Optical and Quantum Electronics (2024) 56:51
https://doi.org/10.1007/s11082-023-05682-z

Propagation of light wave around planets in cosmic space

Tibor Berceli[1]

Received: 13 September 2023 / Accepted: 29 October 2023 / Published online: 28 November 2023

Abstract
The propagation of light wave around planets is studied in this paper. There are planets having an atmosphere with permittivity which is high close to the planet surface and gradually decreases with elevation. Based on the results of our investigations when the light beam propagates parallel to the layers of atmosphere, its propagation direction is gradually deviating from the straight line toward higher permittivity layers. This way the light wave follows a curved route. The aim of the paper is to provide a qualitative picture for the phenomenon of light wave propagation bending around cosmic planets.

Some planets have no atmosphere. Their surface is not smooth, in addition to plains there are hills and mountains with varying heights. Therefore, dielectric layers parallel to the planet surface can be considered by an equivalent average permittivity which is high at the planet surface and gradually decreases with the elevation. As its consequence the light beam tangentially incident to the planet surface deviates from the straight line and follows a curved route.

Based on the results of present investigations, it is not necessary to assume that the cosmic space is curved close to a planet containing a huge mass.

Keywords Bent light beam · Inhomogeneity · Layered dielectrics · Planet atmosphere

1 Introduction

The propagation of light wave in inhomogeneous media has been investigated by several authors. There were thorough theoretical studies based on the diffraction of light wave which is described by differential equations of field components (Fock 1965; Keller and Givoli 1989; Felsen and Marcuvitz 1994). Distributed and structured inhomogeneity were also studied (Yeh 2005; Brekhovskikh 2012). Investigations covered the problems of localized inhomogeneity which provides diffraction of light (Fock 1945; Hogan 1967). In the

✉ Tibor Berceli
berceli.tibor@vik.bme.hu

[1] Budapest University of Technology and Economics, Budapest, Hungary

propagation route scattering centers are typically obtained (Quinten 2011; Yushanov et al. 2013). They produce additional loss. Atmospheric turbulences cause unpredictable wave propagation conditions (Sasiela 2012; Blaunstein and Kopeika 2017). As a summary of publications, several investigations have already been carried out on the propagation of light wave in inhomogeneous media usually resulting in wave propagation influenced by diffraction and scattering.

The relevant publications use the principle of the diffraction of light wave and apply differential equations for the electric and magnetic field components. The result is obtained by solving these equations. In the present paper another approach is introduced. According to that method the light wave propagation route is defined by the different propagation velocities in a medium having layers with appropriate permittivity distribution. The aim of the paper is to present a qualitative picture for the phenomenon of light wave propagation bending around cosmic planets. First a dielectric medium with structured inhomogeneity is studied. The investigated medium has parallel layers with different permittivity and therefore the medium is inhomogeneous. The layered medium can have continuous change in its permittivity in such a way that the permittivity is continuously increasing or decreasing perpendicular to the layers guiding the light wave.

2 Planar dielectric layer structure

As a first step, the propagation of light wave is studied in a planar layered structure of a dielectric medium which can guide the light beam. The extension of layers in the cross direction to the wave propagation is much higher than the wavelength of light. The direction of wave propagation is parallel to the layers having different permittivity. Therefore each layer can guide the beam. That planar layer structure with 3 layers is shown in Fig. 1.

Every layer has a smaller permittivity than the permittivity of layer below it and higher permittivity than the permittivity of layer above it. In the case when the optical beam is much wider than the thickness of layers, the beam will propagate parallel in several layers. Wave propagation in three layers is studied now. In the present case ϵ_1 the permittivity of layer 1 is higher than ϵ_2 the permittivity of layer 2 which is higher than ϵ_3 the permittivity of layer 3. E_v is the vertical electric field strength. Therefore we can write:

$$\epsilon_1 > \epsilon_2 > \epsilon_3$$

We take a very short, elementary section of the layers. In the same time interval the wave propagation distance in the layers will be different because the wave propagation velocities in the layers are different. This structure is shown in Fig. 2,

The velocity of wave propagation in the n-th layer v_n is inversely proportional to the square root of layer's permittivity ϵ_n:

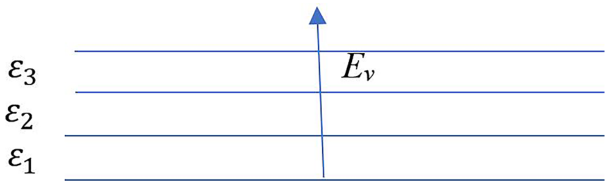


Fig. 1 Planar dielectric layer structure with different permittivity

Fig. 2 The wave propagation distance in 3 planar layers in the same time interval

$$v_n = \frac{c}{\sqrt{\epsilon_n}}$$

Therefore, the wave propagation in layer 3 is faster than in layers 1 and 2. The wave propagation in layer 2 is faster than in layer 1. As its result, the wave propagates to a shorter distance in layer 1 than in layers 2 and 3 and the wave propagates to a shorter distance in layer 2 than in layer 3. This way the wave front is a little bit tilted in clockwise way which is shown in Fig. 2. As its consequence, the propagation direction will be changed accordingly. Then the same effect is noticed in the next elementary section of the inhomogeneous layer structure. That means the light propagation will step-by-step deviate from the straight line.

3 Circular layer structure

A more interesting case is when the layers are curved. A special case is considered when the layers are circular. Such an inhomogeneous structure is presented in Fig. 3.

In Fig. 3 the layers are concentric circles. The radius of the inner circular layer is denoted by *R* and the thickness of layers is denoted by *d*.

The velocity of wave propagation v_n in an *n*-th layer is proportional to ϵ_n the *n*-th layer permittivity: $v_n = \frac{c}{\sqrt{\epsilon_n}}$

This relationship is applied for a medium containing circular layers with continuously decreasing permittivity like:$\epsilon_1 > \epsilon_2 > \epsilon_3$

In circular layers the wave propagation distance has to produce the same Δϕ rotation angle change for each layer in the same time interval. That requirement can be met by an appropriate permittivity distribution. In that case the wave front is tilted according to the Δϕ rotation angle change as seen in Fig. 4.

The detailed derivation of the equations is presented in the Appendix. The result is as follows:

$$\frac{R + nd}{R + (n-1)d} = \sqrt{\frac{\epsilon_n}{\epsilon_{(n+1)}}}$$

That general equation provides the requirement for the permittivity in *n*-th layer (with the limitation: $\epsilon_{(n+1)} \geq 1$). That means satisfying the above relationship in each layer the light beam will follow a circular route with a curvature radius of *R*.

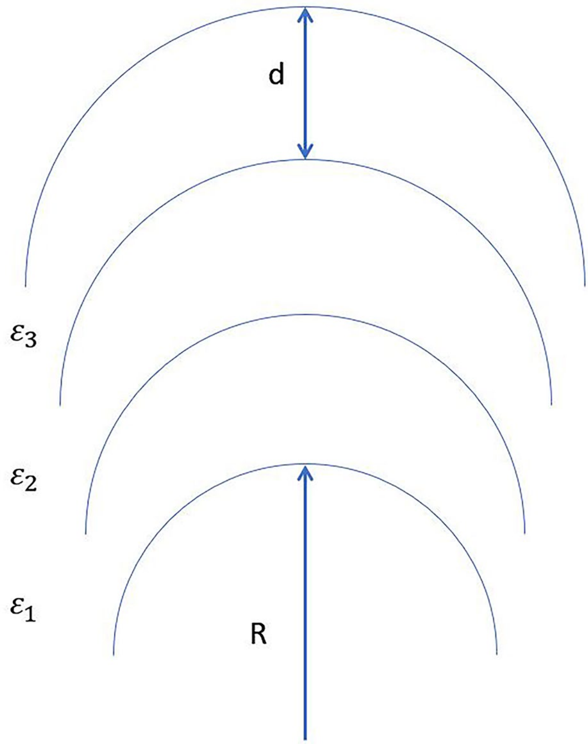


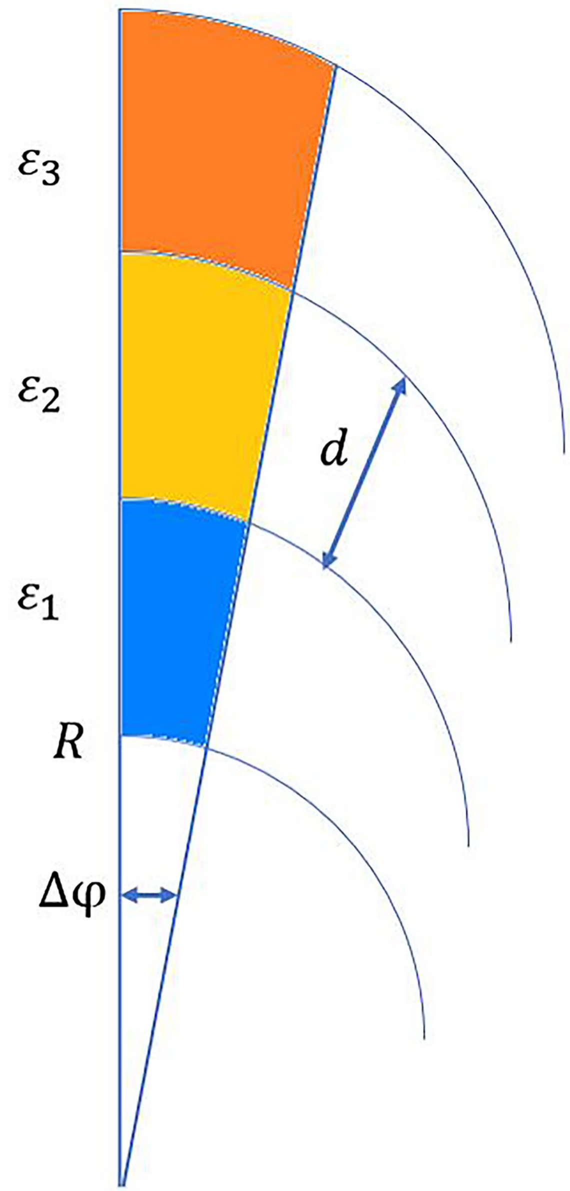
Fig. 3 Circular layer structure with different permittivity

4 Planets with atmosphere

There are planets having an atmosphere composed of some kind of gas. Due to the planet gravitation the density of gas is higher close to the planet surface and it is decreasing when the distance from the planet surface is increasing. As its consequence, the atmosphere permittivity is higher close to the planet surface and it is gradually decreasing with the distance from the planet surface. There is an interesting question: what is the light propagation in such an inhomogeneous medium? To answer this question: the investigation of light wave propagation in a circular layer structure is applied to determine the propagation of light close to a planet having atmosphere.

The planet atmosphere is divided into thin layers parallel to the planet surface. These layers work as circular dielectric waveguides of light wave. The beam is wide enough to propagate in each layer. In that case the wavelength in the layers is longer and longer with the elevation from the lower layer to the upper layer. This relationship makes possible that we can get the same phase condition in each layer at the same rotation angle. Therefore, the propagation of a tangentially incident light wave will deviate from the straight line and will follow a curved route. Usually the curvature radius of wave propagation is higher than the planet radius. Therefore, the light wave leaves the vicinity of planet in a direction deviating from the direction of incident light wave.

Fig. 4 The wave propagation distance in circular layers in the same time interval



Some typical cases are studied in details. For that purpose, we take the ratio of layer thickness (d) to the radius (R) of circle 1 as a parameter. Based on the derived equations three typical cases are presented in Fig. 5.

In Fig. 5 the permittivity of atmosphere is plotted as a function of elevation distance from the planet surface for the case of circular wave propagation route. The permittivity of atmosphere is decreasing from its value at the planet surface as a function of the elevation distance. There are three typical cases as follows:

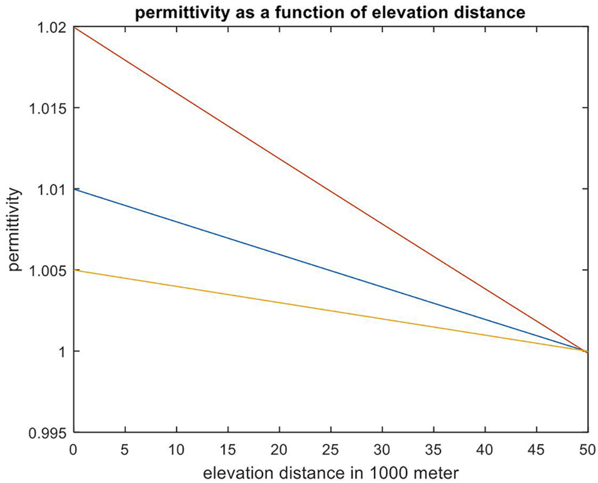


Fig. 5 Permittivity of atmosphere versus the elevation distance from the planet surface for the case of circular wave propagation route

1. In case of yellow line the permittivity of atmosphere at the planet surface is 1.005. The circular route of the light beam has a curvature radius of 2.0×10^7 m, that is 20 000 km.
2. In case of blue line the permittivity of atmosphere at the planet surface is 1.01. The circular route of the light beam has a curvature radius of 1.0×10^7 m, that is 10 000 km.
3. In case of red line the permittivity of atmosphere at the planet surface is 1.02. The circular route of the light beam has a curvature radius of 5.0×10^6 m, that is 5 000 km.

In the above cases the boundary of atmosphere is the same which is at 50 000 m elevation distance where the permittivity is unity, i.e. the permittivity of vacuum. The thickness of guiding layers of the atmosphere can be chosen arbitrarily. When choosing thinner layers then more calculation steps are needed to get to the boundary of atmosphere.

Figure 5 shows an interesting relationship. When the permittivity is higher, i.e. the atmosphere is composed of a denser gas the curvature radius of wave propagation is smaller. By other words the wave is deviating from the straight line more strongly. Therefore, observing stronger bending of wave propagation refers to an atmosphere with denser or heavier gas. Similar relationship is obtained for an atmosphere having some humidity. In the case when the permittivity distribution in the atmosphere is known the derived equations can be used to determine the propagation route of light wave.

It is also interesting to note how much change is in permittivity between the layers. It is seen in Fig. 5 that the ratio of change in permittivity is almost constant from layer to layer. However, the permittivity is dependent on the curvature radius R. Stronger curvature, i.e. smaller R needs higher permittivity and higher ratio of permittivity between the neighboring layers. A further observation shows that even a very rare atmosphere with a permittivity only a little bit higher than unity can cause bending of light.

In the present case the electric field is perpendicular to the layers, that is perpendicular to the planet surface, which case is called vertical polarization. For the orthogonal polarization, which is the horizontal polarization, the wave propagation is similar to the case of vertical polarization. However, the wave propagation with horizontal polarization excites surface waves and its loss is higher than the loss of vertically polarized wave. That is due to multiple diffractions, higher reflections and scattering caused by surface irregularities.

The previous investigation shows that bending of light propagation can be caused by a proper permittivity distribution in the atmosphere. The natural permittivity distribution of a planet atmosphere usually does not follow exactly the permittivity distribution required for circular propagation route. Therefore the wave propagation will not follow exactly a circle line, but it will follow a parabolic route.

5 Planets without atmosphere

In the case when the planet has no atmosphere the light beam still can be bent due to the roughness of planet surface. The planet surface is not smooth, plains alternate with hills, mountains and valleys. The planet is in a cooled state, that is, its surface is essentially made up of rock formations. Their relative permittivity is significantly greater than 1.00. The amount of rocks gradually less and less with increasing elevation from the surface, that is, as the height increases the mass of the rocks becomes less and less. Therefore, layers with average dielectric properties can be assumed around the surface of that planet.

An average permittivity can be determined for each layer. The permittivity in the individual layers is thus not homogeneous, which means significant multiple diffractions, reflections and scattering can arise. That property has to be considered. As a result, the light beam will not propagate in a straight line, instead of that the light beam bends towards the surface of planet. As its consequence a tangentially incident light beam can follow a circle or curved route close to the planet. However, due to the uneven planet surface, a significant part of the incident wave is diffracted, reflected and scattered while only a part of it is transmitted with a significant decrease in its intensity.

The previous studies concerned the propagation of wave with vertical polarization, i.e. when the electrical field is perpendicular to the planet surface. The other part of the light beam which has horizontal polarization, i.e. when the electrical field is parallel to the planet surface, has to be considered as well. In this case the light wave is traveling along a curved line as well. However, its intensity is lower than the intensity of wave component with vertical polarization. Its reason is that the horizontal polarization wave excites surface waves which have stronger loss due to higher reflections and scattering. From this property, it can be deduced whether the planet has an atmosphere or not.

6 Additional comments

A ray of light coming from a distant star can be detected at a point on Earth at different times. This beam of light can reach the Earth at different locations and in different time and also under different conditions, for example by traveling in a direct route or in a route close to a planet. If a ray of light passes tangentially a planet, we experience a bent light.

In the case of bent light, by dividing the incoming light beam into two components with polarizations perpendicular to each other, we notice that the intensity of the two components is different. If the difference between the intensity of the two mutually perpendicularly polarized components is well distinguishable but not big, then the planet has an atmosphere and that caused the light beam to be bent. The magnitude of the difference can characterize the atmosphere. Some estimations can be done. The larger difference can indicate that the atmosphere contains a denser or heavier gas.

In the other case, i.e. when the intensity of the two perpendicularly polarized components does not differ noticeably, the planet presumably has no atmosphere the deflection of light beam could be caused by surface irregularities on the planet surface. In this latter case, the deflection of light is smaller and the total intensity of light beam suffers a significant loss due to reflections and scattering as results of surface irregularities. In such a case, the intensity of bent light beam is significantly smaller than that of the light arriving in a direct route.

A further remark concerns the propagation of light beam in a distance from the planet surface where the effect of atmosphere is negligible. That beam propagates in a straight line. Therefore, the light beam of a distant star propagating in the vicinity of a planet is divided into two beams: one part which is close to the planet surface is bent, while the other part propagates in a straight line. In the case when both beams can be received together with their parameters like intensity, angle of incidence, distance between the two reception points, etc. then the distance between the planet and the reception points can be determined.

We can state that the light wave propagating close to a planet can deviate from the straight line and follow a curved route. There is no need to assume that the cosmic space is curved around a planet having a huge mass.

7 Conclusion

An inhomogeneous dielectric medium having parallel layers with different permittivity has been studied. The layered medium has continuously increasing or decreasing permittivity in the direction perpendicular to wave propagation. According to the presented study, the propagation of light gradually deviates from the straight line in the direction toward the higher permittivity layers. The aim of the paper was to provide a qualitative picture for the phenomenon of light wave propagation bending around cosmic planets. It was illustrated by examples of typical cases.

Based on the present investigations, in the vicinity of a planet having atmosphere with an appropriate permittivity distribution the propagation of light beam deviates from the straight line. In that case the light wave follows a curved route close to the planet.

There are planets which have no atmosphere. Their surface is not smooth, they have plains, hills and mountains with varying heights. Therefore, we can have layers parallel to the surface with an equivalent average permittivity which is high at the planet surface and gradually decreases with the elevation. As its consequence a tangentially incident light beam deviates from the straight line, it follows a curved route close to the planet.

Based on the results of present investigations, it is not necessary to assume that the cosmic space is curved in the vicinity of a planet containing a huge mass.

Appendix

In circular layers the wave propagation distance has to produce the same $\Delta\phi$ rotation angle change for each layer in the same time interval.

The velocities of wave propagation in layer 1 and 2 are: $v_1 = \frac{c}{\sqrt{\epsilon_1}}$ and $v_2 = \frac{c}{\sqrt{\epsilon_2}}$.

In this case the relation between the permittivity of layer 1 and 2 is: $\epsilon_2 < \epsilon_1$

Therefore, the relation between the wave propagation velocities is: $v_2 > v_1$

After a Δt elementary time period the propagation distance Δl_1 in layer 1 is: $\Delta l_1 = \frac{c}{\sqrt{\epsilon_1}}\Delta t$

At the same time the propagation distance Δl_2 in layer 2 is: $\Delta l_2 = \frac{c}{\sqrt{\epsilon_2}}\Delta t$

In circular layers the wave propagation distance in the two layers in the same time interval can correspond to the same Δϕ rotation angle change in case of a proper permittivity ratio.

Therefore, it can be written: $\Delta l_1 = R\,\Delta\phi$ and similarly: $\Delta l_2 = (R+d)\Delta\phi$.

Here *R* is the radius of the first circular layer and *d* is the thickness of a layer.

Equating the two expressions of Δl_1 we get: $R\,\Delta\phi = \frac{c}{\sqrt{\epsilon_1}}\Delta t$

Similarly equating the two expressions of Δl_2 we get: $(R+d)\,\Delta\phi = \frac{c}{\sqrt{\epsilon_2}}\Delta t$

As the time interval Δt is the same in both cases, the last two equations can be divided as: $\frac{R+d}{R} = \sqrt{\frac{\epsilon_1}{\epsilon_2}}$

In this case the wave front is tilted according to the Δϕ rotation angle change.

In the next step the effect of the third layer is determined. The velocity of light v_3 in layer 3 has to be higher than the velocity of light v_2 in layer 2: $v_3 > v_2$

Therefore, the permittivity ε_3 of layer 3 has to be smaller than the permittivity ε_2 of layer 2: $\epsilon_3 < \epsilon_2$

By performing operations on the equations similar to the previous case we get the following: $\frac{R+2d}{R+d} = \sqrt{\frac{\epsilon_2}{\epsilon_3}}$

Finally, for an *n*-th layer a general relationship is obtained as follows: $\frac{R+nd}{R+(n-1)d} = \sqrt{\frac{\epsilon_n}{\epsilon_{(n+1)}}}$

That general equation provides the requirement for the permittivity in *n*-th layer (with the limitation: $\epsilon_{(n+1)} \geq 1$). That means satisfying the above relationship in each layer the light beam will follow a circular route with a curvature radius of *R*.

Author contributions I, Tibor Berceli made all work for composing the idea, the derivations to obtain the results. I also agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding Open access funding provided by Budapest University of Technology and Economics.

Data Availability Not applicable

Declarations

Competing interests The authors declare no competing interests.

Ethical approval Not applicable

References

Blaunstein, N. and Kopeika, N. (eds.): Optical Waves and Laser Beams in the Irregular Atmosphere, Taylor & Francis Group, CRC Press, (2017)
Brekhovskikh, L.: Waves in Layered Media, Elsevier, (2012)
Felsen, L.B. and Marcuvitz, N.: Radiation and Scattering of Waves, Wiley-IEEE Press, (1994)
Fock, V.A.: Diffraction of radio waves around the earth surface (originally in Russian). Zhur. Eksp. Teor. Fiz. **15**, 479–496 (1945)
Fock, V.A.: Electromagnetic Diffraction and Propagation Problems, Pergamon Press, Oxford, (1965)
Hogan, M.: Ionospheric Diffraction of VHF Radio Waves, ESL Inc., Palo Alto, California, IR-26 22 May (1967)
Keller, J.B. and Givoli, D: *Numerical methods for problems in infinite domains*. Journal of Computational Physics, **82**(1), 172–192, Elsevier, (1989)
Quinten. M.: Optical Properties of Nanoparticle Systems: Mie and beyond, Wiley, (2011)
Sasiela, J.R.J.: Electromagnetic Wave Propagation in Turbulence. Springer (2012)
Yeh, P.: Optical Waves in Layered Media. Wiley (2005)
Yushanov, S., Crompton, J.S. Koppenhoefer, C.K.: Mie scattering of electromagnetic waves. Proceedings of 2013 COMSOL Conference, Boston (2013)