Waves & Coffee – Approximately speaking.

Why do we have near, mid, and far fields in antennas?

By Stephen W2WF

As we've seen, antennas are a fascinating subject. In science and engineering we often resort to models of the real world and once we have a model in mind, we apply mathematical equations to our model. By their very nature, the model equations tend to be very general. Sometimes too general. Therefore, in our studies of antennas we resort to approximations as tools that will give us useful answers to practical problems.

Approximations can be thought of as ways to apply our physical intuition to the problem at hand. They serve to trim down the scenarios and restrict them to our particular situation. For example, it would make no sense to solve a model that would apply to under water VLF antennas when we're trying to model radio wave propagation in the atmosphere.

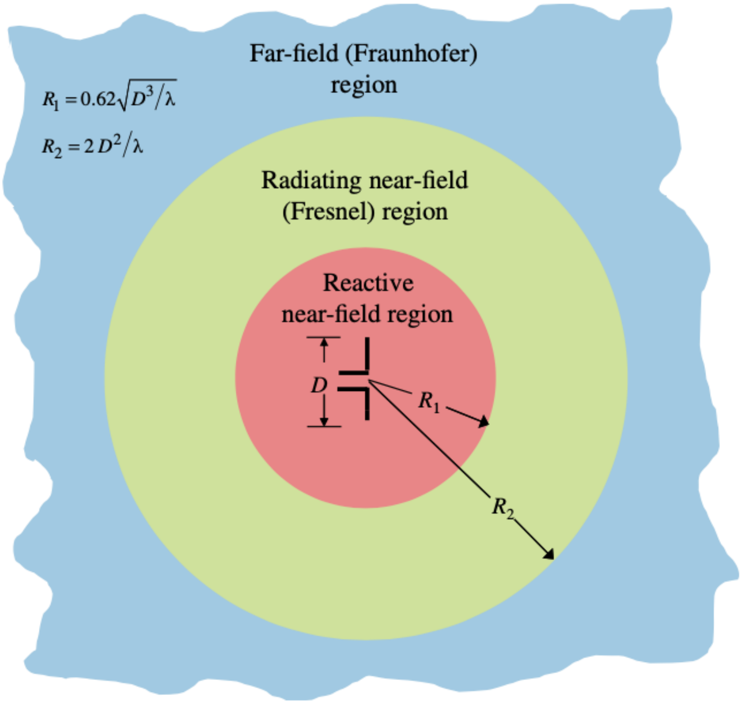
Restricting our model scenarios is also helpful since the more general the equations are, the more difficult they usually are to solve.

The tool present in our toolbox that we are going to look at in this brief note is called "approximation".

There's nothing wrong with using approximations as long as we're careful to always be mindful of the regime where our approximations hold true. Say in the case of a dipole antenna, we know that the equations close to the antenna will be quite different than the equations far away from the antenna.

Hams in general are interested in the latter. We want to know how our antenna will behave in the "Far Field" or far away from our antenna.   This is because our antenna modeling programs like MMANA GAL or EZNEC show "Far Field plots" and we use that information to improve our antenna systems. We'd also like to know where that "Far Field" begins so that we make sure that we're getting answers for the region farther away than that boundary.

To attack the problem, first let's split the space around our antenna into three regions: Reactive near-field region, Radiating near-field or "Fresnel" region, and Far-field or "Fraunhofer" region. These names come from the study of optics where similar effects were first seen.



$$R_1 = 0.62\sqrt{\frac{D^3}{\lambda}}$$

$$R_2 = 2\frac{D^2}{\lambda}$$

Where,

$R_1 = Reactive\ near - field\ radius$

$R_2 = Radiating\ near - field\ radius$

$D = Dipole\ antenna\ length\ tip\ totip$

$\lambda = wavelength\ of\ radiation$

Let’s zero in on the Far Field or Fraunhofer region. Per the diagram above we see that we really care for the boundary denoted by the quantity R_2:

$$R_2 = 2\frac{D^2}{\lambda}$$

Crunching the numbers for a dipole antenna, the Far Field region would ***start*** at the following distances from the antenna and go outwardly from there:

D (meters)	D (feet)	λ (meters)	R2 (meters)	R2 (feet)	Comments
38.04	124.80	80.00	36.18	118.69	3.75MHz
19.88	65.22	40.00	19.76	64.83	7.175MHz
14.09	46.23	30.00	13.24	43.42	10.125MHz
10.06	33.01	20.00	10.13	33.22	14.175MHz
7.87	25.83	17.00	7.29	23.92	18.120MHz
6.71	22.00	15.00	5.99	19.67	21.275MHz
5.72	18.77	12.00	5.45	17.89	24.940MHz
4.99	16.36	10.00	4.98	16.33	28.6MHz
2.74	9.00	6.00	2.51	8.23	52MHz

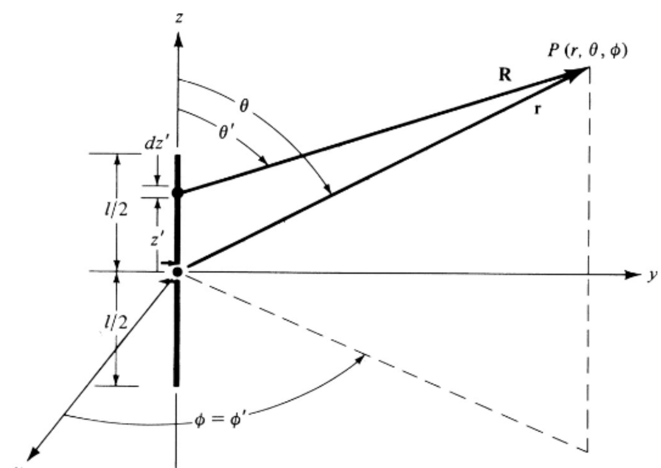
So, our rule of thumb that we need to be about one “dipole antenna length”, or λ/2, ***away*** from our antenna for the Far Field approximation to work is pretty much correct!

What approximations are we using for the Far Field? The following:

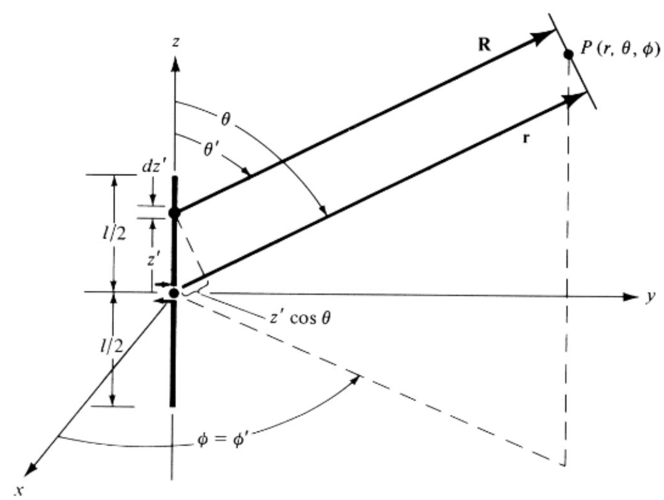
$$R \cong r - z' cos\theta \ for\ phase\ terms$$

$$R \cong r \quad for\ amplitude\ terms$$

Another way of looking at this is that we’re concentrating on the region where the Electric (**E)** and Magnetic (**B)** fields are plane waves since we’re so far away. So the antenna looks ***very small*** from the point where we are measuring at. As you can see from this plot, we’re interested in the region where R can be approximated by r.



(a) Finite dipole geometry



(b) Geometrical arrangement for far-field approximations

We are interested in the Electric (**E)** and Magnetic (**B)** fields at a point P away from the feedpoint of our dipole antenna. The starting point to get to these two fields is to begin with a third vector quantity called the Vector Potential. It may not be as well-known as the Electric (**E**) and Magnetic (**B**) fields but from it we derive the other two. The equation for the vector potential $\boldsymbol{A}(x, y, z)$ is the following:

$$\mathbf{A}(x, y, z) = \frac{\mu}{4\pi} \int_C \mathbf{I}_e(x', y', z') \frac{e^{-jkR}}{R} \, dl'$$

Here $I_e(x', y', z')$ is the current in our antenna, μ is the permeability constant of air, and the exponential term has the imaginary constant $j = \sqrt{(-1)}$. The parameter $k = \frac{2\pi}{\lambda}$ is the wavenumber which is a quantity like the angular frequency.

Once we apply our approximation above, we can pull out the $\frac{e^{-jkr}}{r}$ term out of the integral and our equation looks like this, which is a step in the right direction:

$$A(x,y,z) = \frac{\mu}{4\pi}\frac{e^{-jkr}}{r}\int I_e(x',y',z')e^{+z'cos\theta}dl'$$

Now, the term $z'cos\theta$ can then be approximated as zero since $r \gg z'$. This makes our problem a lot simpler with our vector potential taking this form:

$$A(x,y,z) = \frac{\mu}{4\pi}\frac{e^{-jkr}}{r}\int I_e(x',y',z')dl'$$

The next step would be to put in a current distribution I_e and integrate to get an expression for the Vector Potential:

$$A(x,y,z)$$

Once we know this expression, we can get the magnetic field:

$$B(x,y,z) = \nabla \times A$$

and then finally the electric field:

$$E(x,y,z) = \frac{1}{j\omega\epsilon\mu}\nabla \times B(x,y,z)$$

So, approximations are an important tool in solving for antenna radiation patterns as we've seen in this brief article. Indeed, approximations play a central role in the study of antennas and as such are a central part of our hobby.

References:

Antenna Theory Analysis and Design 4th edition. Constantine A. Balanis.