

## How It Works – The PPM Radio Control System: Part 2

### 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.

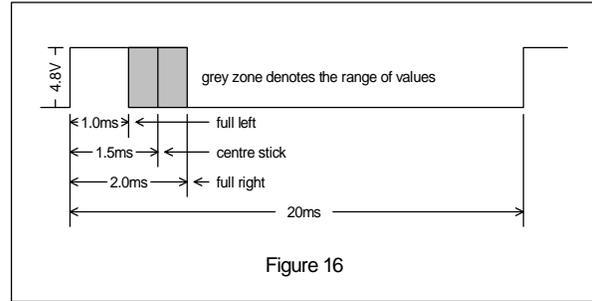
### Introduction

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. This 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. Part 3 (MECTN005.PDF) examines the receiver and describes how it decodes the information contained in a multi-channel frame into the separate signals required for driving the servos.

### The Servo Control Signal

Each channel in an R/C system can be used to provide control over one aspect of the behaviour of a model and typical examples, for a system with only two channels, might be the rudder and motor speed. Each channel requires a separate signal in order to effect control over the model and, typically, this is a short pulse whose width is made to vary with the transmitter stick movement. There is a generally accepted standard for the pulse width range to ensure inter-operability between the

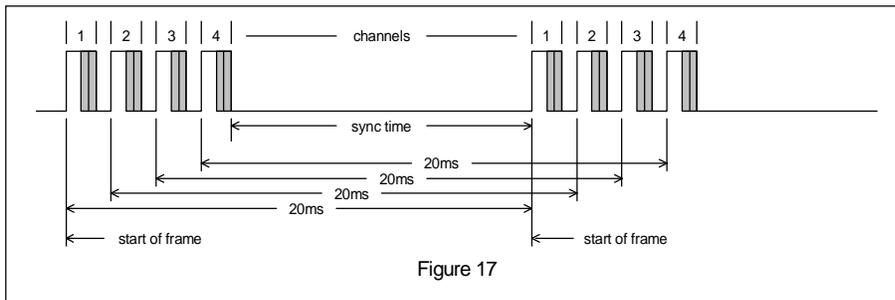
products of various manufacturers and a typical signal is represented in Figure 16.



The full  $\pm 0.5\text{ms}$  range of pulse widths is shown although most systems do not utilise it all. Also shown is the pulse repetition rate, or frame rate, of 20ms which means that each channel is updated 50 times per second. A servo, when driven by this signal, will adopt a position determined by the width of the pulse with, for example, 1ms representing fully anti-clockwise and 2ms fully clockwise.

### The Multi-Channel Frame

In order to have control over more than one servo over what is effectively a single RF link the information relating to each channel is sent in a 'serial' fashion, i.e. one after the other. Figure 17 shows this in diagrammatic form for a system with 4 channels and, as can be seen, the information for each channel repeats in the same place in every frame. When this compound signal, or multi-channel frame, is separated back into 4 separate servo control signals each will resemble that shown in Figure 16. The space between the pulse relating to the final channel, channel 4 in the example shown, and the start of the next frame is known as the synchronisation time, or sync time for short. This time is, effectively, the 'dead time' and varies with the number of channels and also with the channel content. However, even



for a system with 8 channels, it is much longer than the time between successive channel pulses and the receiver uses this to synchronise itself to the pulse train. This ensures that the positional information for channel 1 always drives the correct servo.

### The Transmitted Signal

Figure 17 illustrated the concept of sending multiple information channels over a single RF link. In actuality the signal transmitted differs somewhat as shown in the various sections of Figure 18 below.

Figure 18a shows that a single channel section of the transmitted waveform is made up of two distinct parts. These are a fixed time, shown as  $T_f$  and typically 0.5ms in length, and a variable time,  $T_v$ , which ranges from 0.5ms to 1.5ms depending on the stick position. Combining these two times gives a total channel time that can vary between 1.0ms and 2.0ms.

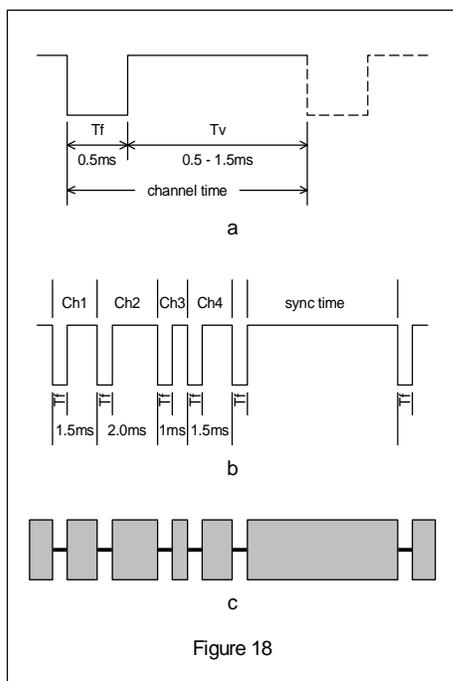


Figure 18

Figure 18b shows 4 of these individual channel times, with varying lengths, concatenated into a multi-channel frame and shows the 'time-slice' relating to each one. It can be seen that the position, relative to the start of the frame, of each successive  $T_f$  time depends on the information content of the preceding channels and it is this characteristic that provides the description of pulse

position modulation, or PPM, for the data encoding method. The key to understanding the final decoding process, to be described in the final part of the series, is to know that the receiver uses the falling edge at the start of each channel time to also indicate the end of the previous channels information.

Figure 18c shows the transmitted RF carrier for an AM system sending the information shown in Figure 18b. Note that rather than just reducing the amplitude of the carrier for the duration of each  $T_f$  period it is actually switched off momentarily. This is done to deliver the maximum change in signal level to the envelope detector, described in the first part of the series, and results in the fastest response and hence the best possible timing accuracy.

### The Transmitter

The transmitter performs the functions of interpreting the various stick and channel switch positions, encoding these into a repeating train of pulses and impressing this pulse train onto an RF carrier.

### The RC Time Constant

In order to understand how the transmitter interprets the stick positions it is necessary to introduce the RC time constant. This is a characteristic of a simple circuit made up from a resistor and a capacitor. Figure 19, overleaf, shows the two basic arrangements with Figure 19a showing a capacitor charging circuit, and Figure 19b, a discharge circuit. The time constant,  $T$ , is defined as the length of time taken, in seconds, for the capacitor to charge, or discharge, to approximately 63% of its final voltage and is calculated as the product of the two component values.

As an example if 'R' has a value of 10 Ohms and 'C' has a value of 0.1 Farads the circuit time constant is 1 second ( $T=C \times R$ ). The final voltages, as shown in the circuits of Figure 19, are +V for charging and 0V for discharging and are reached in approximately  $5 \times T$ .

Figure 19c combines the two circuits and adds two switches. When closed switch, SW1, will charge the capacitor, C, via resistor, R1, and when open will cause the capacitor to hold its charge provided that switch, SW2, is also open. Closing SW2 will discharge the capacitor provided SW1 is open. The action is, thus, similar to that of the envelope detector described in the previous part of the series with the capacitor behaving rather like a

bucket with two taps, one to fill it and the other to drain it. For a capacitor with a given value the rates of charge and discharge are set by the values of R1 and R2, the smaller the resistor the quicker the action. Figure 19d shows the response of the circuit to a particular switch operating sequence. The value for R1 is smaller than that for R2 and, therefore, the capacitor is charged more quickly than it is discharged.

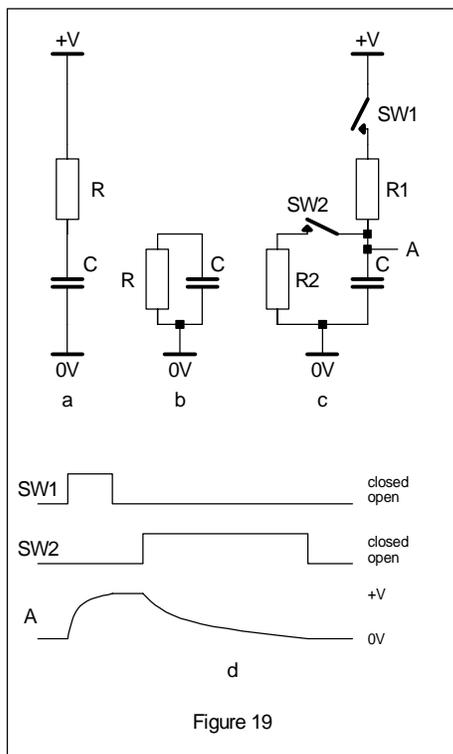


Figure 19

### Interpreting the Stick Position

Figure 20a shows the simplified circuit of a method for determining the stick position and is an extension of the circuit shown in Figure 19c with the addition of automatic control of the two switches based on the voltage on capacitor, 'C'. Operation of the circuit can be understood by first considering it at rest. Under these conditions switch, SW1, is closed but a special circuit contained in the comparator block clamps the capacitor voltage at 0.33(+V). On receipt of a trigger pulse, depicted as 'A' in Figure 20b, the output, 'C' in the figure, changes state and the clamping circuit 'lets go'. The capacitor begins to charge, shown by 'B' in Figure 20b, toward the supply voltage '+V' and after a time, determined by Rf, the capacitor voltage reaches the upper

threshold of 0.66(+V). When this point is reached the output changes state back again, SW1 is opened and SW2 is closed and the capacitor discharges back toward 0V at a rate set by the current value of variable resistance Rv. Each transmitter stick controls the value of a variable resistance, also often called a potentiometer, and, as shown in Figure 20b, changing the stick position alters the discharge time and hence the duration of time, Tv. When the capacitor voltage reaches 0.33 (+V) the clamping circuit is switched on again, SW1 is closed and SW2 is opened. The final action in the sequence is the generation of a termination pulse, Tt, to signal the end of the channel time. The power supply to this circuit, +V, is usually regulated at about 5V to ensure that the circuit performance remains essentially constant even when the batteries are almost fully discharged.

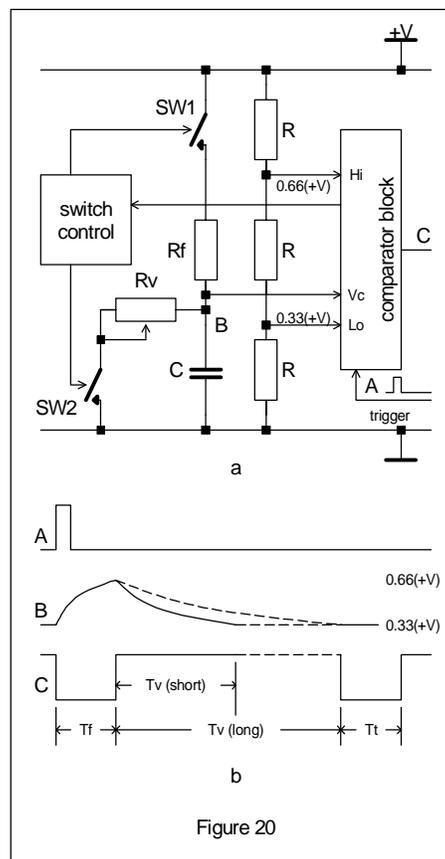


Figure 20

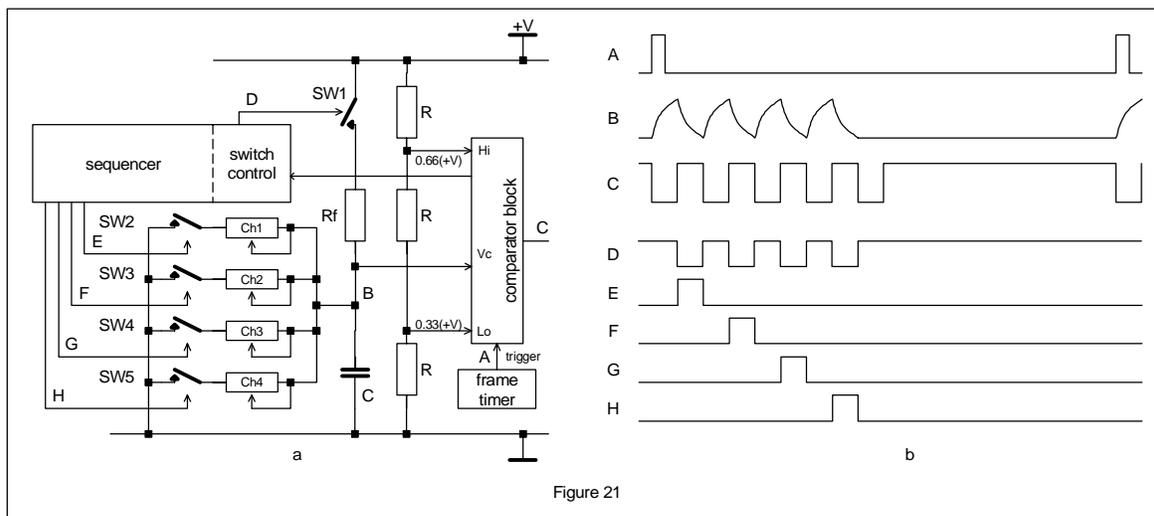


Figure 21

### Making it Multi-Channel

The block diagram shown in Figure 20 only provided single channel control. Figure 21a illustrates a multi-channel version of the same basic circuit. A sequencer has been added to the switch control block, to select each of the 4 variable resistors in turn, and an additional timing circuit has been included to provide a trigger pulse every 20ms thus setting the frame rate. The waveforms depicted in Figure 21b show the signals at important circuit nodes during a complete frame. Traces A through C show the same nodes as in Figure 20 and with traces D through H showing the various switch states, a high level denotes that the switch is closed, and the action of the sequencer can clearly be seen. Note that in a real R/C transmitter the switch functions, SW1 through SW5, would be implemented using transistors rather than switches. When a comparison is made between trace C in Figure 21b and that shown in Figure 18b it can be seen that the output signal from the comparator block is the signal used to modulate the RF carrier.

switch, SW1, is closed the discharge time,  $T_v$ , is determined by just R1 and is, therefore, short. With SW1 open the duration of  $T_v$  is longer as both R1 and R2 determine it and, with suitable values, the channel time may be set to either 1.0ms or 2.0ms.

### More Than 4 Channels

Many transmitters have more than the 4 channels shown in the example system presented in this Technical Note. The extra channels are usually controlled by switches and are suitable for functions with only two states, e.g. the undercarriage. From the transmitters point of view the switch is treated as if it were an ordinary stick that has only two positions, full left or full right. Replacing any of the variable resistors shown in Figure 21 with the circuit shown in Figure 22a will provide that channel with two-state control. When

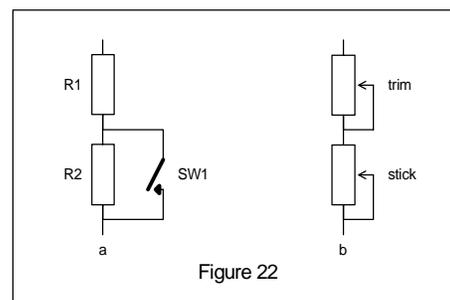


Figure 22

### The Trim Controls

These devices are fitted to each of the stick axes and may be used to trim a model, perhaps to counteract a tendency to climb, or to correct for any slight inaccuracies in the centre-stick position. Their method of operation falls into two categories; the first, which is essentially mechanical, can rotate the body of the potentiometer a few degrees in either direction relative to the stick and thus alter the setting slightly. The second method, shown in Figure 22b, is purely electrical and places an additional variable resistance, which has a total value of about 10% of the stick potentiometer, in series with the main one and so gives the capability of minor adjustments to the total resistance.

### Modulating the RF Carrier

The first part of this series introduced the basics of communication by radio and showed, in Figure 13, a block diagram of an AM transmitter. It is reproduced in this part as Figure 23, shown below, with a little more detail and a crystal, X1, replacing the tuned circuit. In this diagram transistor, Q1, performs the function of the variable power supply and is driven by the modulating signal from the comparator block.

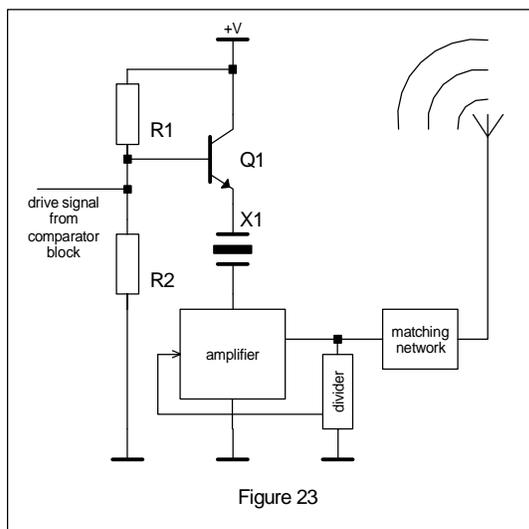


Figure 23

Figure 18c shows that the RF carrier is actually switched off for the duration of each  $T_f$  period and thus it would be reasonable to assume that the supply to the oscillator was removed completely during this time by the action of Q1 in Figure 23. In fact this is not the case because the period of  $T_f$  is so short at around 0.5ms. The power supply is actually reduced to a level that ensures the RF carrier is rapidly switched off by retaining a low level of bias on the oscillator circuit. This action is required because the crystal, when operating at resonance, behaves like a tuned circuit and has a tendency to continue oscillating after the removal of its power supply. In order to prevent the residual oscillations reaching the aerial, where they would cause the carrier-off instant to be less well defined and therefore lead to timing inaccuracies, they need to be 'short circuited' and this is achieved by maintaining both Q1 and the oscillator circuit in conduction.

In Figure 23 resistors, R1 and R2, provide the low level of bias for the duration of  $T_f$  and the output stage of the comparator block is arranged to drive Q1 so as to increase the oscillator supply voltage to about +5V when the carrier is required to be on. This voltage is significantly below the battery voltage and ensures that the RF output power is held at its designed level, and hence the operating range is unaffected, even when the batteries are almost flat.

### Putting it all Together

Figure 24 shows a typical block diagram for a 6-channel R/C transmitter. All the circuit functions shown within the dotted line may be contained within a single integrated circuit and, although the figure shows a somewhat simplified diagram, it can be seen that, due to the relative complexity of the IC, the amount of additional circuitry required is very small.

The 4 sticks are represented by VR1 through VR4 and SW1 and SW2 provide the settings for channels 5 and 6. The frame timer uses capacitor, C1, to determine the frame period and the inclusion of capacitor, C2, controls the rate at which the amplitude of the RF carrier increases after being switched off for the time period,  $T_f$ , and thereby prevents interference to nearby channels. The crystal, X1, sets the RF carrier output frequency and this is the only component that needs to be changed to select a different channel of operation.

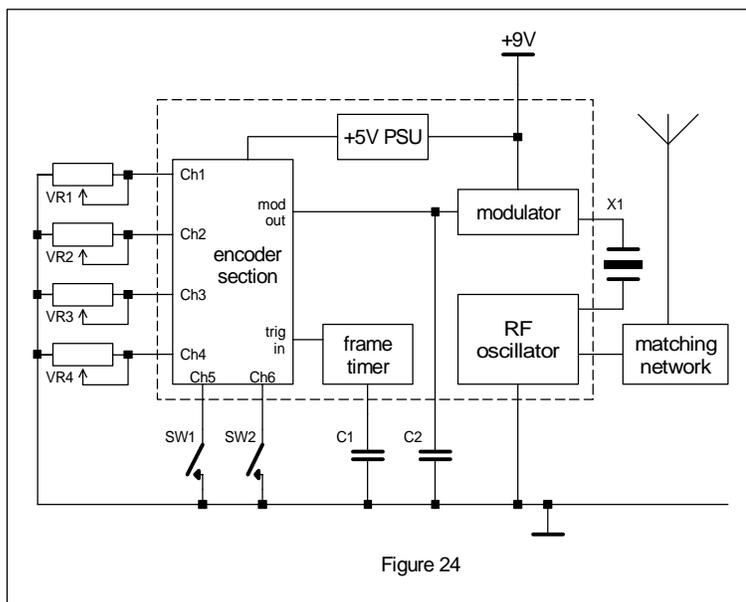


Figure 24

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## Conclusion

This second part of the series has given an in-depth description of the operation of a typical R/C transmitter and has explained the processes involved in generating the multi-channel frame, encoding the transmitter stick and switch settings and how this information is impressed onto the carrier. The final part, MECTN005.PDF, examines receiver and describes how it receives and decodes the information contained in the multi-channel frame into the separate signals required for driving the servos.

## Notes

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