Physical substantiation of Huygens principle and the reciprocity theorem

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Abstract

Huygens principle is the basic postulate of geometric optics; however, it does not reveal physical nature of this phenomenon, which is up to now unknown. In antenna design there is a reciprocity theorem, which asserts that antenna directivity with the method of signal and its transfer are identical. This phenomenon also does not have its of explanation. In the article the physical explanation of Huygens principle and reciprocity theorem is given.

Huygens principle says, that each element of wave front can be examined as the center of the second disturbance, which generates second spherical waves, and the resulting light field at each point of space will be determined by the interference of these waves. This principle is the basic postulate of geometric optics; however, it does not reveal physical nature of this phenomenon. From geometric optics it is known that any beam of light is dispersing and that the area of its section in the process of propagation always increases. This phenomenon is subordinated to the Huygens principle. But is there any physical explanation of this principle? It occurs, there exists.

Let us examine flat monochromatic TEM the wave, passing through the slot, whose width is considerably longer more than wavelength (Fig. 1).

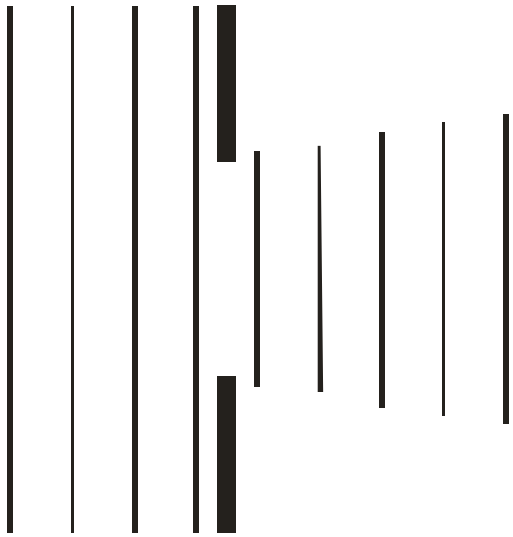

Fig. 1. Passage of the plane wave through the slot.

After passage through the slot wave begins to be enlarged in the transverse direction, and this expansion is subordinated to Huygens principle. In this case in the expanding wave the ends of the paths of constant phase in the process of their motion move with the speed of light still, also, in the transverse direction. But since with this expansion increases beam section, begins to decrease the Poynting vector, which indicates the decrease of electrical and magnetic field on the paths of constant phase. This process of the self-expansion of electric vectors on the paths of constant phase is such to the process of the self-expansion of electric-current wave in the long line described in the thirteenth paragraph. Difference is only the fact that in the line the wave of transverse electric field is propagated, and self-expansion occurs in the direction of propagation. In this case occurs the self-expansion of the vector of electric field still, also, in the transverse direction. In the long line there is no such expansion, since wave in the transverse direction I limit the conductors of line. The transverse transformation of wave is accompanied by the fact that, beginning from the center of path of constant phase along it begins leak bias current. This process is very similar to the expansion of the

compressed elastic, when all its sections begin evenly to be enlarged. In this case the energy density of electromagnetic wave begins to decrease, being evenly distributed in the increasing volume, occupied by the expanding wave.

This simple examination, he indicates the physical causes for the Huygens postulate and is in fact new physical law.

With this phenomenon is connected the so-called reciprocity theorem for the antenna systems, which does not up to now have its physical substantiation. This theorem says, that the mu-factor of the directional antennas is identical both with the emission and with the reception of signal. The strangeness of this theorem consists in the fact that the directional antenna can form the narrowly directed beam, when the radiated energy is concentrated in some direction. This means that the energy density is concentrated in the space limited from the lateral sides. This one can see well based on example of laser beam. However, receiving directional antenna is located in the fields of transmitter, which are evenly distributed in the space, and in order to increase its mu-factor to the directional receiving antenna it is necessary to know how to gather energy from the lateral space. This actually so, but as this it makes, until now, it remains riddle. A question does consist in that, is it possible to find some physical causes for this strange behavior of the directional receiving antennas.

Is known that the laws of geometric optics, when ray can be considered practically rectilinear, work when beam width considerably more than wavelength. In this case Huygens's principle works. Therefore, if we limit the width of beam with the aid of the slot, then its divergence will begin grow, and when the width of slot will become commensurate with the wavelength, after the slot we will obtain the strongly divergent ray, and when slot will become less than the wavelength, then after slot we will obtain the radially divergent waves.

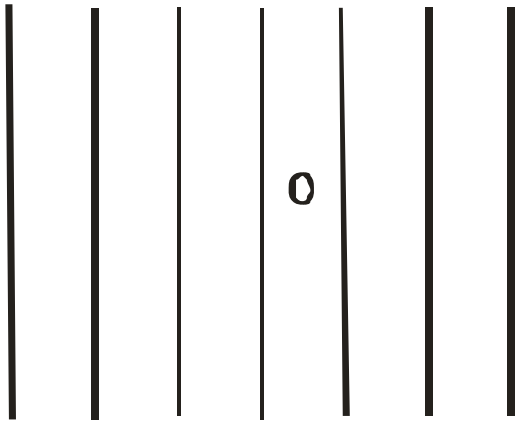

Fig. 2. Diffraction by the waves of the obstacle, whose dimensions are considerably lower than the wavelength.

However, that will be, if we on the way of transverse wave place obstacle? Let us examine two cases. In Fig. 2 is depicted the case, when the width of obstacle is considerably lower than the wavelength. Practically it they do not feel with the diffraction of this obstacle of wave.

We see other entirely picture, when obstacle is considerably more than wavelength (Fig. 3)

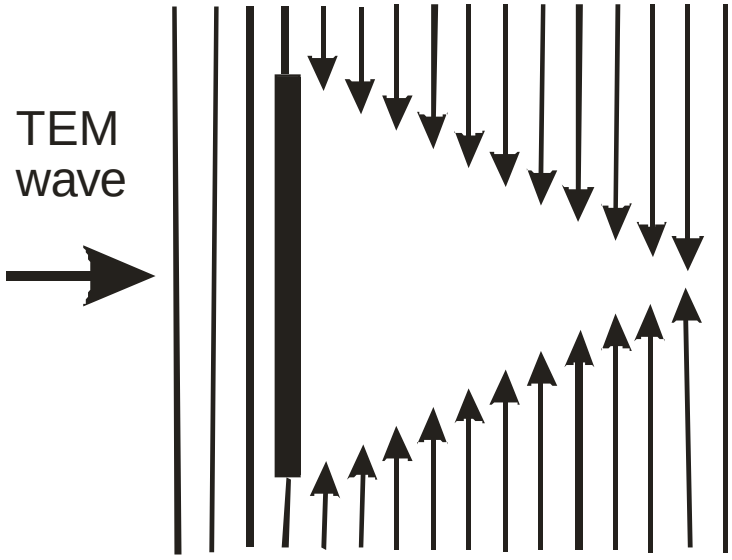

Fig. 3. The case, when on the oscillation loop is located the obstacle, whose dimensions are greater wavelength.

If obstacle on the oscillation loop is executed so that it completely absorbs energy of the incident to it waves, then the picture of wave process appears in the manner that shown in Fig. 2. It is evident that from the right side from the absorbing obstacle there is a shadow zone, where the waves be absent. But passing obstacle, the ragged ends of the waves in accordance with the Huygens principle again begin to converge, bringing additional energy into the space of shadow from the lateral space, which is located beyond the limits of the possible arrangement of the following elements of the directional antenna. This phenomenon bears the name of diffraction. And it is characteristic for any wave processes, including for the electromagnetic waves. But this process has one special feature, which is obvious. Since the absorbing obstacle absorbed the part of wave energy, the wave amplitude to the right of shadow, will be somewhat less than wave amplitude to the left of the absorbing obstacle. This being connected with the fact that the sections of the waves to the right of obstacle, enlarged, they redistribute their energy in the shady section of space after the obstacle. Direction the motions of energy in the expanding section of wave are shown by pointers. This means that in order to liquidate shadow and to restore normal wave process, wave energy begins to be pumped over from the lateral sections of those removed from the shadow zone, enlarging the sections of waves torn by obstacle. In this case summary wave amplitude after the obstacle will decrease.

Let us return to the receiving directional Yagi antenna and let us assume that the second director we arranged out of the shadow in that place, where electric fields arrived, after bringing additional energy from the lateral regions. Situation in this case will be repeated, again shadow is formed after this director. The third director we also can arrange beyond the limits of the shadow of the second director, etc. And each time each new director will occur in the fresh electric fields, taking away in them the energy assumed to him.

But situation with the real directed antenna of the type wave duct is somewhat another. First, the length of director is equal to half of wavelength, and after it practically there is no shadow and the ragged pieces of wave practically immediately are clamped after the director, but in this case energy transfer from the lateral sections into the region of the arrangement of the following director nevertheless occurs.

Let us examine, as behaves this antenna in the field by the flat TEM wave (Fig. 4). Let us assume that numbered wave consecutively occupies positions 1, 2, 3 and 4. After flying so far to the first director, it excites in it currents, making with its emitter, but in this case the part of its energy loses. In this case the first director re-emits the obtained from the wave energy into that surrounding space correspondence with his radiation pattern. Therefore wave after the passage of the first director directly in the region after it has the smaller amplitude of electric field, than to its passage.

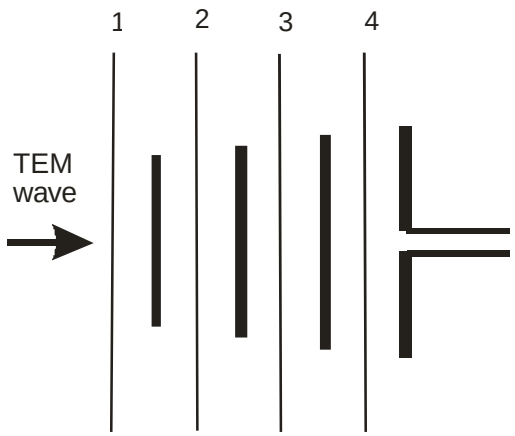

Fig. 4. Yagi antenna in the field of flat TEM of the wave.

In order to compensate for the losses indicated energy from the lateral sections, which lie beyond the limits of antenna field, will begin to be pumped over to the side of the axis of antenna. After the passage of the second director will occur the same. Thus, the phenomenon of diffraction will lead to the fact that the wave energy from the sections beyond the

limits of antenna field will begin to be pumped over into the region of finding the directors. But the currents, induced in the directors, will make the active vibrators, which will increase currents in each subsequent director and after reaching the pick-up dipole, of them, these fields will considerably exceed the fields of wave itself in position 1. With this is connected the circumstance that the directional receiving antenna possesses larger effectiveness than single vibrator. Although to, of course, assert that the mu-factors, both in the regime of transfer and in the reception mode they will be identical, are cannot. Therefore reciprocity theorem although is carried out, most likely, not fully.