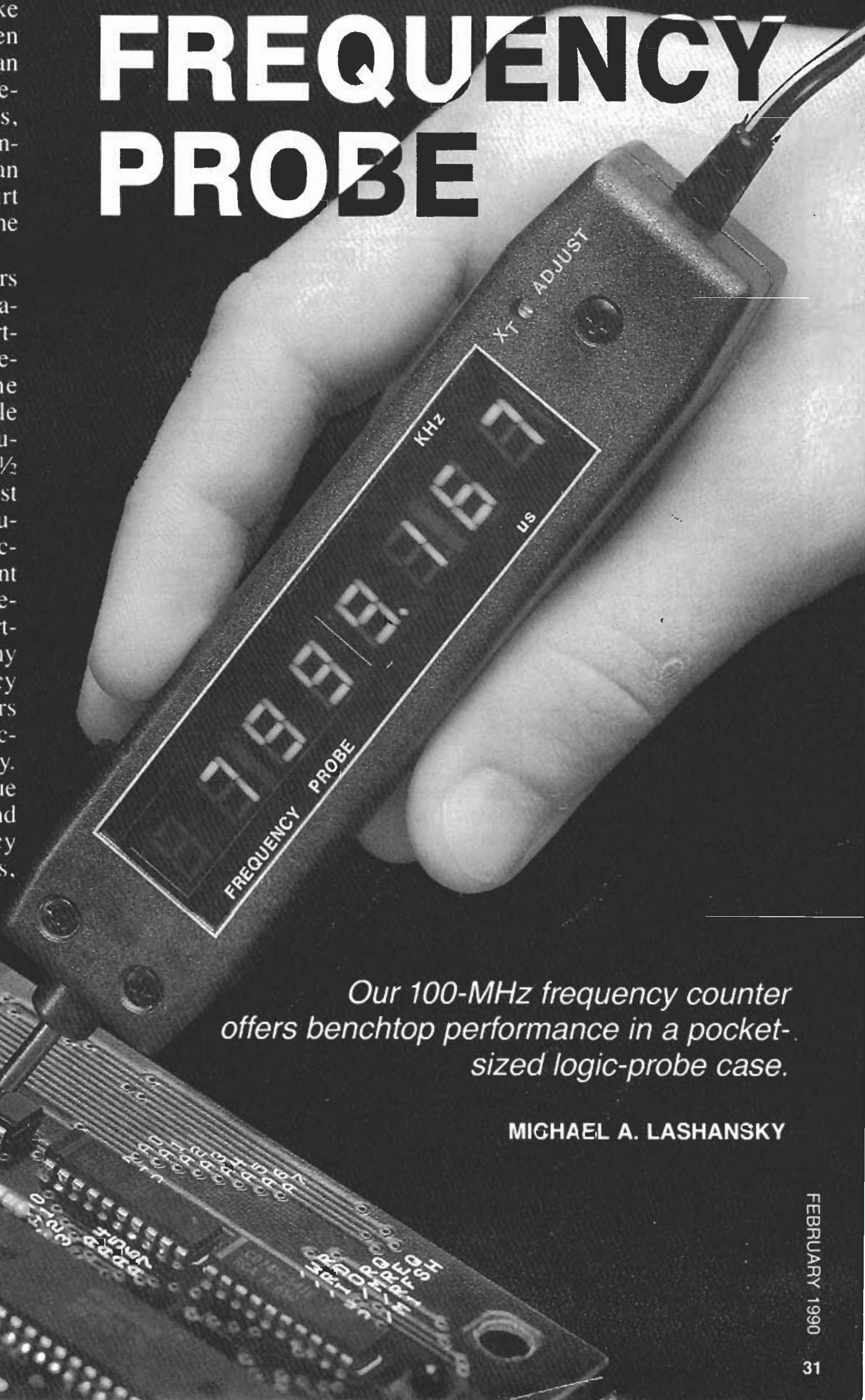
BUILD THIS

100 MHz FREQUENCY PROBE

TEST EQUIPMENT HAS SURE COME A long way since the days of the bulky analog meter. The newest generation of portable test gear boasts features that would make technicians of a decade ago green with envy. Single instruments can measure everything; voltage, resistance, capacitance, logic levels, and even frequency. In fact, an entire test bench of equipment can now be packed away in a shirt pocket, and carried easily to the source of the trouble.

As good as those new meters are, they still have a few limitations that can be rather disconcerting at times, Frequency measurement is a good example; the highest range on most portable DMM-sized instruments is usually less than 1 MHz, and the 3-½ –4-½ digit LED displays on most meters don't offer much resolution. It seems as if most manufacturers add frequency measurement as an afterthought. As newer designs hit the market, those shortcomings will improve. But why wait? You can build the frequency probe described here. It offers benchtop performance at a fraction of what you'd expect to pay.

The frequency probe is a unique combination of a logic probe and an 8-digit, 100-MHz frequency counter. It uses only three IC's,



Our 100-MHz frequency counter offers benchtop performance in a pocket-sized logic-probe case.

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TABLE 1—FREQUENCY PROBE SPECIFICATIONS

Parameter	Waveform Type	Condition	Performance (*)	
			Frequency	Period
Measurement Range	Any	Unmodified PC Board, XTAL1 is 1 MHz	00000.000—99999.999 X 1 kHz, 10-s gate	00000.500—99999.999 X 1 μs, 10-s gate
		Modified PC Board (see text), XTAL1 is 1 MHz	000000.00—099999.99 X 1 kHz, 1-s gate	000000.50—099999.99 X 10 μs, 1-s gate
		Unmodified PC Board, XTAL1 is MHz	00000.000—0999.999 X 10 kHz, 1-s gate	00000.500—99999.999 X 10 μs, 1-s gate
		Modified PC Board (see text), XTAL1 is 10 MHz	000000.00—009999.99 X 10 kHz, 0.1-s gate	000000.50—099999.99 X 1μs, 0.1-s gate
Input Sensitivity	Sinusoid	N/A	35 mV p-p	
	Square	N/A	50 mV p-p	
Maximum Period	Any	N/A	2 MHz	
Logic High	Any	N/A	3 VDC	
Logic Low	Any	N/A	1.8 VDC	
Supply Voltage	Any	N/A	4.5–15 VDC	
Maximum Current	Any	N/A	190 mA DC	
Input Impedance	Any	n/A	51 ohms	

(*) NOTE: All leading zeros are suppressed during normal operation of the frequency probe for both frequency and period measurement, and are reproduced here merely for illustration.

and fits in a standard logic-probe case, modified for the purposes of the 8-digit LED display. Table 1 lists the probe's specifications. It features switchable AC/DC coupling and both frequency- and period-measurement capability. The builder of the probe can modify the useful frequency range by selecting a different crystal, and can also modify the gate time (or sampling time) by making a simple PC-board modification. The effects of the modifications are summarized in Table 1, and we'll discuss how they're made shortly.

The probe can be powered either by the circuit-under-test, or by connecting its leads to +9-volts DC. Building the probe isn't difficult, but it requires care and patience, because the components are very tightly packed.

Circuit operation

Figure 1 shows the block diagram of the frequency probe. The input can be AC- or DC-coupled to the divide-by-10 prescaler, whose output is fed to the main counter section and the LED display block. That counts the prescaler pulses, and includes the necessary logic for the 8-digit LED display. The logic block indicates with LED1 and LED2 which coupling mode is in use, and indicates logic levels.

The frequency-probe schematic is shown in Fig. 2. S1 either DC-couples the input through R1, or AC-couples it through C1. The center pole of S1 goes to the clock-pulse input (CP) of IC1, a National Semiconductor 11C90 prescaler. The 11C90 is an ECL divide-by-10 prescaler, uses +5 volts, has TTL-output, and operates over a DC–650 MHz bandwidth with only an RF-bypass capacitor on V_{CC}. Input sensitivity for AC-coupling is 350 mV p-p from DC–100 MHz, and 250 mV p-p above 100 MHz. The frequency response of the 11C90 is shown in Fig. 3, but that's the guaranteed minimum, and actual performance can exceed it substantially. S2 is located between the frequency counter and the LED display, and selects between the frequency- and period-measurement modes.

Triggering is simplified in IC1 by connecting the reference terminal (pin 15) to clock pulse (pin 16). By doing so, the probe input is automatically centered about the input threshold. A 50% duty cycle gives the fastest operation, and since the flip-flops are master-slaves with offset input thresholds, there are no minimum frequency restrictions. That ensures that the circuit will operate with inputs with very slow rise and fall times. The 11C90 can divide-by-10 or -11 depending on the levels on pins 1 and 2 (M1 and M2). A logic low on those pins places the divider into divide-by-11 mode, while tying them high produces divide-by-10 mode. IC1 is enabled by tying pin 1 (CHIP ENABLE) and pin 14 (ASYNC MASTER SET) low.

There are two V_{EE} terminals (pins 12 and 13). The TTL output operates from the same V_{CC} and V_{EE} levels as the counter, but a separate pin is used for the TTL V_{EE}. That minimizes noise coupling when the TTL-output switches, and reduces power consumption by leaving pin 12 open when the ECL outputs are used. Because the IC operates linearly with the transistors always on, the current drawn can go up to 80 mA, with 35 mA typical. Thus, the IC's run pretty warm, but heat-sinking isn't needed.

The TTL-output of IC1 is pulled up to CMOS levels by R6 and connected to the clock input of IC2, an ICM7216B frequency counter. The 7216B has gating, timebase, latching, decoding, and 8-digit LED display-driver circuitry. In addition, the 7216B measures period, frequency ratios (f_A/f_B), time intervals, or total

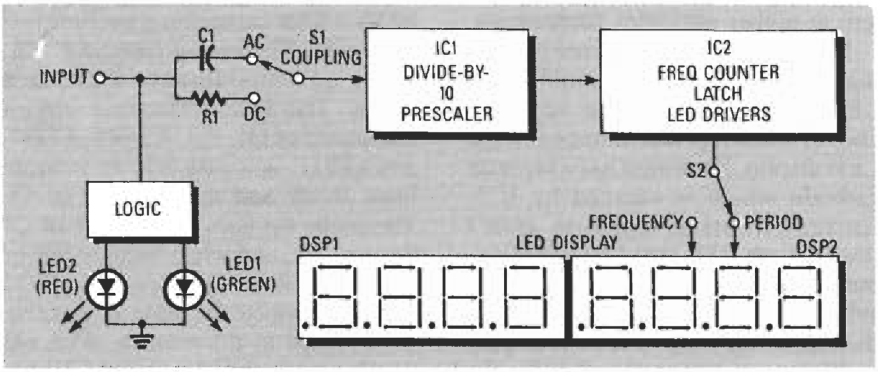

FIG. 1—FREQUENCY PROBE BLOCK DIAGRAM; the input is either AC- or DC-coupled to the divide-by-10 prescaler (IC1) then sent on to the counting (IC2) and LED display (DSP1 and DSP2) blocks.

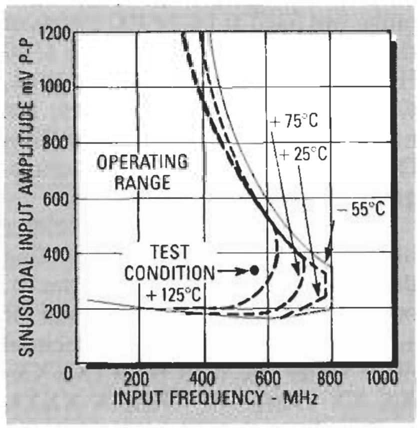

FIG. 3—SENSITIVITY OF IC1 AS A FUNCTION of sinusoidal input amplitude in mV p-p vs. frequency, for –55°C, 25°C, 75°C, and 125°C.

counts. Due to limited space, only the frequency and period functions were used.

The 7216B has a 10-MHz crystal timebase, and accepts inputs up to 10-MHz, which are divided internally by 10^5. Inputs are gated with that clock for a period determined by the RANGE INPUT (pin 14) setting, and passed to the main counter. The RANGE INPUT automatically adjusts the LED display decimal place, and allows longer gate periods for lower frequency inputs. When prescalers like IC1 are used, XTAL1 should be scaled accordingly. Thus, the input was divided-by-10 using IC1 and a 1-MHz crystal. That multiplies the internal gate time by 10 (from the original range times), allowing 100-MHz measurements with 1-Hz resolution.

Also, the 7216B has 10-ms, 100-ms, 1-s, and 10-s gate times. Selection of the gate time and decimal-point location is achieved by connecting the range input (pin 14) through R10 to digit-driver terminals D1–D4 (pins 4–7). The digit-drivers are time-multiplexed with the range, control, external decimal point, and func-

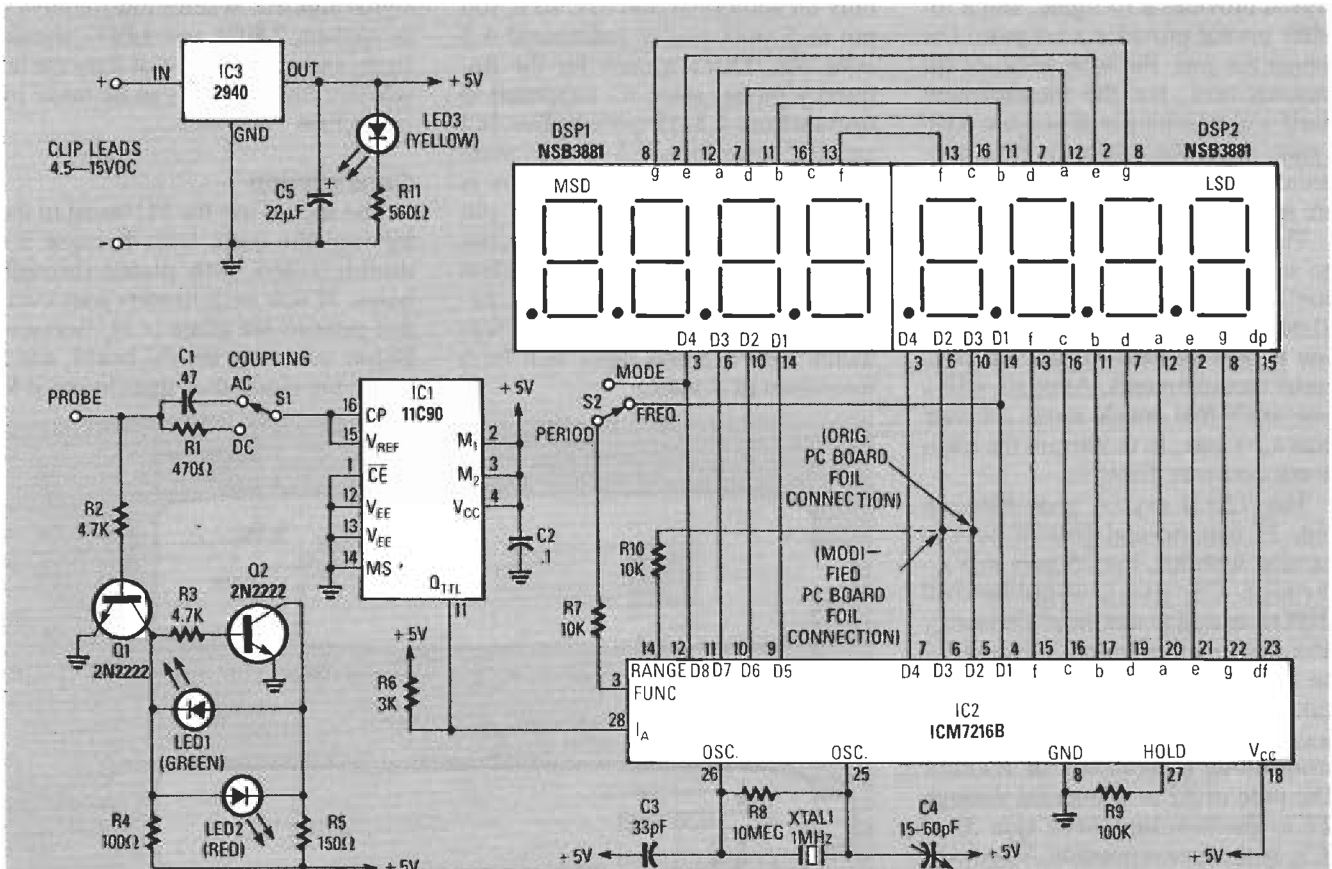

FIG. 2—SCHEMATIC DIAGRAM FOR THE FREQUENCY PROBE. Note the dotted line connecting R10 with pins 5 or 6 of IC2; that variable connection controls the decimal point and total count appearing on DSP1 and DSP2. The relative intensities and durations of ON/OFF time for LED1 (green) and LED2 (red) give a rough indication of logic level and duty cycle.

tion selects to save on pin count. The range was fixed at 1 s, or 100 counts of the 10-Hz reference counter (100 Hz/10). That gave a 10-s gate time, which is inconvenient at times, but necessary for 1-Hz resolution from DC–100 MHz, without using space-grabbing range-select switches.

To achieve a 1-s gate, you can either modify the PC board by connecting the RANGE input (pin 14) to D2 (pin 6), or you can use a 10-MHz crystal. If you modify the PC board, the decimal place shifts one digit right (XXXX-XX.XX instead of XXXXX.XXX), and the least-significant digit means 10 Hz, not 1 Hz. The interpretation of the display remains as multiples of 1 kHz, but the absolute range of the probe increases from 10 MHz to 100 MHz. To do that, cut the foil on the component side from pin 5 of IC2, and solder a jumper from the foil side to pin 6.

If you change the crystal frequency, the decimal place stays unchanged (XXXXX.XXX before and after); the LED display value reads in multiples of 10 kHz instead of 1 kHz. A 1-MHz crystal provides a 10-s gate, and a 10-MHz crystal provides a 1-s gate. The longer the gate, the more accurate the measurement, but the measurement itself will take longer. If you use a 10-s gate, the probe might slip off a connector or IC pin before the 10 seconds are up.

The best of both worlds would be to go with a 10-MHz crystal, because you'll save some money ($2.00 for 10-MHz vs. $12.00 for 1-MHz), and you'll also be able to take quicker, easier measurements. After all, a 10-s gate isn't that much more accurate than a 1-s gate, as to warrant the additional cost (see Table 1).

The 7216B crystal goes between pins 25 (OSC IN) and 26 (OSC OUT) in parallel with R8. Pin 26 goes to V_{CC} through C3; use a nonpolarized (NPO) version to minimize frequency drift due to temperature. Trimmer C4 on pin 5 lets the user adjust the oscillator output to 1 MHz for maximum accuracy. S2 selects the counter operating mode (FREQUENCY or PERIOD). The pole of S2 is connected through R7 to the FUNCTION INPUT (pin 3) of IC2. In the PERIOD position, S2 goes to D8 (pin 12), so IC2 is in period counting mode. In FREQUENCY position, S2 is connected to D1 (pin 4). Also, R7 and R8 prevent false triggering due to AC-coupled signals from the multiplexed digit drivers, which is a problem at higher multiplex frequencies.

Next, DSP1 and DSP2 are each 4-digit, common-cathode, multiplexed LED displays with the segment anodes wired together to form a single LED display. Each digit has a separate cathode which is sourced by IC2. Current-limiting resistors aren't needed with NSB3881 LED displays, but if a high-efficiency LED display is substituted, use 40-ohm resistors on the segment drivers. The LED display multiplex rate is directly related to the crystal frequency. For a 10-MHz crystal, the multiplex rate of the LED display is 500 Hz; the 1-MHz crystal yielded a 50-Hz rate. As was shown in Fig. 2, pin 28 (HOLD) is grounded through R9, which pulls pin 28 low, and allows the internal counter contents to be displayed after each measurement cycle.

Power is supplied by IC3, a National Semiconductor 2940 low-voltage dropout +5-volt regulator. Ordinary voltage regulators need an input voltage at least 2 volts above the desired output. The 2940, however, needs only an additional 500 mV, so if you put in 5 volts you're guaranteed 4.5 volts out. That's a must for the frequency probe, since it's supposed to operate from 4.5–15 volt supplies. IC1 and IC2 need from 4.5–6 volts maximum, so some voltage regulation is needed. That's not a problem if you attach the power leads to 12 volts, but the probe may be rendered useless when measuring 5-volt signals, because the output of a +5-volt regulator with a 5-volt input will be a maximum of 3 volts.

The 2940 is, however, noisy, and needs a filter capacitor, sometimes on each side. The output capacitor (C3) takes up considerable PC-board space. The level-indicating circuit composed of Q1, Q2, R2–R5, LED1, and LED2, is a easy way to indicate logic levels and the position of S1. The probe tip goes to the base of Q1 through R2, and when brought low or allowed to float, Q1 is cutoff and Q2 conducts, since the base is positive with regard to the emitter. With Q2 conducting, LED1 should light. Touching the probe to a logic high makes Q1 and Q2 complement states (Q1 conducting and Q2 cutoff), and LED2 should light.

That feature indicates the position of S1 since, in DC-coupled mode, the reference voltage of IC1 is coupled through R1 and R2 to the base of Q1. That's about 3 volts (a logic high), so LED2 should light. In AC-coupled mode, no DC voltage from IC1 is passed to the base of Q1, and it's allowed to float (a logic low), so LED1 lights. That's a useful way of visually checking the coupling mode with no signal applied. When a low frequency is applied, LED1 and LED2 should light, and a rough idea of duty cycle, whether high or low, can be made by inspection.

Construction

You should use the PC board in the kit (see the parts list), because it's double-sided with plated-through holes. If you wish to etch your own, foil patterns are given in PC Service. Before soldering the PC board, use a metal file along the edges to get it to

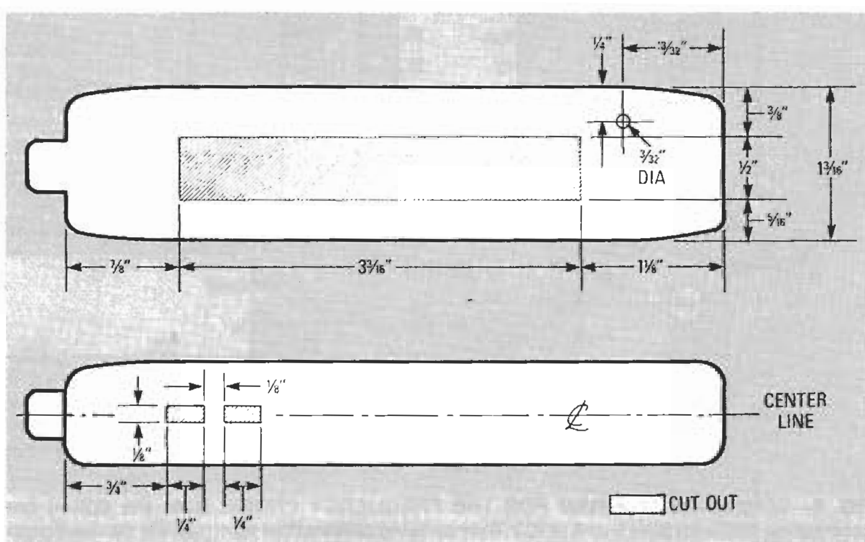

FIG. 4—THE FREQUENCY PROBE CASE. Cutout dimensions for DSP1, DSP2, and C4 are shown in (*a*). Cutout dimensions for S1 and S2 are shown in (*b*).

PARTS LIST

All resistors are ⅛-watt, 5%, unless otherwise indicated.

R1—470 ohms, ¼-watt
R2, R3—4700 ohms
R4—100 ohms, ¼-watt
R5—150 ohms, ¼-watt
R6—3000 ohms
R7, R10—10,000 ohms
R8—10 Megohms, ¼-watt
R9—100,000 ohms
R11—560 ohms, ¼-watt

Capacitors

C1—0.47 µF, ceramic
C2—0.1 µF, ceramic
C3—33 pF, nonpolarized (NPO) ceramic
C4—15–60 pF trimmer (Active Components # 17016)
C5—22 µF, tantulum

Semiconductors

IC1—11C90 National Semiconductor 650-MHz, divide-by-10 prescaler
IC2—ICM7216B Intersil 8-digit, frequency counter/timer
IC3—2940 National Semiconductor +5-volt regulator
Q1, Q2—2N2222 NPN transistor
DSP1, DSP2—NSB3881 National Semiconductor 4-digit, 7-segment LED display
LED1—green light-emitting diode (miniature)
LED2—red light-emitting diode (miniature)
LED3—yellow light-emitting diode (miniature)

Other components

XTAL1—1- or 10-MHz crystal (case size HC49)
S1, S2—SPDT switch (Active Components # 22196)

Miscellaneous: Logic-probe case with probe tip and clip leads (Global Industries # CPT-1), solder, wire, etc.

NOTE: A complete kit of parts, logic-probe case, and carrying case is available for $139.95 U.S. or $159.95 Canadian from Tristat Electronics, 66A Brockington Crescent, Nepean, Ontario, Canada K2G 5L1, (613) 225-9883. The kit without the PC board is $117.95 U.S. or $137.95 Canadian (Visa orders welcome). The PC board alone is $22.00 U.S. or $25.00 Canadian. All orders require $6.00 for shipping and handling. The sources for certain components are Active Components, 1023 Merival Road, Ottawa, Ontario, Canada K1Z 6A6, (613) 728-7900, and Electrosonic, 1100 Gordon Baker Road, Willowdale, Ontario, Canada M2H 3B3, (416) 494-1555.

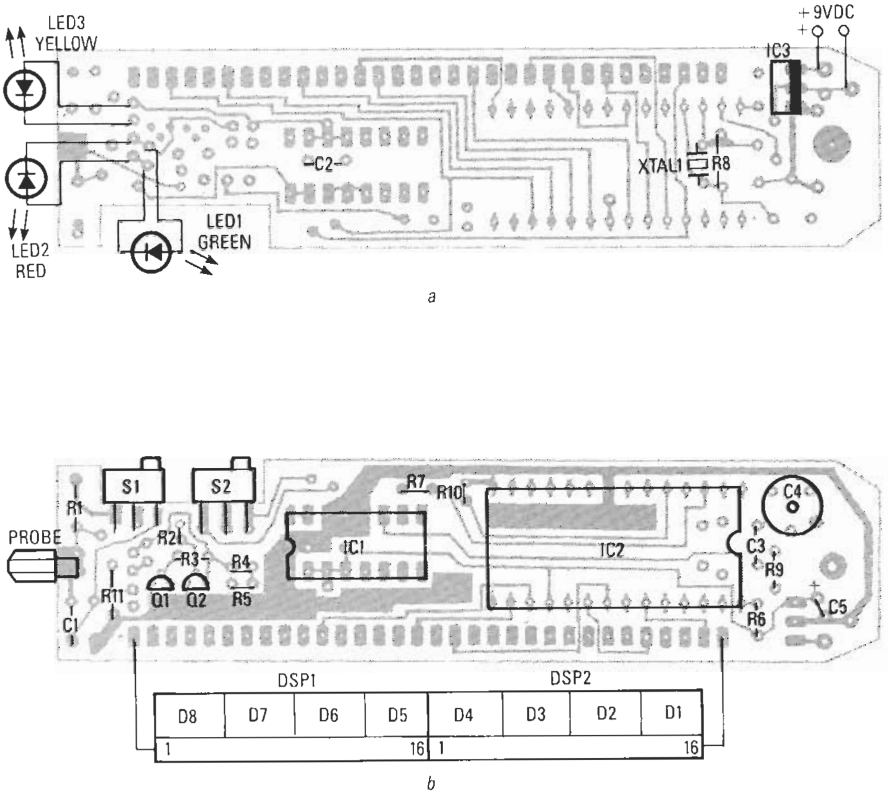

FIG. 5—THE PARTS-PLACEMENT DIAGRAM for the frequency probe, showing the foil (*a*) and component (*b*) sides. In (*a*), both IC3 and XTAL1 are bent flat.

fit in the case. If you're using the case in the parts list, clip the four plastic standoffs extending from the top with a pair of wire cutters as close to the base as possible. Next, cut the openings for the LED display and switches in the case as shown in Figs. 4-*a* and *b*. The case is polyethylene, so it can be cut initially with an X-acto knife, and finished with a jeweler's file or emery board.

Solder S1 and S2 first; clip the leads so their length is identical to that of the pads. Next, place each on top of its pads, and secure with solder, tweezers, or tape. Solder the three terminals to the pads, and repeat for the other switch. The bodies of S1 and S2 should fit snugly into the recess in the PC board, and the fronts of both switches should line up with the edge of the PC board. Then, solder all parts except IC3 and LED1–LED3, which go on the foil side. When soldering a component on a two-sided PC board without plated-through holes, you must solder the leads on both sides of the board. You must also solder short pieces of wire through any holes that do not have component leads going through them. Mount C2 on the foil side, leaving a slight space. Solder the leads as they go through the component side, clip as close as possible,

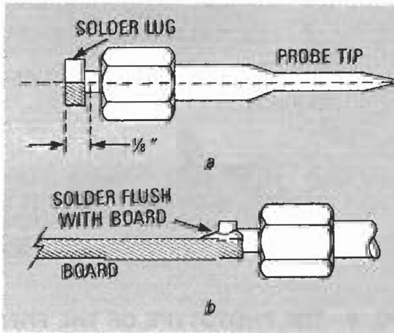

FIG. 6—TO MOUNT THE LOGIC PROBE TIP onto the frequency probe PC board, file ⅛-inch of the bottom of the hex-nut-shaped solder lug flat down to the centerline of the logic probe tip. Then, solder it flush to the correct pad on the component side of the PC board.

and inspect for poor solder joints. Care here will go a long way to having the probe work on power-up.

Next, install XTAL1; it lies flat along the PC board surface, so bend the leads at a 90° angle as close to the crystal housing as possible. Use heat-shrink tubing or electrical tape to insulate the housing against the foils. Next, solder R8, IC1, and IC2, inserting from the component side, and solder all the pins on the foil side. Solder the rest of the component-side components, paying attention to the parts-placement diagram of Fig. 5-*a* and *b*. Also, R2–R7 and R10 are mounted

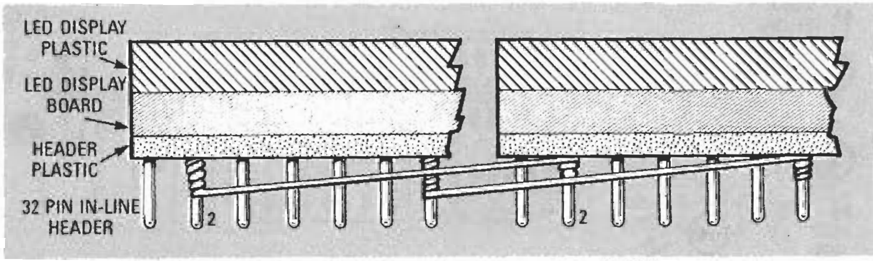

FIG. 7—YOU MUST CONNECT pins 2, 7, 8, 11, 12, 13, and 16 of DSP1 to the corresponding pins of DSP2 using wirewrap.

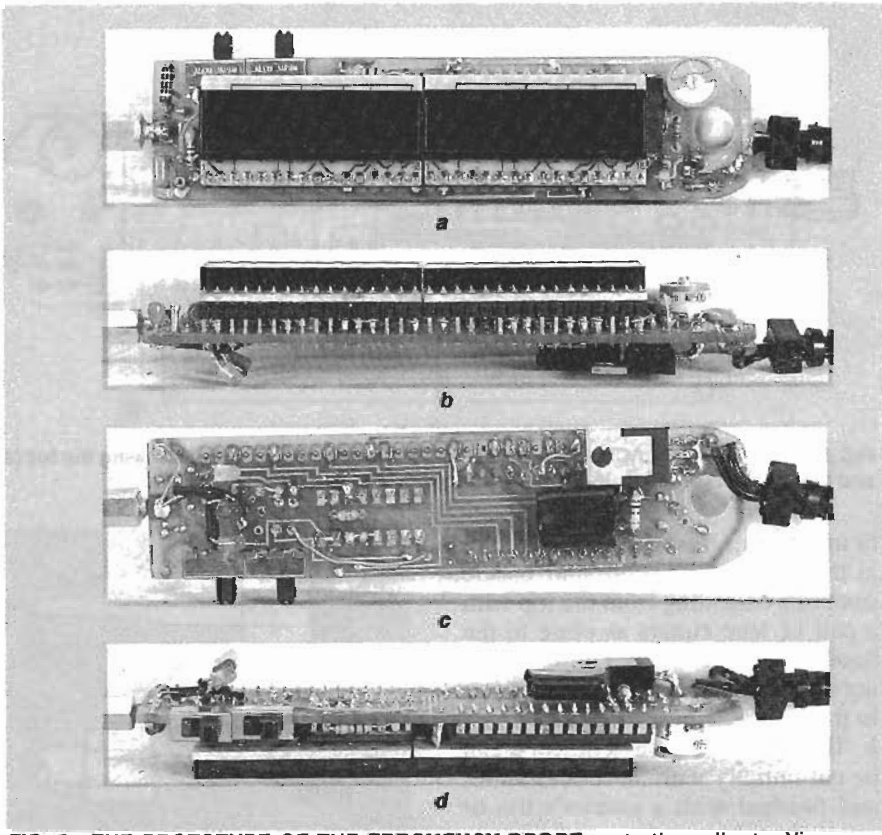

FIG. 8—THE PROTOTYPE OF THE FREQUENCY PROBE; note the callouts. Views are shown from the component side (*a*), edge-on showing the header strip for DSP1 and DSP2 (*b*), from the foil side (*c*), and edge-on showing C4, IC2, IC1, S1 and S2, from left to right (*d*).

vertically, and R1, R9, and R11 horizontally on the PC board.

The foil layout for C4 should accept different size trimmers, but they shouldn't exceed 0.5-inch in height or diameter. Strip 1 inch of insulation from the leads of the alligator clips. Solder the white stripped lead to the positive pad on the foil side, and the black lead to the negative pad. The probe tip should be 0.125 inch down to its center line as shown in Fig. 6-*a*, and soldered flush to the component side as shown in Fig. 6-*b*. Once the probe is soldered, let it sit for awhile because it'll get pretty hot.

The 8-digit LED display is composed of two National Semiconductor NSB3881 4-digit displays DSP1 and DSP2, and their segment anodes have to be wired together to form one complete display. Insert a 32-pin, single in-line male header through the underside of the LED display boards (LED side up), so that the LED display sits on the header insulation strip. Solder the LED display to the header from the top; don't apply excessive heat, or the LED display pads may lift. Using wirewrap or fine insulated wire, connect the pins of DSP1 indicated in Fig. 7 to the corresponding pins of DSP2.

If you use wirewrap, use 4–5 turns because you'll need to leave about ¼-inch of header pin bare to insert into the PC board. Wirewrap is recommended, and once the pin has been wrapped, a little solder will ensure that the connection is sound. Once DSP1 and DSP2 are wired correctly, insert the header into the PC board until the back of the LED display board touches the top of IC1 and IC2, and solder the header in place.

Fig. 8 shows the prototype from several perspectives, with component callouts. Fig. 8-*a* was taken from above and shows DSP1, DSP2, and the component side of the PC board, Fig. 8-*b* from the side of the header for DSP1 and DSP2, Fig. 8-*c* shows the PC board from the foil side, and Fig. 8-*d* shows the fronts of S1 and S2. The completed PC board fits very tightly in the PC board case, so there are several specific actions to take to ensure proper operation. Just note that there are several minor differences between the prototype and the plans we're giving you, so don't worry if you see something in the photos that does not agree with the plans.

Checkout and calibration

To check out the probe, connect the alligator clips to a 9-volt battery; the LED display should read 0.000 if it works. If not, use a meter to check voltages. Look for +5 volts on pin 3 of IC3; if it's not +5 volts, the display might be upside down. If it keeps changing, or segments flicker on and off, there's probably a cold joint. If you lightly flex the PC board, you'll usually find the trouble. If the LED display reads 0.000, you can calibrate the probe.

Connect a 500-Hz signal to the probe tip, and adjust C4 until the LED display reads correctly. Aim for maximum accuracy at the low end, because errors there will be substantial, compared to signals at 50 MHz or more. Next, try different frequency signals, and adjust C4 until satisfied. You don't need a function generator to check high-end operation; the average household has sources of suitable high-frequency test signals. Two examples used on the prototype were a Fisher-Price remote infant monitor (50 MHz), and an R/C model-car transmitter (72 MHz). To do that, just connect the clips to 9-volts DC, hold the probe nearby, and read the LED display.

The frequency probe can be used for RF, but is primarily for high-frequency logic circuits. When measuring a signal, use the second or later gating for best accuracy. Once you've gained experience with the probe, you'll be surprised by its simplicity. **R-E**