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# Surface Electromagnetic Waves

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## Research Article

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**ABSTRACT**

Surface electromagnetic waves (SEW) known 200 years. The first of them has told mankind monk David Brewster (Brewster's angle). Now they are widely used in optical and investigated at THz frequencies in the area which form the basis of the current status and future development of nanotechnologies (plasmonics). History of the research of electromagnetic waves that are different in nature from spatial Maxwell-Hertz waves and emerging on the boundary of two media with different dielectric properties, developed from universal acceptance in the early XX century the concept of SEW Sommerfeld-Zennek, until her categorical denial by middle-century, the revival of interest in 60-years and an experimental confirmation by the beginning of XXI century. In Russia, intensively developed theory of SEW, were experimental proof of the existence of SEW: waves of ultrahigh frequencies detected and investigated in the laboratory in the magnetized semiconductor ; on salt (ocean) water; gas plasma and metals; were observed in vivo. SEW exist at frequencies up to optical. To date, they are best explored in the ultra high frequency range. Extended field studies in the field of high, low and Ultralow frequencies holds exciting prospects: (OTH) radar, new channels of global telecommunications, monitoring the surface of oceans, weather management, wireless transfer of energy flows on the surface and the bottom edge of the ionosphere from continent to continent. SEW have dramatic past, pragmatic present and a great future.

## INTRODUCTION

Existence and properties of SEW follow from solutions of Maxwell's equations with appropriate boundary conditions. Known Fresnel task (shooting, bounced, refraction waves) additional task carried out on eigenvalues associated on the boundary of fluctuations of the electromagnetic field and matter (called Plasmon optics or Plasmon-Polariton) [1] (**Figure 1**).

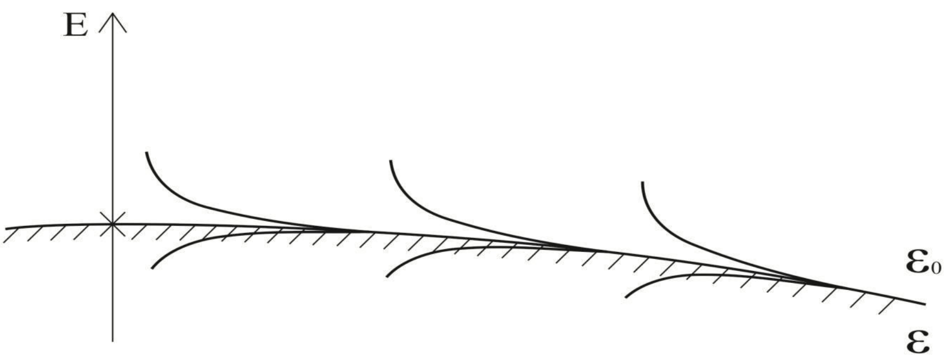


**Figure 1.** Surface electromagnetic wave, spreading along curved surface. E-field strength; Ɛ , Ɛ0 -dielectric permeability of media.

## NATURE OF SEW

- Surface electromagnetic waves -characteristic oscillations for type surface section two media. They represent the

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fluctuation of charge carriers involved (atoms and molecules of the dielectric) or free (conductive media), accompanied by the emergence of electromagnetic waves whose amplitude decays exponentially when you delete in both sides of the interface, as well as along it; maximum amplitude is on the surface. When removing from the axial-symmetric source along the surface in the absence of the attenuation of the amplitude of the SEW decays is inversely proportional to the square root of the distance (divergence). Wave "glued" to the surface and follows its curvature.

- The nature of spatial and surface electromagnetic waves varies. The spatial waves Maxwell-Hertz are «waves field» [2].
- Surface waves Tesla-Sommerfeld- Zenneck price tag is "wave current" inciting "wave field" in both neighbouring media [3].

## OBSERVATION OF SEW

- SEW observed in a wide range of frequencies: from the lowest to the optical. Theory of the SEW has been developed by scientists from different countries for decades, but experimentally the existence of the SEW has been proven by Russian scholars: in vitro in range SHF installed physical properties of waves distributed in salt water, gas plasma, in the magnetized semiconductor, metals, on the human body.

### History of Research

- 3 July 1899 Nikola Tesla in Colorado have watched standing surface electromagnetic wave brought lightning strikes the Earth [4,5].
- 1899 Arnold Sommerfeld introduced the concept of "surface electromagnetic waves", when considered the task of axial current in a long live wire and got the solution of Maxwell's equations, the amplitude drops exponentially with distance from the surface of the wire [6].
- 1901 Guglielmo Marconi the broadcast took place across the Atlantic at a frequency of 30 kHz. This is an amazing discovery made on the reflections on the propagation mechanism over the ocean. About the existence of the ionosphere at that time not yet suspected, so the possibility of long-distance radio communication due to reflection from the ionosphere radiobeam was not discussed. Instead, it was suggestedt that in his experiences, as well as in the experiments of Tesla, abandonment of new type electromagnetic wave-surface wave. It is interesting to note that their experiments Marconi crossed the Atlantic Ocean 80 times! Perhaps, because he was only 22 years old. Currently, there are reasonable grounds for believing that in his experiments surface wave excited with Marconi on ocean water and spatial wave was directed into the ionosphere. His excite antennas inverted cone provided wavefront slope forward and part of the radiated energy is directed at the surface wave; the rest energy is directed in a spatial wave going into the ionosphere [7].
- 1902. Robert Wood, studying the properties of metallic gratings of diffraction, found on some frequencies of light deflection from the laws of diffraction, named then "anomalies Wood." In 1941 U. Fano explained these anomalies-the energy of the incident radiation enters brought them surface electromagnetic waves [8].
- 1907.J Zennek pointed out the relationship research with Sommerfeld radiowaves spread over the Earth's surface and showed that Maxwell's equations with the relevant boundary conditions allow a decision which can be called a surface wave sent flat surface section two media, i.e. is a combination of two plane waves, one of which is localized in the air and another in **Figure 1** the earth.
- 1909 A. Sommerfeld first strict theory of propagation of electromagnetic waves emitted by dipole located on a flat surface section of two homogeneous media (land and air)- significant step forward he was in spite of the fact that he did not land a perfect conductor, and atmosphere-ABSOLUT-insulator, and attributed to each half of the ultimate dielectric permeatability and conductivity.
- 1910 A. Sommerfeld had showed that excited be dipole electromagnetic field can be represented as the sum of surface and bulk waves. He believed that, at large distances from the source of the SEW prevails and so they contacted surface wave radiation source; considered proven that on distances from source is a surface wave.
- 1916 N.Tesla wrote that A.Sommerfeld confirmed his (Tesla) conclude the existence of electromagnetic waves propagating on the surface of the Earth.
- 1919-1933 In the theoretical works of Weil, van der Pol, V.A. Fok, etc. Sommerfelds output has been challenged and found to be erroneous.
- 1933-1941 In large-scale field experiments Feldman (1933), Barrow (1937), Mandelstam and Papaleksi (1934-41), studying propagation near the surface of the Earth (the Earth's Ray), animated by conventional radioantennas, surface electromagnetic waves have not been observed. The reason is that conventional radioantennas SEW not excite; they excite only electromagnetic waves Maxwell-Hertz strictly are cross section. For SEW excitation need a special antennas (datskole) creating oblique electric field, possessing both transverse and longitudinal components.

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- 1950 World Radio-established opinions:bring a SEW by real emitters impossible and the concept of SEW records showed physical reality: this wave-myth, Phantom, Mirage, the Flying Dutchman, mathematical focus Academician L.I [9,10]. Mandelstam claimed:"Surface electromagnetic waves do not exist and, in principle, in contrast to surface acoustic waves, may not exist" [11]. It's a misconception to 70 years delayed the development of the world of Radiophysics.
- 1951 Goubo excitecited, observed, but not investigated SEW in metal lines.
- 1950-1970 SEW "blindly" used in the technique, but experimental studies were not because they were «closed».
- 1970 V.N.Datsko found at room temperature on MICROWAVE slow surface electromagnetic waves (surface magnetoplasmon) in magnetized InSb [12-17].
- 1974 P. Hansen watched SEW at frequencies below 15 MHz at Highway 237 km over the ocean, but not realized his results- «anomaly Hansen» [18,19]. In 1989 BDK showed that Hansen has piqued the SEW [20-23].
- 1971-1980 V.Bajbakov@V.Datsko experimentally installed physical properties slow magnetoplazmons MICROWAVE propagating into magnetized semiconductors with high mobility of charge carriers at room temperature; theory of slow SMPW (surface magnetoplasmon) was built by V. Yakovenko and, independently, by J.Kistovich (1983) [24-35].
- 1981-1990 V.I. Bajbakov, V.N Datsko, Yi.V.Kistovich found SEW in salt water [20]. Using a fictional V. Datsko emitter, they stirred SEW the salt water and have explored all her properties.
- 1990-2010 A new direction SEW in the optical frequency range-plasmonics [36].
- 2008 Yi.D.Rotenko constructed logoperiodical antenna SEW Roundhouse type [1].
- 2010-2014 V.N. Datsko watched SEW on human body ; in outdoor metal waveguides ; in metal ; on train tracks.
- 2014-2016 V.V.Shevchenko built the modern theory of SEW to salt water [36-38].

**The Slow Surface Wave (Magnitoplazmon)**

"Previously unknown physical phenomenon, representing great scientific and practical value " - Nobel Prize winner academician A. M. Prokhorov.

- **The Opening Formula**
  - As a result of the violation of the homogeneity of space section of the border media and girotropie of semiconductor in the magnetic field , electromagnetic field spreads on its surface in the form of a one-sided directional surface wave phase velocity, which is much less than the speed of light and depends on the size of an external magnetic field, i.e., the refractive index of medium can be changed in the process of wave propagation (**Figure 2**).

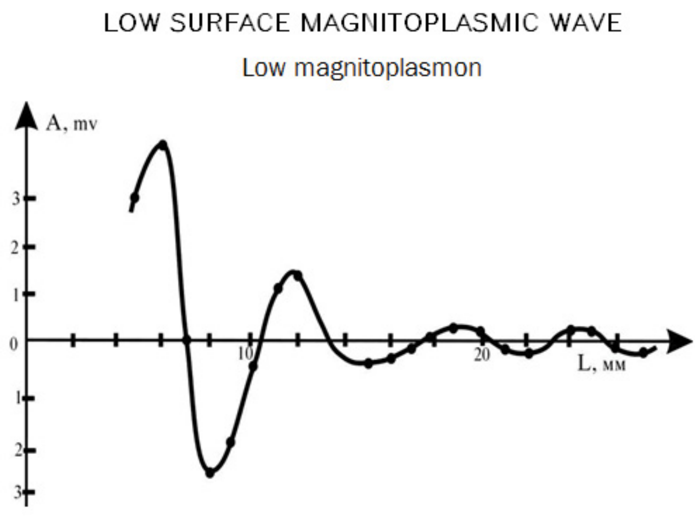


**Figure 2.** Low surface magnitoplasmic wave in InSb. Magnetic field 1,2 T, frequency 35 MGz, angle =- 50°.

**Scientific Novelty and Practical Value of Discovery**

- Slow SEW is making a fundamental change in the understanding of the electrodynamic properties of surface conductive media, structure and surface properties of electromagnetic waves. They can be used to create new methods of research of the surface of semiconductors and metals (at low temperatures), define their parameters and diagnostics of semiconductor plasma. The specific properties of slow waves provide an opportunity to create new sensors magnetic field functional radio device, Active solid state MICROWAVE devices and magnitoplazmennye lamps of running waves,

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managed elements planar optical information processing systems. The SMW devices for which the refractive index may be (depending on the type of plasma) 10-109, could complement the device on SAW (surface acustic waves) and even replace them in the fields of microwave technology, which SAW devices do not apply. SEW are there at frequencies below plasma and cyclotron; on this basis you can create devices that are in range of a few Hz to 1012 Hz, up to-infrared range. These devices are based on a single principle, blocked a broad frequency range if possible smooth frequency agility using magnetic field (**Figure 3**).

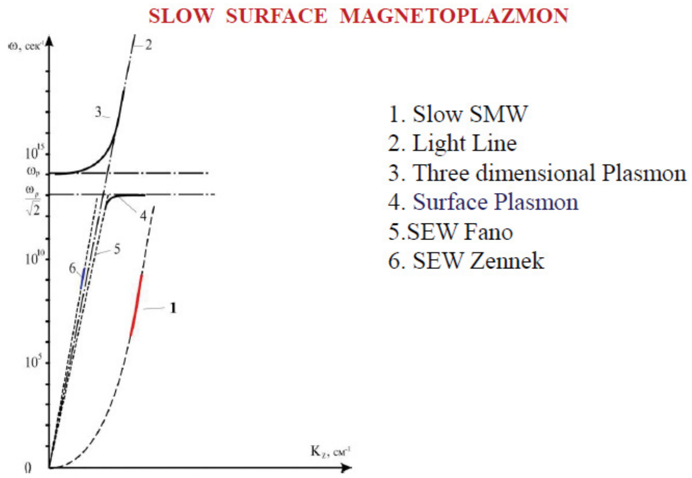


**Figure 3.** Dispersion characteristics of surface waves.

# SEW OPTICAL FREQUENCY RANGE

## Surface Plasmons

- Under certain conditions, between light waves, aimed at border section between metal and dielectric and moving electrons on the surface of the metal resonance interaction occurs: electrons begin to vibrate in tact with the fluctuations of the electromagnetic field on metal in the resulting surface electromagnetic waves or over constitute plasmons – Electron density waves that propagate along the border section like ripples on the surface of a pond, disturbed a fallen stone **(Figures 4-13).**

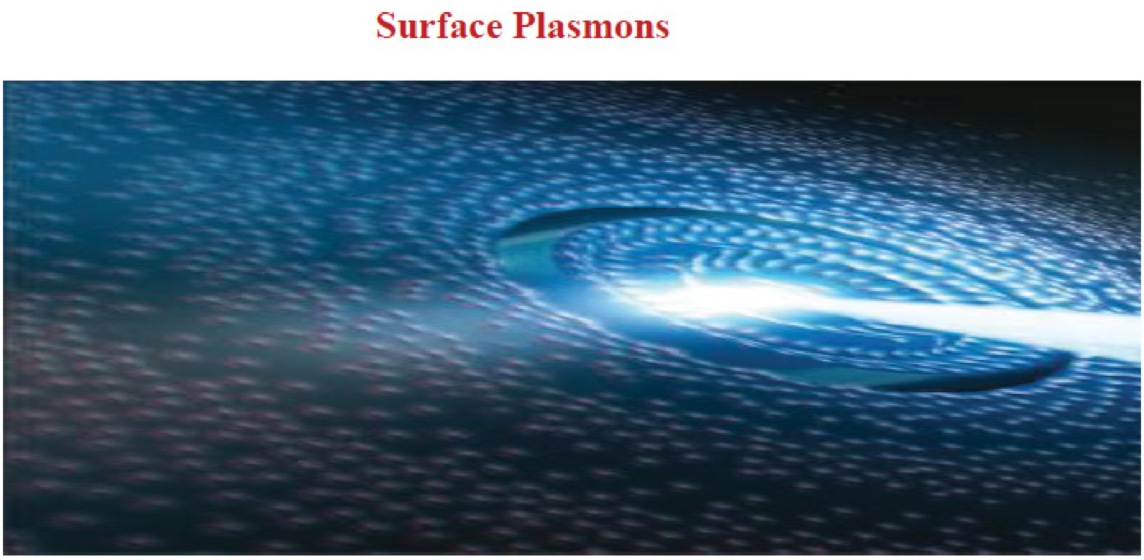


**Figure 4.** Beam of light falling on the surface of the metal, creates plasmons – Electron density waves, which can be used to send huge flows of information. If the light is focused on the surface of the ring groove, there are concentric waves with rings of high and low electron density, as shown in figure.

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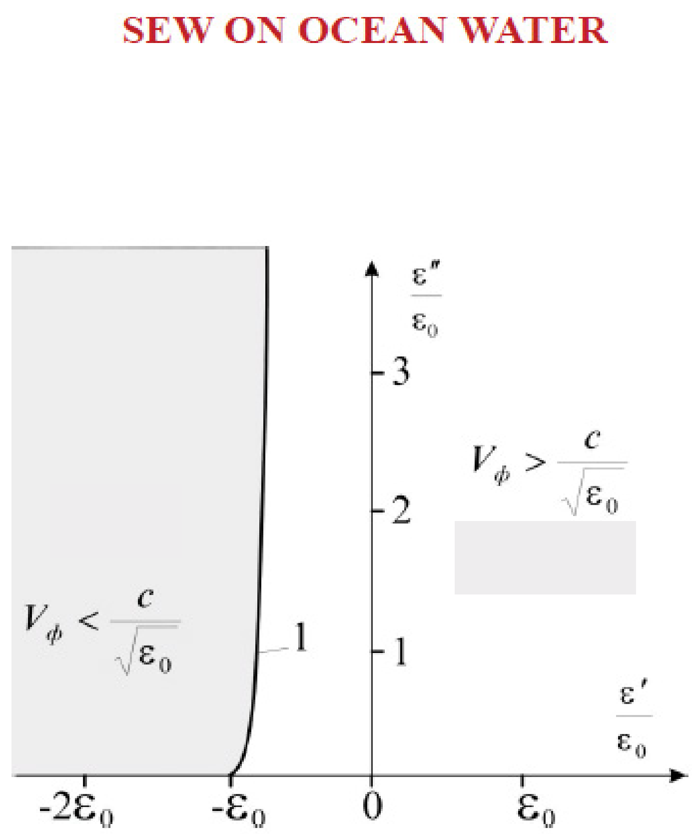


**Figure 5.** The existence of waves of Fano and Zennek.

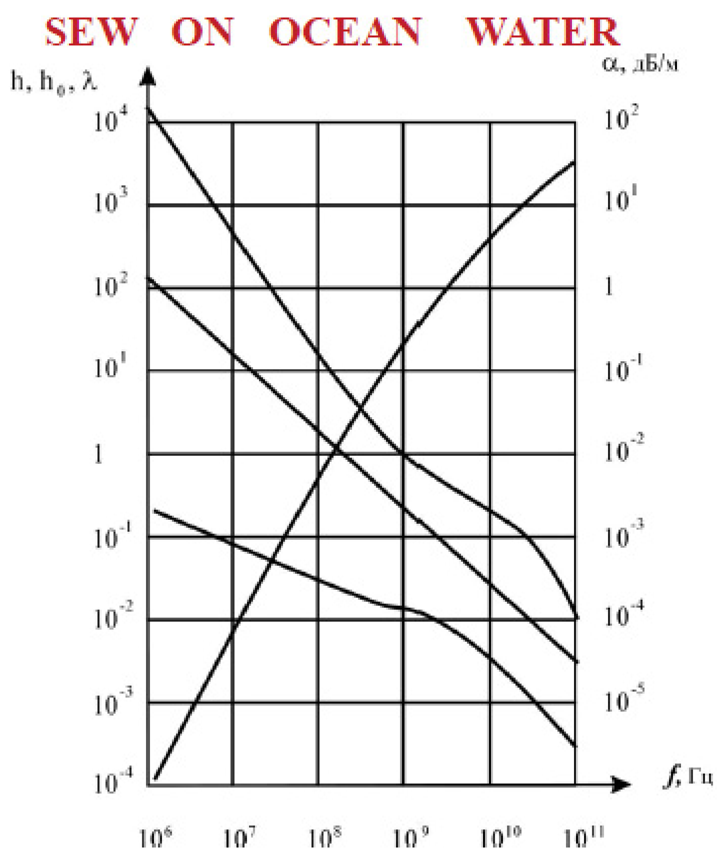


**Figure 6.** Localization of SEW to ocean water and air, and wavelength attenuation as a function of frequency.

Payment data is confirmed experimentally.

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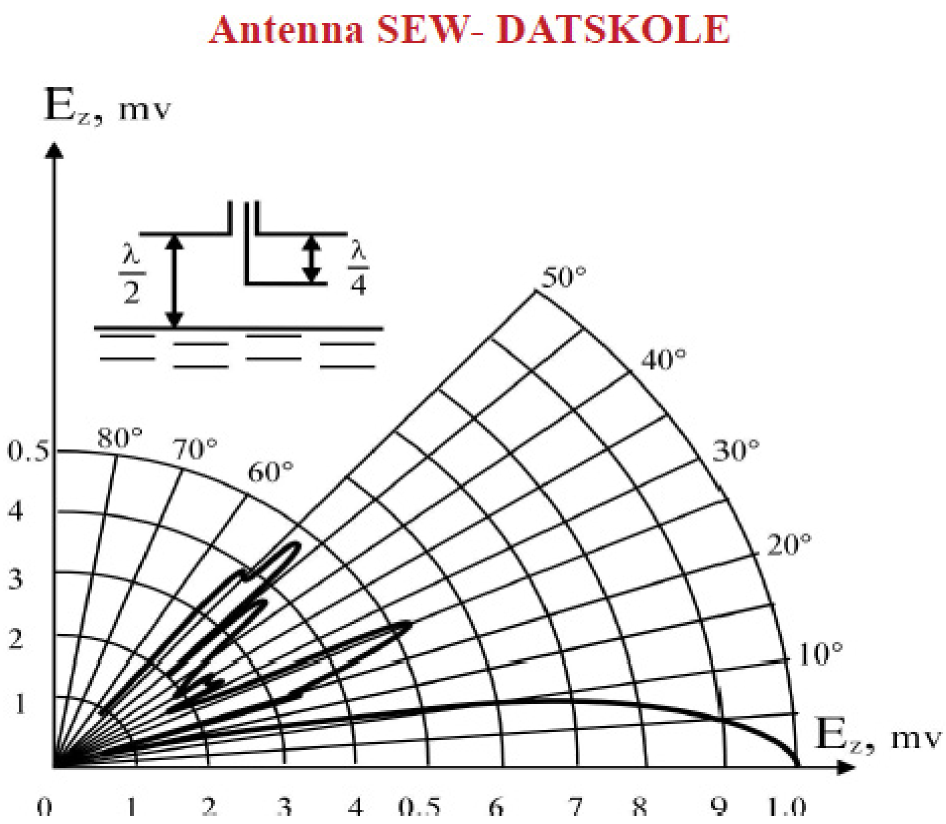


**Figure 7.** Direction diagram: The problem was solved by SEW excitation using Datskole-cavity antennas for a resonance type, which ensures maximum directional on the surface of the water.

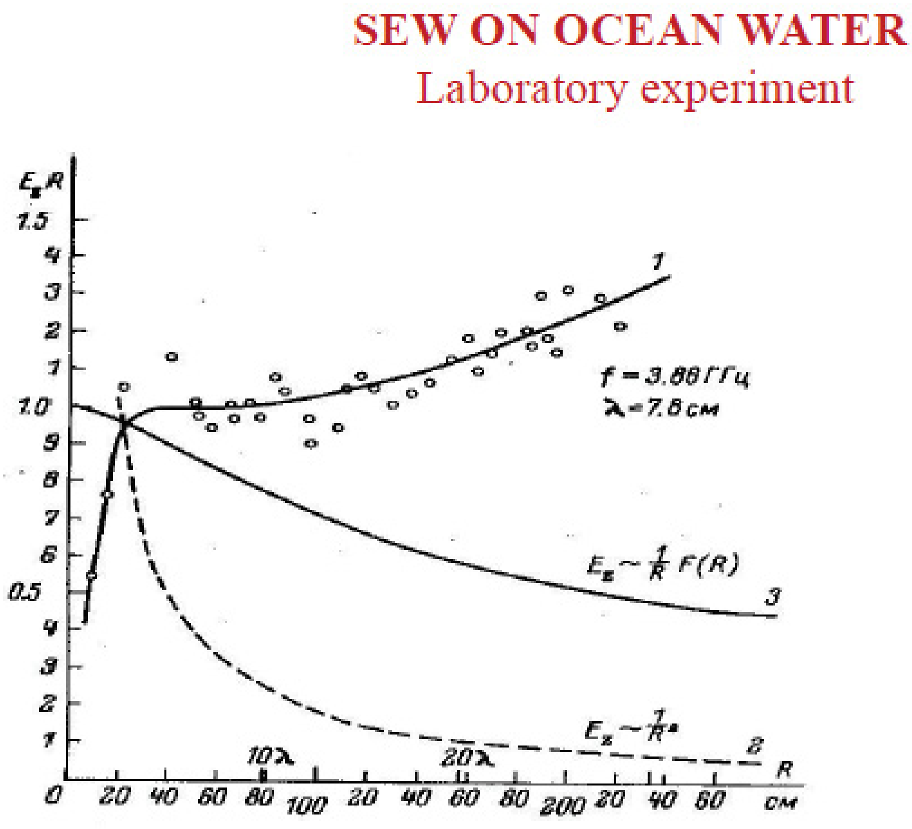


**Figure 8.** Recession electromagnetic field excited by dapole on the surface of the ocean water, removing from the exciter: 1. surface wave; 2. bulk (spatial) wave; 3. "Earth's Ray" (a mixture of surface and spatial electromagnetic waves). Points-experiment, solid curves-the calculation. 3.88 GHz frequency, wavelength 7.8 cm Water salinity of 35 ‰.

The graph on the horizontal axis distance (R, cm), vertical axis-the product of the intensity of the longitudinal components of the electric field of the wave Ez and the distance R(mV x sm).

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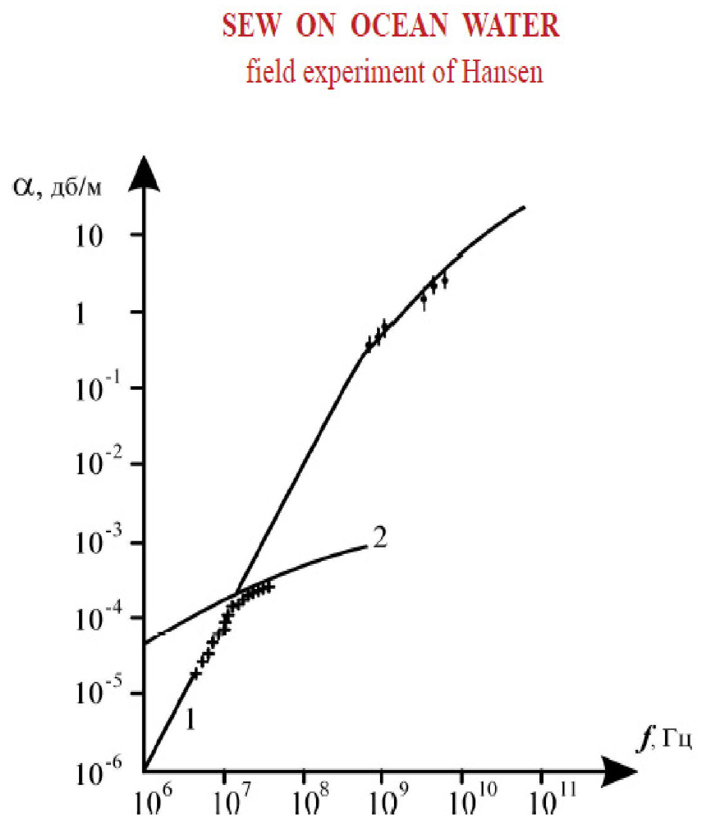


**Figure 9.** Attenuation SEW (1) and the « Eath beam» (2) depending on the frequency of the ocean water.

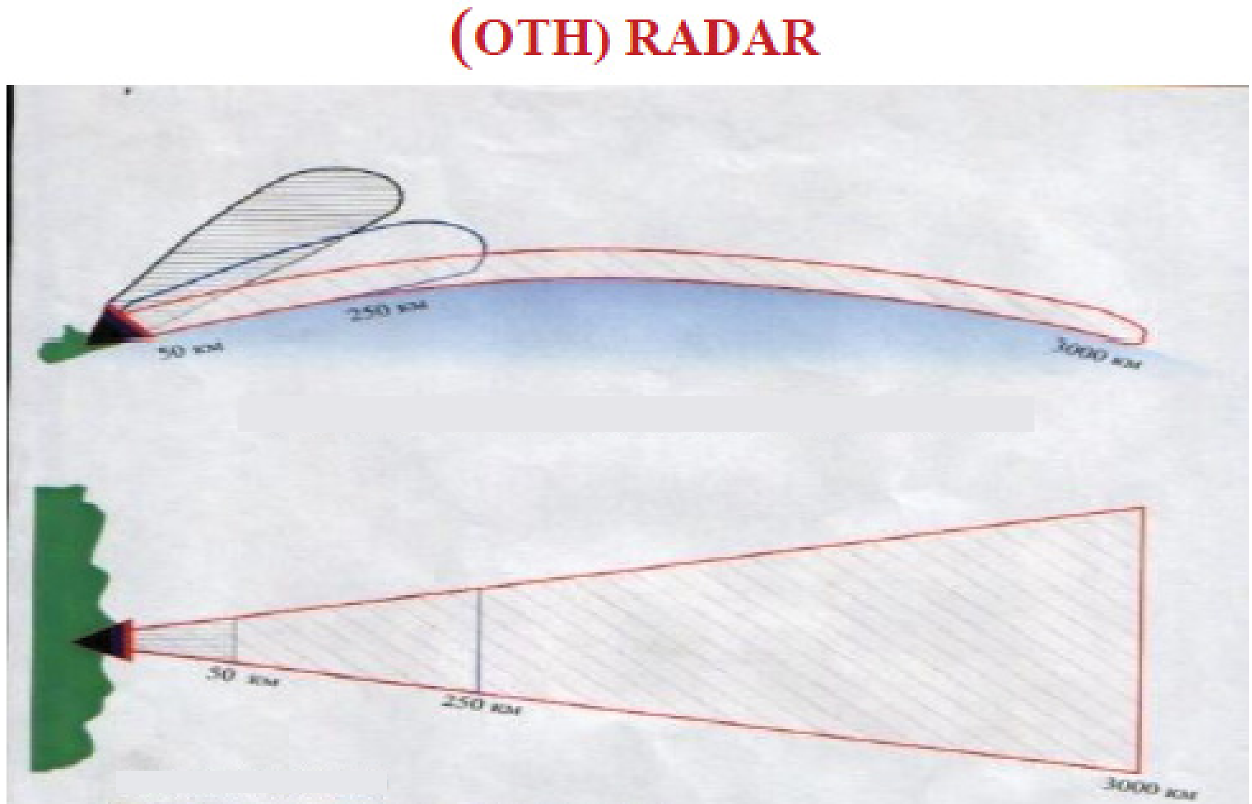


**Figure 10.** Directional pattern and RADAR detection range in volumetric (spatial) electromagnetic wave (black), on ground beam (blue), and the SEW (red).

The range of the RADAR on the VEW-40 km; the "earthly" beam-300 km; the SEW-over 1000 km.

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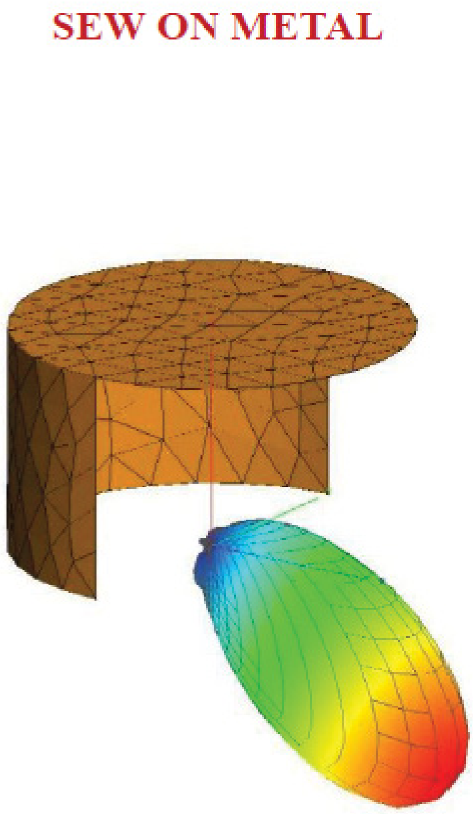


**Figure 11.** Exciter SEW (datskole) and its radiation pattern. Used for excitation of SEW on metal tracks. The Patent of RF.

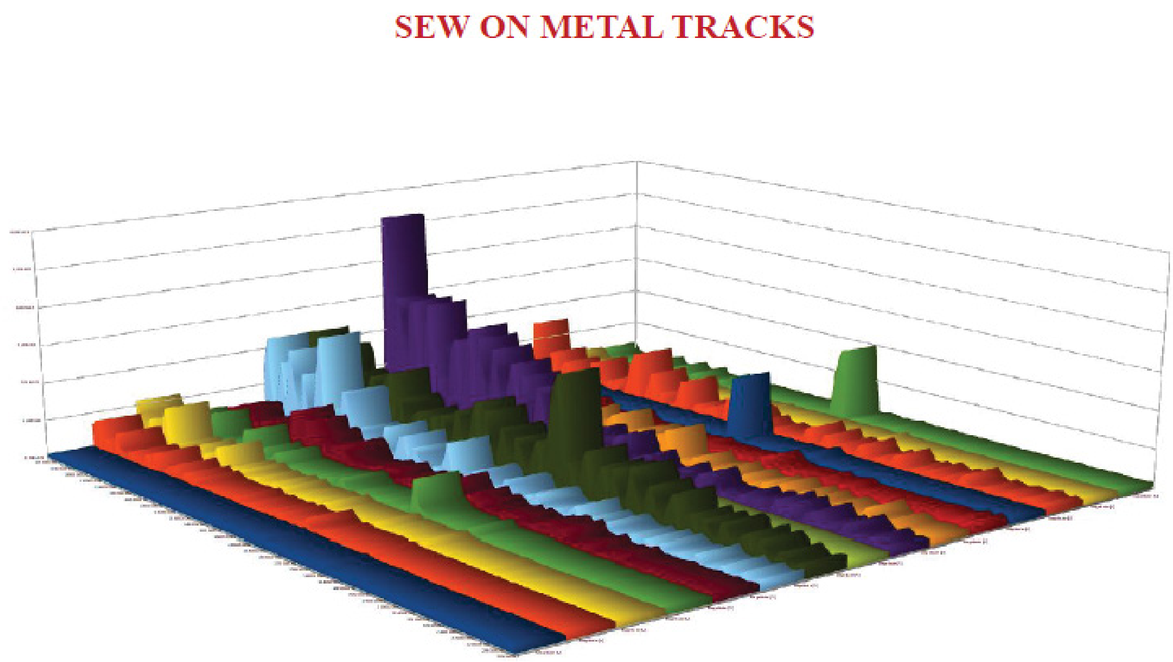


**Figure 12.** Dependence of the intensity of the surface waves (z- axis) of frequency (x- axis) and the distance to the transmitting antenna (y-axis). Minimum distance (3 m) in the center of the violet histogram. In the foreground blue track-background.

Scanning by frequency was produced in each of 14 points (3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39.42 m) distance to the pathogen.

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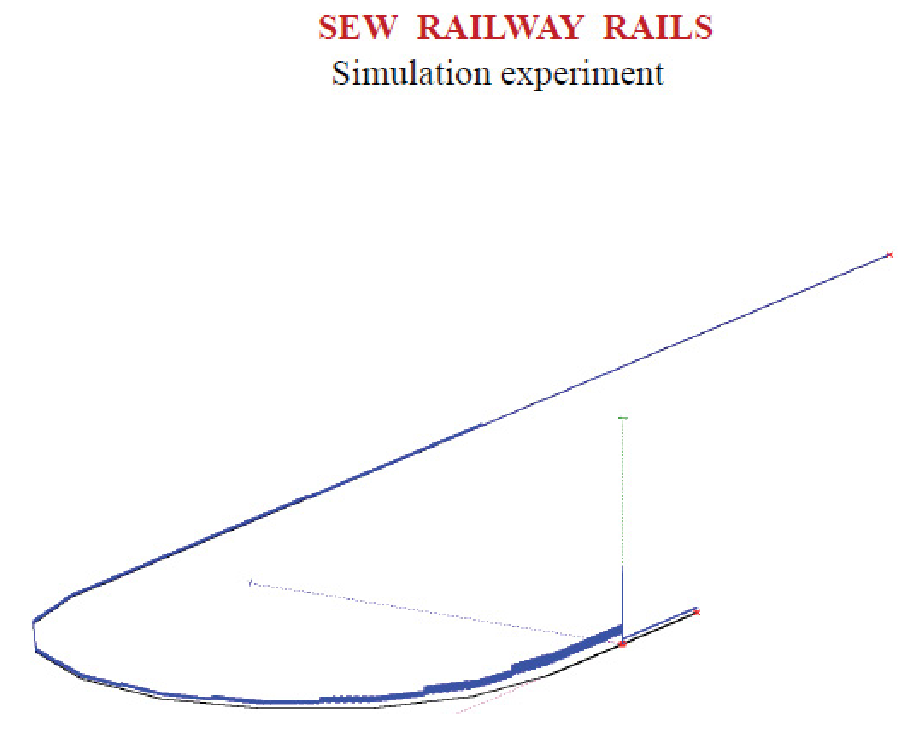


**Figure 13.** SEW on the railroad tracks. The amplitude of the current rail depending on the distance from the pathogen. Red crosses indicate the beginning and end of the plot.

## CONCLUSION

- The concept of surface electromagnetic waves Sommerfeld-Zennek-Tesla, different in nature from Maxwell-Hertz electromagnetic waves-the classical problem of Radiophysics XX century-proven Russian physicists.
- It is necessary to inform the scientific community about the existence of beside us in addition to the spatial (3D) electromagnetic waves also the surface (2D) electromagnetic waves, which are more closely associated with the surrounding media than spatial, and give the scientist the opportunity to look into any secret corner of the investigated space, object or system.
- SEW-the fundamental problem of physics and technology the XXI century. Scope of practical applications is enormous: monitoring of the Earth's surface, the oceans, the ionosphere; nanotechnology, radar, radio communications, navigation, etc.-new directions of scientific and technical progress. The first country that implements the capabilities of SEW will be leaders of scientific and technical progress.

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