Reading 23

Ron Bertrand VK2DQ
http://www.radioelectronicschool.com

ELECTROMAGNETIC RADIATION

THE MECHANISM OF RADIATION

The purpose of this reading is to describe electromagnetic radiation and how it actually radiates. We also cover the concept of wavelength and frequency. We look at an overview of the electromagnetic spectrum.

Again I am faced with the dilemma of providing some information which is not examinable. However, such information provides useful insights to the topic, which I believe makes it more interesting.

Though radio waves can have different wave shapes, I would like you to think of them as sine waves for this exercise. Actually many are just that, sine waves. We have already looked at alternating current and voltage at lower frequencies, for example the mains, which is 50 Hertz. Radio waves are produced by AC, yes the AC you have already learned about. The difference is the frequency of oscillation is much higher than 50 Hz.

We have also learnt that current, either alternating or direct (or any other), has associated with it electric and magnetic fields. It is usual to refer to the combined fields as electromagnetic fields.

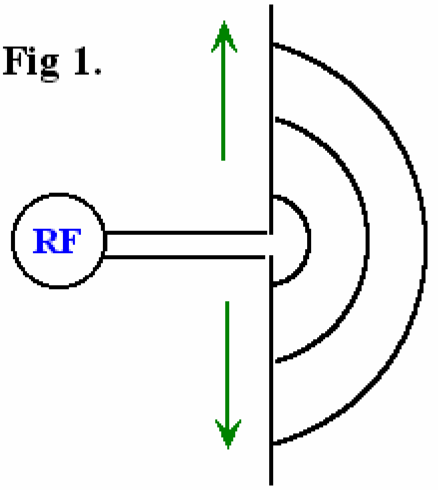
It was discovered that high frequency electromagnetic currents in a wire (antenna), which in turn result in a high frequency electromagnetic field around the antenna, will result in electromagnetic radiation which will move away from the antenna into free space at the velocity of light (approx. 300,000,000 metres per second).

I remember when I was studying at the Marconi School of Wireless under Mr. Cecil Bardwell, I was a pain in insisting that I wanted to know how the electromagnetic radiation is actually radiated. I have lost those notes that he gave me but I do remember what he told me. Strangely, I have never found a textbook or reference that does explain it since. So here is my attempt thanks to Mr. Bardwell.

Firstly, for electromagnetic radiation to exist the frequency must be reasonably high - I will explain this. Also, because the drawing of both electric and magnetic fields around a wire in three dimensions is difficult, I will just use the electric field. I repeat, this is not a must know, you can just accept it as most do if you wish and move on.

Figure 1 shows two wires connected to a radio frequency (RF) generator, and at a certain point the two wires have been split to form an antenna.
Figure 1 shows (the green arrows) the charges moving towards the ends of the antenna. The black semi circles are the electric field lines set up by the charges (current). I am not showing the magnetic field. As you can see the electric field expands outward from the antenna following the flow of current. When the current direction reverses, the electric field will follow the current and collapse back into the antenna returning all of the energy to the RF source.

Fig 1.

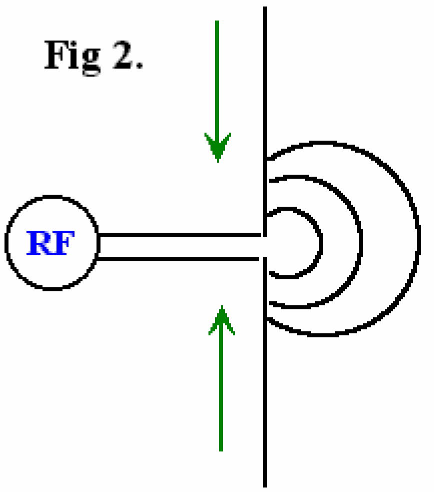


However, it takes <u>time</u> for the electric field to collapse. How much time the electric field has got to collapse back into the antenna is determined by the frequency of the RF source.

So, if we increase the frequency of the RF source the electric field has less time to collapse back into the antenna.

In figure 2 I have increased the frequency of the RF generator a bit, to demonstrate that the rate of collapse of the electric field is lagging behind the current flowing in the antenna.

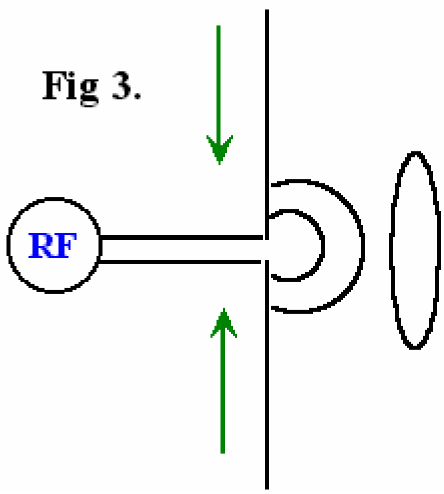
Fig 2.



The RF generator continues to produce alternating currents and voltages on the antenna (reversing each half cycle). Now, lets increase the frequency, and keep on doing so. A point is reached where the electric field cannot completely collapse into the antenna because the current is changing direction too fast.

I have shown one electric line of force stranded (figure 3). Having nowhere to go, it just sits there in free space and forms a loop. Of course, now energy has been taken from the RF source as it has not all been returned.

Fig 3.

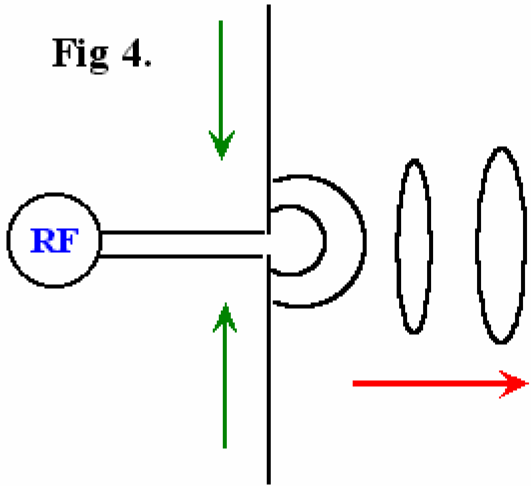


Make sure you have a good look a figure 3. The closed loop is an electric line of force stranded in free space near the antenna. When the RF source causes current to flow in the opposite direction again, and because of the high frequency involved, **more** electric field loops will be stranded in free space as shown in figure 4.

The first loop is now repelled away from the antenna by the second one. If you can imagine the RF source operating at thousands or millions of hertz, then there will be many of these loops and they will all be repelled away from the antenna. The magnetic lines of force which I have not shown, link the electric lines horizontally, and what has happened is, the production of an electromagnetic wave in free space.

The electromagnetic wave created will propagate (travel, move) away from the antenna at the speed of light. An electromagnetic field, or more correctly an electromagnetic wave, is light. There is no difference between a “radio” electromagnetic wave and a light wave except the frequency.

Fig 4.



Our eyes are radio wave receivers tuned to receive electromagnetic waves within a certain frequency range, which we call visible light.

In my very simplified diagrams I have only shown the radiation in one direction. Depending on the design of the antenna, radiation may occur in many directions.

I often think we should be thankful that our eyes are narrow band electromagnetic wave receivers. Imagine if they were not! All radio waves, CB, amateur, television etc. would be visible and drive us nuts!. A large television tower would be seen as streaming out light, though I could not tell you what the colour would be as colour of electromagnetic waves in the visible light spectrum is a biological interpretation of our brain. In fact, I can’t even say that what you see as green is what I see as green - I think it is more that we are educated that “the grass is green”. So light waves are just electromagnetic waves, which our eyes can detect, and the multitude of colours is our biological perception of those different frequencies.

USES OF ELECTROMAGNETIC RADIATION

Naturally, since the electromagnetic radiation travels so fast (300,000,000 m/s) we can use it to transfer information from one place to another. In most cases because the velocity is so great, it appears to be instant, though it is important to realise that it is not instant. A fact, that is very obvious when we communicate through satellites and with space vehicles. As an example, it takes about eight and a half minutes for light to reach earth from the sun, so you never see the sun where it is, you only see it where it was eight and a half minutes ago.

Of course man (is this politically correct!) has been using electromagnetic radiation to communicate for thousands of years, though we have been using visible light frequencies.

To communicate over distance we need to impress information on the electromagnetic wave. The simplest way to do this would be to turn it on and off - turning a light on and off, using flags etc., are all methods of communicating with visible electromagnetic radiation.

Light has disadvantages to electromagnetic radiation at lower frequencies. The properties (except the velocity) of electromagnetic waves at lower frequencies changes, providing advantages such as easier interception, boosting and re-transmission, to name just a couple.

The process of impressing intelligence or information on to an electromagnetic wave is called modulation.

In radio transmission a radiating antenna is used to convert a time-varying electric current into an electromagnetic wave, which freely propagates through a nonconducting medium such as air or space. In a broadcast radio channel, an omni directional antenna radiates a transmitted signal over a wide service area. In a point-to-point radio channel, a directional transmitting antenna is used to focus the wave into a narrow beam, which is directed toward a single receiver site. In either case, the transmitted electromagnetic wave is picked up by a remote receiving antenna and reconverted to an electric current.

Radio wave propagation is not constrained by any physical conductor or wave-guide. This makes radio ideal for mobile communications, satellite and deep-space communications, broadcast communications, and other applications in which the laying of physical connections may be impossible or very costly. On the other hand, unlike guided channels such as wire or optical fibre, the medium through which radio waves propagate is highly variable, being subject to diurnal, annual, and solar changes in the ionosphere, variations in the density of water droplets in the troposphere, varying moisture gradients, and diverse sources of reflection and diffraction.

All of these aspects we will be looking at in more detail.

Of course with the world communicating so much and using electromagnetic radiation, steps must be taken to have different users share different frequencies so that communications do not interfere with each other. The range of useful frequencies is a finite resource which many governments including ours (Australian) has capitalised on by selling parts of it very much like real estate even to the point of Spectrum Auctions.

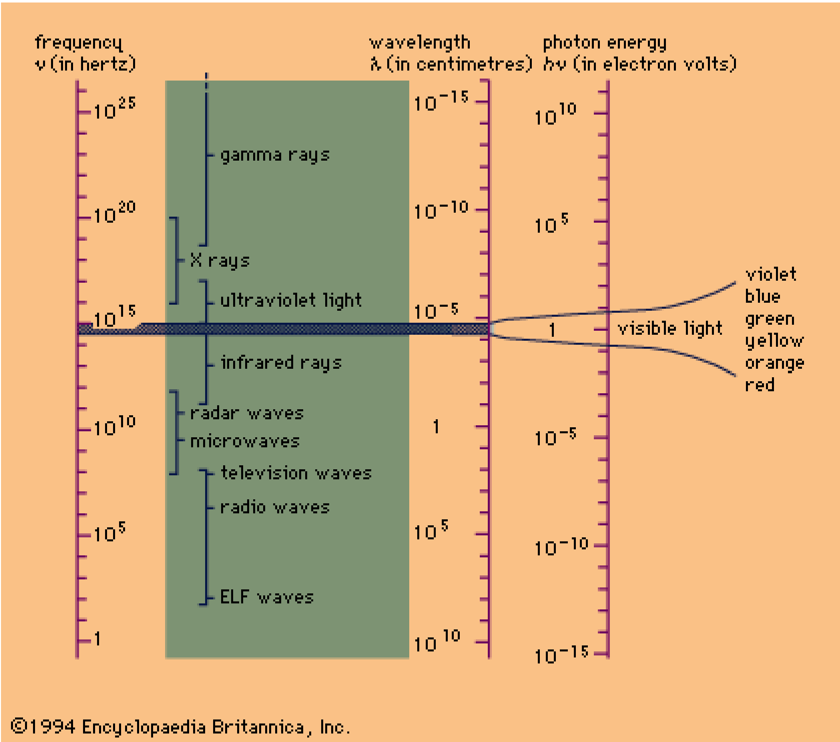


Figure 5.

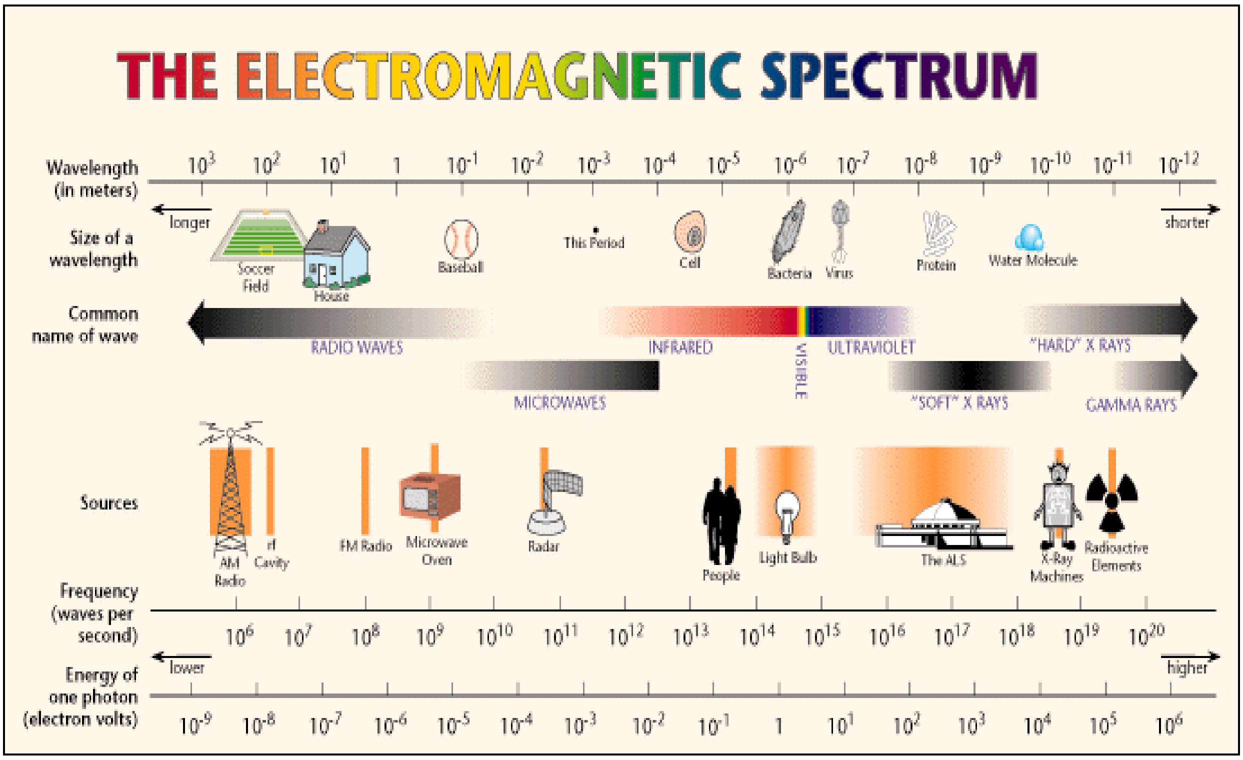
THE ELECTROMAGNETIC SPECTRUM

Refer to figure 5 showing the electromagnetic spectrum from small frequencies (long wave radio) to exceedingly high values of (gamma rays). Going from the values of radio waves to those of visible light is like comparing the thickness of a piece of paper with the distance of the Earth from the Sun, which represents an increase by a factor of a million billion.

Similarly, going from the (frequency) values of visible light to the very much larger ones of gamma rays represents an increase in frequency by a factor of a million billion. This extremely large range of values is called the electromagnetic spectrum, together with the common names used for its various parts, or regions.

Figure 6 is another chart of the electromagnetic spectrum with a graphical representation of the frequency and wavelength.

Figure 6.



FREQUENCY AND WAVELENGTH

This conversion is a must know for examinations, the relationship between frequency and wavelength is:

Wavelength(λ) = c / F

Where 'c' is 299,792,458 metres per second, though in radio communications it is nearly always rounded to 300,000,000 metres per second.

A more useful form and easier to memorise is:

λ = 300 / F(Mhz)

CALCULATING WAVELENGTH

For example, what is the wavelength of 146 MHz, which just happens to be the middle of the 2 metre amateur band?

λ = 300 / 146 = 2.0547 metres.

When describing a 'band' the wavelength is rounded to '2' metres.

More often, accurate measurements of wavelength are required, such as cable lengths and antennas dimensions. Where more accuracy is required, the wavelength as calculated from the above equation must be expressed using the appropriate number of decimal places.

Frequency bands are given the following common names:

3 - 30 kilohertz	Very low frequencies (VLF)
30 - 300 kilohertz	The long wave band (LW)
300 - 3000 kilohertz	The medium wave band (MW)
3 - 30 megahertz	The shortwave band (SW) Referred to by Amateurs as the HF Band (High Frequency)
30 - 300 megahertz	Very high Frequency Band (VHF)
300 - 3000 megahertz	Ultra high frequency band (UHF)
3 - 30 gigahertz	Super high frequency band (SHF)
30 - 3000 gigahertz	Microwave frequencies
Above	Above 3000 gigahertz we have infrared, visible light with all its colours, ultraviolet, X-rays, and at the very top gamma rays

Table 1 – Frequency Bands

POLARISATION

The electric and magnetic fields of an electromagnetic wave are perpendicular (at right angles) to each other.

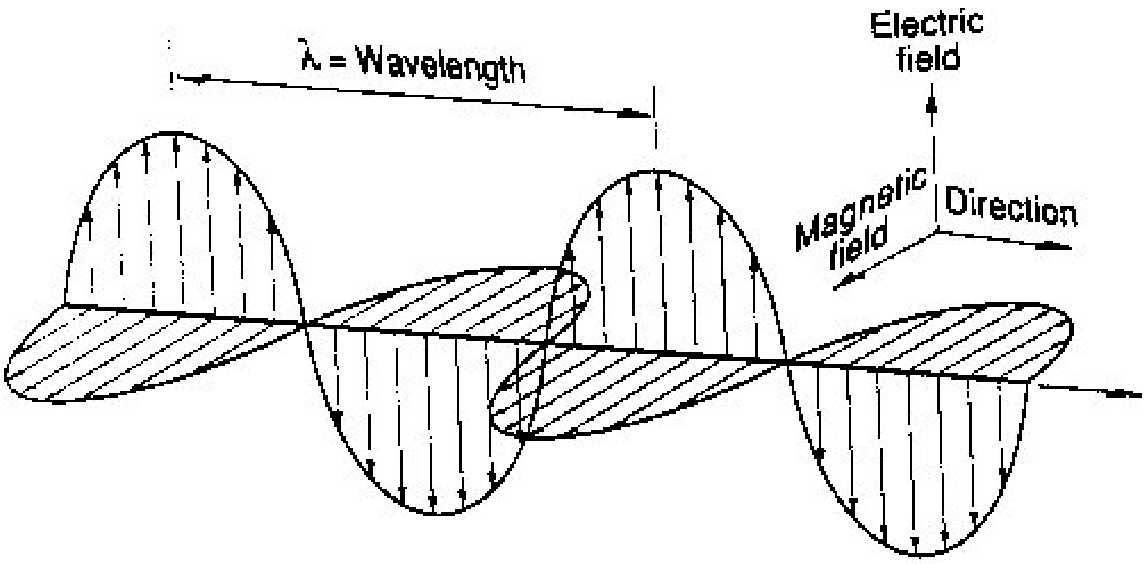


Figure 7.

The polarisation of an electromagnetic wave is always described in terms of the direction of the electric field relative to the earth. If the electric field is vertical relative to the earth the wave is said to be vertically polarised. If the electric field is horizontal relative to the surface of the earth then the wave is said to be horizontally polarised.

If the antenna is horizontal with respect to the earth the wave is horizontally polarised. If the antenna is vertical with respect to the earth the wave is said to be vertically polarised. The important factor is that the direction of the electric field is what determines whether a wave is called vertically or horizontally polarised. This has been asked in the exam.

However, when there is propagation via the ionosphere, it is possible for a wave radiated from a vertical antenna to have its polarisation twisted – this is called Faraday rotation. So even though a wave may be radiated from a vertical antenna it can have its polarisation twisted by the ionosphere and become horizontal. For this reason we do not define the polarisation of a wave by the type of antenna which is radiating it. We always define polarisation by the direction of the electric field. Never assume that radiation from a horizontal or vertical antenna will be received at a remote location by ionospheric propagation in the same polarisation that it left the antenna.

RADIATION AND RECEPTION

How much electromagnetic energy is able to leave an antenna depends on the relation of its length to the wavelength of the current.

Just as a wire or antenna carrying an RF current is surrounded by electric and magnetic fields, so a wire placed in an electromagnetic field will have a current induced in it. As far as antennas are concerned, transmitting and receiving antennas are basically interchangeable, apart from power handling considerations. In fact, a so-called principle of reciprocity exists, which states that the characteristics of antennas, such as impedance and radiation pattern, are identical regardless of the use for transmission or reception.

To receive a vertically polarised wave (electric field vertical) a vertically polarised antenna should be used.

However as explained earlier, Faraday Rotation over a high frequency (HF) circuit can modify the polarisation.

SOMETHING NEW ABOUT IMPEDANCE

We have talked about impedance in the past as belonging to something, ie. resistors, capacitance and inductance. Impedance is the total opposition to current flow in an AC circuit. When we talk about electromagnetic waves impedance our concept of impedance needs to be broadened. This is particularly true of transmission lines (eg. coaxial cable) and antennas. Impedance should not be thought of as belonging to a thing**,** but as the ratio of voltage over current. From Ohm's law R=E/I and we extend that to impedance with Z=E/I. Normally we have been talking about the voltage across something, and the current through the same thing, to calculate the impedance. This might appear a bit of a leap, but when talking about electromagnetic waves, we need to take the concept of the impedance *belonging* to a component(s) away, and think of the impedance as the ratio E/I. This is particularly true of antennas and transmission lines. I am just preparing you for it here. For example, free space has impedance! When an electromagnetic wave travels through free space its electric and magnetic components settle into a specific ratio that just happens to be 120Π or 377 **-** so we say the impedance of free space is 377 Ω. Likewise, an electromagnetic wave travelling down a transmission line will cause certain voltage and current ratios to exist at different points. We then have to think beyond the transmission line and think about the ratio of voltage and current at different points on it to understand or define the impedance at those points.

In other words, electromagnetic waves can be impedance upsetters. A wave travelling down a cable may determine the impedance, and not the cable. This will become clearer as we go (I hope). For now, yes, impedance is the total opposition to current flow in an AC circuit. Introduce electromagnetic waves into transmission lines and antennas and the wave and its behaviour will be what determines the impedance at any given point. Impedance is always the ratio given by Ohms law E/I.

We will also be discussing propagation of waves. It will help if you think about light waves, something you are very familiar with. Whatever we can imagine light doing, we can do it, or it is done with, electromagnetic waves, because they are one and the same thing, just on a different frequency.

Reflection, refraction, absorption and anything else you can think of pertaining to light, pertains equally to electromagnetic waves.

DOPPLER SHIFT

When a car blowing its horn approaches you the pitch (frequency) of the horn sounds higher. As it immediately passes you, you hear the actually pitch of the horn. As it moves away from you, you hear a lower pitch. This effect is called Doppler Shift.

The same happens to electromagnetic waves which are being radiated from a moving source. This is most noticeable when communicating through satellites. When the satellite is moving at high velocity towards you, the frequency of your receiver has to be tuned a little higher than the actual frequency. When the satellite moves away the receiver has to be tuned to a lower frequency.

Stars give off visible light. Red light is a lower frequency than blue light. Scientist are able to tell if a star is moving towards us (or us towards it), by the blue shift (increase in frequency) of the light reaching us. If the star is moving away then there will be a red shift.

This is also precisely how police Doppler Radar works. An electromagnetic wave pulse is sent to the target (the vehicle). If the reflected wave is echoed on the same frequency the vehicle is not moving. If the car is moving there will be a down shift or an upward shift in the frequency of the echo. How much shift there is can be used to compute exactly how fast the vehicle is moving.

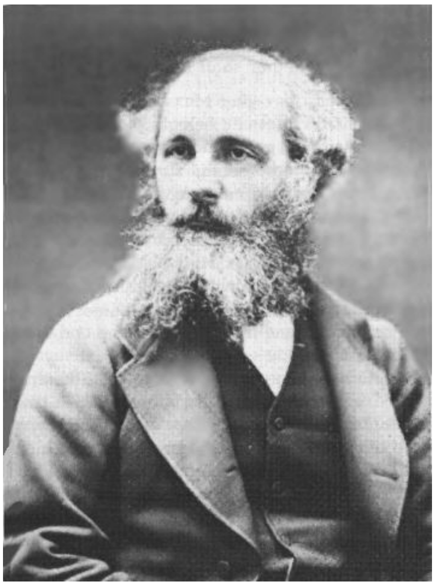
Doppler shift does get a mention in AOCP examinations sometimes. All you need to know is that an apparent shift in frequency of a source of transmission of an electromagnetic wave will occur. The apparent shift will be upwards in frequency if the source is moving towards you, or you towards it, and a downward shift if the source is moving away from you, or you away from it. For amateur operators the Doppler shift must always be taken into consideration when communicating through Amateur Satellites.

Extra reading – the material below is not required learning but is provided here as background information for interest sake.

THE BEGINNINGS OF THE ELECTROMAGNETIC SPECTRUM

Michael Faraday (1791-1867) developed the concept of electric fields. He believed that a charged particle creates an electric field about it in all directions. If a second charged particle is placed in the field, there is an interaction between the fields. This will result in an attraction or repulsion of the two fields.

In 1820, a Danish physicist by the name of Hans Christian Oersted, while experimenting with electric currents in wires, found that when a compass was placed parallel to a current carrying wire, the compass needle would rotate until it was perpendicular to the direction of current in the wire. Although trying to prove that there was no connection between magnetic and electric fields, this experiment indicated to Oersted that electric and magnetic fields were indeed connected.

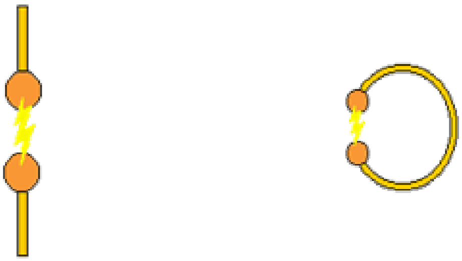


From these experiments by Faraday and Oersted, in 1860, a Scottish scientist named *James Clerk Maxwell* predicted that a changing electric field can produce a magnetic field and a changing magnetic field can produce an electric field. This propagation of electric and magnetic fields formed an electromagnetic wave. Maxwell was able to create a mathematical formula for Faraday's theory of electricity and magnetism. According to the Maxwell formula, these waves travelled at 3×10^8 metres per second.

In 1888, Heinrich Hertz demonstrated the production and detection of electromagnetic waves. Hertz placed a circular piece of wire containing a small gap near an induction coil. He then rotated the ring until a spark was created. The spark created in this experiment was the first collaboration that electromagnetic waves do exist.

In the beginning these waves were called Hertzian waves.

Technically, Hertz was the first person to prove the existence of electromagnetic waves by experiment.



Hertz's experiment consisted of a spark gap, and a loop nearby was the receiver. The gap sparked when the transmitter sparked.

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E-mail: manager@radioelectronicschool.com
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