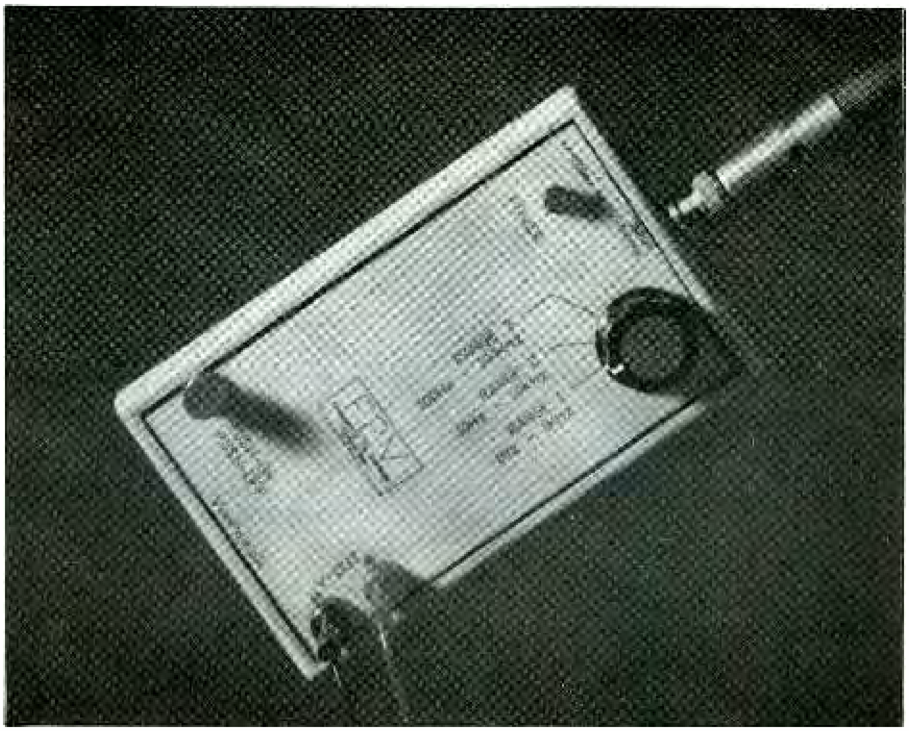
Frequency-Counter Adapter for Digital Multimeters

Adapter enables almost any waveform up to 1 MHz to be read accurately on a DVM or DMM

By Crady VonPawlak



Virtually everyone involved in electronics today owns a digital voltmeter or multimeter. A significant portion of these people would also like to, but do not yet, have a frequency counter. This project can change all this. I will show you how to build an inexpensive, handheld adapter that can provide accurate frequency measurements when plugged into either a DMM or DVM.

The basic adapter is actually a voltage-to-frequency converter. It enables the user to directly read frequencies from 1 Hz to 100 kHz on a DMM. In addition, if you want to accurately measure frequencies up to 1 MHz, you can add an optional subassembly that both conditions the input signal as well as divides it by any number from 2 to 10 to bring it within the range of the converter.

Our F/V converter is a relatively simple device built around a universal voltage-to-frequency/frequency-to-voltage chip from Teledyne Semiconductor. It is about the size of a hand-held DMM and is battery powered for portability. Best of all, you can build it for a fraction of what you would have to pay for a full-blown frequency counter. To provide maximum reading accuracy, the converter accessory should be used with a DMM that has a display with at least 3½ digits. Input sensitivity is about ±200 millivolts to ±15 volts rms without modification.

About the Circuit

As Fig. 1 illustrates, the frequency adapter circuit is really quite simple in terms of component count. Almost all of the circuit's complexity is contained inside the Teledyne 9400CJ universal voltage-to-frequency (V/F) converter chip, shown here as *U1*. This integrated circuit has a guaranteed 0.05-percent linearity, which makes it ideal for upgrading a DVM (or DMM set to a low dc voltage range) to give the latter a frequency-counting capability.

When used as shown in Fig. 1, the 9400CJ chip will accept virtually any waveform shape throughout its 1-Hz to 100-kHz counting range. The only proviso is that a minimum 20-per-

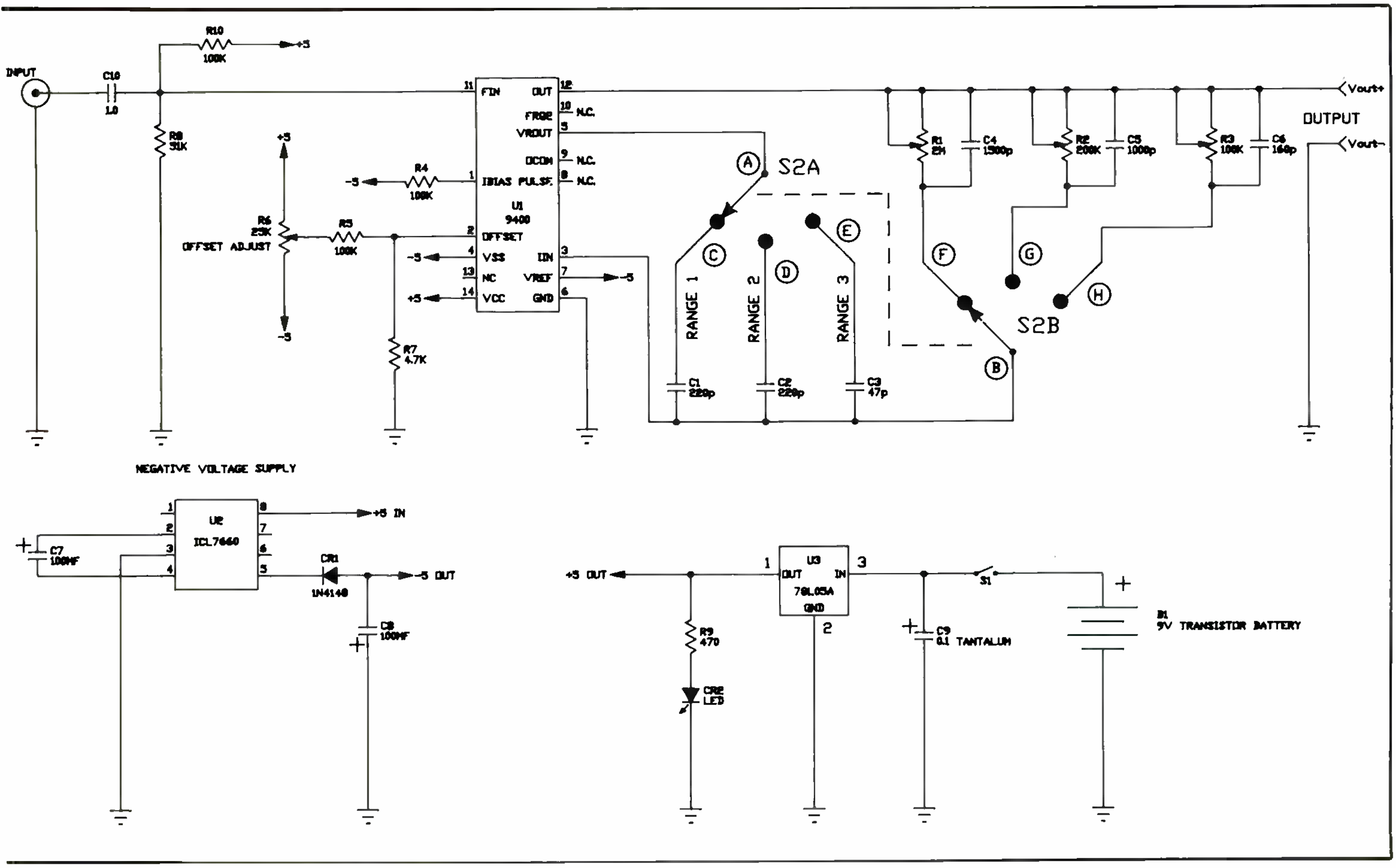


Fig. 1. Schematic diagram of frequency-to-voltage converter, including its split ±5-volt battery power supply.

cent duty cycle be maintained for the input waveform. Because of this, the 9400CJ is well suited to measuring the outputs from a wide variety of oscillators and clock circuits.

Although the V/F converter can function well with a single supply voltage, use of a ±5-volt split supply is much preferred because this arrangement maintains tight accuracy as delivery of the battery supply used with the project drops to about 6.5 volts. Hence, a split supply increases overall circuit stability and prolongs battery life. Ideally, an 8-volt or so nickel-cadmium battery supply could be used with this circuit, along with a simple charger circuit to restore the charge on the battery as needed.

In the Fig. 1 circuit, the positive rail of the power supply is maintained at +5 volts with fixed +5-volt regulator *U3*. The negative rail of the supply is obtained by feeding the +5-volt output from *U3* into voltage inverter *U2*. This arrangement yields a well-regulated split supply from one 9-volt battery.

The 9400CJ F/V converter is unique in that it generates an input voltage that is linearly proportional to the input frequency. That is, whatever numbers appear in the display of the dc voltmeter with which it is used will be the absolute numeric value of the waveform being counted, though you will have to mentally multiply the reading by some convenient figure (×1K on Range 1, ×10K on Range 2 or ×100K on Range 3 for the arrangement shown in Fig. 1). Consequently, if switch *S2* is set to range 1 and the meter displays 1.234 volts, the measured frequency would be 1.234 × 1,000, or 1,234 Hz. If *S2* is set to Range 2 or Range 3 and the voltage displayed on the meter remained the same, the actual frequency would be multiplied by 10,000 (Range 2) or 100,000 (Range 3) to yield 12,340 or 123,400 Hz, respectively.

Shown in Fig. 2 are the internal details of the 9400CJ chip. In operation, each time the waveform applied to the input of the chip passes through zero at the comparator's noninverting (+) input, reference capacitor C_{ref} charges to the reference voltage. This charge is applied to integrating resistor R_{int} to produce voltage pulses at the output of the amplifier. Integrating capacitor C_{int} across R_{int} averages these pulses into a dc voltage that is linearly proportional to the input frequen-

PARTS LIST (Converter)

Semiconductors

CR1—1N4148 or similar switching diode

CR2—Light-emitting diode

U1—9400CJ F/V and V/F converter (Teledyne)

U2—ICL7660CPA voltage inverter (Intersil)

U3—78L05 +5-volt regulator (National Semiconductor or Motorola)

Capacitors

C1,C2—220-pF, 6-volt ceramic

C3—47-pF ceramic

C4—1,500-pF polypropylene or polyester

C5—1,000-pF polypropylene or polyester

C6—160-pF polypropylene or polyester

C7,C8—100-μF, 16-volt electrolytic

C9—0.1-μF, 25-volt tantalum

C10—1.0-μF Mylar

Resistors (¼-watt, 5% tolerance)

R4,R5,R8—100,000 ohms

R7—4,700 ohms

R9—1,000 ohms

R10—51,000 ohms

R1—2-megohm, 15-turn cermet potentiometer

R2—200,000-ohm, 15-turn cermet potentiometer

R3—100,000-ohm, 15-turn cermet potentiometer

R6—25,000-ohm, 15-turn cermet potentiometer

Miscellaneous

B1—9-volt transistor or 8-volt Ni-Cd battery (see text)

S1—Spst slide, toggle or push-on/push-off switch

S2—2-pole, 3-position nonshorting rotary switch (Radio Shack Cat. No. 275-1386 or similar)

Printed-circuit board; panel-mount female BNC socket for input (Radio Shack Cat. No. 278-105 or similar); red and black banana jacks for outputs; 14- and 8-pin IC sockets; 9-volt battery snap; suitable enclosure (Pactec No. HP-9VB-002 or similar —see text); pointer-type control knob for S2; small-diameter coaxial cable; LED mounting hardware or cement; lettering kit; clear acrylic spray; machine hardware; hookup wire; solder; etc.

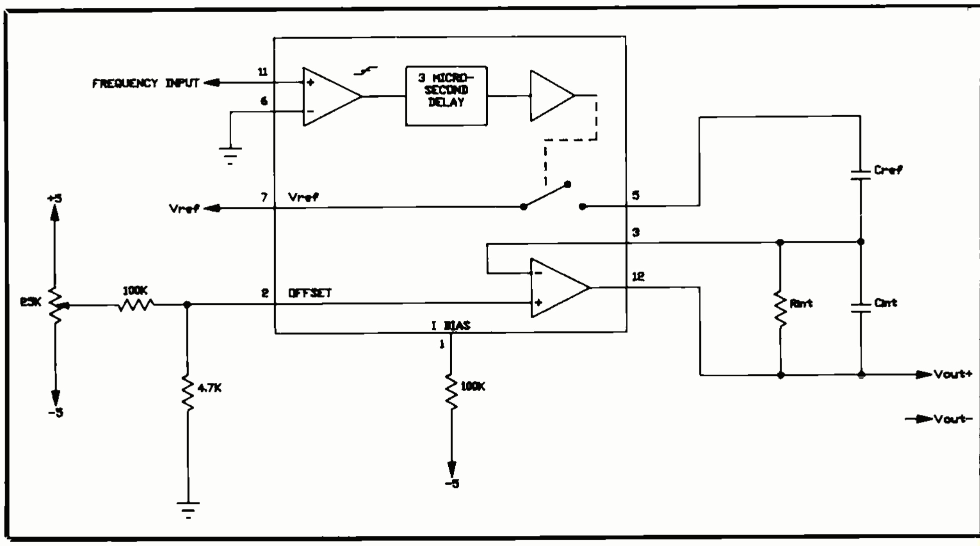


Fig. 2. Internal details of 9400CJ universal voltage-to-frequency/frequency-to-voltage chip that does all the work in this project.

cy. This can be expressed as: $V_{out} = R_{int} \times C_{ref} \times V_{ref} \times$ Frequency. For our application, the ranges are as follows:

	Frequency In (Hz)	Dc Output (Volts)
Range 1	1.0	0.001
(×1000)	500	0.500
	1k	1.000
Range 2	10.0	0.001
(×10K)	5k	0.500
	10k	1.000
Range 3	100	0.001
(×100K)	50k	0.500
	100k	1.000

The F/V converter accessory connects to the meter with which it is to be used via the OUTPUT jacks shown at the top-right in Fig. 1, with VOUT+ going to the meter's "hot" input and VOUT− going to the meter's common or ground input. The waveform whose frequency is to be measured is coupled into the converter via the INPUT jack shown at top-left in Fig. 1.

Greater versatility can be achieved by adding the Fig. 3 circuit to the basic Fig. 1 converter circuit. The Fig. 3 circuit conditions the input signal and gives the basic converter a high sensitivity to low-level signals.

The Fig. 3 circuit precedes the Fig. 1 circuit. In this circuit, CA3130 high-speed comparator *U1*, with hysteresis and adjustable threshold, gives the front end of the converter accessory a high sensitivity. Added insurance is provided by overvoltage diodes *CR1* and *CR2*.

CMOS decade counter/divider *U3*, a CD4017BC integrated circuit, has selectable outputs. By setting *S1* to the appropriate position, the input frequency can be divided down by a factor of 2, 3, 4, 5, 6, 7, 8, 9 or 10 before being coupled into the converter accessory. This feature greatly enhances the accessory, allowing it to measure frequencies to 1 MHz.

Note that this circuit has two outputs. The lower (DIVIDED) output couples the signal to be measured to the converter accessory after it has gone through the entire conditioning/dividing arrangement. However, should only the comparator's conditioning and overvoltage protection be required, the upper (UNDIVIDED) output can be used instead.

CMOS hex Schmitt-trigger inverter *U2*, a CD14106BC device, serves three purposes in the Fig. 3 circuit. Firstly, it cleans up the output from

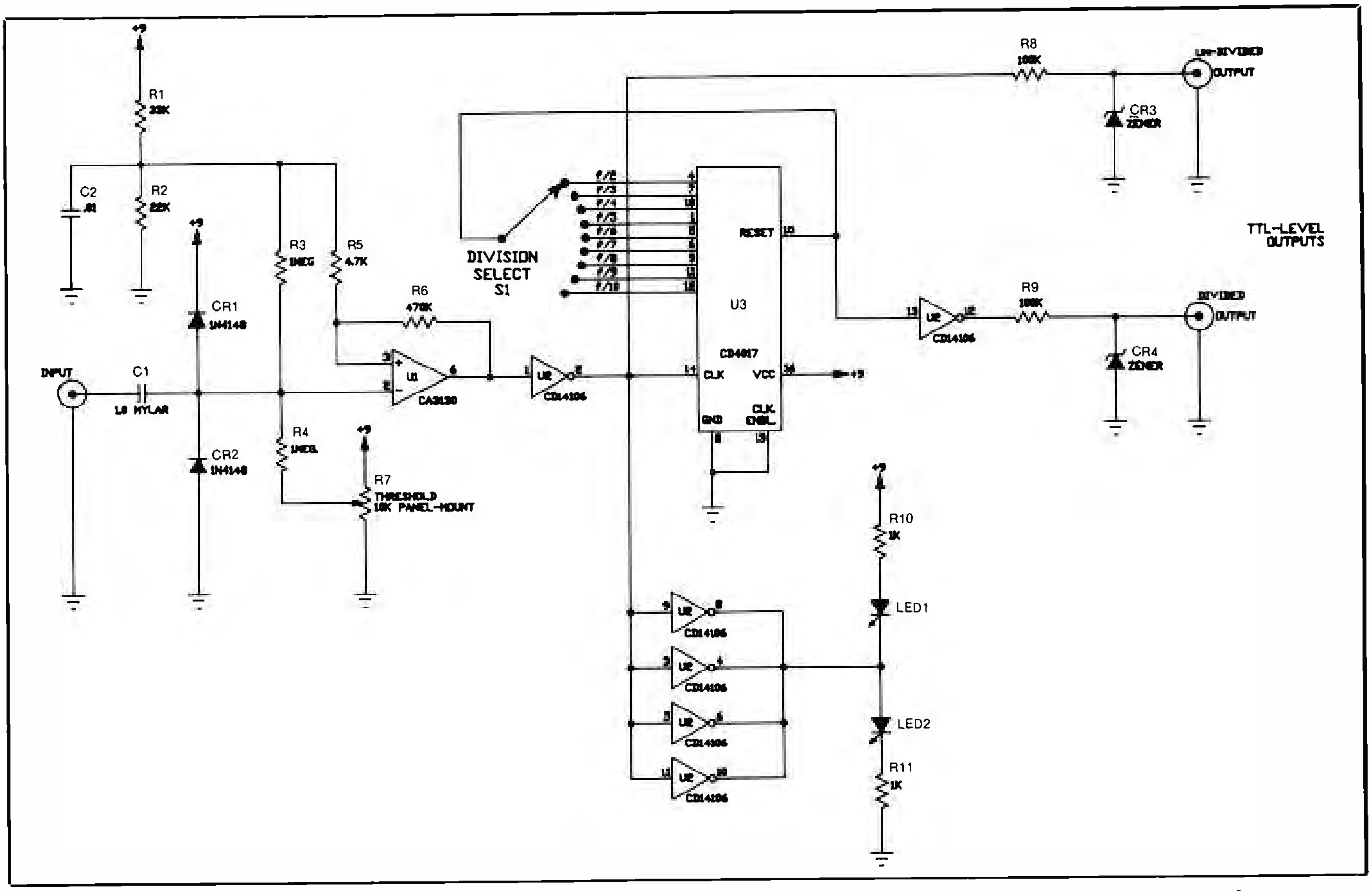


Fig. 3. An optional input signal-conditioner/frequency-divider circuit that can be used to increase the performance of the basic F/V converter.

U1 to provide a glitch-free square wave to the clock input of *U3*. Secondly, three inverters are connected in parallel to provide sufficient drive current to drive "signal present" light-emitting diodes *LED1* and *LED2*, which give a visual indication of the triggering action of *U1*. (Proper triggering is indicated when both LEDs are flashing or appear to be continuously on.) Finally, the last inverter changes the polarity of the low duty-cycle pulses from *U3* into the higher duty-cycle waveform required by the converter accessory.

Ideally, the Fig. 3 circuit should also be powered from a 9-volt battery. The only consideration here is that the final output must remain at a constant TTL level (switch between 0 and 5 volts) to insure compatibility with a wide array of test equipment. This is most easily accomplished with the zener diodes that immediately precede both outputs.

PARTS LIST (conditioner/divider)

Semiconductors
CR1,CR2—1N4148 switching diode
CR3,CR4—4.7-volt, 1-watt zener diode
LED1,LED2—Light-emitting diode (one red, one green)
U1—CA3130 high-speed comparator
U2—CD4106 hex inverter/buffer
U3—CD4017 decade counter/divider with selectable outputs

Capacitors
C1—0.01-μF disc
C2—1.0-μF Mylar

Resistors (¼-watt, 5% tolerance)
R1—33,000 ohms
R2—22,000 ohms
R3,R4—1 megohm
R5—4,700 ohms
R6—470,000 ohms
R8,R9—1,000 ohms
R10,R11—100,000 ohms
R7—10,000-ohm linear-taper, panel-mount potentiometer

Miscellaneous
S1—10-position, nonshorting rotary switch
Printed-circuit board; suitable enclosure (see text); sockets for ICs; three chassis-mount female BNC connectors; small-diameter coaxial cable; machine hardware; hookup wire; solder; etc.

Construction

Though it is possible to assemble the basic converter using just about any traditional wiring technique, use of a printed-circuit board is highly recommended to ensure operating stability and minimize noise. Fabricate

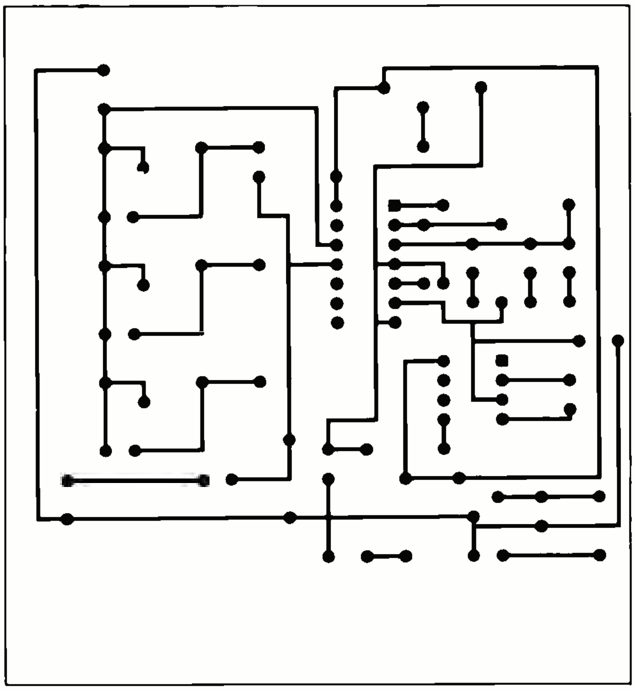


Fig. 4. Actual-size etching-and-drilling guide for F/V converter circuit.

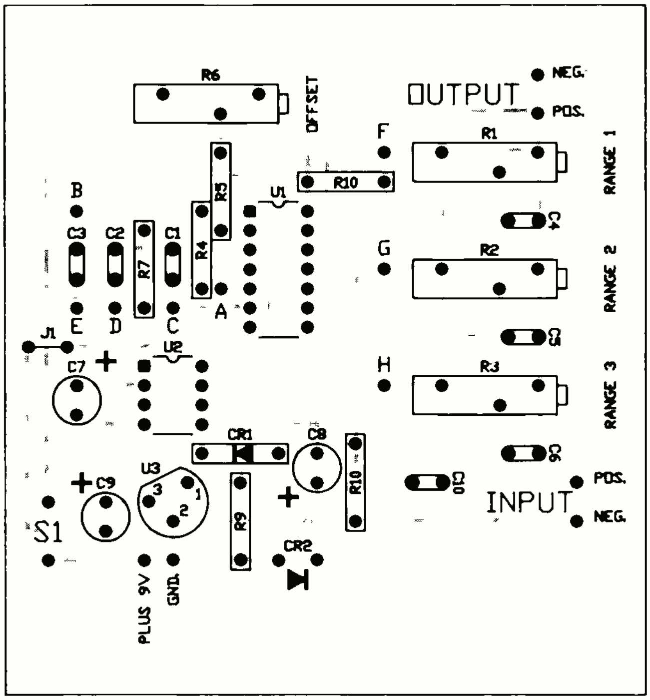


Fig. 5. Wiring guide for F/V converter pc board.

a pc board using the actual-size etching-and-drilling guide shown in Fig. 4.

After etching, drilling and trimming to size the board, wire it exactly as shown in Fig. 5. Begin populating the board by installing and soldering into place the DIP sockets for *U1* and *U2*. If you wish, you can also use a transistor socket for *U3*, though it would probably be easier and better to simply plug the leads of this IC into the U3 holes in the board, solder them to the copper pads and trim off excess length.

Continue populating the board by installing and soldering into place first the resistors and 15-turn trimmer potentiometers. Then proceed with the capacitors and diode. Make sure *C7, C8* and *C9* are properly polarized and *CR1* is properly oriented before soldering their leads to the copper pads.

Install *U2* in its socket (make sure no pins overhang the socket or fold under between IC and socket) and either install *U3* directly on the board or trim its leads to about ½″ in length and plug them into the transistor socket. Do *not* install *U1* in its socket at this time.

Install and solder into place a short wire jumper in the location indicated by *J1* in Fig. 5. Use either a cut-off resistor or capacitor lead or a bare solid hookup wire.

Now prepare 12 5″ lengths of stranded hookup wire by removing about ¼″ of insulation from both ends. Tightly twist together the fine wires at both ends of all wires and sparingly tin with solder. Plug one end of these wires into the POS and NEG OUTPUT and S1 holes (four wires) and solder them to the pads on the bottom of the board. Similarly, plug the remaining eight wires into the holes labeled A through H and solder them into place.

Trim ¾″ of outer insulation from both ends of a 5″ length of small-diameter shielded cable. Separate or peel the shield back to the insulation at both ends. Then trim ¼″ of insulation from the inner conductor at both ends. Tightly twist together the fine wires of the inner conductor and lightly tin with solder. If your cable has a wire-mesh shield, do the same for the fine wires that make it up. Plug the inner conductor and shield at one end of the cable into the holes labeled INPUT POS and NEG, respectively, and solder them into place. When you are finished, there should be two holes, labeled PLUS 9V and the GND near it that are unoccupied.

If you decide to incorporate the optional Fig. 3 conditioner/divider circuit in your project, assemble it now. As with the F/V converter assembly, the recommended wiring medium for the Fig. 3 circuit is a printed-circuit board, the actual-size etching-and-drilling guide (the same size as that for the basic converter assembly) for which is shown in Fig. 6. Once you have fabricated the board, refer to Fig. 7 and mount the three DIP IC sockets—*not* the ICs themselves—in the indicated locations. Then install the two switching and two zener diodes in their respective locations, taking care to properly

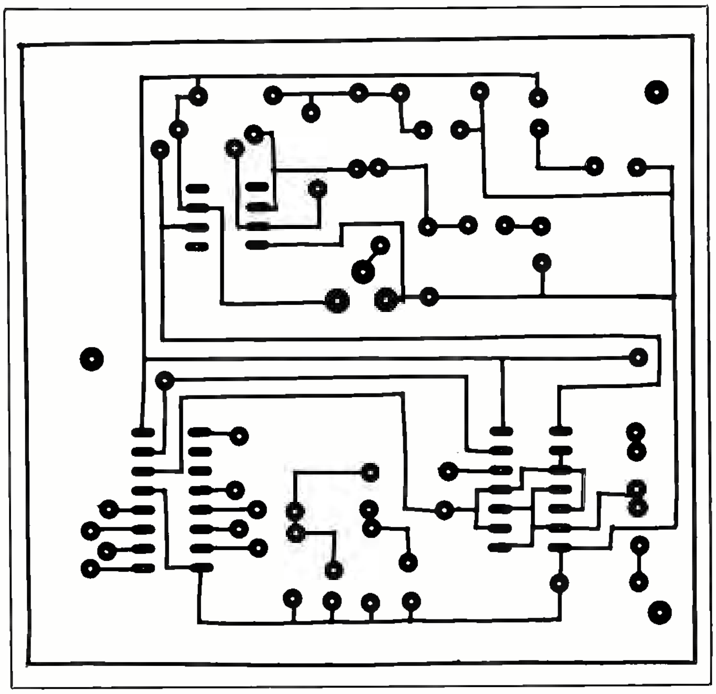


Fig. 6. Actual-size etching-and-drilling guide for conditioner/ divider circuit.

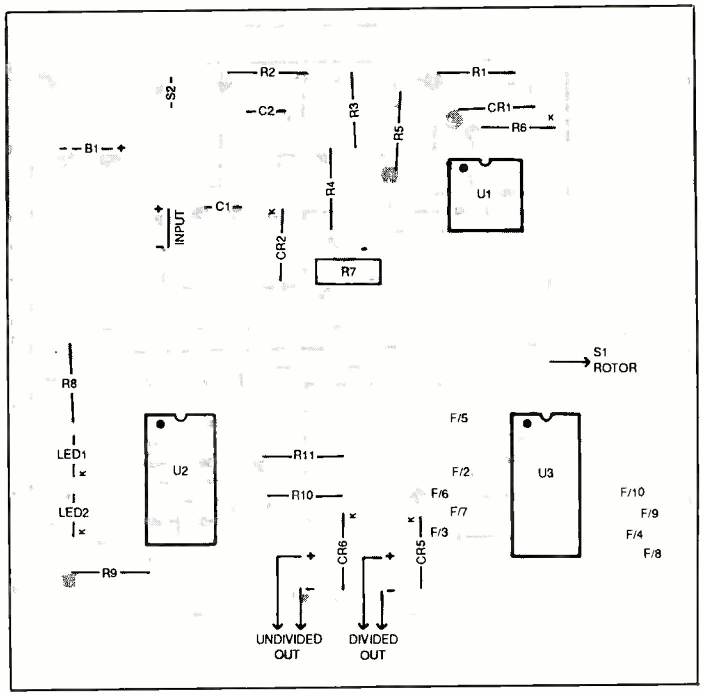


Fig. 7. Wiring diagram for conditioner/divider board.

orient them before soldering their leads to the copper pads. This done, install and solder into place the capacitors and fixed resistors.

Trim to about 5" length 17 hookup wires and strip from both ends ¼" of insulation. Install and solder into place one end of each of these wires in the holes labeled F/2 through F10, S1 ROTOR, R7 and LED1. Then prepare three 5" lengths of small-diameter coaxial cable as described above for the converter assembly. Plug one end of one of these cables into the board holes labeled INPUT with the center conductor in the + and shield in the GND holes and solder into place. Repeat with the other two cables for the UN-DIV and DIV and their nearby GND holes.

Note that the Parts List that accompanies Fig. 1 calls for a PacTec project box to serve as the enclosure for the basic converter accessory. This type of box was selected for the prototype because it has a battery compartment that is large enough to accommodate a 9-volt battery. The compartment has its own separate slide-off cover that eliminates having to remove screws to open the box whenever the battery has to be replaced. If you prefer, you can substitute any other box that is large enough to accommodate the circuit-board assembly and battery in its holder and has enough panel room on which to mount the power and range selector switches, BNC INPUT jack and OUTPUT banana jacks without interference.

If you are planning to build the optional signal-conditioner/divider assembly into the same enclosure with the basic F/V converter, plan on using a larger box. Though the two circuit-board assemblies are the same size and can be stacked to obtain a compact project, the extra switches, panel-mount potentiometer and two LEDs, along with their legends, will require much more layout area on the panel.

When building just the basic F/V converter, it is a good idea to mount the BNC INPUT connector at the top of the box, as shown in the lead photo. You can then mount the rotary RANGE switch on the front panel with the OUTPUT banana jacks spaced well away from it. Machine the enclosure as necessary to facilitate circuit-board assembly and component mounting.

Start final assembly by twisting together the fine wires of each of the battery snap's conductors and lightly tin with solder. Now, assuming you are using the specified PacTec box, feed the free ends of the battery snap connector's conductors through the slot in the battery compartment and plug them into the two unoccupied component holes in the converter board, red to the PLUS 9V hole and black to the GND hole. Solder both connections securely into place.

If you choose a different type of enclosure, one that does not have a separate battery compartment, mount the battery in a clip inside the enclosure proper. (In this event, you might want to substitute a nickel-cadmium battery in place of the stan-

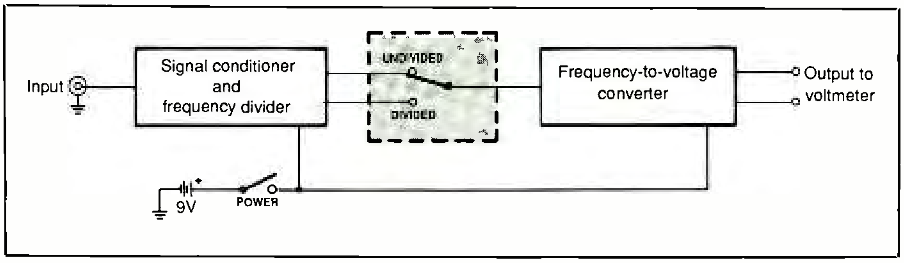


Fig. 8. Switching arrangement permits internal selection of divided or un-divided signal to be fed from output of conditioner/divider into input of F/V converter and eliminates three BNC connectors.

dard non-rechargeable 9-volt transistor battery and incorporate into the project a simple recharging circuit. If you go this route, be sure to include a jack into which the recharging source can plug.)

Once the circuit-board assembly is mounted, mount the BNC connector, banana jacks and the rotary and toggle or slide switches in their respective holes. Make the nut on the switch only finger tight. Place a knob on the shaft of the rotary switch and rotate it through each of its three positions and note where the knob's pointer is aimed for each position. If necessary, readjust the orientation of the switch so that the knob's pointer stops at locations as shown in the lead photo. Securely tighten the nut, without allowing the switch to move as you do so.

Connect and solder the center conductor at the free end of the coaxial cable to the center contact of the BNC connector. Then connect and solder the shield to the connector's ground lug. Next, connect and solder the free end of OUTPUT POS wire to the red banana jack and the OUTPUT NEG wire to the black banana jack. Finally, connect and solder the free ends of the remaining wires to the rotary switch, ıeferring back to Figs.-1 and 5 for details.

Snap a 9-volt battery into its connector and set the POWER switch to ON. Use a meter to measure the voltages at the pins of *U1*'s socket. With the meter's common lead connected to circuit ground (pin 6 of *U1*), you should obtain the following readings: + 5 volts at pin 14 and − 5 volts at pins 1, 4, 7 and 11. If everything checks out this far, set the POWER switch to off. Plug *U1* into its socket (observe orientation), making sure that no pins overhang the socket or fold under between IC and socket.

After assembling the project, label its connectors, range switch and power switch with appropriate legends. The lead photo gives one suggested way of arranging the legends for the basic F/V converter accessory.

Assuming you have decided to build the optional signal-conditioner/frequency-divider circuit shown in Fig. 3 proceed as follows. First prepare a printed-circuit board on which to mount its components, using the actual-size etching-and-drilling guide shown in Fig. 6. When the board is ready, mount DIP sockets in the U1, U2 and U3 locations shown in the Fig. 7 wiring diagram. Do *not* install the ICs themselves in the sockets at this time.

Plug into the appropriate holes and solder into place the leads of the fixed resistors and the two capacitors. Then do the same for the switching and zener diodes, making sure to properly orient them before soldering their leads into place.

Now strip ¼ ″ of insulation from both ends of 17 5 ″ lengths of hookup wire. Plug one end of 10 of these wires into the holes labeled S1 ROTOR and F/2 through F/10 and solder into place. Plug one end of three more wires into the holes labeled R7 and solder them into place. Do the same with four more wires and the holes labeled LED1 and LED2.

Prepare both ends of three 5 ″ lengths of small-diameter coaxial cables by removing ¾ ″ of outer insulation, peeling or separating the shields back to the insulation cut-off points and stripping ¼ ″ of insulation from the inner conductors. Tightly twist together the fine wires of the inner conductors (and the shield wires if they are mesh) and sparingly tin with solder. Then plug one end of one of these cables into the holes labeled INPUT + (inner conductor) and nearby GND (shield). Repeat with the remaining two cables and the UN-DIVIDED + and DIVIDED + OUTPUT holes and their nearby ground holes.

Tightly twist together the fine wires at the free ends of the battery snap connector and sparingly tin with solder. Plug the free ends of the wires into the holes labeled B1 + (red-insulated wire) and B1 − (black-insulated wire) and solder them into place. This assumes you plan to power the optional conditioner/divider from a separate 9-volt battery. If you plan to use the same battery that powers the basic F/V converter, use hookup wires to bridge from the B1 + and B1 − pads on the optional board to the converter board.

Having wired the conditioner/divider circuit board, you are ready to mount it inside its enclosure. For the stand-alone version, use an enclosure that is large enough to accommodate the circuit-board assembly and a 9-volt battery clip without crowding and has enough panel space for the POWER and DIVISION SELECT switches, two LEDs, THRESHOLD control and whatever INPUT and OUTPUT connectors you decide to use. All connectors should be female BNC types, and all switches, if possible, should be miniature types to conserve space so that the project can be made as compact as possible.

Machine the box as needed and then mount the circuit board assembly. Mount the switches, LEDs and connectors in their respective locations. When you plan your layout, make sure the rotary switches in both modules do not interfere with each other. Also, if you are using a separate 9-volt transistor (or rechargeable Ni-Cd) battery for each circuit board, it is more convenient to use a dpdt slide or toggle switch to power up and down both circuits simultaneously, rather than separate spst switches for each.

Make the DIVISION SELECT switch only finger tight. Place a knob on the shaft of this switch. Rotate the knob and note where the pointer stops for each position. If necessary, adjust the orientation of the switch for balanced positioning and then tighten the mounting nut.

Referring to Figs. 3 and 8, wire the free ends of the S1 ROTOR and F/2 through F/10 wires to the appropriate switch lugs. Next, connect and solder the free ends of the S2 wires to the POWER switch. Then, taking care to observe proper polarity, wire the LEDs into the circuit, using the free ends of the appropriate wires on the board to make the connections. Finally, connect and solder the free ends of the three coaxial cables to the INPUT and OUTPUT BNC connectors, center conductors to center contacts and shields to ground lugs.

You can simplify operation of the combined instrument with an UN-DIVIDED/DIVIDED switch that replaces the OUTPUT BNC connectors indicated in Fig. 3 to let you select only signal conditioning (UN-DIVIDED) or both conditioning and division (DIVIDED). Wire this switch as shown in Fig. 8. The original INPUT BNC connector now becomes the INPUT connector for the conditioner/divider module and, thus, the entire accessory. Making this modification eliminates three BNC connectors. It also saves your the task of having to plug and unplug cables to bridge modules and select different outputs.

Another modification you might wish to incorporate, illustrated in Fig. 9, makes it possible to use the signal conditioner/frequency divider as a stand-alone unit to condition (and divide) waveforms that might not otherwise reliably trigger a logic probe or other digital instrument. In this case, you should use separate battery supplies and POWER switches for each subassembly and install a female BNC connector after the UN-DIVIDED/DIVIDED switch just discussed followed by a second switch that allows you to route the output of the conditioner/divider to either the new BNC connector or the input of the F/V converter.

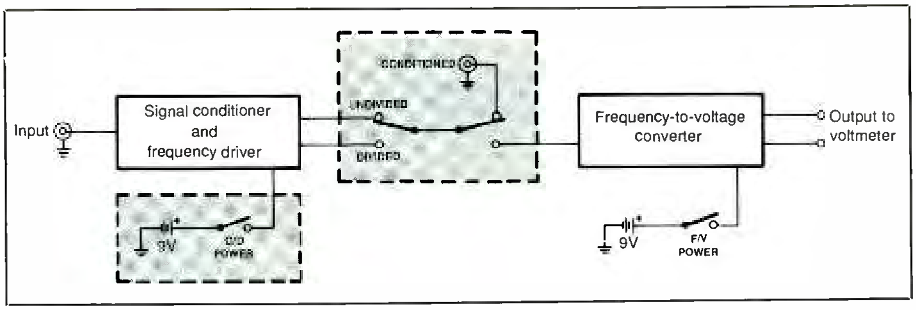


Fig. 9. By adding yet another switch and separate switched battery supply, you can choose between signal conditioning/frequency division and F/V conversion or just conditioning/division for other instruments.

When you want to use only the conditioner/divider, you set the just installed CONDITION/COUNT switch to CONDITION, select either the UN-DIVIDED or UNDIVIDED function with the previous switch, and flip on only the conditioner/divider's POWER switch. Now you simply connect the signal source to the INPUT con-

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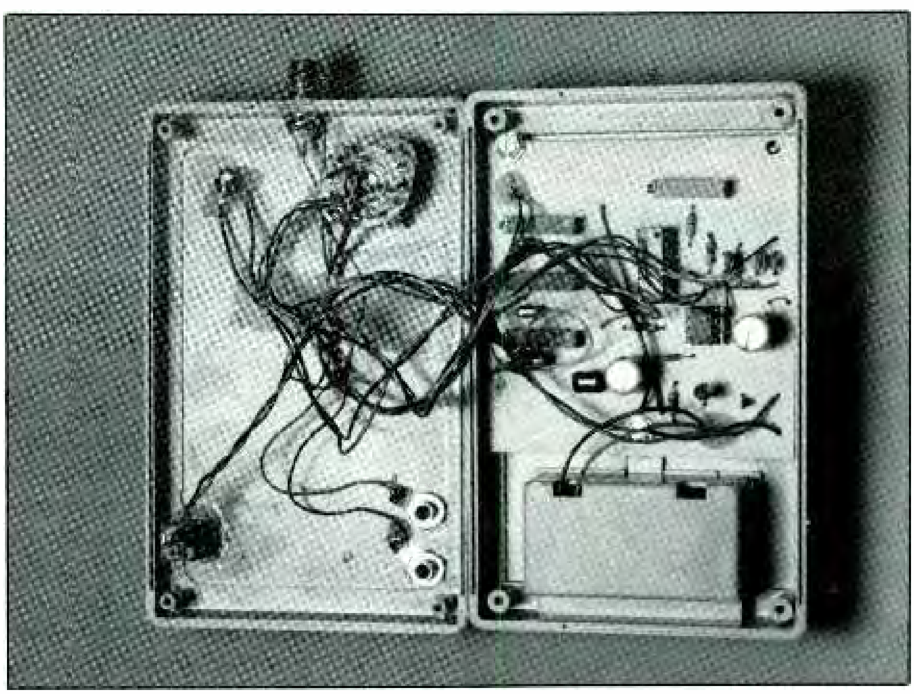
Interior view of assembled basic converter project inside PacTec box that has separate outside-access battery compartment.

nector and whatever instrument you are using it with to the newly installed CONDITIONED BNC connector. If you selected DIVIDED, you also have to set the DIVISION SELECT switch to the appropriate position.

With the ICs still not plugged into the sockets on the conditioner/divider board, set the POWER switch to on (if you are using a separate battery to power this board, snap one into its connector before turning on the power.) Connect a dc voltmeter's common lead to the ground lug of one of the BNC connectors. Then measure the voltage at pin 7 of *U1*, pin 14 of *U2* and pin 16 of *U3*. The measured potential in all three cases should be +9 volts.

Calibration

Due to the 9400CJ's linear/proportional operation, its output voltage can be read directly without postscaling. This means that an input frequency of 1,345 Hz will be displayed on a voltmeter as 1.345 volts, providing that the F/V converter is set to the appropriate range. To perform calibration, you need an accurate frequency source of 500 Hz, 5 kHz and 50 kHz—the center points for the basic converter's three ranges.

Before calibrating the F/V converter, you must adjust the offset null. To do this, power up the instrument with your DMM (set to read low dc volts) across the OUTPUT terminals in the proper polarity and measure the output voltage with nothing connected to the INPUT. Slowly adjust *R6* until the output voltage reads as near to zero as possible. This done, connect a function generator to the INPUT jack and begin calibrating each of the three ranges as follows:

To calibrate RANGE 1 (1 Hz to 1 kHz full-scale), you can use a 6-volt rms power transformer directly at the converter's INPUT BNC connector. Adjust *R1* for an indicated output of 0.6 volt, which, in this case, corresponds directly to 60 Hz.

Calibration of RANGE 2 (10 Hz to

10 kHz full-scale) and RANGE 3 (100 Hz to 100 kHz full-scale) is identical except for a change in input signal frequency. Set the switch to RANGE 2 and inject a 5-kHz signal into the INPUT connector and adjust *R2* for an indicated 0.5 volt. This done, switch to RANGE 3, inject a 50-kHz signal into the INPUT and adjust *R3* for an indicated 0.5 volt. This completes calibration of the F/V module. The conditioner/divider module needs no calibration.

Your DMM can now double as an accurate portable frequency counter that can be used in audio through ultrasonic work and, with the optional conditioner/divider, can even be used in low-frequency r-f work. Though the converter/DMM combination is not truly a "counter," its accuracy and linearity rivals the real thing. ME