Lect. 24: Charge-Pump PLL

Limitations of PLL using PD

-Narrow locking range

It can be shown PLL locking range is roughly on the order of $\omega_p$

Simulation setup: $f_{in} = 1\text{Hz}$, $K_{PD} = 5V/\text{rad}$, $K_{VCO} = 2\pi \times 0.01\text{rad}/s/V$, and $f_p = 0.032\text{Hz}$

$\Delta f_{in} = 0.01\text{Hz}$ (Locked)

$\omega_{in} = 0.05\text{Hz}$ (Lock failed)

Phase detection alone cannot provide sufficient PLL locking range
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Limitations of PLL using PD:

- Limitation is due to narrow linear phase detection range
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Wider phase detection range?

D Flip-flop: Q becomes D at the rising clock edge

⇒ Phase and Frequency Detector (PFD)
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Subtraction and integration

Voltage mode using OP amplifiers

Current mode using charge pump

Subtraction

Integration

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Linear Model

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Open loop gain:

\[
G(s) = \frac{1}{2\pi} I_{CP} K_{VCO} \frac{1}{s^2 C_1}
\]

No phase margin \(\Rightarrow\) Unstable
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Open loop gain:

\[ G(s) = \frac{1}{2\pi I_{CP} K_{VCO}} \frac{sRC_1 + 1}{s^2 C_1} \]

Large ripple during transient
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Charge Pump PLL

- Ripple reduction with small $C_2 \approx C_1/10$
- Simplification as 2nd-order system

Open loop gain:

$$G(s) \sim \frac{1}{2\pi} I_{CP} K_{VCO} \frac{sRC_1 + 1}{s^2 C_1}$$
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Closed loop transfer function

\[
H(s) = \frac{\frac{I_{CP}}{2\pi C_1} K_{VCO} (RC_1 s + 1)}{s^2 + \frac{I_{CP}}{2\pi} K_{VCO} R s + \frac{I_{CP}}{2\pi C_1} K_{VCO}}
\]

Natural frequency

\[\omega_n = \sqrt{\frac{I_{CP} K_{VCO}}{2\pi C_1}}\]

Damping ratio

\[\zeta = \frac{R}{2} \sqrt{\frac{I_{CP} C_1 K_{VCO}}{2\pi}}\]
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Transient simulation for various damping ratio and fixed $\omega_n$

$f_{in} = 200\text{Hz}$
$I_{CP} = 100\mu\text{A}$
$K_{VCO} = 2\pi \times 100 \text{rad/s/V}$
$f_n = 1\text{Hz}$
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Transient simulation for various $\omega_n$ and fixed damping ratio

$$f_{in} = 200\, \text{Hz}$$
$$I_{CP} = 100\, \mu\text{A}$$
$$K_{VCO} = 2\pi \times 100\, \text{rad/s/V}$$
$$\zeta = 0.7$$

$\Rightarrow$ Optimization for desired performance!

![Graph showing transient response with different $\omega_n$ values]