LOW POWER RADIO CONTROL SYSTEM

★ **27MHz Operation For Ground-Based Model Control**
★ **Two Positive Pulse PWM Channels**
★ **Two Digital On/Off Channels**

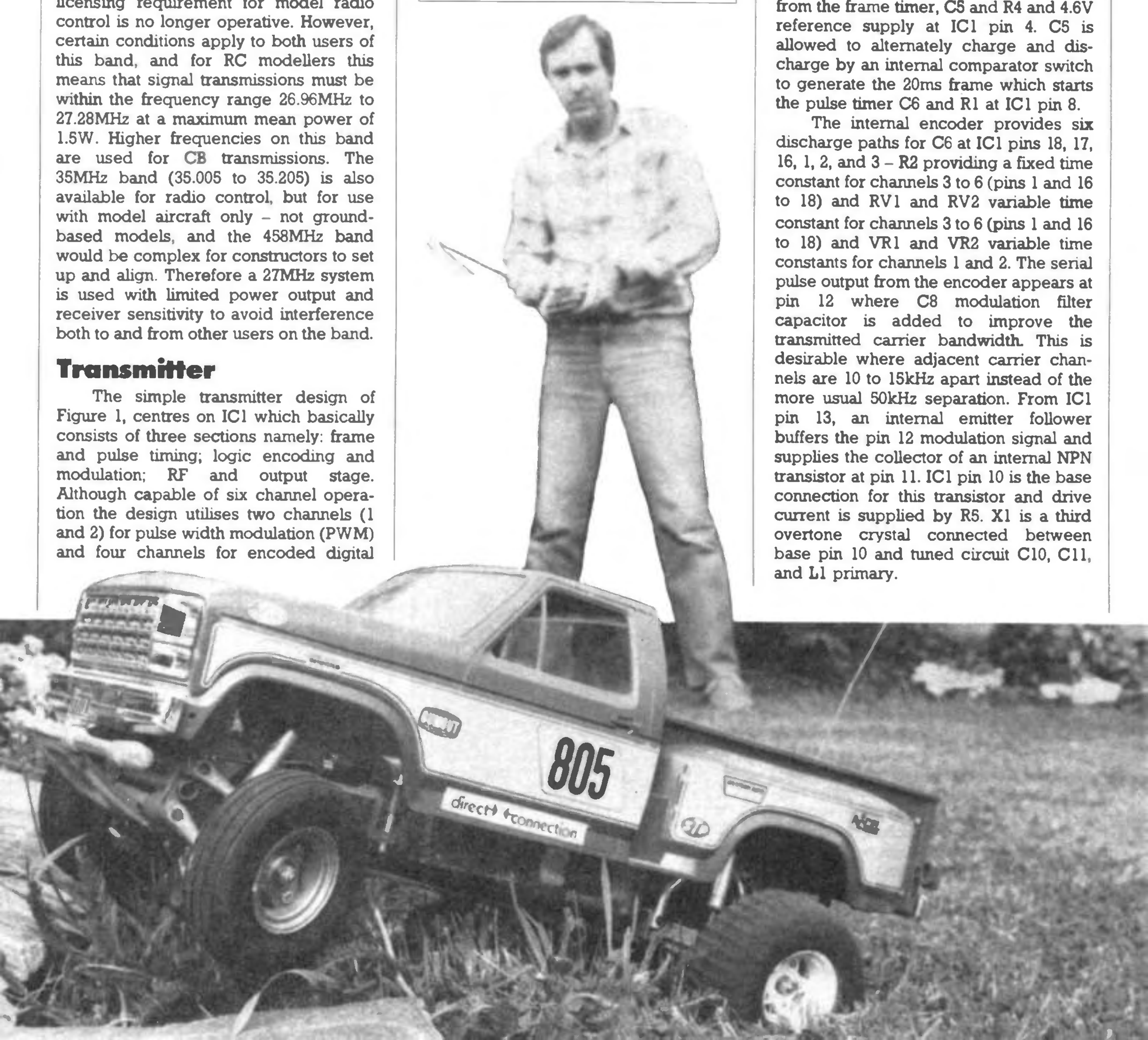
by Dave Goodman

Since 1981 and the legalising of Citizens Band Radio on 27MHz, the licensing requirement for model radio control is no longer operative. However, certain conditions apply to both users of this band, and for RC modellers this means that signal transmissions must be within the frequency range 26.96MHz to 27.28MHz at a maximum mean power of 1.5W. Higher frequencies on this band are used for CB transmissions. The 35MHz band (35.005 to 35.205) is also available for radio control, but for use with model aircraft only – not ground-based models, and the 458MHz band would be complex for constructors to set up and align. Therefore a 27MHz system is used with limited power output and receiver sensitivity to avoid interference both to and from other users on the band.

Transmitter

The simple transmitter design of Figure 1, centres on IC1 which basically consists of three sections namely: frame and pulse timing; logic encoding and modulation; RF and output stage. Although capable of six channel operation the design utilises two channels (1 and 2) for pulse width modulation (PWM) and four channels for encoded digital (on/off) information. A train of six pulses (Figure 3) is generated every 20ms (50Hz) from the frame timer, C5 and R4 and 4.6V reference supply at IC1 pin 4. C5 is allowed to alternately charge and discharge by an internal comparator switch to generate the 20ms frame which starts the pulse timer C6 and R1 at IC1 pin 8.

The internal encoder provides six discharge paths for C6 at IC1 pins 18, 17, 16, 1, 2, and 3 – R2 providing a fixed time constant for channels 3 to 6 (pins 1 and 16 to 18) and RV1 and RV2 variable time constant for channels 3 to 6 (pins 1 and 16 to 18) and VR1 and VR2 variable time constants for channels 1 and 2. The serial pulse output from the encoder appears at pin 12 where C8 modulation filter capacitor is added to improve the transmitted carrier bandwidth. This is desirable where adjacent carrier channels are 10 to 15kHz apart instead of the more usual 50kHz separation. From IC1 pin 13, an internal emitter follower buffers the pin 12 modulation signal and supplies the collector of an internal NPN transistor at pin 11. IC1 pin 10 is the base connection for this transistor and drive current is supplied by R5. X1 is a third overtone crystal connected between base pin 10 and tuned circuit C10, C11, and L1 primary.



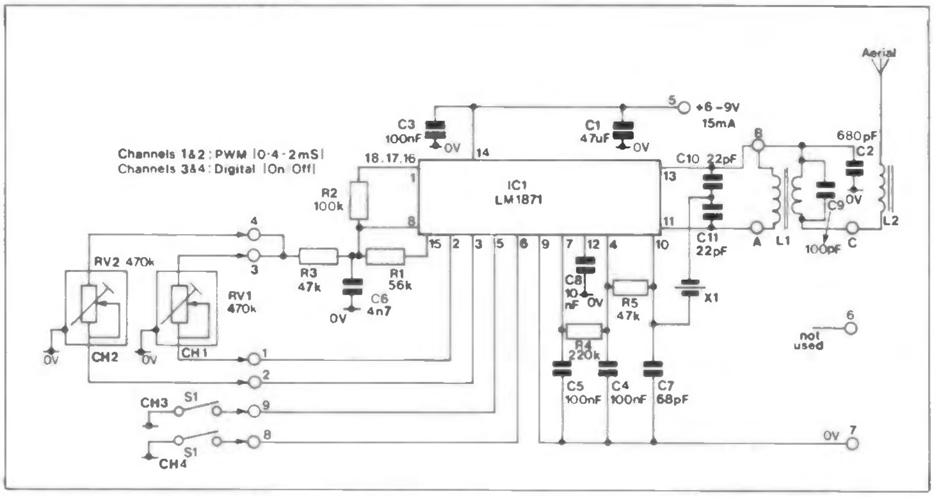


Figure 1. 27MHz Transmitter circuit diagram

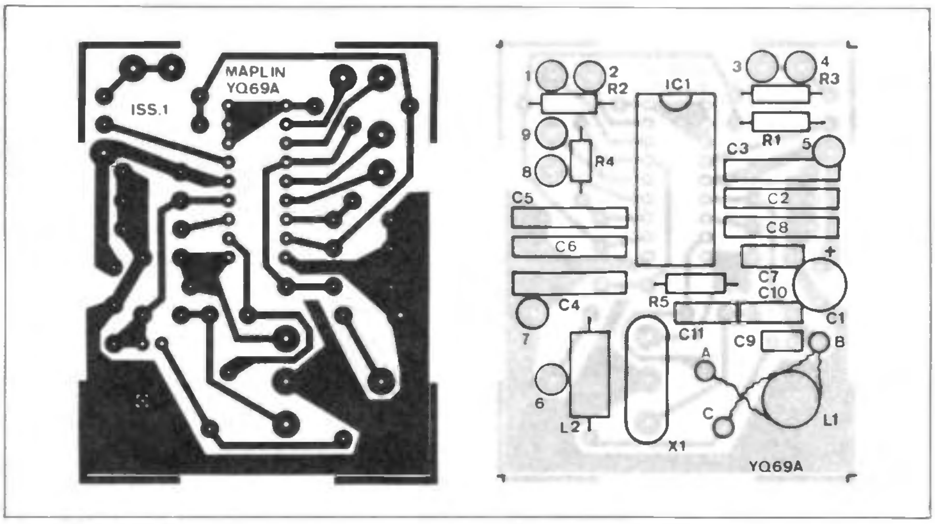
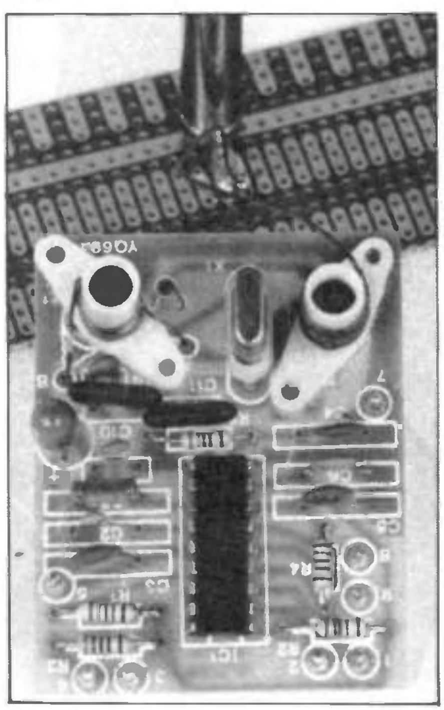


Figure 2. Track layout and overlay of Transmitter PCB

When the modulation output is high (+3.8V) at pin 13, the collector pin 11 and tuned circuit are pulled up into the active range of the internal transistor. RF feedback is via the crystal and pin 10, causing the tuned circuit to resonate at the desired frequency. Because third overtone crystals are used in this application a tuned collector load must be used to guarantee operation at the correct frequency. Tuning L1 by moving its dust core in and out of the former has very little effect on oscillator frequency, but does vary the angle of conduction and hence oscillator efficiency and harmonic suppression.

C3 and L1 secondary are also tuned to 27MHz and dust core adjustment determines coupling between both coils. For precise PWM detection it is necessary to produce a high on/off ratio when modulating the carrier. When modulation from pin 13 is low, crystal X1 continues to oscillate for some 500μs due to the high Q characteristics of the circuit. This 'ringing-on' would reduce the carrier modulation depth and C7 damps the crystal during this time; short carrier off times also help overcome this problem, but require X1 to be isolated from the aerial circuit, hence the split tuning capacitors C10 and C11. L2 further low-pass filters the transmitted carrier, thus reducing upper harmonic content and doubles as a base loading coil for the aerial.



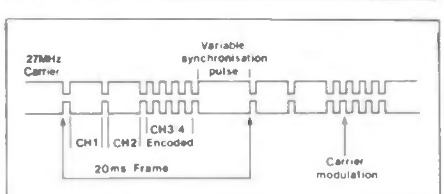


Figure 3. Transmitter envelope

Aerials

When calculating wavelength for 27MHz, the optimum aerial length is approximately 17ft. – hardly practical for a hand-held portable transmitter! Aerials of half, quarter, or sixteenth wavelength are far more practical, these being some 8½ft., 4ft., and 2ft. in length, but do not radiate as efficiently. A dipole system could be used, where a telescopic aerial is connected to L2 and an equal length of wire connected to 0V is left to hang towards ground. The aerial's capacitance would change as the wire is moved and transmissions become irregular so either centre or base loading of the aerial becomes desirable. Centre loading requires a telescopic aerial to be centrally cut and a coil inserted between both halves, whereas base loading, although not as efficient, does allow the impedance of the load at the feed point of the RF output stage to be adjusted, thus improving signal strength. With the output stage components as Figure 1, distances of 50 to 100 yards are possible depending upon terrain or surroundings.

Construction

Refer to the overlay and Figure 6. Pin 6 on the overlay is not used, as L2 fits over this position. Identify and insert resistors R1 to R5. Next insert capacitors C1 to C11. C1 is polarised and its + lead must align with the legend. C10 and C11 are a little large and will require being offset slightly to facilitate fitting. Ensure these components are pushed down as close as possible to the PCB. Solder all leads and cut off excess wire ends. Insert the crystal holder and IC1. Pin 1 is immediately below the circular indentation close to one corner of the package. Insert Veropins 1 to 5 and 7 to 9 and solder these and all remaining components.

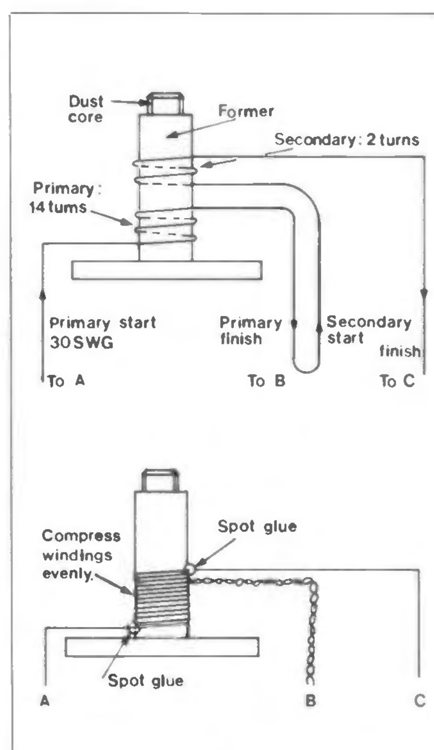


Figure 4. Winding details for coil L1

Good, accurate soldering is required if problems are to be avoided and cleaning the back face with thinners will help when inspecting the work.

Coil Winding (L1)

Both L1 and L2 have to be wound by hand. Although this may appear a daunting task, it is really not that difficult. For L1 you will need 1 metre (3ft.) of 30swg enamelled copper wire, a 7mm former and dust core and a tube of fast drying glue such as cyanoacrylate. Before construction examine Figure 4 to familiarise yourself with the turns requirements.

Primary winding A is begun at the base and fourteen complete turns wound up the tube. It does not matter which direction is chosen to wind the coil as long as both primary and secondary turns are in the same direction. It may be helpful to use the former's base mounting holes as wire anchor points when starting and finishing the coil as this will prevent the wire from unwinding until firmly glued. Once you have wound the primary coil, compress the windings together as shown and take up any slack by pulling the loose ends tight.

Apply a small amount of glue to the beginning and end of the coil and leave to harden. The finish wire from L1 primary is also the start for L1 secondary and allowance must be made for connecting it to to point B on the PCB by looping the wire out a few inches. Continue winding up the tube in the same direction as before for two complete turns. There should now be two single wire ends (A & C) and a double wire (B) extending from the coil. Again, apply spots of glue to both start and end windings of L1 secondary and leave to harden.

Coil Winding (L2)

For L2 you will need 1 metre (3ft.) of 24swg enamelled copper wire and a 7mm former with dust core. Winding procedure is similar to L1 except that a single coil of 12 turns is wound up the tube starting 2mm from the base as shown in Figure 5. Because this wire is thicker, it will be necessary to remove any kinks by gently stretching the length before winding, else the coil will be difficult to compress neatly. The 2mm gap is not critical and the coil could be wound centrally along the tube if desired. A small allowance should be made though for tuning purposes. Glue the start and end windings as before and leave to harden.

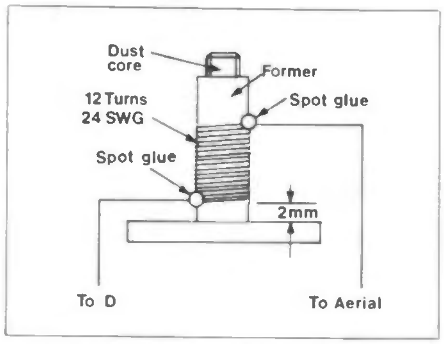


Figure 5. Winding details for coil L2

Mounting L1 & L2

Space is rather limited on the PCB, therefore both coils are mounted diagonally inwards from the right-hand corners as shown in Figure 6. Apply glue to each former base and stick the assembly in position.When mounting L1, be careful not to cover holes A and C and for L2 keep hole D clear. Leave both to harden before inserting the dust cores in case excess glue jams the threads. Insert a wire nearest to the base of L2 into hole D, then scrape off the enamel coating and tin with a soldering iron before soldering to the pad. On L1, insert the centre double wire into hole B, the primary start wire nearest the former base into hole A and the secondary finish, or topmost wire, into hole C. Each wire length from coil to terminating point should be kept short and direct otherwise tuning may be affected. When soldering these connections, heat the wire close to its pad and apply solder. The enamel will melt allowing contact with the copper to be made, then solder in place. Finally remove excess wire ends and fit crystal X1.

Choice of Crystal

Table 1 lists six available channel frequencies. These crystals come as Tx/Rx (Transmit/Receive) pairs and the frequency is stamped on the body of each one. Choose the channel to be used and insert a crystal marked with the higher frequency into the socket on the transmitter PCB. The lower frequency fits into the receiver which is explained later.

Channel	Transmit frequency	Receive frequency	Code
Brown	26.995MHz	26.540MHz	HX30H
Red	27.045MHz	26.590MHz	HX31J
Orange	27.095MHz	26.640MHz	HX32K
Yellow	27.145MHz	26.690MHz	HX33L
Green	27.195MHz	26.740MHz	HX34M
Blue	27.245MHz	26.790MHz	HX35Q

455kHz IF and 50kHz channel spacing.

Table 1. Radio control matched crystal pairs.

Notes on Assembly

A close inspection of all components, assemblies and solder joints is worthwhile before applying power to the project. Ensure all components are fitted as closely to the PCB as possible and all leads are correctly soldered. Check for short circuits across the tracks and clean off any flux that may have accumulated. Many projects fail due to poor assembly detail and bad soldering, so be fastidious at this stage if problems are to be avoided!

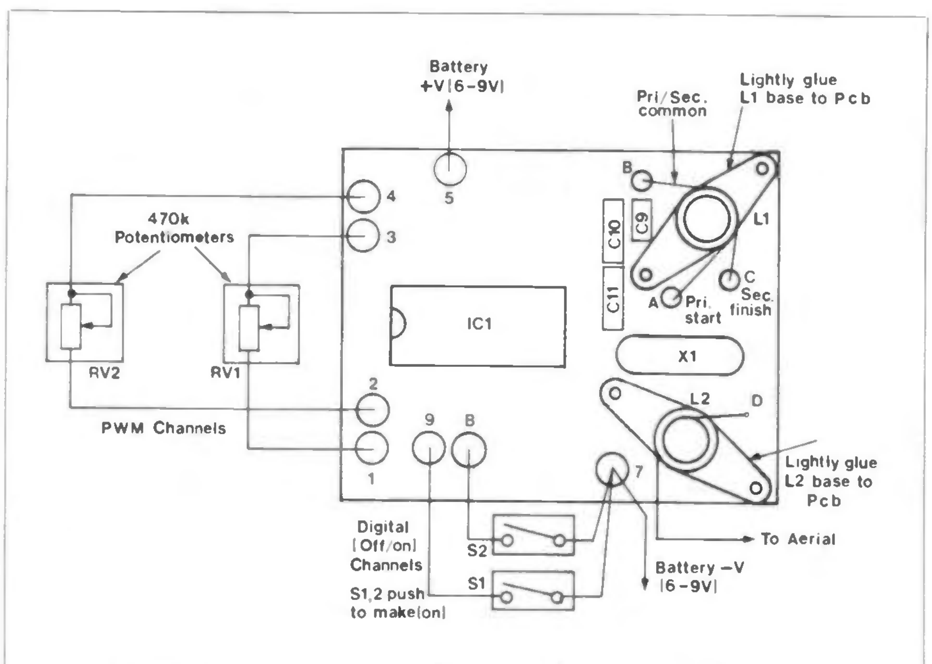
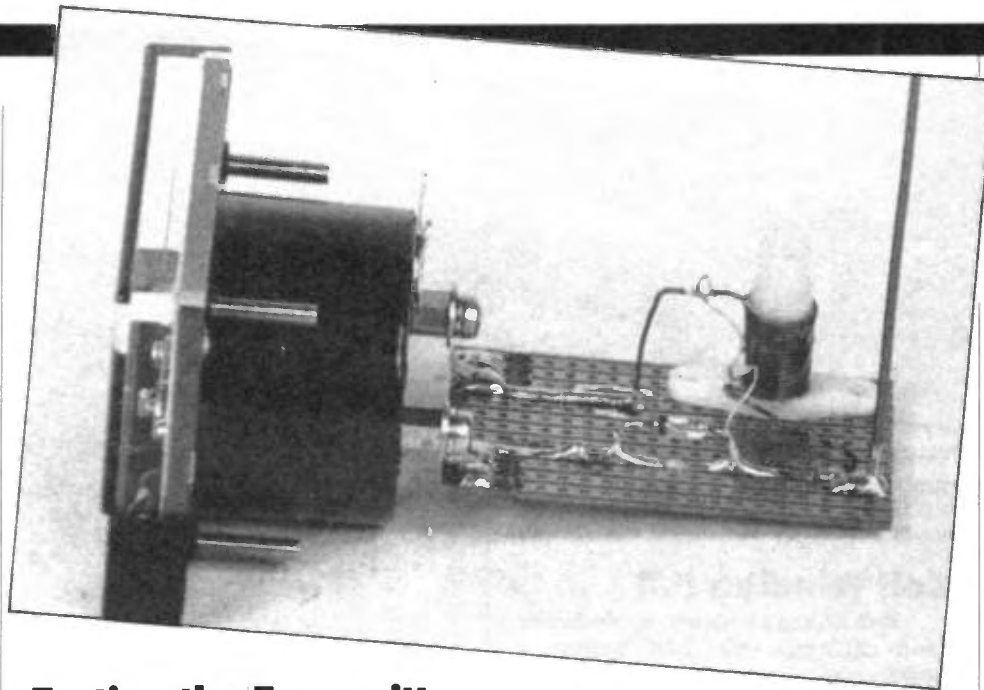


Figure 6. Wiring to Transmitter PCB

Wavemeter

Unfortunately, accurate adjustment of simple transmitters such as this does require test equipment other than a multimeter. A dedicated wavemeter, or grid dip meter that can be used as a wavemeter, is required for peaking L1 and L2. These items can be costly if not readily available so a simple circuit is given in Figure 7. If intending to build this circuit, it should be pointed out that no PCB is available and construction is a matter of choice. Figure 7B shows the prototype layout which was built on 0.1in. matrix Verostrip board. All components should be kept in close proximity with each other and the aerial soldered upright at its base. The coil is close wound on a 7mm former using 24swg enamelled wire (similar to L2, but without a dust core fitted). Make a small loop on top of the 18swg aerial wire and solder its base to the junction of L1, C1 and the diode. The circuit resonates at 27MHz and the meter indicates when a signal is being transmitted, but is not calibrated for field strength, and can only be used as a guide to maximum efficiency.



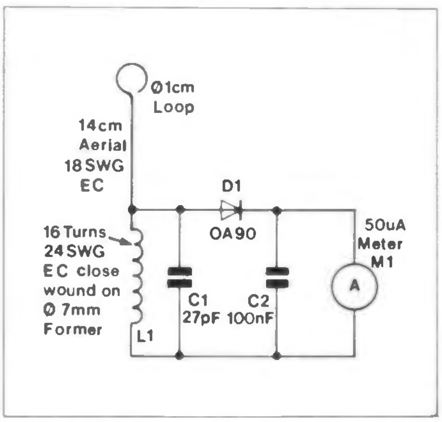


Figure 7A. Circuit diagram of a simple Wavemeter

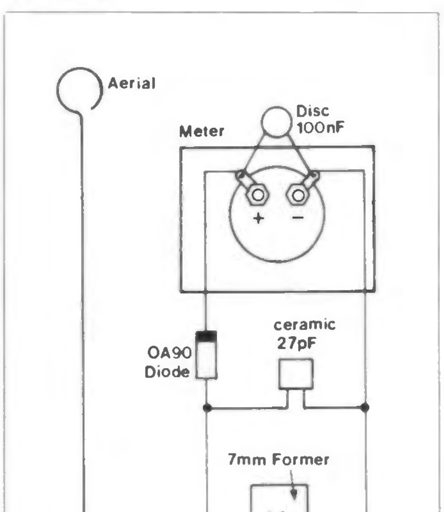


Figure 7B. Wiring diagram of simple Wavemeter

Testing the Transmitter

Connect RV1 between pins 1 and 3, and RV2 between pins 2 and 4 on the transmitter PCB (Figure 6). Connect the pot wiper to one of the resistance ends as shown in each case so that when turned its value is varied from 0Ω to 470kΩ. S1 and S2, if used,are wired between 0V (pin 7) and pin 8 or 9 as shown. These switches should be push-to-make and either latching or momentary action to suit requirements. Table 2 gives the result of S1/2 operation and approximate values for RV1/2. Current consumption of the transmitter is 10-15mA at 9V so a PP3 could be used for short periods. For preference use 6 AA size ni-cads (see Parts List) and a PP3 clip.

Connect the battery negative (black lead) to pin 7 and a multimeter between battery positive (red lead) and pin 5. The remaining wire end from coil L2 should be cut off allowing three inches extending from the coil. Place the pick-up from a wavemeter close to L2 or twist two turns of L2 round the aerial wire if using the Figure 7 circuit. Apply power and monitor the current on the multimeter set to read milliamps. Screw down the dust core of L1 in a clockwise direction and check the wavemeter reading which should gradually increase to a maximum field strength and minimum current which will be around 13mA. The Figure 7 meter should read close to half scale (10-30). Screw L2 core clockwise down into the former and the wavemeter reading should gradually increase then decrease. Finally readjust both L1 and L2 for maximum field strength and minimum current readings. As a guide, the prototype unit peaked at 12.98mA with 9V supply and a reading of 35 on the Figure 7 wavemeter. These figures will of course vary between different transmitters, but give an idea of what to expect.

If the current reading does not change when tuning and the wavemeter gives no indication, recheck RV1 and RV2 connections again as modulation stops if these connections are missing. No constant RF carrier is developed; it is only there when modulation is present. Check that crystal X1 is fitted correctly into its socket and L1 has been wired up correctly to the appropriate terminals. No

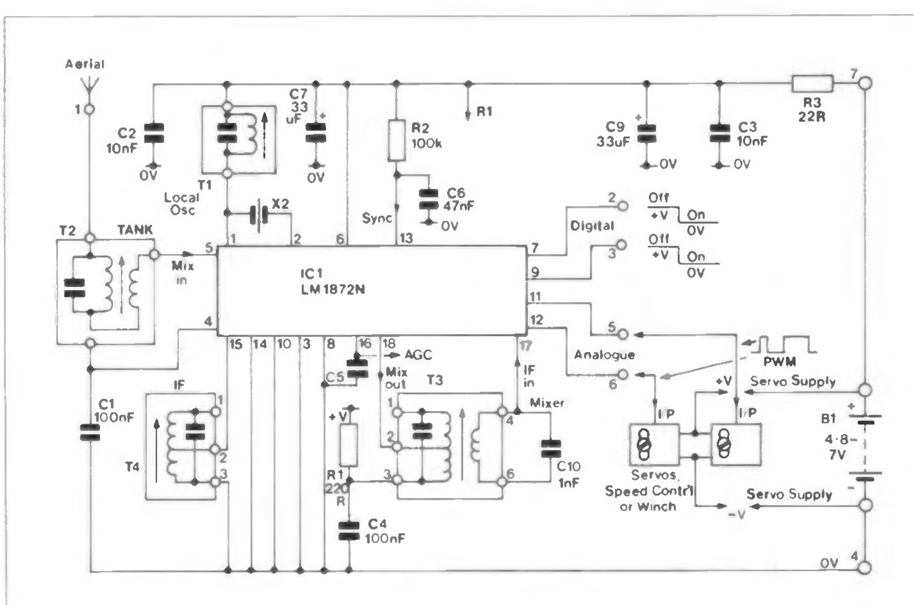
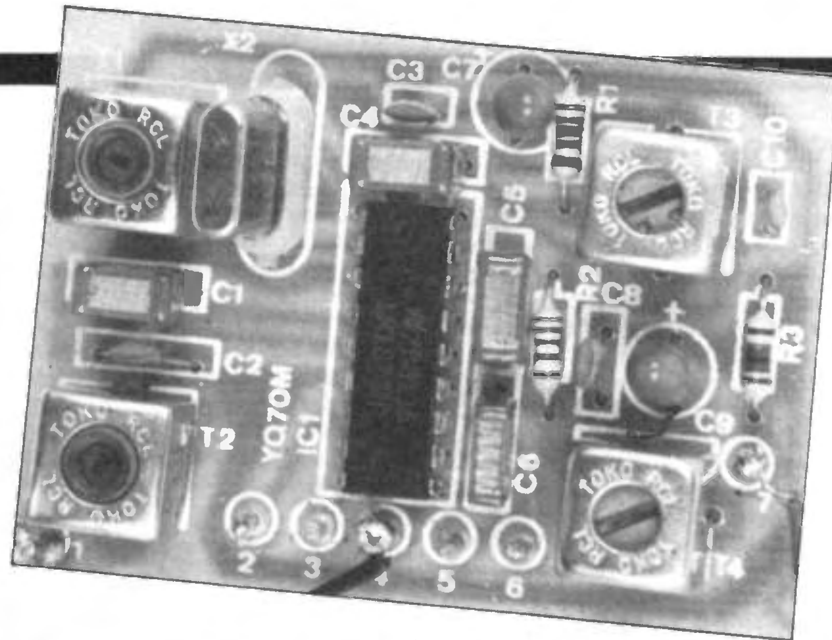


Figure 8. 27MHz Receiver circuit diagram

current or excessively high current readings could indicate anything from flat batteries to faulty meter leads or more serious PCB faults and further assistance must be sought. For constructors with oscilloscopes, connect a high impedance probe – preferably below 10pF capacitance to the aerial wire from L2 or wind a few turns of insulated wire around L2 connecting one end to 0V and the other to the probe. A waveform similar to Figure 3 (without the 1ms channel 3 and 4 pulses) should be displayed. If the scope bandwidth is low then you will only see the modulation present from IC1 pin 13.



Receiver

Figure 8, the circuit diagram, shows the receiver and external connections. Transmitted 27MHz signals are picked up by the aerial and coupled to the mixer via tank coil T2. This coil effectively keeps strong out-of-band signals like TV and FM broadcasts from cross-modulating with the required signal. A local oscillator consisting of T1 and X2 connects via IC1 pins 1 and 2 to the internal mixer section where the local oscillator and aerial signals are mixed at T3 primary (pin 18). The stepped down signal appears on IC1 pin 17 which is the intermediate frequency (IF) input. IF tuning is performed by T4. In the case of using 'blue band' crystals for example, the transmitter frequency will be 27.245MHz and the receiver local oscillator will run at 26.790MHz. When these two signals are present at the mixer, a difference signal is produced, in this case 27.245 – 26.790MHz = 455kHz. This is true for all crystal pairs which is why matching is important. The 455kHz signal or IF (since it is intermediate between the input RF frequency and the desired audio frequency) is recognised by a tuned bandpass filter T4, which only responds to frequencies in the range 455kHz ±3.2kHz (3dB). Sum and difference signals above 460kHz and below 450kHz are not amplified and become ineffective. This is basically how superheterodyne receivers, of which this is an example, function.

Pulsing the transmitted carrier on and off at set intervals will result in the IF producing a DC pulse related to this carrier modulation from an internal-detector within IC1. The detected signal is compared with an internal voltage reference so that whenever the peak IF exceeds 25mV, a comparator resets the internal digital envelope circuitry. This threshold level can vary according to the distance between the transmitter and receiver, which can result in high IF signal levels being developed. To minimise this, automatic gain control (AGC) is used to regulate the peak carrier level to 100mV by comparing it with an internal 100mV reference. An error signal is then produced which determines the gain of the IF amplifier at C5 pin 16. Digital outputs pins 2, 3, 5 and 6 are decoded and generated within IC1. Both pin 2 (channel 3) and pin 3 (channel 4) are normally high or positive and active low, so that a negative pulse is produced whenever S1 or S2 are operated at the transmitter end. See Table 2. Pin 5 (channel 1), controlled by RV1 (pins 1 and 3) on the transmitter, develops a positive pulse output, whose width is 0.3ms to 2.0ms, every 20ms. Similarly, pin 6 (channel 2) is controlled by RV2 (pins 2 and 4) with the same duration positive pulse variation. Both channels are independent of one another and do not affect operation of channels 3 and 4 (see Table 3).

Transmit	Receive
RV1 or RV2 resistance	Pin 5 or 6 pulse width
0Ω	0.3ms
50kΩ	0.5ms
200kΩ	1.0ms
330kΩ	1.5ms
480kΩ	2.0ms
S1 open	Pin 2 high (+V)
S1 closed	Pin 2 low (0V)
S2 open	Pin 3 high (+V)
S2 closed	Pin 3 low (0V)

Frame rate = 20ms
Repetition frequency = 50Hz

Table 2. Transmit-to-receive characteristics

Construction

Identify and fit the three resistors R1 to R3. Insert IC1 and solder all leads onto their pads. Cut off excess wires and fit C2, 3, 8 and 10 followed by the remaining capacitors. C7 and 9 are both polarised and their positive leads must align with the PCB legend. Fit crystal socket for X2 and Veropins 1 to 7. Again solder all components and remove excess wire ends. Correctly identify T1 to T4. Identification codes appearing in the Parts List are printed on the side of the metal cans. These components can only be fitted one way round, but some may have extra wide screen terminals connected to the metal can. If so it will be necessary to trim a small amount from the width with a pair of cutters. Carefully solder the 20 coil terminals and 8 screen terminals onto the PCB. As mentioned in the transmitter construction, clean and inspect the back face of the PCB carefully before proceeding.

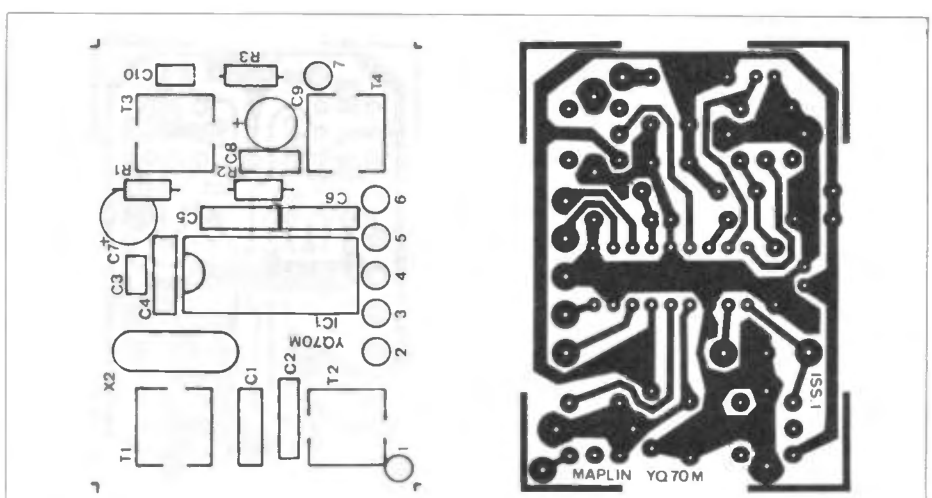


Figure 9. Track layout and overlay of Receiver PCB

Transmitter	Receiver	Description	Uses
RV1 – Pins 1 and 3	Pin 5	Channel 1 PWM O/P	Drives servo's, speed
RV2 – Pins 2 and 4	Pin 6	Channel 2 PWM O/P	controllers and yacht winches.
S1 – Pin 9 and 0V	Pin 2	Channel 3 Digital O/P	Active low operation, TTL com-
S2 – Pin 8 and 0V	Pin 3	Channel 4 Digital O/P	patible. Drives loads above 22kΩ.

Table 3. Pin connections and channel functions

Testing the Whole System

It is likely that you will wish to use the transmitter as a hand-held device and operate a model of some kind. Therefore a suitable case is required in which to mount the transmitter PCB, batteries, pot's and switches. Although it is a matter of taste, it is suggested that a small plastic box be used, large enough to accommodate the hardware and small enough to hold comfortably. A static system could best employ a metal box for better ground plane effect and hence possible increased range, especially with a larger transmitting aerial (see Aerials section). Whatever system is employed, re-tuning of L1 and L2 will have to be done after boxing up as tuning will be altered according to the proximity of additional components and your hand. Repeat the transmitter setting up procedure as before for optimum results. Leave the transmitter operating at a level of three to four feet above ground. Hold the working receiver with aerial attached and battery pack in one hand and move away from the transmitter. The earpiece buzz will most certainly stop after a while. Go back to the last working position and adjust T2 for maximum volume. Adjust T1 if necessary and continue moving away from the transmitter. Now T3 and T4 can be peaked for maximum. You will find that as the distance is increased, tuning becomes sharper and slug variations become smaller. In this way the optimum can be found for both transmitter and receiver.

Using the System

PWM output signals from either pins 5 or 6 (Rx PCB) will operate our servo and speed control projects for model boat and car applications. Because of the low power output from the transmitter, it is definitely not recommended that free-flying models be used as two or three pounds of balsa wood and aluminium hurtling out of the sky can be extremely dangerous! It is possible though for this project to be used with robotics models, with a microcomputer replacing S1, S2, RV1 and RV2 via a digital or D to A interface.

Testing the Receiver

Insert the lower frequency crystal, from the selected pair, into the holder. Connect the PP3 clip with positive (red) to pin 7 and negative (black) to pin 4. Solder an M3 tag onto pin 1 and bolt a telescopic aerial to the lug with a 12mm M3 bolt. Aerials of 1 to 2 feet in length should be satisfactory for short distance use. 20swg wire could be used, but a telescopic aerial is easier to manage. With the recommended trimming tool, turn T1 and T2 tuning slugs until they are level with the can top plate. Screw T1 clockwise into the former for 2 full turns and T2 for 3 full turns. Carefully turn T3 slug anticlockwise as far as it will go, and then turn it clockwise – down into the former – for 1¼ turns. Do the same to T4. These settings are approximate to begin with and readjustment will be necessary

PARTS LIST FOR 27MHz TRANSMITTER

RESISTORS: All 0.4W 1% Metal Film			
R1	56k	1	(M56K)
R2	100k	1	(M100K)
R3,5	47k	2	(M47K)
R4	220k	1	(M220K)
CAPACITORS			
C1	47μF 16V Tantalum	1	(WW76H)
C2	680pF Ceramic	1	(WX66W)
C3,4,5	100nF Minidisc	3	(YR75S)
C6	4n7F Ceramic	1	(WX76H)
C7	68pF Ceramic	1	(WX54J)
C8	10nF Polycarbonate	1	(WW29G)
C9	100pF Ceramic	1	(WX56L)
C10,11	22pF Mica	2	(WX08F)
SEMICONDUCTORS			
IC1	LM1871	1	(YY71N)
MISCELLANEOUS			
	Former 351	2	(LB17T)
	Dust Core Type 6	2	(LB42V)
	Printed Circuit Board	1	(YQ69A)
	Crystal Socket 25u	1	(HX60Q)
	E.C. Wire 30swg	1 roll	(BL40T)
	E.C. Wire 24swg	1 roll	(BL28F)
	Veropin 2141	1 pkt	(FL21X)
OPTIONAL			
X1	MCR Crystal (see Table 1)	1	(HX30H - HX35Q)
	Aerial 8-section	1	(RK48C)
	Aerial 6-section	1	(RK49D)
	PP3 Clip	1	(HF28F)
	Battery Holder 9V	1	(HQ01B)
	Battery AA Ni-Cad	6	(YG00A)
	Trimming Tool TT5	1	(BR50E)
RV1,2	Pot Lin 470k	2	(FW07H)
S1,2	Push Switch	2	(FH59P)

A kit of above parts (excluding optional items) is available.
Order As LK55K (27MHz Tx Kit) Price £9.95

PARTS LIST FOR 27MHz RECEIVER

RESISTORS: All 0.4W 1% Metal Film			
R1	220Ω	1	(M220R)
R2	100k	1	(M100K)
R3	22Ω	1	(M22R)
CAPACITORS			
C1,4,5	100nF Polycarbonate	3	(WW41U)
C2,3,8	10nF Ceramic	3	(WX77J)
C6	47nF Polycarbonate	1	(WW37S)
C7,9	33μF 10V Tantalum	2	(WW74R)
C10	1nF Ceramic	1	(WX68Y)
SEMICONDUCTORS			
IC1	LM1872	1	(YY72P)
MISCELLANEOUS			
T1,2	Toko CSK3464	2	(YG31J)
T3	Toko YRCS12374	1	(YG30H)
T4	Toko YMCS17104	1	(YG32K)
	Printed Circuit Board	1	(YQ70M)
	Crystal Socket 25u	1	(HX60Q)
	Veropin 2141	1 pkt	(FL21X)
OPTIONAL			
X2	MCR Crystal (see Table 1)	1	(HX30H – HX35Q)
	Aerial 8-section	1	(RK48C)
	Aerial 6-section	1	(RK49D)
	PP3 Clip	1	(HF28F)
	Battery Holder 6V	1	(HF29G)
	Battery AA Ni-Cad	4	(YG00A)
	Trimming Tool TT5	1	(BR50E)
	Crystal Earpiece	1	(LB25C)

A kit of above parts (except Optional items) is available.
Order As LK56L (27MHz Rx Kit) £10.95

later on. The coils perform the following functions:

- T1 Local oscillator coil
- T2 Aerial tank coil
- T3 Mixer coil
- T4 IF coil

As with the transmitter, expensive test equipment is needed for accurate alignment of the receiver stages, though not really necessary. A small crystal earpiece can be used to monitor one of the PWM channels, where a low-pitched 50Hz buzz can be heard. Remove the 3.5mm jack plug from the earpiece lead and solder one lead to 0V (pin 4) and the other to pin 5. Connect a multimeter set to read milliamps between pin 7 and the battery positive lead and apply power. Current reading should be about 13mA. Place the transmitter 2 to 3 feet away from the receiver and with no transmitting aerial fitted, switch that on as well. Ensure that RF energy is being developed with your wavemeter and listen to the earpiece. If no buzz is heard, adjust T4 so that the slug screw slot faces along a line with pin 6 and pin 7 on the PCB. Turn T3 slug to the same position. Slight adjustment of both may be necessary to find the correct operating areas. When this is done, remove the meter and reconnect battery positive to pin 7.

PARTS LIST FOR WAVE METER

CAPACITORS			
C1 27pF Ceramic	1	(WX49D)	
C2 100nF Minidisc	1	(YR75S)	
SEMICONDUCTORS			
D1 OA90	1	(QH71N)	
MISCELLANEOUS			
M1 Hi-Z 50μA Meter	1	(FM98G)	
Former 351	1	(LB17T)	
E.C. Wire 24swg	1 roll	(BL28F)	
E.C. Wire 18swg	1 roll	(BL25C)	