第四章 正弦振荡器

4.1 反馈型正弦振荡器基本原理

4.2 振荡器分析预备知识

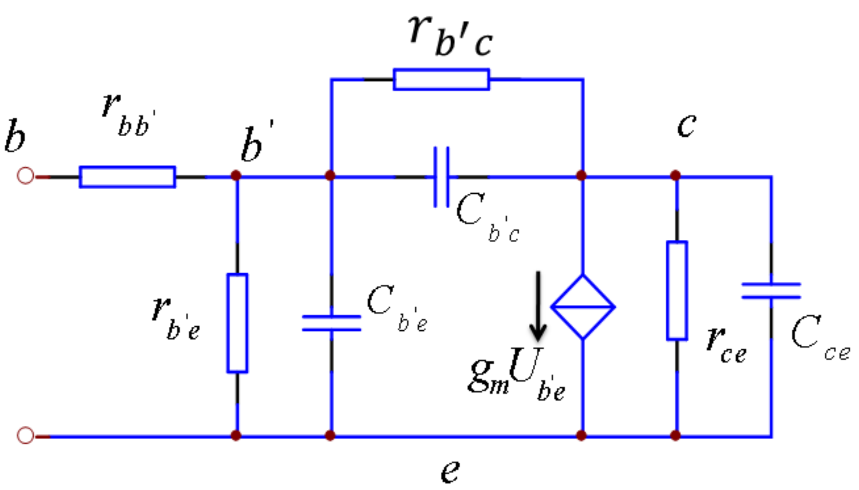
4.3 正弦振荡器分析举例

4.4 石英晶体正弦波振荡器

4.5 阻容振荡器（RC振荡器）

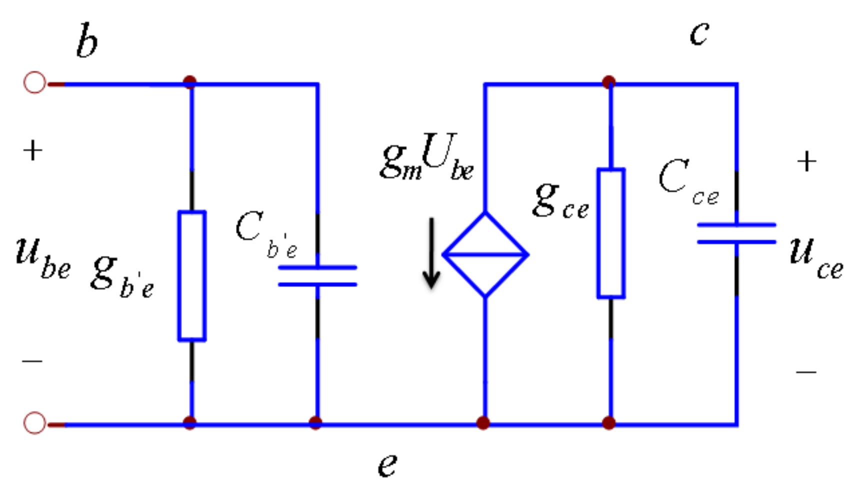
一、晶体管模型

完整晶体管模型（混合π参数模型）



高频晶体管

$$\begin{cases} r_{bb'} << r_{b'e} \\ r_{ce} - \text{几十甚至几百}K\Omega \\ C_{b'c} - \text{很小} \quad << C_{b'e}, C_{ce}, \text{近似分析中可忽略} r_{b'c}, C_{b'c}, r_{bb'} \text{的影响} \\ r_{b'c} - \text{集电极反偏电阻，很大，} >> r_{ce} \\ f_T \text{一般为} f_{osc} \text{的} 5-10 \text{倍} \end{cases}$$

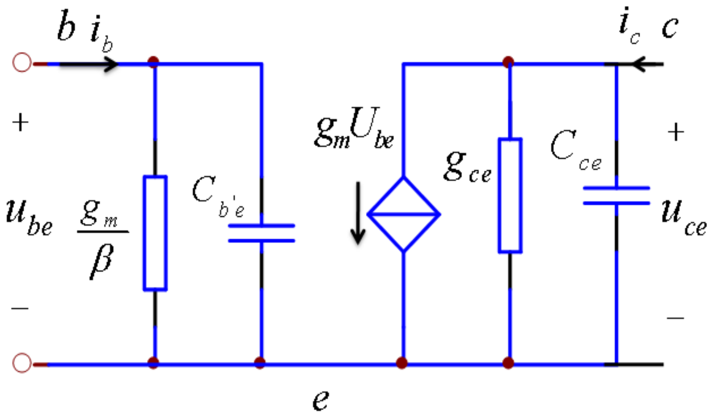


简化晶体管模型

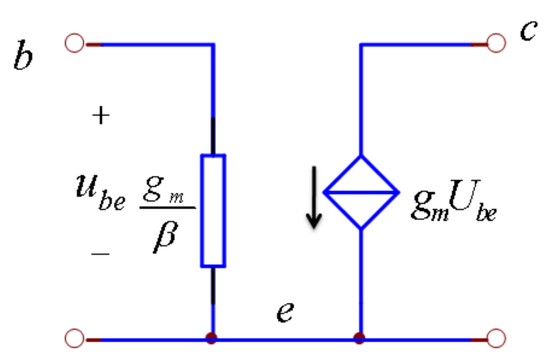
1. 共射极简化模型

$$r_{b'e} = (1+\beta)\frac{U_r}{I_{EQ}} = (1+\beta)r_e \qquad g_m = \frac{\alpha I_{EQ}}{U_r} \Rightarrow r_e = \frac{U_r}{I_{EQ}} = \frac{\alpha}{g_m}$$

$$\therefore r_{be} \approx (1+\beta)\frac{\alpha}{g_m} = (1+\beta)\frac{\beta}{(1+\beta)}\frac{1}{g_m} = \frac{\beta}{g_m} \Rightarrow g_{b'e} = \frac{g_m}{\beta}$$



共射极简化模型

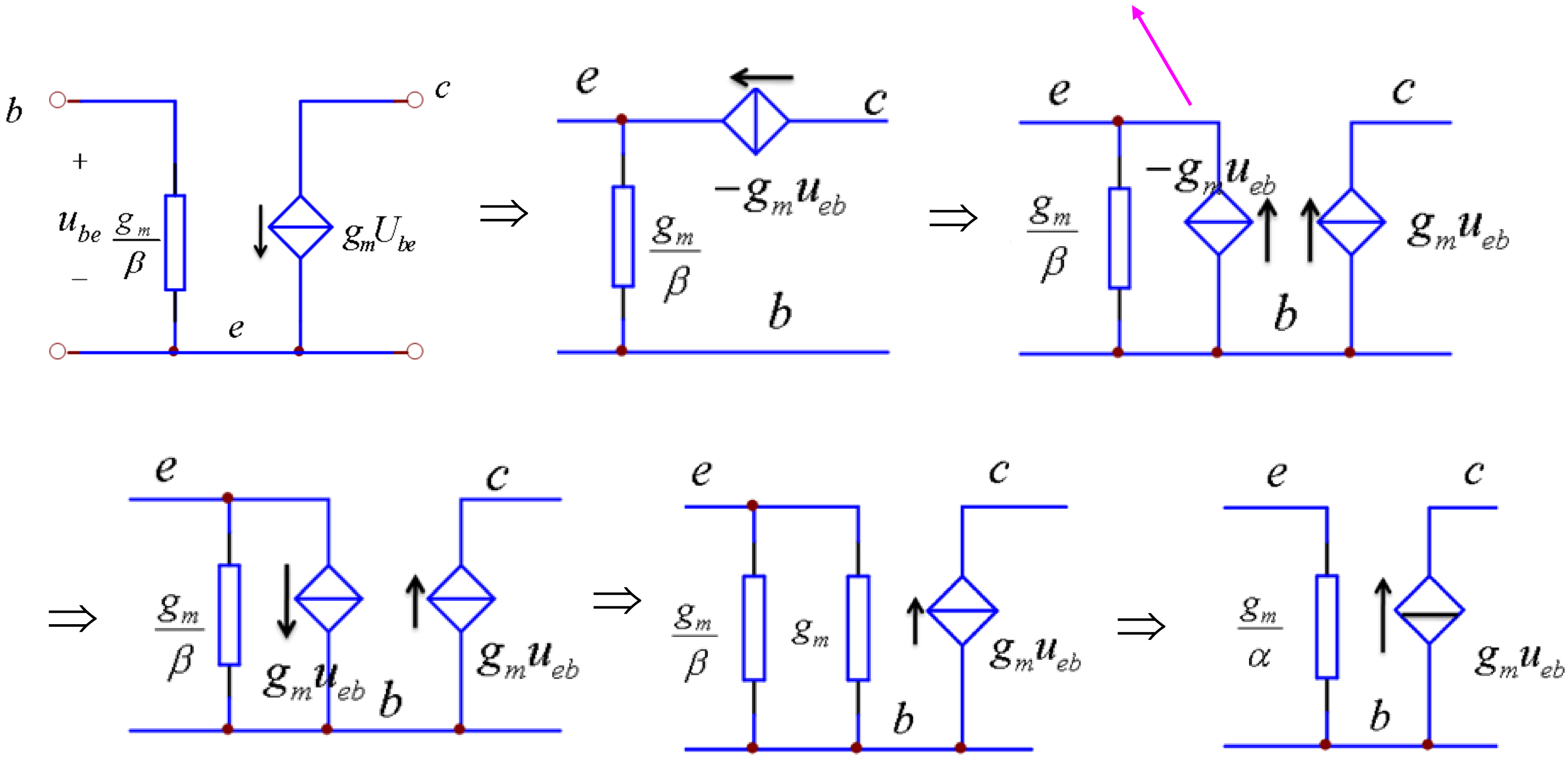


最简化模型

4.2 振荡器分析预备知识

2. 共基组态简化模型

注：等效未改变输入、输出端的电流关系。



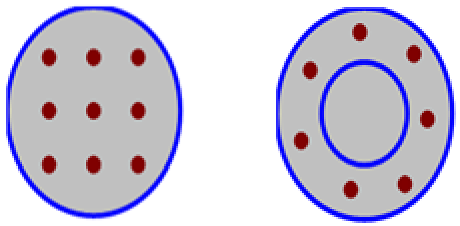
共基简化模型

4.2 振荡器分析预备知识

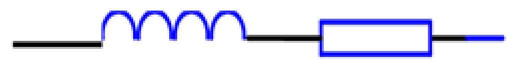
二、阻抗变换器

阻抗变换的目的是将高阶电路变为2阶电路，使电路计算变得简单，误差控制在5%以下。

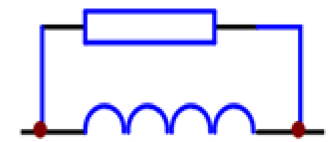
1. 元件Q值



低频　高频



串联等效



并联等效

①电感有磁损

②绕制电感的导线在低频下横截面电流密度均匀，在高频下密度分布不均匀，有效面积减小。

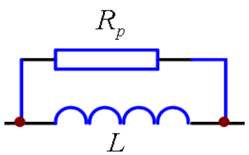
$$Q=\frac{\text{电抗所存的最大能量}}{\text{电阻消耗的能量}}$$

①

$$Q=\frac{\frac{1}{2}\omega L I^2}{\frac{1}{2}I^2 R_S}=\frac{\omega L}{R_S}=\frac{X_L}{R_S}$$

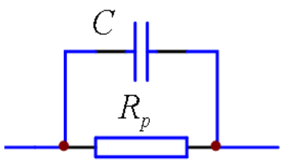
4.2 振荡器分析预备知识

②

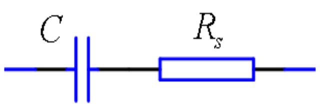


$$Q=\frac{\frac{1}{2}\omega L I^2}{\frac{1}{2}\frac{U^2}{R_p}}=\frac{\frac{1}{2}\omega L\frac{U^2}{\omega^2 L^2}}{\frac{1}{2}\frac{U^2}{R_p}}=\frac{R_p}{\omega L}=\frac{R_p}{X_L}$$

④



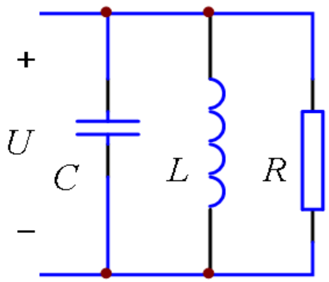
③



$$Q=\frac{\frac{1}{2}I^2\frac{1}{\omega C}}{\frac{1}{2}I^2 R_S}=\frac{1}{\omega R_S C}=\frac{X_C}{R_S}$$

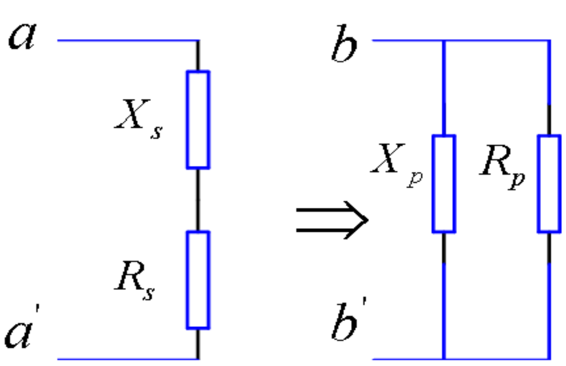
$$Q=\frac{R_p}{\frac{1}{\omega C}}=\omega R_p C=\frac{R_P}{X_C}$$

⑤



$$Q=\frac{R_P}{X_C}=\omega_0 R_p C=\frac{R_P}{X_L}=\frac{R_P}{\omega_0 L}=\frac{R_P}{\sqrt{L/C}}=R_P\sqrt{C/L}$$

2. 串并转换



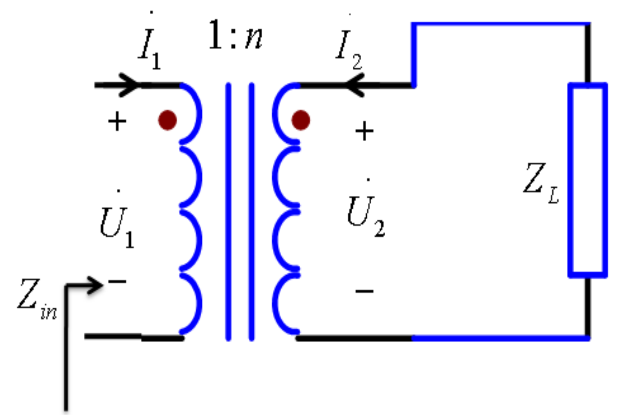
$$Q=\frac{X_s}{R_s}=\frac{R_p}{X_p}$$

$$R_p=R_s[1+Q^2]\approx Q^2 R_s$$

$$X_p=(1+\frac{1}{Q^2})X_s\approx X_s$$

即有：$\begin{cases}X_p=X_s\\R_p=Q^2R_s\end{cases}$　反过来：$\begin{cases}X_s=X_p\\R_s=\frac{1}{Q^2}R_p\end{cases}$

3. 理想变压器的阻抗变换



关于理想变压器的说明：

①只有一个参数，即变压比n（次、初级线圈匝数比）；

②初、次级线圈绕组必须标注同名端。特性方程中的正、负号是由电压、电流与同名端的相对关系决定；

③虽然采用了电感或互感的表示符号，但不代表任何电感或互感的作用，其唯一功能是对电压及电流的数值起变换作用。

④不消耗能量，也不存储能量，是一种无损耗、无记忆的非动态元件。

⑤阻抗变换性质将负载阻抗改变了n^2倍。

$$\dot{U}_2 = n\dot{U}_1$$ 变压关系

$$\dot{I}_2 = -\frac{1}{n}\dot{I}_1$$ 变流关系

$$Z_{in} = \frac{1}{n^2} Z_L \ (G_{in} = n^2 G_L)$$ 变阻抗关系

Z_{in} − 从初级看进去的等效电阻

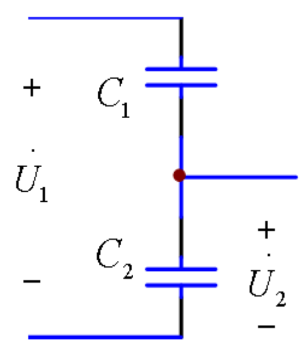
Z_L − 次级线圈所接纯电阻

$$\dot{U}_1 \dot{I}_1 = \dot{U}_2 \dot{I}_2$$ 能量守恒

4. 分压式外阻抗接入电路的阻抗变换

在实际并联谐振回路中，为了减少外接阻抗对回路有载 Q_T 值的影响，外接阻抗多用“**部分接入**”的方法。

n – 接入系数

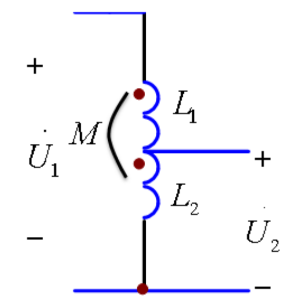


电容分压式

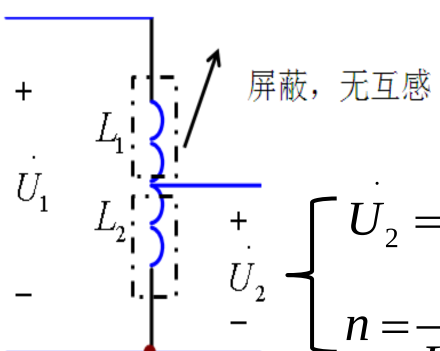
$$\dot{U}_2=\frac{\frac{1}{j\omega C_2}}{\frac{\frac{1}{j\omega C_1}\cdot\frac{1}{j\omega C_2}}{\frac{1}{j\omega C_1}+\frac{1}{j\omega C_2}}}\dot{U}_1=\frac{C}{C_2}\dot{U}_1=n\dot{U}_1$$

$$\begin{cases} C=\dfrac{C_1C_2}{C_1+C_2} \\ n=\dfrac{C}{C_2}=\dfrac{C_1}{C_1+C_2} \end{cases}$$

自感变压器（自耦空芯变压器）

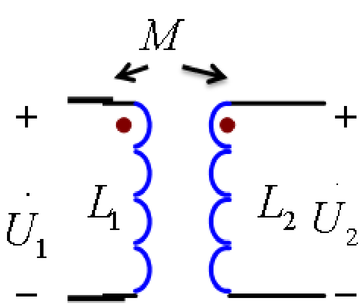


$$\begin{cases} \dot{U}_2=\dfrac{L_2+M}{L_1+L_2+2M}\dot{U}_1 \\ n=\dfrac{L_2+M}{L_1+L_2+2M} \end{cases}$$



电感分压式

$$\begin{cases} \dot{U}_2=n\dot{U}_1 \\ n=\dfrac{L_2}{L_1+L_2} \end{cases}$$



互感式

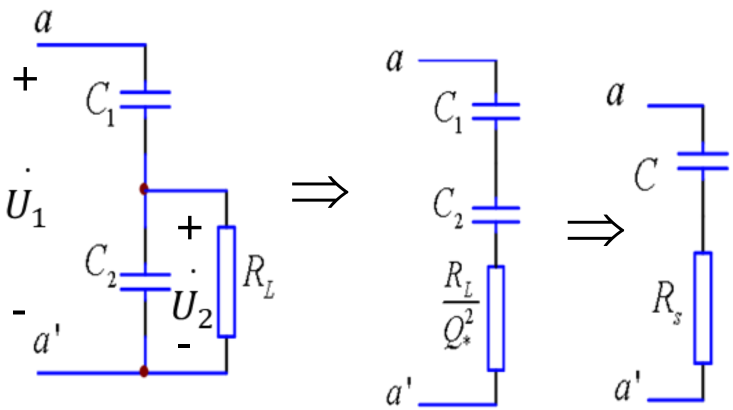
耦合系数

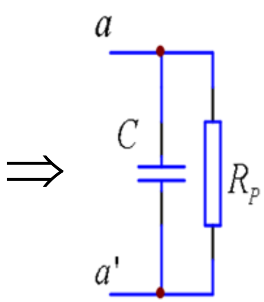
$$\begin{cases} k=\dfrac{M}{\sqrt{L_1L_2}} \\ \dot{U}_2=n\dot{U}_1 \\ n=\sqrt{\dfrac{L_2}{L_1}}=\dfrac{M}{L_1}\quad(k=1) \end{cases}$$

全耦合变压器

4. 2 振荡器分析预备知识

以电容分压式部分接入为例





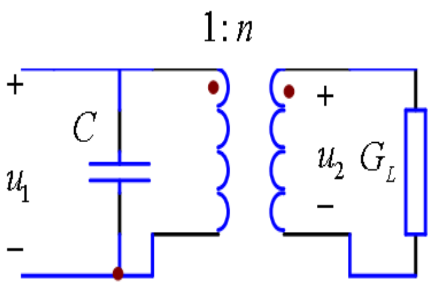
假定： $Q_* = \dfrac{R_L}{X_{C_2}} = \omega C_2 R_L > 10$

$$
\left\{
\begin{aligned}
& C = \frac{C_1 C_2}{C_1 + C_2} \qquad n = \frac{C}{C_2} = \frac{C_1}{C_1 + C_2} \qquad R_S = \frac{R_L}{Q_*^2} \\
& Q_{*2} = \frac{X_C}{R_S} = \frac{1}{\omega R_S C} = \frac{(\omega R_L C_2)^2}{\omega R_L C} = \frac{C_2{}^2}{C}\omega R_L = \frac{C_2}{C} Q_* > 10 \\
& R_P = Q_{*2}^2 R_S = (\frac{C_2}{C} Q_*)^2 R_S = (\frac{C_2}{C} Q_*)^2 \frac{R_L}{Q_*^2} = (\frac{C_2}{C})^2 R_L \\
& \text{或} G_P = (\frac{C}{C_2})^2 G_L = n^2 G_L
\end{aligned}
\right.
$$

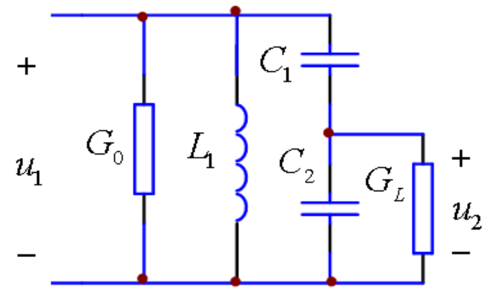
$$
\therefore \frac{\dot{U}_2}{\dot{U}_1} = \frac{\dfrac{1}{j\omega C_2} // R_L}{\dfrac{1}{j\omega C_1} + \dfrac{1}{j\omega C_2} // R_L} = \frac{j\omega C_1 R_L}{1 + j\omega (C_1 + C_2) R_L}
$$

$$
\left\{
\begin{aligned}
& \left| \frac{\dot{U}_2}{\dot{U}_1} \right| = \frac{\omega C_1 R_L}{\sqrt{1 + \omega^2 (C_1 + C_2)^2 R_L{}^2}} \approx \frac{\omega C_1 R_L}{\omega (C_1 + C_2) R_L} = \frac{C_1}{C_1 + C_2} = \frac{C_1 C_2}{C_1 + C_2} \cdot \frac{1}{C_2} = \frac{C}{C_2} = n \\
& \varphi_{\frac{\dot{U}_2}{\dot{U}_1}} = 90^0 - arctg[\omega (C_1 + C_2) R_L] < 3^0, \text{即相位影响很小}
\end{aligned}
\right.
$$

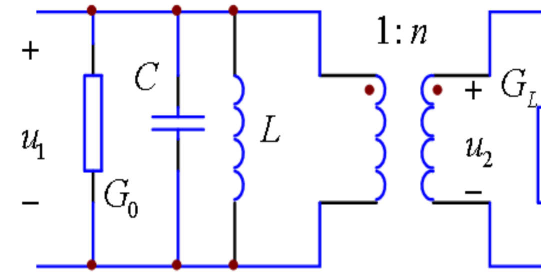
近似条件下，电容分压式
可看成图示变压器



$$\dot{U}_2 = n\dot{U}_1$$

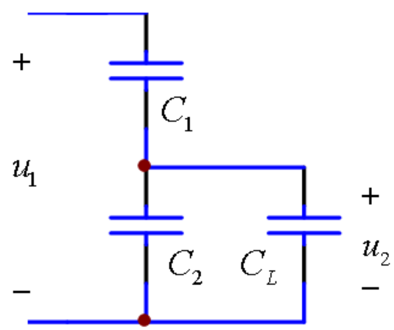


⇒



$$\begin{cases} Q^* = \dfrac{\omega_0 C_2}{G_L}, \quad C = \dfrac{C_1 C_2}{C_1 + C_2}, \quad n = \dfrac{C}{C_2}, \\ L = L_1, \quad \omega_0 = \dfrac{1}{\sqrt{LC}}, \quad Q_T = \dfrac{\omega_0 C}{G_0 + n^2 G_L} \end{cases}$$

容性负载



$C_2' = C_2 + C_L$ $\qquad$ C_L较小

$$C_\Sigma = \frac{C_1 C_2'}{C_1 + C_2'} = \frac{C_1(C_2 + C_L)}{C_1 + C_2 + C_L} = \frac{C_1 C_2 (1 + \frac{C_L}{C_2})}{(C_1 + C_2)(1 + \frac{C_L}{C_1 + C_2})}$$

$$\frac{1}{1+x} = 1 - x$$

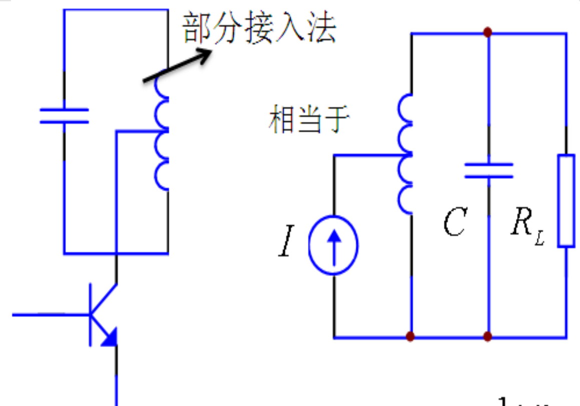
$$\overset{C_L小}{=} C(1 + \frac{C_L}{C_2})(1 - \frac{C_L}{C_1 + C_2}) = C[1 + \frac{C_L}{C_2} - \frac{C_L}{C_1 + C_2} - \frac{C_L}{C_1 + C_2}\frac{C_L}{C_2})$$

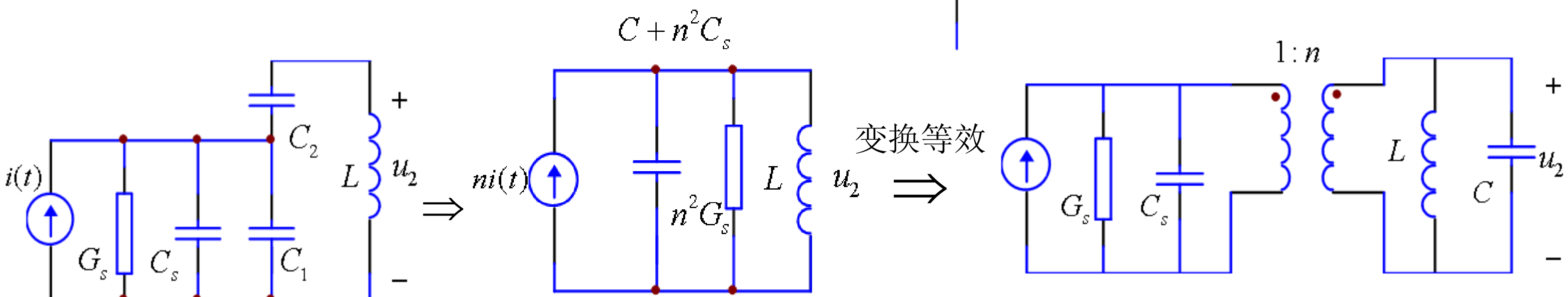
$$= C[1 + \frac{C_L}{C_2} - \frac{C_L}{C_1 + C_2}) = C + \frac{C}{C_2}\frac{C_1}{C_1 + C_2} C_L = C + n^2 C_L$$

上述变换方法同样适用于其它类型的阻抗变换器，如电感分压式，阻抗变换器，自感式阻抗变换器等。见教材表4. 2. 1。为了保证变换的准确性，要保证 $Q_* > 10$

4. 受控源阻抗变换

$$n=\frac{C}{C_1}<1 \qquad C=\frac{C_1C_2}{C_1+C_2} \qquad \omega_0=\frac{1}{\sqrt{LC}}$$





理想变流器

Cs对回路的影响相当于在回路中引入一个比Cs小得多的n^2Cs。

$$\dot{U}_2(\omega)=\dot{I}(\omega)\left\{\frac{1}{G_s}//\frac{1}{j\omega C_s}//\frac{1}{j\omega C_1}//\left(\frac{1}{j\omega C_2}+j\omega L\right)\right\}\times\frac{j\omega L}{j\omega L+\frac{1}{j\omega C_2}}$$