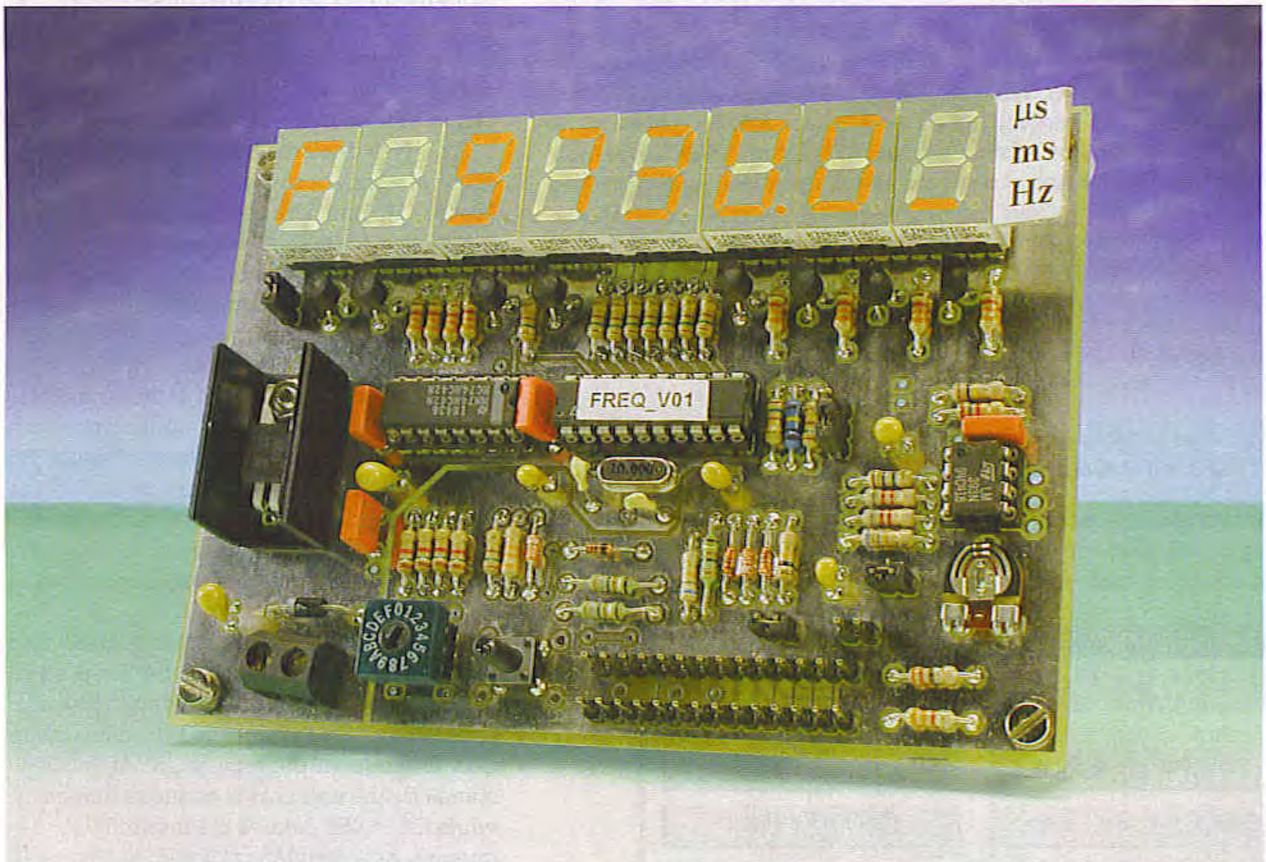
Multifunction Frequency Meter

For all time-related measurements

Design by R. Zenzinger



Despite its surprisingly simple hardware design and construction, the superb frequency meter / event counter described in this article couples ease of use to a plethora of measurement options. The successful combination is mainly due to the use of a microcontroller running some really ingenious software. The keywords in the general design of the instrument were noise immunity, reliability and functionality.

Main Specifications and Functions

- Frequency measurement using 3 gate times
- Period duration measurement in milliseconds and microseconds
- Pulse duration measurement of positive and negative half cycles in milliseconds and microseconds
- Event counter up to 10^7 events
- Stopwatch with lap time function; resolution 10 ms
- 8-digit 7-segment LED readout
- Selectable pause of 1-5 s or manual restart
- Resolution 0.1 microsecond or 0.1 second
- 4 MHz maximum input frequency
- 1 microsecond minimum pulse length
- 1,000 s maximum pulse length
- 10 mV – 5 V input voltage range protected up to 30 V (higher swings possible by adding an external voltage divider)
- Overflow indication; leading-zero suppression; measurement error signalling
- Tried, tested and approved by the Elektor design laboratory

A frequency meter / event counter is an indispensable instrument on the electronics laboratory workbench. In general, the basic circuit of the instrument is not particularly complex. Digital integrated circuits have been available for quite some time that are capable of performing frequency and time measurements, as well as pulse counting. The same ICs also cheerfully handle the job of displaying measurement results on an LC or LED display. These days, counters are just 'add-ons' to function generators and get the matching amount of attention!

So what should a multi-purpose frequency meter be capable of doing for you? Absolute priority, we feel, should be given to the measurement accuracy, which you should be able to rely on for many years ('long-term stability'). Of course, a wide frequency range is desirable, without breaking the bank! Also, the instrument should be suitable for a good

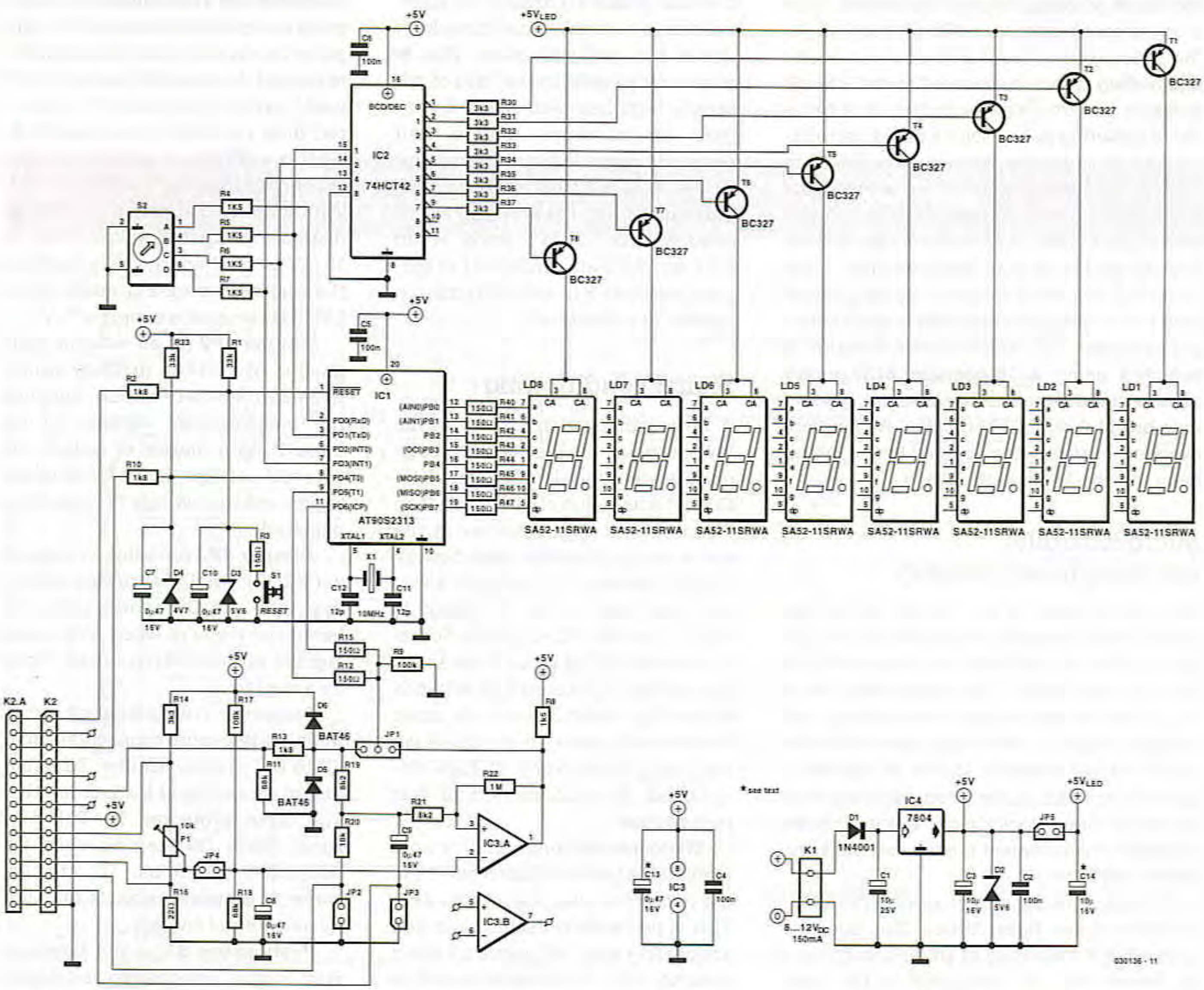


Figure 1. Circuit diagram of the Multifunction Frequency Meter designed around an AT90S microcontroller.

many measurement functions while being easy to control. Add to that the sensitivity and noise immunity issues, and you'll appreciate that it will be hard, if not impossible, for all these requirements to be fulfilled without the odd compromise.

So what does our instrument have to offer? To begin with, we have a frequency range of DC to 4 MHz. This may look a bit measly, but it does strike a good compromise. On the one hand, higher frequencies should not occur that often (unless your are into radio amateurism or RF design in general). On the other hand, a measurement range extending into the megahertz or even gigahertz ranges poses considerable problems in the design and realisation of preamplifier and prescaler units which serve to shape and reduce (i.e., divide) the measured frequency down to values that can be handled by a microcontroller like the one we've in mind. The same design effort could be used to implement high measurement accuracy for our instrument. The measurement error is ±100 ppm ±1 digit. The description 'multi-function' would be misleading if our instrument were able to measure just frequencies. In fact, it is capable of capturing pulses with a minimum duration of 1 μs and pulse / period durations of up to 1,000 seconds. The input signal level may lie between 10 mV and 5 V. In order to measure larger signals, external voltage dividers may be added to your requirements. Likewise, the frequency range of the instrument may be extended by the addition of an external prescaler. The measurement function is selected using a 16-position BCD rotary switch, and the measurement result appears on a bright 8-digit LED display. A complete overview of all functions offered by the instrument may be found in the **Table**.

Microcontroller and peripheral circuitry

A block diagram of the multifunction frequency meter would be superfluous at this point. After all, the functional elements that make up the circuit — microcontroller, readout, mode switch, signal conditioning and voltage supply — are easily spotted in the actual circuit diagram shown in **Figure 1**. Let's have a look at the practical realisation of each of these blocks before discussing the available measurement modes and the associated software.

The heart of the circuit is an AT90S2313 microcontroller from Atmel. The micro is clocked at a frequency of 10 MHz and offers no fewer than 15 configurable I/O lines divided across two ports. The lines in Port B are all programmed as outputs, driving the individual segments of the 7-segment displays. By contrast, the lines in Port B have different functions, acting as inputs or outputs. Only PD0 and PD4 are invariably output lines with their internal pull-up resistor (approx. 50 kΩ) activated. PD.1, PD.2 and PD.3 are only active after a reset or when a different measurement mode is selected on the rotary switch. During operation, output mode is selected in order to drive the display.

Port lines PD.5 are configured without internal pull-up resistors. However, with an open-circuited input these lines should be at '0'. This is achieved with the aid of R9. Inputs PD.5 and PD.6 are effectively connected in parallel through decoupling resistors R15/R12. This is necessary because PD.5 has a special function in directly driving the internal timer/counter, without making use of the cyclic program. This is particularly useful in the case of relatively high frequencies. PD.6 triggers an interrupt routine and responds immediately to the input signal. This is essential for period / pulse measurements on very short-lived signals. In Clock mode, when PD.5 and PD.6 are configured as outputs, resistors R12 and R15 limit the current to a safe level.

Signal conditioning

A 14-way pinheader, K2, carries the link between the measurement signal as well as the signals to and from the external control elements. The measurement signal arrives at the measurement amplifier input by way of K2.6. Resistor R11 ensures a stable Low level when the input is open-circuited. R13 and fast Schottky diodes D5/D6 protect the input against damage caused by voltages exceeding about 30 volts. A zener diode in this position would cause too much attenuation of high frequencies, or rounding off of fast pulse edges.

The measurement signal is now ready to be taken to pins 9 and 11 of the microcontroller, via **jumper JP1**. This is particularly useful when you are dealing with TTL signals having a swing of 0/5 V, whose frequency is too high for conditioning by the comparator. The circuit around comparator IC3.A only acts when the jumper is in the other position, when the signal is fed to the non-inverting input of the LM393 via R19 and R21. The inverting input is held at a fixed level (threshold) of 2 V by R17/R18. If the input voltage at pin 3 exceeds this level, the comparator toggles and with it the logic state of port lines PD.5 and PD.6. By the addition of R22, the comparator is given some hysteresis to prevent slow pulse edges causing spurious oscillation.

So far, we have assumed that neither jumpers JP2, JP3 or JP4 are fitted, nor connections have been made to pins K2.8-K2.13. **Jumper JP4** actuates voltage divider R16/P1/R14. These resistors are clearly smaller than R17/R18, preventing the voltage divider from having an effect on the adjustable threshold set at the inverting comparator input by means of P1. The potentiometer, by the way, may be relocated to the instrument front panel. In that case, preset P1 is omitted from the board and pins K2.9, K2.10 and K2.11 are used to connect the potentiometer through wires. With the values shown in the circuit diagram, the span ranges from about 10 mV to 3.7 V, which nicely matches the realistic operating range of an LM339 opamp at a supply of 5 V.

Jumper JP2 (or an external connection of K2.12 to ground) brings R13+R19/R20 into circuit, causing the measurement voltage to be halved. As a matter of course, an external voltage divider will allow higher voltage swings to be accommodated.

Jumper JP3 (or a link to ground via K2.13), finally, actuates damping capacitor C8, whose effect is beneficial if you're faced with noisy signals or when driving the input by a contact.

Besides the measurement input, there are two more connections from K2 to the microcontroller. K2.3 is a digital control input leading to PD.4. The input protected by R10 and zener diode D4 may be used for additional functions. C7, finally, serves to debounce signals supplied by an external contact.

Pushbutton S1 is the Reset or Start control. Debouncing and damping is effected by R1 and C10. R3 protect the sensitive contacts on S1.

Optionally, a second pushbutton may be connected to pin K2.1. This connection is protected up to 30 V by means of R2/D3.

The instrument mode is selected by the user on **rotary BCD switch S2**. The four BCD lines A-D are taken to microcontroller port lines PD.0-PD.3 by way of R4-R7. Port lines PD.1, PD.2 and PD.3 have double functions In operation, these lines are configured as outputs, multiplexing the displays. This is also the reason for the presence of current limiters R4-R7, which prevent damage caused by short-circuits.

The readout

A 74HCT42 IC decodes the three BCD lines required for an 8-digit readout to decimal format. Transistors T1-T8 enable all display digits in succession at a refresh rate of about 80 Hz, each transistor carrying a current of about 160 mA when switched on. The display turn-off delay should be as short as possible (less than 1 microsecond) to prevent overlap in the display-enable signals occurring and causing undesirable visual effects on the readout. In this circuit, this effect is eliminated by software, allowing 'not too fast' transistors to be used.

All identically named segments of the 8-digit readout are taken together and driven directly via Port B. The current limiting needed for the LED segments is realised by resistors R40-R47.

Power supply

The 8-12 VDC supply voltage for the instrument is applied via PCB terminal block K1, with diode D1 acting as a reverse polarity protection. The voltage regulator, a 7805 (for 1 A) is fitted with a small heatsink if it is to handle rather high input voltages (up to 15 V). If a much lower voltage is used, then the PCB ground plane will provide sufficient cooling. Capacitors C1, C2 and C3 are the usual reservoir and decoupling components. Zener diode D2 limits the circuit supply voltage to a maximum level of about 5.6 V in case too much current flows into the supply circuit as a result of the input overvoltage protection. In addition, all integrated circuits are locally decoupled with 100-nF caps (C4, C5, C6).

On the board, the supply tracks to the display are routed separately to prevent noise owing to the multiplex signals. After all, a pulsed current of about 160 mA flows through these tracks. Depending on the ripple voltage on K1 two more electrolytic caps, C13 and C14 may be fitted on the board.

Operation

Despite the low overall cost of the components used, the instrument offers a comfortable, simple operation employing the 8-digit 7-segment display. As shown in **Table 2**, eleven modes are available and three auxiliary functions (settings, really). Any one of

S2	LED readout								Mode/Function
	7	6	5	4	3	2	1	0	
0	—	—	—	—	—	—	—	—	None (spare)
1	8.	8.	8.	8.	8.	8.	8.	8.	All segments and DP on (display test)
2	n	V6	V5	V4	V3	V2.	V1	‾	Pulse duration of positive half cycle in microseconds
3	n	V6	V5	V4	V3	V2.	V1	-	Pulse duration of positive half cycle in milliseconds
4	u	V6	V5	V4	V3	V2.	V1	‾	Pulse duration of negative half cycle in microseconds
5	u	V6	V5	V4	V3	V2.	V1	-	Pulse duration of negative half cycle in milliseconds
6	4	V6	V5	V4	V3	V2.	V1	‾	Period duration in microseconds
7	4	V6	V5	V4	V3	V2.	V1	-	Period duration in milliseconds
8	F	V6	V5	V4	V3	V2	V1	0	Frequency, gate time 0.1 s
9	F	V6	V5	V4	V3	V2	V1	-	Frequency, gate time 1.0 s
10	F	V6	V5	V4	V3	V2.	V1	_	Frequency, gate time 10.0 s
11	E	V6	V5	V4	V3	V2	V1	.	7-digit Event Counter
12	C	V6	V5	V4	V3.	V2	V1	.	Stopwatch with lap time function, resolution 0.01 s
13	—	—	—	—	—	—	—	—	None (spare)
14		C	F	C	—	1..5 —			Pause before next measurement (1-5 s) manual restart
15		C	F	C	—				Select positive / negative pulse edge

V6-V1: value or count.
When the measured value or count exceeds 6 digits, digit 7 is automatically added. The instrument function is then no longer displayed.
Digit 7 flashes during measurements.
Decimal point in digit 7 indicates overflow / limit value.

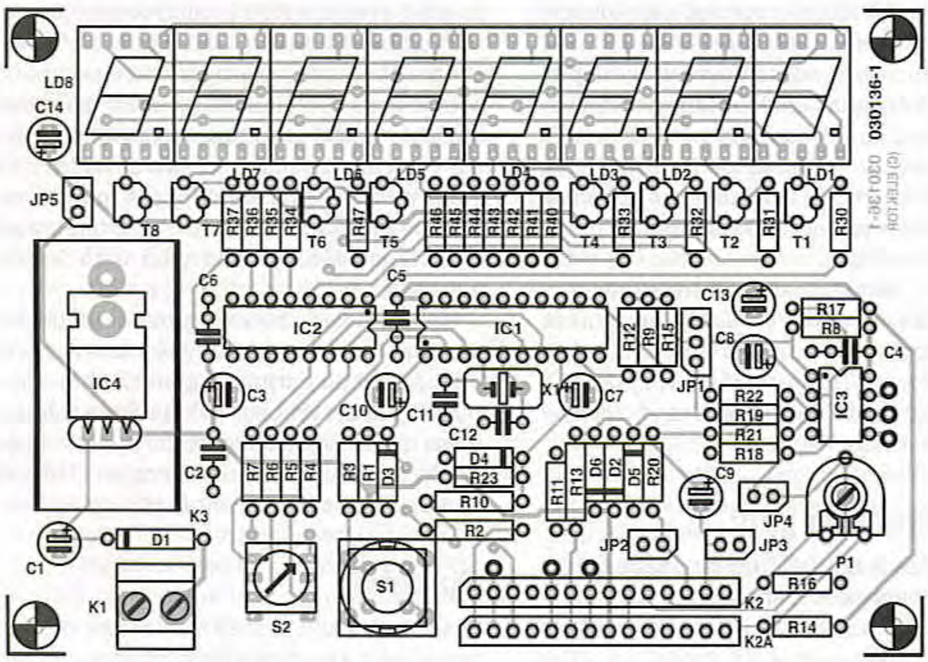


Figure 2. This double-sided board allows the versatile instrument to be built in a very compact way.

these may be selected at any time with BCD switch S2.

At **power-on**, a number of default settings are loaded (e.g., pause = 3 s; count edge = positive). If necessary, these settings may be modified via switch positions CONFIG1 and CONFIG2. Simply select the CONFIG you want to change and press the reset key until the desired setting appears on the display. Next, determine the desired mode of operation.

Each time the instrument function is changed or switched on, a new measurement cycle is launched. The displays will flash during the delay leading up to the trigger instant, as well as during the actual measurement. When the measurement is finished, the decimal point of digit 0 (DP.0) lights briefly. This is a valuable indication about the status of the measurement process, particularly in the case of short measurements and 'display refresh on end of measurement'. Depending on the values entered into CONFIG1 a new measurement is automatically started after a fixed delay, allowing you to read the value from the display. This pause can be anything between 1 and 5 seconds in length, while it is also possible to select manual starting.

The separate **gating input** (K2.3 or PD.4) allows various functions to be realised for example, intermediate value displaying while in frequency meter or event counter mode. When the gating input is pulled Low, the readout will be frozen. If it is permanently Low, the measured value is only refreshed at the end of the measurement cycle, in other words, it remains visible during the entire measurement. The gating input allows a start/stop/reset facility to be realised in Stopwatch mode.

Overflow is indicated by the decimal point in digit 7. Normally, the measured value will be displayed across display digits 1-6. When digit 6 overflows, the measured value also appears on digit 7, instead of the function indicator. When digit 7 overflows, too, the condition is flagged by the decimal point coming on and the digit starting to flash. The overflow indicator is also actuated with pulse duration measurements if you are applying pulses with a duration less than 1.6 microseconds, or a frequency greater than 300 kHz. In these cases, the display will act as a warning device.

The circuit features **automatic leading-zero suppression**. Only in 'refresh at end of measurement' mode, the zeroes will appear on the display in accordance with the progress of the measurement. When the measurement is finished, the readout is refreshed. The zeroes are retained when subsequent measure-

COMPONENTS LIST

Resistors:

R1,R23 = 33kΩ
R2,R10,R13 = 1kΩ8
R3,R12,R15,R40-R47 = 150Ω
R4-R8 = 1kΩ5
R9,R17 = 100kΩ
R11,R18 = 68kΩ
R14,R30-R37 = 3kΩ3
R16 = 22ΩΩ
R19,R21 = 8kΩ2
R20 = 10kΩ
R22 = 1MΩ
P1 = 10 kΩ preset H (with spindle, see text)

Capacitors:

C1 = 10μF 25V radial (optionally tantalum)
C3 = 10μF 16V radial (optionally tantalum)
C2,C4,C5,C6 = 100nF
C7-C10 = .47μF 16V radial optionally tantalum)
C11,C12 = 22pF
C13,C14 = 10μF 16V radial optionally tantalum) (only if required)

Semiconductors:

D1 = 1N4001
D2,D3 = zener diode 5V6, 500 mW
D4 = zener diode 4V7, 500 mW
D5,D6 = BAT46
T1-T8 = BC327-25
IC1 = AT90S2313-10PC, programmed, order code **030136-41**
IC2 = 74HCT42 or 74HC42
IC3 = LM393 (8-pi DIP)
IC4 = 7805

Miscellaneous:

JP1 = 3-way jumper
JP2-JP5 = 2-way jumper
K1 = 2-way PCB terminal bock, lead pitch 5mm
K2,K2A = 14-way SIL pinheader
S1 = pushbutton, 1 make contact (small model)
S2 = BCD switch (16 positions)
X1 = 10MHz quartz crystal
LD1-8 = SA52-11SRWA (Kingbright)
IC sockets: 6-way, 8-way, 16-way, 20-way
Heatsink for IC4 (U25, 30K/W)
PCB, order code **030136-1**
Disk, project software, order code **030136-11** or **Free Download**

ments yield smaller values (clearing is possible by means of a RESET). With intermediate results on the readout (display refresh halted by separate input) the leading zeroes will be visible on the display as the counting operation progresses. After re-enabling the gate, the display (showing, for example, the stopwatch or the event counter) is immediately refreshed.

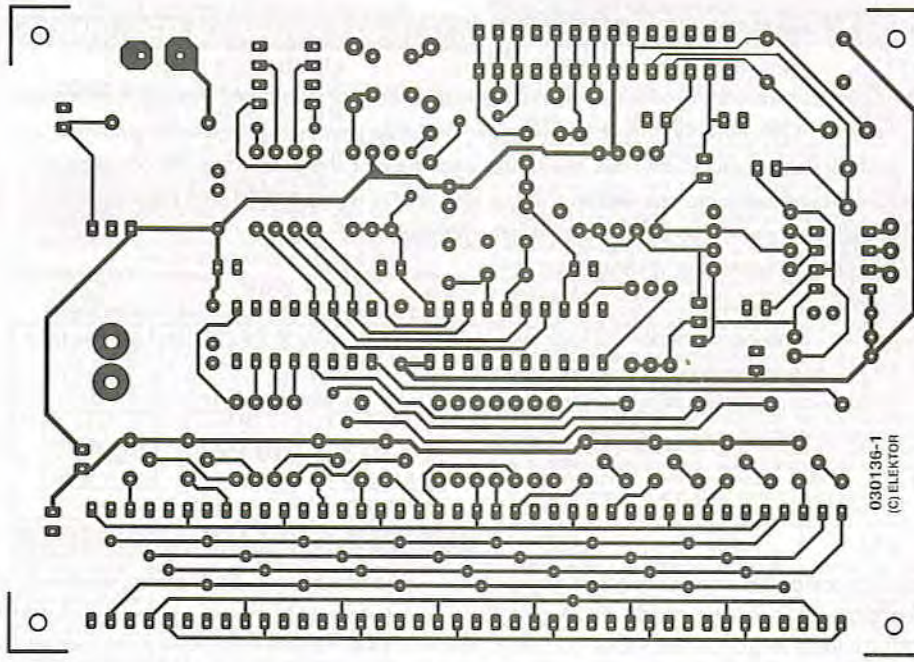
Functions

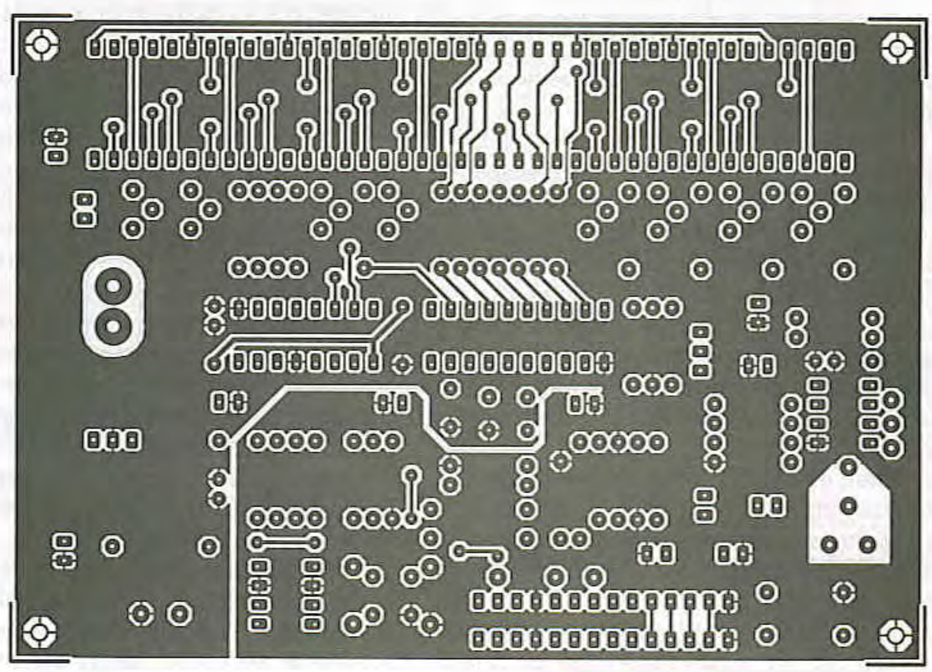
The function **Pulse/Period Measurement** is self-evident. As you can see on the photograph, the three horizontal segments in digit 0 are switched to indicate μs, ms or Hz units. Also on the photograph, the symbol for the actual function appears in digit 7. The decimal point appears in position 2. When the measurement is started, the instrument is triggered by the next (and, depending on the setting) valid pulse edge. With period measurements, triggering always takes place on a positive pulse edge. Optionally, a trigger threshold may be set using a comparator. This will be needed particularly with pulse duration measurements on non-rectangular signals.

In **Frequency Meter** mode you have gate times of 0.1 s, 1 s and 10 s to choose from. The lower horizontal segment for 'Hz' will be indicated by digit 0, and an 'F' (for 'frequency') will appear on digit 7. The decimal point only appears on digit 2 when 10-s gating has been selected. With the other gate times, display digits 0 or 1 will show a fixed 0.

In **Event Counter** mode the decimal point will light in display digit 0, while digit 7 indicates if positive or negative pulse edges are used to increment the counter. The selection is made using CONFIG2 (the default is 'positive'). Pulses with a frequency of up to 4 MHz are counted and displayed. Intermediate result viewing is possible by pulling the counter gate input low, which is flagged by DP.0 starting to flash.

The **Stopwatch** has an accuracy of 0.01 s. Its control, (start, intermediate value display, reset) only takes place via the separate pushbutton or input K2.3. The stopwatch defaults to the value '0.00 ms' on the display.





In digit 0, the central horizontal segment for 'ms' lights and a 'C' (for 'clock') will appear in digit 7. DP.0 is switched off. The stopwatch is started when the pushbutton is briefly pressed. The elapsed time will be displayed and DP.0 will light continuously. Intermediate (lap) and finish times may be requested by briefly pressing the pushbutton again. The display will freeze and DP.0 flashes to indicate the ongoing measurement. When you actuate the pushbutton again, the display will be refreshed and DP.0 lights again. This sequence may be repeated as many times as you like. The stopwatch is reset by keeping the pushbutton depressed longer than about 2 seconds, or by pressing the Reset switch.

Construction

Figure 2 shows the double-sided printed circuit board designed for the Multifunction Frequency Meter. Despite its small size there are no dreaded SMD components to fit — all com-

DIY Programming

The microcontroller used in this circuit is available ready-programmed through our Readers Services. If you have the means and wherewithal to do your own programming, there's nothing to stop you as the HEX and source code files for this project may be obtained as Free Downloads from our website. Simply look for file number **030136-11** under month of publication or order a disk with the same number.

DIY programmers should know that

LB1 = 1 (unprogrammed)
LB2 = 1 (unprogrammed)
SPIEN = 0 (default, serial programming allowed)
FSRT = 1 (default)

ponents are of the normal 'leaded' type. Construction on a ready-made PCB obtained through our Readers Services (order code **030136-1**) is not expected to cause problems if you work carefully. While populating the board, guidance on the positioning of polarized components is obtained from the component overlay. All DIL ICs may be fitted in good-quality sockets.

With the soldering work on the board finished, we suggest running a visual inspection on all solder work, if necessary using a magnifying glass. Without the ICs and displays mounted on the board, apply a supply voltage of about 8 V, preferably using a bench supply with current limiting. Check if the supply voltage arrives on all relevant points in the circuit. At this stage the overvoltage protection at the input may also be subjected to a quick test.

When everything seems to work so far, you may start fitting the displays onto the board. It is suggested to use two wires for a test of all individual segments. One wire is used to connect pins 1-7 and 9 of display position IC2 to ground. The other wire is used to switch IC3 pins 12-19 to ground. This will enable every individual segment to be tested. If this test is also successful, the displays and the associated transistor drivers can be assumed to work properly, which means that all ICs may be fitted in their sockets (observing their orientation, of course). Finally, all functions may be checked. The accuracy of the instrument is totally dependent on the drift and tolerance of the crystal oscillator. If necessary and provided high-end test equipment is available, the oscillator may be calibrated by making small changes to C11 and C12.

Well before starting your solder work on the board you should make up your mind which enclosure will be used to house the instrument. But even without a case, the board should be very much alive and ready for use with just four PCB spacers secured to the corners — just hook up an 8-12 VDC/0.3 A mains adapter to K1 and away you go.

When the instrument is built into a stylish ABS enclosure, its controls should be moved from the board to the front panel. A case with a transparent cover, for example a Teko type P3 or P4, saves a lot of tooling as no clearance has to be cut and trimmed for the LED display — all you have to do is mount the displays in stacked sockets. Basically, the same applies when a case with a normal (non-transparent) lid is used — the displays may be positioned at the correct height above the board by using wire-wrap sockets whose pins are cut to length.

The board is secured to the inside of the front panel using four small PCB spacers. Although the actuator spindle of S2 may simply protrude from the panel, the hole for Reset switch S1 requires a much larger hole to make sure the cap is easily accessible.

The functions of jumpers JP2, JP3 and JP4 have been discussed above. If you want to use switches instead, do rummage around in your junkbox in search for miniature pushbuttons that, with some luck, can be fitted onto the board at (more or less) the right position. If you're unlucky, you can still connect the switch of your choice to the relevant pins on K2 and K2a, which have identical pinouts. The same goes for the potentiometer: it is not necessary to mount one onto the front panel and wire it to the board if you can find an equivalent type that fits on the board and comes with a removable spindle. Alternatively, a preset may be mounted on the board and a hole drilled in the front panel to allow a small screwdriver to pass.

The counter gating input is realised by a pushbutton switching to ground and a two-way socket in parallel with it. These elements allow the gating input to be operated manually or electronically (by an external circuit). The measurement input should be a BNC socket.

Noise immunity

The input circuit has been laid out to represent a relatively high impedance. Depending on the jumper settings the input impedance will be between 15 and 65 kΩ. When long, open measurement wires are used, or the measurement is performed in an electrically noisy environment, strong 50-Hz signals may stray into the instrument (for instance, emanating from a phase angle control circuit). Although it is great to see that the mains frequency can be measured without an (unsafe) electrical connection, it is better to stick to defined conditions.

Since the instrument should be suitable for frequencies up to 4 MHz, damping (parallel) capacitors at the input are inappropriate. The following rules of thumb should be observed in this respect: (1) the signals sources should exhibit a low impedance and (2) long measurement cables should be screened. If necessary, a termination resistor (<10 kΩ) should be connected to the measurement input.

(030136-1)