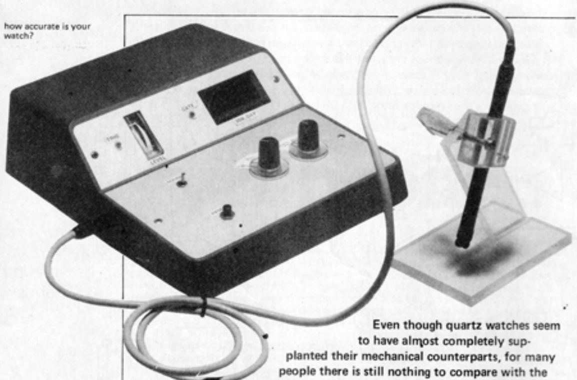


Even though quartz watches seem to have almost completely supplanted their mechanical counterparts, for many people there is still nothing to compare with the fine mechanical craftsmanship that goes into a clockwork watch. That regular tick, coming from so many carefully made parts, tirelessly assembled to make one whole unit, is something completely different from the invisible, silent shuffling of electrons in a quartz controlled watch.

The 'watch tester' described in this article is a crystal controlled circuit that is used as an aid to set a mechanical watch accurately. A crystal is used as a reference to determine, within a few seconds, how much time the watch gains or loses, and this is shown on a display as a certain number of minutes per day. Knowing the error is essential to be able to set the watch accurately.

how accurate is your watch?

quartz precision for mechanical watches

Man has always tried to measure time in one way or another. Sundials, water clocks, oil lamps, candles and hour glasses are just some of the things that have been used to measure time down through the ages. Then came the mechanical clock. Nobody knows for certain exactly when this first came into existence but they have been made at least since the fourteenth century. Since then, mechanical clocks have been consistently improved and refined.

Watches have been made since about the end of the fifteenth century, but it took a long time before the 'portable clock' was improved enough so that it worked reasonably accurately. The best clocks in the seventeenth century had an error of about a minute per day. With an average watch an error of a quarter of an hour a week could be expected.

Until the beginning of this century watches were normally carried on a chain and it was only around the year 1900 that somebody came up with the idea of a wrist watch. Since then watches developed very quickly. In 1924 the automatic wrist watch arrived and after the second World war the 'electric' watch. In 1957 a watch appeared on the market that used an electromagnetic system to drive the balance weight. Four years later the firm of Bulova produced a much more interesting idea, using an electronically driven tuning fork instead of the balance weight. This tuning fork watch was guaranteed to be accurate to within one minute per year!

1

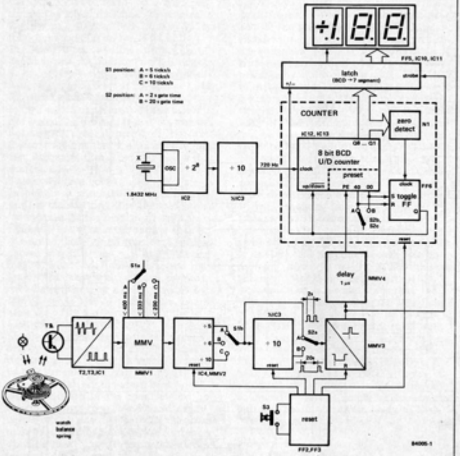


Figure 1. The block diagram of the circuit. The pulses picked up at the balance wheel of the watch can be converted to a measuring signal with a time of 2 or 20 seconds. This signal is compared to a reference time and the error is shown on a display.

The modern watch is the final stage (so far) and uses a quartz crystal as the time base. The accuracy of this design is such that the error per year is neglegible.

A mechanical watch always has much more charm than its 'cold' electronic counterpart. It is a testament to the skill of the craftsman who made it, and this alone is a great point in its favour. Clockwork watches do have one undeniable advantage, of course: they have no batteries to fail at the most unexpected and inconvenient moment.

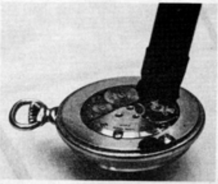
There are, of course, still a lot of mechanical watches in circulation and several firms currently sell clockwork watches at the 'expensive' end of the market. Mechanical 'tickers', it seems, are always in fashion.

Adjusting a mechanical watch is a lengthy process because changing the effective length of the balance spring does not give an immediately noticeable change. A good watchmaker, certainly, has expensive equipment that can measure the error fairly quickly, but anybody else simply could not afford one. With the watch meter here anybody can quickly adjust almost any clockwork watch accurately.

The block diagram

This circuit uses an optical pick-up. An acoustic pick-up should also be possible but in practice that seemed to be more susceptible to problems with ambient noise. With this optical pick-up we use a small lamp to shine light on the spokes of the balance wheel and the reflections are received by a photo transistor. The pulses given by the photo transistor are processed and compared with a 'standard' frequency, and the error is then shown on a display.

The block diagram of figure 1 is a bit more complex than our usual circuits, but this simply makes the circuit easier to understand. The photo transistor pulses are converted to 'proper' digital signals in the



2

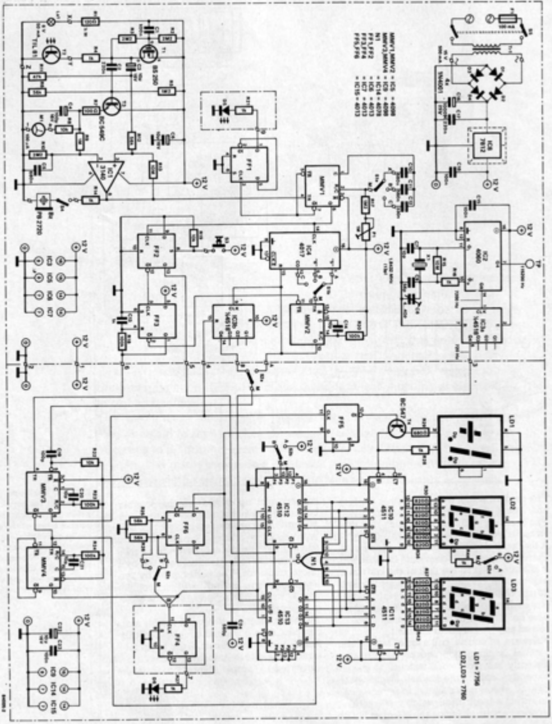


Figure 2. The various sections of the block diagram can easily be recognized in the circuit diagram here, especially as the make-up of each block is indicated in the block diagram.

first block. These pulses then go to a monostable multivibrator. The monostable time can be set to three different values with switch S1a. These values are < 400 ms, < 333 ms and < 200 ms, and they require a short explanation.

Almost every mechanical watch falls into one of two standard tick frequencies, namely 18000 ticks per hour (= 5 ticks per second) or 21600 ticks per hour (= 6 ticks per second). The first generally applies to older watches. There are also some clocks that beat with 36000 ticks per hour (10 ticks/s). One complete swing of the balance (from the middle to one side, back to the other side and to the middle again) consists of *two* ticks. Five ticks then consist of 2.5 swings. Because we want to measure *swing* times with this circuit the MMV time must be chosen so that only every second tick is registered. In other words the MMV time must be about 5 . . . 10% less than the time for two ticks. For 5 ticks per second the MMV time must be relative to 2 x 200 ms = 400 ms. This drops to 333 ms for 6 ticks and 200 ms for 10 ticks.

The MMV is followed by a divider that, depending on the position of S1, divides by 5, 6 or 10. A signal with a period of 2 seconds now appears at the wiper of S1b (provided that S1 is in the correct position for the watch under test). If the period is not 2 seconds, this means that the watch is not keeping time. A period of less than 2 seconds means that the watch is running fast, and more than 2 seconds means it is running slow.

This signal then goes to switch S2a which enables us to select the 2 second signal or one ten times as long. The 20 second signal 'contains' a greater number of ticks and is therefore better than the shorter time for measuring the error of a watch. The signal chosen with S2a then goes to MMV3 and MMV4, which drive the counter and the latch. The latch with a seven segment decoder is driven by a pulse supplied by MMV3, while MMV4 presets the counter after the count has been stored in the latch (and shown on the display).

Finally, the counter. Because we want the display to show the error in minutes per day, the counter has to be a bit special. It must be able to count positively and negatively as we can have an error in either direction. The clock frequency of the counter must be carefully chosen to enable the read out to be in minutes per day. Furthermore the counter must be capable of being preset, so that its output is exactly zero if the watch is working accurately. To enable all this to be done, an eight-bit BCD up/down counter is used.

Now to the clock frequency. There are 1440 minutes in a day (except Monday, which has at least twice as many). If a measuring time of two seconds is used, the counter must receive 1440 clock pulses in these two seconds. The error measured by the counter relative to this 1440 is then the error in minutes per day. If a time of 20 seconds is used the counter must count 14400 clock pulses. This means that the clock frequency for the counter must be 1440/2 (or 1400/20) = 720 Hz. This reference frequency is supplied by a crystal and a few dividers.

With a measuring time of 2 seconds the preset value of the counter must be −1440 so that the count is exactly zero if the watch is running correctly. The counter can actually only count from −99 to +99, so a preset value of −1440 is impossible. Because the read out only shows two figures, we set the preset to −40 (the last two digits of −1440). The counter will then be at zero after two seconds. This 'trick' works here because a normal watch will never have an error of more than 99 minutes a day. The counter starts by counting from −40 to zero then from zero to 99 and six times from −99 to +99 and finally from −99 to zero making 1440. Note that there is a delay of one clock cycle every time the count crosses zero on its 'jump' from +99 to −99. Without this our arithmetic would not be correct. If 20 seconds is used as the measuring time the counter is preset to zero (the last two digits of 14400).

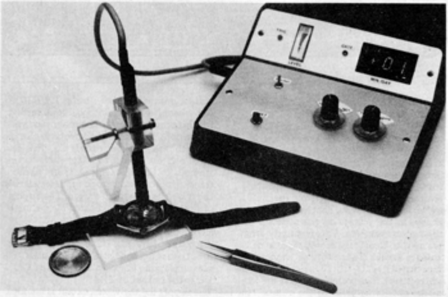
In practice the counter cannot itself work out if its count is positive or negative, so the '+' or '−' sign is stored by a flip-flop. This flips (or flops) every time the counter is at zero, and drives the ± sign in the display.

Finally there is a reset circuit whereby all counters can be reset simply by pressing one button. The circuit is then ready to begin measuring anew.

The practical layout

As we have spent quite a long time talking about the block diagram, we do not really need to say much about the actual circuit diagram of figure 2. The block diagram also simplifies matters by stating which components make up each block.

We will have a look at the input stage separately. The d.c. voltage setting of photo



Parts list

Resistors:

R1 = 120 Ω ½ W**
R2,R3*;R10 = 2M2
R4,R14,R16,R21,R27,
  R28,R44 = 1 k
R5,R17 = 1M2
R6,R12,R25,R26 = 56 k
R7 = 100 Ω
R8,R19,R22 = 10 k
R9 = 1 M
R11 = 47 k
R13,R15 = 10 M
R18,R20,R23,R24 = 100 k
R29 = 680 Ω
R30 . . . R43 = 820 Ω
P1 = 1 M preset

Capacitors:

C1,C15,C18,C23 = 100 n
C2,C17 = 220n
C3,C6,C22 = 10 µ/16 V
C4 = 100 µ/16 V
C5,C10 = 680 n
C7,C14,C20,C21 = 10 p
C8 = 4 . . . 40 p trimmer
C9 = 56 p
C11 = 560 n
C12 = 330 n
C13 = 1 n
C16 = 1000 µ/25 V
C19 = 100 p
C24 = 560 p

Semiconductors:

D1 . . . D4 = 1N4001
D5,D6 = LED
LD1 = 7756 universal
  overflow ± 1 display
LD2,LD3 = 7760 common
  cathode seven segment
  display
T1 = BS 250, BC 516*
T2 = TIL 81**
T3 = BC 549C
T4 = BC 547
IC1 = 3140
IC2 = 4060
IC3 = 4518
IC4 = 4017
IC5,IC9 = 4098
IC6,IC7,IC15 = 4013
IC8 = 7812
IC10,IC11 = 4511
IC12,IC13 = 4510
IC14 = 4078

3

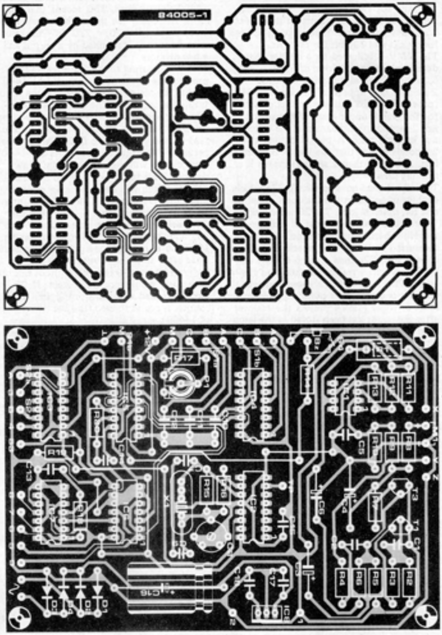


Figure 3. This is the printed circuit board design for the measuring section of the circuit.

transistor T2 is handled by FET T1. For low frequencies and d.c., T1 acts as a voltage source; its drain voltage is then fed back to the gate via R2. The low-pass filter consisting of R3 and C1 ensures that T1 acts as a current source at higher frequencies. Slow variations in the light picked up (from ambient conditions for example) are therefore compensated by the FET, while fast changes in light cause a large change in the voltage on the collector of the photo transistor. This is exactly what we need to detect the moving spokes of the balance wheel. These voltage changes are transmitted via C2 to T3 where the pulses are rectified. The voltage on C4 is the same as the maximum value of the pulses. This voltage goes via voltage divider R9/R10 to IC1 where it acts as the trigger-level setting for this schmitt trigger. The other input of the schmitt trigger is fed the voltage changes from the photo transistor via C3. This set-up allows the circuit to adapt itself to the strength of the input signal. If the photo transistor provides a strong input signal then the triggering threshold is high. The strength of the input signal is indicated by the meter connected parallel to C4. If switch S4 is closed the output of IC1 is heard through the buzzer. An LED, D5, at the Q output of FF1 flashes in time with the tick pulses. The measuring time is shown by means of LED D6 at the output of FF4.

The supply for the whole circuit is handled

Miscellaneous:

Bz = buzzer, Toko 2720
F1 = 100 mA slow blow fuse and holder
heatsink for IC8
La1 = 6 V/50 mA miniature lamp**
M1 = moving coil meter 100 μA FSD
S1 = 2 pole 3 way switch
S2 = 4 pole 2 way switch
S3 = push button
S4 = single pole toggle switch
S5 = double pole mains switch
Tr1 = mains transformer, 15 V/500 mA
X1 = crystal, 1.8432 MHz (13 pF)

* If T1 is BC516, R3 = 3M9

** Reflection sensor OPB 730 can be used instead of a lamp and photo transistor; then R1 = 560 Ω

4

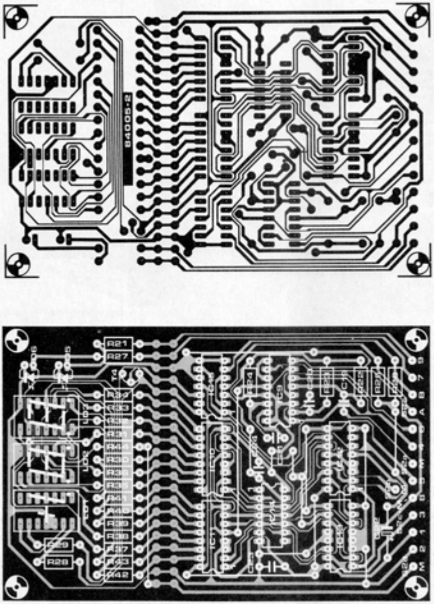


Figure 4. The printed circuit board for the counter section and the read-out, which can, if desired, be separated to enable the display to be mounted away from the counter.

by the same 7812 regulator IC. The current consumption is about 250 mA.

Constructing the circuit

The circuit has been divided between two printed circuit boards that are shown in figures 3 and 4. The 'measuring' section is located on the board shown in figure 3 and contains all the components shown in the left half of the circuit diagram, with the exception of R21 and D5. The second board consists of two sections which may be separated if desired. These are the counter section and the read-out (the right half of the circuit diagram with the exception of FF4). The numbered points on the two boards must be connected to each other. The supply for the display *must be* taken from points 1 and 2. Trying to tap a supply from anywhere else will probably cause problems.

It is quite possible that the BS 250 FET may prove difficult for some people to get their hands on. If this is the case, a BC 516 may be substituted for T1, but R3 must then be 3M9. Fortunately this transistor can be fitted to the board exactly the same as the FET.

When all the electronics is assembled we can turn our attention to building the sensor. The photo transistor and the lamp are mounted next to each other, but in such a way that the light from the bulb does not

fall directly on the photo transistor. This is easily done with a piece of black paper between the two. The emitter of the transistor can now be soldered directly to the collar of the lamp. This leaves three connections which can be linked to the printed circuit board with a piece of screened stereo cable. The collar of the lamp (which can be a miniature type) must be connected to the screen. This unit can then be fitted into something like a big felt tip pen. A clip can be made up to hold this 'pen' steady during a measurement. The photos and the front cover show how our prototype was built.
A nicer (but also more expensive) possibility is to use a reflection sensor, such as the OPB 730, which contains a LED and a photodarlington. If this is done the sensor must be well screened from ambient light, and the value of resistor R1 must be increased to 560 Ω.

Adjustment and use

Adjustment is very easy. The frequency of the crystal can be set to the exact value required with trimmer C8. To do this a frequency meter with a maximum error of 0.005% is needed. A frequency of 115200 Hz must be measured at test point TP. If you cannot get hold of a good frequency meter then simply put C8 in mid position. In most cases the frequency will then be reasonably accurate.
Next, MMV1 must be set, preferably with an oscilloscope. Potentiometer P1 is set so that the monostable time is 360 . . . 380 ms with S1a in position A. If you do not have an oscilloscope, this MMV can also be adjusted with the aid of a watch that is known to be accurate. Place the watch under the sensor and turn the sensor until the meter shows a strong signal and the buzzer ticks regularly. Turn the preset to maximum, set switch S2 to position A (2 s measuring time) and adjust the preset by turning it backwards a little at a time. After each adjustment wait until the measuring time has passed and see what the read-out shows. At some stage an error of about zero minutes will be displayed. Turn the preset a little bit further and then leave it at that.
A few words about using this circuit will certainly not go astray. First we must know the tick frequency of the watch to be tested. Older gents watches generally have 5 ticks per second, whereas modern gents watches and ladies watches usually have 6. After a bit of practice this can even be heard from the ticking of the watch. Lay the watch under the sensor and point the photo transistor towards the spokes of the balance wheel. Move the watch carefully until the meter reading is as large as possible. If S4 is closed the pulses from the phototransistor can be heard from the buzzer. This should be a regular tick. If it sounds more like 'sawing' then the transistor is pointing at the adjusting screws and must be moved slightly.
The COUNT LED, D5, should flash regularly to show that the circuit is receiving the pulses. The correct ticking frequency (5, 6, or 10 ticks per second) must be set with S1.

A measuring time of 2 seconds is selected using S2. Press the RESET and after 2 seconds LED D6 (GATE TIME) 'changes'. What we mean is that the LED lights if it was out and it goes out if it was lit. The display now shows the error in minutes per day. Whenever D6 changes the measurement has been taken and the result is shown on the display.
If the error of the watch is less than ten minutes, S5 can be moved to position B (20 s measuring time). First press the RESET again and after 20 seconds LED D3 changes and the error is shown on the display in tenths of minutes.
With a pocket watch the photo transistor can also be focused on the balance screws and this usually gives good results. In this case, however, it is important to reduce the level of ambient light as much as possible. Incandescent lamps and fluorescent tubes in particular can cause problems.
A period counter could also be used in the circuit in place of the counter section and read-out. It is simply connected to the wiper of switch S2a. However, IC2, IC7, X1, C7, C8, C9, C13, R15, R16 and R18 can then be removed and point 4 of the measuring board and pin 1 of IC3 must be connected to earth. The read-out on the meter will not, of course, be in minutes per day any more. It is a simple matter to convert the output to minutes per day using the formula $60 \times 24 \times (2 - T)/T$, where T is the period measured in seconds. If T is 1.986 seconds the error of the watch is $60 \times 24 \times (2 - 1.986)/1.986 = +10$ minutes per day. ◼

A mechanical watch works with almost incredible accuracy considering that it has to tick nearly a half million times per day

A mechanical chronometer has an error of one minute per month at most; with an automatic watch that is about one minute per week.

S1 position: A = 5 ticks/s
B = 6 ticks/s
C = 10 ticks/s

S2 position: A = 2 second gate time
B = 20 second gate time