Instituto Superior Técnico

Sistemas de Processamento Digital de Sinais

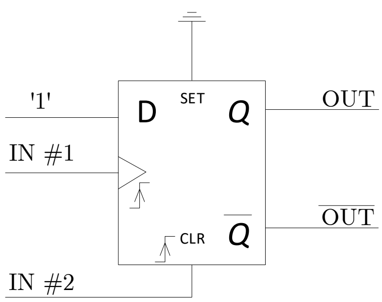
XOR phase detector

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.

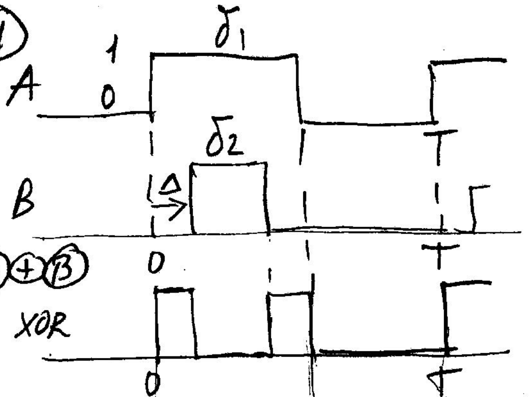
Phase detector with a D-type flip-flop

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.

1

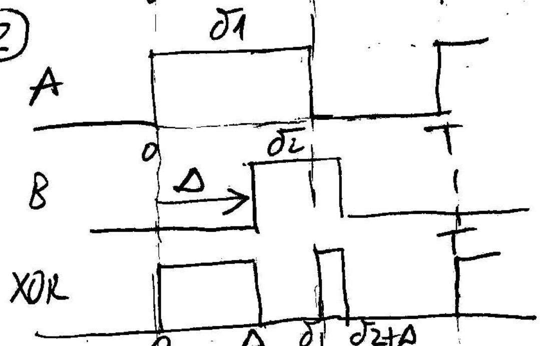


Conditions, $\Delta > 0$ and $\Delta + \delta_2 < \delta_1$

$$\boxed{0 \leq \Delta < \delta_1 - \delta_2}$$

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

2



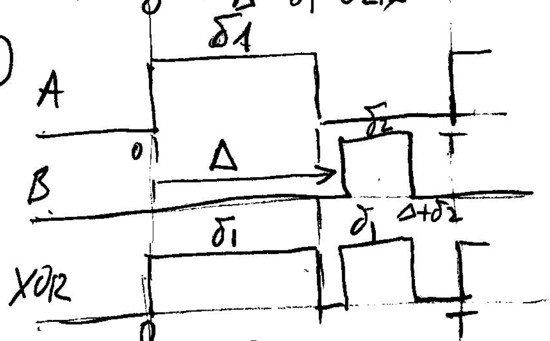
Conditions: $\Delta + \delta_2 \geq \delta_1$ and $\Delta < \delta_1$

$$\boxed{\delta_1 - \delta_2 \leq \Delta < \delta_1}$$

$T\langle XOR \rangle = \Delta + \Delta + \delta_2 - \delta_1 = 2\Delta - (\delta_1 - \delta_2)$

depends on Δ!

3

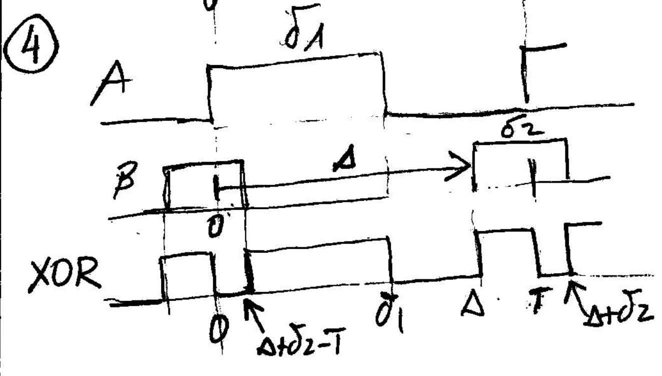


Conditions: $\Delta \geq \delta_1$ and $\Delta + \delta_2 < T$

$$\boxed{\delta_1 \leq \Delta < T - \delta_2}$$

$T\langle XOR \rangle = \delta_2 + \delta_1 \rightarrow$ does not depend on Δ

4

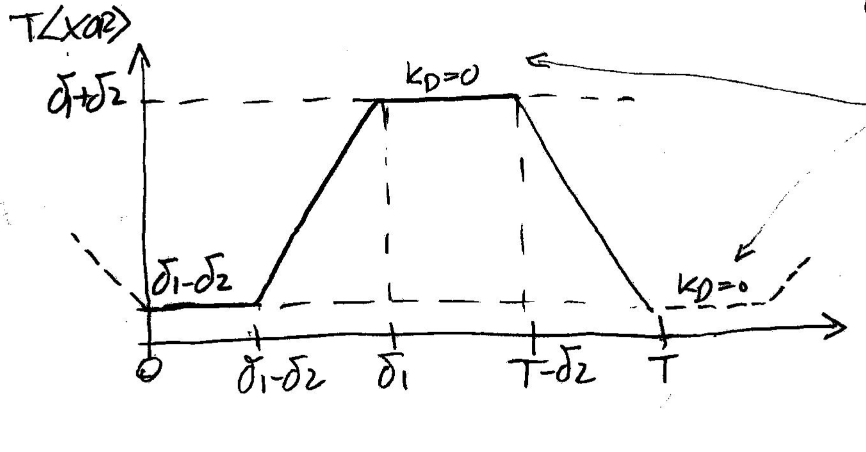


Conditions: $\Delta + \delta_2 \geq T$ and $\Delta < T$

$$\boxed{T - \delta_2 \leq \Delta < T}$$

$$T\langle XOR \rangle = \delta_1 - (\Delta + \delta_2 - T) + T - \Delta$$
$$= -2\Delta + 2T + (\delta_1 - \delta_2)$$

depends on Δ



- periodic, period T
- Dead zones, $K_D = 0$
- Limited range of operation for $\Delta\phi = 2\delta_2$

In fact $\Delta\phi = \delta_2 = \min\{\delta\}$ because only one region ($K_D > 0$ or $K_D < 0$) can be used!

Generic voltages V_N and V_P $\Longrightarrow$ $\boxed{T\langle XOR\rangle \times V_P + (T - T\langle XOR\rangle)\times V_N}$

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

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

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

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

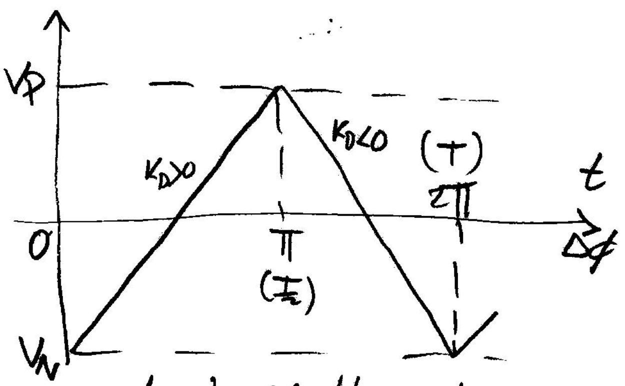
Square-wave: $\delta_1=\delta_2=\frac{T}{2}$ $\Rightarrow$ dead zones (1) and (3) do not exist

(2) $T\langle XOR\rangle = 2\Delta V_P + (T-2\Delta)V_N = 2\Delta(V_P-V_N)+TV_N$

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

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

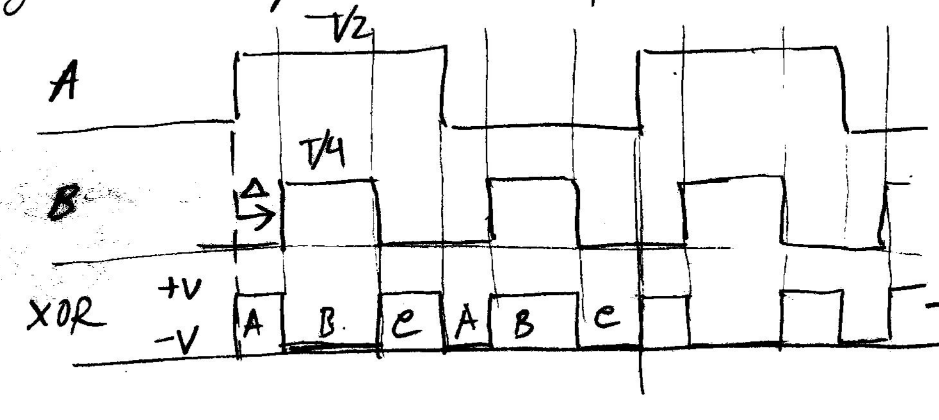
$\langle XOR\rangle = -\frac{2\Delta}{T}(V_P+V_N) + (2V_P+V_N)$



• no dead zones!
• $\Delta\varphi_{max} = \pi$ $(\frac{T}{2})$

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

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

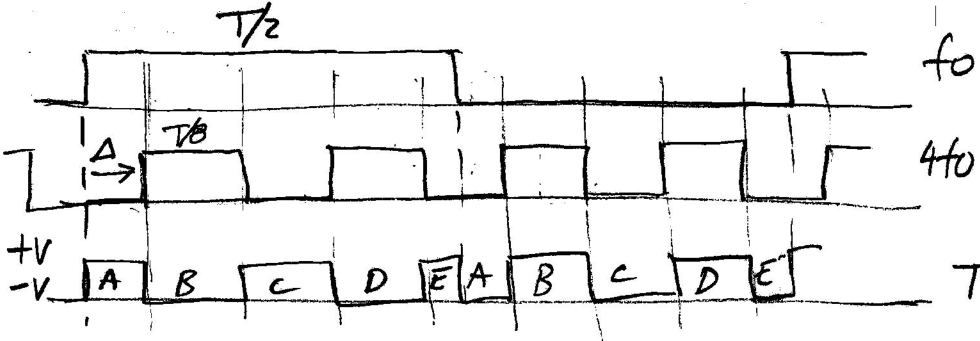


f_0

$2f_0$

$0 \leq \Delta \leq \frac{T}{2}$!

$T\langle XOR\rangle = 0$

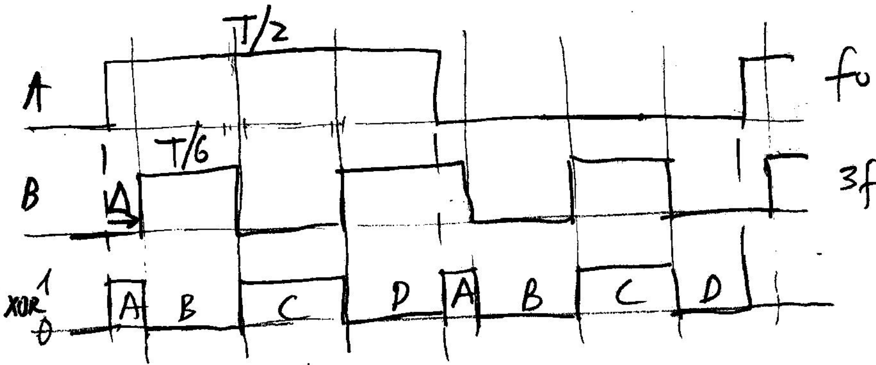


$0 \le \Delta \le \frac{T}{4}$

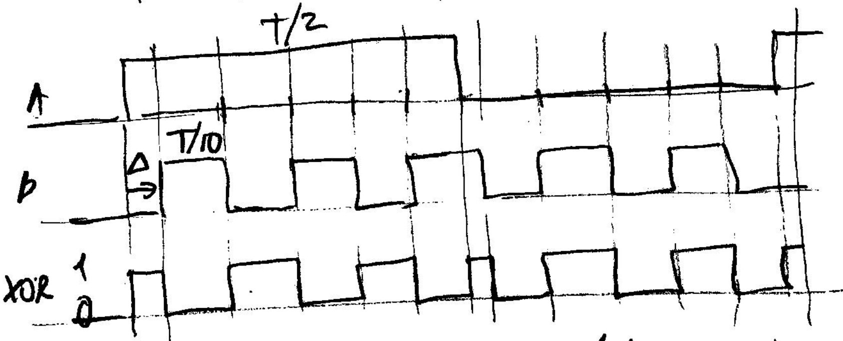
$T\langle XOR\rangle = 0$

$T\langle XOR\rangle = 0$ whenever the relation between frequencies is <u>even</u>.

For an <u>odd</u> relation <u>m</u>:



$T\langle XOR\rangle = 2\left(\Delta + \frac{T}{6}\right), \quad 0 \le \Delta < \frac{T}{6}$

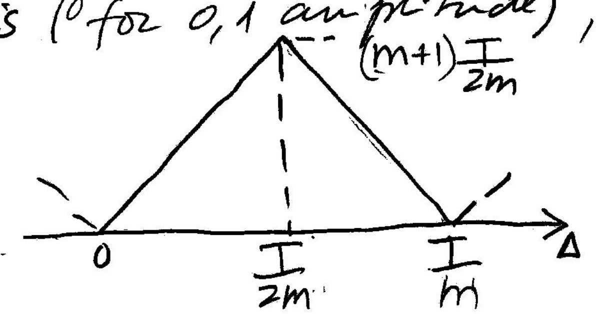


$T\langle XOR\rangle = 2\left(\Delta + 2 \times \frac{T}{10}\right), \quad 0 \le \Delta \le \frac{T}{10}$

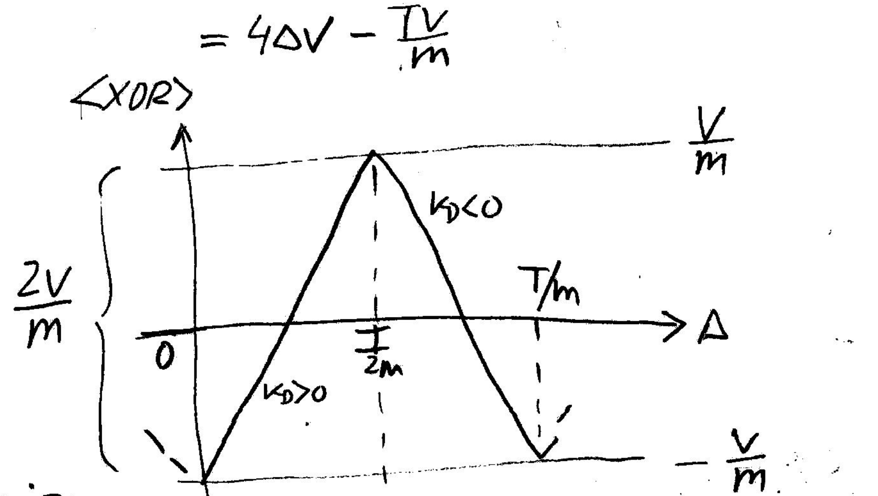
So, for general m odd $\quad T\langle XOR\rangle = 2\left(\Delta + \frac{m-1}{2}\frac{T}{2m}\right), \quad 0 \le \Delta \le \frac{T}{2m}$

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

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



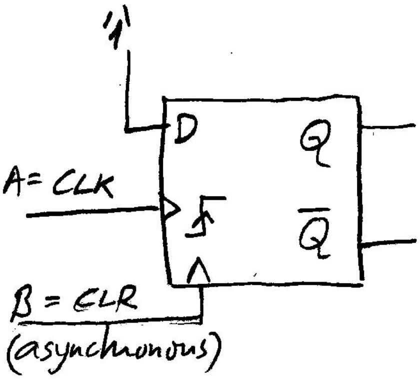
$$T\langle XOR\rangle = \left(2\Delta + \frac{m-1}{2}\frac{T}{m}\right)V - \left(T - 2\Delta - \frac{m-1}{2}\frac{T}{m}\right)V$$
$$= 4\Delta V - \frac{TV}{m}$$

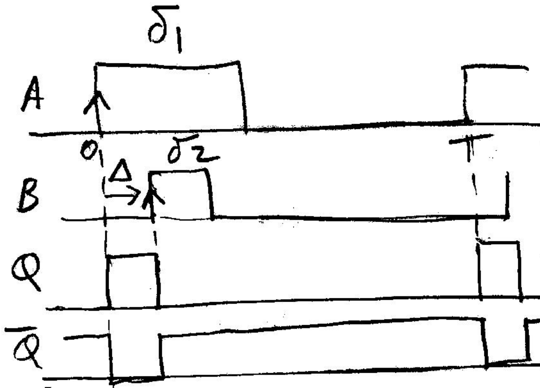


As m (odd) increases, we still get a phase detector function <u>but</u>:

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

Flip-flop (D type) phase detector



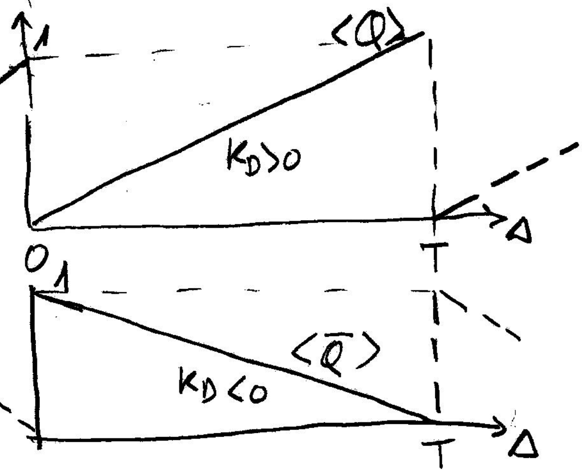


$\boxed{0 \leq \Delta \leq T}$

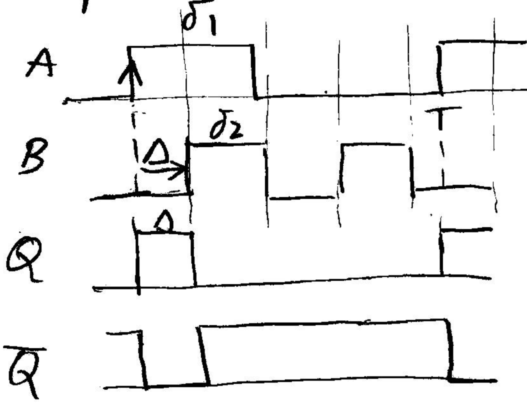
$T\langle Q\rangle = \Delta$

$T\langle \overline{Q}\rangle = T - \Delta$

- 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 dos 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 $\langle \overline{Q}\rangle$ interchange (show!)
- Operation with harmonically related frequencies



A: f_0

B: $2f_0$ $\qquad 0 \leq \Delta \leq \frac{T}{2}$ → if you advance or retard B by $\frac{T}{2}$ (its period) you get the same waveform!

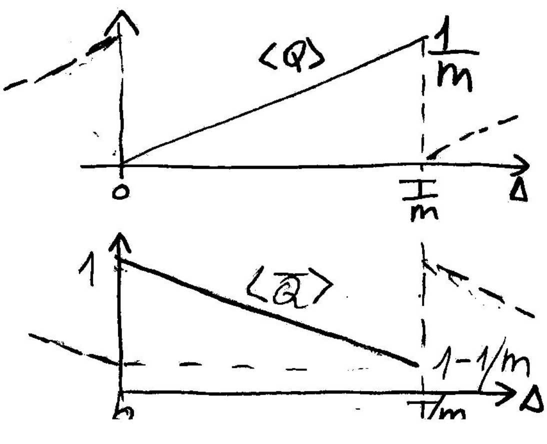
$T\langle Q\rangle = \Delta$

$T\langle \overline{Q}\rangle = T - \Delta$

In general for any m (either odd or even)

$T\langle Q\rangle = \Delta$

$T\langle \overline{Q}\rangle = T - \Delta$) $\quad \boxed{0 \leq \Delta \leq \frac{T}{m}}$



- 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