Frequency Counter In A Probe

Completely self-contained in a handy probe, this frequency counter was constructed using a unique assembly method that makes possible an instrument that is rugged, compact and convenient to use.

WALTER T. CARDWELL, JR.

MANY CONSTRUCTION ARTICLES DEAL with digital frequency meters, and some of these meters are quite small and portable. A few offer prescalers to increase the range of operation, but the increase in performance means one more box and more cables to clutter your work area.

The frequency meter described in this article is constructed using a new method (see "IC Bricklaying" in the December 1977 issue) that results in a complete crystal-controlled, dual-range, six-digit frequency meter not much larger than a pen. The meter operates from 0 to 750 kHz with 1-Hz resolution, or to 2.5 MHz with 10-Hz resolution. You can build prescalers that plug into the tip of the meter, and that can extend the range to 1 GHz. Additional circuits, combined with plug-in probe tips, greatly increase the device's capabilities and functions.

How it works

The meter is constructed by using what can best be described as a bricklaying technique. (See "IC Bricklaying", *Radio-Electronics*, December 1977.) The IC leads are cut flush with the bottom of the package. The wide section of the IC leads that remain on the side of the package is used as a bonding pad for making connections. Normal AWG No. 30 solid wire-wrap wire is used to connect the IC's, using point-to-point wiring. This quick-and-easy method allows you to change the circuit more easily than when PC boards are used. In addition, no chassis or other structural support is required. The IC's themselves are the supporting structure.

Circuit description

The meter is built around two MC14553B three-digit CMOS (*C*omplementary *M*etal *O*xide *S*emiconductor) counters. Figure 1 shows the block diagram of the IC, which incorporate three decade counters, three 4-bit (quad) latches and an output multiplexer, with multiplexer oscillator. The master reset signal not only clears the counters but also sets the multiplexer to the first digit. One MC14553B counter is used as a master whose multiplexer oscillator drives the slave multiplexer.

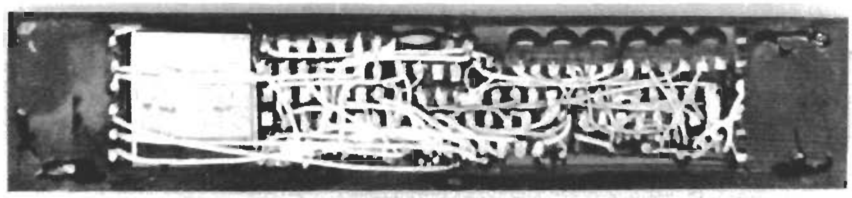
Figure 2 shows the schematic of the probe's main body. Two MC14553B's, IC10 and IC13, are cascaded to form a six-decade counter, and only one scan clock is used. Capacitor C2 sets the scan-oscillator frequency of IC13, which acts as the master and drives the slave IC10. Both master resets are connected to synchronize the multiplexers. By using a master/slave scheme, only one clock capacitor and one set of digit drivers are required.

The latch output is applied to the Q-outputs, and the appropriate digit select line, DS, goes low. The Q-outputs connect directly to two seven-segment, decoder-latch drivers, IC9 and IC12; the latch section is not used. Drivers IC9 and IC12 incorporate NPN pull-up transistors on the output lines so that no external segment drivers are required.

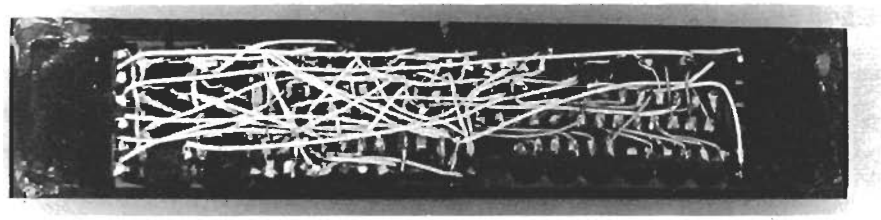
The DS-outputs of IC13 connect to PNP transistor bases Q2–Q4, which are used as emitter-follower digit drivers.

You can use any 100-mA PNP transistor, but it should be housed in a small TO-92-style plastic case. When transistors are used, the wire-wrap wire is wound around the transistor lead and soldered. The transistor lead is then clipped as close to the case as possible.

There is a design compromise in the display driver circuit. As shown in Fig. 2, there are no segment current-limiting resistors because fifteen ¼-watt resistors would be required, which would take up too much room. Instead, transistor Q5 sets the current level by setting the voltage on the driver-transistor collector. Transistor Q5 should handle about 300 mA of current. The three-digit displays are fairly well matched and the digits all have equal brightness. If both three-digit readouts are not matched to each other, use two sets of drivers to set the levels independently. So far, this modification



SMALL SIZE of probe-type frequency counter is due to IC "bricklaying" construction technique. IC's are glued together for maximum use of alloted space.



POINT-TO-POINT wiring is used exclusively in construction. Wires are soldered directly to the IC pins. Discrete components are attached wherever room permits.

PARTS LIST

All resistors ¼-watt, 10%
Probe body:
R1,R5—100,000 ohms
R2-R4,R6,R12,R16—10 megohms
R8-R11—1 megohm
R13,R15—10,000 ohms
C1—25 pF, 10-volt disc
C2—.001 μF, 10-volt disc
D1-D6—1N914 diode
Q1—2N5220 (Motorola), any 100-mA NPN No. T0-92 transistor
Q2-Q5—2N5221 (Motorola), any 300-mA PNP No. T0-92 transistor
IC1,IC2—CD4013 (RCA), MC14013 (Motorola), dual type-D flip-flop
IC3—74C04 (National), hex inverter
IC4—CD4001 (RCA), MC14001 (Motorola), quad 2-input NOR gate
IC5—CD4518 (RCA), MC14518 (Motorola), dual BCD up counter
IC6—CD4017 (RCA), MC14017 (Motorola), decade counter/divider
IC7—CD4023 (RCA), MC14023 (Motorola), triple 3-input NAND gate
IC8—MM5369 (National), programmable oscillator divider
IC9, IC12—CD4511 (RCA), MC14511 (Motorola), BCD-to-seven segment latch/decoder/driver
IC10, IC13—MC14553B (Motorola), 3-digit BCD counter
IC11—74C08 (National), quad 2-input AND gate
XTAL1—3.57-MHz crystal
DSP1, DSP2—3-digit, common-cathode, 7-segment LED display (HP 5082-7433 or equal. Three 2-digit displays may be substituted.)
S1,S2—cut from 80-pin, .125-in. edge connector
Misc.—⅛-in. and ¹⁄₁₆-in. black opaque acrylic plastic, ¹⁄₁₆-in. transparent amber acrylic plastic, ABS plastic sheet (*Plastruct*) and I-section, AWG No. 30 wire-wrap wire, cyanoacrylate glue.
Battery pack:
BATT 1—(4) 20-mAH NiCad cells
R1—1000-ohm, 10-turn trimmer
IC2—MC1403 (Motorola), precision low-voltage reference (2.5V ± 25 mV)
One miniature mike connector
Misc.—Double-clad, ¹⁄₁₆-inch No. G-10 PC board. ¹⁄₁₆-in. black acrylic plastic.
Probe tip:
R1,R3—100,000 ohms
R2—10 megohms
C1,C2—0.01 μF, 50-volt disc
D1—1N914 diode
IC1—CD4013 (RCA), MC14013 (Motorola), dual type-D flip-flop
S1—SPST normally open miniature pushbutton switch
S2—2 copper nails
Misc.—¹⁄₁₆-in. black acrylic plastic, double-clad ¹⁄₁₆-in. No. G-10 PC board, ½-in. clear plastic, ⅛-in. piano wire.

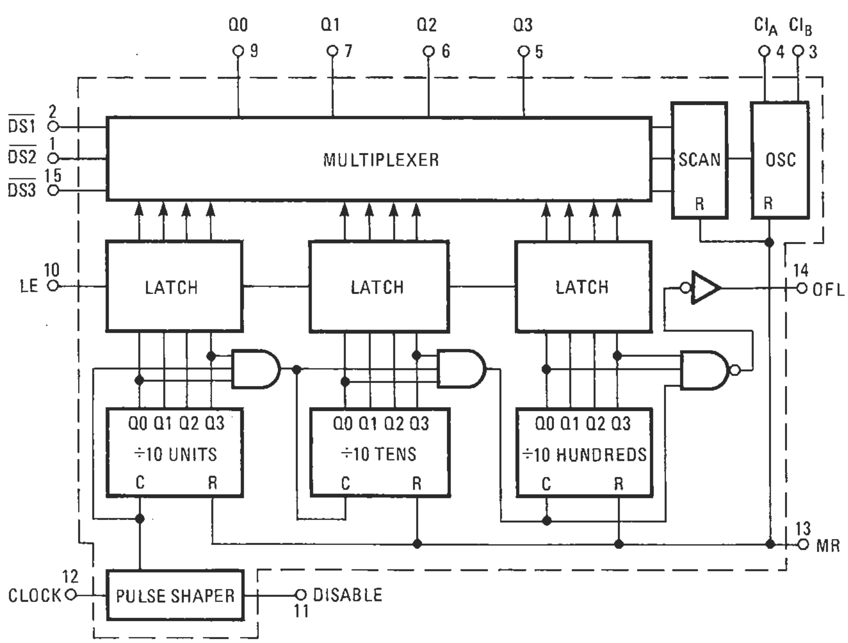


FIG. 1—BLOCK DIAGRAM of the MC14553 CMOS 3-digit BCD counter used as the heart of the frequency-counter-in-a-probe. Two are required for the 6-digit LED readout.

has not been necessary. The brightness of the digits varies slightly, depending on which number is displayed. However, this variation is not objectionable.

You can use any three-digit common-cathode seven-segment readout. With these readouts, the total current drawn by the entire meter is 35 mA, with a 10K resistor from the base of Q5 to ground. A 4.7K resistor increases the display brightness, but it also increases the current drain to 50 mA. The base lead is brought to the power-supply socket to increase the intensity when the meter is not being battery-operated.

The MC14553B IC's 10 and 13 count when the DIS signal is low. An IC13 overflow clocks IC10. The counter data is transferred to the latches when the latch signal is low. Master reset MR resets both counters and multiplexers.

The input amplifier consists of a 74CO4 hex inverter used as a linear amplifier. Each inverter has a gain of about 10 dB at 2 MHz and 5 volts. The first inverter is biased in the linear region

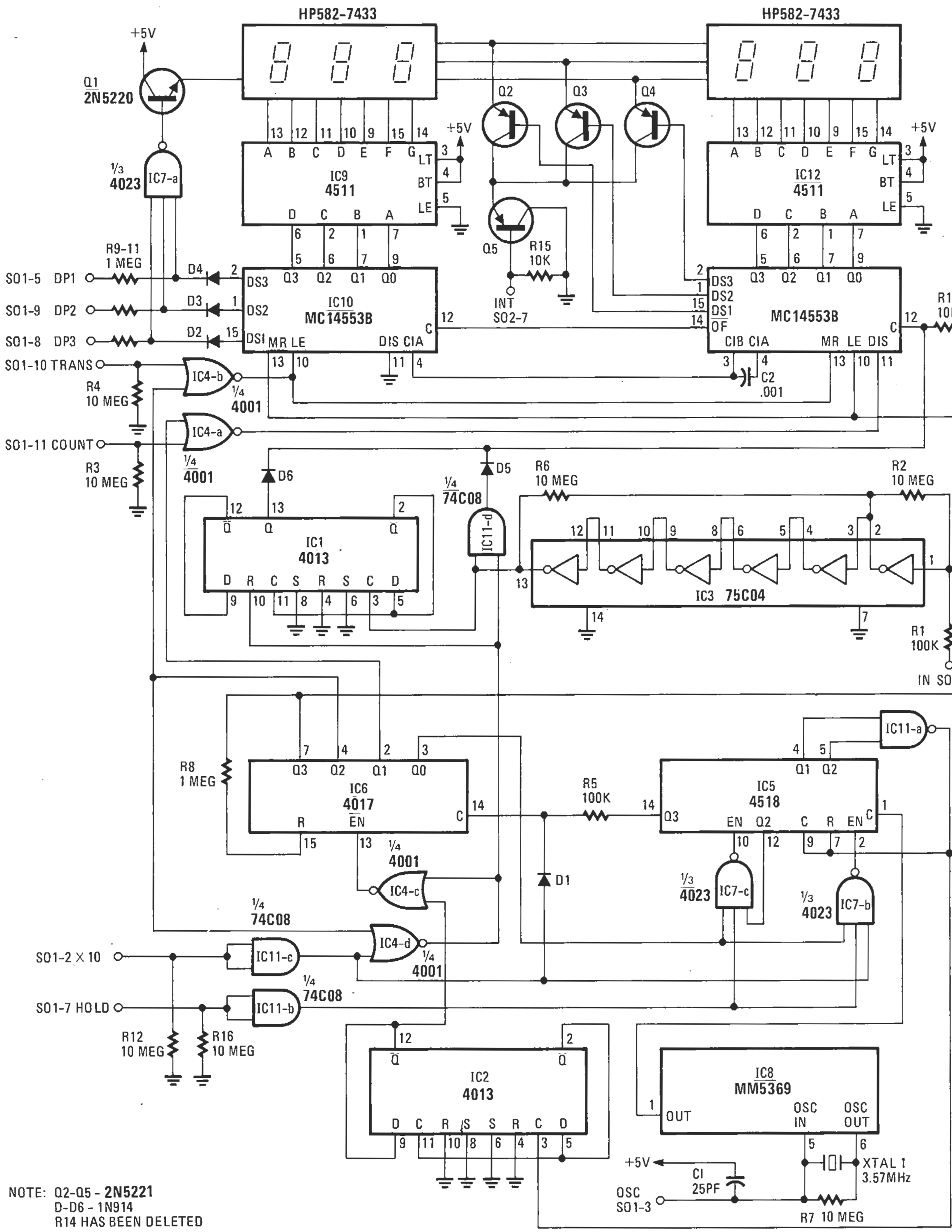


FIG. 2—FREQUENCY-COUNTER schematic shows the simplicity of this novel instrument. CMOS-type IC's and the transistors are used to reduce power consumption.

by R2. Resistor R1 limits the input current on high-level signals. The maximum input current to any CMOS input pin is 10 mA and is set by the IC's internal metallization. Higher currents can cause the device to fail, either because the metal migrates or the aluminum melts. While the CMOS input impedance is usually high, it falls to a low value when the input protection diodes conduct. This occurs when the input exceeds the supply voltages. The 100K input resistor insures that the input-current limit of 10 mA is not exceeded until the input is greater than 1000 volts. When the diodes conduct, the input impedance is 100K; when they are not conducting, the input impedance is 10 megohms.

The remaining five inverters are brute-forced for maximum gain and are biased by resistor R6 to operate in the linear region. The input sensitivity depends on the IC; sensitivities can sometimes be as *continued on page 100*

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low as 50 mV and as high as 1 mV. The input is not filtered for noise since the 74C04 gain decreases rapidly above about 2 MHz. You can add a noise filter, if necessary, to the input probe section. All IC stages are direct-coupled, so that the input blocking capacitor in the probe tip determines the low-frequency response. The capacitor is located in the tip so that add-on devices can be direct-coupled to the counters.

When the meter is used as a frequency counter, the input pulses are counted for 1 second in the normal mode or for 0.25 second in the ×10 mode. Because the MC14553B IC only counts to 750 kHz at 5 volts, dual-D flip-flop IC1 is used as a divide-by-4 prescaler in the ×10 range. The input-amplifier output is fed to the prescaler and to AND gate IC1-d. In the normal mode, the gate is on and the input is applied directly to the counter through D5. The divide-by-4 prescaler is disabled by a reset signal that overrides the clock. In the ×10 mode, AND gate IC11-d is off, and the input is divided by IC1 and applied to the counters through D6. Diodes D5 and D6 and resistor R13 form a simple OR gate since there was no room for another IC.

The time interval is generated by a crystal-controlled reference oscillator, in which XTAL1 is a 3.5795-MHz color-TV color-oscillator crystal. The 3.57-MHz frequency is divided by IC8 to produce a 60-Hz output. A trimmer can be added to the oscillator from pin 6 to +5 volts.

(A color-TV crystal usually comes in a large metal crystal can that cannot fit into the meter; therefore, the crystal case must be altered. The crystal should have a phenolic base, not a metal base. Remove the metal case carefully by cutting and peeling it with diagonal cutters. The crystal itself is supported in the center of the can by the two leads that pass through the bottom, as shown in Fig. 3-a. Once the crystal is removed from the case, glue two short plastic "I" sections to the phenolic base with the support wires sandwiched inside the channel (see Fig. 3-b). Glue a short piece of plastic to the top and then glue two flat covers to the "I" beams and the phenolic base. When the crystal is completely enclosed and protected, file the case so that it is flat and square on all sides, as shown in Fig. 3-c. You can use the ABS plastic known as *PlasTruct* available at most hobby shops in both flat sheets and structural shapes. This plastic material is easy to work with since you

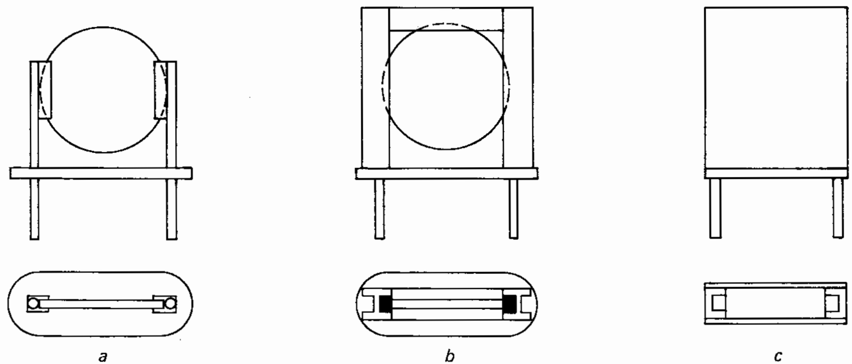

FIG. 3—HOW CRYSTAL CASE IS MODIFIED so the crystal can be fitted inside the probe case. The crystal is fragile. Be careful so you won't damage it.

can cut it either with a razor blade or with scissors. Cutting down the crystal case allows room for two extra IC's on the top of the case—IC1 and IC2. *Caution*: Even in its usual case the crystal is isolated from shocks only by the wire leads. The crystal is very delicate and can crack if it is dropped. For this reason, handle the meter carefully when it is finished.)

The 60-Hz output of IC8 goes to BCD up-counter IC5. One section is used to divide the 60-Hz output by 6. When 6 is reached, IC11-a resets the counter. The output of the divide-by-6 counter then feeds the next BCD counter to produce a 1-second clock period. It is also divided by dual-D flip-flop IC2, to produce a 0.25-second period used by the ×10 mode.

The control signals for the counters are generated by IC6, a 10-output decade counter. Each output used performs one function. Output 0 is the start of an operation. When the hold input is high, IC7-b stops the divide-by-6 clock when in the ×10 mode and when the 0 state is reached, and IC7-c stops the divide-by-10 clock when in the normal mode and the 0 state. When the hold line is low, a conversion begins on the next clock. Output 1 of IC6 is the count state and lasts for 1 second in the normal mode, or for 0.25 second in the ×10 mode. During this

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time, the DIS signal of IC13 is low, which enables counters IC10 and IC13. Output 2 of IC6 is the latch state; it lasts for 0.25 second, in any mode. Output 3 is the reset state, and resistor R8 stretches the reset pulse so that the main counters will clear. If the hold line is held low, the conversions will be continuous.

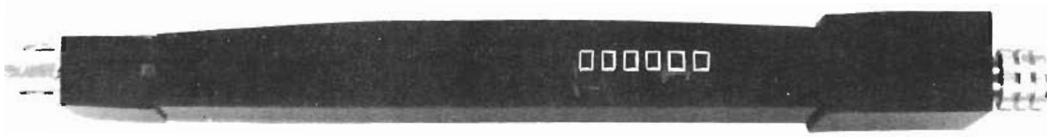
To save on the number of gates used, IC6 is clocked by the 1-second clock at the clock input and is clocked by the 0.25-second clock at the enable input. For the clock input to be active the enable input must be low; for the enable input to be active the clock input must be high. Diode D1 holds the clock input high in the ×10 mode, and IC4-c and IC4-d activate the enable input for use as a clock during the ×10 mode and during the latch state of the normal mode. Both the ×10 input and hold input are buffered to allow touch control operation from the probe section.

You can use IC4-a and IC4-b to disable the control circuitry. A count line and a transfer line are carried to the front socket. A high signal on both lines, with the hold line low, causes the display to act as a counter. The meter can then be used as an event counter.

Integrated circuit IC7, along with diodes D2–D4 and resistors R9–R11 are used to control the decimal point of the display. Only the first three decimal points are used. If no decimal point is lit, the frequency is in Hz. If any decimal point is lit, the frequency is in MHz; thus the first three decimal points allow a 999.999-MHz range. Transistor Q1 is an NPN emitter-follower to match the emitter-followers of IC9 and IC12. It is not critical. Any NPN transistor should work. If any resistor (R9–R11) is grounded, that decimal point will light. The diodes charge the input capacitance when the DS-outputs of IC10 are high. This charge will remain due to the CMOS high-input impedance unless the resistors are grounded. All decimal-point resistors are left floating in the main body of the meter.

continued next month

Frequency Counter In A Probe



Part 2—Completely self-contained in a handy probe, this frequency counter was constructed using a unique assembly method that makes possible an instrument that is rugged, compact and convenient to use.

WALTER T. CARDWELL, JR.

Beginning last month, this article describes an instrument that is constructed using an unusual technique (see "IC Bricklaying" in the December 1977 issue). Counter measures to 2.5 MHz with 10-Hz resolution.

Now build one

Figure 4 shows component placement using the "bricklaying" technique and keying of sockets S01 and S02. Glue a 12-pin socket on each end of the block of IC's, and a 1/16-inch acrylic plastic spacer between the socket pins. Then clip the socket flush with the spacer to allow 1/16-inch of space for soldering leads to the socket. Cut the sockets from an 80-pin PC-board edge connector.

The case is made from black opaque acrylic plastic. Glue a 1/8-inch-thick piece, as wide as the IC block, to the sides of the sockets at each end. On the front, glue a 1/16-inch black opaque piece of plastic to a 1/16-inch piece of transparent amber plastic; this strip is then glued to the front side with the transparent part placed over the readouts. Use cyanoacrylate glue, but don't get glue on the plastic surface.

Once the two sides are in place, file the top and bottom of the block flat using a metal file. You can curve the top to make it more comfortable to hold and easier to identify. When you file the block, bring the sides down as close to the IC's as possible to keep the overall size of the meter small. Be careful of the wires when you file. If the wiring is covered with tape, you are safe until the tape is marked by the file. You may have to add shims to the top of the sockets if the sockets are not as thick as the IC block. Once the top and bottom have been filed, glue two more pieces of 1/16-inch black plastic to the top and bottom. If you use cyanoacrylate glue, you can open the case easily by inserting a razor blade along the seam.

The square block that plugs into the back is the battery pack and is made from 1/16-inch glass-epoxy double-sided PC board. The battery case is also made of black acrylic plastic. The meter is powered by 20 mAH NiCad button cells. Also included in the power supply is a 2-volt reference, using an MC1403 IC and a 1000-ohm, 10-turn trimmer (see Fig. 5). This voltage reference will be used by certain meter accessories (still on the drawing board) that will plug into the front of the unit. You can use larger batteries if you don't find their weight and size objectionable.

The probe tip on the front contains the blocking capacitor, the ×10 prescaler and hold switch. A CD4013 dual-D flip-flop generates the hold and ×10 signals. The two dots on the top of the probe tip are two small copper nails inserted through a 1/4-inch black plastic strip and filed flush. These nails serve as a touch-control switch (S2) to select the ×10 range. One side is connected to the +5-volt supply through a 100,000-ohm isolation resistor, as shown in Fig. 6-a. Placing your finger across the pins charges capacitor C2 through resistor R3 and the skin resistance. Diode D1 and capacitor C2 must be used to eliminate the 60-Hz charge that the body receives from the

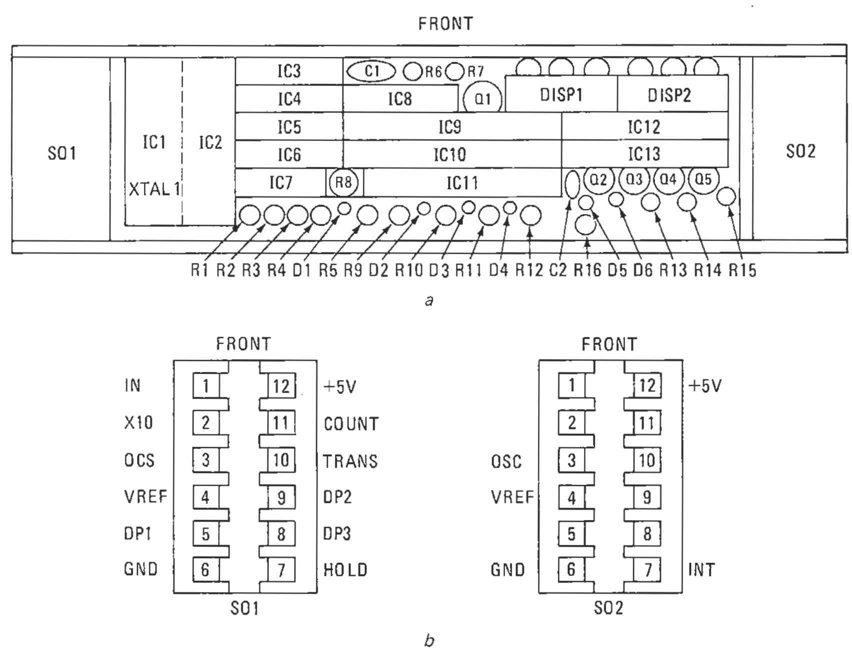


FIG. 4—INTERNAL LAYOUT of probe showing component placement. Location of signals on socket pins is shown in *b*.

power lines. Resistor R2 discharges capacitor C2. Charging C2 sets the dual-D flip-flop; the ×10 input is high and the DP1-display is low. As soon as connector S goes low, output from the 3.57-MHz oscillator resets the flip-flop.

The clear plastic front holds momentary contact switch S1. Cut the front piece from ½-inch clear acrylic plastic, which you then glue to the front of the completed black plastic back section of the unit. Sand both pieces with 100-grit sandpaper in a disc sander until you obtain the final shape (see Fig. 6-b). The drawings do not show dimensions since the size depends on the components used. Sand the probe tip with finer-grit paper, stopping at 400 grit.

Once the shape is roughed out, remove the clear plastic section with a razor blade. Drill a 1/16-inch hole through the center to hold the wire probe tip, which is made from ⅛-inch piano wire ground to a point. Wrap AGC No. 10 copper wire once around the back end and silver-solder it using a propane torch. Then, file the copper until the tip resembles a long flathead nail.

The ⅛-inch hole in the clear acrylic plastic is drilled out from the back deep enough so that the SPST miniature push-button switch fits completely in the clear plastic section. Remove the pushbutton and metal section. Then, remove a white spacer on the red pushbutton to the end of the copper head on the probe tip. Room is hollowed out in the clear plastic to contain the switch lugs, which are bent at right angles to the switch body.

Solder two wires to the copper part of the probe tip. These wires must be flexible; we recommend phonograph pickup wires. Before assembling the switch, glue the clear plastic back on the probe front. Then, to restore the gloss on the plastic, polish the entire unit, using jewelers' rouge on a cloth buffing wheel. Be careful not to let the edges catch in the buffing wheel.

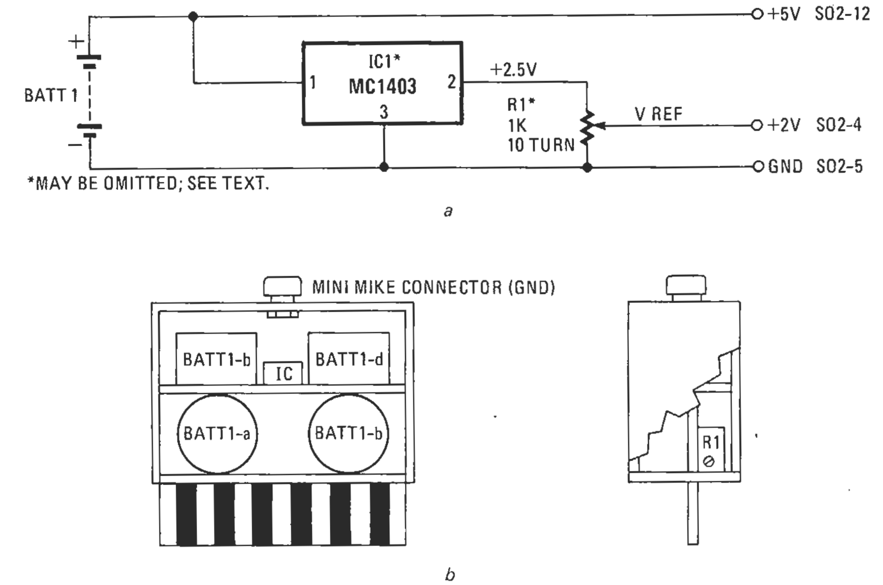


FIG. 5—POWER SUPPLY SCHEMATIC AND PARTS LAYOUT. The MC1403 voltage-regulator IC and the 1K pot are for a 2-volt source used as a reference for accessories not yet completed.

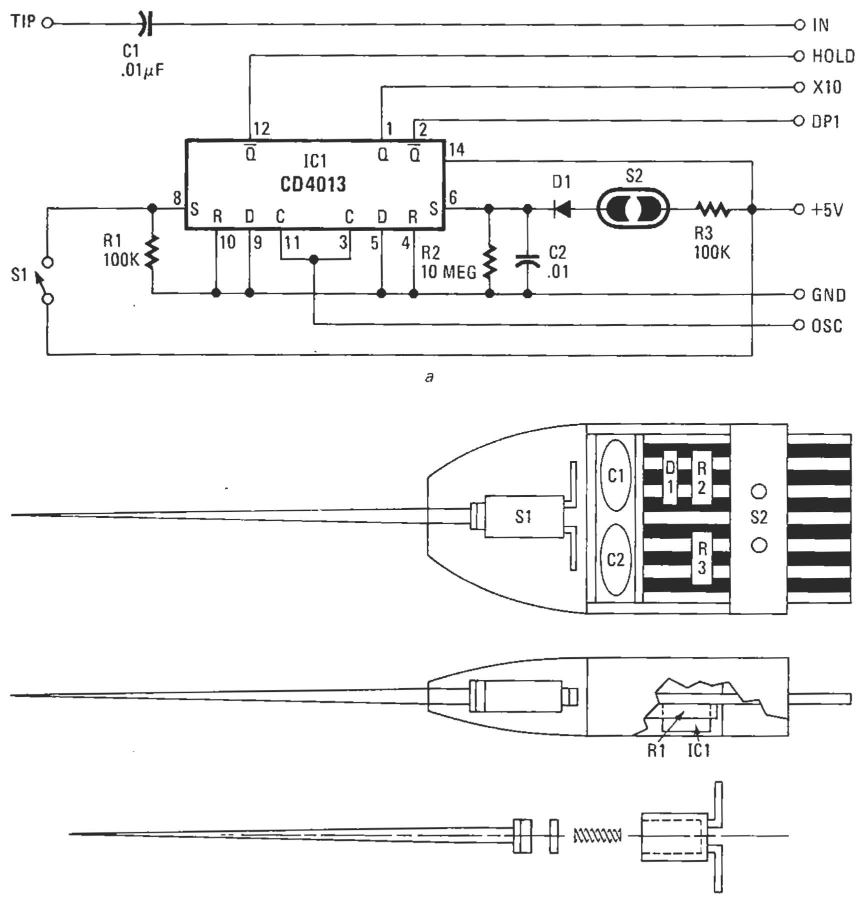


FIG. 6—CONSTRUCTION AND SCHEMATIC DIAGRAM of the probe front-end. The prescaler uses a CD4013 and is turned on by touch switch S2 consisting of two tiny nails.

Calibration is the next step

After the probe tip is polished, you can assemble it. Unglue the clear plastic section again and file off the old glue from both sections. Push the probe tip through the ⅛-inch hole that was drilled in the clear plastic section. Insert first the spring and then the flat contact disc into the switch body. Place the switch assembly in the back of the clear plastic section and glue it in place. There should be sufficient room at the front of the switch body to allow the wires on the probe tip to move. Check the switch to make sure that it closes when the probe tip is pushed in. When the switch is finished, connect the wires to the switch, and the probe tip wires to the input capacitor. The clear plastic section is now glued to the front permanently. Any glue that appears on the surface can be removed with the buffing wheel. Be especially careful of the sharp point waiting to get you if it catches in the wheel!

When the tip is pushed in, the meter will convert until it is removed. The count will be held as long as the tip is not pushed in. When the prescalers are added you insert them between the probe tip and the meter body.

The usefulness of the basic frequency probe can be greatly expanded by accessories that plug into the main body. You can add a 5-volt calculator battery eliminator so that the meter can function off the AC power line. You can also construct a new front section so that you can use the probe as a normal bench meter. You can also add a 20-MHz to 125-MHz prescaler. Due to the construction of the main body, the number of accessories you can add is almost unlimited. R-E