Radio Waves – Part II

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(Dated: May 28, 2013; modified: June 12, 2013)

Abstract

In Part I of this series on Radio Waves, I have tried to show that *Maxwell's theory of electromagnetic waves is untenable* because electric fields cannot exist in vacuum where there are no electric charges to produce them and because experiments have yet to prove that electric fields can be produced in vacuum by changing magnetic fields. My aim was to show that a new theory of radio waves is needed since that based on Maxwell's theory of electromagnetic waves claiming that a radio wave travelling in vacuum consists of oscillating electric and magnetic fields mutually inducing one another is not supported by experiments, being based on assumptions and mathematical manipulations. Comments received from interested readers prompted me to offer further arguments against Maxwell's theory and this led to an extended version of the same paper titled "Trouble with Maxwell's Electromagnetic Theory: Can Fields Induce Other Fields in Vacuum?".

In this article I return to my original aim when I began this series on Radio Waves and I will try to show what I think radio waves really are and how are they produced in an antenna.

Introduction

In this article I will try to present my view on radio waves, on how they are produced and how they propagate.

Of course, there is a theory in place today. The only problem is that this theory has some inconsistencies, the major one being exactly its foundation, Maxwell's electromagnetic theory. I have shown in Part I that Maxwell's theory has flaws, and that these flaws are not due to the fact that it cannot be applied to quantum mechanical or relativistic effects (although this limited applicability should in itself raise questions about its correctness) but that these flaws are *intrinsic* – they stem from the very logical construction of the theory.

While presenting my own view, I will continue to expose the reader to the accepted theory to assist in seeing the differences between the two and especially the inconsistencies in the latter. This time I will not refer solely to works (textbooks) that deal with the fundaments of Maxwell's theory but I will discuss the inconsistencies existing in books on radio waves proper.

Beside others, the main book I will refer to is what has been dubbed "Antenna Bible": John D. Kraus, *Antennas*, 2nd Edition, McGraw-Hill Book Company (1988). This work was published for the first time in 1950 and re-edited 38 years later, in 1988; however, as the author puts it in its preface "the basic theory and principles remain unchanged" - so the main misconceptions, summarized below, have not been revised:

(M1) - that the charges oscillating in an antenna move in the antenna from one end to the other

(M2) - that the charges oscillating in an antenna move in the antenna at the speed of light

(M3) - that the electric field lines linked to the charges oscillating in an antenna *detach from the charges* and travel as electric waves

(M4) - that an antenna emits radio waves because the charges oscillating in it are accelerated.

Discussing many types of antennas is not profitable for the aim of such a work as this whose object is only to explain how radio waves are produced in an antenna, so I chose to focus on the simplest antenna possible – the straight wire. But even in the case of a straight wire there are a few choices possible due to the different points where the lead wires from the radio oscillator can be connected to the antenna. So I had to look again for the simplest case and I chose to discuss the *center-fed dipole antenna*, which is a straight wire cut at its middle and connected to the a.c. generator (radio oscillator). This antenna is shown below [Gerald L. Hall (K1TD), *The ARRL Antenna Book,* 13th Edition, The American Radio Relay League, Inc. (1980), p.28]:

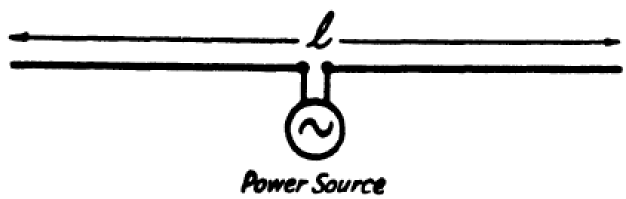
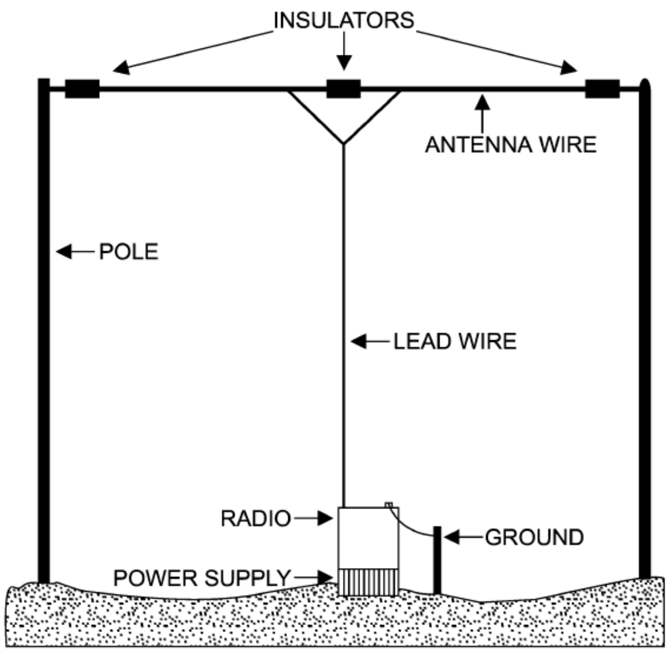


Fig. 2-5 — The center-fed antenna discussed in the text. It is assumed that the leads from the source of power to the antenna have zero length.

Let us see a short description of its physical construction and of its working principle in the next section.

A. The center-fed dipole antenna – short description of its physical construction and of working principle

As can be seen in the figure shown in the Introduction and in the figure shown below [U.S Marine Corps, *Field Antenna Handbook*, (1999), p.4-16], the *center-fed dipole antenna* (hereafter referred to as *CFDA*, for short) consists of two straight wires of equal length, placed end on end, insulated from each other, and connected to a radio oscillator which acts as a source of alternating signal (an a.c. power supply). It can also be described as a straight wire cut in the middle and connected to a radio oscillator (an a.c. power supply) with two lead wires.

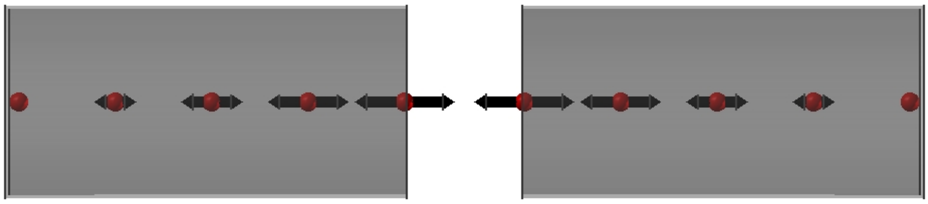


The role of the a.c. power supply (radio oscillator) is to pull charges (electrons) out from one side of the antenna and push them in the other side alternately. This movement of charges in the antenna is at the origin of the radio waves the antenna releases in space. The challenge is to find an explanation of *how does this movement of charges lead to emission of radio waves from the antenna* – this is the key matter of this work and this is where, in my opinion, the theory currently accepted is in error and gives wrong and inconsistent, self-contradictory answers.

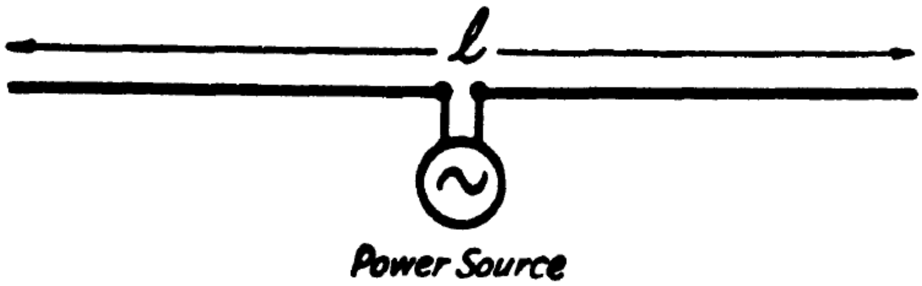
The radio waves emitted by the antenna have the same frequency as that of the a.c. power supply connected to it. While the antenna may release radio waves at any frequency the a.c. power supply may have, the antenna emits radio waves with *maximum intensity* when the general movement of the electric charges along the antenna is that of **stationary waves**. This is why in practice we try to produce *stationary waves of electric charges* in an antenna and in this work we will focus our attention on this situation.

B. The *CFDA* with stationary waves of electric charges in it – an antenna at resonance, and a true harmonic antenna

The **stationary waves** formed in a *CFDA* by the electric charges oscillating in it are very similar (I would say, almost identical) to the stationary waves of sound produced by the movement of air particles in two tubes closed at one end and placed with their open ends facing each other. Compare the two tubes …



… with the center-fed dipole antenna shown in the introduction:

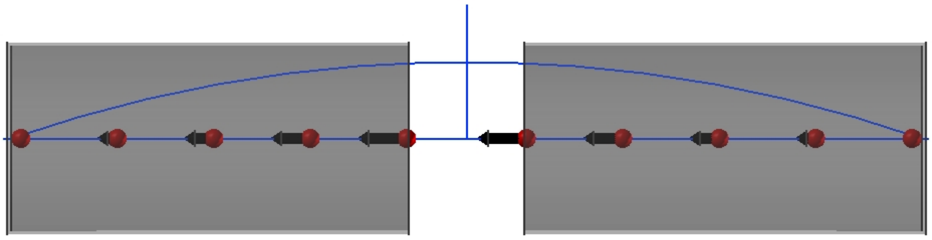


The movement of air particles in the tubes and of the electrons the antenna is oscillatory: they move forwards-backwards (to-and-fro) along the antenna about fixed positions executing simple harmonic motions.

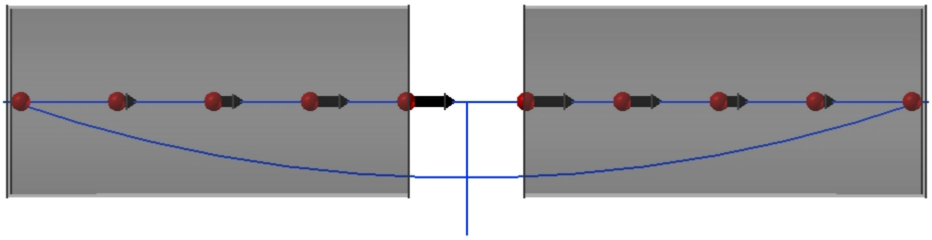
The closed ends of the tubes correspond to the extremities of the *CFDA*. Just as the air particles near the closed ends of the tubes do not move because they cannot go beyond the limit of the wall, the electrons at the extremities of the antenna cannot move because they cannot go beyond the ends of the antenna. Since the movement of the electric charges at the ends of the antenna is zero, the electric current there is always zero.

The air particles at the open ends of the tube move with greatest amplitude, being connected to a source of vibrations (loudspeaker, tuning fork). You can also blow air through the space between the tubes and will observe that at certain speed of the air between the tubes a loud sound will be heard: it is because you made the air molecules in the tubes oscillate and form stationary waves. The same is the case with the electrons at the center of the *CFDA* – only that in this case the electrons are set in a to-and-fro oscillatory motion by the a.c. power source.

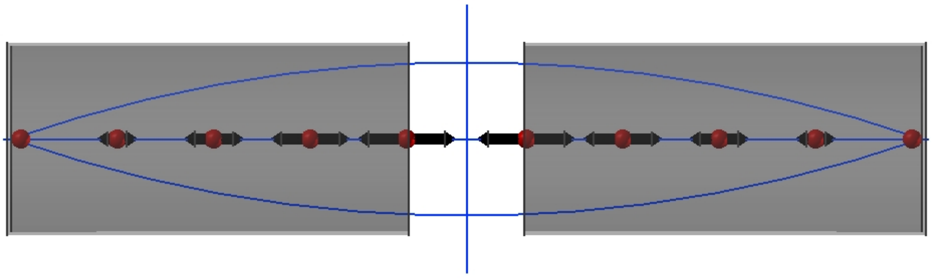
The forward-backward motion of the electrons is along the antenna and, for this particular case when *electrons form stationary waves in the antenna*, the oscillatory motion of the electrons has constant amplitude at any position along the antenna. We represent the *amplitudes* of electron oscillations at each point along the antenna on an axis perpendicular to the axis of the antenna - we do the same to represent the motion of air particles when stationary waves are formed in tubes. When the electrons move to the left we represent their amplitude at each point along the antenna upwards on the axis:



Note that the electrons move to-and-fro along the antenna about fixed positions in the antenna and what we represent on the vertical axis is only their maximum displacement from their fixed points (which is the amplitude of their oscillation). When the electrons move to the right we show their maximum displacement (amplitude) downwards:



Sometimes the following more complete diagram is used…



… that shows electrons oscillating backwards and forwards along the antenna and their respective amplitudes (maximum displacements in each direction along the antenna).

As already noted above, when the electric charges in the antenna form **stationary waves**, the radio waves emitted have the *greatest intensity* – we say that the antenna is at **resonance**.

As can be seen from the figures above, this state of **resonance** is achieved when the total length of the antenna L (the distance between one extremity to the other) is equal to $\lambda/2$ (one half-wavelength) of the *stationary wave* formed by the electrons in the antenna – this is its simplest mode of operation, called *fundamental mode*.

From the wavelength λ of the stationary wave formed by the electrons in the antenna we can calculate the frequency f of their oscillation about their fixed positions inside the antenna and find the frequency f of the radio waves emitted by the antenna. *This is because experiments show that the frequency of the radio waves emitted by the antenna is equal to that of the a.c. power supply connected to it.* Since in the *fundamental mode* the electrons make one oscillation for every reversal of the polarity of the a.c. power supply, it follows that the electrons emit one wavefront of radio wave at each complete oscillation.

So all we have to find is the frequency the a.c. power supply must have to produce *stationary waves of electrons* of wavelength λ in a *CFDA* whose length is $L= \lambda/2$.

(Note: We have not said yet *when* does an oscillating electron emit radio waves. This is related to the challenge set in this work, which is to explain why and how an antenna emits radio waves. We explore the functioning of the antenna in as much detail as we can to discover this mechanism of emission of radio waves. From the fact that an antenna emits radio waves with **greatest intensity** when it is at *resonance*, and from the fact that at *resonance* electrons achieve the **greatest amplitude** of oscillation it is clear the emission of radio waves from an antenna is related to the amplitude of oscillation of the electrons in it: <u>when the amplitude is maximum, the intensity of radio waves emitted is also maximum</u>. We will see later that when oscillating with maximum amplitude, electrons have **maximum acceleration** (at maximum displacement) and **maximum velocity** (when passing through their point of equilibrium). So we can see that there are a few possibilities regarding what makes an electron emit radio waves; thus, an electron can emit radiation: (i) when it is passing through its position of equilibrium (fixed position in the antenna) because then it has the highest velocity; (ii) when it is at the greatest displacement from its position of equilibrium because then it has the greatest acceleration (although it is not moving); (iii) when it is moving towards the position of equilibrium because it accelerates from rest to maximum velocity; (iv) when it is moving away from its position of equilibrium because it decelerates from maximum velocity to rest; (v) *all the time* while it is in motion, etc. When we detect the radio waves coming from an antenna, we find out that the antenna does not emit radio waves equally in all directions, but only in some specific directions and in others it does not emit at all; this observation can help us a lot in determining *when* does an oscillating electron emit radio waves and we will actually try to relate these specific directions in which radio waves are emitted by the antenna to the oscillatory motion the electrons in the antenna. But even if we look at the radio waves along one direction, the frequency of the waves arriving there is the same as that of the oscillating electrons (i.e. of the a.c. power supply), so we can be sure that the electrons emit radiation -one wavefront- in <u>that specific direction</u> *once* during one oscillation.)

Now let us look at the action of the a.c. power supply. It pushes electrons at the feed point in one side of the antenna (one side of the antenna has a length L/2, which is equal to λ/4); these electrons push the ones next to them in that side of the antenna and so on until this wave of compression (increased electronic density) reaches the end of the respective side of the antenna; the electrons at the extremity of that side of the antenna do not have where to go so the electrons next to them start to move backwards in the direction towards the feed point; exactly when this wave motion arrives back at the feed point, the a.c. power supply reverses polarity and pulls the electrons out, helping to maintain the oscillations of the electrons in stationary waves; all this takes place in a half of the total time of a complete cycle (T/2) as this is the time taken by the a.c. power supply to reverse its polarity once.

The speed of the *compression wave of electrons* in the wire of the antenna can be found from Maxwell's theory, about which we have discussed in Part I, and found that it is valid for matter *containing charges and currents* (but **invalid for vacuum**) - so we can apply it for the case of metals containing electrons. We have seen in Part I that this kind of electron-electron interaction takes place at a speed given by the equation

$$v = \frac{1}{\sqrt{\mu \cdot \varepsilon}}$$

We can approximate that for conductors like copper and aluminum (of which antennas are usually made) the constants μ and ε are equal to μ_0 and ε_0 for vacuum. This makes v equal to the speed of light c in vacuum, so the *electrons compression wave* travelling from the feeding point to one of the ends of the antenna and coming back travels at the speed of light. (Please note that this speed is the speed of a wave -the *electrons compression <u>wave</u>*- and it is not the speed of the electrons themselves in their oscillatory motion. It corresponds to the speed of sound in the air tubes, which is different from the speed the air molecules themselves have when executing their oscillatory motion about their fixed positions in the air tube.)

From this we can see that the *electrons compression <u>wave</u>* travels a distance d= L/2 + L/2

= L at the speed of light c in an interval of time t of half period (T/2), i.e.

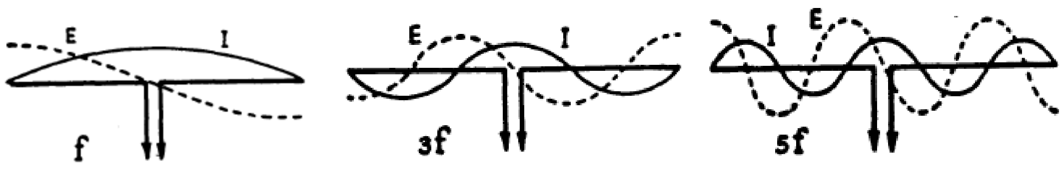
$$c=d/t=L/(T/2)=2L/T$$

Since the frequency f and the period T are related by the equation f=1/T, we obtain

$$c=2Lf, \text{ or } f=c/2L$$

for the frequency of the electrons oscillation in the stationary wave in the antenna.
From this last relationship we can see that the length L of the antenna is an important factor in determining the frequency f at which the antenna is at **resonance** (frequency at which the electrons in it will oscillate in a **stationary wave**) and, consequently, in determining the frequency of the radio waves the antenna emits with the *highest intensity*. This frequency f is called the *fundamental frequency* of the antenna to distinguish it from other possible situations discussed below.

From the diagrams above, one can observe that the situation can become complicated because *the same CFDA* of length L can be at **resonance** not only when its length L is equal to one half-wavelength ($\lambda/2$) of the stationary wave but also when it is equal to any *odd multiple of other half-wavelengths* $\lambda_h/2$; in these cases the same length L of the antenna is divided into more half-wavelengths, so these new wavelengths λ_h are shorter than the original λ ($\lambda_h < \lambda$). These stationary waves of shorter wavelengths than the wavelength of the *fundamental wave* are called *higher harmonics* and are exemplified in the figures below [Gerald L. Hall (K1TD), *The ARRL Antenna Book,* 13th Edition, The American Radio Relay League, Inc. (1980), p.106-107]:



We can see that for an antenna of length L there can be situations like,

$L=\lambda/2$ (*fundamental mode*) or $L= 3\lambda_1/2$ or $L= 5\lambda_2/2$ …and so on…

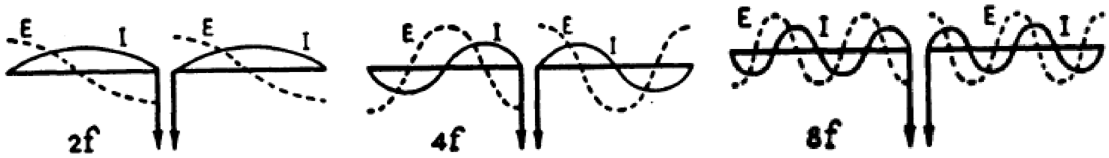
from which we can find the wavelengths of the stationary waves that can be set up in the antenna by the oscillating electrons

$\lambda= 2L$ or $\lambda_1= 2L/3$ or $\lambda_2= 2L/5$ …and so on…

We can also find the frequencies of the oscillations corresponding to these situations, by the same reasoning as that used to find the *fundamental frequency* above and obtain:
$f= c/2L$ (*fundamental frequency*), $f_1= 3c/2L=3f$ (first harmonic), $f_2= 5c/2L= 5f$ (second harmonic), and so on.
When operated in any one of these modes the *CFDA* is a *true harmonic antenna*, characterized by the following: (i) the frequencies of the higher harmonics are *odd*

multiples of the fundamental frequency and (ii) the motion of charges have a maximum amplitude at its center (feeding point) for any of the resonant frequencies (fundamental and higher harmonics); due to this last property the antenna is said to be *current fed* because the a.c. supply connected to it delivers currents of great intensity in the antenna.

There is another situation in which the oscillating motion of the charges in the dipole antenna is maintained by providing voltages at the feeding point with the right frequency so that stationary waves are produced in each of the two halves of the dipole antenna:



In this situation the antenna is said to be *voltage fed* because the a.c. supply connected to it does not deliver much current in the antenna: the a.c. supply *does* deliver charges but these charges arrive at the feed point exactly when the charges flowing in the antenna come in opposite direction and are stopped there, building up a great voltage. It can be calculated by the same principles illustrated above that the higher harmonics in such cases are *even multiples* of the fundamental frequency f: 2f (first harmonic), 4f (second harmonic), 6f (third harmonic – not shown), 8f (fourth harmonic), and so on.

In closing this section I would like to stress the validity of the *analogy of the antenna with air tubes*: it is recognized that in metals electrons are free to move and behave like a gas that can be compressed, rarefied, made to flow through a wire like through a pipe, or expelled (evaporated) from the metal through heating the metal at high temperatures - process called *thermionic* (thermoelectronic) emission. Even the electrical resistance of a wire is said to be caused by the collision of the electrons flowing through the wire with the atoms of the metal wire; the increase of the resistance of a metal wire with temperature comes to support this idea because at higher temperatures the atoms of the metal oscillate with greater amplitudes about their fixed positions in the lattice and cause collisions with the flowing electrons to occur more often.

It is time now to discuss the first two misconceptions mentioned in the Introduction and encountered in the books on antennas and radio waves, namely:

(M1) - that the charges oscillating in an antenna move in the antenna from one end to the other

(M2) - that the charges oscillating in an antenna move in the antenna at the speed of light

C. The charges oscillating in an antenna do not move in the antenna from one end to the other and do not travel in the antenna at the speed of light

We have seen in the previous discussion that in a *CFDA* **at resonance** electrons oscillate and form **stationary waves** in it. Does that mean that the electrons move from one end to the other end of the antenna? And does that mean that they (the electrons) move in the antenna at the speed of light?

The answer to both questions is no.

It is *the electrons compression **wave*** travelling along the antenna that moves at the speed of light, not the electrons themselves. It is very much like the air molecules producing a compression wave in the air tubes: the compression wave (sound) travels at the speed of sound in the tube but the air particles themselves do not travel at the speed of sound, neither do they (the air particles) travel from one end of the tube to the other – they just execute oscillations about fixed positions inside the tube. So is the case with the electrons in the antenna: they execute oscillations centered on fixed positions in the antenna, they do not travel from one end of the antenna to the other.

Discussing this misconception is important because, as we shall see later, the purported high speed of electrons (speed of light) in the antenna is used as a support for another misconception: that the electric field lines linked to the electrons *detach from them and form electric waves*.

Look first at the excerpt below, from A. Gerald L. Hall (K1TD), *The ARRL Antenna Book,* 13th Edition, The American Radio Relay League, Inc. (1980), p.24, where both misconceptions mentioned above can be found.
Thus, it is stated that
"If the speed at which the charge travels is equal to the velocity of light, […]."
and that
"Since the charge traverses the wire *twice* […]."

RESONANCE IN LINEAR CIRCUITS

The shortest length of wire that will resonate to a given frequency is one just long enough to permit an electric charge to travel from one end to the other and then back again in the time of one rf cycle. If the speed at which the charge travels is equal to the velocity of light, approximately 300,000,000 meters per second, the distance it will cover in one cycle or period will be equal to this velocity divided by the frequency in hertz, or

$$\lambda = \frac{300,000,000}{f}$$

in which λ is the wavelength in meters. Since the charge traverses the wire *twice,* the length of wire needed to permit the charge to travel a distance λ in one cycle is $\lambda/2$, or one-half wavelength. Therefore the shortest *resonant* wire will be a half wavelength long.

The textbook John D. Kraus, *Antennas*, 2nd Edition, McGraw-Hill Book Company (1988), p.54-55 claims the same:
"The charges are assumed to move with velocity v=c along the dipole".

2-30 RADIATION FROM PULSED CENTER-FED DIPOLE ANTENNAS. Five stages of radiation from a dipole antenna are shown in Fig. 2-24 resulting from a single short voltage pulse applied by a generator at the center of the dipole (positive charge to left, negative charge to right). The pulse length is short compared to the time of propagation along the dipole.

At the first stage [(*a*) top] the pulse has been applied and the charges are moving outward. The electric field lines between the charges expand like a soap bubble with velocity $v = c$ in free space. The charges are assumed to move with

velocity $v = c$ along the dipole. At the next stage [(*a*) middle] the charges reach the ends of the dipole, are reflected (bounce back) and move inward toward the generator [(*a*) bottom]. If the generator is an impedance match, the pulses are absorbed at the generator but the field lines join, initiating a new pulse from the center of the dipole with the pulse fields somewhat later, as shown in (*b*).

The second edition of this book was published in 1988 and making such an assumption in the year 1988 of this era is unrealistic, especially when it was known by that time that electrons achieve speeds close to the speed of light in particle accelerators, where they move in a special environment of high vacuum (almost free space) and therefore with few collisions with atoms.

But what is more controversial is that this idea of charges moving in the antenna at the speed of light is used by the author of this book to show that the electric feld lines attached to the electrons *detach from them and travel away from the antenna as electric waves*.

So we are now ready to argue against another misconception cited in the Introduction, namely:
(M3) - the belief that the electric field lines linked to the charges oscillating in an antenna *detach from the charges* and travel as electric waves.

D. The electric field lines do not detach from the charges oscillating in the antenna. An antenna does not emit electric waves. What we call *radio waves* emitted by an antenna are not electric waves.

As we have discussed in the previous section, pointing out the falsity of the idea that charges oscillating in an antenna move at the speed of light is important because it is used by the author John D. Kraus, *Antennas*, 2nd Edition, McGraw-Hill Book Company (1988), p.54-55, to explain why and how the electrons oscillating in the antenna emit radio waves: it is claimed that the lines of electric field linked to these charges *detach* from the charges, become separate entities and constitute waves that travel away from the antenna.

In essence the book claims that *the **original** waves emitted from the antenna are **electric waves*** since they are electric field lines freed from the charges they were attached to.
(Note. This claim is then followed by another purporting that these ***original electric waves** induce magnetic fields in vacuum* – a claim which we have shown in Part I it is just an assumption made by Maxwell based on mathematical manipulations -substitutions of equations- and not proven experimentally since his time; it is known as Maxwell's additional term to Ampere's law called "displacement current". Below is an excerpt from an old textbook on electromagnetism showing that this issue has been a recurring theme throughout in the works on electromagnetism [George W. Pierce, *Electric Oscillations and Electric Waves,* McGraw-Hill Book Company Inc. (1920), p. 368] :

> **28. The Generalized Current Density Equation.**—With this assumption the current density equation (12) may be generalized into
>
> $$\frac{4\pi \mathbf{u}}{c} + \frac{1}{c}\frac{\partial \mathbf{D}}{\partial t} = \text{curl } \mathbf{H} \qquad (24)$$
>
> which may be called *Maxwell's Generalized Current-density Equation*. The addition of the first two terms is a vector addition.
>
> It is apparent that there is no mathematical inconsistency in Maxwell's method of generalizing the conception of an electric current, in respect to its effect in producing or responding to a magnetic field. Whether or not this generalized current is related to the magnetic field intensity by an equation of the form of (24) is a question for experimental determination. The experimental test has never been adequately made on the assumption directly. The validity of Maxwell's Assumption rests on his prediction from it of the existence of electric waves, and on his prediction of the electromagnetic character of light. These predictions have been amply verified.

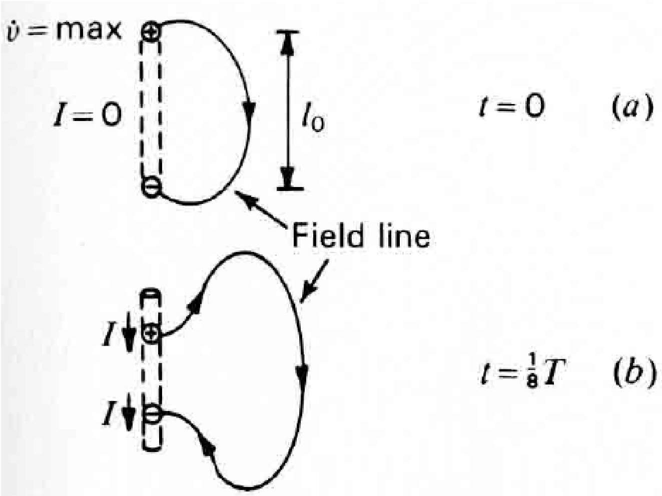
Observe that Maxwell's assumption is considered valid due to its "prediction of the electromagnetic character of light"; the claim that this prediction has been "amply verified" has been one of the points of criticisms raised in Part I of Radio Waves, where it was shown that *the electromagnetic character of light (and radio waves) has not been proven* and therefore is objectionable; it is not only hard to believe but also *not experimentally proven* that these waves consist electric and magnetic fields that induce (create) one another in vacuum.)

In contrast to this, my opinion is that the original waves emitted by the electrons oscillating in the antenna are not electric, but **magnetic**, and that these **magnetic waves** travel as such (as *magnetic waves*) through the vacuum of space without inducing electric fields; when these *magnetic waves* encounter another wire (used as a receiving antenna), the time-varying magnetic field of the magnetic wave induces electric currents in this receiving antenna through the phenomenon of electro-magnetic induction discovered by Michael Faraday.

Going back to the way in which the generation of electric waves by the charges moving in the antenna is explained in the theory generally accepted today, let us see below the excerpts in which the electric field lines of the charges are claimed to *detach* from the charges oscillating in the antenna [John D. Kraus, *Antennas*, 2nd Edition, McGraw-Hill Book Company (1988), p.54-59]:

> To illustrate radiation from a dipole antenna, let us consider that the dipole of Fig. 2-22 has two equal charges of opposite sign oscillating up and down in harmonic motion with instantaneous separation l (maximum separation l_0) while focusing attention on the electric field. For clarity only a single electric field line is shown.
>
> **Figure 2-22** Oscillating electric dipole consisting of two electric charges in simple harmonic motion, showing propagation of an electric field line and its detachment (radiation) from the dipole. Arrows next to the dipole indicate current (I) direction.

At time $t = 0$ the charges are at maximum separation and undergo maximum acceleration $\dot{v}$ as they reverse direction (Fig. 2-22*a*). At this instant the current I is zero.

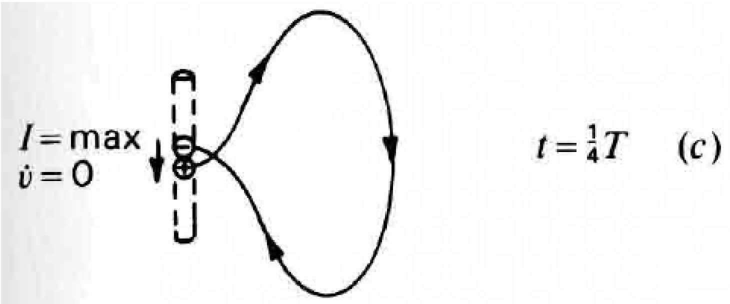


At an $\frac{1}{8}$-period later, the charges are moving toward each other (Fig. 2-22*b*)

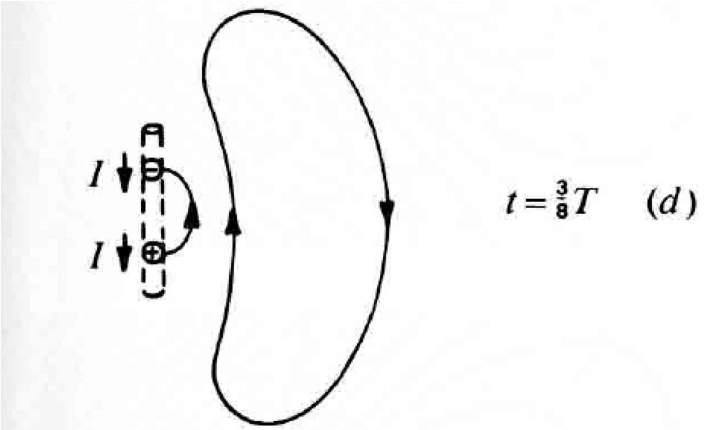
By comparing the field lines in figures (a) and (b), observe that the author claims, *without bringing any evidence to support his statement*, that the field line lags behind the moving charges and that the *field line moves on its own further away* from the charges producing it.

This contradicts the common understanding according to which the field lines *follow the charges* (especially since the charges move at speeds much lower than the speed of light) and *shrink* with the decreasing distance between the charges – the field line therefore is supposed to *dissapear once the charges cancel each other at the middle of the antenna (feed point)*.

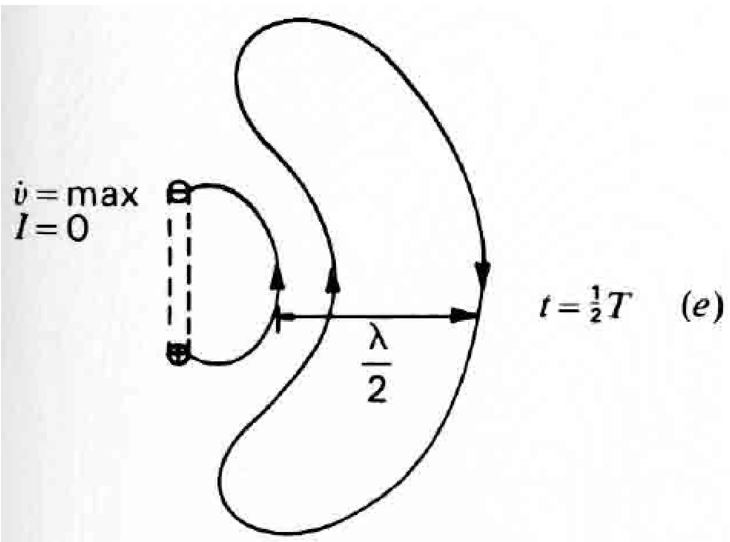
The author however, does not believe that the field lines disappear when the charges meet at the midle of the antenna but claims (without bringing any experimental evidence to support this claim) that "as this happens [charges pass at the midpoint], the field lines detach and new ones of opposite sign are formed" - see below:



and at a $\frac{1}{4}$-period they pass at the midpoint (Fig. 2-22*c*). As this happens, the field lines detach and new ones of opposite sign are formed. At this time the equivalent current I is a maximum and the charge acceleration is zero.



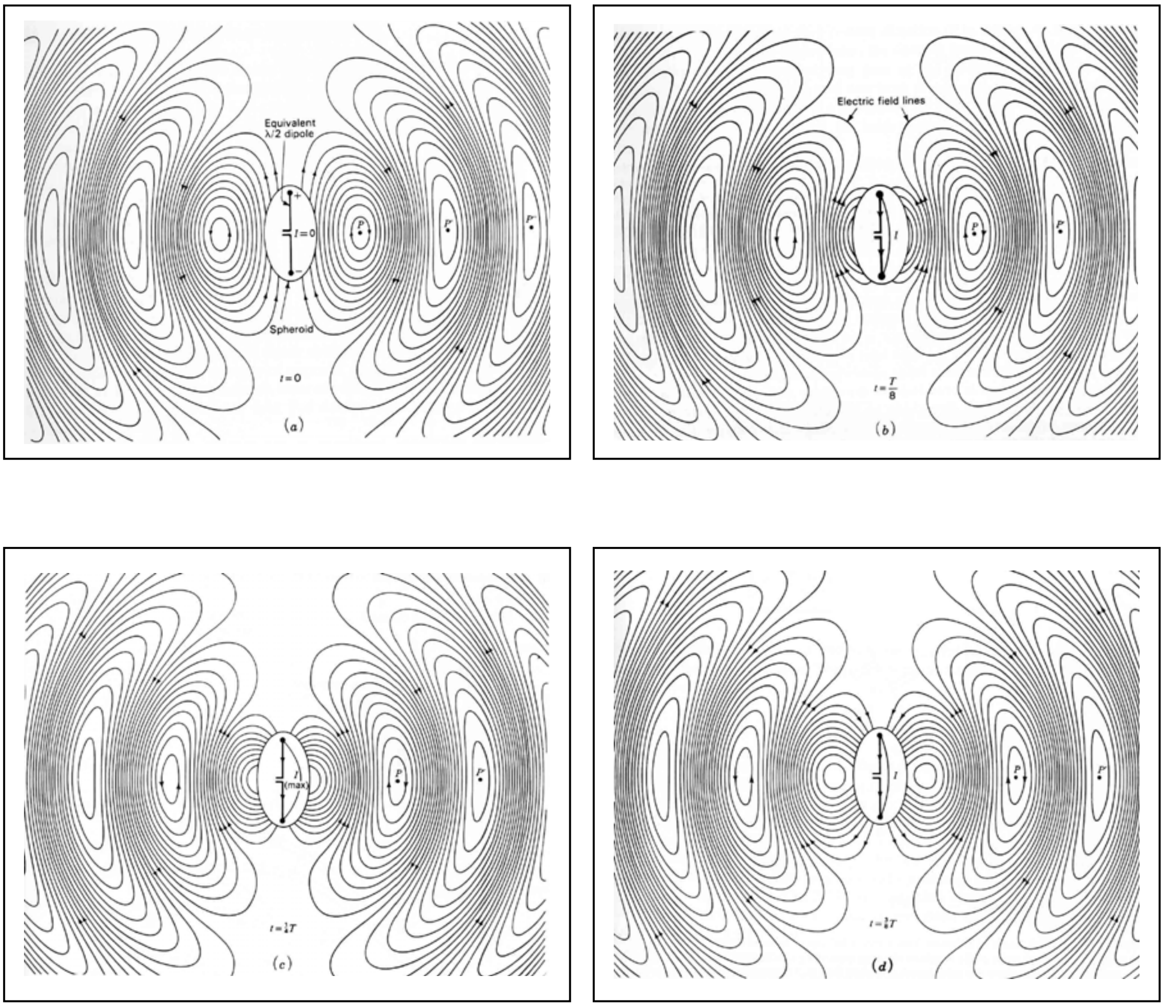
As time progresses to a $\frac{1}{2}$-period, the fields continue to move out as in Fig. 2-22*d* and *e*.



Other explanations from the same textbook are shown below:

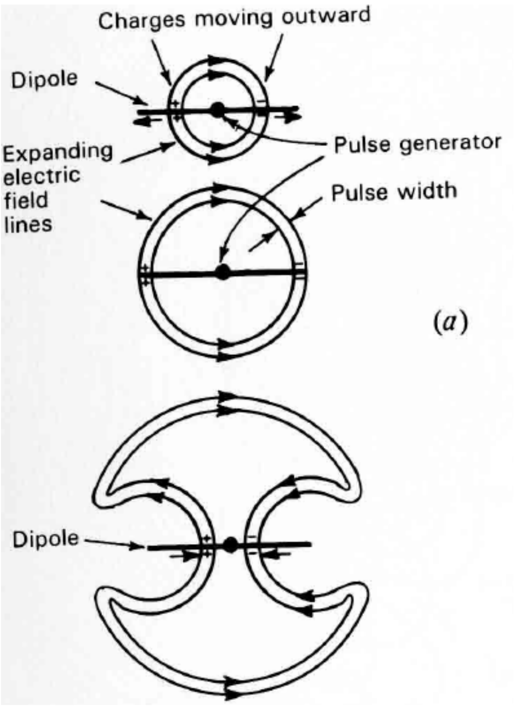
An oscillating dipole with more field lines is shown in Fig. 2-23 at 4 instants of time.

Figure 2-23 Electric field configuration for a $\lambda/2$ antenna at four instants of time: (*a*) $t = 0$, (*b*) $t = T/8$, (*c*) $t = T/4$ and (*d*) $t = \frac{3}{8}T$, where T = period. Note outward movement of the constant-phase points P, P' and P'' as time advances. These points move with a velocity $v = c$ remote from the dipole but with $v > c$ in the near field, as may be noted by measuring the distances between successive points. The strength of the electric field is proportional to the density of the lines. (*Produced by Edward M. Kennaugh, courtesy of John D. Cowan, Jr.*)



Five stages of radiation from a dipole antenna are shown in Fig. 2-24 resulting from a single short voltage pulse applied by a generator at the center of the dipole (positive charge to left, negative charge to right). The pulse length is short compared to the time of propagation along the dipole.

At the first stage [(*a*) top] the pulse has been applied and the charges are moving outward. The electric field lines between the charges expand like a soap bubble with velocity $v = c$ in free space. The charges are assumed to move with velocity $v = c$ along the dipole.



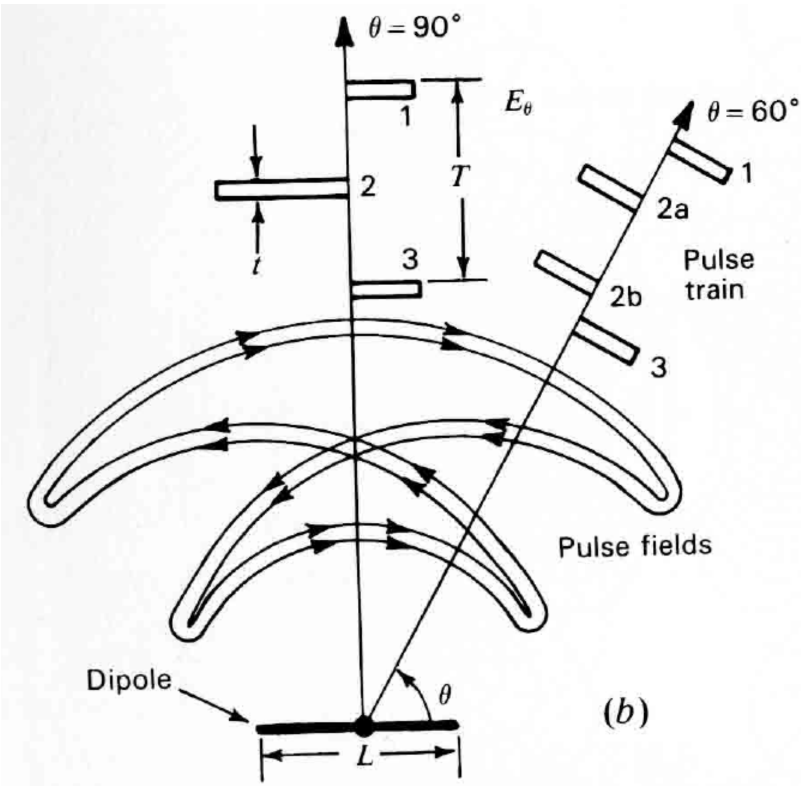
At the next stage [(*a*) middle] the charges reach the ends of the dipole, are reflected (bounce back) and move inward toward the generator [(*a*) bottom].

The claim that, as the charges are moving outwards, the "electric field lines between the charges expand like a soap bubble with velocity v=c in free space" is based on the misconception stated afterwards, that the "charges are assumed to move with velocity v=c along the dipole".

If this unrealistic assumption had not been made it would have been impossible to claim that the lines of electric field expand at the speed of light: they would have followed the charges producing them and would have *dissappeared* when the charges cancelled each other at the center of the dipole.

Next the author claims (again without bringing any evidence) that the field lines *join* when the charges are “absorbed at the generator” (mid point of the antenna):

If the generator is an impedance match, the pulses are absorbed at the generator but the field lines join, initiating a new pulse from the center of the dipole with the pulse fields somewhat later, as shown in (*b*).



[Fig. 22-4 (b)]

In the following excerpt the author attempts an explanation of the radiation pattern of the antenna based on the claim that it is produced by the charges emitting radiation when accelerated [p. 55,59]:

“It is evident from Fig. 2-24 that radiation occurs from the points where charge is accelerated […].”

Maximum radiation is broadside to the dipole and zero on axis as with a harmonically excited dipole. Broadside to the dipole ($\theta = 90°$) there is a symmetrical pulse triplet, but, at an angle such as 30° from broadside ($\theta = 60°$), the middle pulse of the triplet splits into two pulses so that the triplet becomes a quadruplet as shown in (*b*). Thus, the pulse pattern is a function of angle. The time T between pulses 1 and 3 is the time required for the charges to travel out and back from the generator. This is the same as the travel time over the length L of the dipole, or

$$T = \frac{L}{c} \qquad (1)$$

Thus, the dipole length determines the pulse spacing T while the pulse length t determines the much shorter wavelength of the pulse radiation.

[...]

It is evident from Fig. 2-24 that radiation occurs from the points where charge is accelerated, i.e., at the center or feed point and at the ends of the dipole but not along the dipole itself.[1]

---

[1] G. Franceschetti and C. H. Papas, "Pulsed Antennas," Sensor and Simulation Note 203, Cal. Tech., 1973.

The author here is very confusing because he still works on the idea that a charge travels from the feed point all the way to the end of the antenna. As we have seen, charges do not travel such long distances (see also below an estimation) but execute simple harmonic motions about every point along the antenna, except at its ends where the charges (electrons) do not move at all. So the explanation cited above is completely erroneous, as is the claim that charges emit radiation because they are accelerated (this will be discussed in the next section).

Even considering that one charge that oscillates about a fixed point of the antenna forms the *small dipole*, the author of this textbook contradicts himself when stating that
"radiation occurs from the points where the charge is accelerated"
and in the same time that
"[radiation does] not [occur] along the dipole itself"
This is a self-contradiction because when a charge executes simple harmonic motion it has accelerated motion *all along the dipole*. From the equation for simple harmonic motion

$x=A \sin\omega t$ (where x is the instantaneous diplacement and A is the amplitude)

the acceleration of the particle is obtained as

$$a=\omega^2 x$$

and it can be seen that the charge accelerates ($a \neq 0$) *all along the dipole* ($x \neq 0$) except at the instant when the displacement x is zero, i.e. when charge is passing through its point of equilibrium (the fixed position about which it oscillates, which is the center of the *small dipole*).

The acceleration of the charge is maximum when it is at maximum displacement x=A

$$a_{max}=\omega^2 A$$

but then the velocity of the charge is zero (the charge does not move at all) as can be seen from the general expression for the velocity for a particle in simple harmonic motion

$$v = \omega\sqrt{A^2 - x^2}$$

Also note that the charge moves with maximum velocity when x=0, i.e. when it passes through the fixed position about which oscillates: $v_{max}=\omega A$

Here is a different author who attempts to explain his belief that electric field lines *detach* from the charges oscillating in the antenna [Constantine A. Balanis, *Antenna Theory Analysis and Design*, 2nd Edition, John Wiley & Sons, Inc. (1997)]; he is asking the legitimate question [p. 7-8]…

1.3 RADIATION MECHANISM

One of the first questions that may be asked concerning antennas would be "how is radiation accomplished?" In other words, how are the electromagnetic fields generated by the source, contained and guided within the transmission line and antenna, and finally "detached" from the antenna to form a free-space wave? The best explanation may be given by an illustration. However, let us first examine some basic sources of radiation.

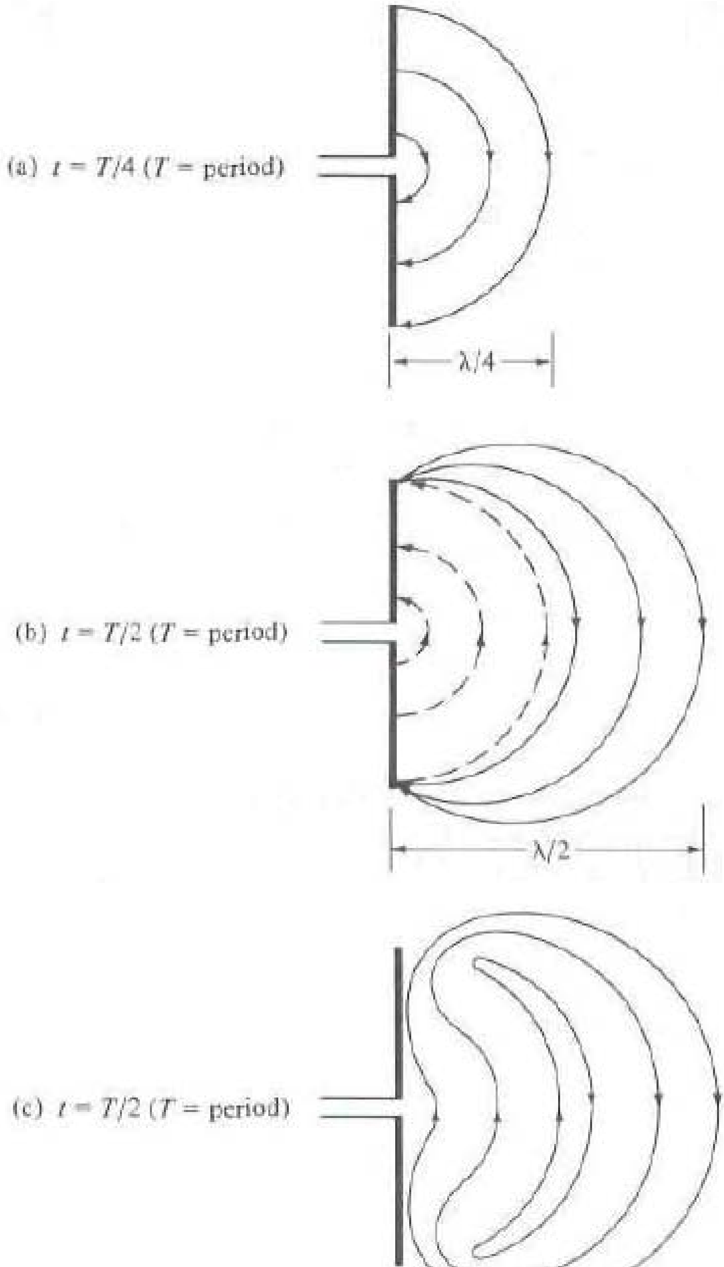
…but his attempt at an explanation fails [p.14-15]:

1.3.3 Dipole

Now let us attempt to explain the mechanism by which the electric lines of force are detached from the antenna to form the free-space waves. This will again be illustrated by an example of a small dipole antenna where the time of travel is negligible. This is only necessary to give a better physical interpretation of the detachment of the lines of force. Although a somewhat simplified mechanism, it does allow one to visualize the creation of the free-space waves. Figure 1.14(a) displays the lines of force created between the arms of a small center-fed dipole in the first quarter of the period during which time the charge has reached its maximum value (assuming a sinusoidal time variation) and the lines have traveled outwardly a radial distance $\lambda/4$. For this example, let us assume that the number of lines formed are three. During the next quarter of the period, the original three lines travel an additional $\lambda/4$ (a total of $\lambda/2$ from the initial point) and the charge density on the conductors begins to diminish. This can be thought of as being accomplished by introducing opposite charges which at the end of the first half of the period have neutralized the charges on the conductors. The lines of force created by the opposite charges are three and travel a distance $\lambda/4$ during the second quarter of the first half, and they are shown dashed in Figure

1.14(b). The end result is that there are three lines of force pointed upward in the first $\lambda/4$ distance and the same number of lines directed downward in the second $\lambda/4$.

Since there is no net charge on the antenna, then the lines of force must have been forced to detach themselves from the conductors and to unite together to form closed loops. This is shown in Figure 1.14(c). In the remaining second half of the period, the same procedure is followed but in the opposite direction. After that, the process is repeated and continues indefinitely and electric field patterns, similar to those of Figure 1.22, are formed.



As you can see, this author does not offer any *scientific explanation* as to why the field lines *detach* from the charges: “Since there is no net charge on the antenna, then the lines of force must have been forced to detach (*sic!*) themselves from the conductors and to unite together to form closed loops.”
The author gives no reason why the field lines **do not shrink**, collapse and **dissapear** althogether when there is no net charge on the antenna, but claims instead that they *detach* themselves from the charges and form closed loops.

The author has an interesting insight though [p.14]:

> The question still unanswered is how the guided waves are detached from the antenna to create the free-space waves that are indicated as closed loops in Figures 1.11 and 1.12. Before we attempt to explain that, let us draw a parallel between the guided and free-space waves, and water waves [7] created by the dropping of a pebble in a calm body of water or initiated in some other manner. Once the disturbance in the water has been initiated, water waves are created which begin to travel outwardly. If the disturbance has been removed, the waves do not stop or extinguish themselves but continue their course of travel. If the disturbance persists, new waves are continuously created which lag in their travel behind the others. The same is true with the electromagnetic waves created by an electric disturbance. If the initial electric disturbance by the source is of a short duration, the created electromagnetic waves travel inside the transmission line, then into the antenna, and finally are radiated as free-space waves, even if the electric source has ceased to exist (as was with the water waves and their generating disturbance). If the electric disturbance is of a continuous nature, electromagnetic waves exist continuously and follow in their travel behind the others. This is shown in Figure 1.13 for a biconical antenna. When the electromagnetic waves are within the transmission line and antenna, their existence is associated with the presence of the charges inside the conductors. However, when the waves are radiated, they form closed loops and there are no charges to sustain their existence. *This leads us to conclude that electric charges are required to excite the fields but are not needed to sustain them and may exist in their absence. This is in direct analogy with water waves.*

The most we can agree on is the *good analogy between radio waves and water waves*, in which case the conclusion in the last sentence should read “electric charges are required to excite the *radio waves* but (the electric charges) are not needed to sustain them (the *radio waves*) and may exist (the *radio waves*) in their absence (the absence of electric charges)”.

Seeing these unsatisfactory explanations, we consider that the question *when and why* does a charge (electron) in simple harmonic motion in an antenna emit radio waves is *still without an answer*. Since it is clear that an electron does not emit radiation when it is at rest, two possibilities remain: does the electron emit radiation because it is accelerated, or because it simply moves at certain velocities? In the former case the intensity of radiation should increase with increased acceleration, in the latter case the intensity of radiation should increase with increased velocity. What we know is that **at resonance**, when the electrons in the antenna form stationary waves and the emitted radiation has **the greatest intensity**, electrons attain the **greatest amplitude** of oscillation.

Since in a simple harmonic motion both the acceleration and the velocity of the particle increase with the amplitude

$$a_{max}=\omega^2 A \qquad v_{max}=\omega A$$

it seems that we do not have a criteria to discriminate between these two.

However, the choice should not be difficult if we ask ourselves: can a charge at rest (even if it *is* accelerated) emit radiation? Or it is more plausible that the charge emits radiation because of the speed it has in its motion? Since we have just said that a *charge at rest does not emit radiation*, it seems that the charge emits radiation because of the speed it moves at: we will see later that this second possibility is more plausible; my view is that a charge produces a wake in the aether due to its motion about its fixed point; more charges will produce more wakes and these wakes will contribute to the formation of a wavefront that will continue to move on its own in space after the particle changed its direction of its motion at the point of maximum displacement.

We are now ready to discuss the last misconception mentioned in the Introduction:

(M4) - that an antenna emits radio waves because the charges oscillating in it are accelerated.

………………………………………………………………………………………………

Estimation of the maximum distance travelled by a charge in an antenna

We use the equation $v_{max}=\omega A$ to find the amplitude A of oscillation of a charge. The maximum velocity v_{max} can be found from the equation $I_{max} = Snev_{max}$ (where I-intensity of electric current, S-cross sectional area of antenna, n=N/V-number of free electrons in unit volume, e-charge of the electron).

For a maximum value for the intensity of the current I_{max} =10[A] (at the feed point of a *CFDA*) in a wire of diameter 4[mm] ($S\approx10^{-5}$ [m^2]), knowing that $e\approx10^{-19}$[C] and that copper contains $n\approx10^{29}$ [electrons/m^3], v_{max} is approximately 10^{-4} [m/s]. (Observe that the maximum speed v_{max} of the electron in its simple harmonic motion is much less than the speed of light $c = 3 \cdot 10^8$ [m/s]).

For a frequency f=10[MHz] the angular speed is $\omega=2\pi f\approx10^8$ [rad/s], and we obtain for the amplitude A an approximate value of 10^{-12}[m] (smaller than the size of an atom).

This is an underestimation (the amplitude should be much greater) because it ignores the fact that at high frequencies conduction does not occur through the whole cross section of the wire but mostly near its surface (the ‘skin effect’); but it still can give us an idea of the distances travelled by the charges oscillating in an antenna.

……………………………………………………………………………………………

E. An antenna does not emit radio waves because the charges oscillating in it are accelerated

As discussed in the previous section, the radiation emitted by an electric charge in simple harmonic motion *cannot be due to the fact that it is in accelerated motion*. This is supported by the simple reasoning that, when the charge has the greatest acceleration $a_{max}=\omega^2 A$ (for x=A), it in the same time has zero velocity which means it does **not move**. How can a charge that does *not move* emit radiation (even if it *is* accelerated)? In the same time we know that, conversely, the charge in simple harmonic motion has zero acceleration when it travels at its highest velocity $v_{max}=\omega A$ (when x=0). Is it plausible to suppose that the *velocity* of the charge does *not* matter at all in the emission of radio waves?

We see therefore that the most important question remains: **When an electron is in simple harmonic motion, what part of this motion is responsible for the emission of radio waves?**

Before offering an answer to this question, let us see on what grounds do the textbooks dealing with this subject claim that the emission of radio wave is due to the acceleration of the charge and that the speed of the charge *does not matter at all*.

We refer again to Constantine A. Balanis, *Antenna Theory Analysis and Design*, 2nd Edition, John Wiley & Sons, Inc. (1997), p. 10:

$$l\frac{dI_z}{dt} = lq_l\frac{dv_z}{dt} = lq_l a_z \qquad (1\text{-}3)$$

Equation (1-3) is the basic relation between current and charge, and it also serves as the fundamental relation of electromagnetic radiation [4], [5]. It simply states that *to create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge*. We usually refer to currents in time-harmonic applications while charge is most often mentioned in transients. To create charge acceleration (or deceleration) the wire must be curved, bent, discontinuous or terminated [1], [4]. Periodic charge acceleration (or deceleration) or time varying current is also created when charge is oscillating in a time-harmonic motion, as shown in Figure 1.17 for a $\lambda/2$ dipole. Therefore:

1. If a charge is not moving, current is not created and there is no radiation.
2. If charge is moving with a uniform velocity:
   a. There is no radiation if the wire is straight, and infinite in extent.
   b. There is radiation if the wire is curved, bent, discontinuous, terminated, or truncated, as shown in Figure 1.10.
3. If charge is oscillating in a time-motion, it radiates even if the wire is straight.

Observe that, although the author claims that his equation 1-3 "states that to create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge", really there is absolutely *nothing* in that equation that connects any phenomenon of radiation with time-varying currents (or accelerated/decelerated charges): what equation 1-3 shows is only a relationship between a time-changing current and the acceleration of the charges producing it and does *not* say how this time-changing current originates the radio waves emitted by the antenna.

The references [4] and [5] mentioned in this excerpt in relation to radiation are:

4. E. K. Miller and J. A. Landt, "Direct Time-Domain Techniques for Transient Radiation and Scattering from Wires," *Proc. IEEE*, Vol. 68, No. 11, pp. 1396–1423, November 1980.
5. J. D. Kraus, *Antennas*, McGraw-Hill, New York, 1988.

… so we go again to John D. Kraus's book *Antennas*, 2nd Edition, McGraw-Hill Book Company (1988) to see if there is any demonstration of the fact that a charge emits radiation because it is accelerated. At p. 52 we find the same equation as that shown in the excerpt above but the explanation why an accelerated charge emits radiation is still missing:

$$\boxed{\dot{I}l = q\dot{v} \qquad (\mathrm{A\ m\ s^{-1}})} \qquad (4)$$

where $\dot{I}$ = time-changing current, A s^{-1}
l = length of current element, m
q = electric charge, C
$\dot{v}$ = acceleration, m s^{-2}

This is the *basic continuity relation between current and charge for electromagnetic radiation*. Since accelerated[1] charge ($q\dot{v}$) produces radiation, it follows from this equation that *time-changing current* ($\dot{I}$) *produces radiation*. (Fig. 2-19*e*). For transients and pulses we usually focus on charge. For steady-state harmonic variation we usually focus on current. Whereas a pulse radiates a broad spectrum (wide bandwidth) of radiation (the shorter the pulse, the broader the spectrum), a smooth sinusoidal variation of charge or current results in a narrow bandwidth of radiation (theoretically zero at the frequency of the sinusoid if it continues indefinitely).

Observe that the statement "[…] the accelerated charge […] produces radiation" is not supported by any evidence.

The explanations continue with:

> It may be shown[2] that an accelerated charge radiates a power P as given by[3]
>
> $$P = \frac{\mu^2 q^2 \dot{v}^2}{6\pi Z} \quad \text{(W)} \tag{5}$$
>
> where μ = permeability of medium, H m^{-1}
> q = charge, C
> $\dot{v}$ = acceleration, m s^{-2}
> Z = impedance of medium

The superscripts [1,2,3] in the above excerpts are:

> [1] Or decelerated.
> [2] L. Landau and E. Lifshitz, *The Classical Theory of Fields*, Addison-Wesley, 1951.
> [3] Equivalent expressions are
>
> $$\frac{q^2 \dot{v}^2}{6\pi\varepsilon c^3} = \frac{\mu q^2 \dot{v}^2}{6\pi c} \quad \text{(W)} \tag{6}$$
>
> where ε = permittivity (F m^{-1}) and c = velocity of light (m s^{-1}).

…. so it seems that we have to go this time to the book of L. D. Landau, E. M. Lifshitz, *The Classical Theory of Fields*, 3rd Edition, Pergamon Press Ltd. (1971) mentioned above to see if we can find any demonstration of the fact that a charge emits radiation because it is accelerated.

We find the equation shown the previous excerpt for the power radiated by an accelerated charge at p. 175:

> If we have just one charge moving in the external field, then $\mathbf{d} = e\mathbf{r}$ and $\ddot{\mathbf{d}} = e\mathbf{w}$, where $\mathbf{w}$ is the acceleration of the charge. Thus the total radiation of the moving charge is
>
> $$I = \frac{2e^2 w^2}{3c^3}, \tag{67.9}$$

We follow the calculations backwards to see on what grounds was this expression obtained, especially how and why did the *acceleration* of the charge appear in it (but the *speed* of the charge did not). We find that the equation 67.9 in the excerpt above was obtained from the equation 67.8 [p. 175]:

Substituting (67.5) in (66.6), we get the intensity of the dipole radiation:

$$dI = \frac{1}{4\pi c^3} (\ddot{\mathbf{d}} \times \mathbf{n})^2 \, do = \frac{\ddot{\mathbf{d}}^2}{4\pi c^3} \sin^2 \theta \, do, \qquad (67.7)$$

where θ is the angle between $\mathbf{d}$ and $\mathbf{n}$. This is the amount of energy radiated by the system in unit time into the element of solid angle do. We note that the angular distribution of the radiation is given by the factor $\sin^2 \theta$.

Substituting $do = 2\pi \sin \theta \, d\theta$ and integrating over θ from 0 to π, we find for the total radiation

$$I = \frac{2}{3c^3} \ddot{\mathbf{d}}^2. \qquad (67.8)$$

… which in its turn was obtained from equations 67.5 [p. 174] …

With the aid of formula (66.3) we find that the magnetic field is equal to

$$\mathbf{H} = \frac{1}{c^2 R_0} \ddot{\mathbf{d}} \times \mathbf{n}, \qquad (67.5)$$

… and 66.6 [p. 171]:

The radiated electromagnetic waves carry off energy. The energy flux is given by the Poynting vector which, for a plane wave, is

$$\mathbf{S} = c \frac{H^2}{4\pi} \mathbf{n}.$$

The intensity dI of radiation into the element of solid angle do is defined as the amount of energy passing in unit time through the element $df = R_0^2 \, do$ of the spherical surface with center at the origin and radius R_0. This quantity is clearly equal to the energy flux density S multiplied by df, i.e.

$$dI = c \frac{H^2}{4\pi} R_0^2 \, do. \qquad (66.6)$$

Since the field H is inversely proportional to R_0, we see that the amount of energy radiated by the system in unit time into the element of solid angle do is the same for all distances (if the values of $t-(R_0/c)$ are the same for them). This is, of course, as it should be, since the energy radiated from the system spreads out with velocity c into the surrounding space, not accumulating or disappearing anywhere.

Observe that the magnetic field H appearing in equation 66.6 for the radiated energy (and given by equation 67.5) contains the *acceleration* of the charge. But how was equation 67.5 obtained? It is known that a moving electric charge produces a magnetic field, but how is it possible to obtain that the magnetic field depends on the acceleration *only*? We go on and investigate how was equation 67.5 obtained from equation 66.3. At p. 170-171 we find the equation 66.3 and the explanation of how it was obtained:

> In a plane wave, the fields **E** and **H** are related to each other by (47.4), $\mathbf{E} = \mathbf{H} \times \mathbf{n}$. Since $\mathbf{H} = \text{curl } \mathbf{A}$, it is sufficient for a complete determination of the field in the wave zone to calculate only the vector potential. In a plane wave we have $\mathbf{H} = (1/c)\dot{\mathbf{A}} \times \mathbf{n}$ [see (47.3)], where the dot indicates differentiation with respect to time.† Thus, knowing **A**, we find **H**
>
> † In the present case, this formula is easily verified also by direct computation of the curl of the expression (66.2), and dropping terms in $1/R_0^2$ in comparison with terms $\sim 1/R_0$.
>
> ....
>
> and **E** from the formulas:†
>
> $$\mathbf{H} = \frac{1}{c}\dot{\mathbf{A}} \times \mathbf{n}, \qquad \mathbf{E} = \frac{1}{c}(\dot{\mathbf{A}} \times \mathbf{n}) \times \mathbf{n}. \tag{66.3}$$
>
> † The formula $\mathbf{E} = -(1/c)\dot{\mathbf{A}}$ [see (47.3)] is here not applicable to the potentials ϕ, **A**, since they do not satisfy the same auxiliary condition as was imposed on them in § 47.

Observe that there is an inconsistency here:
- on one hand it is stated that $\mathbf{H} = curl\mathbf{A}$, which is the usual correct equation connecting the magnetic field **H** and its potential vector **A**;
and
- on the other hand it is stated that $\mathbf{H} = (1/c)\dot{\mathbf{A}} \times \mathbf{n}$ which says that the magnetic field **H** is proportional to the time derivative of its own potential vector **A** (!?) How was this new equation obtained? We are referred to equation 47.3 to see why this is so.

We find equation 47.3 and the explanation of how it was obtained at p. 111:

> We consider a plane wave moving in the positive direction of the X axis; in this wave, all quantities, in particular also **A**, are functions only of $t-(x/c)$. From the formulas
>
> $$\mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}, \qquad \mathbf{H} = \text{curl } \mathbf{A},$$
>
> we therefore obtain
>
> $$\mathbf{E} = -\frac{1}{c}\mathbf{A}', \mathbf{H} = \nabla \times \mathbf{A} = \nabla\left(t - \frac{x}{c}\right) \times \mathbf{A}' = -\frac{1}{c}\mathbf{n} \times \mathbf{A}', \tag{47.3}$$
>
> where the prime denotes differentiation with respect to $t-(x/c)$ and **n** is a unit vector along the direction of propagation of the wave.

Observe how the authors of this textbook claim that their calculations show that the magnetic field **H** becomes proportional to the time derivative of its own potential vector

A. But are these calculations correct? How can the *curl* operator ∇, which is an operator differentiating with respect to coordinates, return as a result differentiation with respect to *time*? I, for one, have serious doubts that these calculations are correct (if you, dear reader, think otherwise, I will be obliged if you will let me know why).

Now that we have found that there is a *mistake in the calculations purporting to show that the radiation emitted by a moving charge is due to its acceleration* (and does not depend at all on its speed) we are ready to give an explanation of why and how an electric charge in simple harmonic motion (as that executed by electrons in an antenna at resonance) emits radio waves.

F. The centre-fed dipole antenna - its radiation pattern at resonance

I was often asked: if Maxwell's theory of electromagnetic waves is not correct for vacuum (which is what I believe and discussed in Part I of this series on Radio Waves), then how is it possible that engineers (and physicists) can calculate the *radiation pattern* of an antenna and that this pattern turns out to be very close to that measured experimentally?

The answer to this question is very intriguing. If you look over the calculations with attention, you observe that, although these people *seem* to apply Maxwell's theory, what they *really* do is:

(i) calculate the <u>changing magnetic field</u> **H** produced around the antenna by the current alternating in it (i.e. by the oscillating charges) using **Biot-Savart's law** (*not* Maxwell's theory of electromagnetic waves);

and

(ii) find the <u>intensity of radiation</u> (and therefore the *radiation pattern*) by **squaring the amplitude** A of the changing magnetic field.

I will show later what other calculations they do, in which they *seem* like they work with Maxwell's theory. But in fact they obtain the radiation pattern only from the two steps mentioned above, the first one being just applying Biot-Savart's law, the second being just applying the well-known experimental finding that the energy transferred by a wave (*any* wave: sound, water waves, etc.) in unit time through unit area (i.e. the intensity I of a wave) is proportional to the square of its amplitude A ($I \propto A^2$).

But before discussing how exactly the radiation pattern of an antenna is calculated (and we will focus on *CFDA* in special) let us remember that in the previous sections we have mentioned the experimentally found fact that antennas do not emit radio waves with equal intensity in all directions. In fact, it is found that there are directions in which an antenna does not emit radio waves at all. This leads to the idea of *radiation pattern* which is a graphic representation of the intensity of radio waves emitted by an antenna along the directions in space.

Look below at an example of calculated and measured radiation pattern of a *CFDA* [Ryosuke Matsuzaki, Mark Melnykowycz, Akira Todoroki, *Composites Science and Technology*, 69 (2009), 2507–2513]:

(CFRP in the figure stands for *carbon fiber reinforced plastic* because the authors investigated the properties of a *CFDA* made not of a metallic wire but of a composite material which is also a good conductor.)

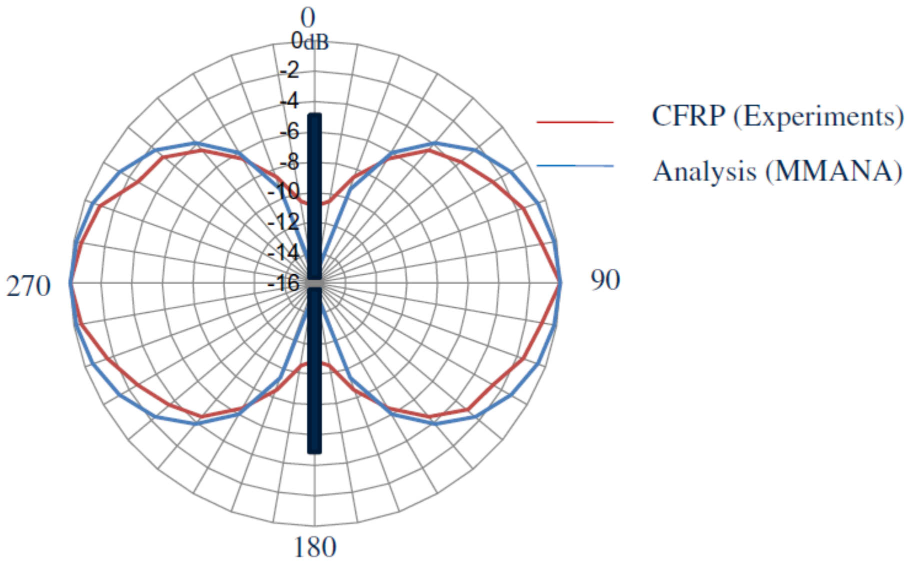


Fig. 8. Experimental and analytical two-dimensional radiation patterns of dipole antennas using the CFRP rectangular specimens. The analytical pattern was obtained using the antenna simulation software MMANA.

Observe that the radio waves emitted by a *CFDA* have *the greatest intensity* in a direction *perpendicular* to the length of the antenna and smallest intensity in a direction along the antenna.

Notice also the astonishing agreement between the measured and the calculated pattern. In article the authors mention that the simulation software MMANA that they have used is based on a code published in Constantine A. Balanis, *Antenna Theory Analysis and Design*, 3rd Edition, Wiley-Interscience (2005) – we have mentioned this reference earlier in this work.

What is going on? Why do these patterns agree so well? Let us look at how calculations of the radiation pattern are made.

We will refer again to John D. Kraus's book *Antennas*, 2nd Edition, McGraw-Hill Book Company (1988). At page 202, we find that the magnetic potential vector **A** produced at a distance *s* by the current due to the charge oscillating in a dipole is written as:

$$A_z = \frac{\mu_0}{4\pi} \int_{-L/2}^{L/2} \frac{[I]}{s} \, dz \qquad (3)$$

You can recognize that this is **Biot-Savart's Law**.

The current [I] in the equation is the alternating current produced in the antenna by the charges. Notice that it is *assumed* that this current transmits its effect through the distance *s* with velocity c (the speed of light), as shown in the equation at page 203:

$$[I] = I_0 e^{j\omega[t-(s/c)]} \qquad (3a)$$

After some approximations, the magnetic potential vector **A** due to the current in the antenna is found to be

$$A_z = \frac{\mu_0 L I_0 e^{j\omega[t-(r/c)]}}{4\pi r} \qquad (4)$$

… which is again **Biot-Savart's Law**.

Then the author calculates the magnetic field **H** corresponding to the magnetic potential vector **A** with the help of the correct equation [p.205]:

$$\mathbf{H} = \frac{1}{\mu} \nabla \times \mathbf{A} \qquad (18)$$

After a series of approximations the author obtains the magnetic field **H** produced by the current in the antenna at great distances from it as [p.206]:

$$H_\phi = \frac{j\omega I_0 L \sin\theta \, e^{j\omega[t-(r/c)]}}{4\pi c r} = j \frac{I_0 \beta L}{4\pi r} \sin\theta \, e^{j\omega[t-(r/c)]} \qquad (35)$$

Observe that the magnetic field is variable in time because the current in the antenna was taken variable in time. Observe that the amplitude of the waving magnetic field is

$$\frac{I_0 \beta L}{4\pi r} \sin\theta$$

… which shows that the *amplitude* of the waving magnetic field is proportional to $\sin\theta$ and therefore changes with the angle θ between the direction of the antenna and the direction of observation.

Of course, the intensity of the wave (giving the energy transferred by this wave and therefore its radiation pattern) would be proportional to the square of the amplitude of this wave, namely

$$I \propto \left(\frac{I_0 \beta L}{4\pi r} \sin\theta \right)^2$$

.. this last equation shows that the intensity of radiation depends again with the angle θ with the direction of the antenna, being proportional to the square of $\sin\theta$.

The plot of the dependence of the *amplitude* of the field with the with the angle θ ($\sin\theta$) made with the direction of the antenna is shown at page 207:

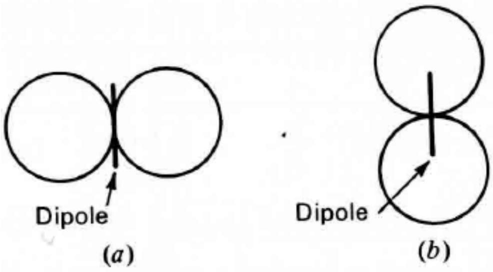


Figure 5-5 Near- and far-field patterns of E_θ and H_ϕ components for short dipole (*a*) and near-field pattern of E_r component (*b*).

The plot of the radiation pattern has a very similar shape.
Observe the similarity between the figure 5-5 (a) and the plot shown at the beginning of this section made with the MMANA simulation software.

As you can see in the figure, there is a mention of the *electric field*, about which it is said that its amplitude has the same dependence with the directions in space as the magnetic field. This amounts to saying that, when the energy (and intensity) of the wave(s) is calculated using Poynting's formula [p. 215] …

$$\mathbf{S} = \tfrac{1}{2}\,\mathrm{Re}\,(\mathbf{E} \times \mathbf{H}^*) \qquad (1)$$

… the final formula contains in fact *only the square of the amplitude of the magnetic field*.
Indeed, this is what is obtained towards the end of the calculations [p.215]:

The total power P radiated is then

$$P = \iint S_r\, ds = \frac{1}{2}\sqrt{\frac{\mu}{\varepsilon}} \int_0^{2\pi} \int_0^{\pi} |H_\phi|^2 r^2 \sin\theta\, d\theta\, d\phi \qquad (5)$$

Observe that this final formula is in fact the second step (ii), mentioned at the beginning of this section: to find the intensity of radiation you have to square the amplitude of the magnetic wave ($I \propto A^2$).

When you look back at all these calculations and approximations, what you realize is that, indeed, the whole calculation of the *radiation pattern* of a simple dipole (and of a whole antenna) can be summarized in these two simple steps:
(i) calculate the changing magnetic field **H** by applying **Biot-Savart's law** and
(ii) find the intensity of radiation by **squaring the amplitude** of the changing magnetic field obtained at (i).

The conclusion is that the good agreement between the experimental and calculated *radiation pattern* of an antenna is not due to the fact that Maxwell's theory is correct but merely due the fact that **Biot-Savart Law** is correct.
While we have shown why Maxwell's theory of electromagnetic waves is not valid for vacuum as is built on assumptions not verified experimentally and on faulty method of theoretical investigation (Maxwell's displacement current), Biot-Savart Law is a law found experimentally and therefore necessarily correct.

G. So what are radio waves? And how are they produced?

In the previous section we have seen that *Maxwell's theory of electromagnetic waves is not needed to obtain the radiation pattern of an antenna*. This, together with the fact that no experimental evidence exists that a changing electric field induces (creates) a changing magnetic field in vacuum, or that a changing magnetic field induces (creates) a changing electric field in vacuum, come to support the idea that Maxwell's theory according to which radio waves travelling in vacuum are a system of electric and magnetic fields mutually inducing one another may not be correct after all.

So if radio waves are not electromagnetic, what are they?

As we have seen in the previous section, **the radiation pattern of an antenna can be found by the sole application of Biot-Savart's Law**.
This can only lead to the conclusion that radio waves are magnetic only and do not have an electric component. To be more exact, the theory advanced in this work is that radio waves are waves of the magnetic potential **A**, which is a vector physical quantity that, when its curl is non-zero, produces the whole class of phenomena which we call *magnetic*. This is stated mathematically by the equation:

$$\mathbf{B} = \nabla \times \mathbf{A}$$

It should not be conceived that **A** is only a mathematical concept. The magnetic potential **A** actually has *physical existence* as proven in observations of the Aharonov-Bohm effect made by Akira Tonomura.

The *physical existence of the magnetic potential* **A** is a proof of the existence of the aether because **A** **contributes to the total momentum of the electron** (see the excerpts below). **My opinion is therefore that the magnetic potential A (whose curl is the magnetic field B,** $\mathbf{B} = \nabla \times \mathbf{A}$**) is identical with the velocity vector of the flowing (moving) aether.**

See below an excerpt from Akira Tonomura's inspiring book [*The Quantum World Unveiled by Electron Waves*, World Scientific Publishing Co. Pte. Ltd. (1998), p.99-100] in which he explains how the magnetic potential vector **A** contributes to the total momentum of the electron and therefore explains the observation of Aharonov-Bohm effect:

However, since there exists vector potential $\boldsymbol{A}$ outside the coil, an additional phase shift is produced by it. The sign of the phase shift is opposite on both sides of the coil, or the wavefronts are displaced in the opposite directions as illustrated in Fig. 80. On the left-hand side of the coil, the vector potential $\boldsymbol{A}$ points downward as does $\boldsymbol{v}$. Therefore, $|m\boldsymbol{v} + q\boldsymbol{A}|$ is smaller than mv, since $q < 0$. That means, the wavelength, *i.e.* the wavefront spacing given by $\lambda = h/p = h/|m\boldsymbol{v} + q\boldsymbol{A}|$ becomes larger there. On the right-hand side of the coil, the opposite thing happens and the wavefront spacing is shortened. Thus, the electron wavefronts on both sides of the coil proceed differently.

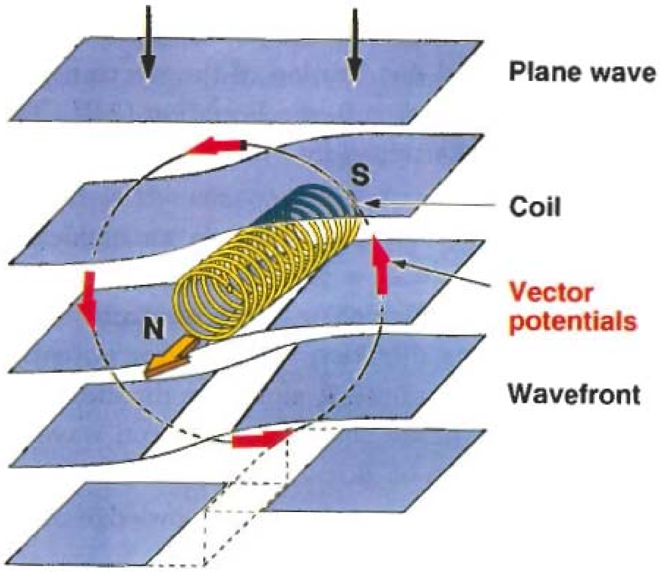


Fig. 80. Wavefronts of electron waves passing through both sides of the coil.
The phase of a traveling electron wave with speed v changes by 2π when the position is shifted in the propagation direction by $\lambda = h/mv$. Although an incident wave has wavefronts with an equal interval, when the wave enters the region where $\boldsymbol{A}$ exists, wavefronts are further advanced or retarded by $\boldsymbol{A}$ depending on which side of the coil they pass through. The total phase difference is given by $\frac{2\pi q}{h}\Phi$.

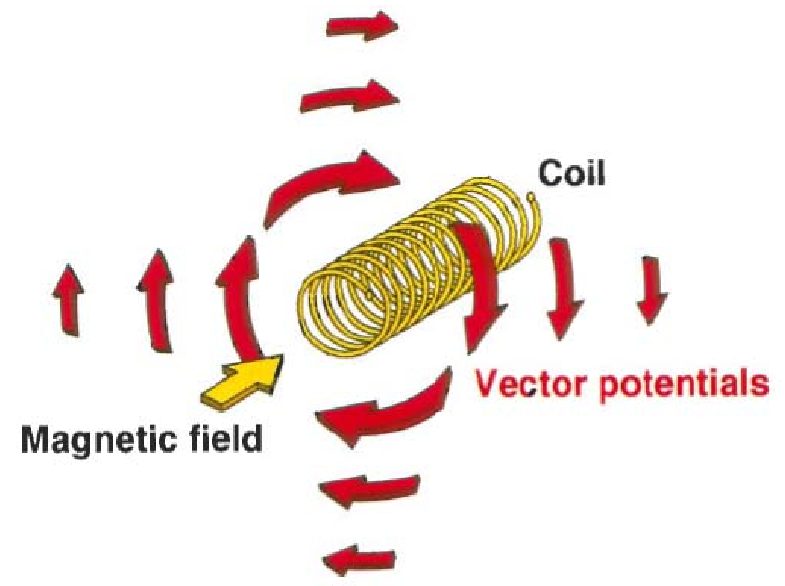
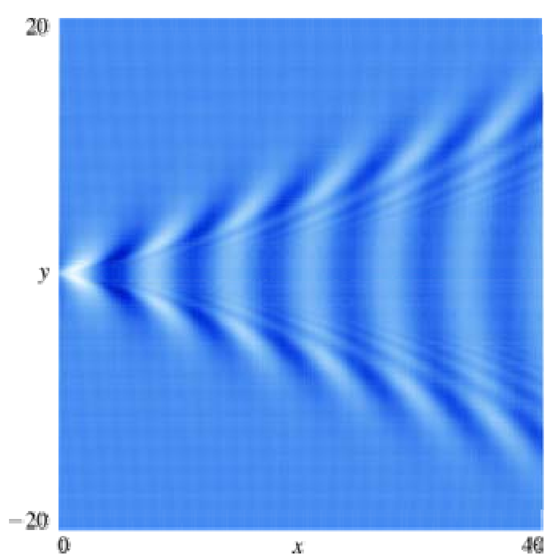


Fig. 77. The vector potential around an infinitely long coil.
No magnetic fields are produced outside the coil, but vector potentials exist outside of it because of the relation, $\oint \boldsymbol{A}\, d\boldsymbol{s} = \Phi$ [see Equation (18)].

Finally, let us give a description of the mechanism whereby radio waves are produced by the electrons in simple harmonic motion in an antenna:

1. Charges flowing in a wire produce a magnetic field; the magnetic field is a system of a great number of aether wakes since they are produced by the great number of charges flowing in the wire; these wakes can be described with the help of potential vector **A**.
See below a simulation of Kelvin's ship wave pattern [*NIST Digital Library of Mathematical Functions (DLMF)*, http://dlmf.nist.gov/36.13.F1]:



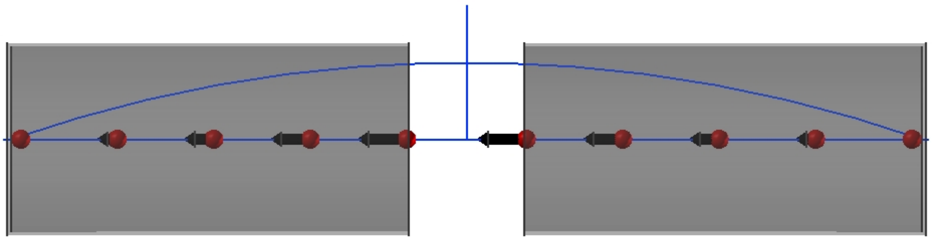
Imagine a great number of such bodies (as are the electrons flowing in a wire) producing aether wakes in their motion. The resulting system is what we call "the magnetic field produced around a wire carrying an electric current".

2. Due to their great number, the wakes produced by the electrons moving in the wire cannot be detected as waves, but as a general movement of aether. This movement can give rise to an attractive/repulsive force if charges are made to move in a *second wire* parallel with the first. This attractive/repulsive force is due to Bernoulli effect in aether (see "Bernoulli Equation for the Aether and Ampere's Effect", *Electric Spacecraft Journal*, Issue 43 (2007), p. 7-10, or "Rudiments of a Theory of Aether", *General Science Journal*, March 20, 2010, http://gsjournal.net/Science-Journals/Research%20Papers-Astrophysics/Download/2370).

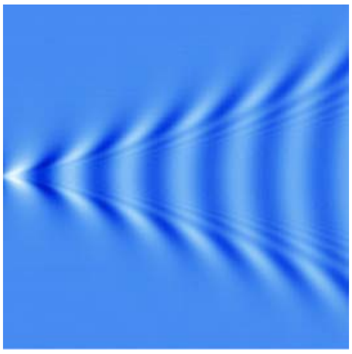
3. When the charges flowing in a wire are made to oscillate, they produce wakes in a coherent manner: a wavefront of small thickness composed of a multitude of wakes coming from each oscillating electron is produced in one direction; this wavefront is followed by another similar wavefront produced when the charges executing simple harmonic motion in the antenna move in the same direction after one period of oscillation. The distance between two such wavefronts (composed of a multitude of wakes) is the wavelength of the radio wave.

See below pictures based on the simulation of Kelvin's ship wave pattern shown above and pictures of the electrons in simple harmonic motion in the antenna shown at the beginning of this article.

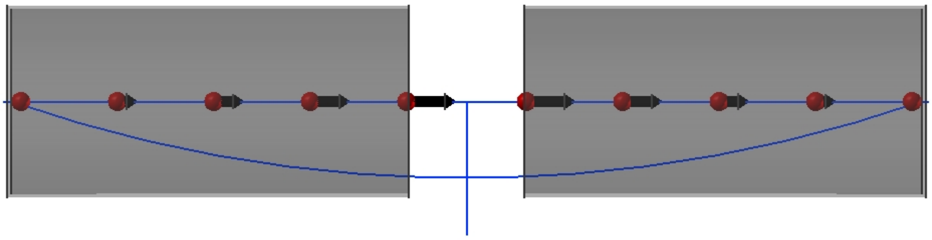
Each electron in the antenna…

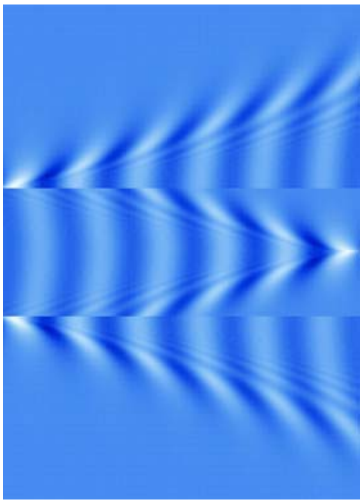


produces a wake as in the picture below:

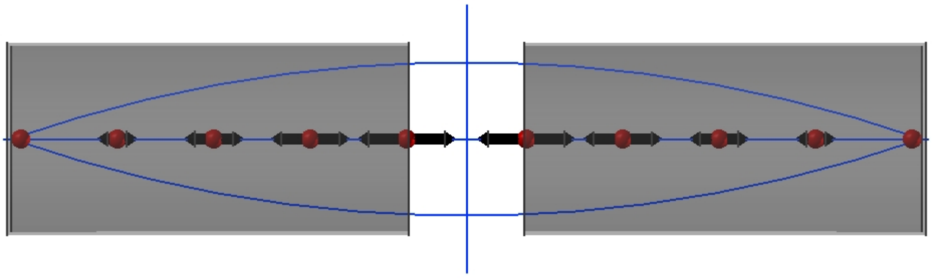


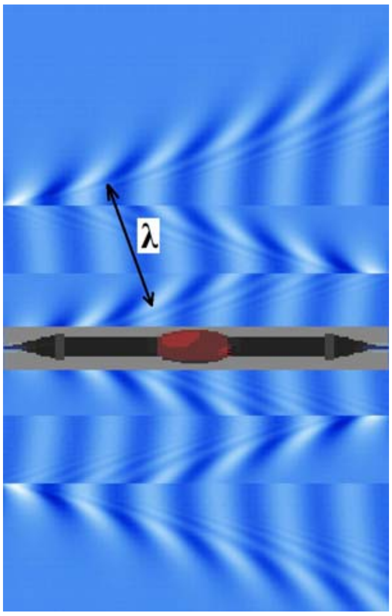
The wakes produced by all electrons form one wavefront.
When the electrons reverse motion the original wakes (and therefore the whole wavefront that their wakes build up) continue to move on their own and *new wakes* are formed travelling in the opposite direction:



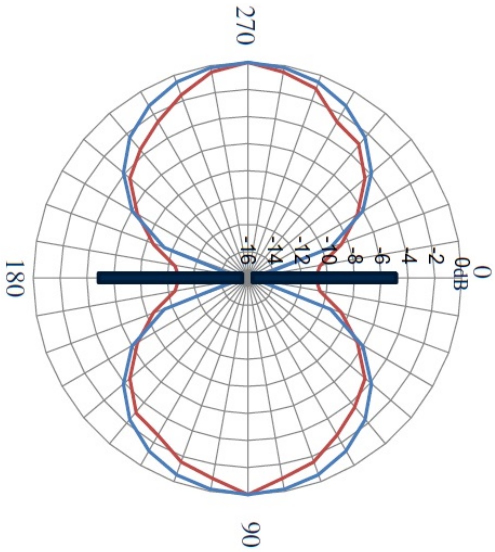


After a few oscillations a number of wavefronts moving in directions approximately perpendicular to the direction of the antenna are formed; the distance between two of wavefronts is the wavelength λ of the radio wave emitted:





The intensity of the wave varies with direction as [Ryosuke Matsuzaki, Mark Melnykowycz, Akira Todoroki, *Composites Science and Technology*, 69 (2009), 2507–2513]:



I have made a short movie with an experiment showing the analogy between systems of wakes on water and radio waves [YouTube: Ionel DINU - Unravelling the NATURE of RADIO Waves (http://www.youtube.com/watch?v=ySuxV0j2cP4)].

Conclusion

In this article I have discussed some misconceptions commonly encountered in textbooks on antennas and how they are used to give erroneous explanations of the production and nature of radio waves.

I have shown that the calculations of radiation pattern of an antenna do not use Maxwell's theory of electromagnetic waves and that they in fact apply Biot-Savart's Law and the fact that the intensity of a wave is proportional to the square of its amplitude.

I have presented my view according to which **radio waves** are **aether waves** whose **wavefronts** are built up from **a great number of aether wakes** each wake being produced by one charge oscillating in an antenna.