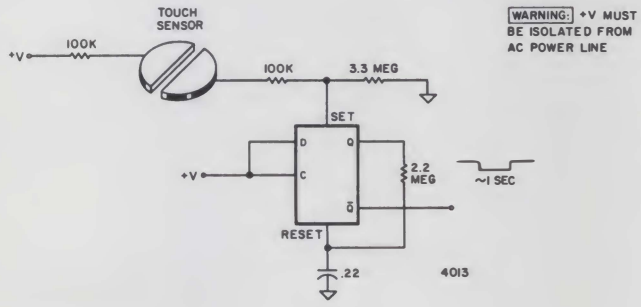
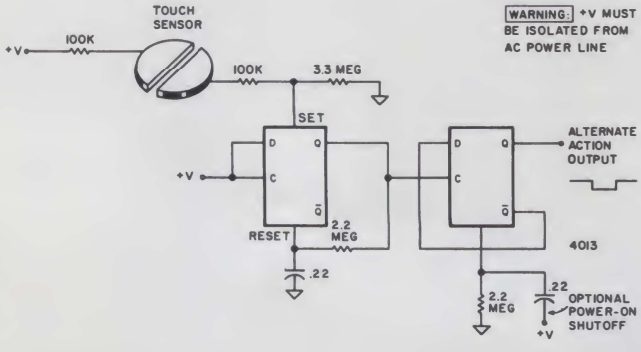
Don Lancaster
SYNERGETICS

Clocked Logic



(a) Pulse output.



(b) Alternate "off-on" action.

Fig. 15. Touch switches based on conductivity.

In this third and final article in his series on flip-flops, Don Lancaster presents some of the most interesting and unusual applications we've seen in some time. Most of the circuits deal with some form of A-to-D and D-to-A conversion and are made possible by the electrical characteristics of the Complementary Metal Oxide Semiconductors (CMOS) circuits used throughout. As a matter of fact, the material has been extracted from his upcoming "cookbook" to be published by Howard W. Sams . . . CMOS Cookbook. — *John.*

The nearly infinite input impedance of CMOS makes it ideal for use in *touch* or *proximity* circuits. Usually a touch sensitive circuit needs physical contact, while a proximity circuit only needs a nearby presence.

This article is excerpted from the *CMOS Cookbook*, copyright 1977 by Howard W. Sams. Reprinted by permission.

There are several characteristics of the human body that may be used for touch sensors. Human skin resistance is usually several hundred thousand Ohms, but varies with the individual, the contact spacing, and physiological factors. The capacitance of the human body is usually around 300 picofarads referenced to ground. Touching a point in a circuit usually has the effect of adding 300 picofarads of loading to that point. Just coming near a sensor provides a capacitive divider set by the 300 pF and the capacitance between sensor and person. Usually this is only a very few picofarads and drops dramatically as spacing is increased.

Finally, the human body acts as an antenna, picking up the 60 Hertz power line near field in virtually all indoor and most outdoor situations.

There are several important things to watch for if you want a reliable touch sensor. The sensing circuit works best if it is solidly grounded. Portable or ungrounded circuits may not work at all unless they have a reference against which to work.

Hot chassis techniques of

. . . Part 3:

Data Converters

and Special Functions

any kind where the sensor returns to one side of the power line should, of course, be avoided entirely. Even if ultra high series resistors are used, what ends up as an unnoticeable leakage current to one person can end up as a mild shock or at least a "liveness" or fuzziness sensation to others.

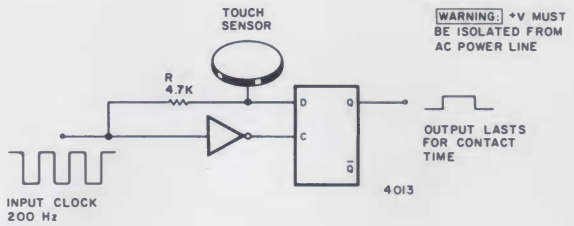
Most touch sensors should be debounced with a long time constant, preferably a second or so. This prevents any nervousness or hesitancy from being entered as multiple hits. Always use only the absolute minimum sensitivity you need for any touch sensor and provide as much protection as possible to the sensor. This minimizes both static damage potential and possible false alarms from power line transients, AM radio signals, and so on.

Let's look at some examples. Fig. 15 shows us two touch switches based on conductivity. Fig. 15(a) illustrates the triggering of a monostable via the Set input when the touch sensor is bridged with a resistance that is small compared to 3 megohms. A conditioned output pulse one second long results.

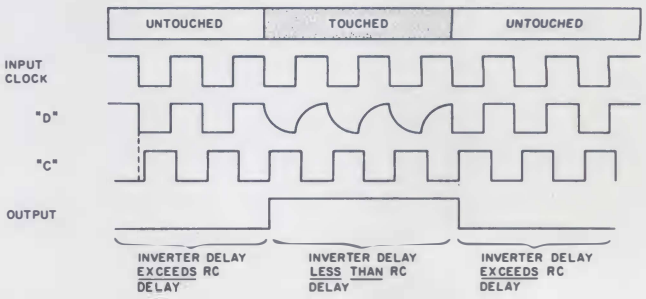
We can convert this to an alternate action off-on circuit (Fig. 15(b)) by adding a binary divider to the output, using the other half of the 4013 with its $\overline{Q}$ output cross coupled to D. The final resistor and capacitor are an optional external reset that makes sure the sensor comes up in the off state.

A capacitance operated touch system for electronic music keyboards is shown in Fig. 16. An input square wave is used as a clocking signal. Normally, the inverter delays the clocking till *after* the D input has accepted a new value, so an output low results. Touching the D input adds 300 picofarads or so of capacitance to ground. This gives us a resistor-capacitor delay network that slows down the waveform reaching the D input. In fact, it slows things down so much that the clock gets there first, giving us an output high condition. The choice of clock frequency sets the debouncing you'll get. Always use the lowest possible frequency for any particular use. For many electronic music uses, 500 Hertz or higher is a good choice.

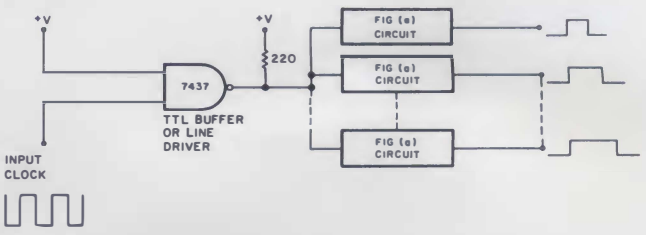
Note that our series



(a) Basic circuit — input clock frequency sets debounce time. R sets sensitivity.



(b) Waveforms.



(c) Input buffer minimizes interaction between multiple contacts.

Fig. 16. Touch switches based on capacitance have many electronic music uses.

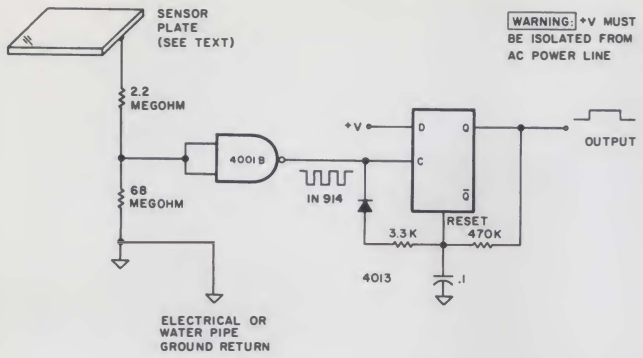
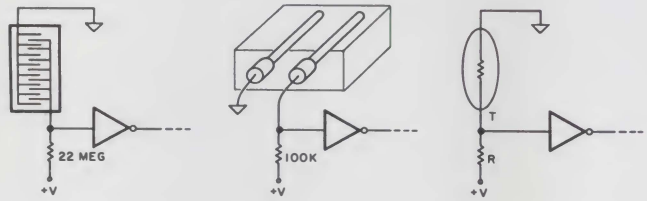
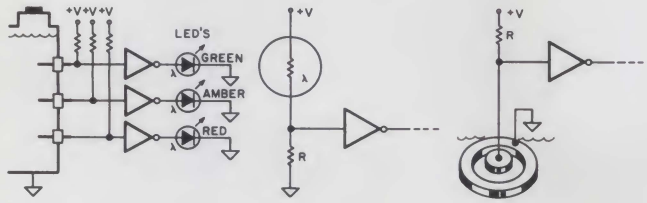


Fig. 17. Proximity switch based on power line "hum" coupling.

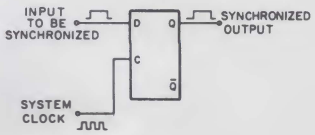


(a) Rain sensor. *(b) Nutrient saturation (hydrophonics).* *(c) Thermistor or thermostat.*

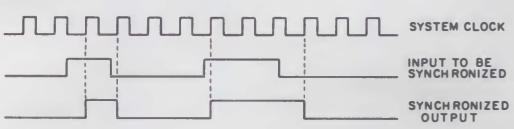


(d) Booster tank level (firefighting). *(e) Photoconductive cell.* *(f) Splash alarm (swimming pool safety).*

Fig. 18. Other high impedance conductivity sensors such as these may be directly CMOS compatible. Unless conductivity change is constant, sudden, and dramatic, an input CMOS operational amplifier is recommended for conditioning and adjustment.



(a) Circuit.



(b) Waveforms.

Fig. 19. The synchronizer circuit is used to lock erratic, delayed, or outside-world signals to system timing.

resistor is somewhat low in value. This is used to set the sensitivity. Since this is a fairly low impedance point, hum and interference pickup is unlikely as is finger-to-finger conductivity when multiple keys are hit.

In multiple key systems, such as Fig. 16(b), some means of keeping the fingers from loading the clock source rise and fall time must be provided. You can do this with an extra inverter or else you can provide an exceptionally stiff (low impedance) driver for the entire circuit. A TTL line buffer is a good choice.

Fig. 17 shows us a proximity switch based on human coupling of the 60 Hertz power line. A hand very near the plate induces hum into the first gate. This is squared up and used to trip the retriggerable monostable as shown. A clean output results from the instant of first proximity till a few milliseconds after release. The sensitivity depends on the size of the plate and the amount of allowable false alarms from induced noise sources.

Some Related Sensors

The thing activating the resistance style sensor of Fig. 15 does not have to be a people; any high impedance that can't be heavily loaded will work as well. Fig. 18 gives several examples. The rain sensor of 18(a) uses the conductivity of rainwater to conduct across a sensor grid. Two probes in the bottom of a hydrophonic greenhouse bed in 18(b) will conduct when nutrient solution reaches them. A thermistor or thermostat is shown in 18(c). As the resistance drops, the output of the inverter will go high. A liquid level system suitable for the booster tank on a fire engine is shown in 18(d). A photocell system is shown in 18(c), followed by a splash alarm for swimming pool safety in 18(f).

One thing is essential for all these applications to work. The difference between the OFF and ON resistances has to be very large and very stable. If the resistance drifts with time or a sharply defined threshold is needed, you'll have to add an input conditioning circuit, perhaps using a 3130 op-amp.

Synchronizers

Synchronizers are a very important class of circuits. They are used to lock outside world signals (or other signals that are random or somehow out of step) to system timing.

Our basic synchronizer connection for the 4013 appears in Fig. 19. The signal to be synchronized is applied to the D input. A system clocking signal goes to the clock. The locked signal output is taken from Q. As the waveforms in Fig. 19(b) show us, both the leading and trailing edges of the input are delayed until the next positive clock edge. The output locked signal will be a delayed replica of different width than the input, but the output will always be locked to the clock timing. The output will also always be an exact number of clock intervals in width.

For some synchronizer uses, we can refer to Fig. 20. In 20(a), we use a synchronizer following a memory or character generator. The synchronizer samples and holds the data only when it is valid, relocking the outputs to system timing. This eliminates possible times when the memory is accessing, settling, or otherwise putting out garbage. What we have done is convert a short mixture of good and bad data for an always-accurate answer delayed one clock pulse interval in time. In 20(b), we make a ripple counter look like a synchronous one by decoding a state *one count early* and relocking it to the input clock. This eliminates any ripple delay and propagation times. In 20(c), we've used a synchronizer to eliminate the "inherent" one count bobble or ambiguity of a frequency

counter. We do this by delaying the counter's time reference gate until a pulse to be counted gets there. A whole number of input pulses are always counted this way. This eliminates the random starting and stopping points of the time gate and the apparent one count bobble.

One and Only One

The one-and-only-one is a very important synchronizer circuit, detailed in Fig. 21. It will give you exactly one clock interval as an output in response to an outside world command. Our outside world command is shown as a positive edge. This sets the first flip-flop. The first flip-flop absorbs the time difference between the arrival of the outside world signal and the system clock edge. Our second flip-flop generates a one clock wide output pulse and resets the first stage. Every time you outside-world trigger the circuit, you get one and only one clock pulse interval as an output. Waveforms are shown in 21(b).

The one and only one may be used as a single frame update generator for a TV Typewriter per Fig. 21(c). The positive edge of an "enter" command from a keyboard is used to direct set the synchronizer. An output one vertical interval (16.7 milliseconds), and lasting one frame, is provided. This circuit also gives us a repeat option. If we make D high and put a low frequency (7.5 Hertz) *blinker clock* on the first stage clock input, we get repeated single frame outputs reoccurring at the blinker rate. For normal operation, hold D low; for repeat make D high.

You can convert a one and only one circuit into a N and only N by adding a counter that delays resetting the first stage until N counts have gone by. A gate may be added to make this circuit into a generator of N clock pulses.

Two Sequential Circuits

Two sequential circuits that use 4013s are shown in Fig. 22. The *bucket brigade* of Fig. 22(a) sequentially gives us self-decoded outputs as shown, first at A, then at B, then C, as shown. Only one start command must be provided per sequence if you are to avoid multiple outputs. You can close the circuit on itself for a continuous "electronic stepper" operation, but you'll have to add some method to make sure only one output is high at a time.

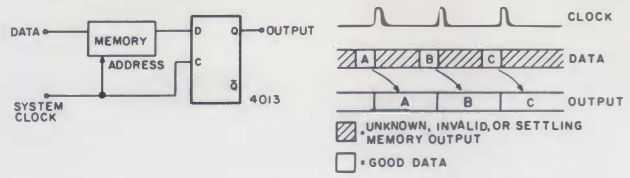
The *sequential pass-on* of Fig. 22(b) is handy for alarms, electronic locks, and other circuits where events must follow each other in a certain order. You get an output only if the leading edge of event A happens and is followed by event B and then event C. Events in the wrong order or not present prevent an output. Since the event inputs all go to clocks, they must, of course, be properly conditioned, bounceless, and noise-free.

A Programmable Divider

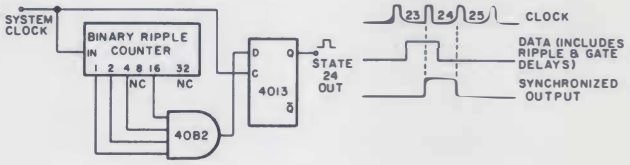
An interesting if somewhat oddball use of a 4013 is the programmable divider of Fig. 23. The circuit will divide a clock either by one or two. This is handy in digital data recording circuits where a string of clock cycles related in frequency by 2:1 may be needed. With the *Mode* input high, the 4001 NOR gate is disabled and the 4013 acts as a binary divider. We get the binary division through the $\overline{Q}$ to D external feedback connection. If you ground the Mode input, the leading edge of the clock sets the 4013 and the trailing edge resets it via the direct set input, all in one clock cycle. For proper operation, the RC network has to have a short time constant compared to twice the clock frequency. The clock input must have a symmetrical (50-50) duty cycle.

Digital-to-Analog Converters

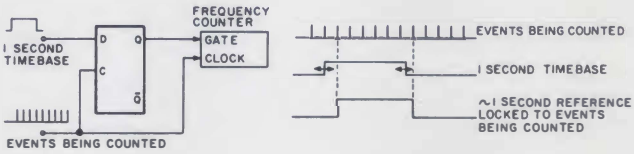
Most digital-to-analog con-



(a) A synchronizer following a memory samples the memories output only when data is valid and stable. It saves the good output for the entire next system clock cycle.

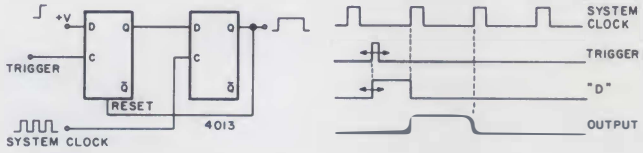


(b) State #24 of this counting chain is synchronously decoded and output by ripple decoding state #23 and resynchronizing. This eliminates ripple delay times.

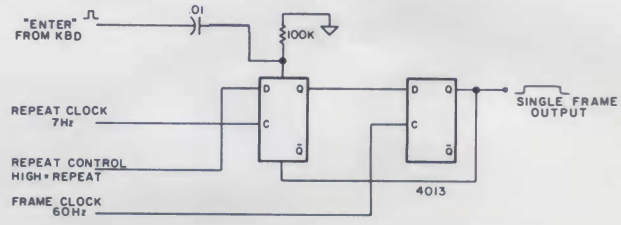


(c) The one count ambiguity or bobble of a frequency counter may be eliminated by delaying the time reference so it starts and stops on an event being counted.

Fig. 20. Using synchronizers.

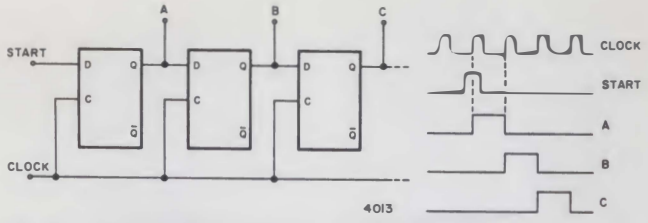


(a) Circuit. *(b) Waveforms.*

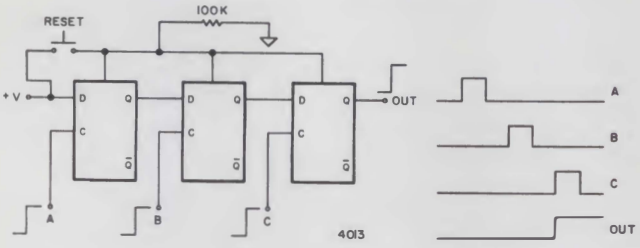


(c) Single frame update generator for a TV typewriter.

Fig. 21. The one-and-only-one.

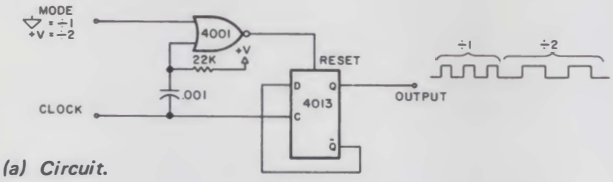


(a) The bucket brigade synchronously self decodes.

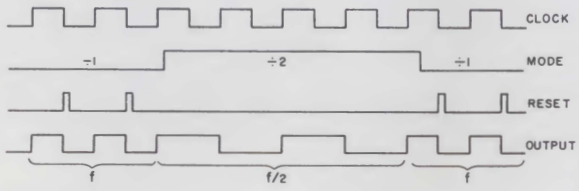


(b) Sequential pass-on provides an output only if C follows B follows A.

Fig. 22. Sequential circuits.

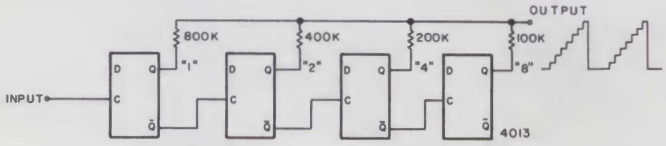


(a) Circuit.

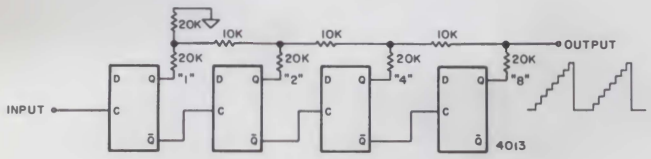


(b) Waveforms.

Fig. 23. Programmable divider divides by one or two.



(a) Current mode uses "1-2-4-8" network. Low output impedance and voltage;



(b) Voltage mode uses "R-2R" network. High output impedance and voltage.

Fig. 24. Digital to analog (D/A) converters.

version schemes are based on digitially switching current sources, voltages, or resistors and then summing the resulting current as an analog output. CMOS output stages are especially attractive for this because they swing the full supply range and have no offsets.

Fig. 24 gives us two different digital-to-analog conversion schemes. We've shown the digital portion as a binary divider using 4013s. The counter is advanced to the desired count and then output as an analog voltage. As an alternate, we could use our D-flops as latches and apply a parallel digital word. The word is updated every time we want a new analog conversion.

The two circuits differ in our choice of summing resistors. In Fig. 24(a) we use the classic "1-2-4-8" resistor weighting method. But note one important detail: The current through our resistors is inversely proportional to resistance, so the 800k resistor is weighted 1 and the 100k resistor is weighted 8.

Traditionally, this circuit summed into the virtual ground summing input of an operational amplifier. But thanks to CMOS being able to identically source or sink current to either supply rail, our output loading can be anything from an open to a short and can be returned to any voltage between the supply limits without affecting resistor values or linearity. (You can prove this hard-to-believe bit with Thevenins theorem; the "source impedance of our multiple supply is constant; only the equivalent "single source" voltage changes.)

For more resolution, the resistor values tend to get out of hand. We can combine the resistors with a current or voltagydivider circuit and eliminate this restriction. This is called the "R-2R" method and is shown in Fig. 24(b). Outputs of both circuits are the same, but the R-2R circuit easily expands to long word lengths. Another of its advantages is that the source and sink currents of each stage are identical, so any internal drops tend to compensate themselves rather than getting progressively worse.

You can make these circuits into analog-to-digital converters by insiding them out. The analog output goes to a comparator that starts or stops the clock pulses depending on an input analog signal. The digital output is then taken from the counter.

Phase Shifters

Digital *phase shifters* may be used to generate various delays in a signal. This is handy for color TV processing, audio filtering, radar signal correlation, and similar uses. The same idea is also used to generate multiphase ac power source signals and the multiple clocks needed for some microprocessors. Fig. 25 gives us some details.

The binary divider of 25(a) is the simplest example. It starts with a double frequency clock and gives us two clock phases that are spaced 180 degrees from each other. If some "daylight" is needed between clock phases, a narrow clock pulse can be ANDed with the outputs to provided a zero state between the phase outputs.

In Fig. 25(b), we generate two *quadrature*, or 90 degree phase shifted, digital signals. We start with a 4F clock and use an even length walking ring counter to generate the phases for us. Unlike audio networks, the 90 degree phase shift is independent of frequency and follows the input clock over any desired frequency range. By decoding both-outputs-high and both-outputs-low, we can generate the type of two-phase clock signal needed by a microprocessor where one clock goes high, followed by daylight, followed by the other clock high, followed by more daylight.

Incidentally, its extremely important in many electronic

circuits to *exactly* obey the multiphase clocking requirements. Be sure to pay particularly close attention to the allowable clock overlap and underlap, minimum spacing, allowable width variations, the states (if any) you are allowed to stop in, and so on.

A three phase power generator circuit is shown in Fig. 25(c). It starts with a 6X clock (360 Hertz in the case of a 60 Hertz power system) and gives us three square waves phase shifted by 120 degrees. The AND gate is a disallowed state eliminator but otherwise doesn't enter the circuit.

Phase Detectors

We can also use a 4013 and an RC filter network to produce an analog output proportional to the phase shift between two signals such as shown in Fig. 26.

We use phase two or Ø2 as our reference. It sets the flip-flop with its positive edge. The positive edge of phase one (Ø1) resets the flip-flop. The time the Q output is high depends on the phase difference between Ø1 and Ø2. The output RC filter averages the high to low time ratio into a continuous analog output voltage. As the response curve shows us, the greater the phase lag of Ø1, the more output voltage you get. The best operating point is at the half-way up point at 180 degrees, as the dot in the response indicates. Operating near Ø or 360° isn't recommended due to the discontinuity as the detector slips cycles.

Sometimes we can cheat a little and make a circuit do much more than we would first suspect. Fig. 26(b) is an example of a phase detector that only works over the first 180 degrees of phase shift and only provides one-half the output voltage of the first circuit. Its best operating point is at a 90 degree phase shift. This is not as desirable as the Fig. 26(a) circuit, but probably still useful, particularly as the line lock for a TV typewriter.

But, now we can shove a plain old power line sinewave reference into the direct reset input without any conditioning, and let the *same* flip-flop do our power line conditioning and our phase detecting simultaneously. This example of do-more-with-less shows how some extra design time and rethinking can cut the amount of circuitry apparently needed in half.

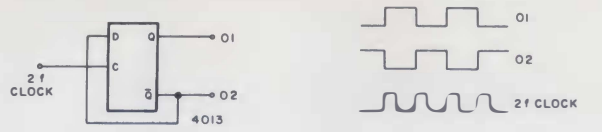
Digital Mixer

For some uses, a 4013 can act as a mixer that gives us the difference between two input frequencies. The circuit of Fig. 27 shows us the basic idea.

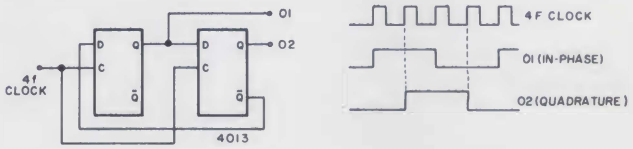
Suppose F1 and F2 were identical in frequency. The output would always be in one state. Which state depends on whether F1 was high or low at the positive edge of F2. Now, suppose that F1 is slightly lower in frequency than F1 and it starts "slipping cycles" with respect to F2. As it slips cycles, the Q output will also slip, and give us a square wave nearly equal to the difference frequency between the two inputs.

There are several restrictions to mixers of this type. Unlike analog mixers, both F1 and F2 must be single frequency, clean, digital waveforms. Our digital difference frequency is always *quantized* to be some exact submultiple of F2, so some apparent frequency jitter noise will *always* appear on the output. This jitter becomes less pronounced when you are measuring the small difference between two nearly equal high frequency signals. (Actually, this frequency jitter represents the sum term of the two frequencies. You normally can't separate sum from difference frequencies in a single mixer; it takes sine and cosine channels, single sideband techniques, or something similar.)

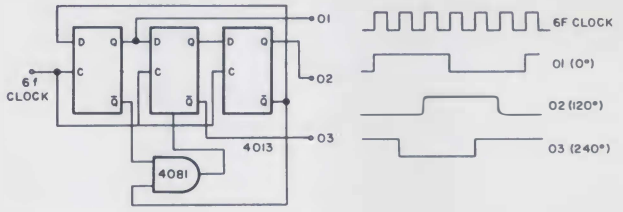
The circuit is also harmonic sensitive. For



(a) Two clock phases spaced 180°, 2f input.

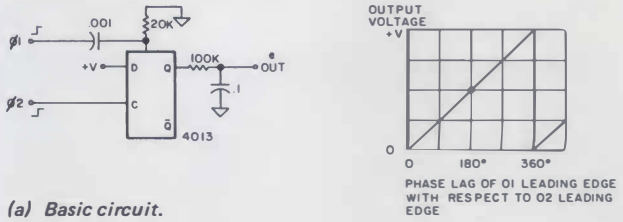


(b) Two clock phases spaced 90°, 4f input.

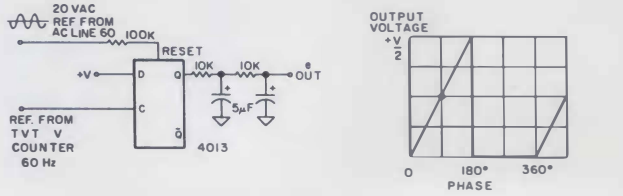


(c) Three clock phases spaced 120°, 6f input.

Fig. 25. Digital phase shifters form multiphase clock sources.



(a) Basic circuit.



(b) Line lock phase detector for a TV typewriter (TVT) simultaneously conditions power line reference.

Fig. 26. Clocked logic phase detectors.

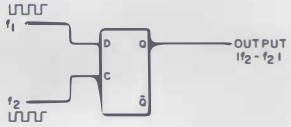


Fig. 27. Digital mixer provides difference frequency between f1 and f2.

instance, if F2 is 10 kHz and F1 is 20.003 kHz, a 3 Hertz beat note results. Mixers like this can be used in frequency synthesizers and phase lock loops. They are pretty much limited to uses where a somewhat noisy low frequency difference between two faster signals is useful.

A Tuning Indicator

We can wrap up our look at the clocked logic flip-flops with a rather stunning example of a do-more-with-less circuit. It uses a single 4013 to replace what, on first glance, would seem to be a bunch of MSI circuitry.

The problem and its solution appears in Fig. 28. The problem involves a digital data cassette recording system. To minimize errors, this recording system must be properly tuned. This is easily done by adjusting a monostable, but this could take a scope or other special test setup to do. It would be far better to come up with a "turn the knob till the red light goes out" circuit.

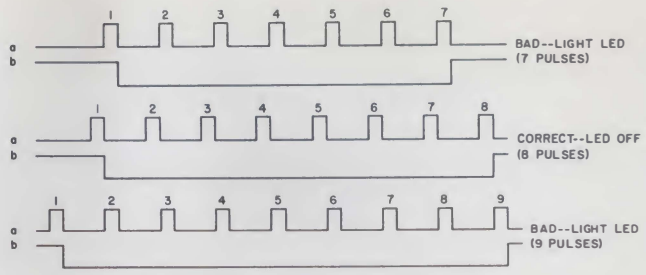
The recording system involves two signals A and B. The system is in tune if there are exactly 8 A pulses for one B pulse. If there are 7 or 9 A pulses, it is out of tune. What we want to do is build a simple and cheap circuit to put a light ON for 7 or 9 A pulses and OFF for 8.

Well, let's see. We'll need a divide-by-nine counter, a digital comparator, gating for the greater than and less than outputs, some control logic, a latch . . . a lot of parts. Can we do the whole job with a single 4013?

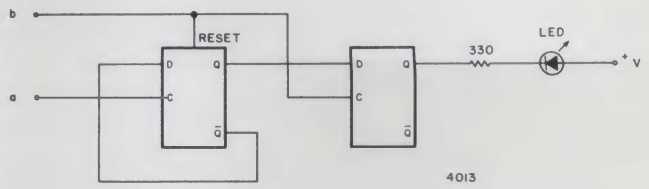
Instead of actually measuring the total number of A pulses, we observe that an *even* number (8) is valid, while the *odd* numbers 7 and 9 are not. So, we'll use half a 4013 as an even-odd detector and the other half as a result memory and LED driver, following Fig. 28(b).

Waveform B high holds the first stage in the low state. When B goes low, the first stage binary starts counting A pulses, going high on odd counts and low on even counts. When B goes back high again, the even-odd answer is stored in the second flip-flop and output to light or not light the lamp. You can do the entire circuit with a 4013, a LED, and an optional resistor.

Always watch for your chance to "do more with less" in any design problem. Very often, the simpler clocked flip-flops we have examined can eliminate or simplify things enough to greatly reduce your circuit cost and complexity. ■



(a) The problem — show correct tuning of a bit boffer cassette interface.



(b) Solution using a single 4013. First stage is even-odd detector; second stores result.

Fig. 28. Tuning indicator for a digital cassette storage system.

THE PROKO PAPER TAPE READER: A fully TTL buffered optical tape reader for reading 8 level paper tape. It's compatible with nearly all parallel input ports and has both positive & negative strobe outputs. The power (+5V @ 20ma) is derived from your I/O board... Just supply a light source (study lamp), grab the tape and pull!
PTR - II KIT - $54.00 ASSEMBLED $68.

TOP QUALITY $28

HEAVY DUTY POWER TRANSFORMER 5VDC

ADD CALCULATOR FUNCTIONS without adding more memory to your micro. The R.G.S. mathmatical function unit uses a calculator chip to provide floating point add, sub, mult, divide, log, trig & power functions for your micro.
PC BOART AND MANUAL.....$27.00

the proko electronics shoppe
439 marsh st.
san luis obispo, ca. 93401
805/544-5441
P11

Check or money order only. Calif. resident 6% tax. All orders postpaid in the U.S. $10 Min. order. Prices subject to change without notice.

cybercom
A DIVISION OF SOLID STATE MUSIC

4Kx8 Static Memories
MB-1 MK-8 board, 1 usec 2102 or eq. PC Board..... $22

MB-2 Altair 8800 or IMSAI compatible Switched address and wait cycles. PC Board.....$25

MB-4 Improved MB-2 designed for 8K "piggy-back" without cutting traces. PC Board $30
Kit 4K .5 usec.....$129.95 Kit 8K .5 usec.....$199

MB-3 1702A's Eroms, Altair 8800 & Imsai 8080 compatible Switched address & wait cycles. 2K may be expanded to 4K. Kit less Proms.....$65 2K Kit.....$145 4K Kit.....$225

MB-6 PC Bd.....$35

MB-6A 8Kx8 Switched address and wait assignments Memory protection is switchable for 256, 512, 1K, 2K, 4K and 8K. 91L02A .5 usec rams, Altair 8800 & IMSAI compatible. With battery power option.
Kit.....$250 Assembled & tested.....$290

I/O Boards
I/O-2 I/O for 8800. 2 ports, committed pads for 3 more, other pads for EROMS UART, etc.
Kit.....$47.50 PC Board only.....$25

91L02APC	$2.55	2102AL-4C	$2.00
32	$2.50 ea.	32	$1.80
64	$ 225 ea.	128	$1.70
2101	$4.50	2111-1	$4.50

64 x 16 VIDEO BOARD Altair plug compatible display 32 x 16 or 64 x 16 switch.selectable. Composite and parallel video ports, upper and lower case with software.
Kit $179.95
PC board.....$35

Misc
SP-1 Synthesizer board. Computor controled wave forms 9 octaves 1 vrms ½% distortion includes high level music language.
KIT.....$250
Altair compatable mother board. Room for 15 connectors 11" x 11½" (w/o connectors).....$45
With 15 connectors.....$110.00

Altair extender board (w/o connectors).....$9.50
With w/w connector.....$13.50

90 Day Guarantee on SSM Products Kits. MB-2, MB-3 (2K OR 4K), MB-4, MB-6, 10-2 video board and mother board with connectors may be combined for a discount of 10% in quantities of 10 or more.

1702 A	10.00
*programming send hex list	5.00
AY5-1013 UART	$6.95
2513 prime spec. upper or lower case	11.00
8080A prime CPU	25.00
8212 prime latch buffer	4.00
8224 prime clock gen	5.00
8228 prime sys controller	8.90

MIKOS
419 Portofino Dr.
San Carlos, Ca. 94070

Please send for xistor, IC & kit list

For large orders please send money order or cashiers check to avoid delays in waiting for checks to clear.

Check or money order only. Calif. resident 6% tax. All orders postpaid in U.S. All devices tested prior to sale. Money back 30 day guarantee. Sorry we can not accept returned IC's that have been soldered to. $10 min. order. Prices subject to change without notice.

Thinly disguised affiliates of KO Electronics and Surplus, SLO Ca. 93401