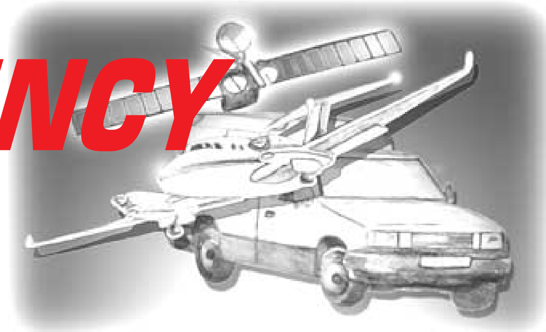
Constructional Project



F.M. FREQUENCY SURFER

TOM MERRYFIELD

Riding the airwaves at 88MHz to 125MHz will trawl-in many unusual and unexpected contacts

As a variation on Amateur Radio, the idea for this project came about after operating a commercial v.h.f. (very high frequency) receiver which unfortunately was "deaf" to narrowband transceiver signals beyond 100MHz.

Adding a long aerial, an impedance matcher and a wideband aerial amplifier offered a marginal improvement, but it soon became clear an improved detector stage and better low-pass filtering was required. Although built from scratch, the result is a circuit based on the Philips IDA7000 f.m. processor i.c., incorporating phase-locked loop detection, mixer and necessary oscillator stages.

Strictly speaking, the project is really a v.h.f. receiver providing a nominal coverage from 88MHz to 125MHz but in use it covers a variety of signals. (The range can also be extended to a top limit of approximately 146MHz. See later.) This includes wideband f.m. broadcasts, aeronautical communications, fixed and private mobile radio, amateur bands activity on the lower frequency channels and the occasional shortwave transmission via satellite.

With a little care and a few precautions, this project can be easily built and set up using a long aerial as opposed to a co-axial cable and feeder system. The cost of a slow-motion drive (these can be difficult to obtain) is also avoided since accurate tuning can be achieved using ordinary tuning capacitors.

F.M. IN CONTEXT

As most readers will recall, the mediumwave and longwave bands pertain to amplitude modulation (a.m.), the audio information being impressed upon a carrier of constant frequency by varying its amplitude. At the receiver end a simple diode detector can be used to retrieve the audio from the carrier.

In some cases only a small portion of the modulated waveform may be transmitted as in single side-band (s.s.b) transmission used, for example, in Amateur Radio transceiver activity.

A frequency modulated (f.m.) signal however, is where the carrier frequency is made to deviate from the central carrier frequency. Clearly, this implies the need for an f.m. detector as opposed to an a.m. type, the desired output being a voltage proportional to the amplitude of the modulating signal (or audio) relative to the degree of frequency deviation.

PLL DETECTION

Whereas a simple ratio detector could be used to detect wideband f.m. signals, a more sophisticated form – namely, Phase-Locked Loop detection (PLL) – is required to adequately demodulate narrowband transceiver signals intercepted by the aerial system.

As incorporated in the TDA7000 f.m. processor (IC1 – see Fig.1), the PLL loop includes a phase detector comprising two inputs; that is, a signal from the reference oscillator and that generated by the Voltage Controlled Oscillator (VCO). Due to the existing phase difference or error, the output from the phase detector is fed into a low-pass filter which removes unwanted harmonics and noise whilst blocking all a.c. components of the waveform.

Hence, only the d.c. component, referred to as the control or error voltage, is inputted to the VCO (pin 6 of IC1). This in turn modifies the VCO frequency so the phase offset is compensated for with the VCO "locked" on to the incoming reception frequency.

The advantage here is that narrowband signals can be similarly processed – even at frequencies of some several hundred megahertz! Also, since the VCO is linked directly to the tuned circuit (Fig.2), sharper tuning is more easily accomplished so long as a high *Q* is maintained over the relevant band of frequencies.

CIRCUIT OPERATION

The full circuit diagram for the F.M. Frequency Surfer is shown in Fig.3. Although the circuit may seem relatively complex, it can be easily broken into stages as shown in the block diagram of Fig.2.

Furthermore, coils L1, L2, L5 and L6 are home-wound and easy to construct, with coils L3, L4 and L7 being ordinary widely available inductors. These, however, are not the suppression type which tend to be more expensive but don't actually work very well in the circuit!

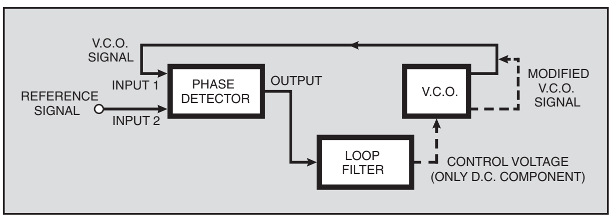


Fig.1. Simplified block diagram for the PLL

In order to employ the long aerial effectively and reduce losses, the twin coil L1/L2 provides some impedance matching whilst also forming a part of the aerial filter circuit. As shown in Fig.3, the signal is proportionately tapped off via two tappings on L1 and the finish winding of L2 as switched inputs to the filter circuit.

Since even very expensive scanning equipment can be hampered by poor front-end filtering, the latter plays an important role by aiding front-end selectivity, reducing interference and bypassing out of band

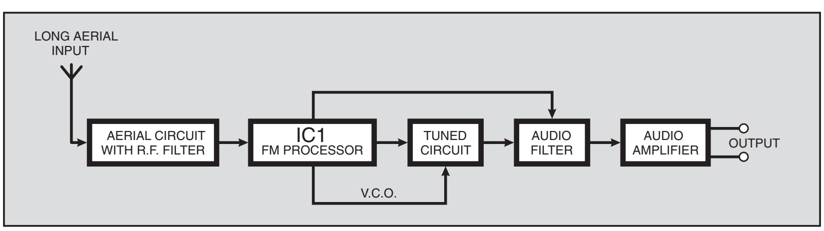


Fig.2. Block schematic diagram for the F. M. Frequency Surfer

signals to ground. This also avoids using tuned circuits in the aerial circuit with capacitors C1 to C8 offering stepped-up attenuation via the 12-way single-pole rotary switch S1.

In terms of high frequency signal processing, most of the work is carried out by IC1. Apart from PLL detection (discussed earlier), other necessary stages include an r.f. input and mixer to convert the reception frequency to a much lower intermediate frequency, in this case 10·7kHz.

Despite employing quite a few external capacitors mostly for decoupling purposes the actual connections for IC1 are straight forward. The signal is inputted to pin 13 via the aerial circuit with pin 2 as the output terminal coupled to the audio filter via capacitor C22. Note the tuned circuit is connected only via pin 6 of IC1.

Resistor R1, with bypass capacitor C23, set the nominal output voltage. If using an external power supply (mains adaptor), it must not exceed 10V d.c., this being the maximum permissable supply voltage for IC1.

VCO

No separate tuned circuit is needed to resonate the VCO since the VC1/VC2 network caters for both this and selecting the reception frequency. The sharp tuning capability required to adequately tune in narrowband transceiver activity is assisted by this network, including capacitors C25 and C26, in maintaining a high *Q* over the fairly broad tuning range.

For instance, without capacitor C24 and coil L6 the frequency response beyond 115MHz becomes flatter, thus reducing the selectivity. Further, since the margin of error becomes more critical with narrowband signals, VC1 (trimmer) and VC2 (variable) capacitors therefore have to he adjusted very carefully (see In Use).

In comparison, s.s.b. signals, can be missed altogether since only a part of the modulation envelope is transmitted making the signal extremely narrowband.

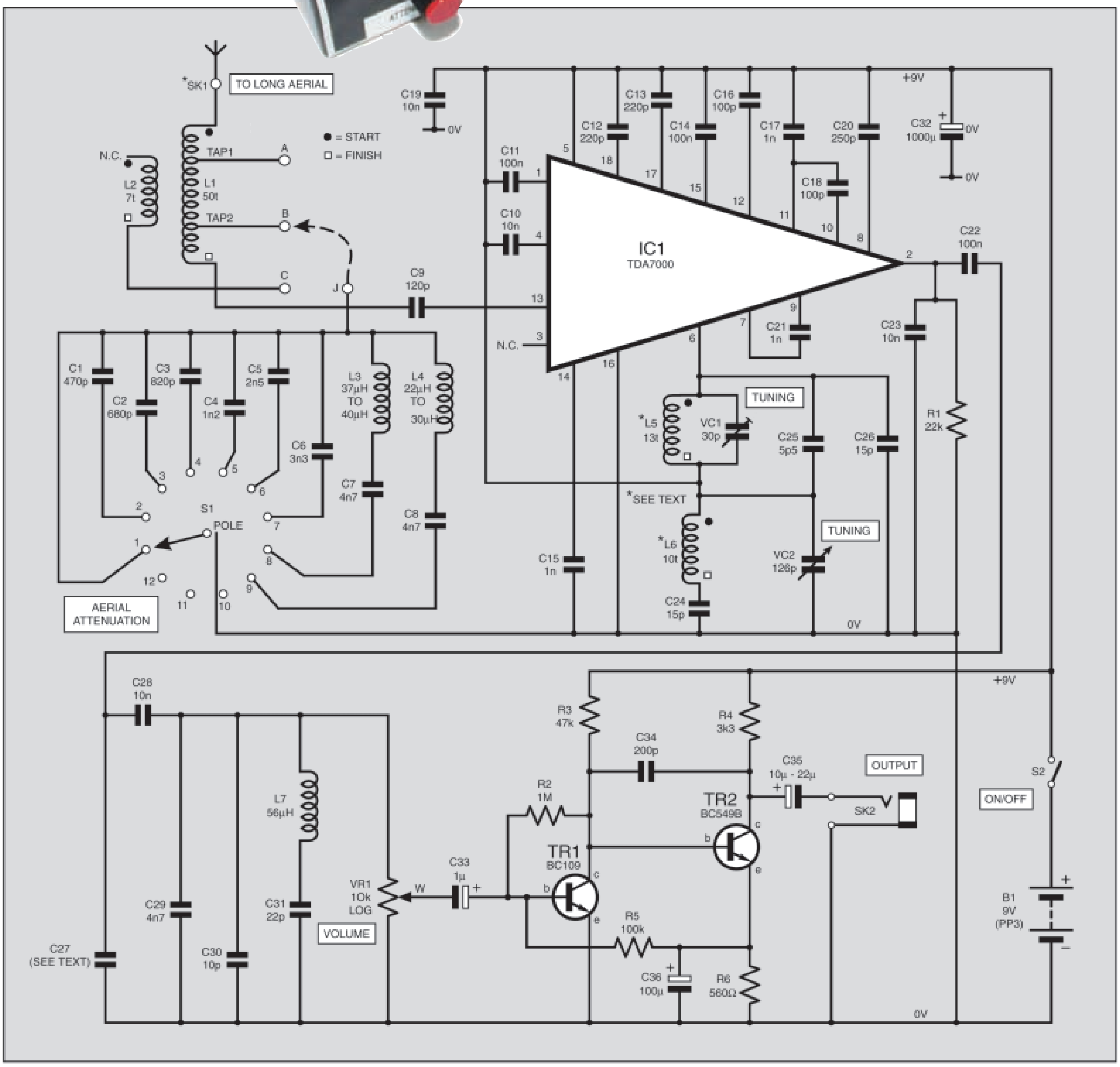


Fig.3. Full circuit diagram for the F. M. Frequency Surfer. The audio output is fed into a crystal earpiece or high impedance headphones.

Table 1: Broad Classification of Frequencies

Frequency	*Type*	*Predominant Usage*
0·3MHz to 3MHz	Medium Frequency	A.M. – Domestic Radio, including longwave and medium wave
3MHz to 30MHz	High Frequency	A.M. / S.S.B. – Shortwave Radio, Amateur Bands, Maritime etc.
30MHz to 300MHz	Very High Frequency	F.M. – Commercial wideband f.m. (88MHz to 108MHz) and narrow band transceiver activity, s.s.b. also used

AUDIO FILTER

Capacitors C27 to C31 and inductor L7 comprise a simple audio filter network prior to the audio amplifier. They also reduce the noise component of the demodulated signal whilst bypassing stray r.f. to ground, which could otherwise distort the audio output.

Note that C27 is a home-made capacitor constructed from two short off-cuts of p.v.c. covered wire twisted with a couple of turns and soldered in place. The free ends however, are not wired but instead kept “loose” to avoid introducing a short.

The filtered audio signal is now coupled to a simple audio amplifier through variable potentiometer VR1 and electrolytic capacitor C33.

AUDIO AMPLIFIER

Transistors TR1 and TR2 form a high gain audio amplifier stage, with resisitors R3, R4 and R6 providing local biasing. Resistor R5 and capacitor C34 are needed for stability at high frequencies with C35 decoupling the stage from the audio output.

Note that whereas capacitor C32 caters for any voltage surges, C19 is required for bypassing any a.c. signals present in the supply line and as such, is placed strategically next to the processor stage.

Due to the output impedance being relatively high, a crystal earpiece or high impedance type headphones are needed to hear the output.

TUNING MECHANISM

Since using the wrong type of tuning capacitor can significantly reduce the performance of high frequency circuits, it is worth mentioning that VC2 is a 126pF device with a built-in f.m. section that is usually sold as being for use with i.c. radio chips. If a 6-lug type is obtained the middle and side lugs will have to be correctly identified with the middle lug wired to 0V.

Due to VC1 playing a critical role in making precise adjustments, a modern film type trimmer is not really suited for this sort of application. A 30pF differential type trimmer was used in the prototype, this being a bulky, airspaced device of the metal vane variety.

It should be pointed out that obtaining the exact type is not crucial; other single turn air-spaced devices of 30pF – perhaps bought second hand and in good condition – will perform well. The main advantage is that minute adjustments can be made easily. A 25pF device will also work, but the value of capacitor C25 will have to be increased to around 10pF with coil L5 wound with two extra turns.

COIL CONSTRUCTION

Constructing the coils is a simple process so long as it is not hurried and the coil wire handled very carefully.

To be effective, the twin coil L1/L2 is wound on a 10mm diameter former with irregular gaps left between most windings. Coil L1 is constructed from 30s.w.g. wire. Initially wind 20 turns then make a small loop of about 15mm to 20mm secured by a couple of twists to form the first tapping.

After winding another 15 turns, the second tapping is similarly made. Complete the coil with a further 15 turns and seal over the end sections only using insulation tape so it keeps from unwinding. The start

COMPONENTS

Resistors

R1	22k
R2	1M
R3	47k
R4	3k3
R5	100k
R6	560Ω

All 0·25W 5% carbon film.

See SHOP TALK page 71

Potentiometers

VR1	10k rotary carbon, log.

Capacitors

C1	470p polystyrene
C2	680p polystyrene
C3	820p polystyrene
C4	1n2 polystyrene
C5	2n5 polystyrene
C6	3n3 polyester
C7, C8, C29	4n7 polyester (3 off)
C9	120p polyestyrene
C10, C19, C23, C28	10n ceramic disc (4 off)
C11, C14, C22	100n ceramic disc (3 off)
C12, C13,	220p polystyrene (2 off)
C15, C17 C21	1n ceramic disc (3 off)
C16, C18	100p polystyrene (2 off)
C20	250p polystyrene
C24, C26	15p ceramic, low K
C25	5p5 ceramic, low K
C27	homemade (two pieces of p.v.c. covered wire – see text)
C30	10p ceramic, low K
C31	22p ceramic, low K
C32	1000µ radial elect. 25V
C33	1µ radial elect. 25V
C34	200p polystyrene
C35	10µ to 22µ radial elect. 25V
C36	100µ radial elect. 25V
VC1	30p differential single turn air-spaced trimmer or similar – see text
VC2	126p min. a.m./f.m. tuning capacitor (ZN414/6 radio i.c. type)

Semiconductors

TR1	BC109 *npn* low power transistor (no suffix)
TR2	BC549B *npn* low power transistor
IC1	TDA7000 f.m. processor

Coils and Inductors

L1/L2	50 turns (L1) and 7 turns (L2) 30s.w.g. enamel coated copper wire – see text
L3	37µH to 40µH axial inductor (non-suppression)
L4	22µH to 30µH axial inductor (non-suppression)
L5	13 turns 24s.w.g. enamel coated copper wire – see text
L6	10 turns 26s.w.g. enamel coated copper wire – see text
L7	56µH to 60µH axial inductor (non-suppression)

Miscellaneous

S1	1-pole 12-way rotary switch
S2	s.p.s.t. on-off toggle switch
SK1	phono socket, single hole fixing chassis mounting
SK2	3·5mm mono jack socket, with matching plug
B1	9V battery (PP3 type), with connectors

Stripboard, size 27 holes × 14 copper strips (Aerial), 44 holes × 17 strips (R.F.), 31 holes × 17 strips (Audio), and 0·1in matrix copper pad (single or tri-pad) board 15 × 15 holes (Tuner); plastic case, size approx. 200mm (W) × 110mm (D) × 62mm (H); potting box, 75mm (L); 18-pin d.i.l. socket; 20-pin d.i.l. socket; 10 metres plastic coated wire for long aerial (optional); plastic knobs, with skirts (3 off); connecting wire; M4/M3 nuts, bolts and spacers; circuit board stand-off pillars; self-adhesive pads; rubber grommets; solder pins; solder etc. Crystal earpiece or high impedance headphones.

Approx. Cost Guidance Only **£30** *excl. case, batt. and headphones* of the winding is indicated on the circuit diagram with a ●, and the end with a □.

The coupling coil L2 is simply seven turns of 30s.w.g. wire wound over the length of L1 with turns kept in the same direction as for L1. Note that the start of this winding is not actually connected up once in-circuit.

Once the enamel insulation has been scraped off from the "ends" using sandpaper, plastic-covered, flexible (multistrand) leads should be soldered to the tappings; including the start lead of L1, which will be used for the long aerial connection.

TUNING COILS

The tuning coil, L5, is wound from 24s.w.g. wire at exactly 13 turns on a 6·5mm dia. former. Conveniently, a pencil of similar diameter can be used to wind the coil on then slid out with most turns having a gap of about 1mm.

As with the preceding coils, L6 is also air-cored but constructed from 26s.w.g. wire at 10 turns on a 10mm dia. former. Reserve a gap of 2mm to 3mm approx. between most turns.

Coils L3, L4 and L7 are commercial inductors and should be easily obtainable. Typical ratings (micro Henries) are shown on the circuit diagram Fig.3.

ALIGNMENT AND SCREENING

Unfortunately, simply "slapping the coils on" the circuit boards can distort their effectiveness at v.h.f. frequencies unless properly aligned. For instance, once soldered in place, L5 and L6 stand away from the board as opposed to resting on it.

Positioning of the circuit boards and L1/L2 inside the case. The Tuning board is mounted inside its own potting box. Note the small "screening" partition by L1/L2.

As a stringent check, L5 should take up no more than 16mm to 17mm in length to ensure the correct distribution of turns. If the length seems shorter, gently push the relevant turns a part a fraction so the offset fills out, taking care not to scrape away any of the protective coating.

Although coil L6 is shown parallel to L5 in Fig.3 it should actually be positioned perpendicular to L5 as in Fig.5. Therefore, keep the start and end windings approx. 40mm long so the coil can be rotated easily into position after soldering it in.

Since both coils form a section of the tuned circuit, this is kept separate as a whole from the rest of the project. See "Casing Up" section later.

CONSTRUCTION

The circuit board component layouts, details of underside copper track breaks/links and interwiring, are shown in Fig.4 to Fig.7.

The constructor may be surprised to see several circuits boards being used in this project but this helps to build the circuit in

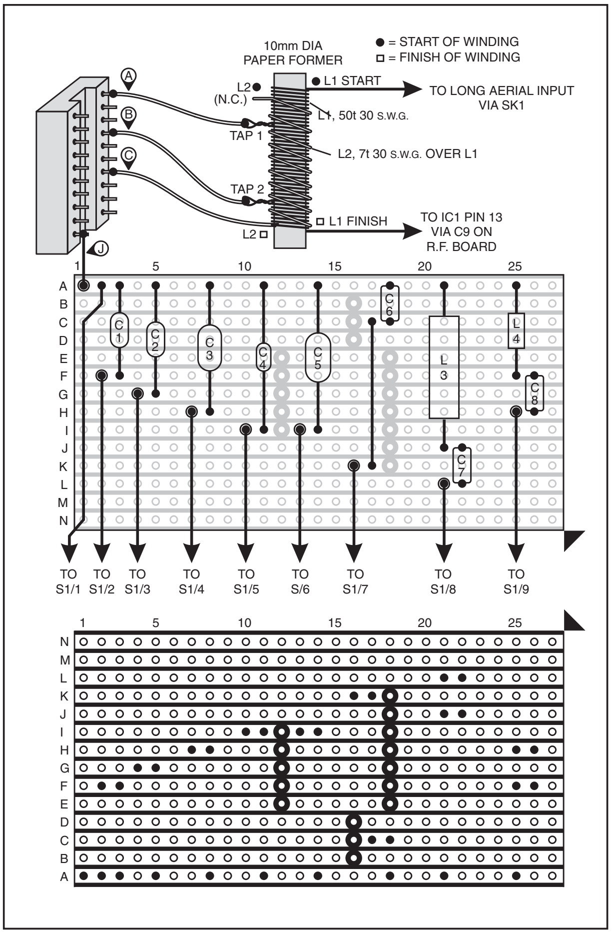


Fig.4. Attenuator board component layout, wiring and underside copper break details.

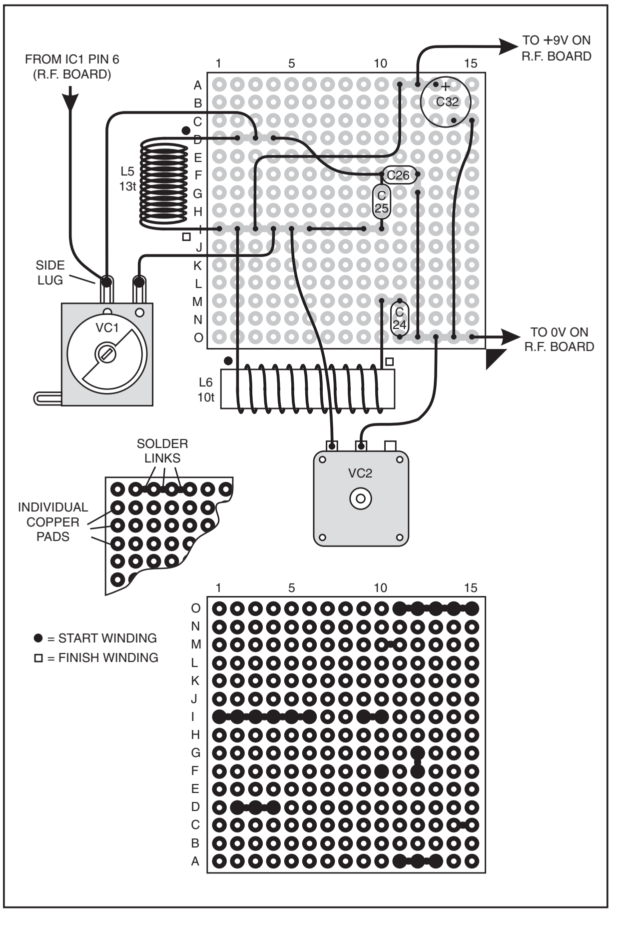


Fig.5. Tuning "pad" board component layout, underside "linking" and interwiring.

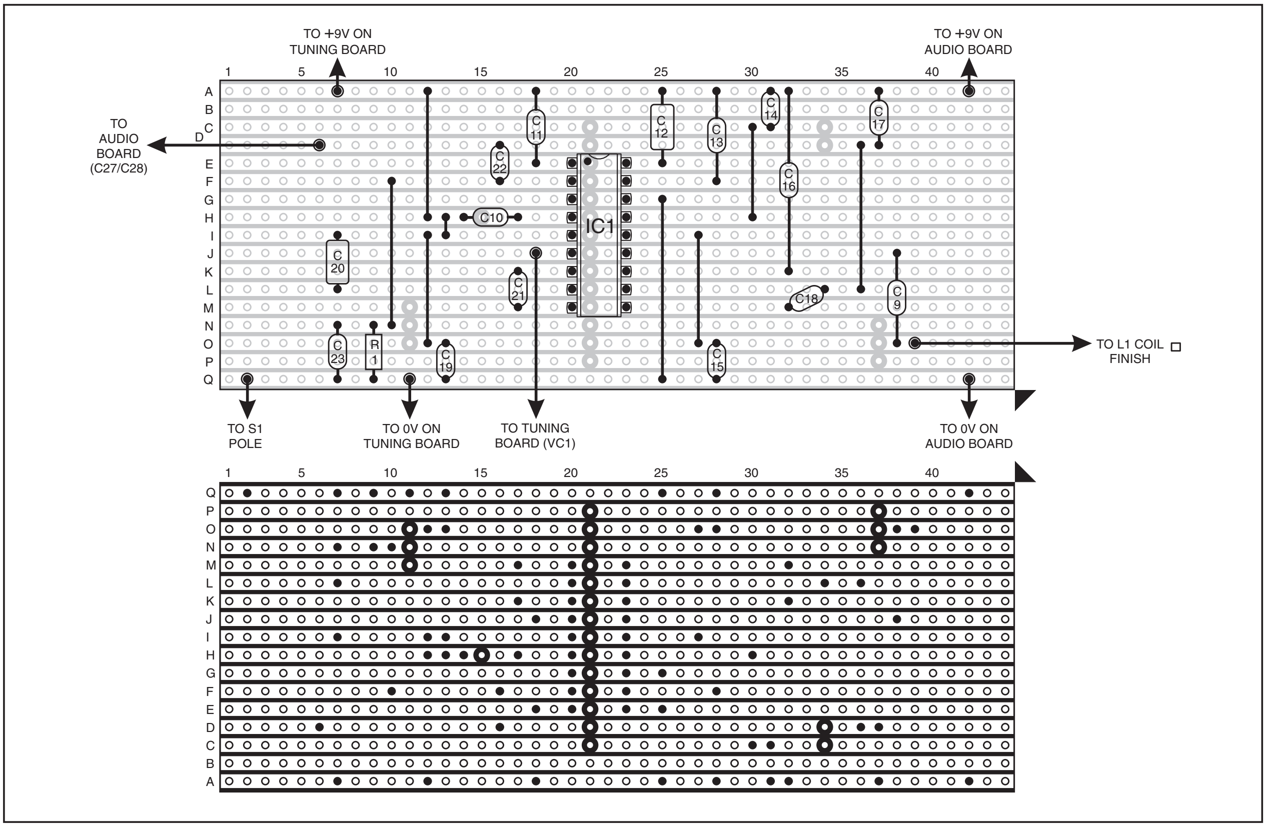


Fig.6. R.F. Tuning board component layout, underside copper strip breaks and lead-off wiring details.

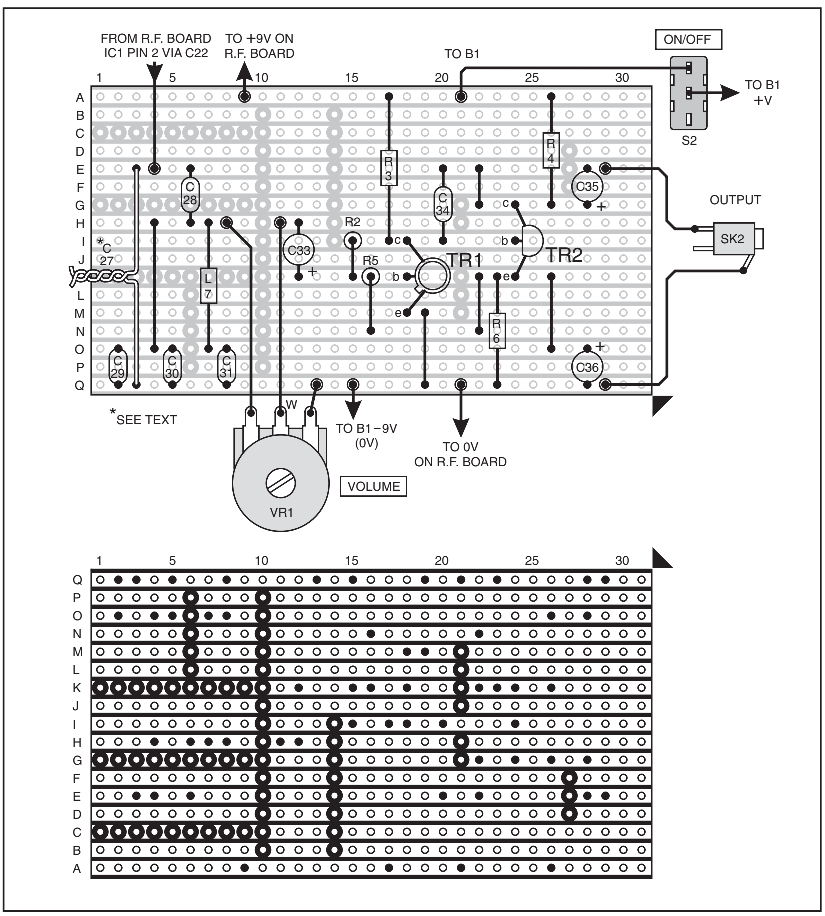


Fig.7. Audio/Filter circuit board component layout, interwiring to off-board components and details of breaks required in the copper tracks.

stages and assists fault-finding; there is, however, a more fundamental reason.

Taking into account the very high frequencies involved, despite building the project without error and confirming correct d.c. voltages using a multimeter, there can still be serious problems with spurious feedback and ineffective decoupling having a detrimental effect on the performance. Hence the need to physically isolate the aerial circuit, IC1 processor and tuner/audio stages.

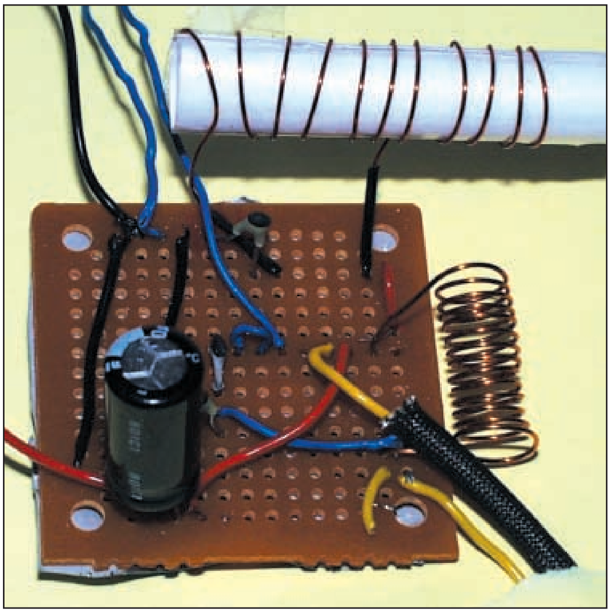
Because the VCO tuning can also be dogged with oscillation problems, the tuned circuit was soldered on to a "pad" or "tri-pad" type board to limit stray capacitances. (Note this type has small, circular pads for soldering connections as opposed to copper tracks running parallel.) The links for this section are made with single core p.v.c. covered wire.

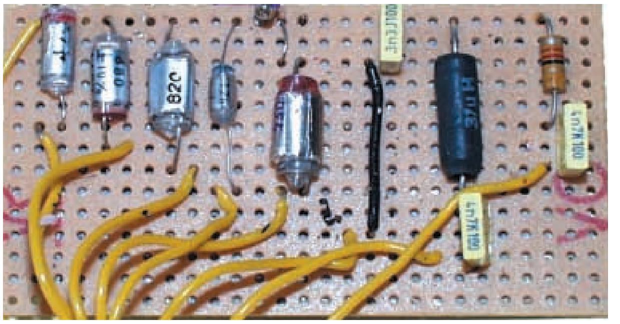
Another measure is to insulate the copper section for each circuit board using p.v.c. or "gaffa" tape once the project has been tested and is ready to be encased. The size of each stripboard required can simply be determined by counting the number of rows and columns in each case and then trimmed from a larger board.

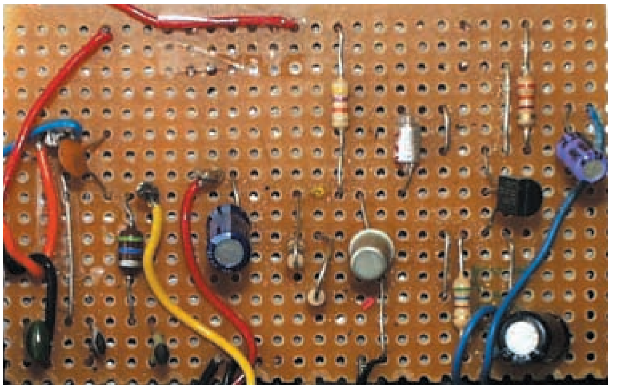
SELECTIVITY

As an auxilliary circuit aiding front end selectivity at higher frequencies, the aerial filter network (lead J) at the junction of C1 to C6 and L3, L4 can be switched in-circuit by wiring it to any one of the three inputs. That is, the first and second tappings and the "finish" lead of coil L2 of the twin coil labelled A, B and C respectively in Fig.3 and Fig.4.

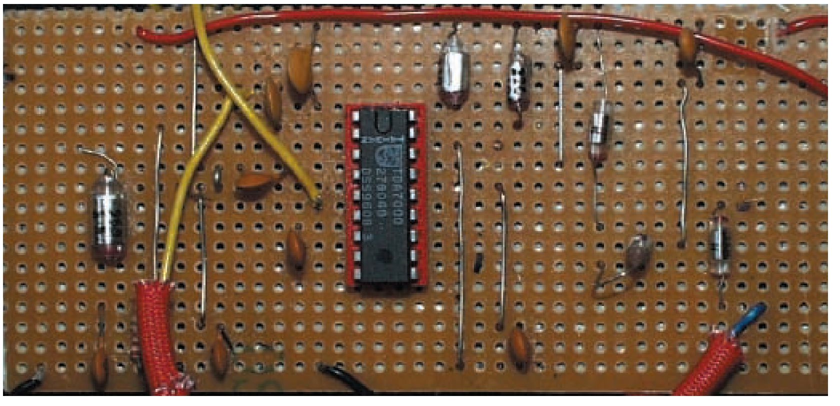
Rather than using a second rotary switch, an easier solution is to employ a d.i.l. socket as shown in Fig.4. At the very







Prototype circuit boards (left to right, top to bottom): Tuning board; Attenuator board; Audio board and R.F. board.



least this should be a 14-pin holder so the inputs are not soldered in close proximity.

Also, the relevant holes will have to be drilled at the side of the casing to accommodate the socket before soldering connections are made. The front or insert side of the socket then makes it possible to "plug in" a jump lead from the filter circuit to coil points A, B or C.

TESTING AND FAULTFINDING

Apart from incorrect wiring and wrongly mounted components, each circuit board should be inspected carefully for short circuits caused by solder splashes bridging over adjacent copper tracks.

Indeed, for the less experienced constructor, it is advisable to practice stripboard soldering before building the project, the rule being not to use excessive solder. You must contain each soldered joint within it's own track area.

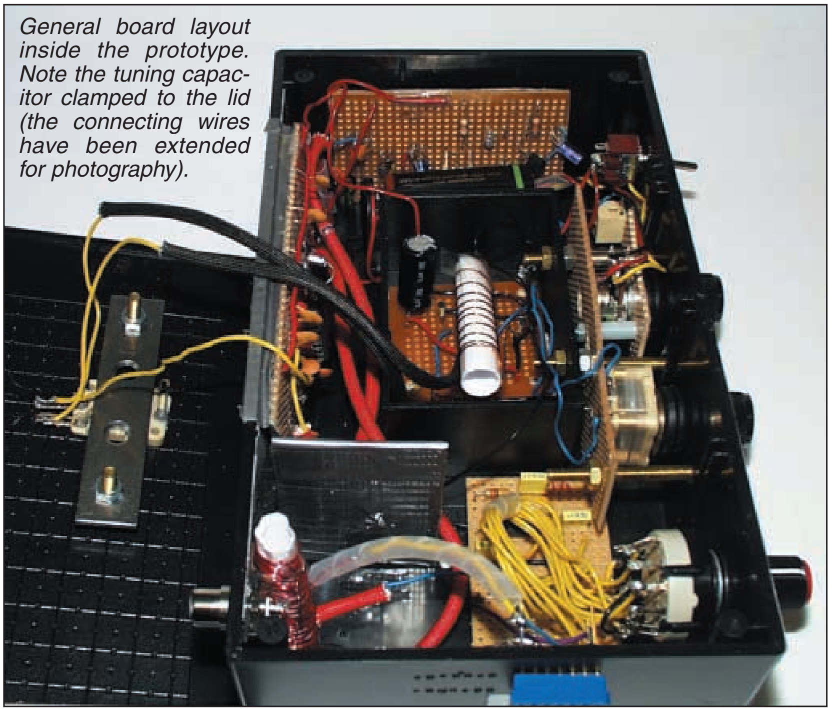
The pinout details for IC1, transistors TR1 and TR2 should, of course, be correctly identified and inserted correctly into the stripboard.

Generally speaking, if the output is silent this indicates a short circuit and/or a wrong connection. For the latter, external wiring and supply lines should also be checked to see if the voltages are correct.

If only static is heard in the output despite VR1 being advanced to full adjustment, this tends to point to a loose connection and/or dry joint. Assuming a 9V supply and no signal conditions, (i.e. the aerial is left disconnected), key voltages can be easily confirmed using a multimeter switched to the 0V to 10V d.c. range. The key voltages are set out in Table 2.

CASING UP

The project can be housed in a large-sized case of approximately 200mm by 110mm. Whereas the processor board (IC1) is situated facing the control panel, the audio stage is placed well out of the way towards the far side of the panel.



General board layout inside the prototype. Note the tuning capacitor clamped to the lid (the connecting wires have been extended for photography).

The aerial coil is screened from IC1 by an insulated section of matrix board positioned vertically. The external connection pertaining to the aerial input (start of L1) is made via a phono socket SK1 fitted to the side or back panelling (see Fig. 10).

As mentioned before, the tuned circuit (including L5 and L6) is kept separate as a whole by housing it in a large sized potting box kept in place via the front panel fixtures – see Fig.8. Incidently, a suggested method for mounting the controls to the front panel is also depicted, with additional supports needed for VC2 and VR1 in order to even out the load-bearing.

Since VC1 is adjustable, via a small pitch screwdriver or trim tool, it is fitted to the top surface or lid of the enclosure. This enables easy access to the adjustment slot, whilst giving the project a more intriguing look!

During trials, it was discovered that the wiring for VC1/VC2 and to pin 6 of IC1 should not exceed more than 80mm. This, however, is assisted by the strategic placing of the tuned circuit in close proximity to the controls and IC1.

IN USE

Any thin, p.v.c. insulated wire can be used as the long aerial, whether single-cored or multistrand. About 10 metres will suffice, the aerial being kept well away from electrical cables and not doubled over on itself.

It should be remembered that strong signals can easily overload the unit, in which case the aerial should be loosely coupled to the aerial input. That is, the flex is simply twisted around the aerial input socket (phono socket) without the exposed strands making electrical contact. Otherwise, the connection is more directly made using a phono plug.

Note also that VC2 is adjusted relative to VC1 to maintain the required "offset". For instance, VC1 is carefully tuned near continuous pulses and/or on-off tone bursts which either precede or indicate transceiver activity. Variable capacitor VC2 is then adjusted for the best signal.

As discussed earlier, the aerial filter can be switched in-circuit via coil L1/L2 tapping inputs A, B or C to reduce interference and improve poor-quality signals beyond 112MHz by applying attenuation a step at a time.

However, due to lower frequency signals being impeded it is advisable to keep the filter circuit disconnected when initially operating the Surfer. Once the output has been gauged, the filter can be switched in-circuit noting any difference in signal quality.

Table 2: Key Circuit Voltages

Test Point		*Voltage*
IC1	Pin 5	9V
IC1	Pin 13	1·8V
IC1	Pin 6	9V
IC1	Pin 2	0·9V
TR1	Collector	1·4V
TR2	Collector	4·8V
TR2	Emitter	0·7V

No Signal Conditions; Vs = 9V
Average current consumption
= 9·8mA approx.

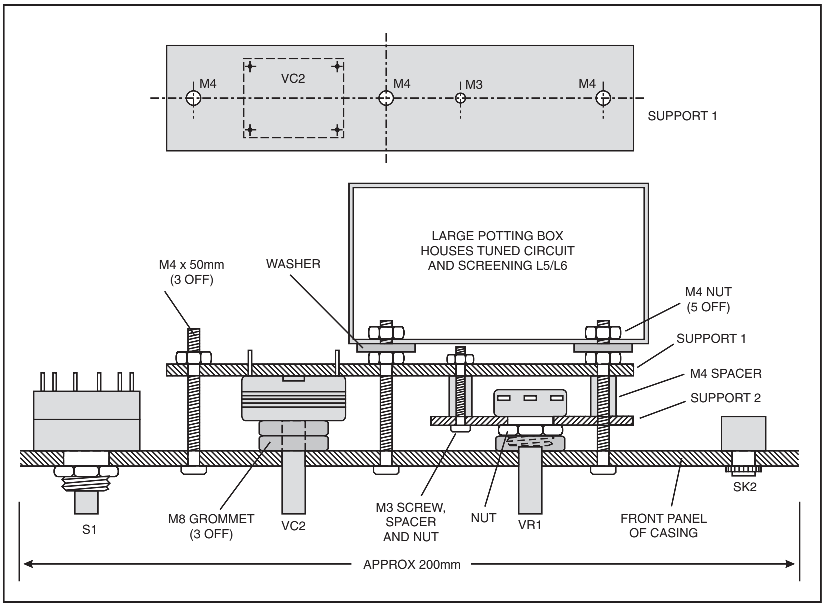
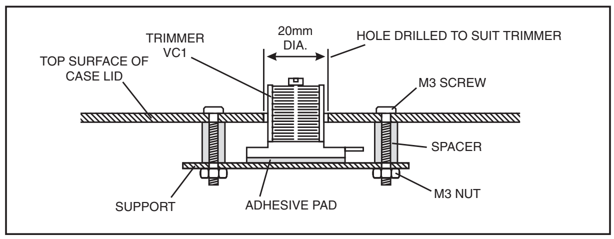


Fig.8. (above) Front panel component mounting details.

Fig.9. (right) Mounting trimmer capacitor VC1 on the case lid.



TUNING-IN

Although practice is needed to operate the unit confidently, the following procedure can be used as a convenient start point.

1 – Set VC2 at a third of its tuning range.
2 – Adjust VC1 incrementally until a signal is approached.
3 – Re-adjust VC2 to fine-tune.
4 – If using attenuation, repeat 1 to 3 for each step-up value.

RESULTS

Despite being a simple circuit (and therefore less prohibitive to build), the prototype picked up a range of transceiver signals on the f.m./v.h.f. bands including fixed/mobile communications and paging systems at around 86·5MHz and 110MHz. In some instances as VC1 is advanced slowly, normal free-floating f.m. static is abruptly interrupted by so called "channel static" indicating a communications line being open.

Apart from aeronautical radio-navigation tone bursts (110MHz, upwards), nearby aircraft signals (117·5 MHz) were also detected though very little may be understood unless the operator is familiar with coded abbreviations!

More accessible is Amateur Bands activity heard frequently on the lower frequency channels with one or both sides of the conversation received clearly.

With a little trial and error, the nominal range can be extended (86MHz to 146MHz) by experimenting with attenuation and, primarily, inputs A, B and C in turn.

Ending on a precautionary note, it should be remembered to loosely couple the aerial where overloading occurs. Secondly, keep the wiring for VC1 and to IC1 pin 6 as *short* as possible – otherwise the reception of transceiver signals may be much reduced.

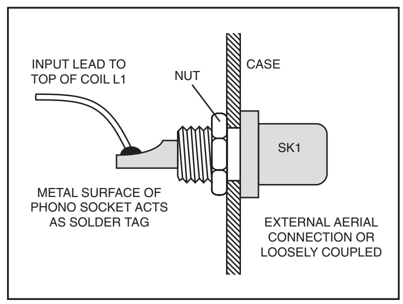


Fig.10. Using a phono socket for the external long aerial connection.