TV Derived Frequency Standard

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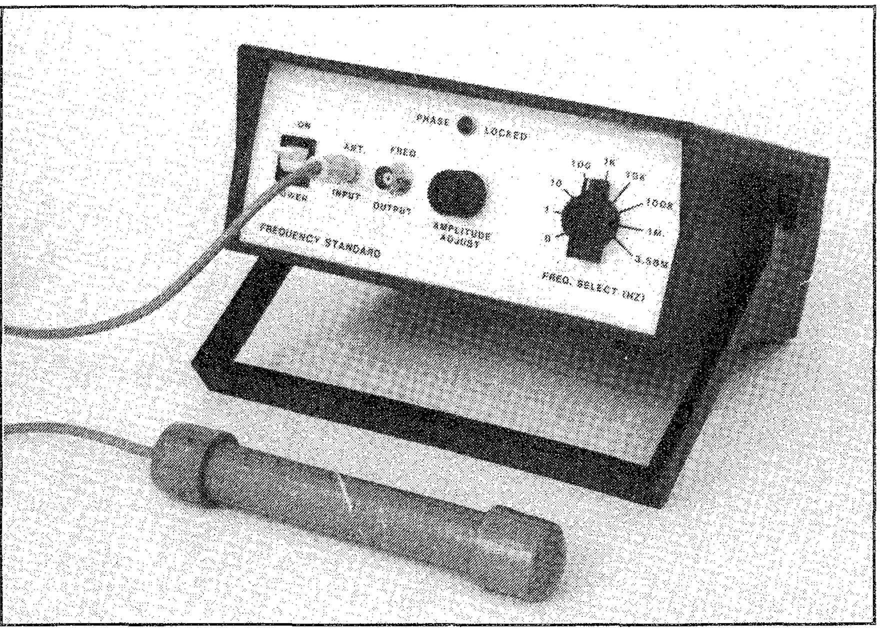

You can use almost any TV as an accurate frequency reference.

REGARDLESS OF THE KIND OF MEASUREment being made, you must always consider the accuracy or tolerance of the tool you're using. Sometimes, overall accuracy isn't important because all that's needed is an approximation of a circuit's voltage, current, frequency, or whatever. But in most cases, simply using an approximation isn't good enough when the technology becomes more complex; in thoseinstances, a more precise degree of accuracy is necessary. The general rule regarding measurement-accuracy is for the test equipment to be at least ten times more accurate than the parameter being measured.

Measurement standards, to which all other standards of measurement are compared, are set for the United States by the *N*ational *B*ureau of *S*tandards (NBS), a branch of the U.S. Department of Commerce. Calibrated measurement devices having documented proof of being compared to the primary standards at NBS are referred to as *secondary standards.* (A system of secondary standards have been worked out world-wide for use by anyone who has a need for such accuracy.)

NBS distributes time and frequency reference standards through a radio system known as WWV, which operates on numerous shortwave frequencies. The system allows your time and frequency standards to be calibrated by comparison to the WWV signals, a somewhat painstaking process. A simpler and more convenient way for the hobbyist and professional to calibrate time and frequency measurement devices, with greater accuracy than most applications require, is by using a television-derived frequency standard.

Color-TV precision

When television broadcasting converted to color, in order to ensure uniformity of color reproduction throughout the broadcast system, the three major networks agreed to carefully control the accuracy of the color-subcarrier frequency. The subcarrier frequency of 3579545.454 Hz (3.58 MHz) is derived from a precision 5-MHz oscillator controlled by a rubidium atomic-standard that is directly traceable to NBS. Since the synchronization pulses for locking the TV receiver's sweep circuits are derived from the 3.58-MHz color subcarrier, the TV's horizontal-sync (H-sync) pulses are directly traceable to NBS when viewing a network-originated broadcast. It is the NBS-referenced H-sync pulse that is used by the television-derived frequency standard to provide more useful reference frequencies for the electronic hobbyists and professional.

How it works

The television-derived frequency standard has three primary functions. First, the 3.58-MHz subcarrier is recreated by frequency-multiplying the H-sync pulse picked up by the standard's antenna (which is a resonant circuit tuned to 3.58 MHz that is placed near a TV set). Second, a submultiple of the 3.58-MHz signal is used to tune and hold a phase-locked oscillator precisely on 1-MHz. Third, the 1-MHz signal is step-divided in 10:1 steps to provide the user with output signals down to 1 Hz.

The schematic is shown in Fig. 1. Ferrite-rod antenna L1 is tuned by C2 to parallel resonance near the TV horizontal-sweep frequency of 15734.265 kHz. The voltage induced in the antenna is amplified by IC11-d —a logic-inverter that is biased for linear operation. It's output triggers IC1, a 555 timer operating as a monostable oscillator having a time delay (set by R1 and C1) of about 90 microseconds. The timer triggers on every other H-sync pulse, creating a 50% duty-cycle square-wave output of one-half the H-sync rate, or 7867.1325 Hz. That signal is applied to one input (pin 14) of phase detector IC5.

Meanwhile, IC2-a functions as a crystal-controlled oscillator whose output frequency can be "rubbered" (changed slightly) by capacitor C10

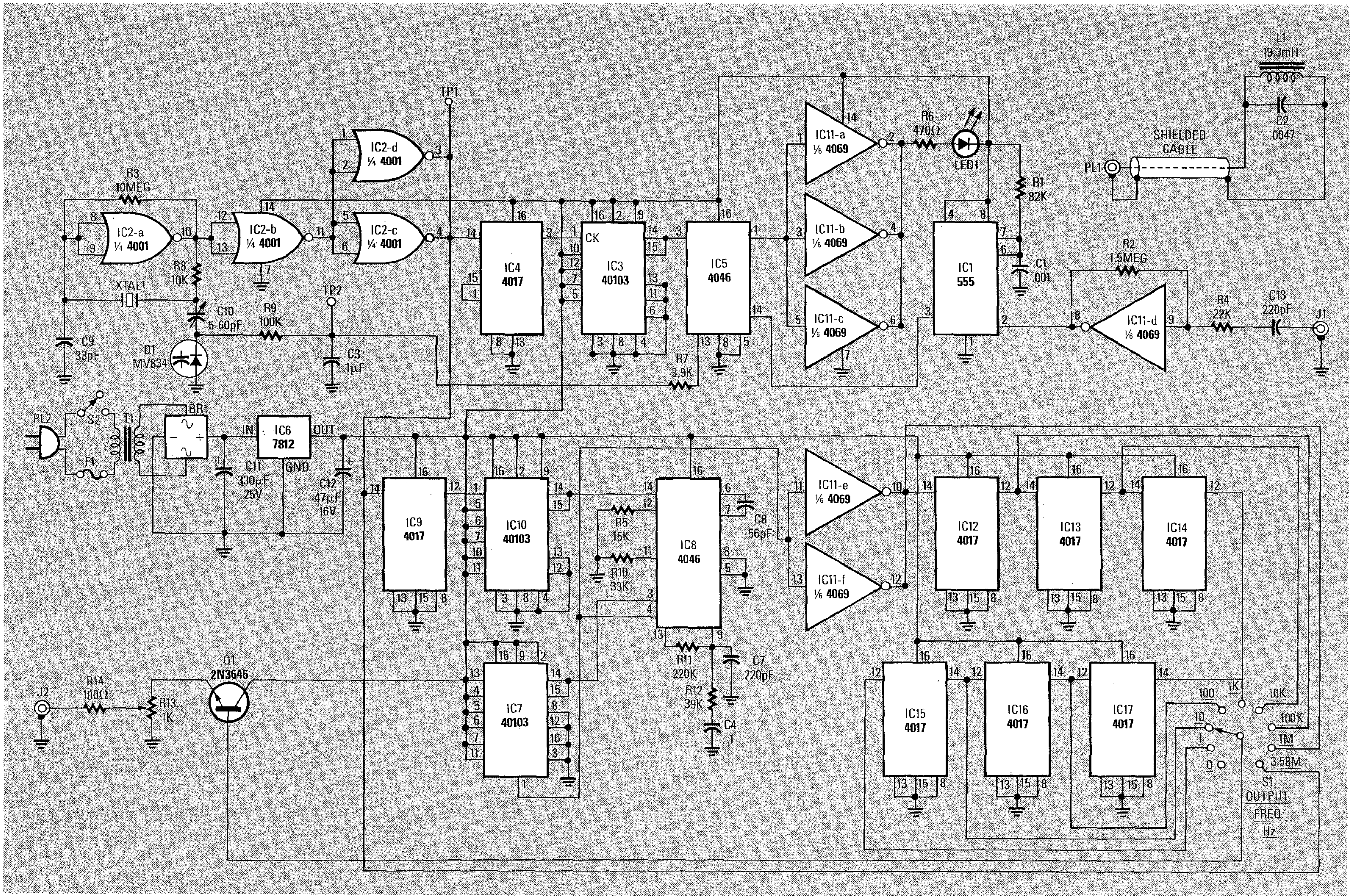

FIG. 1—ALL FOUR SECTIONS OF IC2 are used for the crystal oscillator, while three parallel-connected sections of IC11 are used as the LED driver

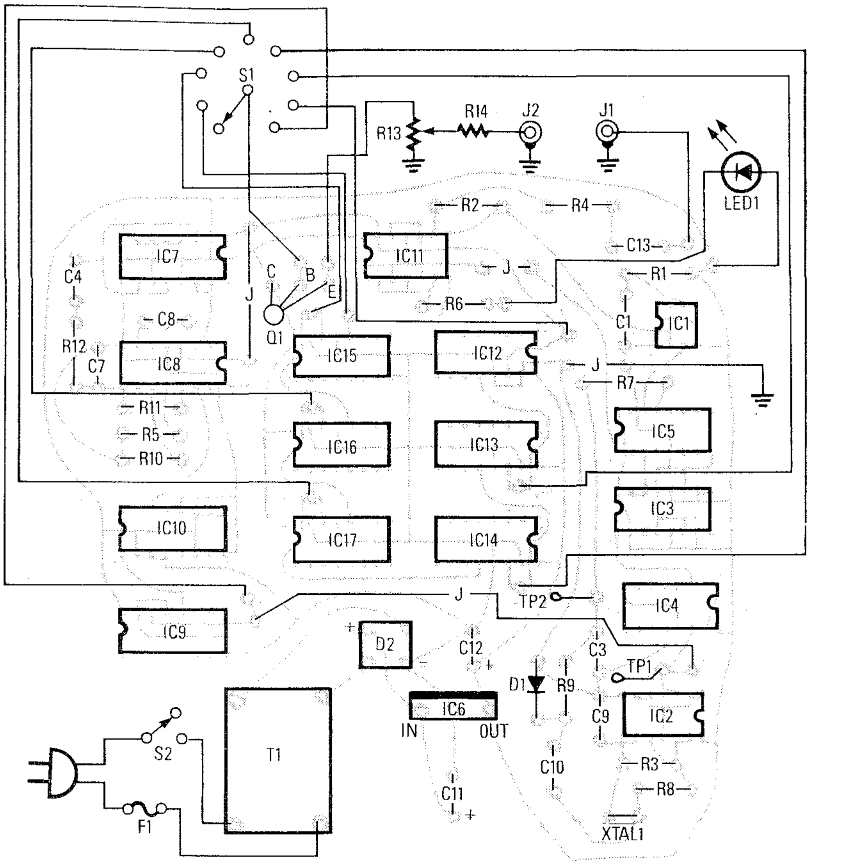

FIG. 2—TAKE EXTRA CARE THAT VARACTOR DIODE D1 is installed with the correct polarity, and double-check the connections to output selector switch S1 before applying power to the circuit.

and varactor diode D1; thus, the crystal-controlled oscillator becomes voltage-tunable. Capacitor C10 adjusts the crystal close to the correct operating frequency, while the capacitance determined by the voltage applied to D1 through R9 determines the oscillator's precise output frequency.

The remaining sections of IC2 are used as buffers to prevent loading the crystal. The output of the buffers, at test point TP1, is divided by IC4 ($\div 5$) and IC3 ($\div 91$) to 7867.1325 Hz, which is applied to the other input (pin 3) of phase detector IC5. The output voltage at IC5 pin 13 varies between zero and 12 volts, depending on the phase difference between the input signals on pins 3 and 14. The voltage at pin 13 is filtered by R7 and C3 and is used to correct the 3.58-MHz oscillator for a zero phase difference at pins 3 and 14. IC5's output voltage (pin 1) is inverted and buffered by three paralleled sections of IC11, which drive lock-indicator LED1.

Something useful

So far, we have multiplied one-half of the horizontal-sweep frequency by 455 to the color sub-carrier frequency of 3579545.454 Hz. Now let's see how we take such an odd frequency and convert it to something that is more useful.

A common sub-multiple of both 3.5 MHz and 1 MHz is used for phase comparison to lock IC8 to exactly 1.000 MHz. The 3.58-MHz reference signal is divided by IC9 ($\div 10$) and IC10 ($\div 63$) to 5681.818 Hz. The frequency of 1 MHz divided by 176 is also 5681.818 Hz, so IC7 is connected as a divide-by-176 counter in the feedback path of IC8, a phase-locked loop oscillator. IC8's free-running VCO frequency is set near 1 MHz by C8 and R5. Resistor R10 creates an offset so that the VCO is restricted to 1 MHz $\pm$ 100 kHz. Restricting the operating range in that manner minimizes the jitter in the output signal caused by system noise when the device is in phaselock.

The output at IC8 pin 13 is a voltage proportional to the difference in the frequency applied to pins 3 and 14. That voltage is filtered by R11, R12, C4, and C7 and is used as the VCO's control voltage input at pin 9. The voltage at pin 9 tunes the VCO frequency until the signals applied to pins 3 and 14 are equal or phase-locked. At phase-lock the VCO's output is a stable, high-accuracy square wave wave of 1.0000 MHz. To review, we have divided 3.58 MHz by 630 and then multiplied the result (5681.818 Hz) by 176 to yield 1.0000 MHz. The original accuracy of the color subcarrier (3.58 MHz) is transferred to the 1-MHz signal.

A series of decade counters, IC12–IC17, divide the 1-MHz signal in decade steps to 1 Hz. Switch S1 selects the desired output frequency signal and feeds it to emitter-follower Q1, whose output level is determined by potentiometer R13. Resistor R14 ensures that the minimum output impedance will be 100 ohms.

Getting it together

While the device can be assembled on perforated wiring board if you're careful to keep lead lengths short, the best method is to use a printed-circuit board. A suitable pattern is shown in PC Service; alternately, the PC board can be ordered from the source given in the Parts List.

The PC board's parts-placement diagram is shown in Fig. 2. Begin stuffing the board by first installing the four jumpers, then the resistors and capacitors—taking particular care that the polarity of the electrolytic capacitors is correct. Next, install XTAL1, using a drop of silicone-rubber adhesive to cement the crystal to the PC board to prevent damage.

Finally, install the IC's, but take note that not all are oriented in the same direction; double-check the location of pin 1 when installing all IC's on the board. And just to be on the safe side, we suggest testing the power-supply section (including IC6) before installing the IC's.

Clean the board with a solvent wash to remove the soldering flux, and then check the board closely for solder bridges, especiallly where the traces pass between the IC pins.

The main circuit can be housed in a metal or plastic cabinet, and just about any kind of layout can be used for the components that are not mounted on the PC board. Figure 3 shows the author's protoype.

The antenna

Antenna-coil L1 should be 19.3 millihenries $\pm$20%. The coil used for

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1—82,000 ohms
R2—1.5 megohm
R3—10 megohms
R4—22,000 ohms
R5—15,000 ohms
R6—470 ohms
R7—3900 ohms
R8—10,000 ohms
R9—100,000 ohms
R10—33,000 ohms
R11—220,000 ohms
R12—39,000 ohms
R13—1000-ohm potentiometer
R14—100 ohms

Capacitors
C1—0.001 µF, 50 volts, ceramic disk or Mylar
C2—0.0047 µF, 50 volts, Mylar
C3,C4—0.1 µF, 50 volts, ceramic disk or monolithic axial
C5,C6—not used
C7, C13—220 pF, 50 volts, ceramic disk or monolithic axial
C8—56 pF, 50 volts, ceramic disk
C9—33 pF, ceramic disk
C10—5–60 pF, trimmer
C11—330 µF, 35 volts, electrolytic
C12—47 µF, 16 volts, electrolytic

Semiconductors
IC1—NE555 timer
IC2—CD4001B quad NOR gate
IC3, IC7, IC10—CD40103B divide by N counter
IC4, IC9, IC12-IC17—CD4017B decade counter
IC5, IC8—CD4046B phase-lock loop
IC6—7812 12-volt regultor
IC11—CD4069B hex inverter
Q1—2N3646 NPN transistor
D1—MV834 varactor diode
D2—Bridge rectifier, 50 volt, 1 amp
LED1—light-emitting diode

Other components
F1—¼-amp fuse and holder
J1—phono jack
J2—BNC jack
L1—19.3 mH, see text
PL1—Phono plug
PL2—Power plug
S1—10-position non-shorting rotary switch
S2—SPST toggle switch
T1—12-volt PC-mounting power transformer
XTAl1—3.58-MHz, type HC-18 color-burst crystal

Miscellaneous: PC board, 70-feet No. 30 enameled wire, ⅜- × 4-inch ferrite rod, enclosure.

Note. The following are available from Pershing Technical Services, P.O. Box 1951, Fort Worth, TX 76101: A drilled and plated-printed circuit board for $20.00. A kit of all board-mounted parts and the printed-circuit board for $65.00. The board is also available assembled, tested, and calibrated for $95.00. Prices are postpaid in the U.S. Allow from 4 to 6 weeks for delivery. Texas residents must add appropriate sales tax.

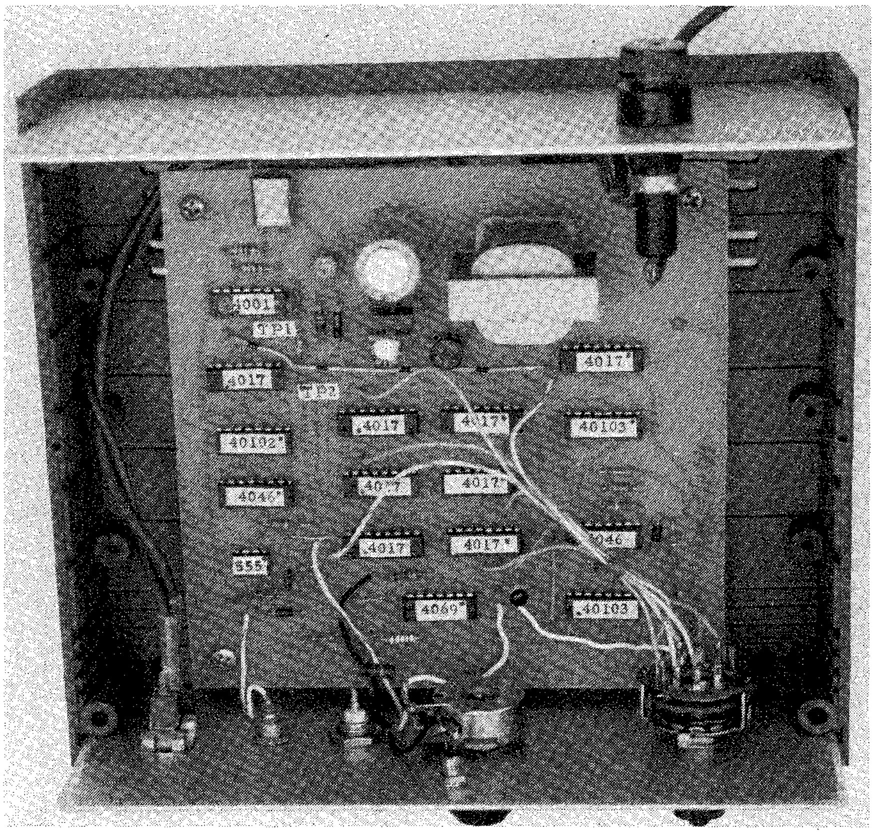

FIG. 3—ANY KIND OF CABINET can be used for the main circuit. Even the layout of the cabinet-mounted components isn't critical. If you wish to use a PC board, the pattern is shown in PC Service.

the prototype is made from 70-feet of No. 30 magnet wire wound on a ⅜- × 4-inch ferrite rod salvaged from a discarded AM radio. (Because reception of the 15,734 Hz pulse from a TV set requires a rather large inductance having many turns of wire, rather than counting turns we are specifying the length of the wire to be wound on the ferrite core.)

The winding is spread evenly along the length of the rod to within ½-inch of either end. (The rod can be inserted in a variable-speed drill because it yields a coil much neater and faster than hand winding.) Secure the wire with tape when finished, but leave three inches free for connection to a length of shielded cable. Tin both free ends and solder C2 and the shielded cable in parallel with the leads. Secure the shielded cable to the coil with tape and set the assembly aside.

The antenna assembly is shown in Fig. 4. The enclosure for the antenna is made from a 5-inch length of ½-in. I.D. plastic water pipe and two end caps. Drill a hole slightly larger than the shielded cable in one of the plastic caps and pass the shielded cable through the hole. Install an RCA-type phono plug on the free end of the cable. Then install a rubber grommet on each end of the ferrite rod and slide the antenna assembly into the plastic pipe. Do not cement the caps in place, just slide them on the pipe.

Connect the antenna to the main circuit via J1.

Adjustment

Place the antenna near an operating TV set and adjust C10 with a plastic

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FREQUENCY STANDARD

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alignment-tool or a non-conducting screwdriver until the LED glows brightly without flicker, and the voltage at test point TP2 is between 6 and 10 volts. If you have problems with the above procedure, perform the following tests:

- Using an oscilloscope, observe the square-wave output at IC1 pin 3; it should be *clean* with no jitter, as shown in Fig. 5. Overcoupling of the antenna to the TV will cause too much signal on IC1 pin 2, which will result in an unstable output.
- Check the operation of IC8 by temporarily jumping pin 9 to pin 16. The VCO output at IC8 pin 4 should be greater than 1 MHz but not greater than 1.1 MHz. Reducing the value of resistor R5 will increase the operating frequency.
- Remove the jumper and check IC8 pin 1 for a narrow negative pulse that indicates the PLL is locked. Connect a frequency counter through a $\times 10$ probe at test point TP1 and adjust C10 for a reading of 3579545 Hz when 6 volts is applied to TP2 from an external power supply. In some cases, the value of C9 will need to be changed slightly to allow a proper adjustment range for C10.
- Connect a frequency counter or a scope to output jack J2 and verify proper operation of the decade counters and wiring of the frequency output select switch. The output level of the standard is adjustable between 0 and 12 volts.

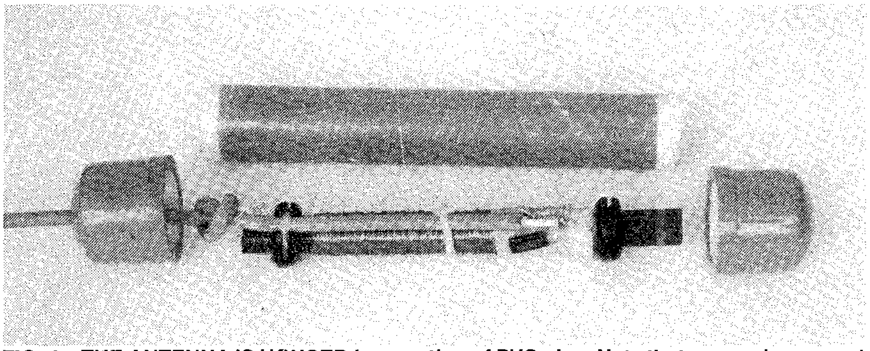

FIG. 4—THE ANTENNA IS HOUSED in a section of PVC pipe. Note that one end cap must be pre-installed on the antenna's connecting cable.

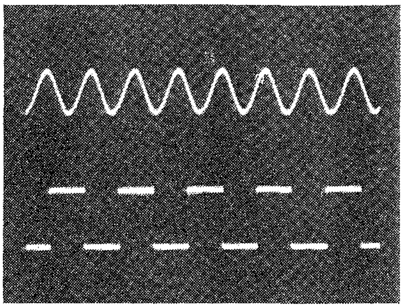

FIG. 5—THE FREQUENCY-STANDARD OUTPUT (bottom trace) should be jitter free. The top trace is the input from the antenna.

Accuracy

You may have noticed that the readings on your frequency counter may not be exactly 1.000 MHz when the output selector is set for 1 MHz. The worst-case error measured when the TV was tuned to a locally-originated TV program was 1-ppm (*p*art *p*er *m*illion), or 1 Hz at 1 MHz. When the TV is tuned to a network-originated program the error is less than 1 part in 10^{-7}, or 0.1 Hz at 1 MHz. (The local broadcasts are not always on the network atomic standard. Local news and local live productions use their own master oscillator.)

Set S1 for a 3.58-MHz output and select a network-originated broadcast. Then change the channel to a different network broadcast and note that the reading on the frequency counter is the same—you are thereby assured that the atomic standard is in use. Adjust the counter's timebase to exactly 3579545.45 Hz. If your frequency counter has an external timebase input you can use the 1-second (1-Hz) or the $\frac{1}{10}$-second (10-Hz) output from the standard to gate the counter for good accuracy without having to calibrate the counter or warm up its crystal oven (if it has an oven).

The internal decade counters can be reprogrammed to divide by any number between 2 and 10, which makes a myriad of other output frequencies available to those wanting to customize the standard. **R-E**

MULTIVIBRATORS

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ferentiating network. It converts the leading or trailing edge of the input waveform into suitable trigger pulses, as shown in Fig 14.

The best way of triggering the 7555 is to use one of the previously described medium-accuracy monostables to generate a narrow (about 100 ns) positive-going trigger pulse, and transistor-couple it to pin 2 of the 7555, as shown in Fig. 15. Note in that circuit, and also the previous one, C2 is used to decouple the trigger circuitry from supply transients.

CMOS monostables

A number of dedicated CMOS monostable IC's are available. The best of those devices are the 4047B monostable/astable IC and the 4098B dual monostable. It should be noted that both devices have rather poor pulse-width accuracy and stability. They are, however, quite versatile, and can be triggered by either the positive or the negative edge of an input signal, and can be used in the standard or the retriggerable mode.

When the 4047B is used in the monostable mode, the trigger signal actually starts the astable and resets the counter, driving its Q output high. After a number of astable cycles, the counter flips over and simultaneously switches the Q output low. Consequently, the circuit will produce relatively long output pulses; the period is approximately $2.5 \times R1 \times C1$.

In practice, R1 can have any value from 10K to 10 megohms, and C1 must be non-polarized with a value greater than 1000 pF. Figure 16 shows how to connect the 4047B in the retriggerable mode. It can be reset at any time by pulling pin 9 high.

The 4098B dual monostable has two sections that share common supply connections, but can otherwise be used independently. The timing period of both monostables is controlled by a single resistor (R1) and capacitor (C1), and is approximately $0.5 \times R1 \times C1$. Resistor R1 can have any value from 5K to 10 megohms, and C1 can have any value from 20 pF to 100 µF. Figure 17 shows the 4098B used as a retriggerable monostable that is triggered by a negative input edge. **R-E**