Top Tenners

SAMPLE-AND-HOLD

OWEN BISHOP

Project 4

This short collection of projects, some useful, some instructive and some amusing, can be made for around the ten pounds mark. The estimated cost does not include an enclosure. All of the projects are built on stripboard, and most have been designed to fit on to boards of standard dimensions. All of the projects are battery-powered, so are safe to build. In a few cases in which, by its nature, the project is to be run for long periods, power may be provided by an inexpensive mains adaptor. Again, the cost of such a unit is not included.

THIS, our fourth Top Tenner project, is an add-on unit for your multimeter, and works equally well if it is an analogue or digital type. As the name suggests, its function is to sample a changing voltage and hold it to give you time to read its value.

Reading a changing voltage can be difficult with a digital meter because the final two or three figures of the reading may be changing too fast to be seen. There is the added complication that a reading of a digital meter is itself a sample-and-hold measurement. The meter samples the input voltage, then holds it while the analogue-to-digital converter in the meter converts the reading to digital form.

Typically, the meter takes several samples per second so it is not possible to read each sample individually. We can only read a value when it is reasonably steady, perhaps varying only in the least significant digit.

An analogue meter is possibly easier to read with a rapidly changing voltage, because the eye can average out the changes over a small interval of time. There is also the inertia of the needle and coil unit to help steady the readings.

Whether you have a digital or analogue meter, there are occasions when you will want to sample and read the voltage at a precise instant, or to sample it and read it at regular intervals of time. This project helps you do just this.

HOW IT WORKS

The principle of the circuit is extremely simple and can be followed by looking at the right-hand half of Fig.1, the full circuit diagram for the Sample-and-Hold project. The voltage is sampled by feeding it to capacitor C4. This has a reasonably low value so that it quickly charges or discharges to attain the same voltage as the "test point" in the circuit under test.

The capacitor is connected to the test point through a switch. We could employ a mechanical switch but it is preferable to use a MOSFET transmission gate, which can be "opened" or "closed" electronically. Here we use a DG419D analogue switch, IC3, which has an "on" resistance of only 35 ohms.

When IC3 is on, current flows from pin 1 to pin 8 or in the reverse direction, depending on whether the existing voltage across capacitor C4 is less than or greater than the present input voltage. There is a control input at pin 6, which closes (connects) the switch when the input is high, and opens (disconnects) the switch when it is low. When the switch is open its resistance is several gigaohms, so it is virtually an open circuit.

When capacitor C4 has been charged, the voltage across it is measured by a meter. To connect the capacitor directly to a meter would make it lose charge rapidly, especially if the meter was the analogue type. It would partly discharge the capacitor before there was time to take the reading.

VOLTAGE FOLLOWER

To prevent this, we use an operational amplifier (op.amp) IC4, wired as a *voltage follower* (buffer). The output voltage of this is equal to its input, the voltage across the capacitor. The reason for using the op.amp is that the input terminal of the op.amp has very high impedance, typi-cally 1 terahohm (10^{12}MΩ) so virtually no current is lost to the op.amp. An op.amp typically has an output impedance of 75 ohms so it can drive the meter, whatever its type, without significant loss of voltage.

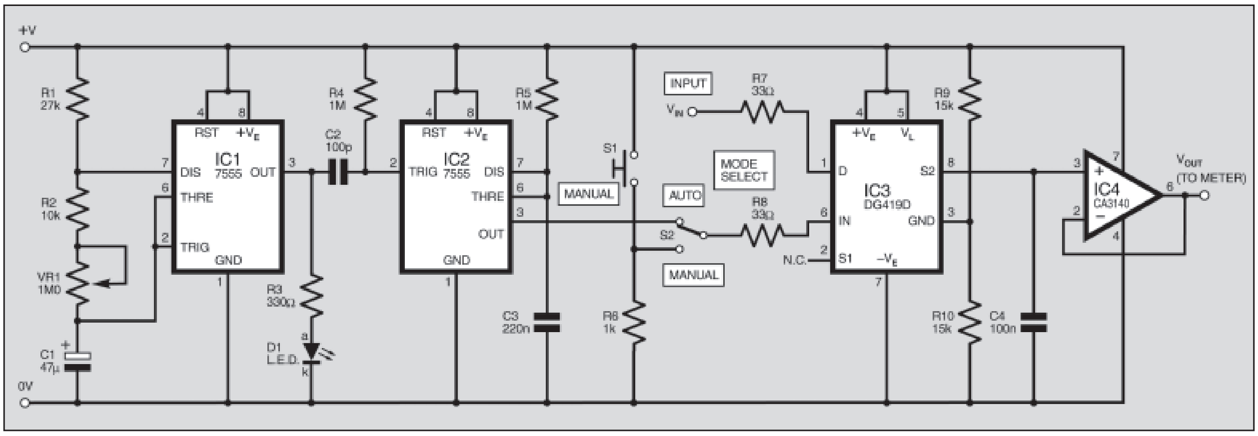


Fig.1. Complete circuit diagram for the Sample-and-Hold. The circuit can be powered from a 6V to 12V supply, see text.

In this kind of circuit, there is always a compromise to be made over the capacitance of C4. It is good for it to be reasonably large. Then any leakage of charge through the switch IC3 or op.amp IC4 makes little difference to the voltage. It stays at the same voltage for several minutes or longer, allowing plenty of time for reading the result. We say that there is little *droop*.

On the other hand, if the capacitance is large, the time constant of the switch resistance and the capacitance is large too. This means that the capacitor takes longer to fully charge or discharge. It cannot follow a rapidly changing input voltage.

The length of time taken for the capacitor to alter its charge from the previous voltage to the present voltage is estimated by calculating the time constant. This is given by:

$$t = RC$$

In this equation, t is the time constant in seconds, R is the resistance in ohms through which current flows to charge or discharge C4, and C is the capacitance of C4, in Farads. In this section of the circuit, R is 35 ohms, the ON resistance of switch IC3, plus 33 ohms due to the current-limiting series resistor R7. This brings R to a total of 68 ohms. C is the capacitance of C4, which is 100nF = 0·1μF. Multiplying one by the other gives t = 6·8μs as the time constant.

It can be shown that it takes five time constants for the voltage on C4 to equilibrate to within one per cent of the new level. This means that it reaches the new level in 34μs, which is certainly fast enough for a simple "sample-and-hold" set-up.

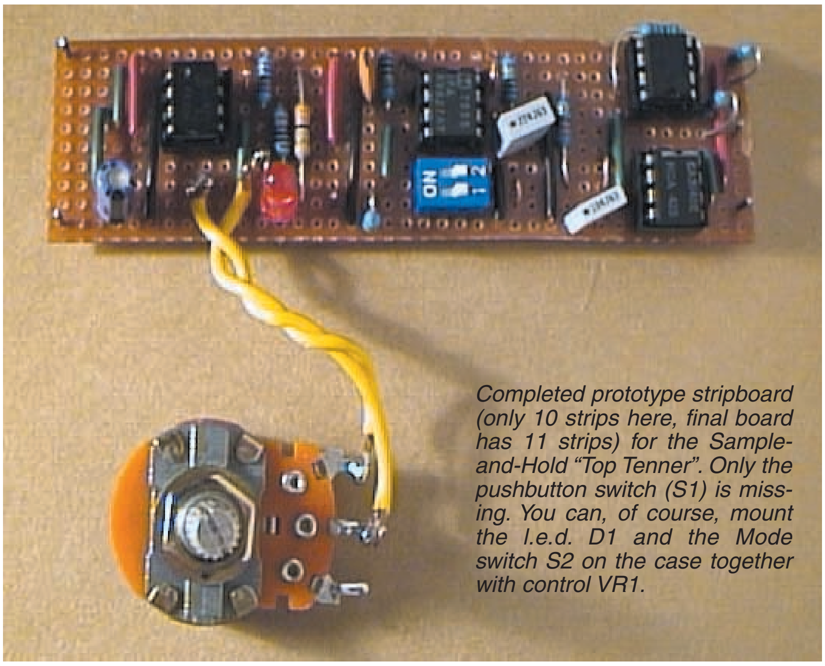
SAMPLING

This Sample-and-Hold circuit provides for manual and automatic sampling. For manual sampling, we set switch S2 to the Manual position. Then resistor R6 holds pin 6 of IC3 low, holding the internal switch of IC3 open. Pressing pushswitch S1, makes pin 6 high connecting pin 1 to pin 8, and closes (connects) the internal switch. The voltage on C4 then follows the input voltage V_{IN}.

To take a sample, we release pushswitch S1, which opens the switch, leaving C4 isolated from the changing input voltage. The attached meter displays the voltage across capacitor C4 at the instant that S1 is released.

Alternatively, the voltage is sampled automatically at regular intervals. There are two CMOS 7555 timer i.c.s, of which IC1 controls the rate of sampling. IC1 is wired as an astable multivibrator, producing a regular series of rectangular output pulses. By adjusting potentiometer VR1, the frequency of the output can be varied from 0·65Hz (just under two samples per second) to 0·015Hz (approximately one sample per minute). The rate of operation of IC1 is indicated by the flashing of l.e.d. D1.

Every time the output of IC1 at pin 3 goes low, it generates a low-going pulse, which passes through capacitor C2 and triggers timer IC2. This is wired as a monostable multivibrator, which produces a single 240ms high pulse when triggered, as set by R5 and C3.



Completed prototype stripboard (only 10 strips here, final board has 11 strips) for the Sample-and-Hold "Top Tenner". Only the pushbutton switch (S1) is missing. You can, of course, mount the l.e.d. D1 and the Mode switch S2 on the case together with control VR1.

The input voltage is sampled as this pulse ends. The pulse length is far longer than five time constants so we can be sure that the charge on capacitor C4 is an accurate sample of the input.

VOLTAGE RANGE

The analogue switch IC3 and op.amp IC4 are powered from the +V and 0V rails. Both can operate on either a single or a double supply. As a single supply, the circuit can be powered from a 6V, 9V or 12V battery. The input voltage must lie within the levels of the power supply rails, so a larger supply voltage is required to cover a larger input voltage range.

The operating range also determines which is the best op.amp to use. It must be one with j.f.e.t. or MOSFET inputs; otherwise, charge will rapidly leak from capacitor C4 through the input of the op.amp. A CMOS op.amp such as the CA3140 is suitable, as it will operate on 4V. Unfortunately, its output will not swing fully to the positive supply rails. Operating on 6V, for example, its output swings from 0V to +4V.

If a wider swing is essential, use the CA3130, which can swing fully to either rail. An alternative is to increase the power supply to 9V or 12V. Incidentally, these op.amps have slew rates of 9V/μs and 10V/μs respectively, so they readily follow rapid changes in input voltage.

Another op.amp that could be used is the TL071, which has a j.f.e.t. input. This has a slew rate of 13V/μs, which is the highest rate achieved by inexpensive op.amps.

However, its output cannot swing fully to either supply rail. For example, with a 6V supply the output swings between 1·35V and 5·5V.

Using this op.amp, the circuit must be operated as if the supply is a dual one. The supply rails are then taken to be plus and minus 3V, 4·5 V or 6V, depending on the battery used. The 0V line is taken from the junction between the appropriate pair of cells, simulated in this instance by the voltage at the junction of the potential divider formed by R9 and R10.

COMPONENTS

See SHOP TALK page

Resistors

R1	27k
R2	10k
R3	330Ω
R4, R5	1M (2 off)
R6	1k
R7, R8	33Ω (2 off)
R9, R10	15k (2 off)

(All 0·25W 1% metal film

Potentiometer

VR1	1M min. rotary carbon, linear

Capacitors

C1	47μF radial elect. 16V
C2	100p, disc ceramic
C3	220n, polyester film
C4	100n, polyester film

Semiconductors

D1	5mm l.e.d., red or green
IC1, IC2	7555 CMOS timer (2 off)
IC3	DG419D, single MOS FET transmission gate
IC4	CA3140 (or CA3130) CMOS op.amp (see text)

Miscellaneous

S1	pushbutton switch, push-to-make
S2	single dual-in-line double-throw style switch (p.c.b. linked), or equivalent s.p.d.t. switch.

Stripboard 0·1 inch matrix, size 11 copper strips by 39 holes; 8-pin i.c. socket (4 off); small plastic case, size and style to choice; plugs to fit multimeter (2 off); crocodile clip or probe for input lead; 1mm solder pins (7 off); solder, etc.

Approx. Cost Guidance Only £10 excluding case & batt.

CONSTRUCTION

The Sample-and-Hold circuit is built on a narrow rectangle of stripboard with the idea of fitting it into a handheld enclosure, perhaps with a probe projecting from one end. However, is not essential for the device to be handheld and it can be accommodated in any small plastic enclosure.

The circuit is built up on a piece of 0·1in. matrix stripboard, containing 11 copper strips by 39 holes. The board top-side component layout and details of breaks required in the underside copper tracks are shown in Fig.2. Dual-in-line (d.i.l.) sockets should be used to hold all i.c.s. Note that some resistors are mounted vertically.

The essential off-board components, apart from the battery box, are the potentiometer VR1 and the pushbutton switch S1. Both are mounted on the case and VR1 should be provided with a pointer knob.

You may also decide to mount the l.e.d. D1 and Mode Selector Switch S2 on the enclosure as well. If you do, run leads to them from the corresponding holes on the circuit board. You will also have to decide how you intend to connect the circuit to the "test circuit" and to the meter.

Begin construction by assembling the first timer (IC1). Use the l.e.d. to test that the timer is operating correctly. Also, use the l.e.d. to calibrate the settings of VR1. Mark the position of the knob of VR1 to correspond to useful timings such as 1s, 2s, 5s, 10s, and so on to one minute.

Next, assemble the second timer (IC2). With a voltmeter attached to its output at pin 3, check that a positive pulse is produced every time the l.e.d. turns off. Also, construct the switching circuits (S1 and S2). There are several ways of providing the s.p.d.t. switching action of S2. Check the way your d.i.l. switch operates before soldering it in place and modify the wiring, if necessary.

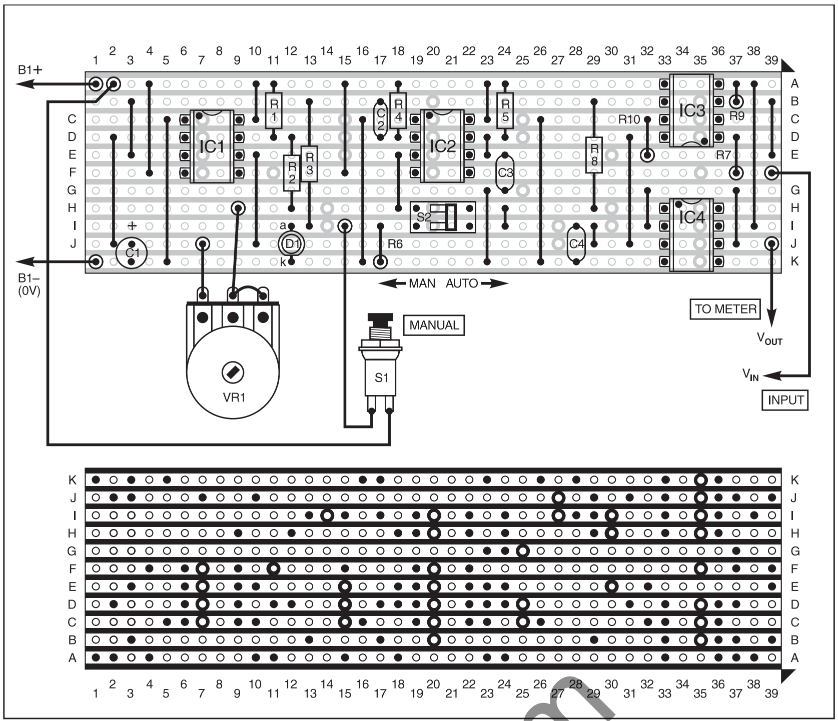


Fig.2. Stripboard component layout, interwiring and details of breaks required in the underside copper tracks.

Finally, assemble the sampling (IC3) and the op.amp (IC4) circuits, noting that IC3 is mounted the other way up, with pin 1 at bottom right. To test the completed circuit board, connect a 10 kilohms potentiometer across the supply rails and run a temporary wire from its wiper terminal to the V_{IN} input, at resistor R7. This provides a full range of input voltages.

Connect your multimeter to V_{OUT} (at IC4 pin 6) and to the 0V rail and then switch the meter on. If you have a spare multimeter, use this to monitor V_{IN} at the same time as V_{OUT}. Select manual control and rotate the potentiometer knob to produce a range of input voltages. Press and release switch S1 as the voltage input is changing and check that V_{OUT} is truly sampled and held. Repeat the tests in automatic mode at various sampling rates. Remove the "test" potentiometer and box-up the board ready for action! □