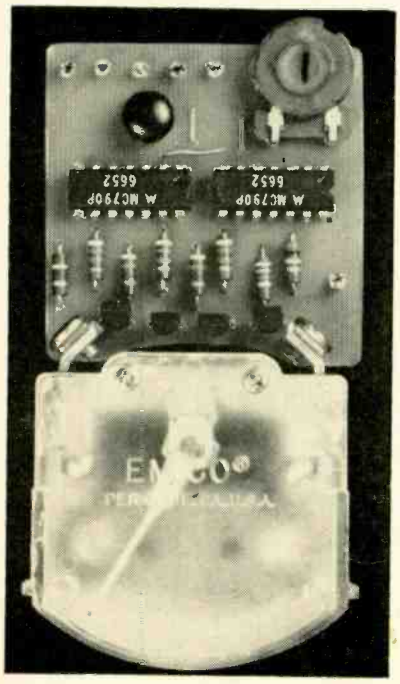
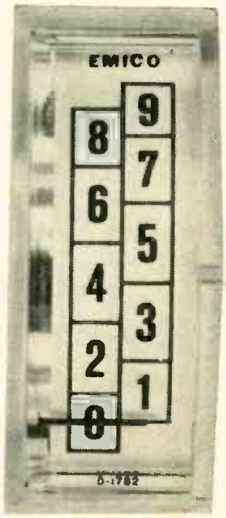
Build a $10 Experimenter's IC Decimal Readout Module





PC module is small (1"x2"x4") and mounts all readout components: decade counter, decoder/driver, and modified panel meter.

By **RALPH GENTER**

THE ASSIGNMENT WAS PLAIN ENOUGH. GET RADIO-ELECTRONICS readers a versatile decimal counting module. Give them a basic block that counts from zero through 9 *and* indicates it. Make it resettable and cascadable, so any number of units can be placed side by side to obtain any desired accuracy.

Now readers would have the modular heart with which they could build their own electronic counters, digital voltmeters, frequency counters, electronic stopwatches, photographic shutter testers, electronic piano tuners, ballistic velocity meters, adding machines, computers, dragstrip speed measurers . . . and heaven knows what else. Besides, there might be quite a bit to be gained simply by studying such a module, as its operating and service principles would be identical with much of the digital industrial electronic equipment in use today.

The trouble began when we started pinning down the specs on such a unit. It had to be small—not over 1" x 2" x 4", and a one-piece unit. It had to be near foolproof. It *had* to use integrated circuits—no neon bulbs, diodes, capacitors or critical pulse circuits allowed. It should be snappy, running anywhere from pushbutton speeds on up to 10 MHz. Less than 0.5 W per module of supply power would be nice. And, of course, it must be legible and easy to read, and must read out in plain numbers. Finally, if anyone was going to build one, it would have to cost less than $10 per decade—experimenter's single-quantity cost.

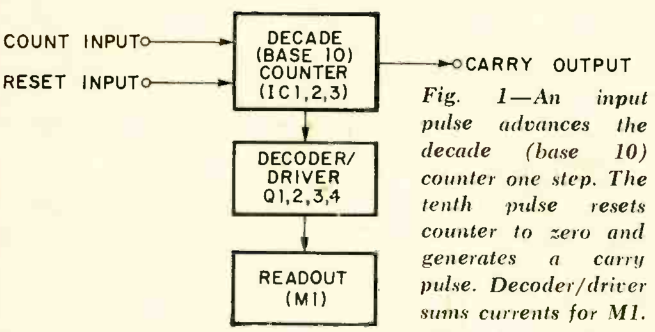


Fig. 1—An input pulse advances the decade (base 10) counter one step. The tenth pulse resets counter to zero and generates a carry pulse. Decoder/driver sums currents for M1.

$10 per decade?

This was the stickler. Off to the catalogs. Let's see—Nixie tubes $8 each . . . DTL integrated decade counters $10 each . . . decoders $16 each. . . . The IC boys are coming along just fine, but that's almost $35 per decade, and we're not through yet. No wonder the cheapest digital instruments start at $300 and work their way up—and up. ($600 is par for a good electronic frequency

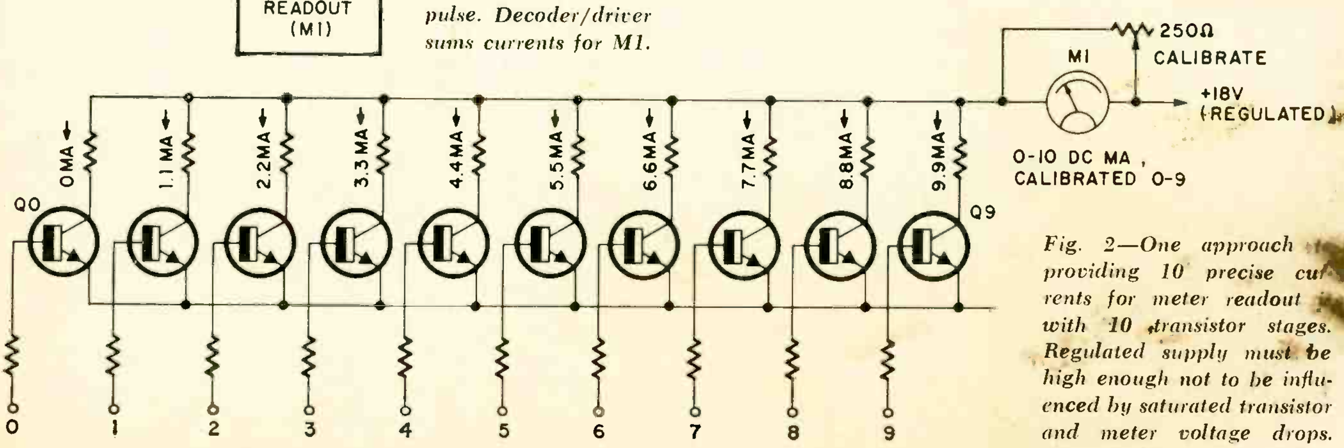


Fig. 2—One approach providing 10 precise currents for meter readout with 10 transistor stages. Regulated supply must be high enough not to be influenced by saturated transistor and meter voltage drops.

meter. But hang on—we're going to show you the same thing for around $60!). No, Nixies are out. So is DTL. Even the old Decatron counters top out above $20, and they can't touch the speed we need. Besides, that bounding orange dot is hard to follow and harder yet to read. So we start from scratch and find a "new" way.

This is easy enough. Let's draw the problem out in Fig. 1. We need three parts: an electronic decade or base-10 counter, a decoder and a readout. The counter has to work like a 10-position resettable stepper, only at a speed anywhere from dc to 10 MHz. Each individual input pulse has to advance the counter one, and only one, count. When the count gets up to 9, the next input pulse has to reset the counter to zero, and produce a CARRY pulse to hit the next decade over. We also have to be able to reset the counter to the zero state anytime we like. This gets our instrument reading 0000 at the start.

We obviously have to have a readout. This is something that brightly and unambiguously indicates the state the counter is in. We suspect that a *binary* counter that is tricked into thinking it is a decimal counter is a good route to follow. Somehow, we must *decode* the counter to find out what state it is really in. The decoded output is an electrical signal that lights up or moves the readout to indicate the proper count. So that's it—we'll need a counter, a decoder and a readout.

The readout

We already voted against Nixie tubes for their price. Ten light bulbs would be nice, but that's at least $4 worth of driver transistors and $2 worth of lamps, jewels and panel work. This leaves little for the counter and nothing for the decoding.

How about a meter? For years, Hewlett Packard used ordinary milliammeters to indicate the least significant states on several of their larger industrial counters. The meters had special scales and the current through the meter was arranged so that the pointer could be only in one of 10 positions—but they were 3", $12 meters.

So, let's update this proved technique. Back to the catalog—Emico's Model 13 horizontal panel meters. All plastic, ¾" wide and less than $3 each, if we do not pick the most sensitive ones. Let's take a 0–10 dc milliammeter and have a special *vertical* 0–9 scale put on it with boxes for each number—no scale markings. Overlap the boxes to gain legibility. Now, put a bright pointer on the whole thing. We have a readout for $2 or so that's as good as any vertical in-line readout going. And, yes, you can get them yourselves in single quantities—see the parts list.

Now, all we have to do is provide 10 discrete currents for the meter to indicate. These currents have to be pretty close—well under 5% if there is to be no question which number the meter is pointing to. We could start with 10 transistor switches, 10 resistors and a regulated power supply, perhaps as in Fig. 2. We'll use an 18-volt supply, high enough that the saturated transistor drops and the drop across the meter will not bother us. Now, we make each resistor provide a suitable current, say 1.1 mA, 2.2 mA, 3.3 mA, and so on.

To go one step better, we provide a little *more* current for each step than we really need and shunt some of the extra current *around* the meter with a calibration pot that lets us get number and pointer positions exactly aligned.

Base current to any transistor provides the proper current to allow the meter to indicate which transistor is receiving current, and our readout is complete. Of course, transistor Q_0 really isn't doing anything, so we can leave it out entirely.

How about some of the other transistors? Can we

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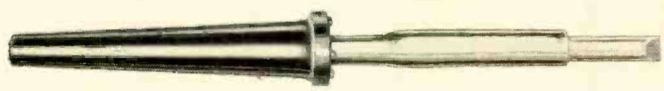

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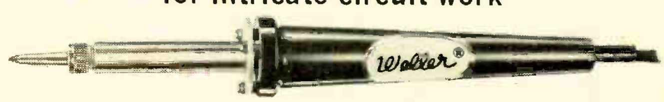

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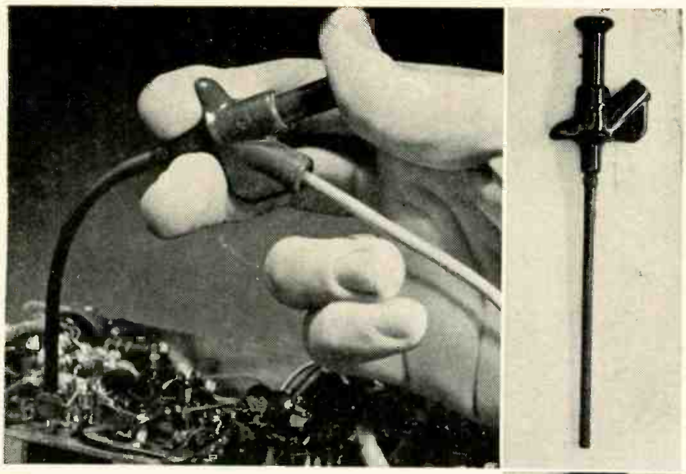

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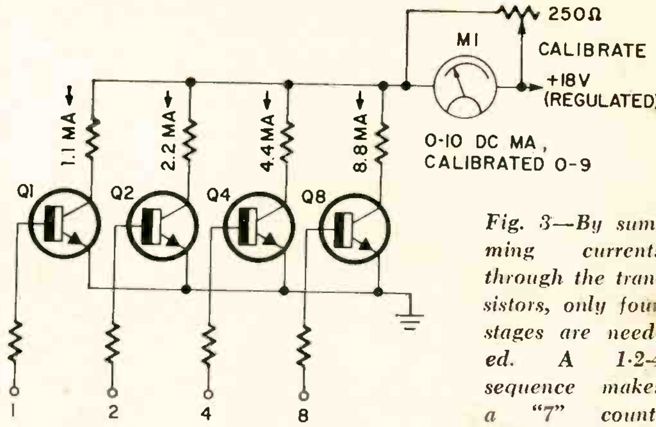

Fig. 3—By summing currents through the transistors, only four stages are needed. A 1-2-4 sequence makes a "7" count.

get rid of a few more? Suppose we *sum* the currents going through the meter, and allow more than one transistor to be on at any one time. If we can get the combinations to line up with the outputs of the base-10 counter, the meter will still give the right answer.

An obvious (but not the best) choice is to use only four transistors and *weight* the currents produced by each transistor in a 1–2–4–8 sequence. To get a 7, we turn on transistors 1, 2 and 4, but *not* 8, giving us 1.1 + 2.2 + 4.4 + 0 = 7.7 mA, or count "7" on our readout. This is detailed in Fig. 3. Note that we save 6 transistors and 12 resistors over the original decoder/driver circuit.

Now we are getting somewhere. Let's refine this decoder/driver slightly, and then we can turn our attention to the counter. The weighting resistors really should be 1% units since most of our positional accuracy is going to be needed for the meter tolerance itself. Also it turns out a 1–2–2′–4 weighting is better than a 1–2–4–8 since it saves us a jumper or two on the circuit board and eliminates an awkward step between counts 7 and 8. We have two transistors weighted "2." Either the 2 or the 2′ transistor can provide 2.2 mA of meter drive. Together they can provide 4.4 mA. We still can get any number on the readout from 0 through 9. Our final decoder/driver circuit is shown in Fig. 4.

Let's turn to the waveforms we'll need at the bases of our driver transistors. One possible combination that is both weighted 1–2–2′–4 and is easy to get out of a counter is in Fig. 5. This is the one we'll use.

Notice that the 2 output comes up on count 2 and stays there for counts 2 through 9, while the 2′ output is used only on counts 4, 5, 8 and 9. The 1 output is used only on the odd counts (1, 3, 5, 7 and 9) and, finally, the 4 output is used only on counts 6 through 9. Taken together, everything adds up to get the right current for the right count.

Our $10 budget still has around $5.80 left after we

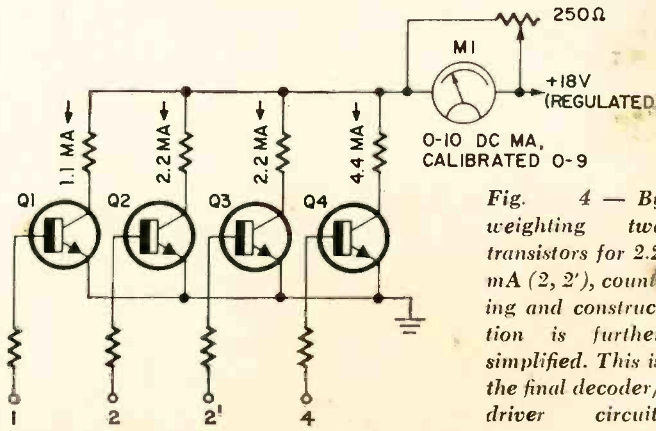

Fig. 4 — By weighting two transistors for 2.2 mA (2, 2′), counting and construction is further simplified. This is the final decoder/driver circuit.

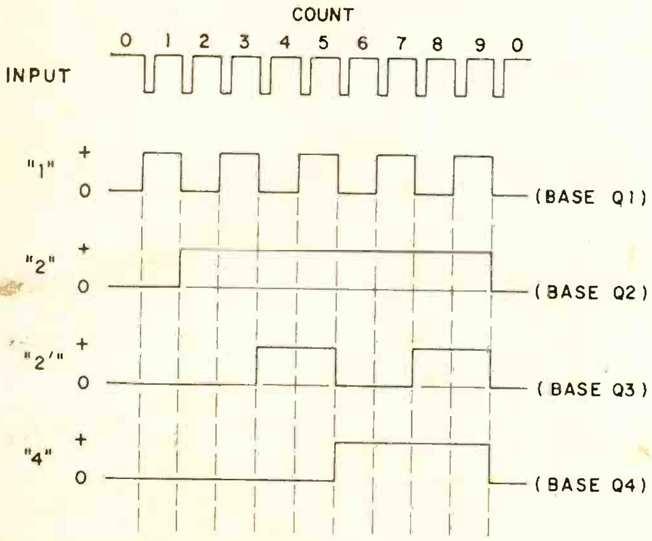

Fig. 5—Waveforms needed on driver bases for correct count.

take out the meter and decoder/driver circuitry. Take out one more dollar for a circuit board, and that leaves $4.80 for a 1–2–2′–4 coded decimal counter. This is easy—we use RTL microcircuits. Two dual flip-flops and a dual gate, and we're home free. Now, all we have to do is figure out how to hook up the counter.

Suppose we take four JK flip-flops and connect them as shown in Fig. 6. This gives us a four-stage binary divider that takes two dual IC's to count to 16. The trick is to somehow convince this type of circuit that it is really a base-10 counter and make it forget the other six states it once knew. We might first note that this connection

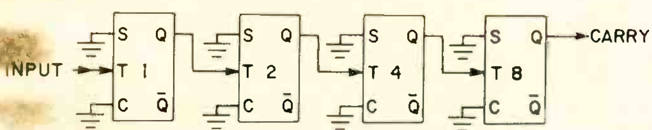

Fig. 6—Four JK flip-flops form a binary divider for a 16 counter.

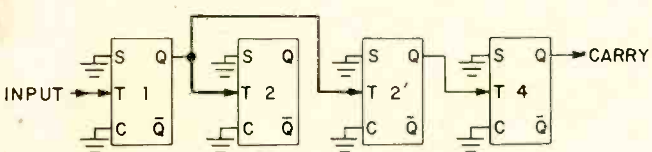

Fig. 7—Connection provides 1-2-2′-4 circuit, but only 8 count.

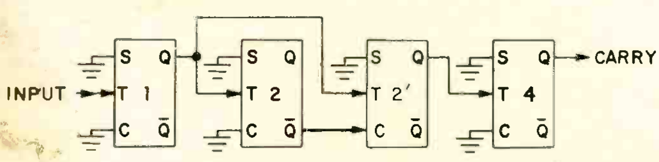

Fig. 8—Hookup inhibits 2′ circuit and corrects 2 and 2′ count.

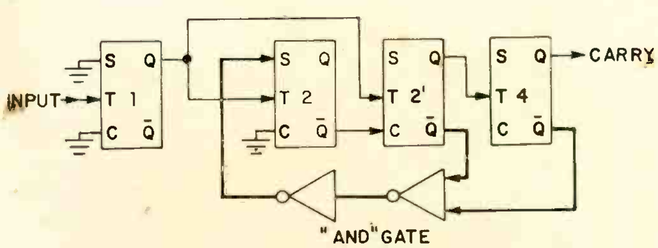

Fig. 9—AND gate inhibits 2 counter for all counts but zero.

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would be a 1–2–4–8 type of deal, so we might rearrange the flip-flops in a 1–2–2′–4 circuit like Fig. 7. Right now, this circuit can count only to 8 and the 2 and 2′ flip-flops are apparently doing the exact same thing.

Now comes the black magic. By lifting some of the grounds on the inputs of the 2 and 2′ flip-flops and by replacing these grounds with signals that change from count to count, we can *inhibit* the operation of these two flip-flops. Look at the timing diagram. We want to inhibit the 2′ flip-flop only when the 2 flip-flop is up, so we add a wire jumper as shown in Fig. 8. That's half the problem. Next, we want to inhibit the 2′ counter *except* for count 0.

We note that *both* the 2′ and 4 flip-flops are up simultaneously on counts 8 and 9 and thus will still be up while awaiting the next count 0. We can add an AND gate to allow this signal to inhibit the 2 counter for every count except count 0, just as shown in Fig. 9. Now, we simply combine both circuits, and out comes our complete 1–2–2′–4 counter in Fig. 10.

You'll find the complete schematic in Fig. 11. IC1 and IC2 are the counter. As these IC's also have a preset

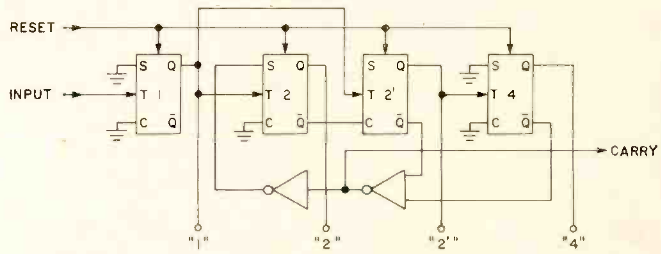


Fig. 10—AND gate and flip flops form complete counter.

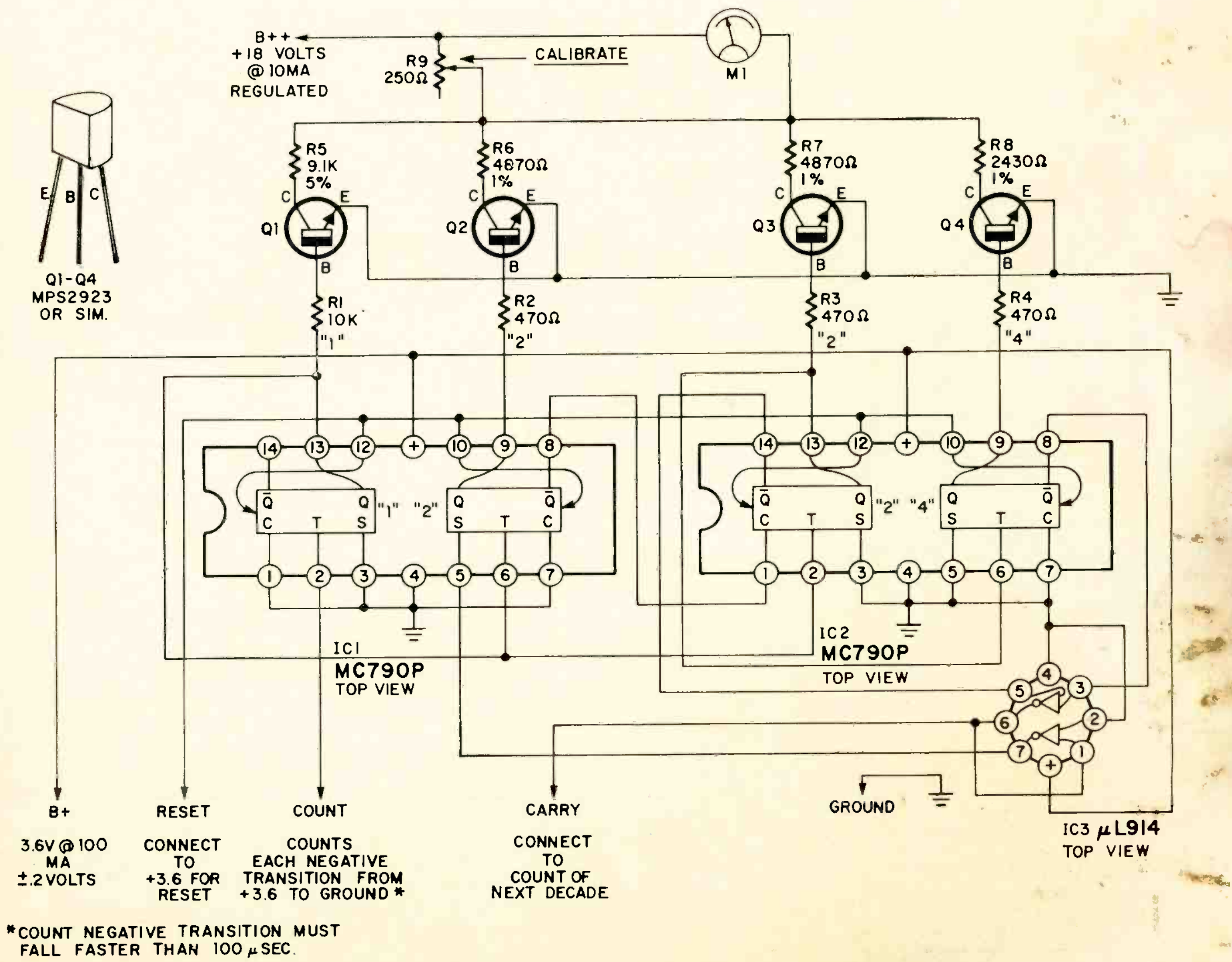
PARTS LIST

IC1, IC2—MC790P dual JK flip-flop (Motorola)
IC3—μL914 dual two-input gate (Fairchild)
Q1, Q2, 3, Q4—MPS2923 or similar npn silicon transistor (Motorola)
Note: Data sheets and distributor lists are available from the following respective sources:
Motorola Semiconductor
Box 955
Phoenix, Ariz. 85001

Fairchild Semiconductor
313 Fairchild Drive
Mountain View, Calif. 94041

R1—10,000-ohm, ¼-watt carbon resistor
R2, R3, R4—470-ohm, ¼-watt carbon resistor
R5—9,100-ohm, 5%, ¼-watt carbon resistor
R6, R7—4870-ohm, ¼-watt, 1% resistor
R8—2430-ohm, ¼-watt, 1% resistor
R9—potentiometer, 250 ohms, CTS No. U201-251 or similar
*M1—0-10 dc vertical milliammeter
Circuit board—1-15/16" x 1-15/16" x 1/16" single-sided PC board
MISC: PC terminals (6); wire jumpers (3); No. 6 spade bolts and No. 6 nuts (2); solder.
*Note: The following are available from Southwest Technical Products Inc., 217 West Rhapsody, San Antonio, Tex. 78216. Etched and drilled PC-1 $1.00; meter M1 with special scale $2.25; complete kit of all parts $10.00; postpaid in US.

Fig. 11—Complete schematic of the counter module. IC1 and IC2 are the two dual JK flip-flops and IC3 is the AND gate. Collector resistors on Q1–Q5 determine weighted current to the meter. Count pulses must have falltime less than 100 nsec.



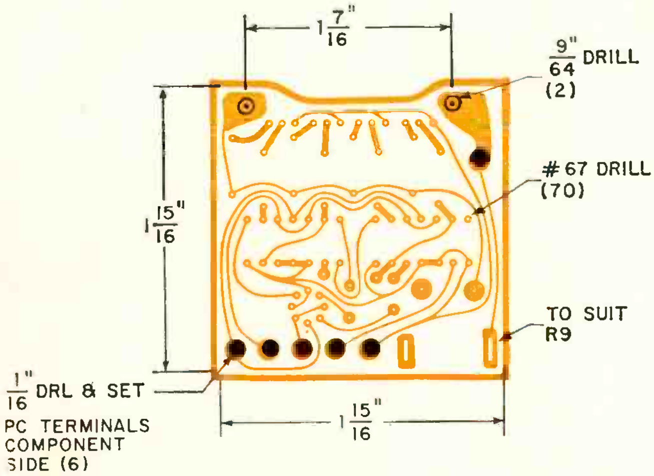


Fig. 12—This 1 15/16"- square PC board will mount on meter.

input, we bring out a common lead that gives you the RESET terminal that automatically resets the counter to 0. IC3 is the AND gate. Transistors Q1 through Q4 drive the meter through weighted precision resistors R5 through R8. R1 had to be a bit bigger than the other base-driving resistors to eliminate a loading problem on IC1.

Two power supplies are required, a regulated 18 volts at 10 mA and a ripple-free +3.6 volts at 100 mA for the IC's. Your COUNT signal should normally be positive, say from +1.5 to +4 volts, and abruptly *drop* to zero whenever a count is desired. *This signal MUST come down only once per count and MUST come down faster than 100-nsec fall time.* If you want to count anything but good square waves, you'll have to "process" your input signals in some simple circuitry we'll talk about later. You'll also find that pushbuttons and mechanical contacts will have to be made bounceless. Once again, this is easily accomplished in a simple circuit.

The CARRY output of any decimal counting module will directly drive the COUNT input of the next module down the line, and you simply cascade as many counting units together as you wish. Four is typical, and allows measurement from 0.1% to 0.01% accuracy.

The RESET input is normally left grounded. To reset the counter, simply apply +1.5 to +4 volts of dc to this input.

The integrated circuits used are guaranteed to operate at an 8-MHz rate, but all the modules we have tested go well beyond 10 MHz. You'll find the meter movement's inertia automatically blanks any high-speed counting, eliminating the need for the strobe or storage circuitry often used in fancier industrial designs.

Construction

Your decimal counting module can be built onto a 1 15/16" square printed-circuit board that mounts directly on the meter terminals. You can buy this circuit board ready to go, but if you prefer, you can lay out, drill and etch your own circuit card, simply by following the layout guide in Fig. 12. Three wire jumpers are needed as shown. The

(continued on page 94)

COMING

Next month, we'll talk about power supplies, input conditioning, time bases and other things that will show you how to build many practical digital readout instruments at a very low cost using these decimal readouts.

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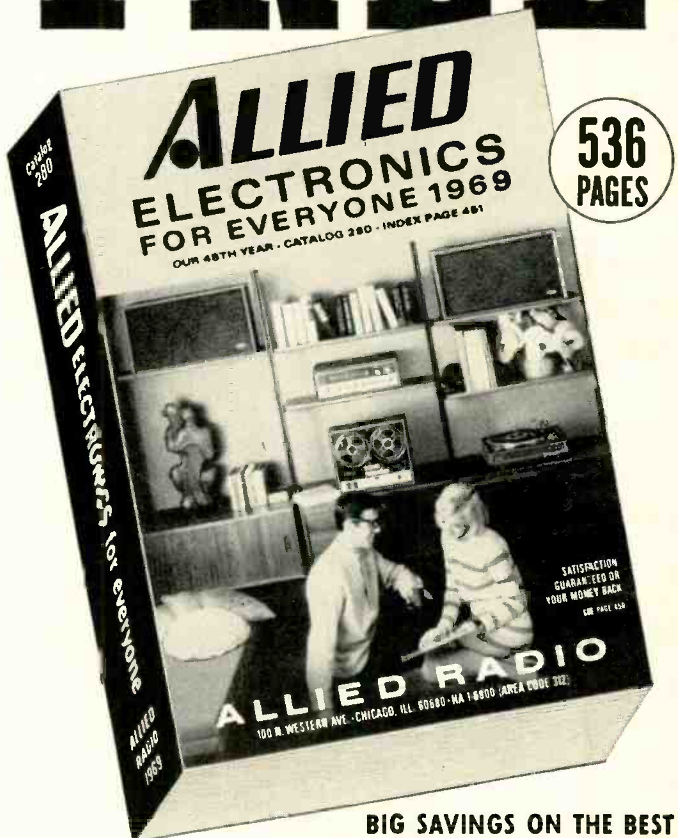

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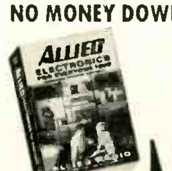

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(continued from page 69)

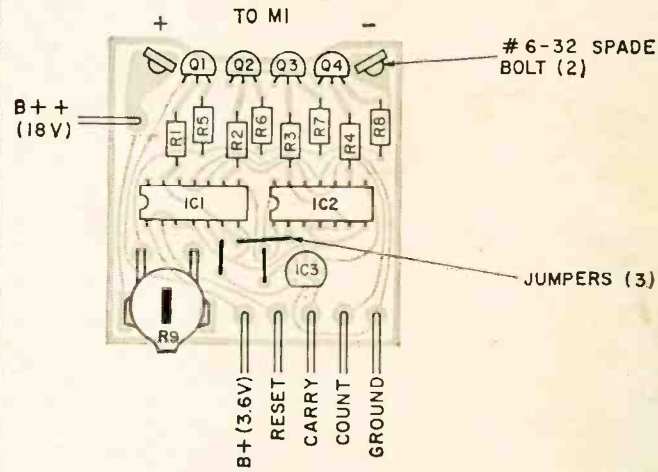

Fig. 13—Component placement and input connections.

component layout is in Fig. 13. IC1 and IC2 go in with their code notch in the direction shown, while the flat side identifies IC3. Two No. 6 spade bolts secure the circuit card to the meter, giving you a rugged, one-piece assembly.

Testing

You can test your unit with two D-cells and a 22½V battery, connected as in Fig. 14. Build up the bounceless pushbutton circuit shown for the input. To calibrate the unit (temporarily, of course, since you'll later be switching to a regulated meter supply), RESET the counter and run the count up to 9. Now adjust R9 to set the pointer precisely to 9. Your counter is complete, and you should be all set to build any of a number of digital instruments at a tiny fraction of their normal cost. R-E

Fig. 14—Test setup for the module uses battery supply for 22.5V and 3.6V. Input (temporary) uses pushbutton circuit.