# *Phase-Locked Loop Design*
# *Part 2*

**RF Circuit Design**

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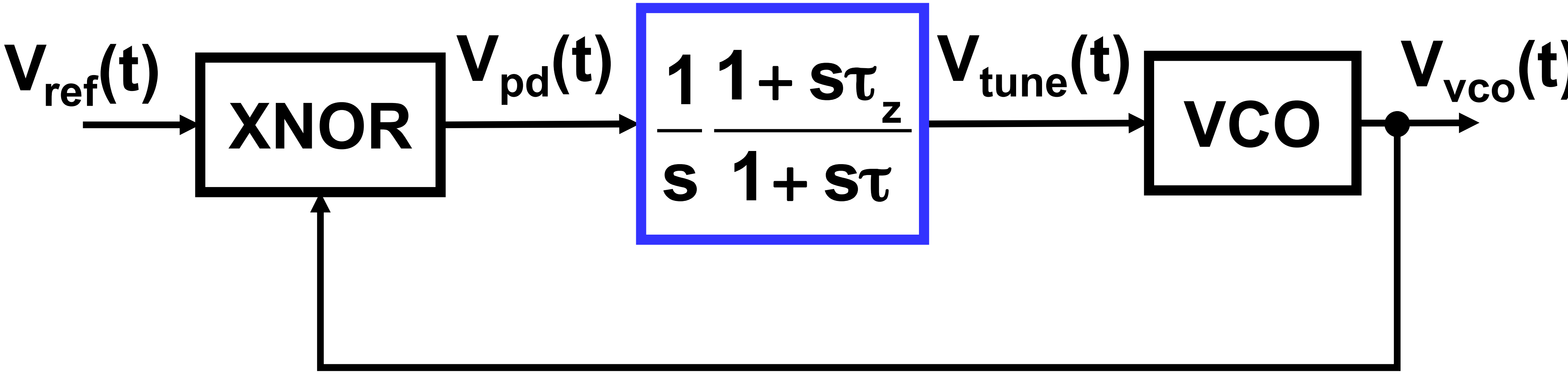
***2020/2021***

## *Outline*

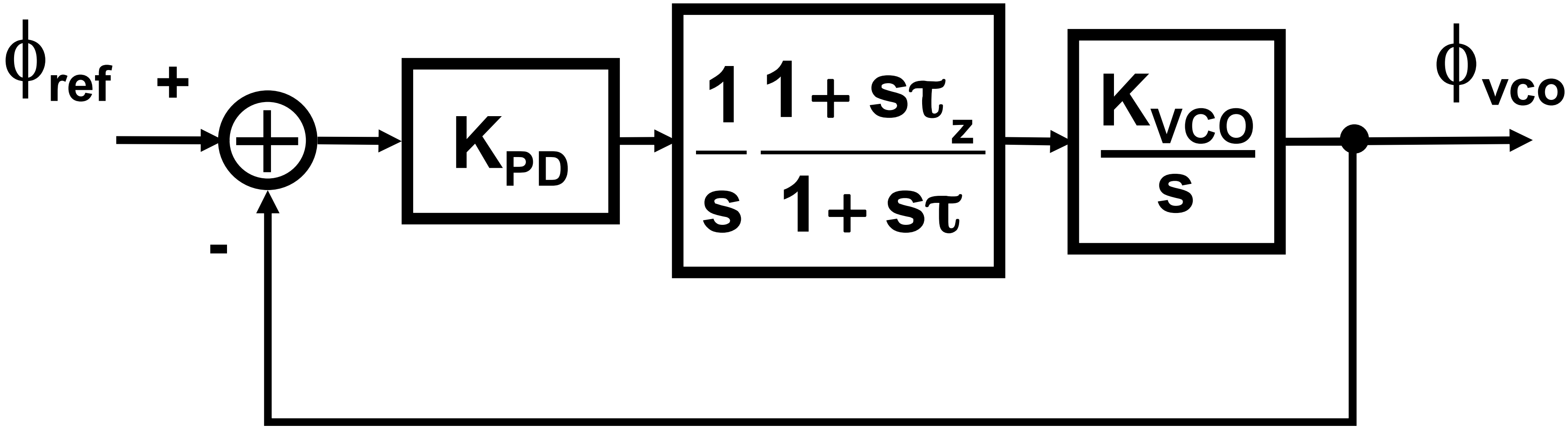
- Type-II PLL with XNOR
- Charge-Pump PLL

# *Type-II PLL with XNOR CT Model*

# *Type-II PLL with XNOR*

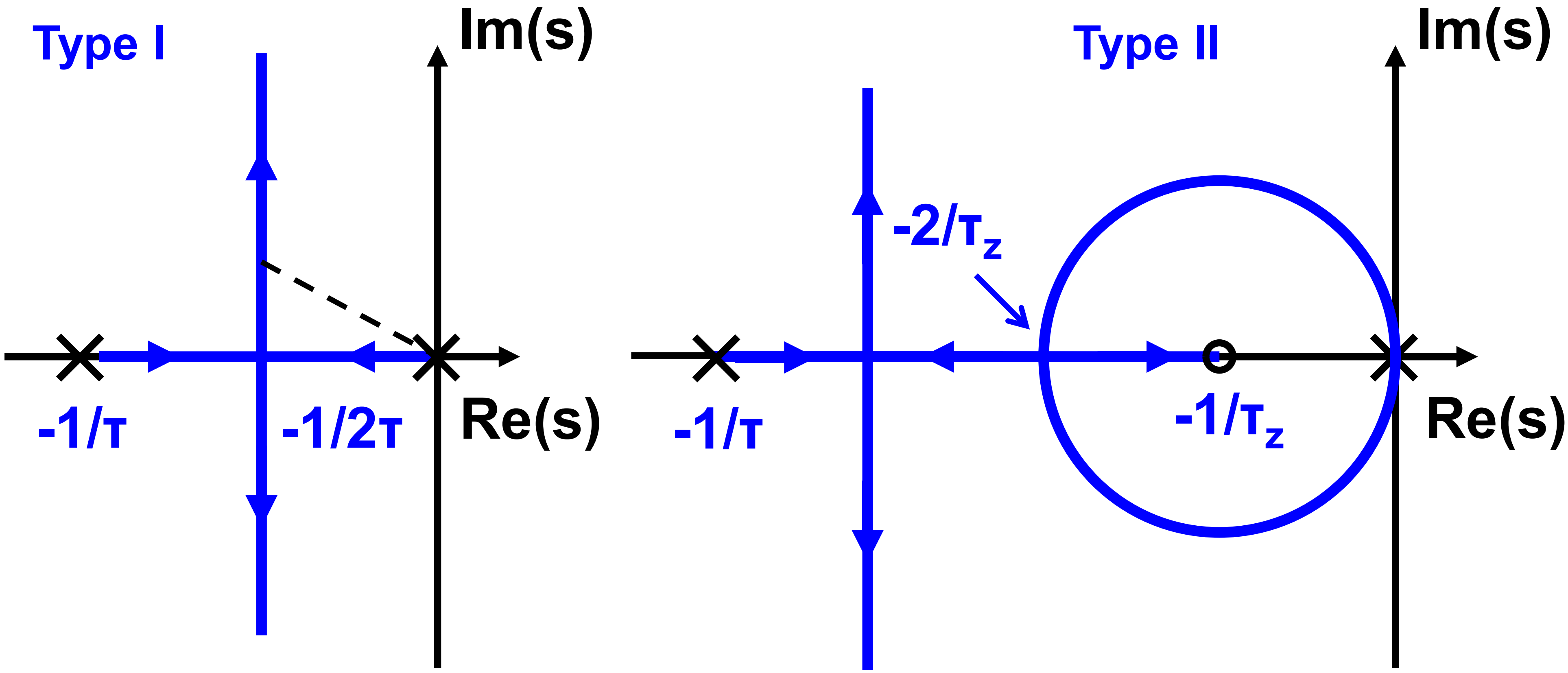


# *Linear CT Model: Third-Order Type-II*




$$G_{loop}(s) = \frac{K}{s^2} \cdot \frac{1+s\tau_z}{1+s\tau}$$

# *Type I and Type II PLL: Root Loci*

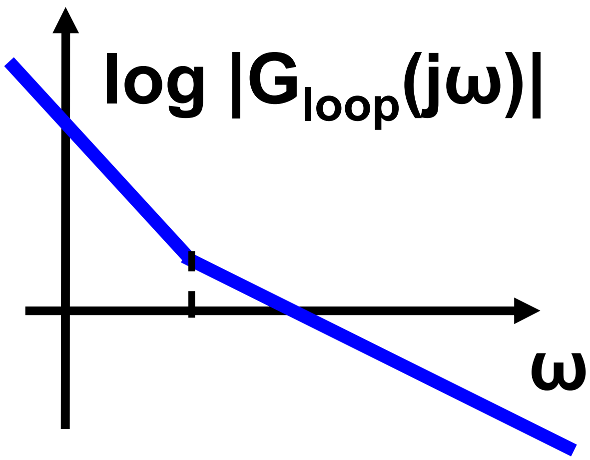



$$G_{loop}(s) = \frac{K}{s(1+s\tau)}$$

$$G_{loop}(s) = \frac{K}{s^2} \cdot \frac{1+s\tau_z}{1+s\tau}$$

# *Approximated Second-Order Analysis*

$$G_{loop}(s) = \frac{K}{s^2} \cdot \frac{1+s\tau_z}{1+s\tau} \approx \frac{K \cdot (1+s\tau_z)}{s^2} \quad \text{if } s\tau \ll 1$$




$$H(s) = \frac{G_{loop}}{1+G_{loop}} = \frac{K(1+s\tau_z)}{s^2 + \underbrace{sK\tau_z}_{2\zeta\omega_n} + \underbrace{K}_{\omega_n^2}}$$

$$\rightarrow \quad \omega_n = \sqrt{K} \qquad \zeta = \frac{\tau_z\sqrt{K}}{2}$$

# *Approximated Second-Order Analysis (II)*

$$\omega_n = \sqrt{K} \qquad \zeta = \frac{\tau_z \sqrt{K}}{2}$$

**BW can be increased if K is increased, until CT approximation breaks down**

$$\zeta = \frac{\sqrt{2}}{2} \quad \Rightarrow \quad \tau_z = \sqrt{\frac{2}{K}}$$

**Parameter set:**

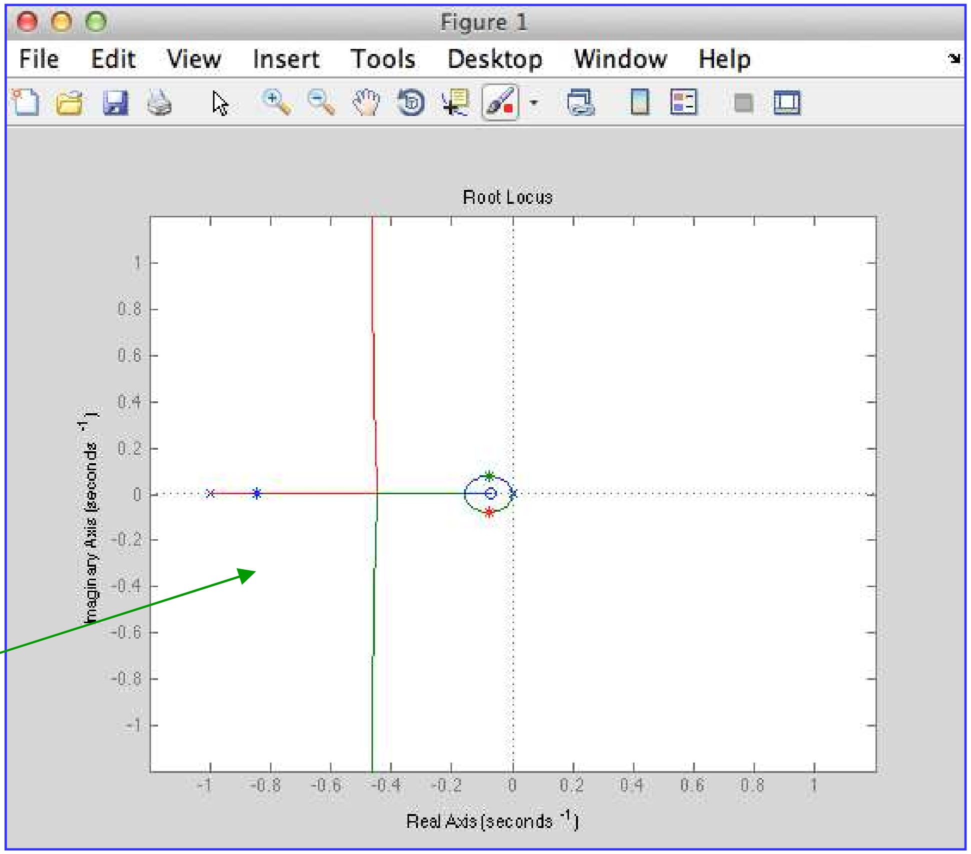
**w0 = 1e3; dw = 0.1; k = 1e-2;**
**tauz = sqrt(2/k); tau = 1;**

**Frequency of third pole is much higher than bandwidth $\omega_n$**

# *Root Locus (Matlab)*

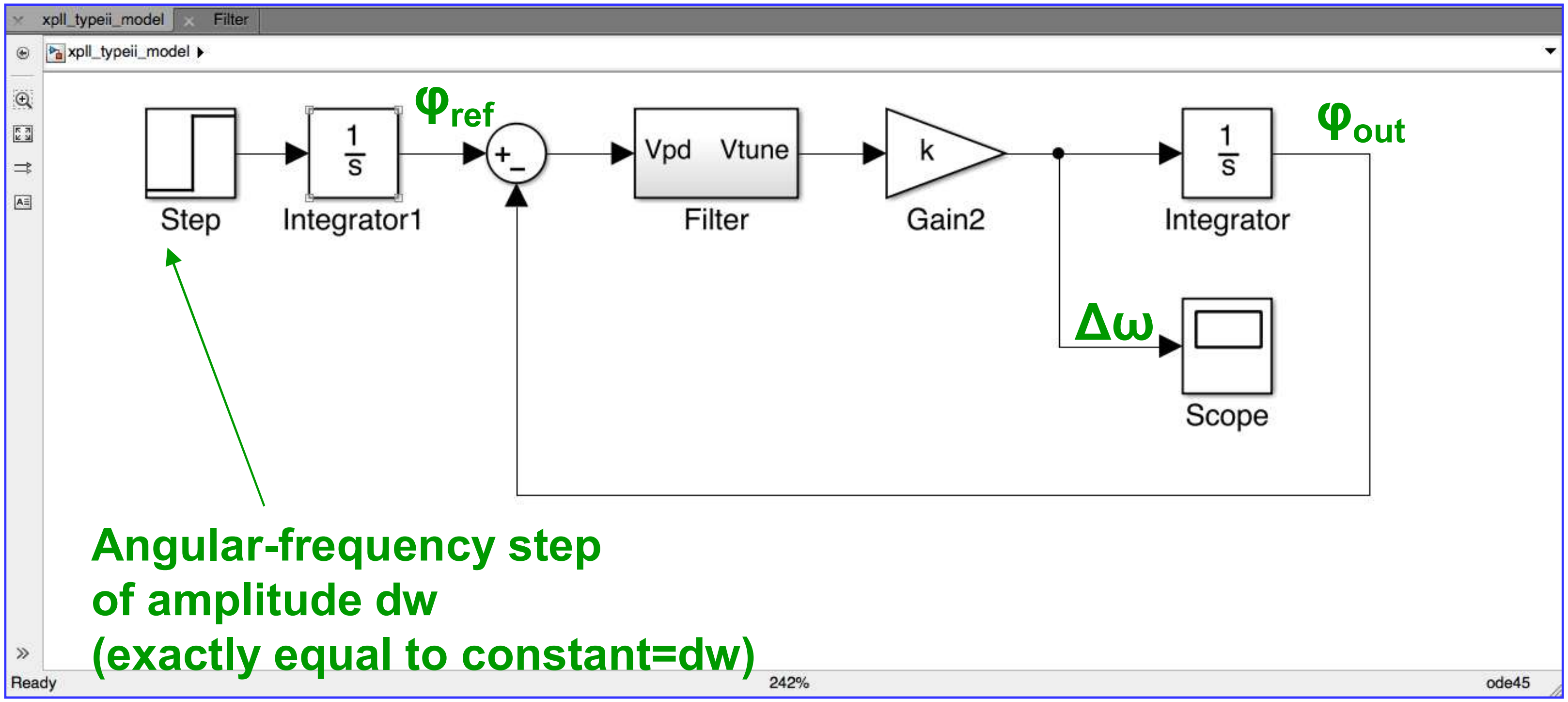
**Matlab Code:**

```
s = tf( 's' );
Gloop = k / s ^ 2 * ( 1 + s * tauz ) / ( 1 + s * tau );
rlocus( Gloop );
hold on;
rlocus( Gloop, 1, '*')
```

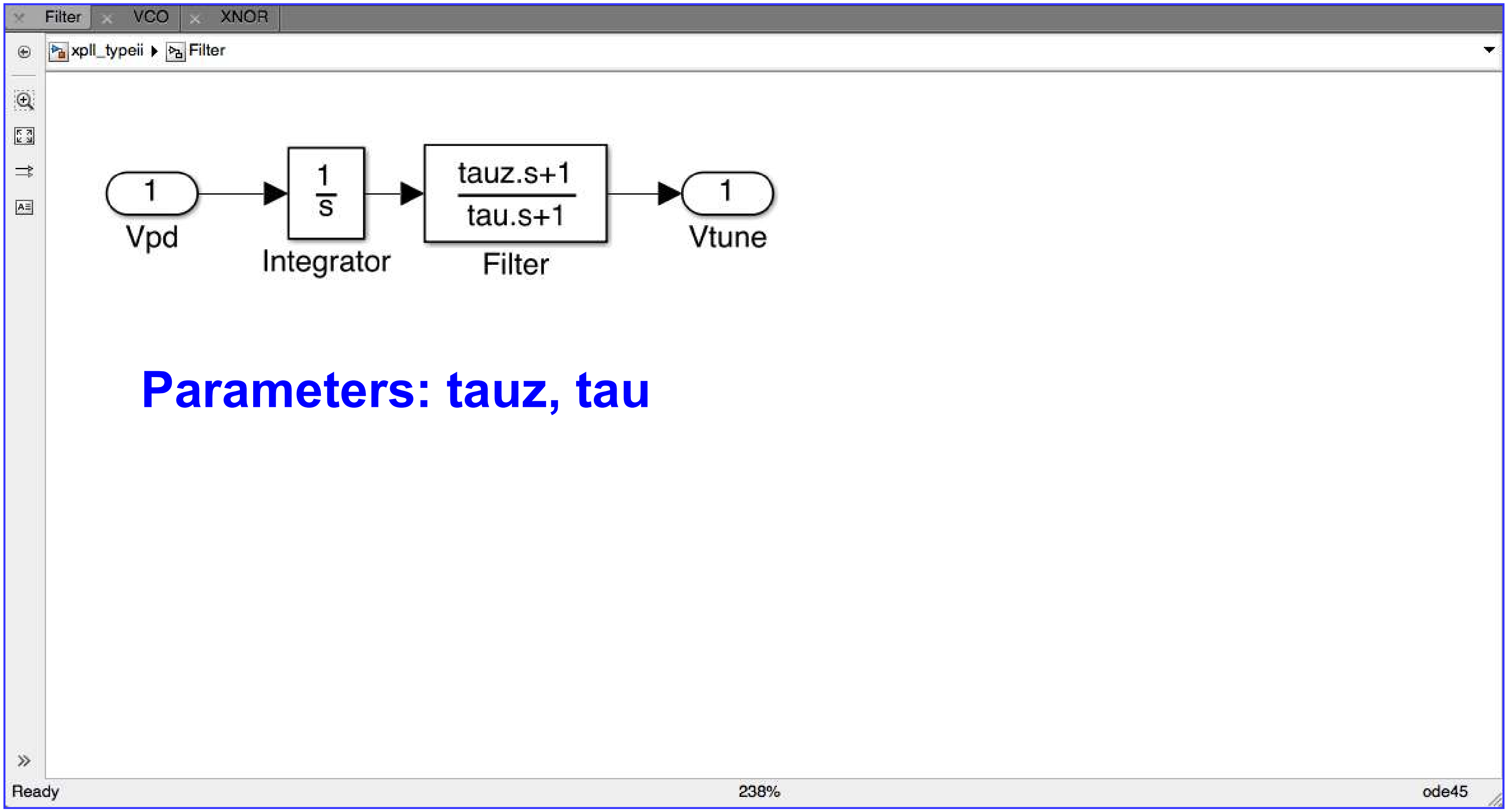



**Two complex poles at 45°**
**and one much faster third pole**

# Linear CT Model (Simulink)

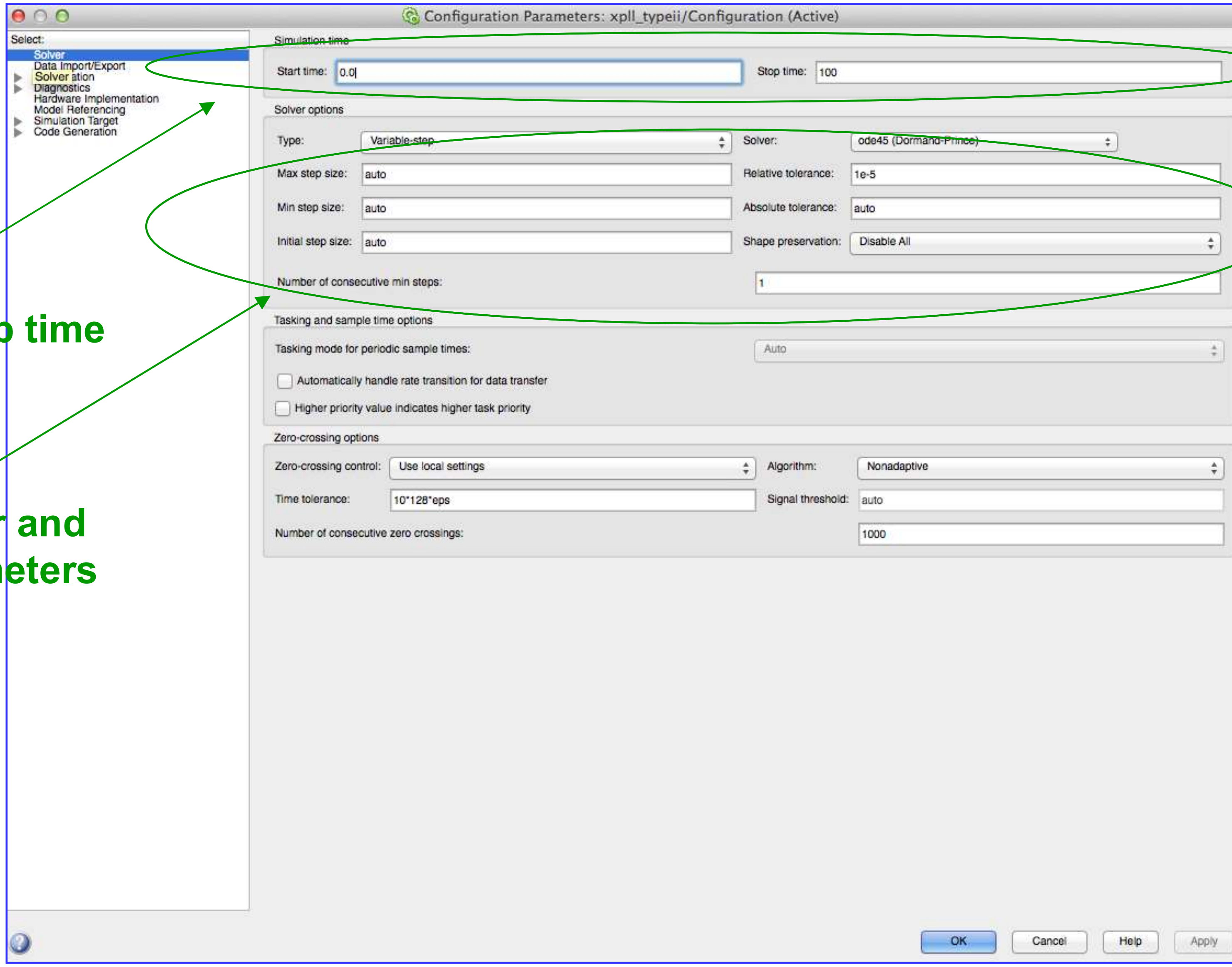


# Loop Filter (Simulink)




**Parameters: tauz, tau**

# *Simulation Parameters (Simulink)*




**Start/stop time**

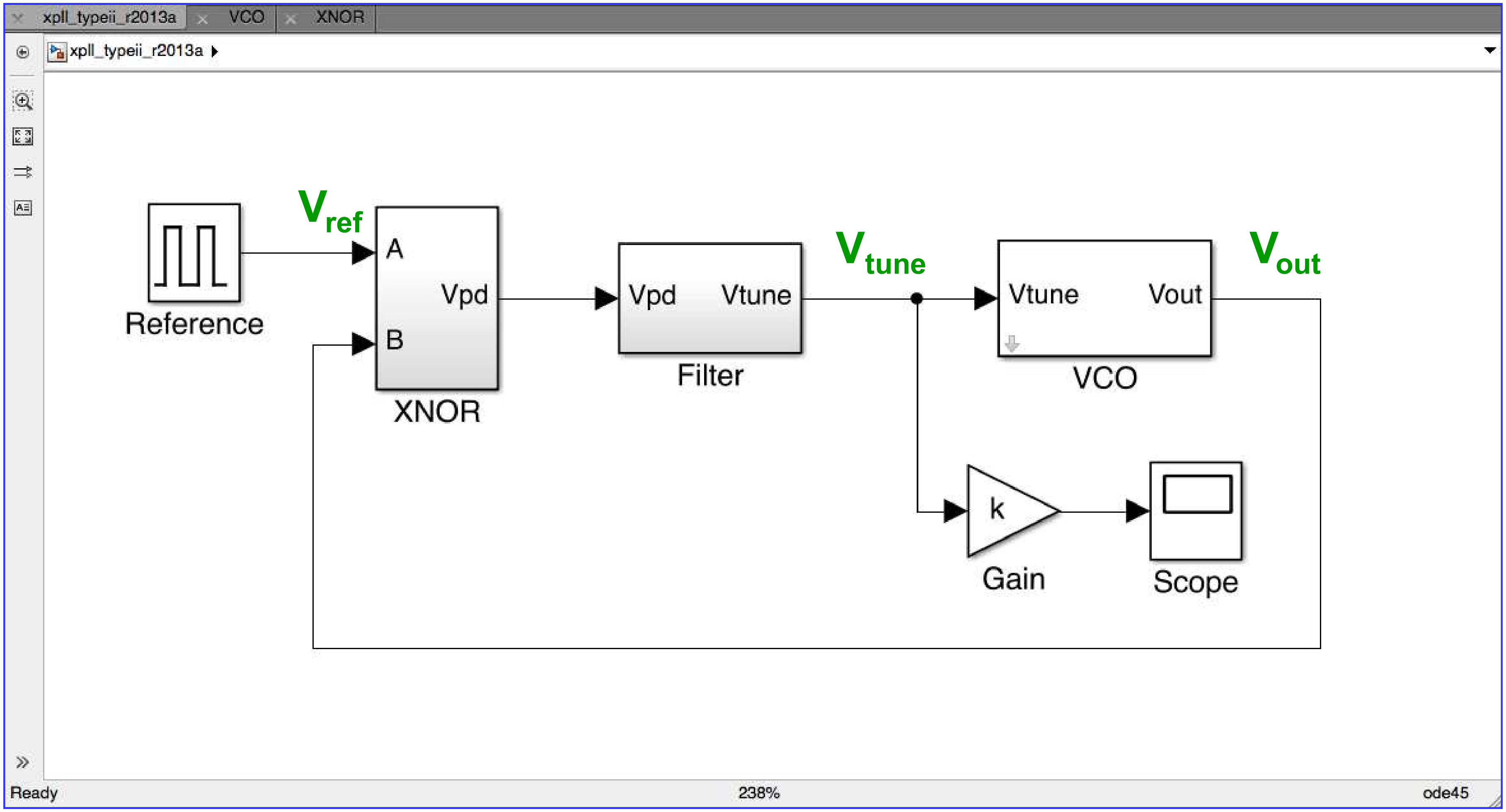
**Solver and parameters**

# *Exercises*

- By means of the root locus, compute the position of the three closed-loop poles and compare their values with the target ones.
- Plot the response of the output frequency to an input frequency step
- Plot the phase error vs time after the application of the input frequency step

# *Type-II PLL with XNOR Behavioral Model*

# *Nonlinear Type-II PLL with XNOR (Simulink)*



## *Exercises*

- **Plot the response of the output frequency to an input frequency step, at different initial delays of the reference. Justify the result.**

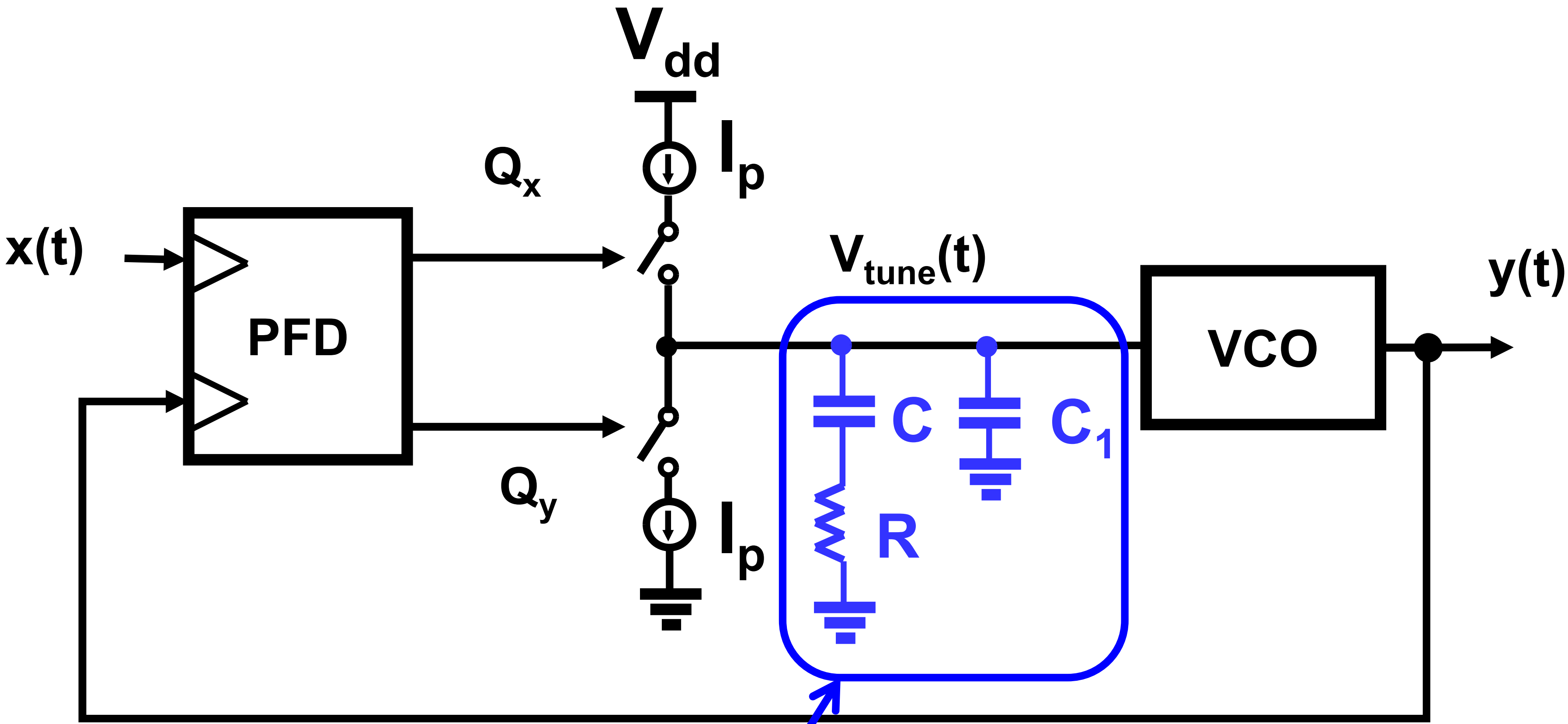
- **Estimate the residual ripple of oscillator frequency from simulation**

- **Discuss what happens to the output frequency when k is increased by 1000x and why.**

- **Starting from the original parameter set, make the time constant of the third pole 10 times smaller and estimate the residual ripple again. Can you justify the change in ripple value?**

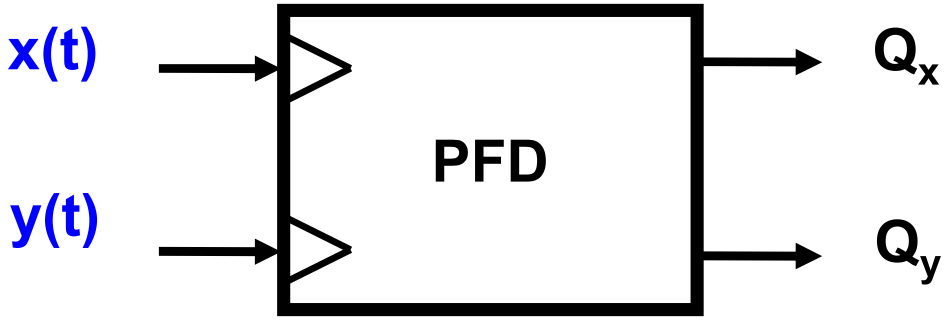
# *Charge-Pump PLL*

# *Third-Order Type-II Charge-Pump PLL*



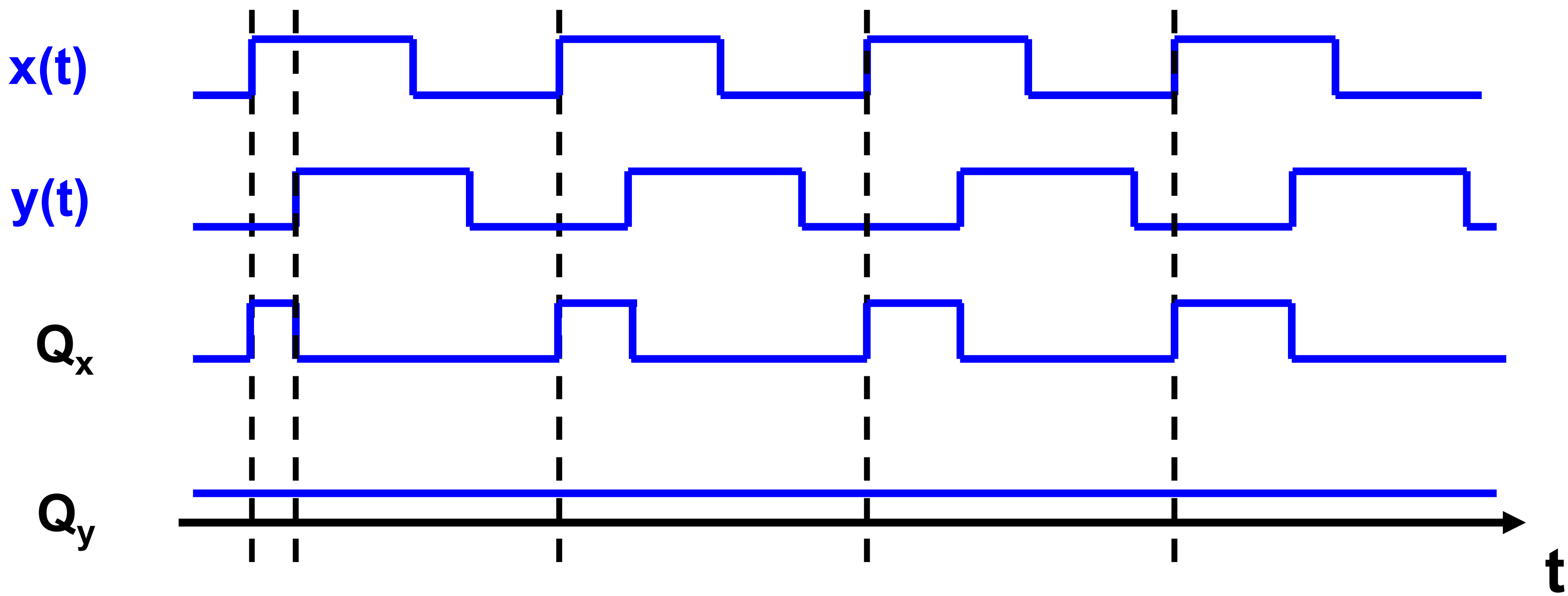

$$Z(s) = \frac{1}{sC_{tot}} \frac{1+s\tau_z}{1+s\tau}$$

# *Phase/Frequency Detector (PFD): $\omega_x > \omega_y$*

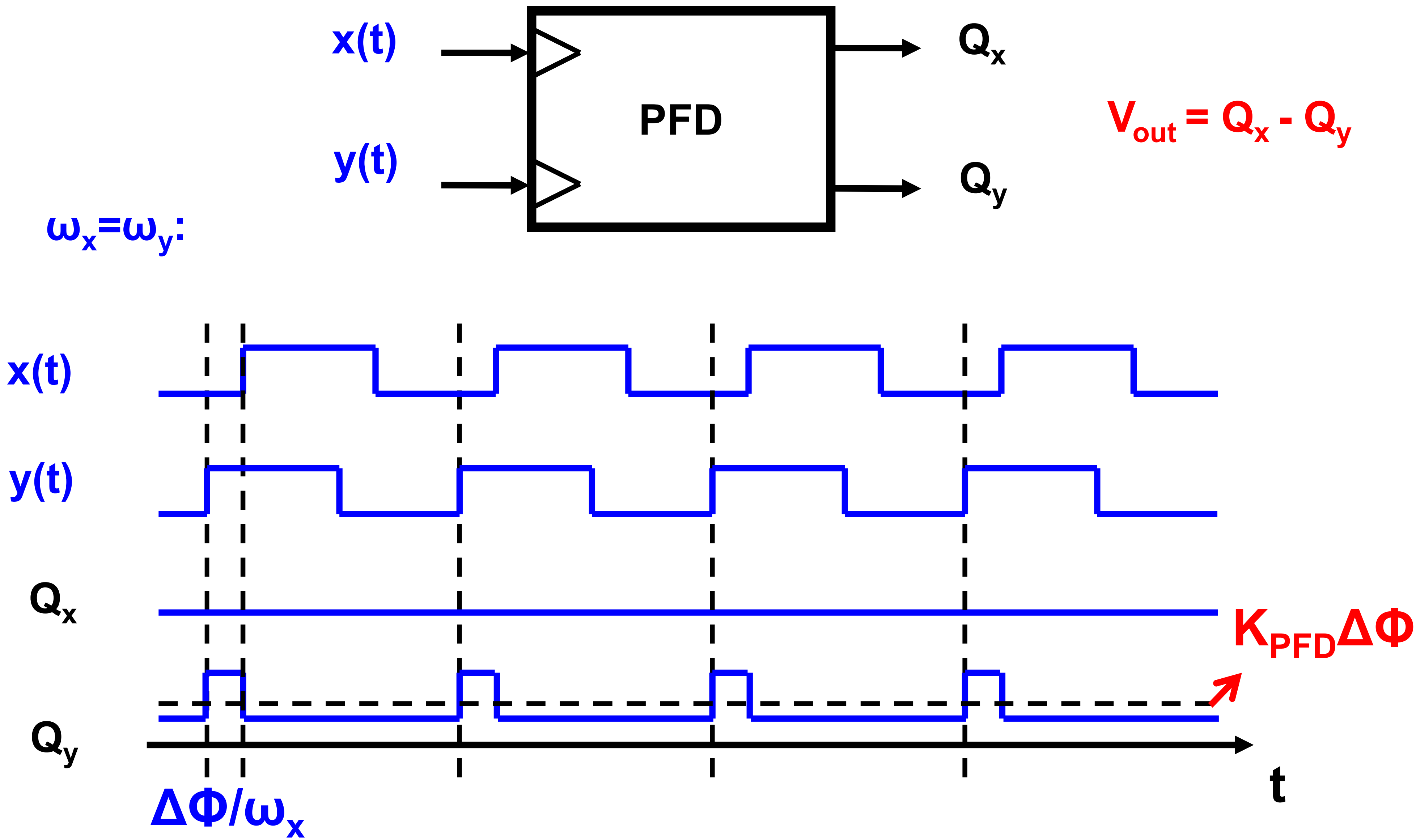



$V_{out} = Q_x - Q_y$

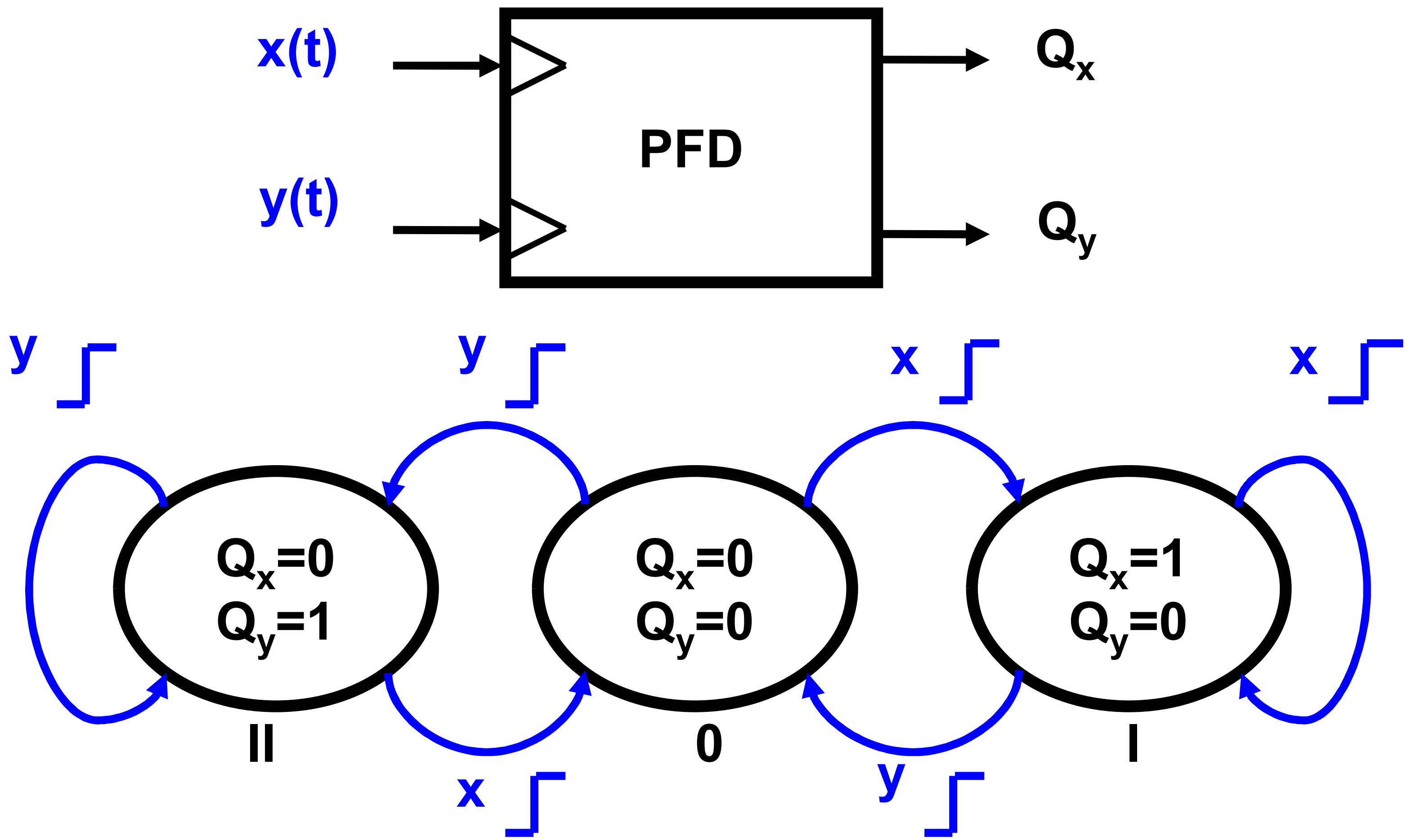
$\omega_x > \omega_y$:



# *Phase/Frequency Detector (PFD):* $\omega_x = \omega_y$

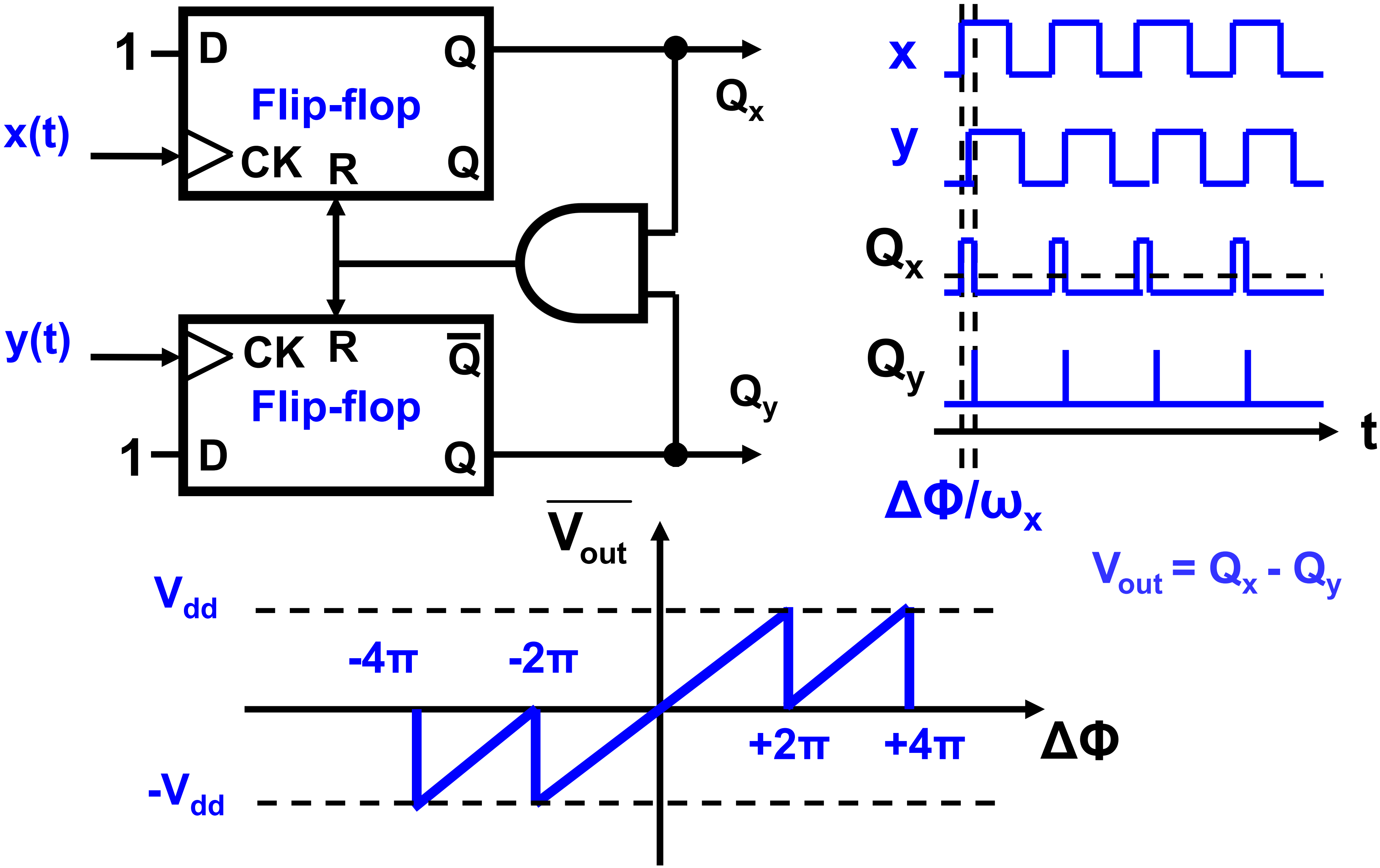


# *PFD State Diagram*

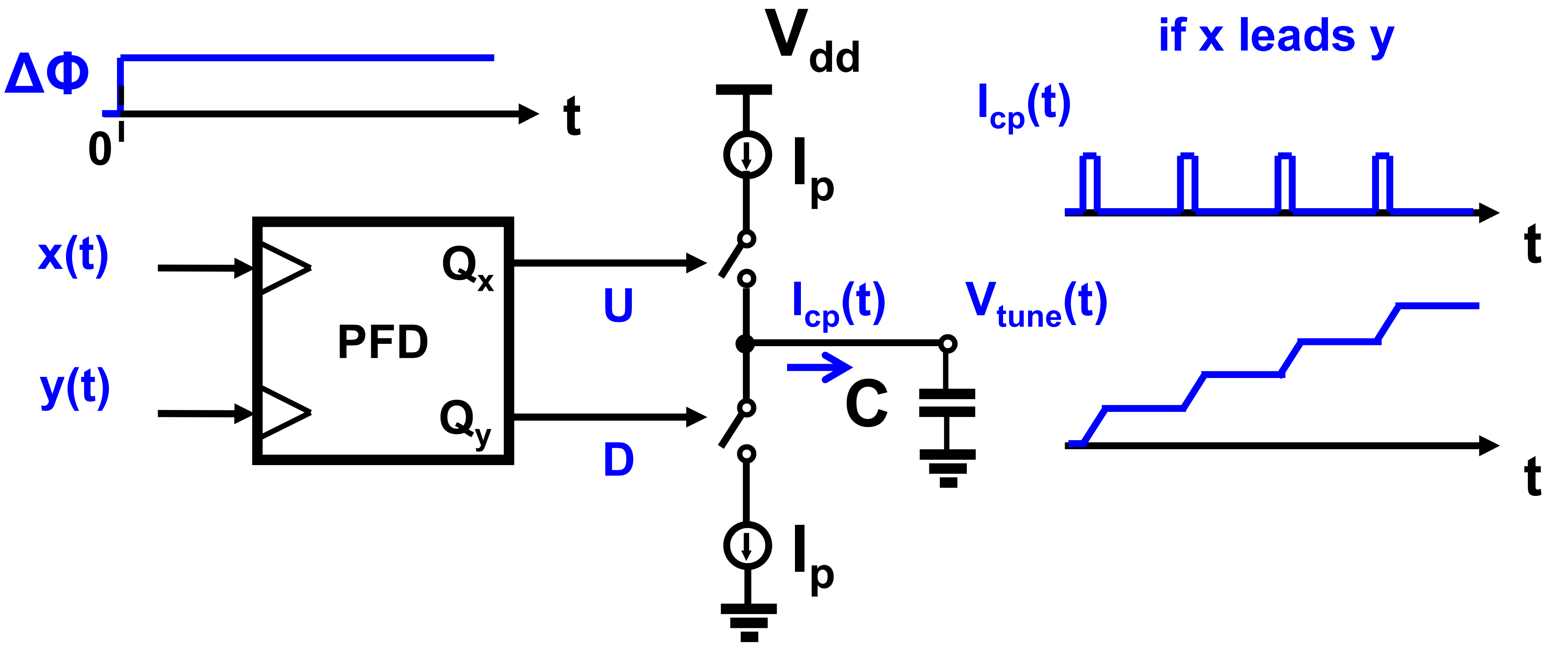



**If $\omega_x > \omega_y$: even starting from state II, it will leave that state**

# PFD Implementation and Static Characteristic

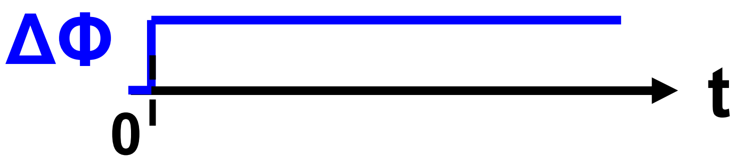


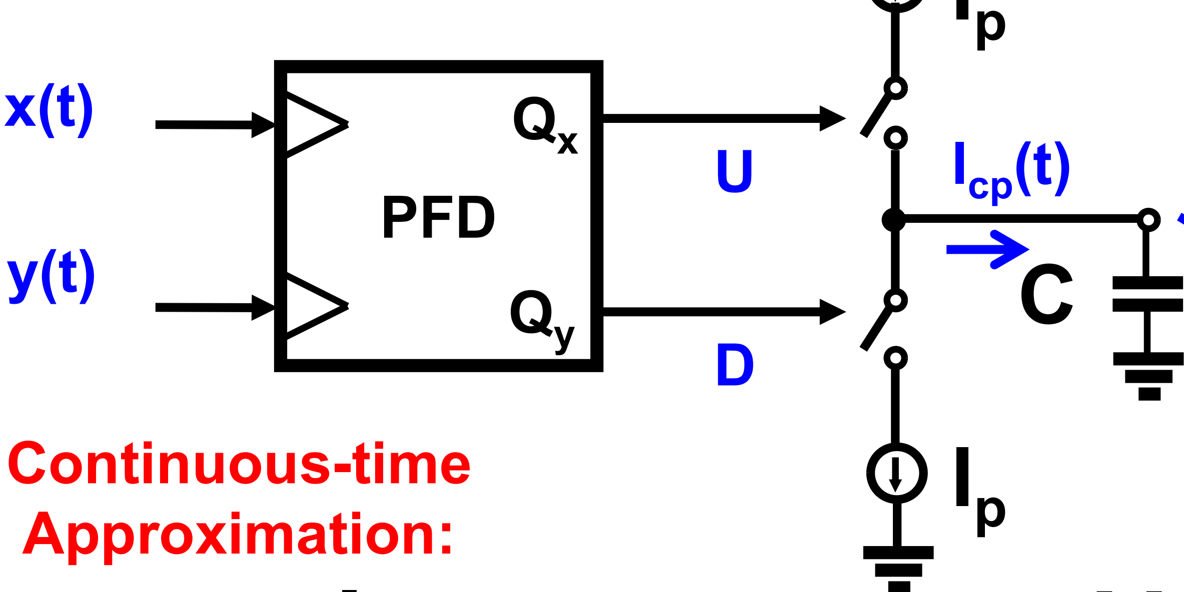
# *Charge Pump*

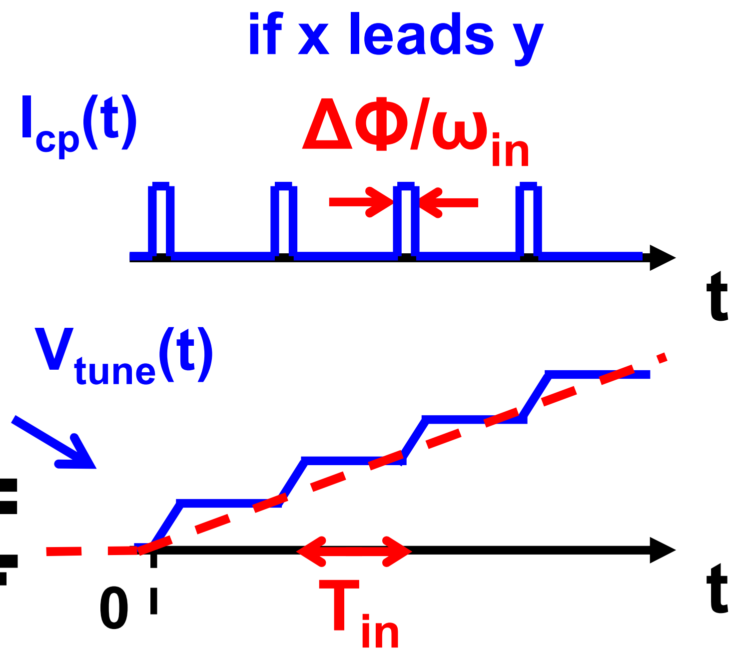


ΔΦ
t
0
x(t)
y(t)
PFD
Qx
Qy
U
D
Vdd
Ip
Icp(t)
C
Ip
Vtune(t)
if x leads y
Icp(t)
t
t

# *Linear CT Model of PFD/CP/Filter*




**Continuous-time Approximation:**

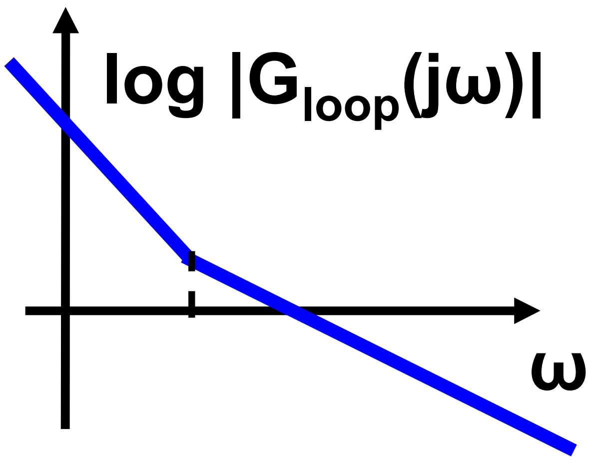
$$V_{tune}(t) \approx \frac{I_p}{C} \cdot \frac{\Delta\phi}{\omega_{in}} \cdot \frac{1}{T_{in}} \cdot t \rightarrow \frac{V_{tune}}{\Delta\phi}(s) = \underbrace{\frac{I_p}{2\pi}}_{K_{PFD/CP}} \cdot \underbrace{\frac{1}{sC}}_{Z(s)}$$

if BW of $V_{tune} \ll \omega_{in}$

# *Approximated Second-Order Analysis*

$$G_{loop}(s) = \underbrace{\left(\frac{I_p}{2\pi}\,\frac{K_{vco}}{C_{tot}}\right)}_{K\ \ [\mathrm{rad/s}]^2} \cdot \frac{1}{s^2} \cdot \frac{1+s\tau_z}{1+\cancel{s\tau}}$$

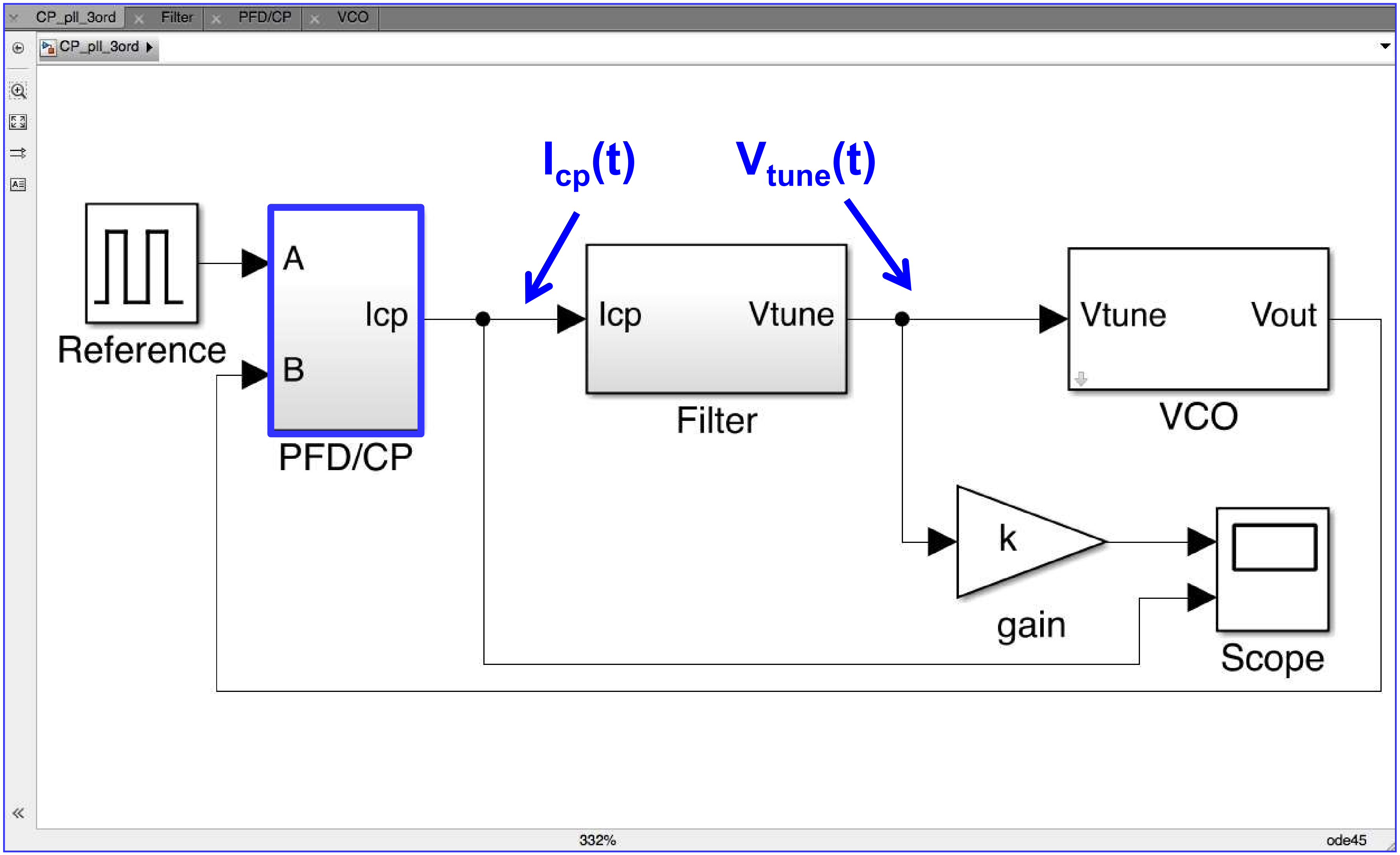
$\downarrow$ if $s\tau \ll 1$



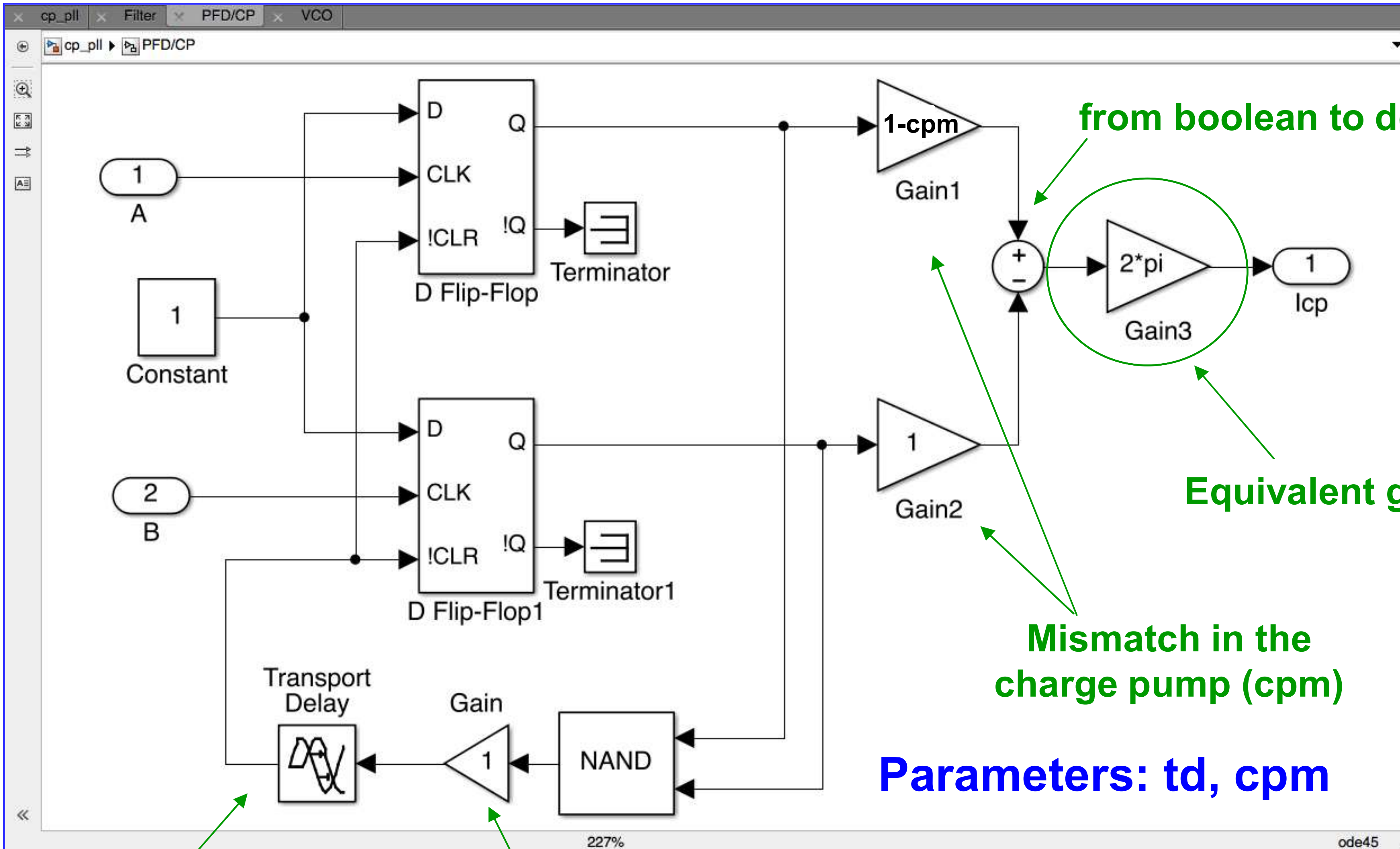

$$H(s) = \frac{G_{loop}}{1+G_{loop}} = \frac{K(1+s\tau_z)}{s^2+sK\tau_z+K}$$

$$\zeta = \frac{\sqrt{2}}{2} \quad \Rightarrow \quad \tau_z = \sqrt{\frac{2}{K}} \qquad \omega_n = \sqrt{K}$$

# Nonlinear CP-PLL (Simulink)



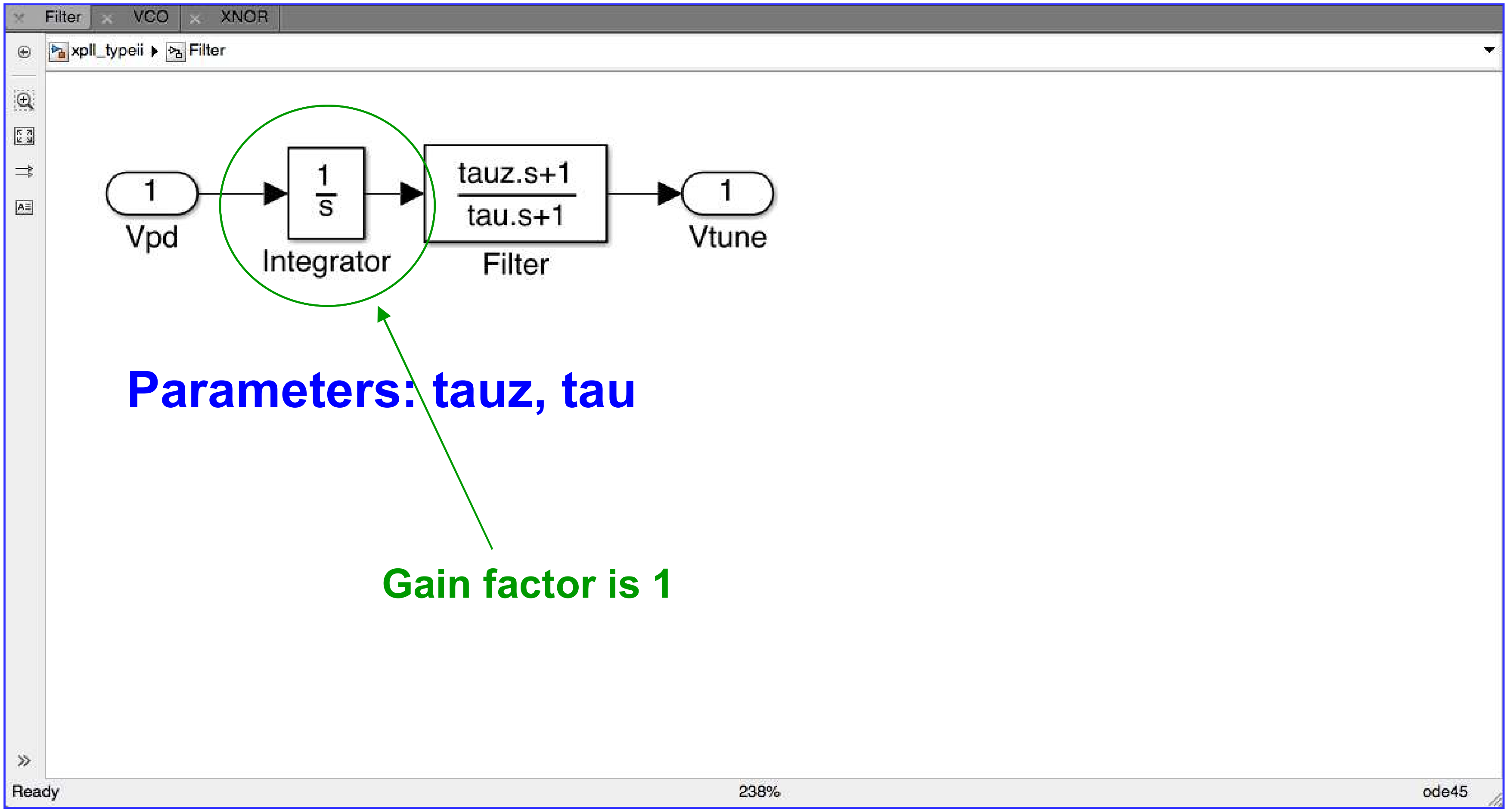
# *PFD/CP Block (Simulink)*



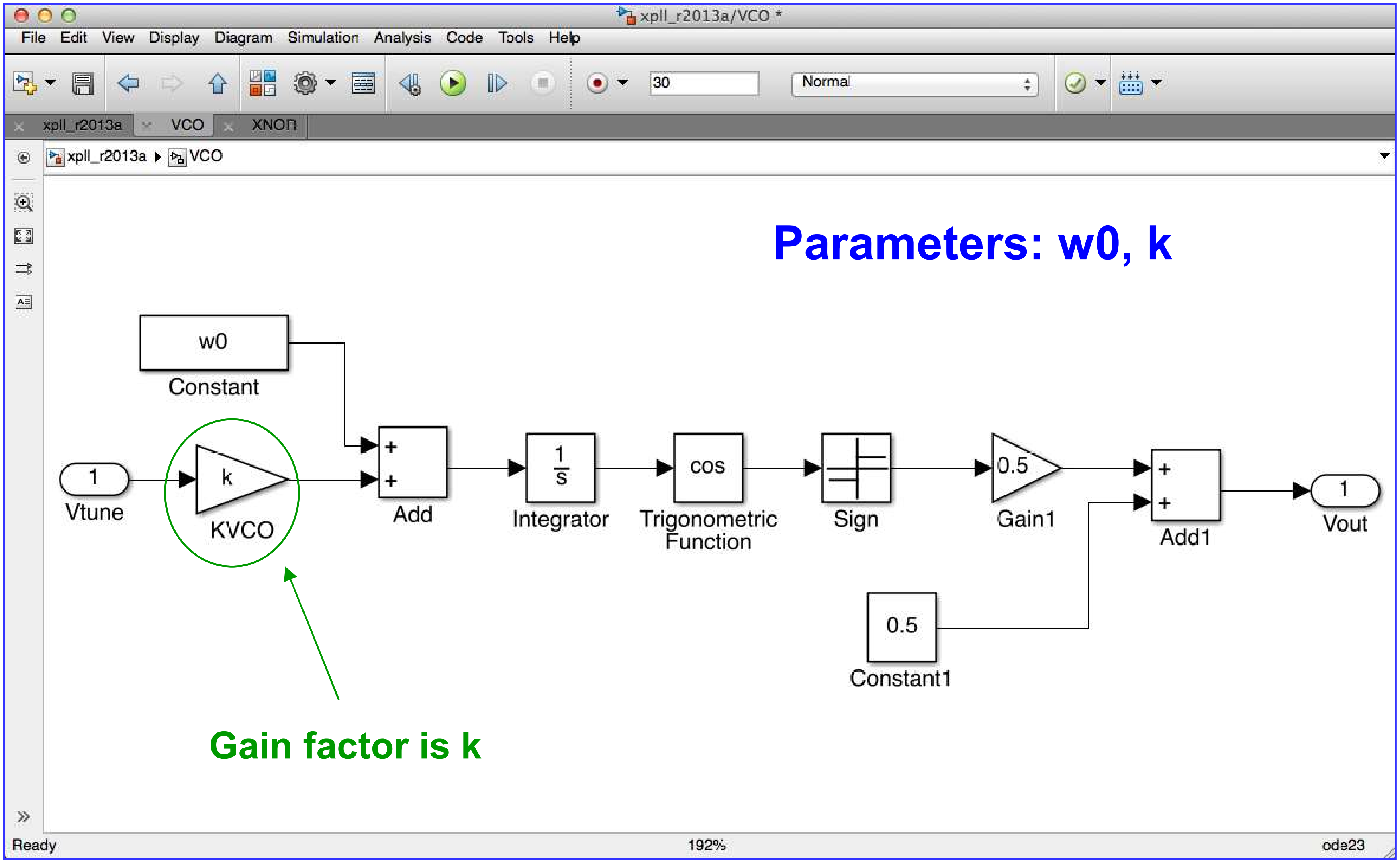

Reset delay in the PFD (td)

For data type conversion (from boolean to double)

# Loop Filter (Simulink)



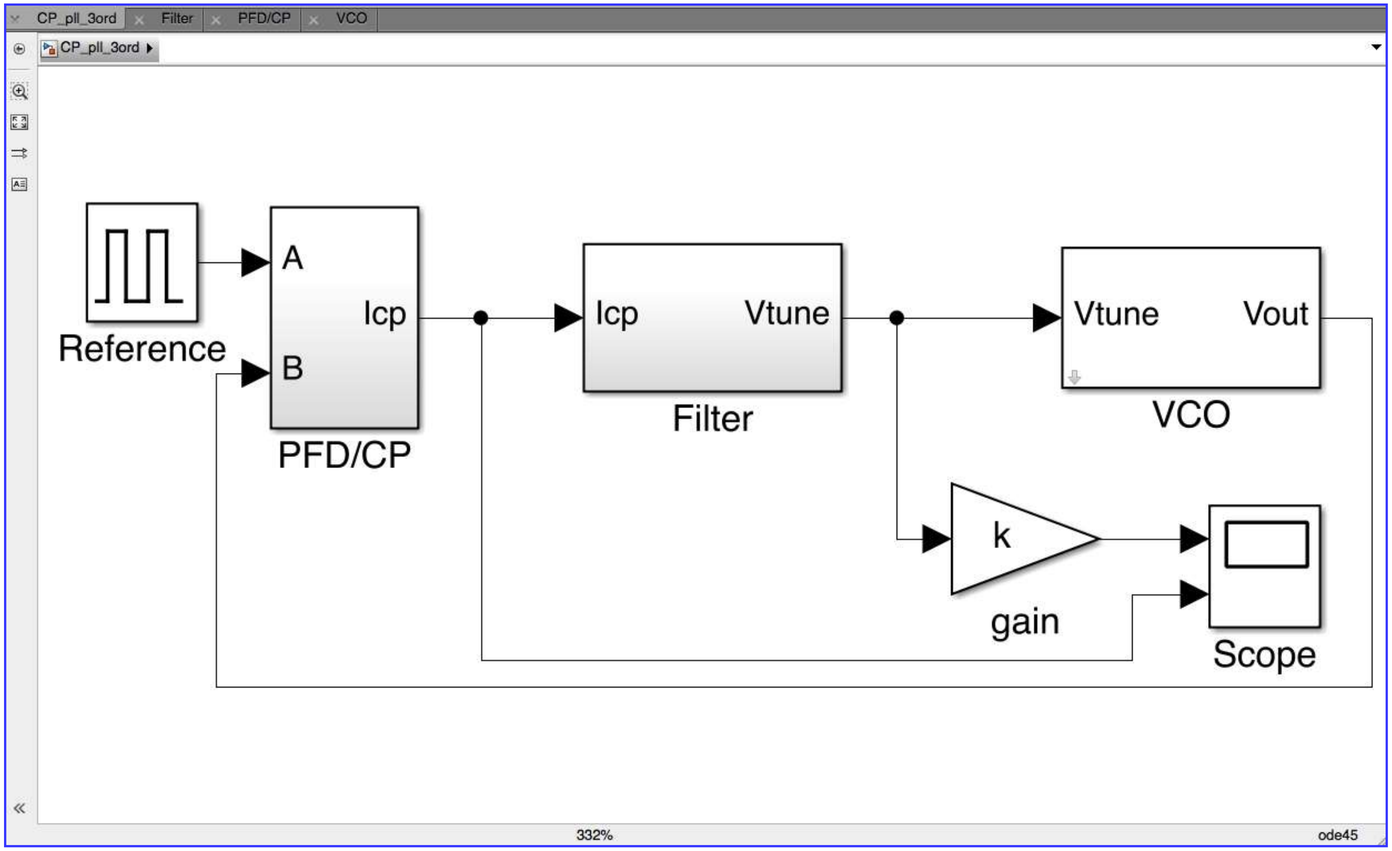
# VCO Block (Simulink)



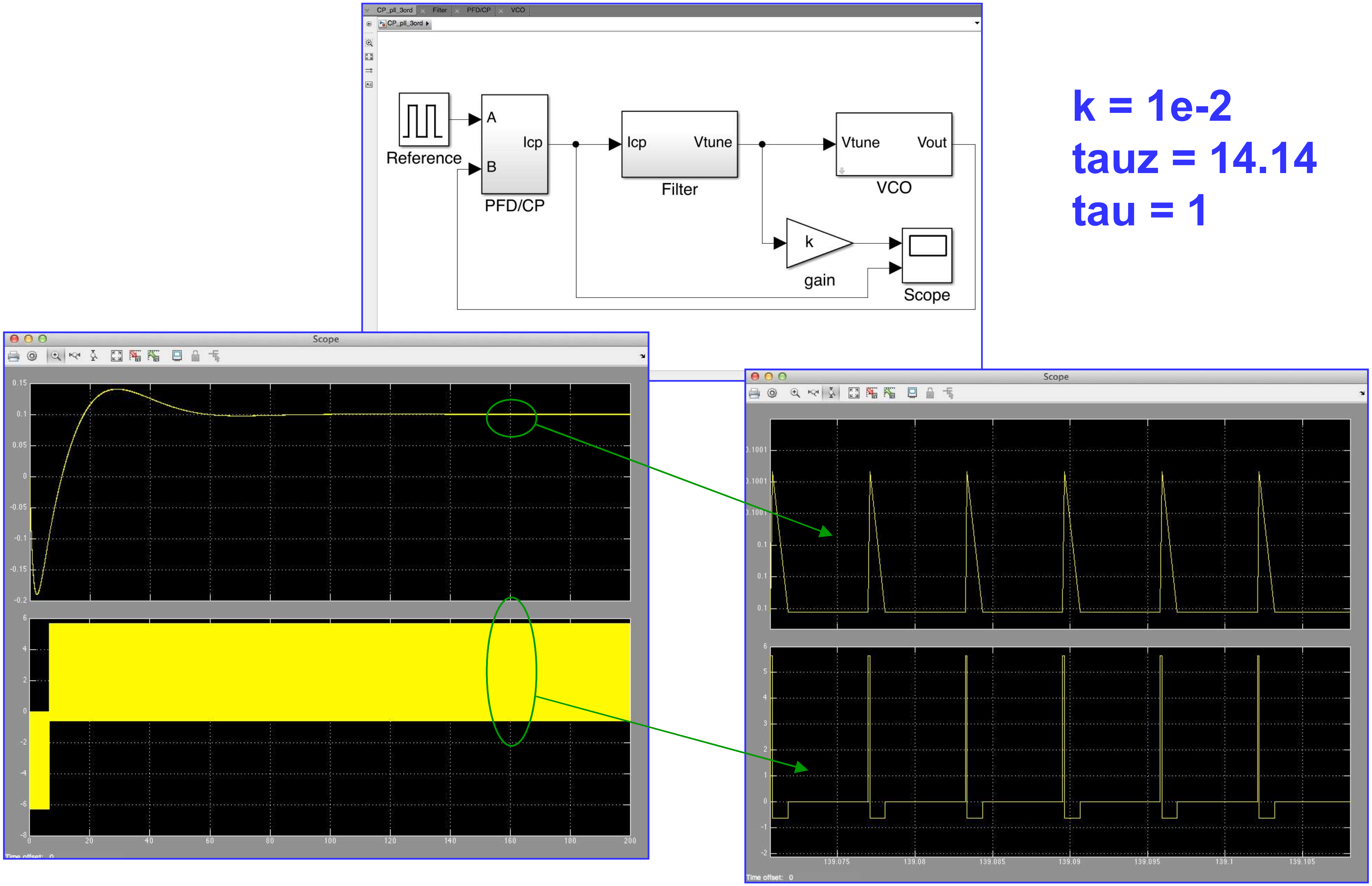
# *Parameter Set*

**Parameter set:**

**w0 = 1e3; dw = 0.1; k = 1e-2;**
**tauz = sqrt(2/k);  tau = 1; td=1e-3; cpm=0.1;**



# *Simulation of CP-PLL (Simulink)*




**k = 1e-2**
**tauz = 14.14**
**tau = 1**

# *Exercises*

- **Plot the response of the output frequency to an input frequency step, at different initial delays of the reference. Justify the result.**

- **Estimate the ripple amplitude of the oscillator frequency  from simulation and justify quantitatively this result using theory.**

- **How does the ripple change applying a mismatch of 20% among the charge-pump branches?**

- **What if the reset delay in the PFD is doubled? Comment the result and draw the conclusion.**