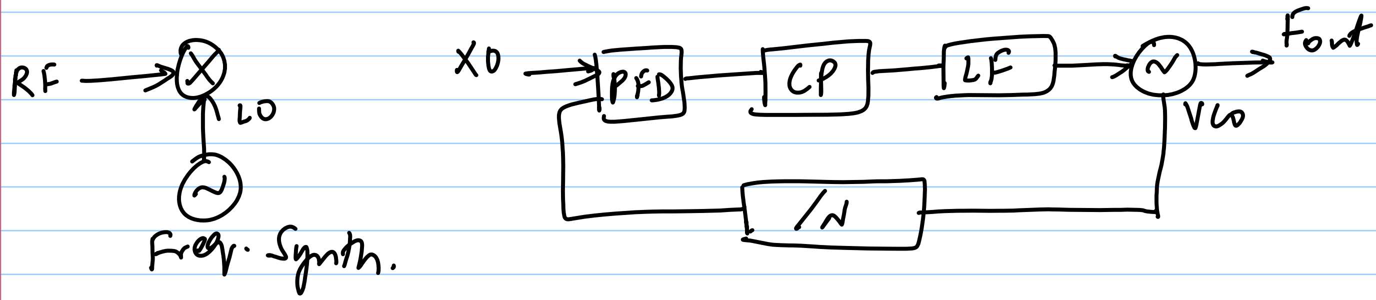
Lecture 27 : VCOs - I



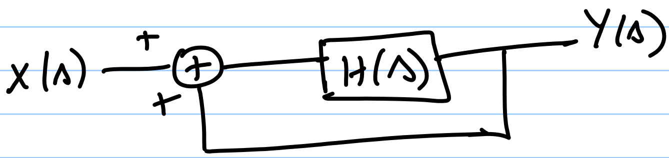
* Autonomous ckt (i.e. needs to be locked with a PLL)
* Applications : → Freq. Synthesis
  → Clock & Data Recovery ckts (also optical comm.)
  → μ-processor clk gen.

Types of Oscillators (RF)

* Relaxation oscillators (typically C-based)
  → Poor spectral purity
  → high phase noise
* Harmonic oscillators
  → LC VCOs, Crystal oscillators
  → good phase noise & spectral purity

In this course, we will study these

Feedback model (2-port)



$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1-H(s)}$$

$H(s_0) = 1 \Rightarrow$ self-sustaining oscillations

Amplitude is constant if $H(s_0 = j\omega_0) = 1$

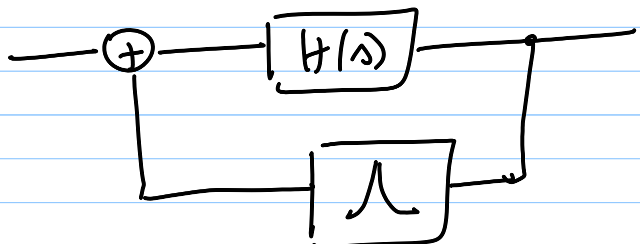
Barkhausen Criterion

(1) $|H(j\omega_0)| = 1$

(2) $\angle H(j\omega_0) = 360^\circ$ (loop phase shift is +ve)

→ if there is DC negative feedback, only 180° excess phase shift is required

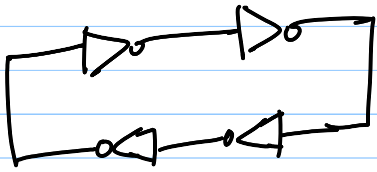
i.e. $\angle H(j\omega_0) = 180^\circ$



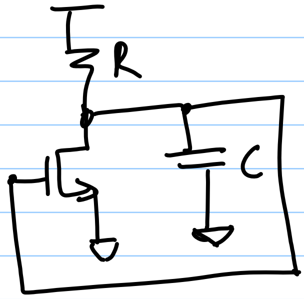
RLC tank = sets frequency ω_0

* Barkhausen criteria are necessary but not sufficient conditions

e.g. #1



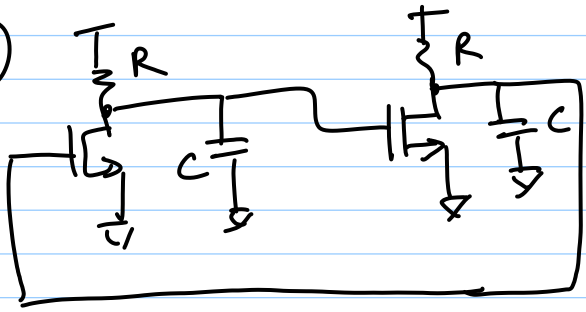
← does not oscillate

① 

* Does not oscillate

only 1 pole; 270° phase shift

@ $\omega = \infty$

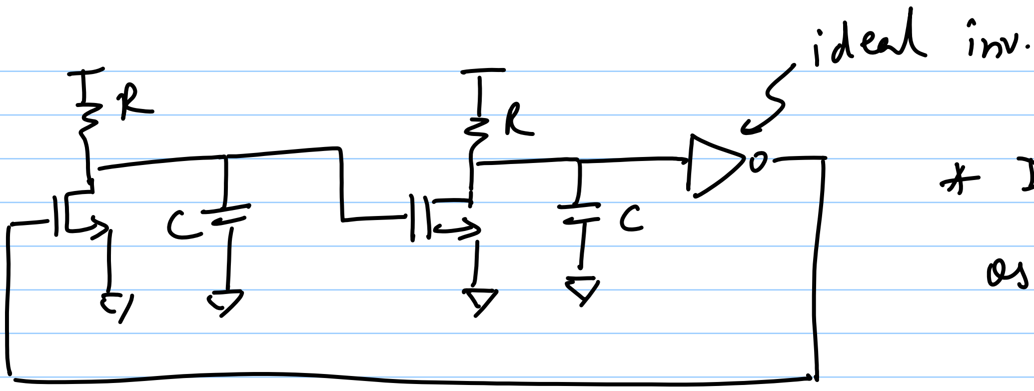
② 

* Does not oscillate

2-poles = 180° @ $\omega = \infty$

but, DC f.b. = 360°

⇒ latch-up

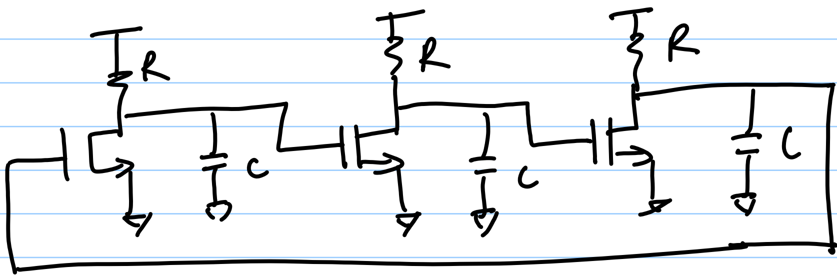
③ 

* Does NOT oscillate

DC f.b. = -ve (180°)

excess phase required = 180°

2-poles ⇒ 180° reached only @ $\omega = \infty$

④ 

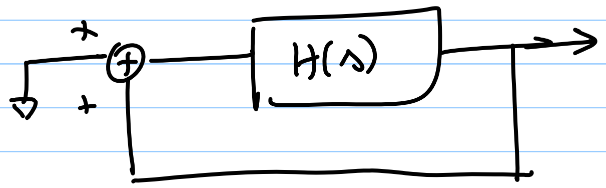
Does oscillate

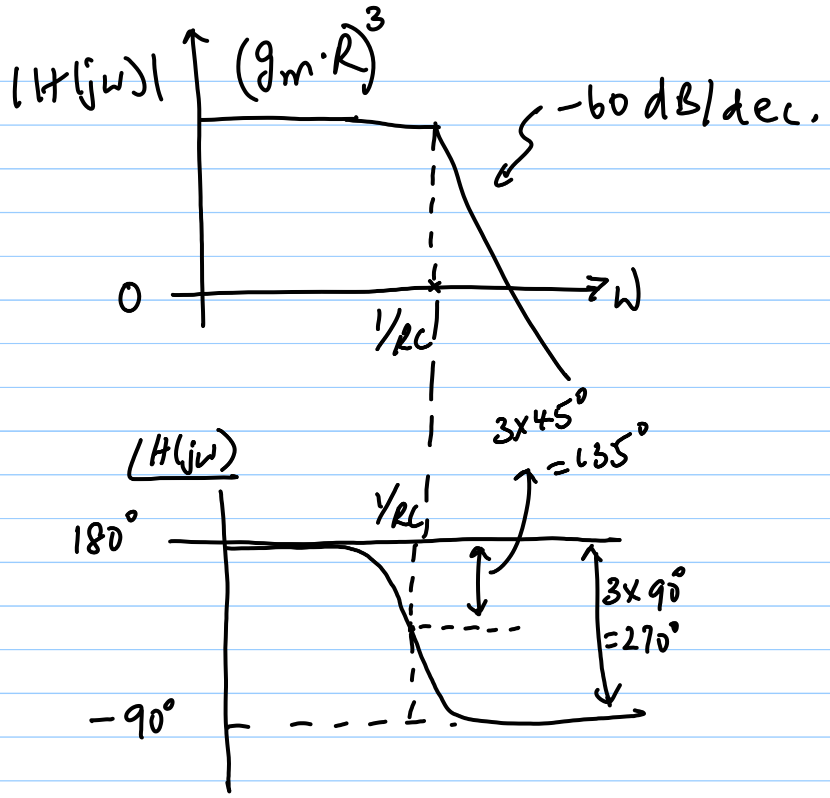
at DC $\Rightarrow$ 180° phase shift

for each stage,

$$\frac{out}{in} = \frac{-A_0}{1 + s/\omega_p}$$

$$\Rightarrow \quad H(s) = -\left(\frac{A_0}{1+s/\omega_p}\right)^3 \quad ; \quad \omega_p = \frac{1}{RC}$$





say oscillation happens @ ω_0

$\angle H(j\omega) = 360°/0°$ has to be satisfied

$$\Rightarrow \quad \pi - 3\tan^{-1}\left(\frac{\omega_0}{\omega_p}\right) = 0°$$

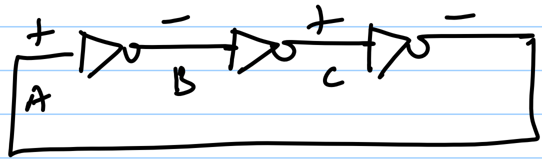
$$\tan^{-1}\left(\frac{\omega_0}{\omega_p}\right) = \frac{\pi}{3}$$

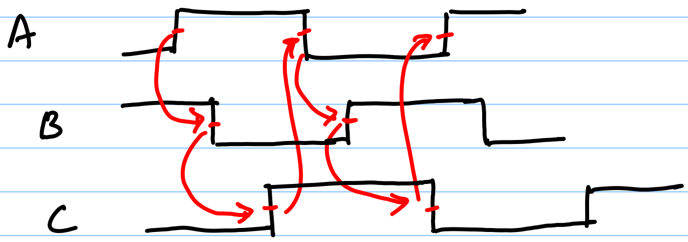
$$\Rightarrow \boxed{\omega_0 = \sqrt{3}\,\omega_p}$$

$$|H(j\omega_0)| = \frac{A_0^3}{\left[1+\left(\frac{\omega_0}{\omega_p}\right)^2\right]^{3/2}} = \frac{A_0^3}{8}$$

$|H(j\omega_0)| = 1$ has to be satisfied $\Rightarrow \boxed{A_0 = 2}$

* What happens if $A_0 \neq 2$?



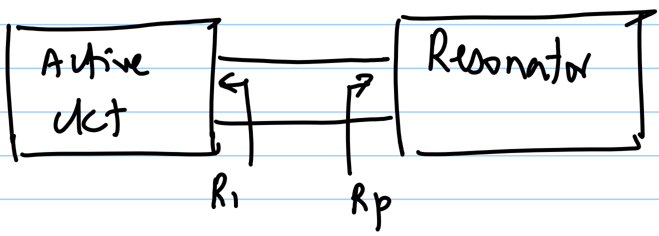


$T = 6\tau$

$$\tau = \frac{t_r + t_f}{2}$$

In general $T = 2n\tau$ for n inv.

<u>One-port view</u> (useful for LC oscillators)



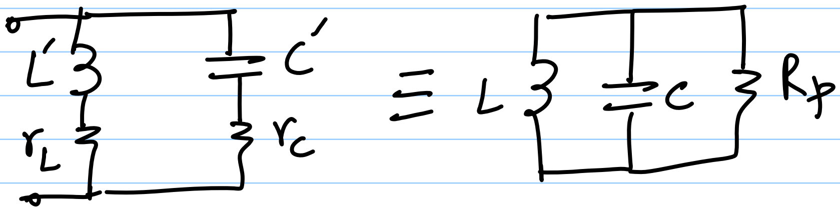
we want

$R_1 = -R_p$

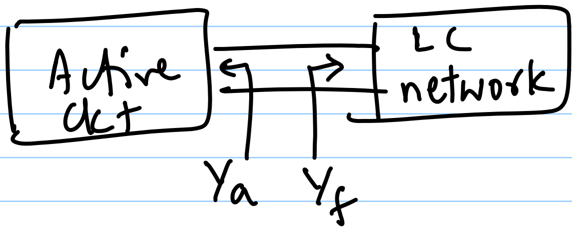
* Energy is lost in R_p every cycle
* This is replenished by active ckt

Remember

lossy $L, C \Rightarrow$



* Freq. determined by L, C



$Y_a = G_a + jB_a$

$Y_f = G_f + jB_f$

$\Rightarrow G_a = -G_f$ <u>and</u> $B_a = -B_f$

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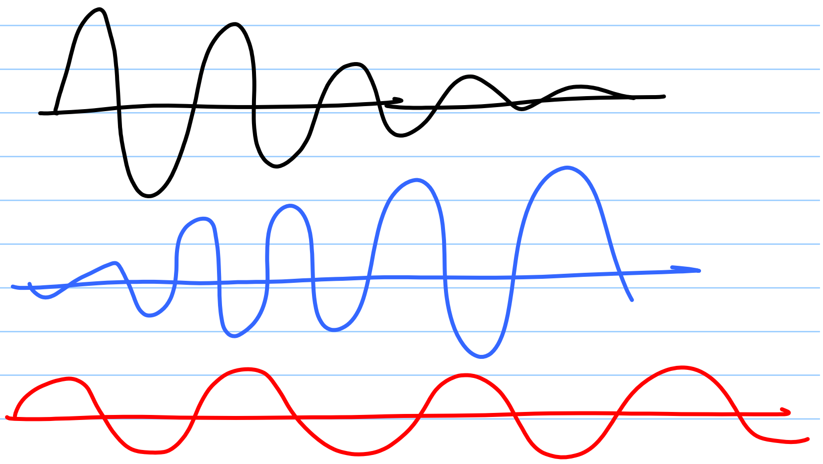
* How about amplitude?
  - → Usually require "startup" loop gain > 1 (e.g. 3)
  - → at steady state, amp inside active block saturates with low gain @ peaks so that <u>average</u> LG = 1

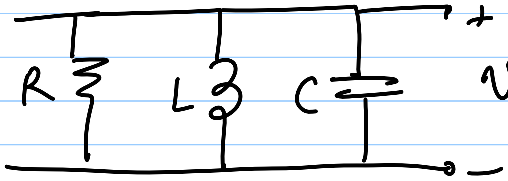
choose $G_a + G_f < 0$ for startup

$G_a + G_f > 0$

$G_a + G_f < 0$

$G_a + G_f = 0$



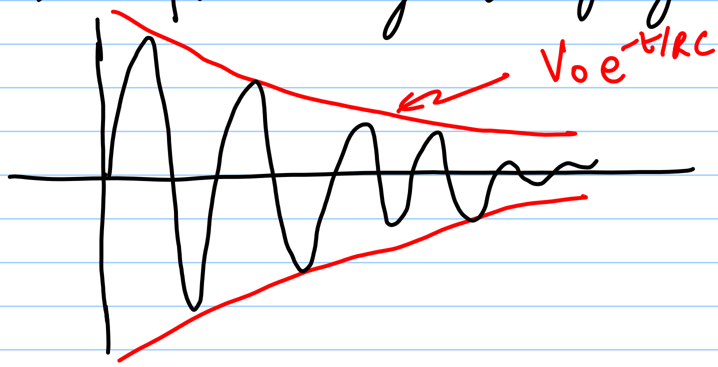


$v(0) = V_0$ = initial voltage across cap.

If $Q = \dfrac{R}{\omega_0 L} = \omega_0 RC = \sqrt{\dfrac{L}{C}} > \dfrac{1}{2}$,

the 2nd-order system will have imaginary roots

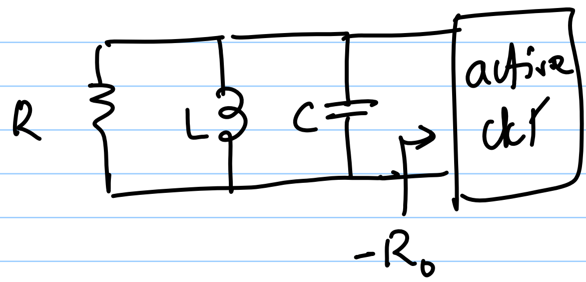
⇒ exponentially decaying sinusoid



$\tau = 1/RC$

as $R \to \infty$, $\tau \to 0$

⇒ amplitude does not decay (ideal LC)



$$R_{eq.} = \frac{R R_0}{R_0 - R}$$

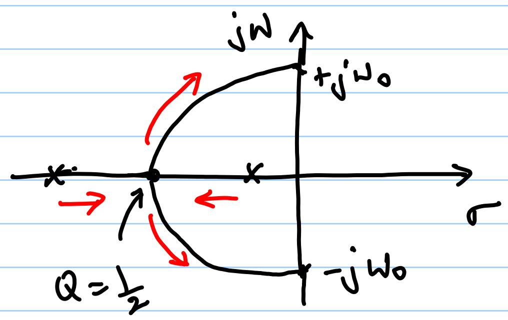
decaying exponential envelope $= V_0 \exp\left[-\dfrac{t}{R_{eq.} C}\right]$

$R = R_0$ ⇒ amplitude never decays

$R < R_0$ ⇒ decaying exp.

$R > R_0$ ⇒ growing exp.

@ $Q = \frac{1}{2}$, poles split into complex conjugate pair

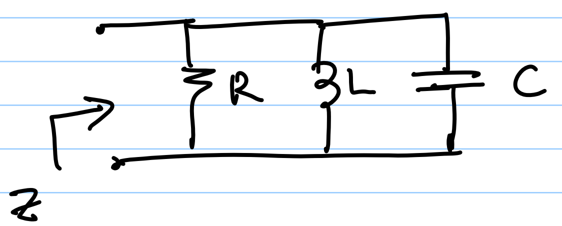


Linear oscillators

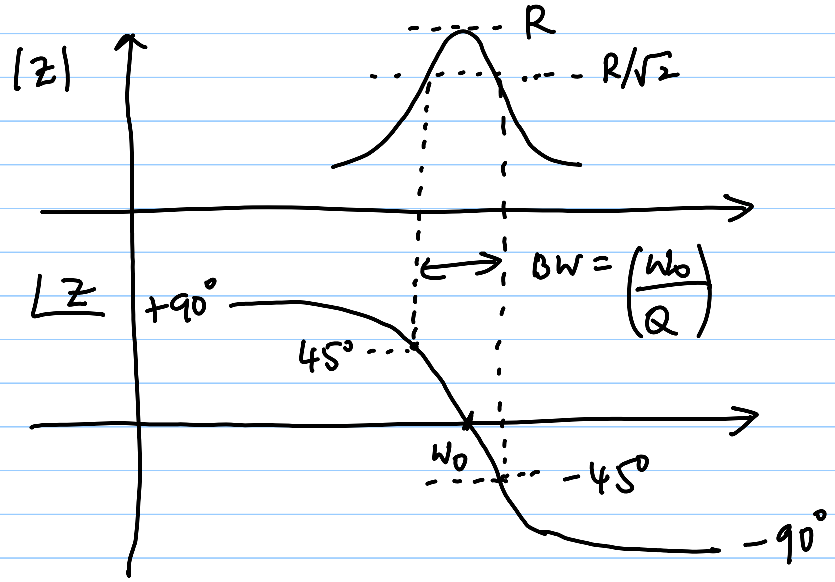
1) $G_{in} + G_p = 0 \Rightarrow$ oscillations are sustained, but startup is compromised

2) $G_{in} + G_p < 0 \Rightarrow$ startup possible, but amplitude not stable ($\uparrow$)

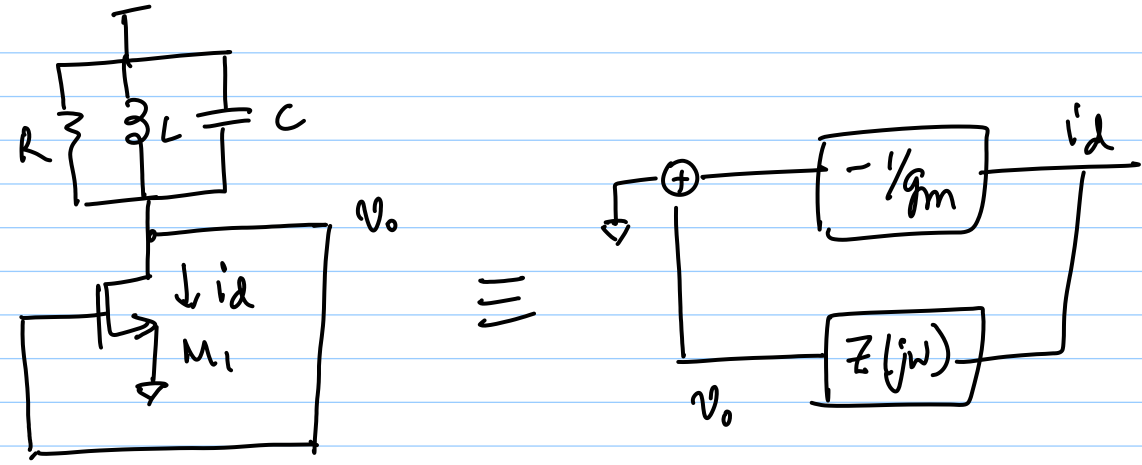
$\Rightarrow$ oscillator needs to be fundamentally non-linear



$$Z(j\omega) = \frac{sL}{LCs^2 + \frac{L}{R}s + 1}$$



$$\omega_0 = \frac{1}{\sqrt{LC}}$$

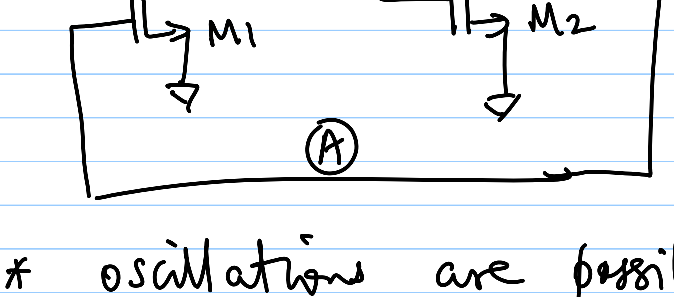


@ resonance, RLC tank phase shift $= 0$

M_1 phase shift $= 180°$

$\Rightarrow \angle H(s) = 180° \Rightarrow$ <u>no oscillations</u>

Let us cascade two of these stages.

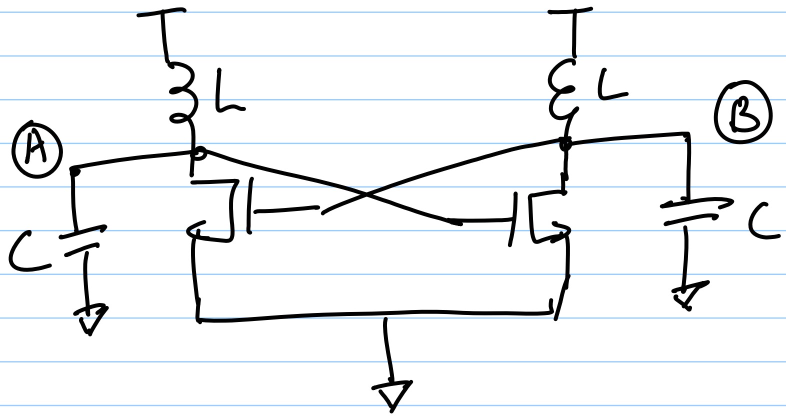


* at $\omega_o = \dfrac{1}{\sqrt{LC}}$, each stage contributes 180° phase shift
* $\angle H(s) = 360°$

* oscillations are possible if $|H(j\omega_o)| \geq 1$

$\Rightarrow (g_m R)^2 \geq 1$ $\left\{ \begin{array}{l} > \;\Rightarrow \text{startup} \\ = \;\Rightarrow \text{steady-state} \end{array} \right\}$

Redraw :



Modern on-chip LC oscillator

A & B are 180° out of phase
⇒ differential outputs