TERRY PLATT DESCRIBES THE RECEIVER DESIGN AND CONSTRUCTION

# RCM&E DIGITAL SYSTEM FM

THE receiving end of a radio control system in many ways presents a greater challenge to the designer than the transmitter. Transmitters work at a high level of signal and, in general, the circuit has no great demands of performance placed on it — it must simply generate a stable clean signal at the required frequency with a minimum of spurious outputs. The receiver, on the other hand, must be undamaged by signals of the order of several volts on the aerial in close range testing but must also be sensitive to signals which are so weak that if they were stored up for a million years they would light a torch bulb for barely a second! It must also reject completely, up to a dozen or more possibly much stronger signals very close to its own operating frequency, run on a miniscule power supply, weigh nothing (or less, preferably) and survive high velocity impacts with immovable objects — several a day, if you fly like I do!

The challenge of designing a receiver with the best possible combination of the above characteristics led to my experimentation with at least seven quite different circuits, most of which worked satisfactorily in some respects but not others. The most persistent problem experienced was that of cross modulation with strong A.M. signals which leads to servo jitter at moderate signal levels followed by complete loss of control at high levels. A.M. interference is normally rejected very well by F.M. receivers and this gives a good performance in the presence of that ever worsening problem on 27 MHz, illegal C.B. signals, but, unfortunately, A.M. radio control signals are modulated 100% and total rejection of these signals is very difficult to achieve. The weak point in the receiver appears to be the mixer stage which is unprotected from interference by a narrowband filter, as is the I.F. amplifier, and can be fairly easily overloaded. The best circuit tried from this point of view was one employing a passive double balanced mixer with no amplification at all before the I.F. filter and this was very nearly the circuit published. However, at almost the last minute, *Motorola* released an integrated circuit with such ideal characteristics for F.M. radio control, that it could not be resisted and I just had to create a design around it.

The A.M. rejection characteristics of this I.C., the MC3357, are surprisingly good and the sensitivity is exceptional, all this is combined with the ability to work well at supply voltages as low as four volts and a current consumption of only 3 mA. The MC3357 was originally designed for use in C.B. receivers as the second mixer, I.F. amplifier, demodulator, and 'squelch' circuit, so in one respect it turns the tables on the C.B.'ers, by using one of their own devices to reject them! It contains so much circuitry that a receiver can be built with no other active devices, other than the decoder I.C., and very few passive components. The receiver previously mentioned had a component count of about 70, whilst the circuit using the MC3357 is down to about 39 and has a correspondingly smaller board size. As you will see from the above I felt I had good reason to use the MC3357 in the final design and so the description of the circuit follows with the hope that everyone who builds it agrees with my decision!

## FM DIGITAL RECEIVER TECHNICAL DESCRIPTION

Having mentioned that no extra active devices are needed in this receiver other than the two I.C.'s, I had better explain the presence of TR1 rather quickly! A common problem with R/C receivers is the fact that the wire aerial is usually connected directly to the input tuned circuit and, as such, becomes a substantial proportion of the tuning capacitance. The result of this is to prevent any alteration of the aerial length without causing a severe loss of range due to de-tuning — inconvenient when the receiver is in a car or boat where a short whip would be preferable and also in the case of large, high-flying aircraft where maximum range is desired with, say, a full quarter wave (8ft. 6in. approx.) wire. To alleviate this problem, the aerial can be buffered-off from the tuned circuit by an R.F. amplifier with a good isolation as in the case of TR1. This is a V.H.F. junction F.E.T. (Field Effect Transistor) and is used in the 'grounded gate' configuration to give high isolation between the aerial and L2/C5, the input tuned circuit. TR1 is a robust device and the transmitter aerial can be directly connected to the aerial pin without causing damage to it but, at the same time, it gives useful amplification of about 12 dB (approx. 4X) and enables any length of aerial to be connected. I was originally somewhat concerned that the lack of tuning before the R.F. stage could lead to cross modulation effects with strong signals that might cause problems but experiments have shown that such effects are not observable and cause no difficulties.

The output of TR1 drives the tuned circuit L2/C5, as previously mentioned, with a somewhat amplified 27 MHz signal and this is bandpass coupled, via mutual inductance, to the second tuned circuit set at 27 MHz, L3/C9. The coupling between these circuits is a little dependant on the relative positions of the windings on L2 and L3 and so the coils should be at about the same level as each other around the centres of the formers. L2 and L3 have different numbers of turns and this gives an impedance transformation for a good match to the input of the MC3357 combined with the correct damping for a bandpass response approximately 0.5 MHz wide at 27 MHz — some useful image signal rejection (at approx. 26 MHz) is thus achieved.

The signal now enters the first stage of the MC3357 which is a double balanced mixer driven by an internal local oscillator transistor. To form the necessary 3rd overtone crystal oscillator, some small changes were needed to the external circuitry of the oscillator from the manufacturer' application notes. The circuit is basically a Colpitts oscillator, like that in the transmitter, (sorry about the name error — my apologies to Mr. Clapp!) but with a small R.F. choke of about 2.7$\mu$H included in the emitter circuit (L1). This choke resonates with C6 at about the geometric mean of the crystal fundamental frequency (approx. 9 MHz) and its third overtone (approx. 27 MHz) thus at 9 MHz the C6/L1 combination is inductive and at 27 MHz, capacitive. The oscillator circuit is thus caused to be degenerative at the crystal fundamental frequency but regenerative at its 3rd overtone, just below 27 MHz! The arrangement seems to be totally reliable and all crystals tried worked correctly within, at worst, about 800 Hz of the marked frequency.

The receiver uses the common I.F. frequency of 455 KHz and so the oscillator runs at 455 KHz below the transmitter frequency giving an output from the mixer at the above I.F. This signal is then applied to the narrow band I.F. filter composed of the rather hybrid arrangement of T1, F1 and F2. Why use such a strange combination? Well, it's the most cost-effective that I've found and as I mentioned in part one, I'm very careful where money is involved! Most F.M. receivers on the market are expensive or, more accurately, very expensive, and, in some degree, this reflects the use of complex ceramic ladder filters in their I.F. amplifiers to get good 10 KHz channel separation. These filters, in small quantities, start at £4 and rapidly escalate to £14 or more in the higher performance versions. The major requirement is for good rejection of signals at ±10 KHz either side of the channel in use while preserving adequate bandwidth for good reception (about 6 to 10 KHz) also the rejection of unwanted signals should remain high over as wide a bandwidth as possible. The ceramic ladders mentioned above give 10 KHz rejection of between 50 and 80 decibels, depending on price, but it is unlikely that it is worth aiming for more than 70 dB owing to the limited amount of isolation which can be achieved on the miniscule P.C. boards used in R/C receivers.

I thus experimented with combinations of low cost filters in an attempt to find one which gave comparable performance at a minimal price. The lowest priced ladder filter, the 'Murata CFU455H', costs about £2.00 but gives only about 40 dB rejection at ±10 KHz with some spurious responses of a troublesome magnitude at other frequencies. These responses can be reduced significantly by driving the filter from a tuned circuit such as a transistor radio I.F. transformer and this also gives a D.C. path for the power supply to the mixer in the MC3357 — hence the inclusion of T1. Although the tuned circuit is a valuable addition to the filter the rejection at ±10 KHz is still not sufficient and to improve this another low-cost filter is cascaded with the first, this time a miniature mechanical filter made by TOKO numbered 'CFM455D'. This device is very small and has an excellent overall response with very few spurious resonances although the 'roll-off' rate is not as high as the ladder filters. Fortunately it can be cascaded with the CFU455H without distorting either characteristic curve noticeably and the combined response gives a rejection of around 70-75 db at ± 10 KHz with an ultimate performance of better than 80 dB throughout the rest of the band.

A response curve of the complete combination is plotted in Fig. 1 on a spectrum analyser display, the 'hole in the middle' being an artefact of the plotting technique. The scale is 10 dB/cm vertically and 5 KHz/cm horizontally.

Well, having quartered the cost of the I.F. filter, I will move on to the rest of the receiver, the next stage being the limiting I.F. amplifier. This stage contains most of the amplification in the receiver and also 'splices off' any A.M. present from interfering signals, the output being a symmetrical square wave at around one volt peak to peak appearing on pin 7. The signal is then split with part directly driving one input of the F.M. demodulator stage (internally) and the rest driving the other input via the phase shift network of C12 and T2. T2 is tuned to the 455 KHz I.F. centre frequency and, at this frequency, the signal at the junction of C12 and T2 is phase shifted by 90° with respect to the direct signal. With this phase relationship between the two inputs the demodulator gives only its normal quiescent output voltage at pin 9, however, if the signal frequency shifts from 455 in either direction, as with F.M. modulation, the phase relationship alters and the output voltage at pin 9 shifts high or low. Conditions are arranged so that when the signal from the transmitter is received the frequency modulation of the signal produces an output waveform at pin 9 of approximately 600 mV peak to peak amplitude, being a close replica of the pulse train generated by the transmitter encoder.

The waveform thus recovered must now be processed to remove as much spurious interference as possible and increased in amplitude to a level at which it can drive the 'Cmos' decoder I.C.

Originally I tried to use the noise amplifier stage in the MC3357 to do this but met with D.C. level shift problems due to the asymmetrical nature of the waveform and so this stage is now unused. It was found that the 'squelch' amplifier could be biased into a linear state with no difficulty at all and having some built-in hysterisis (latching action) and also two antiphase outputs, it proved to be ideal for the function of logic level generation.

The signal has most impulse noise removed by the integrating action of R7 and C14 (A.M. interference tends to appear as sharp noise pulses and so this gives useful A.M. suppression) and is then A.C. coupled into the 'squelch' amplifier stage via C13. R4 biases the amplifier into its linear region and the output appears at pin 13 as a clean, 4 to 5 volt peak to peak, pulse wave, ideal for driving the decoder. A phase inverted output also appears at pin 14 which is actually an uncommitted transistor collector connection, hence this can be used to extract the synchronising pulse from the signal very easily by acting as a clamp for the integrator composed of C15 and R10. The action is such that during the ½mS breaks in the pulse train the transistor is turned on and clamps C15 to ground via R8 but when the transmitter turns off C15 charges slowly via R10 and the voltage at pin 15 of the decoder I.C. rises towards the positive supply. As the time constant of R10 and C15 is about 5 milliseconds the voltage does not rise above about 1 volt at any time during the channel pulse train as C15 is being continually clamped to ground at intervals of 2mS or less, but when the sync. pulse arrives C15 is released for 6 or 7 milliseconds and can charge to about 70-80% of the supply voltage. Any voltage above 66% of the supply is a logic '1' for Cmos (the tolerance range is usually quoted as 33-66% of the supply) and so at the end of the synchronising break the 'data' input of the shift register, IC2, is at a logic '1'. At this point the next ½mS break occurs and C15 begins to rapidly discharge again via R8 but, as the output at pin 13 of ICI rises to a logic 'l' at the same instant, it applies a clock pulse to the clock input of IC2 and 'clocks in' the logic 'l' on the data inout so that the first

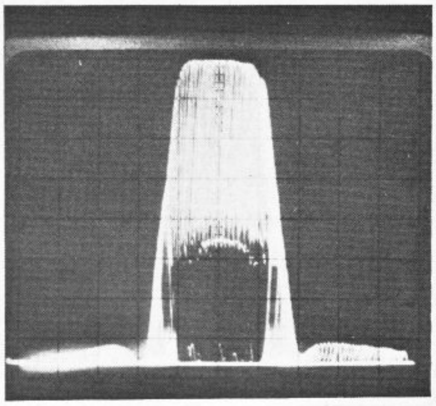


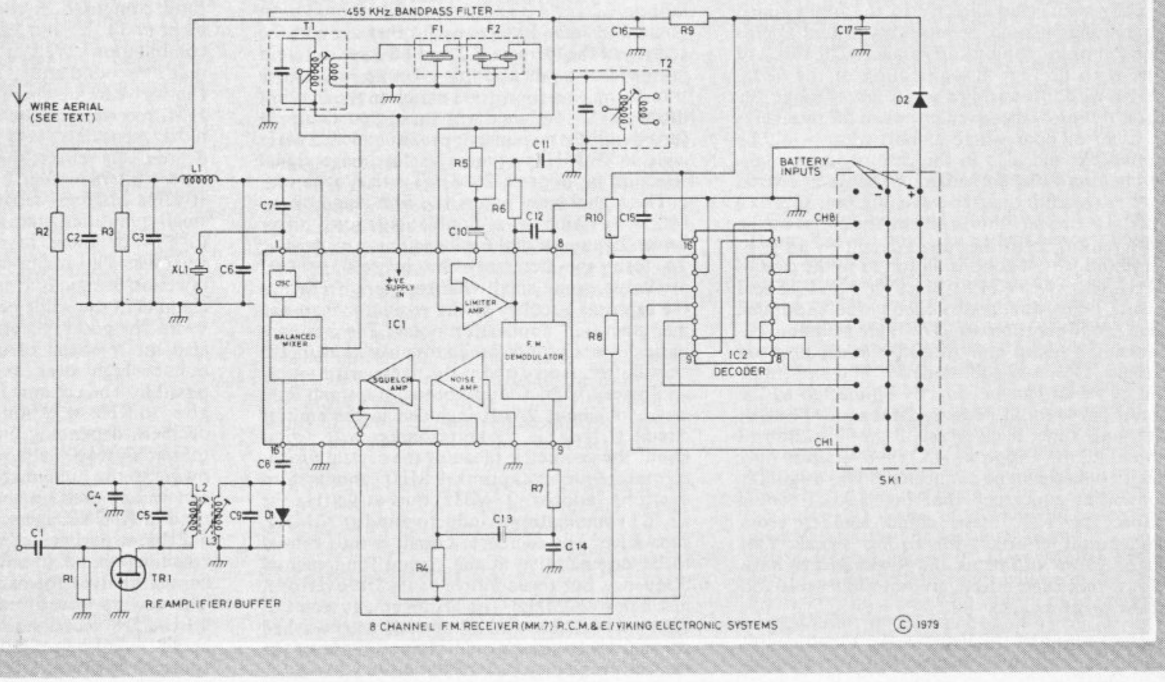
**Fig. 1**

output of IC2 (pin 13) rises to a 'l' level. Immediately after this C15 is fully discharged and pin 15 of IC2 returns to a '0' level.

The '1' on pin 13 of IC2, and hence on the input of the first servo plugged into SK1, remains there until the next ½mS break occurs after a lag of 1 to 2 mS, determined by the transmitter stick setting for that channel, and is then clocked to the second stage of IC2 to appear at pin 12 and the second output of SK1 (output one, of course, returns to a '0' as a '1' is no longer present at the data input, pin 15). This sequence of a '1' being shifted from one output to the next at intervals of 1 to 2 mS continues until output 8 is reached after which the '1' 'falls off' the end of the register and the next synchronising break occurs to initiate the next cycle. It can thus be seen that each servo receives a positive input pulse, varying in width from 1 to 2 mS with corresponding transmitter stick position, every 15 to 20 mS. This is the normal input signal which most servos require for correct operation and our signal generated some distance away in the transmitter has finally arrived at the control surfaces!

Just to clarify the functions of D1 and D2, D2 is simply to protect the receiver (the decoder in particular) against a reversed battery and D1 is an anti-swamping clamp to prevent extremely strong signals from saturating the mixer stage — this stage also gives some protection against A.M. interference at close range.

## FM RECEIVER THEORETICAL CIRCUIT



# RECEIVER COMPONENTS

## Resistors

All $^1/_3$ watt 5% tolerance CR25 or UPMO33.
R1 1K
R2 100Ω
R3 10K
R4 150K
R5 2K2
R6 47K
R7 2K2
R8 1K
R9 100Ω
R10 470K (560K if used with 1.7/1.8mS servos).

## Capacitors

C1 100pF ± 2% 63vwkg. Miniature ceramic plate. R.S. Stock No. 125-610.
C2 0.01$\mu$F + 50/-20% 63vwkg. Miniature ceramic plate. Siemens B37448 (electrovalve).
C3 0.01$\mu$F ± 50/-20% 63vwkg. Miniature ceramic plate. Siemens B37448 (electrovalve).
C4 0.01$\mu$F + 50/-20% 63vwkg. Miniature ceramic plate. Siemens B37448 (electrovalve).
C5 33pF ± 2% 63vwkg. Miniature ceramic plate R.S. Stock No. 125-581.
C6 22pF ± 2% 63vwkg. Miniature ceramic plate R.S. Stock No. 125-575.
C7 33pF ± 2% 63vwkg. Miniature ceramic plate R.S. Stock No. 125-581.
C8 0.01$\mu$F + 50/-20% 63vwkg (as C2).
C9 100pF ±2% 63vwkg (as C1).
C10 1$\mu$F ± 20% 35vwkg tantalum bead R.S. Stock No. 101-771.
C11 1$\mu$F ± 20% 35vwkg tantalum bead R.S. Stock No. 101-771.
C12 10pF ± 2% 63vwkg. Miniature ceramic plate. R.S. Stock No. 125-553.
C13 I$\mu$F ±20% 35vwkg (as C10).
C14 0.047$\mu$F + 50/-20% 63vwkg. Miniature ceramic plate. Siemens B37448 (Electrovalue).
C15 0.01$\mu$f ±5% 250vwkg. Poyester Siemens B32560 (electrovalue).
C16 47$\mu$F ± 20% 6.3vwkg. Tantalum bead.
C17 47$\mu$F ± 20% 6.3vwkg. Tantalum bead. R.S. Stock No. 101-844.

## Integrated circuits

IC1 MC3357P (Motorola) (available from Ambit International).
IC2 MC14015BCP or CD4015BE, etc.

## Transistor

TR1 E300 F.E.T. (Siliconix etc.).

## Diodes

D1 OA47.
D2 OA47.

## Inductors

L1 2.7$\mu$H choke (may be made by winding 50 turns of 40 swg wire onto 470k CR25 resistor — see text).
L2 13 turns 34swg self fluxing enamelled copper wire wound on NEOSID former type 50-005-62 with 3 x 0.5 x 7.5mm F29 core.
L3 7 turns 34swg (as L2).
T1 Toko I.F. transformer type LLC4828 (Ambit International).
T2 As T1.

## Filter blocks

F1 Murata CFU 455H or equivalent (Ambit).
F2 Toko CFM 455D or equivalent (Ambit).

## O/P socket

7 way, 3 pin socket available from S.L.M. (also plugs). (9 way version may be available in due course).

## Case

S.L.M. Type PT101.

## Crystal socket and crystal

Most A.M. and F.M. crystals will work well. S.L.M. Type socket with 0.2in. pin spacing for HC25/U Xtal. The address of Ambit International is 2 Gresham Road, Brentwood, Essex.

# FM DIGITAL RECEIVER CONSTRUCTION NOTES

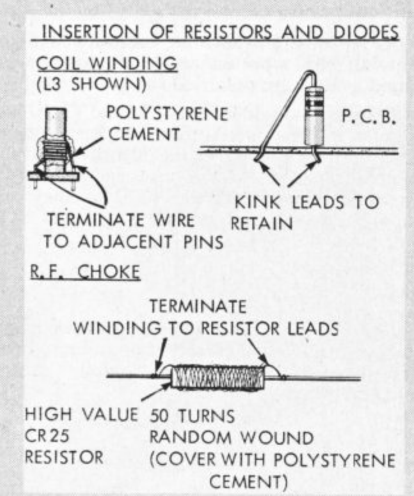
The constructor who has already assembled a transmitter P.C. board should have no great difficulty building the receiver. Less components are involved and the only significant difference is in the closer packing of the board leading to the resistors and diodes inserted vertically (see diagram). When soldering components into the P.C.B. do not be tempted to leave long leads on the capacitors etc. as a forest of rather long floppy wires is bound to suffer from short circuits after a hard landing and may also lead to instability of the receiver with corresponding loss of range. Some components owing to their small size are rather fragile and should be handled with care. This is especially the case with the coils L2 and L3 and the ceramic plate capacitors, none of which should be forced into the mounting holes if they are tight — enlarge the holes with a pin drill of about 0.9-1mm diameter and they will drop in easily.

Begin construction by ensuring that the P.C.B. is a good fit in the box to be used — it is risky filing down a completed receiver board! Polish the track side of the board with a soft plastic eraser and ensure that all the holes are drilled before starting construction. As in the case of the transmitter, carefully check the list of components for correct values and style — owing to the relative lack of space on the receiver board it is important to keep to the manufacturer listed to be sure that things will fit. The list of tools given for assembly of the transmitter board should be more than adequate for constructing the receiver but *please* use a soldering iron with a well-tinned, finely pointed bit — it is almost impossible to avoid shorted tracks and fried components when using an iron intended for plumbing!

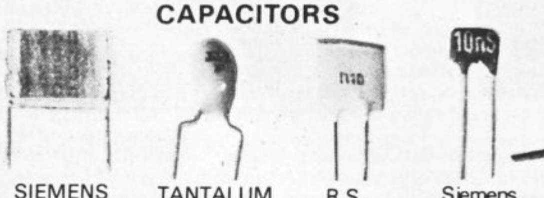
## Coil winding data

The coil formers used for L2 and L3 are very small items similar to those in the transmitter but about half the size. This makes coil winding a rather fiddly job but a little patience works wonders! Start the winding by wrapping the wire once round the top of a pin on the former and soldering in place. Wind on the coil starting just above the pin tops and keeping all the turns touching one another. Terminate the last turn onto a pin adjacent to the start pin, if this is the one immediately before the start pin in the direction of winding it will be easier to solder the connection without damaging the wire coming from the start pin up to the coil. This will reduce the coil by about half a turn but will not cause any difficulty when setting up the receiver. Finish the coil with a few drops of polystyrene cement over winding.

The choke L1 can be made by winding 50 turns of 40 SWG wire over the body of a high value (greater that 100K ) CR25 or UPMO33 resistor in several random-wound layers. The wire is soldered to the resistor leads close to the body to provide the terminations. Ready-wound chokes are available but tend to be difficult to find in most electronic shops, especially in small values hence the home-made version is often the easiest solution. Finish with polystyrene cement as L2 and L3.

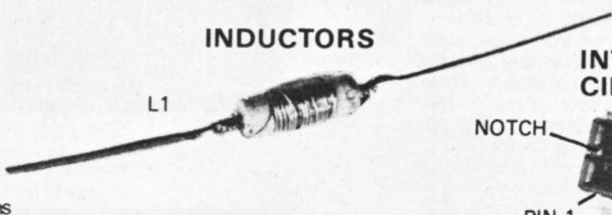



**CAPACITORS**



SIEMENS POLYESTER — TANTALUM BEAD — R.S. Ceramic plate — Siemens B37448 CERAMIC PLATE

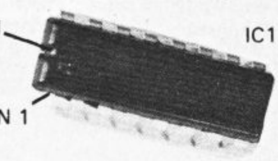
**INDUCTORS**



L1

L2/3

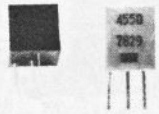
**INTEGRATED CIRCUITS**




IC1


IC2

**FILTER BLOCKS**



F1 F2

**TRANSISTOR**

TR1

# FM DIGITAL SYSTEM RECEIVER ASSEMBLY

As the components tend to interfere with each others' accesibility, it is best to work 'out from the centre' of the board in a spiral manner, which leads to a rather odd order of device fitting as follows:

(1) Insert IC1 (MC 3357P), being careful to fit it the correct way round. Solder into place using a damp sponge heat sink for safety, as in the case of the transmitter IC's.

(2) Fit all the resistors by bending the leads as shown and inserting the way round shown in the ident diagram. Push the resistors down onto the board so that the lower end of the body rests on the P.C. surface with the resistor vertical and kink the leads outwards on the track side before cropping to prevent them falling out. Check off the resistors against the list below as they are soldered into place:

R1 ( ) BROWN, BLACK, RED
R2 ( ) BROWN, BLACK, BROWN
R3 ( ) BROWN, BLACK, ORANGE
R4 ( ) BROWN, GREEN, YELLOW
R5 ( ) RED, RED, RED
R6 ( ) YELLOW, VIOLET, ORANGE
R7 ( ) RED, RED, RED
R8 ( ) BROWN, BLACK, RED
R9 ( ) BROWN, BLACK, BROWN
R10 ( ) YELLOW, VIOLET, YELLOW (or GREEN, BLUE, YELLOW) (SEE PARTS LIST)

(3) Identify the polarity of D1 and D2 and fit them in the same manner as the resistors, taking care to insert them the correct way round. Use only a minimum of heat to solder these items as they can be damaged quite easily by high temperatures. Also fit L1 in the same way.

D1 ( )
D2 ( )
L1 ( )

(4) Fit all the capacitors, ensuring that the tantalum bead types are inserted the correct way round as they are polarised.

(5) Insert and solder F2, F1, T1 and T2. F2 has a notch in the upper surface which should be positioned as shown in the identity diagram (notch nearest to output socket end of board). Do not adjust either T1 or T2 as they are supplied in an almost ready tuned state.

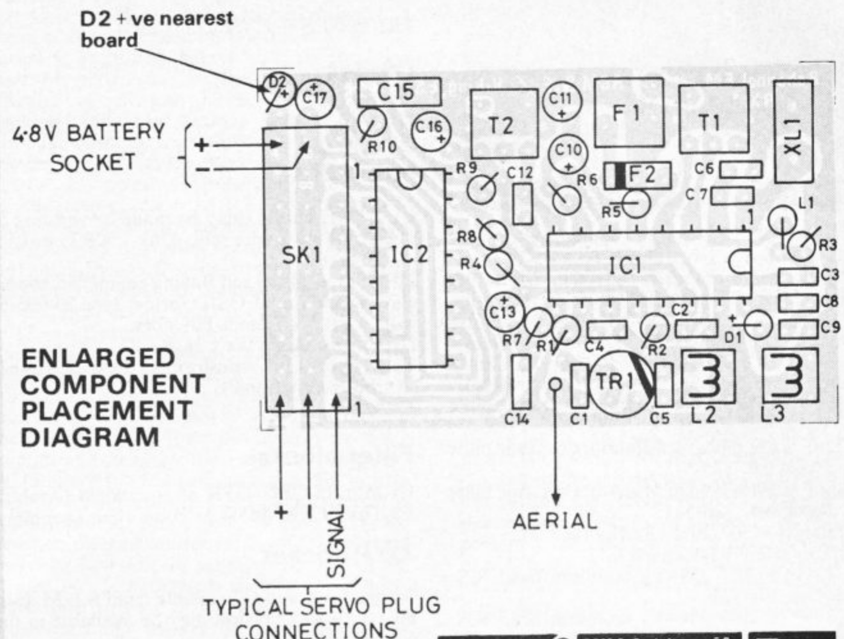
F2 ( )
F1 ( )
T1 ( )
T2 ( )

(6) Fit TR1, IC2, L2 and L3. All these items must be fitted in the correct orientation so consult the identity diagram carefully before soldering them into place.

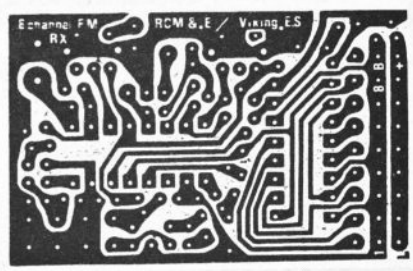
TR1 ( )
IC2 ( )
L2 ( )
L3 ( )

(7) The final items — the crystal socket, the output socket and a vero pin for the aerial terminal. The plastic of both the sockets is readily melted by a soldering iron so be quick when soldering. At present the only suitable socket produced by S.L.M. is a seven way, three pin unit which, of course, allows access to only six channels + battery. It is hoped that S.L.M. will produce a 9-way unit in due course (with a little persuasion)! but the solution to the problem at present is to fit two single way 3-pin sockets in the channel 8 and battery position. If six channels are adequate it is quite permissible to use channel 7 position to bring in the battery connections so that channel 1 to 6 are available with the 7-way socket.

The finishing touches are to trim all the component leads to within 1mm of the board surface and to clean the flux from the tracks using a *little* cellulose thinners and a typewriter brush (avoid thinner getting on the components as the plastic sockets in particular are liable to become a sticky black mess!).

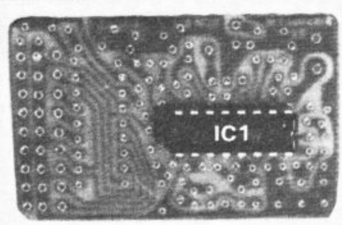



**ENLARGED COMPONENT PLACEMENT DIAGRAM**




**P.C. BOARD COPPER SIDE SHOWN FULL-SIZE**

1

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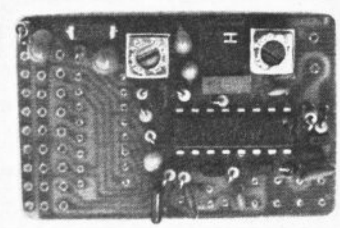

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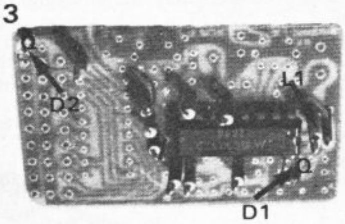


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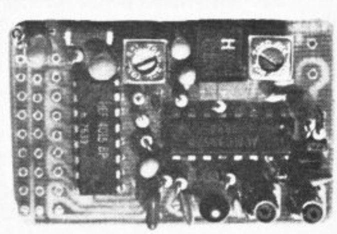

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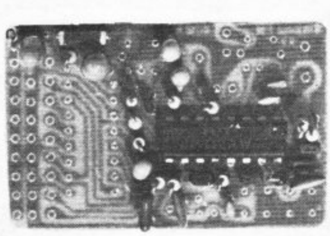

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