## Digital differentiator determines shaft acceleration

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Using standard logic elements to determine the derivative of an input signal digitally, this inexpensive circuit can find the acceleration or deceleration of elements in linear and rotating systems, such as those encountered in moving projectile problems or when measuring changes in shaft speed. The magnitude and sign of the derivative is expressed as a 5-bit word at the output, which makes interfacing with a microprocessor or other processing device in a data-acquisition system easy.

The rate of change of an input signal is measured with the circuit shown in the figure. The input signal, f(t), has been derived by a transducer that converts the speed of the shaft, etc. to a corresponding frequency. With the aid of gates $G_1$–$G_3$, this signal is gated to an up-down counter. Clock signal x(t), which is low for approximately 100 nanoseconds, can be generated by a 555 timer in the astable mode.

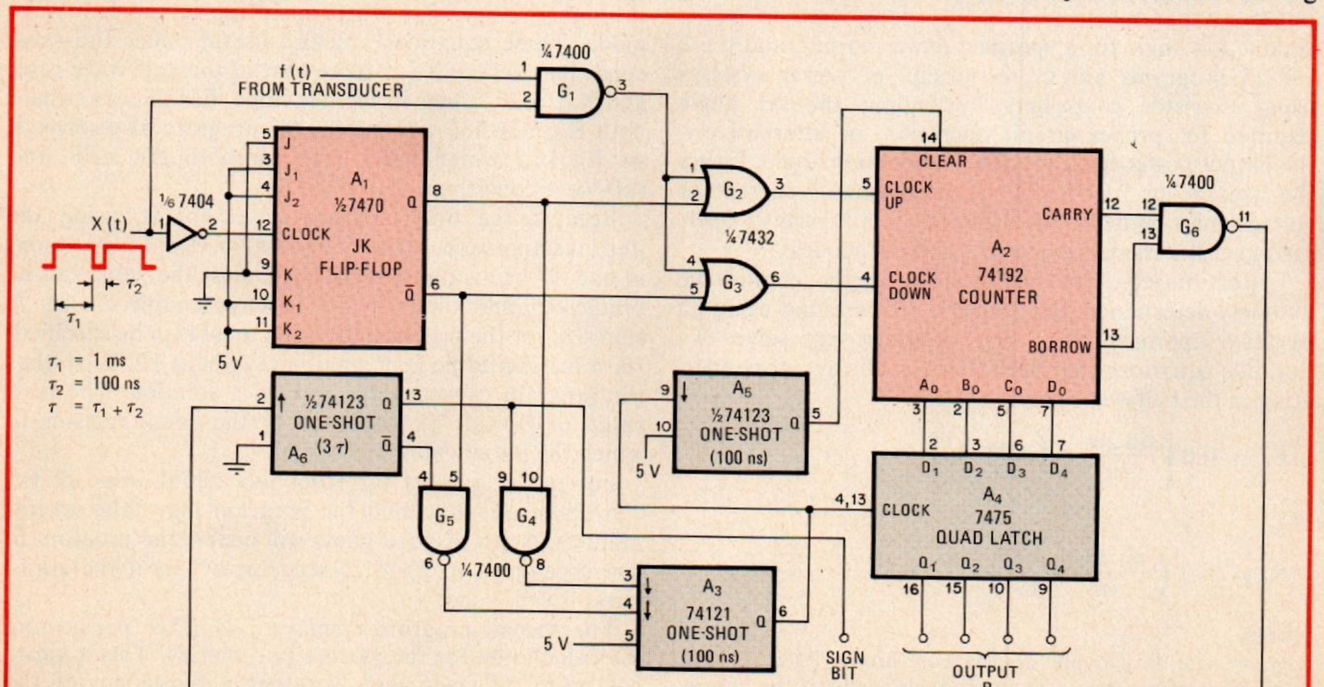
Generally, the negative-going edge of x(t) clocks the flip-flop $A_1$, which operates in the toggle mode. When its output is high (Q = 1), $G_2$ is disabled and $G_3$ is active; hence, the 74192 counter, $A_2$, counts down. Otherwise, $A_2$ is in the count-up mode. In either case the 74192 counts during the time $T_1$.

Consider circuit operation when the change in f(t) is positive. A narrow positive-going pulse is generated by $A_5$ each time the Q output of $A_1$ moves high (at the start of the measuring cycle) and sets the counter to zero. The 74192 first counts down for the period $T_1$. The Q output of $A_1$ then moves low as it is toggled by x(t), and the 74192 counts up during the next $T_1$ period. The net reading from the counter at this time is thus:

$$|R| = (f_u - f_d)T_1 \quad (1)$$

At the end of the counting cycle and at the start of a $T_2$ period, $A_1$ triggers $A_3$ and the one-shot generates a positive-going pulse. This signal clocks latch $A_4$, so that the counter's contents appear at the output. The negative-going edge of the latching pulse then triggers $A_5$, clearing the counter for the next measuring cycle.

During successive cycles, $A_6$ is retriggered continuously by the $A_2$ carry pulse, which is generated during the up-count interval. Continuous retriggering of $A_6$ ensures that circuit timing is maintained, for $A_6$ activates $G_4$ and enables $A_3$ to fire only at the start of every other $T_2$ period. Note that a carry pulse will be generated during each timing interval if f(t) is rising (R in Eq. 1 will be positive), because the number of pulses received during




**Logical derivative.** Digital circuit finds first derivative of input waveform f(t) and thus can be used to determine acceleration or deceleration of elements in linear and rotating systems. Output is expressed as a 5-bit word: 4 bits for magnitude and 1 bit to indicate sign.

the count-up interval must be greater than that encountered during the count-down time.

If the period between $A_1$'s toggling times, and thus the measuring cycle $t = (T_1 + T_2)$, are small, then the derivative of the input wave, $f'(t)$, may be assumed to be constant over the measuring cycle, and $f'(t) = K$. Therefore the change in the average frequency with respect to time t is:

$$\frac{f_u - f_d}{t} \rightarrow f'(t) = K \qquad (2)$$

Substituting for $f_u - f_d$ in Eq. 1 yields:

$$R = KT_1 t \qquad (3)$$

where R now represents acceleration and $T_1$ and t are known constants.

If the change in f(t) is negative (deceleration), the number of pulses received during the first (down) counting interval will be greater than that received during the next (up) counting time. Hence, neither a carry nor a borrow pulse will appear at $A_2$, and $A_5$ is not triggered. Therefore $G_4$ is disabled, $G_5$ is enabled, and $A_3$ is triggered at the end of every other $T_1$ period.

The end result of this operation is that $A_2$ first counts up during the initial $T_1$ period and down for the second $T_1$ period, at the end of which time the Q output of $A_1$ moves low and the next measuring cycle starts. Thus the latched output of $A_2$ is still given by Eq. 3, where K now represents the rate of decrease of f(t). The state of the retriggered $A_5$ indicates whether f(t) is accelerating or decelerating (Q = 1 or Q = 0, respectively). □

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