MICROCONTROLLER P.I. TREASURE HUNTER

MARK STUART

A powerful and stable design that is reliable, easy to assemble set up and operate.

This project is the natural successor to the highly acclaimed and original design featured in the August 1989 issue. This new version retains all of the good features of the original and brings up to date ideas and technology into the design to produce a more powerful stable circuit. It is reliable and easy to assemble, and can be set up without any special tools or equipment.

As well as the electronic circuit design, the hardware has been improved, and is available separately or as part of the full kit.

PULSE INDUCTION - GENERAL

The pulse induction (P.I.) method of metal detection relies on the electrical conductivity of buried objects. Thin sectioned material such as foil is not very conductive and so is largely ignored. Solid objects such as coins, rings, nails, are much more conductive and are readily detected, as of course are larger objects.

The biggest advantage of pulse induction is that it is virtually free of “Ground Effect” - so much so that it works perfectly with the search head immersed in fresh or sea water, provided the coil is adequately protected.

The only real disadvantage of this type of detector is that it detects ferrous and non-ferrous metals alike - and cannot discriminate between different types of metal. This is more than compensated by the sensitivity, simplicity, and ease of use that the P.I. system offers, and it is a firm choice with detector enthusiasts, especially for beach combing.

The sensitivity of a P.I. detector is determined mainly by the current in the search coil, which also determines the battery life. This design has been optimised to operate for a sensible length of time from six AA cells, whilst giving a good practical level of sensitivity - it will detect a new 10p coin at 20cm.

The sensitivity has been optimised for less conductive metals such as gold. This has been done by setting the appropriate pulse sampling time - and will be explained in detail later.

PULSE INDUCTION - PRINCIPLES

The pulse induction method of detection works by subjecting objects to a rapidly changing electromagnetic field. The field is produced by building up a current in a simple multi-turn search coil, and then forcing the current to fall very rapidly by switching off the supply. As the electromagnetic field decays it induces a voltage back into the coil, and also into objects near the coil.

Poor or non-conductive objects are unaffected, but in conductive items a current is induced, producing a small magnetic field which opposes the decay of the original field. This opposing field means that when near metal, the magnetic field around the search coil decays in a different way, and so the voltage induced in the search coil also differs.

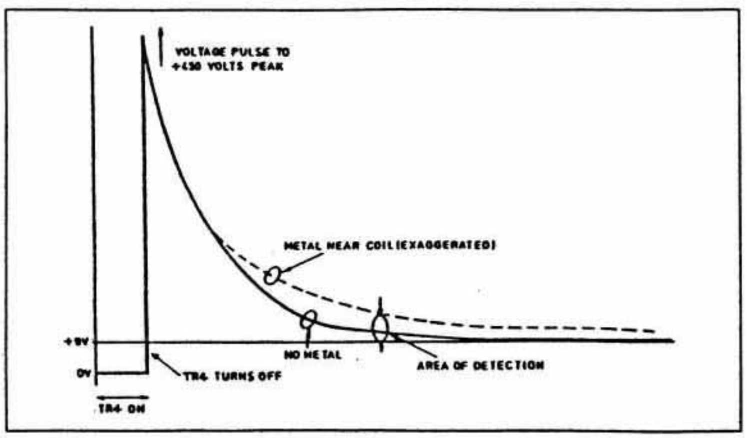

Fig. 1. Graph of the search coil voltage for one complete operating pulse

An exaggerated view of the search coil voltage for one complete operating pulse is shown in Fig. 1. Initially TR4 is turned on and the coil voltage is close to 9 volts as the current builds up. When TR4 is turned off, the voltage across the coil rises rapidly as the magnetic field through the coil falls. After a time, the field falls more slowly and the induced voltage falls accordingly, dropping gradually to zero. The solid line shows the observed waveform when the coil is clear of metal, whilst the dotted line shows the waveform when metal is near.

The difference between the two curves is very small - much less than one millivolt - and so a large amount of amplification is needed to produce a useful signal. The demands on the amplifier are harsh. It must be very fast, be able to respond to a very small signal after being overloaded by a huge one, and have a high voltage gain.

The main (earlier) part of the pulse is of no value as it shows no difference between metal and no metal conditions. As the pulse decays, although the actual voltages fall, there is an increase in the difference between the two conditions. To get the required signal it is necessary to “sample” the waveform at a fixed time after the initial pulse and from this to derive a voltage which can be used to give an audible or visual output.

The timing of when the sample is taken allows a limited degree of discrimination between different types of metal. A later sample shows a larger signal for very conductive metals such as copper and silver, whilst an earlier sample (as set in this design) shows a larger signal for gold (and, unfortunately, aluminium). It is a sad fact that the best setting for jewellery is also that for ring pulls!

DESIGN FEATURES

The main objective of this design was to produce a circuit that could be divided easily into sections. This was considered important because it simplifies fault finding, makes the circuit easier to understand, and most importantly, allows each section to be optimised for its particular function. Fig. 2 shows the circuit in a simplified functional form.

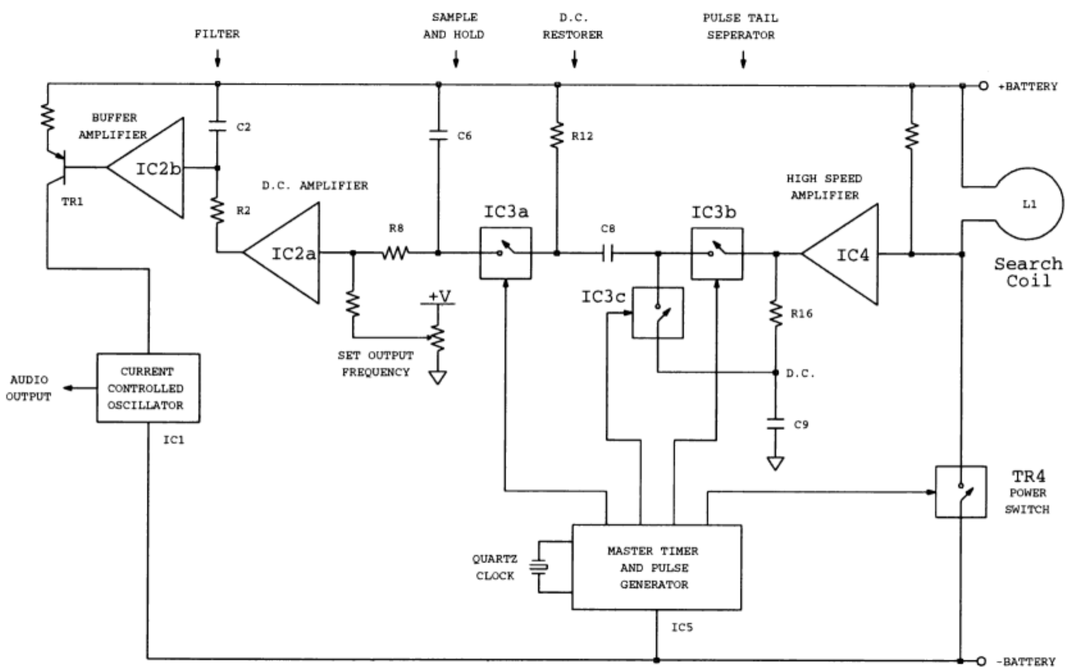

Fig. 2 Simplified diagram of the Microcontroller P.I. Treasure Hunter

The use of a microcontroller I.C. (IC5) has allowed all of the vital pulse timing to be optimised, and set in software during development. All of the timing is set by division from the 4MHz microcontroller clock and so is extremely accurate and free from jitter and drift which would otherwise appear as noise and reduce the circuit sensitivity.

There are two other particularly important features in this design. The first is the method of drift cancellation which is applied around IC4. Despite its mundane sounding number, the LM318 is a very fast high gain amplifier which can recover immediately from large overdrive, and then amplify very small signals without overshoot or “ringing”. To use it to its full benefit in this circuit it needs to be d.c. coupled and operated at the highest gain possible. With this level of gain. battery voltage and temperature changes produce significant output voltage shifts, which would mean regular re-adjustment of the frequency control.

To deal with this problem, a novel piece of circuitry has been added. The essential part of this is the combination of R16 and C9. These act as a low pass filter, removing any pulses and producing at their junction, a smooth d.c. voltage which is the average d.c. output of IC4.

Two analogue gates IC3b and IC3c (which operate as electronic switches) are switched by the microcontroller in such a way that the average d.c. voltage from IC4 is subtracted from its direct output - which contains the same d.c. voltage but with the wanted pulse superimposed upon it. The net result is that the d.c. voltages cancel, leaving just the desired pulse to pass via capacitor C8 to the rest of the circuit. Since the output no longer contains any d.c., there cannot be any voltage drift.

SAMPLE AND HOLD

The second feature is the use of a “sample and hold” circuit to detect the wanted pulse height. Resistor R12 sets the d.c. level at the output from C8 so that the voltage at the junction of C8 and R12 is the positive supply voltage with the wanted negative going pulses superimposed upon it. These pulses need to be converted into a steady voltage proportional to their height which can be used to drive a voltage controlled oscillator to give a variable frequency signal in the headphones.

The conventional approach is to use an integrator circuit with a fast charge and slow discharge rate. This does the job, but as the discharge rate is slow, the circuit is limited in its speed of response. The output also contains a significant amount of the main operating pulse frequency as the integrator voltage rises and falls each pulse cycle, giving rise to a rough sounding tone in the headphones.

The sample and hold circuit uses analogue gate IC3a which is switched on only during the wanted pulse. In this time the pulse voltage is transferred to C6 where it is held during the time that the analogue gate is switched off until the next pulse is sampled. Any change (increase or decrease) in the height of the wanted pulse is immediately transferred to C6 during the sample period and held. Between sample pulses then is no path for C6 to discharge (except via the input resistance of IC2a which is practically infinite) and so the voltage is held perfectly steady.

This is a major improvement over the conventional integrator because it maintains a constant voltage between pulses instead of drifting slowly. The result is that the frequency heard by the operator sounds smoother, and that the circuit responds very quickly and equally to increases and decreases in the pulse height as the search coil moves over metal.

CIRCUIT

The full circuit diagram is shown in Fig.3. It appears very complicated as a whole, but each section is fairly straightforward and will be described separately. Apart from the main 9 volt battery supply there are two other voltages required by the circuit. The first is 5 volts for the microcontroller i.c. This is produced by D5, a simple shunt Zener diode regulator fed with around 10mA via resistor R24. IC5 draws only 2mA and so most of the current passes through D5 giving good solid regulation. Decoupling capacitor C13 maintains a low supply impedance at high frequency to keep IC5 stable.

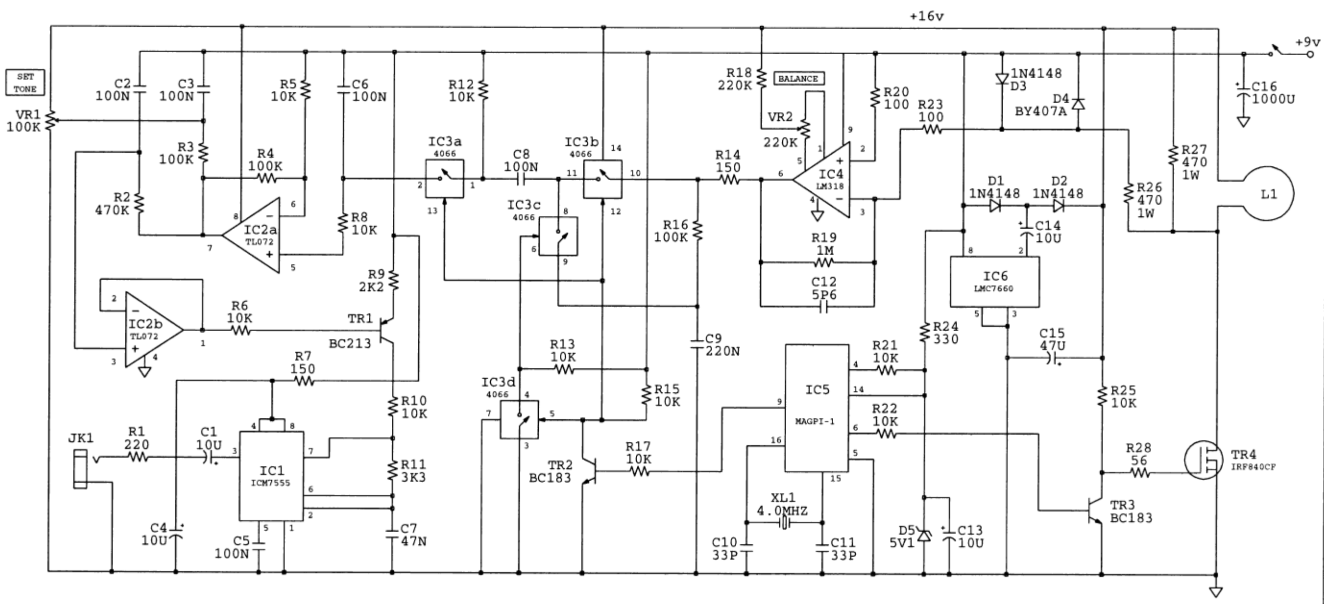

Fig. 2 Full circuit diagram of the Treasure Hunter

The second supply required is higher than the battery voltage and is necessary so that IC2, IC3, and IC4 on be operated with their inputs and outputs at, or close to, the battery supply voltage. Providing plenty of “headroom” like this is very useful in pulse circuits as it ensures that clipping and other forms of voltage limited distortion are eliminated.

The supply is provided by a simple voltage doubler circuit built around “Charge Pump” circuit IC6. This type of i.c. is extremely efficient and versatile, it contains an oscillator driving a number of internal switching devices. In this arrangement C14 is fully charged via D1 and then switched so that its voltage is added to the battery supply and delivered to smoothing capacitor C15 via D2.

The circuit operates at 10kHz and so only small capacitor values are needed to give a ripple free output of the 10mA or so required by the circuit. The two voltage regulators are independent circuit blocks and so will work, and can be tested, on their own.

TIMING AND PULSE GENERATOR

The timing and pulse generation is a very simple application for a microcontroller i.c. but the ease with which such a device can be used to provide carefully timed pulses is justification in itself. Added to that is the benefit of being able to vary the timing during the development simply by altering the software until the optimum values were achieved. The device is a One Time Programmable (OTP) chip which has a section of EPROM but without a window. Once programmed it becomes dedicated to this application.

The timing is derived from the microcontroller clock which is provided by 4MHz crystal XLI and its associated capacitors C10 and C11. Resistor R21 ensures that IC5 resets properly and begins running its program immediately power is applied. There are two pulse outputs, one is to the main coil switching circuit via R22 and the other to the signal processing circuits via R17.

Because the microcontroller runs from only 5 volts it is necessary to add transistors TR2 and TR3 which act as “level shifters” for the pulse outputs, producing pulses which swing from 0 to 16 volts across their collector loads R15 and R25.

COIL DRIVE CIRCUIT

The search coil is energised from the 9 volt battery rail. Current is switched on via a high voltage power MOSFET TR4 which is driven from IC5 via TR3. The 16 volt positive pulse at the collector of TR3 ensures that TR4 is fully turned on and has a very small voltage drop. The turn on of TR4 is relatively slow as its gate capacitance is charged via R25, but the turn off is much quicker because TR3 is turned on and provides a low resistance path for the gate capacitance to be discharged to 0 volts.

Resistor R28 limits the TR4 gate current during switching, and protects TR3 in the event of a power device fault. Supply decoupling capacitor C16 provides a reservoir from which the high pulse current can be drawn without causing a huge dip in the supply voltage.

The search coil current builds up to several amps during the time that TR4 is turned on. Immediately after TR4 is turned off a high voltage positive spike appears across the coil as the current decays via damping resistors R26 and R27. Diodes D3 and D4 clip the voltage spikes via R26 to less than one volt peak-to-peak. After the spikes, as the voltage decays into the sampling area, it is way below one volt and the diodes are completely non conducting and so have no influence on the circuit.

COIL VOLTAGE AMPLIFIER

The clipped coil voltage is amplified by IC4 which has its inverting gain set by feedback resistor R19 and the effective pulse source resistance R23 + R26. Feedback capacitor C12 improves the stability and speed. The non-inverting input of IC4 is connected to the other end of the coil (which also happens to be the battery positive rail) via R20.

The connection point of R20 is very important, and must be close to the coil so that IC4 amplifies the difference in voltage between the coil ends, and does not also get unwanted voltage drops from current drawn in the rest of the circuit from the battery positive rail.

Preset VR2 and R18 allow the output of IC4 to be set to zero when there is no input. This adjustment is to compensate for production differences in the i.c.s input offset voltages and currents and once set should require no further adjustment. The term “zero” should not be taken literally here, as both inputs of IC4 are at the positive 9 volt supply rail and VR2 should be adjusted so that the output is also at this voltage.

Resistors

R1	220
R2	470k
R3, R4, R16	100k (3off)
R5, R6, R8, R10, R12, R13, R15, R17, R21, R22, R25	10k
R7, R14	150
R9	2k2
R11	3k3
R18	220k
R19	1M
R20, R23	100 (2 off)
R24	330
R26, R27	470 5% 1 watt metal film
R28	56

All 5% carbon film 1/4 Watt except R26 and R27.

Potentiometers

VR1	47k to 220k lin. switched carbon
VR2	220k miniature preset

Capacitors

C1, C4, C13, C14	10u radial elect. 16V (4 off)
C2, C3, C5, C6, C8	100n ceramic multilayer (5 off)
C7	47n ceramic multilayer (5 off)
C9	220n min layer type polyester
C10, C11	33p ceramic plate (2 off)
C12	5p6 ceramic plate
C15	47u elect. 25V
C16	1000u radial elect. 10V

Semiconductors

IC1	ICM7555 low power CMOS timer
IC2	TL072 CP dual BIFET op. amp
IC3	4066 or 4016 quad analogue gate
IC4	LM318 fast bipolar op. amp
IC5	MAGPI-1 programmed microcontroller (see Shoptalk)
IC6	LMC7660 voltage converter
D1, D2, D3	1N4148 signal diodes (3 off)
D4	BY407A high speed diode
D5	5V1 500mW Zener
TR1	BC213 pnp transistor
TR2, TR3	BC183 npn transistor (2 off)
TR4	IRF840CF high voltage enhancement mode MOSFET

Miscellaneous

XL1	4MHz crystal
L1	20 metres of 0.71mm diameter enamelled copper wire for search coil
JK1	3.5mm headphone socket

6 x AA battery holder and connecting clip; case for control board; knob for VR1; i.c. sockets; search head, handle, and stem hardware kit. Printed circuit board available from EPE PCB Service, code 882.

PULSE SEPARATION

The wanted part of the pulse from IC4 is selected by a time delayed signal from IC5 which is coupled via TR2 to analogue gate IC3b. The timing is such that IC3b is turned on only during the required part of the amplified decaying coil voltage. IC3d is used to invert the phase of the pulse from TR2 which is then used to drive another analogue gate IC3c which is turned on whenever IC3b is turned off. IC3c has as its input an average voltage derived from the output of IC4 after filtering by R16 and C9.

The combined output of the two analogue gates IC3b and IC3c consists of the wanted part of the decaying pulse, and in between, the average d.c. level to which the decaying pulse eventually settles (this has been explained more fully in the Design Features section). Capacitor C8 removes the d.c. level but passes the pulses, and R12 re-inserts a new d.c. level which is equal to the battery supply voltage. The signal across R12 is simply negative going pulses, the height of which depends on how much metal is near to the search coil.

SAMPLE AND HOLD

Analogue gate IC3a is switched so that it is open during the wanted signal pulses and closed the remainder of the time. During the time that it is open, the wanted pulse voltage charges C6. Once the gate closes the voltage on C6 is held steady because there is no available discharge path - either back through the gate, or into the very high input impedance of IC2a. The result is a stable voltage that is adjusted to each new pulse level. If the pulses do not change in height, the voltage remains the same.

DC AMPLIFIER AND V.C.O.

The signal across C6 is further amplified by IC2a which is configured as a non-inverting d.c. amplifier with a gain which is set to 10 by R4 and R5. To allow the output voltage of IC2a to be adjusted so that the output signal tone can be set, a d.c. voltage is inserted from control VR1 via R3. Capacitor C3 decouples the adjusting voltage to ensure that interference is not introduced.

From IC2a the amplified d.c. signal is filtered via R2 and C2 and buffered by IC2b which acts as a unity gain non-inverting amplifier. The output is then used to drive TR1 which adjusts the charging current of C7 and hence the oscillation frequency of IC1 which is a standard low power CMOS 555 timer thus providing a voltage controlled oscillator (v.c.o.).

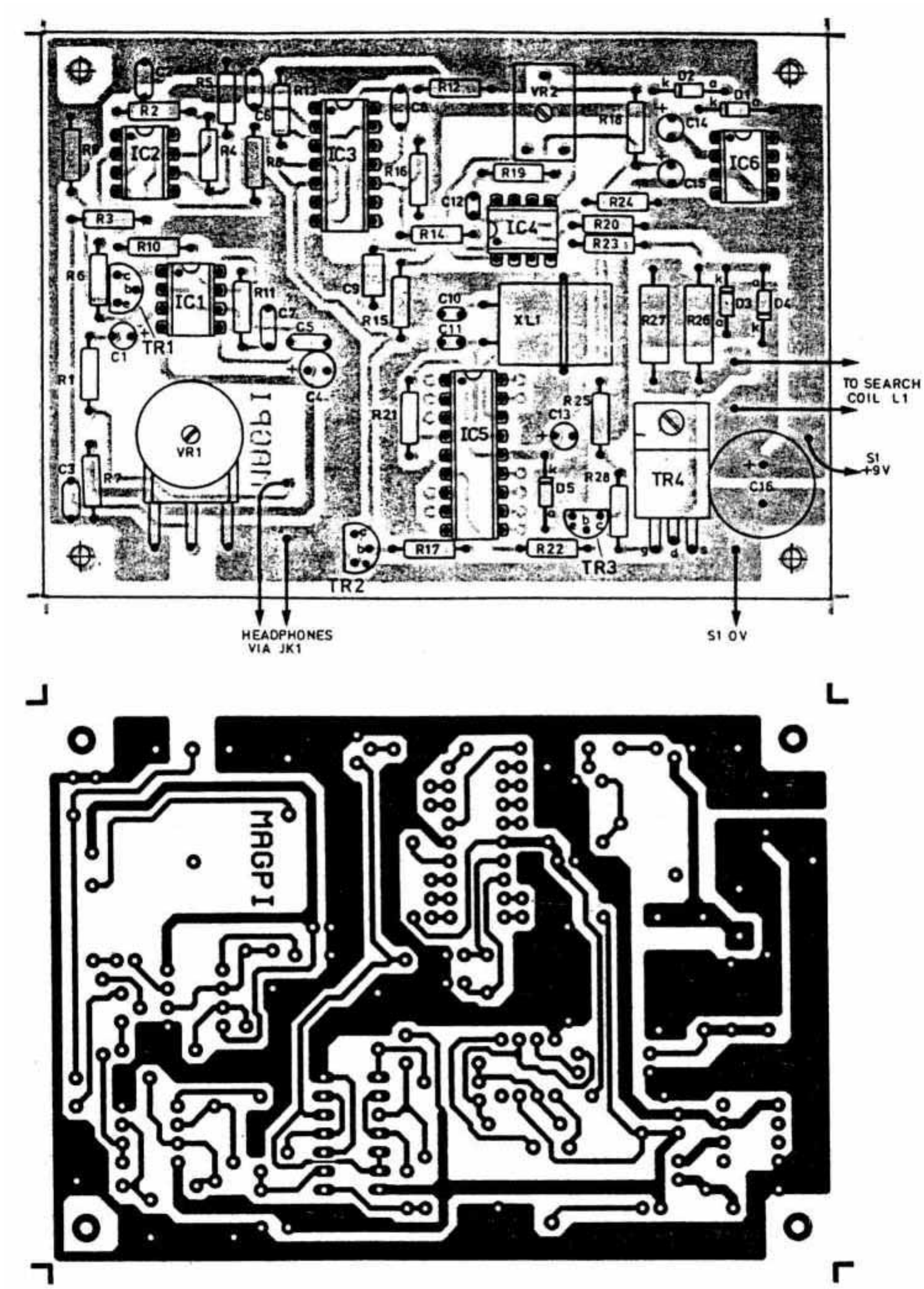

Fig. 4. Printed circuit board design and layout for the Treasure Hunter

The output from IC1 is connected to the headphone socket via C1 and R1 and provides more than enough signal for small personal stereo headphones. Resistor R7 and C4 decouple the supply to make sure that the output signal is clean and does not interfere with the rest of the circuit.

CONSTRUCTION

The circuit is based on a single printed circuit board, and involves very little wiring. The component layout and copper foil pattern are shown in Fig. 4. Sockets can be used for all of the i.c.s and make fault finding a lot easier.

Although the circuit is complicated, the final board layout is not overcrowded and is easy to assemble. Before inserting any components, decide how the board will be fitted into the case, and use it as a template for any case drilling. The prototype board was mounted by the bush of VR1 without any other support, but space has been allowed on the final board layout for additional fixing screws, and VR1 may be mounted elsewhere, off the board if an alternative layout is preferred. Remember before drilling that the board is fitted into the case with its track side down!

The case requires other holes to be drilled to fit two saddle clips, the headphone socket, and for the search coil connecting lead. The positioning of these is left to individual choice, but it is a good idea to keep the socket and search coil holes facing downwards in case of rain.

BATTERY HOLDER

There is space over the main board for a 6 x AA battery holder. Alkaline batteries give the best performance, but rechargeables or standard zinc carbon cells can also be used. The battery space can be separated from the board by a layer of sponge plastic. This holds the batteries in place and protects the board and components.

Once the hardware layout for the case has been sorted out, assemble the printed circuit board. Fit all of the resistors and diodes first, followed by the i.c. sockets, and the capacitors. The i.c. sockets have a notch to indicate which end pin 1 of the i.c. will be fitted and so should be fitted the correct way round. There are several electrolytic capacitors which must be fitted the right way round - usually the negative lead is indicated by a line marked down the side of the case.

The crystal and MOSFET should have their leads bent to 90 degrees so that they can be laid flat on the board. A small dab of glue will hold the crystal down to the board surface. The MOSFET must be fitted with its metal tab closest to the board but does not need any extra support as its leads are quite stiff. TR1 must be a BC213, TR2 and TR3 must be BC183. These have the standard e-b-c pin out. Do NOT use BC183L or BC213L types which look the same but have the collector lead in the centre. All three transistors must be fitted with their flat side as shown on the component layout.

INTERWIRING

There are five connections to VR1, three to the potentiometer section and two to the switch. The three potentiometer connections are self explanatory as they are positioned appropriately on the board. If VR1 is to be mounted on the board, short lengths of tinned wire can be used to make the three connections. For off board operation the three connections need to be made with flexible insulated 7/0.2 or similar wire. The routing of the wire is not critical as it is only carrying d.c. control voltages, but keep it away from the drain of TR4 because of the very high voltage pulses that are around. The connections to the switch section are made by the leads from the battery connectors as shown in the wiring diagram. Fig. 5.

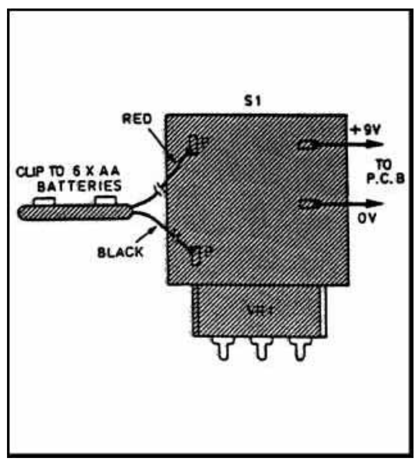

Fig. 5. Supply wiring to S1 and the p.c.b.

Fit two terminal pins to the board for the search coil connections, as this will allow the search coil to be connected without access to the underside of the board. All of the other off board wiring connections, to the battery leads, the headphone socket, and VR1, if it has been mounted remotely, are best done by soldering the wires directly to the board by stripping a short length of insulation, passing the bared wire into the board from the component side, and soldering it on the track side.

SEARCH COIL

The search coil is a simple winding of 27 turns 190mm in diameter. A coil former can be made by marking a 190mm circle on a piece of wood and inserting a 16 panel pins or small nails equally spaced around the line leaving at least 10mm clear above the board. Cover each pin with tape or sleeving to protect the wire, leave 1.5 metres free at the start, and carefully wind 27 turns of 0.71mm diameter enamelled copper wire around the loop leaving 1.5 metres free at the finish. It is not necessary to layer the winding neatly as it will be bunched into a circular section.

Secure the ends with p.v.c. insulating tape, and then carefully slip short lengths of tape under the windings between the nails and fasten the ends together. Fit at least eight pieces of tape and then remove the coil from the board by bending or pulling out some of the pins. The result should be a neat coil that can now be bound with a spiral of tape to enclose it completely.

The start and finish of the winding must be at the same point and should be threaded together through a one metre length of p.v.c. sleeving. The end 30mm of the sleeving should be bound to the coil and the whole coil bound with a further layer of tape spiralled in the opposite direction from the original layer.

Once completed, the two ends of the coil should have their insulating enamel stripped - by using sandpaper, or scraping with a knife. Some types of enamel are solderable, and so can be stripped by applying a hot soldering iron for a while. The bare ends should then be tinned ready to be connected to the pins on the circuit board for testing.

Once the coil has been tested and found to work correctly with the circuit, it can be finished by brushing or dipping it in clear lacquer. Apart from the drying time, this method is simple and effective and if several coats are used will provide adequate protection for use under water.

TESTING

Before connecting the search coil it is useful to make a number of general checks to the circuit. Begin by checking the board thoroughly for dry or missed joints, incorrectly fitted components, and solder bridges. Check also that all of the i.c.s are the right way round, and in their correct places. A simple multimeter that can read volts From 0 to 25 and milliamps from 0 to 100 is extremely useful for testing. If the circuit has been constructed correctly and works first time test equipment is not needed at all. and it is simply a matter of setting up VR2.

Apply power to the board from six AA cells via a small value (10 ohms or so) protection resistor or a bulb. Connect a pair of headphones, set VR2 to mid position, and adjust VR1 until a steady tone is heard. It should be possible to vary the pitch of the tone right down until it becomes a slow regular clicking sound. If all is well so far, switch off remove the protection resistor, and connect the search coil. Position the search coil on a cardboard box well away from any metal, switch on, and re-adjust VR1 for a slow clicking sound.

Moving a metal object near to the coil should result in a immediate increase in the click rate. If not, VR2 needs adjusting. The best way to do this without test equipment is to turn VR2 slowly from end to end. As each end is approached there will be a point beyond which there is no effect on the output tone. The correct position should be halfway between the two.

If a multimeter is available, then adjust VR2 until the voltage on pin 6 of IC4 is equal to the battery positive (9 volt) supply. Check also the 16 volt boosted supply and the 5 volt supply across D5. The circuit will draw approximately 100mA when operating normally.

If an oscilloscope is available then the circuit waveforms and pulses can be checked. This is a very interesting and informative exercise, and will help to give a good understanding of the operation of the whole circuit.

HARDWARE CONSTRUCTION

The hardware kit is straightforward to assemble. It is supplied as a pre-formed handle section, a straight tube coupler, a straight lower stem extension, and a search head disc. Plastic brackets and nylon screws and nuts are also supplied to make a corrosion proof model which is lightweight and strong. Two brackets should be fitted to the search head spaced apart by the thickness of the stem tube. Use two short screws for each bracket and do not tighten them as the brackets need removing again to drill them for the lower stem fixing.

Take care when drilling the search head disk as it will crack quite easily if not supported underneath the point of drilling. The bracket in the prototype was offset from the disc centre to help minimise the folded up length. This is not necessarily the best position however, and a position nearer the centre may be used if the balance is preferred.

Drilling the brackets to take the lower stem fixing bolt is best done, with the brackets off the search head, by aligning and drilling through both together. The lower stem tube should be drilled diametrically with the same size hole 10mm from the lower end.

Corners may be filed on the brackets and the stem tube end to improve appearance and ensure that the assembly swivels properly. The kit includes a nylon wing nut for the search head fixing so that it can easily be slackened and rotated from the storage position to the operating one.

The case containing the electronic components fits inside the fold of the handle section and is fastened by two saddle clips on opposite sides. This arrangement helps to stiffen up the handle assembly. To prevent the saddle clips from rotating, a small amount of glue should be used as well as the contersunk fixing screws and nuts supplied.

HEAD CONNECTION

The search head connecting lead can be routed by any suitable means up to the control board. Either by threading it up through the stem, or taping or clipping to the outside. Leave enough slack to allow the centre stem coupling to be pulled apart so that the detector can be bent double for transporting. If preferred, flexible leads can be soldered to the ends of the search coil inside the search head and used for the connections to the board. Do not use screened cable for this as the extra capacitance is better avoided.

The length of the stem has to be pre set, as any sort of telescopic fitting would be expensive. For regular users of different height it would be possible to have two lower stem pieces, and change them accordingly - provided the search coil wire is run up the outside.

IN USE

The unit is basically automatic in use, the optimum operating conditions having been set into the microcontroller software, this makes it very easy to use in all situations. Simply switch on, adjust VR1 for a slow clicking sound and start hunting.

EPE Microcontroller P.I. Treasure Hunter

A complete kit of parts to build the EPE Microcontroller P.I. Treasure Hunter is available from Magenta Electronics for the sum of £63.95 plus £3 carriage and packing. The kit includes the programmed microcontroller, all hardware and a headphone.

Magenta Electronics, Dept EPE 135 Hunter Street, Burton-on-Trent, Staffs, DEl4 2ST. (0283 65435). Kit code 847.