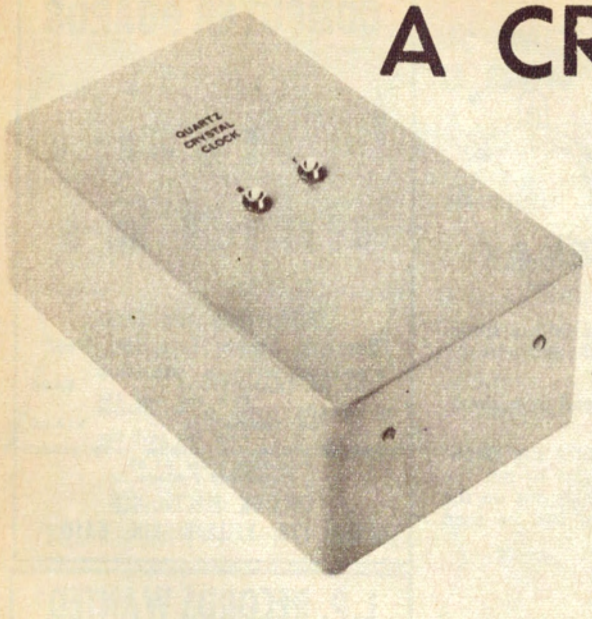
A CRYSTAL CLOCK DRIVE UNIT



Years ago, the pendulum reigned supreme as a timekeeper. More recently it has reluctantly given way to the quartz crystal oscillator and other devices. Here is a simple approach to the design of a crystal clock which can be duplicated at a relatively modest cost.

by Ian Pogson

A few months ago, in December, 1968, to be exact, we presented "Some Thoughts On Crystal Controlled Clocks." This was in response to a large number of requests and inquiries relating to crystal clocks generally. When the foregoing article was written, we had a prototype clock running and undergoing tests, with the view to proving the system before we came up with a project for home construction.

During this time, the fortunes of our clock have risen and fallen, with various obstacles dogging its path. On some occasions, the problems which we had to meet could be put down to "teething" troubles, with all the ramifications that this involves. On other occasions, the problems could be put down to nothing else but bad luck. The unfortunate point about all this is the fact that the unit only had to stop functioning for any reason and for any short period, and the time of the test thus far is virtually wasted. The only choice under these conditions, was to start the checks all over again.

Perhaps readers may have more than a passing interest in the problems which we have had to meet and overcome. They are not necessarily in chronological order, but the following is briefly the story.

About last October, using the setup as shown in the photograph in the article on page 67 for December, all was going quite nicely. The writer went on annual leave and left the unit in the tender care of another member of the staff. For three weeks, all went well, with a reasonably constant losing rate which amounted to four seconds during this period. Although the losing rate may be considered as one which could be improved upon, the important point was the fact that the rate was virtually constant.

Suddenly, on the Monday morning following this run, the clock was four minutes slow! This was indeed a major setback. Checks showed that the clock was in fact, still running at just about the same rate as previously. Inquiries of the engineers responsible for the building revealed that, once a month, the Diesel-operated emergency power supply was tested. The changeover from mains to emergency supply and back again, we were told, took four minutes. So this was the answer.

For convenience, we were running the clock from a regulated and adjustable power supply from the mains. In order to avoid a repetition of this failure, we set up a 12-volt emergency supply made up of eight 1.5-volt flashlight cells. These were connected in parallel with the mains operated power supply. So that there would be no drain on the batteries until the mains failed, we introduced an ordinary power silicon diode in series with the batteries. The mains-operated supply voltage was then set a little higher so that the batteries would not take even a small share of the load.

In the event of a power failure, the silicon diode would allow the batteries to take over. As the drain is only 250 milliamps, the batteries could cope with this for short periods, without any ill-effects on the time-keeping of the clock. This has worked out successfully and readers who may find a standby supply necessary could use this method.

Following solution of this problem the clock appeared to be erratic in its time-keeping, for no obvious reason. By monitoring the 50Hz from the last divider, against the 1000Hz from the previous stage, on a twin beam CRO, we finally traced the trouble to interference from a nearby transmitter. This transmitter is not on continuously but is keyed remotely as required. When keyed, we found that sometimes the last divider came out of lock and then dropped in again. Although the unit was still left generally unshielded, shielding of the output lead was sufficient to cure this one.

Another fault involving the last divider occurred on a couple of occasions, when the last divider came out of lock and stayed out, necessitating readjustment. This could only be put down to aging of components and the answer appears to be to use the very best and most stable components around this stage.

The next fault was a much more subtle one, and requires a fairly detailed explanation. It is a most interesting and informative exercise, to feed the 50Hz output from the clock on one beam of a CRO and the 50Hz from the mains on the other beam. One only of these two components can, of course, lock the CRO time base. From subsequent experience, it is reasonable to assume that the 50Hz from the clock is, for all practical purposes, constant.

Let us assume, therefore, that we lock the time base with the 50Hz from the clock. This allows the 50Hz from the mains to drift with respect to the 50Hz from the clock. Many readers will be under the impression that the mains frequency is substantially stable. However, one only has to observe the setup just described, to find that this is not so. Although the mains frequency averages out to exactly 50Hz over a long period of time, the short term stability is quite a different matter.

A few minutes observation will allow one to observe a gentle drift of the mains frequency in one direction, a pause for a while, and then a drift back in the opposite direction. The point about all this is that the drift between the two very close but slightly dissimilar frequencies leads to some intermittent reaction.

It was found that when the mains drifted in one direction, there was no trouble. However, when drifting in the other direction and when a certain phase relationship was reached, the 50Hz frequency divider would momentarily jump into lock with the mains. This caused an erratic losing tendency and presumably the locking took place as the mains frequency was running slightly slow.

The cure for this problem was the addition of more filtering on the supply line and some slight changes to the triggering circuit component values.

At somewhere about this point, we decided that it would be a good idea to house the unit in the die-cast metal box set aside for it. This was done and all was neat and tidy, with the clock set up again and sent merrily on its way.

As if we had not had enough troubles to iron out, it appeared that the end was not in sight and the writer was beginning to wish that there was no such thing as a crystal clock!

Although all appeared on the surface to the well, after a few days the readout movement would stop and the current consumption would drop to somewhat less than half the normal value. To investigate the trouble, the assembly now had to be removed from the case. During the process, the clock movement started again and everything resumed normality. Much looking, tapping, twisting, voltage measurements and investigations with the CRO revealed nothing. We had no alternative but to put it back and set it up again.

These antics were repeated a number of times and it looked as though there was an intermittent fault in the audio amplifier system somewhere. Finally, the fault persisted for long enough to establish that the crystal oscillator and dividers were all functioning normally. However, after a short while, the fault vanished, leaving the problem still unsolved.

At last, a complete breakdown occurred and it was traced to the second stage of the audio amplifier. Replacement of the transistor and its collector load cured this nasty one. As can be appreciated, these troubles spread themselves over quite a long period and this is a major contributing factor to the delay in publishing details of the completed unit.

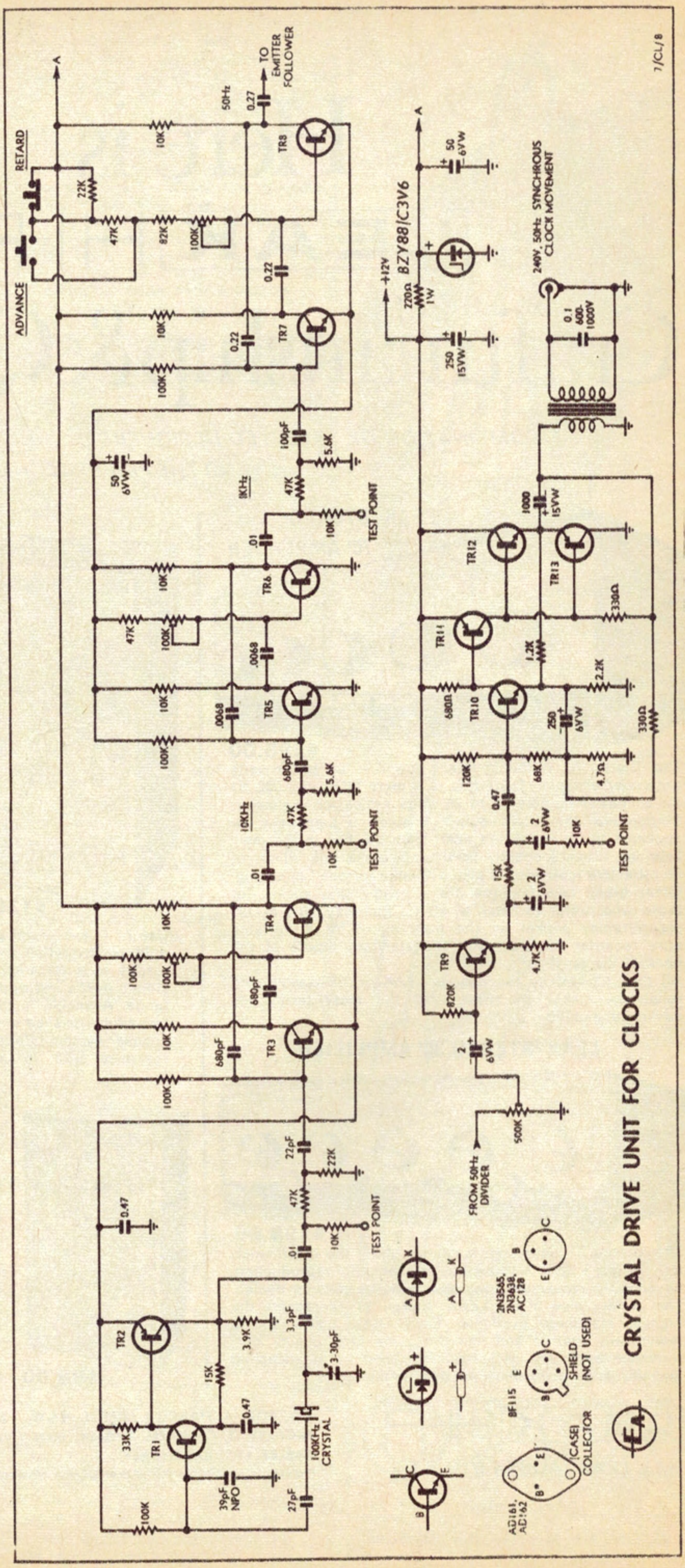
At the time of writing this paragraph, the clock has been running for four days and the rate has been established to be a gaining one, with somewhat less than 0.1 second per day. It will take the next few weeks to establish just what the rate is, and we hope to give more details along these lines later on.

From the foregoing it appears that the system as a whole is capable of quite good performance, in spite of the initial problems. In any case, not all units will need to be operated in close proximity to a radio transmitter and not all will be operated from the mains, thus eliminating even the risk of at least two of our problems. Also, our experience will allow readers to be forewarned against these and other problems, some at least of which have been "designed out" anyway.

On the other hand, our unit operated in a more favourable environment in some respects. It was installed on a bench, making it virtually a fixed installation, as opposed to a mobile installation, with its attendant vibrations etc. Also, although the laboratory is not air conditioned, the changes in weather conditions are not severe. This all adds up to what may be considered quite good environmental conditions. Just how vibration or extreme changes in temperature and humidity would affect the time-keeping qualities, we are not able to say.

Provided the unit is constructed properly and the crystal used is one which will stand up to vibration, then we can

The upper portion of the circuit shows the crystal oscillator and the three frequency divider stages. Note the "Advance" and "Retard" buttons associated with the third divider. The lower portion shows the 50Hz amplifier which drives the synchronous movement.



see no reason why the performance should not be satisfactory from this point of view. With regard to weather conditions, it remains to be seen just how much these factors affect the performance. The only approach to this one would be to try it out and when conclusions are reached, the appropriate action, if any, would suggest itself.

All things considered up to this point, it is the opinion of the writer that this crystal clock unit is still somewhat in the experimental stages. As was pointed out earlier, the design is one which has economy as a high priority factor. This naturally leads to some compromises. One, which is important, is the use of free-running multivibrators as frequency dividers. While they are very good when adjusted properly, they are not foolproof and so not 100 per cent reliable. This point should be considered where a unit is required and where reference is not available against one or preferably two more units.

Although it is not essential, it is highly desirable to have a double beam CRO for setting up and adjusting. In point of fact, we would have been in unenviable trouble had we not been equipped with a double beam CRO, when we had the aforementioned faults to track down.

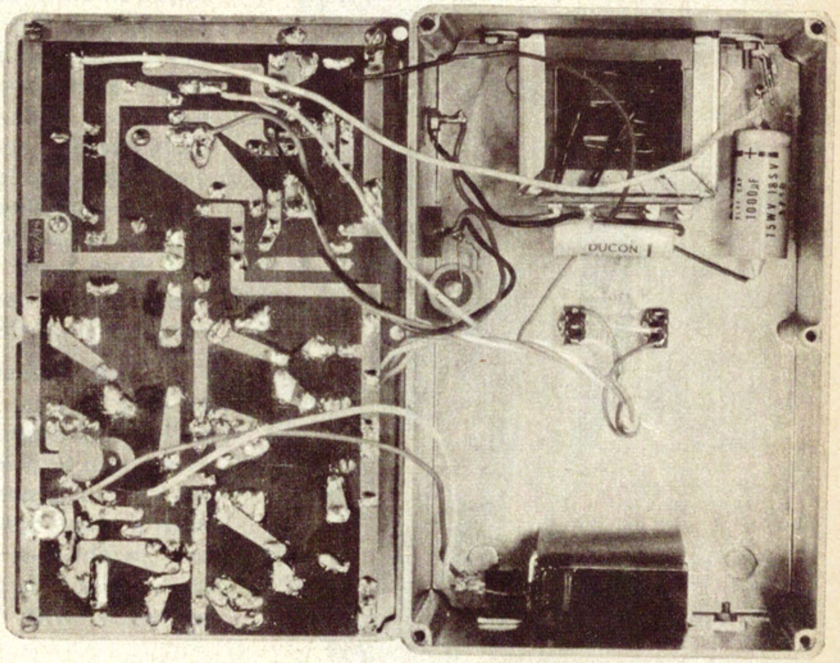
The last few paragraphs may seem to paint a rather dark picture of the whole project. This is not the intention, but, we on the other hand, do not wish to convey an over-optimistic picture. We feet sure that, in spite of the earlier remarks, there will be readers who will want to "have a go," and this is a good thing. Perhaps the unit may not be sufficient on its own for navigational purposes in a small boat on a long sea voyage. On the other hand, there are many other applications, with less exacting requirements, where this clock could do a very commendable job.

There are probably many readers who, like the writer, delight in the pursuit of the elusive ultimate in time and frequency measurement. This leads us on to an alternative application for the clock. Even if you are not interested in its time-keeping as such, more than likely you will have a use for it as a frequency standard. Without alteration, the oscillator and frequency dividers will give accurately, 100KHz, 10KHz, 1KHz and 50Hz. Changes or additions could be made so that more and lower frequencies are made available.

So much for the preliminaries. Let us turn to the circuit diagram. The first stage is the 100KHz crystal oscillator which many readers will recognise as the 100KHz crystal oscillator we have used for a number of recent projects. There is nothing pretentious about this oscillator but it has already proved its worth. Two transistors are used and it should be noted that the second one is of the PNP type and is used "upside down." Circuit constants have been modified for this particular application, to meet the special needs. Emitter currents have been considerably reduced, to reduce temperature effects in the transistors and to keep the crystal oscillation amplitude to a minimum, both in the interests of frequency stability.

A 39pF NPO ceramic capacitor has been placed across the first transistor emitter junction, with the object of swamping, to a degree, any input capacitance variations due to temperature, etc. This, in turn, has necessitated the addition of a 27pF NPO ceramic capacitor in series with the crystal loop. Otherwise it would be difficult to set the crystal precisely on the frequency using a reasonable value for the rate-setting trimmer capacitor. The latter is a high grade Philips 3-30pF trimmer. The transistors which we used are types 2N3565 for the NPN and a 2N3638 for the PNP type.

The output from the crystal oscillator is taken via an attenuator network. which also modifies the pulse shape, to the base of the first of two transistors in a 10KHz multivibrator circuit. This functions as a ten to one frequency divider. The time constant of the frequency divider is adjustable by the 100K potentiometer in the base



A general view of the complete unit assembled in the two sections of a die cast box. The printed wiring board (left) is mounted on the lid, with the power supply, "Advance" and "Retard" buttons, and the crystal in the box proper. The crystal is shown at the bottom of the picture wrapped in foam plastic.

PARTS LIST

1 Die-cast box, 7 3/8in x 4¾in x 3¼in (Eddystone type 903)
1 Printed board, type 68/10cl
1 Output transformer, type 2155 (see text)
1 Coaxial socket (Belling and Lee)
1 2-Pin miniature speaker socket
1 Push-button switch, normally open (see text)
1 Push-button switch, normally closed (see text)
1 2-Tag strip
5 Stand-off pillars, 1in x ¼in brass, tapped 1/8in Whitworth each end
1 100KHz crystal (see text)
1 Socket to suit crystal
1 3-30pF Philips trimmer
9 Transistors, 2N3565, BF115, etc. (see text)
1 Transistor, 2N3638
1 Transistor, AC128 (with heat sink)
1 Transistor, AD161 } matched pair
1 Transistor, AD162 } matched pair
1 Zender diode, BZY88/C3V6
3 100K potentiometers (see text)
1 500K tab potentiometer
Screws, nuts, hookup wire, solder lugs, etc.

RESISTORS
(½ watt unless stated otherwise)

1 220 ohms 1W	*2 15 K*
2 330 ohms	*2 22K*
1 680 ohms	*1 33K*
1 1.2K	*5 47K*
1 2.2K	*1 68K*
1 3.9K	*1 82K*
2 4.7K	*5 100K*
2 5.6K	*1 120K*
10 10K	*1 820K*

CAPACITORS
1 3.3 pF NPO ceramic
1 22pF NPO ceramic
1 27pF NPO ceramic
1 39pF NPO ceramic
1 100pF Styroseal
3 680pF Styroseal
2 .0068 uF low voltage plastic
3 .01uF low voltage plastic
1 0.1uF 600-1000VW polyester (see text)
2 0.22uF low voltage plastic
1 0.27uF low voltage ceramic or plastic
3 0.47 uF low voltage plastic
3 2uF 6VW electrolytics
2 50uF 6VW electrolytics
1 250uF 6VW electrolytic
1 250uF 15VW electrolytic.
1 1000uF 15VW electrolytic

Note: This list does not include power supply components or clock movement.

circuit of the second transistor. Between the two stages, a test point is brought out, with a measure of isolation afforded by the 10K resistor.

The crystal oscillator and the 10KHz multivibrator are "stacked" with respect to the DC supply voltage. The current consumption of the two stages is virtually equal and so they share the supply voltage equally. This practice was adopted early in the development stages, with the object of obtaining maximum economy of operation. Compared with the final figure of 250 milliamps, for the complete unit, this saving is of little significance. However, for any future efforts to produce a clock where current economy is paramount, this approach would be valuable.

The 10KHz output from the first divider is fed, via a network similar to the one just described, to trigger the next divider to 1KHz. This circuit is similar to that of the previous frequency divider, with only the time constant values changed.

The 1KHz output from the second frequency divider, is fed via a similar network to those before, to trigger a 20-to-one frequency divider delivering 50Hz. Again, the circuit constants only are changed, to suit the lower frequency, but with one important addition. In order to advance or retard the time indicated by the second hand on the readout, provision is made to switch resistance in or out of circuit, so that the divider will divide by 21 or 19, instead of 20. This will slow down or speed up the output frequency and will advance or retard the second hand accordingly. The amount of change amounts to approximately 3 seconds for each minute the appropriate push button is held down.

The 50Hz output from the third frequency divider is fed via a level control, to an isolating emitter follower, the output of which is filtered to get rid of any spikes which may have persisted on the waveform and to make it a little more like a sine wave. A test point is also provided here and the signal is then fed into the first stage of the main audio amplifier.

The complete amplifier is a very much diluted version of a 10 watt amplifier originally designed by Philips. At first sight, this may seem to be a strange approach, when only 2 watts or less are required. The original amplifier was designed to give 10 watts with a supply rail of about 30 volts. We wanted 2 watts or so but were limited to a supply rail of a nominal 12 volts, and this is where the problem arose.

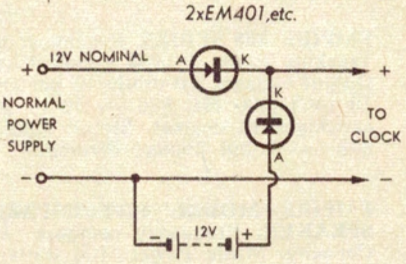
Many ways of obtaining 2 watts of audio at 50Hz, were investigated. This was found not to be an easy matter, when the supply was limited to 12 volts and complete reliability and good economy of power consumption were basic requirements. Finally, we found that the 10 watt amplifier would deliver about 1.5 watts or so, when fed from the 12 volt supply. Also, the current drain at this level of output was about 250 milliamps, which was better than other schemes which were investigated.

However, it is quite unnecessary to use a high quality amplifier such as this one, just to amplify 50Hz to operate a clock movement. Distortion, including crossover distortion, is of little consequence for such an application and so we set out to reduce the number of components to a bare minimum, without prejudicing reliability. The circuit herewith is what we have found to meet the need of the particular application.

The output impedance of the amplifier is such that it should work into something between 8 and 16 ohms. As the impedance of the clock movement is much higher than this, it is necessary to use a transformer to step up the impedance to the optimum value, such that the maximum power transfer is available.

It was found that a transformer with a step-up ratio of about 32 was required and this could be met by a number of transformers which were available over the counter. An ordinary heater type power transformer designed to operate from 240 volts and deliver 7.5 volts from the secondary was found to be very satisfactory. In this application, the primary and secondary functions are reversed.

Some medium fidelity audio transformers are also satisfactory, provided they meet the ratio requirement. If the ratio deviates from the optimum by



A simple diode configuration permitting automatic changeover from mains supply to battery in the event of a mains failure.

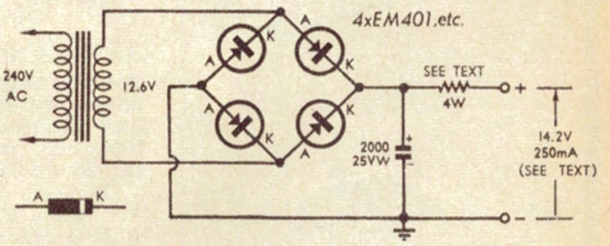
in capacitance would be sufficient to change the rate significantly. Where possible, it would be wise to fix the crystal to the back of the board, insulated and shock-proofed with a piece of foam plastic wrapped around it.

During our tests, we have used two different types of crystal. One was an old disposals unit in a relatively large "box" and having three pins at one end. This was made by Bliley and similar units made by RCA have been available from time to time. We were not able to find many technical details of this crystal but suffice to say that it was the one used when the tests were made last October.

The second crystal is of similar vintage, made by English Marconi and housed in a holder similar to the old familiar DC11. Again, no specific details of its characteristics are available but it is reasonable to assume that it is a square plate, plated on opposite faces and with thin electrodes attached at opposite centres, similar to some types available at present. This is the crystal which we have used for subsequent tests, and more will be said about it later on.

The types of transistors used throughout the unit are not critical with one exception. This applies to TR2, where a PNP type must be used. We used a 2N3638 as this is a type which is readily available, at a reasonable price. The other oscillator transistor, TR1, may be a 2N3563, 2N3565, or similar types. Although we have not tried them on this occasion, types BF115 or even BC108 are possibilities. For the three dividers, TR3, TR4, TR5, TR6, TR7 and TR8 may be the same as TR1. In the audio amplifier, TR9 and TR10 could be BC108 in each case. For TR11, it would be wise to stick with the AC128. Similarly, for the output, TR12 and TR13, a

Suggested circuit for a power supply to drive the clock unit. The resistor value will have to be determined experimentally to provide the recommended output voltage.



more than a restricted amount, the efficiency falls off rapidly and there is not enough power to operate the clock movement reliably. Also, the smaller and cheaper audio transformers have poor efficiency and are not satisfactory.

Apart from a few components, such as the output transformer, some electrolytics, etc., the unit is built on a printed board, measuring 7in x 4in. While on the subject of the printed board, our normal practice is to make available the necessary information to manufacturers so that they can make boards for the market. We are also making available full size glossy prints of the board, through the Information Service, at 50c each.

The location of the crystal is up to the individual and will depend upon the type of crystal used and other considerations. One important consideration is the leads from the crystal to the board, particularly where vibration is involved. The leads, if loose, may move about and the slight change

matched pair consisting of AD161 and AD162 should be used.

The zener diode, BZY88/C3V6, is nominally rated at 3.6 volts. However, at these low voltages, zener diodes have a rather rounded knee, rather than a sharp one which is obtained at around 9 volts and above. As a result, the voltage at the C3V6 zener diode will vary according to the amount of current flowing through it. In short, the voltage which we have on this line is of the order of 4.2 volts and although regulation is achieved, it is limited by the characteristics of the diode.

The output transformer which we used just fits into the space available. It is the A&R type 2155. This is a step-down transformer with taps giving a range between 5 and 15 volts. We found that best results were obtained by using the 7.5 and 15 volts terminals as the primary. The secondary is the 240 volt terminals.

The 0.1uF capacitor across the

secondary winding has quite a severe stress to withstand and we suggest that a voltage rating of a minimum of 600 should be used. This could preferably be raised to 1000 volts. The old paper type could be suitable but it would be wiser to fit one of the modern polyester types. We do not advise the use of a polystyrene capacitor for this service.

The two push-button switches used to advance and retard the indicated time. are imported by Ducon. These units have a micro-switch action and are excellent for this function. There are also other suitable switches available through IRH Components Pty. Ltd.

The potentiometers used to adjust the three multivibrators for correct division are most important, in that they are directly in the time-constant circuits. As such, they must be very reliable both mechanically and electrically. Just how seriously this will be taken, will depend upon the needs of each particular case. We started out by using the ordinary miniature tab potentiometers, which are available under the Philips or IRC brands. The board is actually made to accommodate either of these.

Although these items have an exacting task to perform, and although we had troubles as we have already discussed, at no time were we able to definitely point a finger at them. In other words, they are worth using unless you have other ideas.

After the troubles of last October, and when we were fitting the unit into its case, we took the opportunity to install some very high grade potentiometers in the three positions in question. These potentiometers are made to very exacting specifications by Morganite in England. They are designated as type 81E, 100K rotary Cermet Trimpots and they should be available from Morganite Australia Pty. Ltd., 65-67 Bourke Road, Alexandria, N.S.W. As these potentiometers are precision pieces, the price is rather high, as one would imagine. Although quite different physically from the ordinary tab potentiometers, they can be fitted to the board without difficulty.

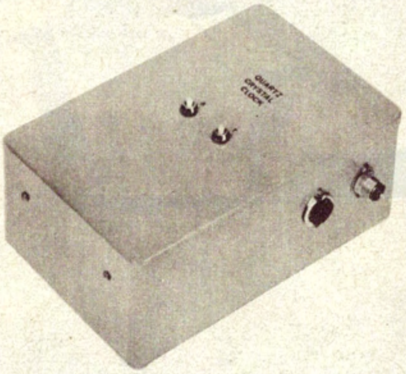
The fourth potentiometer, used to control the drive from the 50Hz divider to the input of the emitter follower and the audio amplifier, is not critical and one of the usual tab potentiometers will be suitable.

So that this project could be made as physically versatile as possible, we have divided it into three sections. The frequency generator, dividers and power amplifier are in one section. We have housed this in an Eddystone die-cast metal box, type No. 903, which measures 7-3/8in x 4¾in x 3¼in. This makes a neat unit and affords protection and shielding to the vital parts and functions.

The readout device is an ordinary 50Hz, 240 volt, synchronous clock movement. The one we used for most of our investigations was a small unit made originally for clock radios. It has switching and alarm facilities, which are not needed for our purpose. It is made by Telechron and it proved very suitable for the job. Unfortunately, stocks of these movements have dried up in the past few months and the possibility of this type being available again and particularly at the attractive price, seem to be remote.

Alternatively, there are many synchronous clock movements available today and the price, although covering a wide range, is not really high. Movements with different characteristics are available. Some are self-starting, moving forward almost immediately power is applied. Others are also self-starting, but they do not always start in the forward direction. If the movement starts in the reverse direction, there is a mechanism which comes into play after a couple of seconds, and the movement is reversed into the forward direction. A third type has to be started with a small knob or other device.

The method of starting can lead to



Another view of the complete unit, showing the DC power input socket (two-pin) and the 50Hz output socket (coaxial).

problems in getting the second hand to read exactly to the correct time. Fortunately, the correction facility we have developed makes it possible to bring the second hand to the correct position.

The type of movement to be used is up the individual to decide, so that it meets his tastes and requirements. The method of housing the movement will also be dictated by local conditions.

The method of powering the clock is again up to individual requirements. However, here are some suggestions which may be helpful. The basic need is for 12 volts DC, well filtered, at about 250 milliamps. This could be supplied by a 12-volt car or similar battery, either charged periodically, or permanently "float charged" or, in the case of mobile use, the 12-volt vehicle battery could be used.

Where AC mains are available for fixed installation, then a simple supply can be made up quite cheaply. A suggested circuit appears on these pages A small transformer with a secondary rating of 12.6 volts at 1 amp would be satisfactory. A bridge rectifier consisting of four low voltage silicon power diodes, is followed by a 2000uF 25VW electrolyctic.

If it is decided to use a mains operated power supply, the possibility of a power failure must be considered. To avoid interruption, it is wise to provide some sort of emergency supply. This can be done easily, with a set of dry batteries having a nominal voltage of 12. They can be connected in parallel with the power supply, with precautions to keep them from sharing the load at normal times. This is done with a silicon power diode in series with the positive lead of the battery supply, as shown in the diagram.

This arrangement has to be adjusted so that, in spite of the diode, the batteries will not share even a little of the load. This is achieved by operating the main power supply at a slightly higher voltage than that of the batteries. There is a further problem to be met with this set-up. Should the power fail, there are circumstances where the power supply itself can present an additional load to the batteries. This can be easily overcome by adding a silicon power diode in series with the main power supply lead. This is also shown in the diagram.

During our current test run with the clock, we are feeding it from the Transistor Power Supply, described in January, 1969. With the emergency battery supply and the protective diodes as shown in the circuit, it is necessary to set the main power supply voltage to just under 14.2 volts. This setting was determined by placing a milliammeter in series with the battery supply and raising the main power supply voltage to the point where no current flowed from the batteries.

To meet this requirement with the suggested power supply, a series resistor must be placed between the 200uF electrolytic and the clock. The value of this resistor will depend upon the output voltage from the rectifier and this could be between about 17 and 19 volts. The value of the resistor can best be determined experimentally. However, a starting point of 15 ohms, rated at 4 watts is suggested.

Next month, we will continue this article, with details how to construct the unit together with all the information for adjustment and putting it into operation.

STUDYING SOLAR WINDS

(Continued from page 11)

the interplanetary magnetic field and solar wind far out beyond the orbit of Mars. This region of space, like that close to the sun, is also not accessible to direct exploration at the present time. The cosmic ray detector used in HEOS depends on the emission of Cerenkov light (emitted by the charged particles moving through the material) in a Perspex cylinder by cosmic ray protons which travel faster than light in this material, which has a refractive index of 1.5. (They do not, of course, travel faster than light in free space.) The Cerenkov light is emitted more or less in the direction in which the particle is travelling and by making use of this property it is possible to build detectors which have directional properties like the solar proton experiment so that the directional distribution of cosmic rays can be measured and related to the magnetic field.

These three closely related experiments will provide new information about the behaviour of the interplanetary magnetic field during the period of maximum sunspot activity and should lead to an improved understanding of the propagation of both solar flare particles and cosmic rays through the field.