How Far is Far Enough?

Additional insight into the nature of the near-field/far-field boundary

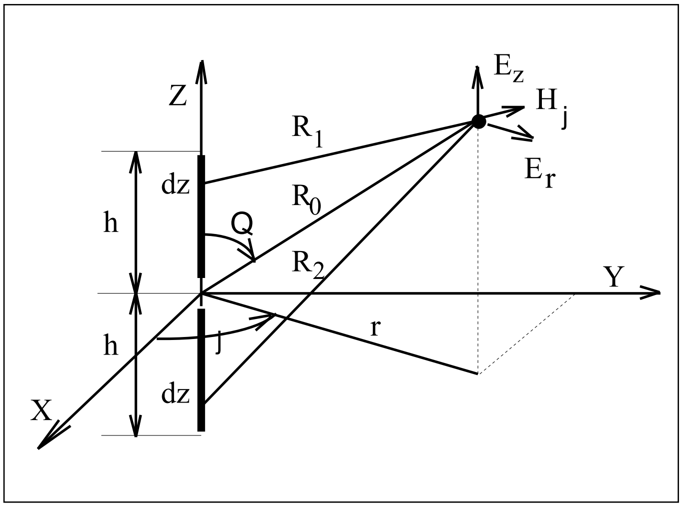
By Ahmed Omar and Hubert Trzaska
Technical University of Wroclaw

In a previous Design Ideas article [1], the author tried to answer this article's title question. This article will provide some supplementary comments to expand on the issue.

While considering the boundary of the far-field, we must take into account two facts: the boundary does not exist in the sense of a discontinuity, and any criterion of the boundary is an arbitrary choice.

The most widely used criterion of the distance (r), at which starts the far-field of a radiating (receiving) system of maximal linear dimension (D), and working at wavelength is

$$r = \frac{2D^2}{\lambda} \qquad (1)$$



▲ **Figure 1. A symmetric dipole in rectangular coordinate system.**

An impressive illustration of the use of this criterion may be its comparison in the case of two antennas, diametrically opposed one to the other with regards to their geometrical sizes. An example would be the world's tallest (0.55 λ) vertical antenna of a LW transmitter working at a frequency of 227 kHz, and a dish antenna of 3.5 m diameter working at 10 GHz. Using the criterion in Equation 1, we will have similar r for both cases. Here we must notice that in some applications (especially in the direct measurement of an antenna's pattern) we have to use more rigorous criteria than given by the previous formula.

Especially for near-field EMF measurements, it is indispensable to know where the far field begins in order to be able to estimate what methodological simplifications we will have and where they are acceptable. To illustrate the issue, an example is provided, based on a half- and a full-wave dipole in the free space conditions. The dipole is located in the coordinate system as shown in Figure 1.

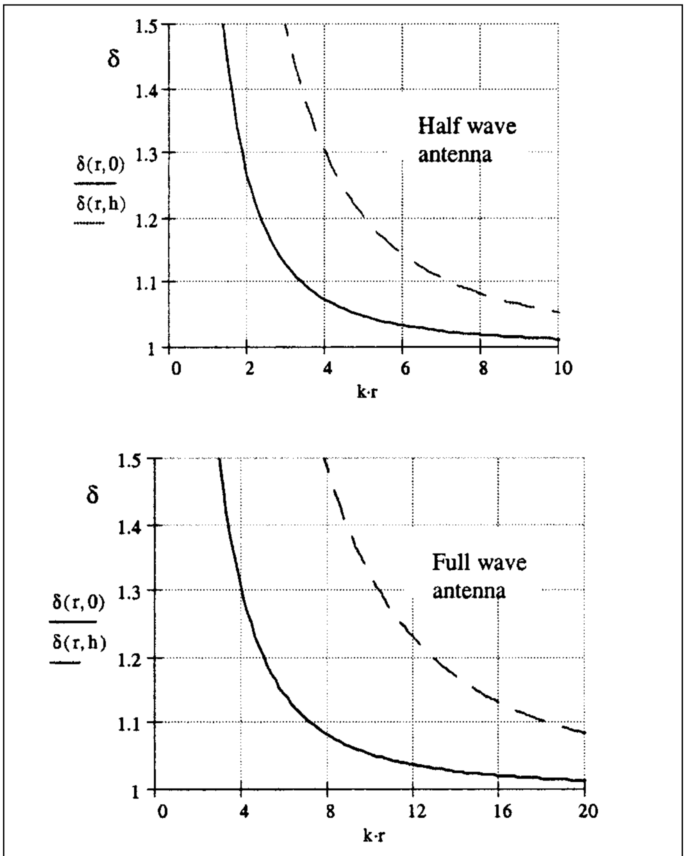
Neglecting phase relations for the XY plane,

$$\delta = \frac{E_0}{E_z} = \frac{Z_0}{Z} = \frac{R}{r} = \frac{\sqrt{r^2 + h^2}}{r} \qquad (2)$$

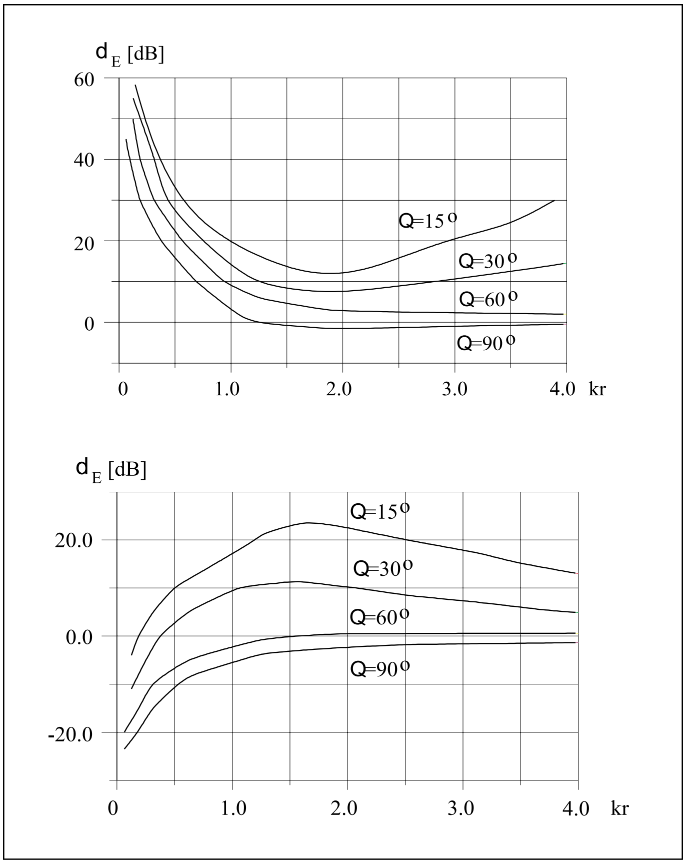
where,

- E_0 is the E-field in the far-field approximation ($E \sim 1/r$),
- E_z is the E-field without the approximation ($E \sim 1/R$),
- Z_0 – intrinsic impedance of free space; $Z_0 = 120\pi$, and
- $Z = E_z/H_j$

Results of calculations are presented in



▲ **Figure 2 The factor δ as a function of *k·r* for the dipole center (continuous) and its end (dashed).**



▲ **Figure 3. Error δ_E around a half-wave (top) and a full-wave dipole (bottom).**

Figure 2 for the center of the dipole, ($z = 0$) is the continuous line, and for the end of the dipole, ($z = h$) is the dashed line.

Similar estimations were performed for the power density around the dipole. Here, the error δ_E indicates difference between the electric power S_E defined as:

$$S_E = \frac{|E|^2}{2Z_0} \quad (3)$$

and the real part of the Poynting vector S_r. In order to show the scale of the error, it is plotted in Figure 3 in logarithmic scale along with the definition [3]:

$$\delta_E = 10 \log \frac{|S_r - S_E|}{S_r} \quad (4)$$

We must also notice here that the estimations of the δ_E are of primary importance because the power density measurements in the near-field are performed, in majority of cases, via an *E*-field measurement as given by Equation (3). On the other hand, S_E is defined in relation to Z_0 because of the measuring probe calibration's conditions.

Using presented considerations, we may define a distance from the dipole at which the far-field starts. If we assume $\delta = 10$ percent, then the boundary of the far-field will be, in the center of the half-wave dipole, almost at the same distance as while using formula (1), i.e. $k \cdot r = \pi$. However, at the dipole's end ($z = h$) the distance is almost doubled. Near the full-wave dipole, the respective distances are more than twice as much as near the half-wave dipole. In the case of the power density, similarly assuming $\delta_E = 1$ dB, we may estimate the distance as a bit more than $k \cdot r = 1$ at the XY plan and going to infinity at axis *Z* (there is no radial *H*-field component).

Examples show that with no regard to the definition of the far-field boundary, the latter is a function of the type of the radiator, as well as the direction to it and the distance from it. Thus these factors should be precisely defined while the boundary is considered on the basis of *E*, *Z*, *S* or other magnitudes. As it could be seen, it was not easy to interpret the results of the estimations in the case of relatively simple radiating structures. We may expect that in the case of more complex structures, an interpretation of the boundary will be incomparably more difficult. This is the main advantage of the definition (1) and the reason of its wide use, although the results of presented estimations are more precise and more informative.

At this point, we should notice that the near-field does not discount the far-field. An intermediate-field exists between them, which together with the near-field is called the Fresnel region.

The boundary of the near-field is defined as [4]:

$$r = \frac{D}{4} + \frac{D}{2}\left(\frac{D}{\lambda}\right)^{\frac{1}{3}} \qquad (5)$$

This formula was derived for the same phase-front difference as Equation (1). Of course, the assumption shown may be modified for specific application requirements.

References

1. R. Bansal; "The Far-Field: How Far is Far," *Applied Microwave & Wireless,* November 1999.

2. A. Omar; "The Near-field of Medium and Long-wave Antennas," Ph.D. dissertation, Technical University of Wroclaw, Poland 1999.

3. H. Trzaska; "Power density near physical radiators," *Proc. of the COST 244 Meeting*, Zagreb 1996.

4. G. Z. Aizenberg; *Short-wave Antennas* (in Russian), Moscow 1962.

Author information

Ahmed Omar and Hubert Trzaska are on staff at the Institute of Telecommunications and Acoustics at the Technical University of Wroclaw, Poland. Mr. Trzasksa may be reached via email at: HUTRZ@zr.ita.pwr.wroc.pl.

Send us your Design Ideas for possible publication!

Any helpful circuit design technique, analytical shortcut or tutorial review may be a candidate for a Design Idea column. Send your ideas to:

Editor, *Applied Microwave & Wireless*
4772 Stone Drive, Tucker, GA 30084
Fax: 770-939-0157, e-mail: amw@amwireless.com