电子电路与系统基础(1)---线性电路---2020春季学期

第14讲：作业选讲

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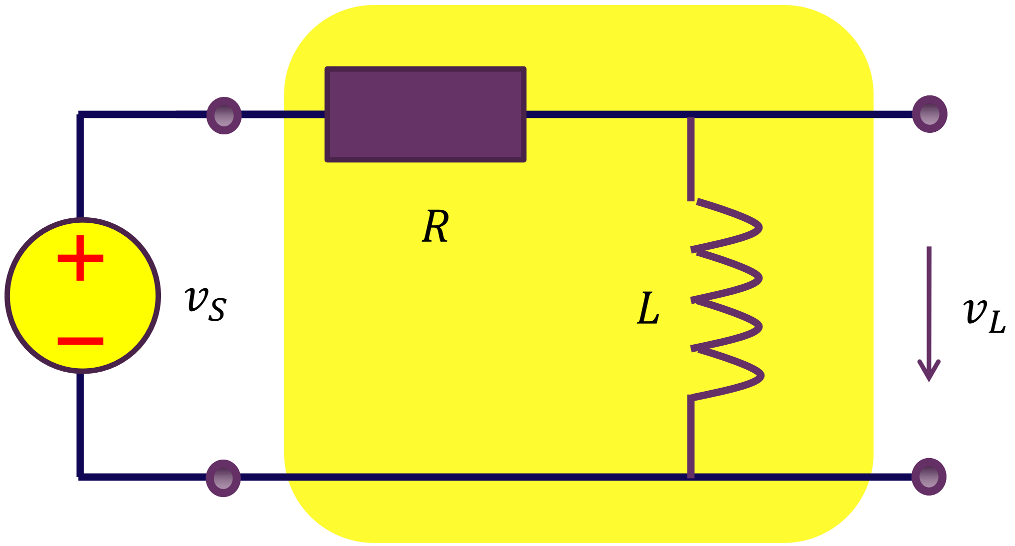
B班课程内容安排

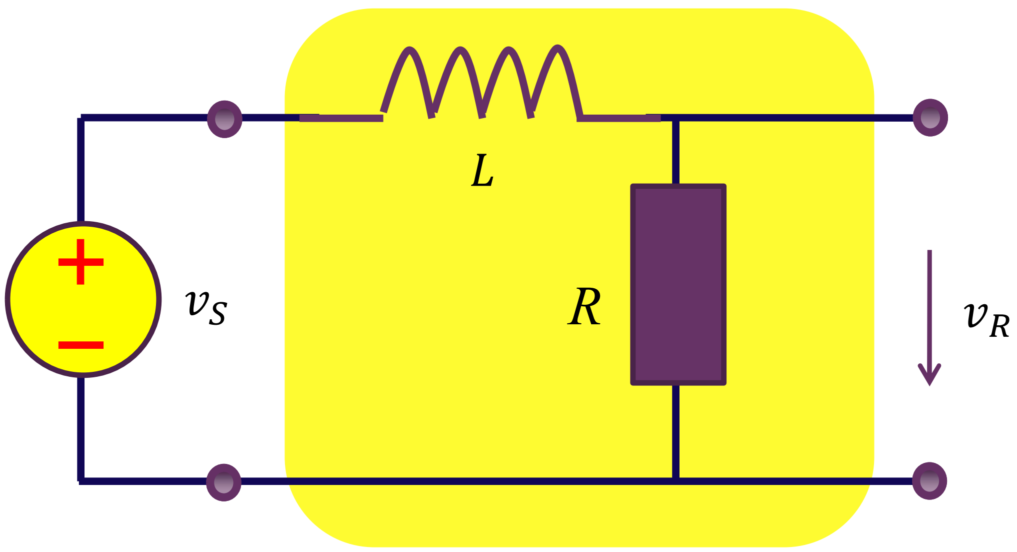
第一学期：线性	序号	第二学期：非线性
电路定律	1	器件基础
电阻电源	2	二极管
电容电感	3	**MOSFET**
信号分析	4	**BJT**
分压分流	5	反相电路
正弦稳态	6	数字门
时频分析	7	放大器
期中复习	8	期中复习
RLC二阶	9	负反馈
二阶时频	10	差分放大
受控源	11	频率特性
网络参量	12	正反馈
典型网络	13	振荡器
作业选讲	**14**	作业选讲
期末复习	15	期末复习

作业选讲 内容

- 一阶电路分析
  - 时域分析要求掌握三要素法
    - 当电阻在0、无穷之间转换时，变成开关电容电路，可对简单开关电容电路进行分析
  - 频域分析能够求传递函数
    - 能够设计一阶滤波器
    - 能够正确判定滤波器类型
    - 可做复功率分析
- 线性电路传递函数分析
  - 回路电流法
  - 结点电压法
  - 网络参量法
  - 等效电路法：戴维南等效，诺顿等效
- 二阶电路分析

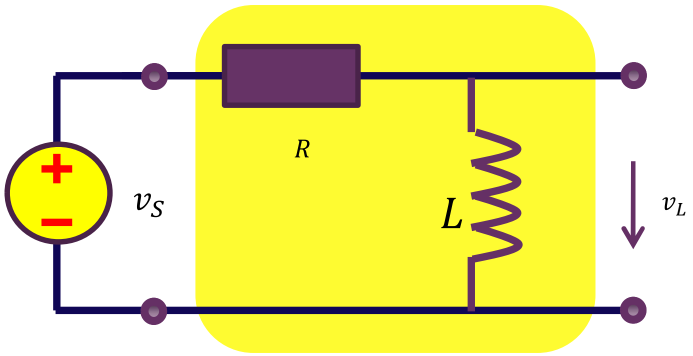
作业7.1 一阶RL电路的时频分析

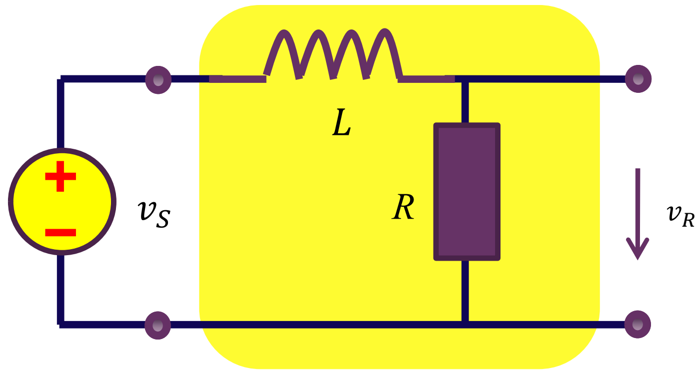




- 请对左侧两个一阶RL电路进行时频分析
  - 频域传递函数，说明低通高通类型
  - 时域冲激响应、阶跃响应分析（三要素法）
  - 验证阶跃响应的微分等于冲激响应
  - （选作）验证冲激响应的傅立叶变换为传递函数

频域分析：传递函数即分压系数





$$H(j\omega)=\frac{\dot V_L(j\omega)}{\dot V_S(j\omega)}=\frac{j\omega L}{R+j\omega L}=\frac{j\omega GL}{1+j\omega GL}$$

$$=H_0\frac{j\omega\tau}{1+j\omega\tau}=H_0\frac{s}{s+\omega_0}$$

典型的一阶高通传递函数

$$H(j\omega)=\frac{\dot V_R(j\omega)}{\dot V_S(j\omega)}=\frac{R}{R+j\omega L}=\frac{1}{1+j\omega GL}$$

$$=H_0\frac{1}{1+j\omega\tau}=H_0\frac{\omega_0}{s+\omega_0}$$

典型的一阶低通传递函数

$$H_0=1$$

中心频点的传递系数

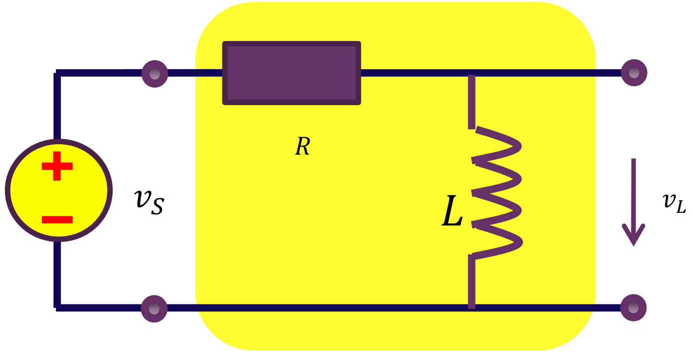
$$\tau=GL=\frac{L}{R}$$

$$\omega_0=\frac{1}{\tau}$$

频域分析：直接写答案

分析：

电感直流短路，输出为**0**，直流信号无法通过；电感高频开路，输出为源电压，高频信号可以通过。因而这是一个一阶高通滤波器，其传函典型形式为



（选1）

$$H(j\omega)=\frac{\dot{V}_L(j\omega)}{\dot{V}_S(j\omega)}=H_0\frac{j\omega\tau}{1+j\omega\tau}=H_0\frac{s}{s+\omega_0}$$

其中，$\boldsymbol{H_0}$为高通滤波器中心频点无穷频点的传递系数

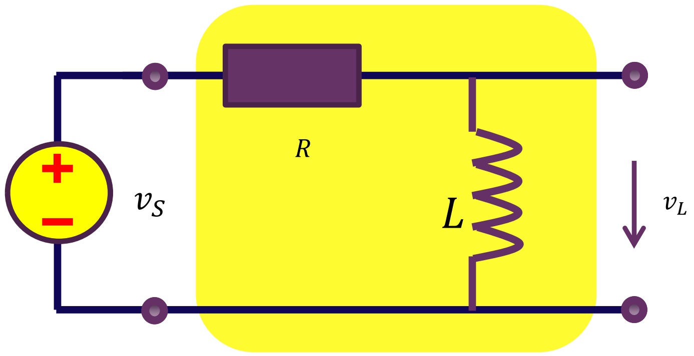
$$H_0=H(j\infty)=\frac{\dot{V}_L(j\infty)}{\dot{V}_S(j\infty)}=1$$

$\boldsymbol{\tau=GL}$为一阶**RL**电路的时间常数，显然该高通滤波器的**3dB**频点为

$$\omega_0=\frac{1}{\tau}$$

时域分析：冲激响应：三要素法

零状态响应分析



$\boldsymbol{\tau V_0 \delta(t)}$

要素1：时间常数

$$\tau = GL$$

要素2：初值

$$t = 0^-, v_L(0^-) = -i_L(0^-)R = 0$$

$\boldsymbol{v_s(t) = \tau V_0 \delta(t)}$冲激电压**t=0**加载瞬间，电感电流不能突变（电感高频开路），$\boldsymbol{i_L(0) = i_L(0^-) = 0}$，故而所有激励电压全部加载电感（开路），电感电流突变，

$$i_L(0^+) = i_L(0^-) + \frac{1}{L}\int_{0^-}^{0^+} v_L(t)\,dt = \frac{1}{L}\int_{0^-}^{0^+} \tau V_0 \delta(t)\,dt = \frac{\tau V_0}{L}\int_{0^-}^{0^+} \delta(t)\,dt = GV_0$$

t=0$^+$时刻，冲激电压支路电压为**0**（短路），于是$\boldsymbol{i_L(0^+)}$电流全部流过电阻，

$$t = 0^+, v_L(0^+) = -i_L(0^+)R = -V_0$$

冲激响应：三要素法

要素1：时间常数

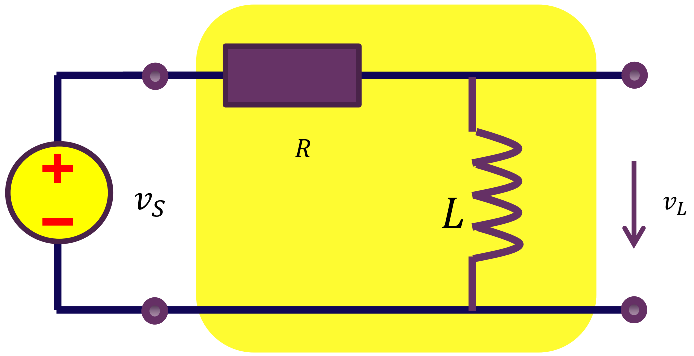
$$\tau = GL$$

要素2：初值

$$t = 0^-, v_L(0^-) = -i_L(0^-)R = 0$$

$$v_{out}(0) = \tau V_0\delta(t)$$

$$t = 0^+, v_L(0^+) = -i_L(0^+)R = -V_0$$



$\tau V_0\delta(t)$

要素3：稳态响应：电感以初始电流GV_0通过电阻**R**放磁，等待足够长时间，电感储存的磁通（磁能）全部被电阻消耗，故而

$$i_L(t \to \infty) = 0 \qquad v_L(t \to \infty) = -Ri_L(t \to \infty) = 0$$

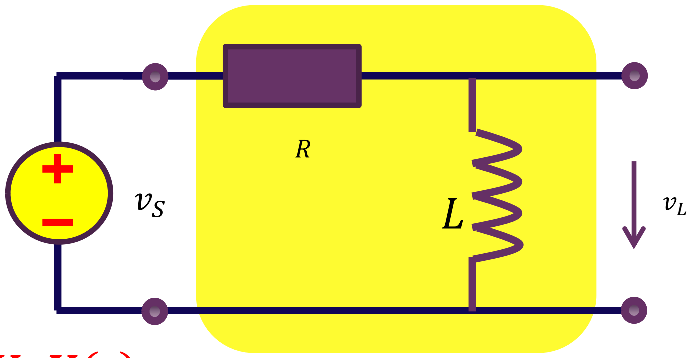
考虑到**t=0**时刻的冲激电压$v_L(0) = \tau V_0\delta(t)$,取$v_{L\infty}(t) = \tau V_0\delta(t)$

$$v_L(t) = v_{L\infty}(t) + \left(v_L(0^+) - v_{L\infty}(0^+)\right)e^{-\frac{t}{\tau}}U(t) = \tau V_0\delta(t) - V_0 e^{-\frac{t}{\tau}}U(t)$$

$$h(t) = \frac{1}{\tau V_0}v_L(t) = \delta(t) - \frac{1}{\tau}e^{-\frac{t}{\tau}}U(t)$$

时域分析：阶跃响应：三要素法

零状态响应分析



$\boldsymbol{V_0U(t)}$

要素1：时间常数

$\tau = GL$

要素2：初值

$t = 0^-, v_{out}(0^-) = -i_L(0^-)R = 0$

$\boldsymbol{v_s(t) = V_0U(t)}$ 阶跃电压**t=0**加载瞬间，电感电流不能突变， $\boldsymbol{i_L(0^+) = i_L(0^-) = 0}$ ，故而所有激励电压全部加载电感两端，产生阶跃电压，$\boldsymbol{v_L(0^+) = V_0}$**，**

要素3：稳态响应：等待足够长时间，电路为直流电路，电感直流短路，故而

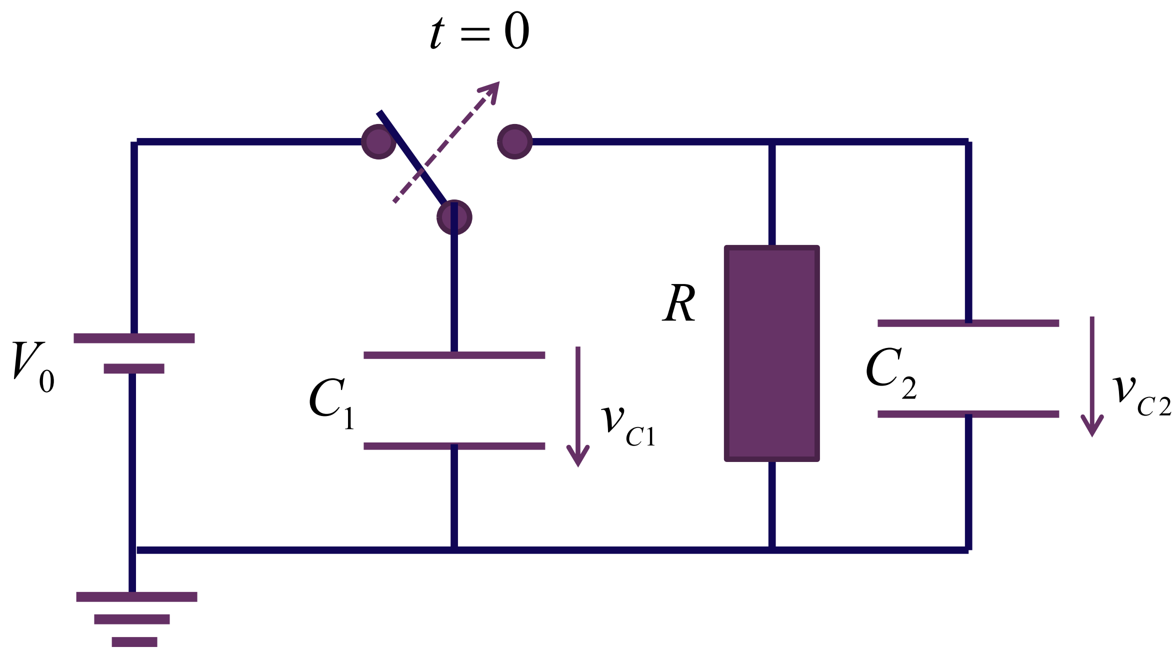
$$v_{L\infty}(t) = 0$$

$$v_L(t) = v_{L\infty}(t) + \left(v_{Lt}(0^+) - v_{L\infty}(0^+)\right)e^{-\frac{t}{\tau}}U(t) = V_0e^{-\frac{t}{\tau}}U(t)$$

$$\boldsymbol{g(t) = \frac{1}{V_0}v_L(t) = e^{-\frac{t}{\tau}}U(t)}$$

作业7.4 电容电压出现跳变

- 在t=0时刻，将开关拨向右侧电路，求电容C_1、C_2两端电压变化规律，写出表达式，画出时域波形

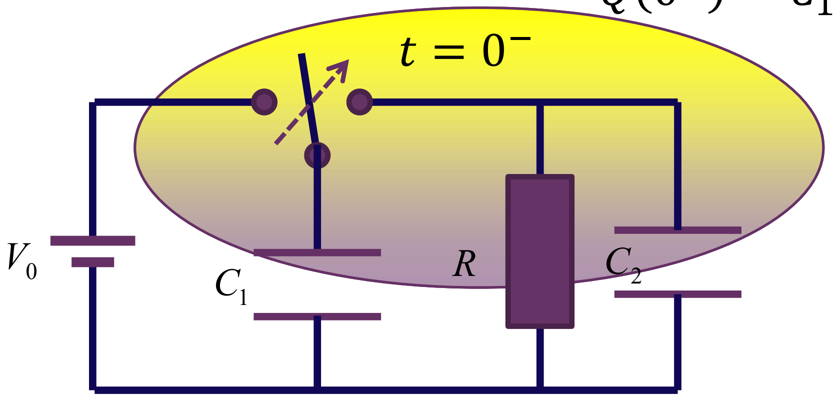


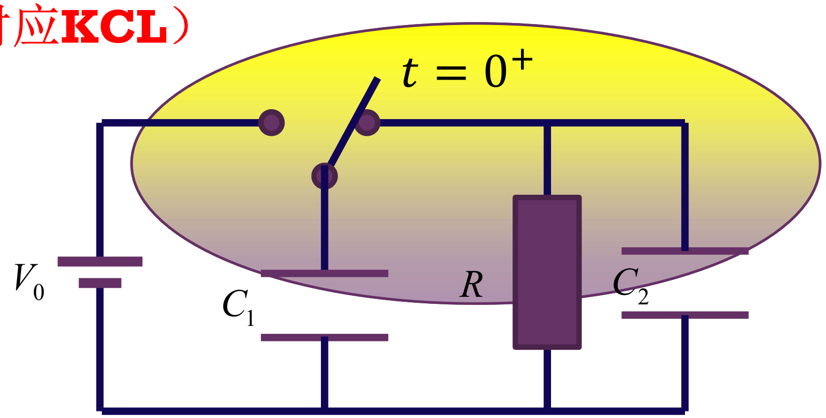
跳变初值的确定

$Q(0^-) = C_1V_0$

电荷守恒定律（对应**KCL**）

$$Q(0^+) = (C_1 + C_2)v_o(0^+) = Q(0^-) = C_1V_0$$

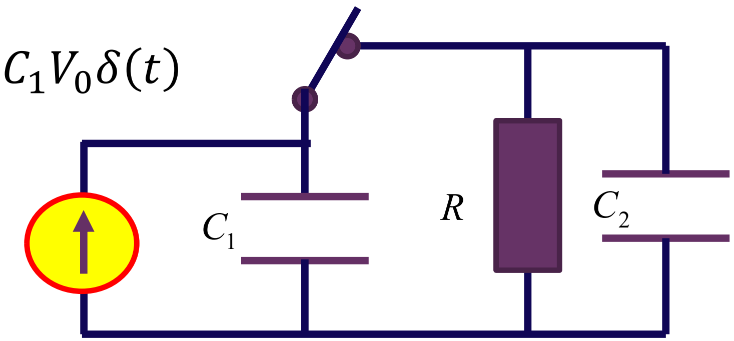




$$v_o(0^+) = \frac{C_1}{C_1 + C_2}V_0$$

也可用等效电路法

$C_1V_0\delta(t)$



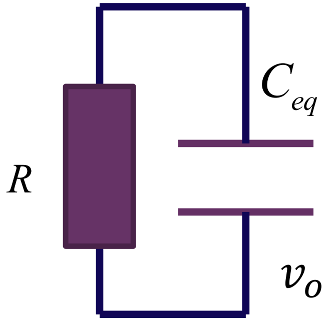
$$v_o(0^+) = \frac{1}{C_1 + C_2}\int_{0^-}^{0^+} C_1V_0\delta(t)dt$$

$$= \frac{C_1V_0}{C_1 + C_2}\int_{0^-}^{0^+} \delta(t)dt = \frac{C_1V_0}{C_1 + C_2}$$

电容电压跳变，必有冲激电流产生，部分能量以电磁辐射形式释放（从电路中分析不出这部分能量到了哪里，是由于电路抽象条件已经不成立）

其后就是简单的电容放电

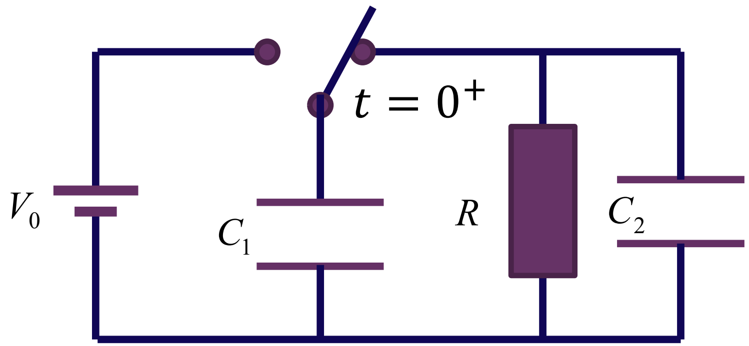
$t > 0$



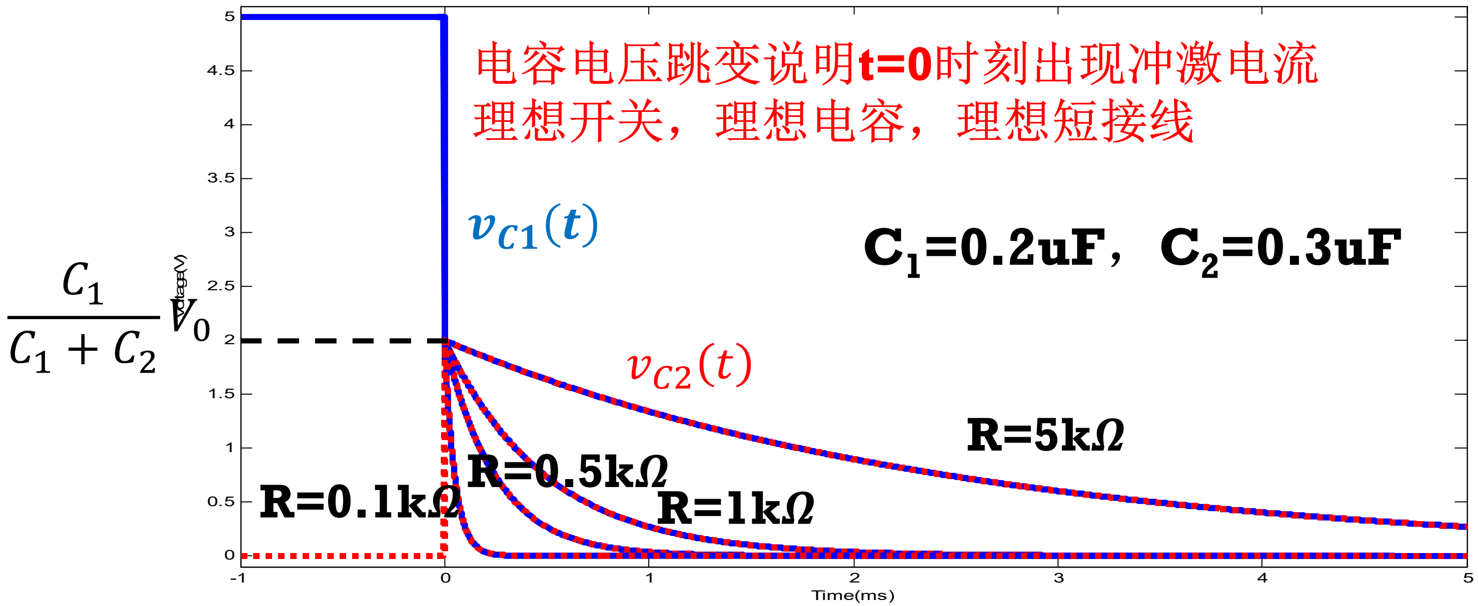
$$C_{eq} = C_1 + C_2$$

$$v_o(0^+) = \frac{C_1}{C_1 + C_2} V_0$$

$$\tau = R\left(C_1 + C_2\right)$$

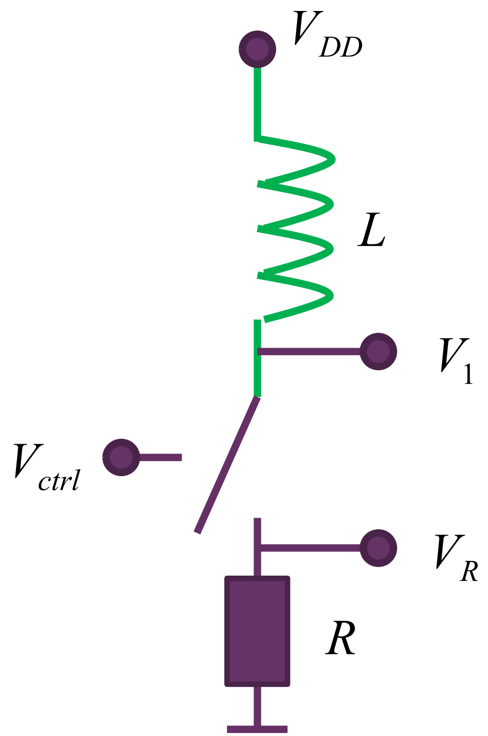


$$v_{C1}(t) = v_{C2}(t) = \frac{C_1}{C_1 + C_2} V_0 e^{-\frac{t}{\tau}} \qquad (t > 0)$$



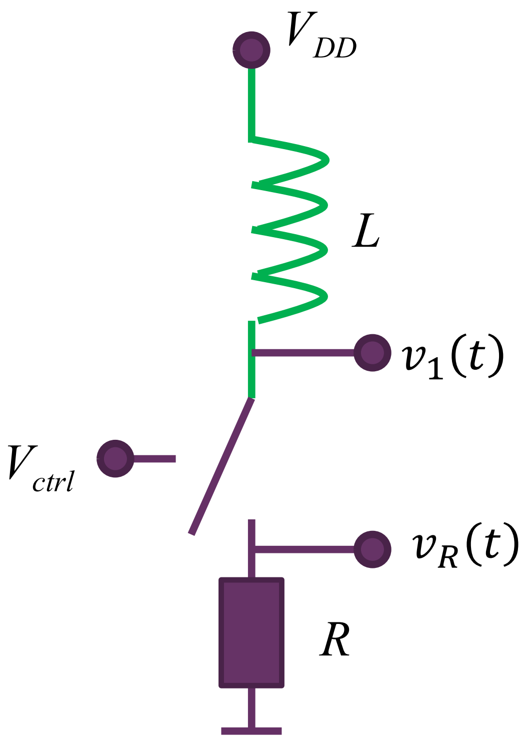
电容两端电压波形

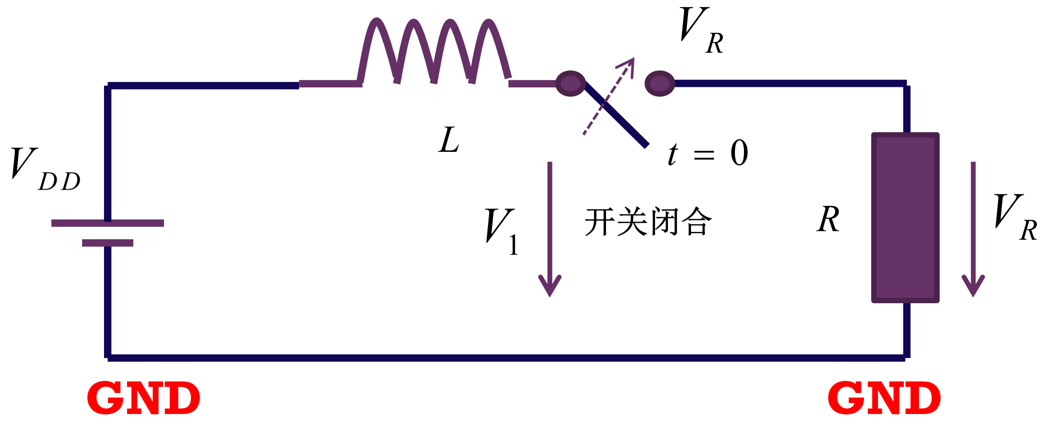
作业8.3 电火花的产生



- 这是一个继电器等效电路，晶体管开关可以接通电路，为负载电阻供电
  - 假设开关是理想开关
- 请分析开关闭合瞬间，负载电阻上的电压变化情况
- 请分析开关断开瞬间，开关两端电压变化情况
  - 机械开关则产生电火花，晶体管开关则击穿，下学期分析其解决方案

开关闭合

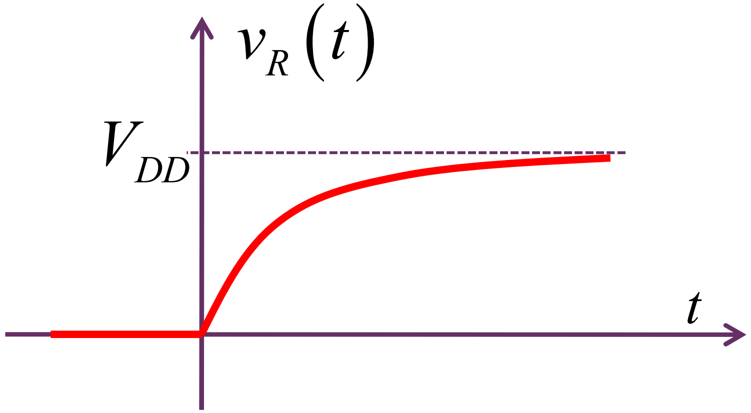




开关闭合：三要素法

$$i_L(0^+) = i_L(0^-) = 0 \quad i_{L\infty}(t) = \frac{V_{DD}}{R} \quad \tau = GL = \frac{L}{R}$$

$$i_L(t) = i_{L\infty}(t) + \left(i_L(0^+) - i_{L\infty}(0^+)\right)e^{-\frac{t}{\tau}} \qquad (t > 0)$$

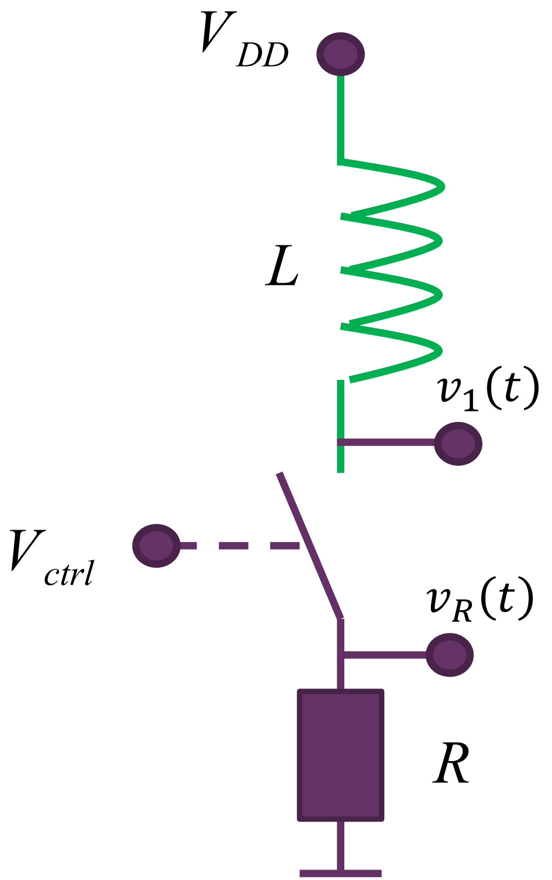


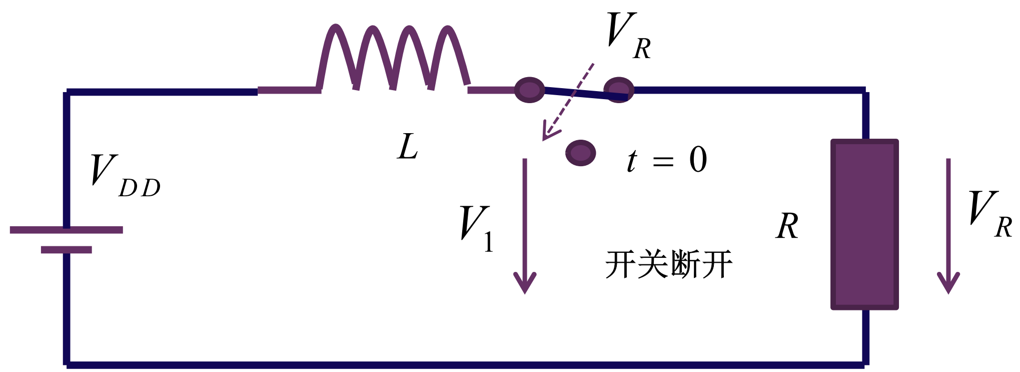
$$i_L(t) = \frac{V_{DD}}{R}\left(1 - e^{-\frac{t}{GL}}\right)U(t)$$

$$v_R(t) = i_L(t)R = V_{DD}\left(1 - e^{-\frac{t}{GL}}\right)U(t)$$

一阶低通系统：通直流阻交流

开关断开





$$i_L(0^-)=\frac{V_{DD}}{R} \qquad i_L(0^+)=0$$

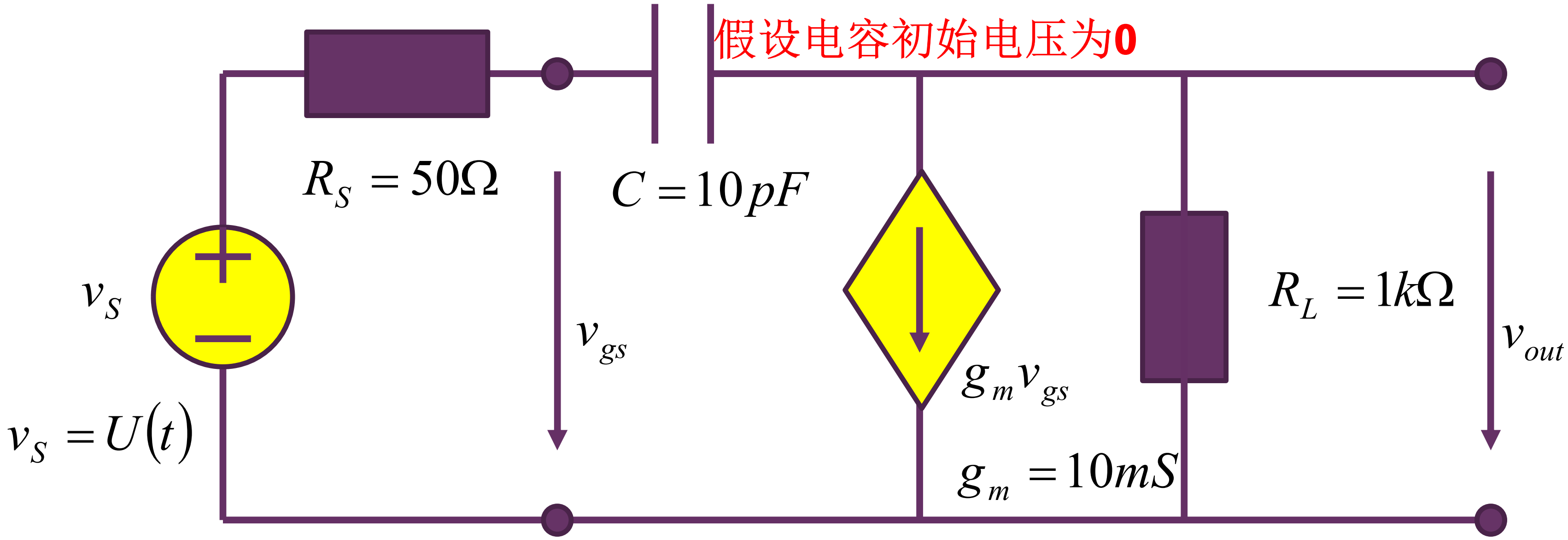
强行断流

$$v_1(0^-)=V_{DD}, \quad v_1(0^+)=V_{DD}-L\frac{di_L(0^+)}{dt}=V_{DD}+L\frac{V_{DD}}{R}\delta(t)$$

开关断开瞬间，开关上端点产生冲激电压

晶体管开关瞬间击穿损毁
（机械开关，空气击穿，产生电火花）

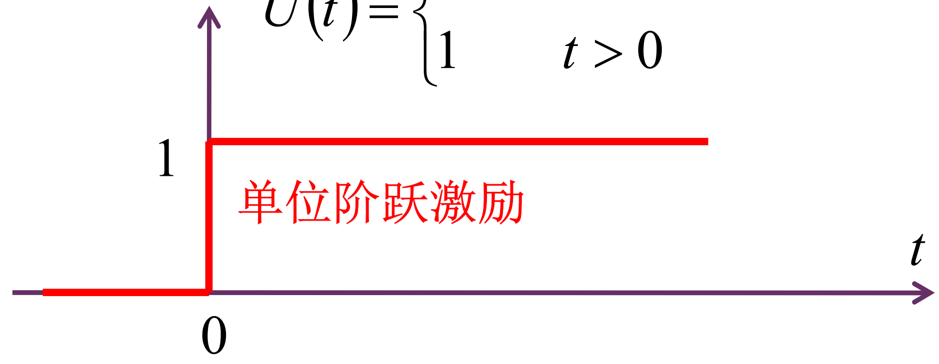
作业11.5 一阶RC电路都可用三要素法分析



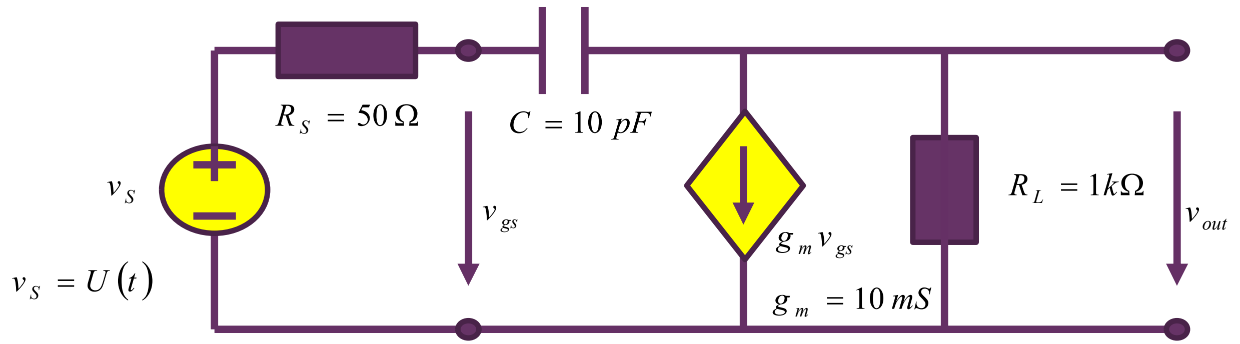
1/用三要素法获得输出电压单位阶跃响应

2/用任意方法在相量域获得电压增益传递函数

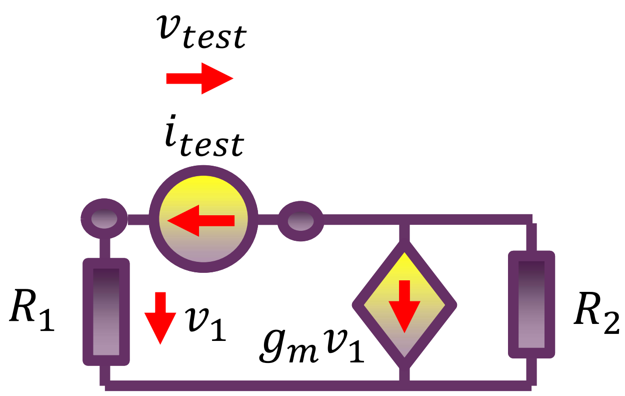
$$U(t) = \begin{cases} 0 & t < 0 \\ 1 & t > 0 \end{cases}$$



三要素法：时间常数



$$v_o(t) = v_{o\infty}(t) + \left(v_o(0^+) - v_{o\infty}(0^+)\right)e^{-\frac{t}{\tau}} \qquad (t \ge 0)$$



$$\tau = R_{eq}C = ?$$

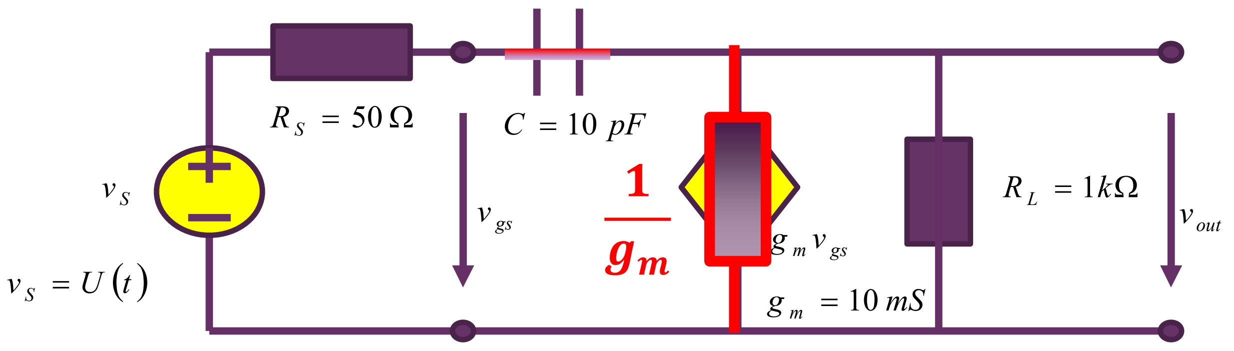
$$v_{test} = i_{test}R_1 + (i_{test} + g_m i_{test}R_1)R_2$$

$$R_{eq} = \frac{v_{test}}{i_{test}} = R_1 + R_2 + g_m R_1 R_2$$

$$\tau = R_{eq}C = (R_S + R_L + g_m R_S R_L)C$$
$$= (50 + 1000 + 0.01 \times 1000 \times 50) \times 10p$$
$$= 1550 \times 10p = 15.5ns$$

求等效电阻时，独立源不起作用，但受控源的作用必须保留

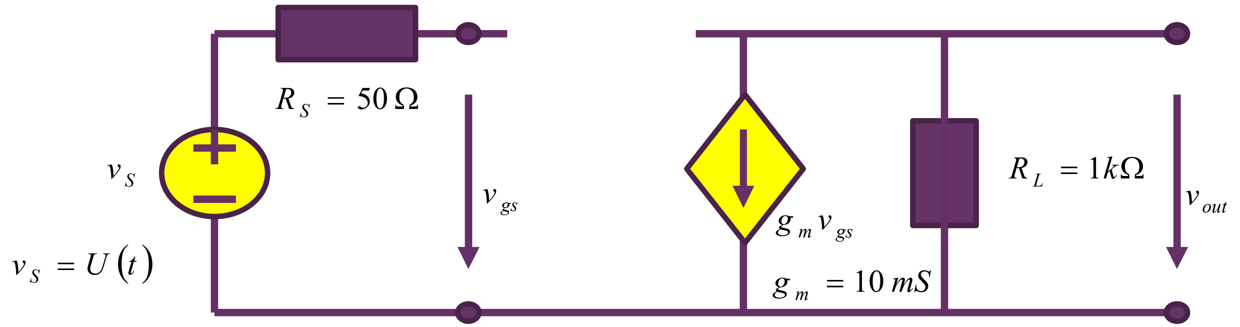
三要素法：初值



$$v_o(0^+) = \frac{R_L || \frac{1}{g_m}}{R_S + R_L || \frac{1}{g_m}} v_S(0^+) = \frac{\frac{R_L}{1 + g_m R_L}}{R_S + \frac{R_L}{1 + g_m R_L}} v_S(0^+)$$

$$= \frac{R_L}{R_S + R_L + g_m R_S R_L} v_S(0^+) = \frac{1000}{1550} \times 1 = 0.645V$$

三要素法：稳态响应



$$v_{o\infty}(t) = -g_m R_L v_{S\infty}(t) = -10m \times 1k \times 1 = -10V$$

$$v_o(0^+) = \frac{R_L}{R_S + R_L + g_m R_S R_L} v_S(0^+) = 0.645V$$

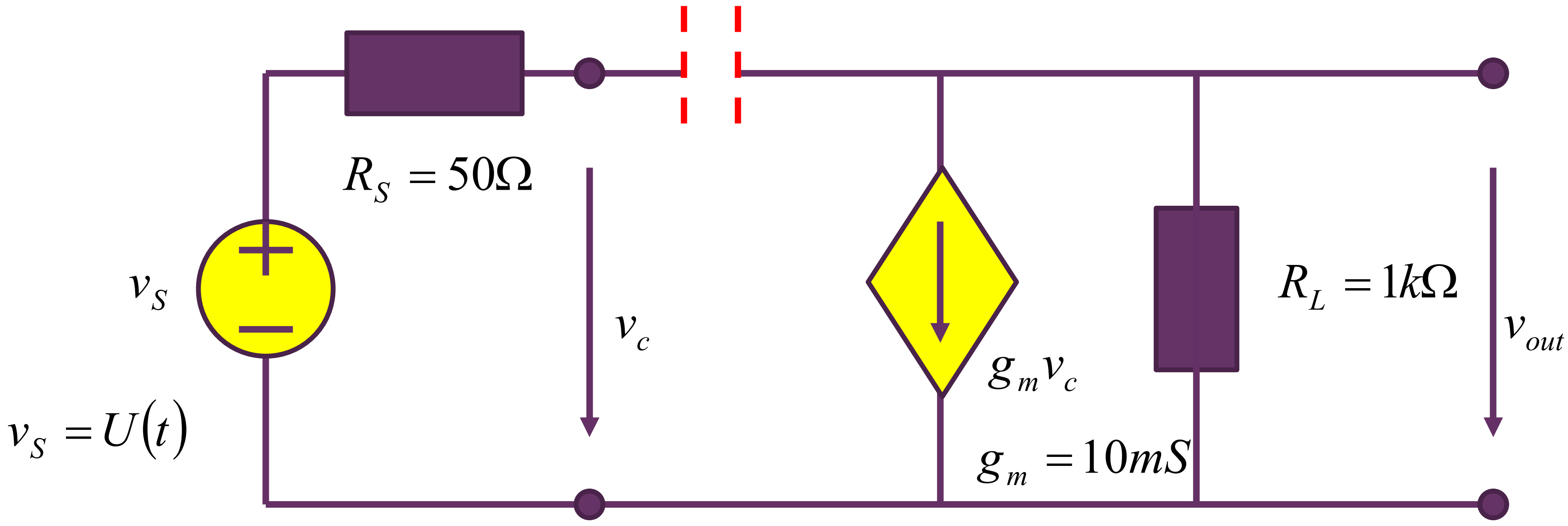
$$\tau = R_{eq}C = (R_S + R_L + g_m R_S R_L)C = 15.5ns$$

晶体管放大器的阶跃响应

$$v_o(t) = v_{o\infty}(t) + \left(v_o(0^+) - v_{o\infty}(0^+)\right)e^{-\frac{t}{\tau}} \qquad (t \geq 0)$$

$$= -10 + 10.645e^{-\frac{t}{15.5n}} \qquad (V)$$

电容的影响



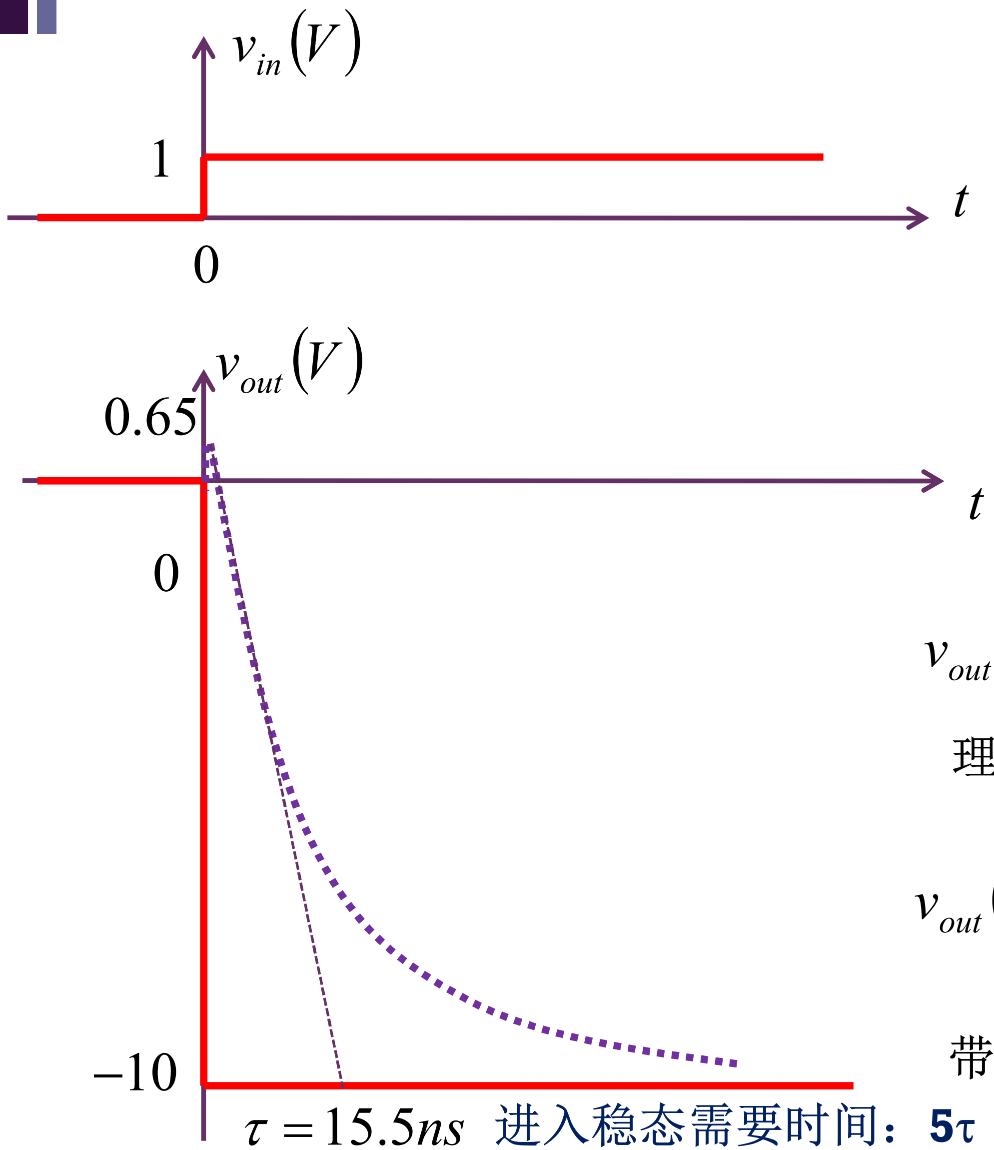
$$v_{out}(t) = -g_m R_L v_S(t) = -10U(t)$$

没有电容，简单的晶体管反相放大器

$$v_{out}(t) = \left(-10 + 10.65e^{-\frac{t}{15.5\times10^{-9}}}\right)U(t)$$

考虑晶体管寄生电容，不再是简单的反相放大电路，还需考虑电容充放电形成的过渡过程

电容导致信号延时传输



$$v_{in}(t)=U(t)$$

输出想要达到理想的稳态，需要等待一段时间：这个等待时间一般称为延时

$$v_{out}(t)=-10U(t)$$

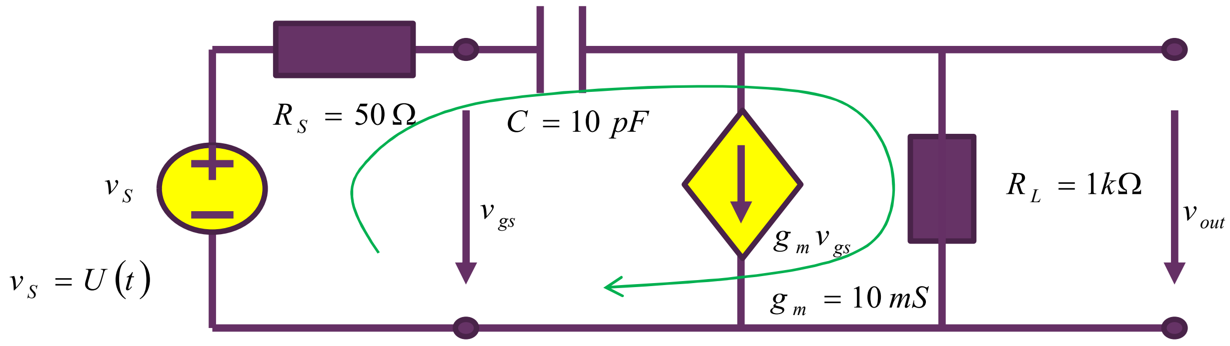
理想晶体管的反相放大输出响应

$$v_{out}(t)=\left(-10+10.65e^{-\frac{t}{15.5\times10^{-9}}}\right)U(t)$$

带跨接寄生电容的反相放大器输出响应

$\tau=15.5ns$ 进入稳态需要时间：**5τ**

传递函数：回路电流法



$$\left(R_S + \frac{1}{sC} + R_L\right)\dot{I}_l = \dot{V}_s + g_m\dot{V}_{gs}R_L = \dot{V}_s + g_m\left(\dot{V}_s - R_S\dot{I}_l\right)R_L$$

$$\left(\frac{1}{sC} + R_S + R_L + g_mR_SR_L\right)\dot{I}_l = (g_mR_L + 1)\dot{V}_s \qquad \dot{I}_l = \frac{g_mR_L + 1}{\frac{1}{sC} + R_S + R_L + g_mR_SR_L}\dot{V}_s$$

$$\dot{V}_{out} = R_L\dot{I}_l - g_m\dot{V}_{gs}R_L = R_L\dot{I}_l - g_m\left(\dot{V}_s - R_S\dot{I}_l\right)R_L = (1 + g_mR_S)R_L\dot{I}_l - g_mR_L\dot{V}_s$$

$$= (1 + g_mR_S)R_L\frac{g_mR_L + 1}{\frac{1}{sC} + R_S + R_L + g_mR_SR_L}\dot{V}_s - \ g_mR_L\dot{V}_s$$

$$= -g_mR_L\frac{1 - s\frac{C}{g_m}}{1 + s(R_S + R_L + g_mR_SR_L)C}\dot{V}_s$$

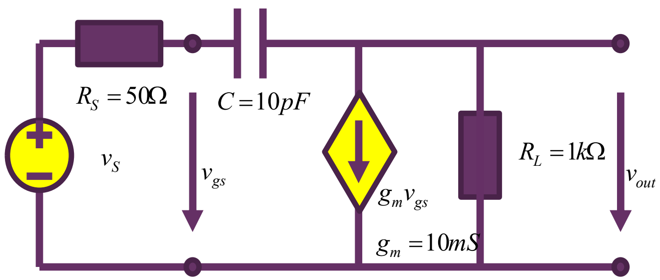
结点电压法自行练习

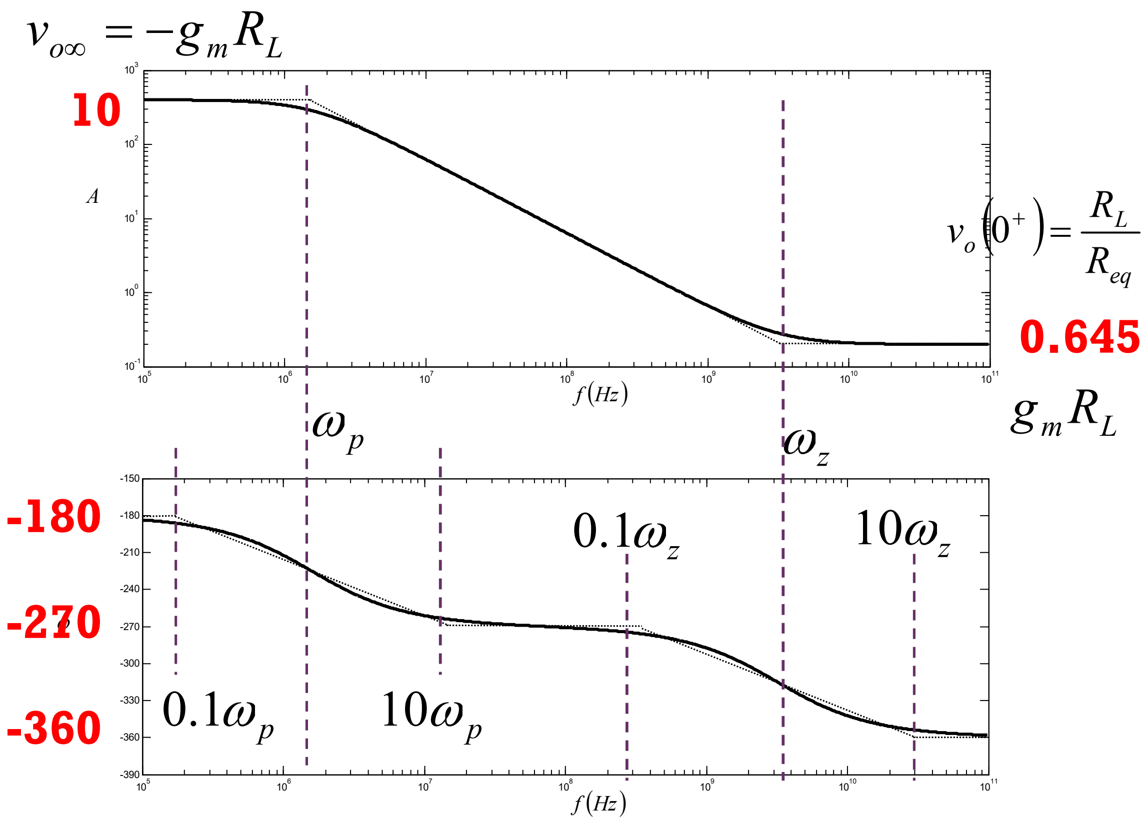
频率特性

$$H(s) = -g_m R_L \frac{1 - s\frac{C}{g_m}}{1 + s(R_S + R_L + g_m R_S R_L)C} = -g_m R_L \frac{1 - \frac{j\omega}{\omega_z}}{1 + \frac{j\omega}{\omega_p}}$$

$$\omega_p = \frac{1}{(R_S + R_L + g_m R_S R_L)C}$$

$$\omega_z = \frac{g_m}{C}$$





时频是对应的

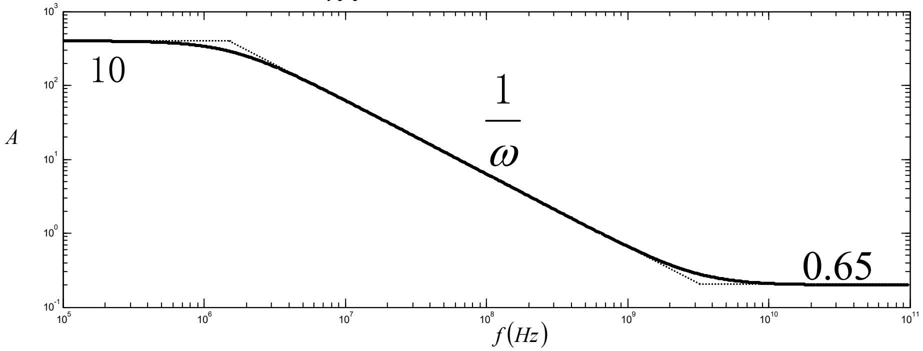
$$H(s)=-g_mR_L\frac{1-\frac{s}{g_m/C}}{1+sR_{eq}C}=-g_mR_L\frac{1}{1+sR_{eq}C}+\frac{R_L}{R_{eq}}\frac{sR_{eq}C}{1+sR_{eq}C}$$

$$R_{eq}=R_S+R_L+g_mR_SR_L$$

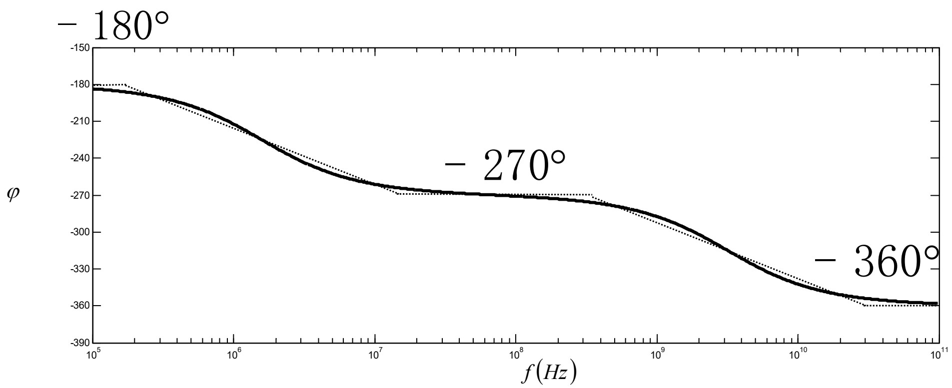
$$g(t)=\left(-g_mR_L+\left(\frac{R_L}{R_{eq}}+g_mR_L\right)e^{-\frac{t}{R_{eq}C}}\right)U(t)$$

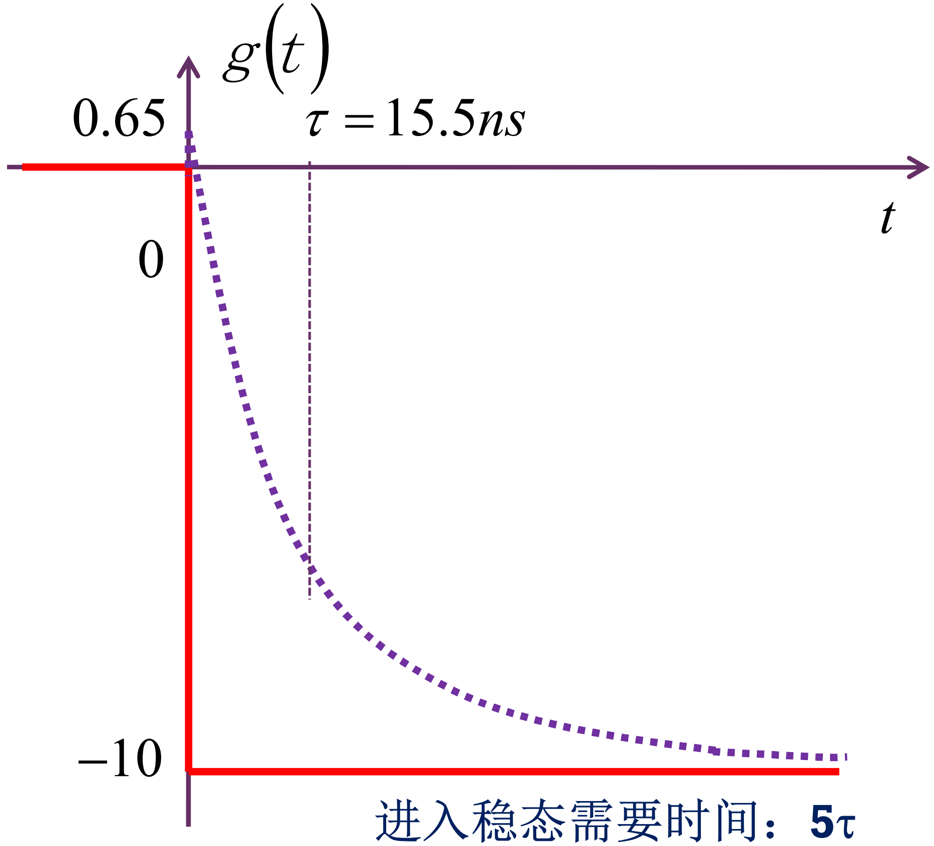
$$=-g_mR_L\left(1-e^{-\frac{t}{R_{eq}C}}\right)U(t)+\frac{R_L}{R_{eq}}e^{-\frac{t}{R_{eq}C}}U(t)$$

$$f_0=\frac{1}{2\pi\tau}=10.27MHz$$

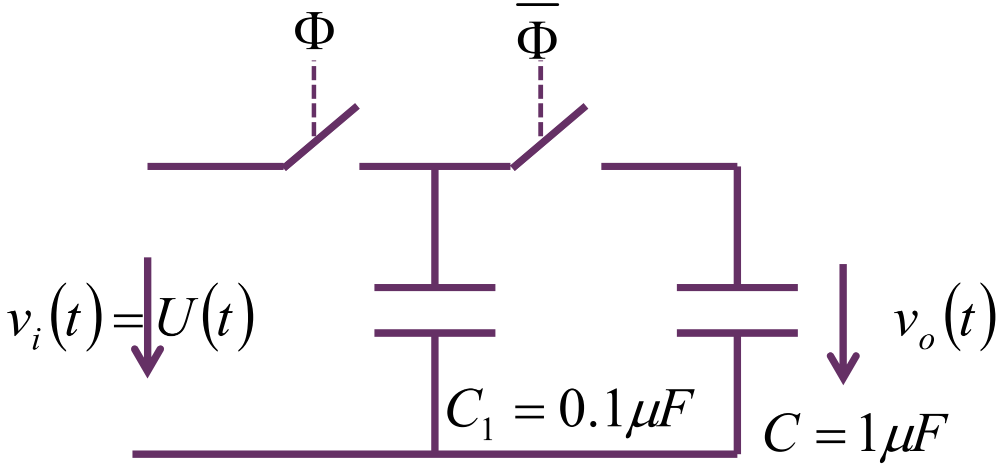


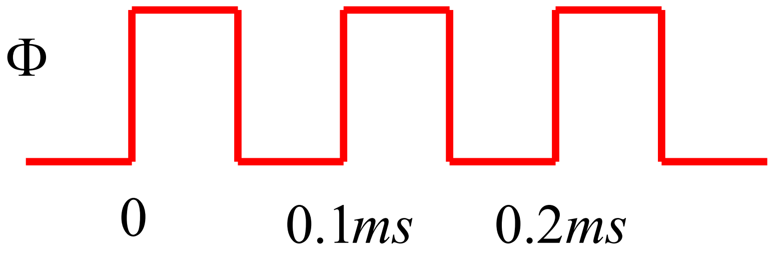
$$10\times f_0=0.65\times f_z$$

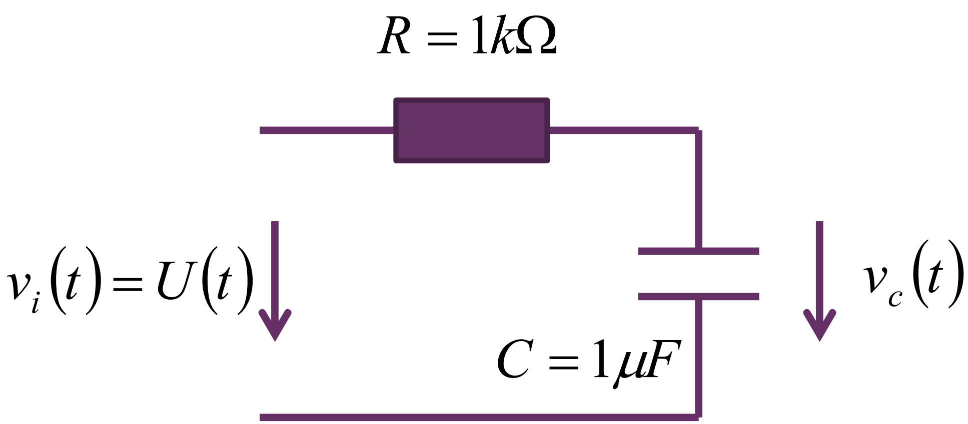




作业8.4 开关电容等效为电阻

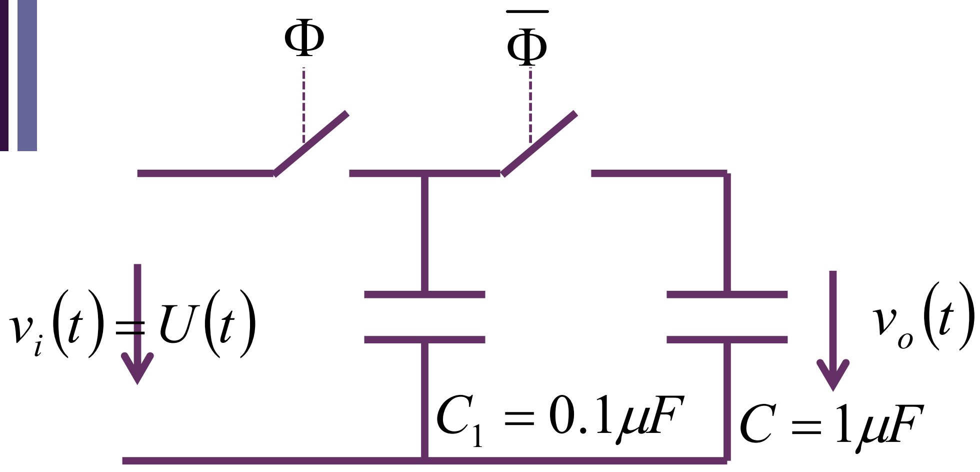


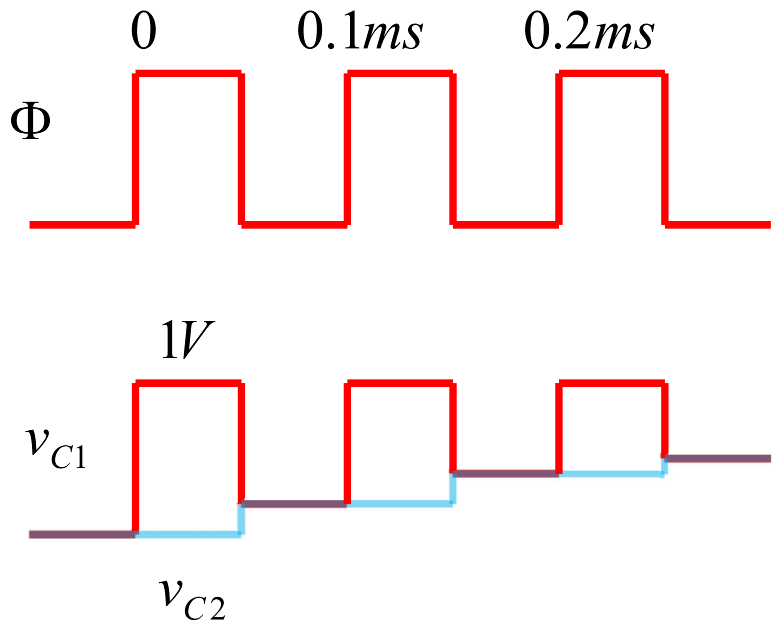




- 假设开关是理想开关
- 考察两个电路输出电压波形是否一致?
  - 写出输出波形表达式
- 研究开关电容对电阻的可替代性?

$$R_{eff}=\frac{T}{C}$$





$t=0.05ms$

$$v_{C2}(1)=\frac{C_1\cdot 1+C_2\cdot 0}{C_1+C_2}=\frac{1}{11}(V)$$

1/电荷守恒
2/源等效

$t=0.15ms$

$$v_{C2}(2)=\frac{C_1\cdot 1+C_2\cdot v_{C2}(1)}{C_1+C_2}$$

$$=\frac{0.1+\frac{1}{11}}{1.1}=\frac{1}{11}+\frac{10}{11^2}(V)$$

$t=0.25ms$

$$v_{C2}(3)=\frac{C_1\cdot 1+C_2\cdot v_{C2}(2)}{C_1+C_2}$$

$$=\frac{1+\frac{10}{11}+\frac{100}{11^2}}{11}=\frac{1}{11}+\frac{10}{11^2}+\frac{100}{11^3}(V)$$

电容电压变化规律

$$t=(0.1n-0.05)ms$$

$$v_{C2}(n)=\frac{C_1\cdot 1+C_2\cdot v_{C2}(n-1)}{C_1+C_2}=\frac{C_1\cdot 1+C_2\cdot\dfrac{C_1\cdot 1+C_2\cdot v_{C2}(n-2)}{C_1+C_2}}{C_1+C_2}$$

$$=\frac{C_1\cdot 1+C_2\cdot\dfrac{C_1\cdot 1+C_2\cdot\dfrac{C_1\cdot 1+C_2\cdot v_{C2}(n-3)}{C_1+C_2}}{C_1+C_2}}{C_1+C_2}=\ldots$$

$$=\frac{C_1}{C_1+C_2}+\frac{C_2C_1}{(C_1+C_2)^2}+\frac{C_2^2C_1}{(C_1+C_2)^3}+\ldots.+\frac{C_2^{n-1}C_1}{(C_1+C_2)^n}$$

$$=\frac{C_1}{C_1+C_2}\left(1+\frac{C_2}{C_1+C_2}+\frac{C_2^2}{(C_1+C_2)^2}+\ldots.+\frac{C_2^{n-1}}{(C_1+C_2)^{n-1}}\right)$$

特性

$$v_{C2}(n)=\frac{C_1}{C_1+C_2}+\frac{C_2C_1}{(C_1+C_2)^2}+\frac{C_2^2C_1}{(C_1+C_2)^3}+....+\frac{C_2^{n-1}C_1}{(C_1+C_2)^n}$$

$$=\frac{C_1}{C_1+C_2}\left(1+\frac{C_2}{C_1+C_2}+\frac{C_2^2}{(C_1+C_2)^2}+....+\frac{C_2^{n-1}}{(C_1+C_2)^{n-1}}\right)=1-\left(\frac{C_2}{C_1+C_2}\right)^n$$

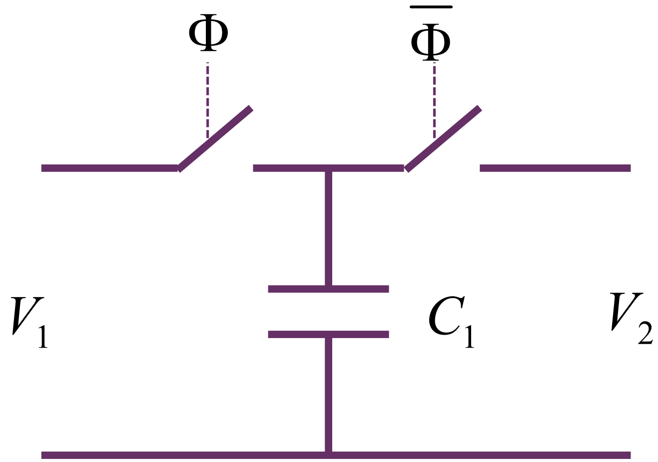
$$v_{C2}(n)=v_{C2}(n-1)+\left(\frac{C_2}{C_1+C_2}\right)^{n-1}\frac{C_1}{C_1+C_2}$$

后一个状态是前一个状态的增量
增量随时间增加是指数衰减的

$$v_{C2}(\infty)=1(V)$$

状态值在时间趋于无穷时趋于终值**1V**

开关电容等效为电阻



一个周期内，有ΔQ的电荷从端口1转移到端口2，相当于有电流从端口1流到端口2

$$\bar{I}=\frac{Q_{\Phi}-Q_{\bar{\Phi}}}{T}=\frac{C_1(V_1-V_2)}{T}$$

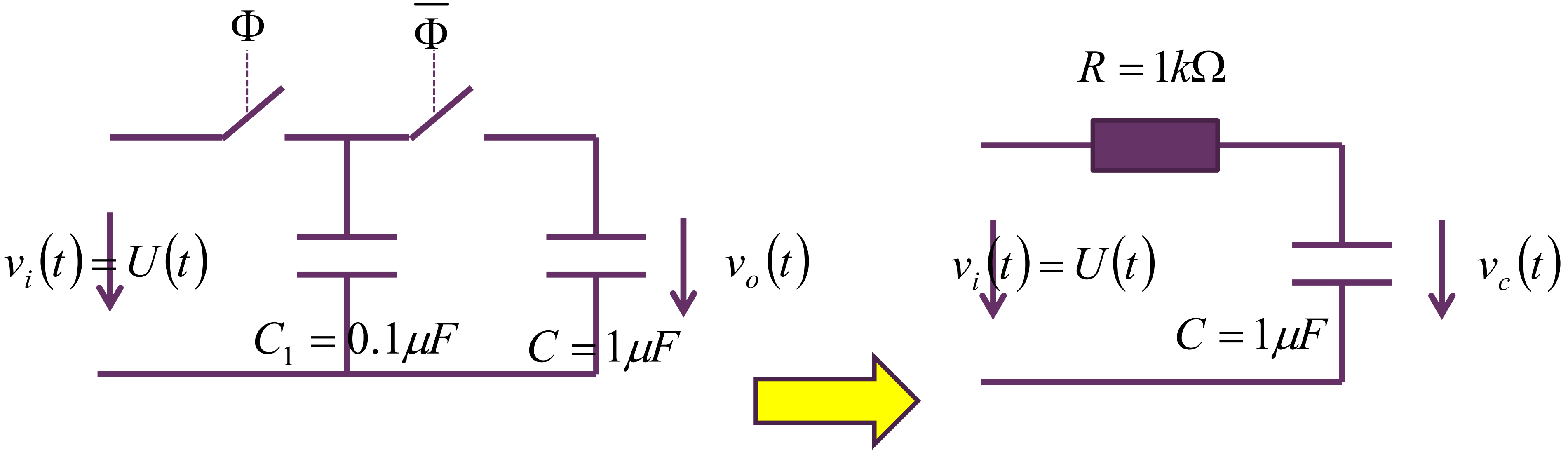
端口1流到端口2有电压差时，就有电流流过，因而可等效为一个电阻

Φ $\quad Q_{\Phi}=C_1V_1$

$\bar{\Phi}$ $\quad Q_{\bar{\Phi}}=C_1V_2$

$$R_{eq}=\frac{V_1-V_2}{\bar{I}}=\frac{T}{C_1}=\frac{0.1ms}{0.1\mu F}=1k\Omega$$

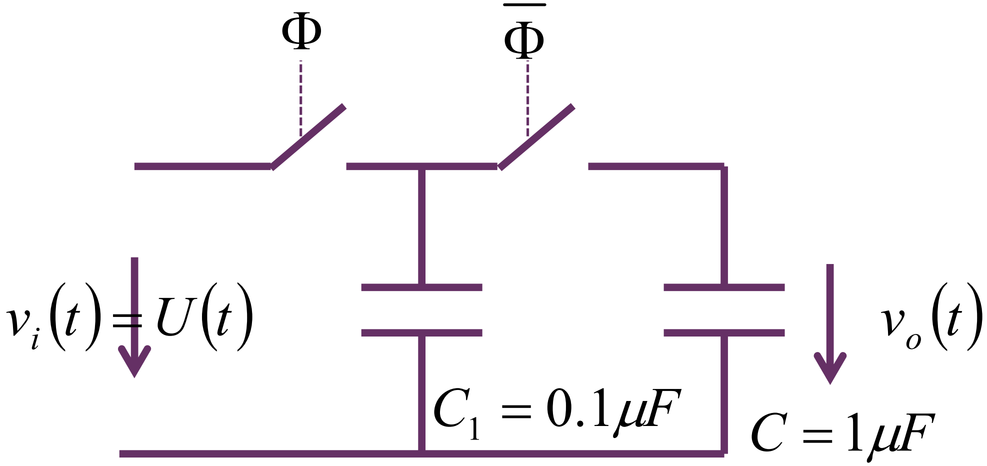
拟合一阶RC充电过程



$$v_{C2}(n)=\left(1-\left(\frac{C_2}{C_1+C_2}\right)^n\right)\cdot U(n)$$

$$v_c(t)=\left(1-e^{-\frac{t}{\tau}}\right)U(t)=\left(1-e^{-\frac{t}{RC}}\right)\cdot U(t)$$

高度拟合条件



$n\geq 0$

$$v_{C2}(n)=1-\left(\frac{C_2}{C_1+C_2}\right)^n$$

离散时间的充电过程：一个时钟周期完成一次快速充电（瞬间充电）

$$v_c(t)=1-e^{-\frac{t}{RC}}\overset{t=nT}{=}1-e^{-\frac{nT}{RC}}=1-\left(e^{-\frac{T}{RC}}\right)^n \qquad t\geq 0$$

连续时间的充电过程：时时刻刻在充电进行中

$$\frac{C_2}{C_1+C_2}\Leftrightarrow e^{-\frac{T}{RC}}\overset{T<<RC}{\approx}\frac{1}{1+\frac{T}{RC}}=\frac{1}{1+\frac{T}{RC_2}}=\frac{C_2}{C_2+\frac{T}{R}}=\frac{C_2}{C_2+C_1} \qquad R=\frac{T}{C_1}$$

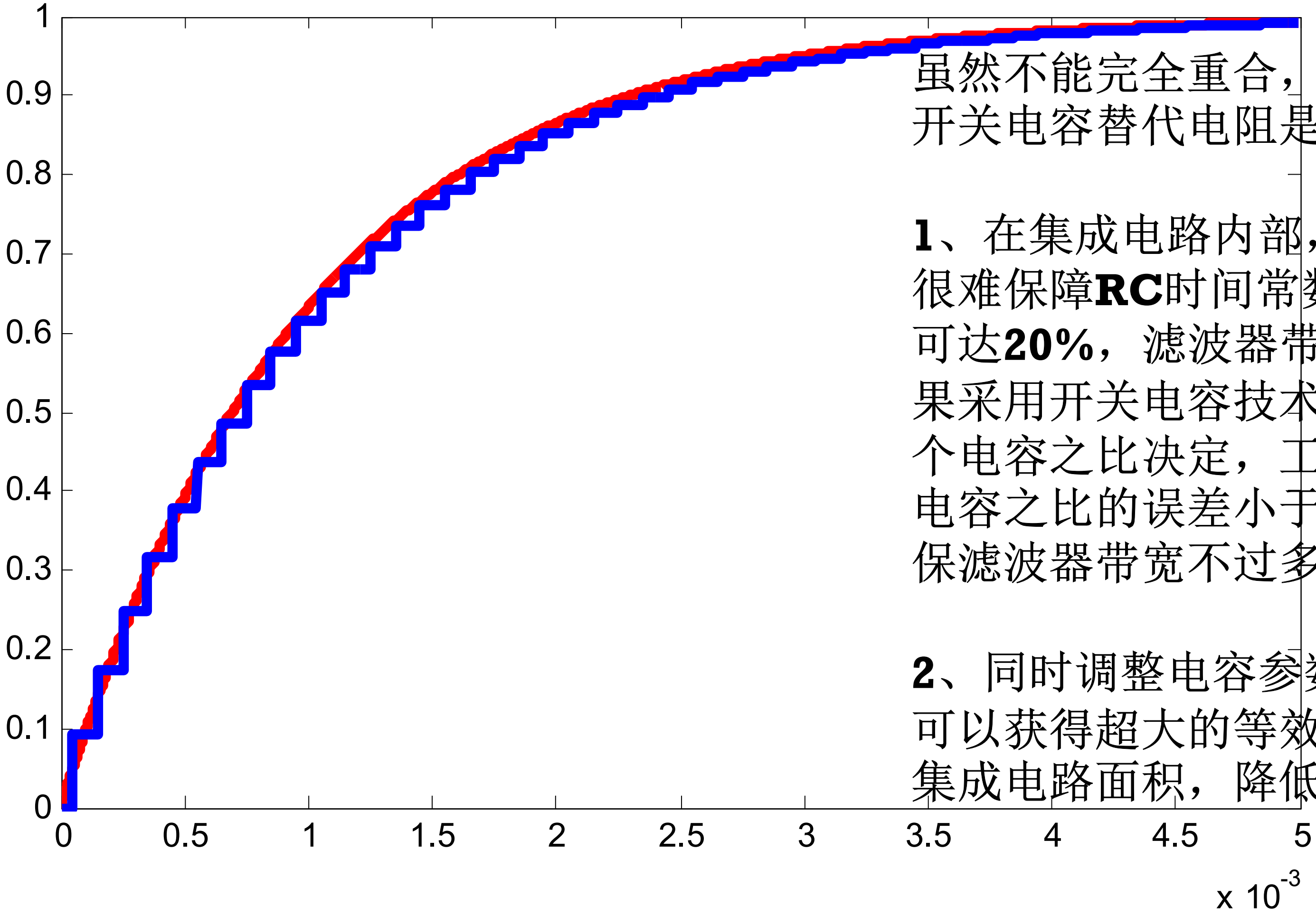
一个周期内的衰减量

$$R=\frac{T}{C_1}<<\frac{RC}{C_1} \qquad C>>C_1$$

转移电荷的开关电容越小，
用电阻等价的误差就越小

时域波形

$$R_{eq} = \frac{T}{C_1} \qquad \tau = R_{eq}C_2 = T\frac{C_2}{C_1}$$



虽然不能完全重合，但足够接近，用开关电容替代电阻是一种合理的选择

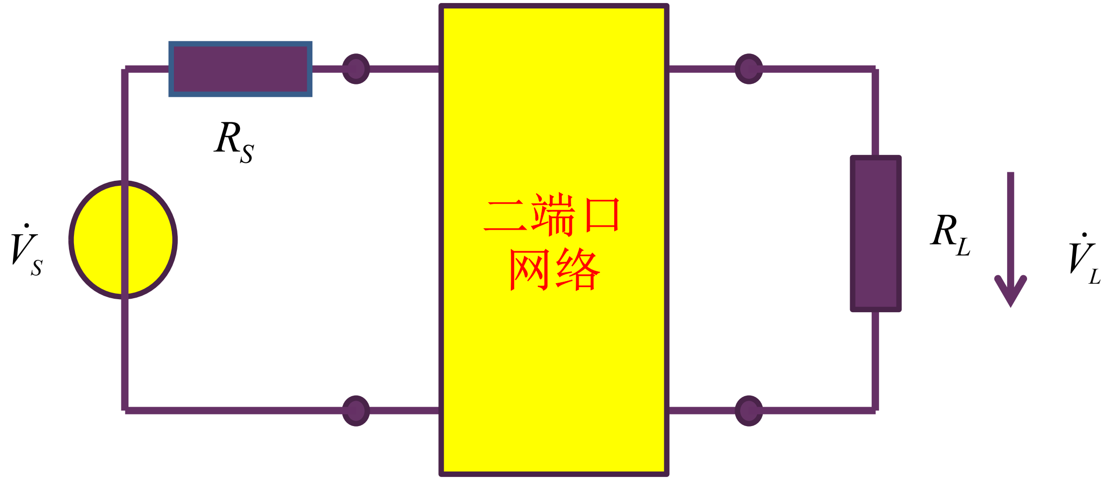
1、在集成电路内部，由于工艺问题，很难保障**RC**时间常数的精度，误差可达**20%**，滤波器带宽无法保证，如果采用开关电容技术，时间常数由两个电容之比决定，工艺上可保证两个电容之比的误差小于**2%**，从而可确保滤波器带宽不过多偏离设计值

2、同时调整电容参数和时钟周期，可以获得超大的等效电阻，可以节约集成电路面积，降低系统成本

作业7.5 一阶滤波器设计

- 设计一个RC低通滤波器，使得其3dB带宽为10MHz，已知信源内阻为50Ω，负载电阻为50Ω
  - 画出其幅频特性和相频特性（画伯特图）
  - 请再设计一个高通滤波器，3dB频点也在10MHz，画出伯特图。
  - 选作：如果用RL滤波器，滤波器形态怎样？参数如何设定？

滤波器是线性二端口网络



$$\left|H(j\omega)\right|^2 = \frac{\left|\dot{V}_L\right|^2 / R_L}{\left|\dot{V}_S\right|^2 / 4R_S}$$

$$= \frac{P_L}{P_{S\max}} = G_p(\omega)$$

传递函数定义：

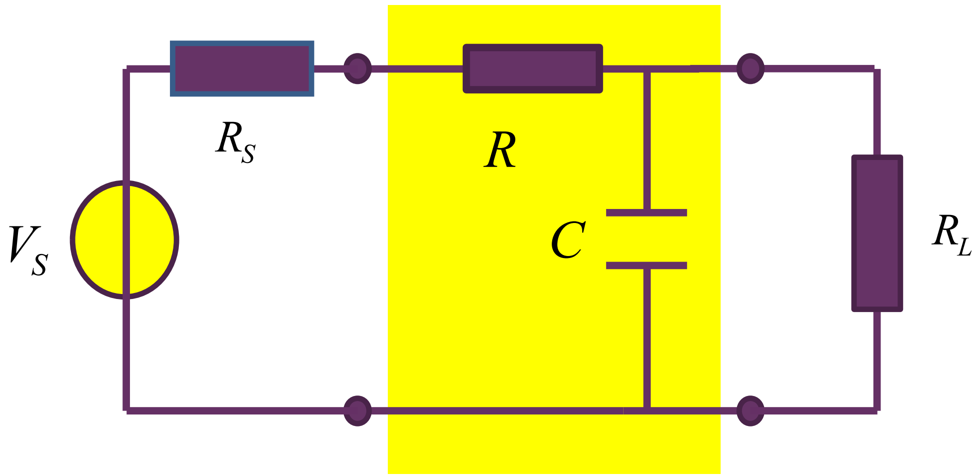
$$H(j\omega) = \frac{\dot{V}_L}{\dot{V}_S}$$

低频应用下的放大、滤波，或信源内阻为零，或负载电阻为无穷（输出开路）情况下，以电压传输为研究对象，做如是定义

$$H(j\omega) = 2\sqrt{\frac{R_S}{R_L}}\frac{\dot{V}_L}{\dot{V}_S}$$

射频应用下的放大、滤波，同时存在信源内阻和负载电阻，以功率传输为考察对象

一阶RC低通设计尝试



$$H(j\omega) = 2\sqrt{\frac{R_S}{R_L}}\frac{\dot{V}_L}{\dot{V}_S}$$

$$\frac{\dot{V}_L}{\dot{V}_S} = \eta \frac{\omega_0}{s+\omega_0}$$

典型低通

$$\eta = \frac{R_L}{R_S + R + R_L}$$

中心频点分压系数

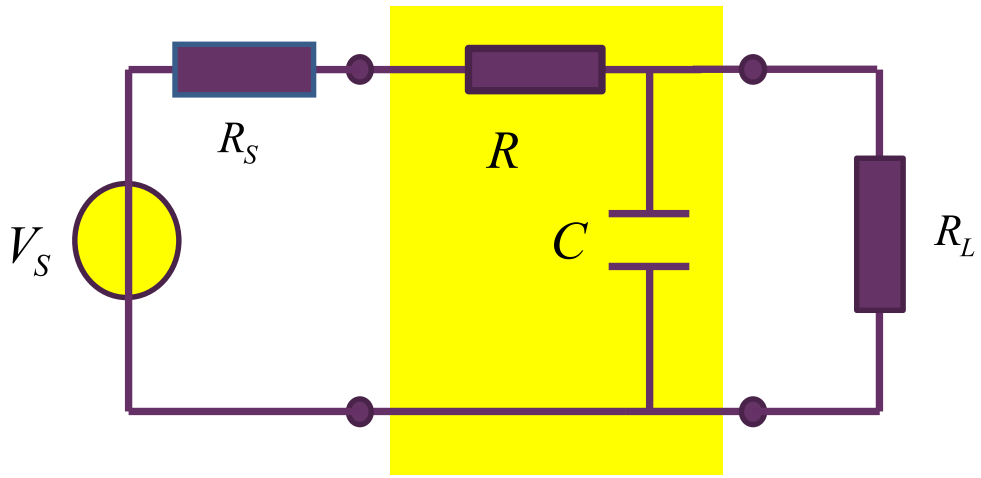
$$\omega_0 = \frac{1}{\tau} = \frac{1}{\frac{R_L(R_S+R)}{R_S+R+R_L}C}$$

3dB频点

$$H(j\omega) = 2\sqrt{\frac{R_S}{R_L}}\frac{\dot{V}_L}{\dot{V}_S} = H_0 \frac{\omega_0}{s+\omega_0}$$

$$H_0 = \frac{2\sqrt{R_S R_L}}{R_S + R + R_L}$$

设计自由度



$$H(j\omega)=2\sqrt{\frac{R_S}{R_L}}\frac{\dot V_L}{\dot V_S}=H_0\frac{\omega_0}{s+\omega_0}$$

$$H_0=\frac{2\sqrt{R_SR_L}}{R_S+R+R_L}$$

$$\omega_0=\frac{1}{\tau}=\frac{1}{\frac{R_L(R_S+R)}{R_S+R+R_L}C}$$

$$BW_{3dB}=10MHz=\frac{1}{2\pi\tau}=\frac{1}{2\pi C\left(R_L\parallel\left(R_S+R\right)\right)}$$

C、**R**两个自由度

$$H_0=\frac{2\sqrt{R_SR_L}}{R_S+R+R_L}=H(j0)\le 1$$

$$R=0: A_0=1$$

H_0^2中心频点功率传输系数

从最大功率传输角度

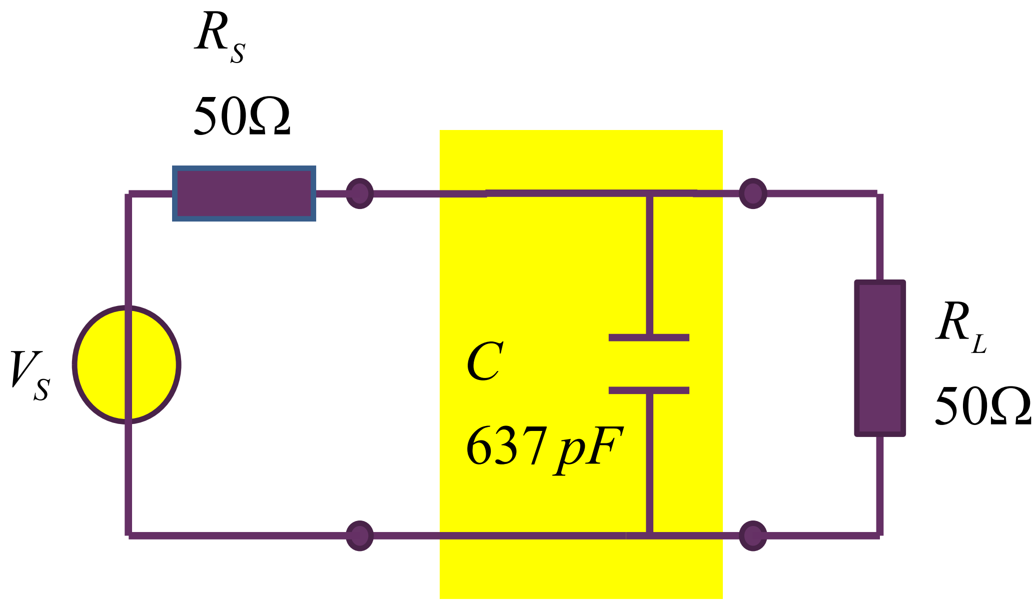
令**R=0**，无损滤波器

最终设计方案

$$BW_{3dB} = 10MHz = \frac{1}{2\pi\tau}$$

$$\tau = \frac{1}{2\pi BW_{3dB}} = 15.9ns = RC$$

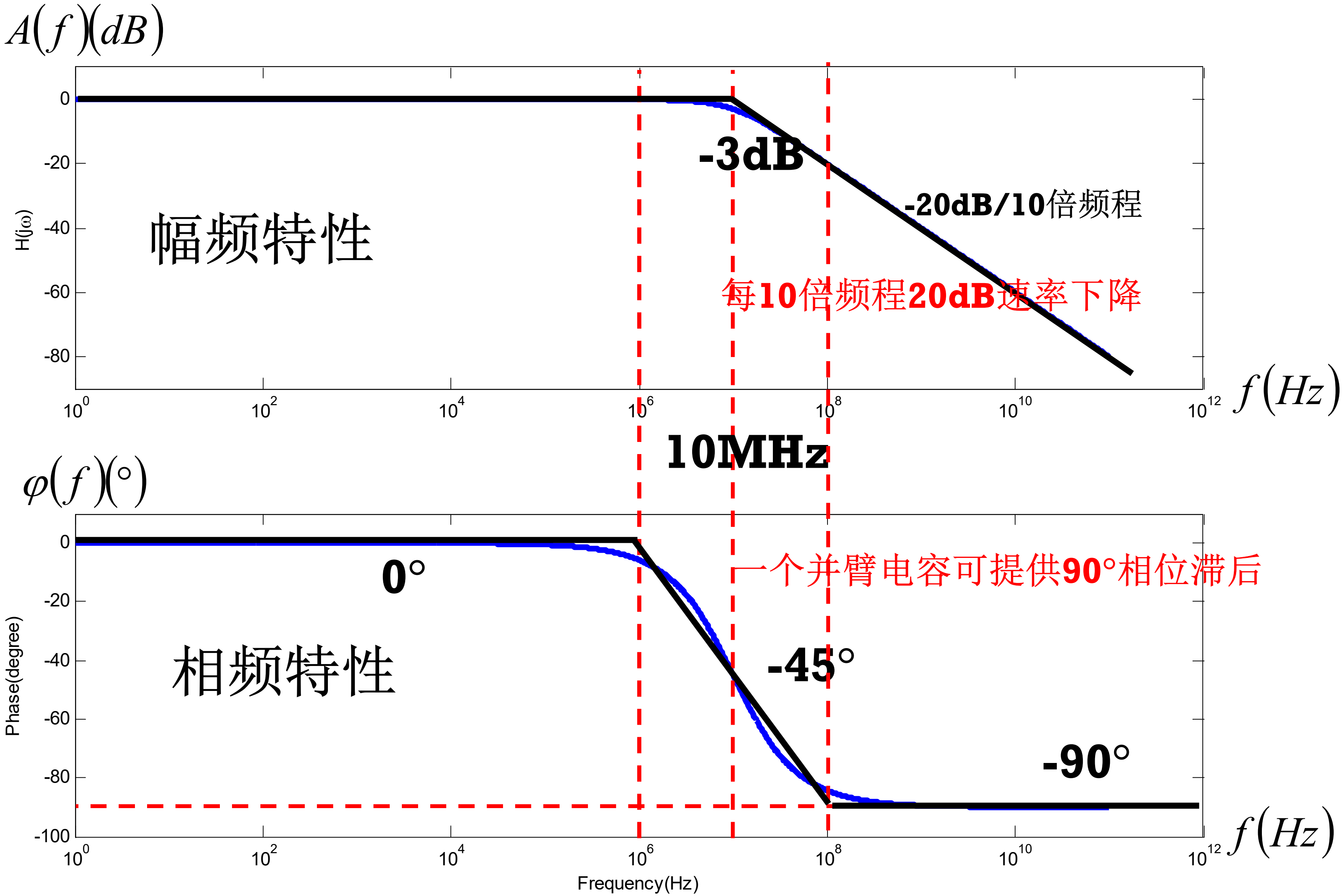
$$C = \frac{\tau}{R} = \frac{\tau}{R_L||R_S} = \frac{15.9n}{25} = 637pF$$



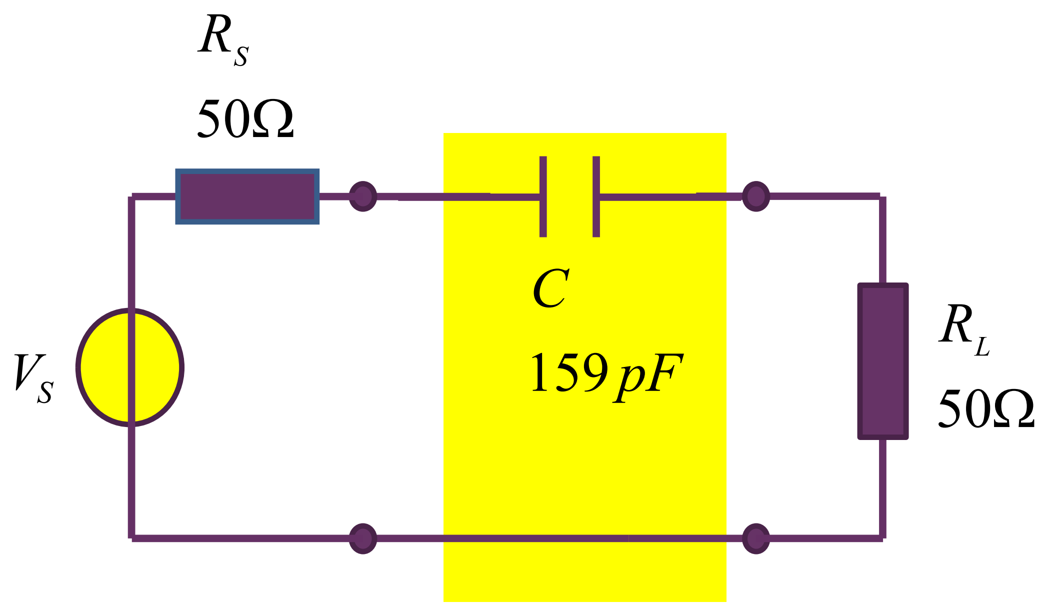
1、有信源内阻和负载电阻的无源滤波器设计，无源滤波器二端口网络应该是无损网络，如果信源内阻和负载电阻不等，可能还需阻抗变换网络

2、所设计的滤波器针对特定信源内阻和负载电阻，否则**3dB**频点会发生偏离

一阶低通滤波特性伯特图

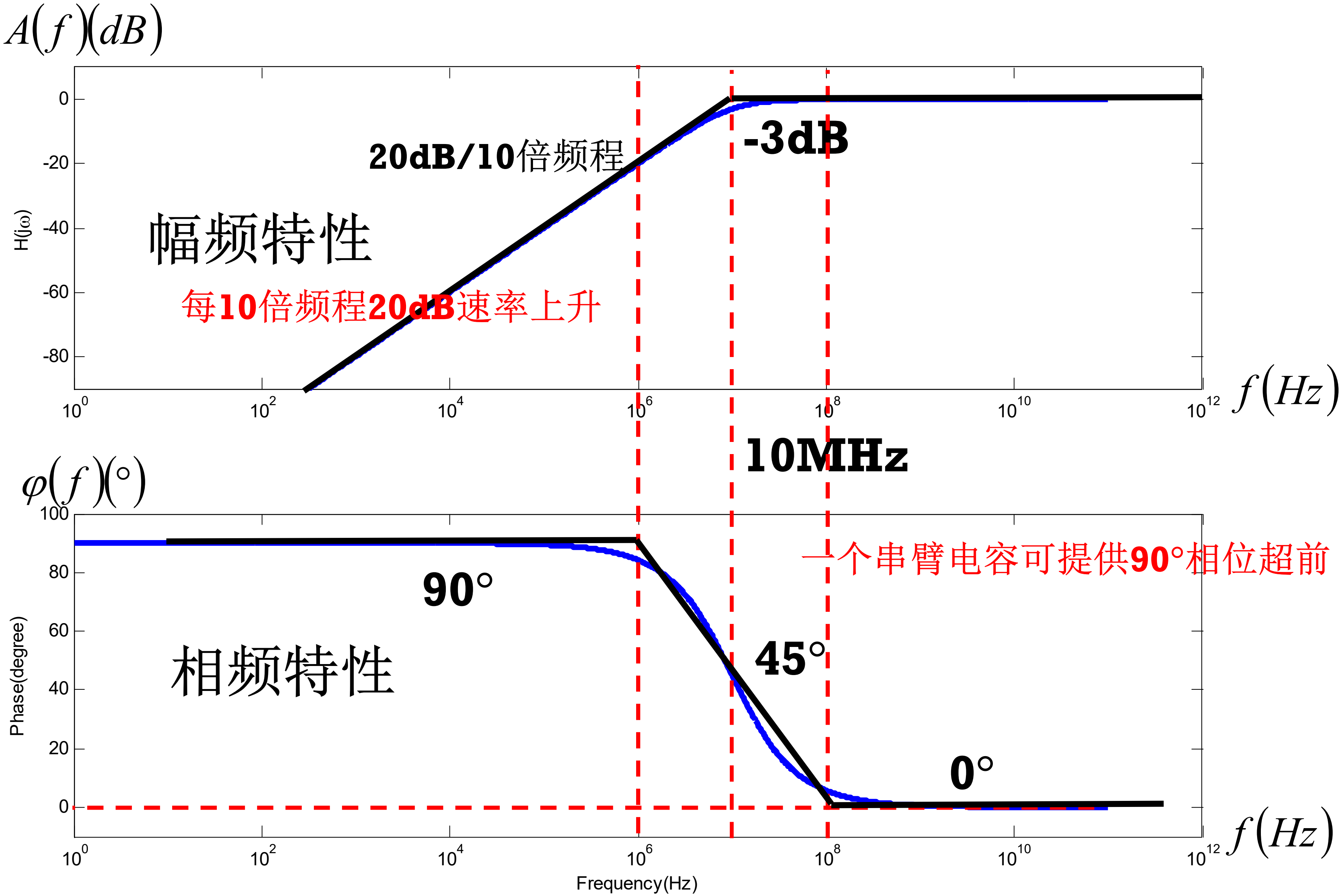


一阶高通滤波器设计

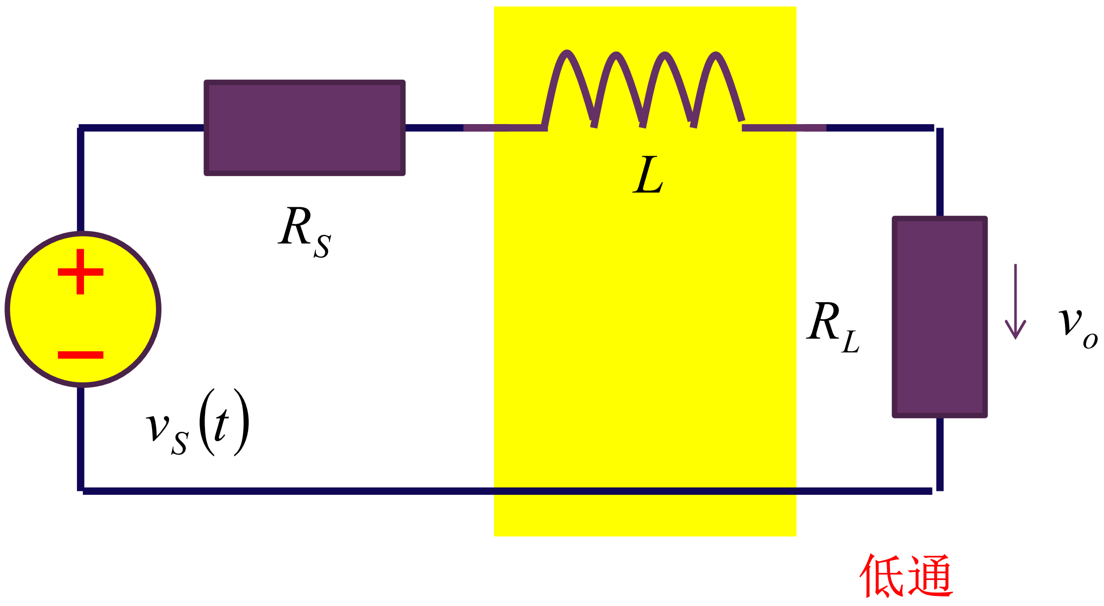


$$C=\frac{\tau}{R_L+R_S}=\frac{1}{2\pi\cdot f_{3dB}\cdot\left(R_L+R_S\right)}=\frac{1}{2\times3.14\times10M\times\left(50+50\right)}=159\,pF$$

一阶高通滤波特性伯特图

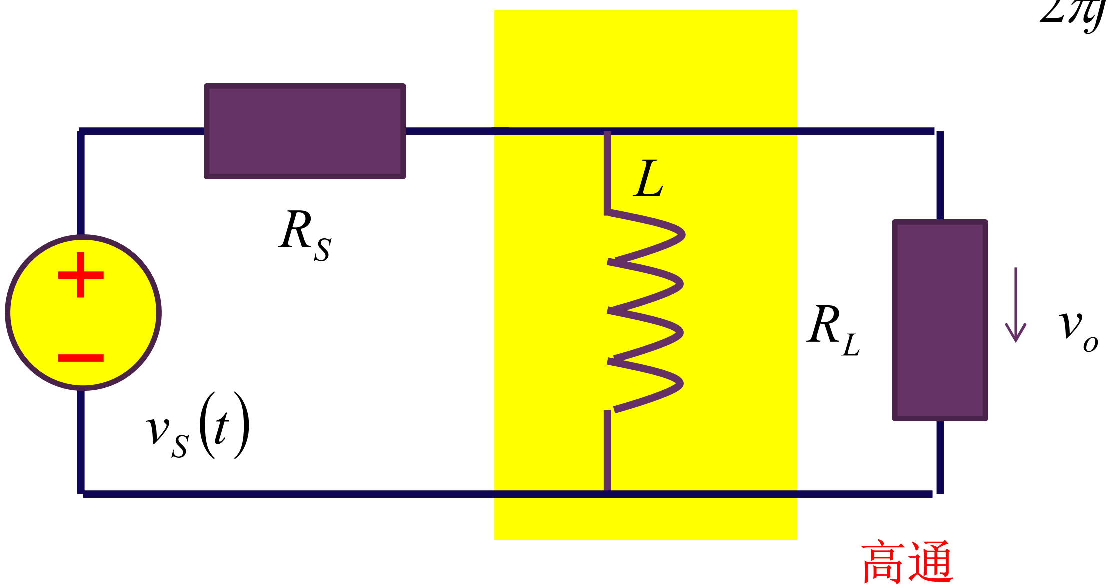


一阶RL滤波方案



$$L = \frac{\tau}{G} = \frac{R_S + R_L}{2\pi \cdot BW_{3dB}}$$

$$2\pi f_{3dB} = \omega_0 = \frac{1}{\tau} = \begin{cases} \frac{1}{RC} \\ \frac{1}{GL} \end{cases}$$

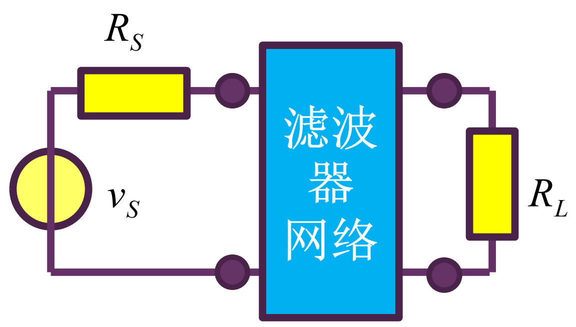


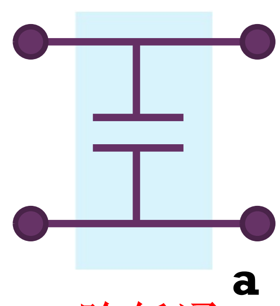
$$L = \frac{\tau}{G} = \frac{R_S \parallel R_L}{2\pi \cdot f_{3dB}}$$

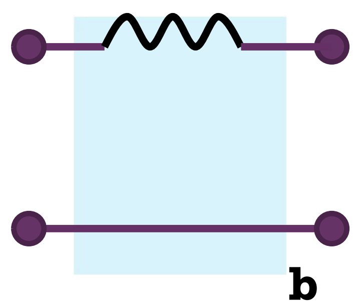
作业10.5 滤波器类型判定

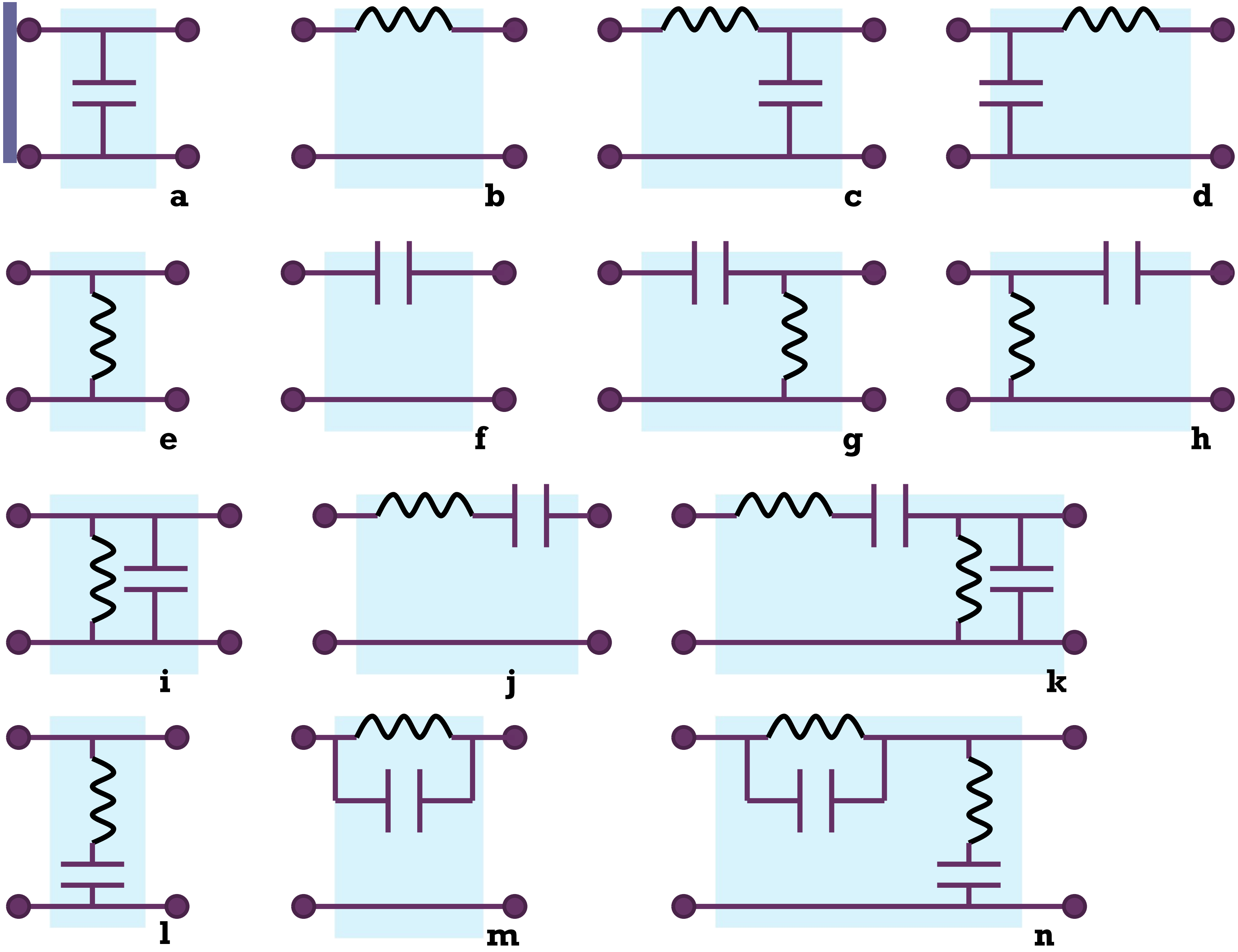
- 电容和电感的记忆能力或者积分效应，导致时域上的延时和频域上的选频特性

- 常见滤波器分类
  - 低通、高通、带通、带阻
  - 请给出正确的滤波器分类

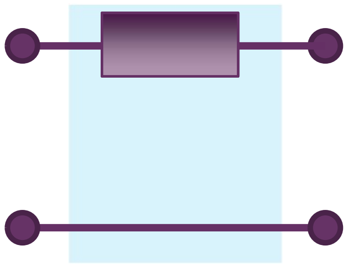




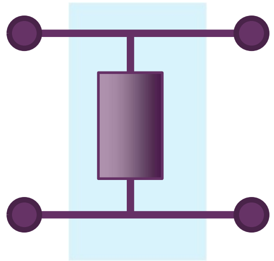



a
b
c
d
e
f
g
h
i
j
k
l
m
n

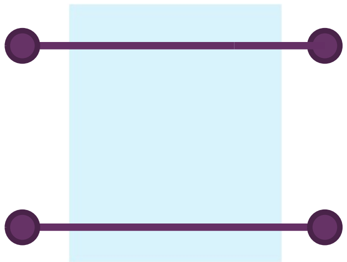
直通



直通节

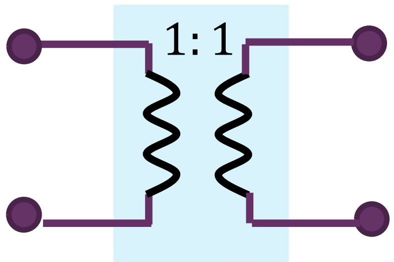


有损直通



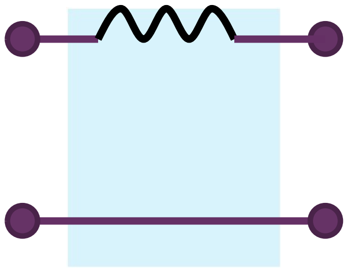
$$v_{out} = v_{in}$$

$$i_{out} = i_{in}$$

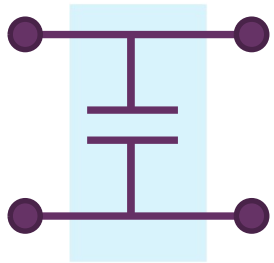


无损直通

低通与高通

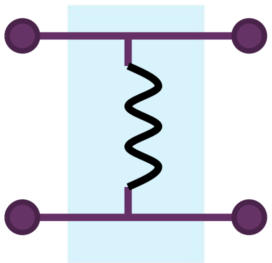


低通节

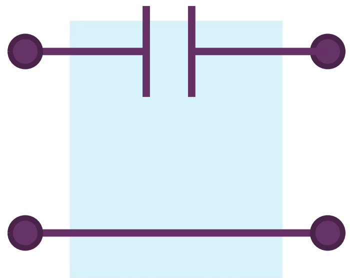


串臂电感：低频短路，信号可以通过，高频开路，信号不能通过，故而低通

并臂电容：低频开路，信号可以通过，高频短路，信号不能通过，故而低通



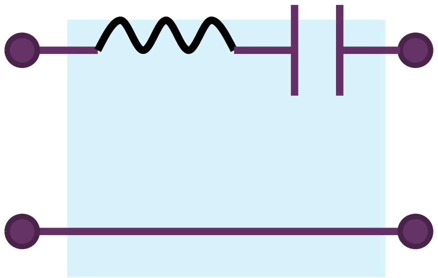
高通节

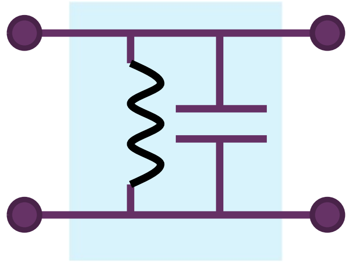


并臂电感：低频短路，信号不能通过，高频开路，信号可以通过，故而高通

串臂电容：低频开路，信号不能通过，高频短路，信号可以通过，故而高通

带通与带阻

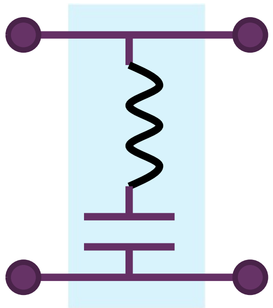


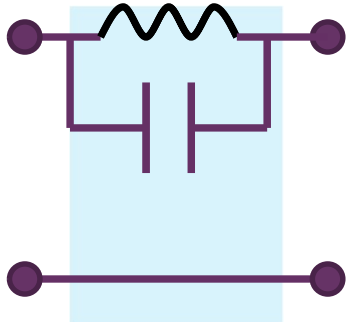


带通节

串联**LC**在串臂：低频电容开路通不过，高频电感开路通不过，谐振频点串联**LC**短路，信号可以通过，故而带通

并联**LC**在并臂：低频电感短路通不过，高频电容短路通不过，谐振频点并联**LC**开路，信号可以通过，故而带通



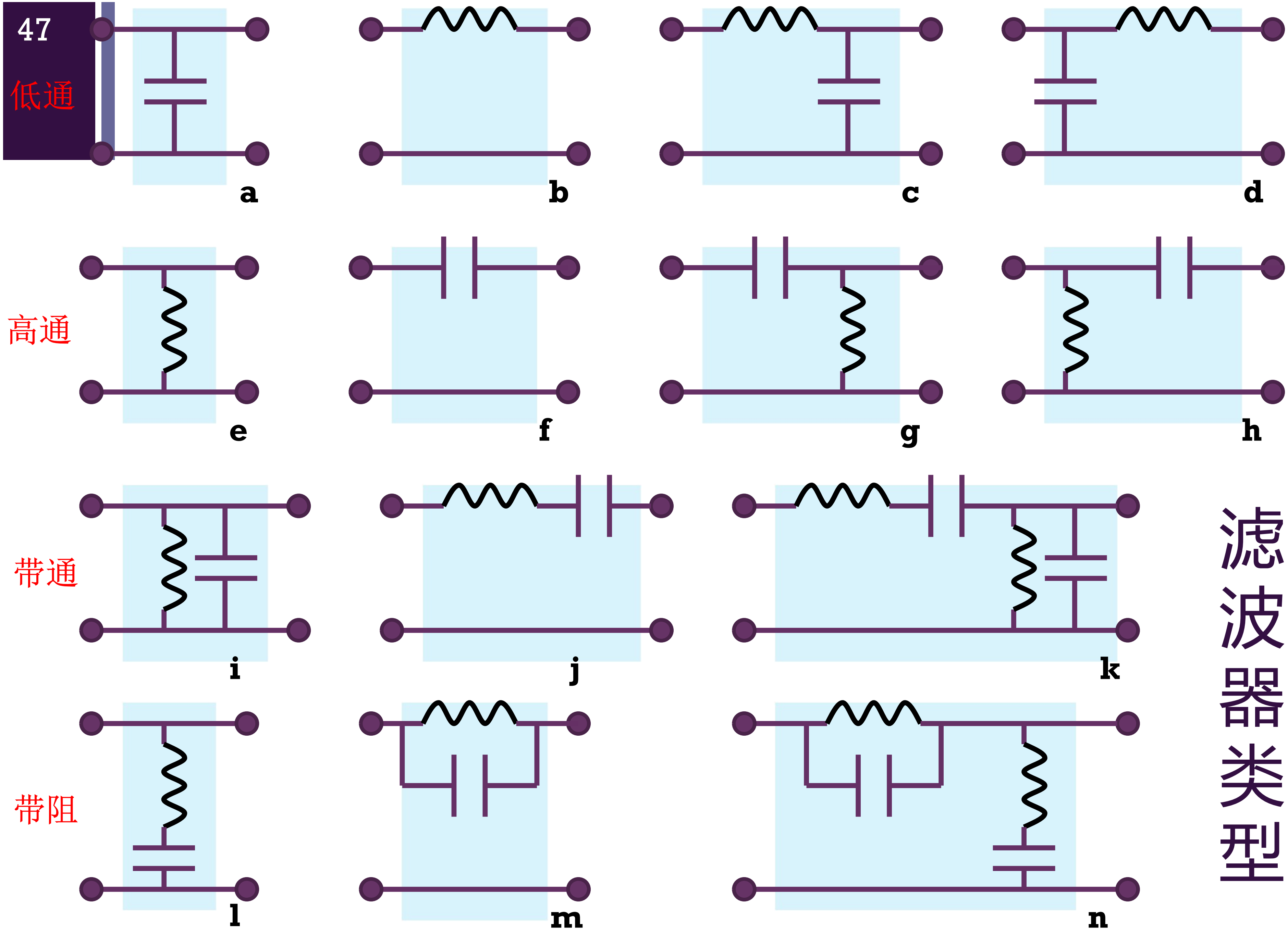


带阻节

串联**LC**在并臂：低频电容开路信号可过，高频电感开路信号可过，谐振频点串联**LC**短路，信号不能通过，故而带阻

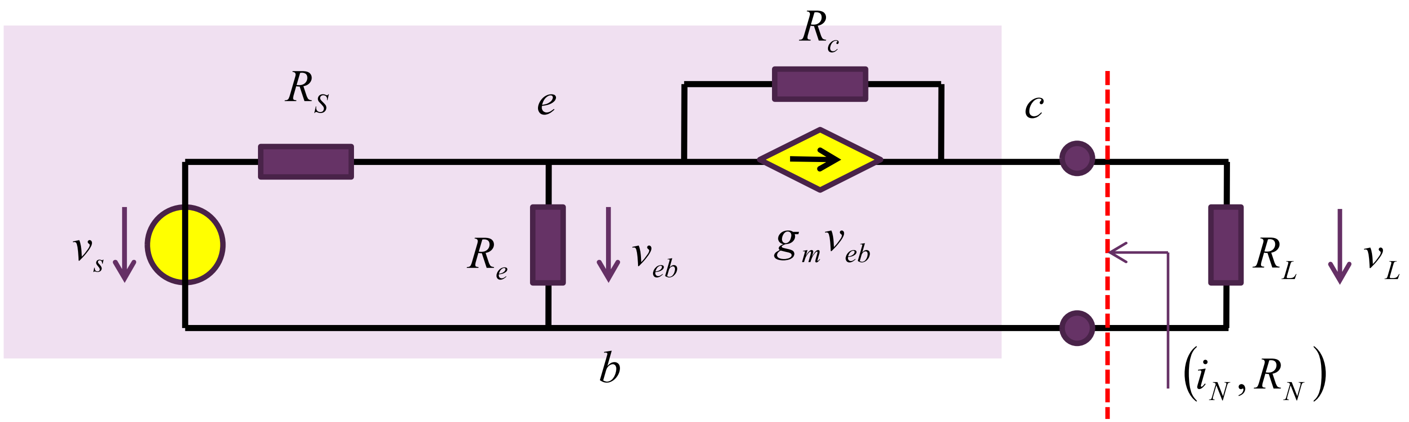
并联**LC**在串臂：低频电感短路信号可过，高频电容短路信号可过，谐振频点并联**LC**开路，信号不能通过，故而带阻

滤波器类型



作业11.3 戴维南定理

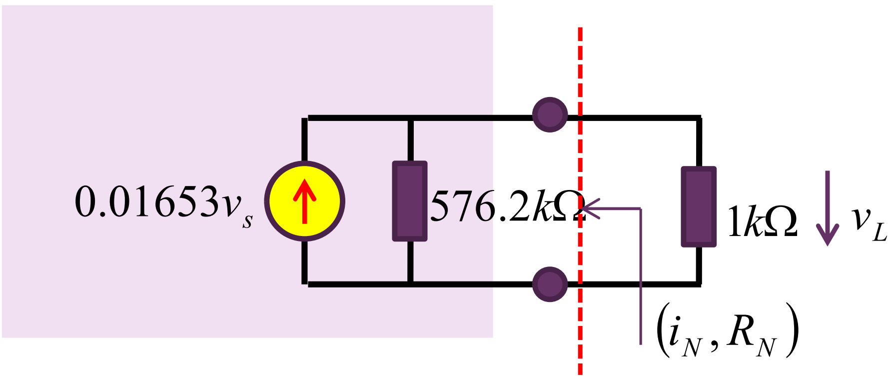
- 例题中将左侧电阻用诺顿定理做了诺顿等效分析，请用戴维南定理做戴维南等效分析



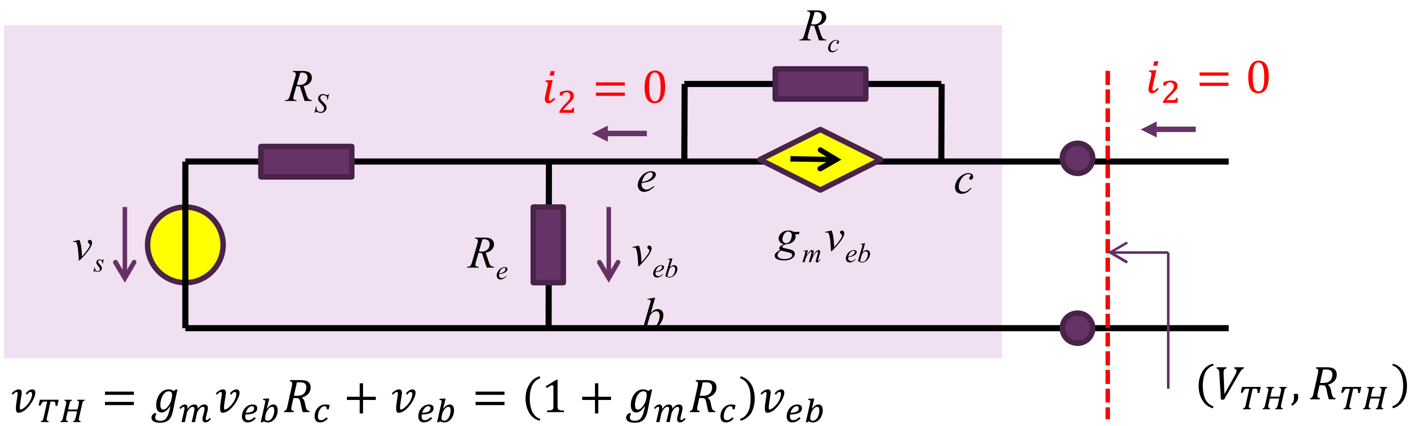
$$v_L = i_N \cdot (R_N || R_L)$$

$$= 16.53mS \times v_s \times \frac{576.2k\Omega \times 1k\Omega}{576.2k\Omega + 1k\Omega}$$

$$= 16.53mS \times 0.9983k\Omega \times v_s = 16.50v_s$$

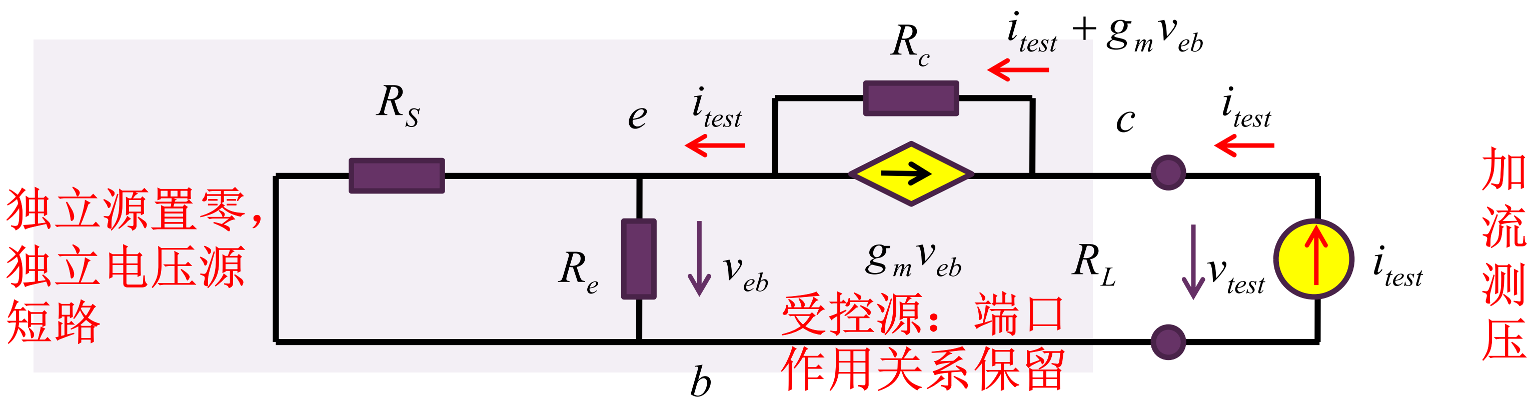


戴维南源电压为开路电压



$$v_{TH} = g_m v_{eb} R_c + v_{eb} = (1 + g_m R_c) v_{eb}$$

$$= (1 + g_m R_c) \frac{R_e}{R_S + R_e} v_S = (1 + 100m \times 100k) \frac{1k}{0.05k + 1k} v_S = 9525 v_S$$

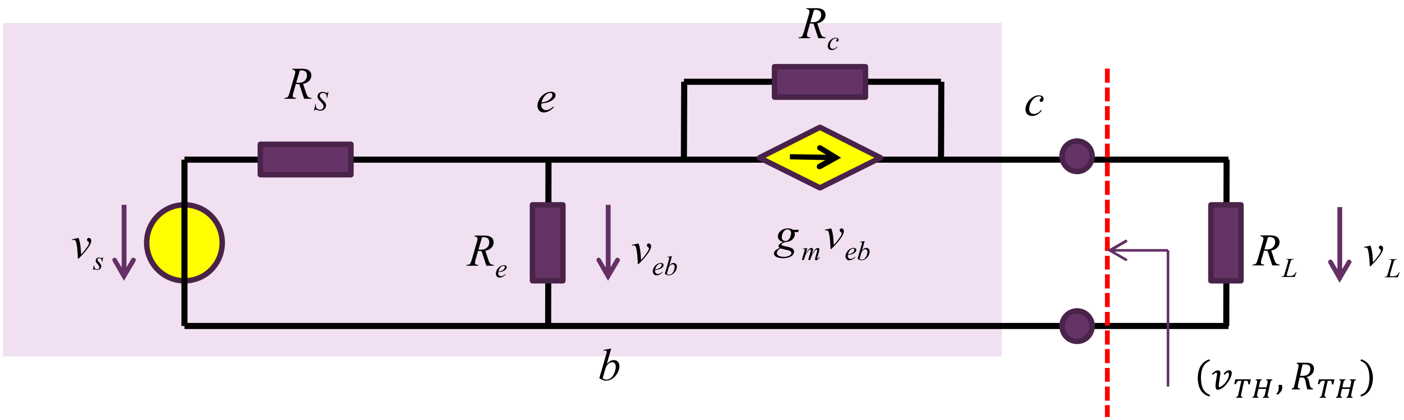


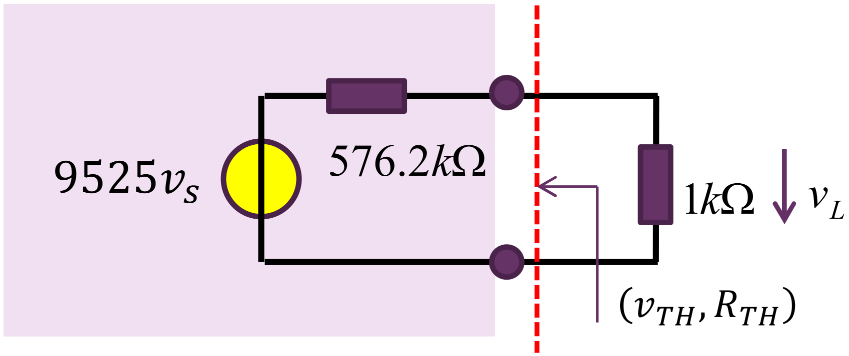
$$v_{test} = (i_{test} + g_m v_{eb}) R_c + v_{eb} = i_{test} R_c + (g_m R_c + 1) v_{eb}$$

$$= i_{test} R_c + (g_m R_c + 1) \cdot i_{test} (R_s || R_e)$$

$$R_{TH} = \frac{v_{test}}{i_{test}} = R_c + (R_s || R_e) + g_m R_c (R_s || R_e) = \cdots = 576.2k\Omega$$

戴维南源驱动负载

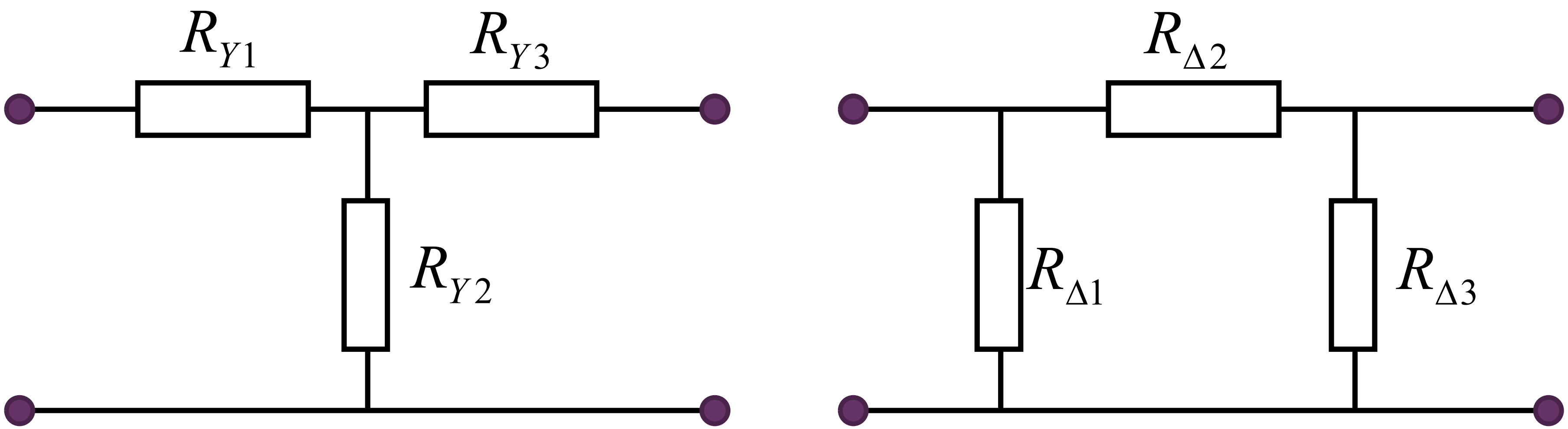




$$v_L = \frac{R_L}{R_{TH} + R_L} v_{TH} = \frac{1k}{576.2k + 1k} \times 9525 v_S = 16.50 v_S$$

作业12.1 Y-Δ转换关系的推导

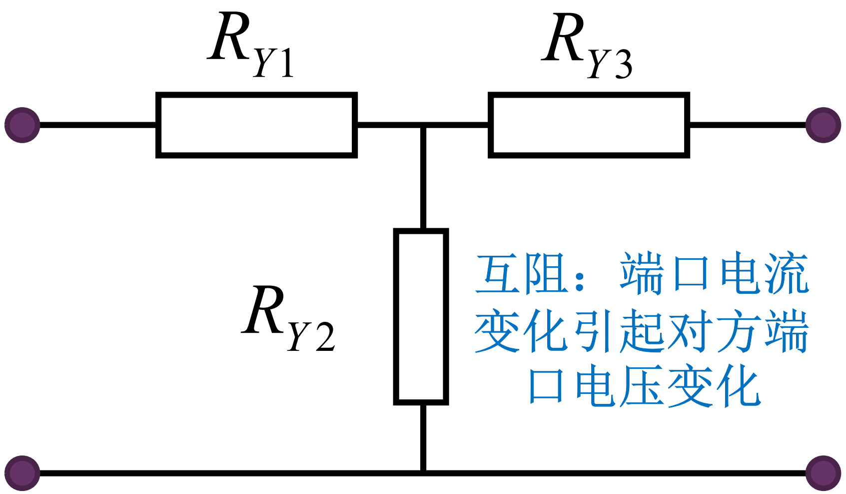
- 如果两个二端口网络具有相同的网络参量矩阵，这两个二端口网络则可认为是等效的
  - Y形网络和Δ形网络等价，显然它们的电阻必须满足某种关系
    - 求Y形网络的z矩阵（用两种方法：方法1，加流求压；方法2，串串连接Z相加），求逆获得其y矩阵
    - 求Δ形网络的y矩阵（用两种方法：方法1，加压求流；方法2，并并连接Y相加）
    - 两者相等，求出Y-Δ转换关系：R_{Δ}如何用R_Y表示?
    - 反之，R_Y如何用R_{Δ}表示?
    - 选作：如果Δ型网络三个元件为电容（二端口电容），给出等效的Y型等效电路
    - 选作：如果Y型网络三个元件为电感（二端口电感），给出等效的Δ型等效电路

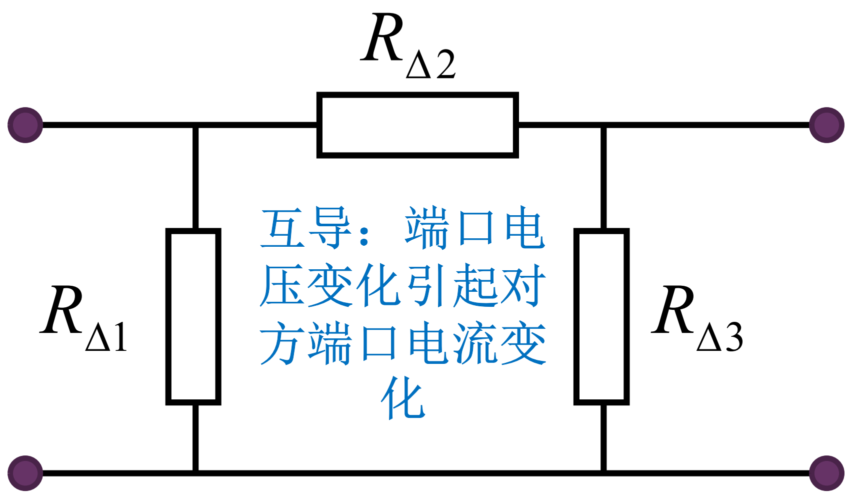


T形网络，Y形网络　　　　π形网络，Δ形网络

具有相同网络参量的电路是等效电路

网络参量就是等效电路模型，等效电路模型一致，网络则等价
从外端口看是等价的





$$\mathbf{z}=\begin{bmatrix} R_{Y1}+R_{Y2} & R_{Y2} \\ R_{Y2} & R_{Y3}+R_{Y2} \end{bmatrix}$$

互阻　自阻

二端口电阻

$$\mathbf{y}=\begin{bmatrix} G_{\Delta 1}+G_{\Delta 2} & -G_{\Delta 2} \\ -G_{\Delta 2} & G_{\Delta 3}+G_{\Delta 2} \end{bmatrix}$$

互导　自导

二端口电导

等效就是一样的网络参量

$$\mathbf{z}=\begin{bmatrix} R_{Y1}+R_{Y2} & R_{Y2} \\ R_{Y2} & R_{Y3}+R_{Y2} \end{bmatrix} \qquad \mathbf{y}=\begin{bmatrix} G_{\Delta1}+G_{\Delta2} & -G_{\Delta2} \\ -G_{\Delta2} & G_{\Delta3}+G_{\Delta2} \end{bmatrix}$$

$$\mathbf{y}=\mathbf{z}^{-1}=\frac{\begin{bmatrix} R_{Y3}+R_{Y2} & -R_{Y2} \\ -R_{Y2} & R_{Y1}+R_{Y2} \end{bmatrix}}{R_{Y1}R_{Y3}+R_{Y3}R_{Y2}+R_{Y2}R_{Y1}} \qquad \mathbf{z}=\mathbf{y}^{-1}=\frac{\begin{bmatrix} G_{\Delta3}+G_{\Delta2} & G_{\Delta2} \\ G_{\Delta2} & G_{\Delta1}+G_{\Delta2} \end{bmatrix}}{G_{\Delta1}G_{\Delta3}+G_{\Delta3}G_{\Delta2}+G_{\Delta2}G_{\Delta1}}$$

$$G_{\Delta2}=\frac{R_{Y2}}{R_{Y1}R_{Y3}+R_{Y3}R_{Y2}+R_{Y2}R_{Y1}}$$

$$G_{\Delta1}=\frac{R_{Y3}}{R_{Y1}R_{Y3}+R_{Y3}R_{Y2}+R_{Y2}R_{Y1}}$$

$$G_{\Delta3}=\frac{R_{Y1}}{R_{Y1}R_{Y3}+R_{Y3}R_{Y2}+R_{Y2}R_{Y1}}$$

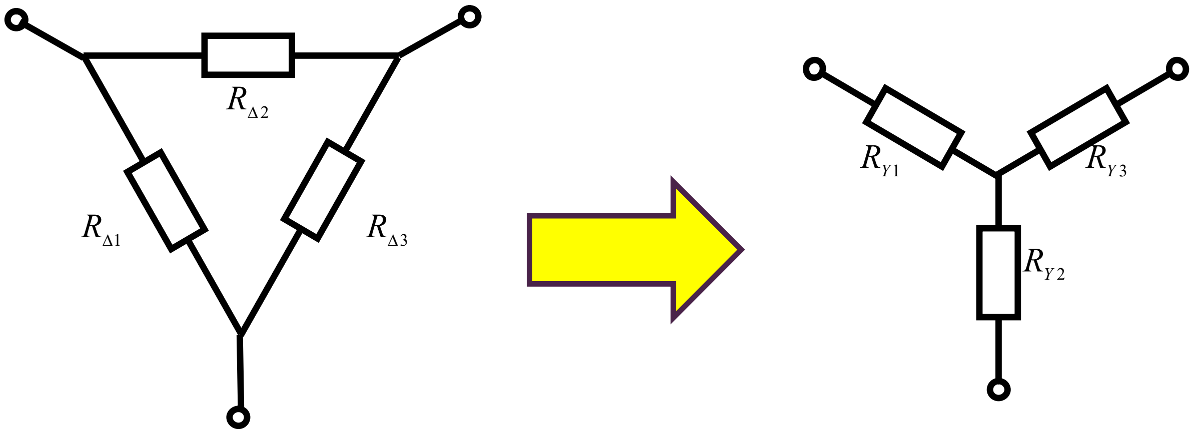
对偶电路，对偶表述

$$R_{Y2}=\frac{G_{\Delta2}}{G_{\Delta1}G_{\Delta3}+G_{\Delta3}G_{\Delta2}+G_{\Delta2}G_{\Delta1}}$$

$$R_{Y1}=\frac{G_{\Delta3}}{G_{\Delta1}G_{\Delta3}+G_{\Delta3}G_{\Delta2}+G_{\Delta2}G_{\Delta1}}$$

$$R_{Y3}=\frac{G_{\Delta1}}{G_{\Delta1}G_{\Delta3}+G_{\Delta3}G_{\Delta2}+G_{\Delta2}G_{\Delta1}}$$

ΔY转换

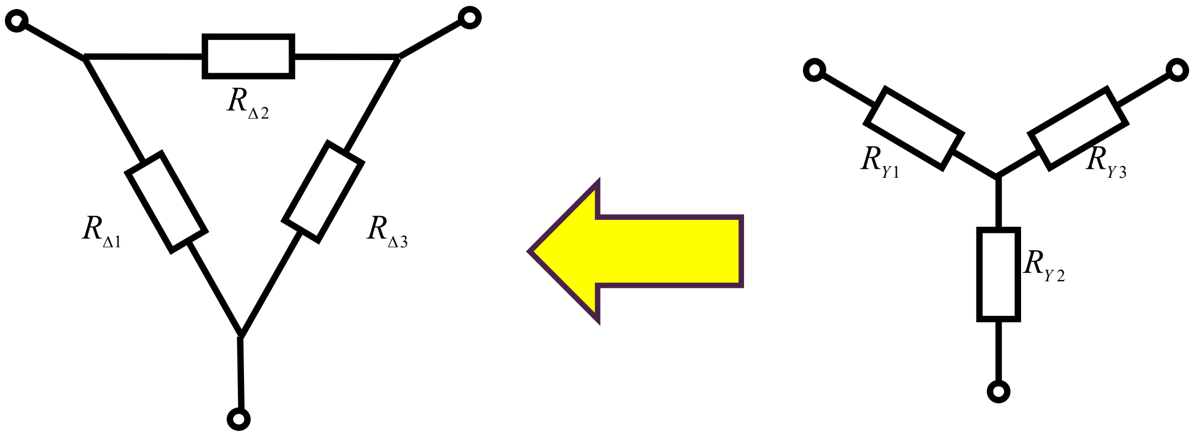


$$R_{Y2}=\frac{G_{\Delta 2}}{G_{\Delta 1}G_{\Delta 3}+G_{\Delta 3}G_{\Delta 2}+G_{\Delta 2}G_{\Delta 1}}=\frac{R_{\Delta 1}R_{\Delta 3}}{R_{\Delta 1}+R_{\Delta 2}+R_{\Delta 3}}$$

$$R_{Y1}=\frac{G_{\Delta 3}}{G_{\Delta 1}G_{\Delta 3}+G_{\Delta 3}G_{\Delta 2}+G_{\Delta 2}G_{\Delta 1}}=\frac{R_{\Delta 1}R_{\Delta 2}}{R_{\Delta 1}+R_{\Delta 2}+R_{\Delta 3}}$$

$$R_{Y3}=\frac{G_{\Delta 1}}{G_{\Delta 1}G_{\Delta 3}+G_{\Delta 3}G_{\Delta 2}+G_{\Delta 2}G_{\Delta 1}}=\frac{R_{\Delta 3}R_{\Delta 2}}{R_{\Delta 1}+R_{\Delta 2}+R_{\Delta 3}}$$

YΔ转换

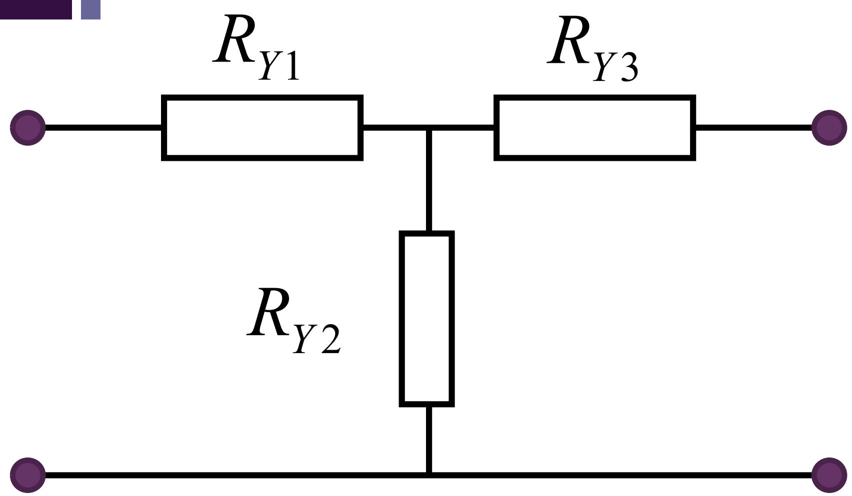


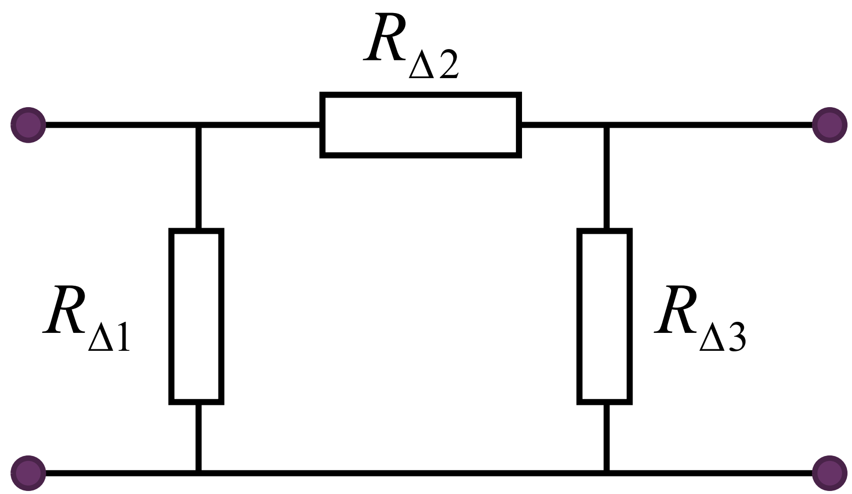
$$R_{\Delta 2} = G_{\Delta 2}{}^{-1} = \frac{R_{Y1}R_{Y3} + R_{Y3}R_{Y2} + R_{Y2}R_{Y1}}{R_{Y2}} = R_{Y3} + R_{Y1} + \frac{R_{Y1}R_{Y3}}{R_{Y2}}$$

$$R_{\Delta 1} = G_{\Delta 1}{}^{-1} = \frac{R_{Y1}R_{Y3} + R_{Y3}R_{Y2} + R_{Y2}R_{Y1}}{R_{Y3}} = R_{Y1} + R_{Y2} + \frac{R_{Y1}R_{Y2}}{R_{Y3}}$$

$$R_{\Delta 3} = G_{\Delta 3}{}^{-1} = \frac{R_{Y1}R_{Y3} + R_{Y3}R_{Y2} + R_{Y2}R_{Y1}}{R_{Y1}} = R_{Y2} + R_{Y3} + \frac{R_{Y2}R_{Y3}}{R_{Y1}}$$

用ABCD参量或许更容易获得结论



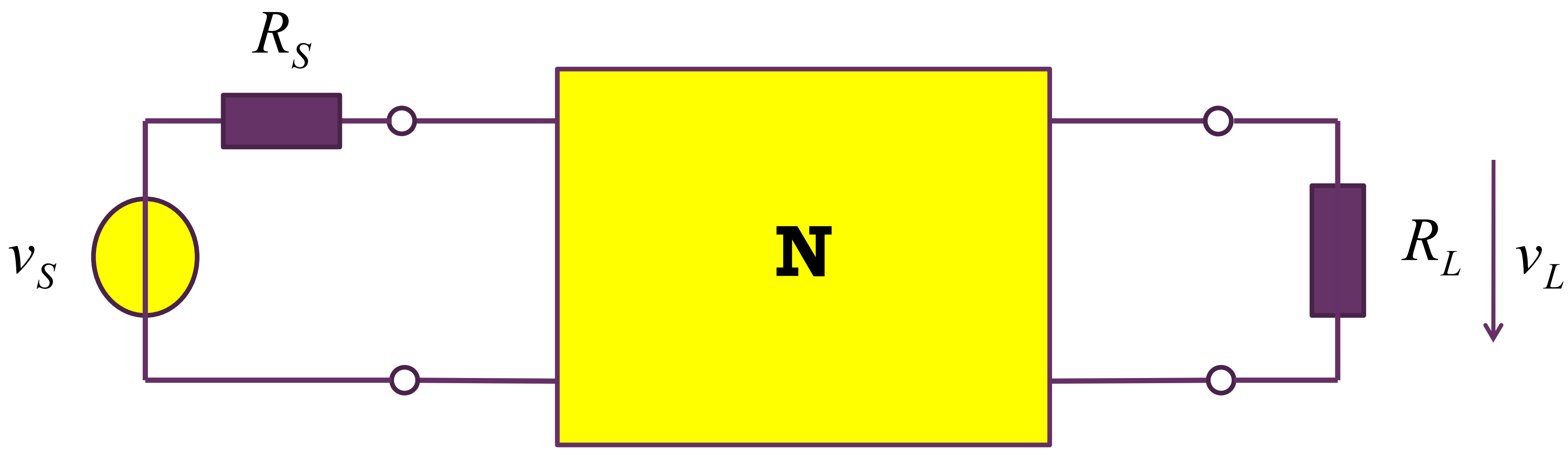


$$ABCD_T=\begin{bmatrix}1 & R_{Y1}\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ \frac{1}{R_{Y2}} & 1\end{bmatrix}\begin{bmatrix}1 & R_{Y3}\\ 0 & 1\end{bmatrix}=\begin{bmatrix}1+\frac{R_{Y1}}{R_{Y2}} & R_{Y1}+R_{Y3}+\frac{R_{Y1}R_{Y3}}{R_{Y2}}\\ \frac{1}{R_{Y2}} & 1+\frac{R_{Y3}}{R_{Y2}}\end{bmatrix}$$

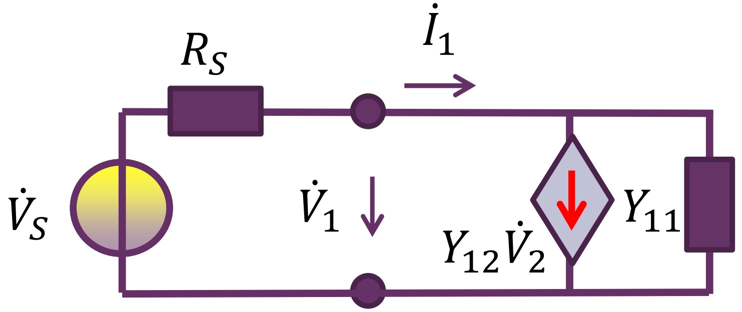
$$ABCD_\Pi=\begin{bmatrix}1 & 0\\ \frac{1}{R_{\Delta 1}} & 1\end{bmatrix}\begin{bmatrix}1 & R_{\Delta 2}\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ \frac{1}{R_{\Delta 3}} & 1\end{bmatrix}=\begin{bmatrix}1+\frac{R_{\Delta 2}}{R_{\Delta 3}} & R_{\Delta 2}\\ \frac{1}{R_{\Delta 1}}+\frac{1}{R_{\Delta 3}}+\frac{R_{\Delta 2}}{R_{\Delta 1}R_{\Delta 3}} & 1+\frac{R_{\Delta 2}}{R_{\Delta 1}}\end{bmatrix}$$

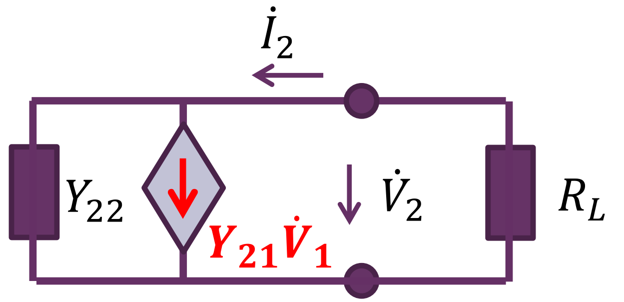
作业12.2 已知网络参量求传递函数

- 已知二端口网络的h参量、ABCD参量，请给出用网络参量表述的电压传递函数，输入电阻和输出电阻
  - 1、h参量，用h参量等效电路求（尽量用等效电路求）
  - 2、ABCD参量，列电路方程求解（尽量用ABCD物理意义求）

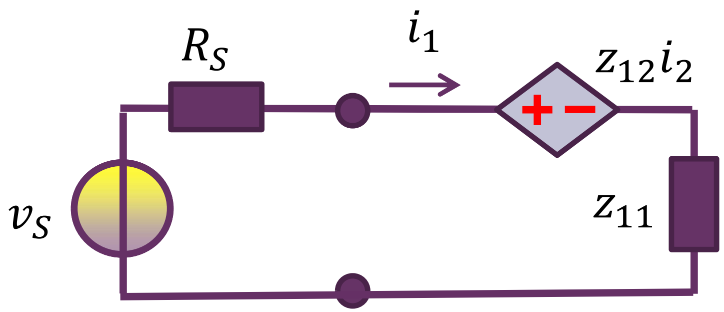


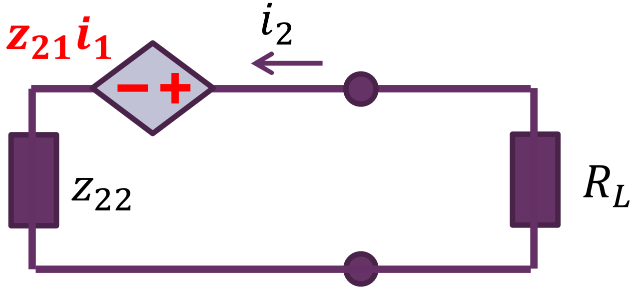
Y参量Z参量早就推导过了，可否直接写答案?





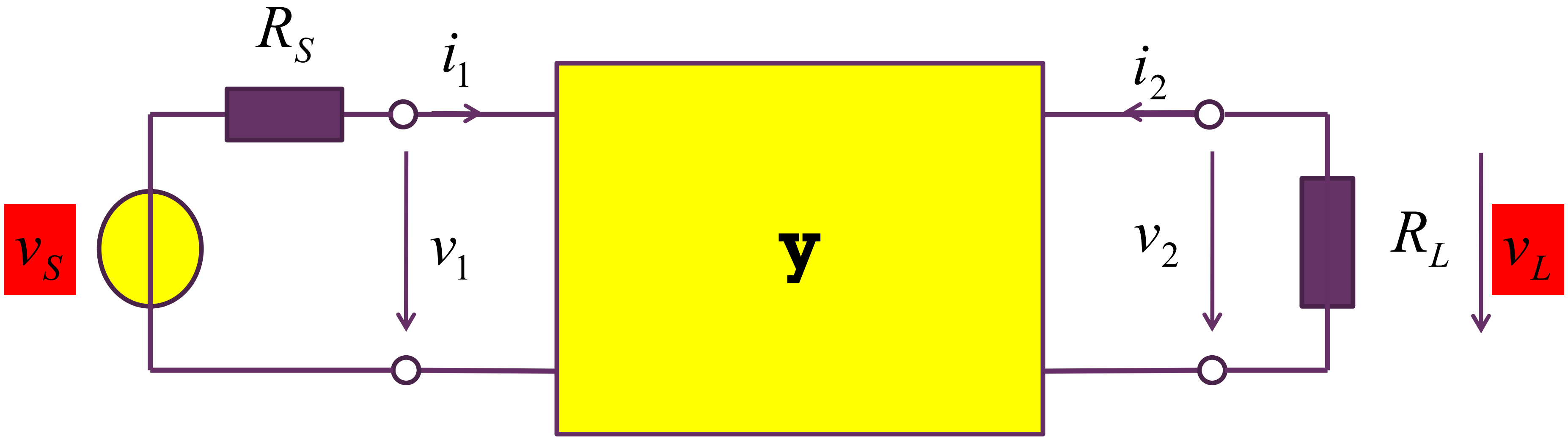
$$H = \frac{Y_{21}G_S}{Y_{21}Y_{12} - (G_S + Y_{11})(G_L + Y_{22})} \overset{Y_{12}=0}{=} \frac{-Y_{21}G_S}{(G_S + Y_{11})(G_L + Y_{22})}$$





$$H = \frac{-z_{21}R_L}{z_{21}z_{12} - (R_L + z_{22})(R_S + z_{11})} \overset{z_{12}=0}{=} \frac{z_{21}R_L}{(R_L + z_{22})(R_S + z_{11})}$$

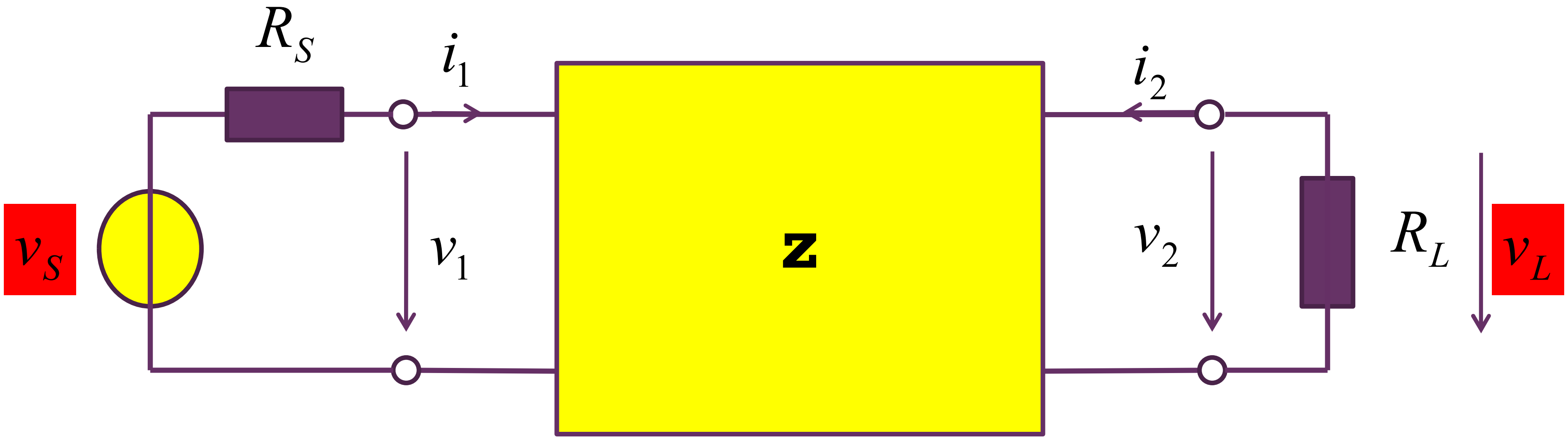
Y参量公式中的规律



如果单向 $$H=\frac{v_L}{v_S}=\frac{R_L R_{out}}{R_L+R_{out}}(G_{m0})\frac{R_{in}}{R_S+R_{in}}=\frac{(-y_{21})G_S}{(y_{11}+G_S)(y_{22}+G_L)}$$

如果双向 $$H=\frac{v_L}{v_S}=\frac{(-y_{21})G_S}{(y_{11}+G_S)(y_{22}+G_L)-y_{12}y_{21}}$$

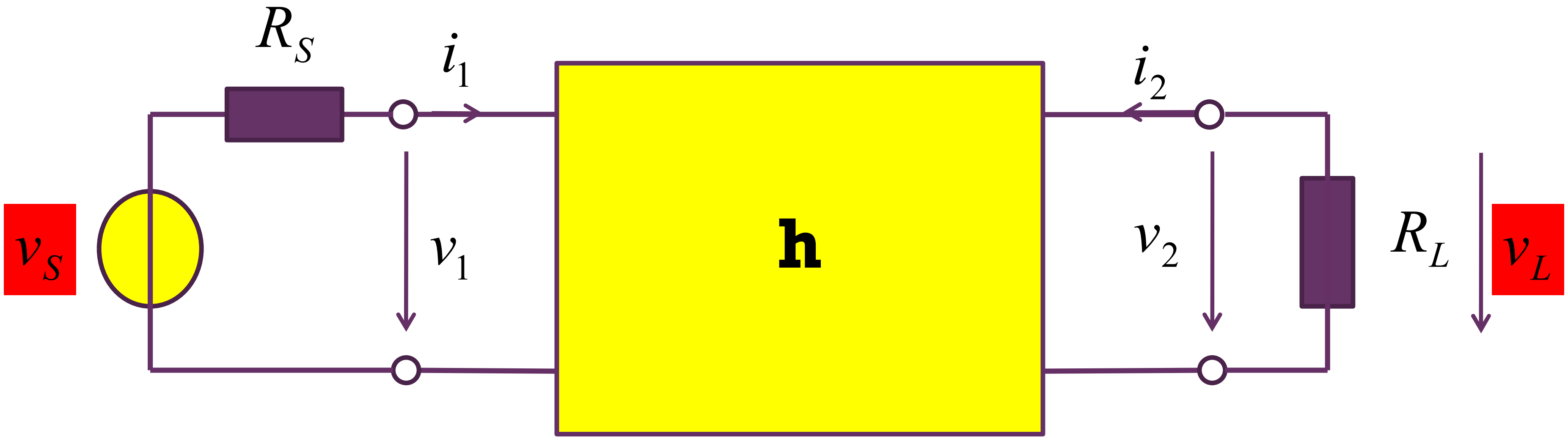
和z参量公式中的规律是一致的



如果单向 $$H=\frac{v_L}{v_S}=\frac{R_L}{R_L+R_{out}}(R_{m0})\frac{1}{R_S+R_{in}}=\frac{z_{21}R_L}{(z_{11}+R_S)(z_{22}+R_L)}$$

如果双向 $$H=\frac{v_L}{v_S}=\frac{z_{21}R_L}{(z_{11}+R_S)(z_{22}+R_L)-z_{12}z_{21}}$$

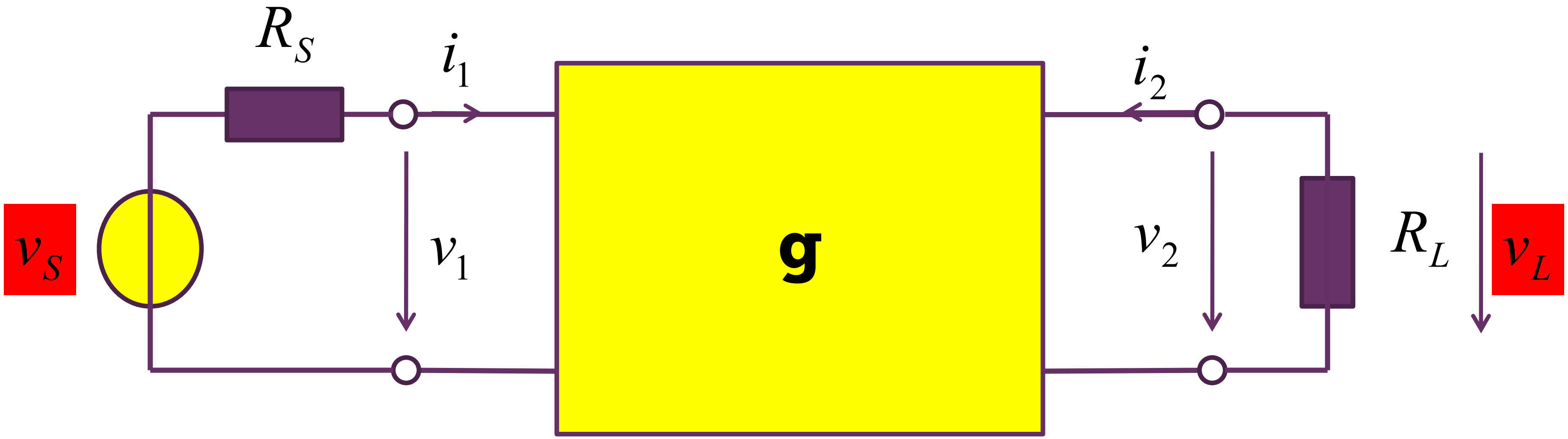
直接推广到h参量公式中



如果单向 $$H=\frac{v_L}{v_S}=\frac{R_L R_{out}}{R_L+R_{out}}(A_{i0})\frac{1}{R_S+R_{in}}=\frac{(-h_{21})}{(h_{11}+R_S)(h_{22}+G_L)}$$

如果双向 $$H=\frac{v_L}{v_S}=\frac{(-h_{21})}{(h_{11}+R_S)(h_{22}+G_L)-h_{12}h_{21}}$$

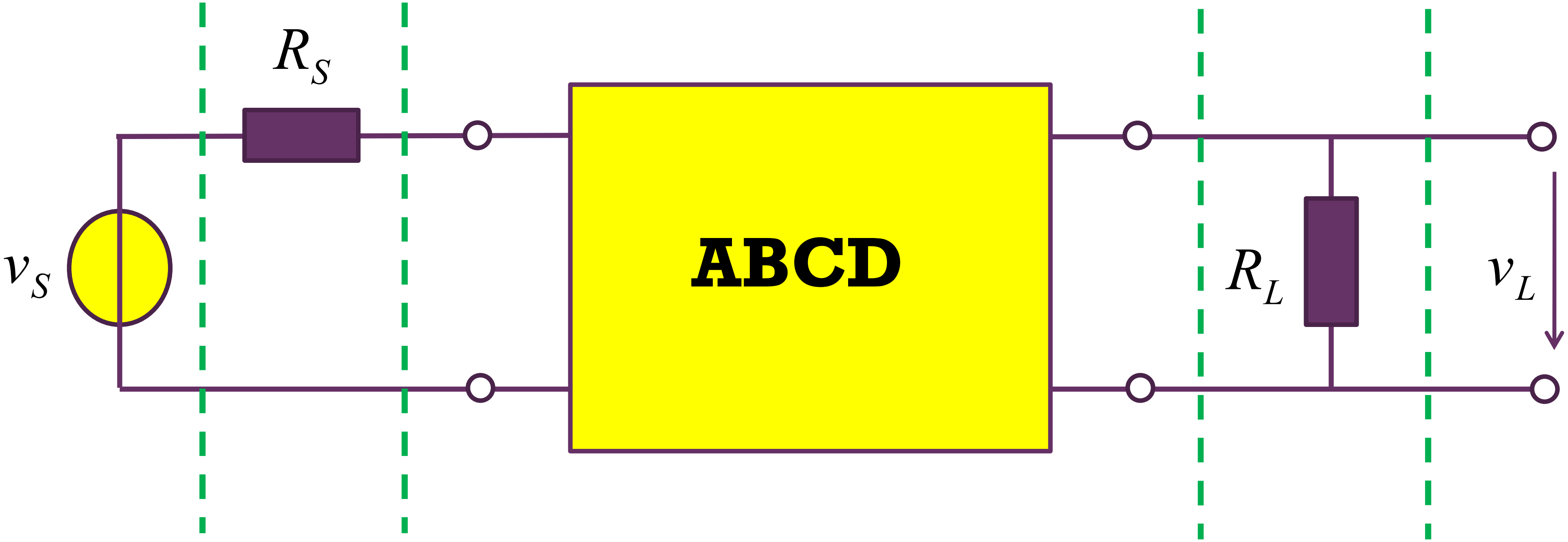
和g参量公式中，并无任何问题



如果单向 $$H=\frac{v_L}{v_S}=\frac{R_L}{R_L+R_{out}}(A_{v0})\frac{R_{in}}{R_S+R_{in}}=\frac{g_{21}G_SR_L}{(g_{11}+G_S)(g_{22}+R_L)}$$

如果双向 $$H=\frac{v_L}{v_S}=\frac{g_{21}G_SR_L}{(g_{11}+G_S)(g_{22}+R_L)-g_{12}g_{21}}$$

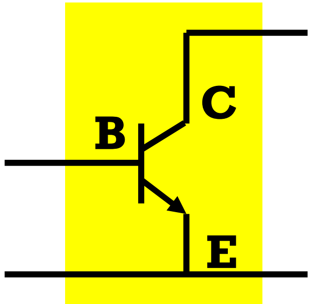
用ABCD参量表述传递函数也很简单



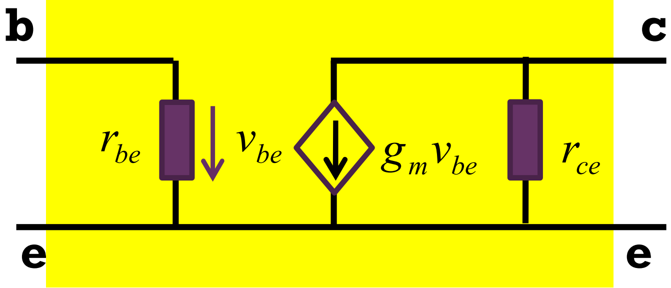
$$\begin{bmatrix} A_c & B_c \\ C_c & D_c \end{bmatrix} = \begin{bmatrix} A_S & B_S \\ C_S & D_S \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} A_L & B_L \\ C_L & D_L \end{bmatrix} = \begin{bmatrix} 1 & R_S \\ 0 & 1 \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{1}{R_L} & 1 \end{bmatrix} = \begin{bmatrix} A + CR_S + \frac{B + DR_S}{R_L} & \cdots \\ \cdots & \cdots \end{bmatrix}$$

$$H = \frac{v_L}{v_S} = \frac{1}{A_c} = \frac{1}{A + CR_S + \frac{B + DR_S}{R_L}} = \frac{R_L}{AR_L + B + CR_SR_L + DR_S}$$

作业12.3 BJT交流小信号电路模型



Common Emitter

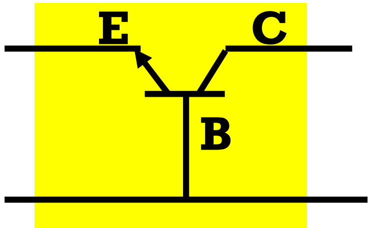


CE：共射组态

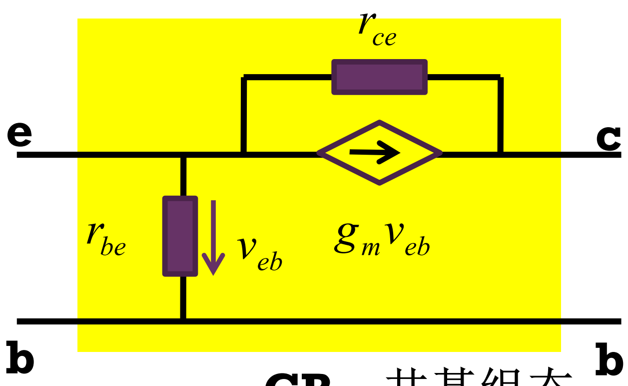
$g_m = 40mS$

$r_{be} = 10k\Omega$

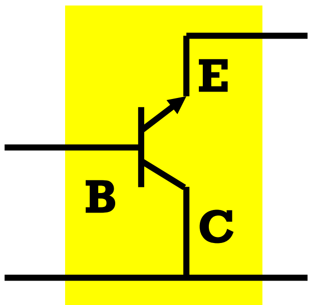
$r_{ce} = 100k\Omega$



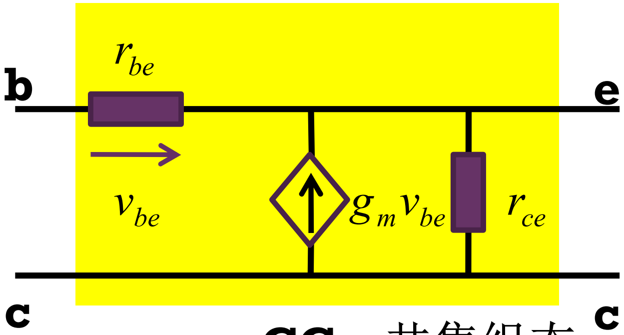
Common Base



CB：共基组态

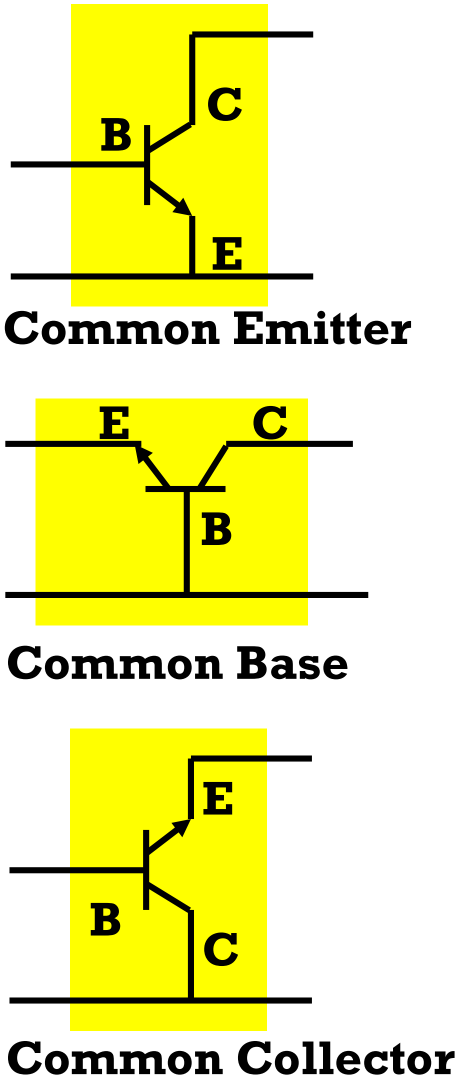


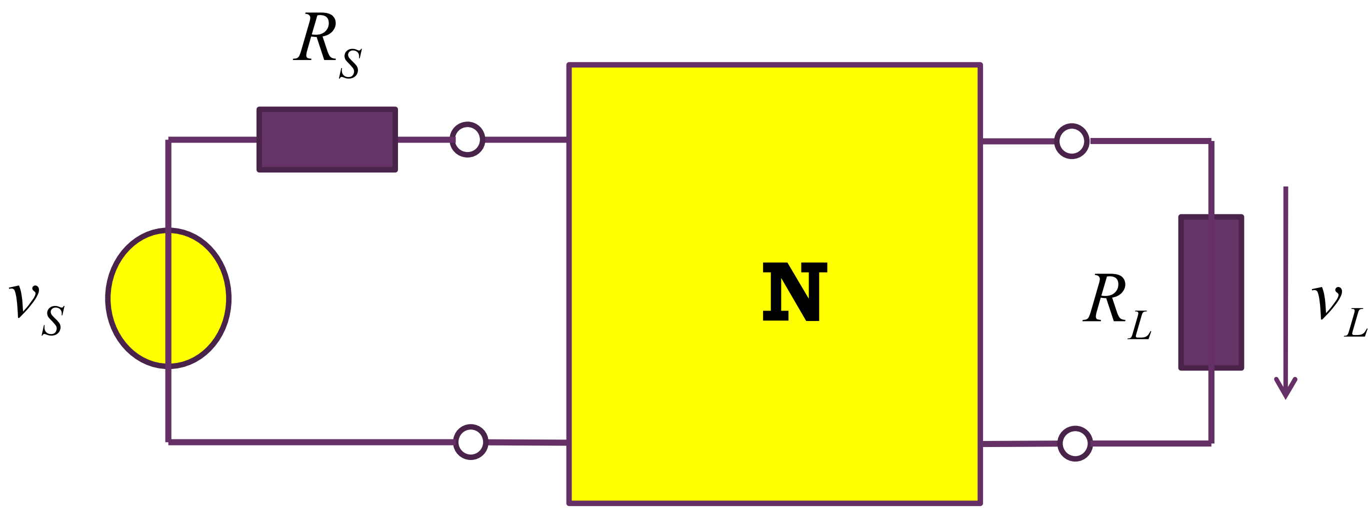
Common Collector



CC：共集组态

晶体管放大器分析

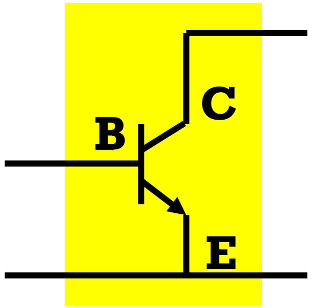




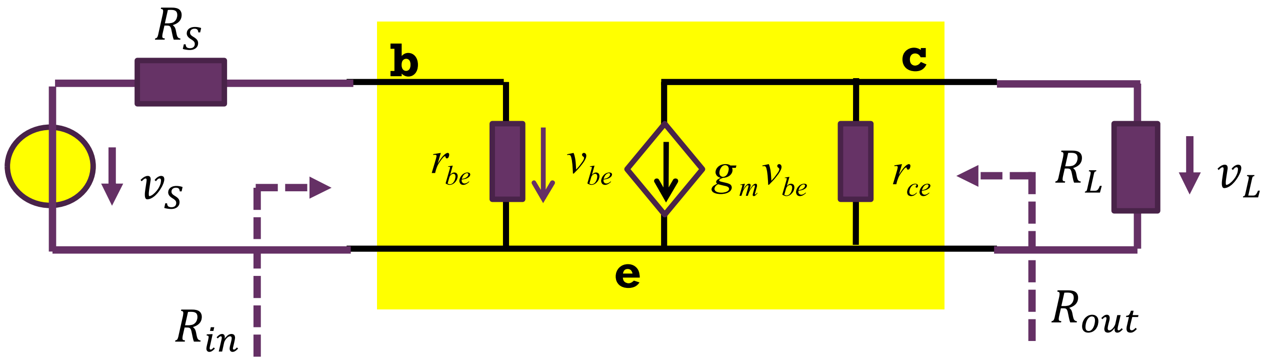
- 求三种组态晶体管放大器的输入电阻，输出电阻，电压传递函数表达式，代入具体数值求其输入电阻、输出电阻和电压放大倍数（R_S=50Ω,R_L=1kΩ）

结点电压法、回路电流法、等效电路法、网络参量法，下面我们选择网络参量法

CE组态晶体管放大器分析



Common Emitter



$$R_{in} = r_{be} = \mathbf{10k\Omega}$$

$$R_{out} = r_{ce} = \mathbf{100k\Omega}$$

单向网络

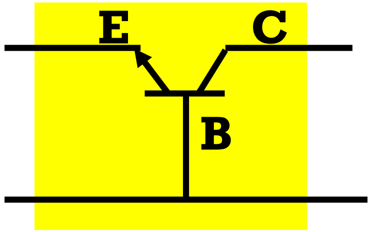
$$H = A_v = \frac{r_{ce} R_L}{r_{ce} + R_L}(-g_m)\frac{r_{be}}{r_{be} + R_S}$$

输出回路总电阻　本征跨导增益　输入回路分压系数

$$= (100k\Omega || 1k\Omega) \times (-40mS) \times \frac{10k\Omega}{10k\Omega + 50\Omega}$$

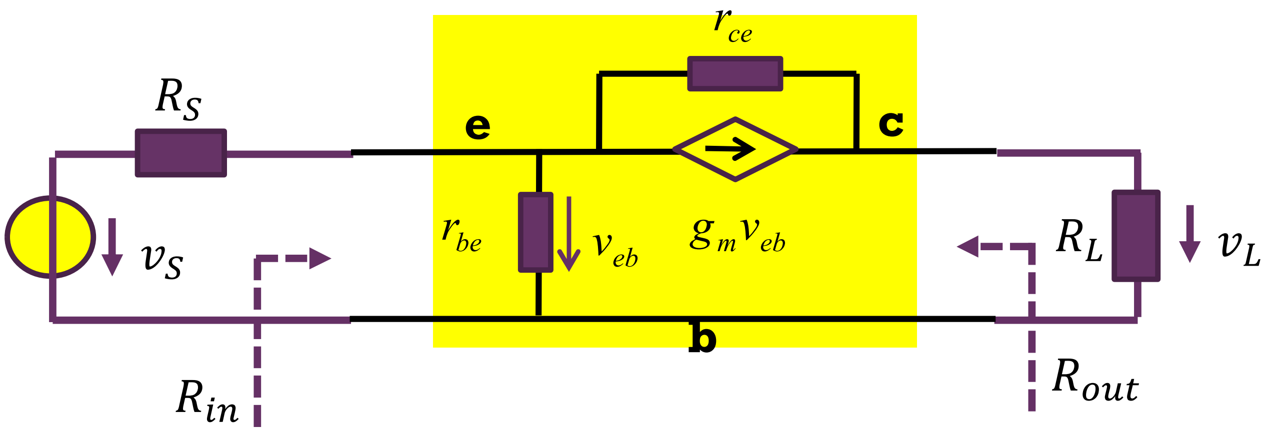
$$= 990\Omega \times (-40mS) \times 0.995$$

$$= -39.4 = 31.9dB$$ 反相电压放大

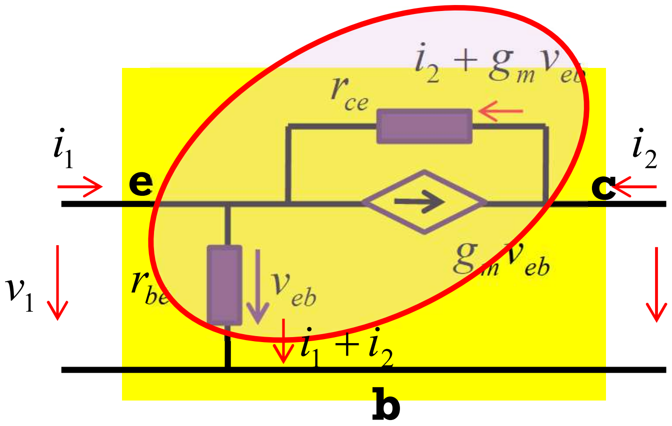


Common Base

CB组态晶体管放大器分析



回路电流法，结点电压法，等效电路法，前面课程中都有，这里只考察网络参量法



$$v_1 = (i_1 + i_2) r_{be} = r_{be} i_1 + r_{be} i_2$$

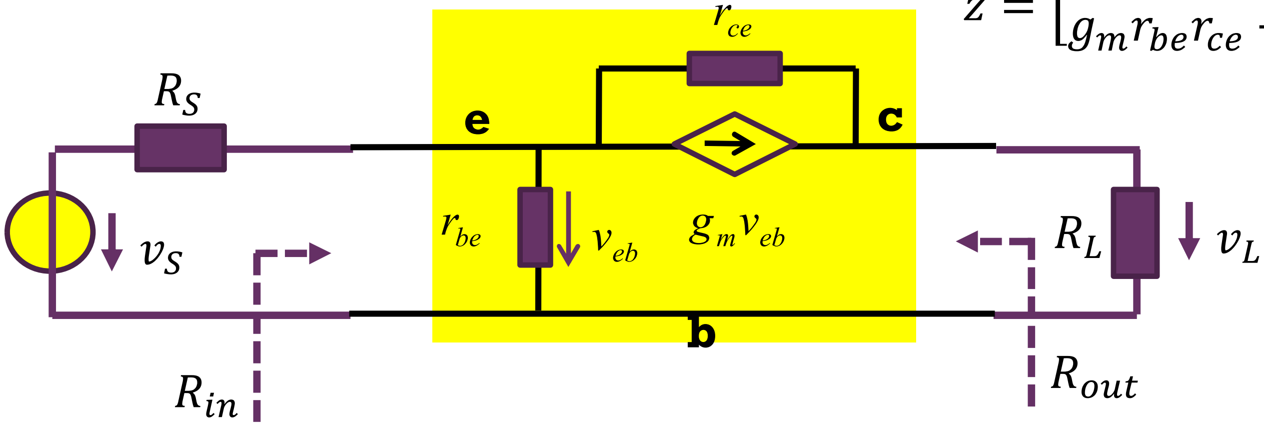
$$v_2 = (i_2 + g_m v_{eb}) r_{ce} + v_{eb} = i_2 r_{ce} + (g_m r_{ce} + 1) v_1$$

$$= (g_m r_{ce} + 1) r_{be} i_1 + (g_m r_{be} r_{ce} + r_{be} + r_{ce}) i_2$$

$$z = \begin{bmatrix} r_{be} & r_{be} \\ g_m r_{be} r_{ce} + r_{be} & g_m r_{be} r_{ce} + r_{be} + r_{ce} \end{bmatrix}$$

输入电阻和输出电阻

$$z=\begin{bmatrix} r_{be} & r_{be} \\ g_m r_{be} r_{ce}+r_{be} & g_m r_{be} r_{ce}+r_{be}+r_{ce}\end{bmatrix}$$



$$R_{in}=z_{in}=z_{11}-\frac{z_{12}z_{21}}{z_{22}+R_L}=r_{be}-\frac{r_{be}(g_m r_{ce}+1)r_{be}}{g_m r_{be} r_{ce}+r_{be}+r_{ce}+R_L}=\frac{(r_{ce}+R_L)r_{be}}{g_m r_{be} r_{ce}+r_{be}+r_{ce}+R_L}$$

$$=\frac{(r_{ce}+R_L)r_{be}}{r_{be}(g_m r_{ce}+1)+r_{ce}+R_L}=\frac{\frac{r_{ce}+R_L}{1+g_m r_{ce}}r_{be}}{r_{be}+\frac{r_{ce}+R_L}{1+g_m r_{ce}}}=r_{be}||\frac{r_{ce}+R_L}{1+g_m r_{ce}}=\mathbf{10k}||25.24=\mathbf{25.18\Omega}$$

发射极对地阻抗

$$R_{out}=z_{out}=z_{22}-\frac{z_{21}z_{12}}{z_{11}+R_S}=g_m r_{be} r_{ce}+r_{be}+r_{ce}-\frac{r_{be}(g_m r_{ce}+1)r_{be}}{r_{be}+R_S}$$

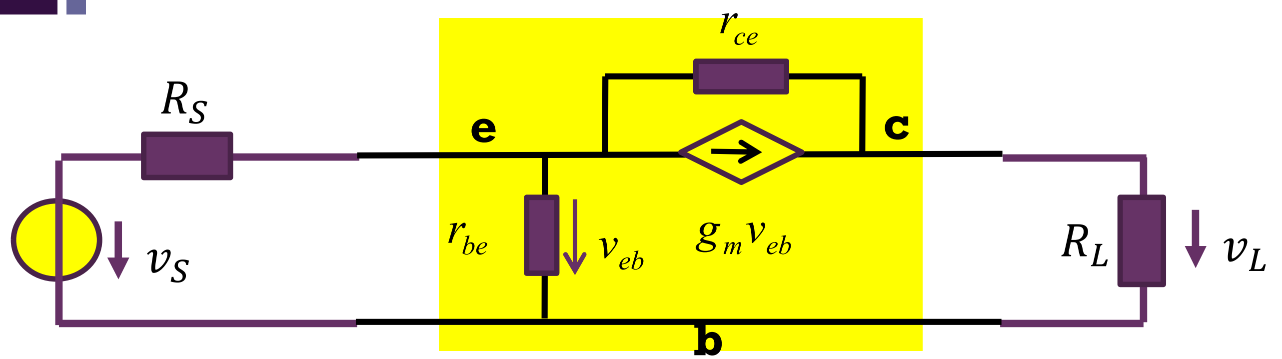
bc端口阻抗

$$=g_m r_{be} r_{ce}\left(1-\frac{r_{be}}{r_{be}+R_S}\right)+r_{be}\left(1-\frac{r_{be}}{r_{be}+R_S}\right)+r_{ce}=g_m(r_{be}||R_S)r_{ce}+r_{be}||R_S+r_{ce}$$

$$=\mathbf{199k+49.75+100k=299.05k\Omega}$$

电压放大倍数

$$z=\begin{bmatrix} & r_{be} & & r_{be} \\ g_m r_{be} r_{ce}+r_{be} & & g_m r_{be} r_{ce}+r_{be}+r_{ce} \end{bmatrix}$$

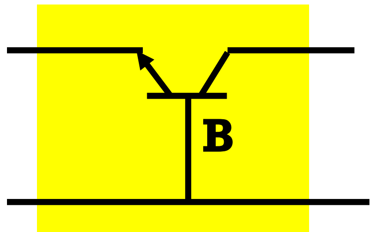


$$H=A_v=\frac{z_{21}R_L}{(z_{22}+R_L)(z_{11}+R_S)-z_{21}z_{12}}$$

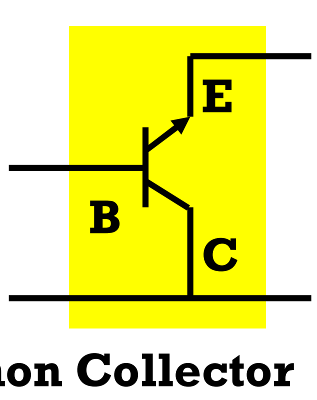
$$=\frac{(g_m r_{ce}+1)r_{be}R_L}{(g_m r_{be} r_{ce}+r_{be}+r_{ce}+R_L)(r_{be}+R_S)-r_{be}(g_m r_{ce}+1)r_{be}}$$

$$=\frac{(g_m r_{ce}+1)r_{be}R_L}{(g_m r_{ce}+1)r_{be}R_S+(r_{be}+R_S)(r_{ce}+R_L)}$$

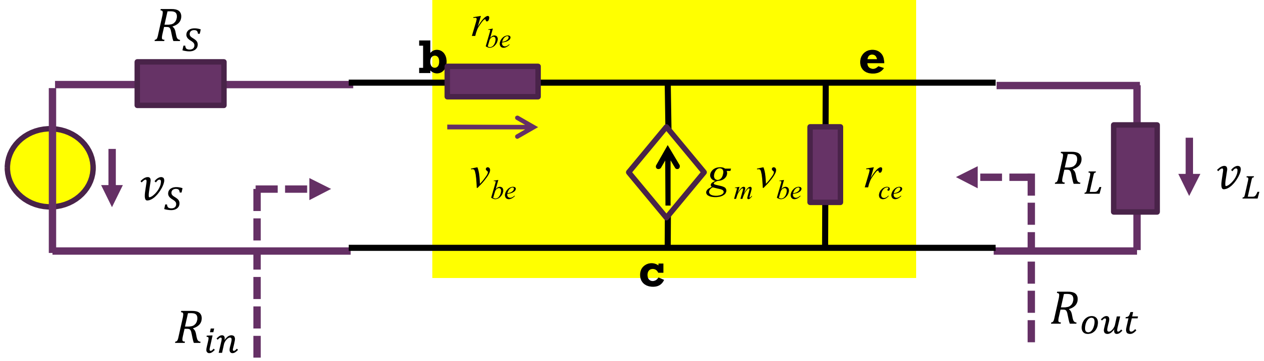
$=\mathbf{13.27}=\mathbf{22.46}\boldsymbol{dB}$同相电压放大

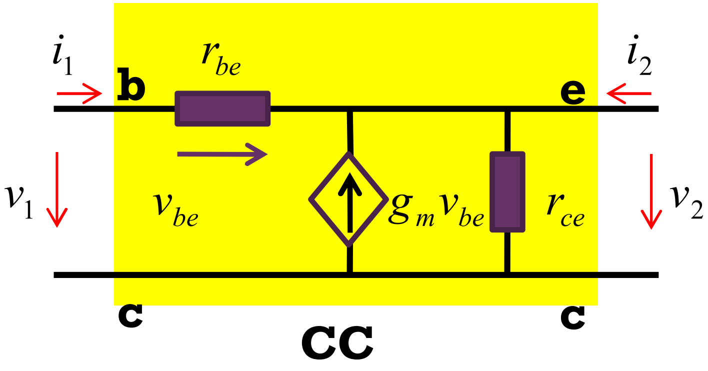


Common Base



CC组态晶体管放大器分析





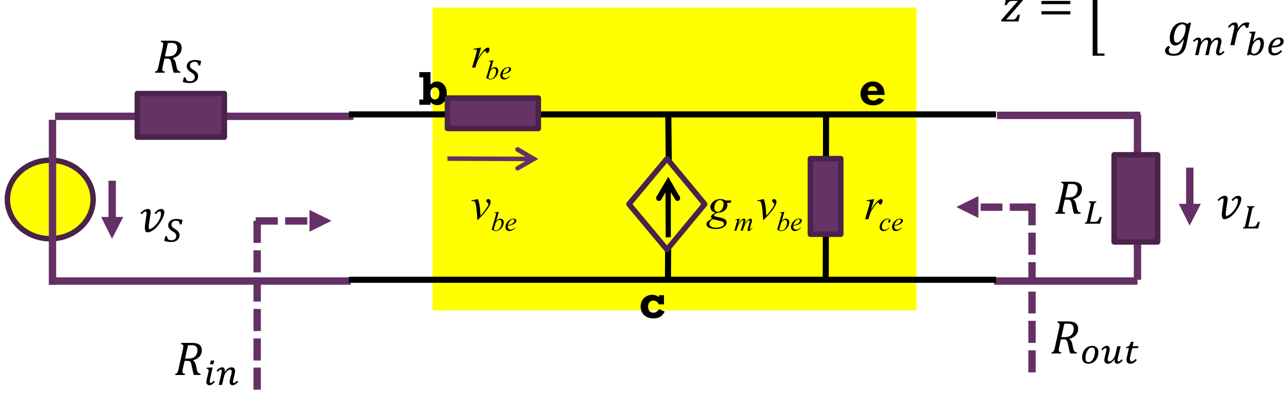
$$v_2 = r_{ce}(i_2 + i_1 + g_m v_{be}) = r_{ce}(i_2 + i_1 + g_m r_{be} i_1)$$
$$= (1 + g_m r_{be}) r_{ce} i_1 + r_{ce} i_2$$

$$v_1 = i_1 r_{be} + v_2 = (r_{be} + r_{ce} + g_m r_{be} r_{ce}) i_1 + r_{ce} i_2$$

$$z = \begin{bmatrix} g_m r_{be} r_{ce} + r_{be} + r_{ce} & r_{ce} \\ g_m r_{be} r_{ce} + r_{ce} & r_{ce} \end{bmatrix}$$

输入电阻和输出电阻

$$z=\begin{bmatrix} g_m r_{be} r_{ce}+r_{be}+r_{ce} & r_{ce} \\ g_m r_{be} r_{ce}+r_{ce} & r_{ce} \end{bmatrix}$$



$$R_{in}=z_{in}=z_{11}-\frac{z_{12}z_{21}}{z_{22}+R_L}=g_m r_{be} r_{ce}+r_{be}+r_{ce}-\frac{r_{ce}(g_m r_{be}+1)r_{ce}}{r_{ce}+R_L}$$

bc端口阻抗

$$=g_m r_{be} r_{ce}\left(1-\frac{r_{ce}}{r_{ce}+R_L}\right)+r_{be}+r_{ce}\left(1-\frac{r_{ce}}{r_{ce}+R_L}\right)=g_m r_{be}(r_{ce}||R_L)+r_{be}+r_{ce}||R_L$$

$$=396\boldsymbol{k}+10\text{k}+990=\boldsymbol{407k\Omega}$$

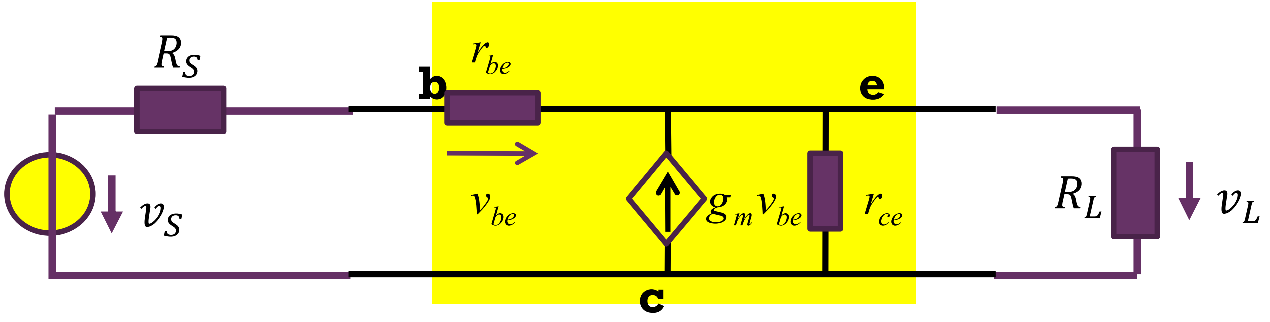
$$R_{out}=z_{out}=z_{22}-\frac{z_{21}z_{12}}{z_{11}+R_S}=r_{ce}-\frac{r_{ce}(g_m r_{be}+1)r_{ce}}{g_m r_{be} r_{ce}+r_{be}+r_{ce}+R_S}=\frac{(r_{be}+R_S)r_{ce}}{g_m r_{be} r_{ce}+r_{be}+r_{ce}+R_S}$$

$$=\frac{(r_{be}+R_S)r_{ce}}{r_{ce}(g_m r_{be}+1)+r_{be}+R_S}=\frac{\frac{r_{be}+R_S}{1+g_m r_{be}}r_{ce}}{r_{ce}+\frac{r_{be}+R_S}{1+g_m r_{be}}}=r_{ce}||\frac{r_{be}+R_S}{1+g_m r_{be}}=\boldsymbol{100k}||25.06=25.06\boldsymbol{\Omega}$$

发射极对地阻抗

电压放大倍数

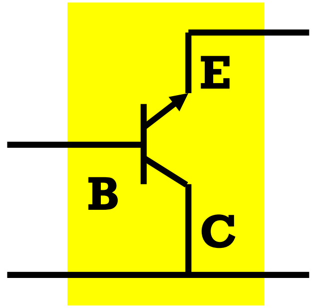
$$z=\begin{bmatrix} g_m r_{be} r_{ce}+r_{be}+r_{ce} & r_{ce} \\ g_m r_{be} r_{ce}+r_{ce} & r_{ce} \end{bmatrix}$$



$$H=A_v=\frac{z_{21}R_L}{(z_{22}+R_L)(z_{11}+R_S)-z_{21}z_{12}}$$

$$=\frac{(g_m r_{be}+1)r_{ce}R_L}{(r_{ce}+R_L)(g_m r_{be} r_{ce}+r_{be}+r_{ce}+R_S)-r_{ce}(g_m r_{be}+1)r_{ce}}$$

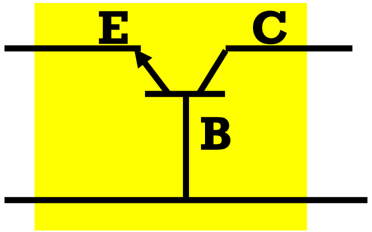
$$=\frac{(g_m r_{be}+1)r_{ce}R_L}{(g_m r_{be}+1)r_{ce}R_L+(r_{be}+R_S)(r_{ce}+R_L)}$$



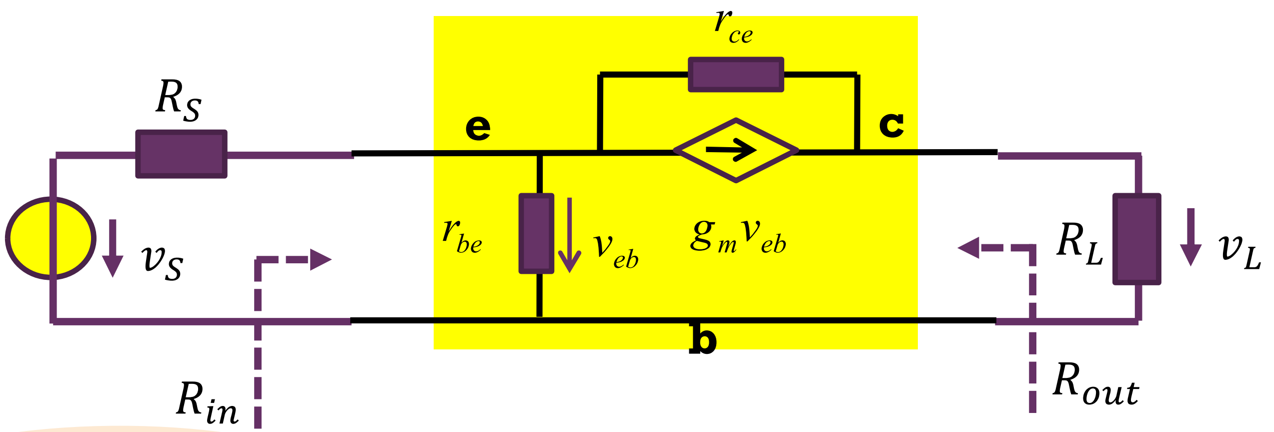
Common Collector

$= 0.9753 = -0.22dB$ 电压缓冲？（电压增益近似为**1=0dB**）

输入阻抗和输出阻抗总结



Common Base



$$R_{in} = r_{be} || \frac{r_{ce} + R_L}{1 + g_m r_{ce}}$$

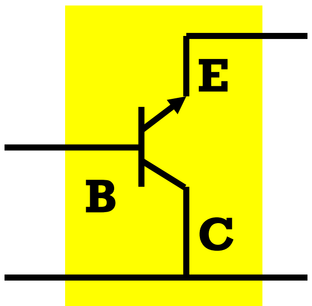
$= 25.18\Omega$

发射极对地阻抗

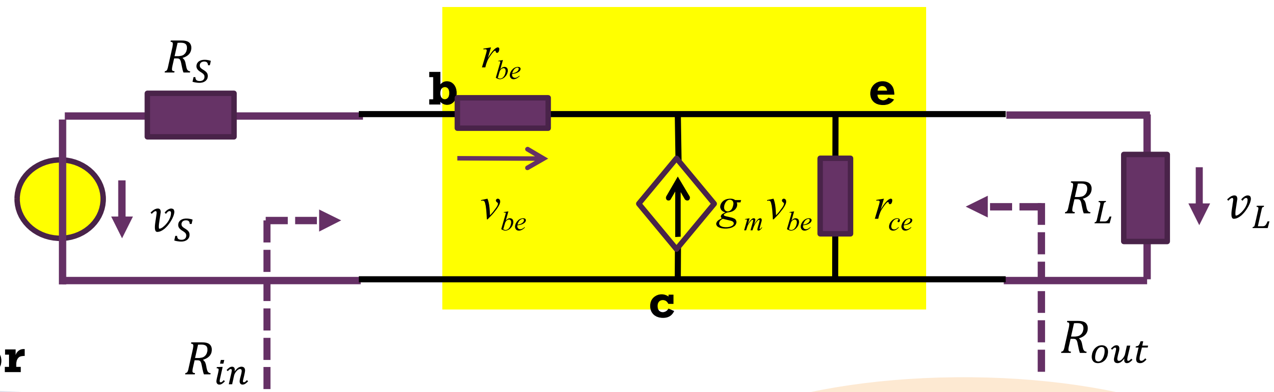
$$R_{out} = g_m (r_{be} || R_S) r_{ce} + r_{be} || R_S + r_{ce}$$

$= 299k\Omega$

bc端口阻抗



Common Collector



$$R_{in} = g_m r_{be} (r_{ce} || R_L) + r_{be} + r_{ce} || R_L$$

$= 407k\Omega$

bc端口阻抗

$$R_{out} = r_{ce} || \frac{r_{be} + R_S}{1 + g_m r_{be}}$$

$= 25.06\Omega$

发射极对地阻抗

电压增益总结

$$A_{v,CE} = \frac{r_{ce}R_L}{r_{ce}+R_L}(-g_m)\frac{r_{be}}{r_{be}+R_S}$$

$$= -39.4$$

$$\approx -g_m R_L = -40$$

反相电压放大

$$A_{v,CB} = \frac{(g_m r_{ce}+1)r_{be}R_L}{(g_m r_{ce}+1)r_{be}R_S + (r_{be}+R_S)(r_{ce}+R_L)}$$

$$= 13.27$$

$$\approx \frac{g_m r_{ce} r_{be} R_L}{g_m r_{ce} r_{be} R_S + r_{be} r_{ce}} = \frac{g_m}{1+g_m R_S} R_L = 13.33$$

同相电压放大

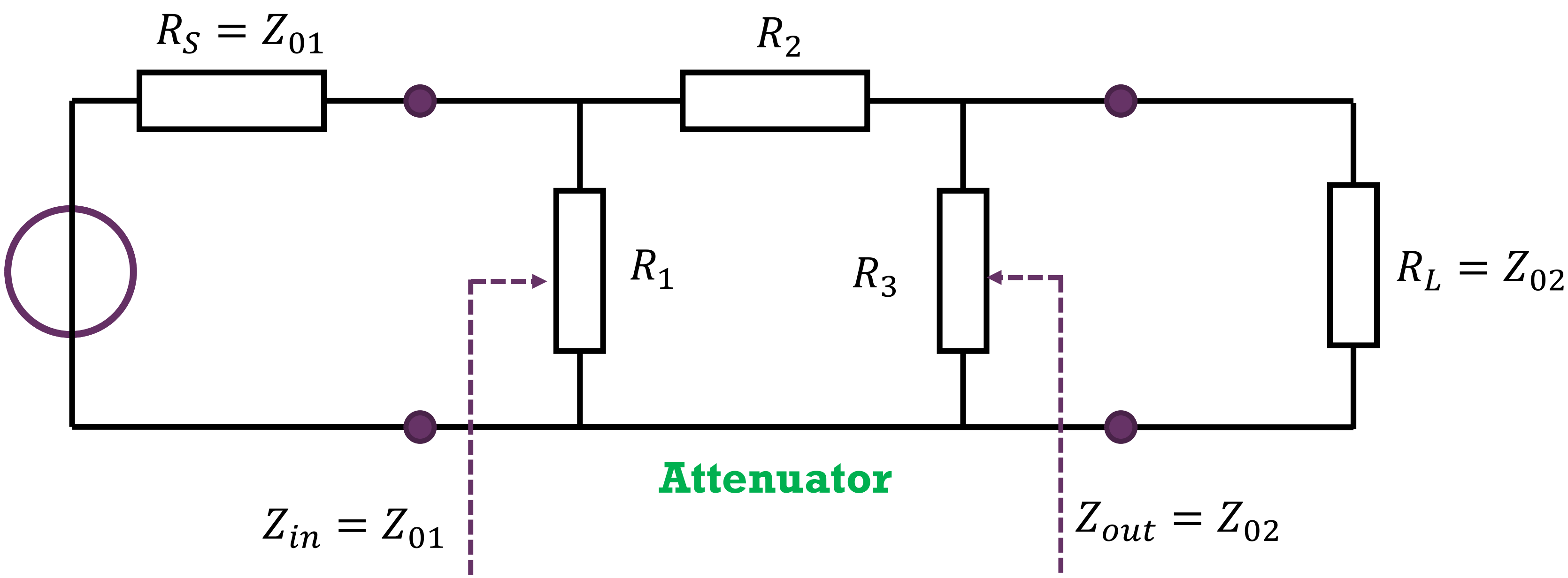
$$A_{v,CC} = \frac{(g_m r_{be}+1)r_{ce}R_L}{(g_m r_{be}+1)r_{ce}R_L + (r_{be}+R_S)(r_{ce}+R_L)}$$

$$= 0.9753$$

$$\approx \frac{g_m r_{be} r_{ce} R_L}{g_m r_{be} r_{ce} R_L + r_{be} r_{ce}} = \frac{g_m}{1+g_m R_L} R_L = 0.9756$$

同相电压放大

练习 匹配电阻衰减器设计



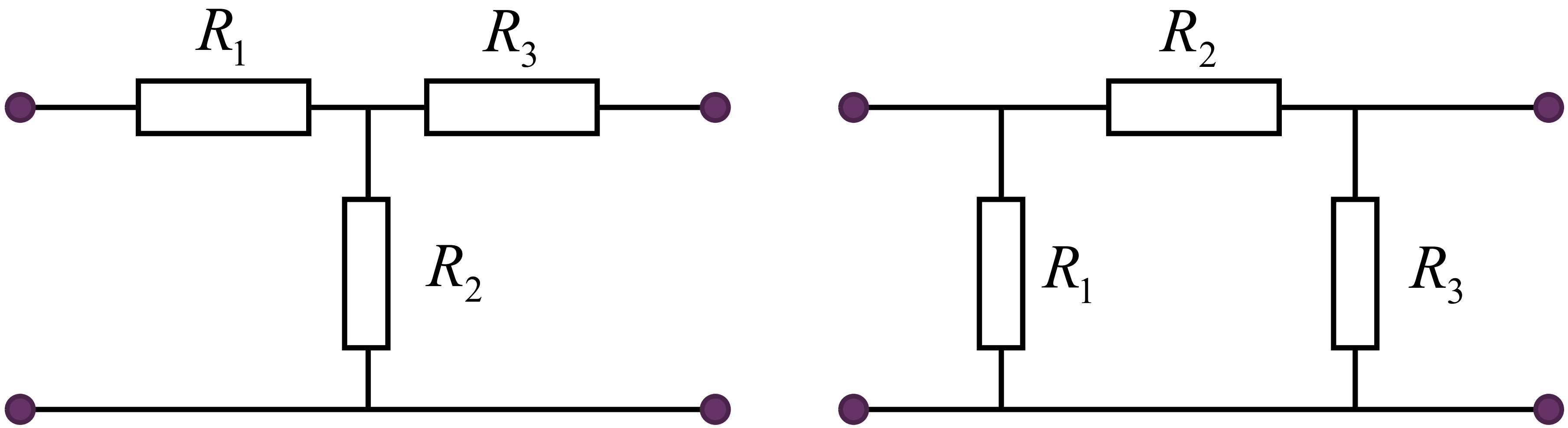
设计要求：端口1匹配于Z_{01}阻抗，端口2匹配于Z_{02}阻抗，功率衰减LdB

答案：

$$\beta = 10^{\frac{L}{20}} \qquad R_2 = 0.5\left(\beta - \beta^{-1}\right)\sqrt{Z_{01}Z_{02}}$$

$$R_1 = \frac{1}{\frac{1}{Z_{01}}\frac{\beta+\beta^{-1}}{\beta-\beta^{-1}} - \frac{1}{R_2}} \qquad R_3 = \frac{1}{\frac{1}{Z_{02}}\frac{\beta+\beta^{-1}}{\beta-\beta^{-1}} - \frac{1}{R_2}}$$

对偶电路



π型电阻衰减器设计公式已知，根据对偶性给出**T**型电阻衰减器的设计公式

并根据公式设计一个**50**Ω系统到**75**Ω系统转换的**20dB**匹配衰减器，验证设计满足要求