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REVIEW

To the Question of the Independence of the Surface Electromagnetic Wave Frequency

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ABSTRACT

Earth's the surface is often strongly inductive, consisting of a dielectric layer thickness endpoint, lying on an unlimited conductor basis. Electromagnetic wave, spreading along the surface, it appears captured dielectric layer, spreading it as in the waveguide channel. Waveguide theory it is known that the spread in the waveguide can only electromagnetic waves with a discrete set of frequencies. And experience shows that the captured waveguide channel electromagnetic waves can be any frequency. The article found that this behavior is due to the fact that electromagnetic waves in free space border - dielectric layer damped height in several wavelengths. Thus the thickness of the dielectric layer becomes more effectively, and this leads to a reduction of the minimum frequency of the waveguide. A discrete set of frequencies is blurred so that cover each other. Thus, a discrete set of frequencies becomes solid, and captured waveguide channel electromagnetic waves are independent of frequency.

1. Introduction

Surface electromagnetic waves (SEMW) started exploring Sommerfeld and his disciples [1-6]. Installed set many properties SEMW. Open regions of the Earth's surface, where possible SEMW [7-9]. However, one question remains open. Why the existence of possible SEMW do not depend on frequency? Addressing this issue is the subject of this article.

2. Waveguide Channel for SEMW

Waveguide created artificially, consists of a well-constructed walls. In fact, the walls are metal [10]. Electromagnetic (EM) waves between the walls form a standing wave, this allows them to virtually lossless distributed over the whole length of the waveguide. In nature there are also waveguide, different channels, such as waveguides, implemented by the different density and salinity layers of water in the seas and oceans [11]. Sound like acoustic oscillations are distributed between two layers of water, when almost no. This allows them to spread very far, which is important for submersibles and other technical devices.

For the EM waves in nature there are also waveguide channels. The fact of the matter is that most of media are often either dielectric in which EM waves travel freely without loss, as in free space. Either conductivity, from where EM waves bounce, as the light from the mirror, and practically do not penetrate the conductivity. Earth media can simultaneously possess and dielectric properties, and conductivity. They can be called semi conductivity (not to be confused with semiconductors!). It turns out this classi-

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fication on dielectrics and limited substantially depends on the frequency of EM waves. At low frequencies the Earth media mostly conductivity (or inductive), and on high - dielectric (or capacitive). At intermediate frequencies of the Earth media is a semi conductivity [12].

The Earth media near the surface can often take composed of homogeneous layers. Each layer is either limited or dielectric, or conductivity. And these properties change with frequency change EM. Many of the Earth's land surface have a peculiar structure. At certain frequencies, the first, the topmost layer of a certain thickness turns dielectric. Following the second layer, which is the first layer, it turns out conductivity. Then they say that the Earth media is double layered. This two-layer waveguide turns media channel for EM waves that allows EM the waves propagate along the Earth's surface over long distances. Such EM waves received a special name - surface electromagnetic waves.

SEMW spreading freely in the dielectric layer, are captured in this layer quickly when in a conductivity basis and more slowly in free space. Border top and bottom layers are the walls of the cavity, thus filtering out everything except the frequency of resonance. Only in such resonant frequencies SEMW captured dielectric layer and, therefore, freely available at far distances in this layer. However, the border above between the dielectric layer and free space is not sharply defined. SEMW, loose in a dielectric layer, though damped in free space, but rather slowly, penetrating into the air. This allows you to measure SEMW above the Earth's surface, and use them to solve a variety of technical tasks. Due to the finite attenuation in free space, the resonance frequency is not strictly defined and blurred. This blurring is proving so large that live up to the following resonance frequency. Thus, the existence of the two-ply SEMW surfaces it is possible at all frequencies. Speaking differently, spreading SEMW along the Earth's surface over long distances is not dependent on frequency EM fields.

3. Attenuation Length SEMW in Free Space

As above said SEMW may extend only if the underlying media consists of a dielectric layer thickness h lying on the long-term basis. When the impedance has the following form:

$$\delta = \operatorname{Re}\delta - i\left|\operatorname{Im}\delta\right|, \text{ with } \left|\operatorname{Im}\delta\right| > \operatorname{Re}\delta. \quad (1)$$

Media with the same impedance are called strongly inductive.

The introduction of the impedance is useful at least of what this value is directly measurable. To take one example.

On one of the salt lakes of Southern Siberia at a frequency of 10 MHz have been measured valid $\operatorname{Re}\delta = 0.063$ and imaginary $\operatorname{Im}\delta = -0.139$ part of the impedance [9]. Hence the module $\left|\delta\right| = 0.185$ and phase $\phi_\delta = -82.5^0$ impedance. See that the ratio of (1) really run. When this $\left|\delta\right|$ noticeably smaller units that anticipated with the introduction of the impedance.

For the only nonzero a vertical axis z components of the vector potential in free space have [13]:

$$A_{z0}\left(R,z\right) = \frac{K_0}{\sqrt{R}} \exp\left(-i\omega t + ik_0\sqrt{1-\delta^2}R - ik_0 z\right) \quad (2)$$

Here R is the radial coordinate on the Earth's surface. Next, consider that the $\delta \ll 1$.

Consider how changes in free space with SEMW height above the Earth's surface. To do this, we can rewrite the formula (2)

$$A_{z0}\left(Z\right) = \frac{K_0}{\sqrt{R}} \exp\left(-ik_0\delta_z\right) \quad (3)$$

Substitute $\delta = \operatorname{Re}\delta - i\left|\operatorname{Im}\delta\right|$. Then

$$A_{z0}\left(Z\right) = \frac{K_0}{\sqrt{R}} \exp\left(-ik_0 \operatorname{Re}\delta z\right) \exp\left(-k_0\left|\operatorname{Im}\delta\right| z\right) \quad (4)$$

As expected, the wave with height decreases. Up SEMW could spread only on the height of

$$H = \frac{1}{k_0\left|\operatorname{Im}\delta\right|}, \quad (5)$$

or, order of magnitude,

$$H \sim \frac{\lambda_0}{\delta} \quad (6)$$

In here λ_0 is the length of the waves in free space.

If δ=0.1, then $H \sim 10\lambda_0$. I.e. SEMW exist on the Earth's surface at an altitude not more than an order of magnitude longer wavelength λ_0. For example EM, it is 100 Mhz frequency wave has a wavelength 3 m. SEMW with such frequency is removed from the surface no more than 30 m. SEMW literally dances along the Earth's surface. Therefore it is called SEMW. Of course, this is not a wave SEMW exists only above the Earth's surface. She simultaneously exist in free space and in underlying media.

4. SEMW Propagator Frequency

SEMW distribution occurs in dielectric layer thickness *h* height, and unlimited in two horizontal directions. Fourier image vector potential in this layer is described by the expression [13]:

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$$A_{x1} = D\exp(\mu_1 z) + E\exp(-\mu_1 z) \quad (7)$$

In here $\mu_1 = -i\sqrt{k_1^{\ 2} - \chi^2}$, $\chi = k_1 k_2 / \sqrt{k_1^{\ 2} + k_2^{\ 2}}$. SEMW differ from other waves that outside of the dielectric layer it exponentially, i.e. quite quickly fades. You can take that at the borders *z*=0 and *z*=-*h* Fourier image vector potential becomes zero. Thus, we believe that

$$A_{x1}(z=0) = 0, A_{x1}(z=-h) = 0 \quad (8)$$

Then from (6) that *E*=-*D*, and

$$\cos\left(h\sqrt{k_1^{\ 2} - \chi^2}\right) = 0 \quad (9)$$

To satisfy the last equality, should be

$$h\sqrt{k_1^{\ 2} - \chi^2} = \frac{\pi}{2} + \pi\, n \qquad n = 0,1,2,... \quad (10)$$

It can be shown that use of magnetic field instead of vector potential for boundary conditions will not change ratio (10).

It is convenient to deal with such frequency that the ratio $\varepsilon_0\omega\rho_2 \ll 1$, when this $k_1 \ll k_2$. Next, use a known ratio $k_1^{\ 2} = \omega^2\varepsilon_1 / c^2, k_2 = \omega\sqrt{i/\varepsilon_0\omega\rho_2} / c$, where is ε_0 - dielectric permittivity of vacuum, ε_1 - dielectric permittivity of the dielectric layer, ρ_2 - resistivity of conductive base. Then (10) takes the form

$$\frac{k_1^{\ 2} h}{k_2} = \frac{\pi}{2} + \pi\ n \quad (11)$$

Highlighting the real part (imaginary part frequency has no physical meaning), we get

$$\frac{\omega}{c}\varepsilon_1 h\sqrt{\frac{\varepsilon_0\omega\rho_2}{2}} = \frac{\pi}{2} + \pi n \quad (12)$$

Hence for frequency find

$$f_n = \frac{1}{2\pi}\left[\frac{1}{2\varepsilon_0\rho_2}\left(\frac{c\ (1+2n)}{\varepsilon_1\ h}\right)^2\right]^{\frac{1}{3}} \quad (13)$$

We got a range of frequencies, which should happen SEMW distribution. The lowest frequency is two values *n=0* and *n=-1*. This difference channel waveguide double layered media from the ordinary waveguide, whose lowest frequency corresponds to one value of a number *n*. For all other values of numbers *n* resonance frequency is increasing. However, it is known that measurements of SEMW exist at all frequencies. Let's try to explain this puzzle.

5. Justification Iindependence SEMW from Frequency

In conductivity EM wave fairly quickly fades. It is therefore possible to accept that the boundary between the dielectric layer and conductivity basis is strong as a mirror to the world. The boundary between a dielectric layer and free space more blurred. Wave in free space at a distance of only fades in multiple wavelengths λ_0. For definiteness, we assume that the attenuation length *H* equal 10 wavelengths, i.e. $H=10\lambda_0$. Therefore resonance cavity wavelength has a width not *h*, and *H*+*h*. For a typical wavelength with metal walls increase the size reduces the resonant frequency at which wavelength freely ignores EM wave. The same pattern will for our two-layer media, lying on conductivity basis. New resonance frequency, as it is easy to see, will always meet the approximation $\varepsilon_0\omega\rho_2$ 1.

Let's take for example. For the Arctic Ocean can take ε=4 (dielectric permittivity of ice), ρ=20 m (resistivity of salty ocean water), *h*=2 m (thickness of pack ice). Under these conditions, f_0=25.2 MHz. At a frequency of f_0 the wavelength is 12 m. Means height wave fade away in the distance 120 m. You can say that the effective thickness of the resonator will 120 + 2 = 122 m. Will meet the lowest resonance frequency f_0=1.6 MHz. Because for us the following resonance frequency f_1=3.4 MHz, the difference f_0 - f_1 = 1.8 MHz. And this difference is greater than f_0. That is, it covers the entire frequency range from 0 to f_0, and so far extends to the next frequency f_1. The result means that in fact our two-ply media skips waves with all frequencies from 0 to $2f_0$. And so it will be for all resonance frequencies. All these intervals frequencies overlap with each other. Means the existence of SEMW perhaps at all achievable technically frequencies to media was strongly inductive.

Let's look at another example. For the area of permafrost areas is aware that ε=5, ρ=5000m, *h*=500m [14]. Next, we find the first f_0 =1.6 MHz. This frequency wavelength is responsible λ_0=187m. Where the effective height of the resonant cavity *H*+*h*=500+1870=2370m. From this height the lowest resonance frequency will f_0=1.6 kГц. So, in this region to use distant radio you should use EM waves at frequencies of 1.6 kHz and above.

6. Conclusion

Examples of clear frequencies should use EM waves for the region with highly inductive impedance. Such waves can be used to establish long-distance radio communication, over-the-horizon radar and other technical tasks.

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