廣東工業大學
Guangdong University of Technology

广东工业大学

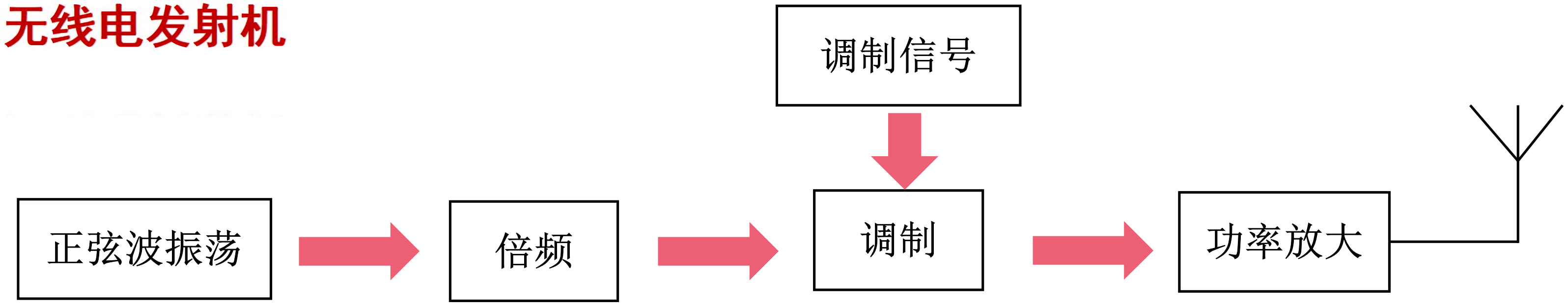
第五章 正弦波振荡器

信息工程学院

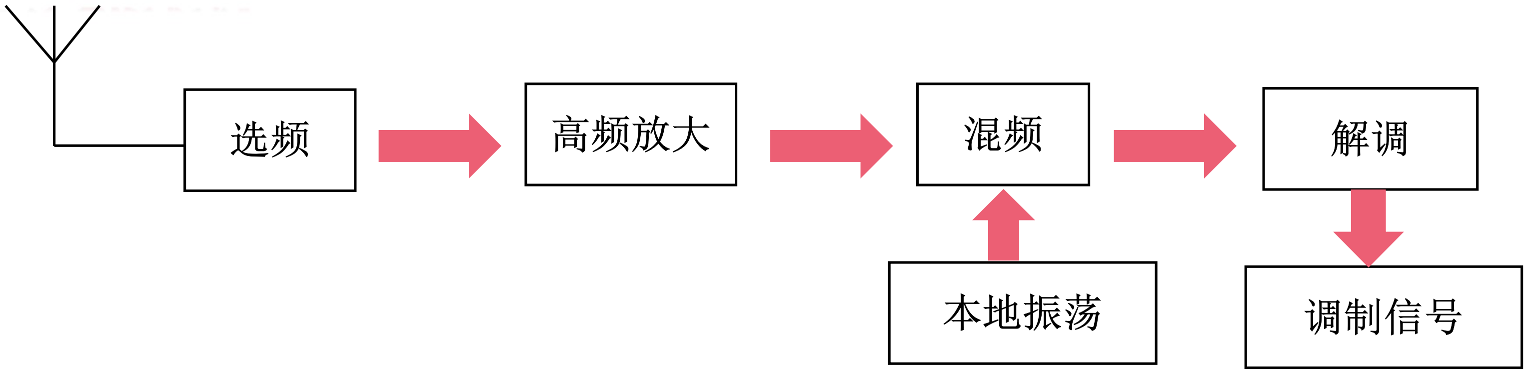
李志忠

目录

无线电发射机



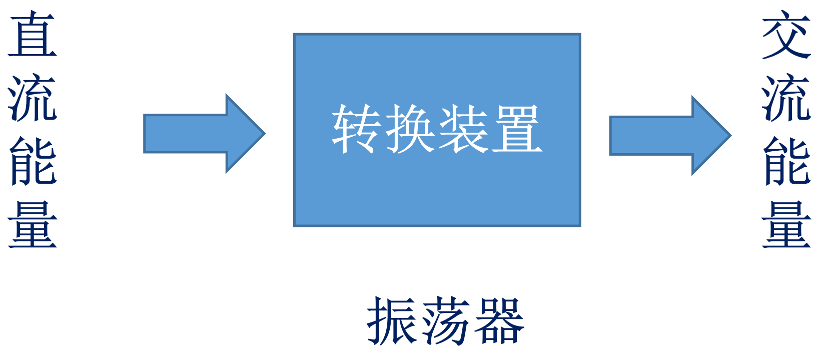
无线电接收机



振荡器？

振荡器（oscillator）：没有输入信号，只有直流电源供电，就可以产生并输出一定波形、一定频率和一定功率的交流信号的电路。

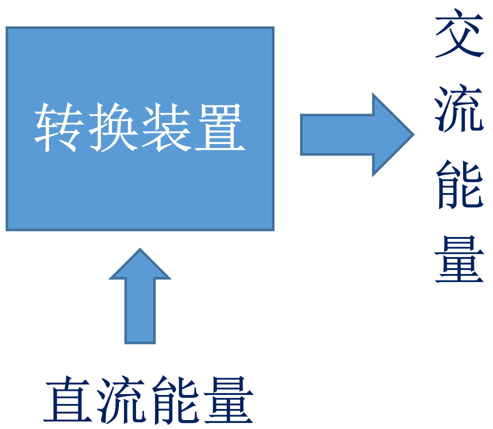
振荡器也可以看作是将直流电源能量转换为交流电能量的装置



振荡器与放大器的区别

振荡器无信号输入

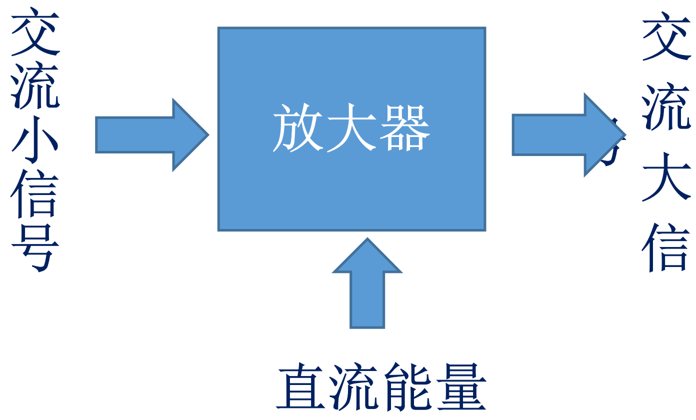
自己产生交流信号



振荡器无中生有

放大器有信号输入

将输入的交流信号放大



放大器照猫画虎

一. Classification

Waveform
- Sine
- Triangular
- Square
- Sawtooth
- 任意波形发生器
  （计算、输入、键盘、鼠标）

Element
- LC
- RC
- Crystal
- Transformer Couple

Principle
- Positive Feedback
- Negative resistance

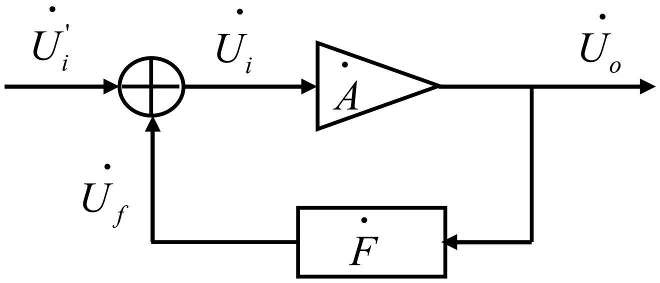
Integration
- Integrated
- Discrete

Use
- Power： MicroWave oven、医疗电子设备
- Frequency : Watch、Carrier Wave 、 Local Oscillator

5.1 反馈式振荡器的工作原理

$\dot{U}_o = \dot{A}\dot{U}_i$ $\qquad\qquad$ $\dot{U}_f = \dot{F}\dot{U}_o$

$\ominus$ $\quad \dot{U}_i = \dot{U}_i' - \dot{U}_f$



$$\dot{U}_o = \dot{A}\left(\dot{U}_i' - \dot{U}_f\right) = \dot{A}\dot{U}_i' - \dot{A}\dot{F}\dot{U}_o$$

$$\therefore \frac{\dot{U}_o}{\dot{U}_i'} = \frac{\dot{A}}{1+\dot{A}\dot{F}}$$

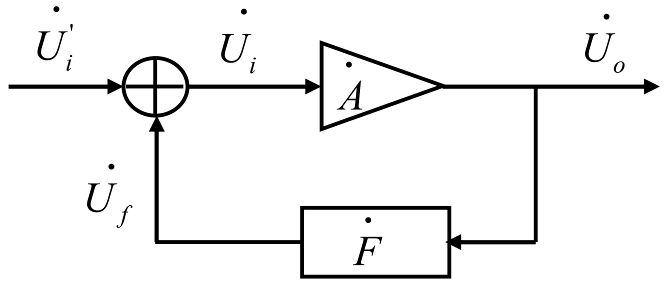
Negative Feedback Amplifier

$\oplus$ $\quad \dot{U}_o = \dot{A}\dot{U}_i' + \dot{A}\dot{F}\dot{U}_o$ $\qquad$ $\therefore \dfrac{\dot{U}_o}{\dot{U}_i'} = \dfrac{\dot{A}}{1-\dot{A}\dot{F}}$

$\dot{A}\dot{F} = 1$ $\qquad\qquad$ $\dfrac{\dot{U}_o}{\dot{U}_i'} = \infty$

5.1.1 平衡条件

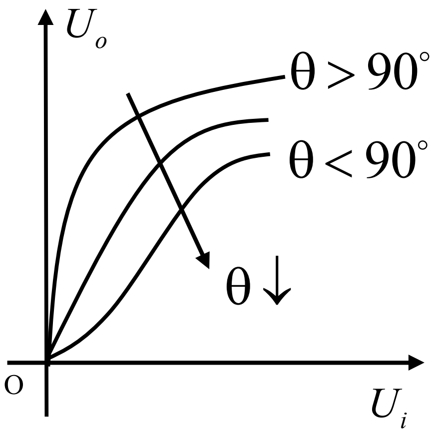
$$\dot{A}\dot{F}=1=\frac{\dot{U}_o}{\dot{U}_i}\cdot\frac{\dot{U}_f}{\dot{U}_o}=\frac{\dot{U}_f}{\dot{U}_i}$$

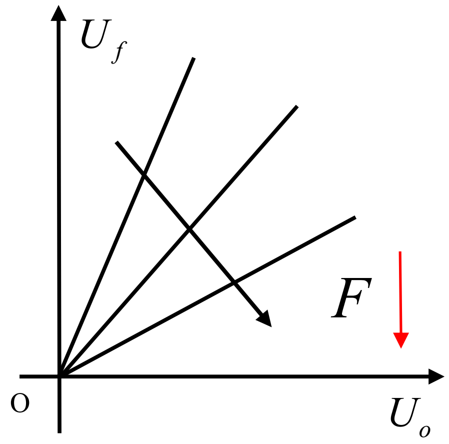


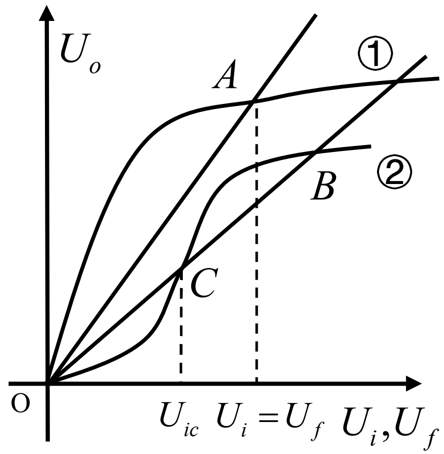
$$\begin{cases}\dot{U}_f=\dot{U}_i\\ \dot{U}_i=\dot{U}_i'+\dot{U}_f\end{cases}\Longrightarrow \dot{U}_i'=0$$

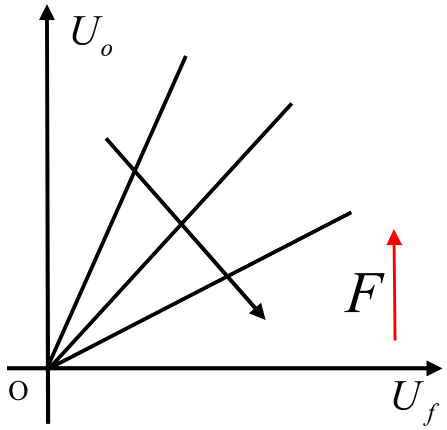
$$\dot{A}\dot{F}=1\Longrightarrow\begin{cases}AF=1\Leftrightarrow U_f=U_i & \text{振幅平衡条件}\\ \varphi_A+\varphi_F=2n\pi,n=0,1,2,\cdots & \text{相位平衡条件}\end{cases}$$

1. 振幅平衡条件





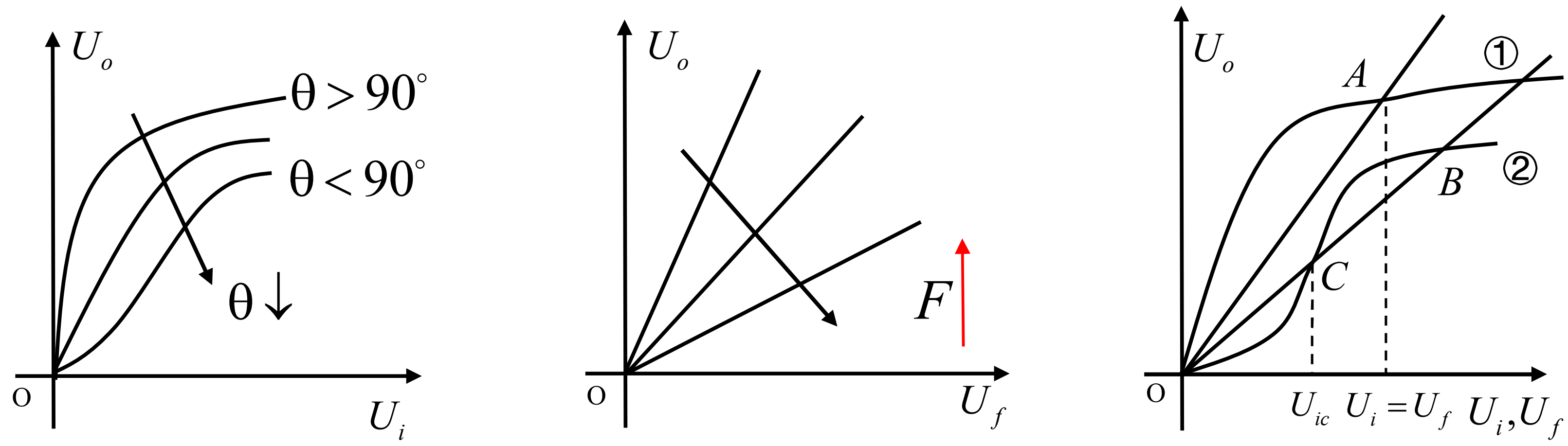




$AF = 1 \Leftrightarrow U_f = U_i$　　振幅平衡条件

振幅平衡条件 ： 反馈电压等于输入电压幅值 ；

$U_f = U_i$ 的点即为满足振幅平衡条件的平衡点，相应的 U_o ，就是振荡器产生的电压振幅



$$\left.\begin{aligned}\dot{U}_o &= \dot{A}\dot{U}_i \\ \dot{U}_o &= \frac{\dot{U}_f}{\dot{F}}\end{aligned}\right\} \qquad \left.\begin{aligned}\dot{A}\dot{F}\dot{U}_i &= \dot{U}_f \\ \dot{U}_i &= \dot{U}_f\end{aligned}\right\} \qquad AF = 1$$

2. 相位平衡条件

$\varphi_A + \varphi_F = 2n\pi$　　反馈电压$\dot{U}_f$与输入电压$\dot{U}_i$同相，即正反馈

$$\dot{U}_o = \dot{I}_L \dot{Z}_L(\omega) = \dot{g}_m \dot{U}_i \dot{Z}_L(\omega)$$

$$A = \frac{\dot{U}_o}{\dot{U}_i} = \frac{\dot{g}_m \dot{U}_i \dot{Z}_L(\omega)}{\dot{U}_i} = \dot{g}_m \dot{Z}_L(\omega) = Ae^{i\varphi_A}$$

$\therefore \varphi_A = \varphi_Y + \varphi_Z$

φ_Y :集电极电流基波分量

φ_Z :负载的相角

$f_0 << f_T$　　$\dot{g}_m = g_m$　　$\varphi_Y = 0$

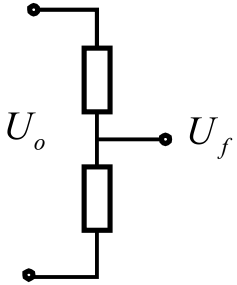
$n = 0$　　$\varphi_A + \varphi_F = 0$　　$\therefore \varphi_A = -\varphi_F$

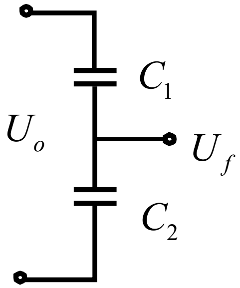
$$\varphi_A + \varphi_F = \varphi_Y + \varphi_Z + \varphi_F = 0$$

若令$\varphi_Y + \varphi_F = \varphi_{YF}$，则 $\varphi_Z = -\varphi_{YF}$

$$\varphi_A + \varphi_F = \varphi_Y + \varphi_Z + \varphi_F = 0 \qquad \varphi_Y + \varphi_F = \varphi_{YF} \qquad \varphi_Z = -\varphi_{YF}$$

φ_F：





$$F = \frac{U_f}{U_o} = \frac{i\dfrac{1}{j\omega c_2}}{i\dfrac{1}{j\omega c_2 // c_1}} = \frac{c_2 // c_1}{c_2} = \frac{c_1}{c_2 + c_1}$$

$\therefore \varphi_F = 0$

一般情况：晶体管少数载流子在通过基区有效宽度时，总需要一定的扩散时间，即I_c总滞后于U_i

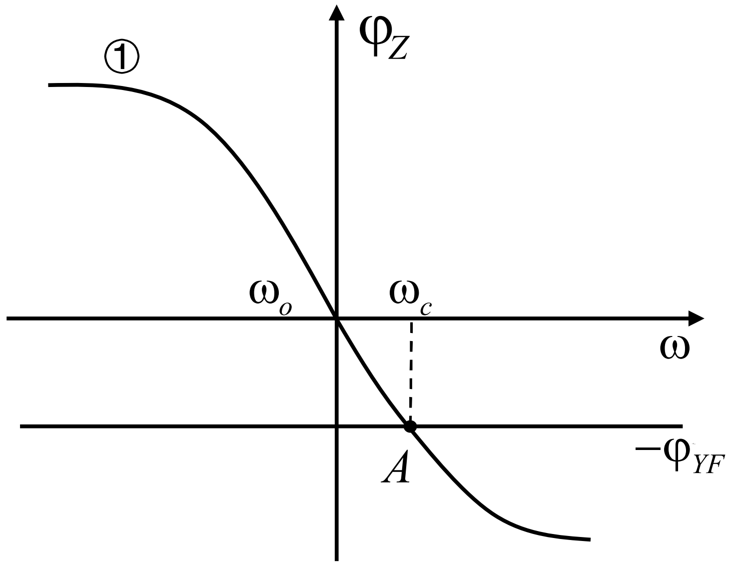
$$\therefore \varphi_Y < 0 \qquad \therefore \varphi_{YF} = \varphi_Y + \varphi_F \neq 0 \qquad \therefore \varphi_Z = -\varphi_{YF} \neq 0$$

$\because$ 谐振时呈现纯阻　　$\therefore$ 失谐工作即：$\omega_c \neq \omega_o$

ω_c：电路参数决定的振荡频率　　ω_o：回路谐振频率

$$\because \left(\omega_c - \omega_o\right)\downarrow$$

$$\therefore \omega_c \approx \omega_o$$

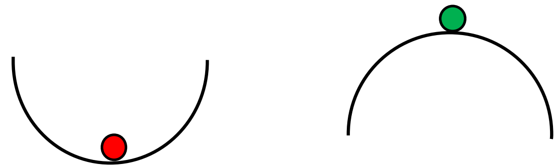


*LC*并联振荡回路

负载相角与频率的关系

5.1.2 稳定条件 stabilization Condition

1. 振幅稳定条件

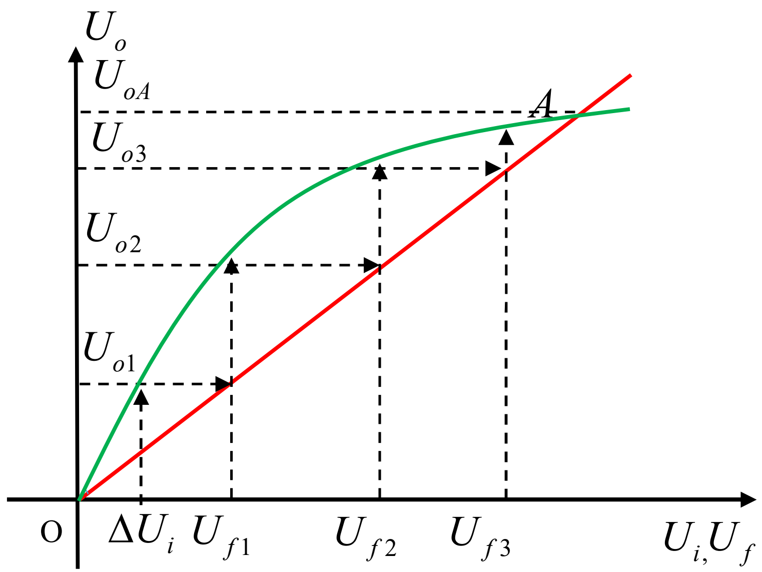


$\theta \geq 90^\circ$

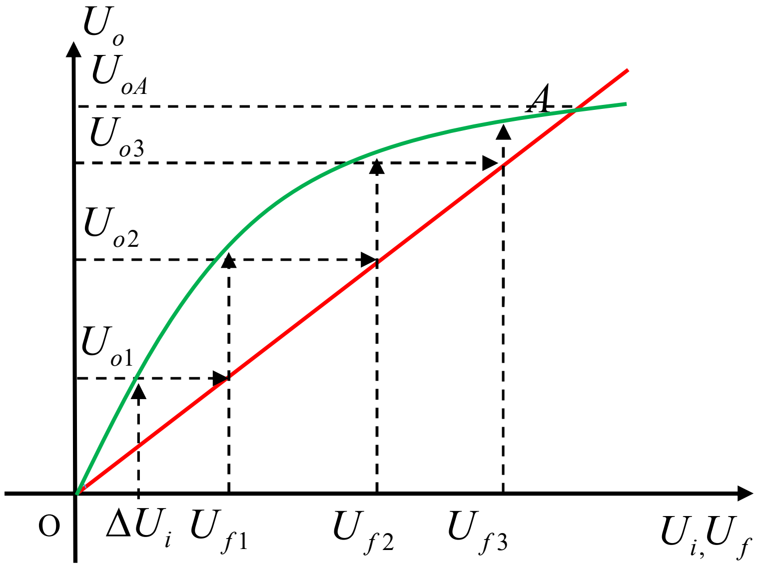
放大特性与反馈特性有两个交点O、A

电源接通瞬间$\dot{U}_i = 0, \dot{U}_o = 0$外界电磁感应在放大器输入端感应电压$\Delta U_i$，放大器输出$U_{o1}$，经过反馈网络，反馈电压$U_{f1}$ ，由于$U_{f1} > \Delta U_i$ ，振荡器就会脱离开原点而振荡起来。

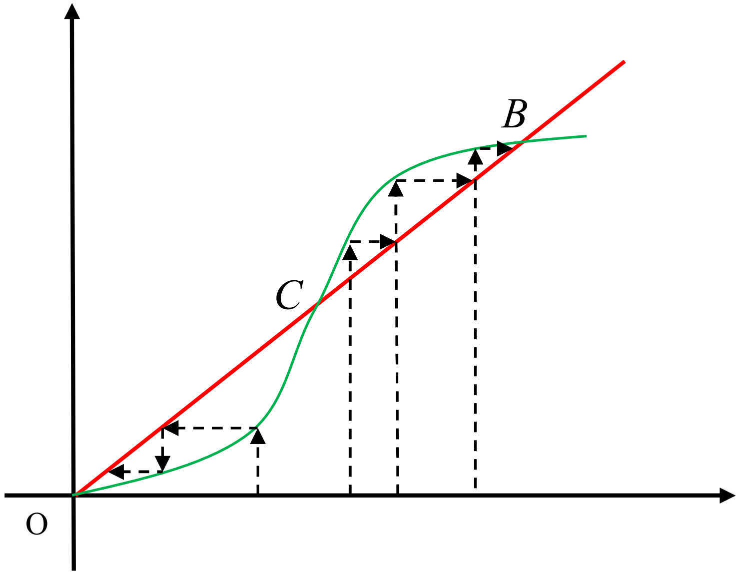
若因外界因素振荡偏离A点，仍可返回



$\theta \geq 90^\circ$ 的放大特性与反馈特性



$\theta \geq 90^{\circ}$



$\theta < 90^{\circ}$

A 稳定点

Soft Self Excitation

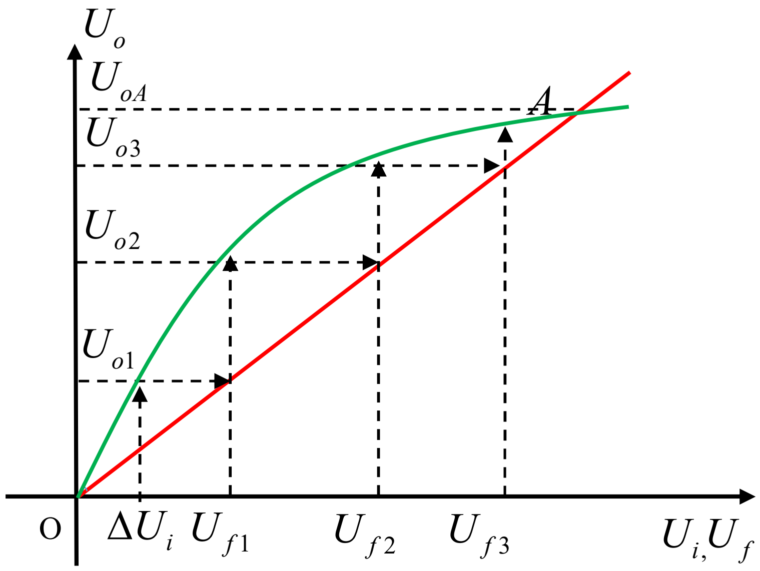
软自激

O、B 稳定点；C 非稳定点

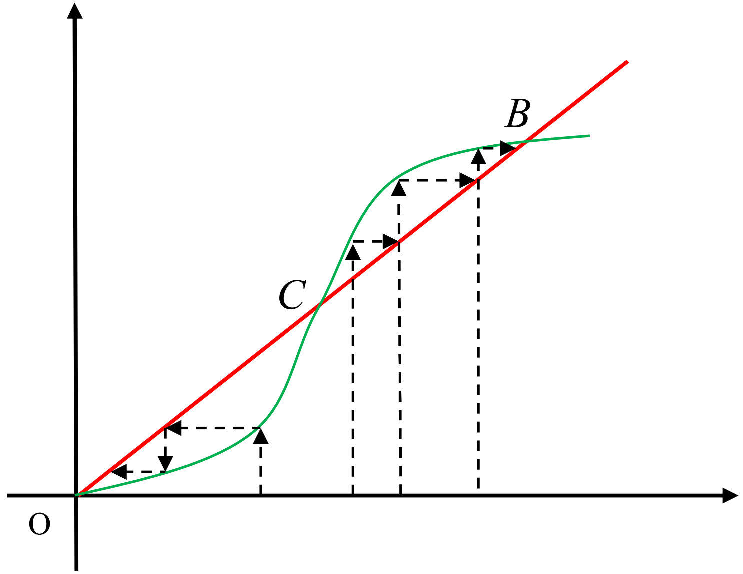
初始为 O，不起振

$U_i > U_c$ 自动起振

Hard Self Excitation 硬自激



$\theta \geq 90^\circ$



$\theta < 90^\circ$

A 稳定点

O、B 稳定点；C 非稳定点

稳定 ：放大特性斜率小于反馈特性斜率

$$\frac{\partial U_o}{\partial U_i}|p < \frac{\partial U_o}{\partial U_f}|p \qquad \frac{\partial U_o}{\partial U_i}\frac{\partial U_f}{\partial U_o} < 1 \qquad \frac{\partial U_f}{\partial U_i}|p < 1$$

$$\frac{\partial U_f}{\partial U_i} | p < 1 \qquad \frac{\partial U_f}{\partial U_i} = \dot{F}\dot{U}_i \frac{\partial \dot{A}}{\partial \dot{U}_i} + \dot{A}\dot{U}_i \frac{\partial \dot{F}}{\partial \dot{U}_i} + \dot{A}\dot{F} \frac{\partial \dot{U}_i}{\partial \dot{U}_i} < 1$$

$$U_f = \dot{A}\dot{F}\dot{U}_i$$

平衡点：

$$\dot{A}\dot{F} = 1 \qquad \dot{F}\dot{U}_i \frac{\partial \dot{A}}{\partial \dot{U}_i} + \dot{A}\dot{U}_i \frac{\partial \dot{F}}{\partial \dot{U}_i} < 0 \qquad \dot{F} \frac{\partial \dot{A}}{\partial \dot{U}_i} + \dot{A} \frac{\partial \dot{F}}{\partial \dot{U}_i} < 0$$

$$\begin{cases} F = \text{常数} \quad \dfrac{\partial \dot{F}}{\partial \dot{U}_i} = 0 \quad \therefore \dot{F} \dfrac{\partial \dot{A}}{\partial \dot{U}_i} < 0 \\ A = \text{常数} \quad \dfrac{\partial \dot{A}}{\partial \dot{U}_i} = 0 \quad \therefore \dot{A} \dfrac{\partial \dot{F}}{\partial \dot{U}_i} < 0 \end{cases}$$

内稳幅条件
非线性放大器

外稳幅条件
非线性反馈网络

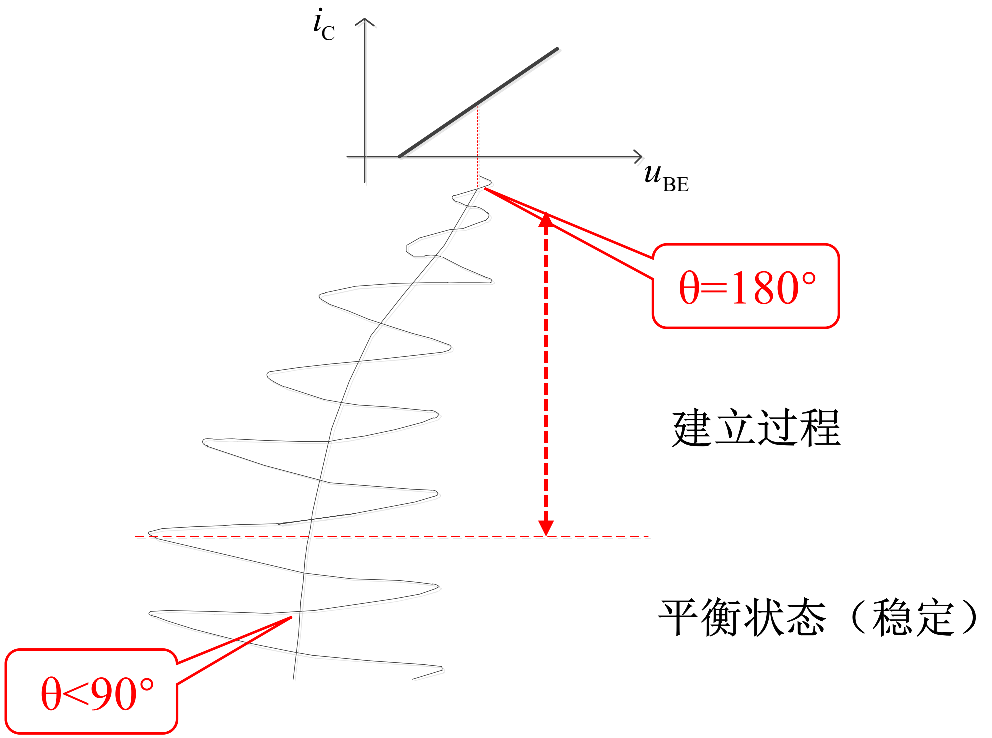
稳定：　θ≥90°　Soft Self Excitation　软自激

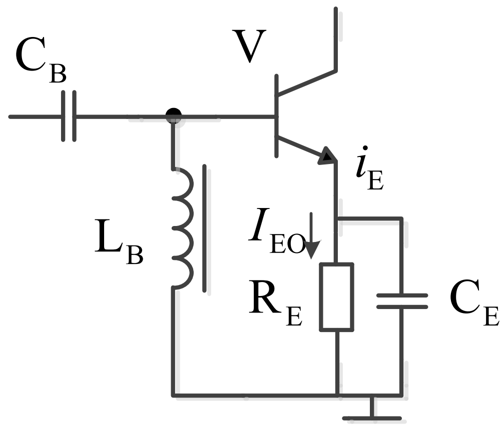
θ<90°　Hard Self Excitation　硬自激

自动起振：电源接通瞬间A类(θ=180°)

$U_i \uparrow$　$U_o \uparrow$　$\theta \downarrow$

θ<90° (C类)达到平衡　$\dot{A}\dot{F}=1$





发射极自给偏置电路

2. 相位稳定条件

$$U = U_m \sin(\omega t + \varphi_0)$$

$$\omega' = \frac{d\varphi(t)}{dt} = \frac{d(\omega t + \varphi_0)}{dt}$$

φ_0: 常数 $\omega' = \omega$

φ_0: 非常数 $\omega' = \omega + \dfrac{d\varphi_0}{dt} = \omega + \Delta\omega$

$\therefore \varphi \uparrow \qquad \omega \uparrow \qquad f \uparrow$

相位超前 频率增大

$$\varphi_\Sigma = 0 \xrightarrow{\text{外界因素使}} \begin{cases} \varphi_\Sigma \uparrow \longrightarrow \omega \uparrow \begin{cases} \varphi_\Sigma \downarrow & \text{稳定} \\ \varphi_\Sigma \uparrow & \text{不稳定} \end{cases} \\ \varphi_\Sigma \downarrow \longrightarrow \omega \downarrow \begin{cases} \varphi_\Sigma \uparrow & \text{稳定} \\ \varphi_\Sigma \downarrow & \text{不稳定} \end{cases} \end{cases}$$

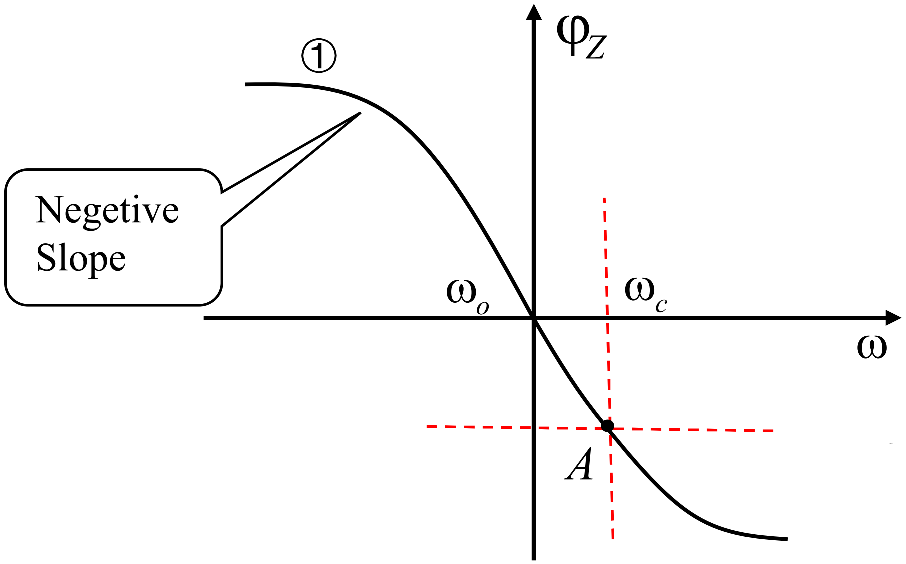
$\varphi_\Sigma = 0 \xrightarrow{\text{外界因素使}}$

- $\varphi_\Sigma \uparrow \longrightarrow \omega \uparrow$
  - $\varphi_\Sigma \downarrow$ 稳定
  - $\varphi_\Sigma \uparrow$ 不稳定
- $\varphi_\Sigma \downarrow \longrightarrow \omega \downarrow$
  - $\varphi_\Sigma \uparrow$ 稳定
  - $\varphi_\Sigma \downarrow$ 不稳定

相位稳定条件： $$\frac{\partial \varphi_\Sigma}{\partial \omega}\Big|_p = \left(\frac{\partial \varphi_Y}{\partial \omega}\Big|_p + \frac{\partial \varphi_F}{\partial \omega}\Big|_p + \frac{\partial \varphi_Z}{\partial \omega}\Big|_p\right) < 0$$

窄带可认为： $$\frac{\partial \varphi_F}{\partial \omega} \approx 0 \qquad \frac{\partial \varphi_Y}{\partial \omega} \approx 0$$

相位稳定条件： $$\frac{\partial \varphi_Z}{\partial \omega}\Big|_p < 0$$



5.1.3 起振条件

$$\begin{cases} A_0F>1 \qquad U_f > U_i & \text{振幅起振条件} \\ \varphi_\Sigma = 2n\pi & \text{相位起振条件} \end{cases}$$

起始 U_i 小，工作于A类，自起振

∴ 起振用小信号微变等效电路分析法

起始状态

$$\dot{A}_0\dot{F} > 1$$

工作于 A 类，θ≥90°

小信号、线性

微变等效电路分析法

稳定状态

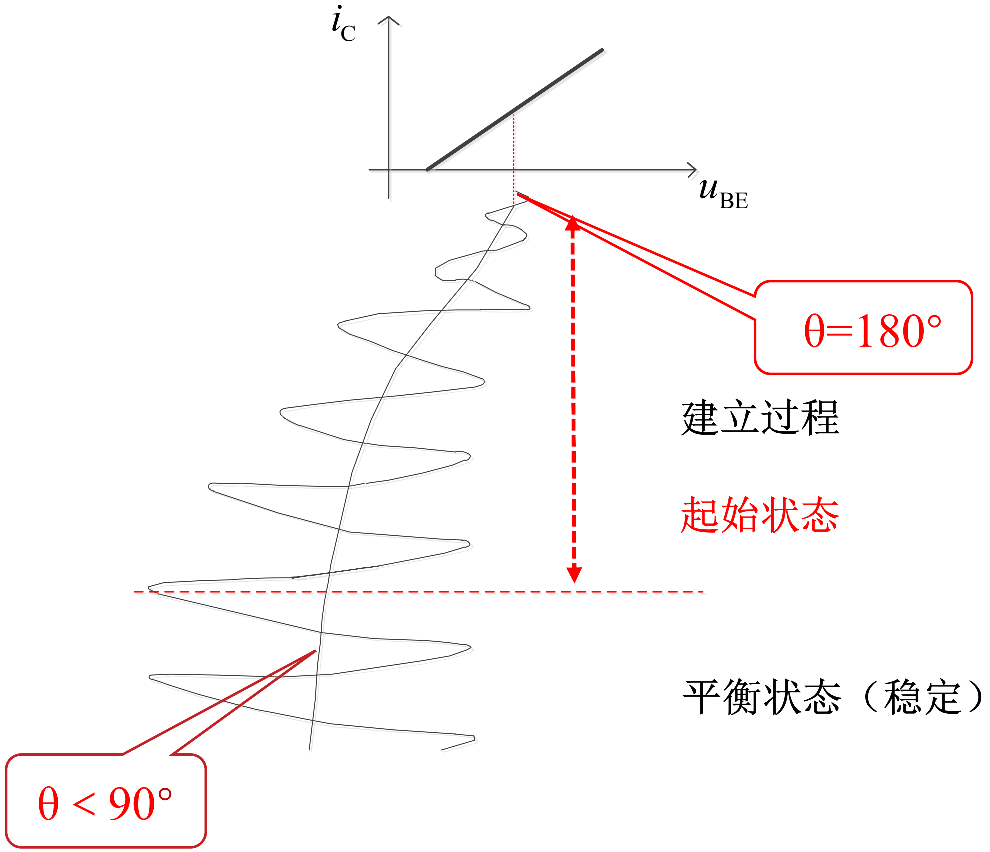
$$\dot{A}\dot{F} = 1$$

工作于 C 类，θ<90°

大信号、非线性

不能用微变等效电路分析法

Y参数等效电路分析法



$\dot{A}\dot{F} > 1$

工作于 A 类，θ≥90°

小信号、线性

微变等效电路分析法

$\dot{A}\dot{F} = 1$

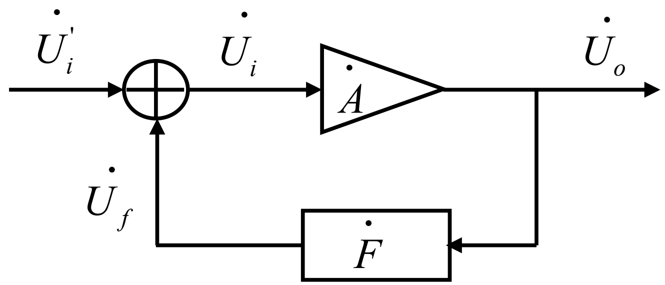
工作于 C 类，θ<90°

大信号、非线性

不能用微变等效电路分析法

Y参数等效电路分析法

- 振荡器振荡条件
  - 平衡
    - 振幅平衡 $AF=1$
    - 相位平衡 $\varphi_{\Sigma} = 2n\pi$
  - 稳定
    - 振幅稳定 $\dot{F}\frac{\partial \dot{A}}{\partial \dot{U}_i} + \dot{A}\frac{\partial \dot{F}}{\partial \dot{U}_i} < 0$
    - 相位稳定 $\frac{\partial \varphi_{\Sigma}}{\partial \omega} < 0$
  - 起振
    - 振幅起振 $A_0F>1$
    - 相位起振 $\varphi_{\Sigma} = 2n\pi$



- 振荡器组成
  - 放大器：BJT、FET、差分放大器、运算放大器等
  - 反馈网络：RC 移相、电容分压、电感分压、变压器耦合或电阻分压网络等
  - 选频网络：LC、RC、晶体滤波器等

谢谢！