Huazhong University
of Science & Technology

Electronic Circuit of Communications

School of Electronic Information
and Commnications

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Stability of Oscillator

Stability of Oscillator

- **Frequency Accuracy:**

Differece between practical frequency f and f_0

$$\begin{cases} \text{Absolute Accuracy} & \Delta f = |f - f_0| \\ \text{Relative Accuracy} & \dfrac{\Delta f}{f_0} = \dfrac{|f - f_0|}{f_0} \end{cases}$$

- **Frequency Stability δ**

During Δt, the max value Δf_{max} of frequency accuracy

$$\delta = \left.\frac{\Delta f_{max}}{f_0}\right|_{t=\Delta t}$$

Stability of Oscillator

Active devices, quartz crystals…

- Long-term Stability:
  ≥ 1 day to several months

Temperature, power supply, circuit

- Short-term Stability:
  < 1 day

- Instantaneous Stability:
  s or ms
  Phase noise

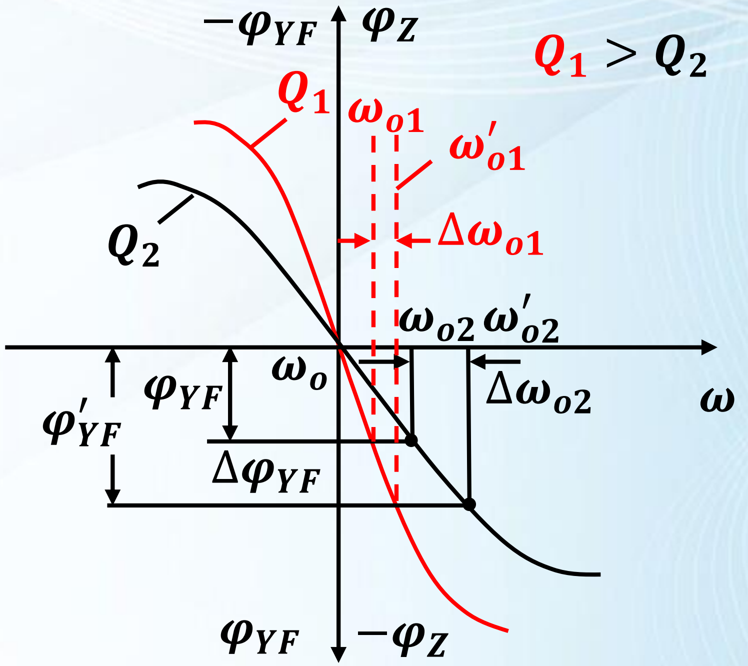
Internal noise

Frequency Stability Factors

- **Oscillator Parameters**

  Frequency $\omega_0 \approx \frac{1}{\sqrt{LC}}$

  Relative Change $\frac{\Delta\omega_0}{\omega_0} = -\frac{1}{2}\left(\frac{\Delta L}{L} + \frac{\Delta C}{C}\right)$



- **Q**

  $Q\uparrow$ Same $\Delta\varphi \rightarrow \Delta\omega\downarrow$

- **Active Device Parameter**

  - Δh Δh_i of Active Devices
  - External Factors(For Example, Power Supply、Temperature、Humidity)

Frequency Stability Methods

1. Remove External Factors

(1) Temperature:

- Constant Temperature Box
- Far Away from Heat Source
- L、C with Positive/Negative Temperature Coefficient, Compensate ΔL、ΔC

(2) Power Supply:

- 2nd Regulated Power Supply
- Independent Power Supply

(3) Humidity & Atmospheric Pressure: Seal

(4) Magnetic Field Induction: Shield

(5) Mechanical Vibration: Robber Absorber

Frequency Stability Methods

1. Remove External Factors

(6) Decrease Influence of Load

- Buffer between Oscillator & Load (Emitter Follower), Increase Q
- Low-Impedance Output (Emitter Follower)
- Loose Coupling(with Small Capacitor)
- Clapp & Seiler Circuit

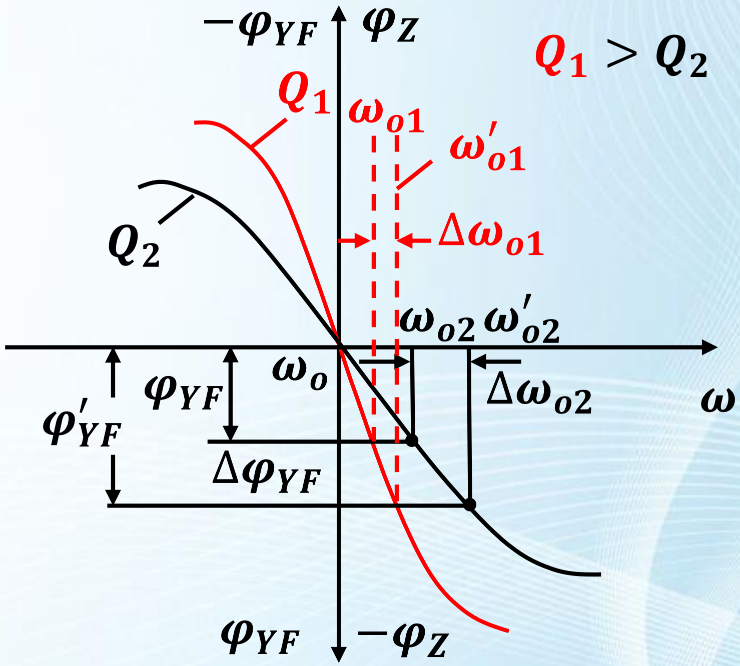
Frequency Stability Methods

1. Remove External Factors
2. Increase Standard

   Decrease ΔL and ΔC

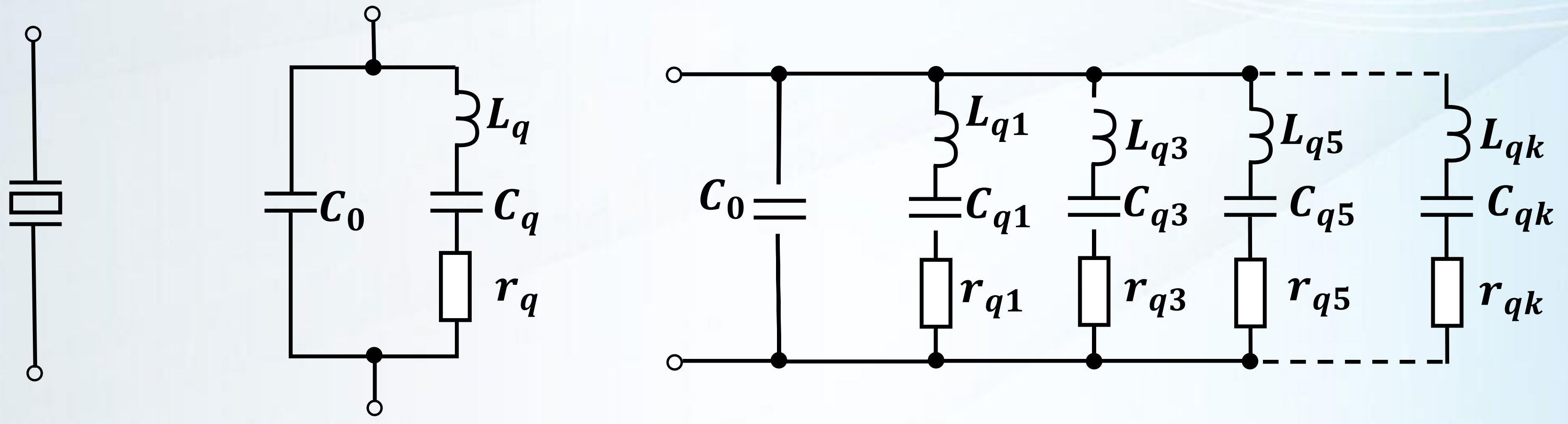
3. Decrease φ_{YF} and $\Delta\varphi_{YF}$

   Example: Capacitive Feedback Oscillator to decrease φ_{YF}



Quartz Crystal Oscillator

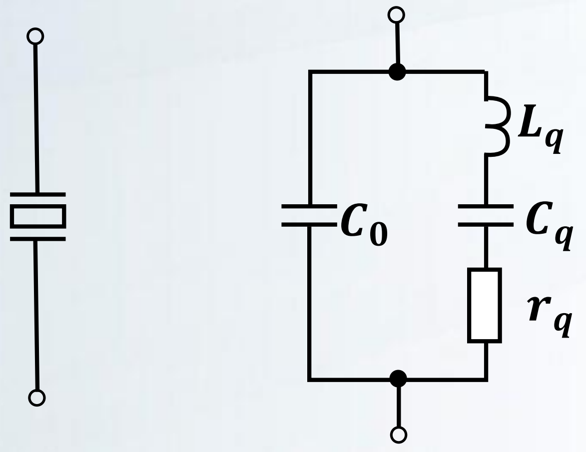
Quartz Crystal



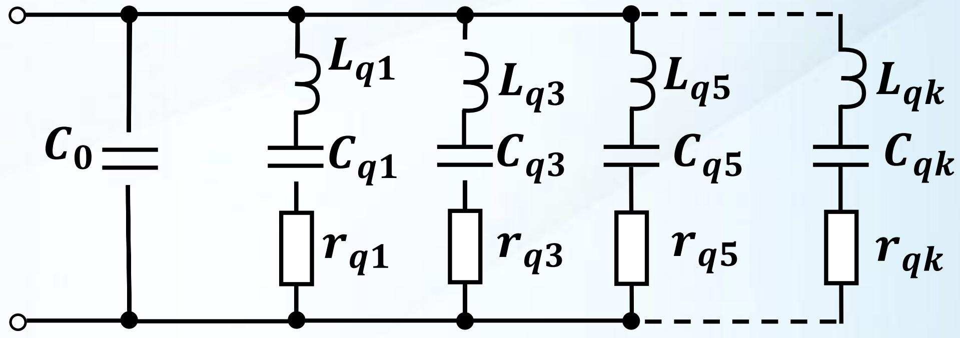
(a)Symbol (b)Basic Frequency ($C_q \ll C_o$) (c)Complete Equivalent Circuit

- Multi-harmonic Crystal
  - Basic Frequency
  - Overtone Frequency → Odd Harmonic Frequency

Quartz Crystal – Equivalent Circuit



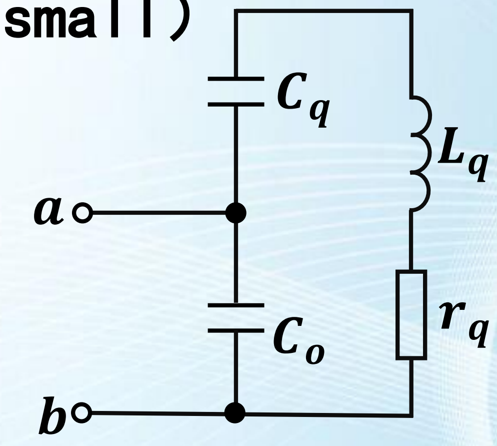
(a)Symbol (b)Basic Frequency ($C_q \ll C_o$)



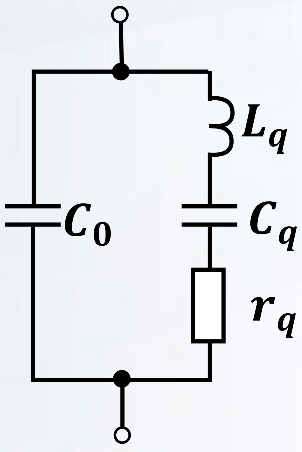
(c)Complete Equivalent Circuit

- $Q = \frac{1}{r_q}\sqrt{\frac{L_q}{C_q}} = \frac{1}{r_q}\rho$ Huge (L_q very big , C_q & r_q very small)
- $p = C_q/(C_o + C_q)$ Tiny ($C_q \ll C_o$)

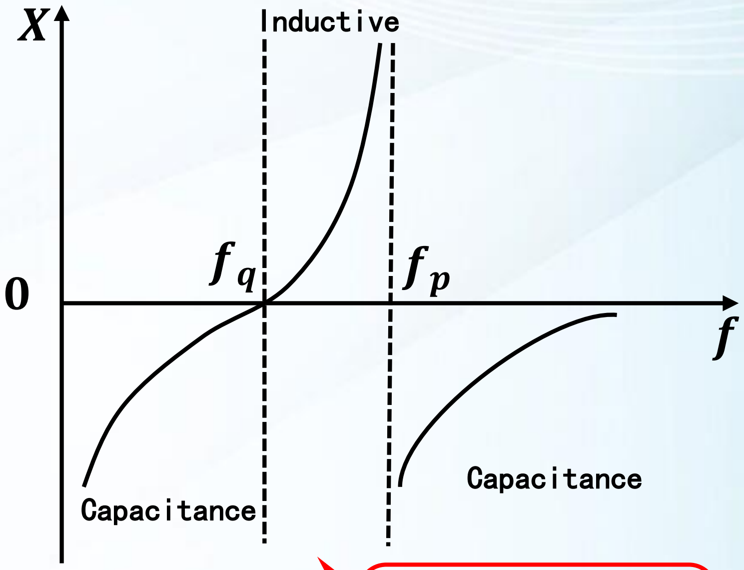
  → little effect on quartz crystal circuit



Quartz Crystal – Frequency



(b)Basic Frequency
$(C_q \ll C_o)$



$f_p \approx f_q$
Narrow

- Equivalent Circuit Frequency

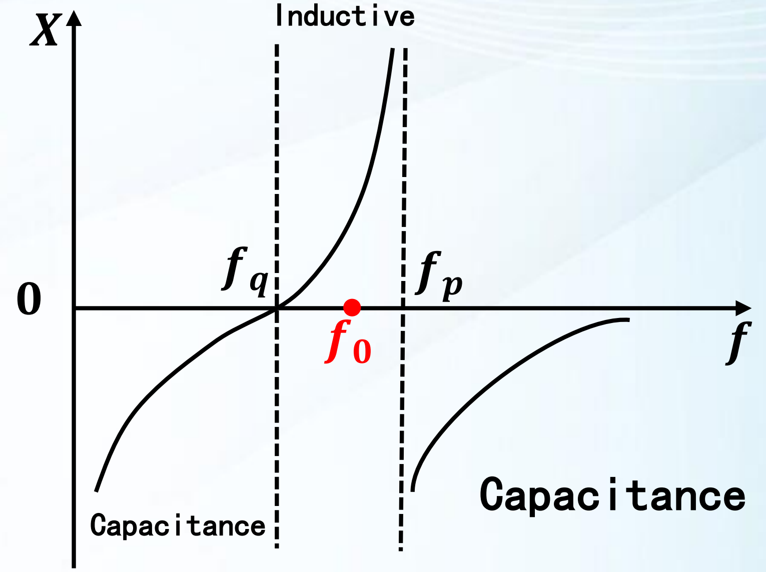
Series Resonance Frequency:

$$f_q = \frac{1}{2\pi\sqrt{L_q C_q}}$$

Parallel Resonance Frequency:

$$f_p = \frac{1}{2\pi\sqrt{L_q \frac{C_q C_0}{C_0 + C_q}}} = \frac{f_q}{\sqrt{\frac{C_0}{C_0 + C_q}}} = f_q\sqrt{1 + \frac{C_q}{C_0}}$$

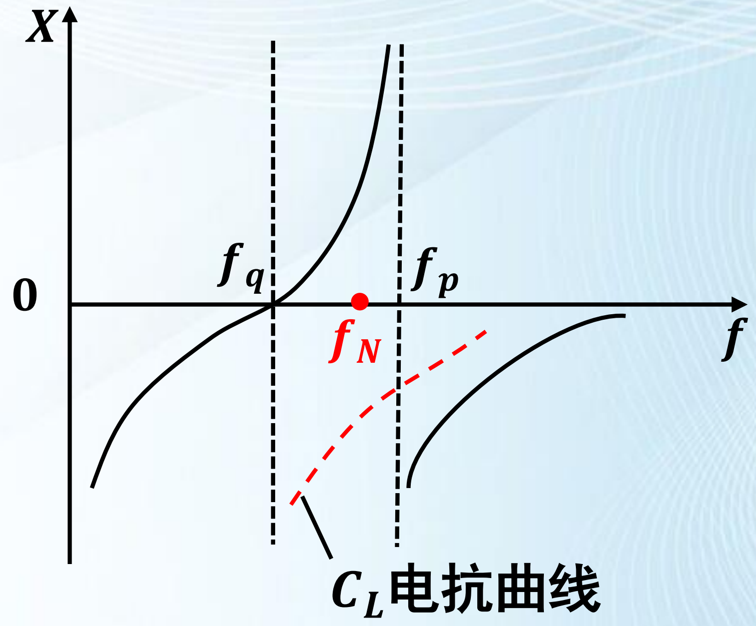
Quartz Crystal – Stable Frequency

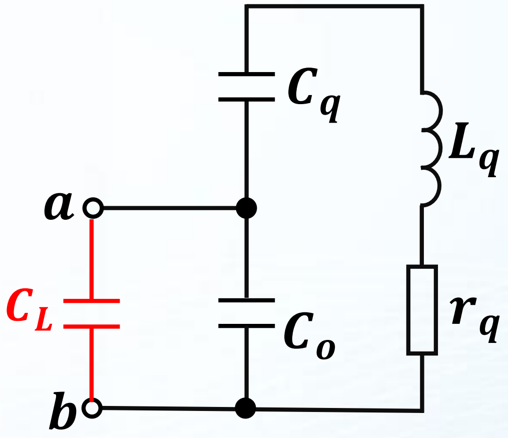


- $f_q \sim f_p$ inductive range:
  - Sharp curve, very big slope: $f_0 \uparrow \rightarrow$ Equivalent $L \uparrow$
  - $f_0 = \frac{1}{2\pi\sqrt{LC}}$: $L \uparrow \rightarrow f_0 \downarrow$

Nominal Frequency f_N with C_L

- Nominal Frequency f_N
  - With Load Capacitor C_L
- Load Capacitor C_L
  - Equivalent Capacitance between ab
  - C_L curve – red dashed line





Oscillators Classification

- Feedback
  - *RC* Oscillator
  - *LC* Oscillator
    - Coupling Oscillator
      - Base-based
      - Emitter-based
      - Collector-based
    - *LC* Oscillator
      - Inductor Feedback (Hartley)
      - Capacitor Feedback(Coplitts)
      - Series Improved Capacitor(Clapp)
      - Parallel Improved Capacitor(Selier)
  - Crystal Oscillator
    - Pierce
    - Overtone Crystal
    - Series Crystal
    - Series Crystal (Example)
    - Miller
- Negative-Resistance

Pierce, Overtone Crystal, Series Crystal: Capacitor Feedback Crystal

Series Crystal (Example), Miller: Inductor Feedback Crystal

Pierce Oscillator

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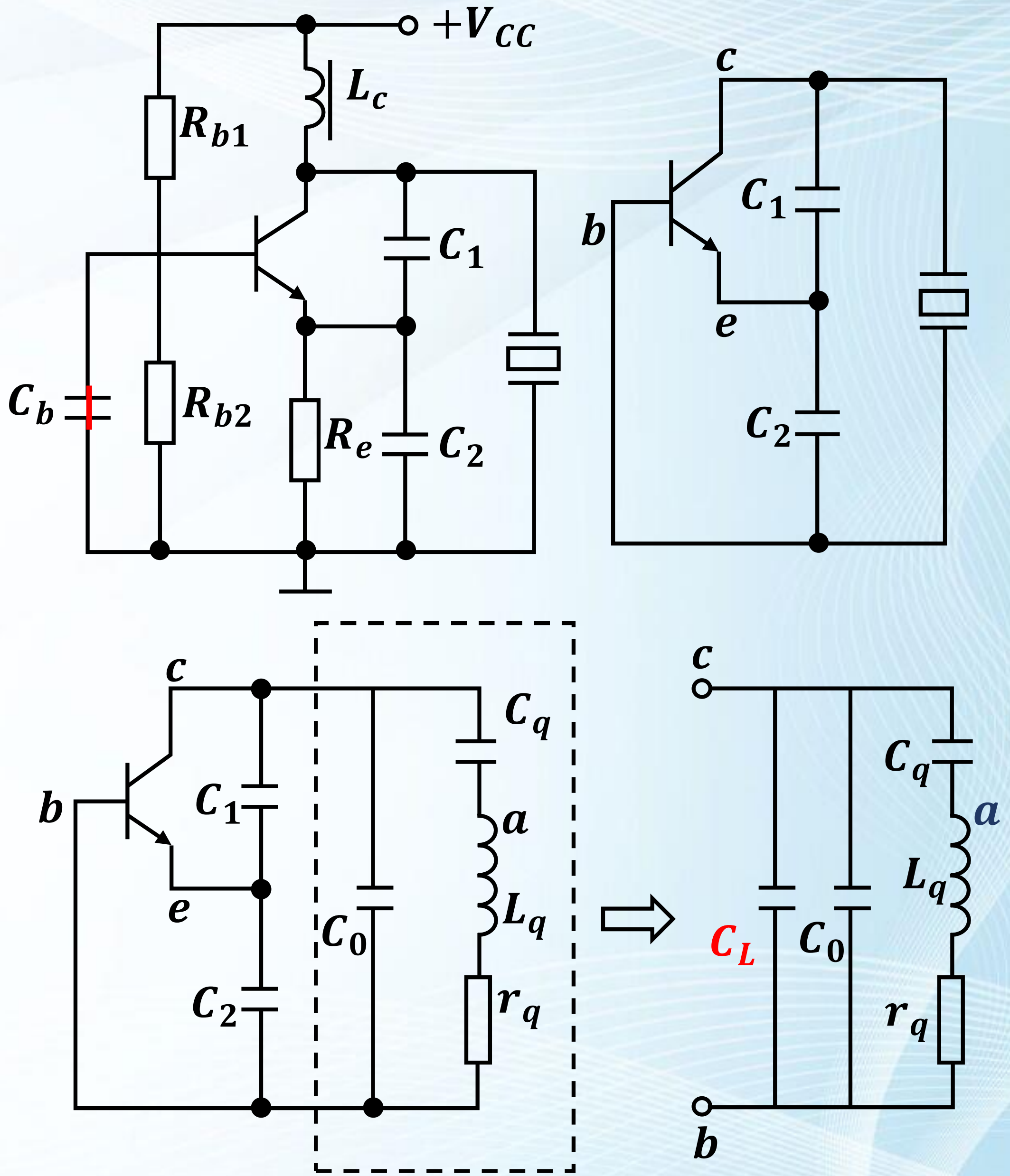
Pierce Oscillator

- RF AC Equivalent Circuit Principle
  - Resistor Open: R_{b1}、R_{b2}、R_e
  - Inductor Open: RF Choke L_c
  - Capacitor Short:
    - Bypass Capacitor: None
    - Coupling Capacitor: C_b
    - Power Filter Capacitor: None



$$C_L = \frac{C_1 C_2}{C_1 + C_2}$$

Pierce Oscillator

(1) Weak Coupling

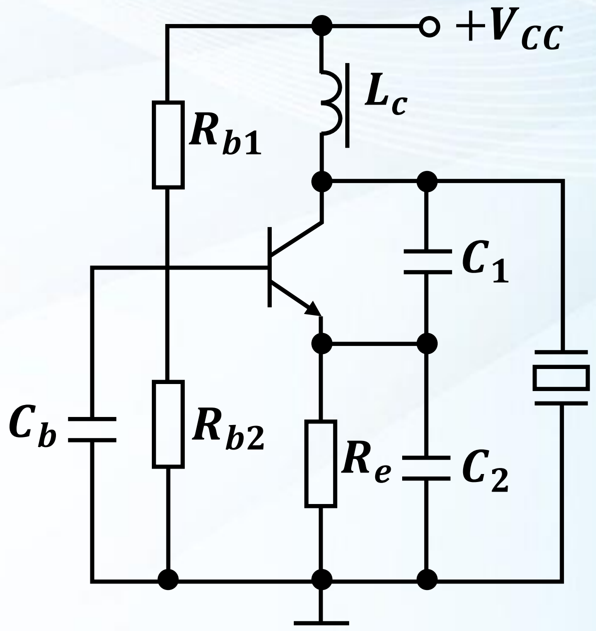
Access Factor:

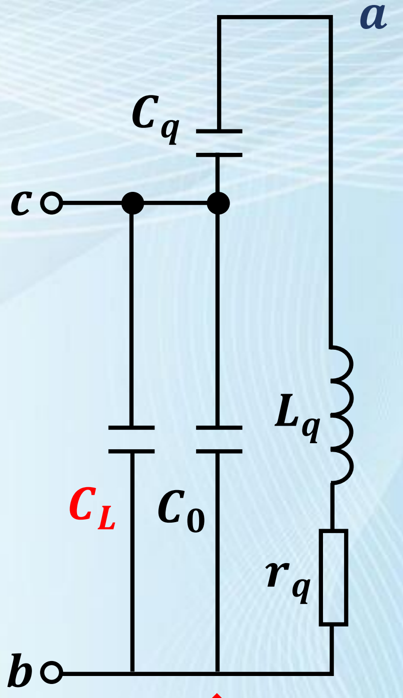
$$p_{cb} = \frac{C_{ab}}{C_{cb}} = \frac{C_q}{C_q + (C_0 + C_L)}$$

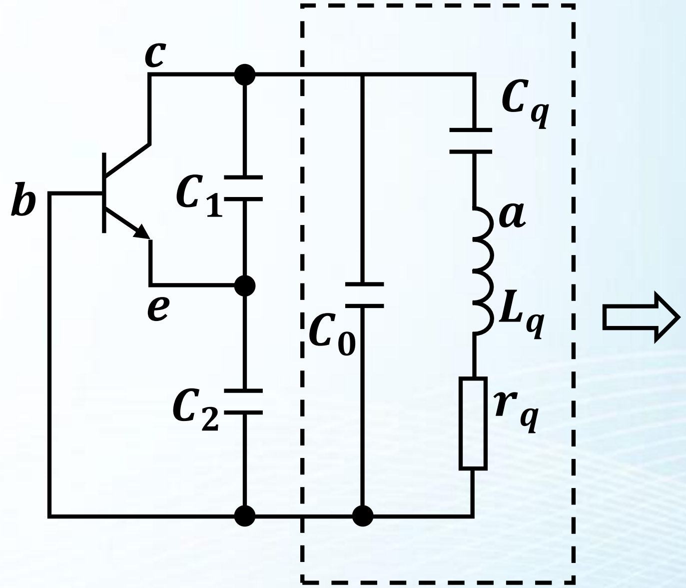
$$\begin{cases} C_{ab} = \dfrac{C_q \cdot (C_0 + C_L)}{C_q + (C_0 + C_L)} \approx C_q \\ C_{cb} = (C_0 + C_L) \end{cases}$$

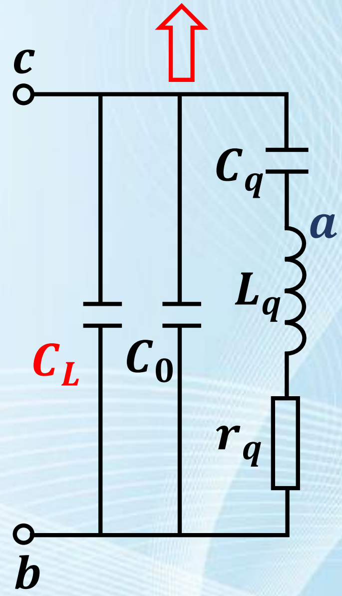
$C_q + C_0 + C_L \gg C_q \rightarrow p_{cb} \downarrow\downarrow$, around 10^{-4}

Stability ↑↑









$$C_L = \frac{C_1 C_2}{C_1 + C_2}$$

Pierce Oscillator

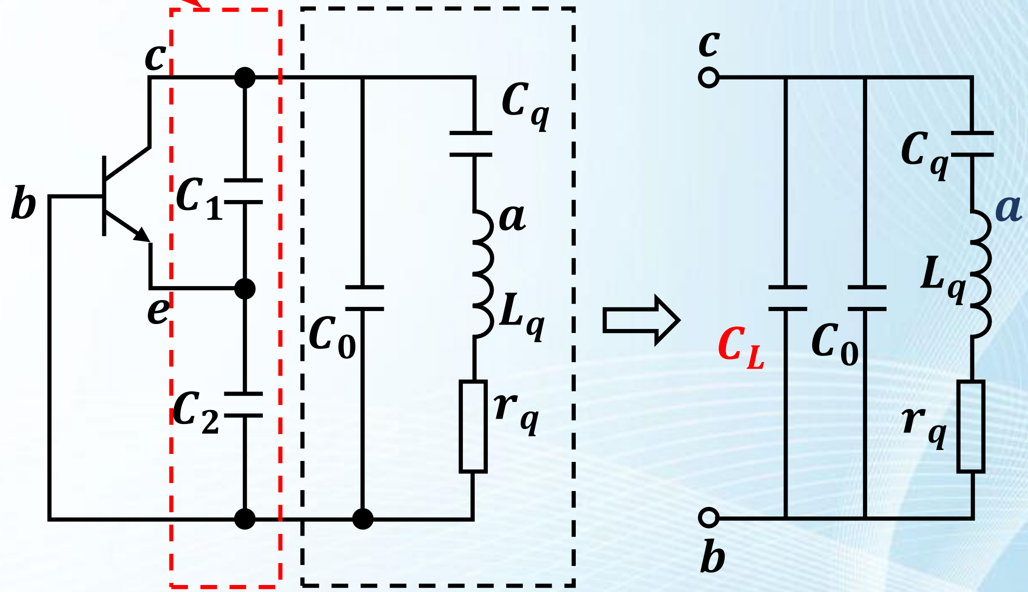
(2) f_0 determinded by quartz crystal, which is stable

$$f_0 = \frac{1}{2\pi\sqrt{L_q \dfrac{C_q(C_0 + C_L)}{C_q + (C_0 + C_L)}}}$$

Load Capacitor $C_L = \frac{C_1 C_2}{C_1 + C_2}$

Note: outside crystal

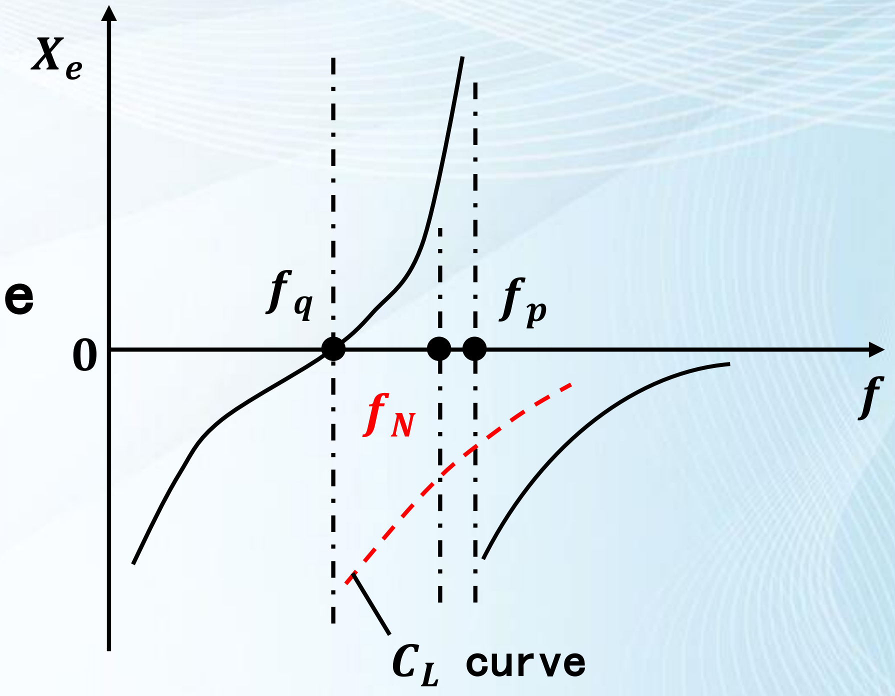
$$C_L = \frac{C_1 C_2}{C_1 + C_2}$$



$$C_L = \frac{C_1 C_2}{C_1 + C_2}$$

Pierce Oscillator

(3) $f_0 = f_N$, inductive, sharp curve, stable



(4) $Q \uparrow\uparrow$ $\rho \uparrow\uparrow$ → $R_p \uparrow\uparrow$ $(\geq 10^{10}\Omega)$

Even if access factor is very small, equivalent R_p is still big

→ Startup condition is easily satisfied

Miller Oscillator

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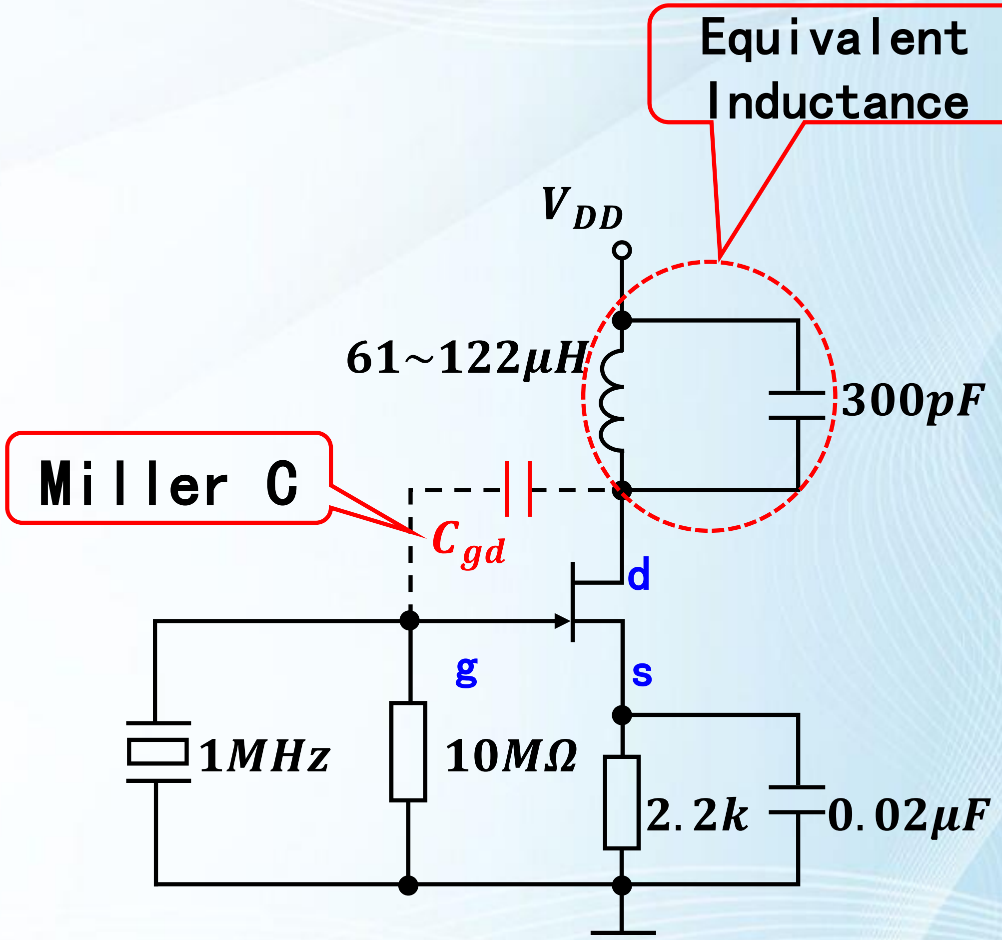
Pierce, Overtone Crystal, Series Crystal: Capacitor Feedback Crystal

Series Crystal (Example), Miller: Inductor Feedback Crystal

Miller Oscillator

- Inductance Feedback Oscillator
  - Crystal → Inductor
  - LC Parallel Resonance→ Inductor
  - C_{gd}→ Capacitor

- Reason using MOS FET:
  - R_i high, Stable



Miller Oscillator

Overtone Crystal Oscillator

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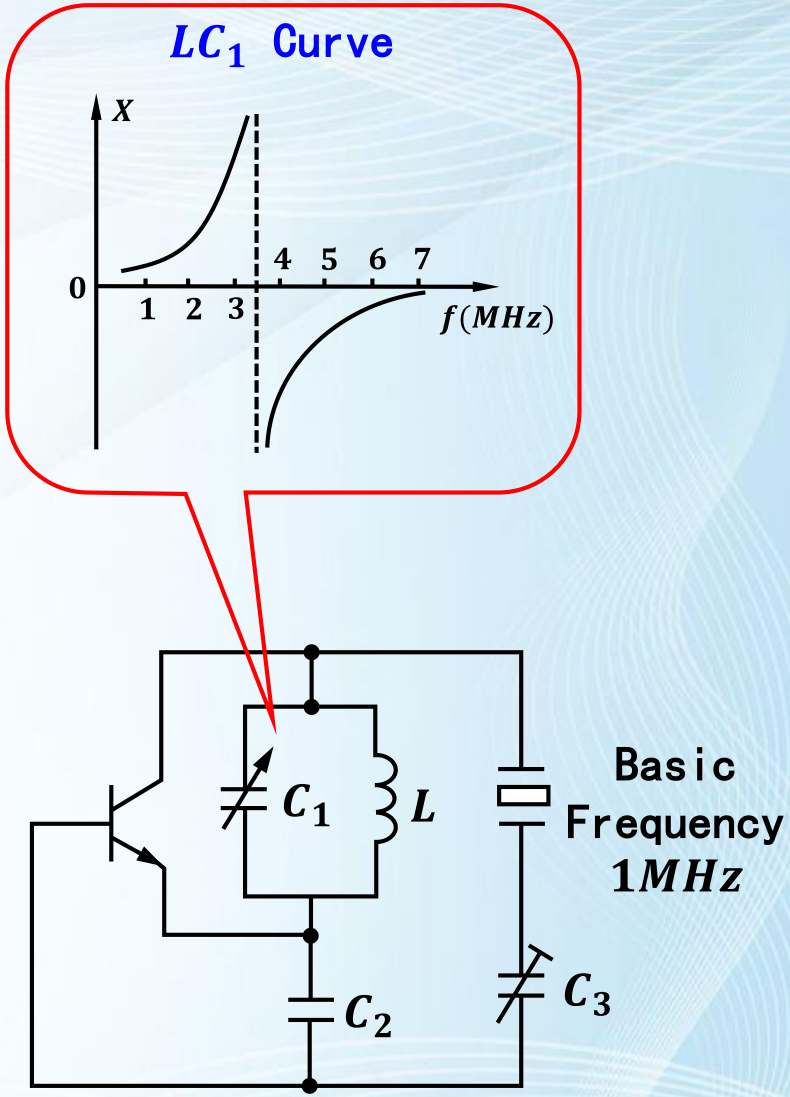
Overtone Crystal Oscillator

➢ C_2 Capacitive → LC_1 Capacitive

✕ 1M & 3M Overtone: LC_1 Inductive → no startup

✕ ≥7M Overtone: LC_1 Capacitive, Capacitance ↓, gain ↓, no startup

√ $5MHz$: LC_1 Capacitive, can startup



Overtone Crystal Oscillator

Series Crystal Oscillator

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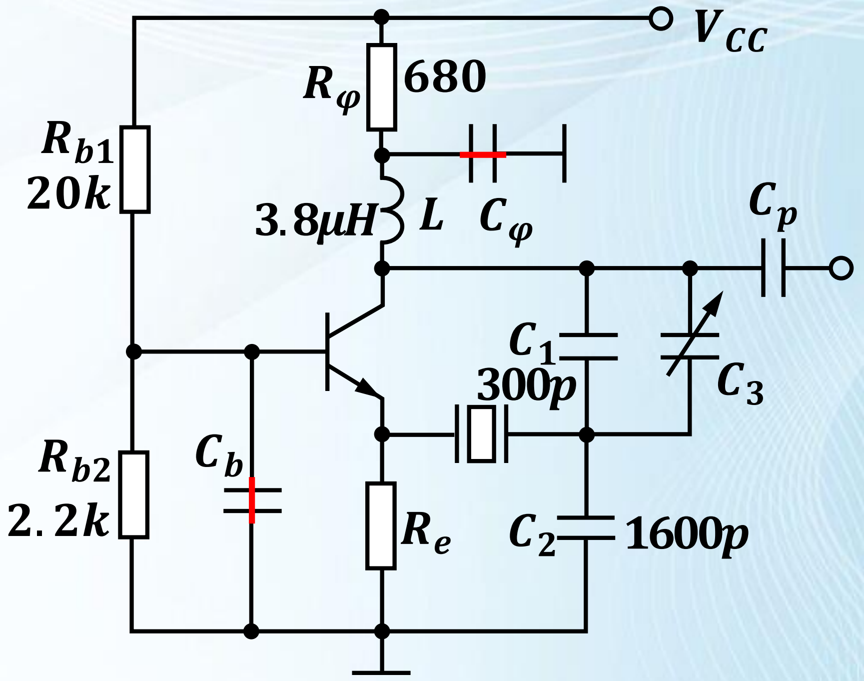
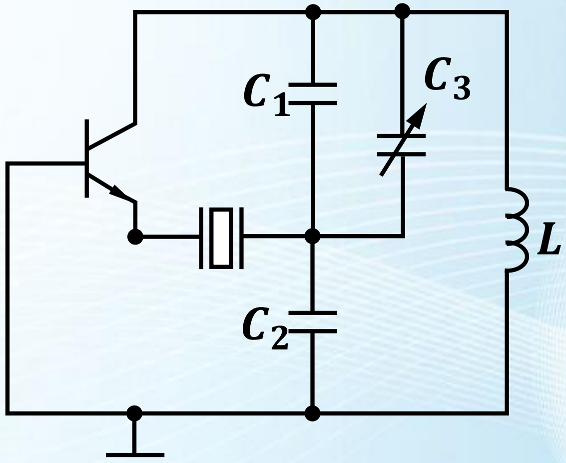
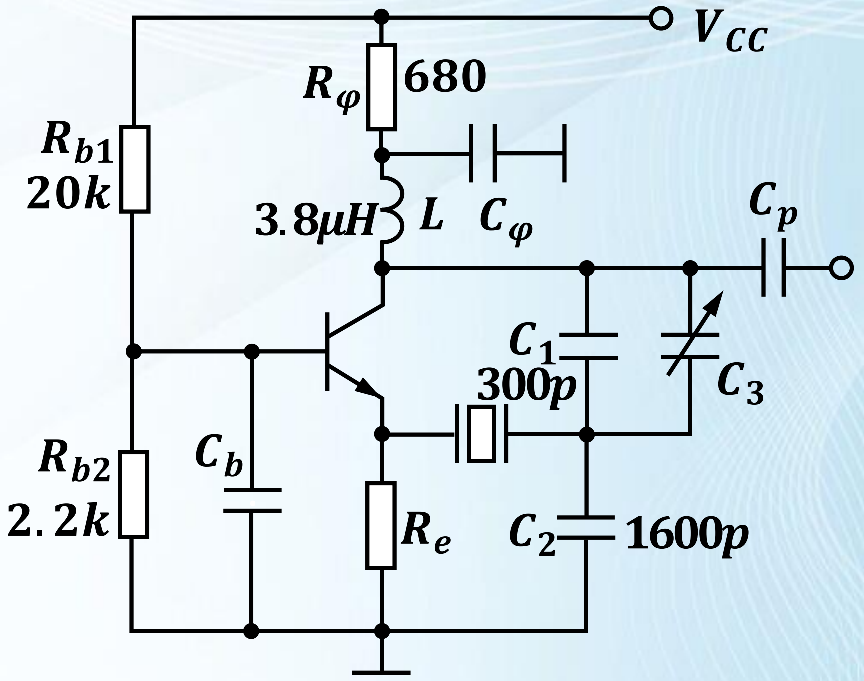
Series Crystal Oscillator

- RF AC Equivalent Circuit Principle
  - Resistor Open: R_{b1}、R_{b2}、R_e、R_φ
  - Inductor Open: No RF Choke
  - Capacitor Short:
    - Bypass Capacitor: None
    - Coupling Capacitor: C_b
    - Power Filter Capacitor: C_φ



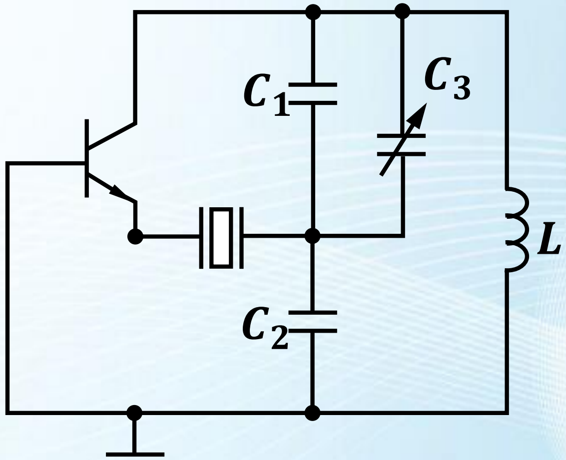


Series Crystal Oscillator



- Quartz Crystal: Short（f_q）
- Capacitive Feedback Oscillator

Q: Inductive Feedback Oscillator?



Example

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Series Crystal (Example), Miller: Inductor Feedback Crystal

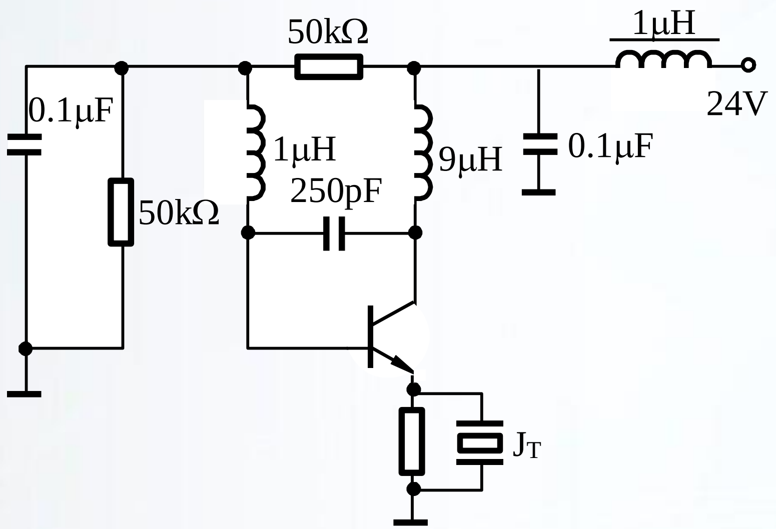
Exp.

The crystal oscillator is as figure. J_T=5MHz

(1) Draw the equivalent circuit & determine the classification.

(2) Compute the oscillator frequency.

(3) Analyze the crystal function.



Exp.

The crystal oscillator is as figure. J_T=5MHz

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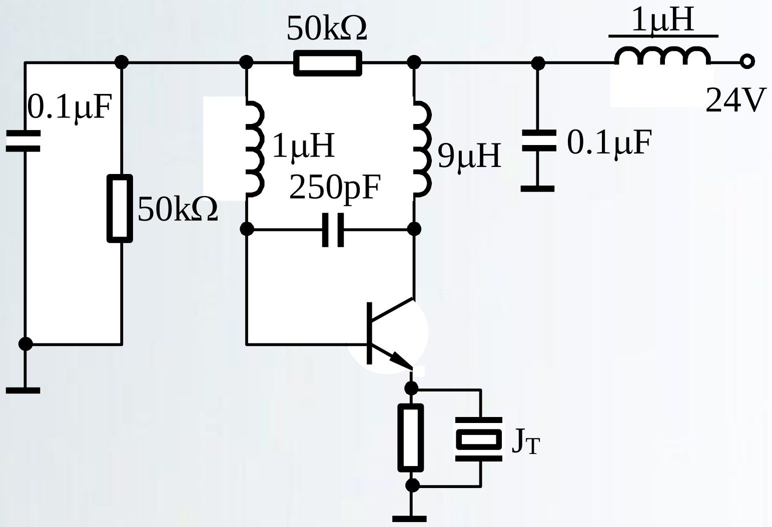

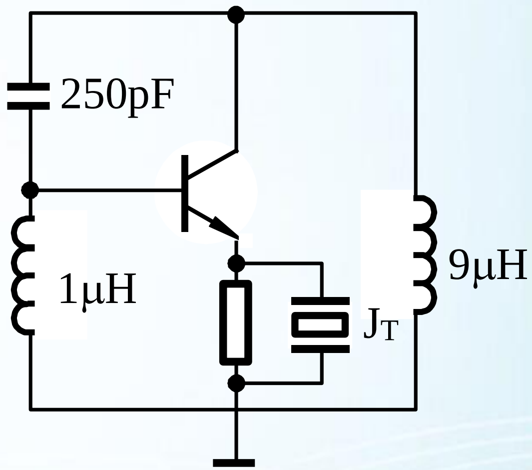

Inductive Feedback Crystal Oscillator
In Series Mode