"Hands on – *to RADIO WAVES*"

THE ELECTROMAGNETIC WAVE: INTRODUCTORY DEMONSTRATIONS

CONTENTS

December 2007 edition

The Purpose of these Demonstrations

> **"One of the most important scientific advances of the last 150 years is the discovery and application of electromagnetic waves. Maxwell in England developed the theory, Marconi from Italy used the waves to communicate across the Atlantic Ocean, and numerous radio amateurs demonstrated very long-distance communication with low-power radio signals. Today, radio communications circle the globe and reach far into space. Without radio, the world would be a very different place."**
>
> - Dr William Pickering KBE in the Foreword to "*Ham Shacks, Brass Pounders and Rag Chewers, A History of Amateur Radio in New Zealand*", by Ian Dougherty, NZART 1997.

Radio waves are all around us. We can't see them, but we can generate them and detect them, we can determine their characteristics and we can measure them. They play a very great part in our daily life, every member of the public uses this technology.

Radio provides the backbone technology for the information economy: radio and television broadcasting, cellphones, mobile communications, remote controls of many types, keyless car locks, remote door openers, wireless local area networks, satellite navigation, radio telescopes, environmental monitoring and so much more in our world. These all use the same "*electromagnetic waves*" so we should all have a working knowledge of them. Radio communication is so ubiquitous that it is almost taken for granted.

The widest public understanding of radio communication is important for our economy. There is a shortage of radio communications engineers, technicians and scientists. Many of these innovations were developed by scientists and engineers who had their interest aroused by a hands-on demonstration, perhaps at school, perhaps at an exhibition, perhaps through a demonstration by a radio amateur.

Experiments with inexpensive home-made apparatus can open up our vision and reveal this unseen radio world to us. Suggestions and guidance for some radio experiments are presented here for the individual and for school-room class demonstrations. These unseen waves and many mysteries of radio can be revealed by your own "hands-on" investigations.

A special radio licence is not required for the demonstrations and experiments described here. The radio-frequency generator falls in the provisions of the "New Zealand Radiocommunications Regulations (General User Radio Licence for Short Range Devices)". It should be noted that voice and similar communications at the frequency used here are not permitted by this licence. Refer to: http://www.rsm.govt.nz

For voice communication at this and at many other frequencies and for many other privileges too, an amateur radio licence can be used. Becoming qualified as a radio amateur is highly recommended. It is an internationally-recognised qualification in radio with a certificate (showing your own callsign) to hang on the wall. Each radio amateur has a listed unique and discrete personal radio callsign. Details about Amateur Radio and how to qualify can be found at: www.nzart.org.nz/nzart

The amateur radio qualification is a useful preliminary to a career in telecommunications. It is attainable by young and old, the youngest radio amateur in New Zealand was age 8.

Getting started

To detect radio waves we need a "receiver". One of the simplest for experimental work is a meter, a diode, and a length of wire.

You also need your own source of radio waves, so an inexpensive off-the-shelf transmitter module with a battery, a switch and a few more components, and an aerial wire, makes a useful "test transmitter".

With these two items you can investigate "radio", you can generate and detect your own radio waves. For many fundamental experiments and demonstrations nothing more is required.

We will investigate how radio waves propagate, we'll see how radio waves can pass through some materials and not through others, how a television aerial works, how information can be conveyed on a radio wave to bridge distance, and we'll learn lots of other things too.

Using this apparatus will raise more questions. With your increasing understanding you will develop experiments of your own to find the solutions to many problems and the answers to many questions.

The gadgetry described here is capable of modification. So you have a chance to try your own experiments.

How we generate a wave

Please stop for a moment and consider some basic theory! This will help you to understand the demonstrations described here.

The intention of this project is to keep things simple and to present only the essential matters. In so doing, some corners may have been cut. Please advise any points that need to be corrected or reinforced so that amendments can be included in the next edition of this manual. Suggestions to nzart@nzart.org.nz are welcome.

The transmitter:

The transmitter is an electronic device fitted at the centre of a *dipole aerial* – two equal-lengths of wire. (We shall call it a "dipole" for short.)

For simplicity, first consider the transmitter to be a very high-speed "switch" or a "pump" – shifting electrons from one of the pieces of wire to the other piece and back again, then continuously repeating.

The "frequency" of the transmitted wave is the rate of switching – in our demonstration, 433.92 megahertz (MHz), i.e. *433.92 million cycles per second!*

An electric field is established between the two pieces of wire forming the dipole – a *changing electric field*, changing at the frequency of the transmitter.

At the same time, a *changing magnetic field* is established around the dipole. This magnetic field is maximum when the flow of electrons being moved between the dipole elements is greatest. It is zero when the electric field is at its maximum.

Energy in the collapsing electric field builds up energy in the increasing magnetic field, then the magnetic field collapses and the energy is transferred back to the electric field. Energy continues to be repeatedly exchanged between the two fields – we have two oscillatory fields, oscillating at the frequency of the transmitter. The energy to maintain the oscillating fields comes from the transmitter and its battery. The battery provides a direct-current. The transmitter converts this into a 433.92 MHz alternating-current. The transmitter signal is sinusoidal, it is a sine-wave.
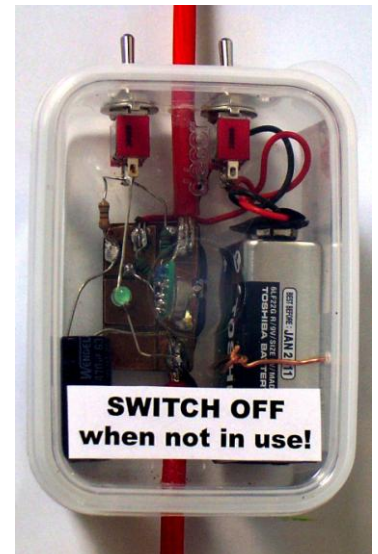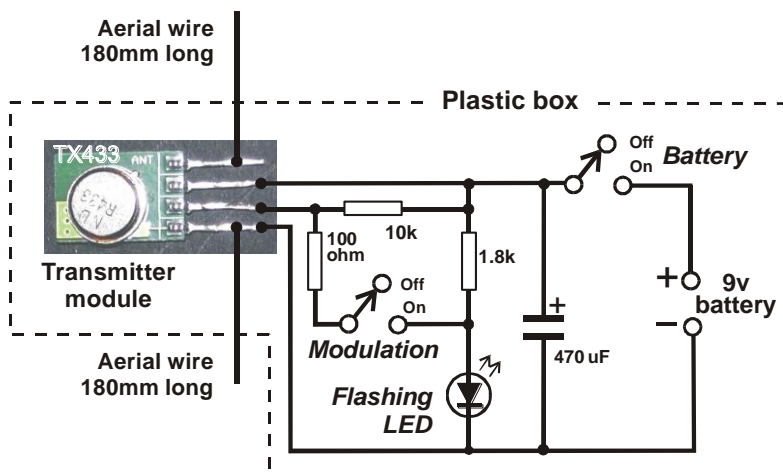
This electric and magnetic field around the dipole is very complex and is known as the "near field" or the "induction field". It extends only a short distance out from the dipole and its intensity drops off very fast as we move away. If we double the distance away, the field intensity drops down to one-quarter. A wavelength or so from the dipole the induction field has all but disappeared. So where does the energy go and how does a radio wave appear?
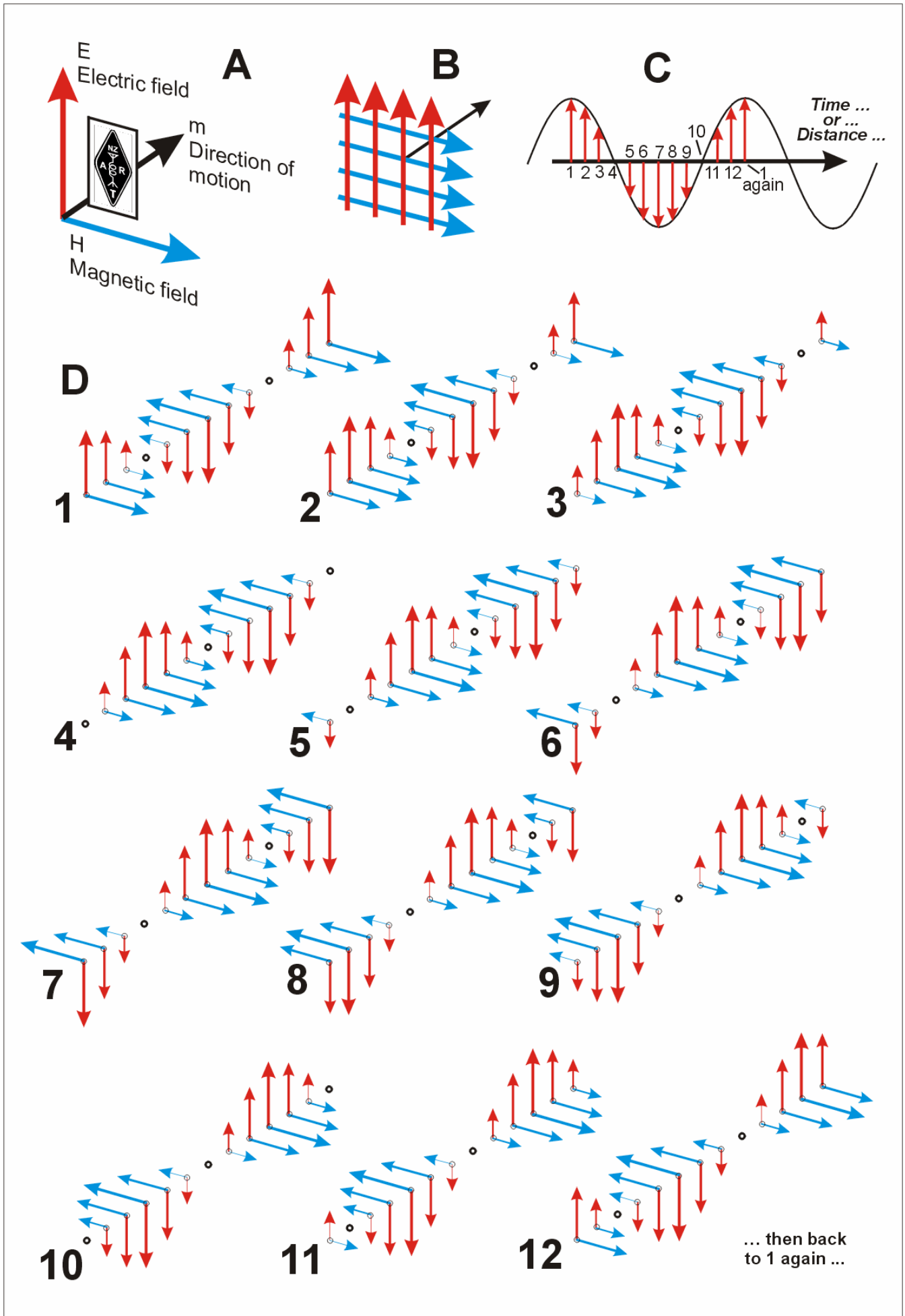
In the late-1860's, James Clerk Maxwell in England, theorised that electric and magnetic fields could detach themselves from wires and go free in the form of waves. He published a set of four partial differential equations in 1873, now known as "Maxwell's equations", these signified the existence of the electromagnetic wave.

In a corner of his laboratory in Berlin in 1888, Dr Heinrich Hertz generated and detected these waves and confirmed that their velocity was the same as the velocity of light. Hertz referred to them as "Maxwell's waves" but they are now more generally known as "Hertzian waves". With our simple modern-day apparatus, we too can generate and detect these waves.

It is recorded that a student asked Hertz about any possible use for these waves and Hertz is reputed to have said: *"I do not think that the wireless waves I have discovered will have any practical application"*.

Further out from the "**near field**" is what is known as the "**far field"**. In the far field, the energy of the field has settled down to what is known as a "**transverse electromagnetic wave**" or "electromagnetic wave" for short. This is the "radio wave" as we will come to know it.

4

E
Electric field
A
m
Direction of motion

B

C
Time ...
or ...
Distance ...
10
5 6 7 8 9
1 2 3 4   11 12 1
again

H
Magnetic field

D

1

2

3

4°

5

6

7

8

9

10°

11

12

... then back
to 1 again ...

The transverse electromagnetic wave

Diagram A represents the electromagnetic wave, drawn so we can consider how it behaves. It is drawn to appear to be three-dimensional. Three arrows are shown and they are all mutually perpendicular. The NZART logo is shown here too to make your eye adopt the correct perspective.

This is a vector representation. The electric and the magnetic field strengths are each shown by arrows. The direction of each arrow shows the **direction** of the field at that point. The length of the arrow shows the **strength** of the field. Both fields are at right-angles to one-another.

The direction in which the wave is travelling is also shown. This direction is perpendicular to the plane of the two field vectors. This is a *transverse* wave. The direction of motion of this wave is also the direction of energy propagation.

> *(The vector structure of a wave can be remembered with this **Corkscrew Rule**. Screw a corkscrew in the direction of energy motion. The thumb moves from the Electric to the Magnetic. E is alphabetically before M.)*

Diagram B is to remind us that a wave is not just a single-point event, it covers an area with undefined edges. We use the simple single vector representation in Diagram A just for convenience in explanation.

We must clearly understand that the two fields are continuously changing in intensity. Both fields are changing sinusoidally. They pass through zero together, reach a maximum together, decrease and pass through zero again, reach a maximum in the opposite direction before decreasing again to pass back through zero. The frequency of these changes is set by the transmitted signal source.

Diagram C shows how the amplitude of each vector changes – a sine wave. The numbers refer to the many separate distance diagrams shown in Diagram D.

Diagram D is a collection of three-dimensional representations. In each little diagram, the source of our signal is at the bottom left and the signal moves up to the top right. The field strengths at many points on the way are shown in our vector form and each changes at the frequency of the source.

Put your eyes on the spot at the start of diagram D1. Follow this spot through the diagrams from the maximum in D1, on through zero in D4, to maximum in the other direction in D7, through zero again at D10 and back to diagram D1 – it has gone through a complete cycle. Refer again to Diagram C.

Note that the maxima and the minima of the electric and the magnetic fields at any spot occur at the same time.

The distant end of the wave is shown in each of these diagrams. These diagrams show the same field circumstances at the distant end as shown at the start. For example, in diagrams D4 and also in D10, a complete wavelength of our wave is shown. In D10, the wave has moved forward by half of one wavelength. The energy of the wave is moving forward to the distant end of the diagrams.

Note the sinusoidal outline set out by the tips of the vectors moving in the direction away from the source. These represent changes in the intensity of the outgoing fields. If the wave could be stopped, the half-wavelength of the wave could be measured by measuring the distance between two adjacent points of zero intensity. We can't do it like that, but we will see in our demonstrations how we can measure the wavelength.

The source dipole of our wave is vertical. The E field of the wave is vertical. This wave is described as being "vertically polarised". Polarisation is described by the direction of the electric field.

Neither an electric field nor a magnetic field will go anywhere by itself. Unlike a STATIC field, a *WAVE cannot exist unless it is moving*. Once created, an electromagnetic wave will continue on forever unless it is absorbed by matter.

Maxwell discovered that a CHANGING magnetic field will induce a CHANGING electric field in the surrounding region and vice-versa. The changing fields in this region will, in turn, induce further fields in a still more distant region, and thus the energy continues to propagate on its journey outwards.

These electromagnetic waves require no material medium to support them. They propagate just as well in a completely empty space, in a vacuum, as in the atmosphere.

So we have a dipole launching a wave, a wave that is made up of changing electric and magnetic fields travelling at the speed of light on its way outwards and towards a distant receiver.

Note: There is a moving diagram in colour showing the vector progression of a wave included in the CD-ROM associated with these demonstrations.

The same moving diagram can be downloaded from: http://www.nzart.org.nz/nzart/waves/radiowaves.html

The signal radiates radially outwards from our source dipole and we must now consider how it disperses.

We can consider our source of radio frequency signal as a point source. The true radiated wavefront is then spherical but because we view it at a distance from the source we can regard it as a plane wave. However, due to this spherical spreading, the wave becomes weaker as it travels. The intensity of the electric and magnetic fields of the signal each vary inversely with the distance they travel. Travel twice the distance and each of these has dropped to half.

This "inverse distance law" is related to another law, the "inverse square law" which is a power consideration. The power passing through a spherical surface is the same as that passing through a spherical surface at twice the distance but at twice the distance it is distributed over four times the surface area, so the power-per-unit-of-area there is one-quarter.

When dealing with waves, we usually consider their "strength" or "intensity" as the electric or magnetic field strength, or the voltage induced in an aerial, and with these words we mean their amplitude. Similarly, when we consider two separate waves at a point, we are usually interested in the sum of their amplitudes, the sum of the amplitudes of their electric fields.

A changing electric field **_induces_** an **_adjacent_** changing magnetic field, which in turn **_induces_** another **_adjacent_** changing electric field, then another **_adjacent_** changing magnetic field… We now have a **_transverse electromagnetic wave_**… energy in the **_changing_** electric and magnetic fields moving away … at the speed of light.

Points to note:

A **_CHANGING_** electric field will induce a **_CHANGING_** magnetic field in the surrounding region and vice-versa. The changing fields in the surrounding region will, in turn, induce further fields in a still more distant region, so the energy continues to propagate on its journey outwards.

An **_electromagnetic wave_** cannot exist unless it is moving. Once created, it will continue on forever unless it is absorbed by matter.

Electromagnetic waves require no material medium to support them. They propagate just as well in a completely empty space, in a vacuum, as in the atmosphere.

At the receiver:

A dipole aerial at a receiver can act as the recipient of energy from the wave. A wave arriving at a receiver, an electromagnetic wave passing by a conductor, **_induces_** a current in that conductor.

Our simple diode-type field-strength-meter receiver indicates the electrons being shifted between the two sections of the dipole by the passing wave. It shows the resulting signal from the sum of all the waves present and cannot separate out energy being received from individual waves. It has a current induced in it from all the passing waves. It contains a rectifier which rectifies the resulting signal current to produce a half-wave-rectified direct current which deflects the meter. The meter responds to only the positive-going half-waves of each component signal and this unidirectional current is a relative indication of the intensity of the resulting wave.
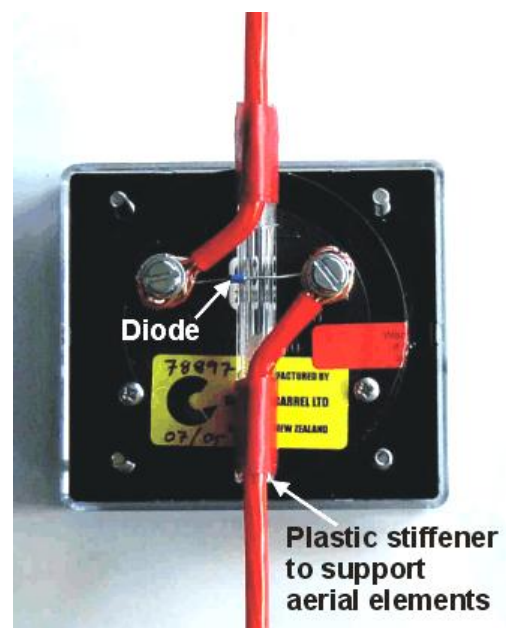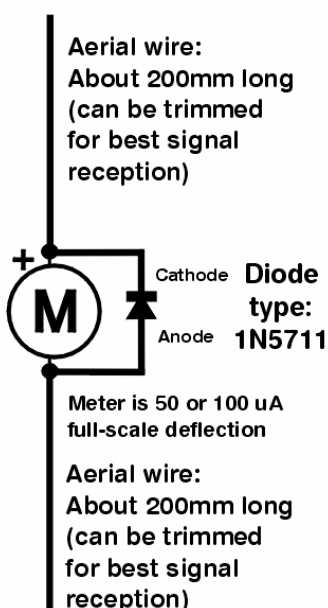
DEMONSTRATION 1

Investigating materials, radio waves and radio noise

Aim:

To investigate the characteristics of different materials to the passage of radio waves,
to consider radio and sound waves, and,
to investigate radio noise.

Apparatus:

*(The two major items used in this demonstration can usually be borrowed! An **AM** receiver is required, FM is not suitable.)*
A battery-driven pocket-size AM broadcast radio receiver.
A battery-driven electric razor or a small battery-driven electric motor.
Some aluminium kitchen foil,
A selection of plastic bags.

Method:

A:

1. Take a battery-driven pocket-size AM broadcast-band radio and tune it to a part of the dial where you hear a loud station.

2. Adjust for very loud audio volume from its loudspeaker.

3. Wrap the receiver in aluminium foil. Kitchen foil is suitable. The complete receiver must be totally enclosed in conductive foil and must be making a loud programme noise when you start wrapping.

Consider:

a. Can you still hear the broadcast program?
b. Explain any residual noise that you hear. *(You may have to hold the wrapped-up receiver close to your ear to listen to the noise through the foil.)*
c. Consider the "signal-to-noise" ratio of this receiver. What should the ideal S:N ratio be?

B:

1. Remove the foil.

2. Repeat this experiment but wrap the receiver in ordinary plastic. (Use a plastic bag.)

3. First use a clear transparent plastic bag.

4. Then use a coloured plastic bag which is not transparent to light.

Consider:

A ***radio wave*** is being received by the receiver and an ***audio signal*** is coming from the loudspeaker:

a. Why does the foil wrapping but not the plastic wrapping affect the radio wave?
b. Why did the coloured plastic block the light but not the radio wave?
c. Why did the sound "get through" all types of wrapping?

C:

1. Switch an electric razor on and bring it near to the working AM radio.
2. Wrap the working razor in aluminium foil and repeat.

Consider:

Compare the "wrapped" and the "unwrapped" razor cases.

a. Useful things can be unknowing generators of interfering and undesirable radio waves!
b. "Shielding" may be possible, but can it be made effective?
c. Why are radio and television aerials often placed on high poles outside buildings?
d. Why is "coaxial cable" often used as the "transmission line" from an aerial to a radio or television set?

_____

DEMONSTRATION 2

Establish and describe a Radio Link

Action

Put the *Transmitter Unit* on its stand on a wooden table near the centre of an uncluttered and spacious room. Keep it clear of large metal objects.

Ask all observers to remain motionless during the demonstration because movement can disturb the field pattern and interfere with results.

Describe the Transmitter Unit – the source of our signal, the generator of our electromagnetic wave (see page 3).

Switch the transmitter ON.

The first observation: there is nothing to observe – the wave (if any) is not visible!

There is need for a means *to detect the presence of*, and *to measure*, the features of the wave.

Switch the transmitter OFF.

Hold the *Receiver Unit* by the case of its meter and with its aerial elements vertical.

Describe the Receiver Unit – note its simplicity – a meter indicates the intensity of the received signal (see page 6).

Now switch the transmitter ON again.

Note that the meter reading changes as you move the receiver near to and away from the transmitter.

Note that the receiver unit does not contain a battery or any other energy source.

Question: How does the energy to deflect the meter get from the transmitter battery to the receiver meter?

Consider the medium in which this wave is travelling (air). The medium plays no part in supporting the wave. The wave can travel in a vacuum!

Question: How far can you move away from the transmitter before you lose any indication of a signal?

Summary

The wave can travel through the air and through a vacuum. It is invisible, we can't see it - but with our receiver we can detect it and we can consider its intensity.

DEMONSTRATION 3

Communication, Remote Control, and the principles of Modulation

Switch the transmitter ON and OFF.

Note that the receiver meter indicates when the transmitter is ON or OFF.

We have a form of elementary communication between this transmitter and the receiver! The receiver meter can indicate when the transmitter switch is ON or OFF.

Switch the "Modulation" switch ON. The flashing LED in the transmitter unit now keys the transmitter on and off for us! Note the effect on the receiver meter.

Questions

Could this remote ON or OFF indication be used for any useful application?

What would be the effect on the receiving meter if the modulator flash-rate were to be increased/decreased?

Could this radio link be used for communication of information?

Make up a table to show how the different received signals relate to the switch positions at the transmitter.

Note that in this simple radio link, there is no certainty that the required transmitter is being received. A transmitted callsign or a coded signal could be used in practice to positively identify the signal source.

Summary

This simple link example is the basis of all radio communication, the "carrier wave". It can be "modulated" in different ways to carry speech, music, data and other information in practical applications.

Different methods can be used to positively identify the signal source.
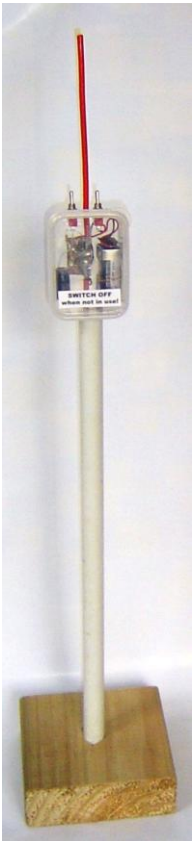
A transmitter on a plastic-tube stand

A receiver on a bamboo stand

DEMONSTRATION 4

The Transmitter Aerial Radiation Pattern

Demonstration

Set the receiver on its stand placed at a suitable distance for a half-scale reading.

First: Carefully rotate the transmitter stand so that the transmitter unit rotates through 360 degrees.

Next: Holding the transmitter unit at its centre, remove it from its stand and carefully rotate it through its vertical axis. Note the signal strength when an end of the aerial points directly at the receiver and again when it is side-on to the receiver.
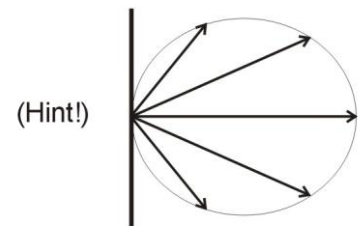
Action

Consider the "polar diagram" of signal strength: plot the meter reading against the angle the aerial makes with a direct line to the receiver. (Receiver meter current in μA plotted against the aerial direction in degrees each side of the maximum signal direction can illustrate the principles.)

(Hint!)

Consider the "solid of revolution" of your diagram and how it represents the direction of radiation from this aerial (revolved around the vertical axis).

Note that in this demonstration we are viewing the radiation from the transmitter, a vertical radiator, in its Horizontal Plane and again in its Vertical Plane.

Return the transmitter unit to its stand and repeat using the receiver unit. Note the deep null when the receiver aerial is "end on" to the transmitter. Could this be used for elementary direction-finding? Stand on a chair and repeat from a different height!

Note too that the field pattern varies at points in the room. (Multiple reflections of the wave within the room space are considered later in these demonstrations.)

Questions

Is the transmitter radiating equally in all directions in its horizontal plane? ("Omni-directional"?).

Are the complete "polar diagrams" for the transmitter and receiver aerials similar?

Summary

This transmitter unit has a simple "dipole" radiator, a classic and basic form of radio aerial. Its "doughnut" radiation pattern should be clearly envisaged.

In practice, other aerial "elements" can be added to make an "array" to increase the radiation in the wanted direction and to reduce it in unwanted directions.

Receiver aerials have the same characteristics and can also be enhanced for reception of the wanted signal from one direction while minimising reception of unwanted signals from other directions.

DEMONSTRATION 5

The concept of Polarisation

Demonstration

Rotate the receiver between vertical and horizontal positions.

(A *second check*: Hold the receiver with its elements vertical and change the transmitter to make its elements horizontal.)

Action

The "polarisation" of a wave – the direction of its electric field – is determined by the launching element (the aerial at the transmitter) – horizontally or vertically positioned.

Note that the received signal reduces to a negligible level when "cross-polarised".

For maximum received signal, the receiver and the transmitter aerial (signal) polarisations should be the same.

Questions

Are the elements of the television aerials on houses in your area "horizontally or vertically polarised"?

Summary

The polarisation of a wave is determined by the direction of its electric field. In our demonstration it is decided by the positioning of the dipole radiator at the signal source. For maximum received signal, the same polarisation is required for the receiver aerial.
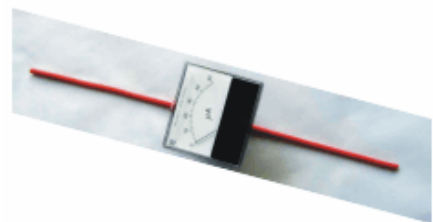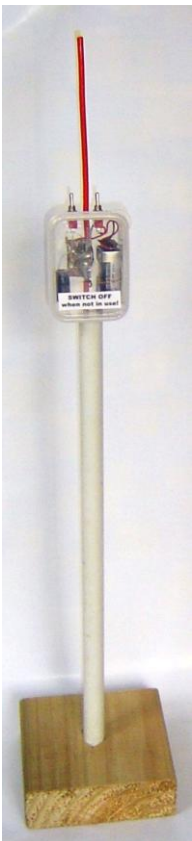
DEMONSTRATION 6

Materials in the path of a wave

Demonstration

Position the receiver on its stand spaced from the transmitter so that the meter is showing a steady reading, and:

> a. SLOWLY bring a ***transparent plastic*** sheet into the path between the receiver and the transmitter. (*The lid of a plastic transit case can be used*).
> b. Then try a ***non-transparent*** plastic sheet (non-transparent to light).
> c. Then SLOWLY bring a ***metal*** sheet into the path between the transmitter and the receiver.

Action

Note that ***non-conducting (insulating)*** materials (e.g. plastic) have negligible effect on the wave.
Note that ***conducting*** materials (metal) produce great changes to the field pattern.

Questions

Did the colouring material in the non-transparent plastic sheet have any effect?
Does the plastic covering on the transmitter and receiver aerial elements have any effect on the wave?

Consider:

The approaching wave ***induces*** an electric current in a ***conducting*** sheet; and because a current in a (perfect) conductor cannot dissipate energy, perhaps that ***induced current*** in turn produces and launches a new wave of its own?

Summary

We now have two waves, an incident wave approaching the conductor and a reflected wave moving away! We have reflection from a metal surface!

A current flow in the conducting surface is a necessary part of the reflection process.
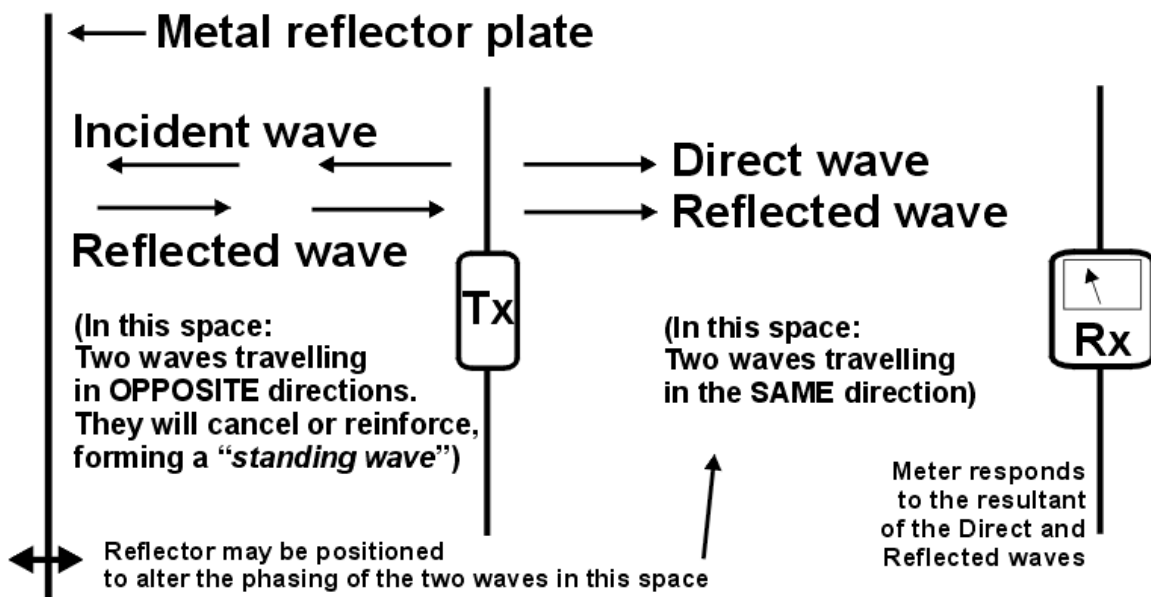
DEMONSTRATION 7

A metal sheet as a reflector

Demonstration

Use a metal sheet as a reflector, first behind the transmitter unit and then behind the receiver unit.

At each place, SLOWLY move it towards and away from the adjacent aerial element and note the increase/decrease in received signal level.

Action

Note that conducting materials can be used to reflect or re-direct a wave to increase its energy in a required direction.

Note that we now have TWO waves:

1. A direct wave from the transmitter to the receiver, and,

2. a reflected wave, from the transmitter to the metal sheet and then on to the receiver.

Note that by moving the position of the metal reflector we can alter the path length of the reflected wave and hence the phase difference between the two waves arriving at the receiver to make them ***reinforce*** or to ***cancel***.

Measurement of wavelength

Start with the sheet reflector close to the transmitter and note the receiver meter reading.

Move the reflector away. Note the position of the reflector at the first "null" (node) in the received signal.

Move the reflector further away and note the position of a second node.

Measure the distance between nodes. What is the wavelength of the signal?

Can you find a third node?

Questions

With the transmitter fitted with a reflector, could the receiver be moved further away from the transmitter and an effective communication link still continue over this increased distance?

Could the receiver also be fitted with its own reflector to further extend the communication distance?

Try it – with a sheet of aluminium foil.

Summary

Radio frequency energy can be redirected by reflectors to increase the energy in the required direction and to minimise it in unwanted directions. Communication distances can be extended using the same transmitter power.

We can measure wavelength by measuring between nodes in a "standing wave" – we measure a half-wavelength (see diagram D on page 4).

DEMONSTRATION 8

A "Polarisation Grating" in the path of a wave

Demonstration

Insert a grating between the transmitter unit and the receiver. Rotate it so the grid wires are at first horizontal and then vertical.

Action

Note the directions of the wires relative to the directions of the aerial elements of both the transmitter unit and the receiver.

The transmitter is radiating a vertically-polarised wave.

Questions

Do vertical wires at the grating pass or "stop" this vertically-polarised wave?

Do horizontal wires at the grating pass or "stop" this vertically-polarised wave?

Is this the result you would have expected? If not, why not?

In which position would the largest *induced currents* flow in the grating wires?

If the wave is "stopped" by the grating, where does it go? Where does its energy go?

Summary

The wave, in passing the grating wires, induces currents in the wires – consider each wire as a "receiver aerial". In one position, maximum induced currents will occur, so the most energy will then be extracted from the wave.

Wire grating
(can be rotated,
wires vertical or
horizontal)
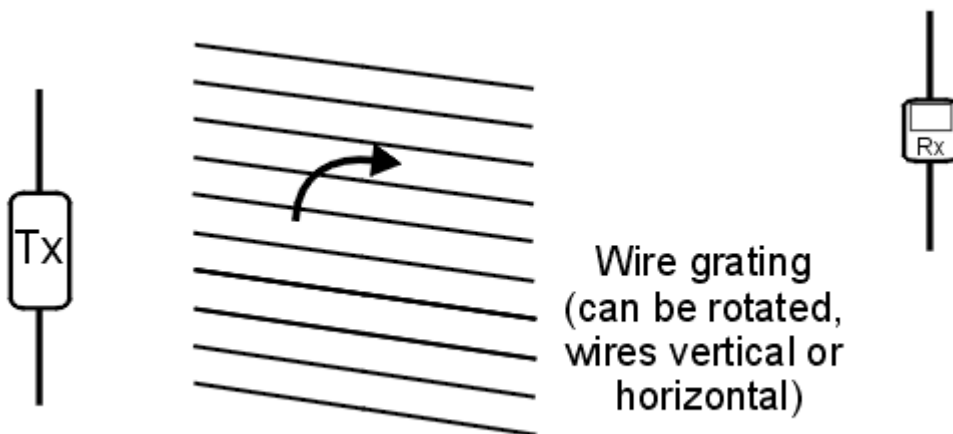
DEMONSTRATION 9

The "Polarisation Grating" as a reflector

Demonstration

As in Demonstration 7, place the grating first behind the transmitter unit and then behind the receiver unit. Rotate it, first vertical then horizontal at each place and adjust its position for maximum received signal.

Action

When positioned to "stop" the wave, note the similarity with Demonstration 7.

Note the practical advantage of gratings in aerial design – a reflector can now be made that uses less material, is cheaper to make and will better survive wind and weather.

Questions

Can a grating be used to identify the "polarisation" of a wave? If so, what could a "simple rule" be for its use?

Have you noticed any TV aerials in your area fitted with a grating as a reflector?

Summary
A grating of parallel wires can be carefully positioned to stop and to reflect a wave.

DEMONSTRATION 10

"Parasitic elements"

Demonstration

Use a single random length of stiff wire to replace the grating. Hold the wire at its centre. Hold it ***behind*** the transmitter at varying distances from the transmitter aerial and rotate it from horizontal to vertical. What happens? Then hold it in ***front*** of the transmitter aerial and repeat.

Action

Repeat, but with a selected length of wire, *shorter* than the transmitter dipole (for in front of the transmitter dipole, known as a ***director***), and *longer* than the transmitter dipole (for behind the transmitter dipole, known as a ***reflector***).

Questions

Attach a director and a reflector to both your transmitter and receiver units. Can you achieve a significant increase in communication distance?

Rotate the whole aerial support and observe the "directivity" of this "array". Can you plot a diagram to illustrate the directivity of each aerial array? (Receiver meter current in µA plotted against the aerial direction in degrees each side of the maximum signal direction can illustrate the principles.)

In a practical TV aerial, why are many directors used but only one reflector?

This design was developed by Shintaro Uda at a university in Tokyo in 1926 and first described in English by Hidetsugu Yagi in 1928. It is known as a "Yagi-Uda" aerial, or "yagi" for short. It is probably the world's most widely-used aerial design.

Summary

Adding "parasitic elements", a reflector and directors, to a dipole, makes an "aerial array". A typical example is the TV receiving aerial seen on house-tops.

The phasing of the waves in the "forward direction" is achieved by adjusting the length and positioning of the parasitic elements.

A "folded dipole" is usually used as the receiving element in a TV aerial. This is to accommodate the wider bandwidth of the TV signal and for improving the level of the received signal passed down the transmission line.
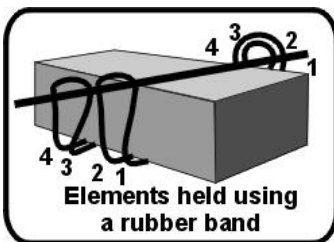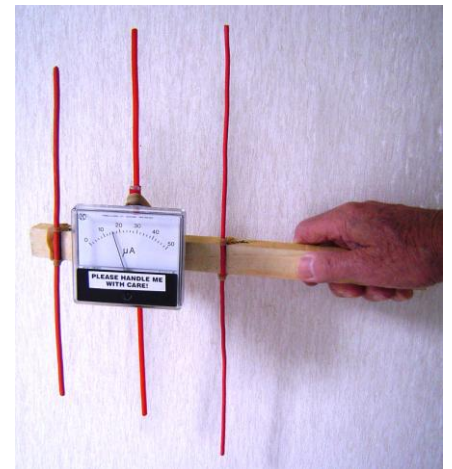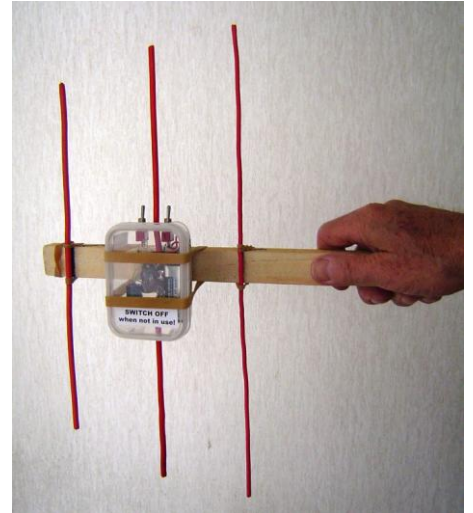
Suggested starting dimensions:

Reflector: 370 mm long, 65 mm behind the radiator.

Director: 290 mm long, 75 mm in front of the radiator.

Appendix 1: The "*Boundary Conditions*"

Our investigations have shown us some basic features of the electromagnetic wave and we can now consider some basic "rules" about what happens when dynamic electric and magnetic fields meet a perfectly conducting surface.

Maxwell's equations lead on to four "boundary conditions". These are sometimes expressed in complicated mathematical language but for ease of understanding, we can use simplified wording of our own:

1. Inside a perfect conductor all electric fields must vanish since inside a perfect conductor no potential can be set up to establish an electric field.

2. An electric field that is tangential to a perfectly conducting surface must vanish at the surface. Surface currents will flow and a reflected wave will be established making this so.

There are two further companion conditions that concern the magnetic field but we need not concern ourselves with them at this time.

Knowing the boundary conditions, we can explain the behaviour of the radio wave where-ever it travels, in a cable and in the many different types of hardware used in communications, in aerials, in waveguides, in the ionosphere, anywhere.

Of course, in practice, conductors are not perfect. The presence of small resistivity in the conductor, however, affects the boundary conditions in only a minor way and is not usually of concern.

_____

Can I build my own test gear?

Why not? There is great satisfaction in developing your own apparatus. These transmitter and receiver units are easy to construct. Much of the apparatus used can be assembled from inexpensive and scrap materials.

The main items you will need to purchase are:

The TX433 transmitter module:

Enter "TX433" into Google. When ordering, ask the supplier to "send it by airmail". This costs a fraction of the other delivery method. Cost delivered to a New Zealand letterbox in about 10 days is around $(NZ)10 to $(NZ)12 each depending on quantity ordered.

Beware of substitutes. Be aware that an 8mW output unit is required. There are some 3mW output units on the market but these produce insufficient signal for these demonstrations.

The 50μA meter:

For classroom demonstration use, an 80mm x 75mm (approx) unit is recommended and preferred. This can be delivered by courier in about 2 days from the manufacturer in Auckland NZ for about $88 in single quantities. Enter "Carrel" into Google and then look further on this site. An email enquiry to the address on the site brings immediate and helpful information.

A smaller (56mm x 50mm approx) meter is available from some of NZ's nation-wide electronics suppliers for about $20. Check their web sites and catalogues. Visibility of the scale is quite limited for demonstration purposes and the other meter is preferred.

Other components:

The 1N5711 diode is available from one of NZ's nation-wide electronics suppliers for about $1 each (check the web site and catalogue). All other components are readily available.

Appendix 2: The Radio Wave: Frequency, wavelength and velocity

Radio waves travel at the speed of light, often expressed as: $c = 3 \times 10^8$ metres per second or 300 000 kilometres per second.

Wavelength, frequency, and the speed of light, are related. The length of a radio wave for a given operating frequency when multiplied by that frequency, gives the speed of light.

The relationship is:

Speed of light = f times λ, (λ = small lambda), where f is the frequency and λ is the wavelength.

Knowing that the speed of light is $c = 3 \times 10^8$ metres per second, and knowing our operating frequency, we can work out the wavelength of a radio wave by transposition:

Wavelength (*in metres*) = 300 *divided by* the frequency *in MHz* (megahertz).

An easy way to remember the value of the constant (300) and the units (metres and MHz) is to remember the example: "10 metres is 30 MHz", (or "30 metres is 10 MHz").

Measurements:

A useful and fundamental measurement in radio aerial work is the "half wavelength". The half-wavelength of a wave is *half* of the wavelength figure you obtain and we must know how to calculate it! It gives the length of an antenna or dipole for any operating frequency.

So a half-wavelength at 10 metres (30 MHz) will be 5 metres. Pick another frequency and calculate the half-wavelength!

In our experiments:

The radio signal we generate for these radio technology experiments operates at a nominal 433.92 MHz (megahertz, meaning 433.92 million cycles per second).

> (The operating frequency of our TX433 unit as quoted on the data-sheet is 433.92 MHz. In practice, devices have been found to operate at this frequency with some at higher and some at lower frequencies but all are still within the spread of the ISM / SRD band 433.05 to 434.79 MHz.)

The wavelength of our radio signal can be found by dividing 300,000,000 by 433,920,000. The answer is 0.691 metres or 69.1 centimetres. So λ = 69.1cm and $\lambda/2$ = 34.5cm.

This is the wavelength in "free space". The best we can do with our apparatus and a little bit of care, is to measure this in the atmosphere with other objects nearby!

In practice:

A wave travels slower in a transmission line or in an aerial conductor. For various reasons, a practical "half-wave dipole" is slightly shorter than the free-space $\lambda/2$ measurement.

Suggestions to prune the aerial element lengths for a more optimal performance are given in the construction booklets for the transmitter and receiver units. The asymmetrical lengths suggested are to provide for the dielectric which surrounds the lower element when inserted in the pipe of the support stand. You will find that the element lengths for these devices are not critical!

_____

Appendix 3: How it all started: – Some of "The Greats" of science and engineering:

In the mid-1800's, a mathematical physicist, **James Clerk Maxwell,** theorised that electric and magnetic fields could detach themselves from wires and go free in the form of waves. **Heinrich Hertz** in 1888 generated and detected these waves and confirmed that their velocity was the same as the velocity of light. These two eminent scientists are commemorated with the maxwell being a unit of magnetic flux and the hertz (Hz) being our familiar unit of frequency, one cycle-per-second.

Neither an electric field nor a magnetic field will go anywhere by themselves, but Maxwell discovered that a CHANGING magnetic field will induce a CHANGING electric field and vice-versa.

Maxwell was born on 13 June 1831 in Edinburgh, Scotland and died on 5 November 1879 in Cambridge, England. He is remembered by his four "Maxwell's Equations", predicting waves of oscillating electric and magnetic fields that travel through empty space at a speed that he predicted using the data available at the time to be a velocity of 310,740,000 metres-per-second. He reasoned that as light travelled at the same speed, light could also be a wave motion. Maxwell was correct in this conjecture, though he did not live to see its vindication by Heinrich Hertz in 1888.

Unlike a STATIC field, a wave cannot exist unless it is moving. Once created, an electromagnetic wave will continue on forever unless it is absorbed by matter.

Heinrich Hertz, a German physicist (born 1857 and died 1894) applied Maxwell's theories to the production and reception of radio waves. The unit of frequency of a radio wave, one cycle per second, is named the "hertz" in his honour.

In a corner of his physics classroom in Berlin in 1888, Hertz generated electric waves by the oscillatory discharge of a capacitor through a spark gap. He detected the waves with a small loop and a spark gap. Hertz's "capacitor" was a pair of metal rods, placed end to end with a small gap for a spark between them. This acted as a short dipole aerial with extra capacitance at the ends to give more energy and lower the frequency of oscillation. When these rods were given electrical charges strong enough to make a spark, the current would oscillate back and forth across the gap and along the rods. The transmitted wave was detected in the receiving loop when the wave induced enough voltage across the gap to produce a spark.

With this signal source, Hertz showed what Maxwell had earlier theorised, how to make the electric and magnetic fields detach themselves from wires and go free as Maxwell's waves and that the velocity of radio waves was equal

to the velocity of light. Hertz showed in his experiments that these signals possessed all of the properties of the electromagnetic waves as predicted by Maxwell.

In speaking to a student, Hertz is reputed to have said: "*I do not think that the wireless waves I have discovered will have any practical application*".

Michael Faraday was an apprentice book-binder who read the scientific works he was handling and this interest led to work at the Royal Institution where he became one of the "greats" of science. He was born on 22 Sept 1791 in Newington Butts, London, and died on 25 Aug 1867 in Hampton Court, Middlesex, England.

He discovered that any change in the magnetic environment of a coil of wire will cause a voltage (emf) to be "induced" in the coil. The change could be produced by changing the magnetic field strength, by moving a magnet toward or away from the coil, by moving the coil into or out of the magnetic field, or by other means such as by rotating the coil relative to the magnet.

This discovery was to change the world, as it allows for electrical energy to be created from kinetic energy.
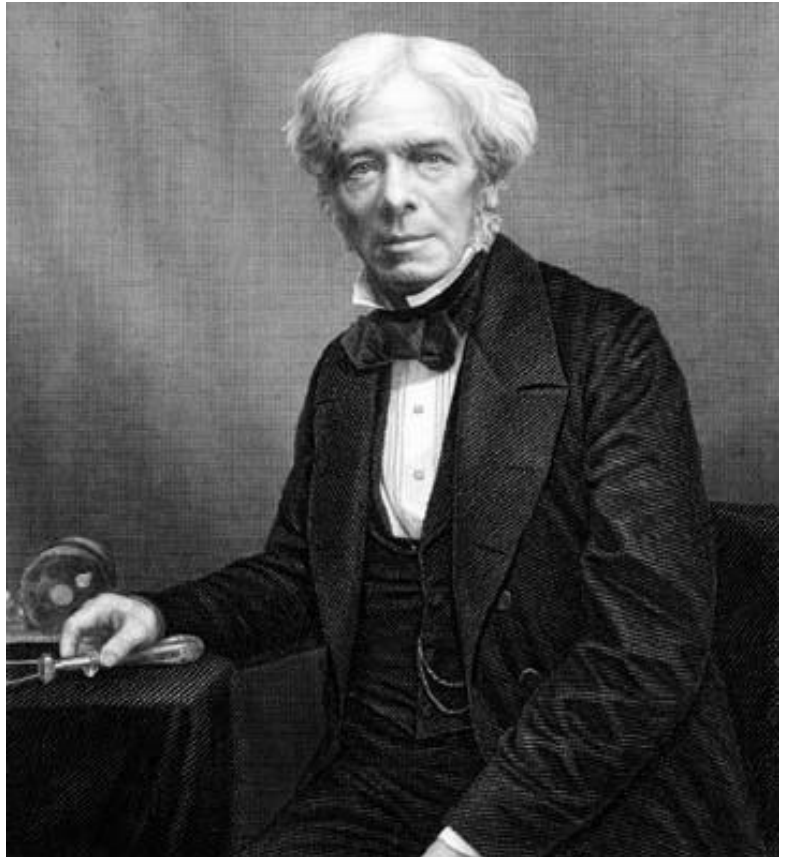
Ernest Rutherford was born on August 30, 1871, in Nelson, New Zealand. He died in Cambridge England on October 19, 1937. His ashes were buried in the nave of Westminster Abbey, just west of Sir Isaac Newton's tomb and by that of Lord Kelvin. His picture appears on the New Zealand $100 note.

The first radio-frequency research in New Zealand was carried out by Ernest Rutherford at Canterbury University College in Christchurch in 1894, using a Hertzian (spark gap) oscillator (see web links following) as an energy source for his study on the transient and high-frequency magnetisation of iron wires. He measured the wavelength of the oscillations with Lecher lines and used frequencies up to 500 MHz. For the transient studies he used mechanically generated 10 ms pulses.

Although Rutherford used radio-frequency waves and developed a very sensitive detector for the waves (later used by Marconi), there is no evidence that he investigated the propagation of electromagnetic waves beyond the laboratory bench in his New Zealand research.

In 1895 Rutherford arrived at the Cavendish Laboratory in Cambridge, England, on an 1851 Exhibition Scholarship to become the University's first research student for the new Cambridge BA degree by research, available to non-Cambridge graduates. Initially he expanded his previous studies in electromagnetic waves by investigating their propagation. By Christmas 1895 he could detect waves through three walls and two floors of the Cavendish Laboratory. Late in 1896 he was able to detect the radio waves over a distance of three quarters of a mile but by then he was already working with Thomson on X-rays and radio-activity and soon discontinued his work on radio propagation.

Rutherford retained an interest in radio propagation during the rest of his career in nuclear physics, including support for research being done in New Zealand and his ready acceptance of New Zealand students to work in the Cavendish Laboratory on radio research as well as nuclear research. He supported Edward Appleton's work on radio wave propagation in the ionosphere and also organised many meetings on radio science in Britain. Before his death he had visited the secret laboratory at Bawdsey where Robert Watson-Watt was directing the development of the radar system which became so important in World War 2.

Rutherford was knighted in 1914; he was appointed to the Order of Merit in 1925, and in 1931 he was created First Baron Rutherford of Nelson, New Zealand and Cambridge. He was elected Fellow of the Royal Society in 1903 and was its President from 1925 to 1930. He received many honours.

Guglielmo Marconi, was born near Bologna, Italy, on 25 April 1874, the second son of Giuseppe Marconi, an Italian landowner and his Irish wife. He died at Rome on 20 July 1937. He was an electrical engineer.

As a boy Marconi took a keen interest in physical and electrical science and studied the works of Maxwell, Hertz, and others. He began laboratory experiments in 1895 at his father's country estate where he succeeded in sending wireless signals over a distance of one and a half miles.

Although many scientists and inventors contributed to the invention of wireless telegraphy, Marconi's practical system achieved widespread use, so he is often credited as the "father of radio".

He took his apparatus to England in 1896 and was introduced to the Engineer-in-Chief of the Post Office. Later that year he was granted the world's first patent for a system of wireless telegraphy, "*Improvements in transmitting electrical impulses and signals and in apparatus there-for*". He demonstrated his system successfully in London, on Salisbury Plain and across the Bristol Channel.

In July 1897 he formed The Wireless Telegraph & Signal Company Limited (later re-named Marconi's Wireless Telegraph Company Limited) and gave a demonstration to the Italian Government at Spezia where signals were sent over twelve miles. In 1899 he established wireless communication between France and England across the English Channel. He erected permanent wireless stations at The Needles, Isle of Wight, at Bournemouth and later at the Haven Hotel, Poole, Dorset. He opened the World's first "wireless" factory in Hall Street, Chelmsford, England in 1898, employing some 50 people.

On 12 December 1901, determined to prove that wireless waves were not affected by the curvature of the Earth, Marconi used his system for transmitting the first wireless signals across the Atlantic between Poldhu, Cornwall, and St. John's, Newfoundland, a distance of 2100 miles. This was surprising at the time as it was thought that a radio signal could only be transmitted line-of-sight. The message received was three dots, Morse code for the letter *S*.

In 1920 Marconi's Chelmsford factory was the location of the first officially publicised sound broadcasts in the UK, one of them featuring Dame Nellie Melba. In 1922 the World's first *regular* wireless broadcasts for entertainment commenced from the Marconi Research Centre at Writtle near Chelmsford.

Our experiments

The items we construct here and use in our own experiments are modern-day equivalents of those used by Hertz and Rutherford. The experiments we perform show us too the nature and the properties of these unseen electromagnetic waves.

The equipment we can use today is much more effective than that available to them.

What new discovery will you be making in a corner of the place you use as your laboratory?

For more details of these and other scientists and engineers, see these and other web pages:

http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Maxwell.html

http://www.sparkmuseum.com/BOOK_HERTZ.HTM **(the equipment used by Hertz is discussed here)**

http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Faraday.html

http://www.rutherford.org.nz/

http://nobelprize.org/physics/laureates/1909/marconi-bio.html

_____

Appendix 4: Radio Wave Highlights

1. Some materials are transparent to radio waves. Conducting material can act as a shield.

2. A sound wave requires a medium such as air to support it, it exhibits longitudinal compression and rarefaction in a supporting medium. The medium is of little significance to a radio wave.

3. Interfering radio noise is very easily generated, but conductive shielding may be useful to keep unwanted noise from the wanted signal.

4. The ratio "signal-to-noise" (internally-generated noise) is a useful measure for comparing the quality of receiving apparatus.

5. A receiving aerial can be moved away from an electrically-noisy environment and a shielded cable used to deliver the required signal back into that environment, to where we need it.

6. The household electrical supply and the signal from a radio transmitter are similar. Both are alternating currents (AC), but they differ in frequency.

7. The frequency of a signal is measured in Hertz (Hz). One cycle in one second is a 1 Hz signal.

8. Radio frequency signals are generated by electronic means.

9. The radio wave comprises a changing electric field and a changing magnetic field working together.

10. Radio signals are very weak and their "*field strengths*" are usually a quoted electric field strength, measured in units such as *microvolts-per-metre*.

11. The "half-wave dipole" is a fundamental type of radio aerial. In practice it is usually a few per cent shorter than a measured half-wavelength.

12. Energy is usually fed into a transmitting dipole at its centre.

13. The centre is also the point of a dipole is where a transmission line could be connected to take a received signal away for processing in a radio receiver.

14. A dipole can be positioned so it is horizontal or vertical.

15. Energy is stored in the electric field of a dipole and then transfers to the magnetic field then back to the electric field, and it keeps on going. The dipole is "at resonance". The signal source at its centre provides the energy to keep the signal going.

16. This field around the dipole is known as the "near field" or the "induction field". It extends only a short distance out from the dipole and its intensity drops off very fast as we move away.

17. The field in the immediate vicinity of the dipole is very complex, called the "**near field**". Further out we have the "**far field**". In the far field, the energy of the field has settled down to what is known as a "**transverse electromagnetic wave**".

18. The electric and magnetic field strengths of a wave change in intensity. Both fields are changing sinusoidally. They pass through zero together, reach a maximum together, decrease and pass through zero again, reach a maximum in the opposite direction before decreasing again to pass back through zero. The frequency of these changes is set by the signal source.

19. James Clerk Maxwell and Heinrich Hertz were pioneers in radio wave investigations.

20. Neither an electric field nor a magnetic field will go anywhere by itself. Maxwell discovered that a CHANGING magnetic field will induce a CHANGING electric field in the surrounding region and vice-versa. A WAVE cannot exist unless it is moving.

21. Once created, an electromagnetic wave will continue on forever unless it is absorbed by matter. The changing fields in this surrounding region will, in turn, induce further fields in a still more distant region, and thus the energy continues to propagate on its journey outwards.

22. These electromagnetic waves require no material medium to support them. They propagate just as well in a completely empty space, in a vacuum, as in the atmosphere.

23. A wave arriving at a conductor, will induce a current in that conductor. So a dipole launches a wave, a wave that is made up of changing electric and magnetic fields travelling at the speed of light on its way outwards and towards a distant receiver.

24. A wave is not just a single-point event, it covers an area with undefined edges. As the signal radiates outwards from our source dipole, it disperses.

25. Our source of radio frequency signal can be considered as a point source. The moving wavefront is spherical but because we view it at a distance from the source we can regard it as a plane wave. Due to this spherical spreading, the wave becomes weaker as it travels.

26. The intensity of the electric and magnetic fields of the signal each vary inversely with the distance they travel. Travel twice the distance and each of these has dropped to half. This is an "inverse distance law".

27. The "inverse square law" is a power consideration. The power passing through the spherical surface at twice the distance is distributed over four times the surface area, so the power-per-unit-of-area is one-quarter while the electric and magnetic field intensities have each dropped to half.

28. We usually consider the "strength" or "intensity" of radio waves as the electric or magnetic field strength, or the voltage induced in an aerial. We mean their amplitude. With two or more separate waves at a point, such as a direct and a reflected wave, we are usually interested in the sum of their amplitudes, generally the sum of the amplitudes of their electric fields.

29. In the horizontal plane through its centre, a vertical dipole radiates energy equally in all directions.

30. In a vertical dipole the electric field of the wave is vertical. This wave is described as being "vertically polarised". Polarisation is described by the direction of the electric field.

31. Our simple diode-type field-strength meter receiver cannot separate out individual waves. It shows the resulting signal from the sum of all the waves present. It has a current induced in it from each of the passing waves. It contains a rectifier which rectifies the resulting signal current to produce a half-wave-rectified direct current which deflects the meter. The meter responds to only the positive-going half-waves of each component signal and this unidirectional current is a relative indication of the intensity of the resulting wave.

32. Two waves of the same frequency but travelling in opposite directions in the same space give rise to "*standing waves*".

33. The distance between adjacent nodes of a standing wave is an indication of the half-wavelength of the component waves. This measured distance is different in free space and in a transmission line (known as the "velocity factor").

34. In a radio system, a reflected wave will have travelled a longer path than the direct wave. This longer path causes a phase-difference between the direct and the reflected waves at the receiver. The two waves may add (reinforce) or they may subtract or cancel. A receiver treats all signals it receives as one resulting wave. Multiple-path radio signals can produce unexpected and bothersome "dead spots" in mobile radio coverage. When out of direct line-of-sight with its base, a mobile station has only reflected waves for communication.

35. In a simple directional aerial, by adjusting the distance between a radiator and a reflector, we can vary the relative positioning of the reflected wave and the original direct wave. Different element lengths and spacings can produce a reinforced forward signal or cause cancellation of the forward signal.

36. A problem with field-strength pattern measurements is the problem of multiple reflections. Reflections from other objects in the proximity can cause confusing results. People moving about can cause changes in the energy distribution and reflections from metal furniture, metal window frames and such-like can mask the real pattern.

37. One of the "*Boundary Conditions*" arising from Maxwell's Equations is that: "*inside a perfect conductor an electric field must vanish because a potential gradient cannot be set up to establish an electric field*".

38. Another "*Boundary Condition*" can be expressed simply as: "*An electric field that is tangential to a perfectly conducting boundary must vanish at the boundary*".

39. This rule enables us to predict the action of a wave when it reaches a conducting surface. The arriving wave induces a current in the conductor and that changing current establishes a reflected wave phased in such a way that the electric field parallel to the surface at the surface is always zero.

40. In brief, the energy of the incident wave arrives at the reflector and finds it has nowhere to go. If the reflector is a perfect conductor, the energy in the wave cannot be dissipated, so the wave turns around and leaves the surface as the reflected wave, the direction of energy travel having been changed.

41. A "Yagi" aerial uses "parasitic elements". The TV aerial is a common example. The Yagi has a low wind-resistance and is weather-tolerant. It is a fixed-frequency device, usually optimised for operation on one frequency only.

42. The Yagi has a "parasitic" reflector. A length of conductor is positioned close to the radiator. It is within the near-field of the radiator and is "excited" by the radiator. This conductor is physically longer than the radiator. It re-radiates a signal. This re-radiated signal can be adjusted in phase by careful adjustment of the length of the reflector element and by its spacing from the radiator. The objective is to produce another signal that will add to the radiated signal from the radiator in the "forward direction" of this Yagi array and cause reduction of signals in the opposite or the "backward direction".

43. The Yagi has a "parasitic" director. Another parasitic element can be placed "in front" of the radiator. This is called a "director". It is physically shorter than the radiator. Again, the phasing of its re-radiated signal can be adjusted by changing its length and position.

44. The objective is to produce directivity by means of a reinforced signal in the "forward direction" of the Yagi array and cause cancellation or reduction of signals in the "backward direction".

You have followed a radio wave through the stages of generation, propagation and reception!
You have a radio link for the communication of information!

Appendix 5   Important – Please Read:

Disclaimer: The compilers of this document offer these demonstrations and experiments in good faith. Each has been tried and tested. Because further use is outside their supervision and involvement, the compilers and NZART are not responsible for any results or outcome, or for personal safety during the construction and use of any apparatus.

Safety with hand-tools: It is expected that students will receive instruction on the proper use of hand-tools and the need for total personal care with attention to the safety of themselves and of others.

Radio-frequency Safety: The radio wave energy level emitted from the apparatus used in these experiments is extremely low and of short duration and at no time presents a hazard. The data specification sheet for the TX433 module used in the transmitter units here quotes a peak radio frequency (RF) **output** power of 10 mW – i.e. *ten one-thousandths of one watt*.

(The measured dc **input** to a typical TX433 unit is about 17 milliamperes from the 9 volt battery - i.e. a dc input of about 150 mW. For comparison, a small pocket hand-torch presents a measured load of about 350 milliamperes from two 1.5-volt batteries – an input of more than one watt.)

The published self-assessment tables for New Zealand amateur radio equipment and installations (from the NZART web site - to find it search with the keyword: 'self-assessment') show that a 10mW e.r.p. signal is well within accepted safe limits and is not a hazard. See Table 2b on page 8 and other Tables on later pages of this self-assessment document.

For the UK, refer to: http://www.hpa.org.uk/radiation/understand/information_sheets/amateur_radio.htm to obtain similar information from the Health Protection Agency.

Laboratory practices: The radio frequency transmitting apparatus described here takes its energy from batteries. Mains power is not involved. The batteries should have long lifetimes in normal use. The **OFF** position of all switches should be clearly marked. Sticky labels should be attached to all battery-driven items with the message:

<div align="center">

BATTERY! SWITCH OFF WHEN NOT IN USE!

</div>

Radio Regulatory: As "*Short Range Devices*", a special radio licence for the demonstrations and experiments described here is not required. The operating frequency of our TX433 unit as quoted on the data-sheet is 433.92 MHz. In practice, devices have been found to operate at this frequency with some at higher frequencies but all still within the ISM / SRD band 433.05 to 434.79 MHz. Please note that the transmission of voice or music on this band is not permitted.

The frequency in use is shared with other users and your transmissions should be kept to a minimum with long transmissions avoided. "**Switch off when not in use"** is important for reasons other than battery-saving. If interference is reported, close down to investigate and perhaps move to another site or pick another time. Other users' interests are to prevail. Short Range Devices generally cannot interfere with nor claim protection from other services.

The radio-frequency generator described here is covered by the New Zealand *Radiocommunications Regulations (General User Radio Licence for Short Range Devices).* It can be found at: http://www.rsm.govt.nz

In the UK, search for: *UK Radio Interface Requirement 2030 Short Range Devices* from: http://www.ofcom.org.uk/ and the following from the appropriate European web sites: *ECC DEC(04)02*; *EN 300 220* and *CEPT/ERC Rec 70-03*.

Feedback: This CD-ROM material has been written and compiled by volunteers. Please provide written comments for consideration so that later editions can reflect any suggestions and ideas that you may develop during your experiences. Your assistance will be sincerely appreciated.

Further information: *The New Zealand Association of Radio Transmitters Incorporated* is the New Zealand radio amateur's society. **Enquiries are welcome**. Further assistance can be provided on radio topics. NZART has Branches in all main centres with members keen to assist with radio communications demonstrations of all kinds.

NZART provides radio training publications and training assistance for anyone who would like to proceed to the New Zealand Amateur Radio Examination and obtain an amateur radio licence and to experience the **W**onderful **W**orld of **W**ireless. Many of these items are free. The examination syllabus and the full question-bank are in the public-domain and can be downloaded from the NZART website. Examinations are computer-generated and conducted by volunteer supervisors at mutually convenient times and places.

NZART Headquarters: PO Box 40 525 Upper Hutt, New Zealand, Phone: +64 4 528 2170.
Fax: +64 4 528 2173.   nzart@nzart.org.nz   www.nzart.org.nz and   www.nzart.org.nz/nzart

Copyright: This CD-ROM and its collection of documents are Copyright © 2007, The New Zealand Association of Radio Transmitters Incorporated.

Further reproduction: These documents and the CD may be further reproduced for training purposes. Permission is given for this CD and these documents to be freely copied for classroom and for individual training use in quantities for that purpose. This permission is for non-commercial purposes and not for on-selling. Commercial enquiries to NZART.

_____

Appendix 6: Our Equipment

All the items needed for our radio wave demonstrations and experiments can be contained in one convenient transit box. Here is one typical collection!
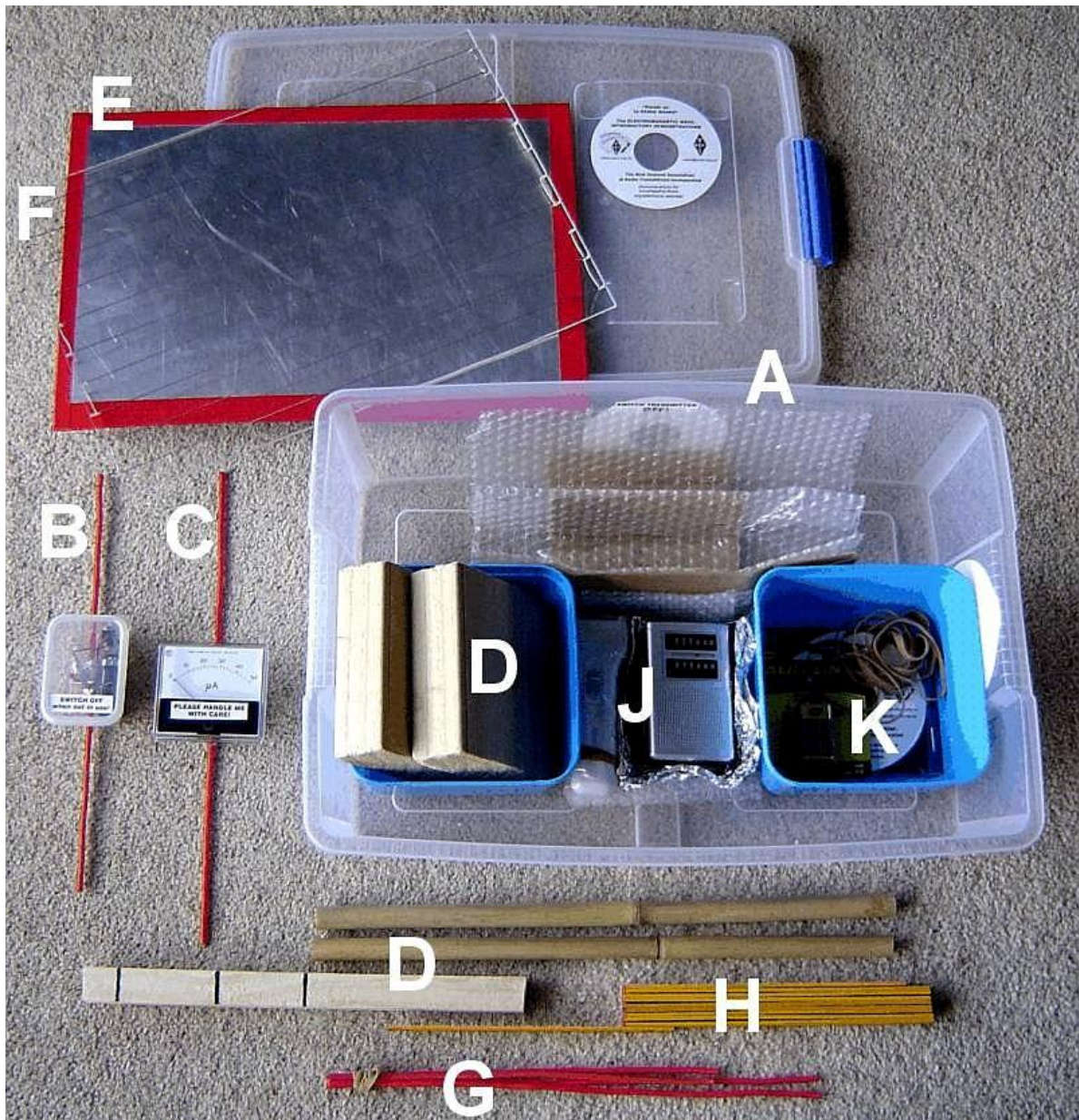
A	Plastic storage container with lid
B	Transmitter unit
C	Receiver unit
D	Transmitter and receiver support stands
E	Reflector plate
F	Polarisation grating
G	Parts for assembling Yagi aerials (see picture on page 16)
H	Metric measuring rule
J	Radio and aluminium foil for 'Demonstration 1'
K	Rubber bands, spare batteries