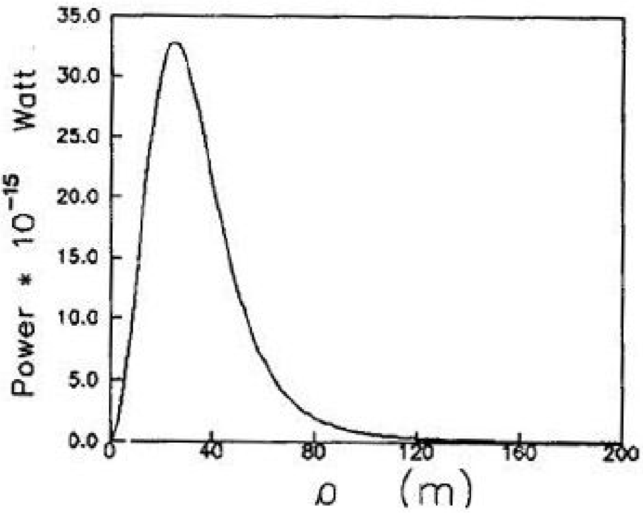


Fig. 5. Transmitted power in sea water
(dipole moment 10Am, f=76Hz, water depth 50M receiver antenna length 40M. )