ELECTROMAGNETIC CHARACTERISTICS OF THE "VERY – NEAR – FIELD" REGION OF A SQUARE UNIFORM APERTURE

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Abstract

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. 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. It is observed the influence of the illumination law and of the aperture shape on the extent of this region, through the cases of parabolic or cosine laws, and the case of square-shape aperture.

1. INTRODUCTION

The space around the reader antenna can be divided into two main regions: far field and near field. In the far field, electric and magnetic fields propagate outward 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 via 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

For antennas whose size is comparable to wavelength, the approximate boundary between the far field and the near field region is commonly given as $r=2D^2/\lambda$, where D is the maximum antenna dimension and is the wavelength. For electrical small antennas, the radiating near field region is small and the boundary between the far field and the near field regions is commonly given as $r = \lambda/2\pi$.

We are interesting in 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.

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

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

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.

For square 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 $D^2/8\lambda$. 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 investigate 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

Now deepen the influence of the aperture-illumination law. This is why, it is determined the "very-near-field" region upper boundary for square aperture with a nonuniform illumination. As for the uniform square case, the "very-near-field" region boundary will be set at the distance where the field magnitude reaches its last minimum.

Four nonuniform equiphase laws are reviewed here: parabolic, squared parabolic, cosine and square cosine distributions. Figure 1 displays the variations of the E-field magnitude along the central axis in the case of a 10λ radius square surface with the four different illumination laws. We can notice that the variations present less pronounced peaks than for the uniform case. Due to these illuminations, the fields of each Fresnel zone do not present the same magnitude, which decreases and lends to zero on the edge of the aperture. So, even if the fields from the Fresnel zones have opposite phases, their magnitudes do not have the same weight. This explains why the interference phenomena are all the more damped as the illumination law is tapered.

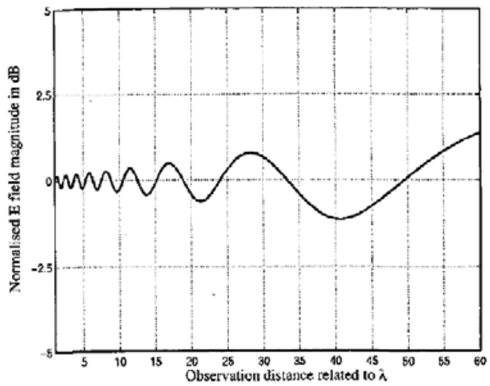

Figure 1a. The axis magnitude of the E field for an aperture of radius equal to 10λ with parabolic illumination

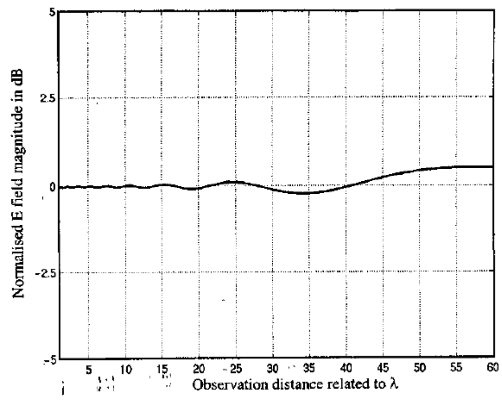

Figure 1b. The axis magnitude of the E field for an aperture of radius equal to 10λ with square parabolic illumination

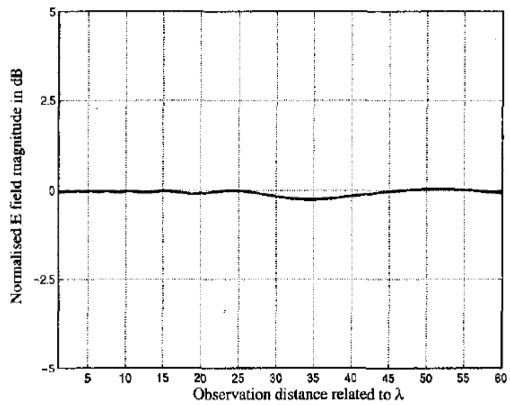

Figure 1c. The axis magnitude of the E field for an aperture of radius equal to 10λ with square cosine illumination

Even so, it is still possible to determine the location of the last minimum. For the 10λ radius aperture presented here, succeeded in concluding with a coefficient applied to $R_r/4$. Indeed, for the parabolic law, for example, the last minumum is located at 0,82 $R_r/4$.

So, reasoning in the same way as for rhe uniform-illumination aperture, it is determined the upper boundary of the "very-near-field" region of apertures with a nonuniform illumination. These boundaried are defined as a fraction of a quarter of the Rayleigh distance, R_r..

Some square apertures with a unifrom illumination have been studied. Figures 2 display the variations of the E-field magnitude along the central axis of such apertures. The square apertures under study are 10λ, 20λ and 50λ wide. Also, in these cases, the interference in less pronounced than in the case of the circular aperture. Indeed, the Fresnel zones – which present a rotational symmetry – are not matched for the square aperture.

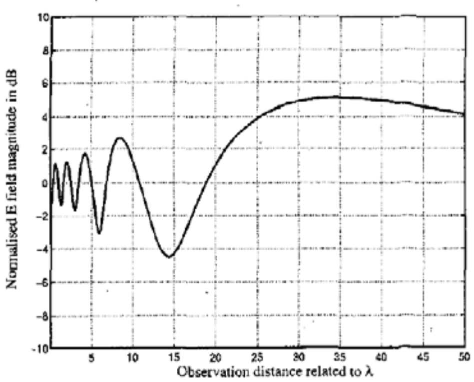

Figure 2a. The axis magnitude of the E field for a 10λ wide ($R_r/4$ = 12,5λ) square aperture

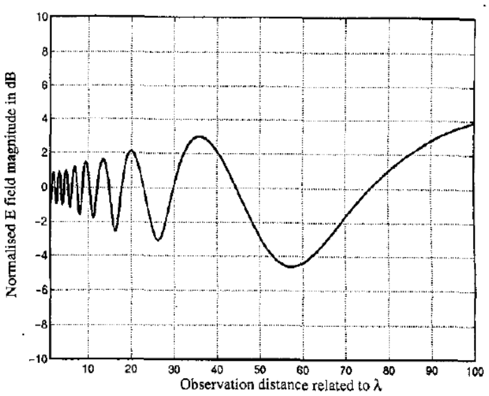

Figure 2b. The axis magnitude of the E field for a 10λ wide ($R_r/4$ = 50λ) square aperture

In order to determine the upper boundary of the "very-near-field" region of these apertures, we pinpointed the last minimum of the E-field magnitude. Once again, it is arrived at a coefficient to apply to $R_r/4$. This time, the coefficient is higher than 1. For the three apertures of different dimensions, the coefficient is equal to 1.14.

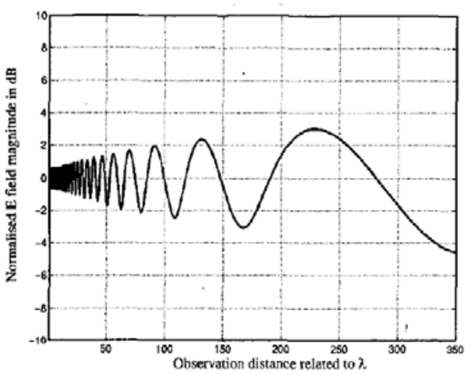

Figure 2c. The axis magnitude of the E field for a 10λ wide ($R_r/4$ = 312,5λ) square aperture.

3.1. Wave Impedance

The interference along the central axis is less noteworthy in the square case than in the circular case. Consequently, the wave impedance criterion variations for the square apertures do not present notable peaks. These variations are shown in Figures 3a, 3b and 3c for the 10λ to 50λ wide apertures. The limiting value of 0.01 is reached at distances really suitable for the square apertures, because it does not present a circular symmetry around this axis.

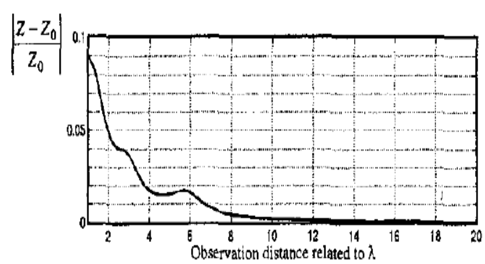

Figure 3a. The wave impedance criterion for 10λ wide square aperture (1,14$R_r/4$ = 14,5λ).

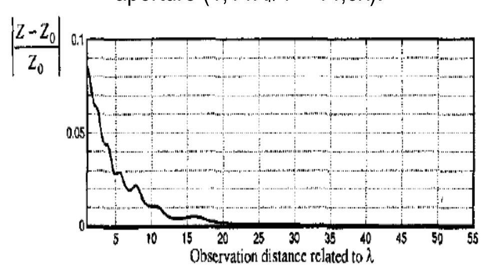

Figure 3b. The wave impedance criterion for 20λ wide square aperture (1,14$R_r/4$ = 57λ).

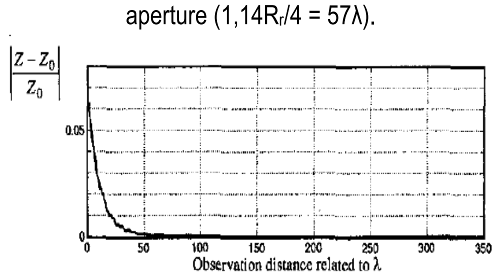

Figure 3c. The wave impedance criterion for 50λ wide square aperture (1,14$R_r/4$ = 356λ).

3.2. Power Density

Figures 4a, 4b and 4c present the variations of the power density criterion for the same square apertures. In the way can notice that the limiting value of -30dB does not occur at distances about $1,14R_r/4$, but closer to the aperture. Moreover, the distances deduced from this criterion are also different from the distances obtained from the impedance criterion. So, in the square-aperture case can assume that these two criteria are not consistent on the central axis.

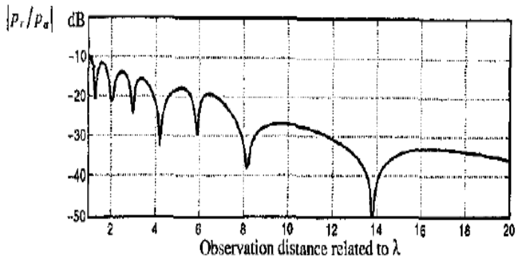

Figure 4a. The power density criterion for 10λ wide square aperture ($1,14R_r/4$ = 14,5λ).

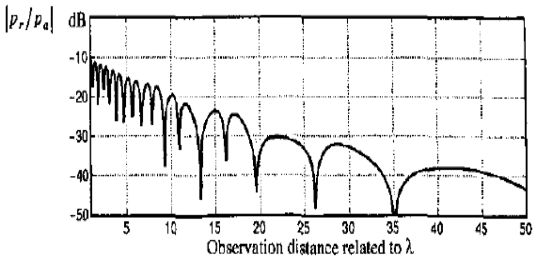

Figure 4b. The power density criterion for 20λ wide square aperture ($1,14R_r/4$ = 57λ).

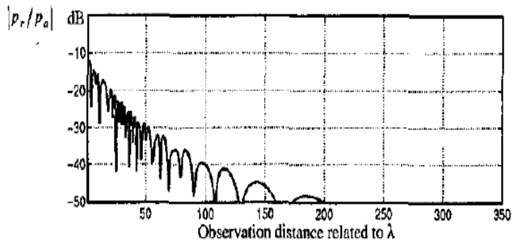

Figure 4c. The power density criterion for 50λ wide square aperture ($1,14R_r/4$ = 356λ).

3.3. Transverse section analysis in the "very-near-field" region

The radiation in the "very-field or Rayleigh" region is concentrated inside a square tubular beam. Figures 5a, 5b and 5c display the variations of the wave impedance criterion for a 20λ wide square aperture, for which the "ver-near-field" region is extended up to 57λ. The first two figure show this criterion on the transverse planes located at 15 λ and 30λ, below this boundary. Referring to them can say that Z is not yet to Z_0. At 60 λ – that is, just after the "very-near-field" region boundary – the criterion is lower than the limiting value of 0,01. It can note from these views that the maximum values of the criterion are not located on the central axis, contrary to the circular case. This justufied the observation that the criterion on the central axis is not conclusive.

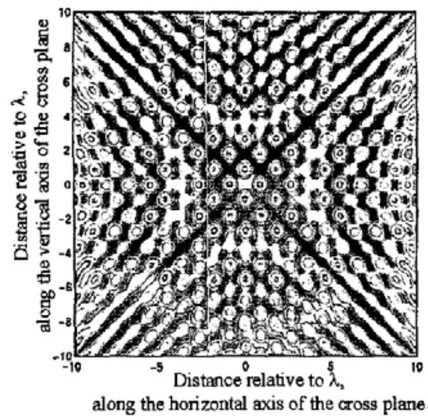

Figure 5a. The variations of wave impedance criterion for 20λ radius aperture ($1,14R_r/4$ = 57λ) on the transverse plane at 15λ from the aperture

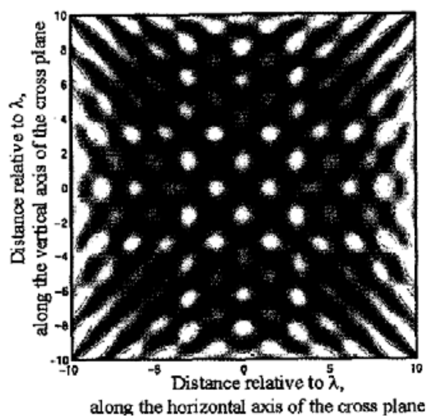

Figure 5b. The variations of wave impedance criterion for 20λ radius aperture ($1,14R_r/4$ = 57λ) on the transverse plane at 30λ from the aperture

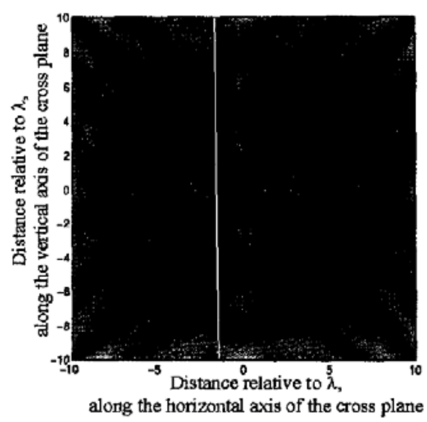

Figure 5c. The variations of wave impedance criterion for 20λ radius aperture ($1,14R_r/4$ = 57λ) on the transverse plane at 60λ from the aperture

Figures 6a, 6b and 6c concern the power density criterion. It emphasizes that the "very-near-field" region boundary set at 57λ seems coherent. Indeed, the figures for the distances of 15λ and 30λ let us see that the reactive power density is not negligible compared with the active power density at such distance. For a distance of 60λ – just after the "very-near-field" region boundary – we can see that the power density criterion is more or less than – 30dB inside the square tubular beam. As for the circular case do not have to consider the maximum value of the criterion inside the tubular beam, but rather its mean value. Indeed, the most important characteristics is the flux of the power density across the transverse section. So, at 60λ, the mean valueof the power density criterion is actually -30dB.

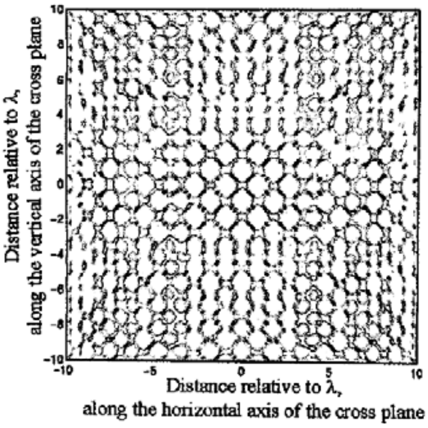

Figure 6a. The variations of power density criterion for 20λ radius aperture ($R_r/4$ = 57λ) on the transverse plane at 15λ from the aperture

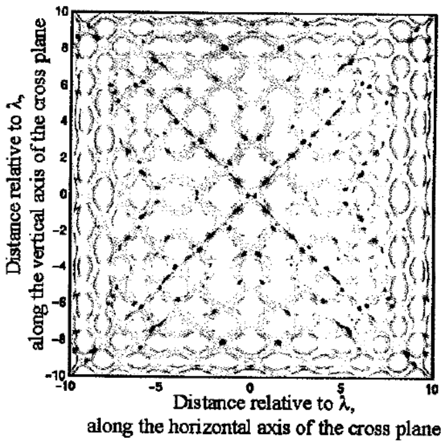

Figure 6b. The variations of wave impedance criterion for 20λ radius aperture ($R_r/4$ = 57λ) on the transverse plane at 30λ from the aperture

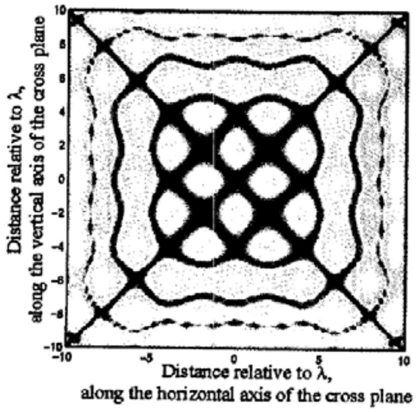

Figure 6c. The variations of wave impedance criterion for 20λ radius aperture ($R_r/4$ = 57λ) on the transverse plane at 60λ from the aperture

4. CONCLUSION

We can assume that the boundary of 1,14$R_r/4$ for the "very-near-field" region is well suited for the uniform square apertures. Can also conclude that the two criteria are consistent, even for the square-aperture case, providing that they are studied inside all of the tubular beam and not only along the central axis. 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

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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.