The science of model flying: Aerials

When we switch on our transmitters we unleash energy that was identified and studied by some of the cleverest people ever. I will tell you about the most remarkable, but the list could be very much longer. Very. My choices are Isaac Newton, Thomas Young, Michael Faraday, Charles-Augustin de Coulomb, Johann Gauss, Chandra Bose, James Clerk Maxwell, André-Marie Ampère and Heinrich Hertz. In our field I would vote for Maxwell or Bose as the most important from that list. What is remarkable is how long ago the foundations were laid and how young many of the workers were when they died. As usual I have included brief word sketches of the scientists. Puzzle corner: whose mother was called Peppercorn?

We fill the space around us with waves that travel away at great speed and are absorbed by the people nearby, the ground, trees and plants, buildings, the air and hopefully one or more aerial wires in our models. This article will try to explain the science behind it and the people involved. So it is about waves and why they are important to aeromodellers. I make no apology for using the English name for aerials. Aerial has the sense of an aetherial something going somewhere or ‘girdling the earth’ to quote The Tempest. Elsewhere they are called antennae, which conjures up insects for me.

At its simplest an aerial is a piece of wire. It might be a hundred metres long or shorter than a centimetre. It is connected at one end to an electrical device – a transmitter - that sends energy up it by applying alternating voltages. The voltages and the resulting currents, produce electric and magnetic field waves that spread out from the aerial at the speed of light. Some reach an aerial in our receiver and allow us to control our models. The waves carry the information about what we want our servos and motors to do, called modulation.

Of course it isn’t that simple. Using a feedwire, the aerial has to be connected to the transmitter circuit that creates the voltages. How we connect the feedwire has a big effect on the power the aerial can send out.

Thought experiment

Imagine a river. The water flows steadily pulled by gravity. If the width of the river is constant the water will flow smoothly. Suppose the river suddenly narrows perhaps due to a bridge arch. The water that cannot flow directly through the arch will be pushed back upstream and some energy will be lost. A turbine well upstream of the arch will generate maximum power. Below the arch the power will be less depending on how narrow the arch is. How rough the water is where it has been reversed is a guide to how much of it is reflected.

At one time I taught Physics in secondary (high) schools. I was a member of the UK Association For Science Education. I remember many articles and letters from teachers in Africa explaining how they did ‘bucket science’ with little or no money. Their ideas were excellent and I made use of them. You can do a lot of science with everyday objects or even none. I have included seven bucket experiments here for you to try.

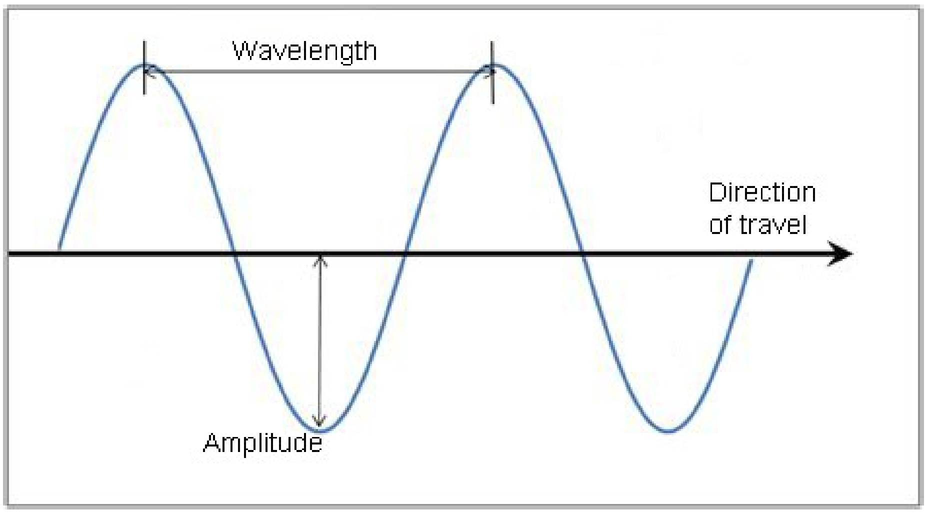
From 1928 to 2001 Scientific American magazine included articles called ‘The Amateur Scientist’ telling you how to carry out home experiments. I particularly remember one describing how to build an ultra-violet laser that carried a hazard warning. In these absurdly litigious days I suppose such things can no longer be published. The articles are still available on compact disk and are well worth a look for children of all ages. I used some of them as holiday projects for my advanced Physics students. The experiments in this article are safe of course (apart from retribution).

What are waves?

Waves are moving energy. They carry the energy from a source to something that absorbs it. For example a moving boat will produce waves in the water that will make a duck bounce up and down or might erode the river bank. Water waves move up and down at right angles to the direction of travel. They are called transverse waves. Most waves are like this. What they travel through is called the medium. Usually this is a solid, liquid or gas. How can a solid carry a wave.? Remember earthquakes. There is another kind of wave where the medium moves backwards and forwards in the direction of travel. These are called longitudinal waves, the most common example being sound waves. After all these are pushed and pulled by a loudspeaker cone.

Light, and other waves like it, travels invisibly through the medium of space. Light – invisible? It’s only when it hits something and makes it glow that we are aware of light. In this article it is these light-type waves, called electromagnetic waves, that we are studying. However I will use other more tangible waves as analogies. We must not forget that an analogy is not the real thing. It is there to help us to visualise something but will have limits to its accuracy.

In picture 1 are the wave shape, dimensions and some words that we will be using. This type of wave is called a sine wave. In picture 1 there are two complete waves. The symbol for wavelength is the Greek letter lambda λ. Another word we must understand is frequency f. This is how many times the wave vibrates each second. It is measured in hertz (Hz), where one hertz is one vibration per second. Waves travel at a certain speed given the symbol v, or c in the case of light.



Picture 1

The quantities are related in the formula:

$v = f\ \lambda$

So, for a given speed, as frequency goes up wavelength goes down. Waves travel at different speeds in different media, or in the case of water at different depths. That is one reason why waves break on the seashore.

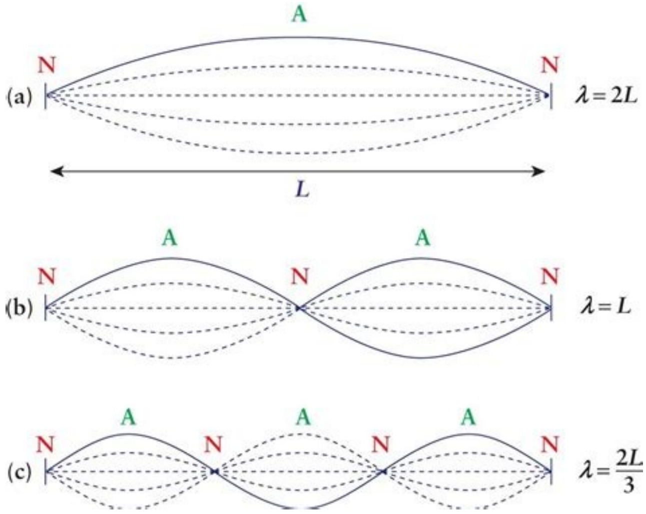
Experiment one

Find a piece of rope. Tie each end to a strong, fixed object. You could use an empty washing line but take care not to break it or revenge will be swift. Waggle one end up and down gradually getting faster. At certain speeds you will see one, two or more loops appear with places where there is no movement. These places are called nodes and the waves are called standing waves. The places of maximum amplitude are called antinodes. The frequencies at which standing waves appear are called resonant frequencies.

Standing waves are the result of the ‘reflected’ waves bouncing back from the far end. They mix with the outgoing ‘forward’ waves. In some places they add together (antinodes), called reinforcement and in other places they subtract, called cancellation (nodes). As you will learn later this is important in setting up up aerials.

Something to note. Once the rope is vibrating it takes little energy to keep it moving. Similarly when pushing someone on a swing only small pushes are needed to keep the amplitude of the swing constant. The message is that something absorbs energy very efficiently if we give it at one of its resonant frequencies.

The rope can resonate at several frequencies. The lowest, called the fundamental frequency, is where there is a single loop, which is half the wavelength. In a string instrument the string will also vibrate at two, three, four and higher times the frequencies at the same time. These are called overtones or harmonics. You can see this in picture 2. Wind instruments also have harmonics but strings are simpler to visualise.



Picture 2
From schoolbag.info

A violin has up to twelve overtones. It is the mix of these overtones that gives violins, and other musical instruments, their characteristic sound or ‘timbre’. It’s also the reason a skilled player can make an instrument sound sweeter. In the case of the violin it is by the way he or she bows the strings to give a pleasing mix of overtones, and why hearing someone learning the violin is such a painful experience. If a skilled guitar player touches the centre of a string as he or she twangs it, it vibrates at double the frequency with a strange, aethereal sound of double the frequency, which is an octave higher.

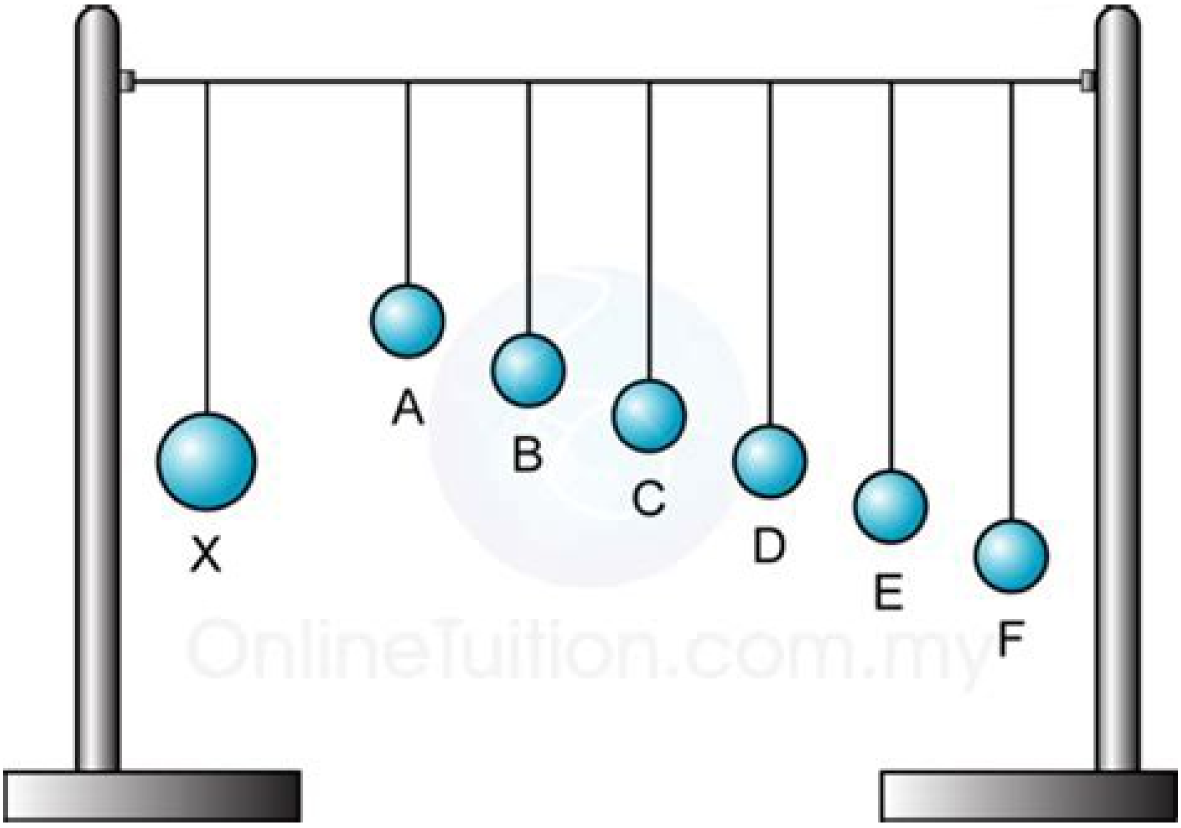
Experiment two

You can also make the water in a bath or tank resonate. Put about 15 cm of water in a bath. At the curved end move your hand backward and forward to push waves down the bath. They bounce back from the square end. Adjust the frequency of the pushes until you start to get standing waves. Take care. They will build up and you could find yourself with wet feet and an angry partner. Perhaps I shouldn’t have said these experiments were safe!

Experiment three

This illustrates how something that resonates at a particular frequency will pick up and appear to amplify a vibration (signal) at that frequency. The kit is shown in Picture 3. How you do it depends on what you have to hand. You need a string stretched fairly tightly between two firm objects and a set of pendulums (A to F) of differing lengths. You don’t have to have six. The weights can be almost anything not too heavy but must all be about the same weight so removing that as a variable. You need another pendulum (X) with a slightly heavier weight on it. Vary the length of that and make it swing. Any other pendulum close in length will start to swing too. The others won’t or not much. If the lengths are exactly the same the transfer of energy will be striking. Vary the length of the input pendulum (transmitter) and see which other pendulum (receiver) moves most. What will happen if a receiver is half or double the length? Try it.

Our radio control receiver is tuned to the frequency of our transmitter. It picks up the signal vibrations extremely well and rejects the rest and the circuit is much better at rejecting other frequencies than our pendulums. This rejection quality is called Q, chosen by its inventor K. S. Johnson of Western Electric not because it is the first letter of quality but because all other letters were already used for something.

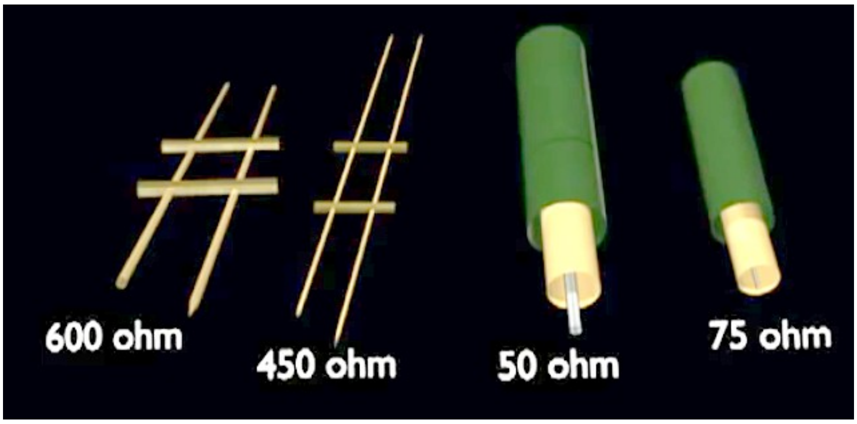


Picture 3
From spmphysicsonlinetuition.com.my

Impedance and Standing Wave Ratio SWR

When a steady voltage is applied to a conductor the current depends on the resistance in the wire. When you put a varying voltage on the wire it is more complicated. The varying current creates a varying magnetic field. Weirdly the field induces a voltage in the wire that opposes the original voltage. This ‘back emf’ reduces the current, so is in effect additional resistance. We call it reactance, but it is still measured in ohms. The more rapidly the current goes up and down the bigger the induced voltage and the higher the reactance. The resistance and reactance added together are called impedance. So impedance in a wire goes up as the frequency of the signal current increases. In some older high quality loudspeakers there is a ‘cross-over’ device that cuts off the higher frequencies from the bass woofer using the reactance of a wire coil. Now it is more often done with circuitry. An item of clothing on the washing line in experiment one is analogous to reactance. Here it is the inertia of the mass – a sort of back force - that reduces the amplitude. Look at overhead power lines. Some have small T-shaped objects hanging from them usually near a tower. These are made of rubber sheets and absorb the vibrations in the wires caused by the wind. These could build up and make the wire oscillate and possibly touch other wires. Near me I have watched a pheasant being fried when standing on one phase wire and being touched by another one waving about wildly in a high wind. Even the phase to phase 440 V is bad news for a bird.

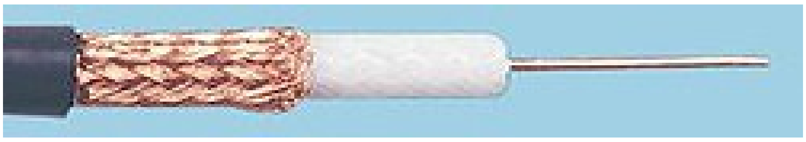
Imagine a wire, called a feedwire, going from the transmitter circuit board to an aerial. The impedance of the co-axial cable used for feedwires is usually 50 or 75 Ω. In our transmitters it is 50. If the impedance of the aerial is the same as that in the feed wire the signal currents will flow with little loss. However if, for example, the impedance of the feedwire is 50 Ω and the aerial is 100 Ω some of the power will be reflected back from where they join, similar to the water hitting the arch. As you saw earlier, when there are two waves travelling in opposite directions, in some places they add and in some they subtract, which as you know is called reinforcement or cancellation. The greater the reflected energy the less energy will go into the aerial. This is called an impedance mismatch.



Picture 4
Picture captured from the youtube video at https://youtu.be/w1eE13UXAKs.

Picture 4 shows old-style open wires used for aerial feeds and the co-axial ones mostly used now, along with typical impedances. Coax varies in quality, particularly the screening around it shown in yellow. It is possible to correct for mismatched connections. You use a transformer device called a balun (**bal**anced to **un**balanced) and normally pronounced bay-lun.

Picture 5 is what a screened television co-axial wire looks like. The outer screen in the best quality wires have a thin sheet of copper rather than braid, but they are more likely to be damaged if bent sharply.



Picture 5
Picture by Peter Scott

The usual test of how well feedwire and aerial are matched is standing wave ratio SWR. You measure the maximum and minimum standing wave amplitudes and divide the first by the second. The best case is that the SWR is 1 where the impedances match. 50 Ω feeding 100 Ω will give a SWR of 2.

In his excellent article titled ‘Understanding SWR by Example’, Darrin Walraven says this: *”The 33 percent reflection from the antenna* [where it joins the feed wire] *alternately adds to and subtracts from the forward voltage wave. At some places on the cable the reflected voltage adds to 133 percent, and others it subtracts to 66 percent of the matched transmitter output. The voltage ratio is 133/66 or 2.0. That voltage ratio defines the SWR.” The link for this article is at the end.*

For us the message is regularly to check the SWR of our transmitter aerial if we can, especially if the aerial might have been damaged. If you can’t measure SWR then the range check gives a guide to efficiency especially if range suddenly drops for all of your models. SWR meters are available for 2.4 GHz but they require the meter to be placed in the feed wire. I suppose that could be done if you change the aerial fitting on your transmitter to an RP-SMA one that allows the aerial to be unscrewed but I have not read anything suggesting that and haven’t tried it. You might remember that I mentioned RP-SMA aerial bases in a previous article or aerial repair.

Here there be dragons. If you read or watch the information put out by radio amateurs (hams) you will discover that aerial matching is in reality much more tricky. It can even involve the use the square root of minus 1, called i or j. We don’t need to go there but if you want to learn more take a look at https://youtu.be/w1eE13UXAKs . It’s an excellent account but note that the speaker uses a presumably Australian pronunciation of co-axial as ‘co-ax-eye-all’, which caught me out at first.

Aerial tuning

When you did the rope experiment you got one or more standing wave loops. A wave goes up to a maximum in one direction, back to zero, then to a maximum in the other direction then back to zero again. The distance from the first node to the third is called wavelength, measured in metres (m). The length of an aerial must be correct for the frequency and wavelength of the signal. For our transmitters the frequency will usually be 2400 or 900 MHz. The corresponding wavelengths in air are 125 and 330 mm. In a metal the wavelengths are roughly two-thirds of these as the signals travel more slowly so the wavelength is less. Some people still use 35 MHz in the UK, giving a wavelength of about 8.6 m. That is why these transmitters have long aerials.

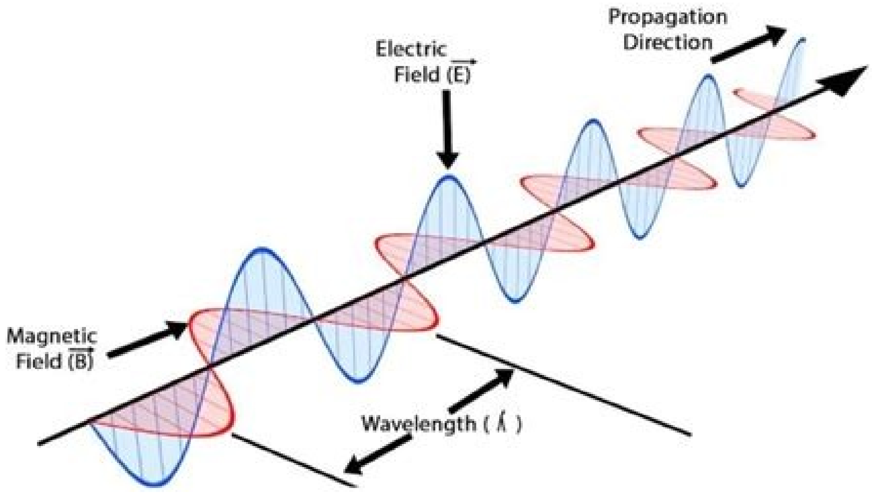
A radio control aerial will effectively be one quarter wavelength. This is because the transmitter circuitry will provide maximum voltage at one end – an antinode – and the far end will be a node. Usually an aerial is made up from two quarter wave parts going in opposite directions. This is called a dipole. You see these in a long television aerial, called a yagi. On such aerials there are other similar size rods parallel to the dipole which also have currents induced in them by the transmitted TV signal. It makes the aerial very directional, which helps to exclude interference from other sources, and they amplify the signal read by the dipole. Some free flight flyers fit their models with location transmitters and use dipole yagi aerials to follow the signal to a lost model and in game reserves tracking of endangered animals is done in the same way. Our transmitter aerials cannot usually be dipoles, though some 900 MHz ones do appear to be.

Experiment four

If your transmitter can display SWR you can try this. Note the number when in normal use. Then grab the aerial with your hand. This will change the impedance of the aerial but not the feedwire. SWR will go up, perhaps as high as 18. Don’t hold it for long as the bounced and wasted energy might harm the transmitter circuitry. Rather confusingly a FrSky transmitter pretends that it measures SWR. Though it measures the same things it does it in a different way that gives perfect transmission the value zero not one. They have now renamed it Relative Antenna Status RAS and you can find it on page seven of Radio Setup on a Taranis X9D.

Electromagnetic waves

When electricity flows up a wire it does two things. The current creates a magnetic field, labelled B in picture 6. The charge/voltage creates an electric field, labelled E in the diagram. These are at right angles to each other and collectively known as electromagnetic waves. They rise and fall exactly in sync, known as being in phase.



Picture 6
From https://brainly.in

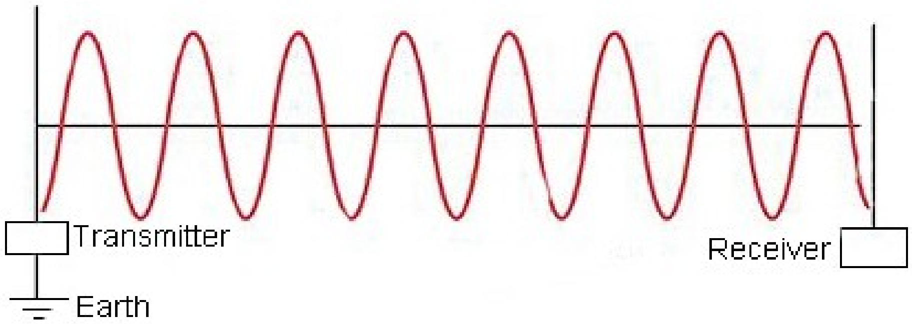
The maths behind electromagnetic waves was finally codified by James Clerk Maxwell's equations. It is not a book for the fainthearted, but if you are mathematically inclined try 'Div, Grad, Curl, and All That' by H. M. Shey.

James Clerk Maxwell (1831 - 1879)
Maxwell was born into a properous Edinburgh family. From the age of three he was one of those children always asking 'why'. Or in his case, ' What's the go o' that?' After an unsuccessful period with a home tutor, he was sent to Edinburgh Academy. Even here he was thought odd but he did not seem to care. He found study at Edinburgh University rather easy and spent a lot of time experimenting there and at home including light polarisation. He used a gelatine block and polarised light to study stress patterns in solids, now done using perspex (plexiglass) sheets. I previously described an article in Scientific American showing how they studied stresses in Chartres Cathedral using perspex shaped the same as the building. After spells at Cambridge, Aberdeen and King's College, London he stayed for a while at Cambridge, where he set up the Cavendish Laboratory and investigated colour and kinetic theory. His greatest achievement was to draw together the work of Faraday, Ampere, Gauss and Coulomb and write a set of equations that described electric and magnetic fields. His ability in maths was proved at Cambridge where he became 'second wrangler' in 1854.
https://en.wikipedia.org/wiki/Senior_Wrangler#Literary_references

Gauss, Faraday, Coulomb and Ampère, are described at the end.

Transmission through space

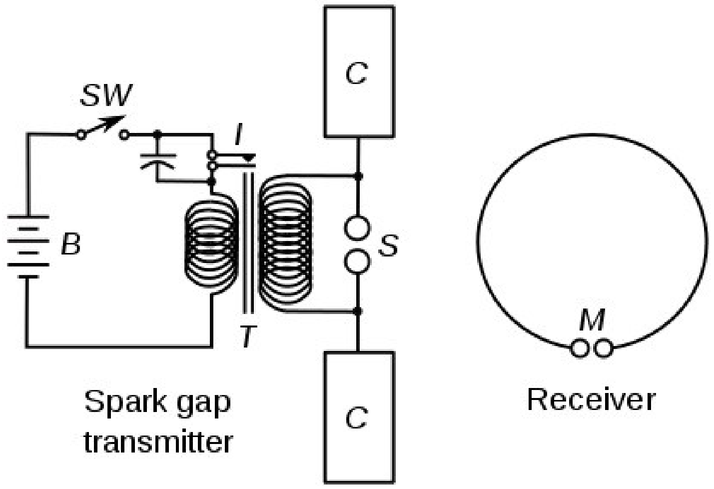
Let's imagine two vertical bits of wire some distance apart. One transmits and the other receives. The transmitter sends out electromagnetic waves like those above – magnetic and electric fields. For simplicity I just show an electric field in picture 7.



Picture 67
The transmitter and receiver aerials must resonate at the same correct frequency. That will depend on their lengths, how they are arranged and the circuit they are connected to. In practice aerial designs in our transmitters are complicated, not just a simple wire, especially when wholly enclosed in the case. The transmitter pushes electrons up and down the aerial, creating the travelling electric field. When it arrives at the receiver this field pushes electrons in an identical way in the aerial wire. The receiver circuitry amplifies and decodes the signal. Some receivers, most notably FrSky ones, will, using telemetry, tell you the strength of the signal received by the receiver. For FrSky it is called Received Signal Strength Indication (RSSI).

Hertzian transmission

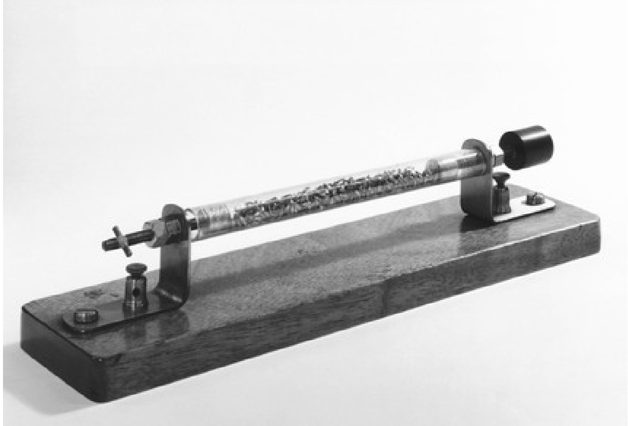
When in 1887 Hertz sent the first radio signals, the transmitter was a huge spark that sent a signal up a wire. The receiver was a metal loop with a gap across which a spark appeared as shown in picture 8.



Picture 8
Picture from http://dingeengoete.blogspot.com

Heinrich Hertz (1857 - 1894)
Hertz's mother had the delightful maiden name of Pfefferkorn. His was a prosperous and upper-class family. He studied science and engineering under illustrious tutors. As professor as Karlsruhe and Bonn Physics Institute he experimented with spark gap transmitters of electromagnetic waves, including refraction and polarisation. He said radio waves were a useless phenomenon but showed that they were transverse waves travelling at the speed of light. He studied meteorology, particularly the effect of moisture in the air and, not directly relevant to us, the photoelectric effect. The SI unit of frequency is named after him.

In 1894 Oliver Lodge, at a memorial lecture about Hertz, demonstrated a detector that was a tube of silver flakes called a coherer, shown in picture 9. When the spark signal was received the flakes clung together forming a circuit that switched on a sound or moved a meter. They were broken apart again by vibration. This sort of radio transmission only gave an on-off signal so could only be used for messages in morse code.



Picture 9
From sslplprints.com

You could build a spark coherer but it would be illegal now as the signal it needed occupied a wide range of the radio spectrum. Men in dark suits and sunglasses would soon be knocking at your door as television pictures collapsed, car engines stopped and garage doors opened and closed all by themselves.

The internationally recognised Indian scientist Chandra Bose designed a mercury'self-recovering coherer' in 1896 that required no vibration. Marconi used a similar design but who was first is uncertain. He also invented a diode signal detector which became commonly known as a cat's whisker.

Sir Jagadish Chandra Bose (1858 – 1937)

Bose was born in Bengali city of Munshiganj, whilst India was under British government. It is now in in Bangladesh. He is less well known than many scientists but he did pioneering work in radio, semiconductors and plant structure and nervous function. Bose's father was a leading civil servant and active member of a branch of Hinduism. He was keen that Bose should know about his native language and culture before moving to English for his studies. After schooling in Calcutta, now Kolkata, he entered the university there graduating in 1879. He studied medicine at London Un iversity but quit because of ill-health possibly due to the body preservation chemicals. He moved to Christ's College Cambridge to study the Natural Sciences Tripos under distinguished scientists including Rayleigh and Dewar and also later graduated from London Universities .

From there he joined the University of Calcutta as a professor of physics. As a protest against the fact that Indians were paid much less than white academic staff he refused a salary for several years until they were equalised. Despite this racial bias and a lack of money he worked on microwave radio waves and was the first to use a semiconductor junction to detect waves. These became known as cats' whiskers. Other inventions included devices we still use such as waveguides, horn aerials, radio lenses and polarisers. His work went up to 60 GHz. The IEEE named him one of the fathers of radio science.

Using sensitive plants such as Mimosa Pudica he investigated the nervous systems of plants and compared their responses to physical stimulae with those of metals. .

In 1917 he founded Bose Institute as Director, a premier research institute of India and one of its oldest. It was the first interdisciplinary research centre in Asia. He remained there until his death. He is not connected with the Bose loudspeaker company.

Early radio control

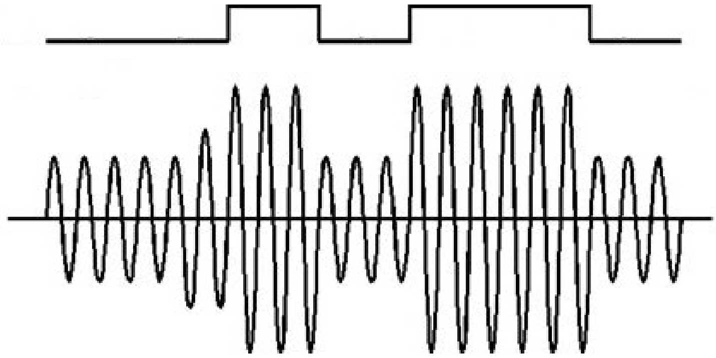
Radio engineers soon learned to send their signals at a particular frequency. They did this by adding tuned circuits rather like the way that instrument strings or pipes store energy at their resonant frequencies. However they were far from perfect so the signal spread over a band of nearby frequencies. As a result only one radio control model could be in the air at the same time. Only when the tuning was sharpened using crystals were six, and then twelve, bands possible on the 27 MHz then used in the UK. Each band was given a colour and flyers clipped a suitable coloured flag on their transmitter aerials. Sensible flyers still avoided using a band next to another already in the air.

Modulation

Connecting a transmitter to a receiver is only the beginning. We now have to send our control signals to the receiver and telemetry data back to the transmitter. The wave that is sent by the transmitter is called a carrier wave. It is this wave that is 2.4 GHz, 900 MHz etc. To send out instructions we must alter the carrier, called modulation. There are several ways of doing this but here are two. You can vary the carrier in its height (amplitude), called amplitude modulation (AM), or frequency, called frequency modulation (FM). For FM the changes in frequency are small to avoid widening the frequency band too much. The disadvantage of AM is that general electrical noise also alters the amplitude at random. You can hear this as background hiss on old AM radios. FM is almost completely immune to this noise.

For radio control the information we need to send is very simple. It is a series of rectangular voltage pulses that vary between 1 ms (millisecond) to 2 ms depending on the position of the control stick, switch or rotary. Each pulse in the series operates one servo, undercarriage or throttle. This is called Pulse Width Modulation (PWM). The carrier flips from one state to another and back again. The time between flips is the length of the servo pulse. This is best shown in diagrams pictures 10 and 11.

Amplitude modulation (AM)

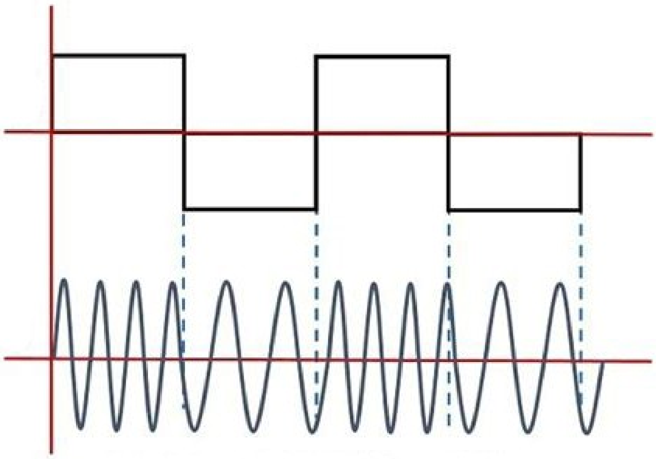


Servo pulses

Modulated carrier

Picture 10
From quora.com

Frequency modulation (FM)



Servo pulses

Modulated carrier

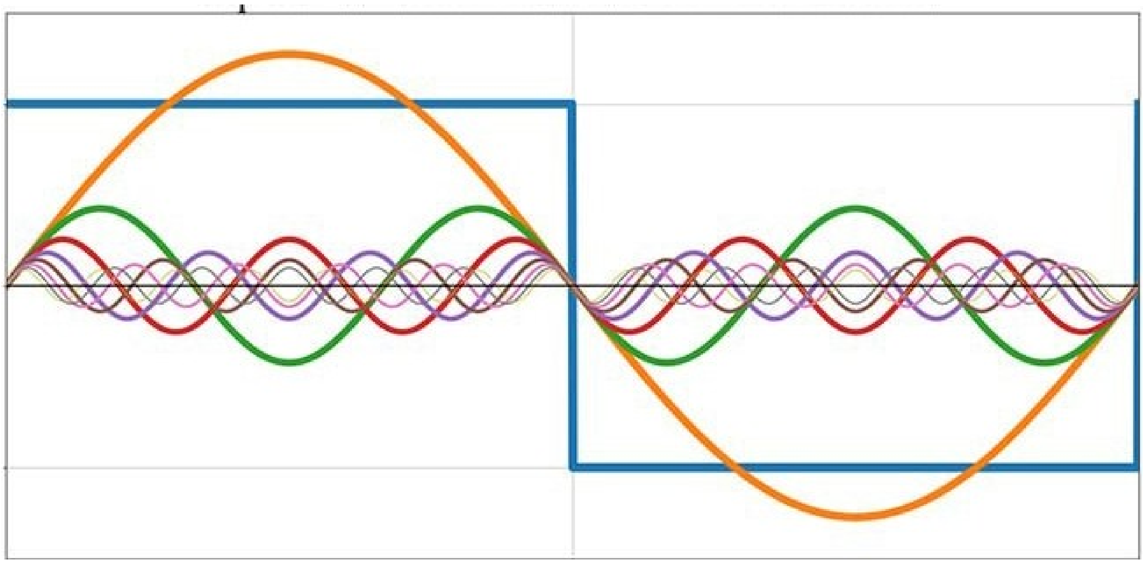
Picture 11
From electronicscoach.com

Experiment five

You can sort of repeat Hertz's experiments. Find a 9 V battery such as a PP3, a metal coin and an old portable AM radio. Hold the battery close to the radio, especially the aerial if it has one. If you then tap the coin across the battery terminals, you hear clicks or other noises from the radio speaker resulting from the tiny sparks The reason it won't work with an FM radio is that the circuitry ignores changes in wave amplitudes, and only responds to frequency changes. This is why there is no background noise.

Rectangular waves and Fourier synthesis

The nearer a wave gets to having right-angled corners the more problems it causes. A mathematician called Joseph Fourier showed that any waveshape can be built up from a series of sine waves of different frequencies and amplitudes. Rectangular waves are built up from the odd harmonics. You can see that intuitively from the diagram picture 12. The waves that add up must rise and fall at the rising and falling edge of the rectangular wave. Only odd harmonics do that. In between the waves average out to make the horizontal line.



Picture 12
From electricalposts.com

To get closer and closer to a right angle you need higher and higher overtone frequencies with steeper leading and trailing edges and for a perfect right angle the series must be infinite. So even a low frequency rectangular wave will include very high frequencies that can cause interference to other equipment. Fortunately the reactance in wires increases with frequency so the highest frequencies are suppressed. The effect is that the corners of rectangular waves are rounded off. You can also use electronic filters that cut off the higher frequencies, again altering the signal shape.

Fourier's idea is used to compress digital sound and picture files using jpeg. The process used is so mind boggling that it is out of place here. My article on the subject is on my website peterscott.website under **Audiovisual.**

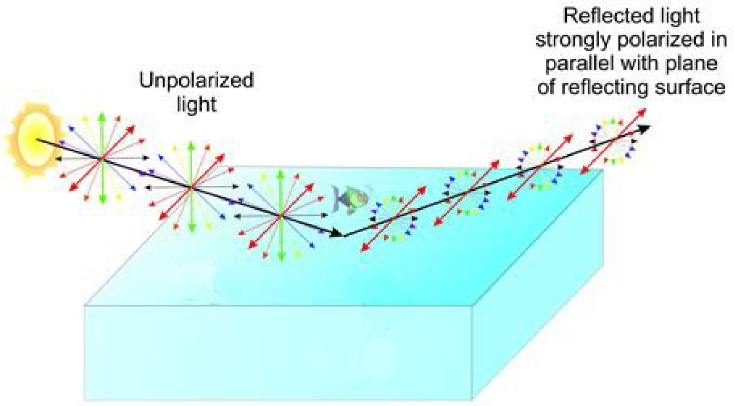
Inverse square law

This was first discovered by Isaac Newton when studying gravity and later confirmed by Coulomb for electric forces. Any energy field spreads out from its source. The area of the sphere over which the energy is spread increases with the square of the distance away from the source ($4\pi r^2$). So the strength of the field goes down with the square of the distance. This is one factor that determines the range of our transmitters. Others will be discussed later, namely polarisation, diffraction and absorption.

Isaac Newton (1642 - 1726)
Newton was a leading worker in many fields. In mathematics he invented calculus. During his self-isolation from the plague in rural Lincolnshire, he connected the fall of objects such as apples near the earth with the motions of planets and the moon by analysing gravitational data and devised his equation. He made advances in the fields of movement, telescopy and colour. Above all he asserted 'satis est', 'it is enough'. If the maths works it is proven. He ran the Royal Mint for some years and tracked down influential counterfeiters, acting as his own private eye. He was religious though unconventially so. In those days science was not disconnected from religion and superstition as it is now, and in his later years he took up alchemy. He was possibly on the autistic spectrum and though he lived long for the time his occasional irrascibility and his death might have been caused by the mercury he absorbed during his chemical experiments. He could be vengeful, especially towards Robert Hook and Gottfried Leibnitz. His name is gven to the SI unit of force the newton, delightfully being the weight of a medium sized apple.

Polarisation

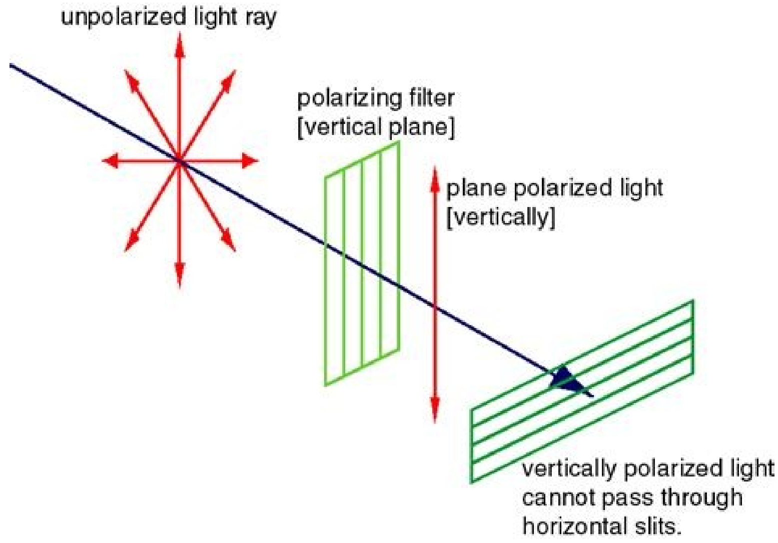
Waves are the movement of a medium. With water and EM waves like light the medium vibrates at right angles to the direction of movement as shown above – transverse waves. When light is produced, for example by the sun, the sideways vibrations are in all directions. We can remove some of these directions by polarisation. For example when light reflects off a surface such as water or a wet road it becomes polarised parallel with the surface as shown in picture 13. The other vibrations are absorbed by the surface.



Picture 13
From https://hackaday.io

Glasses with polarised lenses only allow one polarisation direction through. Vertically polarised lenses block light reflected off water or the road and so reduce glare. You can still see surrounding things lit by the unreflected and unpolarised light.

Experiment six
Find two pairs of polaroid glasses, such as sunglasses. If you only have one pair see if you can pop one lens out replaceably. Look through two lenses, one behind the other, as shown in picture 14. Rotate one lens and you will see the scene getting light and dark.



Picture 14
From www.thestudentroom.co.uk

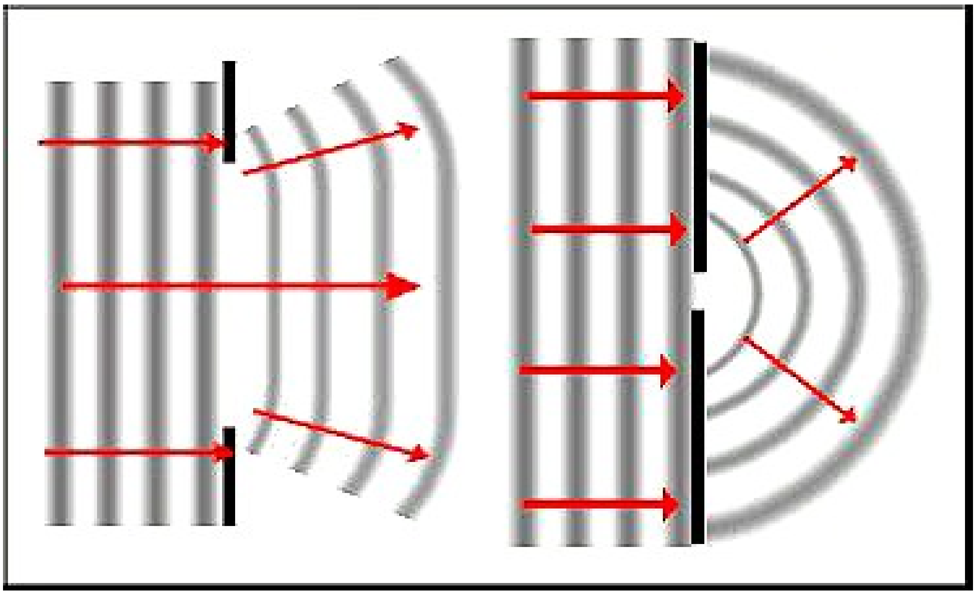
Why polarisation is important for us

Hertz showed that the radiation from our transmitters is polarised. The problem is that our models don’t stay still. A receiver aerial wire will move from vertical to horizontal and in some orientations will get a much lower signal. That is why it is sensible to have two receiver aerial wires orientated differently such as horizontal and vertical or even better to have a second, slave receiver with aerial wires differently arranged from the master.

Diffraction

When I marked Physics public examination papers, diffraction was one thing that students regularly got badly wrong. I could never understand it. I stress humbly that these were not my students. Diffraction is very simple. When a wave goes past the edge of a barrier it spreads out round it. This means there is never a sharp shadow, and why a beam will spread at its edges however sharply focussed it is to start with. I know someone who has his own observatory. He measures the distance to the moon using a red laser bouncing off the half-cube reflectors kindly placed on the moon by NASA. Laser beams don’t diffract and spread as much as normal light but he still has only a tiny amount reflected back to his sensors.

In picture 15 you see how waves bend around edges. A small gap between two barriers behaves like a point source producing near circular waves but of much lower energy as most of the wave energy is absorbed or reflected by the barriers.



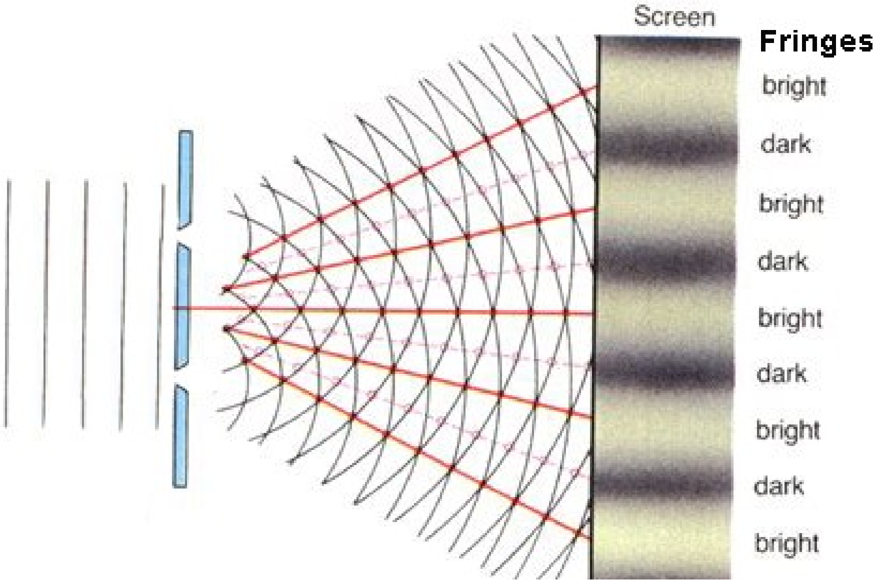
Picture 15
 From www.quora.com

The shorter the wavelength of waves the less they diffract. Suppose you are standing a little way back from the edge on a cliff by the sea. You can still hear the waves. You won’t hear the high frequency hissing sounds but will still hear the deep bass rumbles. It is also why 35 or 900 MHz radio signals are less affected by hills, trees or other barriers as they bend better than 2400 GHz.

Why is this important to us?

It depends on where you fly. If you are likely to fly your model briefly behind a barrier of some sort, like a hill peak or a control tower, the longer wave 900 MHz frequency might be best for you. In open spaces its only advantage is much greater range.

When there are two gaps, or a series of them equally spaced forming a ‘grating’, strange effects happen. Each gap, or slit, produces a pattern of semi-circular waves. They mix and where both amplitudes are high they add together and produce a bright patch, the solid red lines in picture 16. Where a peak meets a trough they cancel, shown by the duller dotted lines. A pattern of bright and dark patches, called fringes, is produced. Waves of shorter wavelength produce fringes that are closer together, which is the subject of the next experiment. Thomas Young was the first to investigate diffraction patterns.



Picture 16
From physics.stackexchange.com

Thomas Young (1773 - 1829)
There was very little that Young did not contribute to. He was described as, ‘The last man who knew everything’, and his work was used by many later scientists. He was born to a prosperous Quaker family, the eldest of ten children. He studied medicine in Britain and Germany and then inherited an estate that gave him a living. For our purposes his work on the wave theory of light is the most important, though his name is attached to Young’s Modulus that predicts how materials change under force and Young-Laplace capillary effects and surface tension. Young asserted that light was waves and demonstrated diffraction and interference. Newton thought that light was particles which caused hilarity until the twentieth century when photons were discovered and it was shown that light could to be either waves or particles depending on how you measured it.

Experiment six
Find a used compact disk. Line it up so light is reflected from a window or an old-fashioned filament lamp. LED lamps won’t work as they don’t produce a full range of colours. You will see rainbows. Why? The burned or pressed data lines form a grating. As explained above, blue light has a shorter wavelength so its fringes are in different places from red. The colours are separated into a spectrum.

Experiment seven
Hold two fingers up in the air so there is a very narrow gap. Look through the gap at a nearby lamp. You will see a blurred shadow between the fingers with lines. This is due to the light diffracting and producing fringes.

Absorption

Waves from our transmitters are absorbed by the environment. What you might not know is the effect of water in the air. Microwave ovens work at about 2.4 GHz - the same as our transmitters. Why? It is because water absorbs that frequency efficiently and the heated water content heats the food or drink. So when it is misty not only should you not let the model get too far away but you should remember the range might be less.

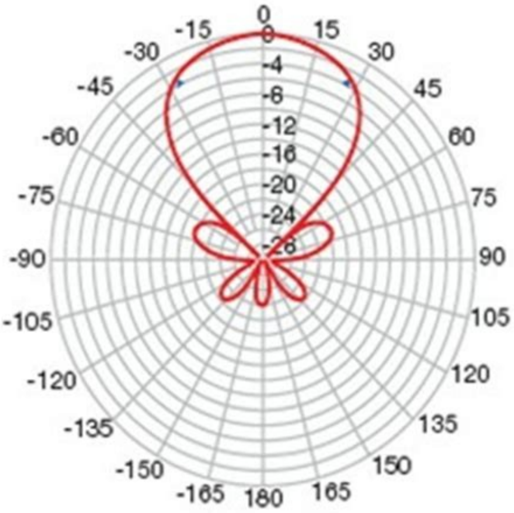
Another absorption risk is the material that fuselages are made from. Carbon fibre is excellent as a building material, but carbon is conductive and will absorb, and so block, the signals from reaching the receiver.

Experiment eight

Here’s a tip using absorption for FrSky flyers. If you land a model out of sight you might be able to locate it using the RSSI signal from the receiver. Obviously this only works if the landing wasn’t hard enough to disconnect the battery, for example if you land in a hedge or your fail safe settings are perfect. Go towards where you think the model is. Turn around 360 degrees while looking at the RSSI reading. It will drop to near zero when your body is between the transmitter and the model. The maximum signal strength will give you an idea of the distance using the idea of the inverse square law.

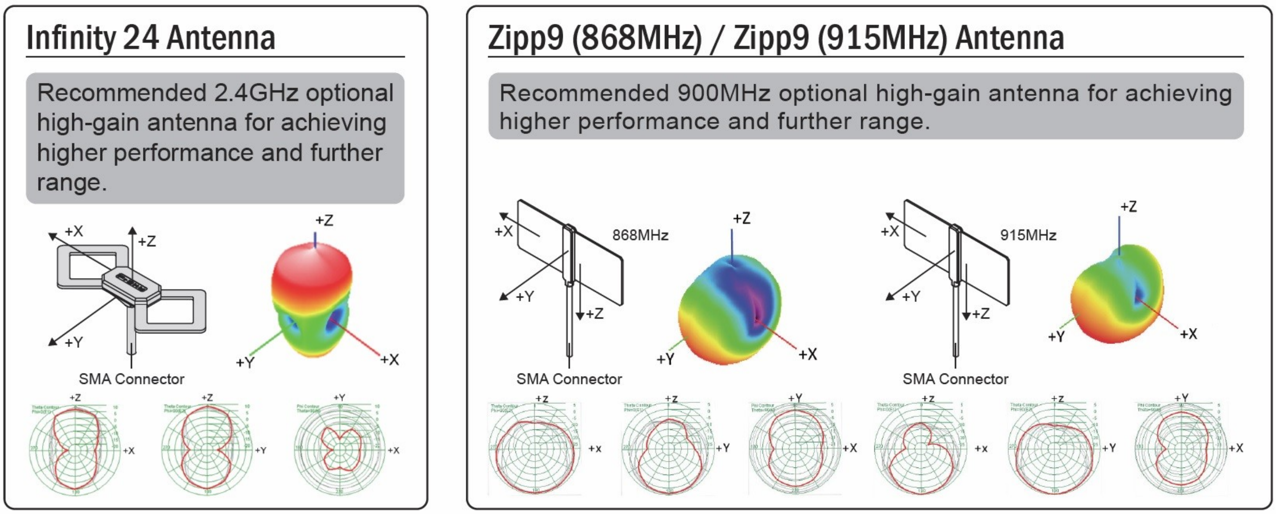
Polar diagrams

Confusingly these are different from polarisation. A transmitter aerial does not send out waves equally all the way round. For example it sends almost none along its axis, probably vertically upwards. That is a third good reason for not letting models get overhead. The other two? Safety and club rules. Even on a horizontal plane the distribution is uneven, for example due to absorption by your body. For aerials in general you can plot their transmitter power and receiver sensitivity on a polar diagram like the one in picture 17.



Picture 17
From www.aerialsandtv.com

Picture 17 is just an example and does not apply to our transmitters. In picture 18 are the polars from the published manual for the 2.4 and 900 aerials on the twin-frequency FrSky Tandem range of transmitters and aerials.



Infinity 24 Antenna

Recommended 2.4GHz optional high-gain antenna for achieving higher performance and further range.

Zipp9 (868MHz) / Zipp9 (915MHz) Antenna

Recommended 900MHz optional high-gain antenna for achieving higher performance and further range.

Picture 18
From FrSky

The famous four

These are the four scientists whose work contributed most to Maxwell’s equations.

Michael Faraday (1791 – 1867)
Faraday was from a modest family and self-educated. He was apprenticed as a bookbinder and read the books he was working on. He attended Humphry Davy’s Royal Institution (RI) and Royal Society lectures and gave Davy a three hundred page bound book based on his notes on the lectures. As a result Davy got him a job at the RI as a technician. He was a superb experimenter even though poor at maths. Two significant areas of work were the magnetic effect of a current and the use of currents in chemistry called electrochemistry and electrolysis. He had two units named after him, the SI capacitance unit the farad and the now outdated faraday unit of charge which was replaced by the coulomb. He refused to work on chemical weapons for the Crimean War. His work was later used by James Clerk Maxwell. On BBC television, the RI continues to this day his Faraday Lectures started in 1825, now renamed Christmas Lectures and aimed at young people. The link is at the end.

Charles-Augustin de Coulomb (1736 - 1806)
Coulomb was born into a prosperous family and was educated in Paris. After financial problems for his family he joined the army as an engineer. After inventing a torsion balance based on the force produced by twisting a wire, he then used the balance to study the inverse square law of the forces between two charged objects and realised that static charge is on the outside of an object, even conductors. Later works included investigation into the forces between currents, or ‘electric fluids’ as he called them, but he did not make the connection between charge and current. He also investigated what we would now call ‘tribology’, the science of friction and lubrication. The SI unit of charge, the coulomb, is named after him. His work was later used by James Clerk Maxwell. His name is inscribed on the Eiffel Tower. He sensibly retired to the country at the start of the French Revolution.

Carl Friedrich Gauss (1777 - 1855)
Born to uneducated working class parents, Gauss showed maths ability from the age of three. By the time he was twenty-one he was seen as a prodigy and had published his first book. His parents did not even know his birthday but he worked it out when he devised a method to find the date of Easter. The Duke of Brunswick was impressed by him and paid

for him to go to university. He collaborated with his professor Wilhelm Weber over magnetism. His cgs (centimetre, gram, second) 'gaussian equations and units' were used until the introduction of SI - Le Système International d'Unités - and his magnetic work was later used by Maxwell in his set of unifying equations. He was a perfectionist and wrote down little about his discoveries. He was a great believer in the pleasure of learning. As soon as he had mastered a subject he left it to start on another. He clarified the Fast Fourier Transform. It is said that someone challenged him with a classic maths puzzle that often fools maths experts due to mind set. "A wasp cannot make up its mind which of two walkers to sting. They start a 1000 m apart and each walks at 2 ms^{-1} towards the other. The wasp goes back and forth directly from one to the other at 5 ms^{-1}. How far does it fly before the two walkers meet and he can sting them both?" Mathematicians use integration of the ever-decreasing separation. Non-mathematicians will realise that at 4 ms^{-1} combined speed the walkers meet after 250 s and the fly has flown 1250 m in that time. To everyone's surprise Gauss instantly gave the correct answer. When someone said, 'We thought you'd integrate it to get the answer', he replied, 'What other way is there?' He had done the integration in his head. His name is still used for normal distribution of data, though the gauss for magnetic field strength in cgs units has been replaced by the SI unit, the tesla.

André-Marie Ampère (1775 - 1836)

André-Marie Ampère was born to a prosperous French family. He was educated using the principles of Rousseau. These were effectively self-teaching and learning by experiencing nature, which is a good start for a scientist. He used his father's extensive library of enlightenment books. Despite the lack of formal education he became a teacher, then a professor of mathematics at a top French school and then professor in experimental Physics. He is best known for investigations of magnetic fields around wires carrying currents. Maxwell used his work and named him 'the Newton of Electricity.' His name is used for the SI unit of electric current. His father was guillotined during the French Revolution. At least Ampere didn't suffer the same fate, unlike Antoine Lavoisier the chemist.

And finally…

Neils Bohr, a Danish physicist, will no doubt pop up again in an article. He was key to quantum physics and won a Nobel Prize. I learned a delightful fact about him recently. The Carlsberg brewery wanted to give him an additional reward for the Nobel. They gave him a house next to the brewery with a permanent pipe from it leading to a tap (faucet) over his kitchen sink. Beer on tap! Great parties!

Sources

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Understanding SWR by Example Take the mystery and mystique out of standing wave ratio. Darrin Walraven, K5DVW*:*
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