How It Works – The PPM Radio Control System: Part 1

Foreword

This Technical Note is divided into 3 parts to reduce the file size when downloading each section from the internet and also to achieve a measure of subject separation. The individual parts may be read as separate documents or the three may be combined to form a comprehensive description of the principles behind radio control.

Introduction

There are a number of types of R/C equipment available with each distinct variant using a different combination of RF carrier modulation technique, either AM or FM, and data encoding method, either PPM or PCM. The standard equipment typically uses either AM or FM modulation and PPM data encoding and this Technical Note aims to provide the reader with an understanding of how this type of system operates.

In order familiarise the reader with the terms and methods involved in sending information using a radio link, Part 1 (this file MECTN003.PDF) concentrates on providing a general description of the techniques used in radio communication. Part 2 (filename MECTN004.PDF) provides a full operational description of a typical transmitter as used in a low-cost R/C system and Part 3 (filename MECTN005.PDF) describes the detailed operation of a corresponding receiver.

Transmission of Information

In order to send information from one place to another it is necessary to have a source of power and a transport mechanism. For a simple telephone system, these may be simply a battery and a pair of wires as illustrated in Figure 1.
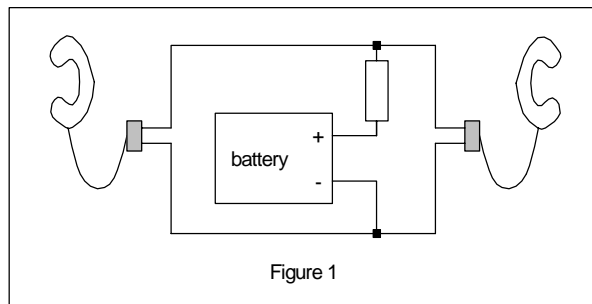
Figure 1

In the diagram the battery provides the power source and the wires provide the method of transporting the information, in this case speech. Each of the handsets contains a microphone, which converts sound to an electrical signal, and a loudspeaker that performs the conversion from an electrical signal back to sound.

However there are information transmission applications for which the need for wires is inconvenient and in these cases a transmitter/receiver pair, as shown in Figure 2, may be used to replace the physical link.
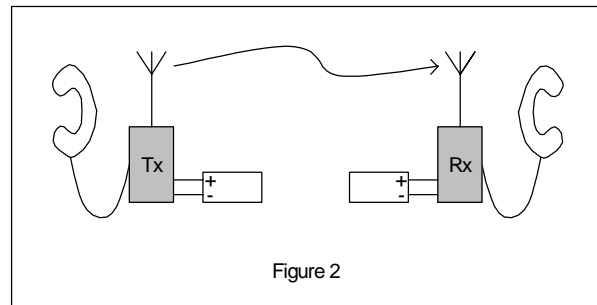
Figure 2

Communication using Radio

When the example shown in Figure 2 is compared with that in Figure 1 it is less easy to see, and so to understand, the transport mechanism involved and the remainder of Part 1 of this Technical Note is devoted to describing the process.

Radio Basics

The transmission medium used in radio communication is an electromagnetic wave, often called a 'radio wave', and in a communications system it is referred to as the carrier. It is produced by the transmitter and is the 'road' on which the information travels. It is typically a high frequency wave but the spectrum of frequencies used ranges from, at the low end, a few thousand cycles per second (kHz), through the million cycles per second (MHz), up to several billion cycles per second (GHz) at the high end. In order that the various communication systems do not interfere with one another the spectrum is divided up into frequency 'bands' and each band is allocated to a particular use. There are 4 such bands allocated for R/C use in the U.K. as shown in Table 1.

Band	No. of Channels	Channel Spacing	Min. Frequency	Max. Frequency	Max. Output Power	Usage
27MHz	13	25kHz	26.975MHz	27.270MHz	100mW	General Usage
35MHz	36	10kHz	34.950MHz	35.300MHz	100mW	Aircraft Only
40MHz	34	10kHz	40.665MHz	40.825MHz	100mW	Boats / Buggies
459MHz	39	25kHz	458.525MHz	459.475MHz	100mW	General Usage

Table 1 : U.K. Radio Control Band Frequency Allocations

The information to be transmitted over the system is impressed onto the carrier by some method which, in the case of an AM system, is known as amplitude modulation and for an FM system the method used is frequency modulation. In both of these methods the receiver 'picks-up' the carrier, extracts the information from it, and provides an output signal representative of the original information.

Amplitude Modulation

This is the process of placing information onto a carrier by changing the strength of the carrier in sympathy with the information being sent. When a communications system is idle, i.e. there is no information to send, the transmitter still produces the carrier but at a constant strength, or amplitude, as shown in Figure 3. When the receiver picks up this constant signal it produces an unchanging output and thus, effectively, provides no information.
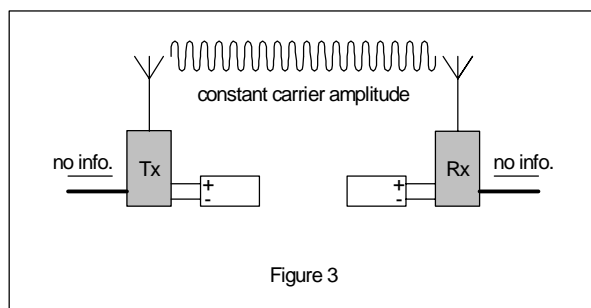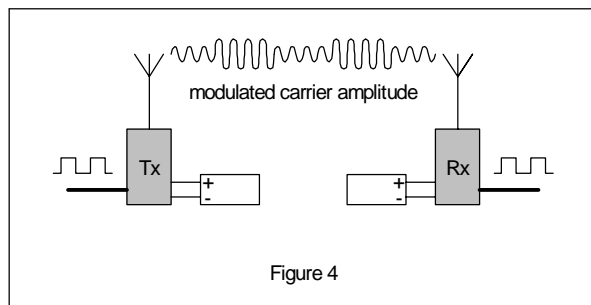

Figure 3

Figure 4

Figure 4 shows a representation of the system when it is sending information, in this case a simple train of pulses. The amplitude of the carrier is seen to be changing from low to high and back again as the amplitude of the input signal changes. The receiver extracts the changing amplitude using a device known as an envelope detector and from this reconstructs the original signal.

The Envelope Detector

The circuit for a simple envelope detector is shown in Figure 5 along with some example waveforms. The input signal at point 'A' is an amplified version of the signal picked up by the receiver aerial. Diode, D1, only conducts when the input signal has positive polarity and thus the signal seen at point 'B' is only the 'top half' of the signal at point 'A' and consists of a high frequency signal, the carrier, with its amplitude changing in sympathy with the original data.
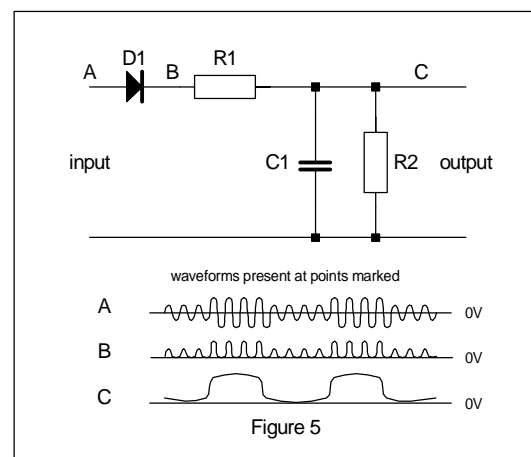

waveforms present at points marked

Figure 5

In the circuit shown the capacitor, C1, is a storage device and behaves rather like a leaky bucket, with R1 representing a tap that can be turned on or off by the amplitude of the signal at point 'B', and R2 providing the leak. When the tap, R1, is turned off the bucket will empty via R2 and will fill, provided the input flow is greater than the leak, when R1 is turned on and it is this combination of actions that recovers the original information. There will obviously be a delay between the tap changing

state and the bucket either emptying or filling but with careful selection of the component values this may be minimised. It can be seen, therefore, that the detector ignores the high frequency carrier itself and only responds to its 'shape', or envelope, and it is this characteristic that gives this type of detector its name.

Frequency Modulation

In contrast to the AM method described above the FM system maintains the carrier at a constant amplitude and conveys the information by rapidly changing its frequency in response to the information being transmitted. When idle, an FM transmitter produces a carrier with a constant amplitude and a constant frequency, known as the centre frequency, similar to that shown in Figure 3. As with the AM system when the receiver picks up this constant frequency signal it produces an unchanging output signal.
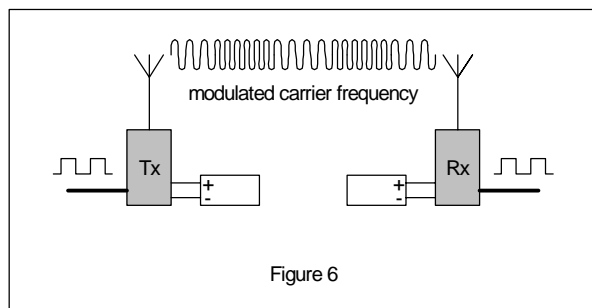

Figure 6

Figure 6 shows an FM system sending information, again a simple pulse train, and, because the information is of a digital nature, the carrier frequency alternates between two distinct frequencies, one slightly lower than the centre frequency and the other slightly higher. Because the carrier amplitude is constant an envelope detector cannot be used to demodulate an FM signal and a circuit known as a discriminator is used instead.

The Discriminator

There are numerous circuits for demodulating an FM signal and Figure 7 shows an example of one of the simpler ones, a circuit known as the ratio detector. Although, at first glance, the circuit resembles two envelope detectors connected together its operation is quite different and considerably more complex and a much-simplified explanation is presented here.

It is best understood by knowing that the tuned circuit formed by L and C is set to be resonant at the carriers centre frequency and, as a starting point, taking the case of an un-modulated carrier. Under these conditions the signals at the two ends of the tuned circuit, shown as points 'B' and 'C' in the diagram below, have the same amplitude and precisely the opposite phase and thus C1 and C2, having equal values, are charged to equal voltages but with opposite polarity.
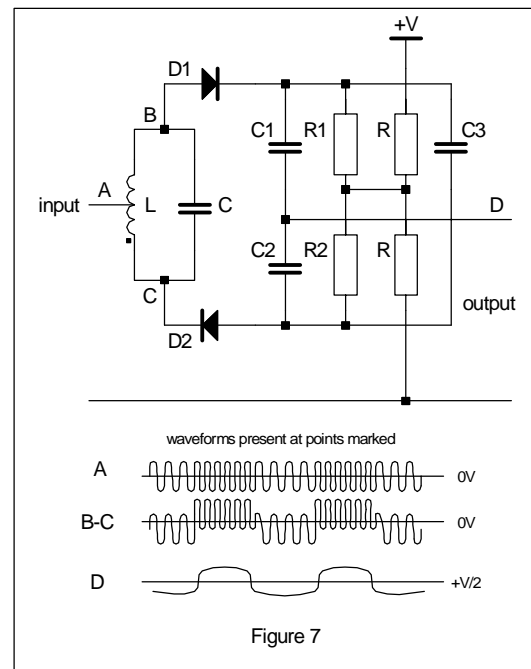

Figure 7

R1 and R2 are also of equal value and thus voltage across each one is the same as that across its corresponding capacitor, C1 and C2. The junction of R1 and R2 is connected to a voltage equal to half the supply voltage and this acts a reference voltage for the output signal. It can therefore be seen that under idle conditions the voltage present at the junction of C1 and C2 equals the reference voltage and thus there is no output signal.

When modulated the carrier frequency shifts slightly so the LC tuned circuit is no longer operating at resonance and is, therefore, unbalanced. The effect of this is to cause the signals at each end of the tuned circuit to differ in amplitude with one signal increasing and the other correspondingly decreasing. As the sum of the two signals remains largely the same the voltage at the junction of R1 and R2 is unchanged but C1 and C2 are now charged to different voltages. This causes the voltage at the junction of C1 and C2 to change with respect to the reference voltage and thus

produces an output signal. For a downward carrier frequency shift the output voltage may go negative and for upward shifts it may go positive.

Tuning

As described above the radio frequency spectrum is divided up into bands. Some of these bands are further divided into 'spot frequencies', or channels, as is the case in the R/C bands and it is this technique that allows the use of more than one model at the same time in the same locality. As an example the 27MHz R/C band is divided into 13 channels each spaced from its neighbour by 25kHz and a few of these are shown in Figure 8.

Figure 8
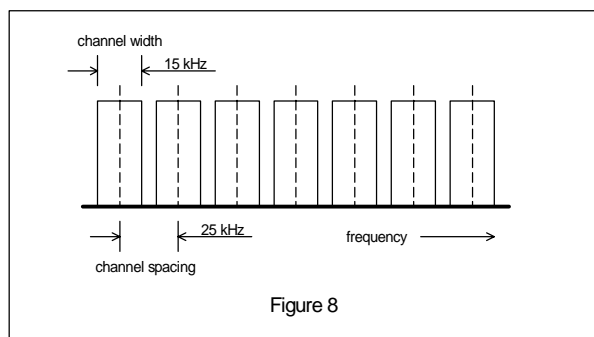
Provided that each model uses a different channel, interference is not a problem. This does mean, however, that a transmitter must only transmit an RF signal on the specific channel to which it is set and that the receiver must be able to ignore, or reject, RF signals with carrier frequencies different from its setting.

The process that facilitates this is known as tuning and is, in principle, just the same as that used by ordinary radios. In a standard PPM R/C system it is usually accomplished by changing a frequency selective component, the crystal, although it is now technically possible to have a system with switch selectable tuning, a bit like a push-button radio. For each channel in each of the four R/C bands it is possible to obtain pairs of crystals, one each for the transmitter and receiver, that are specifically manufactured to set the tuning of the Tx/Rx combination. On each band either a colour or a number uniquely identifies the channels and pennants are often tied to the transmitter aerial denoting the band/channel in use.

For further information on the U.K. Radio Control Bands please refer to the M.E.C. Technical Note MECTN101.PDF obtainable from the web-site address given at the end of this Technical Note.
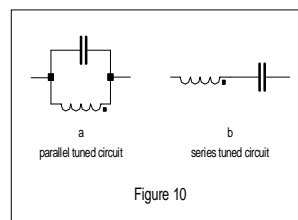
The Tuned Circuit

This apparently simple circuit element is fundamental to all communication by radio and is the basic method by which a system is tuned. The most elementary tuned circuit consists of an inductor and a capacitor and the circuit symbols for these components are shown in Figures 9a and 9b. An inductor is constructed from a length of wire, usually wound in a spiral formation, and a capacitor is formed when two areas of a conducting material, such as a thin

Figure 9
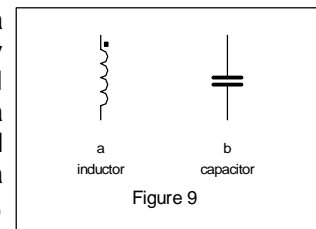
aluminium foil, are separated by an insulating medium, which may be either air or a plastic. In order to reduce the physical size of the capacitor it too is usually wound. Each of these two components possesses the characteristic that its reactance, which is a similar quality to resistance and is actually its AC impedance, changes in a predictable fashion with frequency with the reactance of an inductor increasing with increasing frequency and that of a capacitor reducing.

When these components are connected together to form either a parallel tuned circuit, as shown in Figure 10a, or a series tuned circuit, as shown in Figure 10b, there is a special frequency where the reactance of each of the components is the same.

Figure 10

This is referred to as the resonant frequency and tuned circuits exhibit interesting, and useful, characteristics when operated at resonance. The detailed descriptions of circuit behaviour is beyond the scope of this Technical Note but suffice it so say that, when operated at the resonant frequency, the parallel tuned circuit tends to appear as an open-circuit and the series tuned circuit as a short-circuit. When placed into a suitable circuit these characteristics can be used to provide selectivity; that is the ability to only accept, or let through, frequencies of interest and reject all others.

Figure 11, shown overleaf, gives a simple diagram illustrating this behaviour and shows an aerial that has little, or no, selectivity and thus receives all signals with equal strength, as shown by the line 'A'

in the graph. The following amplifier is combined with a parallel tuned circuit and thus only amplifies signals within a narrow range of frequencies giving a response similar to that shown by the curve 'B'.
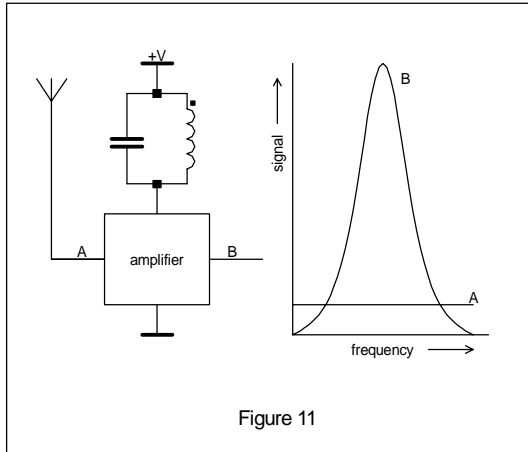

Figure 11

The Crystal

Although used in electrical circuits the crystal is actually a mechanical device. It is usually fabricated from quartz, a material that possesses piezo-electric properties, and can thus convert an electrical signal into a mechanical movement and vice-versa. Crystals are complex devices but, when connected in an electrical circuit, behave as a 'super' tuned circuit and can provide an amplifier with extremely good selectivity.

The Oscillator

There is a further circuit element that is crucial to radio communication, namely the oscillator. The operation of this circuit is similar to that of the amplifier/tuned circuit combination described above with the exception that a small fraction of
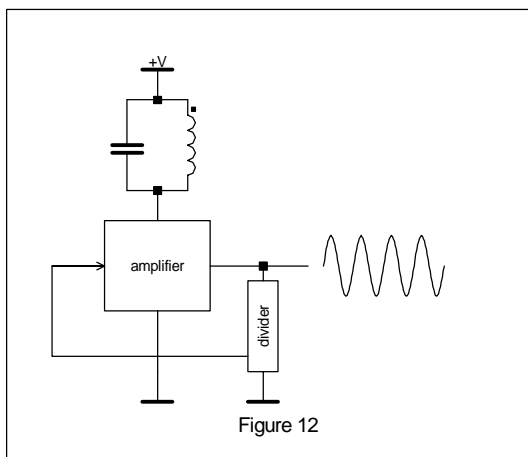
the output from the circuit is fed back to its input, as shown in Figure 12. It can be seen then that the input is amplified to produce the output that is then divided to produce the input. By arranging the component values correctly the circuit can be made to only produce an output signal over a narrow frequency band centred on the resonant frequency of the tuned circuit. By replacing the conventional tuned circuit with a crystal an oscillator may be designed that, for all intents and purposes, produces a single frequency output.

The strength of the output signal produced by an oscillator is dependent on the supply voltage, shown as +V in Figure 12, and this property is used in an AM transmitter to provide an easy method of modulating the amplitude of its output signal. The frequency of the signal produced by the oscillator is determined by the values of the components in the tuned circuit and it is this characteristic that is used in an FM transmitter to modulate the output frequency.

The AM Transmitter

Figure 13 shows the circuit elements of a simple AM transmitter. The power supply to the oscillator is now connected via a circuit whose output can be made to vary with the information being sent and the resulting varying amplitude output signal, similar to that shown in Figure 4, is connected to an aerial through an impedance matching network. This type of network is usually designed to maximise the signal present on the aerial thus ensuring the greatest operating range.
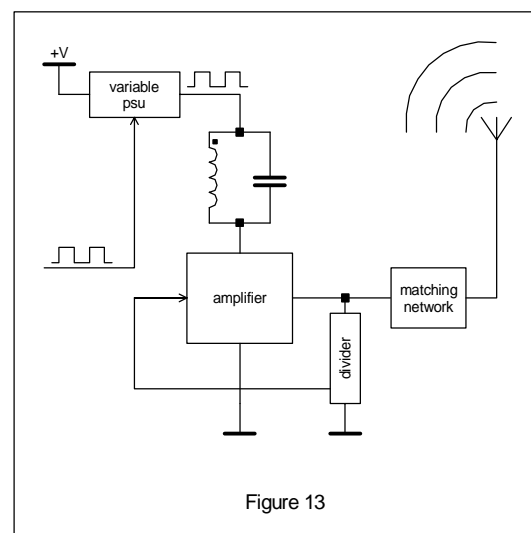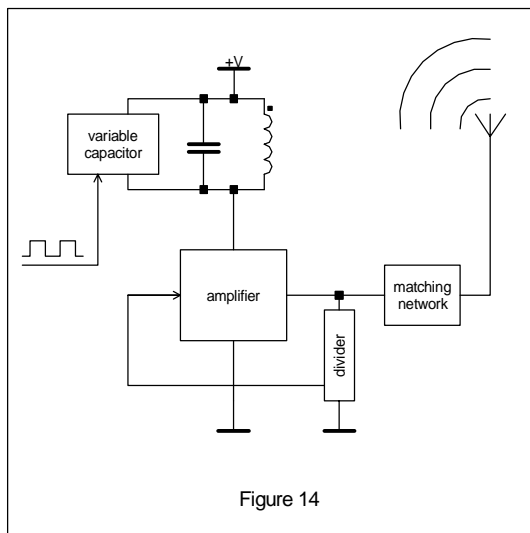

Figure 12

Figure 13

The FM Transmitter

Figure 14 gives the block diagram of a simple FM transmitter and shows it to be very similar to its AM cousin described above. In an FM transmitter, however, the power supply is kept constant and one of the reactive elements, usually the capacitor, is made to vary with the information being transmitted. This has the effect of changing the resonant frequency of the tuned circuit, and hence the oscillator output frequency, which produces a variable frequency carrier similar to that shown in Figure 6.

Figure 14

The SuperHet Receiver

While, in principle, a transmitter is very simple the same is not true for the receiver, which has a few more circuit stages to understand. Figure 15a, overleaf, shows the block diagram of a typical receiver as used in the R/C system. It falls into the class of receiver known as the super-heterodyne, or 'superhet' for short, and is usually constructed using functional blocks as described above plus two previously not mentioned circuit functions, namely the mixer and the IF amplifier, which are described in the following paragraphs

The block diagram of the complete receiver is the same irrespective of the modulation method. The demodulator is the only section with circuitry specific to the modulation method in use and will be an envelope detector in the case of an AM system or a discriminator if FM is being used.

The I.F. Amplifier

As described above, and shown in Figure 8, each of the R/C bands is divided up into a number of channels. For a receiver to operate on a particular channel and ignore adjacent ones its selectivity must match that of the channel width rather than that of the whole band. As shown in Figure 15a the RF amplifier that precedes the mixer is tuned but, in order to prevent the need for a different tuning setting for each channel, its selectivity is set such that it rejects out-of-band rather than off-channel frequencies.

It is the IF, or intermediate frequency, amplifier that provides the channel based selectivity. This is a fixed frequency tuned amplifier typically operating at around 455kHz which, because of its relatively low frequency compared with that of the carrier, is able to provide amplification over only a very narrow frequency range. It is thus able to reject signals that are only a few kHz away.

The Mixer Stage

The name of this class of receiver is derived from the Greek word 'heteros' which means 'different' or 'other' and it is the mixer stage that gives the receiver class its name. The mixer takes in two inputs, one from the aerial via an amplifier tuned to the band of interest, and another from an oscillator, known as the local oscillator, operating at a frequency with a specific offset, often 455kHz, from the incoming carrier. A detailed operational description of the mixer stage is beyond the scope of this Technical Note but, in essence, the two incoming frequencies 'beat' together to produce an additional signal with a frequency equal to their frequency difference, 455kHz in the example shown. The new signal contains all the modulation information of the original signal but is always at the same frequency irrespective of the original carrier frequency and is fed to the fixed frequency IF amplifier for further amplification as described above.

It can be seen, therefore, that the receiver may be tuned to accept an incoming signal of any frequency by simply changing the operating frequency of the local oscillator such that it operates at a frequency 455kHz away from that of the wanted carrier.

Double Conversion

One of the major drawbacks of the superhet receiver, when using a low intermediate frequency such as 455kHz, is that an unwanted carrier present at a frequency equal to twice the IF away

from the wanted carrier will also produce a 455kHz IF signal. In the example shown in Figure 15a the unwanted carrier frequency would be 27.910MHz (27.000MHz + 2 x 455kHz). Strictly speaking this frequency, known as the 'image frequency', is out-of-band but it is close enough for the RF amplifier to exhibit a response particularly if the signal is strong. The IF amplifier does not have the ability to separate the wanted signal from the unwanted one resulting in interference.

A common solution to this problem is to employ 2 separate intermediate frequency amplifiers each operating at a different frequency as shown in Figure 15b. In this, so-called, double conversion system the first IF operates at a high frequency which minimises the image frequency problem by moving it further away from the frequency band. Channel based selectivity is maintained by the use of a low frequency for the second IF in the normal way. The intermediate frequencies shown in Figure 15b are representative of typical use but are, by no means, the only frequencies that may be used.

This modification to the basic superhet design, although adding complexity, has the potential to offer an improvement in performance if the receiver must be operated in the presence of RF carriers with frequencies near to the wanted signal.

Conclusion

This first part of the series has given a brief description of the process of transmitting and receiving information by means of radio and it has also provided an insight into the operation of the circuitry necessary to achieve this. The operation of each of the circuit sub-sections has been explained using digital signals, where appropriate, as R/C equipment relies on this type of signal rather than its analogue counterpart.

The next part, MECTN004.PDF, examines a typical low-cost 27MHz AM PPM transmitter and describes the processes involved in encoding the transmitter stick and switch settings and how this information is impressed onto the carrier. The final part, MECTN005.PDF, discusses how the receiver subsequently receives and decodes the information into the separate signals required for driving the servos.
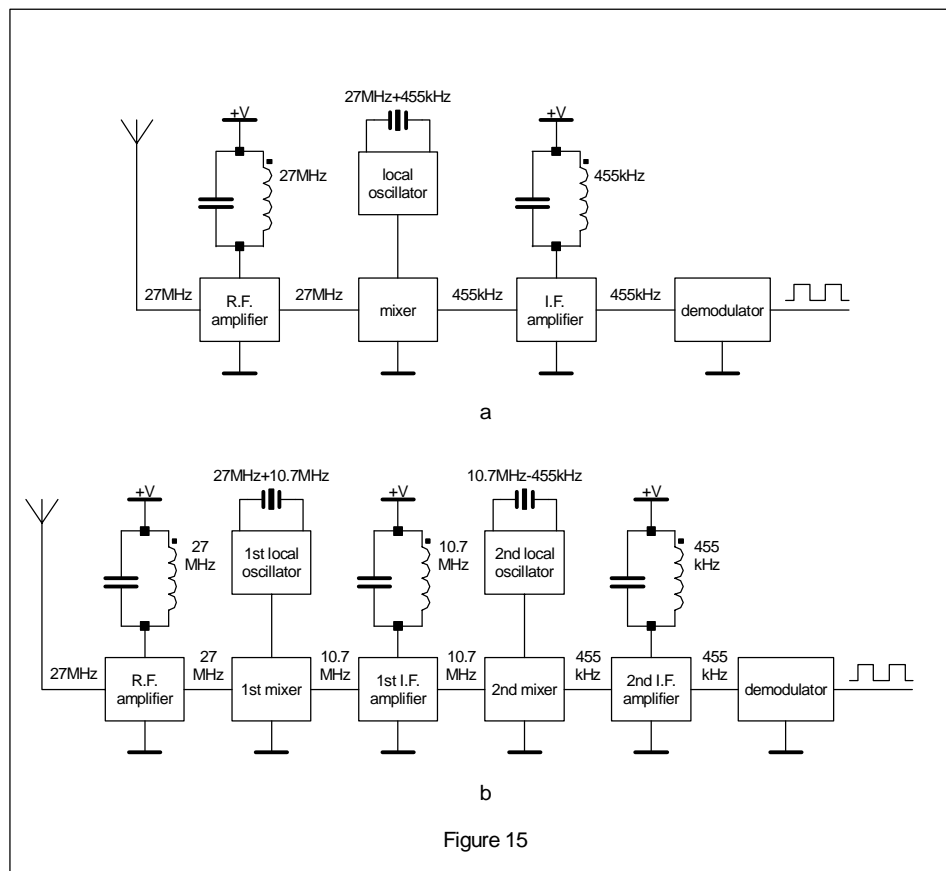

Figure 15

Notes

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