DOI 10.1007/s11182-020-01904-z

Russian Physics Journal, Vol. 62, No. 10, February, 2020 (Russian Original No. 10, October, 2019)

ELECTROMAGNETIC PROPERTIES OF PYRAMIDS FROM POSITIONS OF PHOTONICS

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UDC 538.62, 548:537.611.46

The choice of the operating wavelength of electromagnetic radiation is justified for a pyramid considered as an antenna. It is shown that due to the strong dispersion of the refractive index of the pyramid material, there will always be a part of the spectral range, in which the refractive index corresponds to the condition of electromagnetic wave localization (the photonic jet phenomenon). It is shown that the pyramid can simultaneously serve as a transmitting antenna both at the fundamental frequency and at multiple frequencies. Our consideration and approach are not limited only to the shape of the Cheops pyramid and can be generalized to all other shapes of known pyramids. It can be assumed that, despite the difference in the pyramid shapes throughout the world, such structures can play the role of antennas subject to the principle of mesoscale.

Keywords: pyramid, photonics, antenna.

INTRODUCTION

The pyramids of Egypt are one of the most impressive ancient monuments, and some of them are oriented in space with high accuracy. The functional purpose of the pyramids has long been a controversy among scientists [1, 2]. Hypotheses suggesting that the pyramid can be considered as an antenna used to communicate with space were discussed in [3]. In [4], it was mentioned that the pyramid behaves like an antenna due to its shape. In [5], the hypothesis was discussed that the Egyptian Great pyramids were built for the communication purposes between the Sun, the Earth, and the Moon. In [6], the hypothesis was discussed that the Great Pyramid and possibly many other equally huge pyramids, located on the Earth's surface of our planet, are part of a giant network of complex antennas located and configured to perform a specific set of communication tasks. However, despite a significant number of hypotheses, the possible mechanisms for the operation of the pyramid as an antenna still remain open.

In recent decades, the problem of the electromagnetic field localization using dielectric particles has been of great interest [7]. It was shown that under conditions of mesoscale sizes, a dielectric particle of an arbitrary three-dimensional shape, including a pyramidal one [8, 9], can be used for subwavelength localization of the electromagnetic field if the contrast of the refractive index is 1.2–2.2 [10].

Based on the principle of dielectric photonics [7, 8], we consider an idea of possible use of the pyramid as a receiving and/or transmitting antenna. The main hypothesis of this consideration is the assumption that, in order to ensure focusing of radiation incident on the apex or bottom of the pyramid, the minimum size of its face must satisfy the mesoscale condition, that is, be no less than the wavelength of the incident radiation [7, 8, 10]. This is due to the fact that the nature of the electromagnetic radiation scattering by a dielectric particle of arbitrary shape involves the use of

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a dimensionless geometric parameter, which is calculated as the ratio of the equivalent radius of the scatterer to the wavelength of electromagnetic radiation. Therefore, as long as this ratio is maintained and the refractive index of the particles remains unchanged, we are free to choose particles of any desired size and shape illuminated by radiation in any desired wavelength range [7–10].

A characteristic feature of dielectric materials with low losses and a relatively high refractive index is associated with the ability to excite both electric and magnetic dipole resonances of comparable values [10]. For mesosized particles [7–9], the Mie parameter $q = 2\pi R/\lambda$, where R is the characteristic particle size and λ is the wavelength of radiation irradiating the particle, is usually in the range $1 < q < 10$. The parameter $q = \pi$ corresponds to the situation when the characteristic size of the dielectric particle is equal to the radiation wavelength. In this range of parameters, one can observe the overlap of electric and magnetic resonances, leading to the corresponding effects of directional scattering, field amplification, and also some other effects [7–10].

EFFECTIVE REFRACTIVE INDEX

As an example, we consider the Great Pyramid of Cheops. Today, the exact time of its construction is not known, however, in Egypt, the official start date for its construction is August 23, 2560 BC.

There is a generally accepted opinion that the ancient Egyptians actively used the principle of the golden section in creating the drawing of the pyramid. The geometric dimensions of the pyramid are as follows: the average length of the edge is ~ 230.360 m and the height is initially 146.59 m [11]. For these sizes, in order to observe the localization of the electromagnetic field (based on the photonic jet phenomenon [7–10]), an incident radiation frequency of about 1.3 MHz is necessary (it corresponds to a wavelength of λ = 230.35 m in air). According to modern data, the Cheops Pyramid consists of about 2 million huge blocks, the largest of which weigh several tens of tons (the largest central block, located above the entrance to the burial chamber of the pharaoh, weighs 35 tons). Since the pyramid weight is approximately 6.4 million tons, it is located on solid rocky soil. To eliminate gaps between large blocks, the Egyptians used the gypsum-based solution they invented.

Almost all the stones that make up the pyramid are limestone. Even Pliny the Elder described a certain cement-like technology used by the Egyptians two thousand years ago in the construction of the pyramids. Modern experts in geology and paleontology, having studied the composition and structure of the blocks of the pyramid, concluded that they are processed blocks of natural sedimentary deposits. It is now known that limestones were almost pure calcium carbonate ($CaCO_3$), and sandstones consisted mainly of quartz sand grains (SiO_2) with a small admixture of feldspars. However, accurate data on the dielectric constant of the pyramid material in this frequency range are not available today. At the same time, the dielectric properties of nine rock samples (limestone and sandstone) collected in Evekoro, Ogun, and Nigeria were studied in the range of 10 kHz – 110 MHz in [12, 13]. The joint Egyptian-American research group conducted experiments with an electromagnetic probe in the fall of 1974, setting as its main goal to find archaeologically significant cameras in the Giza region [14]. Losses at radio frequencies in the limestone rocks of this region are from 6 dB/m at 10 MHz to 25 dB/m at 150 MHz. The most reliable data on the dielectric constant of materials in the frequency range 0–500 MHz were given in [15, 16]. A sounding scheme without a carrier frequency with a high current was used – an EMP UWB georadar location scheme. This made it possible to provide high depth resolution and accuracy of measuring the distance to the object under examination in a wide frequency range (0–500 MHz) at short emitted pulse duration (less than 1 ns) and in a large dynamic range (about 117 dB). The Wiener–Hopf equation was used to solve the inverse problem in the pattern identification algorithm for EMP UWB sounding [15, 16], which enabled to simplify the task of detecting spatial heterogeneity of the sounded layer and create a method for extracting information from the measurement results at one point.

Figure 1 shows the real and imaginary parts of the relative complex permittivity of various soils. It can be seen from Fig. 1 that in the low-frequency range, the dielectric constant of sand undergoes strong dispersion and can be uniquely determined at frequencies just above several tens of megahertz.

Moreover, there are still several hypotheses, what the stones (blocks) of the Egyptian pyramids consist of. For example, in the 1980s, a theory was proposed according to which the Egyptians did not deliver blocks to the pyramids, but made blocks one at a time in place [17], or the parts of the pyramid were cast by analogy with the limestone

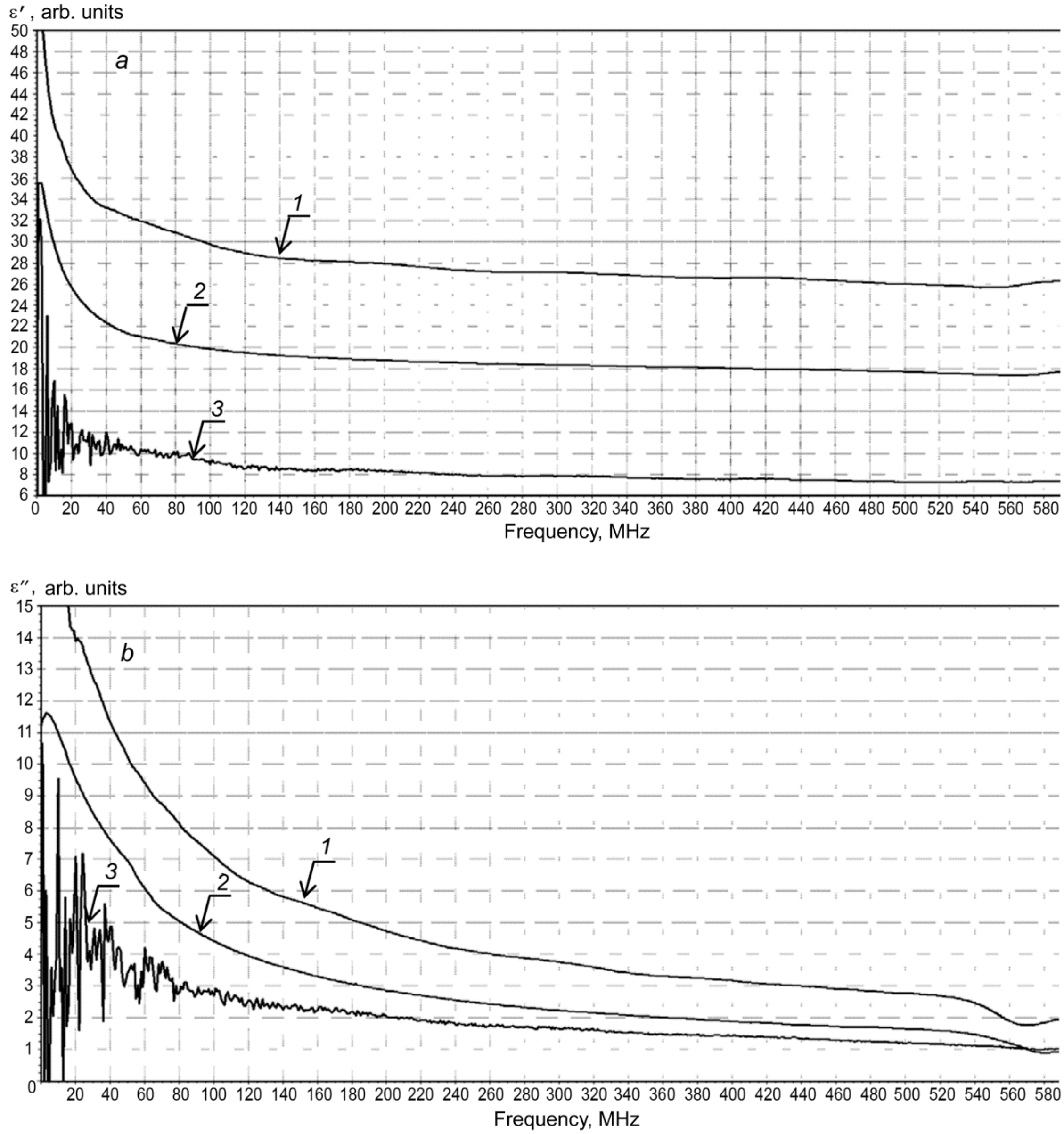

Fig. 1. The real (*a*) and imaginary (*b*) parts of the relative complex permittivity of various soils: clay (*1*), loam (north-west of Eurasia) (*2*), and sand (Middle East – Jordan, Israel) (*3*). With the permission of prof. V. B. Boltintsev.

concrete [18]. Later, another conclusion was drawn that pyramids were built of a mixture of blocks of natural and artificial limestone [19]. Nevertheless, it is possible with a certain degree of probability to assert that at frequencies from several to tens of megahertz, the permittivity of dry sandstone has a strong dispersion. This statement is based on the geolocation data [15, 16, 20]. However, this property can be considered not only as a disadvantage, but also as an advantage, since there are spectral bands (Fig. 1), in which the dielectric constant is in the frequency range required for observing the photonic jet effect. In the first approximation, the dielectric constant of the pyramid material can be determined by the Lichteneker's formula.

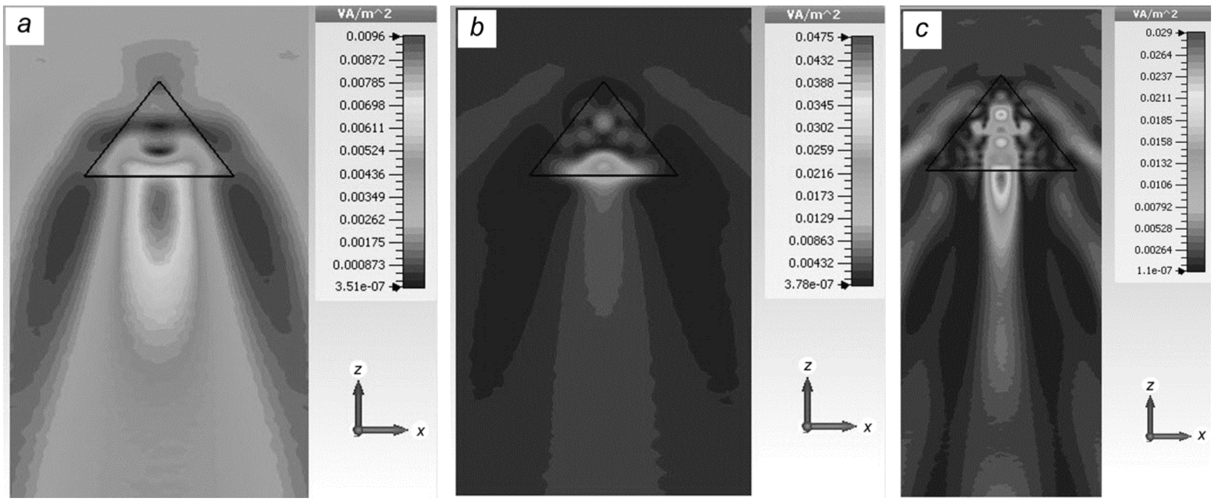

Fig. 2. Distribution of field intensity (E^2) for the pyramid in the receiving antenna mode. The plane wavefront falls from top down, the wavelength is λ = 230.35 m. The effective refractive index of the pyramid material is n = 2.0 (*a*) and 2.65 (*b*), and *c* is the distribution of the field intensity for the radiation at the harmonic $\lambda_1 = \lambda/3$ = 76.78 m for the material with the refractive index n = 2.0.

MODEL

Modeling of the “focusing” properties of the pyramids was carried out using the commercial package CST STUDIO SUITE by the finite element method in the frequency range. Tetragonal volumetric mesh elements with a minimum size 1/10 of the wavelength were used. It is known [4, 14] that the cores of large pyramids were made of the roughly cut limestone blocks, and the seams between them were filled with pieces of limestone and drops of gypsum mortar. These main stones led to the formation of the so-called tiers followed by the masonry, which filled the steps. There was also a softer stone, which builders installed between the core and the casing, and finally, the pyramid was trimmed with a smooth outer casing of limestone or granite. Despite the above, during the simulation, it was assumed that the pyramid is a monolithic homogeneous material.

MODELING RESULTS AND DISCUSSION

Figure 2 shows the distribution of field intensity (E^2) for the pyramid in the receiving antenna mode for two values of the effective refractive index. A wave with a plane wavefront and linear polarization falls from the top down and the wavelength corresponds to λ = 230.35 m. It follows from Fig. 2 that at a refractive index of the order of 2, the pyramid provides the localization of the incident electromagnetic field directly below its base, and at a larger value of the effective refractive index – directly on its base.

It should be noted that at a refractive index of about 2.65, a local maximum of the field intensity is observed in the center of the pyramid, the position of which corresponds to a hollow chamber inside the pyramid [14]. Moreover, as the simulation shows, the pyramids can provide localization of the radiation incident on its apex, not only at the fundamental wavelength, but also at the frequency harmonics ($\lambda_1 = \lambda/m$, where m is an integer). As an example, Fig. 2 shows the field intensity distribution in the vicinity of the pyramid at the third frequency harmonic.

The properties of the mesoscale dielectric emitter in the form of a pyramid allow us to substantiate the hypothesis that the pyramids could also be used as transmitting antennas. Figure 3 shows radiation patterns for

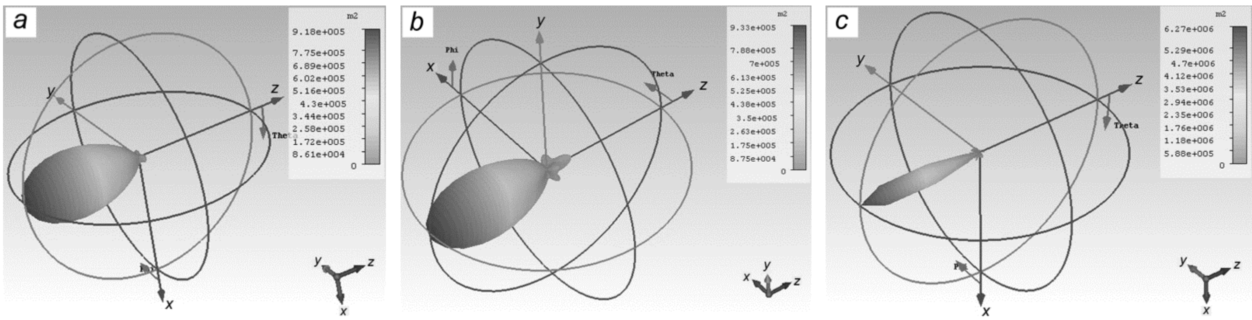

Fig. 3. Radiation pattern for the pyramid in the transmitting antenna mode. The plane wavefront falls from the side of its base, the wavelength is λ = 230.35 m. The effective refractive index of the pyramid material is n = 2.0 (*a*) and 2.65 (*b*), and *c* is the radiation pattern for the radiation at the harmonic $\lambda_1 = \lambda/3$ = 76.78 m for the material with a refractive index of n = 2.0.

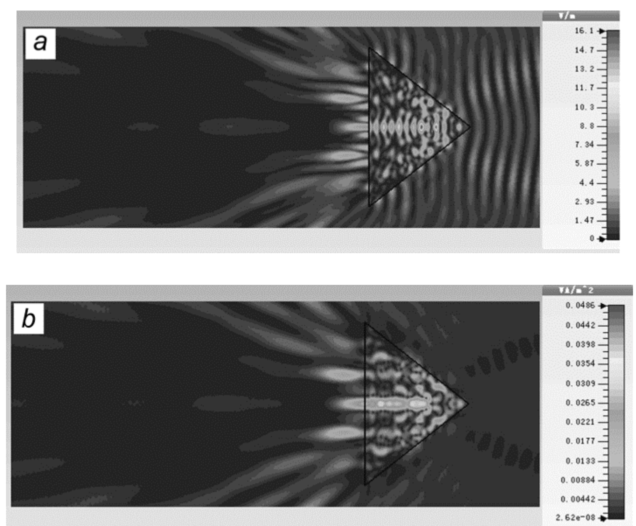

Fig. 4. Electric field intensity E^2 (*a*) and the Poyting vector distribution (*b*) for the pyramid in the receiving antenna mode. The plane wavefront falls from the side of the pyramid apex, the wavelength corresponds to the sixth harmonic $\lambda_1 = \lambda/6$ = 38.39 m. The effective refractive index of the pyramid material is n = 2.0.

a pyramid in the transmitting antenna mode. The plane wavefront falls from the side of its base and the wavelength corresponds to λ = 230.35 m. The effective refractive index of the pyramid material is n = 2.0 and 2.65 (Figs. 3*a* and 3*b*, respectively). The radiation pattern for the radiation at the harmonic $\lambda_1 = \lambda/3$ = 76.78 m for the pyramid material corresponding to the refractive index n = 2.0 is shown in Fig. 3*c*. At higher harmonics, the radiation localization effect is maintained (Fig. 4). Obviously, when operating at the frequency harmonics, the radiation pattern of the transmitting antenna in the form of a pyramid narrows proportionally to an increase in the effective size of the pyramid (Fig. 5).

At the same time, with a decrease in the operating wavelength, the side maxima of the transmitting antenna radiation pattern increase, and the radiation pattern itself becomes more indented.

It is interesting to note that when considering the pyramid as the “receiving” antenna, localization of the electromagnetic field inside the pyramid begins approximately in the region located at a distance of 1/3 of its height (relative to the apex of the pyramid).

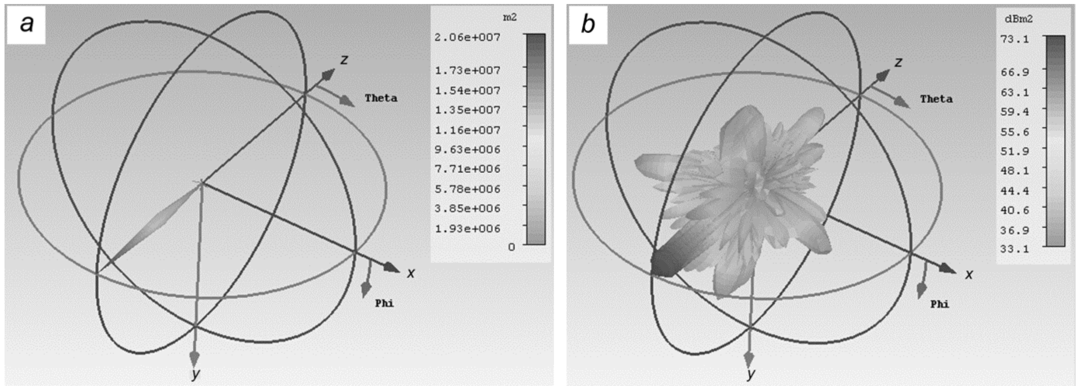

Fig. 5. Radiation pattern for the pyramid in the transmitting antenna mode. The plane wavefront falls from the side of the pyramid base, the wavelength corresponds to $\lambda_1 = \lambda/6 = 38.39$ m. The effective refractive index of the pyramid material is $n = 2.0$, *a* and *b* show the radiation pattern in a linear scale and in a logarithmic scale, respectively.

CONCLUSIONS

However, in general, analysis of the results of the study shows that the pyramids could be used as receiving and/or transmitting antennas in the wavelength range corresponding to the size of the pyramid base or at multiple frequencies. It is shown that due to the strong dispersion of the refractive index of the pyramid material, there is always a part of the spectral range, in which the refractive index corresponds to the localization condition of the electromagnetic wave (the photonic jet phenomenon). It can be assumed that, despite the difference in the pyramid shapes throughout the world, such structures could play the role of antennas, subject to the principle of mesoscale.

At the same time, in further studies, it should be borne in mind that the pyramid is not a monolithic structure. The studies [14] show that blocks are far from uniform in size. Moreover, another surprising feature is the widespread use of irregular blocks and large volumes of filling with mortar and small stones. Recent studies have shown [21] that the Great Pyramid was built of three different materials based on limestone with different inclusions (fragments of crushed shells of mollusks). Moreover, according to [21], three faces of the pyramid, and not just blocks, were made of different materials. Most of the material used was rather rough, since low-quality limestone was used to create the core of the pyramid, while fine white limestone was often used for external coating, as well as for coating internal walls, for which pink granite was sometimes used. Back in the mid-1980s, the French-Egyptian team explored the Great Pyramid using ultrasound technology [22, 23]. Their research showed that large cavities inside the pyramid were filled with clean sand. Thus, the pyramid is a heterogeneous structure. At the same time, studies of limestones from India [24] show that at frequencies of units of megahertz, they have a refractive index close to 4. Nevertheless, the question on the effective refractive index of the pyramid material and its influence on various fine effects remains open.

On the other hand, the hypothesis of using the pyramids as antennas fits into modern research on their astronomical orientation. According to [25], the builders of the pyramids used a pair of fairly bright stars, which in 2467 BC were lying exactly in a straight line, including the north pole of the heavenly radiance. Each star was located approximately 10° from the pole. Based on our current views on astronomy, it can be assumed that prehistoric people were good astronomers with great knowledge of science. There are still many mysteries related to the meaning and origin of the ancient pyramidal structures. Thus, the recent discovery that a cut-through dead-end passage inside the mysterious underground chamber of the pyramid might well function as a sound resonant tube generating infrasound with a frequency in the range of 5 Hz [6, 25–28] is surprising.

Therefore, an approach based on the use of various fields of knowledge is probably the most optimal research method and may well be crucial for our understanding of the true function of not only the Great Pyramid, but also its very mysterious internal structure, and also opens up new possibilities in nanophotonics and plasmonics [29–31]. Moreover, classical methods can be used to study the Pyramids as antennas [32].

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