Universal Counter

Stand up and be counted: a universal counter based on Intersil's ICM7226, by Bill Miller and Jan Vincent.

A QUIET REVOLUTION has been taking place for the past few years. Until now the lowly digital counter has required row upon row of TTL packages and plenty of power to keep the lights flashing. Then Intersil stepped into the arena with a new high density IC, the ICM7226. All those decade registers, crystal oscillators, timing logic and display drivers have been integrated into one small package that can drive eight LED displays, count at a rate of 10MHz, provide period and time measurements, and test itself. That means lower cost and easier construction for a high-quality counter. And, since the chip is CMOS, power drain is minimised, the chip [illegible] cooler, and there is less heat to [illegible]t accuracy.

Now if that was not enough, we wanted more. So we added more. This construction project gives you a complete universal counter with all the features found on a professional frequency counter plus a few added bonuses, like extended range (to 120MHz in all modes), input attenuators, trigger level adjustments on the panel, slope selectors, easy to use controls and a priming circuit to allow you to measure time of just about any one-shot event you could dream up.

The counter is unique in that it is small enough to fit into a standard instrument enclosure, complete with power supply and all the front-end circuitry, right next to your signal generator or radio transmitter. And its construction, with separate display and electronics board, makes the whole unit go together smoothly. You can probably find many other uses for this counter, and there are plenty of applications which would benefit from a simple-to-use counter.

Besides the IC construction and the small size, our counter has these other features. You can measure down to DC with two separate DC-coupled inputs with industry standard 1-megohm input impedance. There's an external adjustable trigger-level control for each channel to adjust input sensitivity on either

How It Works

The counter is constructed around Intersil's universal counter chip, the ICM7226B, which contains most of the circuitry necessary to produce a timer/counter. It combines a high frequency oscillator, a decade timebase counter, an 8 decade counter and latches, a 7 segment decoder, digit multiplexer and 8 segment and 8 digit driver for directly driving a common cathode LED display. The project can be divided into four sections for this discussion; the VHF front end, the LF front end, the 7226, and the power supplies.

VHF front end

The basic element of the VHF front end is the prescaler IC from National Semiconductor (DS8629N). This unit provides the necessary preamplification of the incoming signals to bring them up to the levels required to drive the digital logic. In addition, it prescales the input frequency by dividing it by a factor of 100. This block has a low input impedance needed by high frequency inputs and is protected from overloads by a resistor-capacitor-diode network. The output from this chip is a TTL compatible signal in the rang eof 100k Hz to approximately 1.2MHz, and is applied through Sw7 to the input of the 7226 counter chip.

Low Frequency front end

The low frequency front end is comprised of an input attenuator, a J-FET preamplifier, resistor-diode input protection circuit, and a level adjustment circuit. The input attenuator allows the user to select the required sensitivity to prevent false triggering of the counter due to noise or spurious pulses applied to the input. Once the proper input signal level has been selected, the signal is applied to the J-FET preamp, which provides wideband amplification from DC to approximately 10MHz. The input sensitivity is typically 50mV at 10MHz.

IC1 is an op amp which inverts the incoming signal and performs two functions. It adjusts the trigger level by adding a DC component to the signal and it acts as a Schmitt trigger to square up the signal before it is applied to the logic circuitry. Part of the trigger circuit allows you to apply an inverted or non-inverted signal to the 7226, giving you the capability of triggering on the positive or negative going edge of the waveform. This selection enables the measurement of time for periodic pulses and one shot events. The final output of the low frequency front end is a TTL compatible signal in the range from DC to approximately 10MHz, and is applied directly to the input of the 7226 counter chip. Note, there are two low frequency front end circuits used in this project, one for each input to the counter chip. The two channels are used in combination to measure time intervals of repetitive pulses or events, and in measuring the frequency ratio of two incoming frequencies. A complete discussion of the operation of these types of measurements is found in the description of the operating functions.

ICM7226 counter chip

As stated previously, the basic block of the counter is the Intersil ICM7226B decade counter chip. This counter can function as a frequency counter, period counter, frequency ratio (f_a/f_b) counter, time interval counter or as an event totaliser. The counter uses a 10MHz crystal timebase, and has an on-chip oscillator circuit. For period and time interval measurements, the 10MHz timebase is used to provide 0.1 uS resolution. In the frequency mode, gating times are user selectable from 0.01 sec, 0.1 sec, 1 sec or 10 sec ranges. A complete discussion of the various functions can be found in the list of operating functions and on the Intersil datasheet.

Power supplies

The final section is comprised of four low current power supplies. The basic requirement is to supply well regulated power to the logic chips and the front end circuits. The four supplies are very simple and make extensive use of monolithic regulating ICs. The four supplies required are +10.5 Volts, +5.1 Volts, -10.0 Volts and -5.0 Volts. The printed circuit boards have been designed with the on-board supplies, including the power transformer.

Parts List

Resistors ¼ W, 5%

R1,101	910K
R2,102	91K
R3,17, 18,19,20, 29,31,103	10K
R4,6,10, 23,104, 106,110	100R
R5,105	1M
R7,12,15,16, 107,112	1K
R8,108	1K5
R9,109	200R
R11,111	51K
R13,113	22K
R14,114	20K
R21	100K
R22	22M
R24,30	470R
R25	See Text
R26	820R
R27	47R, 2 Watt
R28	47K
R32	390K
R33	1M2
R38	47R

Switches

SW1,101	DP3T mini slide
SW2,102	SPST mini toggle
SW3	SP6T rotary
SW4	DP4T rotary
SW5	spst N/O mom.
SW6	SPST mini toggle
SW7	TPDT mini toggle
SW8	SPST toggle
SW9	SPST N/O mom.

Capacitors

C1,101	15pF ceramic 300V
C2,102	270pF ceramic 300V
C3,103 4,104	10nF mini
C5,6	100nF mini
C7	22uF 16V tantalum
C8	10nF mini
C9	47pF ceramic 5%
C10	33pF ceramic 5%
C11	5.5 - 65pF trimmer Phillips 010GA/60E
C12-16	10nF ceramic
C17	100nF ceramic
C18	2200uF 25V radial electrolytic
C19	1000uF 25V radial electrolytic
C20	22uF 16V tantalum
C21,22	100nF mini
C23	6u8 16V tantalum
C24,28	4u7 16V tantalum
C25	100nF mini
C26,27	10nF ceramic

Potentiometers

RV1,RV101	2k2 horiz trimmer
RV2,RV102	5k linear

Misc.

Transformer	Hammond 161F20 20V 220 mA
Case	Approx 7x9x3 inch

printed circuit board, knobs, ribbon cable, coax mini cable RG174/II fuse holder, power cord.

Semiconductors

D1,D101 D2,D202 D3,D4,D5 D6,D7	1N4148 or similar
D8,D9	1N4001
Q1,Q101	J308 FET
Q2,Q102	2N3646
Q3	2N4401
Q4	2N6027
IC1,IC101	TL810CN
IC3	MC1458
IC4	ICL7226BIPL
IC5	DS8629N
IC6	LM340T-5 (do not use 7805)
IC7	78L05
IC8,IC9	79L05
IC2	74LS86
IC10	7404
display	2 x NSB5881
LED	mini red LED
Crystal	10MHz 22pF 35R

ing collared (insulated feedthrough) wirewrap pins soldered to both the display and the display board. Be sure to add the seven jumpers to the display board before the completed unit is mounted on the front panel.

Mount all the switches and controls on the front and back panels. Begin wiring up the interconnections by using the component overlay as a guide. The easiest method is to use a length of ribbon cable for all the interconnections. The signal cable must be a high quality shielded cable from the input jacks to the printed circuit board. Be sure to bring the cases of SW1 and SW101 and both trigger level pots to the ground (0 volts), or better yet bring the whole front and back panel to ground level. This prevents hum pick up or spurious coupling between the controls and the inputs.

A few very important precautions are necessary. Keep all signal carrying cables away from the 7226 and the display. The 500Hz multiplex frequency is easily induced into the front end circuit. Check and double check the polarity of the 7226 before applying power; this is a very expensive IC to destroy by applying reverse power.

Using coloured ribbon cable, connect the rotary switches to the PCB (see rotary switch detail drawing). Finally, secure the crystal to the board using a drop of silicon sealant.

Calibration

Calibrating the counter is a snap if you have a frequency standard available. Ideally, that standard should be better than ±0.0005% accurate at room temperature to get the maximum accuracy. Using a 10MHz source, connect the frequency standard and turn on the counter. For best results you should calibrate at room temperature and allow at least five minutes for the counter to stabilise before starting. You should get a reading very close to 10MHz, then adjust trimmer capacitor C11 until the reading is exactly 10MHz. Disconnect the standard and you are ready to go.

If a standard is not available, use a source of known frequency, and adjust C11 for the closest reading possible. Always allow the equipment to warmup before taking any measurements to get the best accuracy. See the schematic for details on adjusting trim pots RV1, RV101.

Now that the counter is completed you will want to begin using your new test instrument. Be sure to connect your signal to the correct inputs, adjust the input attenuator for the correct signal levels; x1 for signals to 1V RMS; x10 for signals to 2V RMS; and x100 for signals over 2V RMS. These levels overlap.

Using the counter is straightforward and needs little explanation. Remember that the decimal point denotes kilohertz for the low frequency inputs and megahertz for the V input. All times are in microseconds. If the prescaler oscillates, connect a 100k resistor from pin 6 to 0V on the bottom of the PCB. This reduces sensitivity and will get rid of any oscillations.

The counter has a wide range of functions to match the wide operating frequency range. The six basic functions that can be selected are:

Frequency measurement — Using the prescaler circuit, frequencies to more than 120MHz can be accurately measured, with little or no loading of the external circuit. By selecting the gating time, the accuracy of the reading is dependant only on the calibration of timebase oscillator of the 7226 counter. Signals of less than 10MHz are applied to the channel A input, which has an impedance of 1M.

Period measurements — The counter can handle input signals to approximately 2MHz in the period measurement mode. The 7226 provides an accurate timebase which is counted and gated by the incoming signal, the result being displayed and scaled in microseconds. The operation of the period measurements is such that the displayed value is an average reading, averaged over several measurement cycles. For period and time interval measurements, the 10MHz timebase gives a 0.1 microsecond resolution, that can be read down to the nanosecond range.

Time Interval — The time interval function allows you to measure the time between two events, such as the time between two pulses. This function requires either a repetitive signal applied to input A and B, or for the two inputs to be prepared before the signals are applied. This is the function of the priming circuit; it prepares the counter inputs for a single event on the two inputs. As input A goes negative the internal counter begins counting time in 0.1 microsecond units. When input B drops, the counter stops and displays the time interval between the two transitions. To initiate the counter into the primed one-shot mode, take the following steps. Set trigger level controls to 11:00 o'clock and scope switches to the open or non-inverting position. The function switch must be in the (time) mode and the range switch in the .01 - 1 range. Depress the prime switch and hold in momentarily. If the gate light does not go out then press reset and try the prime switch again. The gate light turning off indicates the unit is primed and the next transition at input A will start the count and a pause at input B will finish it, displaying the result in uSec. This function will display one-shot events from fractions of a uSec, to 10 Sec.

Unit counter — The counter can be used as a high speed unit or event counter. It can actually count at a rate of 120 million events per second, and display more than 90 million on the display. The operation is very straight-forward. By applying a signal to input A, which drops from a positive voltage level to a ground or negative voltage level, the counter will increment once for each positive to negative transition. The counter is returned to zero by depressing the RESET button, or the display may be held at any value by using the HOLD switch, The hold switch does not reset the counter; it simply prevents further input pulses from incrementing the count. Normal operation is continued upon returning the hold switch to the normal position.

Frequency Ratio — The frequency ratio function allows you to display the relative ratio between two frequencies. In connecting two signals to input A and B, the higher frequency signal should be connected to input A. The resulting display is an average measurement of the ratio between the two inputs. For obvious reasons this ratio must always be equal to or greater than 1. The maximum frequency for this mode of operation is approximately 10MHz at input A and 2MHz at input B.

Oscillator — The counter can be used to monitor the internal timebase by selecting the OSCILLATOR function.

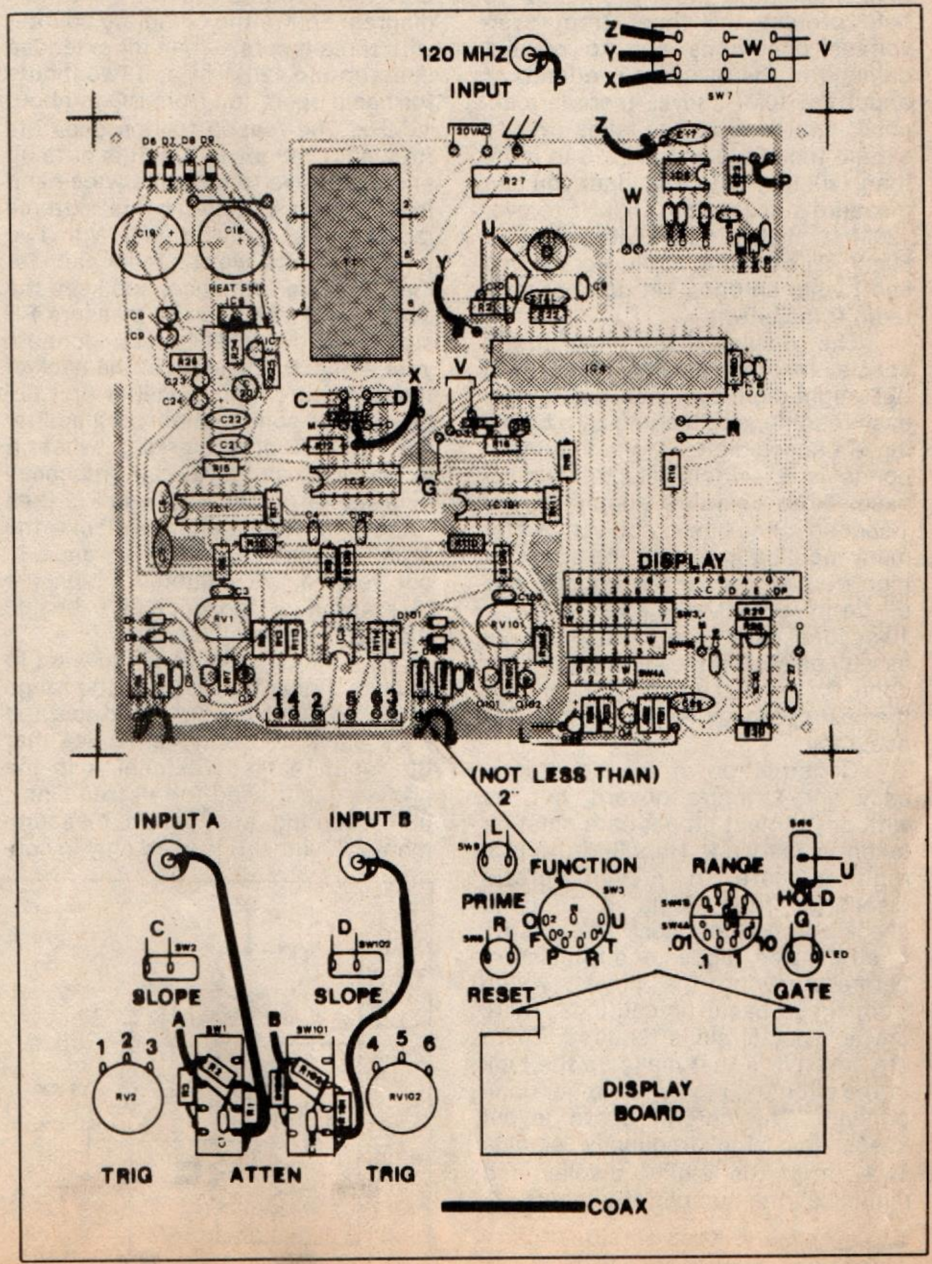


Fig. 1. Parts placement.

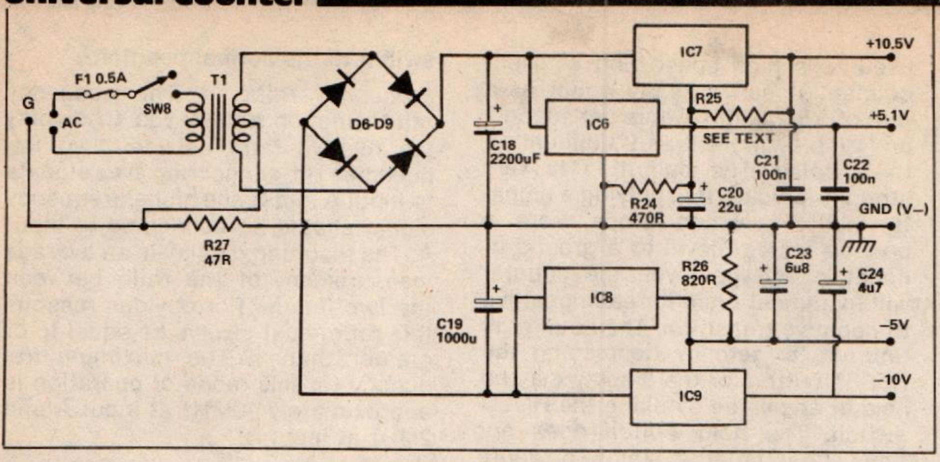


Fig. 2. The PSU.

positive or negative-going signals. plus, there's an input attenuator to help protect the input from over-voltage conditions and to prevent damage in the event of overload. At about the 10MHz level, there is a second input circuit that takes over to extend the range of the 7226 to more than 120MHz. With this input you can measure signals from 150kHz to over 120MHz, with a sensitivity of about 50mV. This counter could work with a short whip antenna set up near your radio transmitter.

The display has some pretty special features as well. There is a LED eight-digit, half-inch display for easy reading, and leading-zero blanking of unused digits. A very important bonus is a switch selectable time-base. Most counters supply only a 1-second time-base, too short for many applications and too long for high frequency use. Our counter has a complete timebase with a 10-second gate time for audio work as well as selectable settings of 1 second, 0.1 second and 0.01 second for the best speed in measurement at full accuracy.

Construction of the counter is easy and straight forward, but, as with any project proper care must be taken in the work. Handling the IC's requires care to prevent static discharge from tools or fingers; check and double check the polarity of all the IC's, diodes and transistors before applying the power. Aside from these basic precautions, there are no special skills required. There are seven IC's that make up the bulk of the circuitry, plus a few other components. The careful board layout keeps the high frequency signals away from the digital display and minimizes the number of jumpers.

The circuit

As mentioned earlier, the counter is based on a single IC that contains the essential electronics for a complete universal counter. The schematic diagram shows the complete counter with three inputs — one for extended operation to 120MHz, and two inputs for basic operation from DC to about 10MHz. The reason for the separate frequency ranges is that it is difficult and expensive to design a wide-band input circuit to handle this extreme range of input conditions. With two types of inputs, we can tailor each for maximum performance, and keep the cost low. If you wish to measure RF signals above 10MHz, you connect your signal to the input at the back of the enclosure. The signal is first applied to a combination preamplifier and ECL/TTL prescaler chip, where it is amplified and divided in frequency by a factor of 100. The result is then routed to SW7, which selects the 120MHz range or the 10MHz range. In our version, we mounted S1 on the rear apron of the enclosure beside the high frequency input.

On the other hand, if you want to apply a signal that falls in the range of DC to 10MHz, you would use the front panel connections. Notice that the input marked Channel A is the primary input used for all frequency, unit counting and period measurements. Channel B is used only in conjunction with Channel A for measu[re]ments of time intervals. More on [how] to use it later. From the input, the signal is amplified and converted to TTL levels, adjusted for trigger level sensitivity and slope, and applied to the counter chip. This chip contains the complete universal counter circuit including a crystal oscillator, time-base divider, control logic, eight decade counters, eight latches and display multiplexing circuits.

Construction

For best results, you should use PC boards to speed construction. The first matter of business in constructing the unit is to build up the power supply. The printed circuit board has been designed to accommodate the power transformer and all the power supply components. Use a fine tip soldering iron and the smallest gauge solder you have. All the components for the power supply except R25 can be installed. Be sure to polarise all the diodes, capacitors and the regulators correctly. Now, temporarily connect a 1k pot and a 220 ohm resistor in series, and place this combination into the circuit instead of R25. Apply power and check the voltages. Using the temporary 1k pot adjust for 10.5 volt (point "h" on the PCB). Replace the pot-resistor combination with the nearest value fixed resistor for R25.

Thanks to that one big IC, the rest of the counter is easy to assemble. Mount all other components on the board, being careful to avoid solder bridges and to double check polarities. Use IC sockets for the large IC's. Once the main board is assembled, clean the bottom of the board with flux remover.

Prepare the front and back panel. In our version, all the controls except the high frequency input and control switch are mounted on the front panel.

Assemble the display board us-

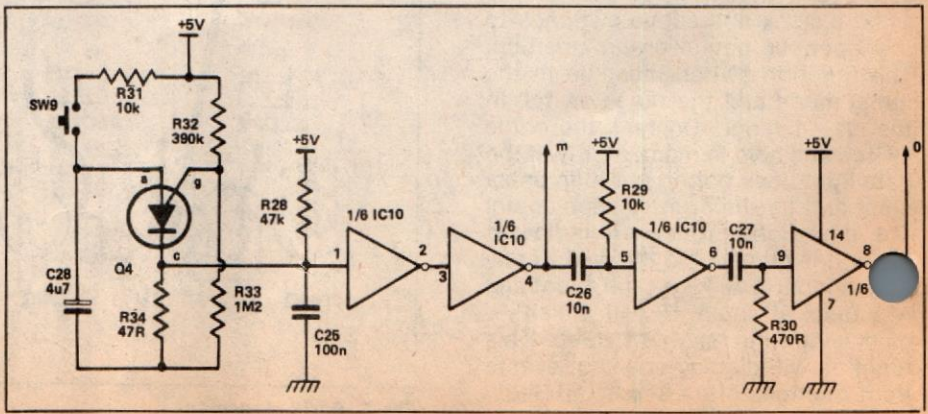


Fig. 3. The priming circuit.

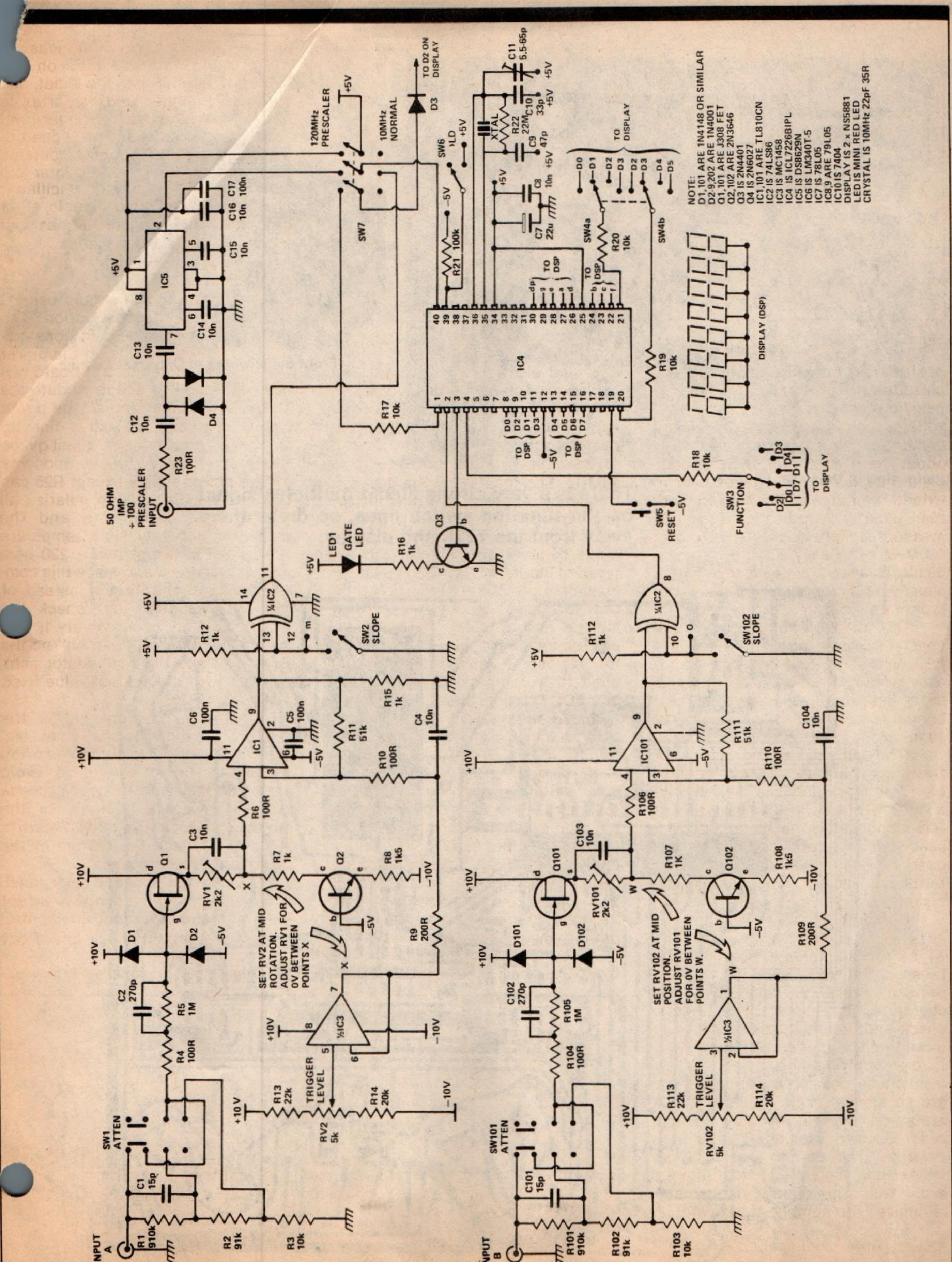
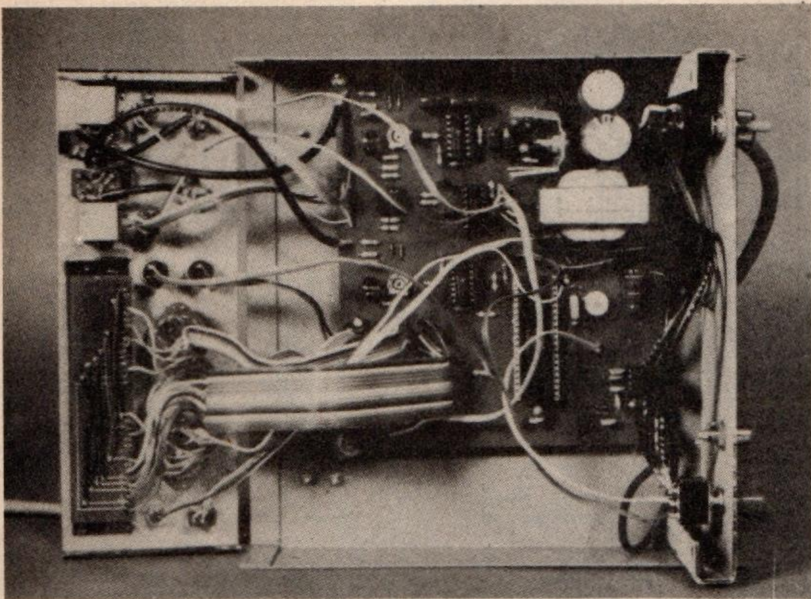
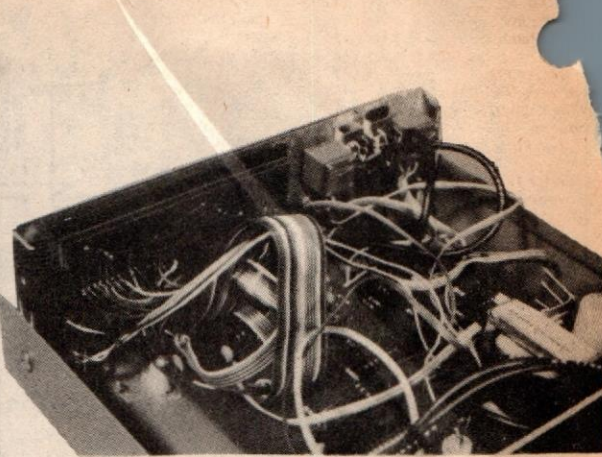


Fig. 4. The circuit diagram.



Interior view of Universal Counter.



Front panel wiring of Universal Counter.

There is a very strong 500Hz multiplex signal on the function switch lines, so dress them away from the 7226 and display.

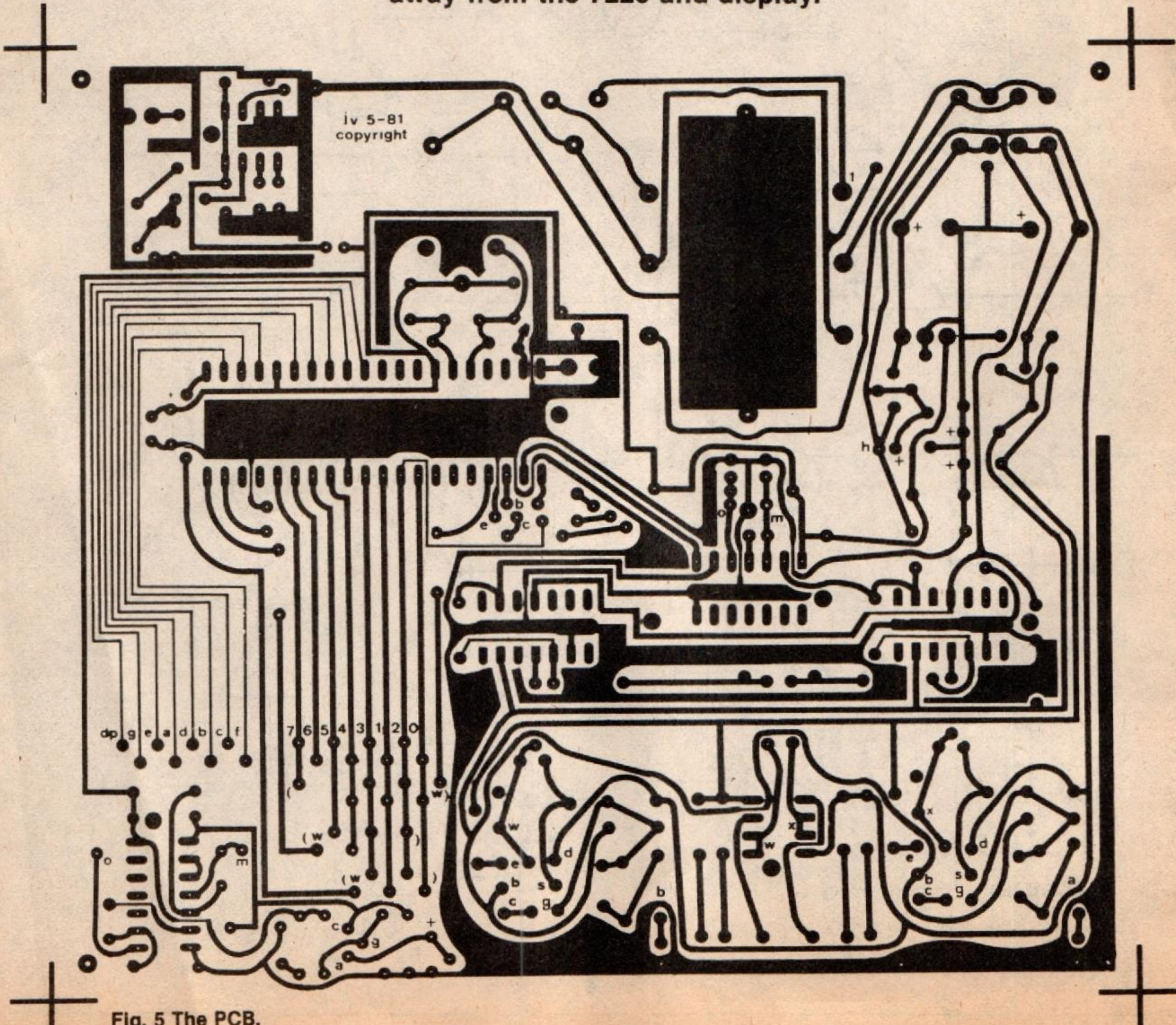


Fig. 5 The PCB.