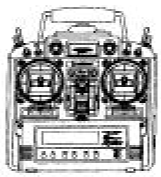


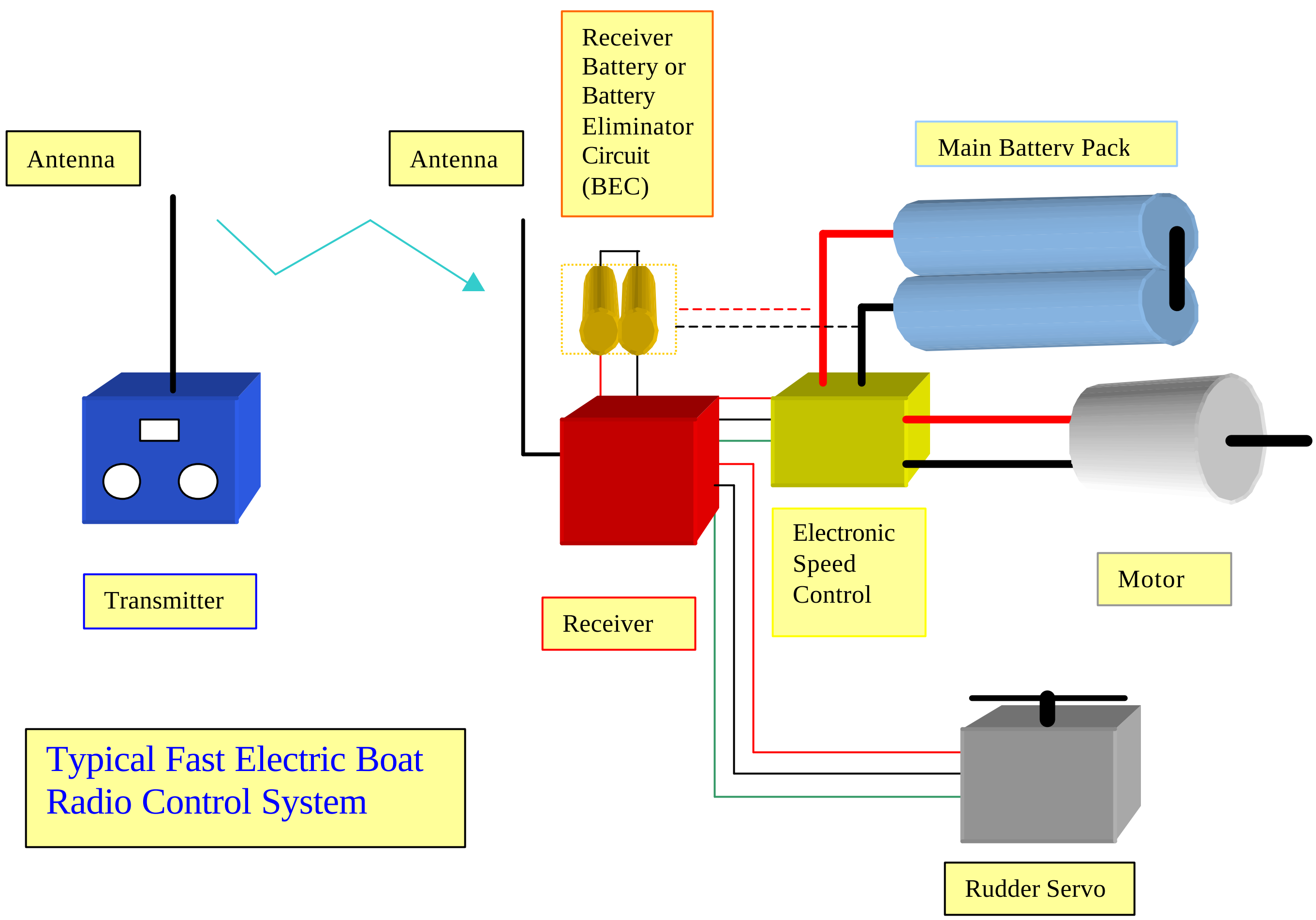
What happens when I wiggle the sticks?

Introduction

We all know that that when you move the sticks on your RC transmitter, your boat will respond by speeding up, slowing down or turning. But what happens inside the black boxes that make up our radio control systems to make this happen?

In this article I will try to explain how our RC systems work. I will describe each electronic element in the control chain from the transmitter stick to the motor or rudder servo, explaining how they operate and what goes on inside the black plastic box. There are various control technologies available to the boat modeller and I hope this will provide you with the information you need to make the right decision when selecting your equipment for fun or competitive racing. I am sure that there will be experts reading this article who will have different preferences to mine, but I hope to show all the options in a balanced manner. If you feel that there is an issue that I have missed or have misrepresented, please let me know.

A summary chart is included at the end of this article, which shows the relative merits of each system.

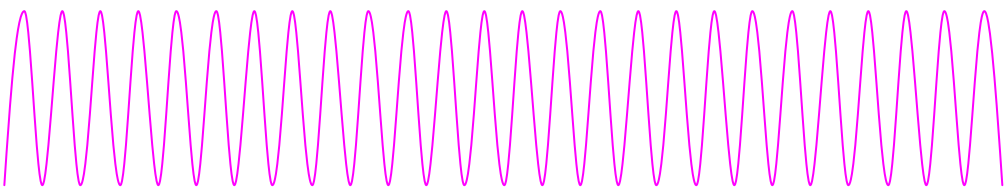


Basic Overview

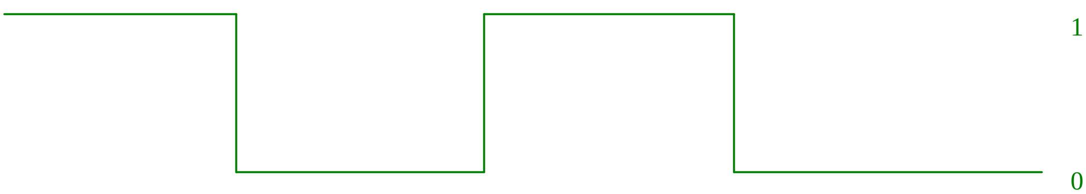
1. The transmitter broadcasts a radio signal via the antenna containing the positional information set by the controls.
2. The receiver picks up the radio signal via its antenna and decodes the positional information.
3. The receiver distributes the information to the electronic speed control and the rudder servo (via the wires shown green on the diagram).
4. The electronic speed control switches the main battery power on and off at high speed to regulate the power output of the motor to the level set by the associated transmitter stick.
5. The servo arm will move to the position set by the transmitter stick.
6. Power for the motor comes from the main battery pack.
7. The power for the receiver comes from an independent battery supply* or a battery eliminator circuit. The BEC will provide a useable voltage to the receiver from the main battery pack.
8. The power supply for the servo and the control circuitry in the speed controller come from the receiver (red and black wires).

AM and FM Systems

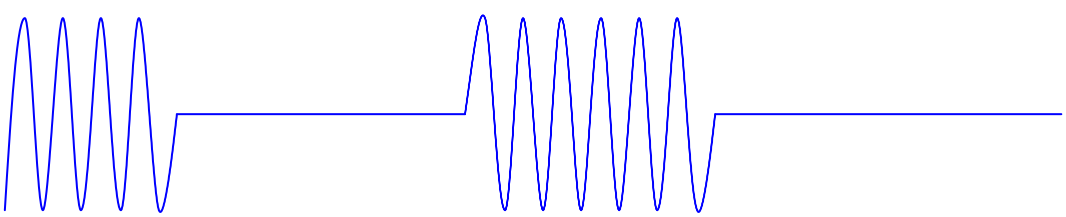
All radio control systems generate a radio carrier wave, at a frequency that is determined by the crystal used in the transmitter. The carrier wave carries no information, so it needs to be modulated to carry the digital information set by the transmitter controls. There are two methods of modulation used by our R/C systems, AM and FM (PCM radios use FM).



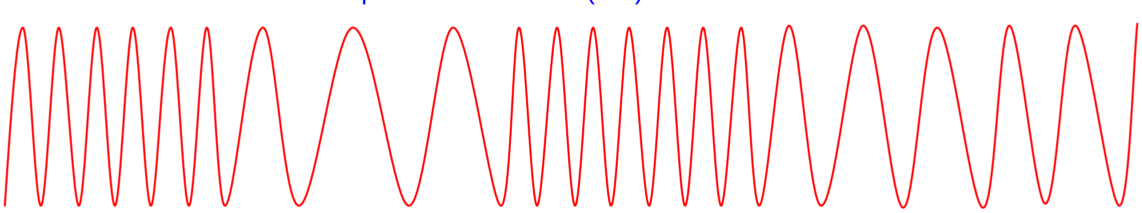
Carrier Frequency



Modulating Signal (digital)



Amplitude Modulation (AM)



Frequency Modulation (FM)

Amplitude Modulation

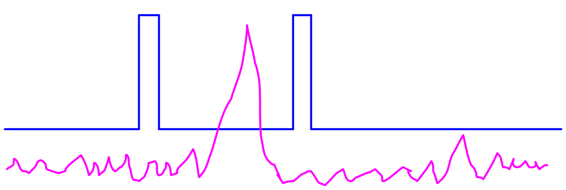
Amplitude Modulation (AM) varies the height (voltage) of the carrier wave to mirror the rise and fall of the modulating signal.

Frequency Modulation

Frequency Modulation (FM) varies the frequency of the carrier wave in accordance with the rise and fall of the modulating signal. All PCM transmitters use FM. A change in carrier frequency (typically 5KHz) is used to signal a zero or a 1.

Advantages of FM

FM is the better system of modulation for R/C use due to a phenomenon called the capture effect. This can be demonstrated if you try to listen to an AM broadcast radio station at night. Weaker stations can be heard underneath the broadcast that you are trying to hear and the signal can also be affected by interference from nearby electrical equipment. By comparison, an FM signal will effectively eliminate any weaker interfering signals and will be less susceptible to local electrical interference (which tends to resemble an AM waveform).



Local electrical noise can result in false pulses, particularly on AM systems.

Interference

Pulse Code Modulation (PCM)

PCM uses fully digital coding, making it more resilient to noise than standard FM. This is one of the reasons that nearly all mobile phone companies have migrated from their old analogue networks to newer digital networks (which use a form of PCM). Radio control systems using PCM also have some additional features:

Hold mode – If a PCM receiver detects an error on its input code, it will remember the previous error free code and maintain the servo position until the next error free signal.

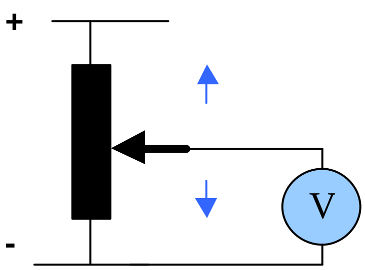
Fail-safe mode – If a PCM receiver detects a string of errors it will revert to fail-safe mode which will set all the controls to a safe holding pattern. The safest holding pattern on a boat is to stop the motor, although some users may prefer to have the boat travelling slowly in a large circle.

One disadvantage of PCM is that the user will not know that the model is going out of range until it reverts to the fail-safe mode holding pattern. Some users have reverted back to PPM so that they can sense when the model is starting to go out of range and take action to try and regain control.

The Transmitter

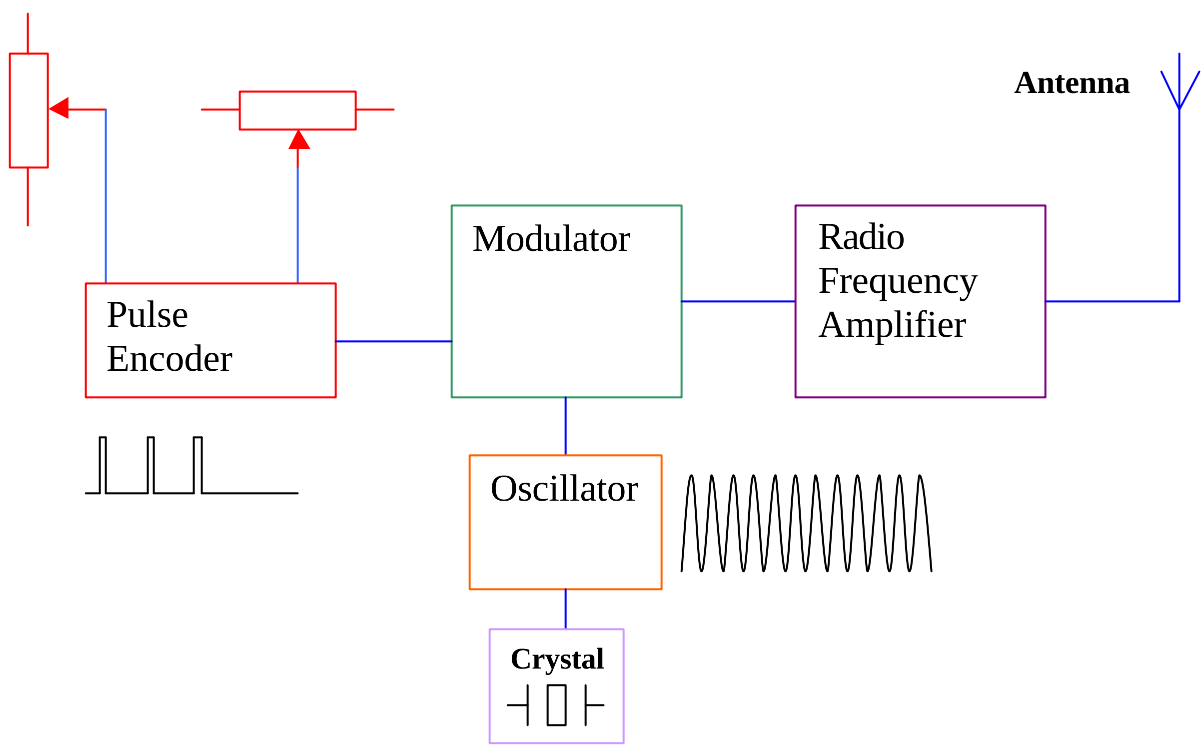
The sticks

Each stick on your transmitter is connected to at least one potentiometer *(dual axis sticks have two, one mounted north-south and another mounted east–west).* Potentiometers are variable resistors, which are commonly used as volume controls on audio equipment. They are made from a strip of electrically resistive material (usually carbon), which is terminated at each end. A wiper (*which is mechanically linked to the transmitter stick*) runs along the resistive strip. Connecting a voltage across the resistive strip results in a voltage on the wiper. If the wiper is moved towards the positive end of the strip, the voltage increases, moving it towards the negative end reduces the voltage.



Moving the wiper upwards increases the voltage measured. Moving the wiper downwards decreases the voltage.

This voltage provides the positional information for your transmitter.

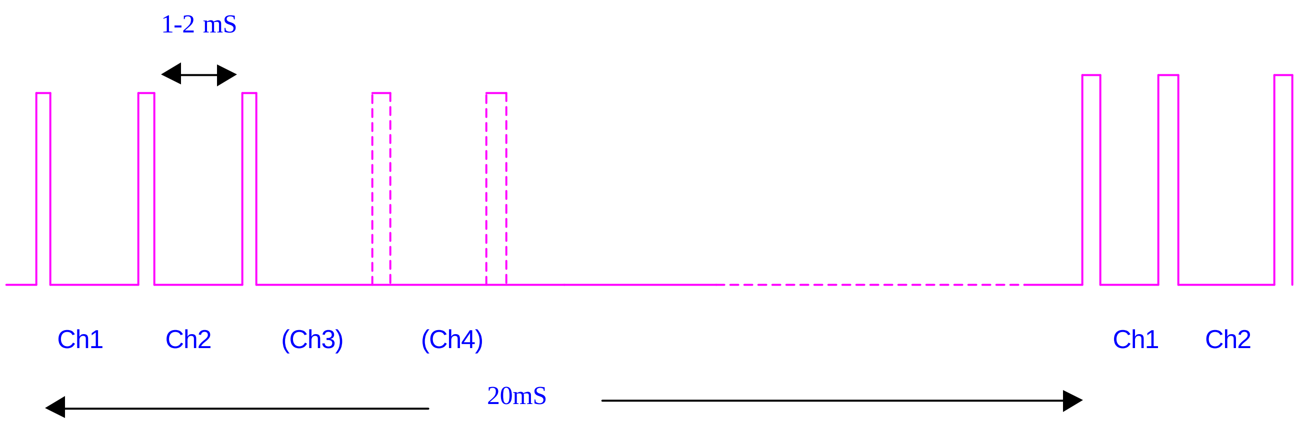


Overview

The position of the transmitter sticks is converted to a train of pulses by the **pulse encoder.** These pulses modulate a radio frequency signal generated by the **crystal** and **oscillator** circuit. The RF amplifier boosts the signal, which is radiated by the antenna.

The Pulse Encoder

Pulse Position Modulation (PPM)



The diagram above shows the pulse-train produced by the most common type of radio. The first vertical pulse synchronises the system. The distance between the first and second pulse varies between 1 and 2 milliseconds depending on the position of the channel 1 control stick. When the stick is in the centre position the distance between the pulses is around 1.5 milliseconds. The channel 2 stick controls the distance between the second and third pulse. The pattern is repeated for the number of channels used by your radio. The cycle is repeated every 20 milli-seconds (equal to 50 times per second). Each vertical pulse typically lasts for 300 microseconds (although this can vary between 100 and 450mS depending on manufacturer).

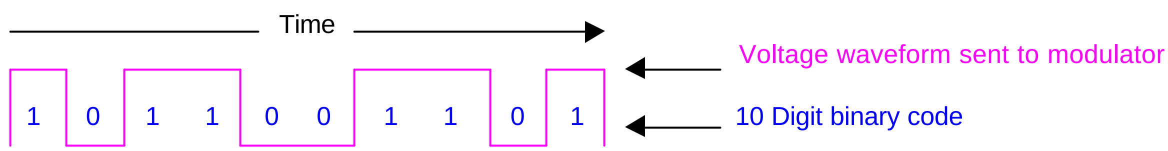
Pulse Code Modulation (PCM)

With pulse code modulation, the range of travel of each control stick is divided into a number of discrete steps. The voltage at the wiper of each potentiometer is sampled and converted to a binary number using an analogue to digital converter. Older PCM systems use a 9 bit binary code giving 512 steps. Newer systems use a 10 bit code giving 1024 discrete steps.

Example

With the stick at approximately 70% of its travel, the position would be step 717 on a 1024 step system. This equals 1011001101 in binary.

The binary code is sent as serial data to the modulator circuitry.



Each channel is sampled in turn and preceded by a synchronisation pulse. Unlike PPM there is no accepted standard for PCM, so manufacturers use their own codes for synchronisation and error checking. For this reason equipment from different manufacturers may not be compatible.

Crystal Oscillator

The oscillator circuit generates the transmitter radio frequency. The circuit is basically an amplifier with feedback applied. You will no doubt have experienced the high pitched screech produced when a microphone is placed too close to its loudspeaker. The oscillator output is produced in the same way, except that the feedback is produced by internal components at much higher frequencies.

The crystal is an accurately cut piece of quartz crystal inside a metal can, which forms an extremely precise tuned circuit. It will resonate at a fixed frequency rather like a tuning fork, except that this is an electrical rather than a mechanical resonance. The crystal is placed in the feedback loop of the oscillator circuit to make it produce a RF output at the desired frequency. This output is called the “carrier frequency”.

Crystals can be affected by mechanical shock, so careful handling is recommended. They can also drift off frequency, which can result in reduced radio range and interference with adjacent channels. Some clubs and dealers have the facilities to check the crystal frequency. Additionally, regular radio range checks can indicate if there is problem with your system.

The Modulator

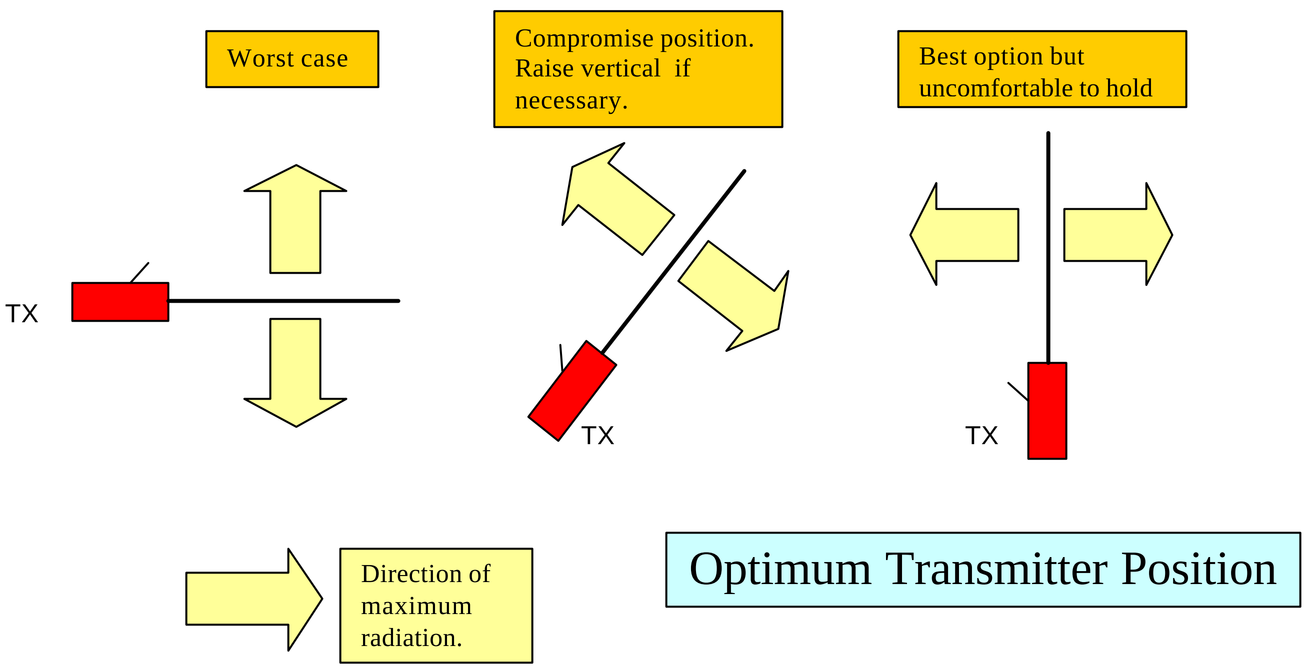
The crystal oscillator produces the radio frequency but it contains no information. The modulator varies the radio signal in time with the pulse encoder output. In an AM system the carrier frequency is pulsed on an off in time with the output of the pulse encoder. On FM the modulator shifts the frequency of the local oscillator by 3KHz in time with the pulse encoder waveform.

Radio Frequency (RF) amplifier

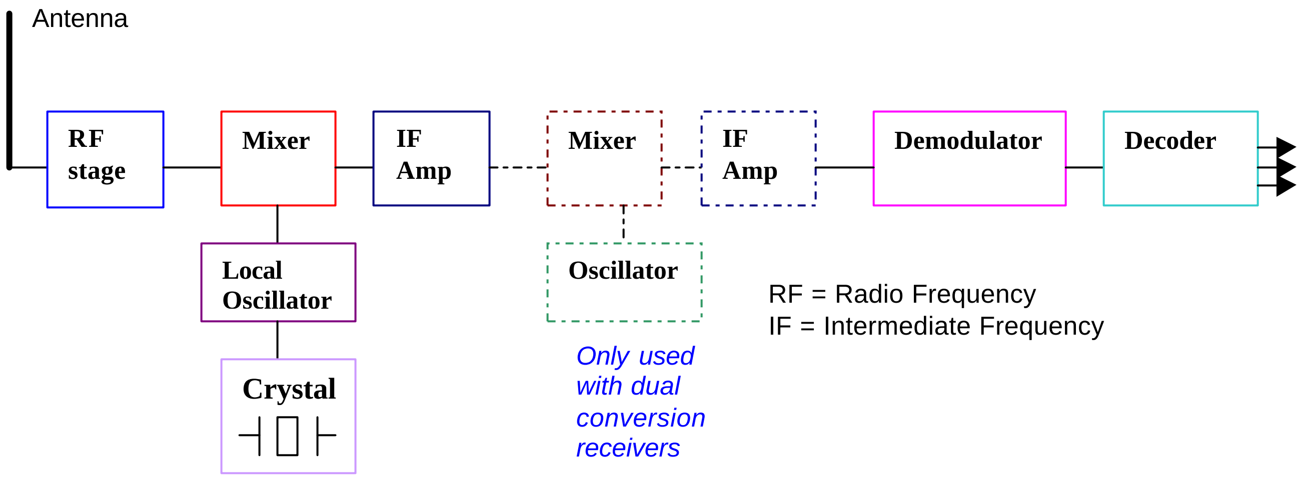
The final stage is the RF amplifier. This amplifies the oscillator frequency to the required output power and matches the output device to the antenna rod for efficient transmission. Budgets priced transmitters tend to use disposable AA size alkaline cells, which have a nominal voltage of 1.5v each cell. Some users choose instead to use rechargeable nicad cells, which have a nominal voltage of 1.2v per cell. A set of 8 Alkaline cells has an output of 12 volts, but the same number of nicads only delivers 9.6v. This can reduce the transmitter output power and limit the range of the R/C system.

Transmit antenna

This much-maligned element in the chain needs to be fully extended to radiate effectively.
The direction of maximum radiation is at right angles to the antenna rod and the end of the antenna radiates very poorly. Always try to hold the transmitter (Tx) so the antenna is as near vertical as possible. If you sense that the boat is failing to respond, raise the Tx above your head. You may look silly, but this action will warn others that you are having problems and the additional height will help to deliver a stronger signal to your model. Console style or pistol grip radios offer a better antenna position than the standard configuration and could be worth considering if you are in the market for a new radio.



The Receiver

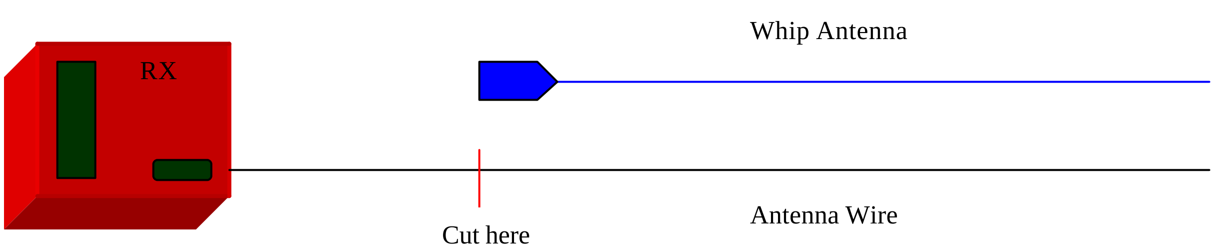


Overview

Radio signals arriving at the antenna are filtered and the wanted signal is amplified by the RF and IF stages. The **demodulator** extracts the pulses created by the transmitter encoder and passes these to the **decoder** for distribution and conversion to the waveform that drives the servos.

The Antenna

The antenna should be mounted vertically as high as possible on the boat and well away from any (dirty) power wiring. The antenna wire has been cut to a precise length that has been matched to the receiver input circuitry. Do not attempt to shorten or lengthen the standard antenna wire. If you need to connect the receiver to an external whip, cut the length of the antenna whip off the original antenna wire to maintain the original length.



Radio Frequency Stage (RF stage)

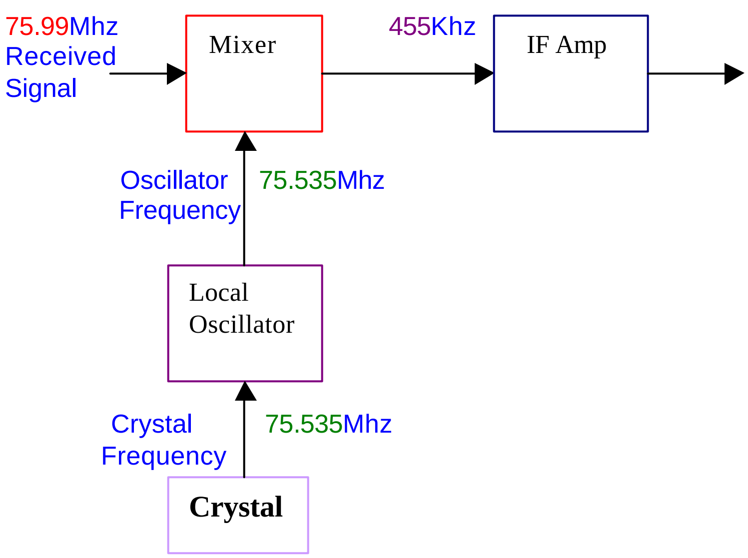
This is the first stage in the receiver chain. This stage matches the antenna, provides the first stage of filtering to eliminate unwanted signals and may amplify the incoming signal.

Intermediate Frequency Amplifier (IF amp) and Mixer

Tuning an amplifier stage in a radio receiver over a range of frequencies poses serious difficulties to the radio designer. It is far simpler to use a fixed frequency amplifier to boost the wanted signal and filter out all the unwanted signals. This fixed frequency amplifier is called the **Intermediate Frequency Amplifier** (**IF Amp**). The **mixer** converts the incoming signal to the intermediate frequency by mixing it with the output from the **Local Oscillator** (*which works in the same way as the transmitter oscillator*). The difference between the wanted signal frequency and the crystal frequency is the intermediate frequency. Changing the radio frequency is simply a case of changing the crystal. The IF amplifier will only amplify a very narrow band of frequencies and will reject all other frequencies. If the local oscillator is off frequency or the IF amplifier is not accurately tuned, the receiver will lack sensitivity and could suffer interference from adjacent channels.

<u>Example</u>

75.99Mhz – 75.535Mhz = .455Mhz



This example shows a receiver tuned to Channel 90 (USA & Canada) which is 75.99 Megahertz (MHz). The Local oscillator is tuned to 75.535Mhz. The difference between the local oscillator frequency and the desired receive frequency is 455Kilohertz (kHz). The 455Khz (heterodyne) frequency is produced when the two frequencies are mixed together.

This technique is used in virtually all types of radio receiver from the simplest pocket transistor radio to communications receivers, televisions and mobile phones.

Single Conversion Receiver

When a radio has one IF amplifier it is called a **Single Conversion Receiver.** Although adequate for most applications it has one serious weakness. The intermediate frequency is a product of the difference between the wanted signal and the crystal frequency. In this case the wanted frequency is 455Khz above the crystal frequency. Unfortunately a signal 455Khz below the crystal frequency will also produce 455khz interfering signal at the input of the IF amplifier. If you accidentally swap the Tx and Rx crystals in a single conversion system your RC system will probably still work but the transmit range is likely to be much reduced. **Do not try this at home, you will be operating illegally outside the designated RC bands.**

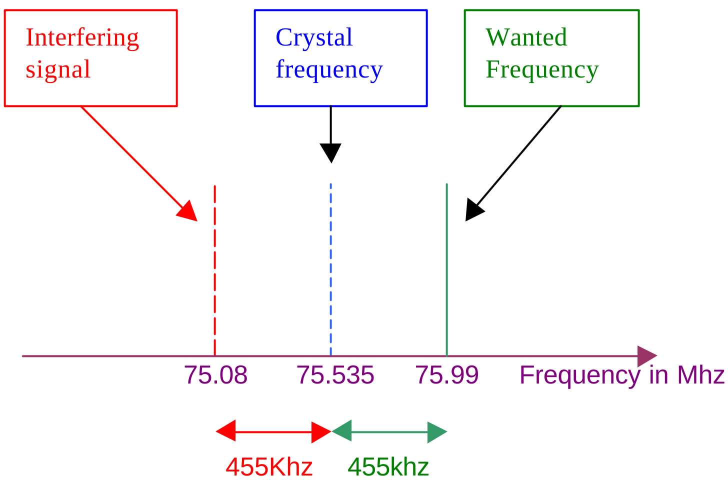
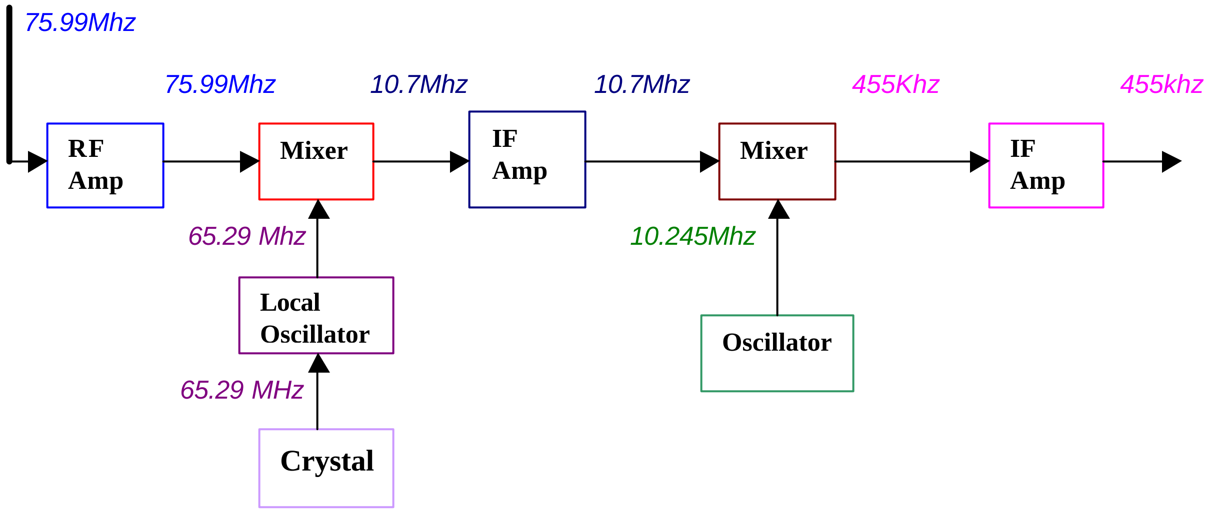


Diagram showing the unwanted “image” frequency on a single conversion receiver

Image frequencies on the surface vehicle R/C bands appear outside the range of allocated frequencies, so no special channel control precautions are required. Image frequencies are present within the US 72Mhz aircraft band and users can suffer interference if certain combinations of FM equipment are used. Users of single conversion receivers should be aware that radio signals originating from outside the R/C band could interfere with their signals.

Dual Conversion Receiver

A dual conversion receiver effectively eliminates the image frequency by first converting the incoming signal to a much higher IF frequency (typically 10.7Mhz) and then mixing it again down to the second IF frequency (typically 455Khz). The image frequency is now more than 21Mhz away from the wanted frequency and can be easily filtered out by the tuning circuitry in the RF stage at the receiver input. The image frequency of the second stage is filtered out by the first IF amp.



75.99Mhz – 65.29Mhz = 10.7Mhz 10.7Mhz -10.245Mhz = .455Mhz = 455Khz

A channel 90 (USA & Canada) signal on 75.99Mhz is mixed with a crystal frequency of 65.29Mhz to produce 10.7Mhz. This is amplified and filtered by the first IF stage then mixed with a second oscillator frequency of 10.245Mhz to produce a final frequency of 455khz to be filtered and amplified by the second IF amplifier.

** The frequencies shown are for illustration purposes only and do not represent the actual frequencies used in all systems*

23 Channel Interference

Two R/C transmitters operating 23 channels apart can mix together in a single conversion receiver (in the same way that the local oscillator mixes with wanted frequency) to produce a resulting interfering frequency at 455KHz on the input to the IF amp. This type of interference is particularly deadly as it can affect every boat on the lake fitted with a single conversion receiver (regardless of their operating frequency). Some clubs have frequency control procedures to ensure that users do not operate their boats on channels that are 23 channels apart. Make sure that your club observes this rule, otherwise you could suffer frustration, damage or injury from boats going out of control.

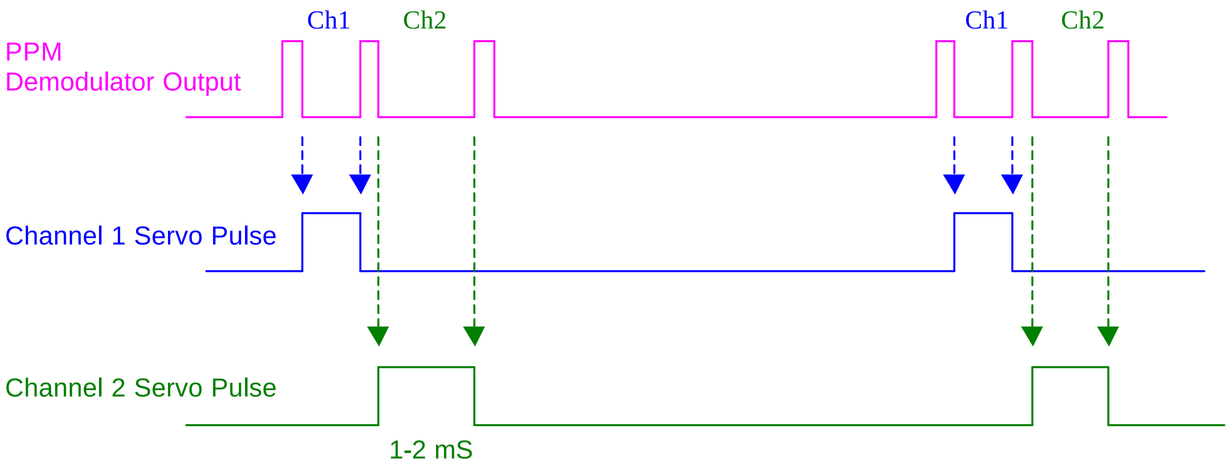
Here in the UK and in Europe we are fortunate not to suffer from this particular type of interference because our R/C bands are less than 455Khz wide. Our control frequencies are 10KHz apart instead of the 20KHz used in North America and some other countries, allowing for more channels in a smaller amount of radio spectrum.

Dual conversion receivers do not suffer from this type of interference although their transmitters can still cause the problem.

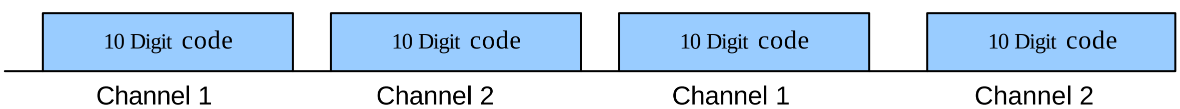
The Demodulator

The demodulator separates the modulation from the carrier (intermediate) frequency leaving just the waveform from the transmitter encoder at its output. FM demodulation is more complicated than AM, which accounts for the higher cost of FM systems.

The Decoder



The demodulated control pulses are the same as those at the output of the encoder stage of the transmitter. These are sampled in turn, and in PPM the distance between the pulses is converted to a servo control pulse with a width of the same duration as the gap between the associated pulses at the demodulator output (between 1&2 milliseconds). The long gap after the final pulse allows the system to synchronise and sample each channel in the correct order. A pulse is sent to each servo 50 times each second.



In PCM, the width of the pulse is determined by the numerical value of the 10-digit code sent by the encoder. The resulting servo control pulses are the same whether a system uses PCM or PPM.

Equipment Compatibility

Radio control equipment will only operate within its designed frequency band.

Crystals for single conversion receivers are not interchangeable with crystals for dual conversion receivers.

AM transmitters and receivers from different manufacturers are usually compatible.

You can usually use a PPM transmitter with a greater number of channels than the receiver.

Most PCM transmitters can also be programmed to operate on PPM if required.

FM transmitters are not always compatible with receivers from other manufacturers, as the frequency shift from a “0” to a “1” can either be positive or negative.

Check first with your dealer that the equipment you are intending to use is compatible and test it thoroughly on dry land before you venture out onto the water.

Synthesised tuning

Some PCM receivers are now appearing on the market with synthesised tuning. The local oscillator uses a device called a phased locked loop to provide its output frequency. This means that you do not have to buy any more crystals for your receiver as it can be tuned, at the touch of a button or the turn of a switch, to the Tx frequency. I have not yet seen a synthesised transmitter but they may start to appear in the near future. Phase locked loops have been around for many years and the technology is fairly cheap. I suspect that the R/C equipment manufacturers have resisted the introduction of synthesised tuning because they have a lucrative trade selling after market crystals.

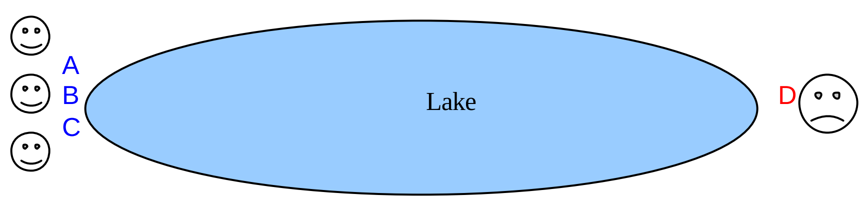
27mhz Band

Some budget systems use the 27mhz band. This is a noisy band for R/C use as there is potential interference from nearby CB transmitters and R/C toys. There are fewer channels available than the main R/C bands so take extra care to ensure that you are not sharing the channel with another user. It is always worth doing a radio range check on dry land (*with the antenna collapsed*) before you put the boat on the water (*this applies whatever frequency band you use).* The channel plan for the 27MHz band is due to change in Europe in the near future, so I do not recommend purchasing new equipment at present. 40 MHz equipment costs about the same and is a better alternative.

Frequency Control

Regardless of whether you use AM, FM or PCM; if two transmitters are operating on the same frequency they will interfere with each other. Always check that your frequency is not in use before you switch on the transmitter.

Local Interference



Here is a little known effect that can cause problems with radio communications. When two or more transmitters operate close together their signals can mix to create an interfering signal on a third frequency (**intermodulation**). In the diagram, Transmitter D is shown on the opposite side of the lake to transmitter A, B & C. As the boat being controlled by D moves towards A, B & C the signal from D's transmitter gets weaker. The interfering signal (**intermod**) caused by A, B & C could cause D to lose control. Very strong local signals on nearby frequencies can also cause the radio receiver to lose its sensitivity (**desensitisation**) as the RF amplifier reaches its saturation point, producing the same result.

There is an easy way to avoid these problems **- BE SOCIABLE!** Always stand together at the lakeside but try to keep at least six feet apart to avoid the generation of intermods.

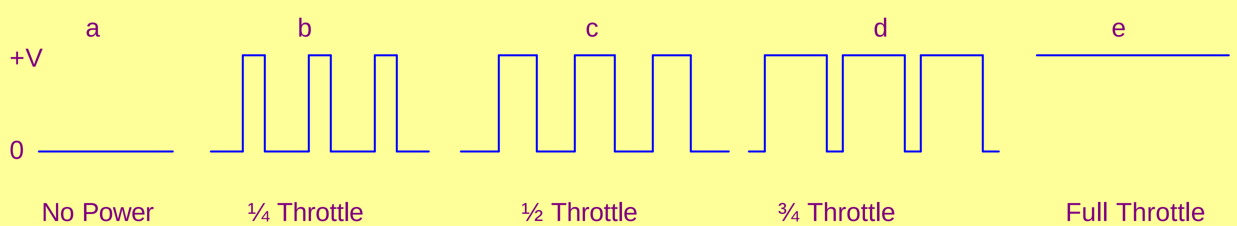
Battery Eliminator Circuit (BEC)

Some receivers are fitted with a BEC circuit to eliminate the need for a separate receiver battery pack. They can also be found in some electronic speed controllers or can be stand-alone units. The BEC consists of a voltage regulator and some filtering components, which converts the drive battery voltage to a lower voltage (usually 5v) suitable for powering the receiver. The regulator device varies its resistance to reduce and regulate the voltage. This means that the device will overheat and fail if the maximum rated voltage or current is exceeded. Most BEC systems require a supply voltage of between 5.5v and 7v (depending on the device used) and will cut out if the battery voltage drops below this level. This is good for your batteries but not very helpful is your boat is stranded in the centre of the lake! The BEC circuit will rob some of the power from your battery pack, but this is likely to be less than one second of run time at the current levels normally used during racing. A separate battery pack will provide a “cleaner” power supply to your receiver because it is not directly connected to the “dirty” wiring that feeds the motor. Racers are divided on the merits of the BEC. You either love them or hate them.

If you use an electronic speed controller based BEC, you do not need to connect anything to the power socket on the receiver. The red and black wires on the servo lead to the ESC will supply the power for your Rx. To disable the BEC supply to your Rx, disconnect or cut the red wire on the ESC control cable.

Electronic Speed Control

An Electronic Speed Controller (ESC) varies the power applied to the motor by switching the battery voltage on and off many times per second.



a) At rest there is no power applied to the motor.
b) As the transmitter stick is advanced the controller starts to apply power to the motor in short pulses.
c) The pulses increase in width as the stick is advanced.
d) As the speed controller approaches the maximum, the battery voltage is applied to the motor for most of the pulse cycle.
e) At full throttle, the pulses join together to form a constant connection to the battery.

Low and High Frequency Controllers

A low frequency controller switches the power to the motor on and off approximately 50 times each second. A high frequency controller switches the power between 1000 and 4000 times per second. High frequency control gives a smoother throttle response from rest and appears to be more efficient at part throttle settings. High frequency controls tend to cause less sparking on the motor commutator, causing less interference to your radio control system and reducing commutator wear. The differences between the two systems are only noticeable at part throttle settings because on full throttle, neither system switches off the power.

If you are not sure which system you have, listen to the motor as you ease the throttle stick forwards. If your motor buzzes, you have a low frequency system. If it whistles you have a high frequency system. Most modern speed controllers use high frequency switching. Nearly all the controllers currently on the market use high frequency switching.

The FETs

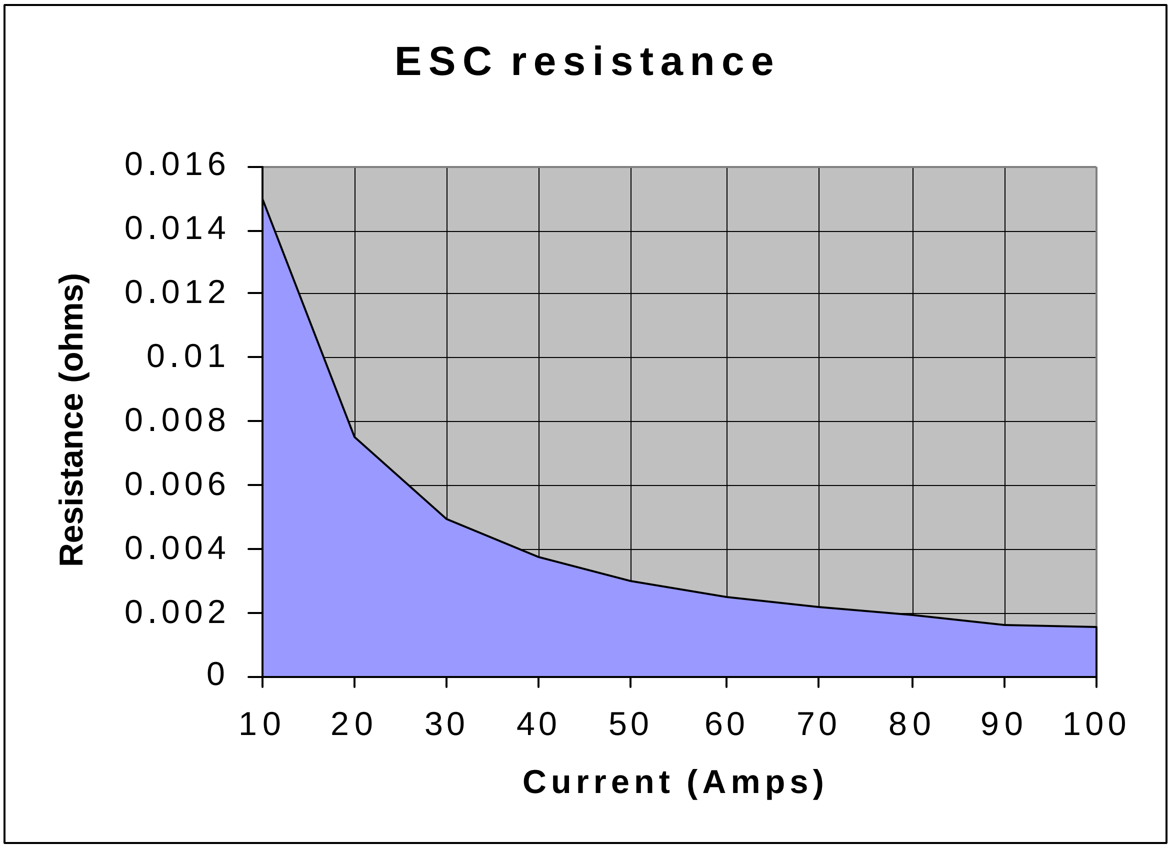
The most important part of any speed controller is the FETs, or to give them their proper title MOSFETs (Metal Oxide Semiconductor Field Effect Transistors). These devices switch the power to the motor up to 4000 times each second at currents that can exceed 100 amps. The most important figure on the specification sheet of any speed controller is its “on” resistance (sometimes called RDS). Some readers may think that the current rating of the controller is the most important parameter, but this rating is often miss-quoted by the manufacturer. The reason for the confusion lies with the current rating of the FET. In a normal piece of electronic equipment a FET is mounted on a large metallic heat sink to dissipate any excess heat. In our boats we need a highly efficient switch which keeps the “on” resistance as low as possible, reduces the heat losses and provides the maximum supply voltage to the motor. This is achieved by running each FET at an average current that is less than one fifth of its maximum current rating. The FETs in a boat speed controller also need to be sufficiently robust to withstand a fouled propeller, which could cause the motor to stall. The stall current of most motors is around **four times** the normal running current. If your prop does get fouled, do not stand with the throttle wide open trying to bring the boat back to the bank (you will cook your FETs!). Pulse the motor gently on and off allowing time for the FETs to cool or better still, use the rescue boat.

MOSFET technology has improved greatly during recent years. A few years ago I built a speed controller for my 12-cell mono using 7 FETS in the output stage. This had an “on” resistance of .0057 ohms. I have just replaced it with a controller using just 5 FETS in the output, which has an “on” resistance of .0028 ohms (less than ½ the loss!). These are certainly not state of the art components. For a few ponds more I could halve the resistance again.

An efficient speed controller with a low internal resistance will run cool. Any heat produced by your speed controller is robbing potential power from your motor. If your ESC is hot after a run, you should consider upgrading.

To choose the right speed control for your application, have a look at the graph on the next page. This shows the **correct** current rating of a controller based on its quoted FET “on” resistance. The “on” resistance of any speed controller will also depend on the design and construction of the printed circuit board, the thickness of the power cables connected to it and the quality of the connectors. This graph is not perfect, but it does illustrate how some of the current handling figures are exaggerated.

The blue area on the graph shows the safe current rating for an ESC with the quoted internal resistance.



To use this graph, you will need to calculate your average current during a normal discharge cycle.

To work out this value, use the equation shown below:

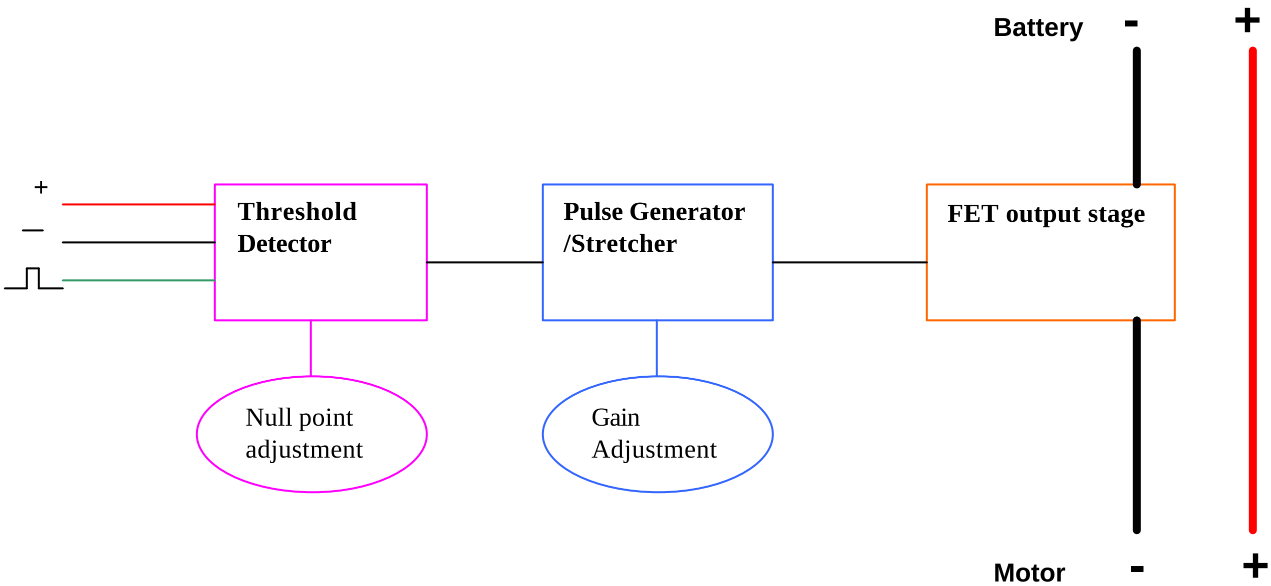
3600 divided by run time (in seconds), multiplied by capacity of battery pack (in amp/hours).

$$\frac{3{,}600}{\text{Discharge time (in seconds)}} \times \text{Battery Capacity (in Amp Hours)}$$

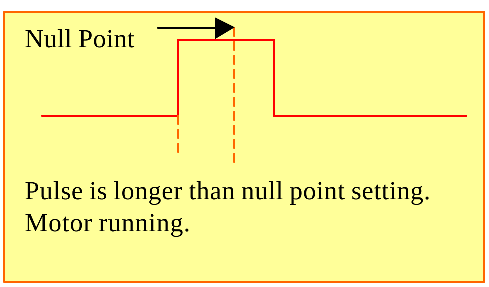
Example: 2000mAH (=2AH) battery pack. Discharge time = 5 minutes (=300 seconds).

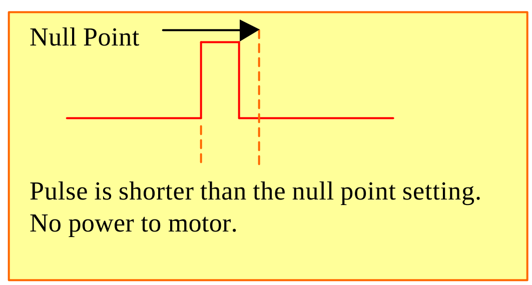
3600/300 x 2 = 24 amps

Electronic Speed Controller Block Diagram



The diagram above shows a simple electronic speed control. Pulses from the receiver arrive at the receiver every 20 milliseconds and vary between 1 & 2 milliseconds in duration (depending on the position of the transmitter control). The threshold detector will measure the width of all the pulses and will suppress any lasting less than the time set by the null point adjustment (This should equate to the position of the transmitter control when the motor is at rest).





On a reversing speed controller the null point adjusts the position of a dead zone where the motor is at rest. If the width of the pulse falls outside the dead zone, the motor will run either forwards or in reverse. Changing direction involves the use of a changeover relay or additional FETs to reverse the positive and negative connections to the motor. These components introduce additional loss into the motor power circuit reducing efficiency. Reversing controllers are OK for fun running and scale applications but should be avoided in racing boats. Always choose an ESC that is designed for marine use. Electric flight or car controllers will often include features that are not required in a boat (who needs a propeller brake or ABS?) and will not normally be protected from water ingress.

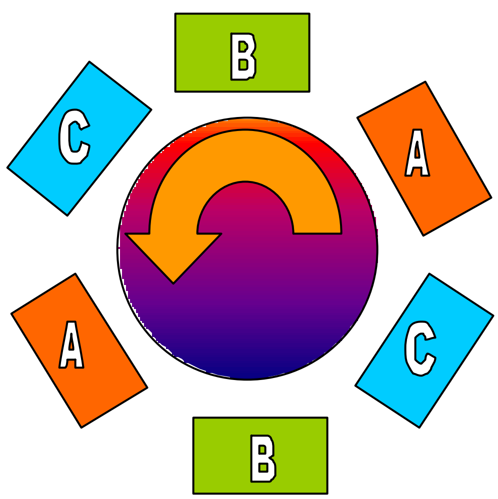
Pulse generator/stretcher

The width of each servo pulse is used as a timing reference to adjust the width of the pulses fed to the FETs. On a low frequency controller the FET pulse frequency is derived from the frequency of pulses generated by the receiver (around 50 per second). On a high frequency controller an internal generator is used to produce the pulses. The gain control adjusts the amount by which the width of the servo pulse affects the width of the pulses to the FETS.

A few years a go nearly all speed control circuits were based around an integrated circuit called a ZN409CE, which was a low frequency device marketed as a servo driver chip. The modern technique is to use a PIC (programmable interface controller) which is a small micro-controller that can be programmed using a PC. This type of controller digitally samples the receiver pulses and applies a computer program to obtain the drive pulses for the FETs. The advantage of using a PIC is that it can be much easier to program advanced features such as “one touch” or automatic set-up of the gain and null point. Individual parameters can also be tailored to suit the user.

Brushless Motor Controllers

A traditional DC motor has fixed magnets on the outer case and a rotating wound armature in the centre. The brushes moving over the commutator as the armature rotates control the direction of the current flowing through the windings. A brushless motor has the windings fixed to the outer can and the magnets rotating in the centre. The speed controller switches the current through each winding electronically based on positional information provided by the motor. The brushless system is more efficient than a traditional brushed motor, due to the elimination of electrical resistance at the brush/commutator junction and a reduction in friction as there are no brushes rubbing against the commutator.



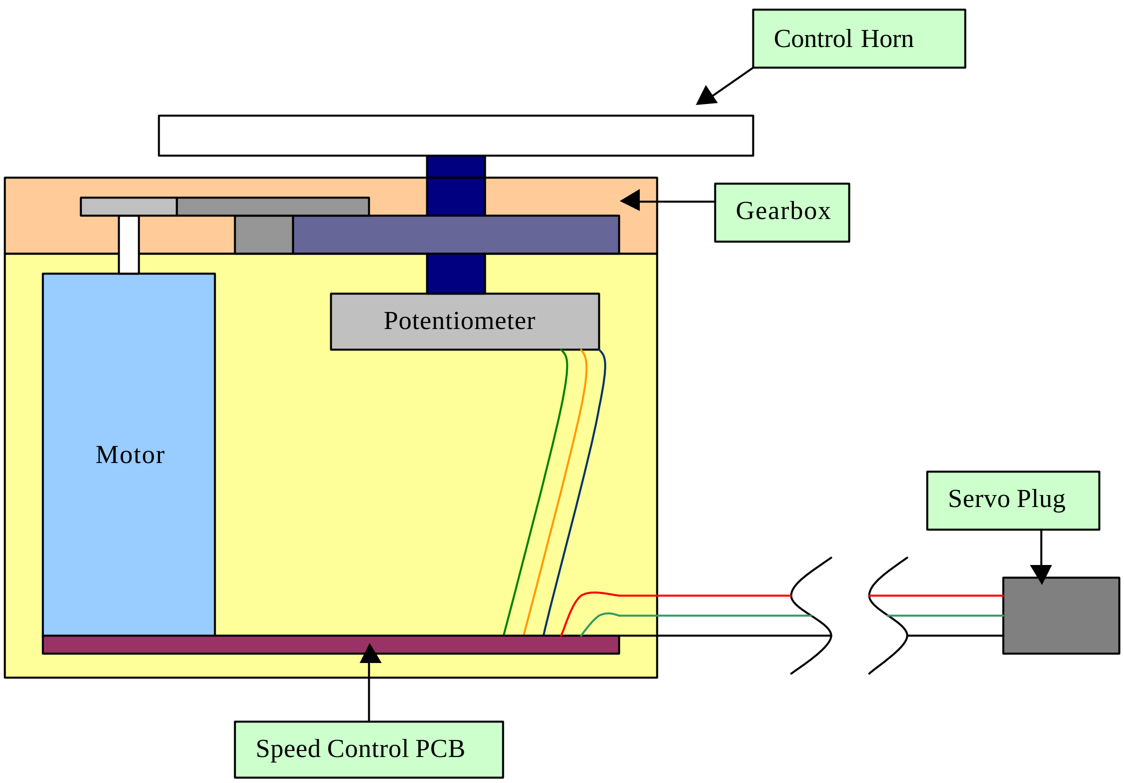
The diagram shows a simple brushless motor arrangement A, B & C are individual coils that are energised by the speed controller. The coils are energised in pairs to set up a rotating magnetic field. This rotating field is continually being chased by the multi-pole permanent magnet attached to the centre shaft. The controller senses the position of the shaft and energises each pair of coils in turn keep the motor spinning.

Sensor-less Brushless Motor Controllers

Earlier versions of brushless motors use a magnetic (hall effect) sensor attached to the motor housing to sense the motor position. This information is fed back to the motor via a sensor cable. The latest generation controllers are called sensor-less because they do not require a position sensor. As only two out of the three coils are energised at any time, the controller can detect the position of the motor by monitoring the voltage on the unused winding. Sensor-less motors have the advantage that they can analyse the performance of the motor and dynamically adjust its timing suit the load, speed of rotation etc… The controlling programs used within these devices are becoming increasingly sophisticated, to improve the efficiency of the motor over a wide range of conditions.

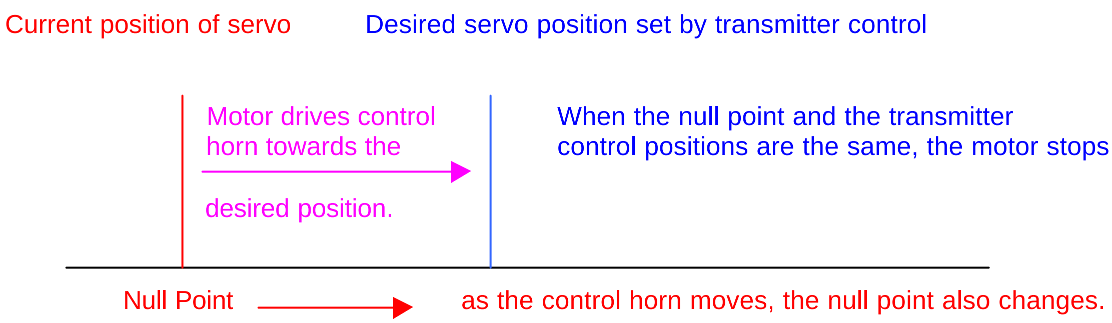
Each brush-less motor has three power wires attached to the controller. Each wire is attached to at least one pair of FETs to control the direction of current flowing through each coil. This means that a brushless controller must have at least six FETs to operate. In practice they usually have at least twelve and I have heard of one that uses 144!

Servos



A servo uses a miniature reversing speed controller circuit to drive a small motor. The motor is linked via gears to the control horn. The shaft that connects the control horn to the final gear is also linked to a feedback potentiometer. This adjusts the position of the “null point” (*see speed control section*) as the control horn rotates.

The speed control will always drive the motor towards the position set by the transmitter stick. When the control horn reaches the “dead zone” (*see speed control section*) the motor will stop. The gain of the speed controller is set relatively high, so that the motor runs at close to full speed even when there is only a small distance for the control horn to travel to its final position.



If the null point was to the right of the transmitter control position, the speed control will reverse the motor to drive the control horn in the opposite direction.

Most servos are designed to operate with supply voltages of between 4.8 and 6 volts. Powering your receiver from a 6v source should produce a faster servo response than running it from a 4.8v source.

Digital Servos

Some servos are described a “digital”. These use digital sampling techniques within the speed control circuitry. This should produce a more precise response and make the servo less susceptible to noise and spurious responses due variations in the supply voltage. Some types can be programmed to have different response characteristics.

Servo Choice

The standard budget servo is adequate for the majority of applications, although some users may prefer a faster, higher-powered version. Metal gears are more robust than the standard plastic types and a small lightweight boat will often benefit from a small lightweight servo. Core-less servos use motors with coils that are wound onto a lightweight drum, which spins around a centrally mounted magnet. These motors can spin up to speed very quickly and the servos are generally the fastest and most powerful for their size. They are also the most expensive and drain the receiver battery faster than standard types. **The choice is yours…**.

Servo Compatibility

The electronic circuits used inside servos are generally compatible with receivers from different manufacturers **but** the connectors are usually different. It is quite easy to modify the plug moulding to fit another manufacturers receiver using a small file or craft knife, or by replacing the connector with one of the correct type. Check that the colour of the wires entering the connector are arranged the same order as the receiver manufacturers standard (typically: black-, red+ and white or yellow for the signal) and ensure that the plug is inserted the right way round.

Comparison Chart

RC Systems

27 MHz AM Limited number of channels. Possible interference from CB. Cheapest to buy.	27 MHz FM Same as AM but. better noise rejection.	40/75 MHz AM More channels available than 27 MHz. Band shared with other users in some countries.	40/75 MHz FM Same as AM but better noise rejection. Dual conversion receivers offer more protection against interference.	40/75 MHz PCM Best noise rejection also the most expensive.

Speed Controllers

Mechanical	**Reversible**	**Low Frequency**	**High Frequency**	**Brushless**
Particularly inefficient at part throttle settings. Most types are not suitable for fast electric applications.	Generally least efficient of the electronic variety. OK for scale applications and fun running	Less smooth than high frequency type and tend to cause more sparks at the motor commutator.	Best option for brushed motors.	Low maintenance highly efficient. Can only be used with a compatible motor.
	Refer to the graph to find the most suitably rated speed control for your boat.			
	Opto-isolation can help to prevent any electrical noise produced in your ESC affecting the receiver, but it is only effective if used with non-BEC systems.			

Servos

Standard	**Mini/micro**	**Metal Geared**	**Ballraced**	**Digital**	**Coreless**
Cheap to buy. OK for most applications.	Great for small lightweight boats.	More robust than plastic geared equivalents	Generally faster than the non-ballraced variant.	Output generally more precise than analogue versions and greater noise immunity. Some are programmable.	Generally the fastest and most powerful for their size. Current consumption is also higher.

In Conclusion

I hope that you have enjoyed reading this article and have found it informative. I must admit that some of the sections are a bit heavy and may need to be re-read them to fully understand the principles involved. I am not professionally involved with the model trade but have always been fascinated by how things work (especially radio and electronic products). I would finally like to thank Andy Kunz, Allan Shillito, Andrew Gilchrist, Ian Williams and Jack Limsilatham for their help in the production of this article.

All about the Author

My name is Neil McGrath and I live with my wife and two children in the county of Kent, (approximately 20 miles Southeast of London) in the UK. I have been playing around with motors, batteries and bits of wire for as long as I can remember. When I left school, I completed a four year Ministry of Defence apprenticeship at the Electrical Quality Assurance Directorate Establishment at "Aquila" in Bromley, Kent. I then spent fourteen years working as a radio engineer with the Metropolitan Police in London. I moved to a managerial position with a mobile phone network in 1997, but soon realised that I was a far better engineer than a manager. I am now working for Thales, as a technical support engineer on a new state of the art communications project for the London Underground railway system.

My interest in fast electric boats began back in 1994. I had an old fibreglass hull, which was originally built as a school project. Originally, I fitted it with a Graupner Speed 600 motor but wanted it to go faster. After reading about fast electric boats in Marine Modelling magazine, I decided to throw out the speed 600 and replace it with a 700BB turbo (much more impressive!). I joined Electra (the UK fast electric club) and attended one of their meetings as a spectator. I quickly realised that my old hull would not be competitive and decided to build a "proper" fast electric. Since then, I have built a number of fast boats (mostly deep vees) and constructed quite a few speed controllers, BEC circuits and even a peak detect charger. I do not race very often but enjoy building and running my boats, mainly for fun.

This is my first attempt at writing for the web and the article has ended up much longer than I had first imagined. If you have any comments regarding this article, please write to neilmcgrath@onetel.net.uk.

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