Huazhong University
of Science & Technology

Electronic Circuit of Communications

School of Electronic Information
and Commnications

Jiaqing Huang

FM Circuits

FM Circuit - Classification

FM

$\Delta v \Rightarrow \Delta f$

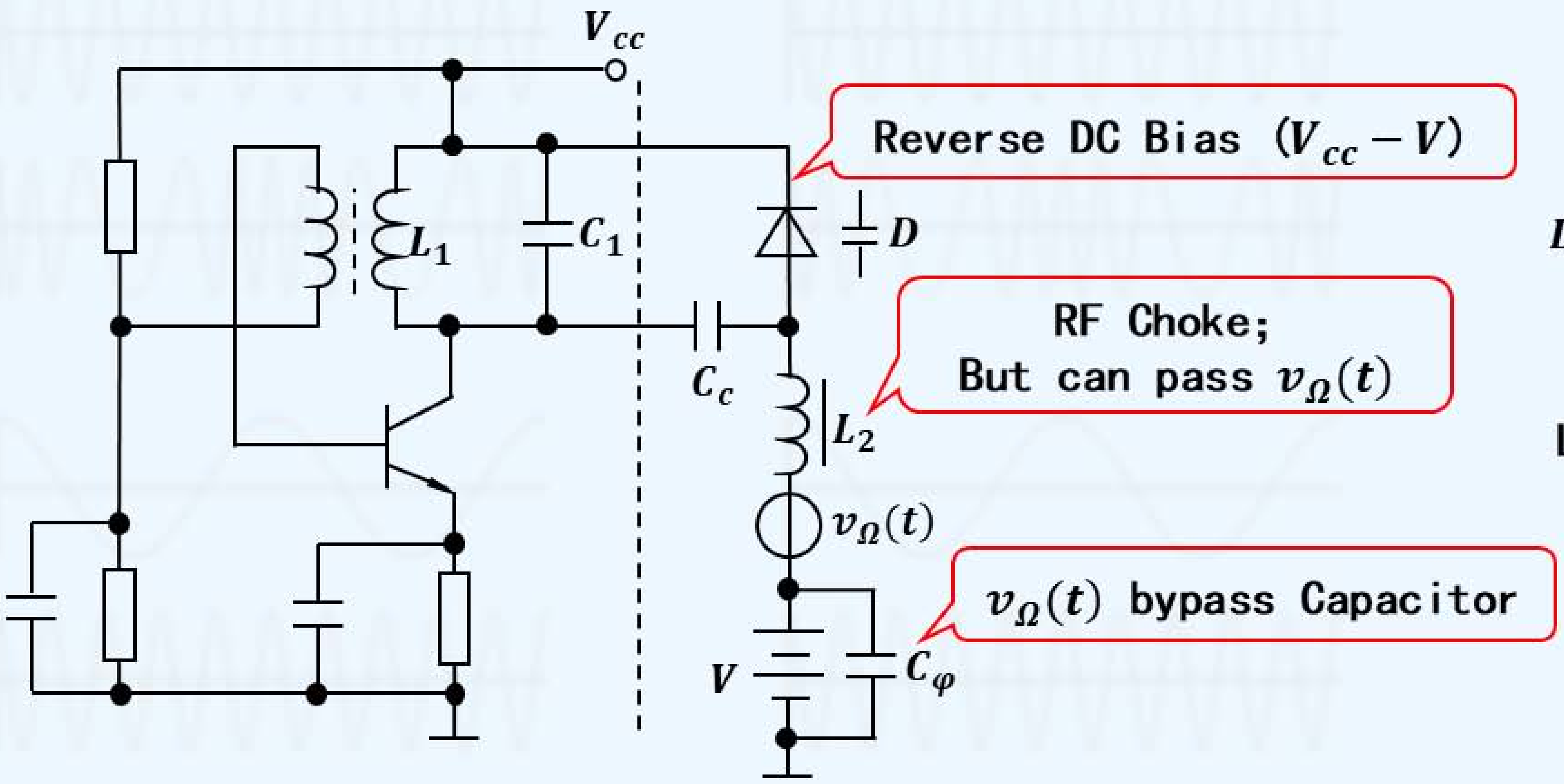
Direct FM

Indirect FM（$PM \rightarrow FM$）

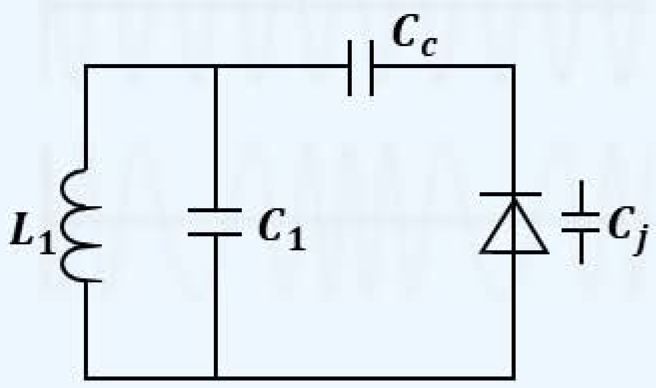
Direct FM Circuits

Modulating → ΔC + Oscillator → Frequency

Direct FM Circuit - Varactor



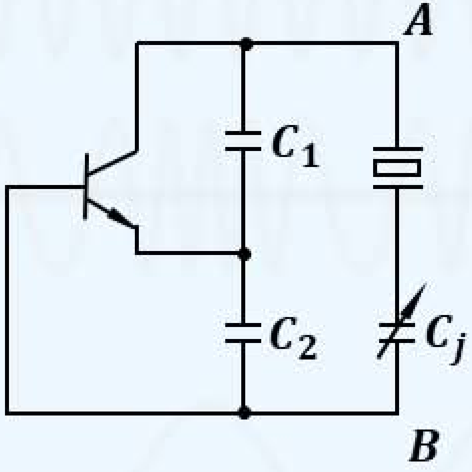
Oscillator + Varactor

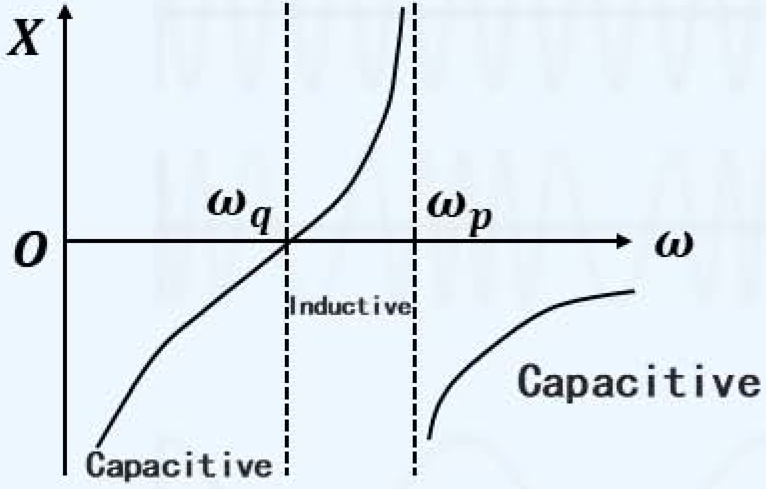


LC Resonance+Varactor

Direct FM Circuit – Crystal Oscillator + Varactor

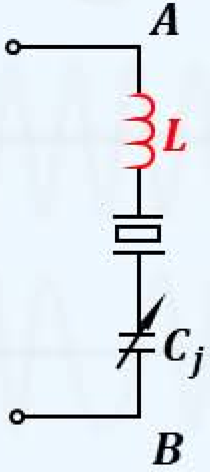
- Crystal Oscillator – Pierce





- Small Δf

- $\uparrow \Delta f \quad \Leftarrow$ Add L



$$\omega_p = \omega_q \sqrt{1 + \frac{C_q}{C_0}} = \omega_q \sqrt{1 + p}$$

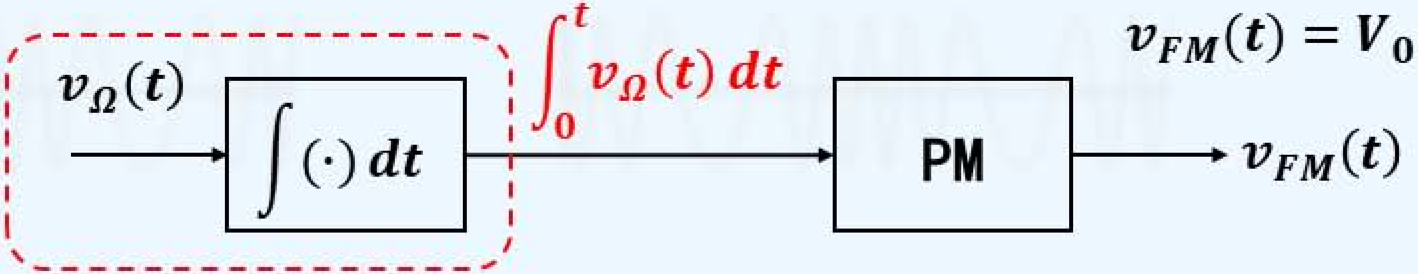
ω_q ω_p Very Close

Indirect FM Circuits

Indirect FM Circuits

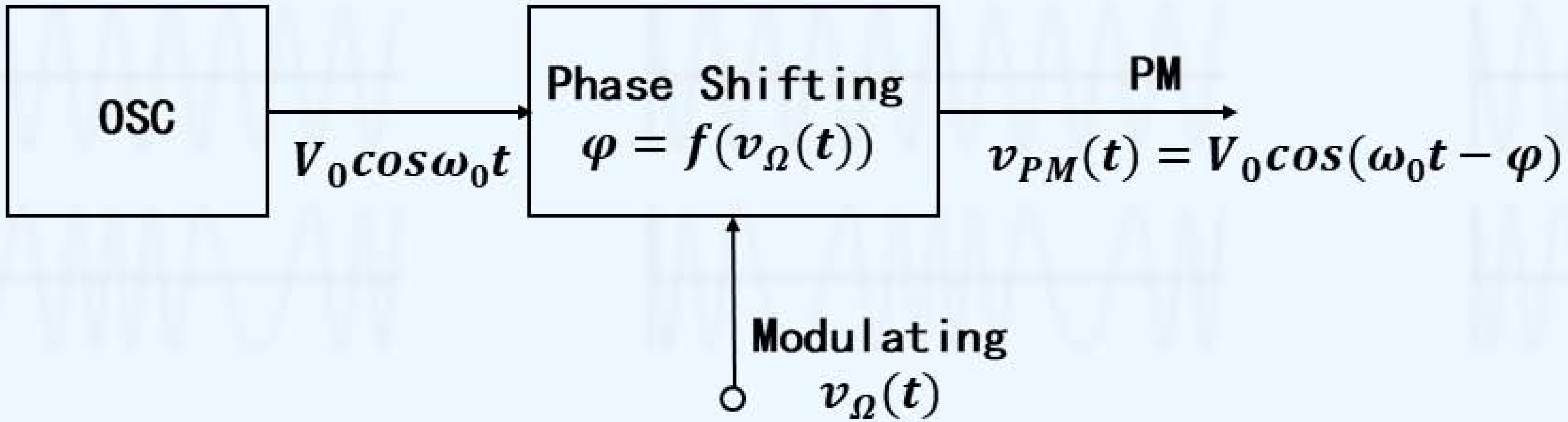
- Modulating signal of PM is $\int_0^t v_\Omega(t)\,dt$

$$v_{FM}(t) = V_0 \cos\left[\omega_0 t + k_f \int_0^t v_\Omega(t)\,dt\right]$$



- PM Method
  - Phase Shifting
  - Time Shifting
  - Vector Synthesis (Armstrong)

PM - Phase Shifting



➢ Single-tone $\quad v_\Omega(t) = V_\Omega cos\Omega t$

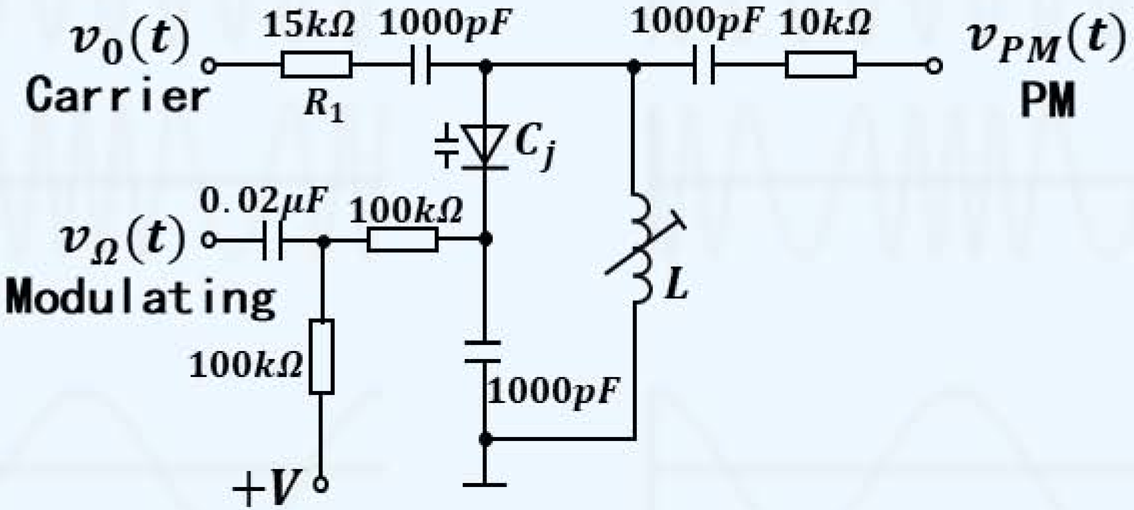
$$\varphi = k_p v_\Omega(t) = k_p V_\Omega cos\Omega t = m_p cos\Omega t$$

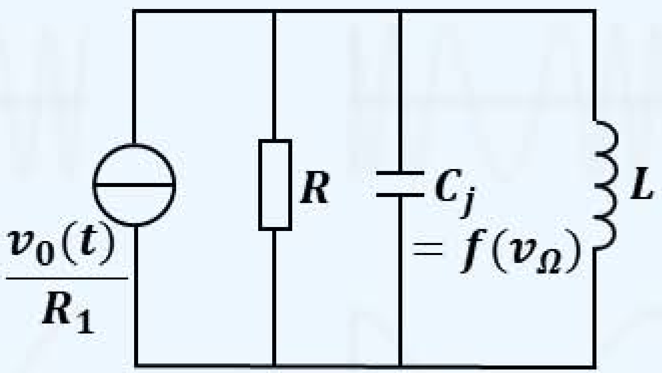
$$v_{PM}(t) = V_0 cos(\omega_0 t - \varphi) = V_0 cos(\omega_0 t - m_p cos\Omega t)$$

➢ Example: RC phase-shift network, LC phase-shift network

PM - Phase Shifting

- Example: Using Varactor

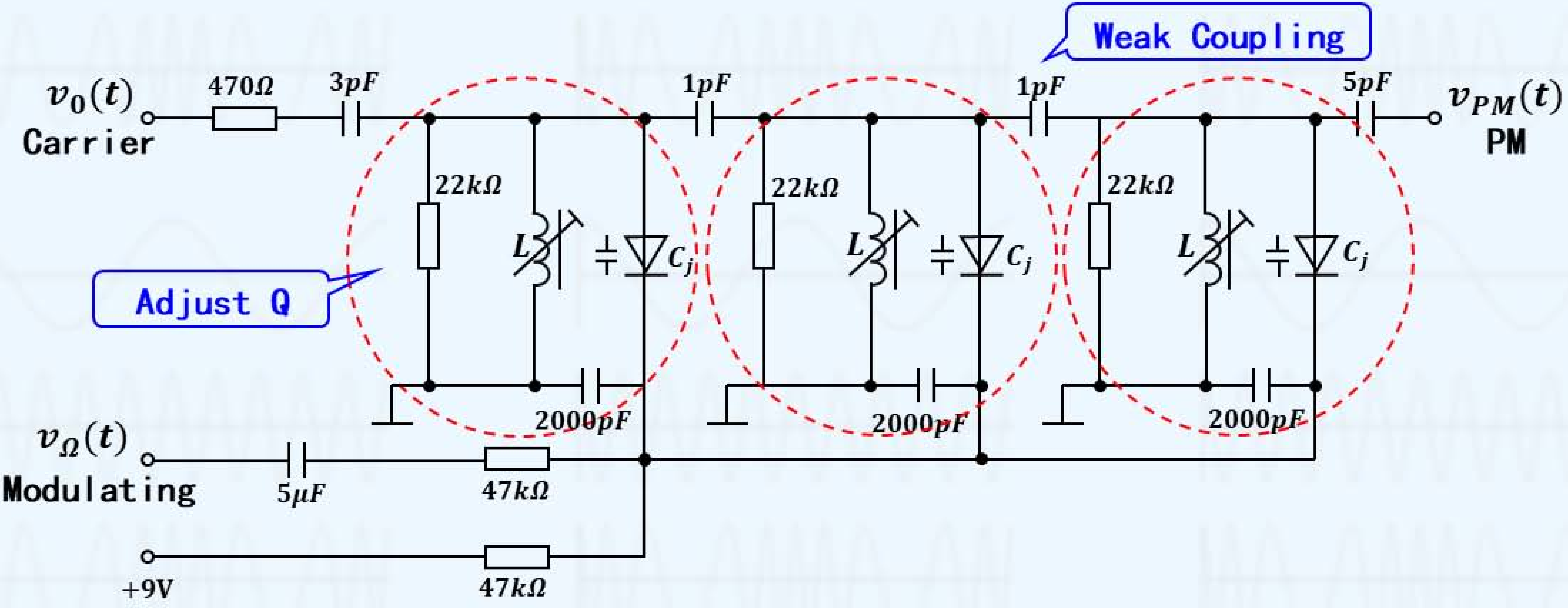




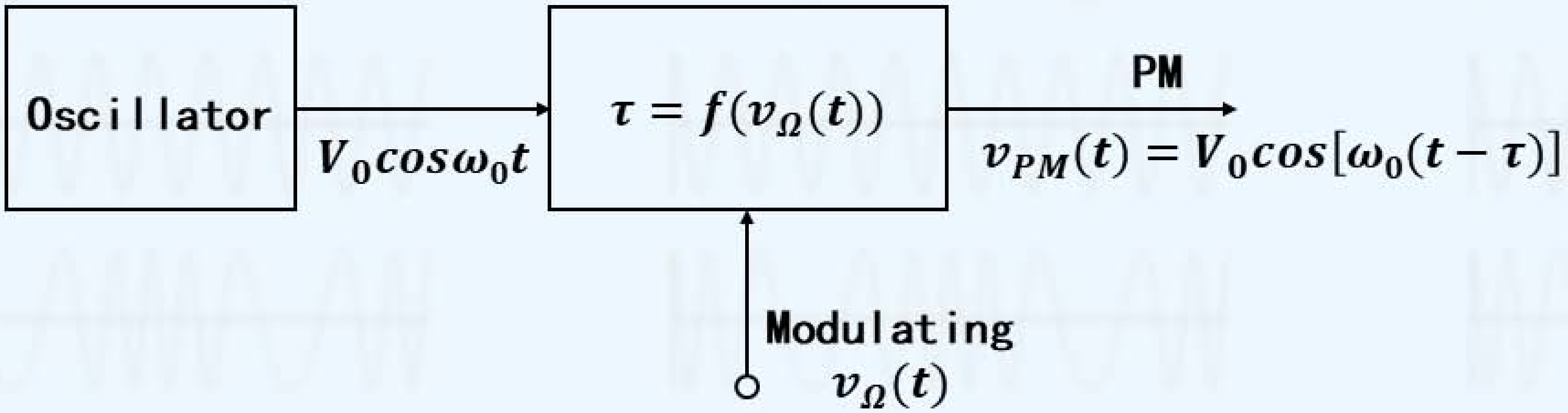
- Principle: $v_\Omega(t) \Rightarrow C_j \Rightarrow f_0{}' \Rightarrow \Delta f(= f_0{}' - f_0) \Rightarrow \Delta\varphi$

PM - Phase Shifting (Continued)

- Phase Shifting < 30°
- Example: 90°



PM - Time Shifting



$$v_\Omega(t) = V_\Omega cos\Omega t$$

$$\tau = \frac{k_p}{\omega_0} v_\Omega(t) = \frac{k_p}{\omega_0} V_\Omega cos\Omega t = \frac{m_p}{\omega_0} cos\Omega t$$

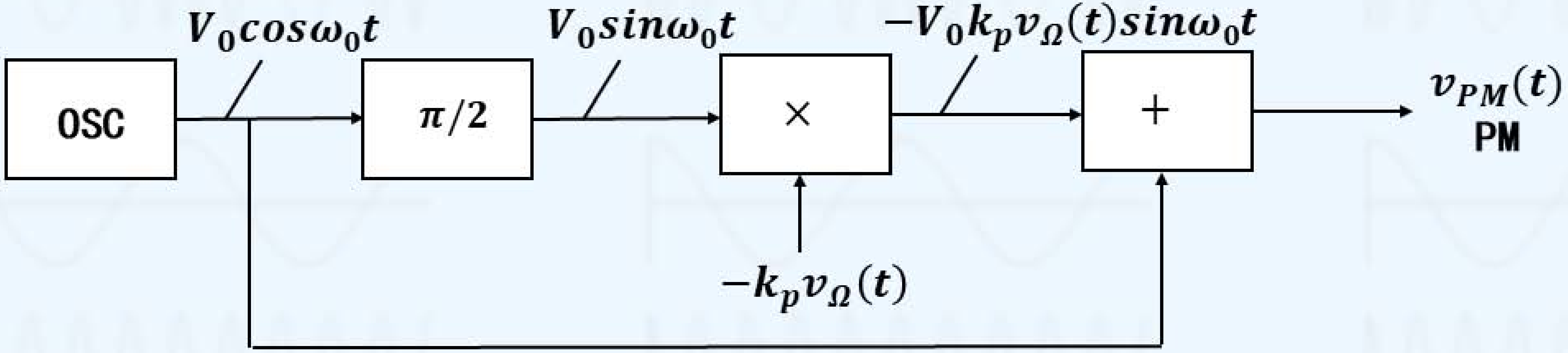
$$v_{PM}(t) = V_0 cos[\omega_0(t-\tau)] = V_0 cos[\omega_0 t - m_p cos\Omega t]$$

- Phase shift $< 144°$

PM - Vector Synthesis (Armstrong)

$\Delta\theta_m$ is small
$\left|k_p v_\Omega(t)\right|_{max} < 30^\circ$

$$
\begin{aligned}
v_{PM}(t) &= V_0 cos\left[\omega_0 t + k_p v_\Omega(t)\right] \\
&= V_0 cos\omega_0 t\, cos\left[k_p v_\Omega(t)\right] - V_0 sin\omega_0 t\, sin\left[k_p v_\Omega(t)\right] \\
&\approx V_0 cos\omega_0 t - V_0 k_p v_\Omega(t) sin\omega_0 t
\end{aligned}
$$



- $\Delta f \downarrow$

Indirect FM Circuits – Improve Δf by Multiplying

- **Multiplying** increases Δf vs. **Mixing**

- Example: If $\Delta f = 50Hz$, $f_0 = 1MHz$

  to implement FM broadcast $\Delta f = 75kHz$, $f_0 = 100MHz$?

- Solution:

  Using Multiplying : $\frac{75kHz}{50Hz} = 1500$

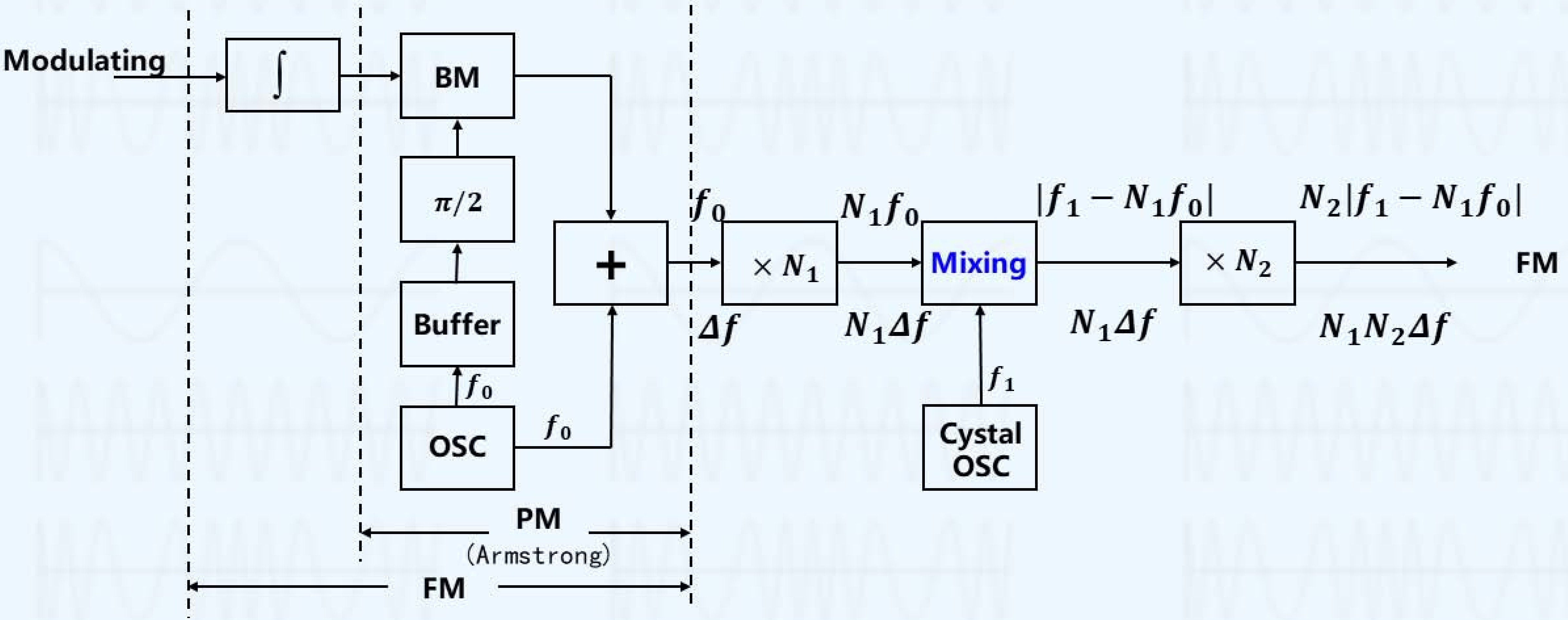
  $f_0 = 1MHz \times 1500 = 1500MHz$

  Using Mixing : $1400MHz$ and $1500MHz$

  obtain $f_0 = 100MHz$

Indirect FM Circuits

➢ Multiplying vs. Mixing



Summary - FM Circuits

- Direct FM
  - OSC + Var Reactance
    - $\Delta f \uparrow$
    - f_0 unstable
  - Crystal OSC+Var Reactance
    - f_0 stable
    - $\Delta f \downarrow$
- Indirect FM
  - f_0 stable （Crystal OSC independent with PM）
  - $\Delta f \downarrow$

Improve Δf :
Multiplying for Δf
Mixing for f_0

Frequency Discrimination

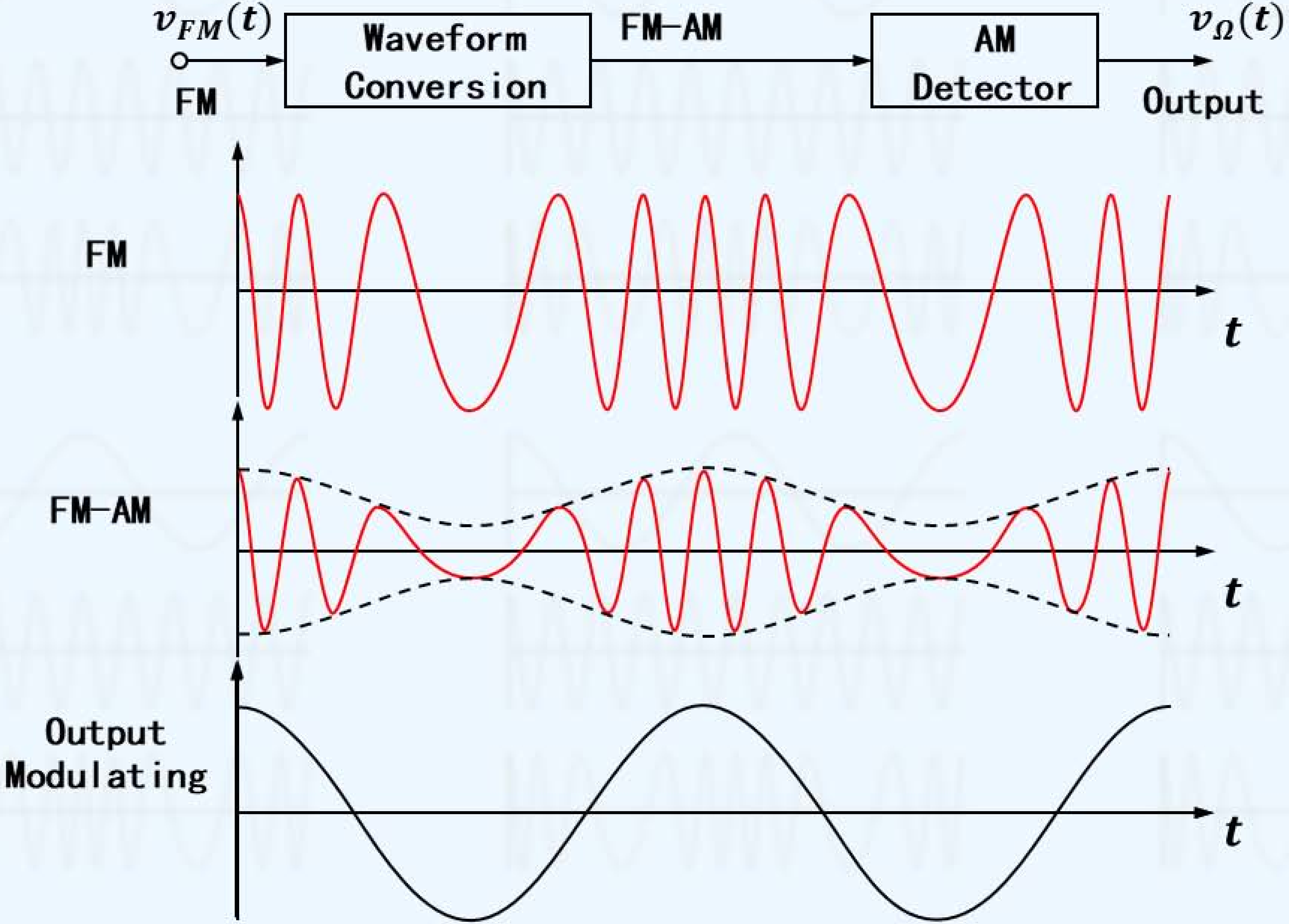
Frequency Discrimination

FD

$\Delta f \Rightarrow \Delta v$

- Waveform Conversion（$FM \rightarrow FM\text{-}AM$）
- Frequency Synthesis（$FM \rightarrow FM\text{-}PM$）
- Pulse Counting Discrimination
- PLL Frequency Discrimination

FD - Waveform Conversion ($FM \rightarrow FM\text{-}AM$)



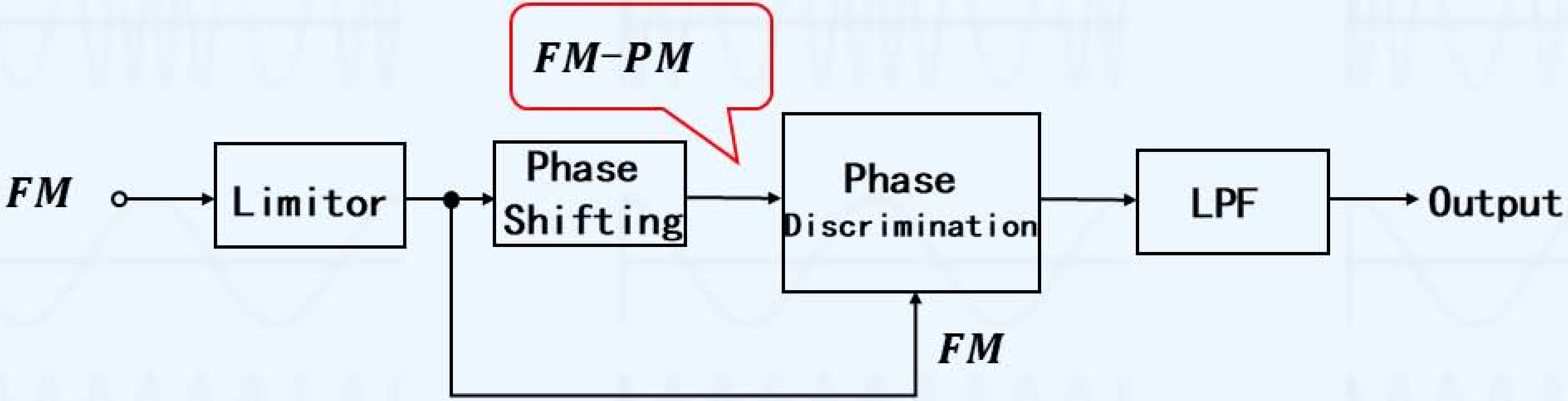
➢ Example:

PD

Ratio FD

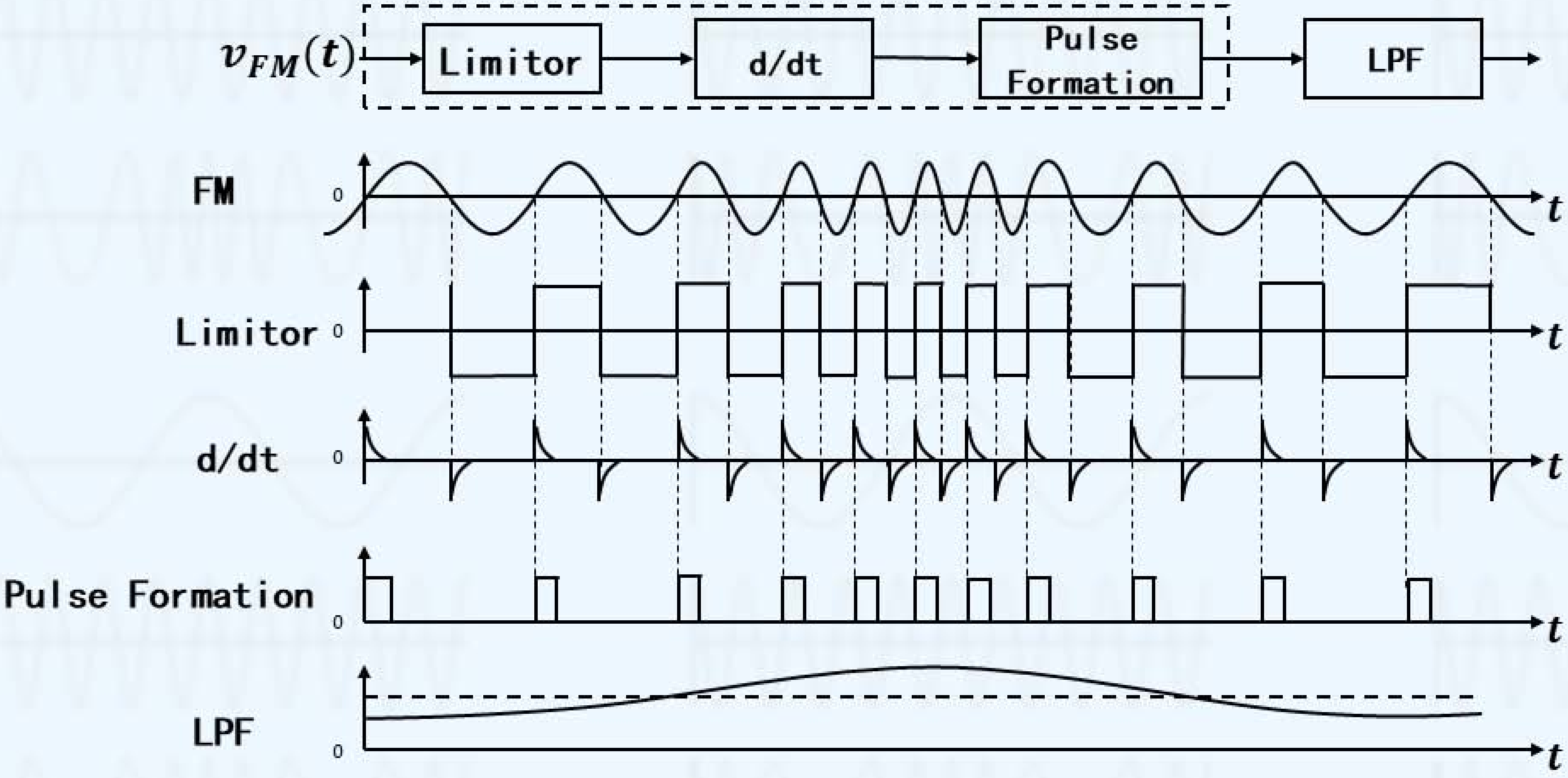
Slope FD

PD - （$FM \rightarrow FM\text{-}PM$）



PD – Pulse Counting Discrimination

- Principle: detect zero-cross points



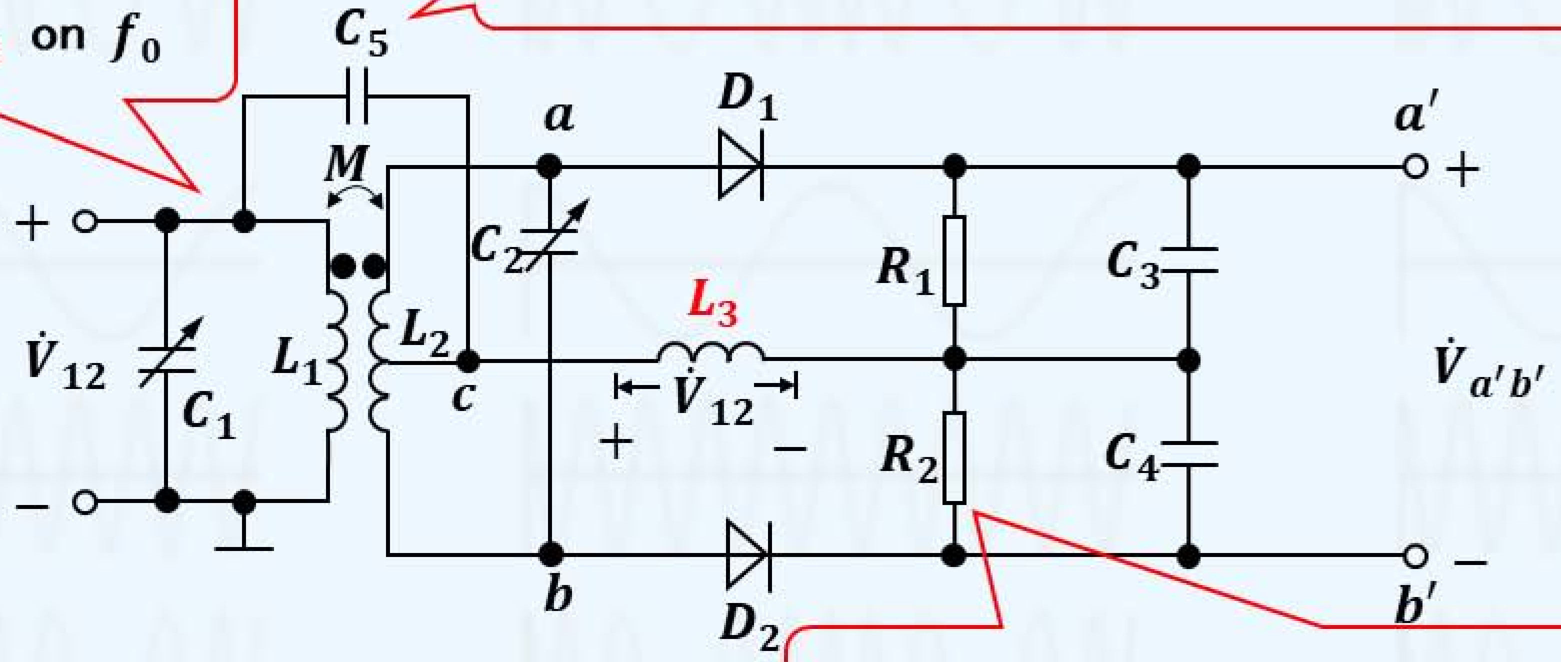
Phase Frequency Discrimination

Phase FD

- Principle: Waveform Conversion （$FM \rightarrow FM$-AM） + Envelope Detection
- C_5 to RF choke L_3

C_1、L_1 & C_2、L_2 on f_0

Capacitance of C_5 & $C_3\,C_4 \ll$ Inductance of L_3



LPF: Capacitance of $C_3\,C_4 \ll R_1\,R_2$

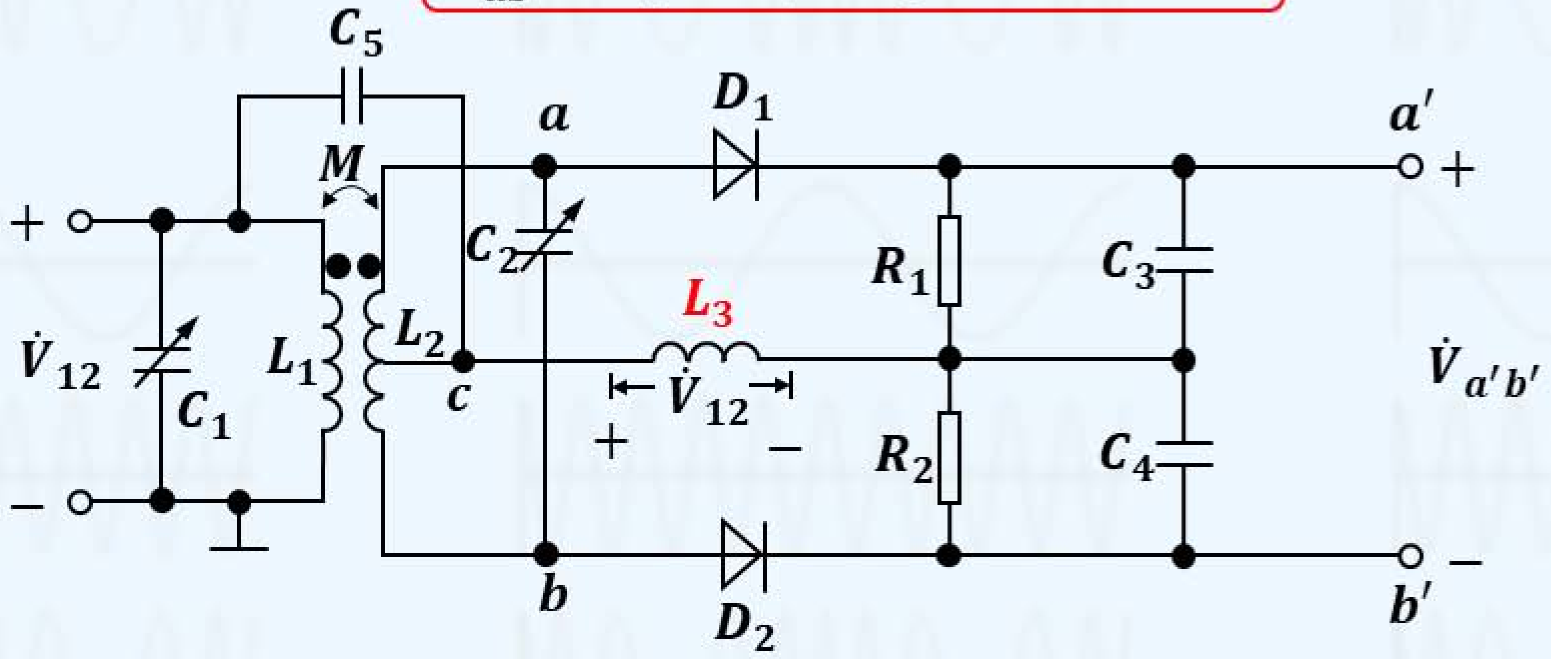
Phase FD

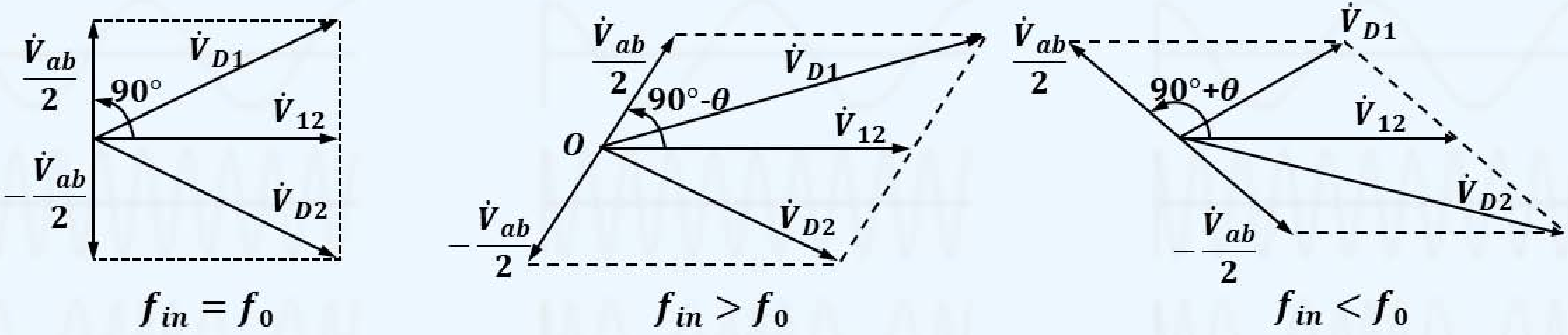
$\dot{V}_{12}$ on $L_3 \Rightarrow$ Direct input signal

$$\left.\begin{aligned}\dot{V}_{D1} &= \dot{V}_{ac} + \dot{V}_{12} = \frac{1}{2}\dot{V}_{ab} + \dot{V}_{12} \\ \dot{V}_{D2} &= \dot{V}_{bc} + \dot{V}_{12} = -\frac{1}{2}\dot{V}_{ab} + \dot{V}_{12}\end{aligned}\right\} \quad V_{a'b'} = k_d(V_{D1} - V_{D2})$$

k_d of detector

$\dot{V}_{ab} \Rightarrow$ by coupling circuit





$$V_{a'b'} = k_d(V_{D1} - V_{D2})$$

➢ $f_{in} = f_0$， $V_{D1} = V_{D2}$， $V_{a'b'} = 0$

➢ $f_{in} > f_0$， $V_{D1} > V_{D2}$， $V_{a'b'} > 0$

➢ $f_{in} < f_0$， $V_{D1} < V_{D2}$， $V_{a'b'} < 0$

Output $V_{a'b'} \propto \Delta f$

$$\Delta f \propto v_\Omega(t) \quad \Rightarrow \quad \text{Output } V_{a'b'} \propto v_\Omega(t)$$