ON THE PENETRATION OF THE LONGITUDINAL COMPONENT OF EM FIELDS INTO METALS

Rumen I. Tzontchev[1], Andrew E. Chubykalo[1], Juan M.Rivera-Ju'arez[1], and Vladimir Onoochin[2].

1. Escuela de Fisica, Universidad Aut'onoma de Zacatecas Apartado Postal C-580, Zacatecas 98068, ZAC., Mexico
e-mails: rumen@ahobon.reduaz.mx and andrew@ahobon.reduaz.mx
2. Sirius, 3A Nikoloyamski lane, Moscow 109004, Russia. e-mail: a33am@dol.ru

Abstract. **Penetration of the EM wave with the frequency 14 MHz through metallic shields of different design has been investigated. Despite for normally incident wave the theory predicts the decay of the signal $E_{out}/E_{in} < 0.01$ (i.e. less – 40dBWt) for the shields used in the experiments, the decay of the measured signal was no less – 1.2 dB, i.e. anomalously large penetration of the signal through the metallic layer was detected. This effect can be caused by suppressing the magnetic component in the incident EM wave.**

I. Introduction.

In modern radio science, the concept of the skin layer is well established and its theory is now explained in textbooks on electrodynamics. However, this concept has been recently called into questioned by some authors. These authors note the possibility that EM fields can penetrate into the metal at far greater depths than the thickness of the skin layer. According to these authors' point of view, this anomalous penetration of the EM fields can be caused either by "suppressing" the transversal component [1] of the EM field or by a "quasi-stationary" type of EM field [2].

Thus, this problem requires detailed research. But first, the physical cause of shielding the EM fields in materials having high conductivity must be determined. It should be noted that until now there are some questionable points relative to this problem. For example, the exponential decay of the amplitude of the EM signal in materials used in the barriers mounted in the waveguides is treated by some researchers working on problem of the superluminal signals as a classical analogue of quantum tunneling the EM pulse through the barrier [3].

It was suggested by one of the authors [4], that shielding the EM field is caused by interaction of the *H* component of the penetrating field with the free carriers of the material. As a result, an additional current is created in the layer into which the applied field penetrates and this current generates the magnetic field, which compensates the original EM field. Therefore, if we create conditions such that either the *H* component of the applied field is absent or it cannot create the additional current in the material, we should be able to detect *anomalously large* penetration of the EM field into the material.

So one experiment [5] was performed with the main goal of checking the velocity of propagation of the scalar potential. Actually, the scalar potential, as a physical quantity, cannot be *directly* detected within the laws of classical electrodynamics. But based on well-established formulas of the electrodynamics, we are able to conclude that under certain conditions, the scalar potential is responsible for the dominant component of the *E* field. Because this *E* field propagates with some velocity, we are able to conclude too that the scalar potential *propagates with the same velocity*.

Indeed, in the formulas for the *E* and *H* fields of arbitrary moving charge (the Eqs. 10 of Sec. 1.3 in [6])

$$\frac{\vec{E}}{q} = -\frac{1-\beta^2}{s^3}(\vec{R}+\frac{\vec{v}}{c}R) + \frac{1}{s^3c^2}\left[\vec{R}\times\left[\left(\vec{R}+\frac{\vec{v}}{c}R\right)\times\frac{d\vec{v}}{dt}\right]\right] \; ; \; \frac{\vec{H}}{q} = \frac{\left[\vec{E}\times\vec{R}\right]}{R} \; ; \qquad (1)$$

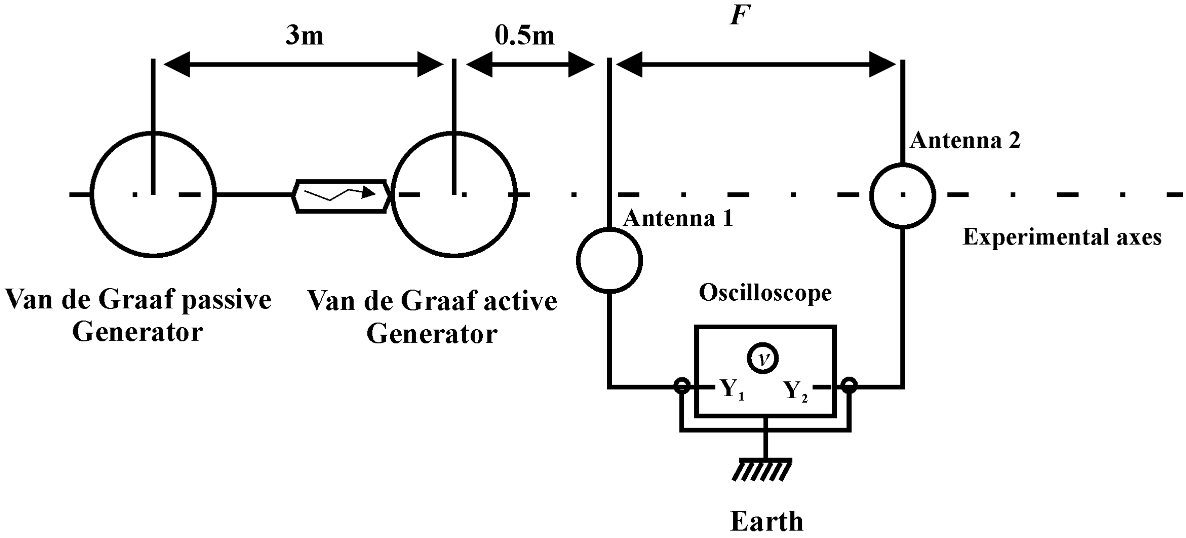
where $\beta = v/c$ and $s = R + (\vec{v}\cdot\vec{R})/c$. It can be seen that the shorter distance from the charge, the stronger the component of the E field, which is independent of the velocity and the acceleration of the charge. So we are able to choose the distribution of the charges and currents in the system in such a way that at a given point in space, the component of the EM field, which can be detected by the measurement device, is created only by the scalar potential and that the intensity of all other components is too weak to exceed the lowest level of detection. (Note: all quantities are given in Gauss units so it is easy to compare values of the electric and magnetic components).

Since only the scalar potential creates the electric component, this EM field, during its penetration in the metal, does not contain the magnetic component. So we should expect the absence of shielding the applied EM field by the metallic layer.

In this paper, we present the results of measurements of the decay of the signal from a Van Graff generator after passes through a metallic shield located in the area where the E component of the scalar potential dominates. By the way, the thickness of the shield is chosen in such a way that, for the resonant frequency of the current oscillations in the generator, the calculated attenuation coefficient must provide the decay of the signal E_{out}/E_{in} < 0.01(< - 40dBWt). The measured decay was less - 1.5 dB.

II. Experimental set-up

For these experiments, the first antenna is fixed at a distance 0.5 m from the sphere of active Van de Graaf generator (the right sphere in the fig. 1, noted below as sphere *A*, the other sphere noted as *B*), which actually is the radiator, and the second antenna is fixed at a distance 1 m from the first antenna. Antenna 1 is connected by a high frequency coaxial cable with characteristic resistance of 50 Ω to channel 1 of the oscilloscope (Tektronix TDS684C) and antenna 2 is connected to the channel 2 of the oscilloscope in the same way. Each cable is impedance matched to both sides. The lengths of the cables are equal, with an uncertainty of 5 mm.



The diagram of the experiment is given in the fig.1.

The Coulomb electric field generator consists of two standard Van de Graaf generators, where the radius of the spheres are equal to 10 cm. A shielded cable connects the spheres, which are separated by a distance of 3 meters and at a height of 1.7 m relative to the ground. But because the discharger is included in the cable, the starting time of the experiment this circuit is disconnected. Two antennas, which are hollow spheres made of copper with radius 9.5 cm, are mounted to the right side of the generator in such a way that the centers of the spheres of both Van de Graaf generators and the second antenna are located on an axis which is the axis of symmetry of the system. The first antenna is slightly displaced from the experimental axis so as not to obstruct the direct visibility between the Van de Graaf spheres and the second antenna. If this does not happen, antenna 1 will behave like a screen and the signal from antenna 2 decreases drastically.

Two types of the experiments conducted. The first was to measure the speed of propagation scalar potential wave and the second was to measure penetration of the E field created by the wave of the scalar potential. The experiments of the first type are described in details in Ref. 5. Here we focus on the experiments to measure the penetration of the E field through the metallic shields.

The noise at the input of the oscilloscope has a value of 10 mVp-p. The measurement sensitivity of the temporal intervals is 0.3 ns. The interference signals, which are due to the effects of the apparatus (interference signal of one channel of the oscilloscope to the other one, possible interference through the power supply circuit, no perfect earth contact etc.), and inductances in the coaxial cables have already been measured. For this purpose, a preliminary experiment was carried out, in which the position of antenna 1 was fixed at a distance of 0.5 m from the sphere *A* and antenna 2 was disconnected from the coaxial cable. The signal in channel 2 of the oscilloscope for various distances between the end of the coaxial cable corresponding to antenna 2 and the sphere *A* was measured. In all cases, the measured signal has a value less than 0.5 % of the signal when the sphere of antenna 2 is connected. The antenna track 1 was checked using analogous methods and the results were similar. This allows means that we do not introduce corrections to account for instrumentation errors.

The temporal symmetry of the antennas of the experimental equipment has been verified. Effect of the aforementioned symmetry can be obtained by using different lengths of the coaxial cables or by introducing an assymmetry into both channels of the oscilloscope. With this end in mind, both antennas were placed symmetrically side-by-side at a distance equal to that of the active Van de Graaf generator. The delay of the arrival of the front end of the impulse in channel 1 with respect to the front end of the impulse in channel 2 for various combinations of the sensitivity of the vertical amplifiers of the oscilloscope was determined. The result is that the delay in all cases is less than 0.3 ns. For this reason, we have considered that, in the following measurements and calculations, the assymmetry in time is equal to 0.3 ns.

III. Measurements.

To detect the effect of penetration, two types of the shields were used in the experiments: thin foils made of aluminum and 5 mm x 5 mm meshes made of iron wire with a diameter of 1mm. For each type of shield, the measurement was made 20 times.

Each measurement was performed in the following way: The sphere *A* (sphere *A*) is charged positively and the sphere *B* is uncharged. The oscilloscope is in a stand-by mode. When electric breakdown occurs in the discharger, galvanic contact is established between spheres *A* and *B*. Because these spheres and the cable with the discharge form the electric circuit, the process of discharging the sphere *A* causes the current oscillations in this circuit. It was found experimentally and confirmed by calculations [5] that in spite of sharp decrease in the amplitude of the oscillations, the resonant frequency of these oscillations is about 14 MHz which corresponds to a wavelength λ = 21.5 m. This value of λ allows us to use the quasi-stationary approximation for the current distribution on the spheres and in the cable to analyze the signal received by the antennas. Actually, the characteristic time of existence of ionized plasma, supporting the galvanic contact between two pieces of the cable, is shorter than the time of some current oscillations with frequency 14 MHz, but it is longer 50 nsec, i.e. the time of measurement of the signal in the antennas. The signals, received by the antennas, were detected by analogue input of the oscilloscope as the voltage on the 50 Ω resistance included serially to the coaxial cable connecting the antennas with the ground. After analogue-digital conversion, the data was stored in the memory of the oscilloscope for each measurement. Then average value of the 20 sets of measured data was calculated.

In order to determine if the magnetic component causes the shielding effect, it is important to eliminate the effects of transversal EM waves, which consist of both *E* and *H* fields, on the antennas, at least during the time the signal is increasing (that is, detection of the front end of the signal). We note that due to symmetry of the experimental set-up, the transversal waves, radiated by the discharger, can affect to the antennas only after reflection from the ground. However, if the reflected transversal waves do affect to the antennas, in the experiments with the shields influence of these waves would be suppressed and we would observe dropping the signal in the antenna 2 when it is put inside the aluminium cylinder. Because we do not observe it in the experiment, we can conclude that influence of these transversal waves is to weak. The other way of influence of the transversal waves to the antennas is the EM radiation caused by the accelerating charge on the surface of the sphere *A* (it is easy to see that due to axial symmetry of the system, the surface current gives the longitudinal component of the *E* field, despite it is composed of the transversal components). To estimate influence of this radiation to the antenna, it was made the following experiment: the cable connecting both spheres was connected to the sphere *A* not at the external surface (extreme left-hand point of the sphere) but the hole was made in the sphere and the cable was placed through the sphere and was connected to the internal surface at extreme right-hand point. With such a design of connection, the surface current must change its direction while discharging. One can see from the Eq. 1 that changing the direction of the vectors of the velocity and acceleration of the charge changes directions of the "velocity field" (created by the vector potential) and of the "acceleration field" (convenient transversal EM waves) but does not change the direction of the electric field created by the scalar potential. This effect allows to separate the account of the *E* field created by the vector potential from the *E* field created by the scalar potential. However, in the experiment with such a design of connection, the value of the signal in the antennas was the same (or it does not exceed the accuracy of the detection), so we are able to conclude that influence of the transversal EM waves radiated from the sphere *A* is below 5% of the detected signal.

We note too that such a design of connection allows to eliminate possible influence of the surface (leaky) EM waves which can be caused by induction of the surface current on the external cover of the coaxial cable by the EM pulse in the discharge. If this current would be essential for forming the signal, the latter would change when the cable connects the internal surface of the sphere *A* because the surface current, and the transversal Em wave created by this current, would stop inside the sphere and suppress while reaching the extreme righ-hand point. Therefore, the signal would change. Because we do not detect it in the experiment, we are able to conclude too that influence of such a surface waves into the signal is below the threshold of detection.

First, measurements were made without the shield before the antennas with the experimental set-up shown in the fig. 1. After 20 acts of measurements were made, average value of the signals detected by both antennas was calculated.

For the experiments with shields, only antenna 2 was mounted inside an aluminum cylinder, one end of which was sealed and the other open. Antenna 1 plays served as a receiver of the reference signal in this experiment. The thickness of the wall of the cylinder is

10 mm and the diameter and length of the cylinder are 600 and 800 mm, respectively. The cylinder is connected to ground. The open end of the cylinder was directed towards the Van de Graaf generator. The shields were used to cover the open end. We note that the shields were mounted on the cylinder in two ways, when the distance between the shield and the edge of the cylinder was 3 mm and when the shield was connected the edge, i.e. to the whole perimeter of the open end, and it was galvanic contact between the shield and the cylinder.

Despite the fact that the decay parameter of the aluminum foil for transversal EM waves (the frequency 14 MHz and the wave vector is directed normally to the surface of the metal, the thickness of the layer is 20 μm) is greater 40 dB [7], the measured (the average of 20 sets of measurements) decay of the signal was about 1 dB for the shield galvanically isolated from the ground and 1.2 dB for the shield connected to the ground.

Correspondingly, for the metallic mesh with a decay coefficient (the frequency 14 MGz and the wave vector is directed normally to the surface of the metal) greater 40 dB (see Ref. 7 too), the measured decay of the signal was about 0.5 dB for the shield galvanically isolated from the ground and 0.6 dB for the shield connected with the ground.

IV. Discussion

We note that these experimental results are in strong contradiction with existing models of EM signal decay in metallic layers. Actually, the concept of the skin layer predicts fast decay of the EM field, no matter the orientation of the *E* and *H* vectors of the incoming wave ([8], Sec. 87). It is easy to see that the concept of the skin layer is based on three points:

- The EM wave are transverse waves, so for any configuration of the waves the *H* component, which is parallel (tangential) to the surface of the metal, always exists; by the way the normal and tangential components of the *E* and *H* fields are linked one with the other via the Maxwell equations;
- The tangential *H* component obeys the equation $\Delta H = -\frac{4pi\, sw}{c^2} H$, so it decreases exponentially with depth ([8], Sec. 59);
- Decrease in the tangential *H* component causes a decrease in depth of all other tangential and normal components of the magnetic field and the surface current (in the metal, the surface current replace the *E* field). Therefore, the depth of penetration of the EM wave is about equal to the thickness of the skin layer and is independent of the angle of incidence of the incoming EM wave.

However, because the incoming wave contains the *E* field only (here we omit discussion why this varying in time E field is not linked with some H field via the Maxwell equation), the above equation for the tangential component does not work in this system and the incoming wave does not drop in the metal.

Finally we note that because the detected signal was in the current form, i.e. it is an energetic not field parameter, we are able to state that the EM waves investigated in the experiment transfer the energy. Therefore, we detected actual transfer of the EM energy through the metallic barrier. Since our result is in strong contradiction with well established concept of the skin layer, we assume that this concept needs in some re-examination. From the other side, about 25% of the energy of the incoming wave was lost or reflected which cannot be caused by interaction of the *E* component with the material of the shield only. So the mechanism of interaction of such longitudinal EM waves with the metallic shields requires more detailed investigations.

References

[1]. E.L. Protasevich, *Radiotehnika i Elektronika*, **35**, 23 (1998) (on Russian).

[2]. T.D. Boyer, *Am. J. Phys*. **62**, 958, 1999

[3]. See, for example, V.S. Olkhovsky and E. Recami**,** Phys. *Rept*. **214,** 339**,** (1992). and LANL ArXiv cond-mat/9802162.

[4]. L.L. Altgilbers and V.V.Onoochin in Proc. 12th IEEE Int. Pulsed Power Conf., 1260 (1999).

[5]. Rumen I. Tzontchev, Andrew E. Chubykalo, Juan M.Rivera-Ju'arez, *Hadronic J*., to be published and LANL ArXiv physics/0010036.

[6]. W. Heitler. *The Quantum Theory of Radiation*, Oxford, 1936.

[7] J. Balcells, F. Daura, R. Esparza, R. Pallas, *Interferencias Electromagneticas en Sistemas Electronicos*, Ed: "Alfaomega-Marcombo", Mexico D.F., 1992.

[8]. L. Landau and E.M. Lifshitz, *Electrodynamics of Continous Media*, New York, Pergamon Press, 1960.