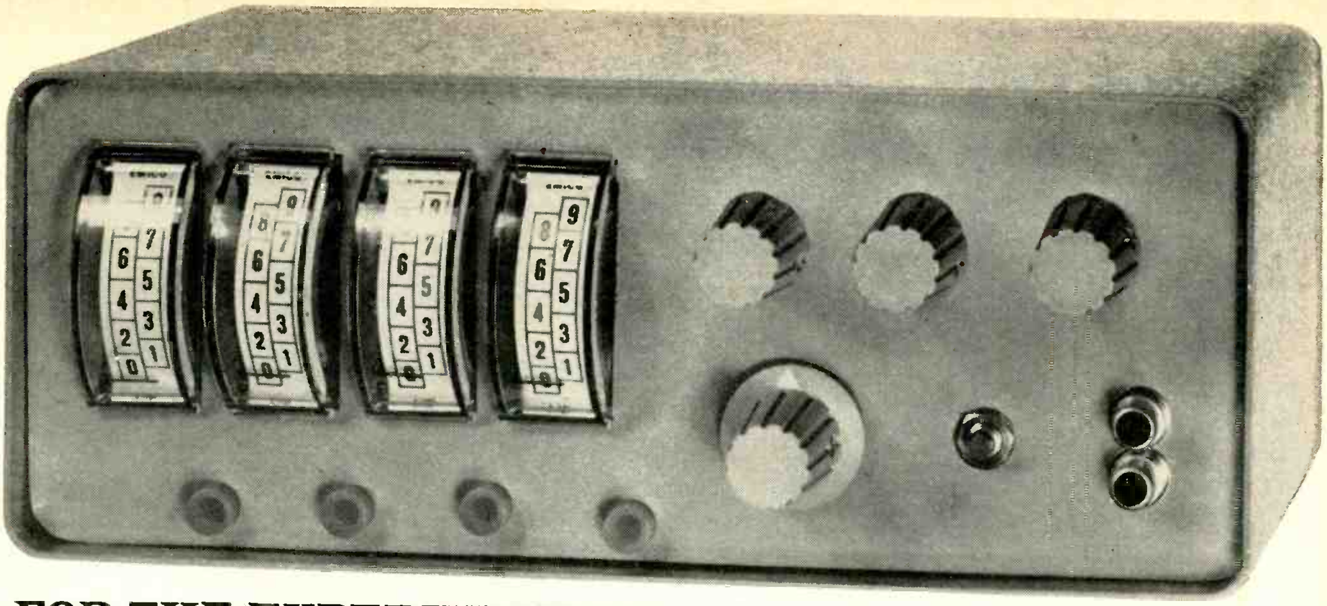


FOR THE EXPERIMENTER

9 Digital Readout IC Instruments

Start with digital readout modules, add a power supply, then try these devices.

By RALPH GENTER

WOULD YOU LIKE TO BUILD A FREQUENCY COUNTER, A digital voltmeter, an electronic piano tuner, and half a dozen other typical digital instruments? You can, and rather easily. First though you'll need some digital readout modules—complete instructions on how to build them at $10 each appeared in November's RADIO-ELECTRONICS.

Powering the modules

The first order of business is a power supply. For a 4-digit readout, we'll need a regulated 40 mA at 18 V; around 0.5A at 3.6 V; and possibly a split, low current dual 6-V supply. The circuit is in Fig 1.

It is vital that the meters in the individual modules do not interact or change their readings with time. The Zener/transistor regulator insures a stable reference voltage. Low ripple is the main problem on the 3.6-V supply. We maintain it through brute-force filtering with two large electrolytics. To get by on a stock transformer, we have to drop the input dc voltage on the 3.6-V supply with the forward drops of several silicon diodes. This is better than using resistors as the voltage drop is nearly constant and independent of loading.

The final portion of the supply provides the low current +6- and −6-V supplies that will be needed if a comparator is part of the particular instrument you want to build.

Driving the modules

Now we can connect our four modules in cascade,

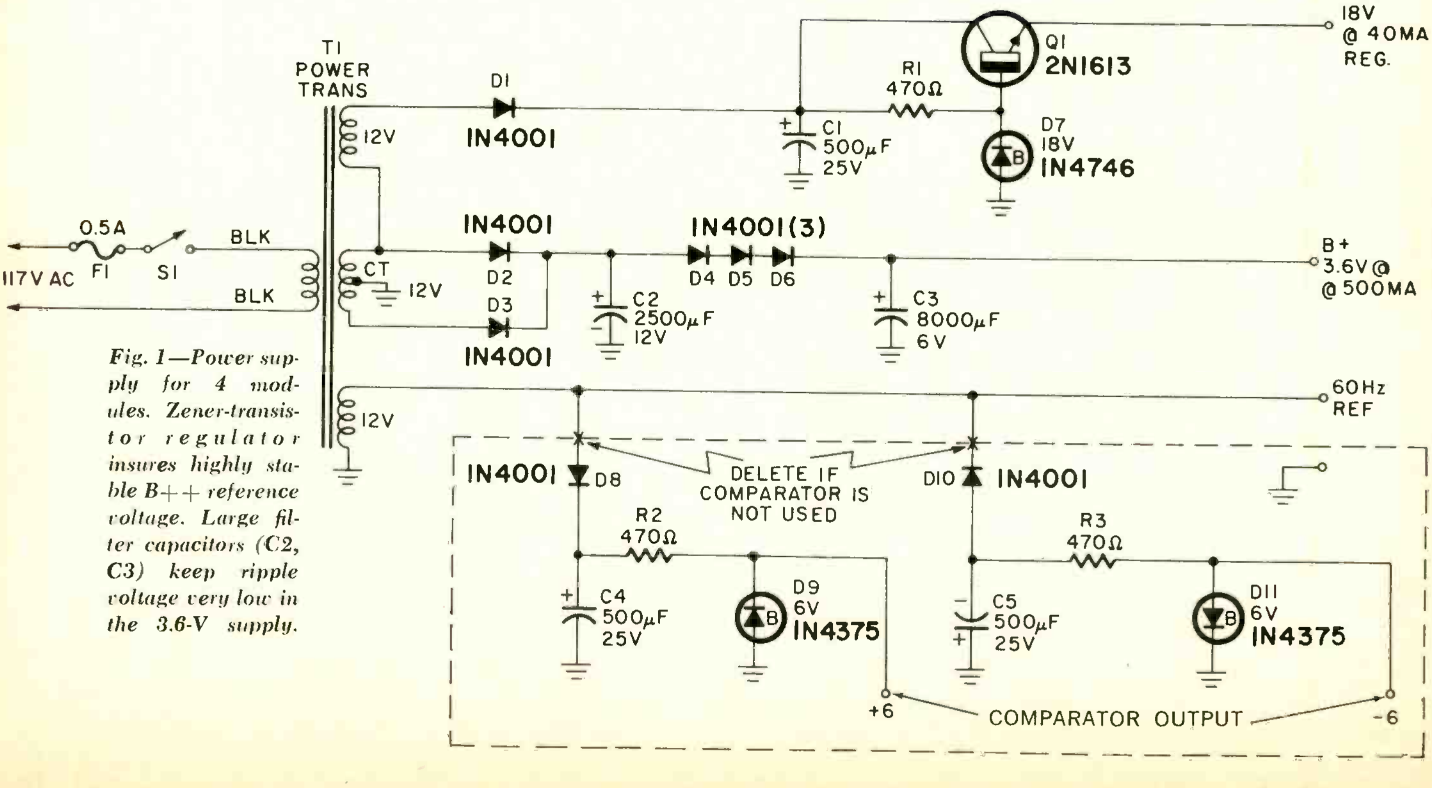


Fig. 1—Power supply for 4 modules. Zener-transistor regulator insures highly stable B++ reference voltage. Large filter capacitors (C2, C3) keep ripple voltage very low in the 3.6-V supply.

powering them off the supply. Each module directly drives the next digit over. simply by connecting the CARRY output of the first to the COUNT input of the next, and so on. As we pointed out last month, the input signal *must* be normally positive by about 2 V or so and must *very abruptly* drop to zero. once and only once, per desired count. Any other form of COUNT input will simply be ignored or will cause very erratic operation.

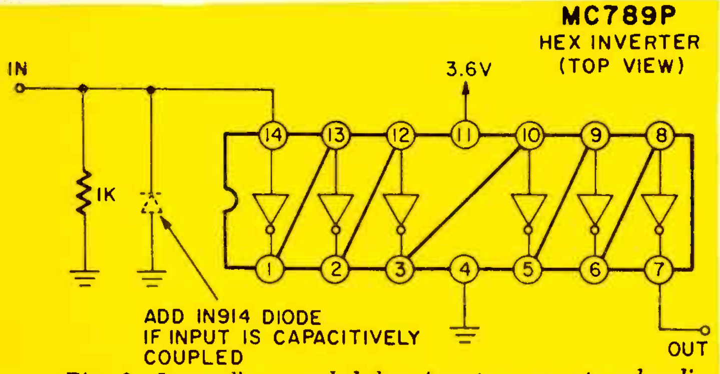


Fig. 2—Internally cascaded hex inverter converts subaudio.

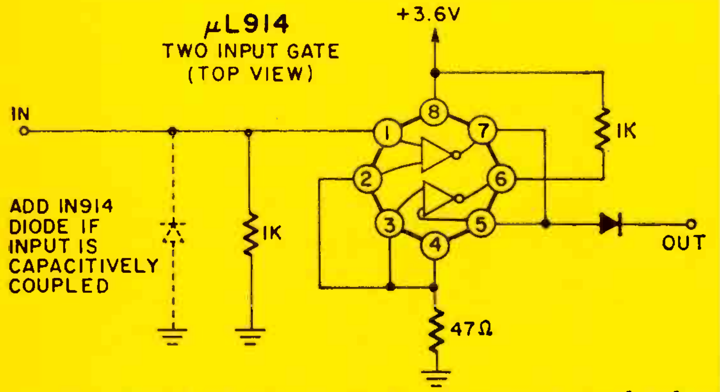


Fig. 3—Schmitt trigger will also shape input signal pulses.

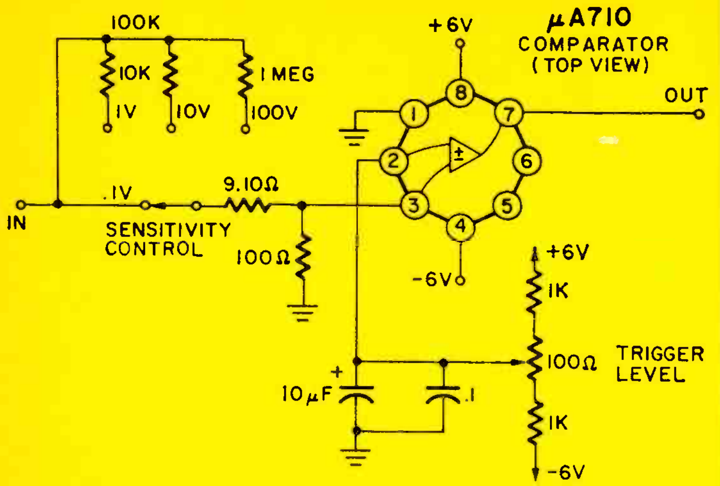


Fig. 4—Best, but costly, an IC comparator works on millivolts.

We can directly drive the COUNT input with a good fast-fall square wave or with pulses that have a good fall time. We can also use sine-waves, if their frequency is above 100 kHz. Any other form of input signal *MUST* be conditioned by one of the circuits described below.

We speak of the process of getting the signals we have into the desired form as conditioning. There are several ways we can condition our inputs. The easiest is to simply amplify and limit our input enough to obtain the necessary fall time. A hex inverter can have all six of its internal gates cascaded together, giving a one-piece, $1.08 limiter that will even handle sub-audio sine-waves (see Fig. 2).

An alternative is a Schmitt trigger (Fig. 3). This one takes two 2-input gates, three resistors, and a diode, and provides a snap action anytime the dc level on its input goes above 1.5 V or drops below 1.2 V. If either of these two circuits is driven by a capacitance-coupled input, you'll have to add a diode dc restorer to the input and have to be sure your capacitor has a low reactance at the *lowest* frequency you'll be concerned with.

If we switch to an integrated-circuit comparator (Fig. 4), we can get much better performance. but not without adding $6.75 worth of IC, and another $5 worth of parts to the circuit. Either of the simpler circuits takes about 4 V peak-to-peak drive. The comparator will operate on a few millivolts. Further, we can pick the highest peak on a lumpy input signal, or establish a threshold level that ignores noise and concentrates on the input signal we are trying to measure. Another big benefit of the comparator is that it works well with a wide range of input signals and voltage levels. You will not need an input sensitivity potentiometer. A simple 0.1, 1. 10, 100 V switched divider will do as well and handle any size signal.

Mechanical contacts

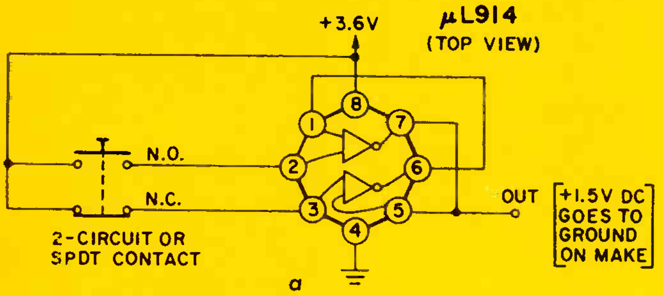
Ordinary pushbuttons have considerable contact bounce and noise. So much, in fact, that if you connected one to the input of a counting module chain, you'd most likely get several hundred counts each time you hit the button. Mechanical contacts of any sort must be made bounceless before they can be used with an electronic counter! Two simple anti-bounce techniques are illustrated in Fig. 5. If you can use a spdt pushbutton, you can connect two gates into a set-reset flip-flop combination that latches in one state the instant the button is pressed and snaps back the moment it is released (Fig. 5-a). One 80¢ integrated circuit is needed.

If you are stuck with a single make contact, you'll have to use a monostable circuit (Fig. 5-b). This takes an additional resistor and capacitor. It produces a constant-width output pulse after the first contact is initially made. Normally a 10-msec pulse width is desirable. but certain applications [slot car track trips, for instance] might require a 1-second pulse width. Just use the larger capacitor and resistor values to get the longer time.

Gating

So far, we have no way to turn the decimal counting modules on and off. This is fine if we are counting events. But for most counter applications. we want to know how many events happened during some known exact period of time [electronic frequency counters, digital voltmeters, etc. . .], or else how many pulses of known frequency occur during the presence of an input event [ballistic velocity meters, piano tuners, etc. . .]. Either method takes an electronic switch called a *gate*, to "start" and "stop" the counter in a predetermined sequence.

An ON-OFF gate is shown in Fig. 6. Here signal **A** is passed only when signal **B** is *grounded*. This takes a dual 2-input gate, or else one 2-input gate and an inverter. All signals must be conditioned properly before they reach this point in the circuit. Another gate form is the START-STOP gate (see Fig. 7). Here input signal **B** starts the gate and allows signal **A** to pass. Signal **C** stops the gate. Thus signal **A** gets through only in the time *between* signal **B** and signal **C**. Usually the ON-OFF gates are used in electronic counters, while the START-STOP are used in instru-



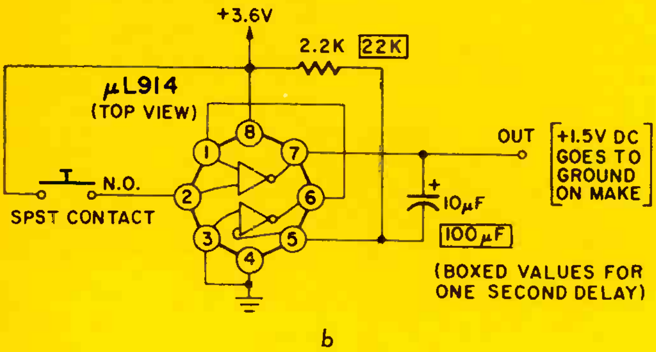


Fig. 5-a—A spdt switch can be made "bounceless" with a μL914. b—External circuit connections to IC for single make contact.

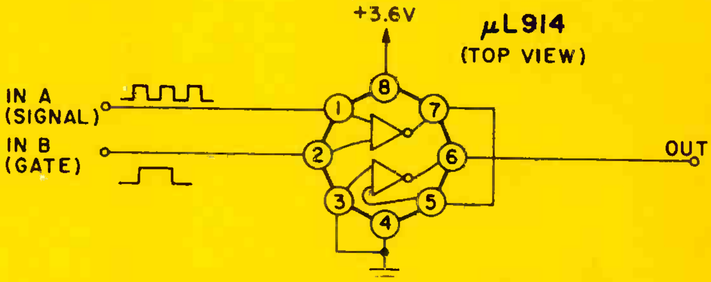


Fig. 6—Module on-off gate. If B is grounded, input A is passed. If input B is positive, output stays positive.

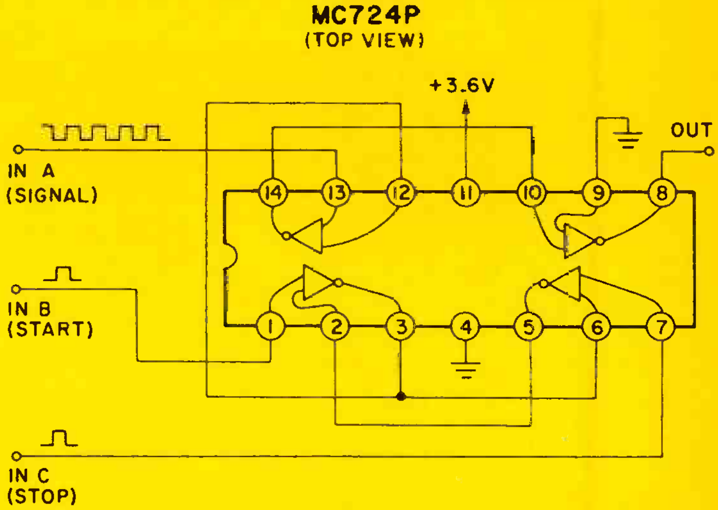
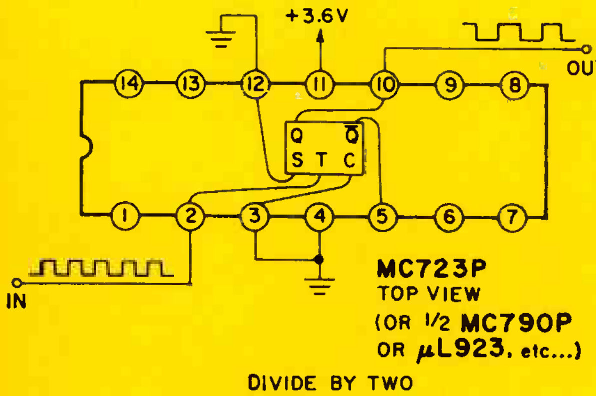
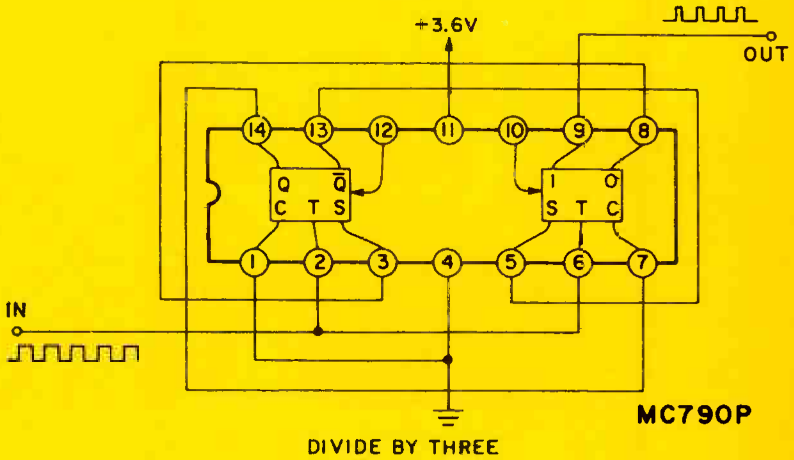
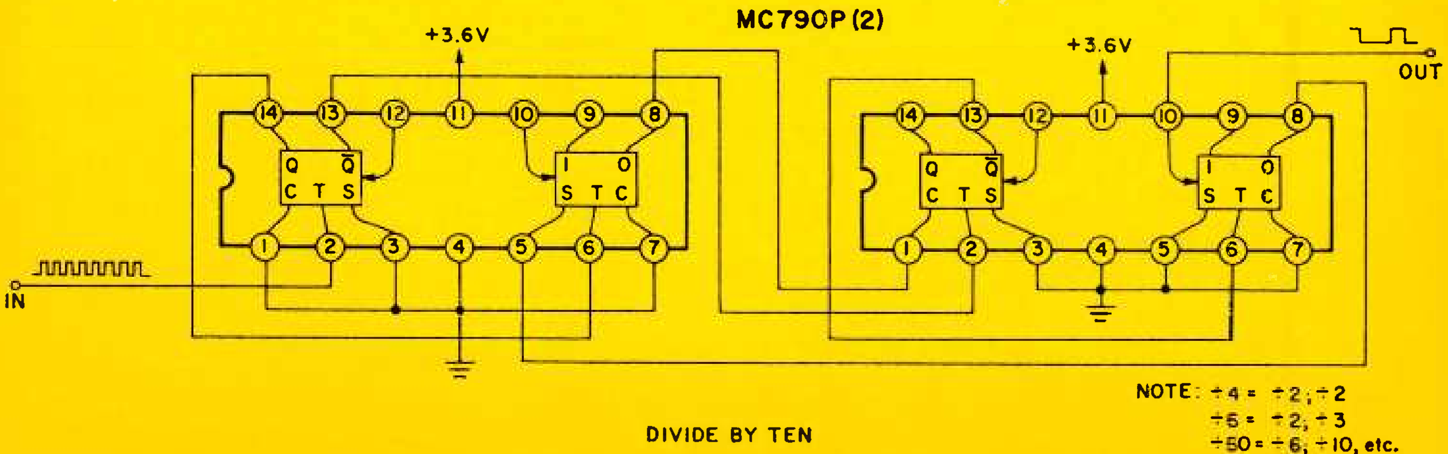


Fig. 7—Start-stop gate. Input A is passed only between pulses B and C. Input B must be off before C arrives.

Fig. 8—Scaling circuits divide input signals for easy counting. Divide by 2 circuit is a binary divider; two JK flip-flops with feedback form the divide by 3 circuit. The divide by 10 is a "Modulo ten minimum hardware circuit" without gates.







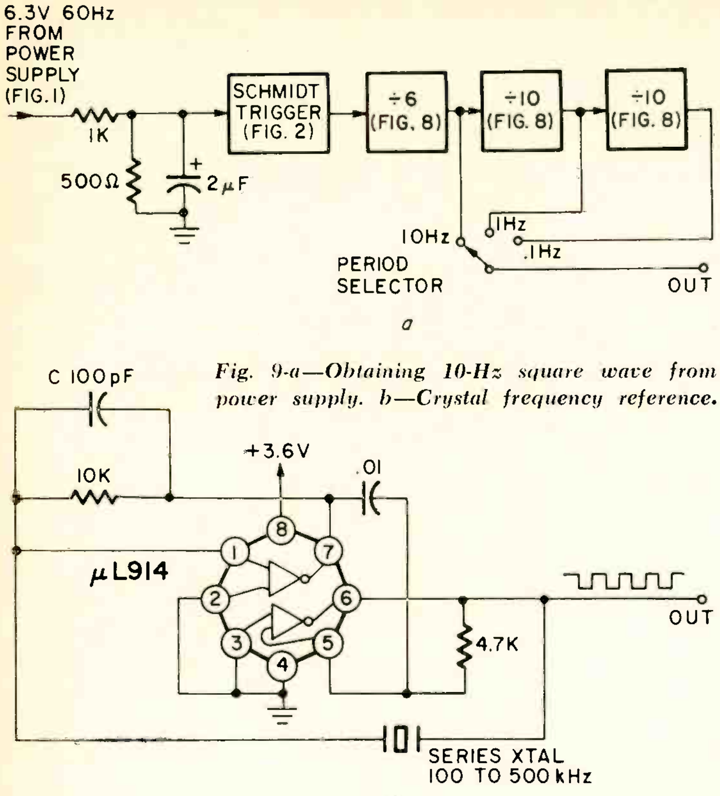


Fig. 9-a—*Obtaining 10-Hz square wave from power supply. b—Crystal frequency reference.*

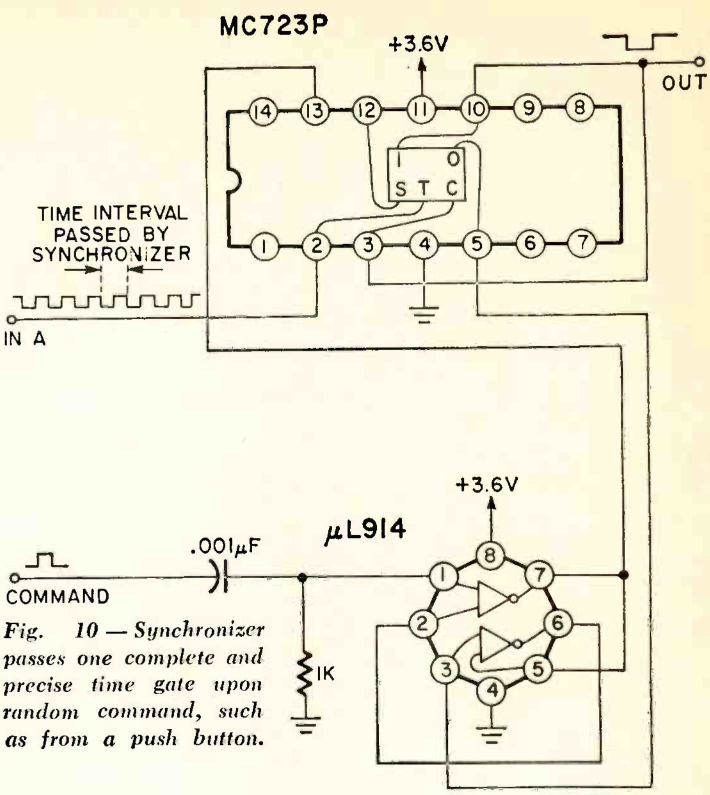


Fig. 10 — Synchronizer passes one complete and precise time gate upon random command, such as from a push button.

ments that take two inputs, such as a drag-strip trap speedometer.

Scaling

We will also need a way to divide down signals, perhaps for a 10-MHz input signal that needs reduction to 100 kHz so it is easily counted, or a 60-Hz power-line signal that is divided by 6 to get 0.1-second pulses, or by 60 to get 1-second pulses. These are called scaling circuits and are easily built from the same JK flip-flops we used in the decimal counting modules. The most common factors we would like to scale by are 2, 3, 6, and 10. The required connections are shown in Fig. 8. The divide by 2 is simply a binary divider, while the divide by 3 uses two JK flip-flops and feedback to produce the division by three. A divide by 6 is nothing but a divide by three followed by a divide by two. The divide by 10 is called a "Modulo ten minimum hardware" circuit, and requires no gates to produce a division by ten.

Time and frequency bases

All but the straight counter applications of the decimal counting modules require either a source of a stable reference frequency or some gates of precisely known time widths. The accuracy of the instrument depends entirely upon the accuracy and stability of these references. A 4-decade instrument is inherently capable of 0.1 to 0.01% accuracy—if the references used *exceed* these figures.

The 60-Hz power line is a handy source of accurate time gates. In most parts of the country, the line is held to within 0.05% of 60 Hz, and the short-term stability is even better. This time base is good enough for most three- and four-place digital instruments, and far cheaper than starting with a high-frequency crystal and dividing down. Fig. 9-a shows how we borrow a 6.3-V ac reference off the power supply, filter it to remove noise, Schmitt trigger it, and divide it by six. This gives us a 10-Hz square wave. Two scalings by ten will then give us 1 Hz and 0.1 Hz, with their equivalent periods of 0.1, 1 and 10 seconds.

For a frequency reference [You'll rarely need both references in a single instrument], we can turn to a crystal, possibly 100 kHz, 500 kHz, or some other frequency that is the magic number that makes the readout and the answer fit the measuring problem. This oscillator (Fig. 9-b) produces a square wave that will directly drive any of our circuits without conditioning. Capacitor C is adjusted to insure the crystal is oscillating on the proper mode and not on an unwanted overtone.

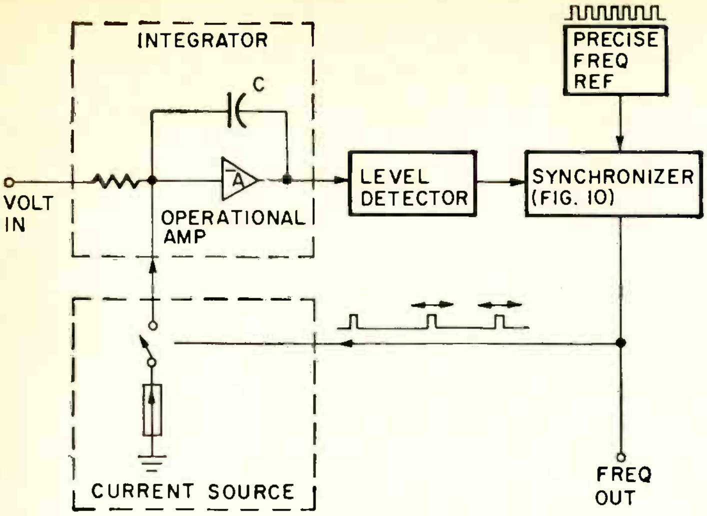
Synchronizing

This is a tricky little problem. How do we produce *one* precise time gate, say one second long, on the command of some totally random event, such as a pressed button? We cannot just use a gate, for we may only get a quarter second's worth of gating if we hit the button at the wrong time. And, if we stay on the button too long, we might get several 1-second gates in a row, piling up the numbers in the decimal counting modules. The required circuit is called a synchronizer, and lets one complete cycle of the input pass upon a random command. The output is a grounded signal that lasts the time between negative transitions of the input signal, and one only is produced upon command. The circuit is shown in Fig. 10. It takes two gates connected as a set-reset flip-flop that drives a synchronizing JK flip-flop.

Voltage to frequency

You'll need a voltage-to-frequency converter anytime you wish to digitally measure an input voltage, such as in a digital voltmeter, ohmmeter, or thermometer. In a digital voltmeter, for example, you scale your input voltage, convert it to a frequency, and then measure the frequency in an events-per-unit-time setup.

You'll find the 0.1% accuracy you need too tight for a conventional voltage-controlled oscillator or multivi-



VOLTAGE TO FREQUENCY CONVERTER

Fig. 11—This charge-integrator circuit offers 0.1% accuracy.

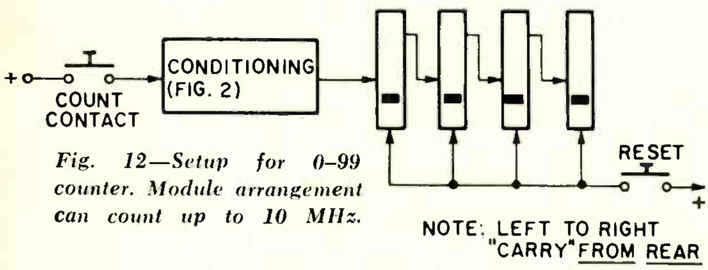


Fig. 12—Setup for 0-99 counter. Module arrangement can count up to 10 MHz.

Fig. 13—By grouping the counting modules in twos, a slot-car lap counter can judge and announce races.

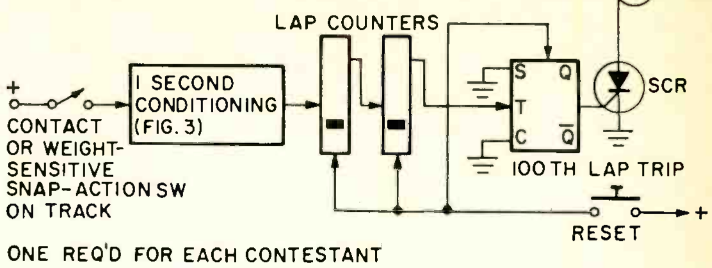
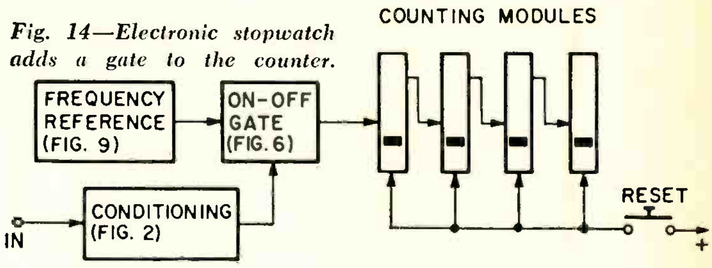


Fig. 14—Electronic stopwatch adds a gate to the counter.



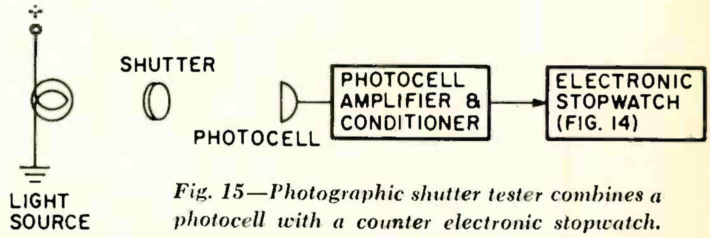


Fig. 15—Photographic shutter tester combines a photocell with a counter electronic stopwatch.

brator setup. Instead a charge integrator circuit, like the one in Fig. 11 is needed. Operational amplifier A charges capacitor C with the input current. Everytime capacitor C swings positive, the output-level detector reaches around and *removes* a constant slug of charge from the capacitor. This is done with a constant current applied for a constant reference time. As charge equals current × time, a constant amount of charge is removed each time the input manages to recharge the capacitor. The greater the input voltage, the faster the capacitor charges, and the *more often* constant charge has to be removed from the capacitor. The output is a series of pulses of accurate width whose frequency varies very accurately with changes in the input voltage.

Let's build some instruments

We now have all the pieces and parts we need for most any digital instrument. Now, how do we put them together? Anything we build will take three or four decimal counting modules, a power supply, and a box. You might like to try a package similar to the one shown in the photo—it's a deep drawn aluminum case about 3 x 4 x 9 in., and with some careful layout, can house almost any digital instrument you like. If you are careful, you can get by on 1/10 the size, 1/10 the cost, and 1/10 the weight of all but the newest equivalent commercial gear!

Let's start with a straight 0-9999 counter built up like Fig. 12. With square-wave electronic input or mechanical contacts with set-reset conditioning, you can count as fast as 10 MHz. The monostable conditioning circuits are limited to a top speed of 20 counts or so per second. The reset pushbutton need not be conditioned. Resetting a counter 193 times is just as good as resetting it once.

Group your counting modules by twos, and you have a lap counter for a slot car race that not only keeps track of the laps, but provides an output signal on the 100th lap. Details are in Fig. 13. You can arrange a mechanical, photoelectric, or weight sensitive track pickoff and run it through 1 second contact conditioning, just to be sure the car's bouncing does not register a false lap.

The heart of many of the instruments is an electronic stopwatch, or events-per-unit-time instrument. The simplest type is shown in Fig. 14. All we do is add a gate to the basic counter, and open and close the gate with the event we wish to measure. We obtain an input from a reference frequency source. Your choice of frequency determines the range and resolution. A 1-MHz clock gives you 1-μsec resolution and a 10-msec range, while a 10-Hz clock gives you 0.1-second resolution and a 100-second range. Make sure your event measuring has an accuracy commensurate with your resolution. Your gating waveform must come up in less than one clock cycle and stay there without noise or breaks for the entire time. Then it must fall in less than a clock cycle. Any other response limitations must be taken into account. You're not about to measure a 10-μsec pulse with a cadmium sulfide photocell with a 10-msec plus rise time. Nor is anything you do requiring human response on a pushbutton going to be much more accurate than 0.1 second.

Photographic shutter tester

This is a snap. We just put a good photocell in front of our counter connected as an electronic stopwatch and shine light on it only when the shutter is open. Of course you'll need a good quality silicon photocell with a 50-μsec rise time or so. A 5-kHz clock is a good choice, as it will cover 1/1000 second down to 1/2 second. The 1/1000 second accuracy will only be 20%. If this is not good enough, a faster clock may be switch selected. Details are in Fig. 15.

A start-stop gate is needed for either the ballistic