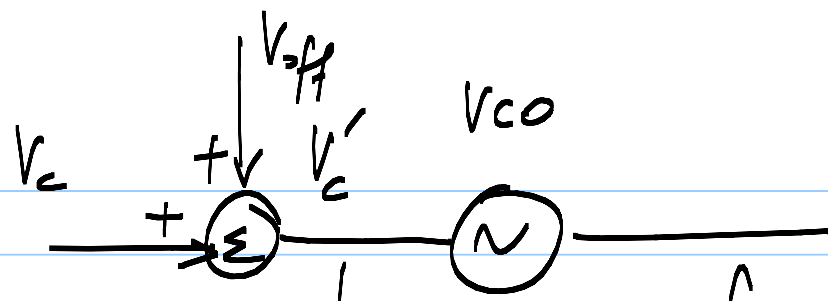
Lecture 48:

* Reference feedthrough due to periodic error of the phase detector

* $e(t) = 0$ if $\underline{\Delta\Phi = \Phi_{ref} - \Phi_{out}/N = 0}$

if the output frequency equals the free running frequency of the VCO.



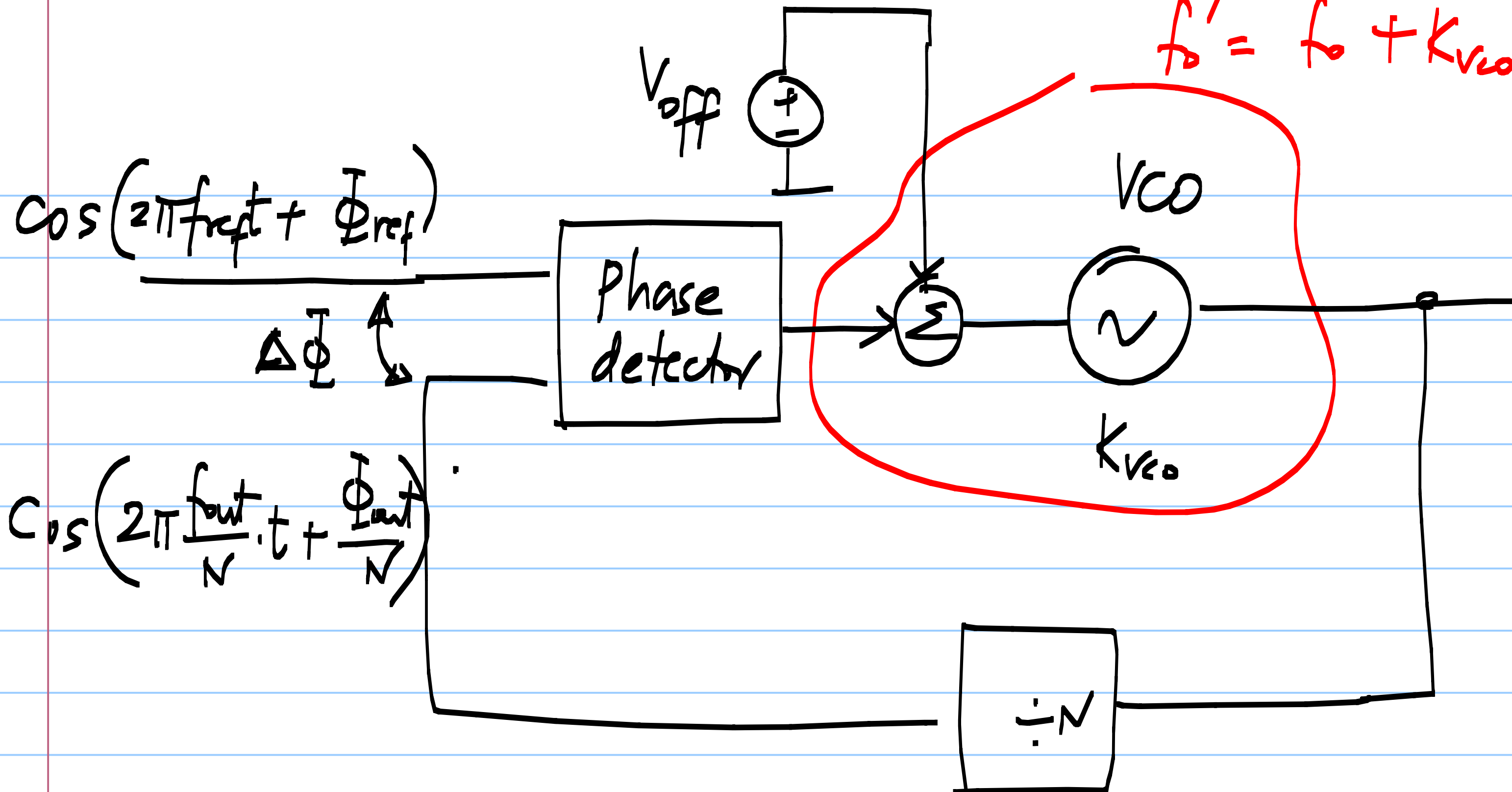
$$V_c' = V_c + V_{off}$$

$$f_{out} = f_0 + K_{vco} \cdot V_c'$$

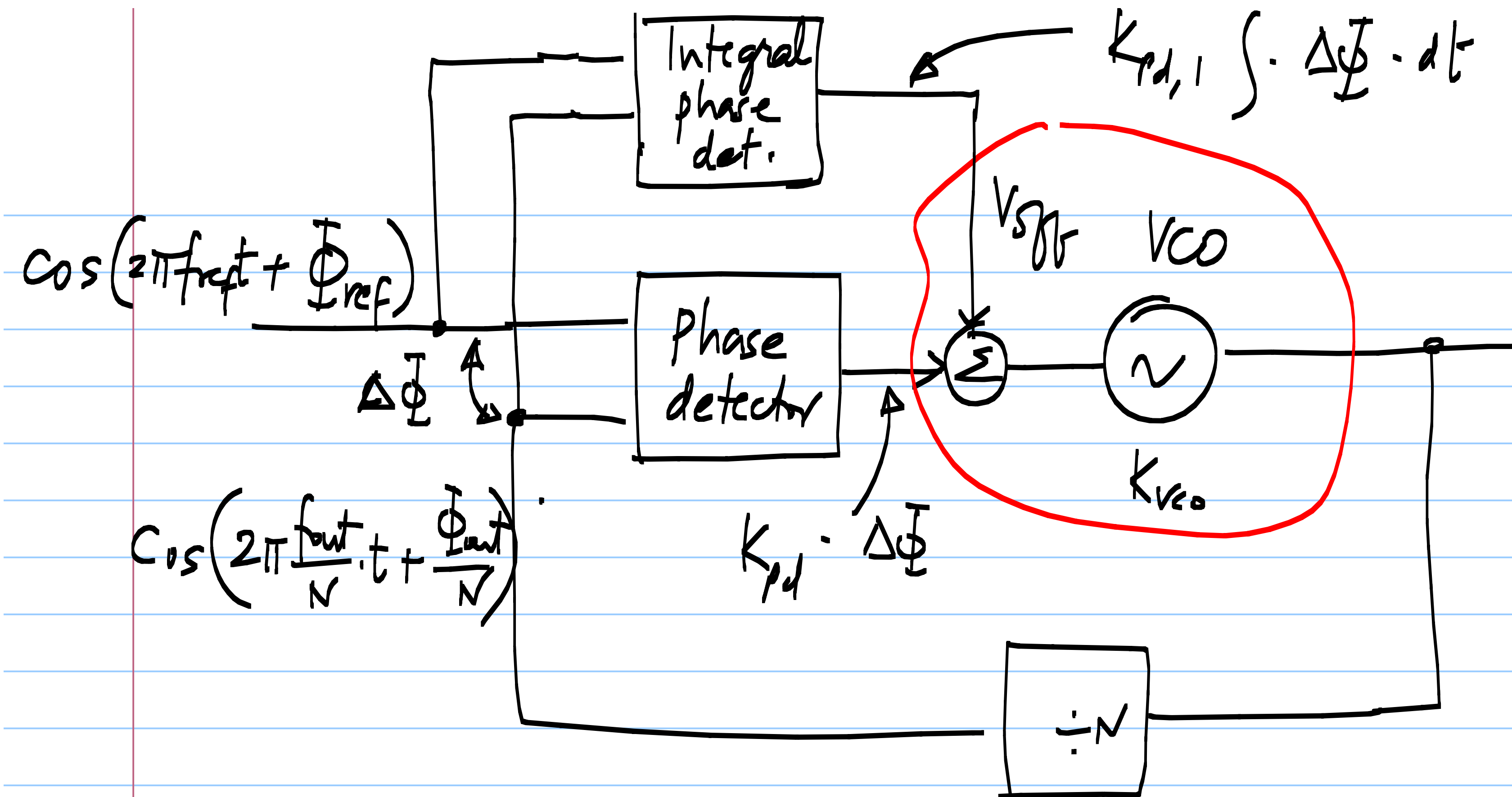
$$= \underbrace{\left(f_0 + K_{vco} \cdot V_{off}\right)}_{\text{free running frequency}} + \underbrace{K_{vco} V_c}$$

$$f_0' = \underline{f_0 + K_{vco} \cdot V_{off}}$$

$$f_o' = f_o + K_{vco} \cdot V_{off}$$

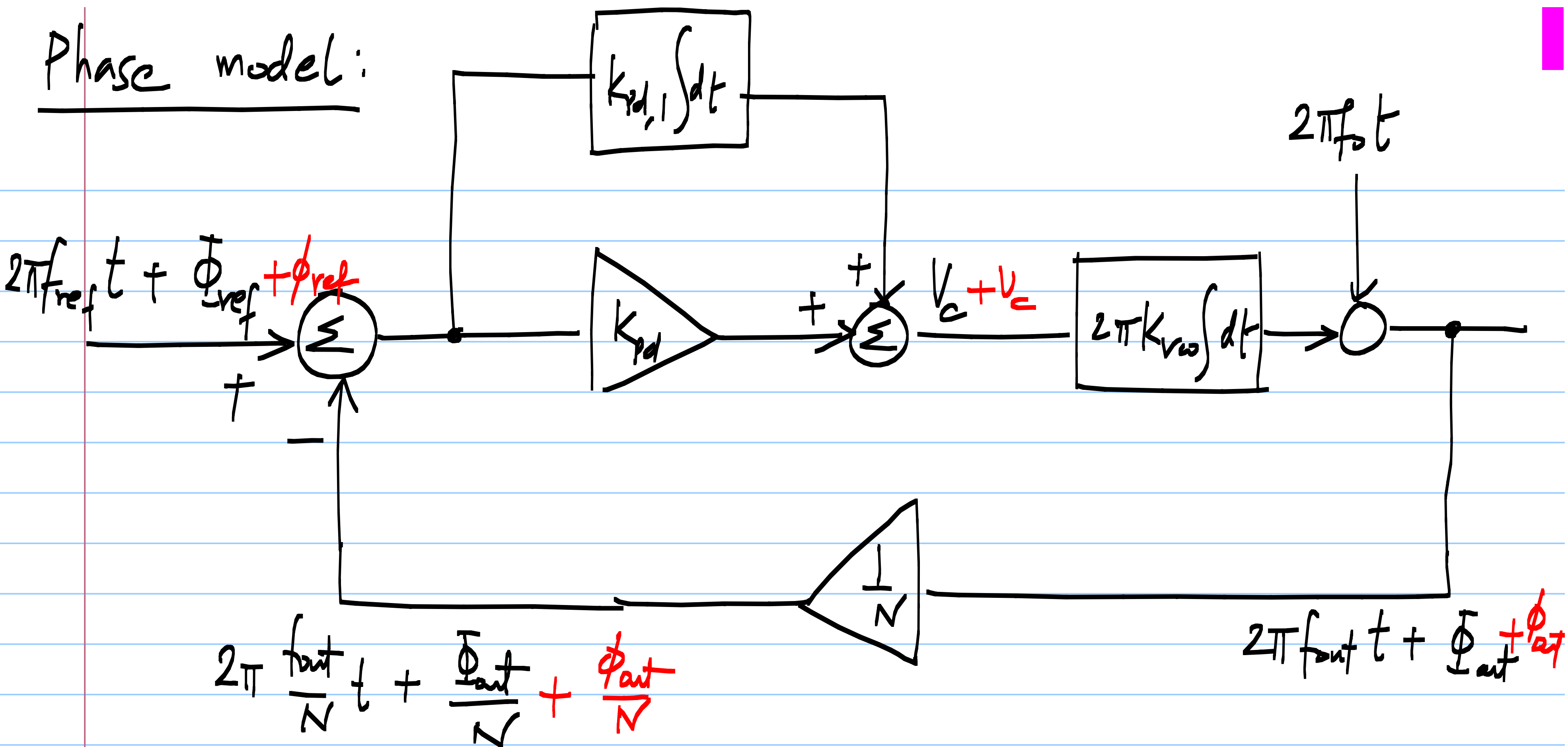


* Adjust V_{off} continuously until f_o' becomes equal to $N \cdot f_{ref}$

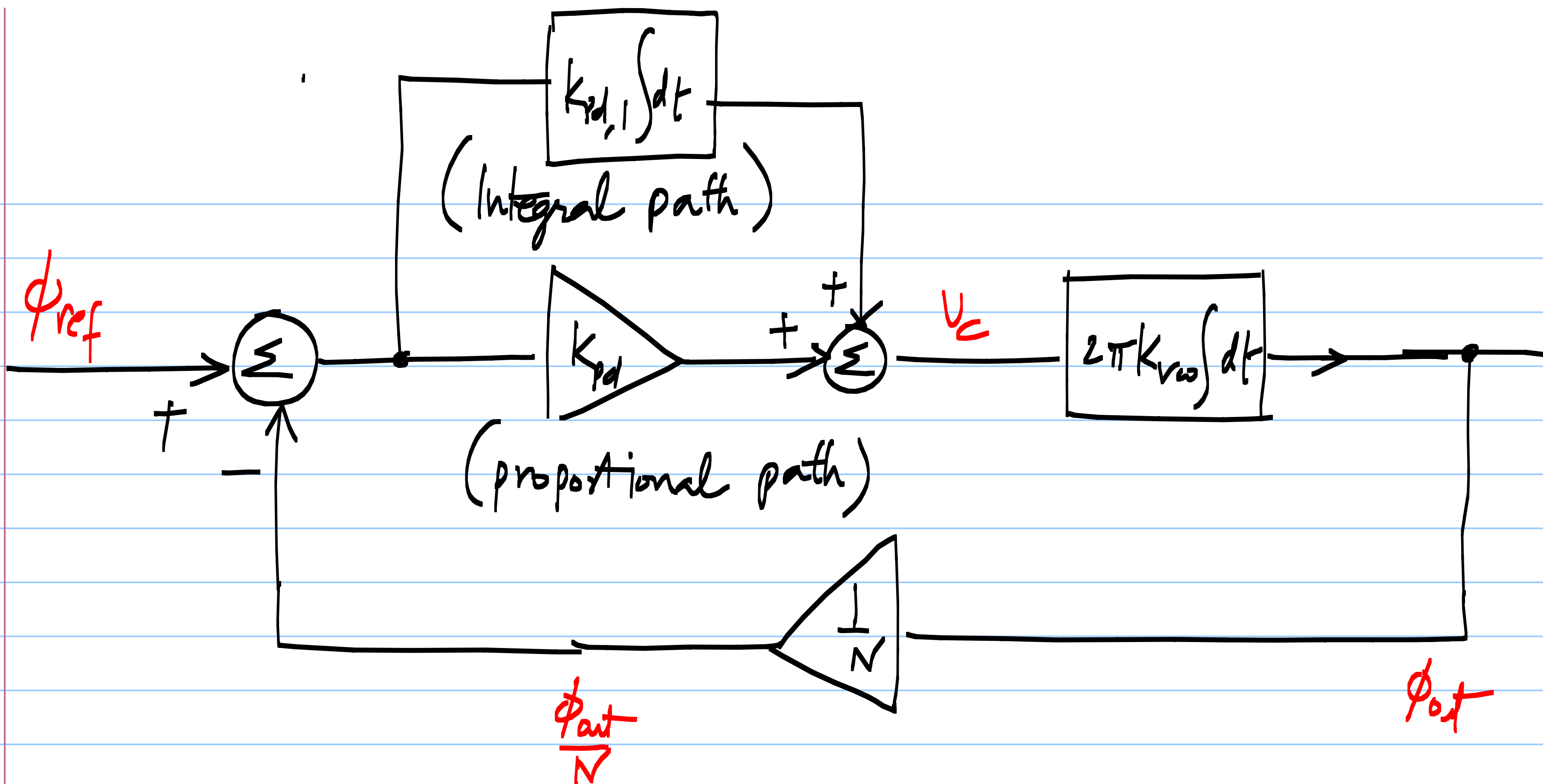


* Integrate $\Phi_{ref} - \frac{\Phi_{out}}{N}$ (slowly) and drive v_{off}.
* $\Phi_{ref} - \frac{\Phi_{out}}{N} = 0$ in steady state; No ref. feed through.

Phase model:



$K_{pd,1}\int dt$
$2\pi f_{ref}t + \Phi_{ref} + \phi_{ref}$
$+$
$-$
Σ
K_{pd}
$+$
$+$
Σ
$V_c + v_c$
$2\pi K_{vco}\int dt$
$2\pi f_o t$
$\frac{1}{N}$
$2\pi f_{out}t + \Phi_{out} + \phi_{out}$
$2\pi \frac{f_{out}}{N}t + \frac{\Phi_{out}}{N} + \frac{\phi_{out}}{N}$



* Type II phase locked loop.

Type II phase locked loop:

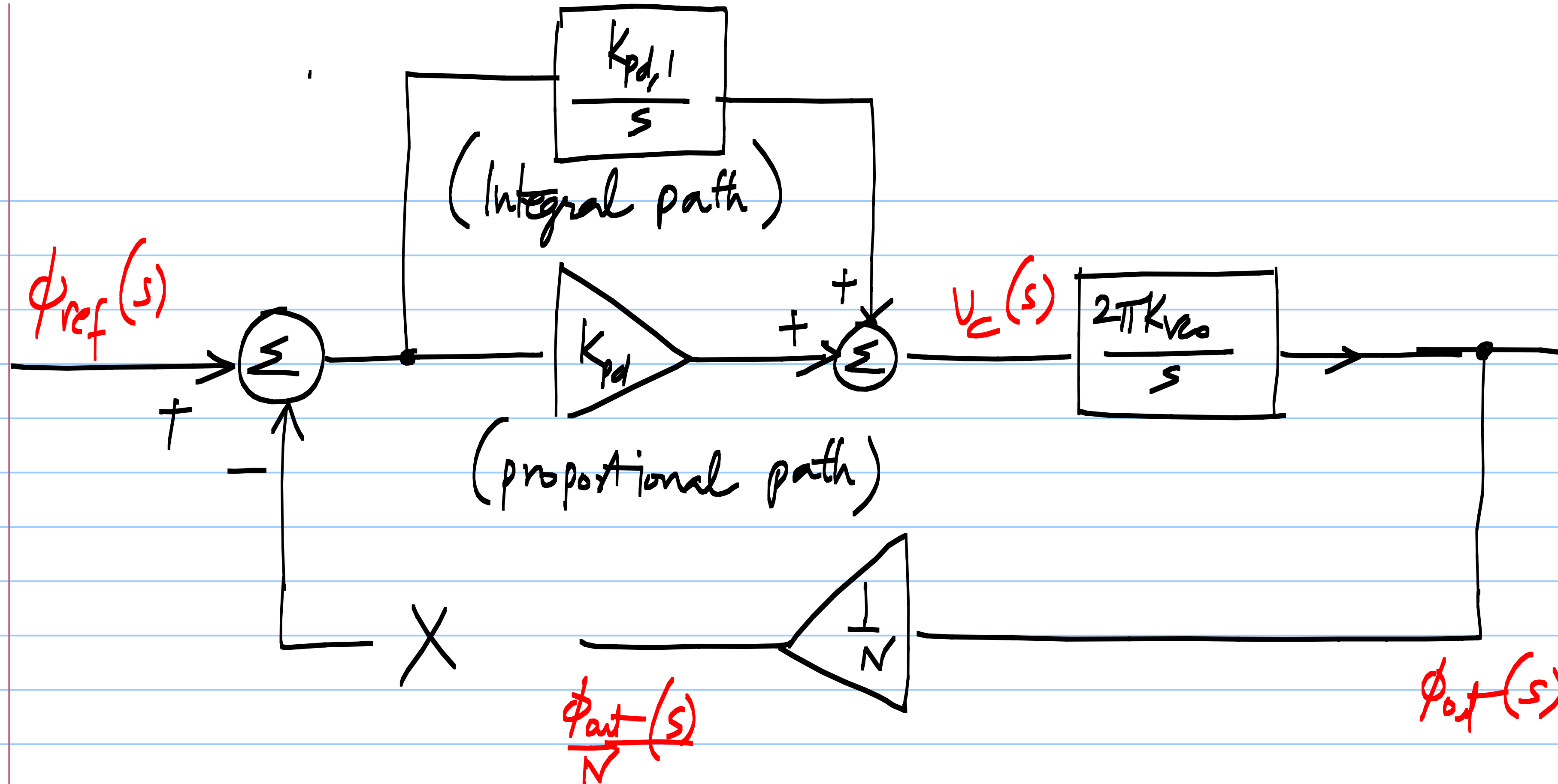
* Operating point: $\Phi_{ref} - \Phi_{out}/N = 0$

$$f_{out} = N f_{ref}$$

$$V_c = \frac{f_{out} - f_o}{K_{vco}} = \frac{N f_{ref} - f_o}{K_{vco}}$$

Integral phase detector

* Periodic error $e(t) = 0 \Rightarrow$ No reference spurs
* Lock range limited by vco range.

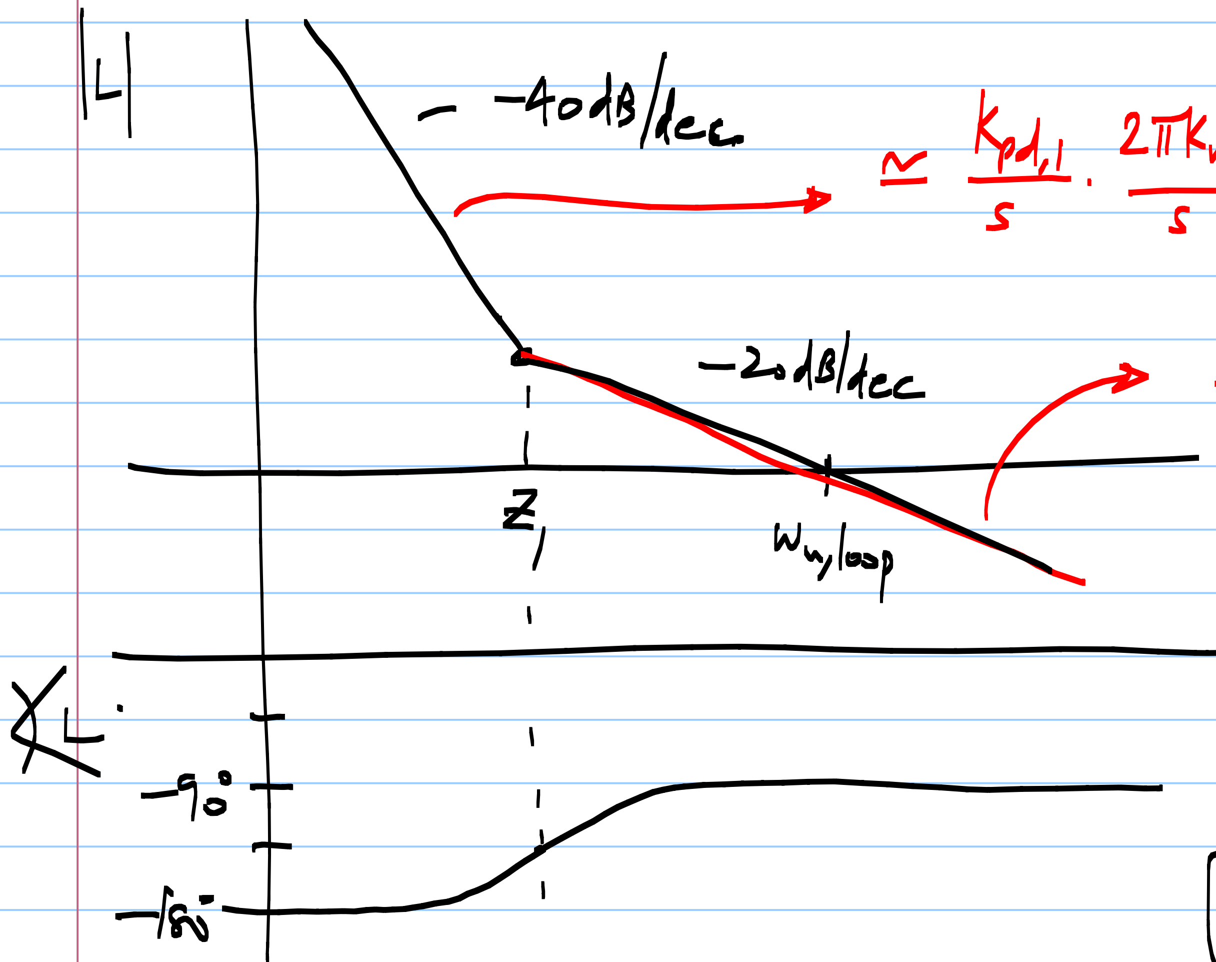


$$L(s) = \left(\frac{K_{pd,1}}{s} + K_{pd}\right) \cdot \frac{2\pi K_{vco}}{s} \cdot \frac{1}{N}$$

$$L(s) = \left(\frac{K_{pd,1}}{s} + K_{pd}\right)\cdot\frac{2\pi K_{vco}}{s}\cdot\frac{1}{N}$$

* Two poles at the origin

* One zero at $\frac{K_{pd,1}}{K_{pd}}$



$$\approx \frac{K_{pd,1}}{s}\cdot\frac{2\pi K_{vco}}{s}\cdot\frac{1}{N}$$

$$\approx K_{pd}\cdot\frac{2\pi K_{vco}}{s}\cdot\frac{1}{N}$$

$$\omega_{BW} = \omega_{u,loop}$$

$$= \frac{2\pi K_{vco}\cdot K_{pd}}{N\cdot s}$$

$$\boxed{z_1 < \omega_{BW}}$$

$$L(s) = \left(\frac{K_{pd,1}}{s} + K_{pd}\right) \cdot \frac{2\pi K_{vco}}{N \cdot s} = \frac{2\pi K_{vco} \cdot K_{pd,1}}{N \cdot s^2}\left(1 + s\frac{K_{pd}}{K_{pd,1}}\right)$$

$$\frac{\phi_{out}(s)}{\phi_{ref}(s)} = N \cdot \frac{1}{1 + \frac{1}{L}} = \frac{N}{1 + \frac{N \cdot s^2}{2\pi K_{vco} K_{pd,1}\left(1 + s \cdot \frac{K_{pd}}{K_{pd,1}}\right)}}$$

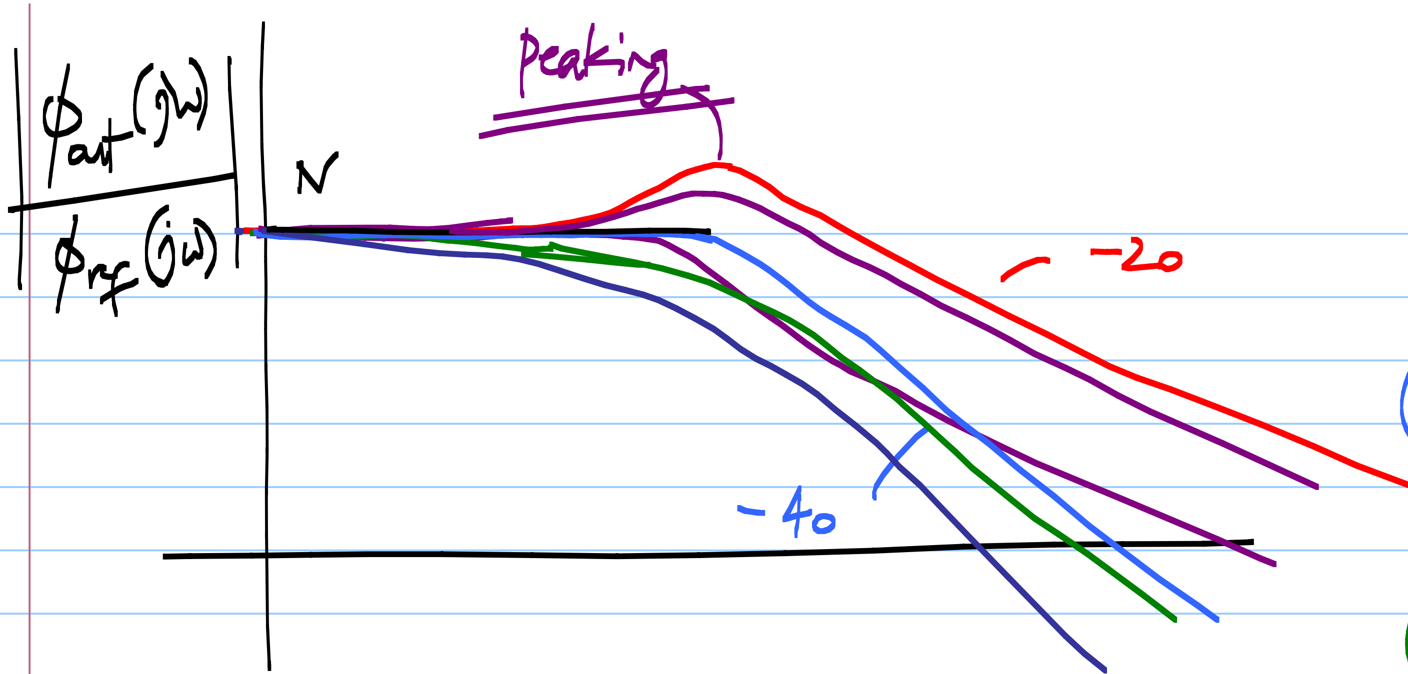
$$= N \cdot \frac{1 + s \cdot \frac{K_{pd}}{K_{pd,1}}}{1 + s \cdot \frac{K_{pd}}{K_{pd,1}} + \frac{N \cdot s^2}{2\pi K_{vco} \cdot K_{pd,1}}}$$

$$z_1 = \frac{K_{pd,1}}{K_{pd}} \; ; \qquad \omega_{u,loop} = \frac{2\pi K_{vco} K_{pd}}{N}$$

$$\frac{\phi_{out}(s)}{\phi_{ref}(s)} = N \cdot \frac{1 + \frac{s}{z_1}}{1 + \frac{s}{z_1} + \frac{s^2}{z_1 \cdot \omega_{u,loop}}}$$

$$\omega_n = \sqrt{\omega_{u,loop} \cdot z_1}$$

$$\xi = \frac{\omega_{u,loop}}{2\sqrt{\omega_{u,loop} z_1}} = \frac{1}{2}\sqrt{\frac{\omega_{u,loop}}{z_1}}$$



dc gain = N

$\xi = \frac{1}{\sqrt{2}}$ (maximally flat)

$\xi = 1$ (critical damping)

$\xi = 10$ (limited peaking)

$$\frac{\phi_{out}}{\phi_{ref}} = \frac{N}{1 + \frac{s}{z_1} + \frac{s^2}{\omega_{u,loop} z_1}} \cdot \left(1 + \frac{s}{z_1}\right)$$

$$\frac{\phi_{ref}(s)}{\phi_{out}(s)} = N \cdot \frac{1 + s/z_1}{1 + \frac{s}{z_1} + \frac{s^2}{z_1 \cdot \omega_{n,loop}}}$$

$$z_1 = \frac{K_{pd,1}}{K_{pd}}$$

$$\omega_{n,loop} = \frac{2\pi K_{vco} K_{pd}}{N}$$

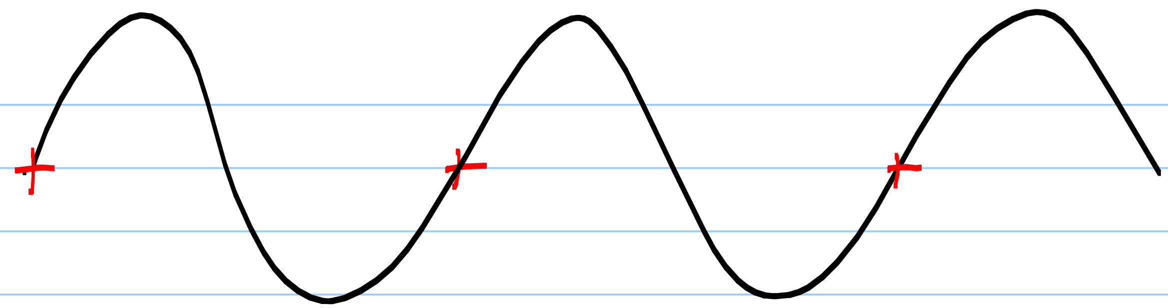
$$\xi = \frac{1}{2}\sqrt{\frac{\omega_{n,loop}}{z_1}}$$

$$\omega_n = \sqrt{\omega_{n,loop} \cdot z_1}$$

* $\xi = 1$: critical damping, result in magnitude response peaking because of the zero

* $\xi \gg 1$: Limit the peaking, but slower response.

$\phi_{ref}(t)$



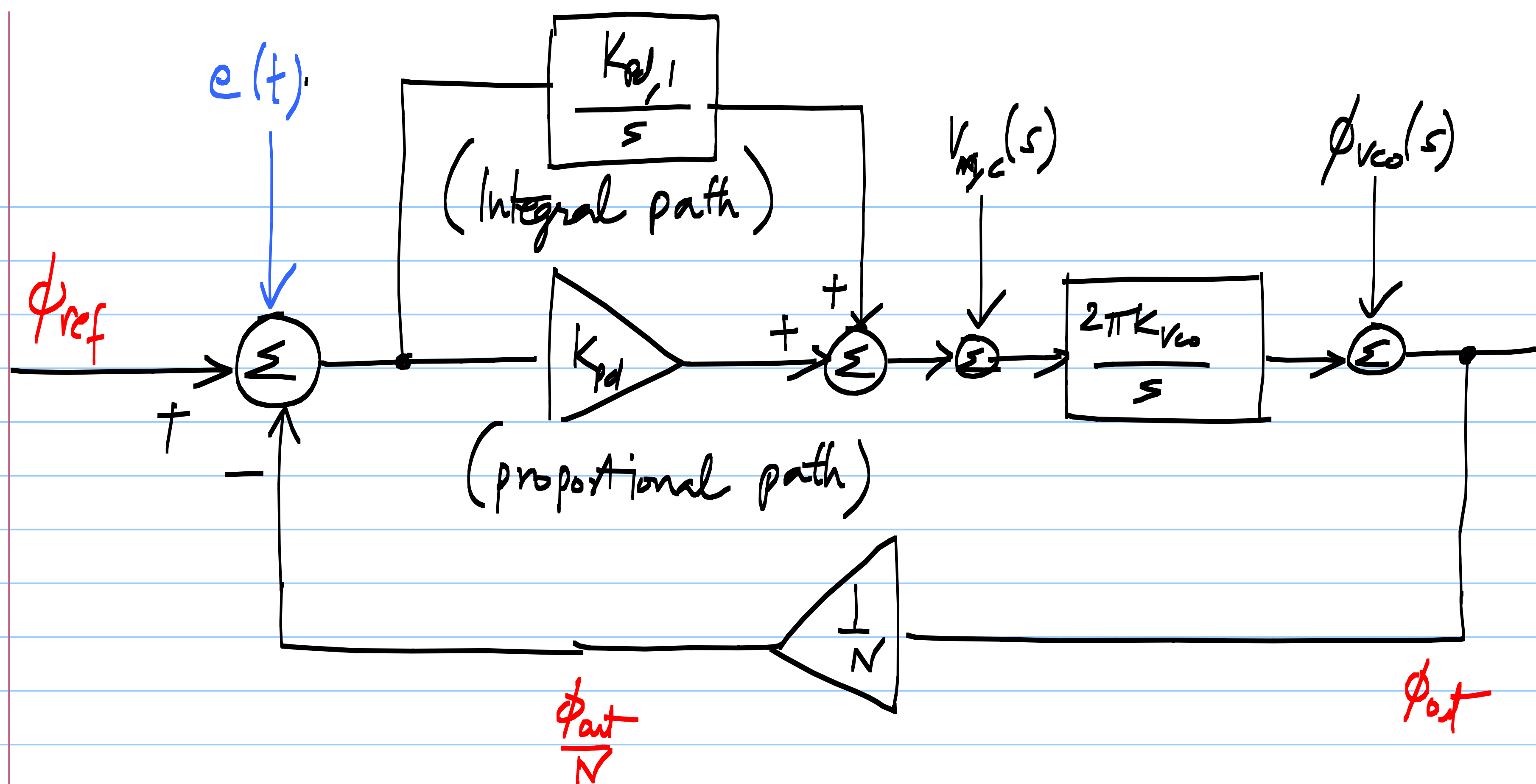
Sampled at f_{ref}

Continuous time approximation valid

if $\quad f_{ref} \gg f_{BW} = \dfrac{K_{pd} K_{vco}}{N}$

(Hz)

$$\underline{f_{ref} \geq 10 \cdot \frac{K_{pd} K_{vco}}{N}}$$



e(t)
$K_{pd,I}$
s
(Integral path)
ϕ_{ref}
+
−
K_{pd}
(proportional path)
+
+
$V_{ctrl}(s)$
$2\pi K_{vco}$
s
$\phi_{vco}(s)$
$\frac{1}{N}$
$\frac{\phi_{out}}{N}$
ϕ_{out}

$$\frac{\phi_{out}(s)}{\phi_{ref}(s)} \; ; \quad \frac{\phi_{out}(s)}{V_c(s)} \; ; \quad \frac{\phi_{out}(s)}{\phi_{vco}(s)}$$

$$\frac{\phi_{out}(s)}{V_c(s)} = \frac{\dfrac{2\pi K_{vco}}{s}}{1 + L(s)} \; ; \quad \frac{\phi_{out}(s)}{\phi_{vco}(s)} = \frac{1}{1+L(s)}$$

$$\frac{\phi_{out}(s)}{\phi_{ref}(s)} = \frac{\left(\dfrac{K_{pd,I}}{s} + K_{pd}\right)\dfrac{2\pi K_{vco}}{s}}{1+L(s)}$$