Electronic Circuit of Communications

Huazhong University
of Science & Technology

School of Electronic Information
and Commnications

Jiaqing Huang

5 Oscillators

Classifications of Oscillators

- Comparison:
- RF Oscillatro *vs*. RF Small Signal Amplifier & RF Power Amplifier?

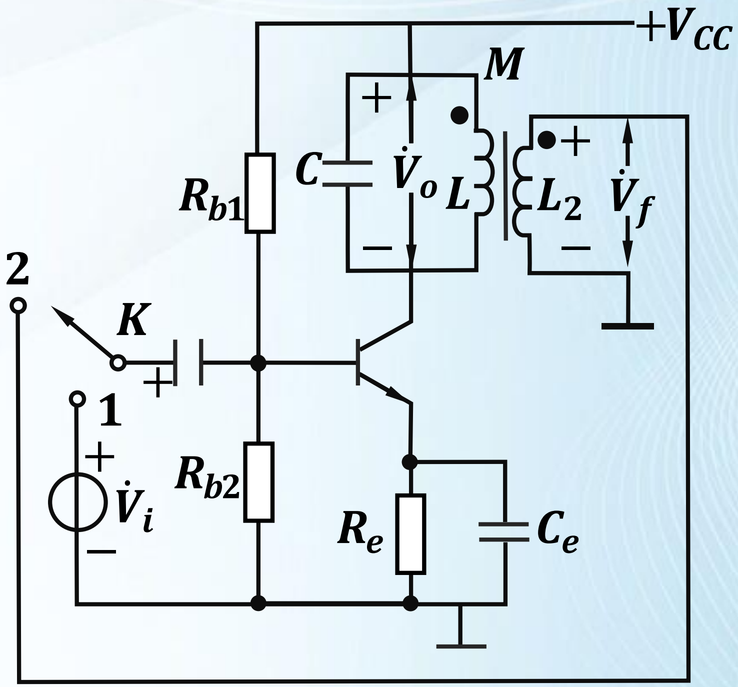
Non-input *vs*. Has input

Oscillator
- Sinusoidal
  - Feedback
    - Feadback *RC* Oscillator
    - Feedback LC Oscillator
    - Quantz Crystal Oscillator
  - Negative Resistance
- Non-Sinusoid

RC Oscillator *vs*. *LC* Oscillator

Feedback LC Oscillator – Principle

- Why? $L\&C$, Positive Feedback
- How?
  - How to start? "0→1"
    - Non-linear (Amplitude cannot be ∞)
  - How to maintain?



- $K=$ "1" , Resonant Amplifier, For $\dot{V}_f = \dot{V}_i$ by adjusting M
- $K=$ "2" , Resonant Amplifier → Oscillator

Feedback LC Oscillator – Essential Elements

- Resonant circuits

  L & C

- Energy for compensating loss of L

  Vcc

- Energy to active devices on right time

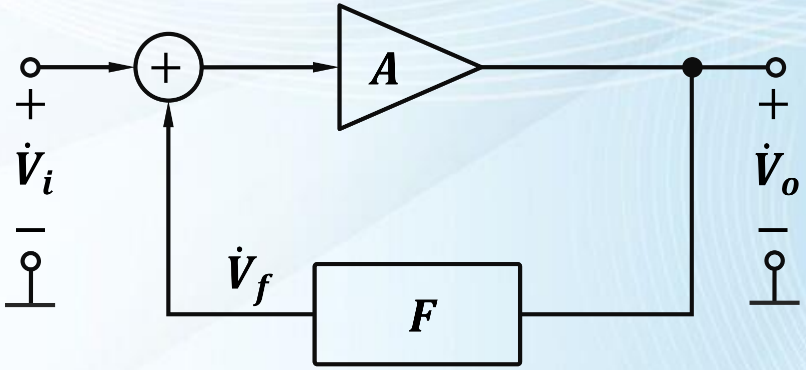
  Positive Feedback + Active Devices

Feedback LC Oscillator – Conditions

- Startup Condition
- Balance Condition
- Stability Condition for Balance

Startup Condition

Startup Condition of Oscillator



- Idea: Amplifier $\dot{A}_f \to \infty \;\Rightarrow$ Oscillator

Open-loop Gain: $\dot{A}_o = \left.\dfrac{\dot{V}_o}{\dot{V}_i}\right|_{\dot{V}_f=0}$

Close-loop Gain: $\dot{A}_f = \dfrac{\dot{A}_o}{1-\dot{A}_o\cdot\dot{F}}$

$\dot{F} = \dfrac{\dot{V}_f}{\dot{V}_o}$

- $1-\dot{A}_o\cdot\dot{F} = 0 \;\Rightarrow\; \dot{A}_f \to \infty$。Non-input, Amplifier $\Rightarrow$ Oscillator
- If $\dot{A}_o\cdot\dot{F} = 1$, amplitude may not be strong
- F Should be big $\Rightarrow \dot{A}_o\cdot\dot{F} > 1$ In general $\frac{1}{8} \sim \frac{1}{2}$

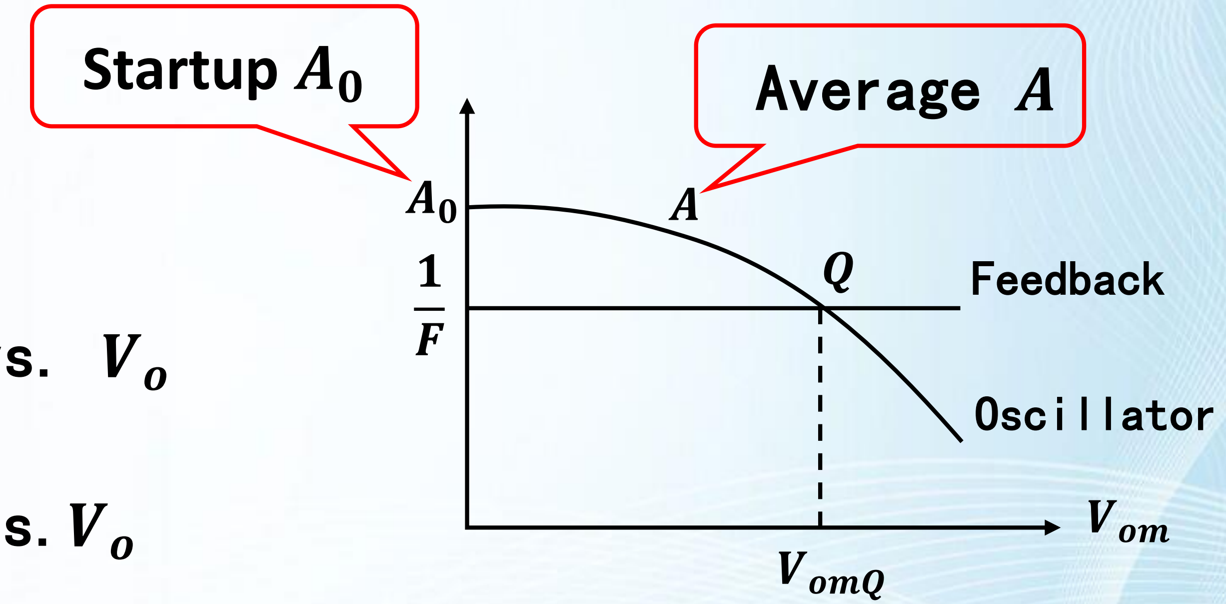
Startup Condition of Oscillator

$$A_o > \frac{1}{F}$$

- $\dot{A}_o \cdot \dot{F} > 1$ $\quad \begin{cases} A_o \cdot F > 1 \\ \varphi_A + \varphi_F = 2n\pi \quad (n = 0, \pm 1, \ldots) \end{cases}$

Amplitude Startup Condition

Phase Startup Condition



Soft-prompting

- Oscillator Characteristics: A vs. V_o
- Feedback Characteristics : F vs. V_o

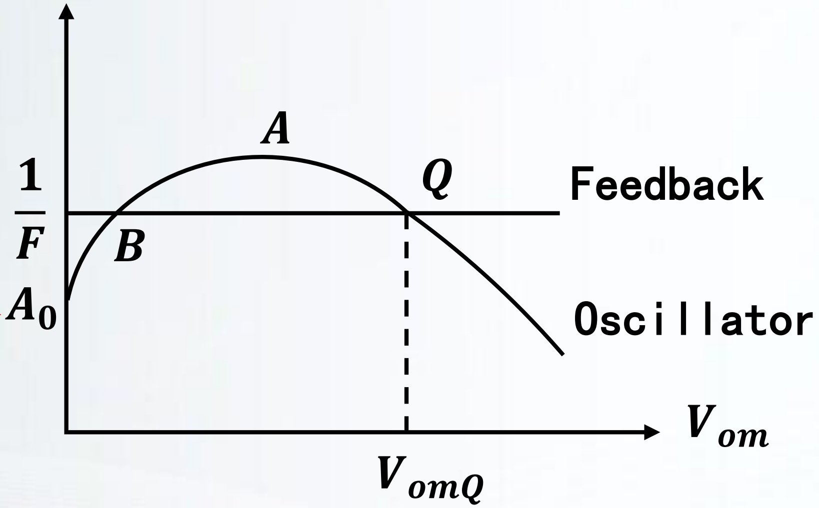
$$A = \frac{A_o}{\tau}, \quad \tau = 2{\sim}4$$

Startup Condition of Oscillator

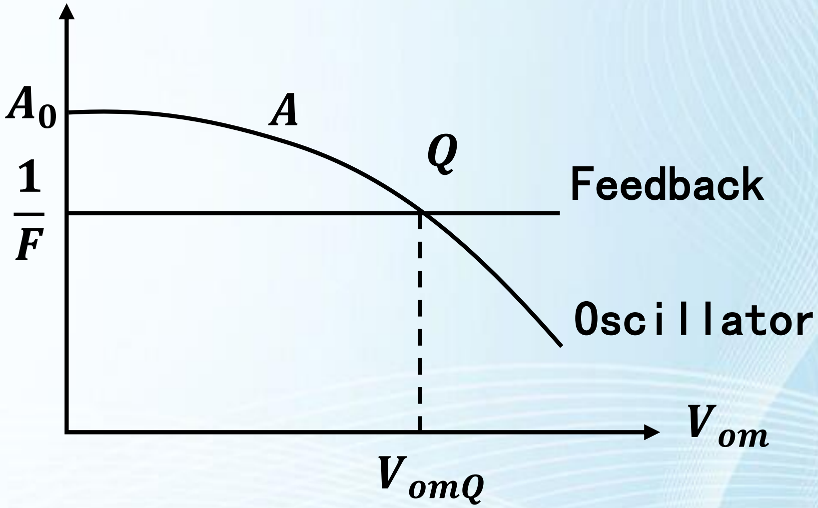
$A_o > \frac{1}{F}$

- $\dot{A}_o \cdot \dot{F} > 1$ $\quad \begin{cases} A_o \cdot F > 1 \\ \varphi_A + \varphi_F = 2n\pi \quad (n = 0, \pm 1, \dots) \end{cases}$ Amplitude Startup Condition / Phase Startup Condition

A_0 is Small, cannot auto-startup



Hard-prompting



Soft-prompting

Balance Condition

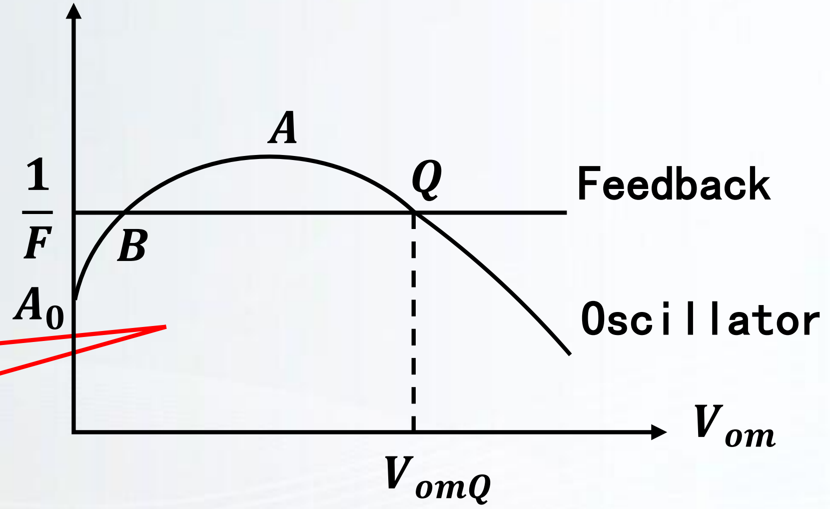
Balance Condition of Oscillator

- $\dot{A} \cdot \dot{F} = 1$ $\begin{cases} A \cdot F = 1 \\ \varphi_A + \varphi_F = 2n\pi \quad (n = 0, 1, 2, 3 \ldots) \end{cases}$ Amplitude Condition / Phase Condition

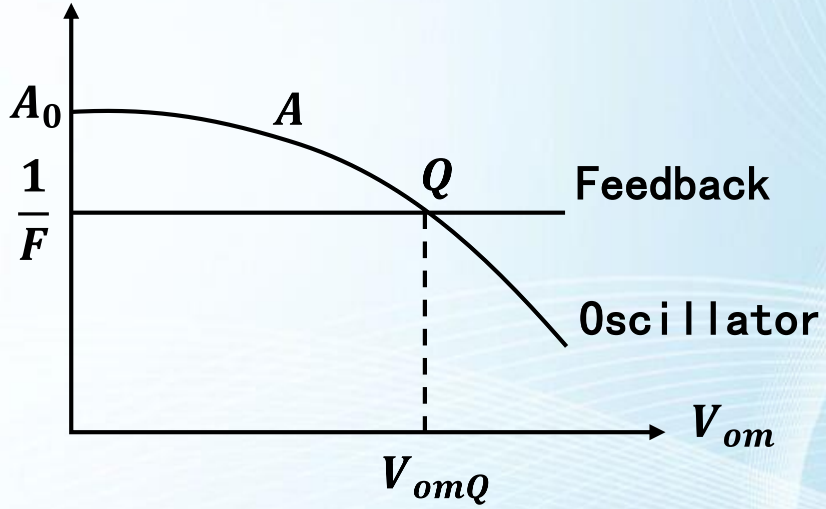
- Physical Significance:

  $\dot{V}_f = \dot{V}_i$, Maintain Oscillator

2 Balance Points



Hard-prompting



Soft-prompting

Balance Condition of Oscillator (Circuit Parameters)

- $\dot{A} \cdot \dot{F} = 1$, To decompose A = Transistor + Parallel Resonance

$$\left\{\begin{aligned} &\dot{A} \cdot \dot{F} = 1 \\ &\dot{A} = \frac{\dot{V}_c}{\dot{V}_i} = \frac{\dot{I}_{c1} Z_{p1}}{\dot{V}_i} = \overline{y_{fe}} \cdot Z_{p1} \end{aligned}\right\} \quad \overline{y_{fe}} \cdot Z_{p1} \cdot \dot{F} = 1$$

Parallel Resonance

Average forward y_{fe}

Circuit Parameters

- $\overline{y_{fe}} \cdot Z_{p1} \cdot \dot{F} = 1$

$$\begin{cases} \left|\overline{y_{fe}}\right| \cdot \left|Z_{p1}\right| \cdot F = 1 & \text{Amplitude Condition} \\ \varphi_Y + \varphi_Z + \varphi_F = 2n\pi \quad (n = 0, 1, 2, 3 \ldots) & \text{Phase Condition} \end{cases}$$

Summary

- Balance: $A \cdot F = 1$, $\varphi_A + \varphi_F = 2n\pi$
- Balance (Circuit): $|\overline{y_{fe}}| \cdot |Z_{p1}| \cdot F = 1$, $\varphi_Y + \varphi_Z + \varphi_F = 2n\pi$

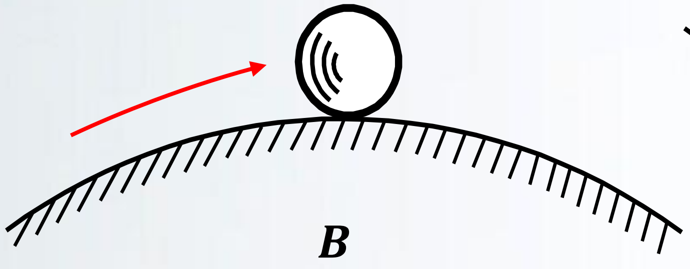
Transistor

Parallel Resonance

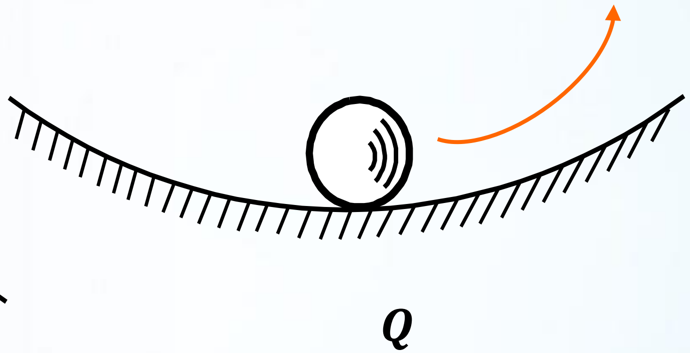
Stability Condition

Balance Stability Condition of Oscillator

- **Stability Condition of Balance:**
  ability to recover automatically to balance status



Unstable Balance

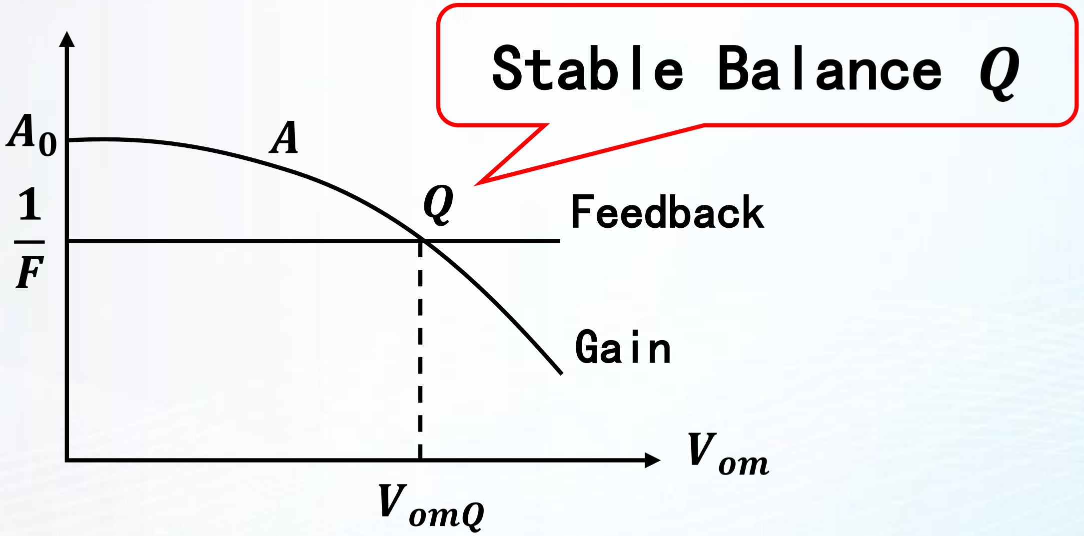


Stable Balance

Balance Stability Condition – Amplitude

① If $V_{om}\uparrow$ $(>V_{omQ})$, $A\downarrow$, $V_{om}\downarrow$, back to Q

② If $V_{om}\downarrow$ $(<V_{omQ})$, $A\uparrow$, $V_{om}\uparrow$, back to Q

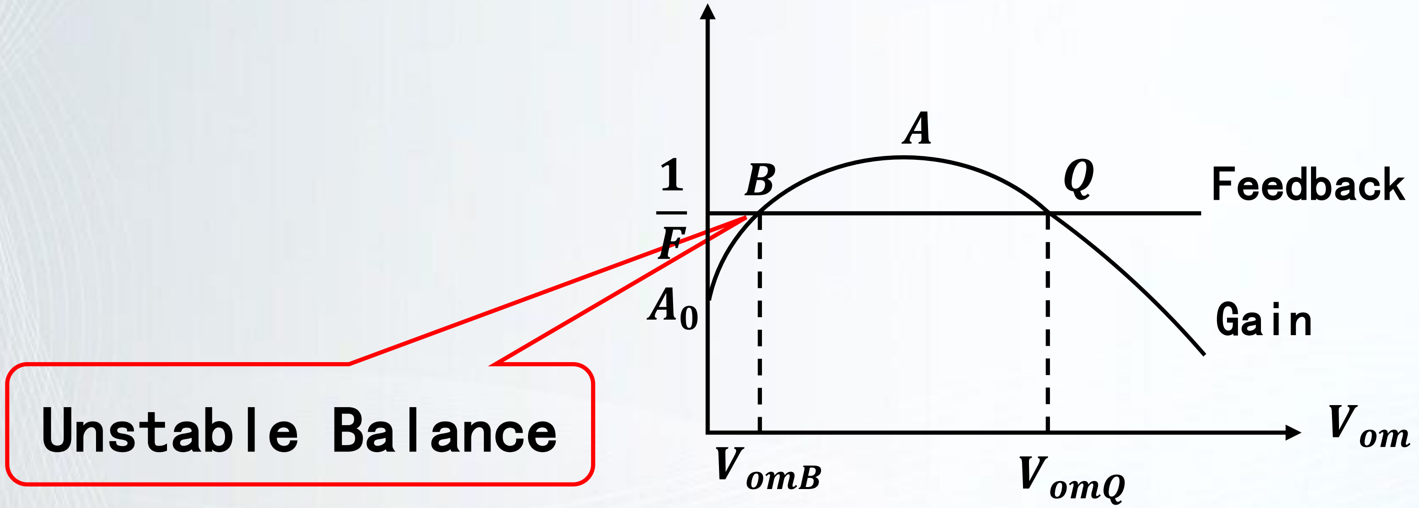


Soft-prompting

Balance Stability Condition - Amplitude

① If $V_{om}\uparrow$ ($>V_{omB}$), $A\uparrow$, $V_{om}\uparrow$, far away from B

② If $V_{om}\downarrow$ ($<V_{omB}$), $A\downarrow$, $V_{om}\downarrow$, far away from B



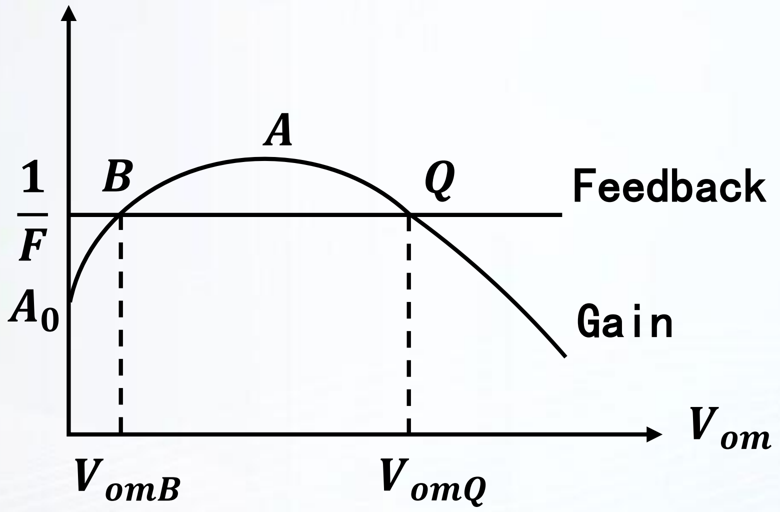
Hard-prompting

Balance Stability Condition - Amplitude

- Condition: Gain A has negative slope around Q

$$\left.\frac{\partial A}{\partial V_{om}}\right|_{V_{om}=V_{omQ}} < 0 \qquad \text{Stability Amplitude Condition}$$

- Active devices (Transistors) have this property, which can help stable amplitude



Hard-prompting

Balance Stability Condition – Phase

- Phase leads by external reasons → Frequency ↑ $\frac{\Delta\omega}{\Delta\varphi} > 0$
- To compensate $\Delta\varphi$: $\frac{\Delta\varphi}{\Delta\omega} < 0$
- Partial Differential Form: $\frac{\partial\varphi}{\partial\omega} < 0$ or $\frac{\partial(\varphi_Y+\varphi_Z+\varphi_F)}{\partial\omega} < 0$
- φ_Z dominates frequency changing

$$\left|\frac{\partial\varphi_Y}{\partial\omega}\right| \ll \left|\frac{\partial\varphi_Z}{\partial\omega}\right| \qquad \left|\frac{\partial\varphi_F}{\partial\omega}\right| \ll \left|\frac{\partial\varphi_Z}{\partial\omega}\right|$$

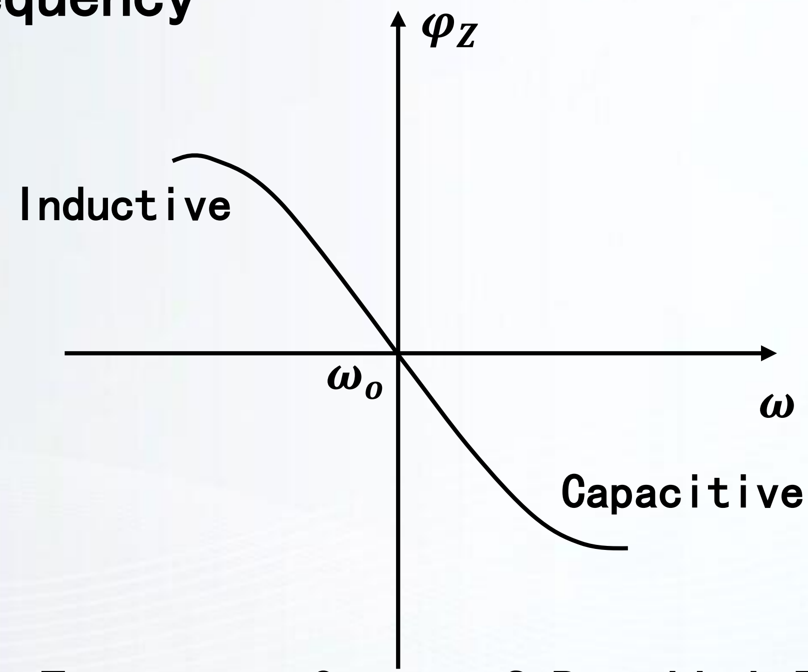
Stability Phase Condition $\frac{\partial\varphi}{\partial\omega} \approx \frac{\partial\varphi_Z}{\partial\omega} < 0$

Balance Stability Condition - Phase

- Condition: Phase-frequency curve has negative slope

$$\frac{\partial \varphi}{\partial \omega} \approx \frac{\partial \varphi_Z}{\partial \omega} < 0 \quad \text{Stability Phase Condition}$$

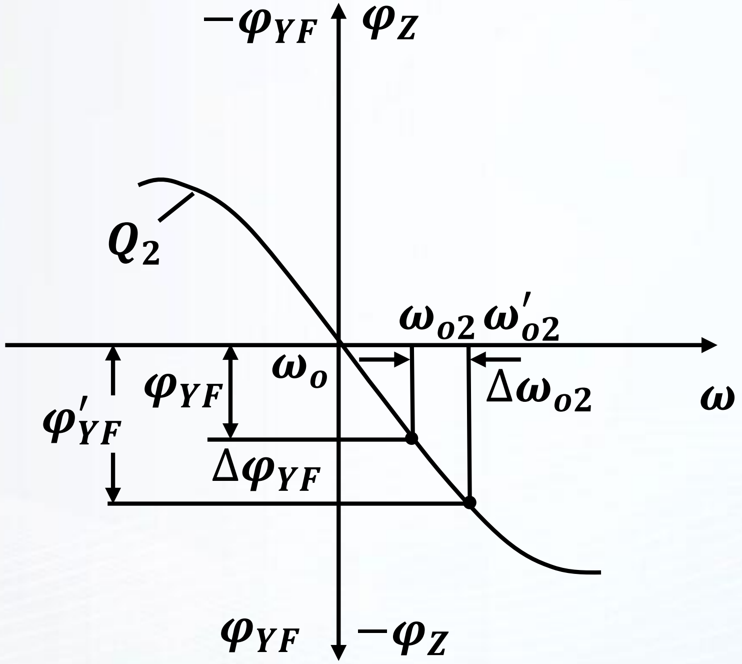
- LC parallel resonance circuits have this property, which can help stable phase. Meanwhile, LC parallel resonance circuits determine frequency



Phase-Frequency Curve of Parallel Resonance

Balance Stability Condition - Phase

- To decrease $\Delta\omega$：
  - $\varphi_{YF} \to 0$ （Resonant） $\Rightarrow$ Stability ↑
  - $\Delta\varphi_{YF} \downarrow \Rightarrow \Delta\omega \downarrow$



$$\varphi_Y + \varphi_Z + \varphi_F = 0$$

$$\varphi_Z = -(\varphi_Y + \varphi_F)$$

$$= -\varphi_{YF}$$

Balance Stability Condition - Phase

- To decrease $\Delta\omega$:
  - $\varphi_{YF} \to 0$ (Resonant) $\Rightarrow$ Stability ↑
  - $\Delta\varphi_{YF} \downarrow \Rightarrow \Delta\omega \downarrow$
  - Increase Q