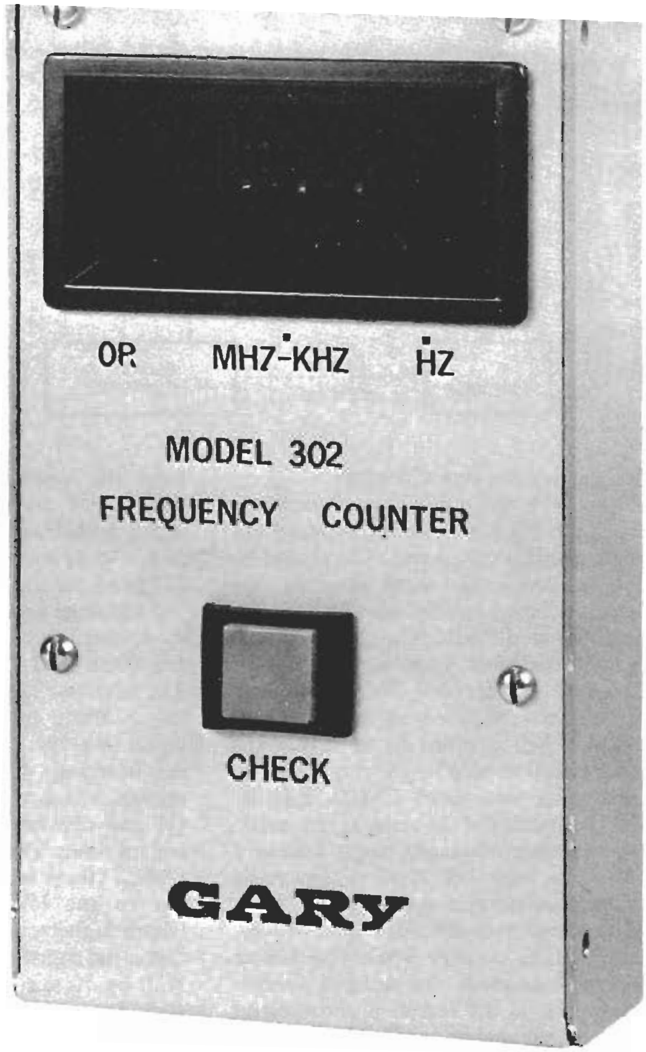
BUILD

Portable 30-MHz Frequency Counter



You can hold it in the palm of your hand. Yet it reads to 28-Mhz and better, has a 70-mV sensitivity and a 4-digit readout that delivers 6-digit resolution.

GARY McCLELLAN

HOW WOULD YOU LIKE TO HAVE A frequency counter that measures frequencies to 30 MHz, and is small enough to fit in your coat pocket! Sure you would, and for good reason; counters are becoming more popular every day.

Our pocket counter may be small, but it has grown-up features. The maximum frequency it will measure is 23 MHz typical, with 70-mV sensitivity. However, you can go as high as 30 MHz with 90-mV sensitivity. The input impedance is the standard 1 megohm, meaning you can use scope probes on this counter for easier circuit checking. Oh yes, overloads can happen and this counter is protected from most of them. It will take 120 volts AC right from the wall outlet without harm! The unit is powered by four rechargeable NiCad batteries, and since the current drain is low, they will last a long time. The batteries also help make this counter portable, like a calculator.

The heart of any counter is its timebase, and this one has a crystal-controlled timebase, just like the big counters. We use a color TV burst crystal (3.58 MHz) in our unit and this gives good accuracy. You can normally expect better than ± 0.005% accuracy with ± 0.003% typical, depending upon the frequency being measured. Like other counters, the higher the frequency you measure, the better the accuracy. The display is all LED—4 digits of 0.112-inch-high display. Don't let that display fool you either! With just a flip of the three-position range switch you can get up to two digits more, for a total of six digits with the power consumption of four digits! Quite a counter!

The pocket counter is easy to build. It has nine IC's, most of which are CMOS and the rest are low-power Schottky. So all of a sudden the counter is easier to build and the power drain is reduced to about a half watt. You should be able to build this project in about three evenings or less. A PC board makes the job easy. And all parts mount on this board, except for a few switches, jacks and the battery that must go on the case. Special arrangements have been made to bring you a low-cost kit to make the construction task easier. Or, if you prefer, the PC layouts are shown so you can roll your own. Nearly all of the parts are available through mail order houses, and the few harder to get parts are available either from the author or from several suppliers mentioned later on.

How it works

The counter uses the classic "window counting" technique that is the basis for almost all frequency counters in use today. Figure 1 is a block diagram of a counter based on this technique. This basic counter has four sections; input amplifier, gate, timebase and decade counter/display section. Here's how it works. Input signals are squared up by the input amplifier and are applied to the gate section. It is necessary to square up the input signals because digital circuitry does not respond too well to analog-type signals such as sinewaves. The *timebase* circuit puts out three synchronized signals in this order: gate-enable, data transfer (latch) and reset. The gate-enable signal is applied to the gate section, causing the signal from the input amplifier to pass through it. This is called the *window*, and the time the gate allows the input signal to pass through is precisely determined.

The gated signal is then counted up by a string of of decade counters, wired in series. Usually, there are at least 4 decades total, with 6 decades being typical. The signals from these counters are then applied to a display latch that transfers the output from the counters to the displays upon command from the transfer line from the timebase. This reading is frozen at the displays while the decade counters are reset to zero and the count sequence is repeated. The latches are very important, because without them you would see the decade counters count up, stop briefly at the correct count, then reset to zero and repeat. This is the basic frequency counter, and there are few

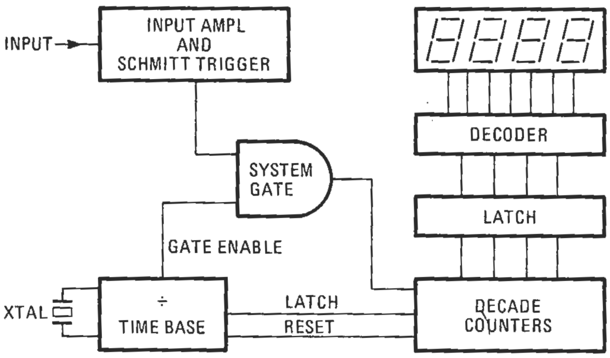


FIG. 1—BLOCK DIAGRAM shows the four sections of the basic counter: input amplifier, gate, timebase, and decade counter display.

designs that are very different.

Now let's take a look at our counter. It is just like the basic counter. Figure 2 is a block diagram of the unit. You should be able to identify the input amplifier, the counter/display and the timebase, but the gate will be difficult. The gate section is part of the input amplifier and will be discussed further on. There are some divider sections following the input amplifier. Their purpose is to divide the input signal so that it will run the counter/display section. A CMOS LSI IC (IC5) handles the counting at this point. Its maximum frequency range is about 2 MHz, so with the dividers (normally called *prescalers*) it is easy for a 2-MHz IC to count over 20 MHz. By the way, that CMOS counter saves you twelve TTL IC's or about 184 soldered connections! This is the secret of a successful counter that anyone can build.

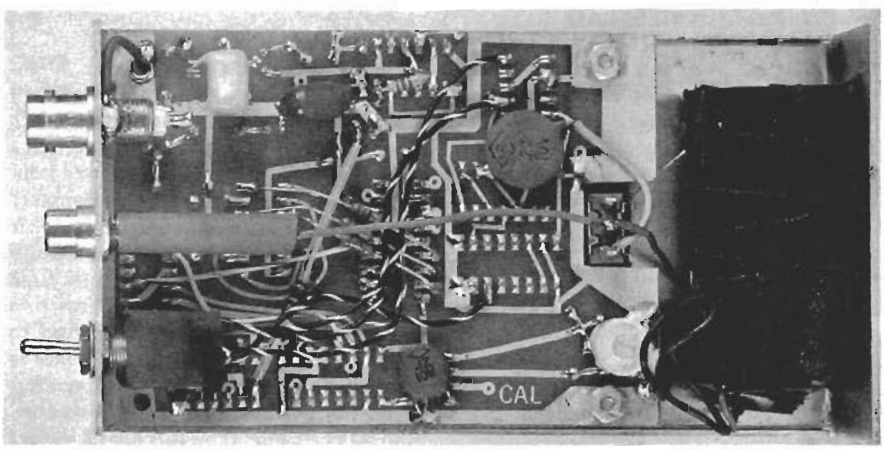
Operation of our counter is just like the window counting method first described. The only difference is the frequency dividers that scale down the input frequency for the CMOS counter/display IC. Normally you don't find them in other counters; instead you change the the timebase frequency by tapping off dividers there to get the different ranges. Our counter provides Hz, kHz and MHz ranges just like the big counters, but with fewer parts and low power drain.

The circuit

Now let's dig deeper into the circuitry. Checking the schematic (Fig. 3) you'll find that the input signal appears at Q1, a FET source follower. Diodes D1 and D2 form the overload protection network. The signal passes from the follower, which is there to give a high-Z input, to IC1, a quad NAND gate. The first section is biased for amplifier operation by R4 and the stage provides about 10× gain or so. Surprisingly, TTL gates make stable amplifiers. Not hi-fi but fine for counters. The next two stages (gates, really) act as the Schmitt trigger, squaring up the signal to proper TTL levels. Resistor R6 sets hysteresis or trigger point. The final section, IC1-d, is the gate, with transistor Q7 and resistor R19 controlling its on and off times. These two parts convert the CMOS (think low current) timebase output to the low-power Schottky TTL (think higher current) gate input. From there, the signal is divided down by 10 in IC2, by 10 again in IC3 and by 100 in IC4. Low-power Schottky 74LS90's in the first two spots insure high-frequency operation and low power drain. A typical 74LS90 will go to 35–40 MHz and draw about 5 mA.

Compare that to a standard 7490 that goes to 20–25 MHz and draws 25 mA! Switch S1 is the RANGE switch. It selects the proper range by switching different places in the divider network. From there, the selected signal goes to IC5, a National Semiconductor MM74C926 counter array that counts the signal, latches it and drives an LED display. This IC houses 4 decade counters, 4 latches, a display driver and multiplex logic.

Now let's take a look at the rest of the counter. The timebase consists of IC6, IC7-a, IC8-a and IC9. A color-TV crystal, XTAL1, generates the reference frequency, with IC6 providing the associated oscillator and counting down to 60 Hz. This signal drives IC7, a divide-by-60 counter, to get the necessary 1-second timebase. IC7 also provides part of the reset and latch signals as well. The 1-Hz output drives IC8, which converts it into a 1-second-on and 1-second-off pulse for the gate section. Finally, the IC9 gates create the reset and latch (or transfer) pulses necessary for proper operation of the counter. Sections IC7-b and IC8-b are wired to form an overrange indicator—that's the circuitry you see wired to LED1. IC7-b acts as an inverter, causing the SR flip-flop of IC8-b to energize on negative edge of the waveform that ap-



INSIDE VIEW OF BASIC COUNTER shows just how easy a construction job it is. Most components go right on the circuit board.

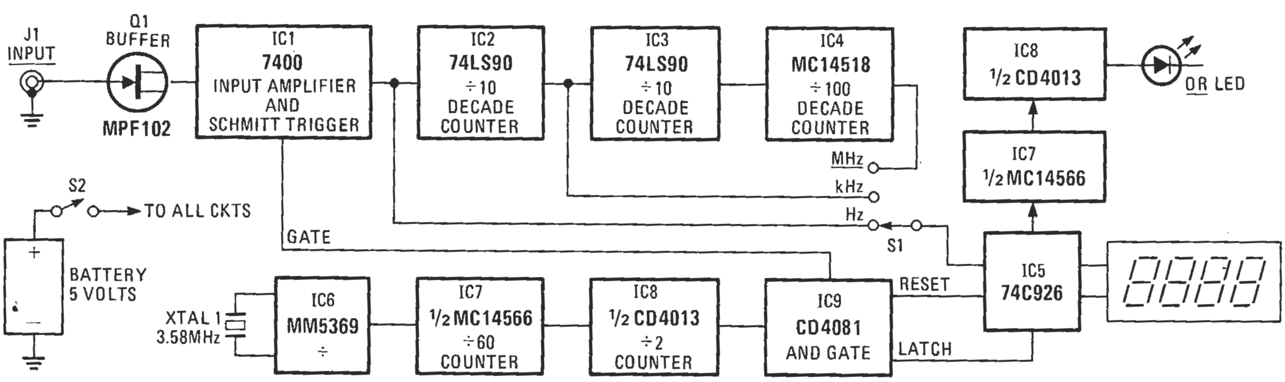


FIG. 2—BLOCK DIAGRAM OF THE COUNTER described in this article. The gate section is different than that shown in Fig. 1 and there are some additional divider stages.

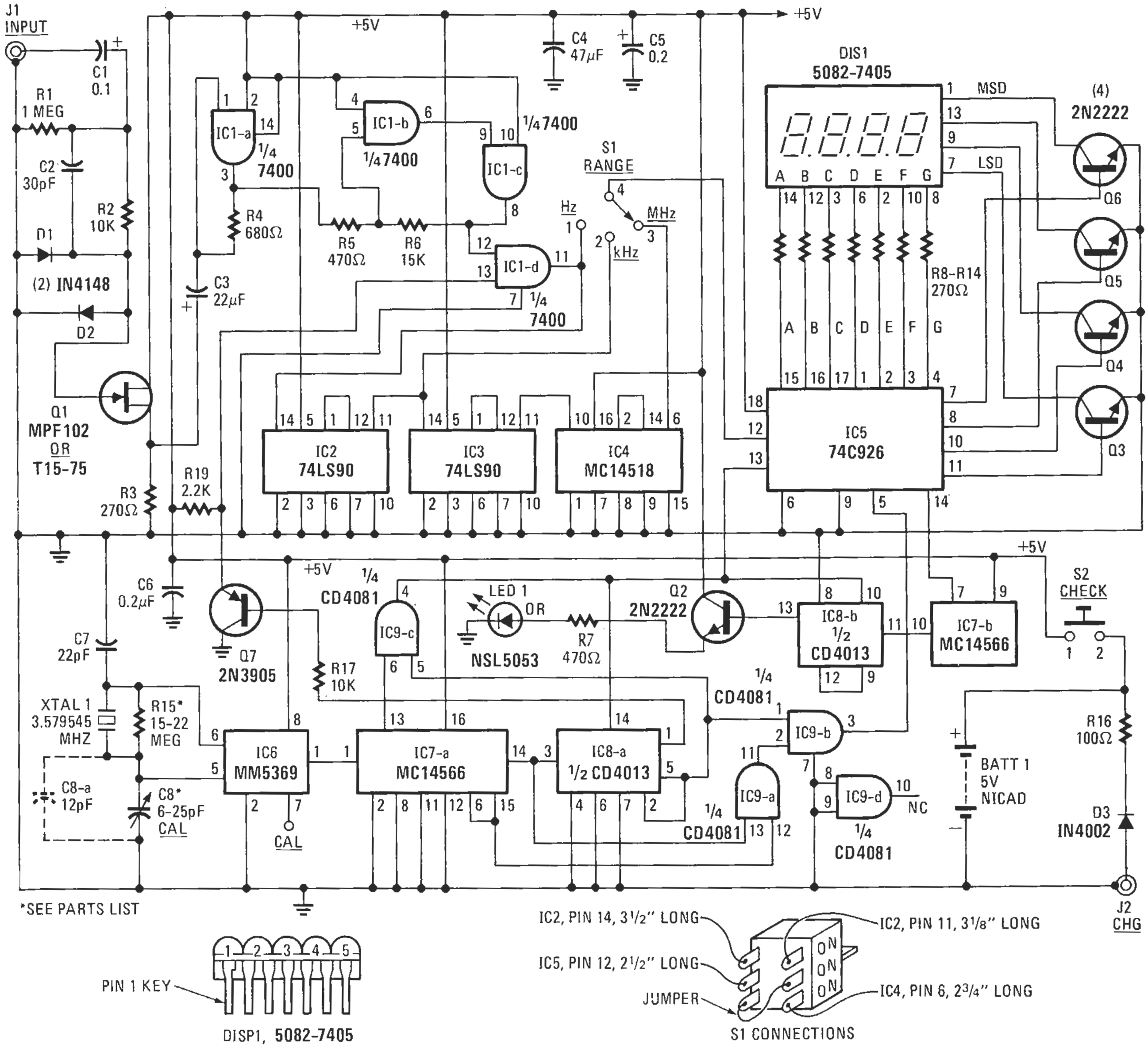


FIG. 3—FULL SCHEMATIC OF THE COUNTER makes it easy to follow the circuit description. Resistor R18 (10K) was inadvertently omitted. It connects between Q2's base and pin 13 of IC8-b.

All resistors ¼-watt carbon film type unless noted.

R1—1 megohm
R2, R17, R18—10,000-ohm resistors
R3, R8-R14—270-ohm resistors
R4—680 ohms
R5, R7—470 ohms
R6—15,000 ohms
R15—15 to 22 megohms
R16—100 ohms, ½ watt
R19—2200 ohms
C1—0.1 µF, 200-volt tubular
C2—30 pF disc
C3—22 µF, 6-volt tantalum
C4—47 µF, 6-volt tantalum
C5, C6—0.2 µF, 10-volt disc (0.1 µF OK)
C7—22 pF mica
C8—either a 6-25-pF trimmer or a 6-18-pF trimmer plus 12-pF mica cap (C8-a)
D1, D2—1N4148
D3—1N4002
DIS1—5082-7405 display (Hewlett-Packard). Poly Paks 92CU3199
LED1—NSL5053 LED National or similar
Q1—MPF102 FET
Q2-Q6—2N2222 transistors
Q7-2N3905 PNP transistor or similar
IC1—SN7400 IC, Active Electronics
IC2, IC3—SN74LS90 IC, Active Electr.
IC4—MC14518P CMOS IC dual BCD up-counter
IC5—MM74C926N CMOS IC (National) Tri-Tek or Liberty Electronics
IC6—MM5369N CMOS IC (National)
IC7—MC14566CP CMOS IC timebase generator (Motorola) or HEP C4055P
IC8—CD4013 CMOS IC
IC9—CD4081 CMOS IC
J1—BNC female coax connector
J2—RCA phono socket
S1—single-pole, 3-position toggle switch, C&K 7211 (Poly Paks 92CU3016)
S2—SPST, normally open pushbutton switch, C&K 8121-J81-3-2 or similar
BATT1—5-volt NiCad battery pack; 4-size AA cells in holder
XTAL1—3.579545-MHz color TV crystal
Misc.—LMB CR531 case, model 302 PC board, display bezel, 12-volt wall plug transformer with RCA plug (battery charger), ⅜-in. threaded spacers, etc.

***Note:* A kit of all above parts is available from Gary McClellan and Co., Box 2085, 1001 West Imperial Hwy., La Habra, CA 90631. Complete kit of all parts and *unpunched* case, $39.95 postpaid. California residents add state and local taxes as applicable. PC board only, $5.95 postpaid. Write for prices on other parts.**

ADDRESSES OF SUPPLIERS LISTED

Poly Paks	PO Box 942 South Lynnfield, MA 01940
Optoelectronics	PO Box 219 Hollywood, FL 33022
Tri-Tek Electronics	6522 North 43rd Ave. Glendale, AZ 85301
Liberty Electronics (Indust. Dist'r)	124 Maryland St. El Segundo, CA 90245
Active Electronics	PO Box 1035 Framingham, MA 01701

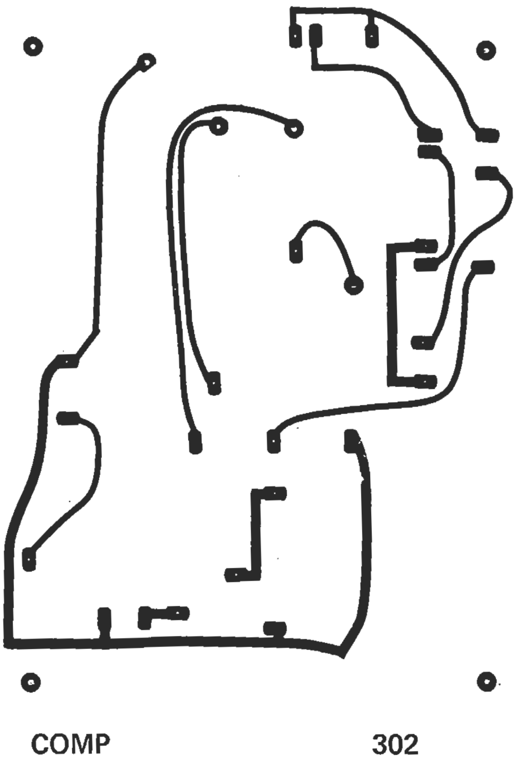


FIG. 4—FULL-SIZE FOIL PATTERN of one side of the 2-sided circuit board. Used with Fig. 5 you can make your own circuit board.

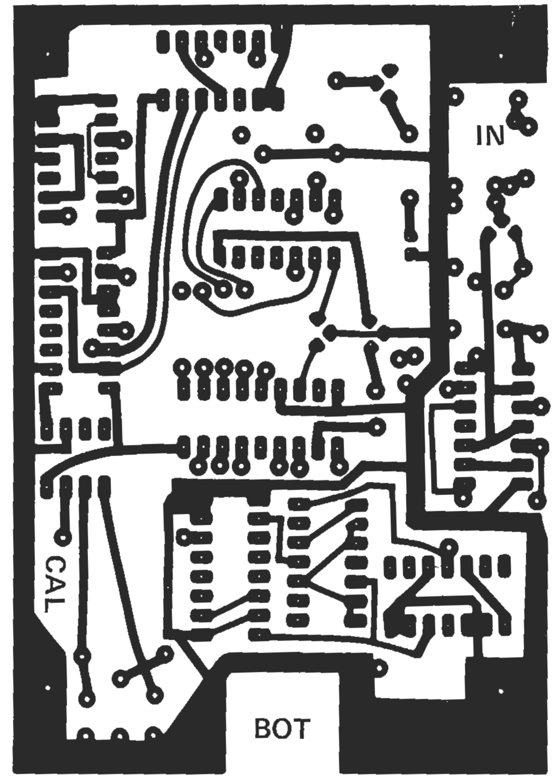


FIG. 5—THE OTHER SIDE OF THE CIRCUIT BOARD. This full-size pattern used with the one on Fig. 4 can be used to make your own circuit board for this instrument.

pears at the overrange output (pin 14) of IC5.

Now that you know how it works, let's get started on the construction!

Put one together

Construction of this counter is pretty easy if you take your time. Also, use of a PC board is strongly recommended. If you wish, you can duplicate one from the patterns in Figs. 4 and 5, or buy one from the author.

The first step is to locate the parts. Sources are given in the parts list for the tougher ones to help you get the components without a lot of problems. Write the sources for more information and prices if you desire. One thing that's important here: *you must use quality parts. That means NO JUNK! Cheap reject "retested" type parts will cause you more problems than you can believe when it's time to check out this counter!* A word to the wise is sufficient.

Start construction by stuffing the PC board. It contains nearly all of the parts, and when you finish stuffing, you can test it prior to putting it into the case.

Study Figs. 6 and 7 before you start. Probably the best way to begin is to install the diodes, D1 and D2. Place the board in the position shown with the side saying "COMP" in the corner face up. Install the two diodes as shown and solder. The next step is to install the transistors. This will require a little extra care, as the holes do not exactly match the leads coming out of the transistors. That means you will have to bend a lead on most of the transistors—an easy task. Install FET Q1 first. Notice how the flat side faces. Next, add the PNP transistor, Q7. This one plugs directly into the three holes with no bending. The same is true of Q2. It mounts near the top of the board. Finish up by installing the four transistors near the center of the board. Bend the emitter lead on two transistors so that it goes between the base and collector leads, then place each transistor in the Q4 and Q5 spots on the board. The emitter leads go to the foil bus on the other side of the board, the collector leads point toward the *center* of the board and the base leads point toward the top *edge* of the board. Transistors Q3 and Q6 are installed last. They go in place without bending. The base leads face the exact center of the board, and the collectors face the top edge. So much for the transistors.

The next step is to install the display. Do LED1 first, noting that the flat spot faces the center of the board. You can substitute almost any LED here, so don't feel stuck with the one specified. Then add DIS1. This is a rather tricky part, and there should be a dot showing pin 1 on the reverse side. If not, you may have to try it and reverse it later if you get strange readings. To make life easier *all readouts supplied with the kit* have an unused pin (pin 4) cut and you simply orient the readout as shown. *(If you use the Hewlett-Packard display specified, pin 1 is notched as shown on the inset in Fig. 3.—Editor)*

Next, you can install the resistors. Stick them in as shown. Leave about $1/8$ inch on the 22-megohm resistor leads because the crystal will mount on them. Oh yes, this resistor is part of a $5.95 kit offered by Optoelectronics and others. It is called a "clock timebase" kit and features many other parts you will be using. Keep the rest of the leads short.

Continue with the capacitors. Since only four mount on the component side, no comment is necessary! If your clock timebase kit included a 12-pF mica capacitor, install this transistor at the place marked C8.

Then install the crystal, XTAL1. Bend its leads over so that they can touch R15 (22 megohms). Make sure the plastic body of the crystal is snug against the resistor, then solder the leads. Take a piece of bare wire and *quickly* solder it to the metal case of the crystal. Bend the wire over the end of the board and solder it to the foil. See the illustrations.

The next step is to install the IC's. Use *Molex* pins for IC5, and don't install this part until just before testing the board. Use a low-power grounded-tip soldering iron for all work here; this is especially important. Remember you are working with CMOS! Double-check for proper placement and proper orientation when you are done.

Now turn the board over as there are some components to be installed on the reverse side. See Fig. 7. Start with the capacitors. Install C4 first, with the positive lead on pin 14 of IC1 and the minus lead on the large foil running near this IC. This capacitor is a 47-μF unit. Be sure

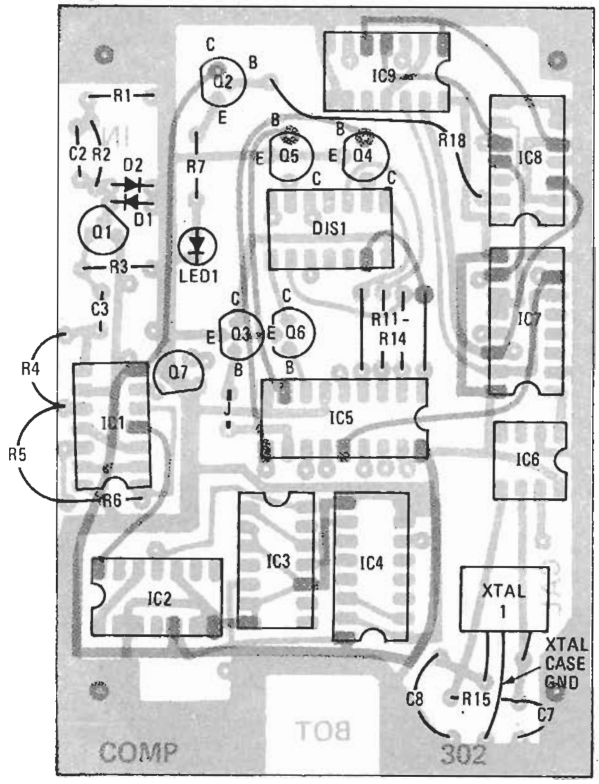


FIG. 6—PARTS PLACEMENT DIAGRAM shows exactly where all the parts mount on the topside of the circuit board. Diagram also shows how the two foil patterns overlap. View is from the top side of the circuit board with the bottom foil pattern shown in the lighter shade of grey.

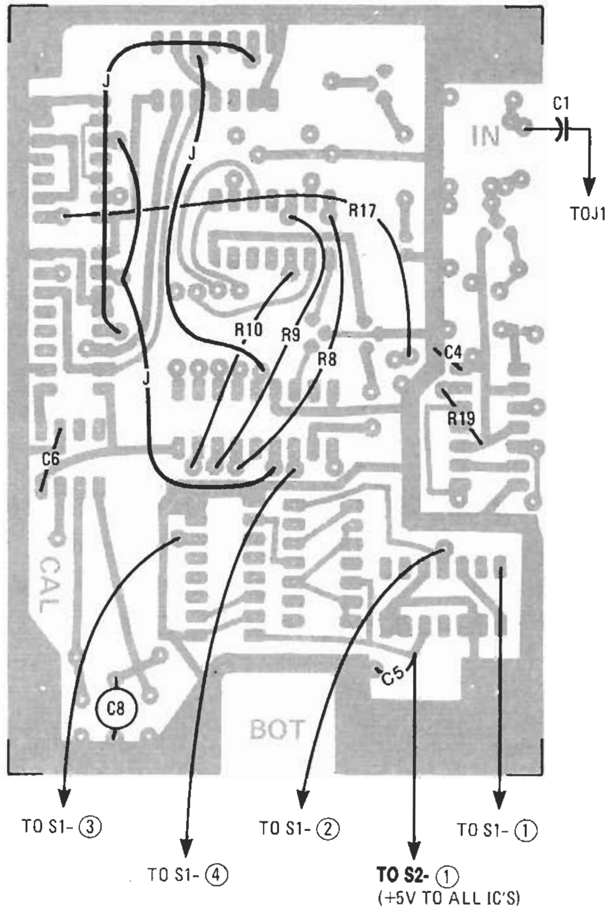


FIG. 7—PARTS PLACEMENT DIAGRAM for the bottom side of the circuit board.

to keep those leads short! Then install C5 (0.2-μF disc) between pin 5 of IC2 and the large foil running near the IC's. *Remember that the large foil running around the edge of the board is ground!* Last, add C6 (0.2-μF disc) between pins 8 and 2 of IC6 (MM5369). Then add trimmer C8 to complete the job.

Now add the jumpers. Even though the board is double-sided, some jumpers are unavoidable. Use insulated wire. Check Fig. 7 carefully.

Next, add the remaining five resistors. Install the three 270-ohm resistors first, from display to IC5 (MM74C926). Then add R19 (2.2K) between pin 4 and pin 13 of IC1. Cut two lengths 1 inch long of spaghetti tubing and slip them over the leads of R17 (10K). Then connect it between pin 1 of IC8 (CD-4013) and the base pad of transistor Q7.

Set the module aside temporarily and turn to switch S1. Check Fig. 3 for details and then attach leads cut to the lengths indicated. Add the jumper. Solder the switch leads to the places indicated. Check over your wiring at this point around the switch, and if everything's OK, proceed to the last step.

Finish up the module by adding a 1½-inch piece of insulated wire to pin 5 of IC2. This is the power lead and it goes to S2. Then add a 2-inch piece of wire from the large foil (ground, remember) nearby. This is the negative battery lead.

That's it for the bulk of the construction. Check your wiring at this point for the usual things—errors and shorts, and correct them if necessary. You may want to proceed to checkout at this point to test the module, then return to finish the box.

Get out the box and lay out the front for the various parts. Use the module you built to determine sizes, etc. Note the cutout in the board. Switch S2 fits in this spot, so don't forget. Turn to the top of the box and lay out the two jacks and switch. Place them as far from the front of the box as you can. This will allow more clearance between the parts and the module when it is installed. Clean up the box and label it.

Install the four ⅜-inch spacers in the box with 4-40 × ¼-inch screws. Then add the display bezel, jacks J1 and J2 and switch S2. Drill holes to match the mounting screws in the module and then drop it in, display facing the box. Secure it with lockwashers and 4-40 nuts. Install S1, noting that the jumper faces the adjacent edge of the box. Then add C1, the 0.1-μF, 200-volt tubular capacitor between J1 and the pad marked IN on the circuit board.

Next, wire switch S2. Attach the short wire that comes from pin 5, IC2 to it. Also, add resistor R16 (100 ohms) and diode D3 (1N4002) between the other switch contact and J2. Cover these parts with a short length of spaghetti tubing. This will prevent problems later! Finish up by installing the four-battery pack between ground on the module and S2. The switch is positive, of course; don't forget!

Checkout and calibration

The checkout part is easy and takes little time. If you have the module only, connect it to a 0–250-mA meter and 5-volt power supply. If all's well, the meter will read about 100 mA and the display will light. It will first show a jumble of numbers and then in a few seconds read 00-00. This is normal and the next step is to touch the pad marked IN with your finger. You will probably get a jumble of numbers and the LED will blink. If not, flip S1 until you get results. Next, connect a signal generator set to around 10 MHz to the IN pad and advance the output level. Flip S1 through its three ranges and you will get a reading close to what the generator is set to. Even without calibration, this counter is surprisingly accurate! If all is well at this point, install the module in the box and proceed to "calibration."

If you already installed your module in the box, you can still perform the simple

continued on page 124

PORTABLE FREQUENCY COUNTER

continued from page 39

checkout. Make sure that the batteries are fully charged, then connect a 0–250-mA meter across S2 and perform the test as described.

There are two ways you can calibrate your counter. Both are pretty easy, but they do require quality equipment that is in calibration. Try to beg or borrow the best equipment to be mentioned you can if you don't have it already. The accuracy of your counter will depend on it!

The first method is probably the best. You'll need a counter that has an accuracy to at least ± 0.001%. Let it warm up for a few minutes (the calibration counter) and attach a X10 scope probe to its input. Ground the probe ground to the case of your counter, and touch the probe tip to the large pad on the board marked CAL. Press S2 and hold it for about a minute. Note that the batteries should be fully charged! Then adjust the trimmer (C8) for a reading of 3,579, 545 Hz. There will be some jitter in the last digit, but try to get it close to a "5" as you can. You must be within ± 179 Hz to meet the accuracy spec. That's it!

The other method is to connect a known signal to the input of the counter and adjust the trimmer until you get a proper reading. Take a signal generator/

counter combination and attach it to the input jack J1. Then set the generator to 10,000,000 Hz or exactly 10 MHz. Next, set S1 to the MHZ position, and press S2. The display will show a jumble of numbers and then two seconds later show a reading close to 10 MHz. If not, adjust the output level on the signal generator until it does. Adjust trimmer C8 for a reading of 10–00. Flip S1 to KHZ and you should get 00–00 with the overrange lamp lit. If not, adjust C8 until you do.

Now put it to work

Using this counter is a snap! Simply unsnap it from your belt (get a surplus calculator case) or take it out of your toolbox and connect it to the signal you want to check. Press S2 and hold it for at least six seconds for two readings. Meanwhile, set S1 to MHZ to get a reading, flipping it to KHZ or HZ for a reading if necessary. Presto! In seconds you have a reading of four digits!

If your frequency is 1 MHz or greater, you can get up to six digits of resolution by combining two ranges. Here's how to do it: Say you are measuring a frequency of 10.125 MHz. On the MHZ position of S2 you will get 10–13, with the dash mark indicating the decimal point printed on the case. On the KHZ position you will get a reading of 25–00 plus overrange (OR). Here's how to combine the readings:

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   10-13
+     25-00
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   10-125-00
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That's all there is to it. But remember to always drop the least-significant digit from the MHz range (that's the "3") when combining the two ranges. As you can see, we actually got seven digits of resolution in this digit. But actually, there will be some jitter in this digit during the measurement, making its usefulness rather limited. You can perform the same stunt of combining readings on the kHz and Hz ranges, too. But in this case three numbers will overlap.

A few last words concerning the display of this counter. Decimal points were left out of the display to save power, and as a result, were printed on the case. Also, a digit was blanked in the readout to emphasize a decimal on the MHz and KHz ranges. On the Hz range, the decimal is at the far right end of the display, so you ignore the gap. With a little practice you will get used to this arrangement. **R-E**