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Some Theoretical Issues of MPT and Development of 1D Model for Microwave Power Transmission Problem in the Mixed Layers Environment from GEO to the Earth

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Abstract—**Wireless Power Transmission (WPT) or Microwave Power Transmission (MPT) has been discussed since the beginning of XX century, but this research field has been only intensively studying since 1973. So far there are many impressive theoretical and practical results as well as applications of MPT in both civil and army fields, but there are still many difficult theoretical and practical issues to be confronted. In this paper the MPT system and some essential different points between a wireless infomation transmission (WIT) system and a MPT system are considered and discussed. Some theoretical issues of MPT with the mathematical methods for finding the transfer efficiencies in both cases are briefly outlined and discussed. After that the authors have developed and proposed a 1D power transfer model with the several concrete parameters of transfer environment from GEO to the Earth with the aim of searching for numerical solution methods of the Beam collection efficiency for MPT problem.**

Index Terms—**Theoretical issues of MPT problem, 1D model of MPT, Gaussian energy distribution, Gaussian beam, collection efficiency of WPT.**

I. INTRODUCTION

The ideal of using space solar energy had been raised since very long in 20 century, but until to 1968 based on the concept of Solar Power Satellite (SPS) and on the patent No. 3.781.647 given by Peter Glaser [1] in which the Author suggested that solar energy can be transmitted wirelessly from an transmission antenna being on orbit (GEO, MEO, LEO) via space and Earth's atmosphere to the rectifier antenna on the Earth surface, in addition the MPT has widely application in many fields, then the MPT has been intensively developing [1]- [3]. Currently the development of sustainable energy sources is being an urgent task, so scientists are focusing intensively on searching the new promising sustainable energy source of clean energy from space to the Earth, This kind of energy so called solar electricity[2]-[4]. In generally, according to proposals and developments of WPT the wireless transfer of power since the 1973's point to point has been also intensively researching. A variety of schemes have been suggested for transferring energy from earth-to-space, space-to-earth, space-to-space, and between points on earth using high power microwave beams. Possible applications include to energize solar power to earth, from satellite to other space vehicle, from earth to the Unmanned Area Vehicle (UAV) or to the hovering helicopter platforms or even satellites by the power be supplied with radiation [4]-[5]. Although these applications are still not appeared very practical at the present time, but the researches and discussions of the basic theoretical and principle aspects of these types of power transmissions are very needed [5]-[6]. The research of MPT includes many aspects: the research and development of Space Solar Power Satellite (SSPS), the problems of the Microwave Power Transmission (MPT) between two points in the space, two points on the Earth and/or from several Orbits (GEO, MEO, LEO) to the Earth surface [3]-[6].

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This paper briefly views and outlines MPT system, the essential different points between WIP and MPT after that discusses some mathematical issues of MPT problems from GEO two the earth. The simple 1D model of MPT has proposed this 1 D model includes some numerical estimated parameters of transfer environment. The mathematical basics of the MPT 1D problem with Gaussian beam based on the Maxwell equations and Fresnel Kirchhoff diffraction theory are discussed for searching a numerical solution method for MPT problem aiming to find the transfer efficiency.

II. WPT SYSTEM BETWEEN TWO POINT AND SOME ESSENTIAL DIFFERENT POINTS IN COMPARISON WITH WIT

A. *WPT system in briefly*

A typical SPS system for MPT consists of three main parts [1]-[4]: (i) the first part is the Solar Power satellite (SPS) flying on an orbit that consists of mirror system, solar cell matrix system, conversion unit from solar energy to the high power microwave beam by microwave devices, transmission antenna;(ii) the second part is Wireless energy Transfer environment including the outer space and the Earth atmosphere regions; (iii) the third part is Ground antenna so called rectenna system that consists of array antenna unit receiving microwave power, filter unit and rectifier unit to converses microwave power to DC voltage and DC power combiners, then this electrical energy connecting to the electrical line network (Fig.1).

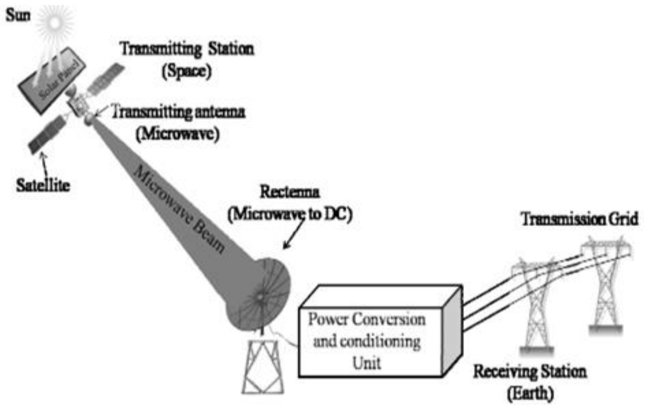

Fig.1 *Block Scheme of WPT system using high power microwave beam (or MPT)*

So far there are many MPT projects that have been designed and implementing in the developed countries [2]-[4]. Concerning those projects, it is worth to note that the magnitudes of the transmission powers from GEO to the Earth surface are very larger in the range of 1.3 GW - 6.72 GW with efficiencies of from 80% up to 95%, the diameters of transmission and receive antennas are from 1 km to 2 km to ensure the WPT occur almost in near field region. The energy distribution at transmission antennas as well as rectenna is the Gaussian distributions (or beams) with optimized conditions [1]-[4].

B. Some essential different points between wirelss communication transmission (WIT) and Wireless Power Transmission (WPT) systems

The main different points between the WIT (Telecommunication, TV, Radar, Radio…) and WPT are followings:

- For the WIT, one uses far field theory with plane wave for mathematical treatment with transmission distance is at least equal to the far-field distance, $2D^2/\lambda$, where D is the diameter of the largest transmission antenna. λ is Wavelength of microwave power beam [3]-[7]. The magnitude of a transmitted power at transmission antenna is usually in the range of several tens Watt (W) - up to about KW depending on purpose of WIT .The power of received signal is in the range of from nW to mW. The transmission coefficient in WIT, this means that the ratio of the received signal power at a receive antenna to transmitting signal power at transmission antenna is very small; its value usually is in the range of from 10^{-10} to 10^{-11} % [7]. Here the transmission signal has the digitalized codes or the modulations With AM, FM (at analog system) containing information, it so called the structured signals. The structured signals usually spread to all directions as the longer the better. The ratio of the transmission antenna size to the receive antenna size is not taking into consideration so much. So far the WIT has also many difficulties and challenges to overcome [4], [6], and [8]-[10].

- For the MPT system, the structure of MPT system is considerable different from that of WIT. Here one uses the beamed technology with the comparison able large apertures sizes of matrix transmission antenna and matrix rectenna in comparison With transmission distance in order to increase transfer efficiency. In the MPT one also uses the near field theory with spherical wave for mathematical treatment. The microwave beam with very high power in the range of from KW to GW spreads only in one straight direction. The frequency of microwave power beam is often chosen at 2.45 GHz or 5.8 GHz sometimes at 30 GHz, where the absorptions of the Earth atmosphere at these frequencies are low [3]-[4]. In the MPT, the transmission efficiency so far is mainly calculated based on the Fresnel- Kirchhoff diffraction theory With Gaussian beam by the ratio of the received power at rectenna to the transmitted power at transmission antenna. Recently the characteristic parameter, so called Gaubou parameter or a modified form of this, is often used to estimate the transfer efficiency of MPT as well as WIT. [2], [3], [5] [7], [11]-[16].

So far many attempts have been devoting for developments of the theoretical and practical problems concerning MPT, especially for the theoretical developments for finding solutions of mathematical problems of MPT between two antennas in the Fresnel zone Some authors have dealt mainly With the general principles underlying the theory of power transmission between two aerials, others instead have been more concerned With the numerical computation of the Transmission Efficiency in particular cases of Gaubou relation or Fresnel parameter With optimized conditions of amplitudes and phase front and energy taper Unfortunately, in general, these works mainly carried out based on Fresnel Kirchhoff diffraction theory[2],[3],[5] [7], [11]-[20].

C. Determination of transfer Collection efficiencies in WIT and WPT systems

In the WIT including satellite telecommunication one often uses Friis transmission equation to calculate the receiving power at receiver antenna, this expression has the following form [3]-[5].

$$P_r = \frac{\lambda^2 G_r G_t}{(4\pi d)^2} P_t = \frac{A_r A_t}{(\lambda d)^2} P_t = \tau^2 P_t \qquad (1)$$

And the transfer efficiency in this case is

$$\eta = \frac{P_r}{P_t} = \tau^2 \qquad (2)$$

Where the τ^2 term is introduced in the following form:

$$\tau^2 = \frac{A_t A_r}{(\lambda d)^2}, \tau = \frac{\sqrt{A_r A_t}}{\lambda d} \qquad (3)$$

where P_r is received power, Gr is receiving antenna gain; Ar is aperture area of a receiving antenna. P_t is transmitted power, G_t is transmitting antenna gain, at is aperture area of a transmitting antenna. Λ is wave length of signal or power beam. This characteristic parameter, τ, is so called Goubau parameter. From the expression of τ, if one choose $A_t = A_r$ then one has:

$$A_r = A_t = \tau\lambda d \qquad (4)$$

From (4) we see that when λ increases (the frequency is smaller) the apertures of A_t and A_r has to increase. Based on this expression, at the given value of τ, λ and transmission aperture A_t, the transmission distance (d) will be calculated.

The magnitude of τ parameter depending on two apertures antennas, wave length and transmission distance that plays very important role in determination of collection efficiencies both in the WIT and WPT cases [3], [5], [6].

As we known, the Friis equation (1) and (2) can only be applied for calculation of transfer efficiency in far field (Fraunhoter Field) With plane wave for WIT [[2]-[5],[7]. Friis equation cannot be applied to calculate collection efficiency for the WPT case where the microwave is spherical wave transmitting in the Fresnel field or near field of the transmission antenna [11]-[16].

For MPT, in order to determine collection efficiency, there has been many attempts devoted for research of mathematical models, approaches and calculation methods for finding collection efficiency, particularly the research works and applications of Fresnel Kirchhoff diffraction theory (physics optics) using paraxial equation of Gaussian beam in the form of the Helmholtz equation under the assumptions that amplitude and phase distributions in the beam are optimized for maximum transmission efficiency [2],[3],[5], [11]-[16]. The power beam efficiency in this case can be estimated as follows expression [2]-[3], [14]:

$$\eta = \frac{P_r}{P_t} = 1 - e^{-\tau^2} \qquad (5)$$

The equation (5) is only approximation based on estimation. So, both the transfer Efficiency of WIT and MPT could be calculated using Gaubou parameter (τ). The collection efficiencies of both cases in the function of τ, Gaubou parameter are shown in Fig.2.

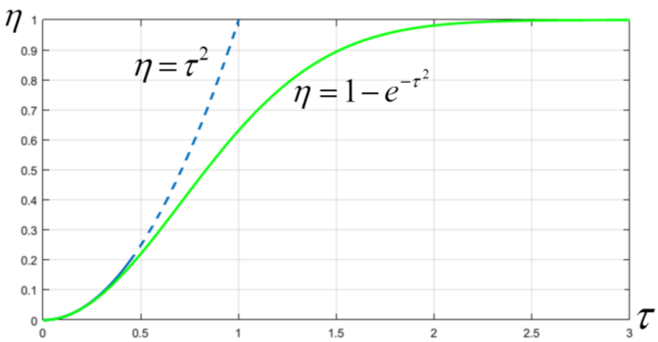

Fig.2 *Estimation of Power transmission efficiencies for Far field - near field transmission vs. Goubou parameter (c) [6].*

Here it is worth to note that with value of τ is smaller then 0.5, two curves are nearly merged. In this case the antennas apertures are small in comparison With transmission distance (d) at given λ. Both of WIT and WPT are mainly occurred in the far field with plane wave. When antennas apertures are increased step by step then two efficiencies curves are separated and increased rapidly. The WPT occurs in the mixed regions of far field and near field region, after that the WPT will be dominated in the near field with spherical wave. When the antennas apertures are increased to the value of τ = 2 the BCE will close to 100%. The theoretical expressions of transfer efficiencies in cases of WIT (Eq. (2) and for WPT Eq.(5) did not depend on power level, therefore we can transmit high power of kWs, MWs… via electromagnetic waves [2], [5], [6].

Table.1. *Some main different points of WIT and MPT in comparison for each parameter concerning*

Features or parameters of WIT and MPT in comparison	WIT (Satellite communication TV, location, Radio, RADAR…)	MPT
Transmission power	In the range of W-kW	In the range of W-MW-TW
Received power at receiving antenna or Rectenna	In the range of nW-mW	In the range of W- KW-MW-GW
Frequency	In many bands With Δf bandwidth	At fix frequency (2.45; 5.8 Ghz or much higher 30 Ghz…)
Transmission region of transmission antenna	In Far field region With $d > 2D^2/\lambda$	In near field region (Fresnel region) With $d < 2D^2/\lambda$
Transmission wave	Plane wave	Spherical wave
Structures of transmission antenna	Single antenna or array antenna (RADA, satellite communication…)	Large array antenna (sometime by Large single antenna)
Signal/field distribution at trans. antenna	The structured signal With AM, FM or digital coding in form of TEM field	Large power beam (or TEM Field combination) Without modulation or coding in the form of the determined Energy distribution such as Gaussian energy function
Gaubou parameter (τ) (or Fresnel parameter (c))	τ << 1 $\tau = \frac{\sqrt{A_r A_t}}{\lambda d}$	τ ≥ 1 $\tau = \frac{\sqrt{A_r A_t}}{\lambda d}$
Structures of received antenna	Single antenna or array antenna (RADA, satellite communication…)	Large array rectenna (or large single rectenna)
Signal/field at received antenna	Uniform With directive pattern	Irregular, in the form of energy distribution depend on energy distribution at trans array antenna
Calculation methods of Transfer Efficiency (%) and its value	-Using Friis Equation or Path loss models - Its value is in range of 10^{-10} to 10^{-12}	-Using Gaubou parameter (or Fresnel parameter) based on Fresnel Kirchhoff Diffraction theory -its value is in the range of 10-95% depending on value of τ
The most important parameter required	Received information With good quality	Highest collection efficiency
Mathematical treatment apparatus often used	Integral equations of EM field based Maxwell equation system	-Integral equations of energy fluxes based Maxwell equation system-Fresnel Kirchhoff diffrection theory -Matrix analysis
Recently developing situation	Well developed for longtime but still face With many challenges	Developing at beginning stage With many challenges of theoretical and practical problems

In briefly, there are many essential different points between the WIT and WPT systems as mentioned in above leading to have treatments of theoretical and practical problems. Table 1 summarizes several different points of two systems.

D. Some Theoretical Issues of MPT Problem, further researches and studies

Here we summarize shortly several theoretical issues for searching solution methods and solving problem of WPT as in the follow:

- The research development and manufacture of WPT are at the beginning stage, the obtained results are still limited both in the theoretical and practical fields although there were many attempts devoted. The further new technological developments must have to fulfill two major requirements: one of these is large amounts of solar electric power at reasonable cost for manufacturing operations in low Earth orbit and the other requirement, based on the obtained results, is for large amounts of power for electric propulsion need for a greatly improved space transportation system [2].

- Mathematical treatment apparatus for WPT is also limited. The researches and developments are so far mainly for setting up theoretical WPT models. There are still lacks of results for real WPT systems. The mathematical apparatus of Fresnel – Kirchhoff diffraction theory has been using for the case of Gaussian beam with some assumptions of the amplitude and phase optimized [5], [7], [11]-[21]. The other mathematic apparatuses such as matrix analysis… have to apply for treatment of the real large energy distributions in transmission antenna and rectenna as well as for WPT of large sizes and large power with large transmission distance between two points in space or from GEO to the Earth.

- There are few works dealt with the analytical and /or numerical solution of energy distribution flux expressions for determining transfer efficiency of WPT between two points due to the difficult issues of mathematical treatments concerning large power with large sizes transmitting in the unclear feature transfer environment of the space and earth atmosphere.

- A questionable fact is raised: by which velocity (phase or group velocity) the energy distribution travels from GEO to the Earth in the case of WPT with very large energy. This question is not discussed clearly.

- In order to find the numerical solution of WPT problem from GEO to the Earth we need to know the numerical valued parameters of the space and atmosphere environment and some factors acting to the travelling energy distribution, but these parameters of transfer environment are not understood clearly although there were several attempts devoted to study transfer environment especially the ionized atmosphere region [22], [23], [25-[27]. In addition, the choice of space –time grid for very large transmission distance from GEO to the Earth for finding numerical solution is also difficult problem.

III. Math 1D Model of MPT with Some Main Features, Assumptions

A. 1D model and the features of transfer environment

Up to presently, the problem of MPT has been investigating, describing and analyzing intensively by many methods but this problem has not yet been described and solved analytically and or numerically clearly in detail due to the lack of a real theoretical model containing the concrete numerical parameters of power transfer environment from GEO to the Earth [22]-[25]. Here We have proposed a 1D model for WPT from GEO to the Earth With the simple transfer environment that is including the space region and earth atmosphere region of the layered different dielectric permittivity (ε_r) and magnetic permeability (μ_r), refraction index (n), conductivities σ estimated under assumptions of the Gaussian energy distributions at transmission antenna and rectenna, (Fig.4).

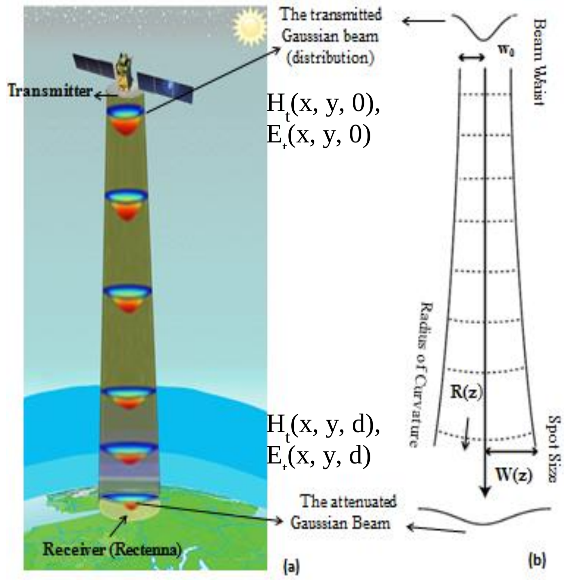

Fig.3 *Proposal 1D model for WPT with Gaussian energy distributions (beams) at transmission antenna and rectenna: WPT with 3D demonstration figure (a) and 2D demonstration figure (b)*

Based on the features and published results of WPT system, we have suggested some following assumptions:

- Energy transfer mainly occurs inside of an approximately cylinder waveguide, along the outside edge of cylinder, the energy densities to be assumed very small (even nearly zero).

- Transmission antenna and rectenna apertures are nearly equal. These apertures areas are very small (about several km^2) in comparison With the transmission distance (d) from GEO to the Earth (D= 35 700 km).

- Energy distributions (beams) at transmission antenna and rectenna assumed to be the volume of Gaussian distributions (beams) as in Fig.3 (a) and the form of the attenuated Gaussian distribution at the rectenna.

- The energy transfer by wireless transmission is governed by energy Gaussian beam with assumptions of amplitude and phase optimized to get maximum transfer efficiency. The antennas apertures have chosen so large i.e. the τ Gaubou parameter is so large that MPT occurs in near field region of transmission antenna.

- The transfer environment from GEO to the Earth surface is divided into the space region with distance of about 34700 km and atmosphere region with distance of more than 1000 km. The earth atmosphere is also divided into two regions: the ionized region is about more than 900 km and the neutral region is about 90 km (Fiug.4)

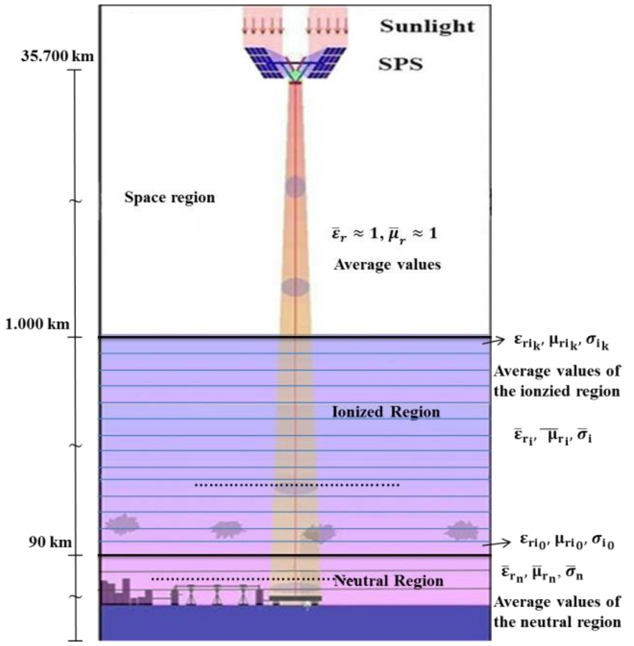

Fig.4 *The simplified transfer environment from GEO to the earth surface with three regions: space region, ionized region and neutral region with the numerical concrete parameters (ε_r, μ_r, n and σ).*

B. Mathematical expressions of WPT problem for 1D model

1. Energy flux distribution for the case of WPT in the near field region

We can write the time-dependent power over a specified volume V With Gauss distribution function as in form of Poynting theorem in the following [22, [25]:

$$\int_V \nabla \vec{P}(t) dV = \iiint_S \vec{P}(t) ds$$

$$= -\int_V \sigma E^2(t) dV - \frac{\partial}{\partial t}\int_V \frac{1}{2}\varepsilon E^2(t) dV - \frac{\partial}{\partial t}\int_V \frac{1}{2}\mu H^2(t) dV$$

= Power Flux through S (6)

The left side of equation (6) expresses the variation of the electromagnetic energy per a time unit in the V volume (Gauss volume in this case) that is enclosed by the surface A. In the right hand side, the first term is a part of energy loss due to the thermal energy dissipation that provides thermal energy for the transmission environment, the second term in the right hand side of (6) expresses the decrease or increase of energy due to the external field being in transfer environment. The third term of equation (6) expresses the variation of electromagnetic energy transferred per unit time through the surface A of volume V.

If we suppose that electrical field -E (ξ) distribution is Gaussian distribution then the form of electrical field distribution function can be written as follows [14], [15], and [18]:

$$E(x) = f(x)\, e^{j\frac{k}{2d}x^2} = f(x)_{\max}\, e^{j\pi\frac{x^2}{d\lambda}}, 0 < x < R_t \quad (7)$$

Where E(x) is the electrical field distribution of transmission array antenna, $f(x)_{max}$ is maximum electric field at central of Gaussian distribution , where d is transmission distance, λ is wave length.

The Equation (6) of energy flux distribution could be solve for finding energy (power) along transmission direction as well as transfer efficiency at receive antenna/rectenna if we know the transfer environment parameters being in the equation (6) and the form of electric field (E) and magnetic field (H).

2. Determination of Transfer efficiency of WPT With Gaussian beam using Fresnel-Kirchhoff diffraction theory

There are many attempts devoted for finding the transfer efficiency of WPT problem with different methods [2]-[8], [11]-[21] but until there are few results published. In order to determine the theoretical efficiency of power transmission in the Fresnel region one must have to know the form of Gauss energy distribution expression, the interaction between Gaussian energy distribution With the parameters (ε_r, μ_r, n and σ) of transfer environment. Here we also assume an idealized transmitting antenna with an aperture At located at the plane z = 0 and energy passing directly to the rectenna With Ar aperture area located at plane z = d as in Fig.5.

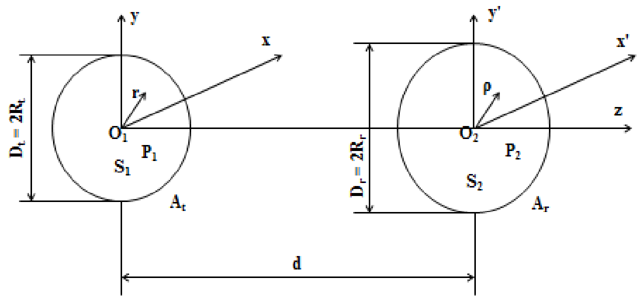

Fig.5 *Simplified scheme of WPT 1 D problem in z direction With the structures of transmission antenna at z=0 and rectenna located at z=d where R_t is radius of Transmission antenna, Rr is radius of rectenna , d is the transfer distance between two antennas is and λ is wavelength of microwave power signal*

Now, the wave equation is, for any field or potential component U0 of Now, the wave equation is, for any field or potential component U_0 of an electromagnetic wave [28]-[29.

$$\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial z^2} + k^2 E = 0 \quad (8)$$

For one dimension we have the normalized form of the electric field distribution is:

$$\frac{\partial^2 u}{\partial x^2} - 2jk\frac{\partial u}{\partial z} = 0 \qquad (9)$$

We can solve equation (9) with some assumptions and constrains [5] [7] [18] to find electric field and magnetic field at the transmission antenna and receive antenna and based on the obtained results the transmission efficiency η can be formulated as in [3]. [5], [7], [[18]

$$\eta = \frac{\mathrm{Re}\left\{\iint\limits_{S_2}\left[E_t(z,y,\mathrm{d})\,\mathrm{x}\mathrm{H}_t^*(\mathrm{x},\mathrm{y},\mathrm{d})\right]e_z dxdy\right\}}{\mathrm{Re}\left\{\iint\limits_{S_1}\left[E_t(z,y,0)\,\mathrm{x}\mathrm{H}_t^*(\mathrm{x},\mathrm{y},0)\right]e_z dxdy\right\}} \qquad (10)$$

where asterisks indicate the conjugate complex values, e_z is the unit vector of the z direction, E_t (x, y, z) is the tangential electric component, and H_t (x, y, z) is the tangential magnetic component of the field. The components H_t(x, y, 0), E_t(x, y, d), and H_t(x, y, d) can be expressed in terms of E_t(x, y, 0) which uniquely determines the field in the entire half-space z > 0 [18],[28], [29].

Based on equations (8), (9), (10) with assumption and our numerical estimated parameters of transfer environment (ε_r, μ_r, n and σ) [26], [27] we can solve the WPT problem using Fresnel- Kirchhoff diffraction theory for finding transfer efficiency. The procedure will be outlined in the forthcoming paper. .

IV. Conclusion

We have summazed the WPT system with some features, discussed some essential different points between WIT and MPT. We have outlined some difficult theoretical and practical issues for solving mathematical problem of WPT. We have offered the 1D model for WPT with Gauss energy distributions with some assumptions and constraints. The transfer environment of 1D model with the numerical calculated parameters for WPT consist of the space region with distance of about 34700 km and atmosphere region with distance of more than 1000 km. The earth atmosphere is also divided into two regions: the ionized region is about more than 900 km and the neutral region is about 90 km. The numerical Solution for finding transfer efficiency of the 1D WPT problems using the calculated data of transfer environment will be shown and discussed in next coming paper.

Acknowledgment

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References

[1] Glaser Peter E. "Power from the Sun: It's Future". Science Magazine, 22 November 1968 Vol 162, Issue 3856, Pages 857-861.

[2] W. C. Brown, "Beamed microwave power transmission and its application to space," IEEE Trans. MTT, Vol. 40, no. 6, pp.1239-1250, 1992

[3] Shinohara, N., Beam Efficiency of Wireless Power Transmission via Radio Waves from Short Range to Long Range. JOURNAL OF THE KOREAN INSTITUTE OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, 2010. 10.

[4] Wireless Power transfer via Radio waves (book) written by Naoki Shinohara , Series Editor: Pierre Noël; ISTE Ltd & John Wiley &Sons, Inc.(2014), ISBN 987-1-84821-605-1

[5] R. C. Hansen, James McSpadden, and James N. Benford, A Universal Power Transfer Curve; IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 15, NO. 5, MAY 2005,pp.369-371

[6] Dao Khac An; Wireless Power transmission using the microwave beam and several applications in civil suit, security and army fileds, Proceedings of Workshop on the Space Technology and Applications" December, 19; **2014**, Hanoi, Vietnam, pp. 410-426

[7] G.Goubou and F. Schwering, Free Space Beam Transmission; Microwave Power Engineering, Edited by ERNEST C. OKRESS, New York: Academic Press, Vol. 1, pp. 241 – 255, 1968

[8] Tapan K. Sarkar, Zhong Ji, Kyungjung, Kim, Abdellatif Medour, and Magdalena Salazar-Palma; A Survey of Various Propagation Models for Mobile Communication; IEEE Antennas and Propagation Magazine, Vol. 45, No. 3, June 2003, pp.51-82

[9] Wilbur. Pritchard; Satellite communication- An overview of the Problems and Programs; Proceedings of the IEEE, Vol. 65, No. 3, March 1977, pp.294-307

[10] Erich Lutz, Issues in satellite personal communication systems; Wireless Networks 4 (1998) 109–124 109

[11] G.Goubou and F. Schwering; On the guided propagation of Electromagnetic Wave Beam, IRE Transaction on Antenna and Propagation, may, 1961, pp.248-256

[12] J.R. Christian G.Goubou; Experimental Studies on a beam Waveguide for Millimeter Waves; IRE Transaction on Antenna and Propagation, May, 1961, pp.257-263.,

[13] Georg Goubou and Paul D. Coleman; Beam Waveguides; MICROWAVE POWER ENGINEERING Edited by ERNEST C. OKRESS, New York: Academic Press,Vol. 1,(1968), pp.228-240

[14] G.Goubou; Microwave Power Transmission from an Orbiting Solar Power Station; Journal of Microwave Power, 5(4), 1970, pp.223-231

[15] Sergey S. Shaposhnikov; Wireless Power Transmission Antenna peculiarities for the Space Power Systems, 08211238Shap.doc; Moscow Radio technical Institute of Russian Academy of Sciences, 132 Warshawskoeshosse, 113519, Moscow, Russia; phone, 7-095-315-3125; ssshmrti@orc.ru

[16] Shaposhnikov and S.S., Garmash V.N.; ONE OF THE NEW FEATURES OF THE SPACE POWER STATIONS; Moscow Technology University of communication and Informatics. Moscow Russia, Copyright ©2002 by the International Astronautical Federation. All rights reserved (unpublished results)

[17] Giorgio V. Borgiotti; Maximum Power Transfer between Two Planar Apertures in the Fresnel Zone; IEEE Transaction ON ANTENNAS AND PROPAGATION; VOL. AP-14, NO. 2 MARCH, 1966, pp.157-163

[18] Herwig Kogelnik; On the propagation of Gaussian Beams of light Through Lenslike media including those With a loss or gain Variation; Applied Optics/Vol.4, No 12/ December 1965, pp.1562-1569

[19] Giacomo Oliveri, Paolo Rocca, and Andrea Masa; Array Antenna Architectures for solar cell Power Satellites and Wireless Power Transmission , 978-1-4244-6051-9/11/$26.00©2011 IEEE

[20] A.K.M.Baki, Kozo HASHIMOTO, Naoki SHINOHARA, Tomohiko MITANI and Hiroshi MATSUMOTO; Isoscelez -Trapezoideal –Distribution Edge Tapered Array Antenna With Unequal Element Spacing for Solar Power Satellite; IEICE Trans.Commun.,Vol.E91-B, No.2 February, 2008, pp.527-535.

[21] Modeling and design of compact microwave components and systems for wireless communications and power transmission, by written Paola Zepeda for the degree of doctor of philosophy, Texas A&M University, May 2003

[22] Dao Khac An, and Tran Manh Tuan; Investigation of General Maxwell equation of attenuation, inhomogeneity and anisotropic and the environment influences on the wireless energy transmission problem from SPS to the Earth surface, Presentation at Session 2A-3, International space Development Conference-ISDC2010,27-31, May2010,Chicago, IL, USA (printed in DVD disk at Conference).

[23] Tao Tang, Cheng Liao, Qingmin Gao, Pengcheng Zhao; Analysis of Reflection Properties of High Power Microwave Propagation in

Mixture-Atmosphere; J. Electromagnetic Analysis & Applications, 2010, 2, 543-548, doi:10.4236/jemaa.2010.29070

[24] Zepeda, P. (2003). Modeling and design of compact microwave components and systems for wireless communications and power transmission; The Office of Graduate Studies, Texas A&M University.

[25] Dao Khac An and Tran Manh Tuan, The issues of sustainable energy and the technological solutions of the solar power harvesting ,converting, and transmitting from the space orbit to the earth's surface. Science Technique publishing House, Viet Nam, 2010 (book in Vietnamese).

[26] An Khac Dao, Dong Chung Nguyen, Phong Viet Tran; The Wireless Power Transmission Environment from GEO to the Earth and Numerical Estimation of Relative Permittivity by Altitude in the Neutral and Ionized Layers of the Earth Atmosphere; Proceeding of The 2014 International Conference on Advanced Technologies for Communications (ATC-14), pp 214-219, 2014.(in IEEE explore).

[27] Khac An DAO and Chung Dong NGUYEN; Numerical Estimations of Relative Permittivity, Relative Permeability and Refractive Index by Altitude in the Non-ionized and Ionized Layers of the Earth Atmosphere Enviroment for applications in Wirelss communication transmission (WIT) and the Wireless Power Transmission (WPT)Report concering of the project of code VT/CB-03/13-15; Energy Materials and Devices Lab, Institute of Materials Science,VAST, 2015, andk@ims.vast.ac.vn (unpublished result).

[28] Goldsmith, P. F.,Quasioptical Systems: Gaussian Beam Quasioptical Propogation and Applications, Wiley-IEEE Press, December 1997.

[29] Galvez, E. J. (2009). Gaussian Beams, Department of Physics and Astronomy Colgate University.

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