ELECTROMAGNETIC CHARACTERISTICS OF THE “VERY – NEAR – FIELD” REGION OF A CIRCULAR UNIFORM APERTURE

Antoniya Petrova Petrova

Technical University of Sofia, Bulgaria
Faculty of Telecommunication, TU-Sofia, “Kl.Ohridsky” str. 8, 1000 Sofia, Bulgaria
E-mail: tony.petrova@gmail.com

Abstract

The main purpose of this paper is to investigate the behavior of the electromagnetic field in the region of “near-field reactive” or “very-near field”. In this unusual and rather unknown region, trying to explore the specific characteristics of the radiated fields, the wave impedance, and the power density. Based on this parameters, it is succeed in determining, the outer boundary of the “very-near field” region of a circular aperture with a uniform illumination law. The big interest of the “near-field reactive” due to the fact that the antennas for physiotherapy are located very close to the human body and the propagation of the electromagnetic waves is precisely in this field. The study and visualization of the electromagnetic field would lead to more effective treatments to patients.

1. INTRODUCTION

Two main regions can be divided into the space around the antenna: far field and near field. In the far field, electric and magnetic fields propagate outside as an electromagnetic wave and are perpendicular to each other and to the direction of propagation. The angular field distribution does not depend on the distance from the antenna. The fields are uniquely related to each other through free-space impedance and decay as 1/r. In the near field, the field components have different angular and radial dependence. The near field region includes two sub-regions: radiating, where angular field distribution is dependent on the distance, and reactive, where the energy is stored but not radiated.

2. THEORETICAL SOLUTION

The first in the “far-field” region, at distances greater than $2D^2/\lambda$, where the angular field distribution is independent of the distance from the antenna and the radiated wave is spherical. The second is the “near-field radiating” (Fresnel) region, at distances less than $2D^2/\lambda$, wherein the angular field distribution is dependent upon the distance from the antenna. In this region, the radiated wave, which is first a plane wave, is progressively transformed into a spherical wave. The third is the “near-field reactive” region, located between 0 and $\lambda/2\pi$ from the antenna, wherein the reactive field predominates.

For circular aperture is determinated the “very-near-field” region as an interference region, inside which the radiated wave presents the following characteristics: the electric and magnetic fields are out of phase; the wave impedance is different from 120π (i.e., the free-space impedance); and the power density has a complex formulation, with a real part and an imaginary part. This region is extended up to one-quarter of the Rayleigh distance: up to $D^2/8\lambda$.

$$\begin{aligned}\vec{E}(P) = -j\frac{k^2}{4\pi}\int_s^{-\infty} &\{-jZ_0(\hat{n}\times\vec{H}) \\ &+ Z_0(2+3j)[\hat{r}\cdot(\hat{n}\times\vec{H})]\hat{r} \\ &+ (1-j)\hat{r} \\ &\times(\hat{n}\times\vec{E})\}exp(-jkr)dS\end{aligned} \tag{1}$$

$$\begin{aligned}\vec{H}(P) = -j\frac{k^2}{4\pi}\int_s^{-\infty} &\left\{\frac{j}{Z_0}(\hat{n}\times\vec{H})\right. \\ &-\frac{1}{Z_0}(2+3j)[\hat{r}\cdot(\hat{n}\times\vec{E})]\hat{r} \\ &\left.+(1-j)\hat{r}\times(\hat{n}\times\vec{H})\right\}exp(-jkr)dS\end{aligned} \tag{2}$$

where Z_0 is a wave impedance and $Z_0 = 120\pi$, r is a distance, $\hat{n}$ is the unit normal to the surface.
Consequently, the Poyting vector $\vec{p} = \frac{1}{2}\vec{E}\times\vec{H}$, is a complex vector. A direct computation of this has shown us that for various apertures the real and the imaginary parts of $\vec{p}$ are nearly equal. So, can say that at the distance r = $\lambda/2\pi$ there is as much reactive as active power density. Thus, this distance cannot represent the end of the “near-field-reactive” region. It seems more convenient to investi-

gate the distance at which the ratio between the reactive and the active power density becomes lower than -30dB,for example. Beyond this distance could consider that the reactive power density is negligible. Moreover, for the same reason as why $\vec{p}$ is complex, the wave impedance, which is the ratio between E and H, is also complex. This feature could also characterize the "near-field-reactive" region.

So,I think that the distance beyond which

- The reactive power density is negligible
- The wave impedance is equal to 120π

Would really show the limit of the "near-field-reactive"region.

The fact that these two electromagnetic characteristics, $\vec{p}$ and Z, are complex is linked to an interference phenomenon of the fields near the aperture. In the reference case of a circular aperture with uniform illumination, such interference is noteworthy, and may be interpreted thanks to the Huygens – Fresnel principle. This will allow us to conclude that the "near-field-reactive"region is located between 0 and $D^2/8\lambda$, i.e. one – quarter of the Rayleigh distance.

3. ELECTROMAGNETIC PARAMETERS OF THE "VERY-NEAR-FIELD" REGION OF A CIRCULAR UNIFORM APERTURE

If we compare the interference lobes of the E and the H fields for a 5λ – radius aperture with a uniform illumination, can see that the E and H maximum magnitudes are not exactly similar. We can then assume that these two fields are not exactly in phase. Figure 1 shows the phase shift between the E and H fields. This difference, first equal to π/8, tends to zero when the observation poin moves away from the aperture. So, close to the aperture, the E and H fields are out of phase. Each peak of the plot (Figure 2) corresponds to a minumum of the interference lobes of the field magnitude. The last one, located at one – quarter of the Rayleigh distance, points to a phase difference about 2˚, beyond, the fields can be consedered to be in-phase.

The first consequence of this shift is that the wave impedance is complex, and therefore different from the free – space propagation impedance, which is Z_0 = 120π. The presence of some reactive power is the second consequence. Indeed, the power density is complex in this region, and it underlines the presence of a stationary wave,confined near the surface, in addition to a travelling wave that radiates. Both features are characteristics of the "very-near-field" region.

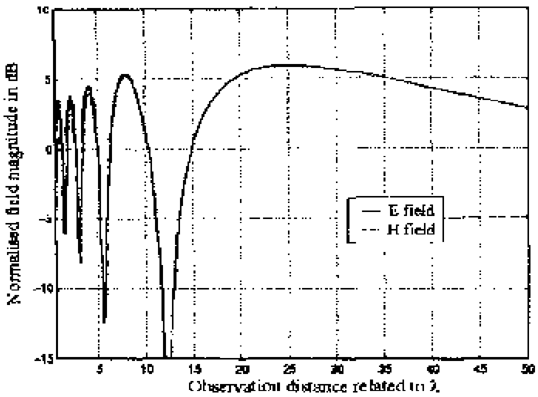

Figure 1. The E and H interference lobes in the "very-near-field" region of a 5λ radius aperture.

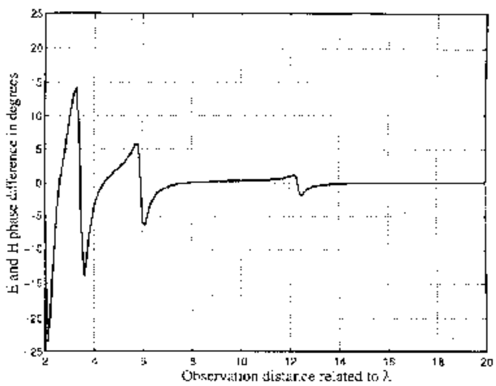

Figure 2. The phase shift between the *E* and *H* fields.

3.1. Wave Impedance

Concerning the wave impedance, is used a criterion that is the relative differce between Z and Z_0, that is $|Z - Z_0| / Z_0$, where Z = E/H is the complex wave impedance and Z_0 = 120π. Point out that close to the aperture, Z is different from Z_0, and it is considered that outside the "very-near-field"region, the wave impedance has to be equal to Z_0. To characteriza the "very-near-field"region of a dipole antenna,the limiting value has been set there to be 0.01.

Figures 3a, 3b and 3c show the variations of this criterion on the central perpendicular axis of the circular apertures studied in the previous section. They also present definite peaks, corresponding once again to the minima of the field magnitude. It is noticed that the value of the criterion, 0.01, is reached exactly for one – quarter of the Rayleigh distance, i.e.,just after the last peak, for the 5λ radius aperture, and just on the last peak for the 10λ and the 25λ radii apertures. Further than one-quarter of use Rayleigh distance, the criterion will be less than this limiting value, and we can consider that Z and Z_0.

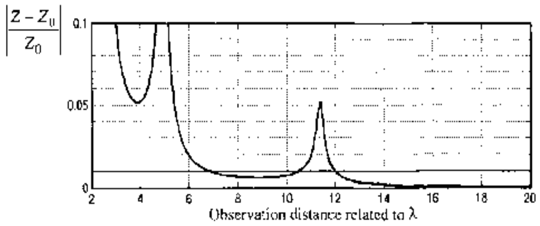

Figure 3a. The wave impedance criterion for 5λ radius circular aperture ($R_r/4$ = 12,5λ).

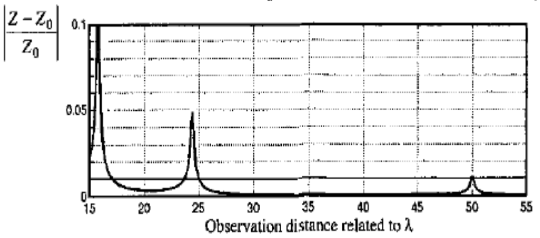

Figure 3b. The wave impedance criterion for 10λ radius circular aperture ($R_r/4$ = 50λ).

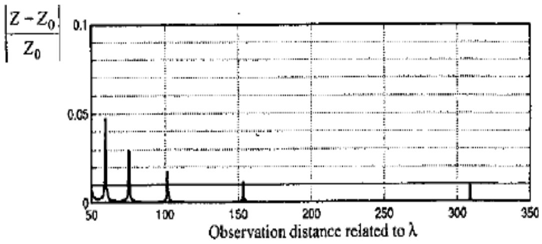

Figure 3c. The wave impedance criterion for 25λ radius circular aperture ($R_r/4$ = 312,5λ).

3.2. Power Density

The criterion is used relative to the power density is the ratio of the imaginary and the real parts of the Poynting vector in the direction of propagation. This ratio, characterizes the presence of reactive power near the aperture and a pertinent limit value was set at -30dB (i.e.,10^{-3} in linear value). Indeed, for such a proportion can consider that the reactive power is negligible, and so conclude that outside the: very-near-field"region there is no more reactive power.

Figures 4a,4b and 4c illustrate the variations of the power-density criterion on the central perperdicular axis of the same circular apertures as in Section 3.1. For the wave-impedance criterion can notice that the limiting value of the power-density criterion is reacherd for one-quarter of the Rayleigh distance,i.e.,just after the last peak for the 5 λ and 10 λ radii apertures ,or just on the last peak for the 25 λ radius aperture.

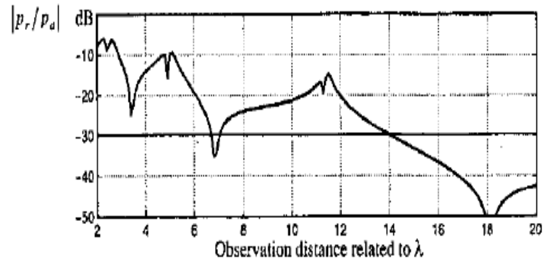

Figure 4a. The power density criterion for 5λ radius circular aperture ($R_r/4$ = 12,5λ).

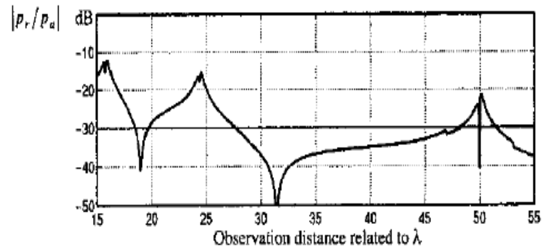

Figure 4b. The power density criterion for 10λ radius circular aperture ($R_r/4$ = 50λ).

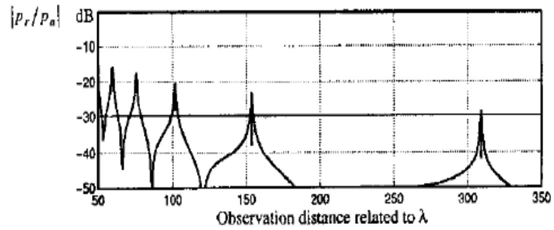

Figure 4c. The power density criterion for 25λ radius circular aperture (Rr/4 = 312,5λ).

3.3. Transverse Section Analysis in the "Very-Near-Field" Region

On the next figures are shown the variations of these criteria, not only along the central perpendicular axis, but also on the transverse planes. Figures 5a, 5b and 5c, concern the wave – impedance criterion for the aperture for 10 λ radius, and Figures 6a,6b and 6c illustrate the power-density criterion. For such an aperture, we saw that the upper boundary of the "very-near-field"region was located at 50 λ. These graphics display the variations of both criteria on the transverse planes, located at distances of 15 λ and 30 λ from aperture – thus,inside the "very-near-field" region - and at a distance of 60 λ, outside this region.The radiation in the "near-field or Rayleigh"region in concentrade in a tubular beam.

That is the reason why the transverse views are focused on this beam inside a circle of 10 λ radius.

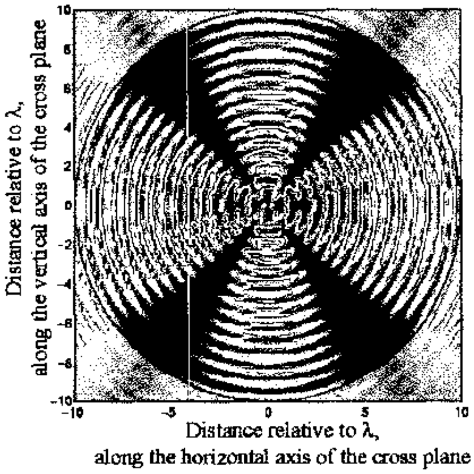

Figure 5a. The variations of wave impedance criterion for 10λ radius aperture ($R_r/4$ = 50λ) on the transverse plane at 15λ from the aperture.

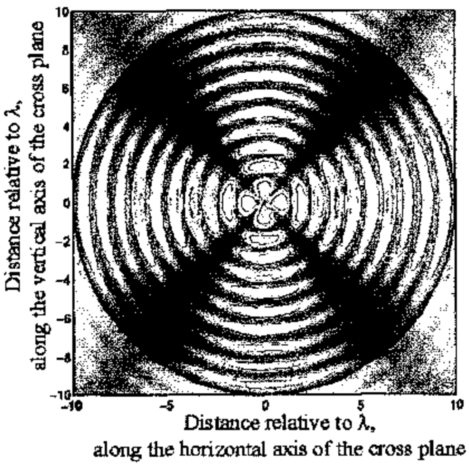

Figure 5b. The variations of wave impedance criterion for 10λ radius aperture ($R_r/4$ = 50λ) on the transverse plane at 30λ from the aperture.

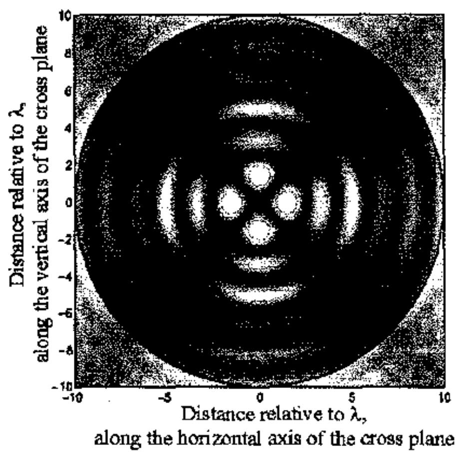

Figure 5c. The variations of wave impedance criterion for 10λ radius aperture ($R_r/4$ = 50λ) on the transverse plane at 60λ from the aperture.

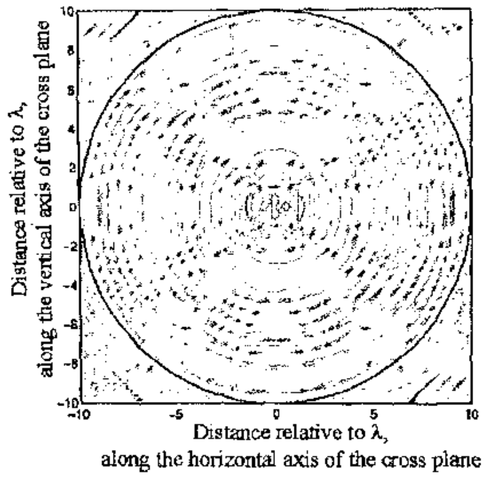

Figure 6a. The variations of power density criterion for 10λ radius aperture ($R_r/4$ = 50λ) on the transverse plane at 15λ from the aperture.

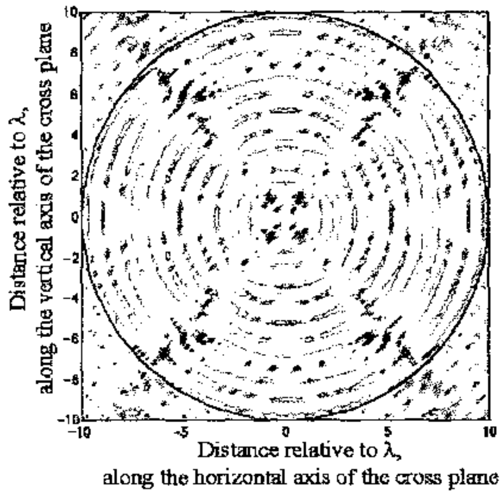

Figure 6b. The variations of power density criterion for 10λ radius aperture ($R_r/4$ = 50λ) on the transverse plane at 30λ from the aperture.

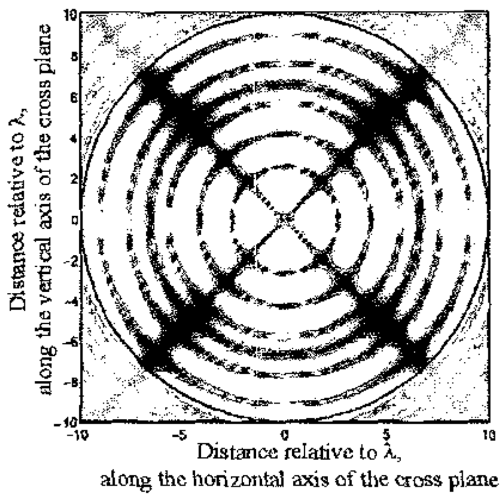

Figure 6c. The variations of power density criterion for 10λ radius aperture ($R_r/4$ = 50λ) on the transverse plane at 60λ from the aperture.

The transverse views in Figures 5 show that the impedance criterion, really disturbed inside the beam for a short observation distance, is higher that the limitinig value of 0.01. According to these variations can conclude that inside the "very-near-field" region, Z isn't equal to Z_0. It tends to be uniform movinig away up to the "very-near-field"region boundary (50 λ). At 60 λ – so just after this limit – can see that almost everywhere in the tubular beam the wave – impedance criterion is less than 0.01. There, Z is equal to Z_0.

The power-density criterion presented in Figures 6 lead to the same conclusions as the impedance criterion. At 15 λ, the ratio of the reactive power density is not negligible compared with the active power density, and up to 50λ, note some reactive power. So,all along the "very-near-field" region, there is still reactive power, first comparable to the active power, and then more and more negligible. At 60λ from the aperture and in the tubular beam of 10 λ radius, there are as many points where the reactive – power criterion is greater than -30dB as points where this criterion is less than -30dB. But can clearly see that the levels less than – 30 dB often decrease down to -50dB, whereasa for only a few points do the levels greater than – 30dB reach -20dB. So, can say that the mean level is lower than -30dB. Outside the "very-near-field" region, there is no more reactive power.

4. CONCLUSION

We can state that for a uniform circular aperture, the behavior of the criteria along the central axis is representative of what happens inside all of the tubular radiated beam. In view of these results can claim that the criteria for the wave impedance and the power density and their limiting values are adequate to define the boundary of the "very-near-field" region at $R_r/4$. So getting to know the electromagnetic field with its characteristics can more easily focus antennas for physiotherapy, which will result in more effective treatment of the patient.

Acknowledgments

The paper will be included in the Proceedings of 7th INTERNATIONAL CONFERENCE on Communications, Electromagnetics and Medical Applications (CEMA'12) Athens, Greece, November 08th - 10th, 2012 on the base of financial support of contract 121пд0009-07, Sector for scientific research of Technical University-Sofia, Bulgaria

References

[1] D. Dimitrov, Medical systems influence of electromagnetic fields on human,education book, TU-Sofia,2007

[2] W. Y. Riadh, "Electromagnetic Fields and Radiation (Human Bioffects and Safety)",Marcel Dekker Inc. Canada, 2001, ISBN 0-8247-0877-3

[3] Shoogo Ueno, Biological Effects Of Magnetic And Electromagnetic Fields (The Language Of Science)

[4] C. A. Balanis, Advanced Engineering Electromagnetics, 2nd Edition,New York, John Wiley, February 2012

[5] C. A. Balanis, Antenna Theory : Analysis and Design, 3rd Edition ,New York, John Wiley, April 2005

[6] S. Laybros and P. F. Combes, "On Radiating Zone Boundaries of Short, λ/2 and λ Dipoles", IEEE Antennas and Propagation Magazine,45,5,October 2004,pp. 53-64.