Why some CMOS circuits don't work as you expect

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A 4093 is a 4093, right? Well . . . yes, and no. There are quite a few pitfalls in the CMOS 'jungle' and it's handy to know about them before venturing forth.

CMOS '4000' SERIES integrated circuits are manufactured by at least six major manufacturers and the 74C series by at least two major manufacturers, but it must not be assumed that a 4XXX from one manufacturer is interchangeable with a 4XXX device from another manufacturer. This article explains some of these differences.

Schmitt gate oscillator

What could be simpler than the oscillator circuits shown in Figures 1(a) and 1(b)? There are so few components that you would expect these circuits to work first time.

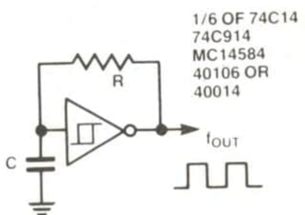

Figure 1a. Different manufacturers ICs will produce different results.

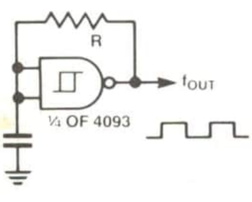

Figure 1b. Such a simple circuit but the value of f_{out} can vary from 52.9 Hz to 249 Hz, depending on the brand of 4093 used.

You have selected stable, close tolerance components and calculated the frequency according to the formula:

$$f_{out} = \frac{1}{CR\log_e\left[\left(\frac{V_{cc}-V_{t-}}{V_{cc}-V_{t+}}\right)\left(\frac{V_{t+}}{V_{t-}}\right)\right]}$$

where C = capacitor value in uF
R = resistor value in kilohms
f_{out} = frequency out in kHz
V_{cc} = supply voltage
V_{t+} = upper trigger level of Schmitt trigger
V_{t-} = lower trigger level of Schmitt trigger

Now, the question is, "what are the values of V_{t+} and V_{t-}?" We need to refer to the manufacturer's data sheet for an answer. But which manufacturer? There are at least six different manufacturers to choose from and each one gives a different range of possible values for V_{t+} and V_{t-}.

Considering the 4093 IC (Figure 1(b)); if all the databooks are consulted it is found that for V_{cc} = +5 V the *highest* typical value of $\mathbf{V_{t+}}$ = 3.6 V (extreme = 4.3 V).

The *lowest* typical value of $\mathbf{V_{t+}}$ = 2.7 V (extreme = 1.7 V).

The *highest* typical value of $\mathbf{V_{t-}}$ = 2.2 V (extreme = 3.3 V).

The *lowest* typical value of $\mathbf{V_{t-}}$ = 1.4 V (extreme = 0.7 V.

Now if V_{t+} = 3.6 V, V_{t-} = 1.4 V, V_{cc} = +5 V, C = 100 nF and R = 10k, then from the formula above f_{out} = 52.9 Hz.

With the same type from another manufacturer, V_{t+} could be 2.7 V and V_{t-} could be 2.2 V, in which case recalculation gives a frequency of 249 Hz!

These figures are based on typical values of trigger level. Extremes of high and low trigger levels could give frequencies ranging from 27.5 Hz to 961 Hz with the same values of C = 100 nF and R = 10k. This gives a frequency range of almost 35:1 if the whole spectrum of possibilities is considered.

Now it will be clear why the circuit may oscillate at a frequency which is considerably different from what was expected or intended by the designer who only consulted one manufacturer's databook!

The monostable

Now let us look at another CMOS circuit often used by the hobbyist — the 4528 dual monostable, shown in Figure 2.

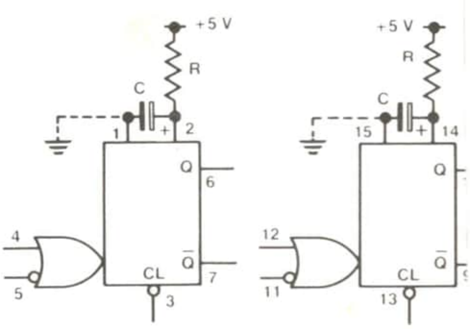

Figure 2. The 4528 dual monostable can have variations in its performance of up to ±50%.

Here again, different manufacturers give different formulae for the monostable time constant. A typical formula (for +5 V supply) is

$$t = 0.37CR$$

However, it could vary from t = 0.32CR to t = 0.42CR typical, with variations up to ±50%.

The pulse width depends very much on the supply voltage. Some manufacturers' 4528s give increasing pulse width with increasing supply voltage, others give a reverse effect.

The formula given above depends on the value of C being greater than 10n. For smaller values of capacitance the manufacturers' data sheets need to be consulted.

It should also be noted that some manufacturers require pins 1 and 15 to be grounded externally for correct operation. To overcome the variations in timing formula, a CMOS 4538 integrated circuit can be used in place of the 4528. The 4538 is pin compatible with the 4528 IC and the formula is:

$$t = CR$$

with variations of only ±5%.

In all timing circuits using CMOS ICs it is wise to make provision for trimming the value of the timing resistor to allow for adjustment.

The counter/divider

Next we come to a well-known decade counter/divider IC — the 4017.

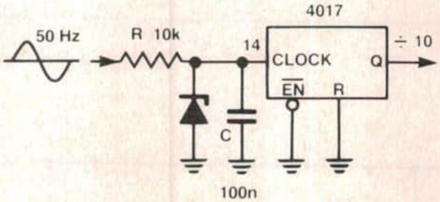

Figure 3. This circuit will only work correctly with particular brands of 4017 decade counter/dividers. The wrong choice can result in false counting.

Will the circuit in Figure 3 always work correctly? No, only with a Motorola 14017 or an RCA 4017, because these have an internal Schmitt trigger on the clock input. Other manufacturers' 4017s do not, so false counting may result.

BCD decoder

Another fairly common integrated circuit likely to give problems is the 4028 BCD-to-10-line decoder. We now come to see that actual logical differences can occur between one manufacturer's 4XXX and another manufacturer's 4XXX.

With the 4028, some manufacturers (Motorola and RCA) do not decode the six 'illegal' binary codes 1010 to 1111 (i.e: 10-15), while other manufacturers (including National, Fairchild and Philips) decode these outputs as if the input was 8 (1000) or 9 (1001).

The problem of logical differences between one manufacturer's device and another manufacturer's device (with supposedly the same type number) applies also to the 4585 four-bit comparator and even to the ubiquitous 555 and 556 timers. There may be other examples too. The problem fortunately does not occur with the range of quad gates.

The moral

The above-mentioned examples were all encountered during the design of one piece of industrial equipment which made use of these common CMOS parts.

You may well ask "If design engineers, who have ready access to all the data books, can run into such problems, what about the unsuspecting hobbyist, who has no data?"

The moral of this article is that "forewarned is forearmed". It is hoped that this article may at least prevent some construction projects from being abandoned because they do not appear to work correctly at first sight. Designers who publish projects should check that there are at least two manufacturers' ICs which will work in the circuit as intended and, if necessary, spell out the names of suitable manufacturers in the parts list. Best of all, only design circuits that will work with all manufacturers devices of the same basic type number (though this may not always be possible).

If problems occur, all that may be required is to try an IC from a different manufacturer. ●