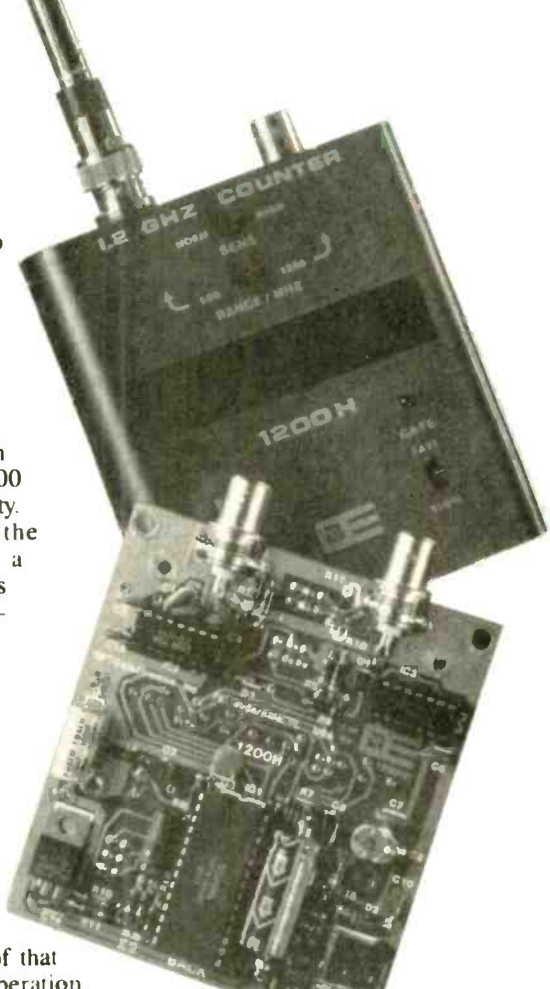
1.2 GHz FREQUENCY COUNTER

Who says a frequency counter must be big and expensive? Our little counter can measure signals into the gigahertz range, and it can be built for under $60!

FRED HUFFT



THE PRICES OF VARIOUS TYPES OF TEST instruments have been dropping like ducks in a shooting gallery the past few years. The latest victim is the frequency counter. When digital frequency counters first appeared in the early 1950's they were very large, very expensive, and, by today's standards, very limited. However, inexpensive LSI frequency-counter IC's and high-speed ECL prescalers have been developed in the past few years.

Those IC's allow us to offer you a high-performance, hand-held frequency counter for under $60. It can measure the frequency of signals ranging from 1 Hz to 1200 MHz, and it has sensitivity under 25 mV throughout most of its useful range. In fact, using a 19-inch telescopic antenna, we can measure the output of a ⅒-watt, 146-MHz handie-talkie that is located more than 20 feet away! Our frequency counter has many other features rivalling units selling for several times its price. Complete specifications are shown in Table 1.

Design Philosophy

Our main design objectives were to produce a 1-GHz counter with good sensitivity, and with minimal size and cost. To meet those objectives we selected two key parts: Intersil's LSI frequency counter, the 7216D (IC1 in Fig. 1), and RCA's ECL prescaler, the CA3179 (IC2).

The Intersil IC was chosen because it contains all the circuitry necessary to count, generate gate signals, latch data, and drive a multiplexed LED display. It also has an MIP (*M*easurement *I*n *P*rogress) output, and control inputs for decimal-point placement and gate time.

The second key part is the RCA CA3179 amplifier/prescaler. It is an ECL part with an exceptional bandwidth of 1200 MHz and with excellent sensitivity. As you can see in Fig. 2, the CA3179's 500-MHz input has a sensitivity of about 10 mV rms above 100 MHz. Below that frequency, sensitivity is inversely related to frequency, rising to 125 mV at frequencies below about 2 MHz. As you can see in Fig. 3, the CA3179's 1200-MHz input is about 25 mV over the 300–1000-MHz range.

The CA3179 requires a single five-volt supply, and it runs barely warm to the touch. That makes it the only IC of its kind we know of that does not run hot in normal operation. Last, it is inexpensive and easy to find.

A few other inexpensive components round out our frequency counter. Refer-

TABLE 1—FREQUENCY COUNTER SPECIFICATIONS

Range	1–1200 MHz
Gate time (fast)	0.25 second
(slow)	2.5 seconds
Resolution	100 Hz (fast gate time) 1000 Hz (slow gate time)
Display	Eight 0.28-inch high, 7-segment LED displays, common-cathode. Decimal point indicates MHz. Leading zero blanking.
Sensitivity (1–10 MHz)	100–150 mV rms
(10–1000 MHz)	1–35 mV rms
(1–1.2 GHz)	10–150 mV rms
Accuracy	±1 PPM RTXO timebase, ±1 count in LSD
Timebase aging	0.1 PPM/month
Input impedance	50 ohms
Gate LED	Illuminates during count
Input connectors	2 BNC female jacks
Input power	9–14 VDC, 150 mA, internally regulated
Optional battery pack	Six AA Ni-Cd cells (7.2 volts)
AC adapter and battery charger	9 VDC, 300–500 ma
Input power connector	⅛-inch jack, center positive
Case	0.060-inch anodized aluminum
Size	3.9 × 3.5 × 1.5 (inches)
Weight	8.5 oz, 13 oz with battery pack

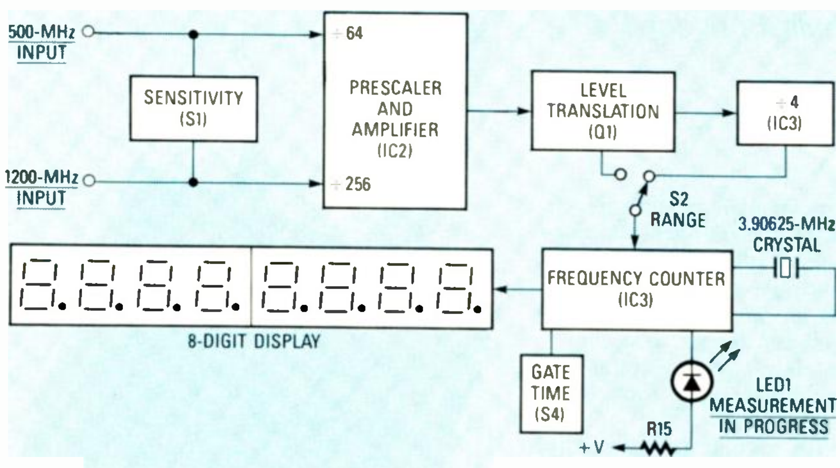


FIG. 1—BLOCK DIAGRAM OF THE FREQUENCY COUNTER reveals that only three IC's and a few discrete components are needed to produce a high-performance 1-GHz counter.

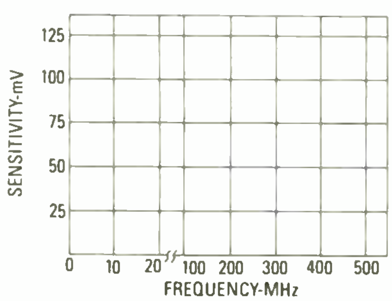


FIG. 2—RMS SINEWAVE SENSITIVITY of the CA3179's 500-MHz input is a flat 15 mV from 100 to 450 MHz.

ring back to Fig. 1, the output of the prescaler is fed through a level translator and then to two "D" flip-flops configured as a divide-by-four counter. We use a 74LS74 dual-D flip-flip because it is inexpensive and readily available, and because it uses little power. RANGE switch S2 allows you to select either the divide-by-four output or the direct output from the prescaler. Your chosen signal is then passed on to IC1, which processes it for output on the LED displays, two four-digit, common-cathode, multiplexed displays with 0.28-inch high digits.

The circuit is powered by an external AC adapter or an optional built-in Ni-Cd battery pack (which is trickled charged by the adapter). Separate switches are

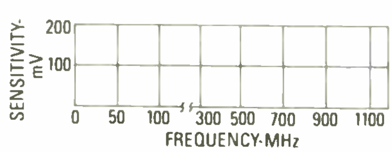


FIG. 3—RMS SINEWAVE SENSITIVITY of the CA3179's 1200-MHz input is a fairly flat 25 mV from 300 to 950 MHz.

provided to control SENSITIVITY (S1) and GATE TIME (S4).

Circuit Description

Referring now to the complete circuit diagram in Fig. 4, you can see that the output of the CA3179 is fed through the D1/Q1 circuit. Those components serve to boost the 1-volt output of the CA3179 to a standard TTL level. Then, depending on the position of RANGE switch S2-b, the signal is passed directly to the 7216, or through the divide-by-four circuit built from the two "D" flip-flops in IC3.

The other half of the RANGE switch (S2-a) controls the voltage at pin 3 of the CA3179. When pin 3 is high, the signal applied to pin 9 is fed through an extra internal divide-by-four stage before it is amplified and output on pins 4 and 5. When pin 3 is low, the signal on pin 13 is simply processed for output without being divided internally.

We use a 3.90625 MHz crystal for our time base; the crystal yields a *fast* gate time of 0.256 second. The displayed frequency equals the input frequency divided by 1000 in the *fast* mode. In *slow* mode, gate time is 2.56 seconds. The displayed frequency equals the input frequency divided by 100 in the *slow* mode.

Switch S4, GATE TIME, performs two functions. First it selects the appropriate gate time according to which digit output of IC1 the RANGE input is connected to. Another of the 7216's inputs is also controlled by S4: the DP SELECT input. The decimal point of the digit output to which that pin is connected will be the one that lights up. In our case, the correct decimal point illuminates, according to the position of S4, to provide a reading in MHz.

Self-oscillation

Due to the high gain, balanced-input amplifiers in the CA3179, self-oscillation can occur with no input signal present. The result is a random, constantly-changing count. Although that does not affect the performance of the counter, it can be distracting.

To settle the display we added SENSITIVITY switch S1 and the associated resistors and capacitors. When the switch is on, the RC networks eliminate display bobble. The difference in sensitivity varies with frequency. For example, at 150 MHz, normal sensitivity is typically 15 mV rms, and high sensitivity is about 6 mV rms. But at 850 MHz, normal sensitivity is typically 40 mV rms and high sensitivity is about 25 mV rms.

The MIP output of IC1 drives Q2, which in turn drives LED1. When it is illuminated, a measurement is in progress. The LED goes out for a fraction of a second between measurements.

For greatest accuracy, trimmer C8 can be adjusted so that the output of the oscillator is exactly 3.906250 MHz. For

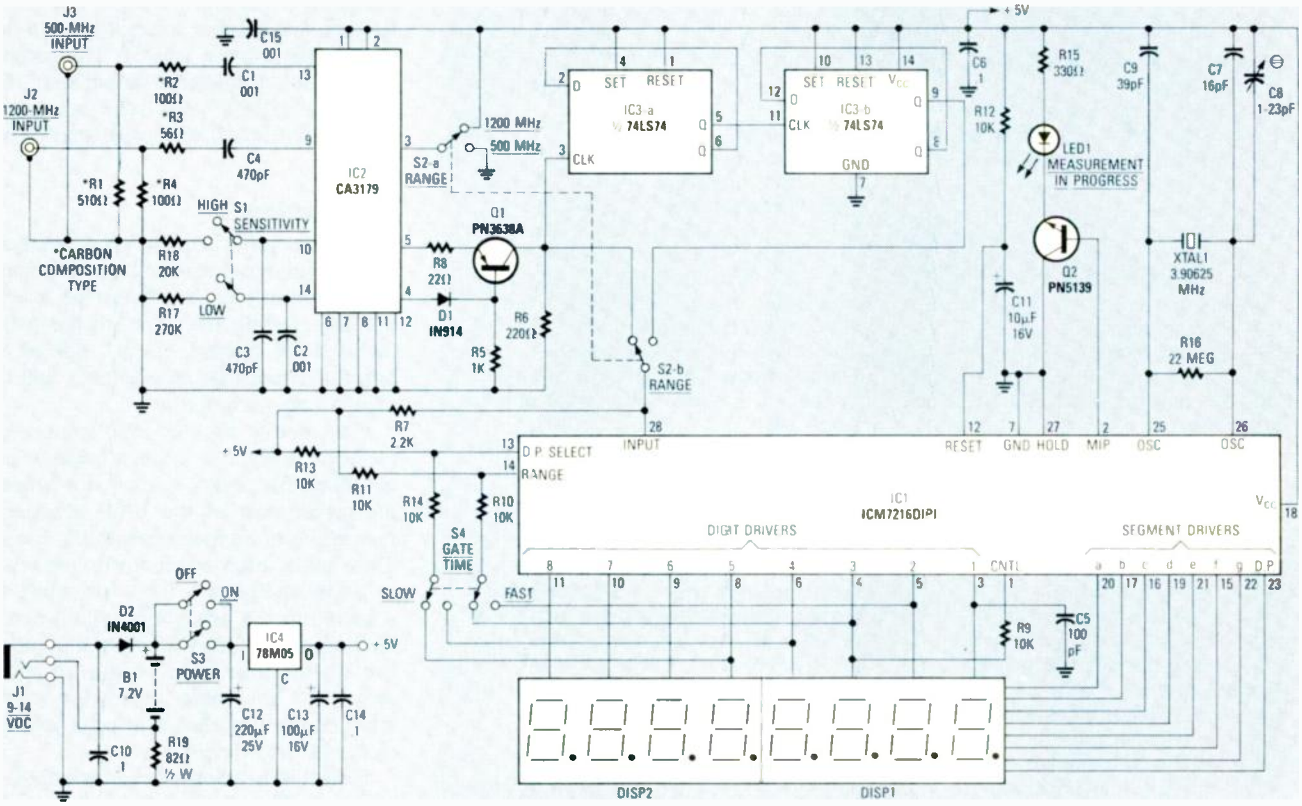


FIG. 4—SCHEMATIC DIAGRAM OF THE FREQUENCY COUNTER is a model of design simplicity. Transistor Q1 and associated discrete components translate IC2's ECL output into a TTL level for IC3 and IC1.

greatest frequency stability, C7 should be an NPO type, and C9 an N750. In case you're wondering, temperature causes almost no change in capacitance in an NPO capacitor; the capacitance of an N750 capacitor will decrease 750 parts per million for each 1°C increase in temperature.

The power supply is a standard 7805 circuit. Input voltage can range from 9–14 volts DC; input should never exceed 14 volts. Diode D2 protects the circuit from an accidental reversed-voltage input.

Power input jack J1 has a switch contact. When no plug is present, the contacts are closed, so the negative terminal of the battery is grounded. When a plug is present, R19 appears in the battery's ground circuit; that resistor is what provides trickle-charging. With a 9-volt input, a charge current of 25–45 mA will be provided. Charging occurs even when POWER switch S3 is off. You should ensure that charge current never exceeds 45 mA; adjust the value of R19 if necessary.

The Ni-Cd battery pack specified in the Parts List is rated at 45 mA. This means that a charge current of 45 mA will fully charge a completely discharged pack in about 14 hours, and that the batteries won't be harmed by continuous charging at that rate (or less). For maximum battery life and capacity, Ni-Cd's should occasionally be "deep cycled" several times by completely discharging and then fully recharging them. That should prevent a discharge "memory" from forming at less than the full rated output voltage.

Voltage regulator IC4 provides a regulated five-volt DC output when S3 is closed. Regulated voltage is especially important to the timebase oscillator, because, as the battery's voltage varied throughout its life, so would the frequency of the timebase. Erroneous measurements would result. With a good source of regulated voltage, however, the timebase circuit should maintain ±1-PPM stability at room temperature. Both temperature stability and accuracy are almost totally dependent upon the crystal used.

The counter circuitry by itself draws about 120 mA; in combination with the battery charger, about 150 mA will be drawn. The optional Ni-Cd battery pack should give up to 5 hours of continuous operation, which is more than adequate for most portable requirements. In any case, we recommend that your DC source be able to supply at least 300 mA for safe and reliable operation.

That's about all there is to the circuit—so let's build a frequency counter!

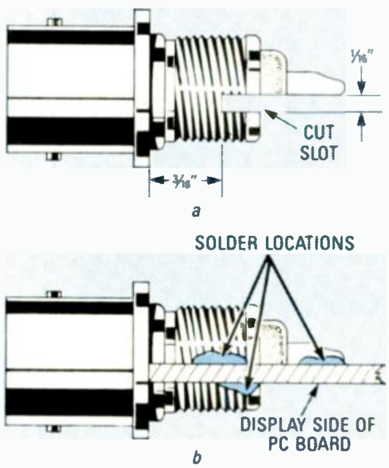


FIG. 5—A BNC CONNECTOR must be modified as shown in *a* so that it can be soldered to the PC board as shown in *b*.

PC board

For ease of construction, we recommend use of a double-sided PC board. You can buy an etched, plated, labeled, and solder-masked board from the source mentioned in the Parts List, or you can etch you own board using the foil patterns shown in "PC Service."

For flexibility, the PC layout has a number of extra pads and holes to accommodate capacitors of various sizes and shapes. That applies to C2, C3, and C4, and to trimmer C8. We designed a partial micro-strip layout for the input connectors (J2 and J3) to simplify assembly and to approximate a 50-ohm input impedance.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1—510 ohms, carbon composition
R2, R4—100 ohms, carbon composition
R3—56 ohms, carbon composition
R5—1000 ohms
R6—220 ohms
R7—2,200 ohms
R8—22 ohms
R9–R14—10,000 ohms
R15—330 ohms
R16—22 megohms
R17—270,000 ohms
R18—20,000 ohms
R19—82 ohms, 1/2 watt, 10%

Capacitors
C1, C2, C15—0.001 µF ceramic disc
C3, C4—470 pF ceramic disc
C5—100 pF ceramic disc
C6, C10, C14—0.1 µf ceramic disc
C7—16 pF ceramic disc, NPO
C8—1–23 pF trimmer
C9—39 pF ceramic disc, N750
C11—10 µF, 16 volts, electrolytic
C12—220 µF, 25 volts, electrolytic
C13—100 µF, 16 volts, electrolytic

Semiconductors
IC1—ICM7216DIPI universal frequency counter (Intersil)
IC2—CA3179 ECL pre-scaler (RCA)
IC3—74LS74 dual "D" flip-flop
IC4—7805 5-volt regulator (TO-220 case)
Q1—PN3638A transistor (ECG159)
Q2—PN5139 transistor (ECG108)
DISP1, DISP2—DL-4770, four-digit, seven-segment, common-cathode multiplexed display (Litronix)
LED1—standard red LED
D1—1N914 switching diode
D2—1N4001 rectifier

Other Components
S1–S4—subminiature DPDT slide switch
J1—⅛-inch power jack with switch
J2, J3—BNC connector, female, bulkhead mount, modified (see text)
XTAL1—3.906250 MHz crystal, parallel resonant, 22 pF, HC-18 case.

Miscellaneous 3/16" high by ¼" OD nylon spacer, IC sockets, PC board, case, power pack, etc.

Note: The following items are available from Optoelectronics, Inc., 5821 N.E. 14 Ave., Ft. Lauderdale, FL. 33334: PC board (no. PCB-1200H), $16; Kit including PCB and all parts less cabinet (no. 1200HK), $59.95; Anodized cabinet with red lens (no. CAB-1200H), $20; Power adapter/charger (no. AC-1200), $7.50; Ni-Cd battery pack (no. NiCd-1200), $20; Telescoping RF antenna (no. TA-100), $12; Vinyl zipper case (no. CC-70), $10; 50-ohm 1 × probe (no. P-100), $18; Wired, tested and calibrated counter (no. 1200H), $110. Individual components also available. Florida residents add 5% sales tax. All orders add 5% for shipping and handling.

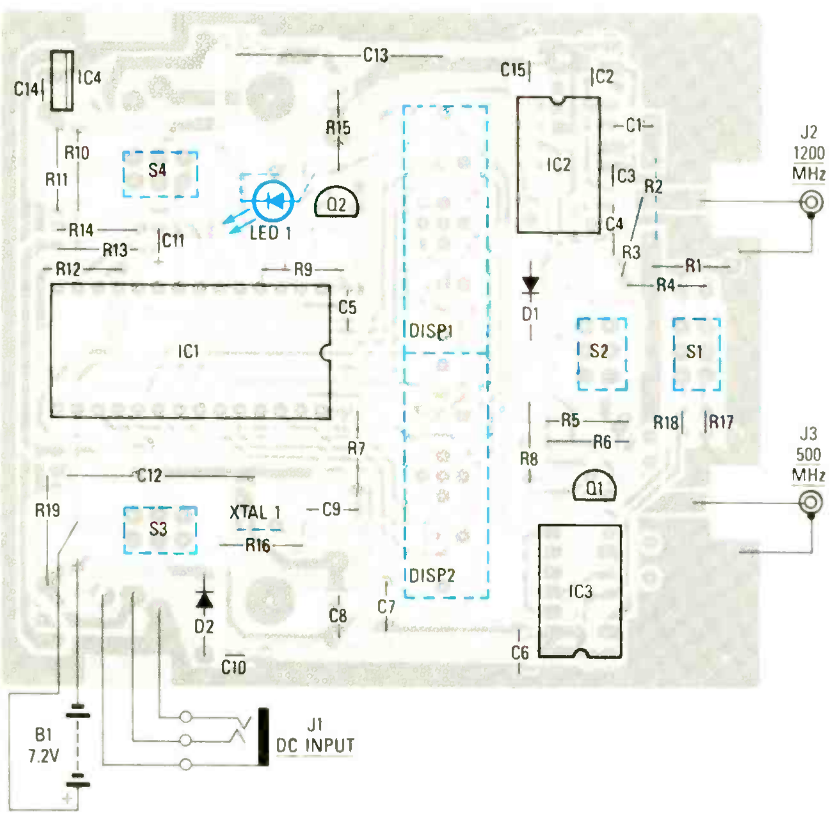


FIG. 6—PARTS PLACEMENT DIAGRAM. Most components mount on the bottom of the board. The switches, displays, R2 and LED1 are shown in dashed lines; they should be mounted on the opposite side of the board. The leads to the battery attach to the bottom side; BNC jacks J2 and J3 should be soldered to both sides of the board.

In addition, the PC board has two notches at the top to accept modified BNC connectors, and another notch along one side for the power-input jack J1. The notches for the BNC connectors should be 0.365" wide and 0.250" deep. The power-jack notch should be 0.430" wide and 0.150" deep.

Construction

Our frequency counter was designed for quick and easy assembly; by following the directions you should have no trouble building, testing, or calibrating the instrument. We'll call the "front" side of the board the side that the switches and the displays are mounted on.

First modify the two BNC connectors as shown in Fig. 5-*a*. Using a hacksaw or a modeling file, cut a 1/16-inch slot beneath the center post of the BNC connector, leaving 3/16 of an inch beneath the flange. Then solder each connector to the board as shown in Fig. 5-*b*. The connectors are soldered to the adjoining ground planes on both sides of the PC board; that makes the installation both strong and well grounded. The center conductors of the BNC connectors should also be soldered to the PC board now.

Next, on the back side of the board, as shown in Fig. 6, install the low-profile components (the diodes and resistors), followed by the IC sockets, then the capacitors, etc. Be certain to observe proper polarity when installing the diodes, the electrolytic capacitors, the IC sockets, the battery connector, and, on the front of the board, LED1 and the displays. By the way, we found almost no difference in performance with and without sockets, but using them makes servicing easier.

Since the counter will be dealing with rather high frequencies, R1–R4 and C1–C4 should be installed with minimum lead length. Also, resistors R1–R4 should be the non-inductive, carbon-composition type; the other resistors may be either composition or film types. Capacitors C1–C4 should be small ceramic disk or monolithic ceramic types. All input components should be installed as neatly as possible.

To complete the back side of the board, install the voltage regulator (IC4), trimmer capacitor C8, and all small capacitors. Bend the leads of the regulator so that its body is parallel to the PC board. A heatsink is unnecessary. Next install power jack J1 and transistors Q1 and Q2.

Clean flux off the front side of the board, and then install the switches, DISP1 and DISP2, XTAL1, LED1, and R2, according to Fig. 6. The LED should be mounted above a spacer 3/16 inch in length. The displays should be mounted flush against the board. When installing the displays, the IC sockets, and any other components with numerous solder connections, it's best to solder two or three

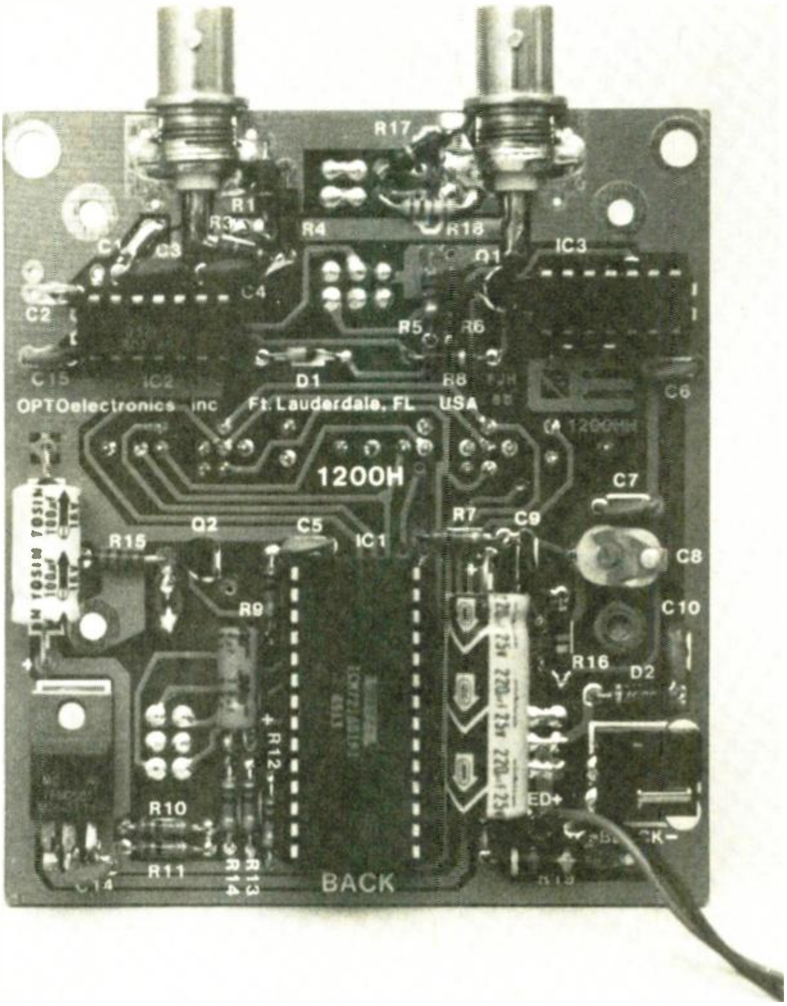


FIG. 7—ONCE ALL COMPONENTS are in place, clean the board and check your work for any shorts or opens.

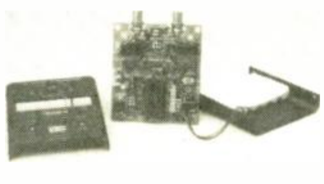


FIG. 8—ONCE INSTALLED IN ITS CASE, the counter makes a neat, compact, and easily transportable test instrument.

pins, check for alignment, correct if necessary, and only then solder the remaining pins. A small piece of double-sided foam tape should be placed under the crystal to insulate its case and to provide a shock mount. Finally, install the electrolytic capacitors, C12 and C13, on the rear side of the board.

Now clean the board and check it thoroughly for solder shorts and opens. When you're satisfied that the board is in good shape, install the IC's. Your board should now appear as in Fig. 7.

Initial check-out

Set the SENSITIVITY switch to NORM and the GATE switch to FAST. With the RANGE switch in either position, apply power. The GATE LED should blink and the display should indicate .000 with leading digits blanked. Move the GATE switch to the SLOW position. The display should now read .0000, and the GATE LED should blink at a slower rate. Now move the SENSITIVITY switch to HIGH; the display should show a random, changing count on both ranges.

If the display is dim or blank, remove power, and make sure all IC's are installed correctly. If so, check the orientation of all the diodes and electrolytic capacitors. Re-check the PC board for shorts and opens if necessary. Finally, your power source may be weak or dead, or a switch may be bad.

Calibration and final assembly

To calibrate the counter, let it warm up for at least ½-hour, connect a stable signal of known frequency to the proper input jack, and then adjust trimmer capacitor C8 for proper display. Use the highest frequency you can and the SLOW gate time in order to get maximum resolution and accuracy.

Remember that a counter's accuracy is specified in PPM (*P*arts *P*er *M*illion), and if a reading is 1 PPM high at one frequency, the counter will read 1 PPM high at all frequencies. At 1 MHz a 100 PPM error would, in many applications, be insignificant. But a 100 PPM error at 1 kHz would be quite significant. So calibrate the counter carefully!

When it is calibrated, you can mount it in its case, see Fig. 8. If you use the case mentioned in the Parts List, the PC board just slips into it. The BNC connectors and the power jack should line up with the holes in the case perfectly. Drop a red plastic filter over the displays and then screw the case together. You're ready to start using your 1.2-GHz frequency counter now!

Usage hints

Keep in mind that the counter requires only a few millivolts to make an accurate reading—seldom more than about 50 mV. Inexperienced users commonly overdrive the frequency counter—and that could cause erroneous readings or circuit damage. Signals of several volts or more should be loosely coupled by a small capacitor or picked up inductively by a loop-type probe or antenna. When connecting the frequency counter directly to a circuit, use a 10K series resistor to reduce ringing and to lighten the load on the test circuit. Other than following those simple precautions, you should have no trouble using the counter.

Since the the price-to-performance ratio of this circuit is so good, you may want to install one permanently in a piece of equipment such as a ham rig or a commercial radio transmitter. That way you could have a continuous indication of output frequency, and any drift could be corrected before it caused interference to stations transmitting on nearby frequencies.

Or, for a very handy and versatile piece of test gear, you could combine our circuit with an inexpensive function generator in a single cabinet. Also, it would be easy to adapt our circuit for automotive or marine use. If you do, be sure to wire a ¼- to ½-amp fuse in series with the counter's power input line.

As you can see, our frequency counter is so inexpensive and so easily adaptable that new applications for it seem to suggest themselves! You'd better start building several—you'll use 'em before you know it! **R-E**