



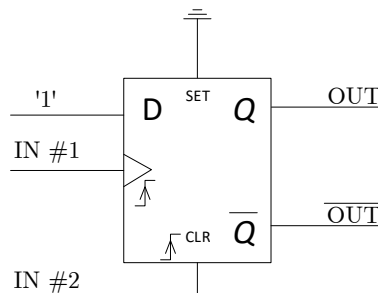
Sistemas de Processamento Digital de Sinais

XOR phase detector

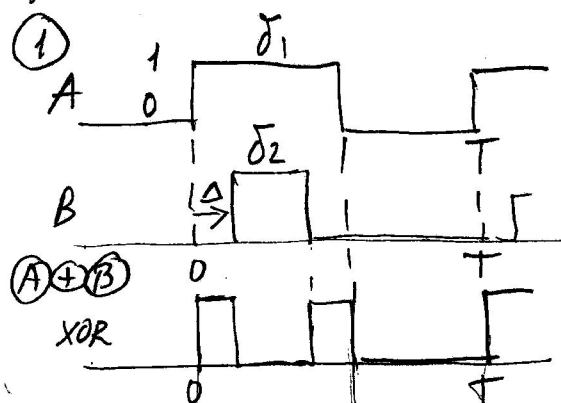
- 1) Consider two rectangular signals with duty cycles δ_1 , $\delta_2 \leq \delta_1$ and period T . Determine and sketch the static phase detector characteristic of a XOR circuit operating with these signals with amplitude 0V or 1V. Generalize for the amplitudes V_N e V_P .
- 2) Show that a XOR phase detector operating with symmetrical square-waves reacts (does not react) when one of the signals has a frequency which is an odd (even) multiple of the other. Determine the static characteristic of the phase detector for $f_2 = mf_1$ with m odd.

Phase detector with a D-type flip-flop

Consider the phase detector in the figure which operates with rectangular signals. Show that its operation is independent of the signal's duty-cycle. Determine and sketch the phase detector static characteristic. What happens when the input signals are switched? And when their frequencies are related by an integer?



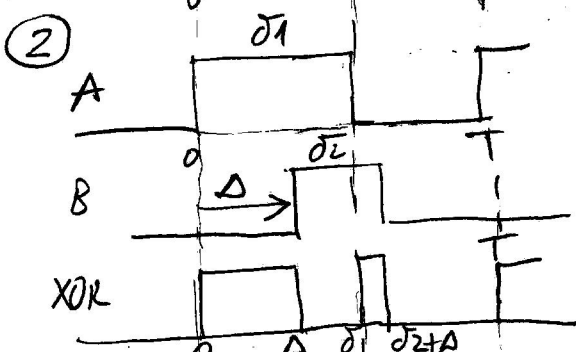
Phase detector XOR: two rectangular signals with duty cycles δ_1 and $\delta_2 \leq \delta_1$, period T (note: no loss of generality in considering $\delta_2 \leq \delta_1$, could be the other way around. Amplitudes 0, 1, then generalize to arbitrary V_N, V_P . The analysis used here is general and can be used with any logic gate or function.



Conditions, $\Delta > 0$ and $\Delta + \delta_2 < \delta_1$

$$0 \leq \Delta < \delta_1 - \delta_2$$

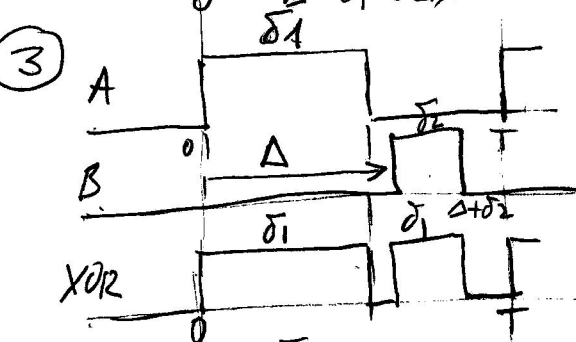
$T(XOR) = \Delta + \delta_1 - (\Delta + \delta_2) = \delta_1 - \delta_2$, which does not depend on $\Delta \Rightarrow$ bad news



Conditions: $\Delta + \delta_2 \geq \delta_1$ and $\Delta < \delta_1$

$$\delta_1 - \delta_2 \leq \Delta < \delta_1$$

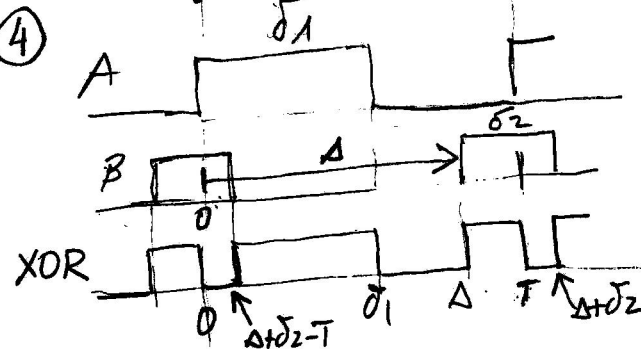
$T(XOR) = \Delta + \delta_2 - (\delta_1 - \delta_2) = 2\Delta - (\delta_1 - \delta_2)$
depends on Δ !



Conditions: $\Delta \geq \delta_1$ and $\Delta + \delta_2 < T$

$$\delta_1 \leq \Delta < T - \delta_2$$

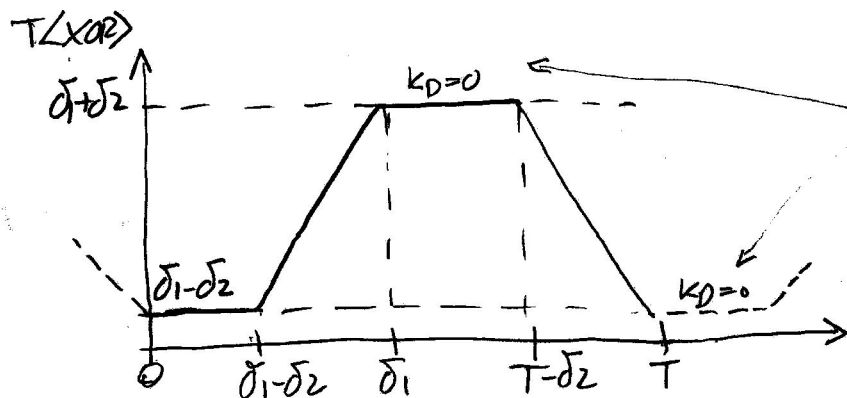
$T(XOR) = \delta_2 + \delta_1 \rightarrow$ does not depend on Δ



Conditions: $\Delta + \delta_2 \geq T$ and $\Delta < T$

$$T - \delta_2 \leq \Delta < T$$

$T(XOR) = \delta_1 - (\Delta + \delta_2 - T) + T - \Delta$
 $= -2\Delta + 2T + (\delta_1 - \delta_2)$
depends on Δ



- periodic, period T
- Dead zones, $K_D = 0$
- Limited range of operation for $\Delta \phi = 2\delta_2$
In fact $\Delta \phi = \delta_2 = \min\{\delta_1\}$
because only one region ($K_D > 0$ or $K_D < 0$) can be used!

Generic voltages V_N and $V_P \Rightarrow T\langle XOR \rangle \times V_P + (T - T\langle XOR \rangle) \times V_N$

$$\textcircled{1} T\langle XOR \rangle = \underbrace{(\delta_1 - \delta_2)}_{\text{time at } t} V_P + \underbrace{(T - (\delta_1 - \delta_2))}_{\text{time at zero}} V_N$$

$$\textcircled{2} T\langle XOR \rangle = (2\Delta - (\delta_1 - \delta_2)) V_P + (T - 2\Delta + (\delta_1 - \delta_2)) V_N$$

$$\textcircled{3} T\langle XOR \rangle = (\delta_1 + \delta_2) V_P + (T - (\delta_1 + \delta_2)) V_N$$

$$\textcircled{4} T\langle XOR \rangle = (-2\Delta + 2T + (\delta_1 - \delta_2)) V_P - (T + 2\Delta - 2T - (\delta_1 - \delta_2)) V_N$$

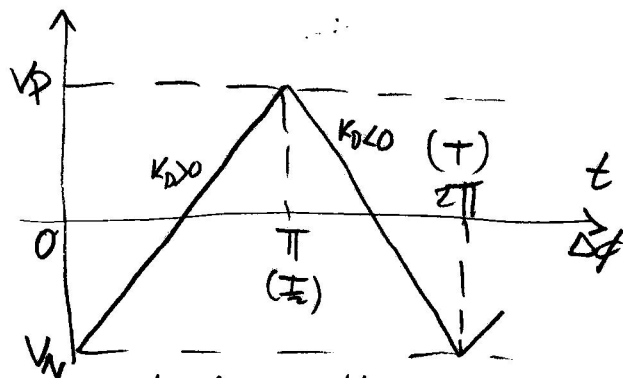
Square-wave: $\delta_1 = \delta_2 = \frac{T}{2} \Rightarrow$ dead zones $\textcircled{1}$ and $\textcircled{3}$ do not exist

$$\textcircled{2} T\langle XOR \rangle = 2\Delta V_P + (T - 2\Delta) V_N = 2\Delta(V_P - V_N) + T V_N$$

$$\langle XOR \rangle = V_N + \frac{2\Delta}{T} (V_P - V_N)$$

$$\textcircled{4} T\langle XOR \rangle = (-2\Delta + 2T) V_P - (-T + 2\Delta) V_N$$

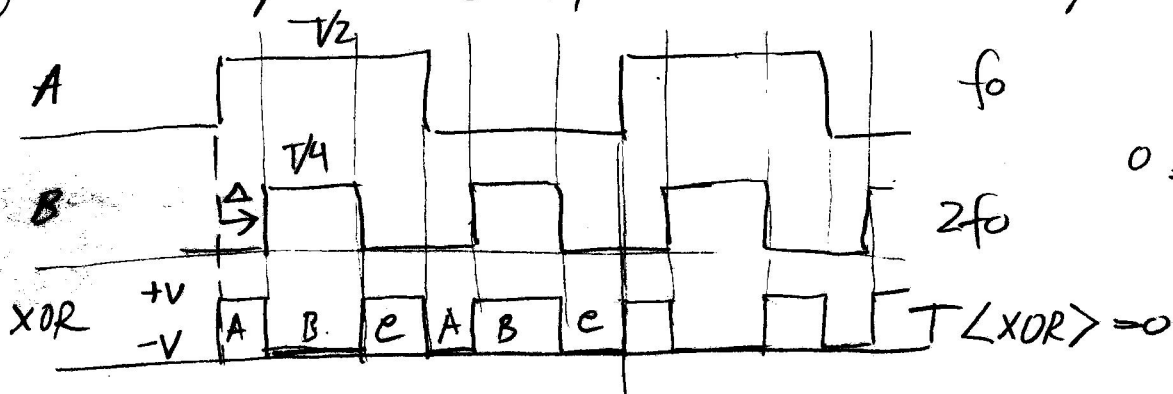
$$\langle XOR \rangle = -\frac{2\Delta}{T} (V_P + V_N) + (2V_P + V_N)$$



- no dead zones!
- $\Delta\phi_{\max} = \pi \left(\frac{T}{2}\right)$

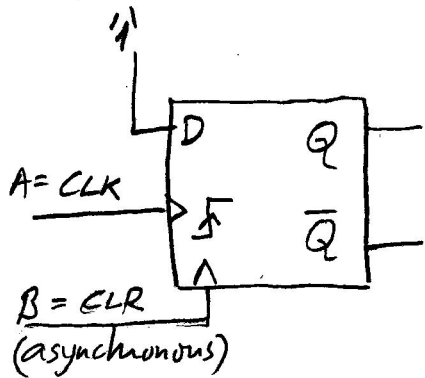
only half the phase excursion may be used because of the stability.

What happens when inputs A and B have harmonically related frequencies? Let's see examples with a square-wave with symmetric amplitudes ($\pm V$), because it's simpler.

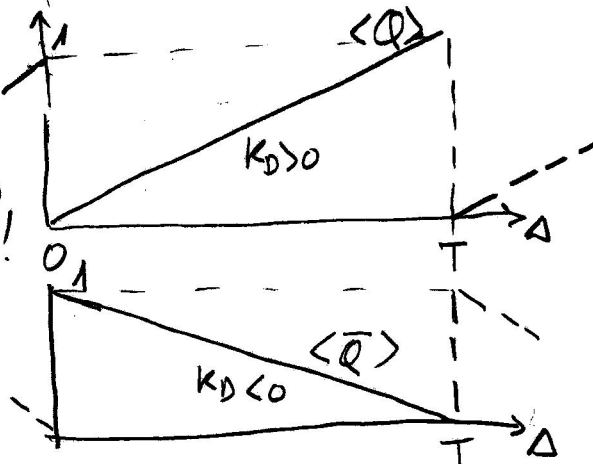


Flip-flop (D type) phase detector

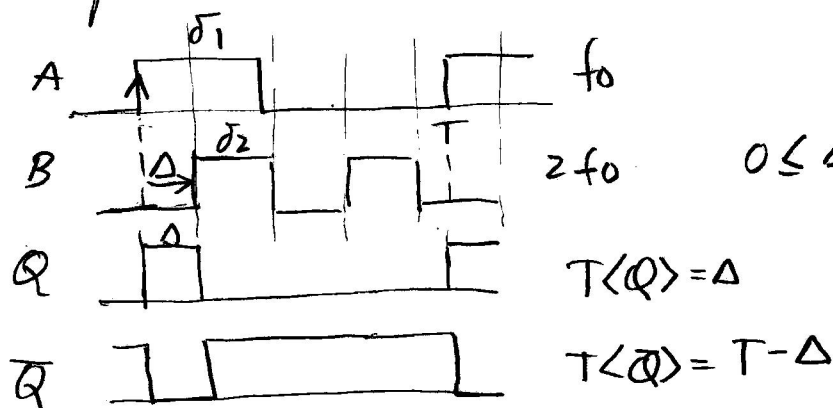
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- Periodic functions (T)
- Only have either positive or negative K_D \Rightarrow careful with stability!
- Works with $\Delta\phi = 2\pi$
- Because inputs are edge-triggered operation does not depend on the duty-cycles δ_1, δ_2



- If input A (CLK) is interchanged with B (Clear), the characteristics $\langle Q \rangle$ and $\langle \bar{Q} \rangle$ interchange (show!)
- Operation with harmonically related frequencies



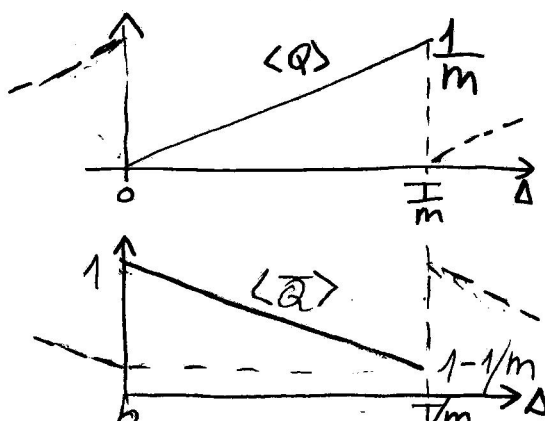
if you advance or retard B by $\frac{T}{2}$ (its period) you get the same waveform!

In general for any m (either odd or even)

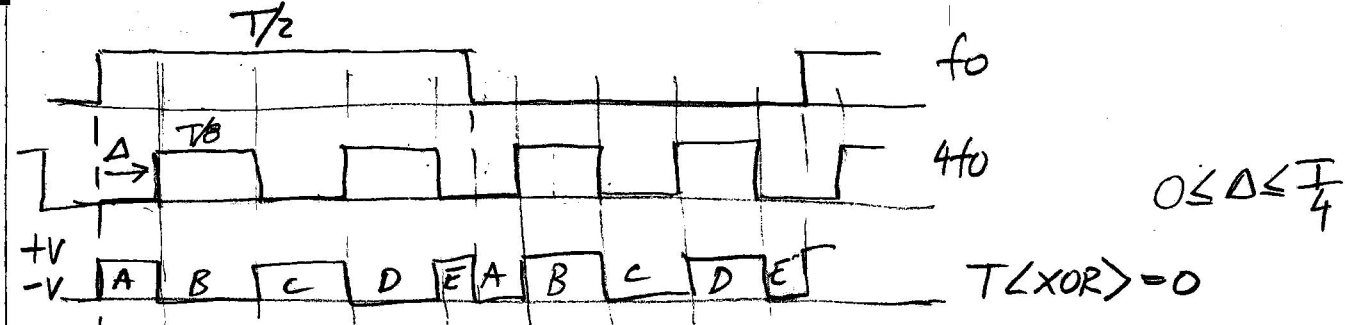
$$T(Q) = \Delta$$

$$T(\bar{Q}) = T - \Delta$$

$$0 \leq \Delta \leq \frac{T}{m}$$

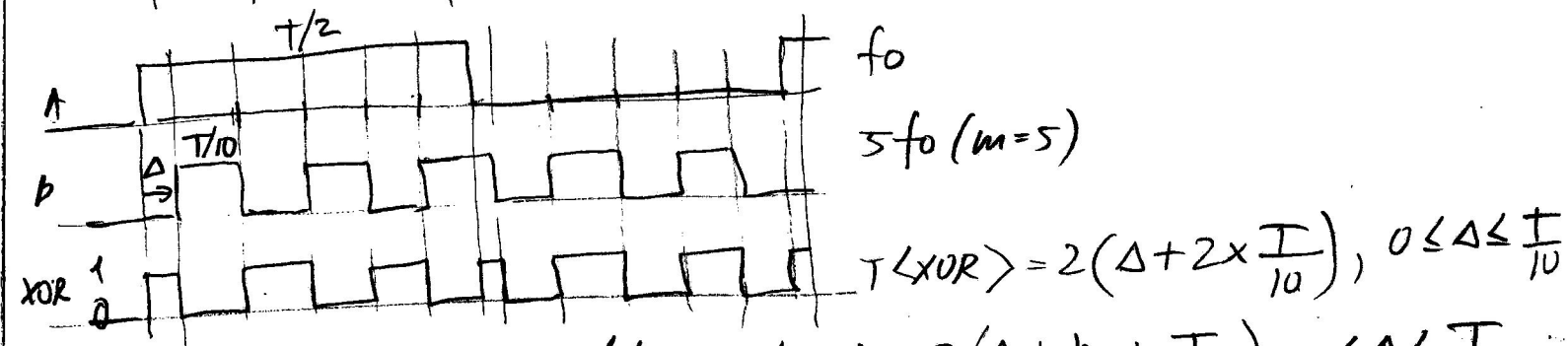
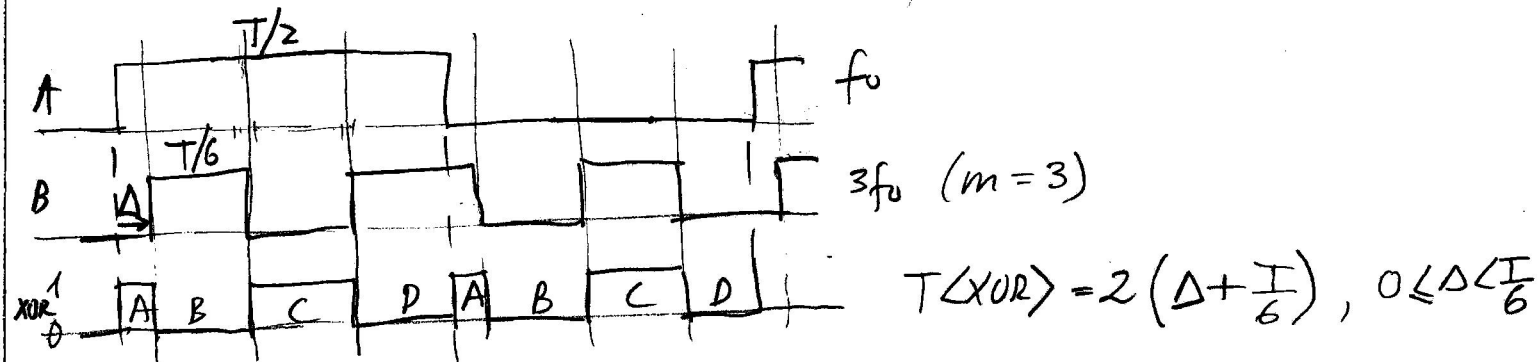


- Works but less phase $\Delta\phi = 2\pi/m$ and less excursion $1/m$ at the output (average)
- Still insensitive to δ_1, δ_2



$T(XOR) = 0$ whenever the relation between frequencies is even.

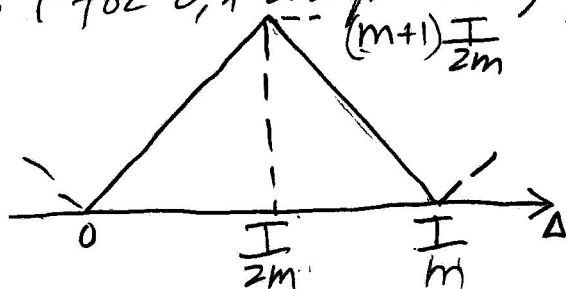
for an odd relation m :



So, for general m odd $T(XOR) = 2\left(\Delta + \frac{m-1}{2} \frac{T}{2m}\right), 0 \leq \Delta \leq \frac{T}{2m}$

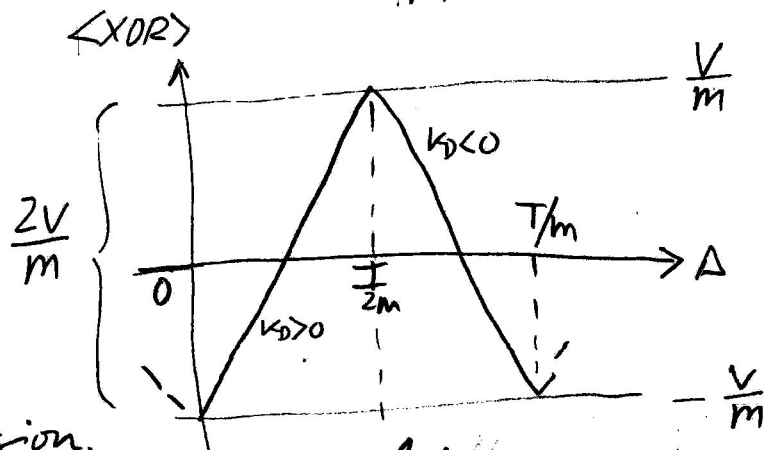
$= 2\Delta + \frac{m-1}{2} \frac{T}{m}, 0 \leq \Delta \leq \frac{T}{2m}$

For square-waves there are no dead zones so the characteristic is (for 0, 1 amplitude), or (for $\pm V$ amplitude)



$$T(XOR) = \left(2\Delta + \frac{m-1}{2} \frac{T}{m}\right)V - \left(T - 2\Delta - \frac{m-1}{2} \frac{T}{m}\right)V$$

$$= 4\Delta V - \frac{TV}{m}$$



As m (odd) increases, we still get a phase detector function but:

- The phase range decreases $\Delta\phi = \frac{T}{2m}$ (or $\frac{T}{m}$)
- The output voltage excursion, $\frac{2V}{m}$ decreases \Rightarrow lower lock and hold ranges.