How It Works – The PPM Radio Control System: Part 3

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

Part 1 of the series (MECTN003.PDF) familiarises the reader with the terms and methods involved in sending information using a radio link by providing background information and a general description of the techniques used in radio communication.

The second part (MECTN004.PDF) describes the operation of a typical low-cost 27MHz AM PPM Radio Control transmitter but the principles involved are basically the same for both AM and FM units operating on any of the frequency bands.

This third part (MECTN005.PDF) examines the final link in the chain, the receiver, and describes how it performs the two functions of receiving the wanted carrier and decoding the information contained in the multi-channel frame into the separate signals required for driving the servos.

The Receiver RF Stages

In the first part of this Technical Note a general description of the superhet receiver was given that provided an insight into its operation. This part provides a more detailed description of the various circuit functions contained within the receiver section.

In a typical situation the receiver will be operating in the presence of more than one transmitter, and hence more than one RF carrier, so one of its primary functions is to isolate, from all the others, the signal being received on the channel to which it is tuned. This is the function of the receivers RF stages.

The RF Amplifier

The strength of the RF carrier seen by the receiver reduces as the distance from the transmitter increases but, because the required range of operation is relatively short, it is not always necessary to provide additional amplification at the carrier frequency in an R/C receiver.

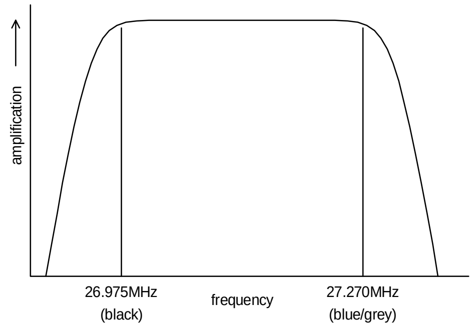

Figure 25

When it is included the RF amplifier provides extra gain at the carrier frequency and therefore increases the receiver sensitivity, that is its ability to pick up weak signals. Because it is a tuned amplifier, designed to amplify all frequencies within the R/C band and to reject those outside, it also improves the selectivity of the receiver, i.e. its ability to reject unwanted signals. This reduces the susceptibility of the receiver to out-of-band interference but, because it amplifies all frequencies within the band equally, it cannot provide any distinction between the various channels. Figure 25 shows the response of a typical amplifier.

The Mixer Stage

This stage is at the heart of the superhet receiver and provides an output signal with a fixed frequency, irrespective of the channel in use, that contains all of the modulation information of the original RF carrier. The mixer operates by taking in two signals, one from the aerial at the carrier frequency and the other from a local oscillator set to operate at a frequency with an offset from the carrier equal to the IF frequency. As stated in part one the operation of the mixer stage is quite complex but it is essentially a modulator, similar in principle to that used in the transmitter shown in

Figure 23 from part two, and it 'multiplies' the two signals together. This action has the effect of producing 'sum and difference' frequencies and Figure 26 illustrates this process using a carrier signal at 27.000MHz and a local oscillator signal at 27.455MHz. There are two additional signals shown in the diagram, these being the 'sum frequency' at 54.455MHz and the 'difference frequency' at 0.455MHz or 455kHz.

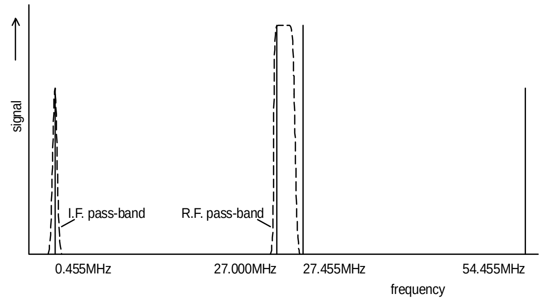

Figure 26

It is the difference signal at 455kHz that is chosen to be the intermediate frequency, or IF, signal and is so named because it comes between any RF stages, operating at the carrier frequency, and the detector. The difference signal is fed to the IF amplifier which, as it operates at a fixed frequency, does not require re-tuning when the system is operated on a different channel and so allows a considerable simplification of the tuning process.

This simplification of the tuning process is one of the main reasons for the widespread adoption of the superhet receiver because, in the case of an R/C receiver, it is just a single component needs to be changed in order to use a different channel. This component is the crystal and there are two such crystals needed to tune a complete R/C system and these are made, and sold, as pairs. The transmitter crystal is made to resonate at the carrier frequency of the chosen channel and the receiver crystal is designed to operate at a frequency with a 455kHz offset, often on the high side.

The frequency offset does not have to be 455kHz and any value may be chosen. It is important, however, that the offset be greater than the width of the band as a smaller frequency difference would lead to the local oscillator operating at, or near, a high channel carrier frequency when the system was operating on one of the low channels.

The IF Amplifier

The IF amplifier is a frequency selective amplifier operating at a fixed frequency, typically 455kHz, irrespective of the RF carrier frequency in use. As previously described the selectivity of an R/C receiver has to be such that it can reject strong signals present on an adjacent channel and, as shown in Figure 8 from part one, this requires a 'bandwidth' of about 15kHz. A typical IF pass-band response is shown as the dashed line centred on 455kHz in Figure 26 and, when compared with the RF pass-band also shown, can be seen to be considerably less wide.

The ratio between operating frequency and bandwidth is a measure of the quality factor, or Q, of a frequency selective amplifier and ratios above about 200 are difficult to attain with low-cost circuitry. As an example, an amplifier operating at 27MHz and requiring a 15kHz bandwidth would need to have a Q of 1800 while a similar amplifier centred on 455kHz would need a Q of only about 30. It is this relative ease of obtaining selectivity that is the second reason for the popularity of the superhet receiver.

The Detector

The envelope detector was described in part one of this Technical Note and is used to extract a representation of the original multi-channel frame signal from the carrier. The output signal it provides depends on the strength of its input signal and, as described above, the strength of the signal arriving at the receiver aerial falls with distance. In order to provide a signal suitable for feeding to the subsequent decoder there is a minimum signal level requirement at the detector input. An obvious solution would be to increase the amplification of the preceding IF stage such that even very small RF signals will provide a sufficiently large input signal to the detector. In an AM system, unfortunately, this method gives problems when operating over a short range because the signal then becomes too large to be handled correctly. To overcome this a system known as automatic gain control, or AGC, is employed.

Automatic Gain Control

The action of the AGC circuit is to control the gain of the IF amplifier based on the strength of the output signal it produces. If the amplitude of the detector output signal falls the AGC system provides a corrective action to increase the IF amplification and thus restore the signal strength at the detector input. Figure 27, overleaf, shows two detector signal levels, one small and one large, and demonstrates that the peak-to-peak amplitude of the detector output signal is proportional to the signal strength at its input.

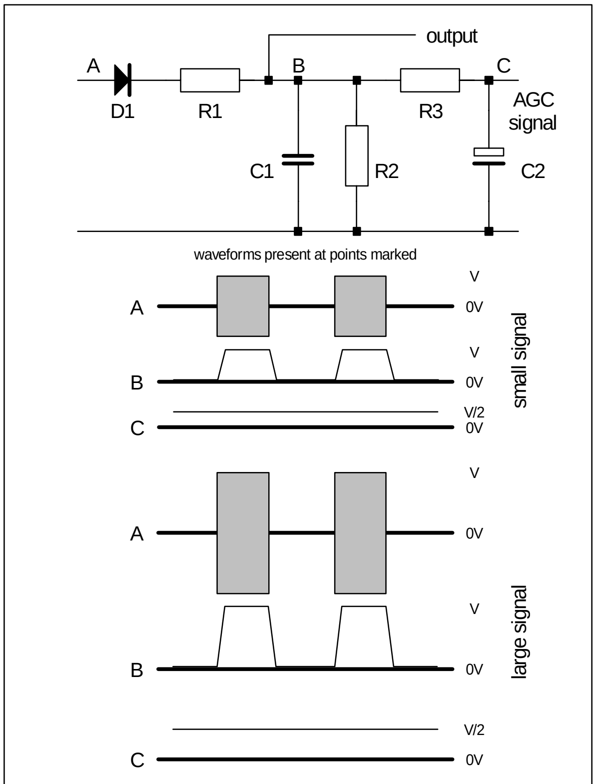

Figure 27

Provided that the signal content is fairly constant, as it is in the case of an R/C system, the average value of the detector output may be used as a measure of signal strength and this is obtained using resistor, R3, and capacitor, C2. The values of these components are such that their time constant is too long to be able to follow the rapidly changing output signal and therefore, over time, the AGC output attains a voltage equal to its average value. Feeding a correctly scaled proportion of this back to the IF amplifier will exert control over its gain maintaining the optimum setting over a wide range of RF carrier signal strengths as shown in Figure 28.

This figure shows the detector input signal and the IF amplifier gain as solid and dashed lines respectively. It can be seen that as the RF signal strength increases from zero so does the detector input. The point depicted as the start of the control range is the point at which the AGC circuit starts to operate. and, as the RF signal level continues increasing, the IF amplifier gain is correspondingly reduced by the AGC circuit to maintain the detector input constant.

At the other end of the scale when the AGC can reduce the IF amplifier gain no further the signal level fed to the detector starts to rise again. With proper circuit design any problems that may be caused by this increasing signal can be all but eliminated.

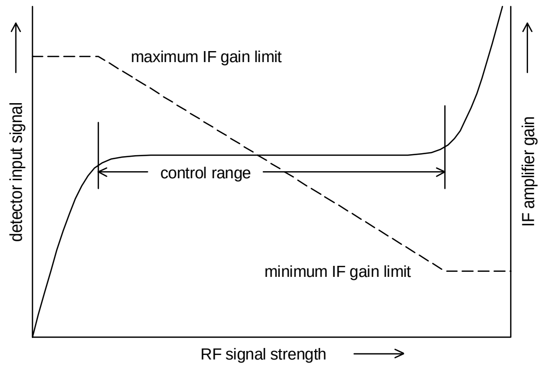

Figure 28

The Decoder Section

The second major function performed by the receiver is the extraction of the information, relating to the individual control channels, from the multi-channel frame and the generation of the separate signals suitable for driving servos. It is the decoder section that performs this task and, in some ways, it operates in a similar fashion to the encoder contained in the transmitter described in part two. It is triggered by the start of each frame to decode the information for channel 1 and then continues to extract channel information until it is reset back to channel 1 by the synchronisation time, or sync time.

Figure 18 from part two provides a representation of a multi-channel frame and shows how the carrier-off periods, Tf, delimit the individual channel information. It is the falling edge of the Tf period that indicates both the start of the information for a given channel and the end of that of the previous one and it is these edges that 'step' the decoder on to the next channel. A typical decoder, suitable for this type of operation, may be fabricated using a device known as a shift register.

The Shift Register

A register, in the electronic context, is a storage device and may be used to store the state of a digital signal at a given moment and 'memorise' it even after it has changed. Figure 29a shows an example and some operating waveforms. At the start of the waveforms shown in the diagram the input, 'B', and the output, 'C', are both at a low state and shortly afterwards the input changes to a high state. The output remains as it was thus memorising the previous input state. The device is made to update its memory by the clock signal, shown as 'A' in Figure 29a, and is arranged to only perform an update when the clock edge rises and, at the first rising edge, the output adopts the state currently present at the input. It is only when the clock signal has fallen and then rises again that the output is once again updated.

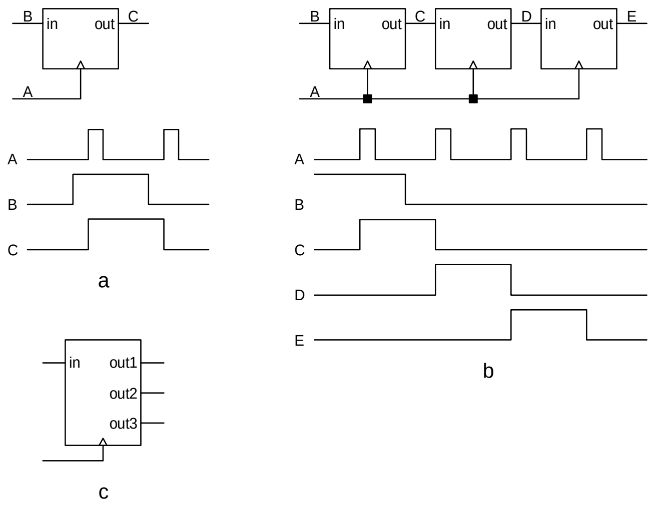

Figure 29

A shift register is a chain of such registers, connected output to input as shown in Figure 29b. The waveforms below the diagram show how the input state, i.e. a high state, present at the beginning of the sequence is placed onto the output of the first register at the time of the first clock. On the following clock edge the second register adopts the output state of the first and, provided the input signal has changed, the output of the first register reverts to a low state. This process continues with the following clock edges and it can be seen that the output of each register temporarily, and exclusively, holds the initial state for the period between clock pulses.

Were this 3-stage shift register to be contained within a single IC the internal connections would be omitted from the diagram and it would be represented as shown in Figure 29c.

Separating the Channel Information

Figure 30, overleaf, shows a simplified diagram of a 4-channel decoder system and a set of operating waveforms with timings based on the multi-channel frame presented in Figure 18 from part two. The waveform shown as 'A' in Figure 30b is the 455kHz amplitude modulated signal into the envelope detector and that at 'B' the demodulated signal. When the RF carrier is present the detector output adopts a high state and thus diode, D1, is not conducting. This allows R1 to discharge C1 such that node 'C' on the circuit attains a voltage equal to +V. This signal feeds one input of a comparator circuit whose other input is set at 0.66(+V) by R3 and R4. With its '+' input at a higher voltage than its '-' input its output is high, as shown by the waveform 'D' in Figure 30b, and thus the data input to the shift register is high. This may be considered the quiescent, or at-rest, state of the circuit.

At the start of a frame the RF carrier is turned off for the first of the Tf periods and the detector output, 'B', immediately switches to a low state and the signal shown as 'E' in Figure 30b, being an inverted version, correspondingly goes high. This signal is the shift register clock and, as it is a rising edge, clocks the high level at 'D' into the first register whose output is shown as 'F' in the figure.

Resistor, R2, has a low value and can charge capacitor, C1, fairly quickly when the detector output goes low during a Tf period. At the end of a Tf period, when the detector output goes high again, C1 begins to discharge through R2 but, because R2 has a relatively large value and is therefore a slow 'leak', it still has much of its charge left when the next Tf period starts. The comparator output, therefore, goes low shortly after the start of a frame and remains low until part way through the sync time when C1 is allowed to discharge fully due to the absence of Tf periods. This action is shown in the waveform at 'C' in Figure 30b and ensures that the output of the first shift register stage returns to a low state, as required, at the second clock pulse.

All of the 4 shift register outputs are shown as the waveforms 'F' through 'I' in the figure and each one is a control signal, with a repetition rate equal to

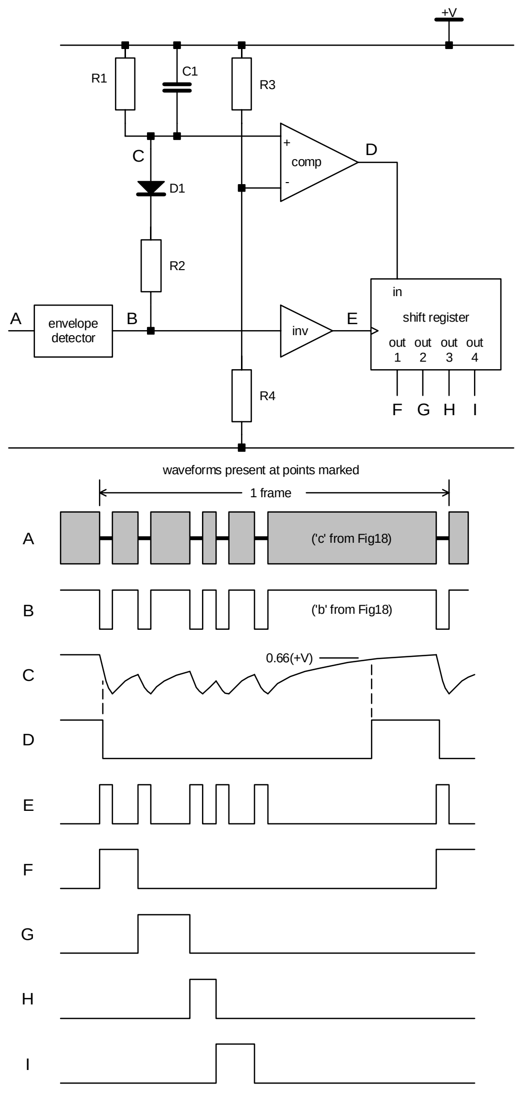

Figure 30

the frame rate, suitable for driving a single servo. As can be seen each output is exclusively high during its allocated channel time and the duration of each channel time depends on the time between its preceding and succeeding Tf pulses which, as described in part two, depends on the transmitter stick positions. The fact that each servo receives its position control pulse at a slightly different time has no real effect on the operation of the system from a model control standpoint, as the times involved are so short.

A Complete Receiver

Figure 31, overleaf, shows a typical block diagram for a complete 6-channel R/C receiver to complement that given for the transmitter in part two and, as before, the diagram shown is somewhat simplified and the functions shown within the dotted line may be contained within a single IC. Note that the tuned circuits are shown with variable inductors rather than variable capacitors and, although variable inductors are fragile components, this is normal practice in receiver construction as the range of tuning required is small and adjustment is only performed at the factory.

The signal received by the aerial is fed to the RF amplifier that is tuned to the R/C frequency band by L1 and C1. This amplified signal, along with the output from the local oscillator, is fed to the mixer stage and, from there, to the tuned transformer, T1. A tuned transformer is similar to an ordinary tuned circuit but has the added benefit of allowing a good impedance match between the stages as well as selecting the difference frequency of 455kHz for passing onto the IF amplifier. The IF amplifier is tuned to 455kHz by L2 and C2 and drives the detector which provides both the reconstructed signal originally sent by the transmitter and also the AGC signal for IF amplifier gain control. Apart from the two capacitors, C3 and C4, which perform the functions of capacitors C2 and C1 from Figure 27, all the demodulator components are contained within the IC. The demodulated signal obtained across C4 is fed to the decoder section and, again, the majority of the necessary components, as indicated in Figure 30, are contained within the IC. The exceptions being R1 and C5, the equivalents of R1 and C1 from Figure 30, which are external to the IC to allow for some design flexibility.

Conclusion

This final part of the series has discussed the detailed operation of the receiver section of a typical R/C system. The two previous parts first present a general discussion on the terms and techniques used in communication by radio and secondly give a detailed presentation on the operation of a typical R/C transmitter.

Having read all three parts it is hoped that the reader now has a better understanding of the intricacies and true complexity of a modern low-cost proportional R/C system normally hidden from most of us by the sculptured plastic case.

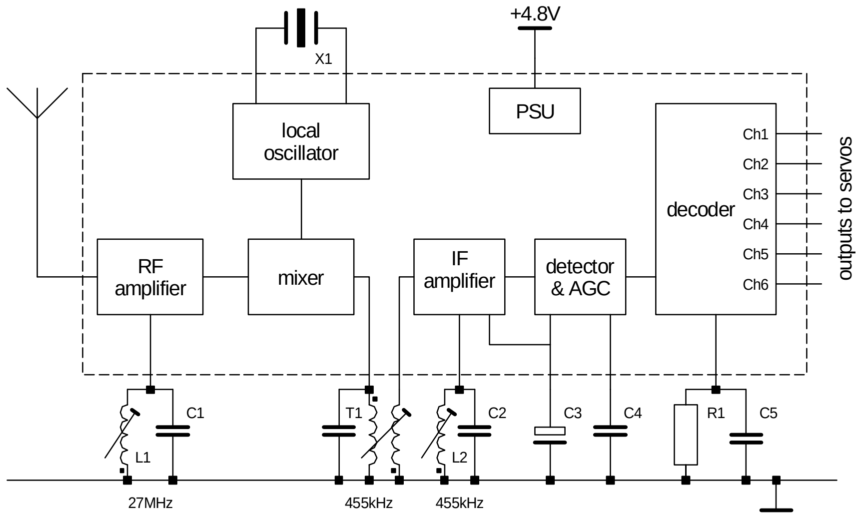

Figure 31

Notes

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