Richard Alan Satterfield 1/27/17
www.richard-alan.com rev. 12/20/17

The Birth Of A Wave

Abstract

This paper applies Maxwell's equations to the actual birth process in an antenna site for generating electromagnetic radiation. The paper embraces the assumption that the field configuration for spawning electromagnetic radiation exists in the immediate space surrounding the antenna (near field) instead of at some large distance from the antenna (far field) which seems to be the prevailing belief of physicists. In order to simplify the dissertation an XYZ coordinate system is defined so that its axis is carefully aligned to the antenna's polarization. In addition, the paper asserts an interpretation of Maxwell's equations that emphasizes the relations in the equations while dispensing with any notion of cause and effect.

Section 1: The Birth Site

A typical site for generating electromagnetic radiation is shown in Fig.1. The site consists of a vertically polarized dipole antenna driven by a sinusoidal voltage applied to its elements. The voltage causes a sinusoidal current to flow in the elements. This current flow gives rise to a sinusoidal magnetic field; it also results in a changing charge distribution which gives rise to a sinusoidal electric field. The two sinusoidal fields resulting from the current flow have a quadrature phase relationship similar to that in an oscillating lumped LC circuit. However, the similarity ends there. In the lumped circuit the electric and magnetic fields occupy different regions of space, and have spatial orientations that depend on the chance layout of circuit components. In the antenna case its design forces the fields occupy the same region of space, and to be spatially in quadrature. Fig.1 depicts the cyclic relationship of the fields surrounding the antenna as they would appear if they weren't obscured by the fields of escaping waves.

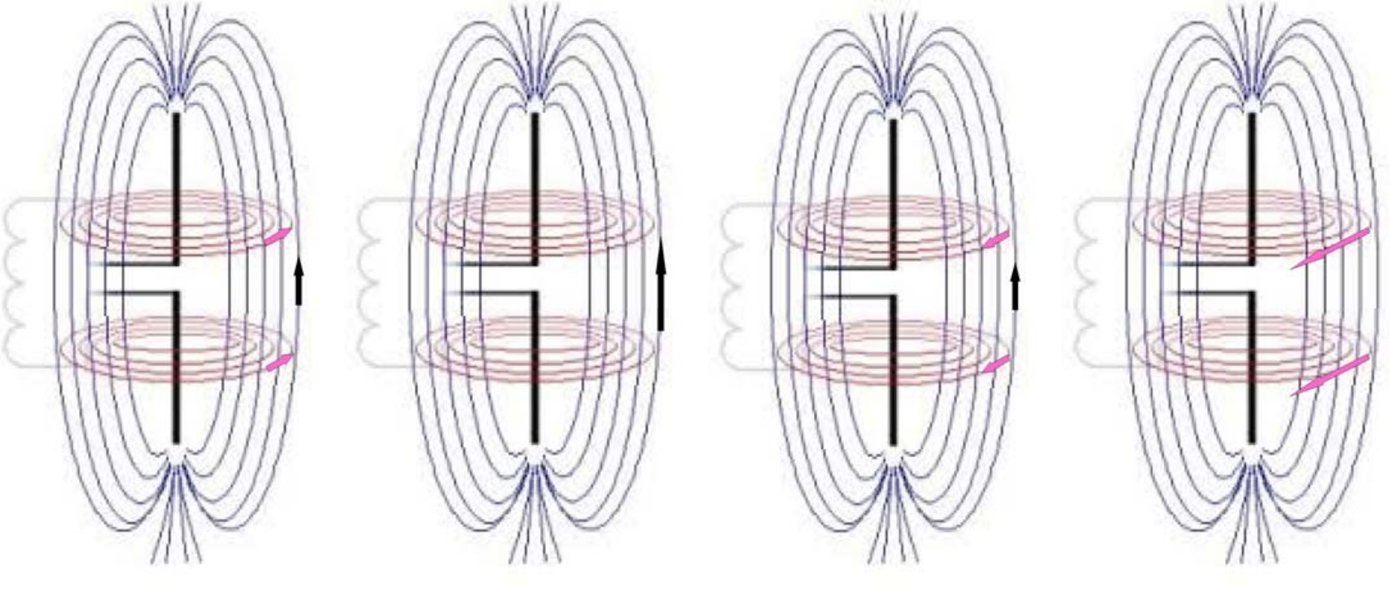


Fig. 1a
Increasing *E*
Decreasing ***-H***

Fig. 1b
Max *E*
Zero ***H***

Fig. 1c
Decreasing ***E***
Increasing ***H***

Fig. 1d
Zero ***E***
Max ***H***

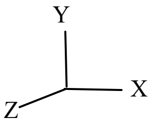
Figure.1. The four drawings depict half of a sinusoidal cycle. Italics are used to denote source fields. The fields of escaping radiation are not shown. Arrows are used to depict the polarity of the fields seen if facing the antenna broadside from the right. The electric field ***E*** is shown in gray; the magnetic field ***H*** is shown in red.

The drawings in Fig.1 show that the phase of ***E*** and ***H*** is not the same. The drawings left to right show the ***E*** field increasing until it reaches a max, then decreasing until it reaches zero. During those transitions, the ***H*** field is shown in quadrature (lags 90°); the magnitude of -***H*** decreases to zero as ***E*** reaches a max, then ***H*** increases to max as ***E*** reaches zero. The second half of the cycle is not shown, but is identical except the fields are in the opposite direction. Note that Fig.1 only shows the source fields. The actual fields immediately adjacent to the antenna would be different; the actual fields would be the superposition of the source fields and the fields of escaping waves.

Section 2: Maxwell's Equations

There are various forms of Maxwell's equations. They differ primarily in how the electric and magnetic fields are depicted. In some forms of his equations the electric and magnetic fields are depicted as "flux density" which is denoted by the variables **D** and **B** respectively. The form used in this paper depicts electric and magnetic field magnitudes rather than flux density which are denoted by the variables **E** and **H** respectively.

With that in mind consider Maxwell's equations[2] as they apply to fields in free space where charge and charge motion is zero. This would include the space adjacent to the antenna, but not the space inside the volume of the antenna.

Assume an XYZ coordinate system 

for the site depicted in Fig.1, so that when the antenna is viewed broadside from the right the ***E*** field is parallel to the Y axis and the ***H*** field to the Z axis. Maxwell's equations for these conditions are shown in Eq.1 through Eq.4.

1. $\nabla \cdot \mathbf{E} = 0$

2. $\nabla \cdot \mathbf{H} = 0$

3. $\nabla \times \mathbf{E} = -\mu_0 \partial \mathbf{H}/\partial t$

4. $\nabla \times \mathbf{H} = \varepsilon_0 \partial \mathbf{E}/\partial t$

Maxwell's Equations
For Fields In Space
where I = 0, Q = 0

In order for the application of these equations to make sense it is necessary to have a clear understanding of their meaning, especially the meaning of Eq.3 and Eq.4.

Meaning of Eq.3 If an electric field in free space has a curl then it will be accompanied by a magnetic field that changes with respect to time ... AND ... if a magnetic field in free space changes with respect to time then it will be accompanied by an electric field that has a curl. In other words, you can't have one without the other.

Meaning of Eq.4 If a magnetic field in free space has a curl then it will be accompanied by an electric field that changes with respect to time ... AND ... if an electric field in free space changes with respect to time then it will be accompanied by a magnetic field that has a curl. In other words, you can't have one without the other.

Note that the above description avoids implying cause and effect. It is the position of this paper that Maxwell's equations should be interpreted literally, that is they should be interpreted as specifying relationships between terms and not cause and effect.

Section 3: Maxwell's Equations 3 and 4 For The Polarized Antenna In Fig.1

Before we can begin we need to simplify Maxwell's equations by taking polarization into account. The analysis of the fields adjacent to the antenna will be greatly simplified if Maxwell's Equations are rewritten to take into consideration the polarized configuration in Fig.1. Actually, only Eq.3 and Eq.4 need to be rewritten. These equations pertain to any volume of space adjacent to the antenna, but not a volume that includes the antenna. In other words, the equations pertain to free space which would include the source fields and the fields of escaping waves. The XYZ coordinate system defined in the previous section shows that the source field, ***E,*** is aligned to the Y axis when viewing the antenna broadside from the right. It also shows that the source field, ***H,*** is aligned to the Z axis. Although the fields from escaping waves are not shown, they will also be aligned to XYZ in exactly the same way since a polarized antenna polarizes all fields associated with it. The bottom line is, the electric fields cannot have an X or Z component since they are aligned to Y, and the magnetic fields cannot have an X or Y component since they are aligned to Z. Incorporating these facts into Maxwell's equations will simplify them for the purpose of analyzing the antenna fields viewed broadside from the right. We will accomplish this simplification by replacing the shorthand vector notation in Maxwell's equations with the more explicit partial derivative notation, and then drop the derivatives that are zero due to polarization.

We start with the left side of Eq.3. Let ***i j k*** be unit vectors in the XYZ direction. Then the curl, $\nabla \times \mathbf{E}$, in Eq.3, can be expressed in terms of its partial derivatives as shown below,

5. $(\underset{\wedge}{\partial E_z/\partial y} - \partial E_y/\partial z)\boldsymbol{i} + (\underset{\wedge}{\partial E_x/\partial z} - \underset{\wedge}{\partial E_z/\partial x})\boldsymbol{j} + (\partial E_y/\partial x - \underset{\wedge}{\partial E_x/\partial y})\boldsymbol{k} = -\mu_0 \partial \mathbf{H}/\partial t$

The flagged terms above are zero since those vector components of **E** are zero. Thus Eq.5 becomes,

6. $-\partial E_y/\partial z\ \boldsymbol{i} + \partial E_y/\partial x\ \boldsymbol{k} = -\mu_0 \partial \mathbf{H}/\partial t$

Now expand the vector expression on the right side of Eq.6 to get,

7. $-\partial E_y/\partial z\ \boldsymbol{i} + \partial E_y/\partial x\ \boldsymbol{k} = -\mu_0 (\underset{\wedge}{\partial H_x/\partial t\ \boldsymbol{i}} + \underset{\wedge}{\partial H_y/\partial t\ \boldsymbol{j}} + \partial H_z/\partial t\ \boldsymbol{k})$

The flagged terms above are zero since those vector components of **H** are zero. A consequence of the ***i*** term on the right being zero is that the ***i*** term on the left must be zero. Thus, Eq.7 becomes,

8. $\partial E_y/\partial x = -\mu_0 \partial H_z/\partial t$ Simplified Eq.3 (Fig.1 polarized antenna)

The above approach will be followed below to simplify Eq.4. We start with the left side of Eq.4 and expand $\nabla \times \mathbf{H}$ so that the curl is expressed in terms of its partial derivatives as shown below,

9. $(\partial H_z/\partial y - \underset{\wedge}{\partial H_y/\partial z})\boldsymbol{i} + (\underset{\wedge}{\partial H_x/\partial z} - \partial H_z/\partial x)\boldsymbol{j} + (\underset{\wedge}{\partial H_y/\partial x} - \underset{\wedge}{\partial H_x/\partial y})\boldsymbol{k} = \varepsilon_0\, \partial \mathbf{E}/\partial t$

The flagged terms above are zero since those vector components of **H** are zero. Thus Eq.9 becomes,

10. $\partial H_z/\partial y\ \boldsymbol{i} - \partial H_z/\partial x\ \boldsymbol{j} = \varepsilon_0\, \partial \mathbf{E}/\partial t$

Now expand the vector expression on the right side of Eq.10 to get,

11. $\partial H_z/\partial y\ \boldsymbol{i} - \partial H_z/\partial x\ \boldsymbol{j} = \varepsilon_0\, (\underset{\wedge}{\partial E_x/\partial t\ \boldsymbol{i}} + \partial E_y/\partial t\ \boldsymbol{j} + \underset{\wedge}{\partial E_z/\partial t\ \boldsymbol{k}})$

The flagged terms above are zero since those vector components of **E** are zero. A consequence of the ***i*** term on the right being zero is that the ***i*** term on the left must be zero. Thus, Eq.11 becomes,

12. $\partial H_z/\partial x = - \varepsilon_0 \ \partial E_y/\partial t$ Simplified Eq.4 (Fig.1 polarized antenna)

Eq.8 and Eq.12 are restated below as Maxwell's Eq.3_p and Eq.4_p where the subscript denotes that polarization and other conditions of Fig.1, have been taken into account.

3_p. $\partial E_y/\partial x = -\mu_0 \partial H_z/\partial t$

Maxwell's Eq.3 and Eq.4 for Fig.1 polarized antenna

4_p. $\partial H_z/\partial x = - \varepsilon_0 \ \partial E_y/\partial t$

Section 4: The Phase Relationship of Electric and Magnetic Fields Escaping From The Antenna

The meaning of Maxwell's Eq.3 and Eq.4 was stated in Section 2. The meaning is restated below:

Meaning of Eq.3 If an electric field in free space has a curl then it will be accompanied by a magnetic field that changes with respect to time ... AND ... if a magnetic field in free space changes with respect to time then it will be accompanied by an electric field that has a curl. In other words, you can't have one without the other.

Meaning of Eq.4 If a magnetic field in free space has a curl then it will be accompanied by an electric field that changes with respect to time ... AND ... if an electric field in free space changes with respect to time then it will be accompanied by a magnetic field that has a curl. In other words, you can't have one without the other.

A simplified depiction of these two equations was derived in the previous section, and is presented as Eq.3_p and Eq.4_p. The meaning of Eq.3 and Eq.4 as stated above still applies in this simplified case, but it is worthwhile to restate the meaning in terms of the simplified equations as shown below:

Meaning of Eq.3_p If an electric field in free space changes with respect to x then it will be accompanied by a magnetic field that changes with respect to time ... AND if a magnetic field in free space changes with respect to time then it will be accompanied by an electric field that changes with respect to x. In other words, you can't have one without the other.

Meaning of Eq.4p If a magnetic field in free space changes with respect to x then it will be accompanied by an electric field that changes with respect to time ... AND if an electric field in free space changes with respect to time then it will be accompanied by a magnetic field that changes with respect to x. In other words, you can't have one without the other.

With the simplification of Maxwell's equations as shown in Eq.3_p and Eq.4_p, we can easily deduce the phase relationship between the electric and magnetic fields in free space. Our approach will be to assume a sinusoidal wave shape for the electric field, and then use Maxwell's equations to derive the corresponding magnetic field's wave shape. To that end, we let E_y be a cosine wave with free parameters k, ω and φ as is shown below.

13. $E_y = E_{max}\cos(kx - \omega t + \varphi)$ Substitute this Ey into Eq.3_p to get,

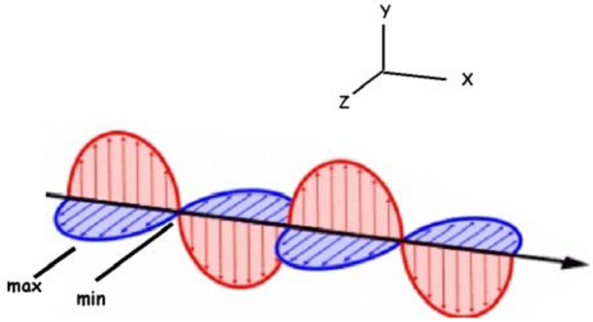
14. $\partial /\partial x \, E_{max} \cos(kx - \omega t + \varphi) = -\mu_0 \partial H_z/\partial t$ Evaluate the derivative on the left side to get,

15. $- E_{max}\, k \sin(kx - \omega t + \varphi) = -\mu_0 \partial H_z/\partial t$ Cancel signs, integrate respect to *t*, rearrange to get,

16. $H_z = k/(\omega \mu_0) \ E_{max}\cos(kx - \omega t + \varphi)$ Same phase as Eq.13

Eq.13 and Eq.16 exposes two fundamental relations for the fields of waves escaping from the antenna. The electric and magnetic fields must be 1) spatially orthogonal to each other and 2) mirror images of each other. If one field is a sinusoid then the orthogonal field must be an identical sinusoid of the same phase. This is shown graphically in Fig.2 for the waves escaping in the positive X direction. Section 5 will explain how this particular field configuration is consistent with the wave equation.

Figure 2. The drawing depicts electric and magnetic fields radiating along the X axis in the free space adjacent to the antenna. The **E** field (red) depicts Eq.13; the **H** field (blue) depicts Eq.16. The fields are exact mirror images of each other so that at each instant of time both fields will have their min and max points coincide at exactly the same point along the X axis.



Note that the source fields depicted in Fig.1 are not in phase like the radiated fields depicted in Fig.2. Section 6 will explain how these out-of-phase source fields spawn escaping waves whose electric and magnetic fields are in phase.

An Important Observation. Although the derivation in this section was based on a cosine wave shape, the conclusions apply for any wave shape. This becomes obvious when you consider that the cosine function used in the derivation was parameterized without specificity. This means that the cosine function actually represents any sinusoid (sine or cosine) of any frequency, and therefore any wave shape having a Fourier transform could be represented by the summation of various magnitudes of cosines like that assumed in Eq.13. Consequently, conclusions reached based on the parameterized cosine derivations, would apply to any wave shape.

Section 5: The Wave Equation

The previous section utilized Maxwell's Eq.3_p to show the relationship between electric and magnetic fields in free space. Eq.4_p has the same form, and it could've been used instead to show exactly the same thing. You can imagine the excitement Maxwell must have felt when he realized his equations defined a bonding of electric and magnetic fields that were not rooted to any charge … mass… or earth. Could such an autonomous bonding of fields propagate through space? In Maxwell's day such things were not heard of. But you can be sure he contemplated that question, and would have immediately checked to see if his equations were compliant with the geometric implications of a wave in motion. We will do the same thing in this section. We will check to see if Eq.3_p and Eq.4_p are compliant with the wave equation.

There are different forms of the wave equation, but regardless of its form it is simply a mathematical description of a fixed shape f in motion relative to a stationary observer. With that in mind we will derive a form consistent with a wave propagating from the antenna in Fig.1, and which is depicted in Fig.2. Consider Eq.17 which shows an arbitrary fixed shape that is a function of X, and that is NOT in motion. A stationary observer in an XYZ coordinate system would visualize the amplitude A of the shape as being transverse (orthogonal) to the X axis.

17. $A = f(x)$ A fixed transverse shape f not in motion

Imagine an observer positioned at some point x on the X axis viewing the amplitude A of the fixed shape at the point x. Now imagine an assistant pulling the fixed shape in the positive X direction at a constant velocity c. The observer would see the transverse amplitude A, vary from moment to moment as the fixed shape is pulled past the observer's viewpoint which is fixed at position x. Therefore, the stationary observer's perception of the amplitude A would be as depicted in Eq.18.

18. $A = f(x - ct)$ The most basic form of the wave equation.

Note in Eq.18 the change in f due to a change in x, is the same as the change in f due to a change in $-ct$. This fact can be expressed in partial derivative notation as,

19. $\partial f / \partial x = \partial f / \partial(-ct)$ This can be rearranged to give,

20. $\partial f / \partial x = (-1/c)\ \partial f / \partial t$ The first order form of the wave equation. *Satterfield*[1]

This form of the wave equation applies to a transverse wave propagating along the X axis in an XYZ coordinate system, as perceived by a stationary observer. It relates the change in transverse amplitude versus x with the change in transverse amplitude versus t. The transverse amplitude of the wave is denoted by the function f, which can be any polarization (i.e., any stable orientation orthogonal to the X axis). The propagation velocity is denoted by the parameter c.

The electric and magnetic field configuration derived in the previous section defines a structure with two transverse amplitudes as depicted in Fig.2. Therefore, there must be an instantiation of the wave equation for each transverse amplitude, one for the E_y component and one for H_z component. The two instantiations are shown in Eq.21 and Eq.22.

21. $\partial \mathrm{Ey} / \partial x = (-1/c)\ \partial \mathrm{Ey} / \partial t$ Wave equation applied to the **E** field

22. $\partial \mathrm{Bz} / \partial x = (-1/c)\ \partial \mathrm{Hz} / \partial t$ Wave equation applied to the **H** field

Our objective in this section is to ascertain that Maxwell's Eq.3p and Eq.4p are compliant with the wave equation as depicted in Eq.21 and Eq.22. There are probably a half-dozen ways to approach this, and they'll all give the same result, and they're all fairly simple. Since we lose no generality by representing Ey and Bz as cosine functions with free parameters as was done in Section 4, we'll begin by replacing Ey and Bz in Eq.3p with the values shown in Eq.13 and Eq16 respectively to get,

23. $\partial / \partial \mathrm{x}\ \mathrm{E_{max}} \cos(\mathrm{kx} - \omega t + \varphi) = -\ \partial / \partial t\ (\mathrm{k}/\omega\ \mathrm{E_{max}} \cos(\mathrm{kx} - \omega t + \varphi))$

Comparing the above equation with Eq.21 shows it to be compliant with the wave equation if the parameter c has the following value.

24. $c = \omega / \mathrm{k}$

Now replace Ey and Bz in Eq.4p with the values shown in Eq.13 and Eq16 respectively to get,

25. $\partial / \partial \mathrm{x}\ (\mathrm{k}/(\omega\ \mu_0)\ \mathrm{E_{max}} \cos(\mathrm{kx} - \omega t + \varphi)) = -\ \varepsilon_0\ \partial / \partial t\ (\mathrm{E_{max}} \cos(\mathrm{kx} - \omega t + \varphi))$

If you were to divide both sides of Eq.25 by "$\mathrm{k}/(\omega\ \mu_0)$" it would be in the form of Eq.22 which would make it compliant with the wave equation if the parameter c has the following value.

26. $c = 1 / (\mu_0\, \varepsilon_0)\ (\mathrm{k}/\omega)$ Since from Eq.24, $\mathrm{k}/\omega = 1/c$ we get,

27. $c^2 = 1 / (\mu_0\, \varepsilon_0)$

When Maxwell discovered the value of c shown in Eq.27 he must have been ecstatic. He was very well acquainted with the parameters μ_0 and ε_0, which were well known in his time. He would have known immediately that the velocity of electromagnetic radiation, if it existed, was the speed of light … and that light might simply be electromagnetic radiation.

Section 6: The Birth of a Wave

Fig.1 depicts a transmitting antenna that is being supplied with a stream of electrical energy that continuously floods the space surrounding the antenna with two fields, an electric field and a magnetic field. The two fields are both spatially and temporally in quadrature. These out-of-phase source fields are continuously morphing into electromagnetic waves that take the energy of their birth with them as they escape into space in all directions away from the antenna. Maxwell's equations dictate at least part of this process, but it requires a multistep derivation to make it understandable. To this end, the strategy in this section will be one of divide and conquer. Since the principal of superposition applies to electromagnetic fields, we will derive the ramifications of Maxwell's equations in two steps. In Step 1 we will apply the equations to the ***E*** field shown in Fig.1 without regard to the ***H*** field that is also shown. In Step 2 we will do the opposite; we will apply the equations to the ***H*** field without regard to the ***E*** field. The final result will be the superposition of results from Steps 1 and Step 2, which will show how out-of-phase source fields spawn the birth of a wave whose fields are in phase. The key elements in both steps are the source fields. They are depicted in Fig.1 as sinusoids with the magnetic field shown in quadrature (lags electric field 90^o).

Step 1. The approach used in Section 4 beginning with Eq.13, will be followed here. We begin by defining the source field Ey as a cosine function. Remember, we lose no generality in using a parameterized cosine function with no parameter specificity.

28. $E_y = E_{max} \cos(kx - \omega t + \varphi)$ Substitute this E_y in Eq.3_p to get,

29. $\partial / \partial x \, E_{max} \cos(kx - \omega t + \varphi) = - \mu_0 \, \partial H_z / \partial t$ Evaluate the derivative on the left side to get,

30. $- E_{max} k \sin(kx - \omega t + \varphi) = - \mu_0 \, \partial H_z / \partial t$ Cancel signs, integrate respect to t, rearrange to get,

31. $H_z = E_{max} k / (\mu_0 \omega) \cos(kx - \omega t + \varphi)$ Eq.31 says you can't have E_y without H_z

Thus, Maxwell's Eq.3_p dictates that H_z in Eq.31 must coexists with the source field E_y defined in Eq.28. Section 5 has shown that the combination of in-phase fields like E_y and H_z are compliant with the wave equation. It is the position of this paper that Eq.28 and Eq31 depict the in-phase electric and magnetic fields of a wave emanating from the time varying electric field (not the magnetic field) of the antenna.

Step 2. The approach here will be the same as in Step 1 except for the function selected to represent the source field ***H***. A cosine function was selected in Step 1, but since the magnetic source field is in quadrature it must be represented by a sine function as shown below.

32. $H_z = H_{max} \sin(kx - \omega t + \varphi)$ Substitute this H_z in Eq.3_p to get,

33. $\partial E_y / \partial x = - \partial / \partial t \; \mu_0 H_{max} \sin(kx - \omega t + \varphi)$ Integrate both sides with respect to x to get,

34. $E_y = \partial / \partial t \; H_{max} \, \mu_0 / k \cos(kx - \omega t + \varphi)$ Evaluate $\partial / \partial t$ to get,

35. $E_y = H_{max} \, \mu_0 \omega / k \sin(kx - \omega t + \varphi)$ Eq.35 says you can't have H_z without E_y

Superposition of Step 1 and Step 2. Step 1 described a wave emanating from the electric source field of the antenna. Step 2 described a second wave emanating from the magnetic source field of the antenna. The two transverse amplitudes of the first wave conform to a cosine function, and those of the second wave to a sine function. The superposition of the two waves corresponds to the summation of equal amplitude sine and cosine functions; one summation for the electric fields of the two waves, and another summation for the magnetic fields of the two waves. These summations require that 1) the magnitude of the sinusoid E_y in Eq.28 must be equal to the magnitude of the sinusoid E_y in Eq.35, and 2) the magnitude of the sinusoid H_z in Eq.31 must be equal to the magnitude of the sinusoid H_z in Eq.32. In order for these conditions to be met the relationship of H_{max} and E_{max} must be derived. We could do this by equating the coefficients of the sinusoids in Eq.28 and Eq.35, or we could equate the coefficients in Eq.31 and Eq.32. We choose Eq.31 and Eq.32 which gives us Eq.36.

36. $H_{max} = E_{\mathrm{max}}\, k / (\mu_0 \omega)$ Equal energy relation of E and H fields

We begin with the summation of the electric fields expressed in Eq.28 and Eq.35 as shown in Eq.37.

37. $E_{\mathrm{sum}} = E_{max} \cos(kx - \omega t + \varphi) + H_{max}\ \mu_0 \omega / k\ \sin(kx - \omega t + \varphi)$ Replace H_{max} from Eq.36 to get,

38. $E_{\mathrm{sum}} = E_{max}\ (\cos(kx - \omega t + \varphi) + \sin(kx - \omega t + \varphi))$

For $x, t, \varphi = 0$ cos+sin $\approx 1.4 \cos(-45^o)$ thus,

39. $E_{\mathrm{sum}} \approx 1.4\ E_{max}\ \cos(kx - \omega t + \varphi - 45^o)$

We now proceed with the summation of Eq.31 and Eq.32,

40. $H_{\mathrm{sum}} = E_{\mathrm{max}}\, k/(\mu_0 \omega) \cos(kx - \omega t + \varphi) + H_{max} \sin(kx - \omega t + \varphi)$ Replace H_{max} from Eq.36 to get,

41. $H_{\mathrm{sum}} = E_{\mathrm{max}}\, k/(\mu_0 \omega)\ (\cos(kx - \omega t + \varphi) + \sin(kx - \omega t + \varphi))$

For $x, t, \varphi = 0$ cos+sin $\approx 1.4 \cos(-45^o)$ thus,

42. $H_{\mathrm{sum}} \approx 1.4\ E_{\mathrm{max}}\, k / \omega\ (\cos(kx - \omega t + \varphi - 45^o)$

Eq.39 and Eq.42 express equal energy electric and magnetic fields that are in phase with each other and which comply with the wave equation shown in Section 5. It is the position of this paper that the energy of these fields is actually the energy of the electromagnetic wave stream escaping the antenna in the positive X direction along the X axis. By induction we can presume that the antenna is spewing out a stream of waves of varying energy in all directions whose phase is that depicted in Eq.39 and Eq.42, and whose aggregate energy equals the stream of energy being supplied to the antenna less resistive losses.

Conclusion

Phase Relationship of Electric and Magnetic Fields in an Electromagnetic Wave. Section 4 applied Maxwell's Eq.3_p to the **E** field of an electromagnetic wave presumed to have emanated from a source like that depicted in Fig.1. The derivation of the corresponding **H** field in Eq.16 showed that its phase was the same as the phase of the presumed **E** field in Eq.13. From that we conclude that Maxwell's equations dictate that the electric and magnetic fields of an electromagnetic wave must always be in phase regardless of their distance from the site of their creation.

It should be noted that although Eq.3_p was used in the above derivation, exactly the same conclusion would have been reached had Eq.4_p been used.

The Birth of an Electromagnetic Wave. In Section 6, Maxwell's Eq.3_p was applied to the electric and magnetic source fields depicted in Fig.1. This was done in two steps. In Step 1, Eq.3_p was applied to the electric source field to derive its coexisting magnetic field of matching phase. In Step 2, Eq.3_p was applied to the magnetic source field to derive its coexisting electric field of matching phase. Section 5 has shown that the combination of in-phase fields derived in Step 1, and those in Step 2, are compliant with the wave equation. It is the position of this paper that the in-phase fields of Step 1 form a wave stream emanating from the antenna whose phase matches the phase of the electric source field, and that the in-phase fields of Step 2 form a second wave stream emanating from the antenna whose phase matches the phase of the magnetic field. The position of this paper is that the two wave streams will coalesce in accordance with the principal of superposition so that the wave stream perceived to emanate from the antenna will have its electric and magnetic fields lag the electric source field by 45^o as indicated in Eq.39 and Eq.42.

It should be noted that although Eq.3_p was used in the above derivation, exactly the same conclusion would have been reached had Eq.4_p been used.

Radiation Escape Requirements. What conditions spawn radiation? More specifically, what is it that causes the electrical energy trapped in physical devices to suddenly escape the bond of their parental charge, and propagate forever through empty space as autonomous packets of static energy? Maxwell's equations do not answer that question. The equations do define electrical phenomena before and after escape, but not the requirements for bringing about an escape. Obviously an antenna creates the conditions required for radiating the energy supplied to it. An antenna does cause electric and magnetic fields to be temporally and spatially in quadrature, and to occupy the same region of space. Could the requirement for spawning a wave be that simple? This paper does not answer that question. However, if the conclusions of this paper could be verified we might be one step closer to an answer.

Verification The position taken in Section 6 of this paper regarding the birth of radiation could be verified by experiment. It would entail comparing the phase of the fields of the wave emanating from the antenna with the phase of the drive to the antenna ... not a trivial task but doable.

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