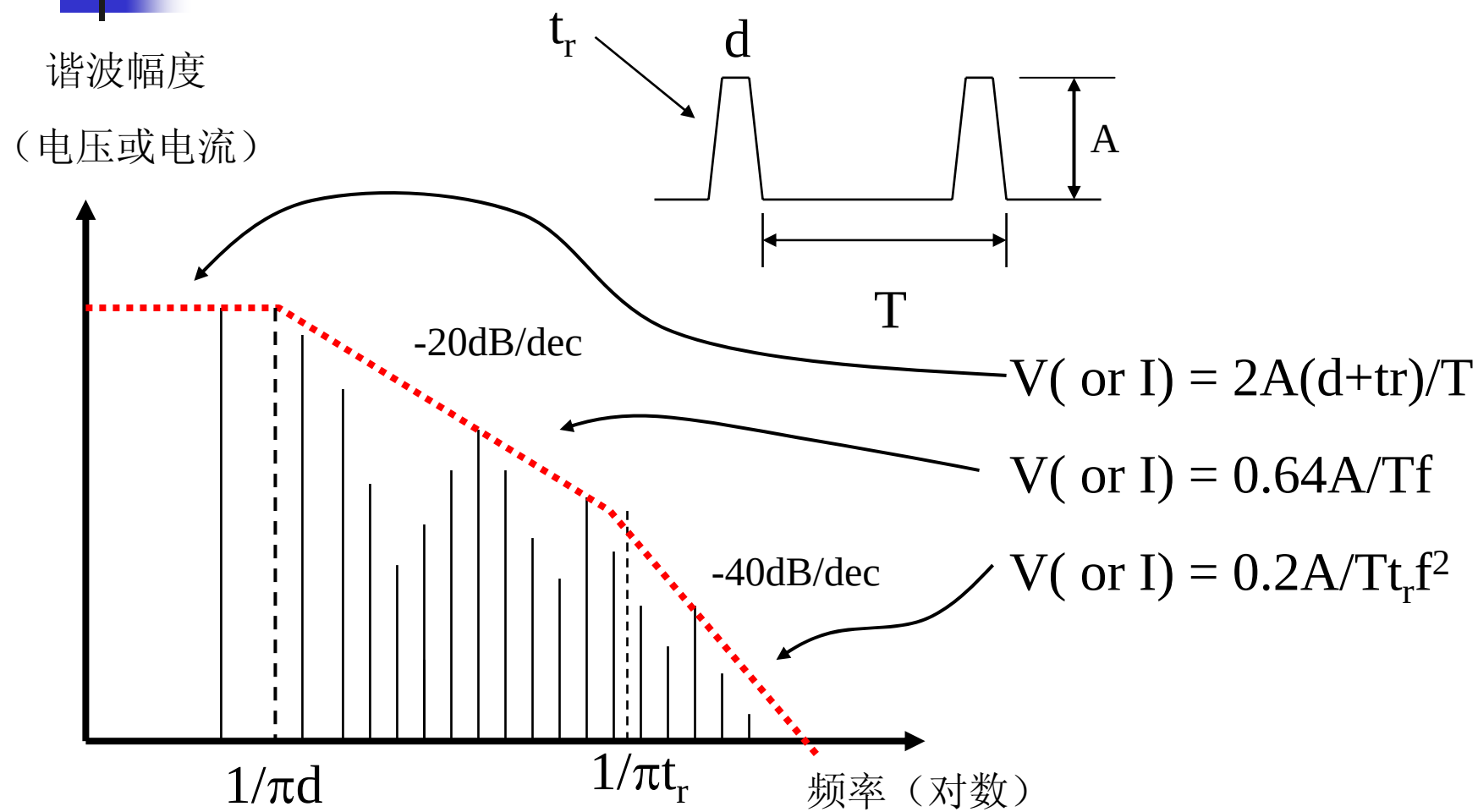
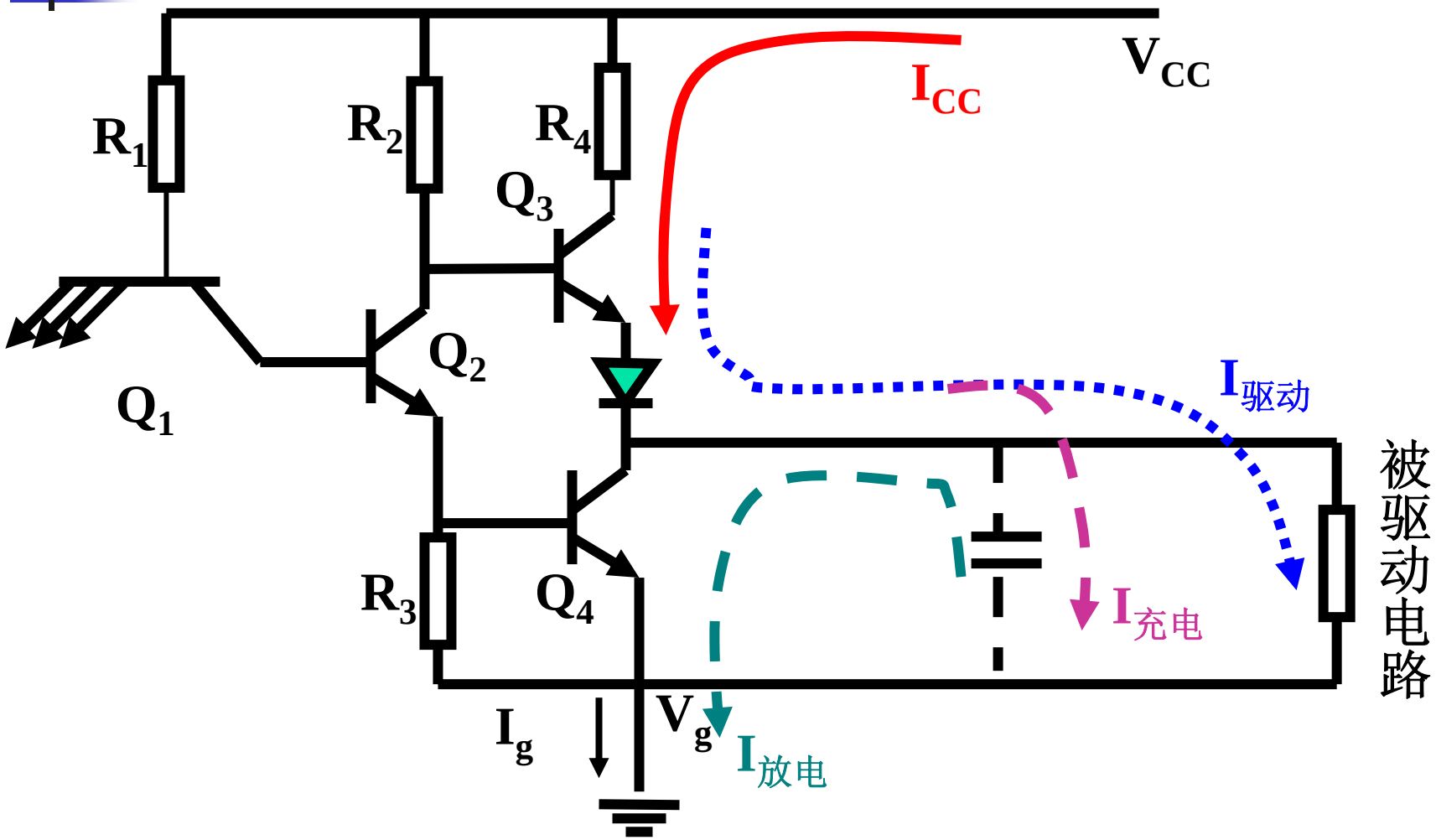
第五章 PCB的电磁兼容设计

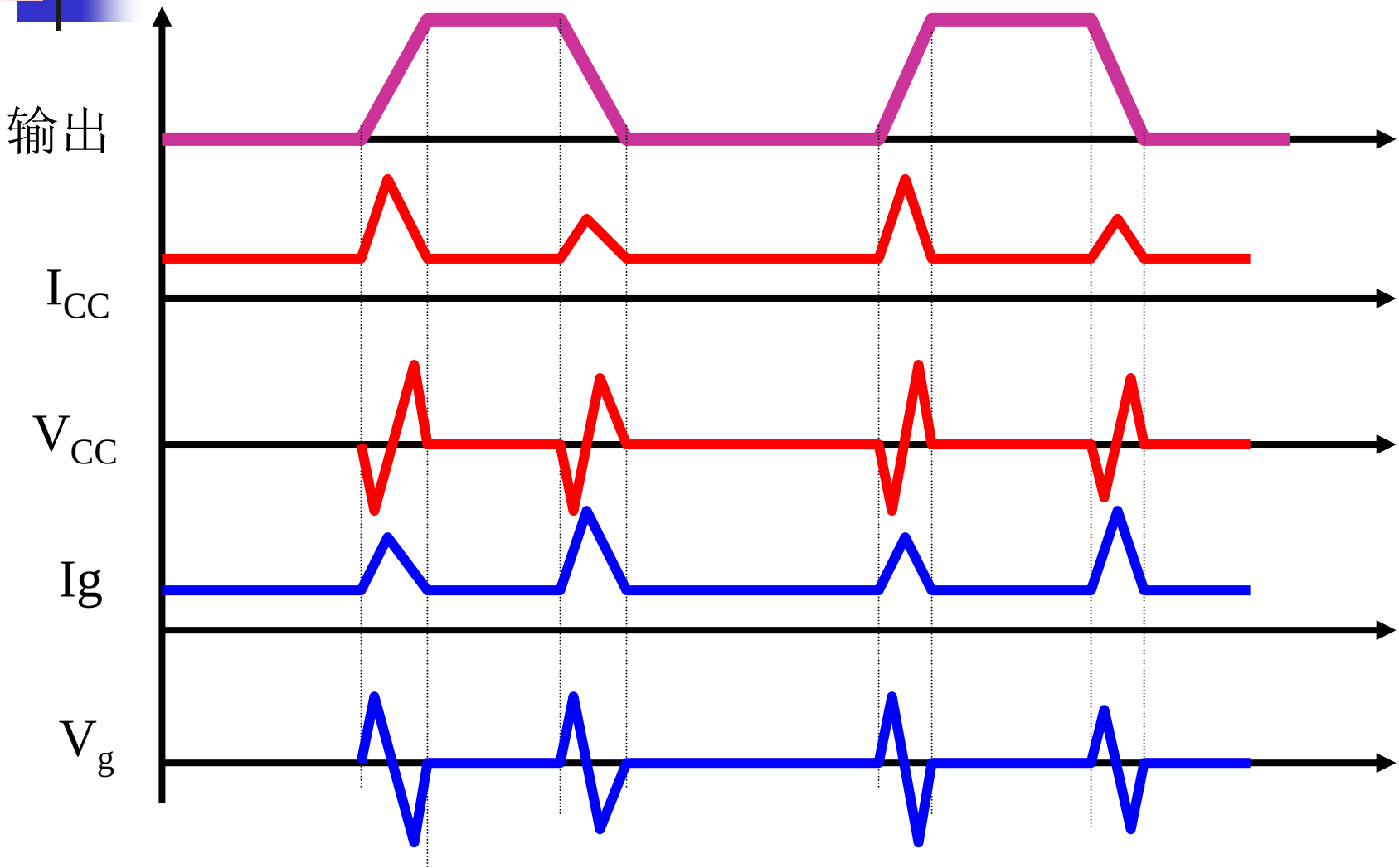
脉冲信号的频谱


谐波幅度
（电压或电流）
t_r
d
A
T
-20dB/dec
-40dB/dec
V(or I) = 2A(d+tr)/T
V(or I) = 0.64A/Tf
V(or I) = 0.2A/Tt$_r$f^2
1/πd
1/πt$_r$
频率（对数）

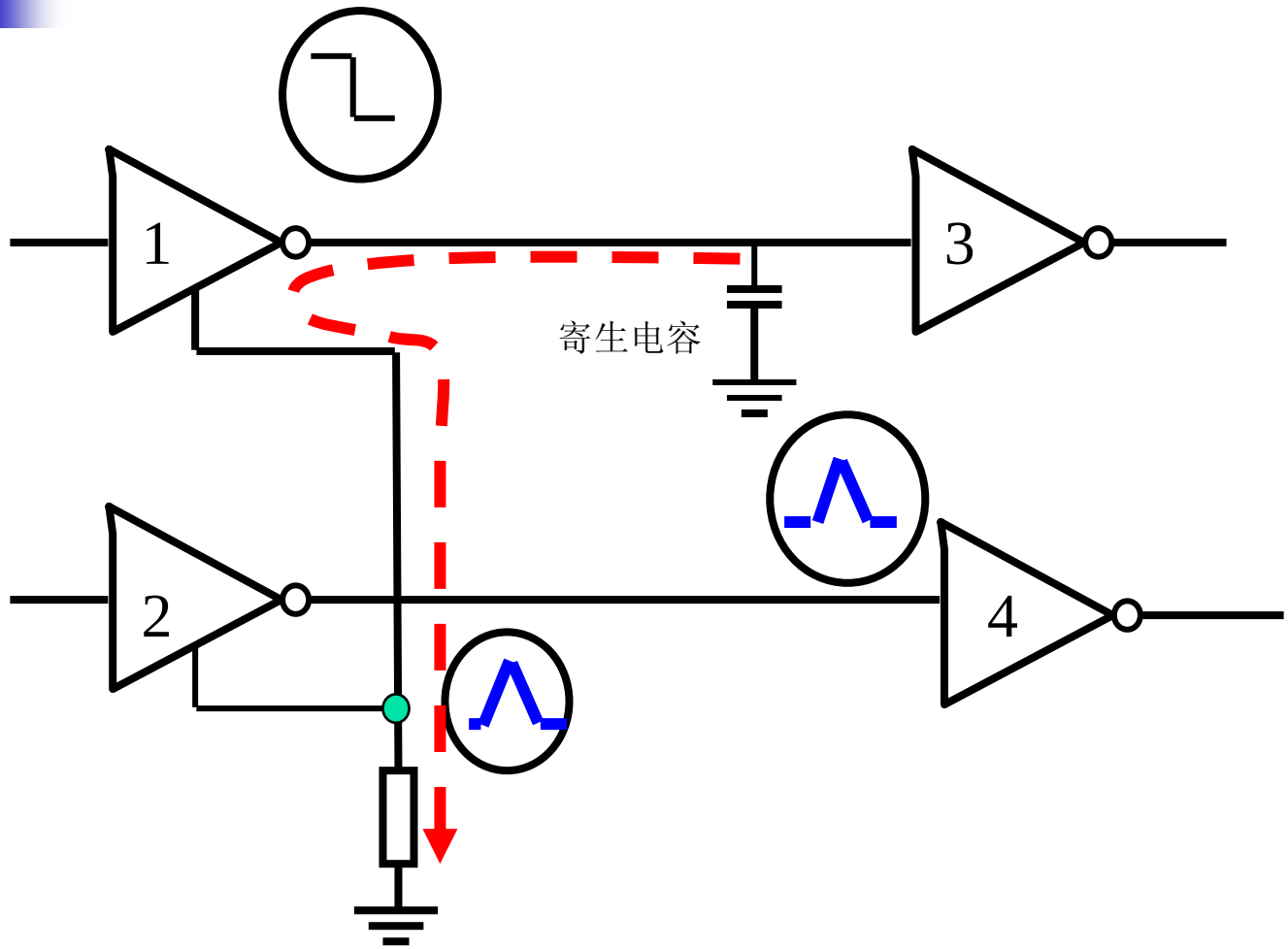
地线和电源线上的噪声



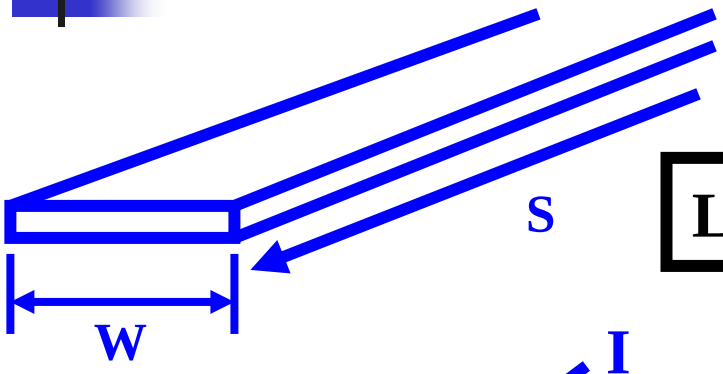
电源线、地线噪声电压波形



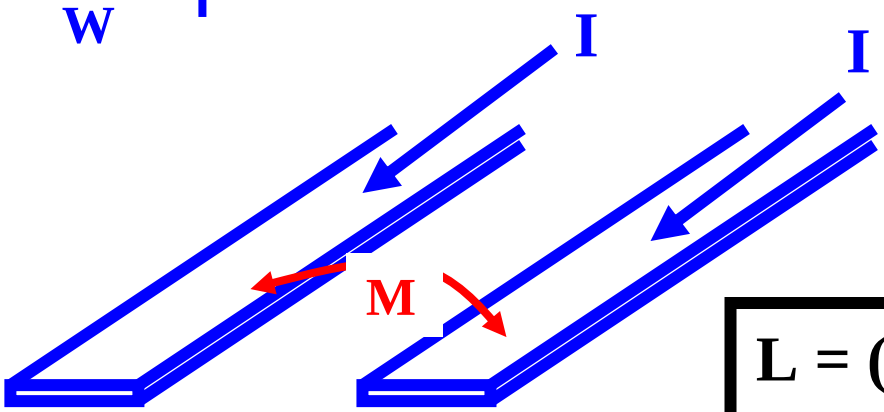
地线干扰



线路板走线的电感



$$L = 0.002S(2.3\lg(2S/W) + 0.5 \quad \mu H$$

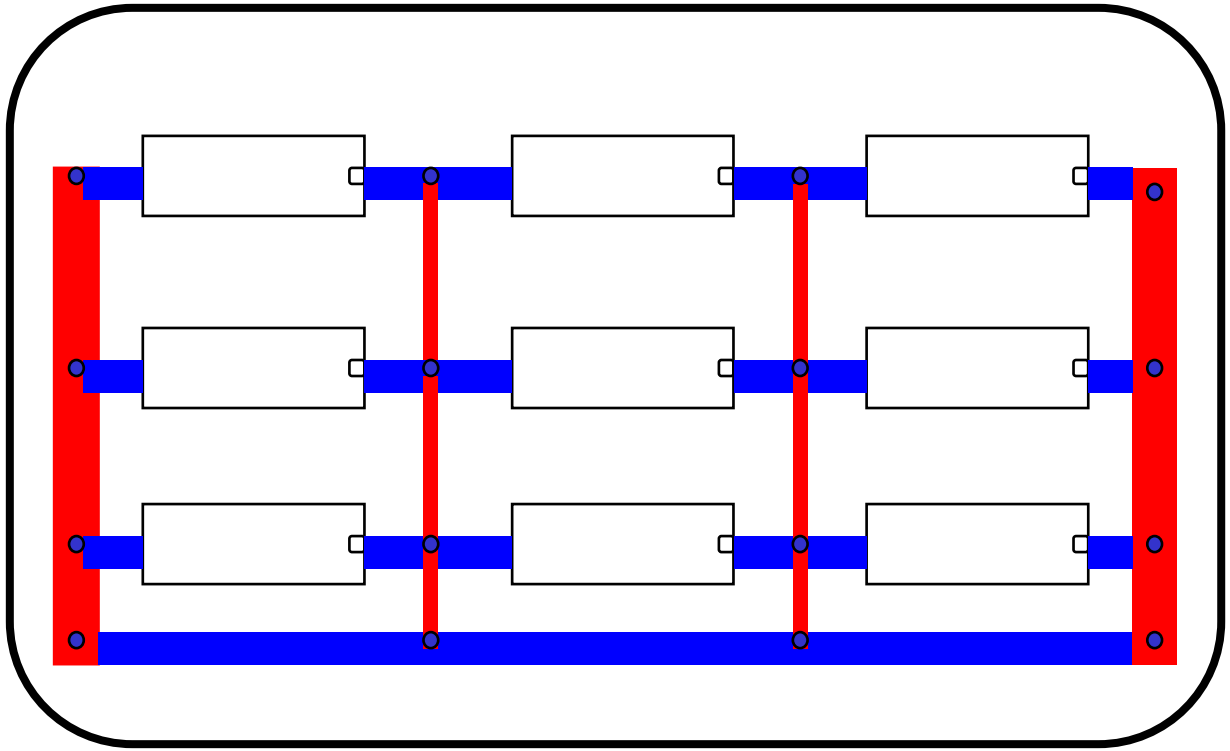


$$L = (L_1L_2 - M^2) / (L_1 + L_2 - 2M)$$

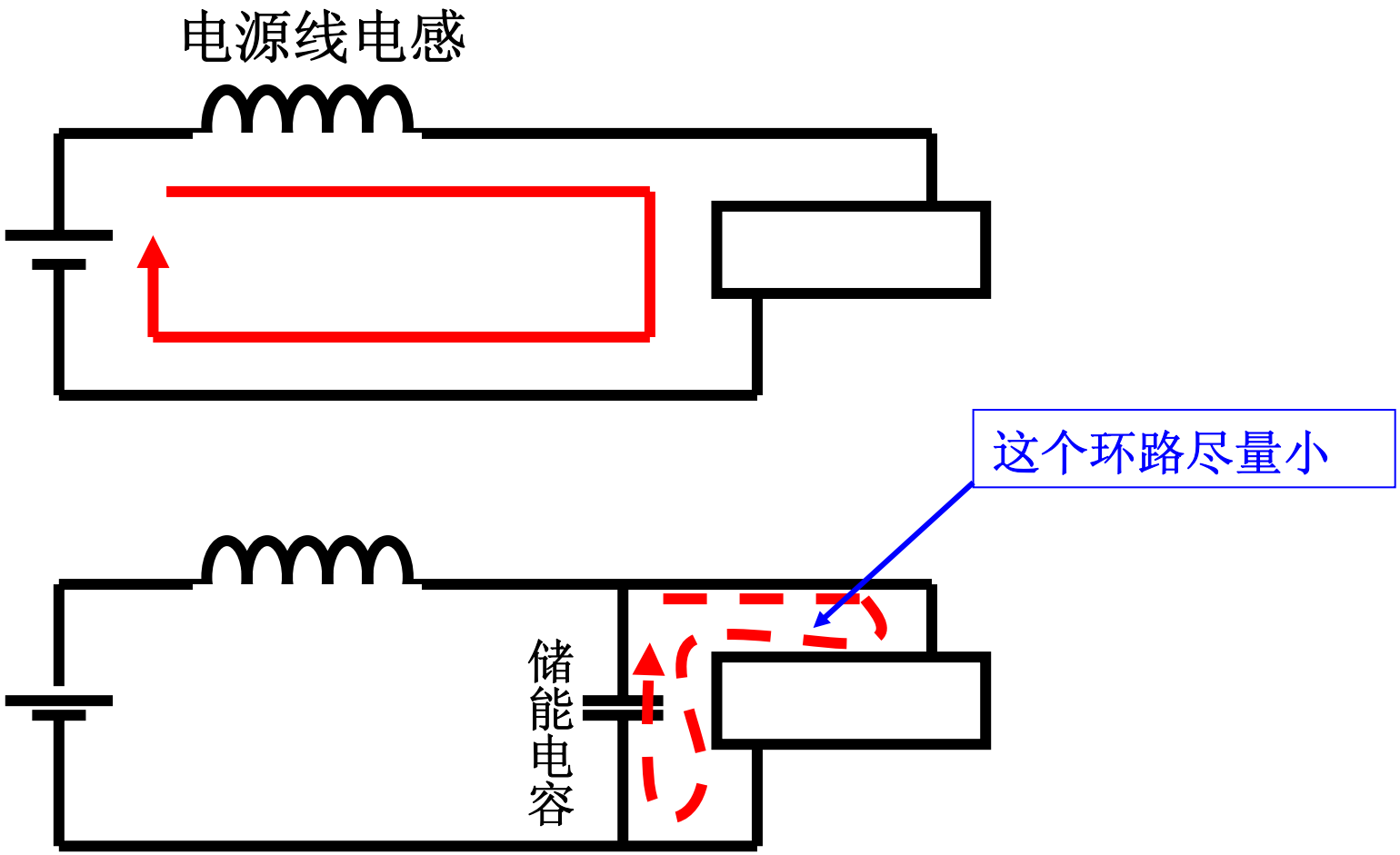
若：$L_1 = L_2$

$$L = (L_1 + M) / 2$$

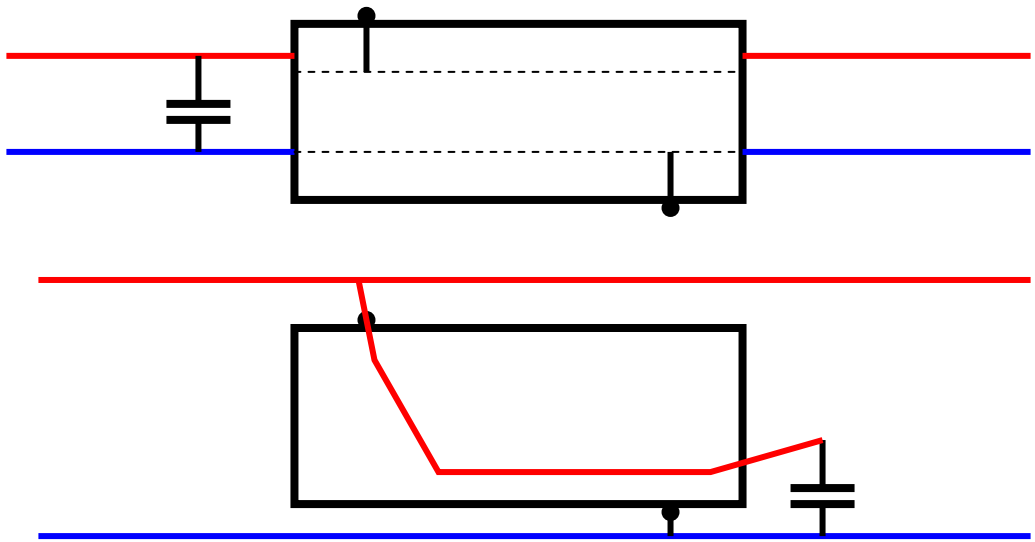
地线网格



电源线噪声的消除



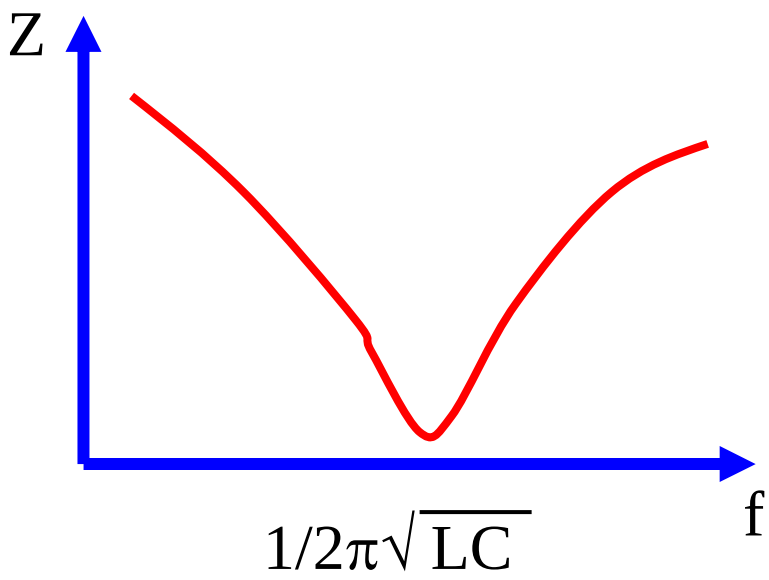
电源解耦电容的正确布置



尽量使电源线与地线靠近

解耦电容的选择

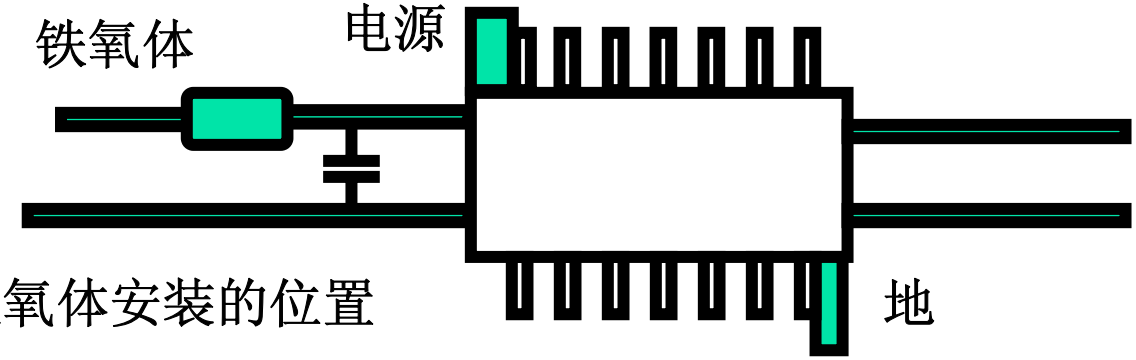
$$C = \frac{dI\ dt}{dV}$$



各参数含义：

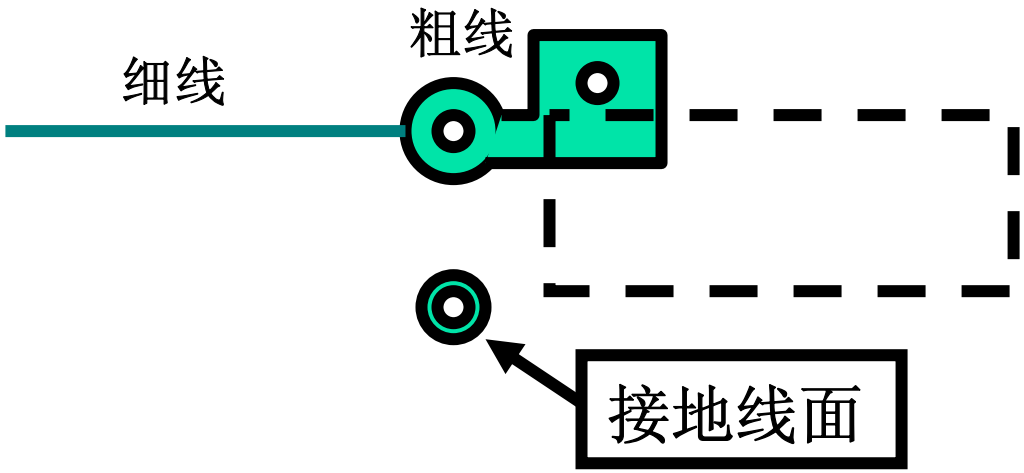
在时间**dt**内，电源线上出现了瞬间电流**dI**，**dI**导致了电源线上出现电压跌落**dV**。

增强解耦效果的方法



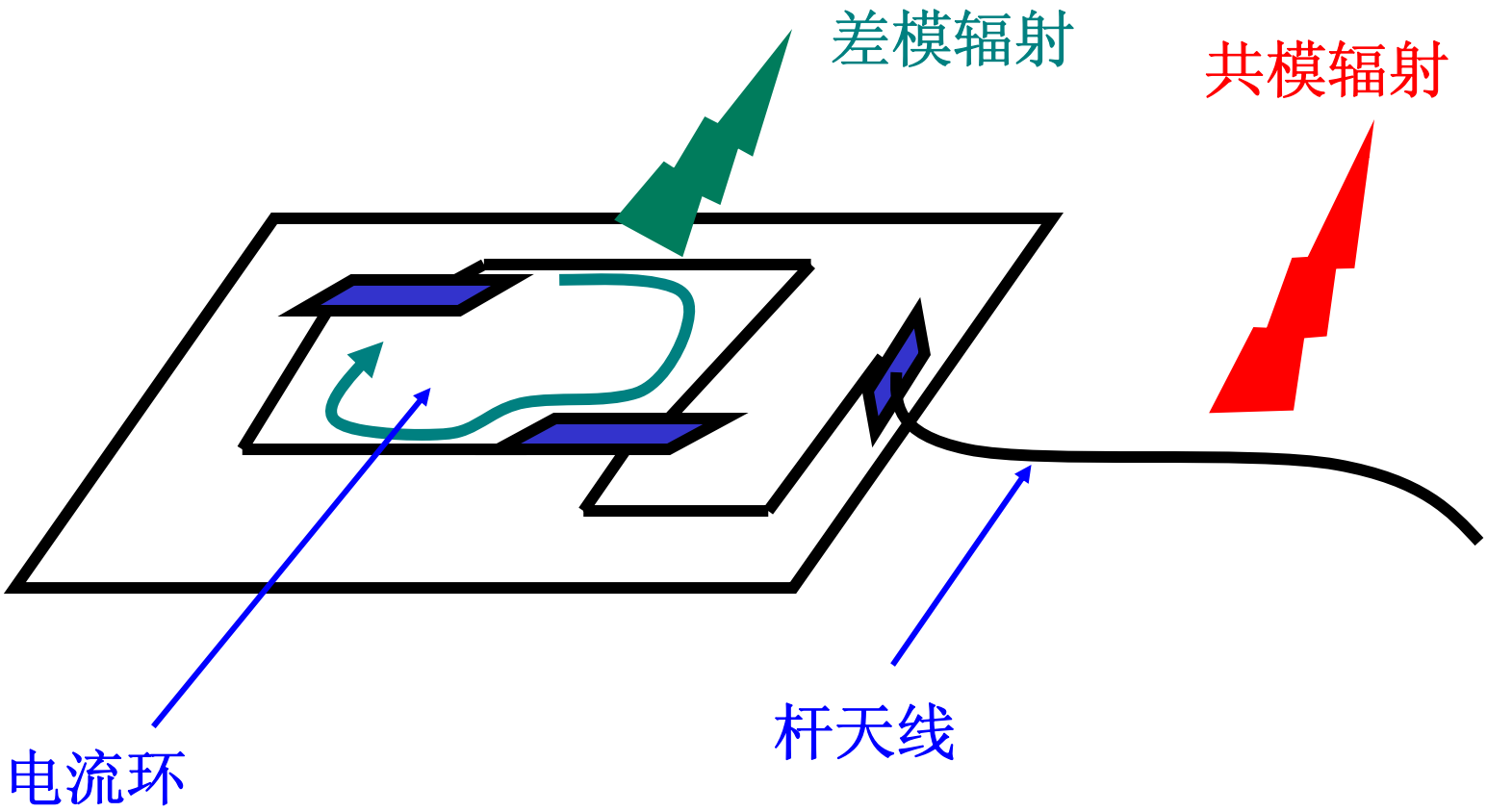
注意铁氧体安装的位置

用铁氧体增加电源端阻抗



用细线增加电源端阻抗

线路板的两种辐射机理

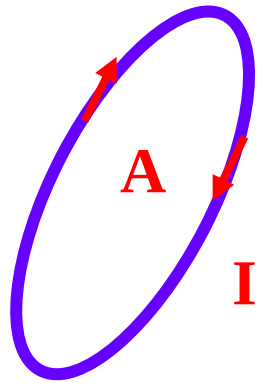


电流环路产生的辐射

近场区内：　$H = IA / (4\pi D^3)$　　A/m

$E = Z_0 IA / (2\lambda D^2)$　　V/m

$Z_W = Z_0（2\pi D/\lambda）$　　Ω

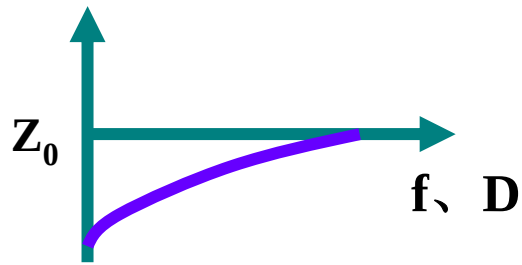


随频率、距离增加而增加

远场区内：　$H = \pi IA / (\lambda^2 D)$　　A/m

$E = Z_0 \pi IA / (\lambda^2 D)$　　V/m

$Z_W = Z_0 = 377$　　Ω

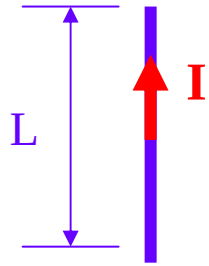


导线的辐射

近场区内：　$H = I L / (4\pi D^2)$　　A/m

$E = Z_0 I L \lambda / (8 \pi^2 D^3)$　　V/m

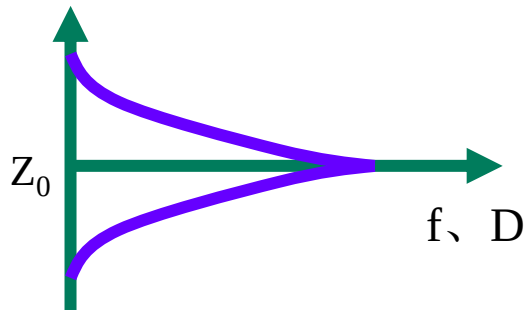
$Z_W = Z_0$（$\lambda/2\pi D$）　　Ω



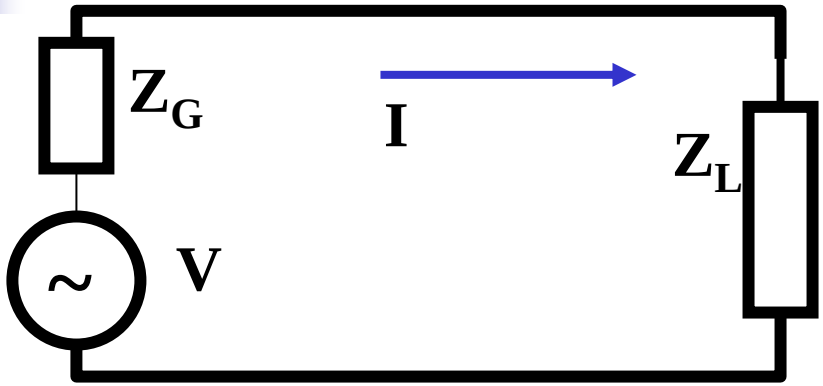
远场区内：　$H = I L / (2\lambda D)$　　A/m

$E = Z_0 I L / (2\lambda D)$　　V/m

随频率、距离增加而减小



实际电路的辐射



$Z_C = Z_G + Z_L$

环路面积 = A

近场：$Z_C \geq 7.9\ D\ f$　　$E = 7.96VA / D^3$　　（μV/m）

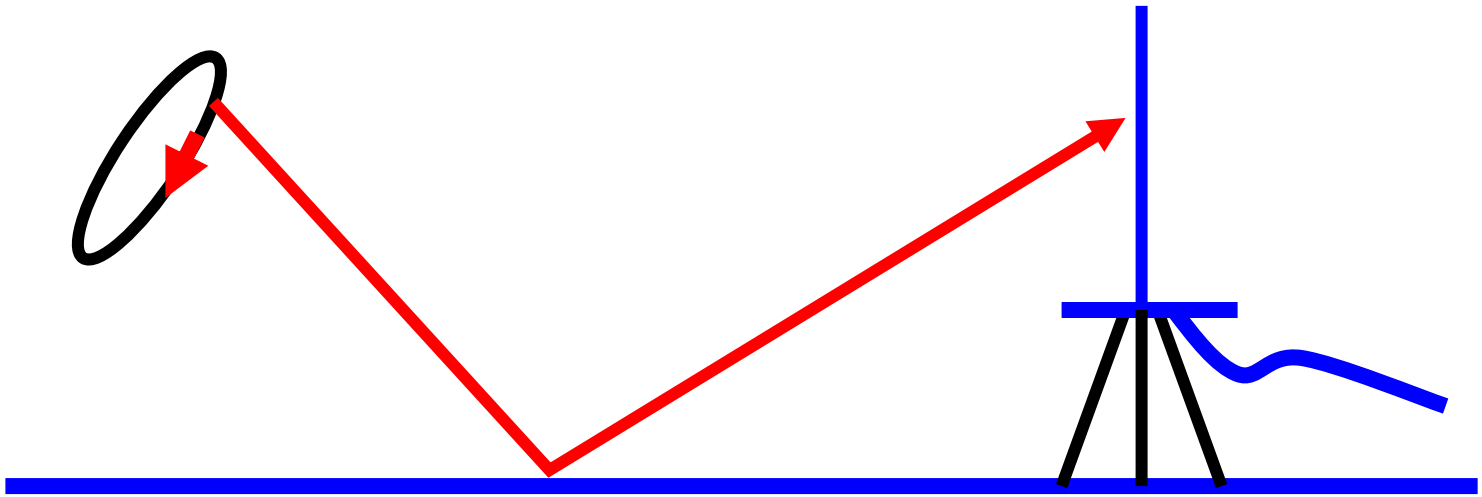
$Z_C \leq 7.9\ D\ f$，　$E = 63\ I\ A\ f / D^2$　　（μV/m）

$H = 7.96IA / D^3$　　（μA/m）

远场：

$E = 1.3\ I\ A\ f^2 / D$　　（μV/m）

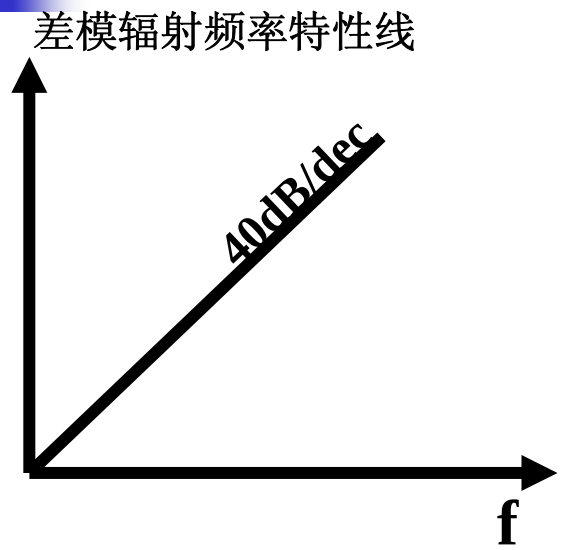
常用的差模辐射预测公式



考虑地面反射时：

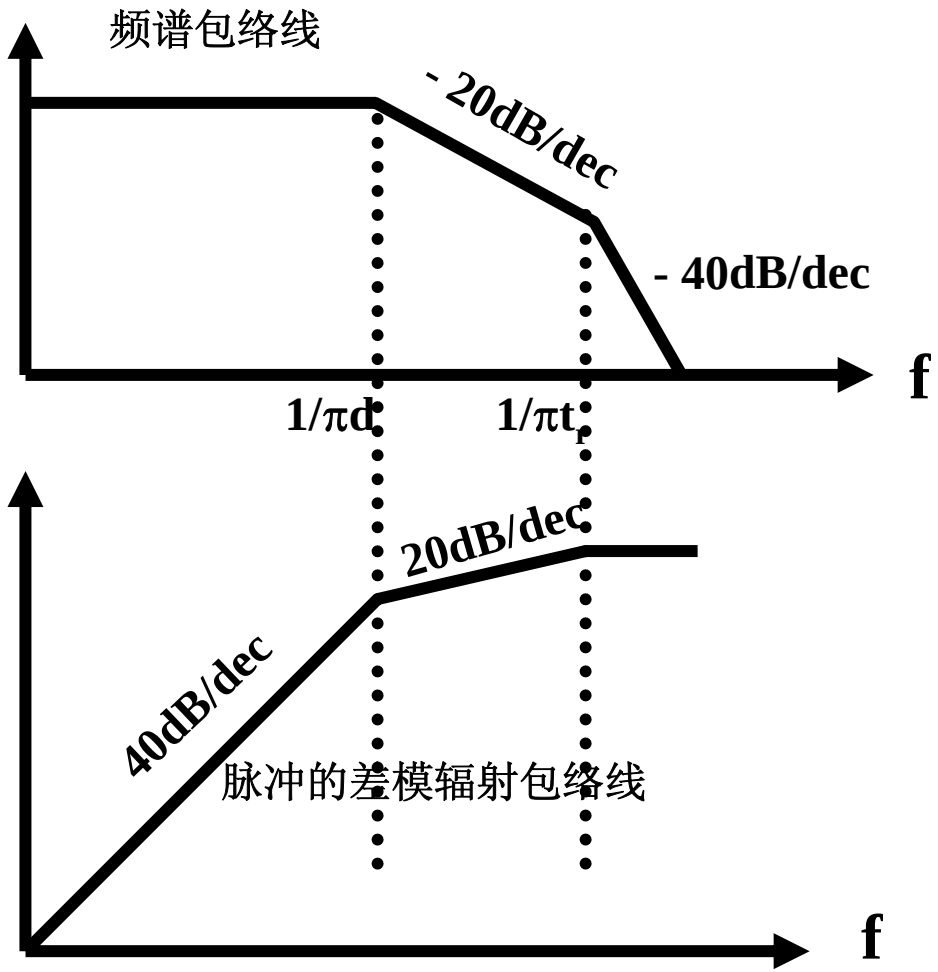
$$E = 2.6\ I\ A\ f^{2}/D \qquad (\mu V/m)$$

脉冲信号差模辐射的频谱



$$E = 2.6\ I\ A\ f^2/D$$

$$E_{dB} = 20\lg(2.6\ I\ A/D) + 40\lg f$$



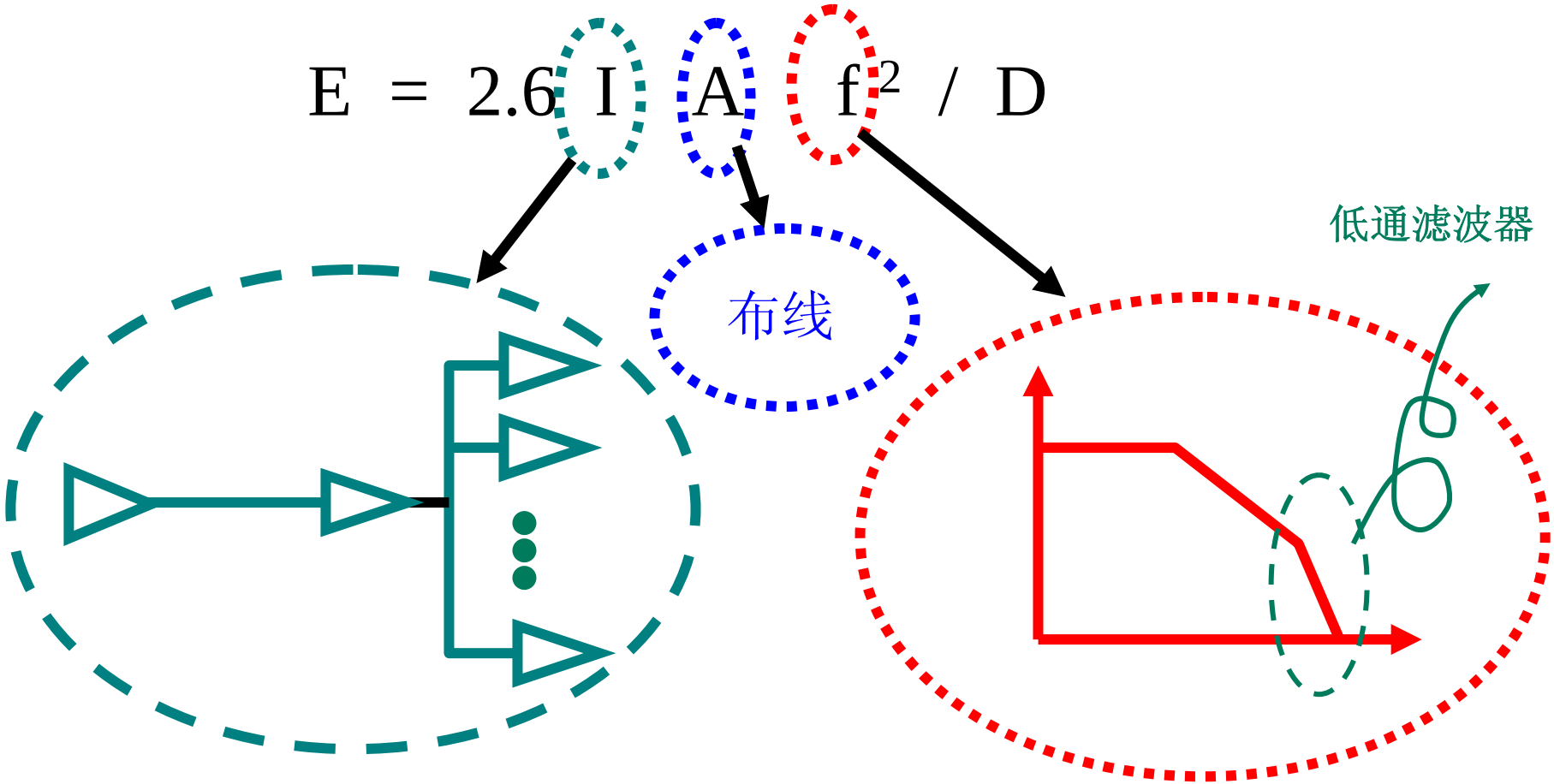
不同逻辑电路为了满足EMI指标要求所允许的环路面积

逻辑系列	上升时间	电流	不同时钟频率允许的面积（cm^2 ）			
			4MHz	10	30	100
4000B	40	6	1000	400		
74HC	6	20	50	45	18	6
74LS	6	50	20	18	7.2	2.4
74AC	3.5	80	5.5	2.2	0.75	0.25
74F	3	80	5.5	2.2	0.75	0.25
74AS	1.4	120	2	0.8	3	0.15

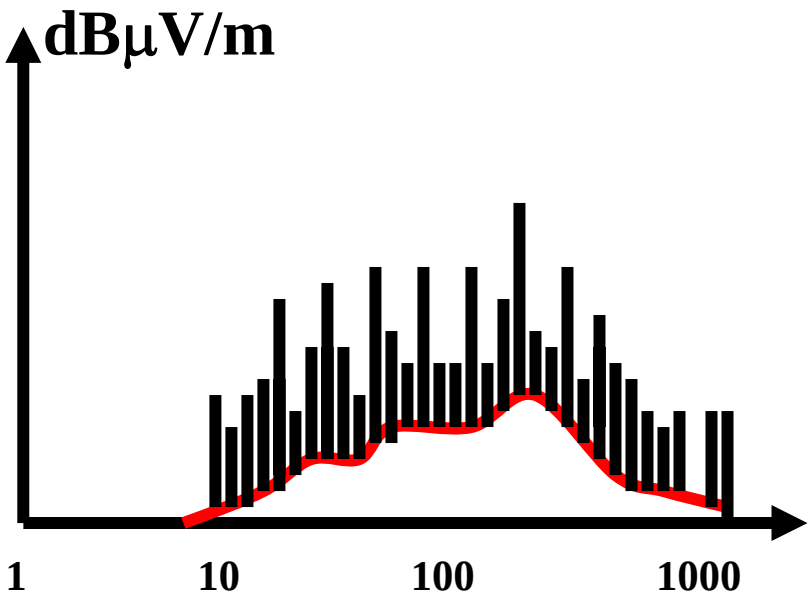
仅代表了一个环路的辐射情况，若有N个环路辐射，乘以 $\sqrt{N}$ 。因此，可能时，分散时钟频率。

如何减小差模辐射？

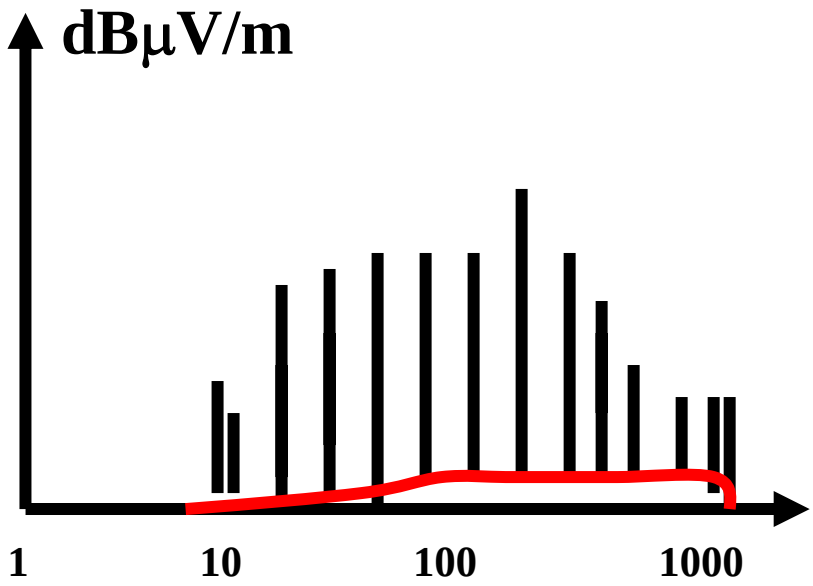
$$E = 2.6\ I\ A\ f^2\ /\ D$$



电路中的强辐射信号

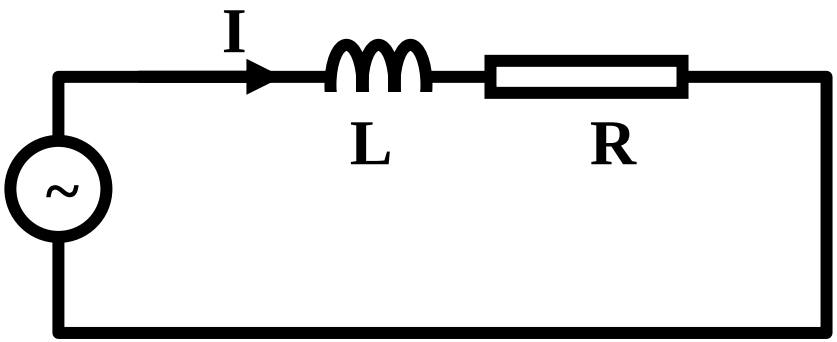


所有电路加电工作



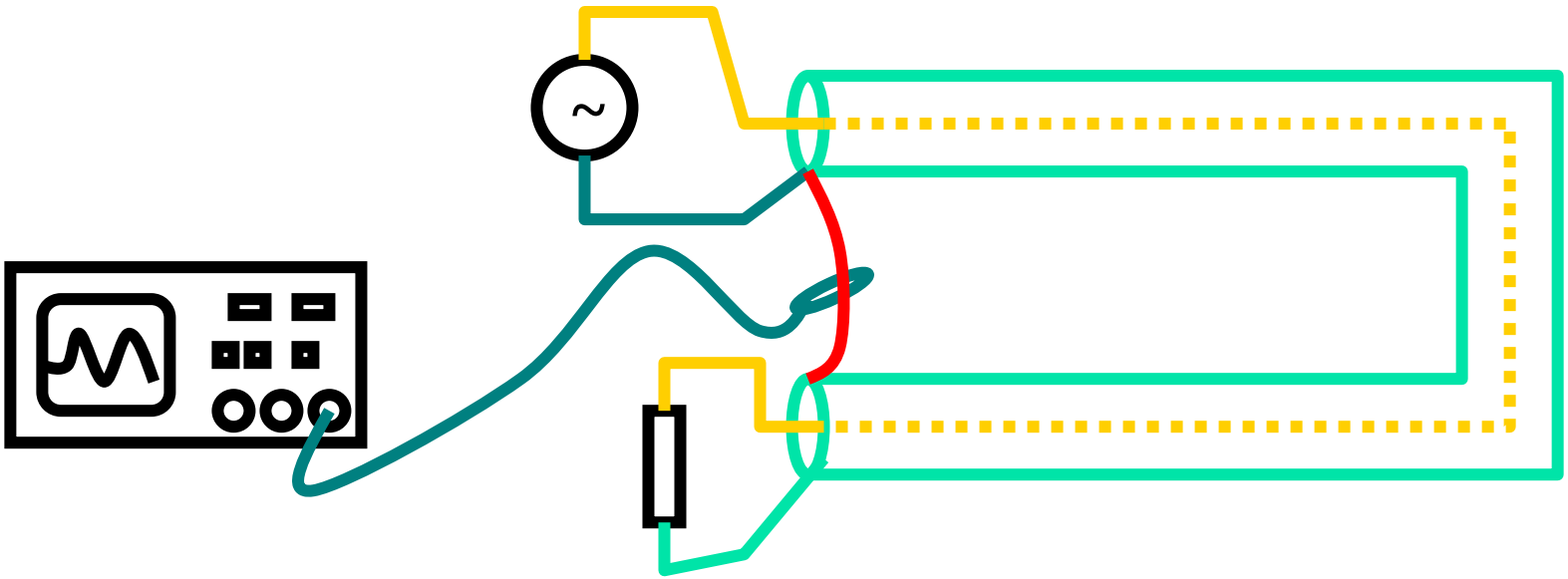
只有时钟电路加电工作

电流回路的阻抗

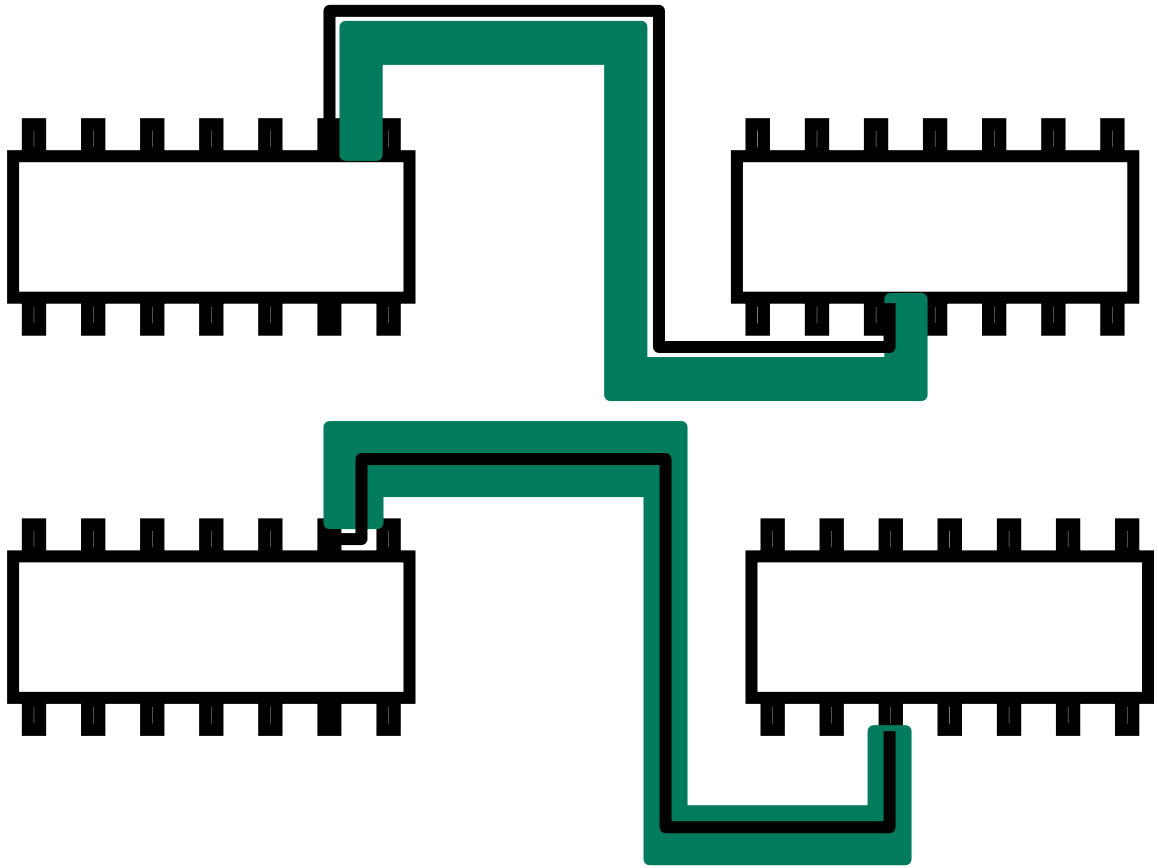


$$Z = R + j\omega L$$

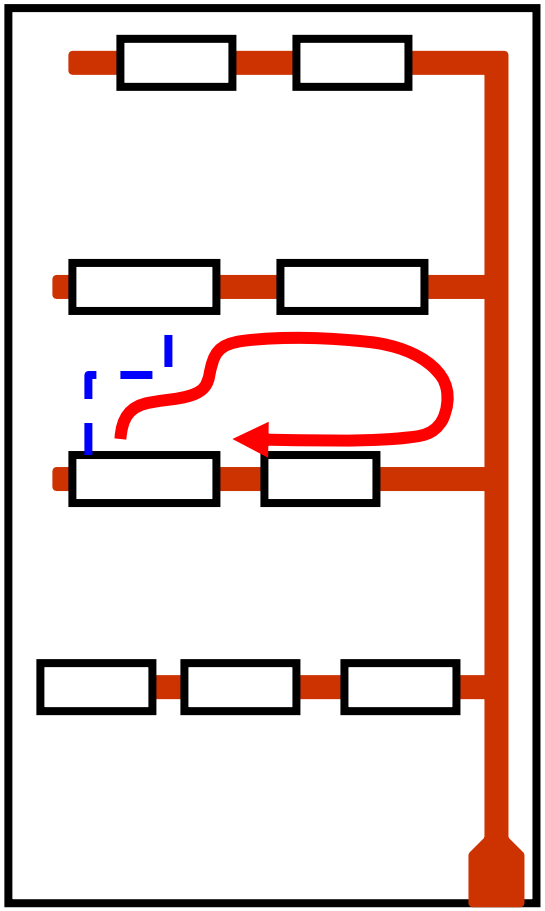
$$L = \Phi / I \qquad \Phi \propto A$$

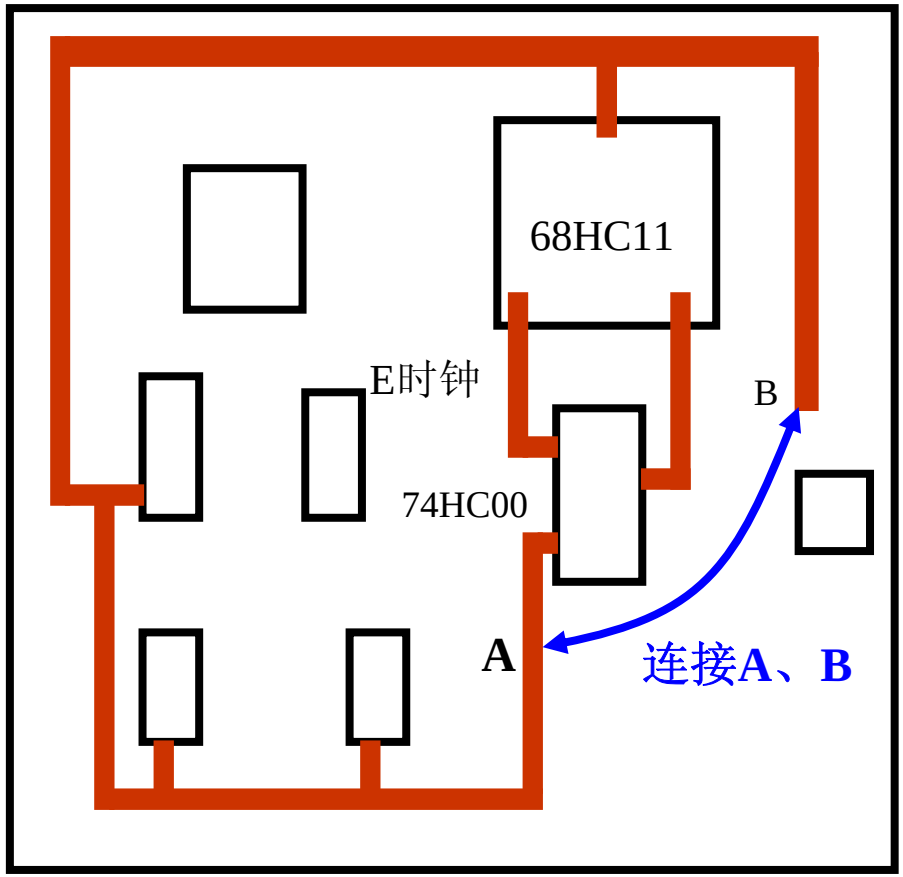


单层或双层板如何减小环路的面积

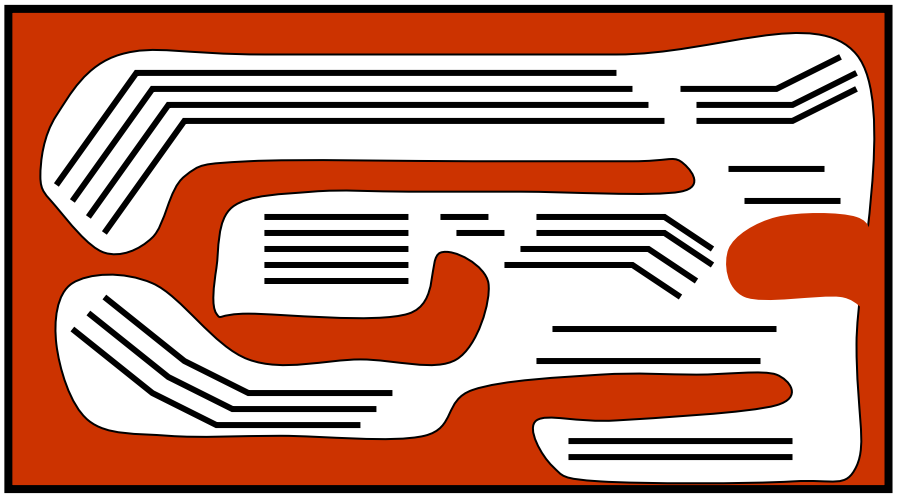


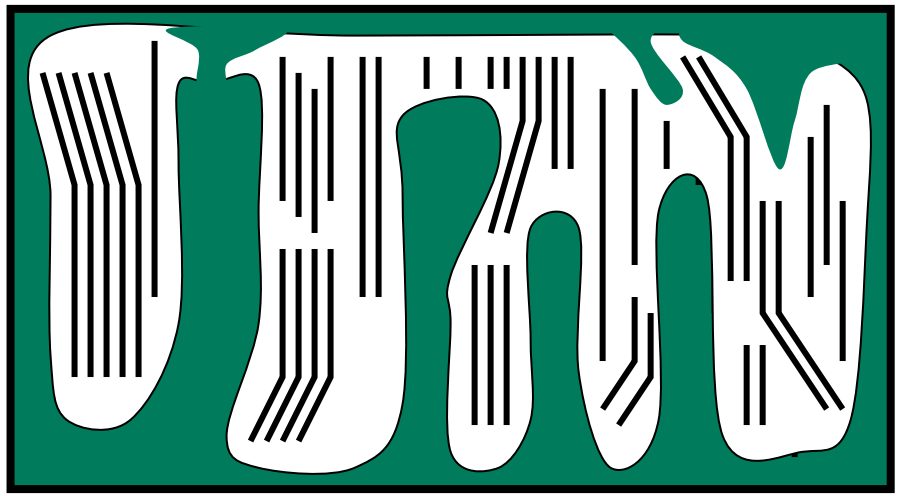
不良布线举例





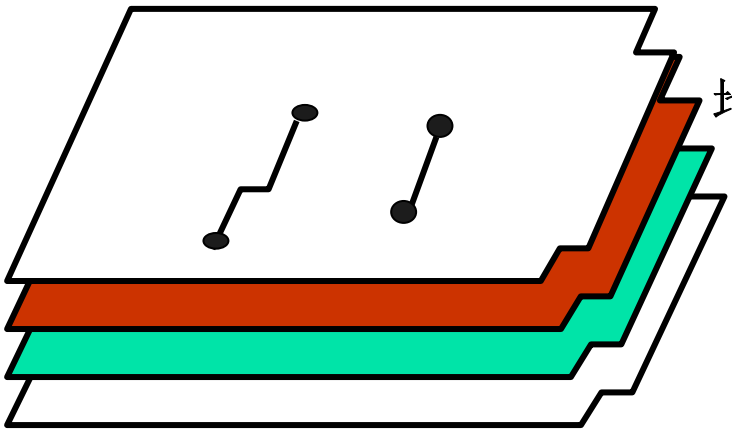
随便设置的地线没有用

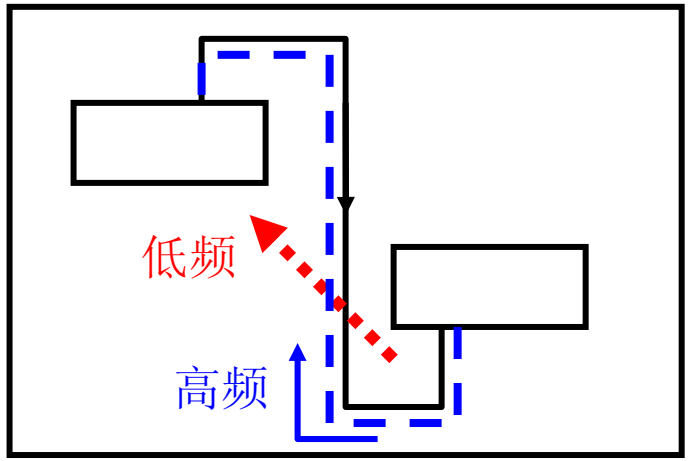


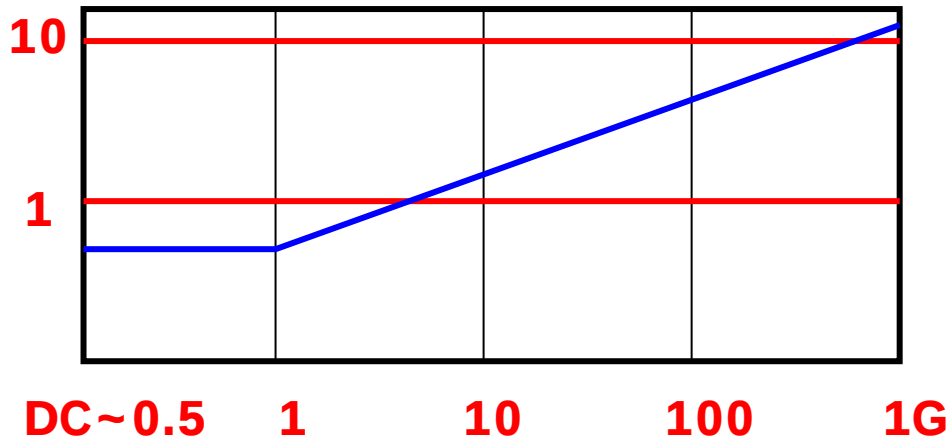


在线路板上没有布线的地方全部铺上地线是**EMC**设计吗？

多层板能减小辐射



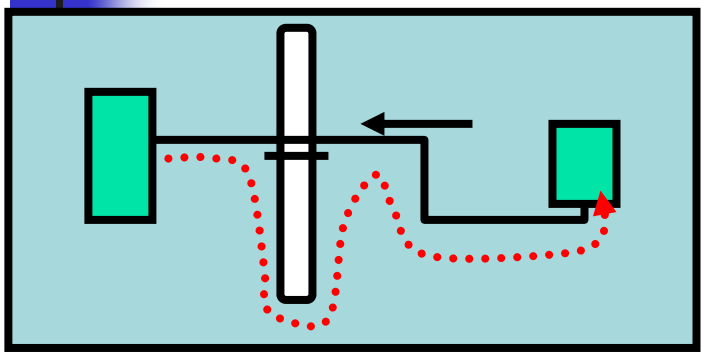


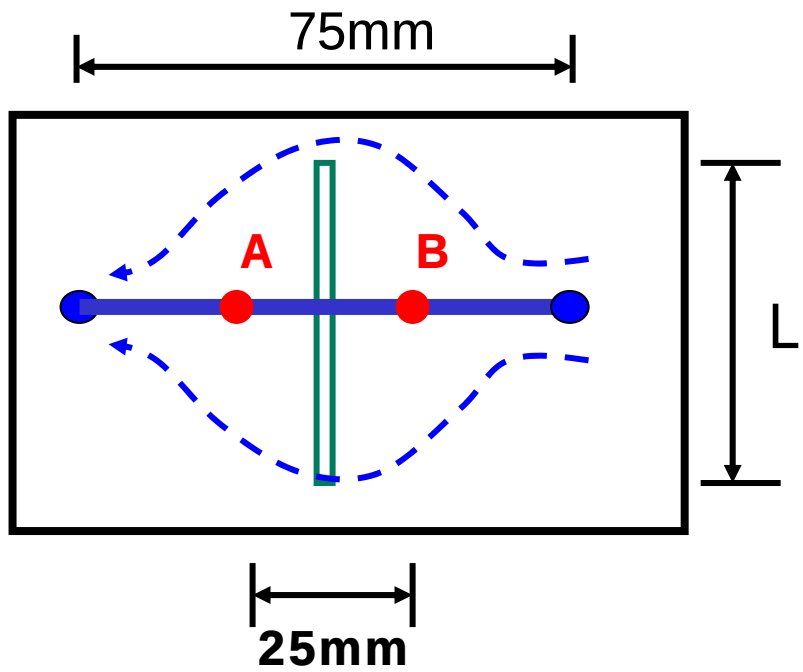


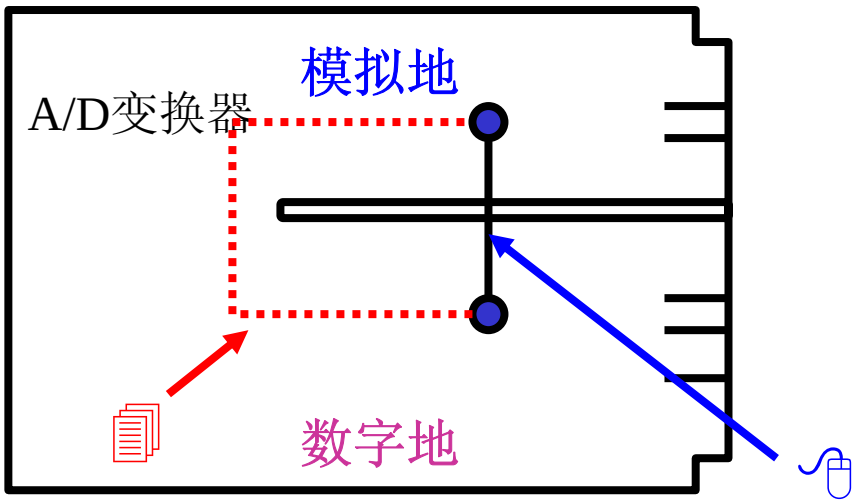
地线面的阻抗，mΩ/ 平方

地线面具有很小的地线阻抗

地线面上的缝隙的影响



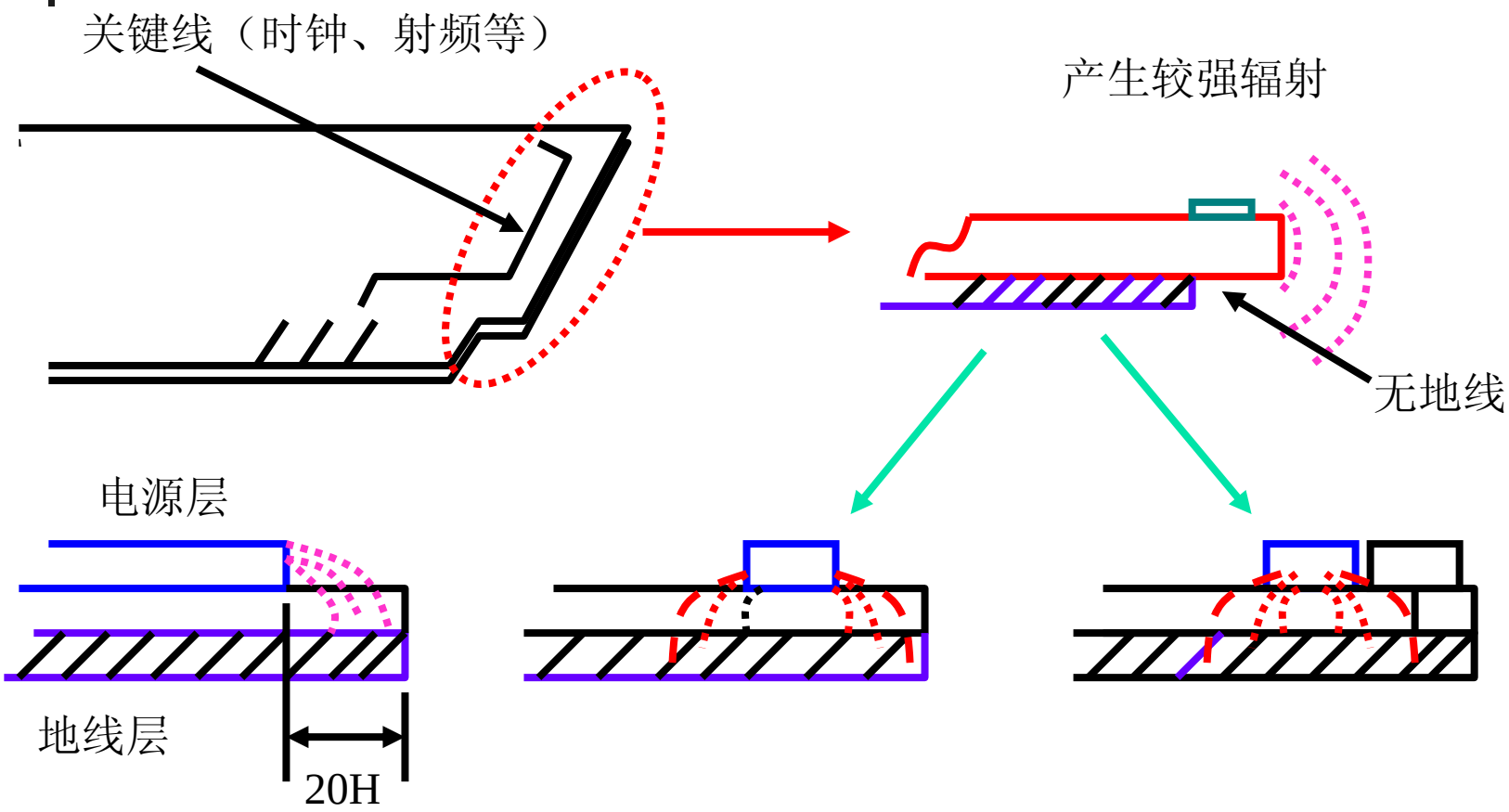




L : 0 ~ 10cm

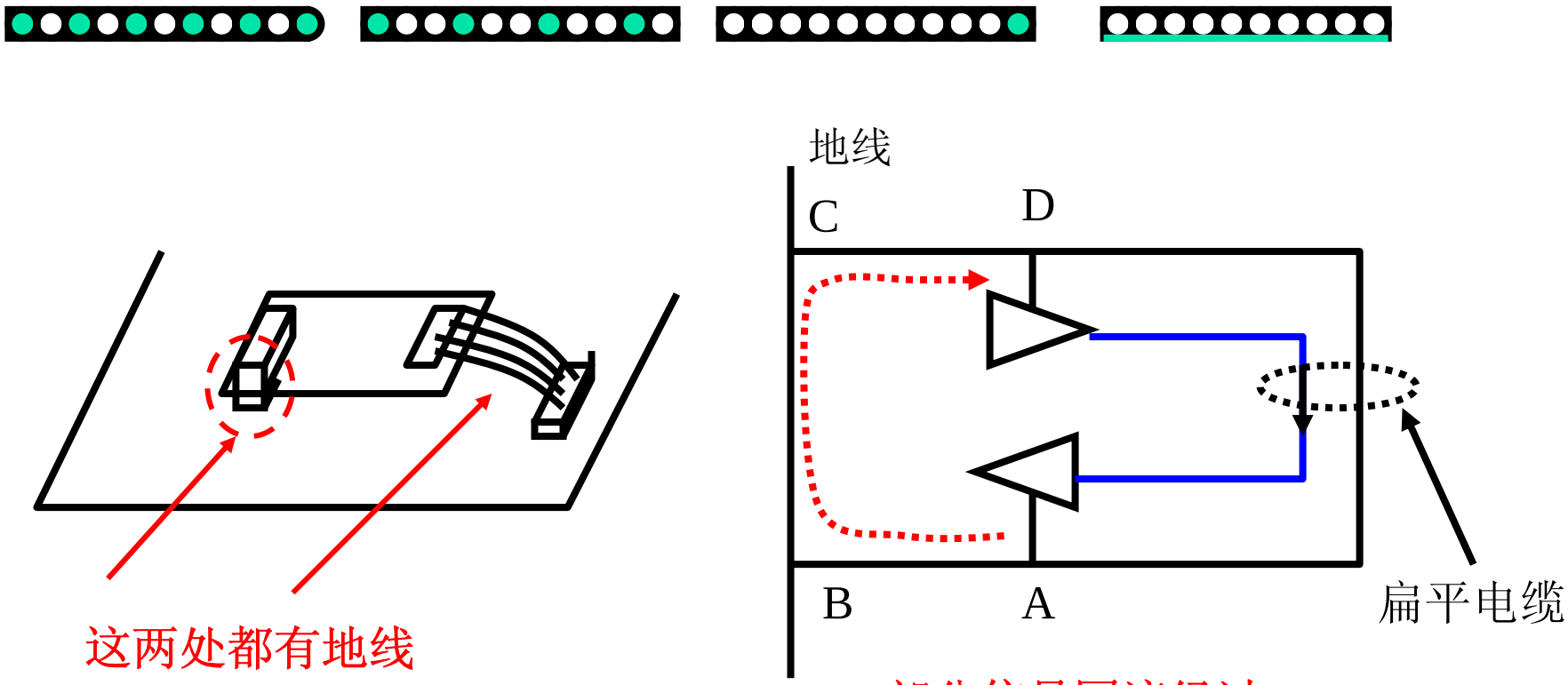
V_{AB} : 15 ~ 75mV

线路板边缘的一些问题



扁平电缆的使用

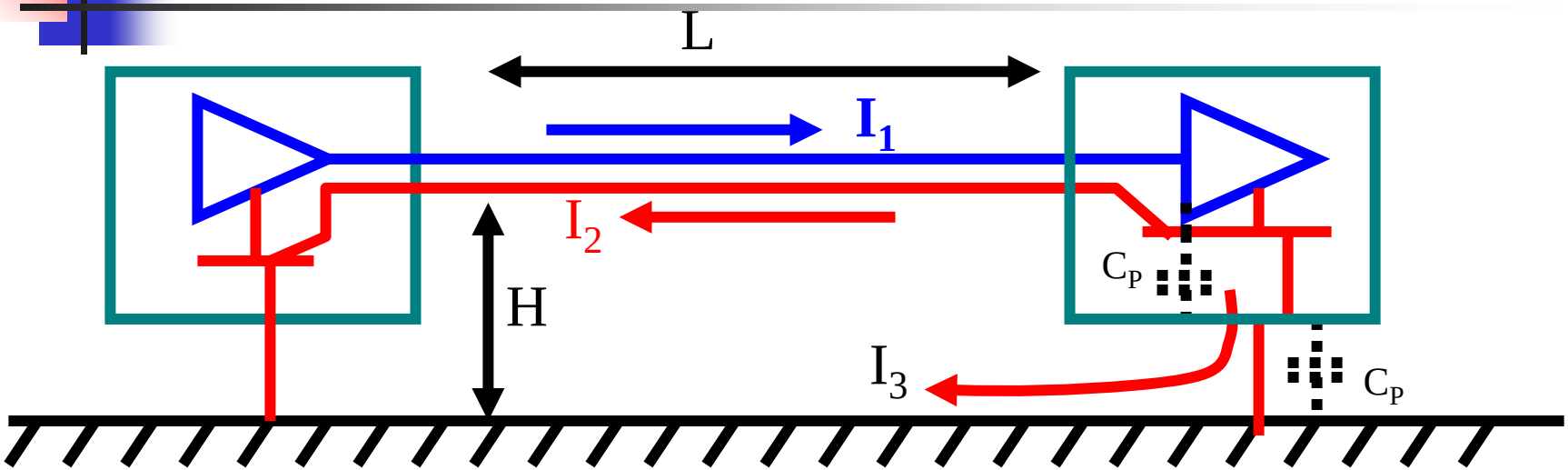
最好　　较好　　差　　较好，但端接困难

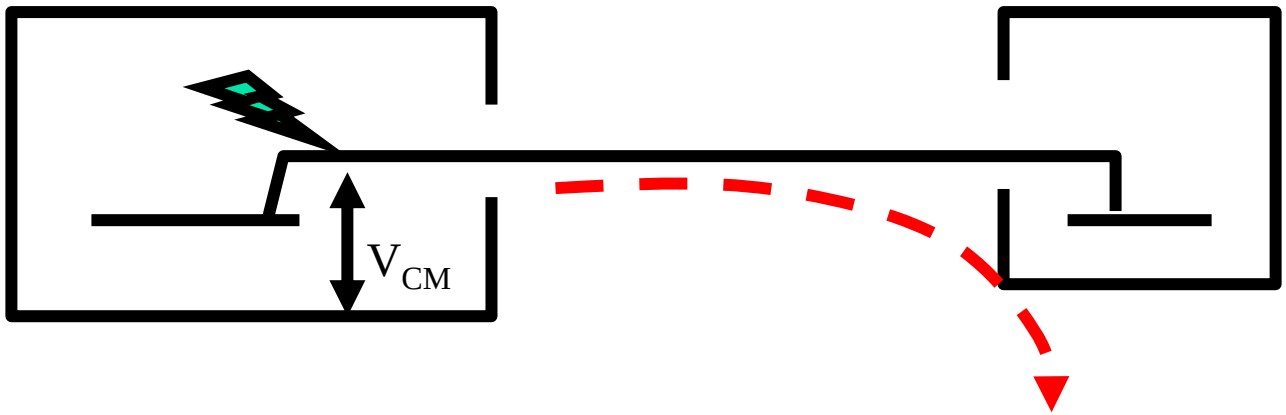


这两处都有地线

一部分信号回流经过**ABCD**

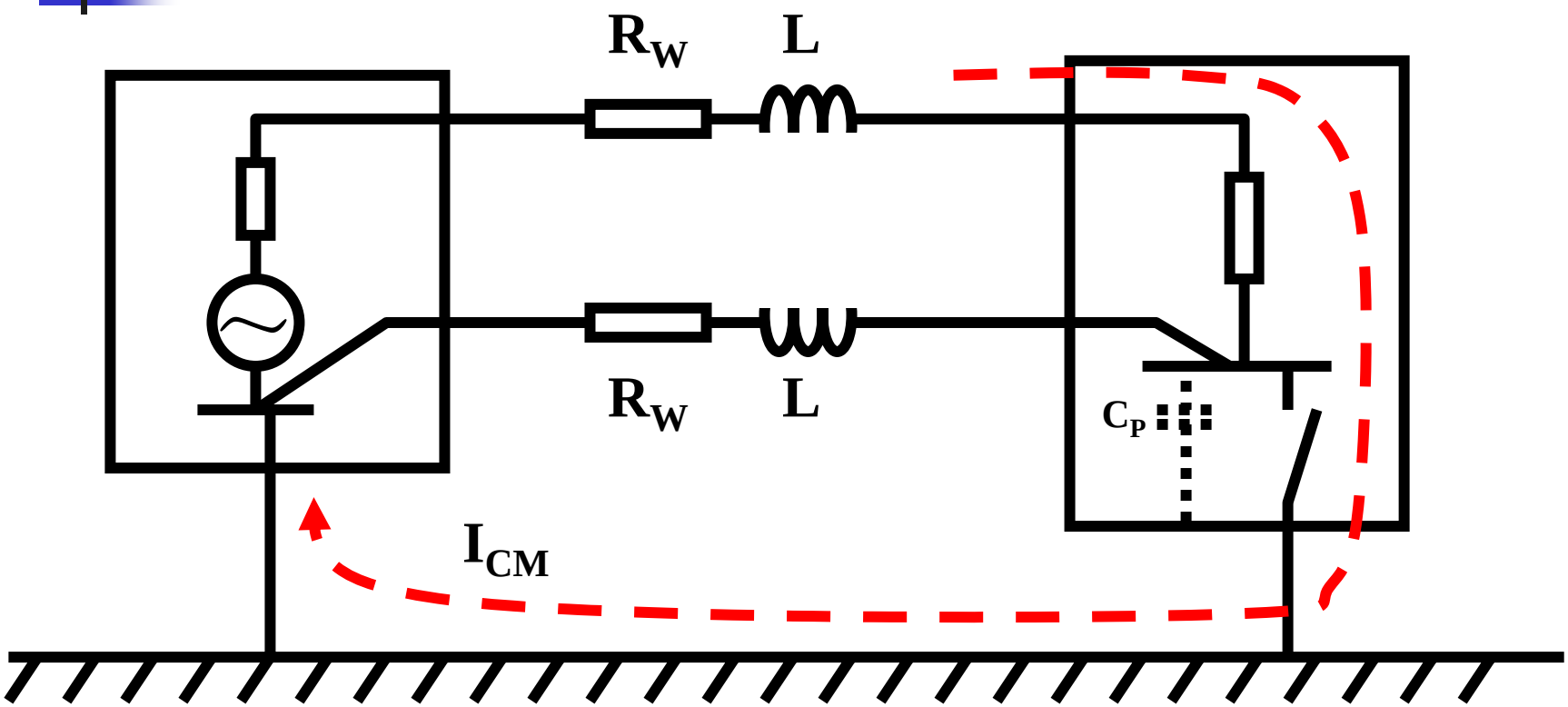
外拖电缆的共模辐射





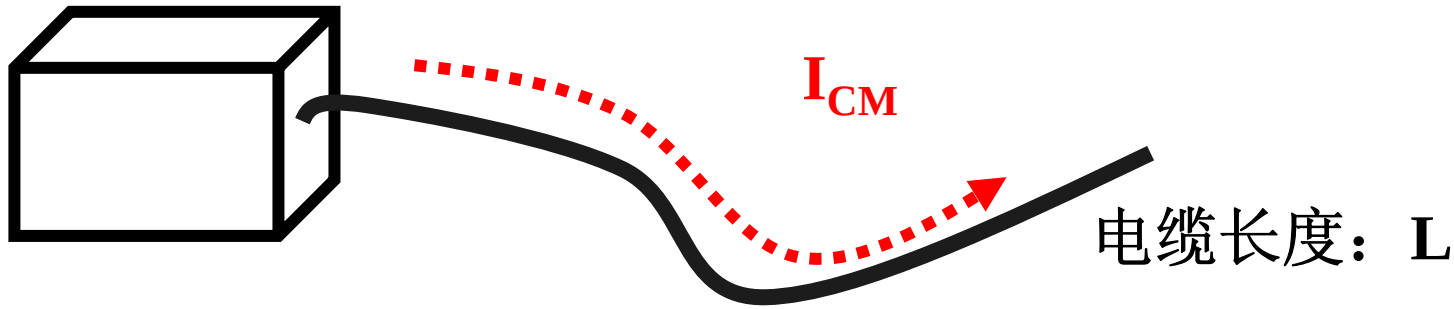
机箱内的所有信号都会通过电缆辐射！

两端设备都接地的情况



$$Z_{CM} = R_W + j\omega L + R_L + 1/ j\omega C$$

悬浮电缆



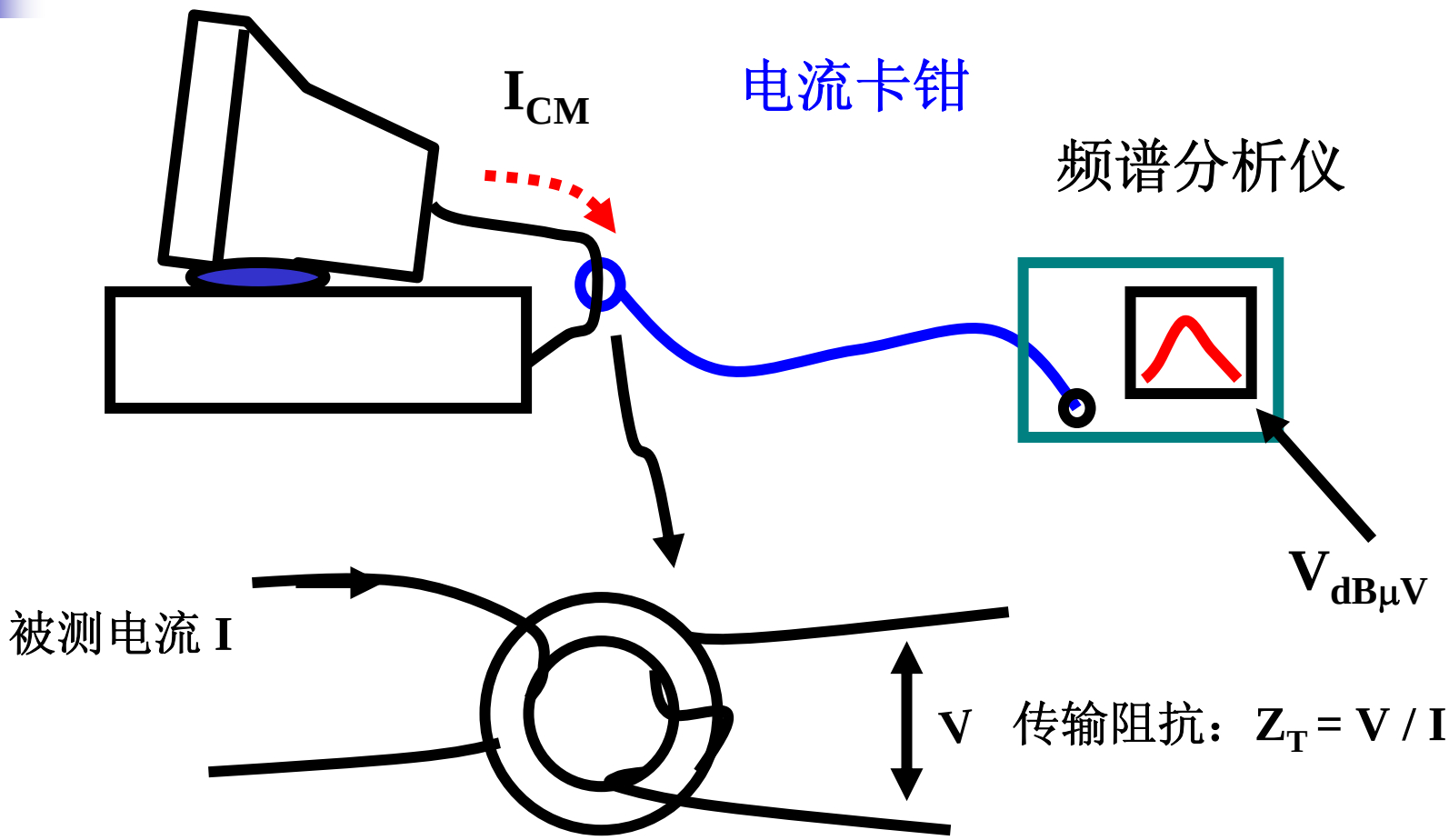
近场区内：　　$E = 1430 I L / (f D^3)$　　μV/m

远场区内：　　$E = 0.63 I L f / D$　　μV/m

考虑地面反射：　$E = 1.26 I L f / D$　　μV/m

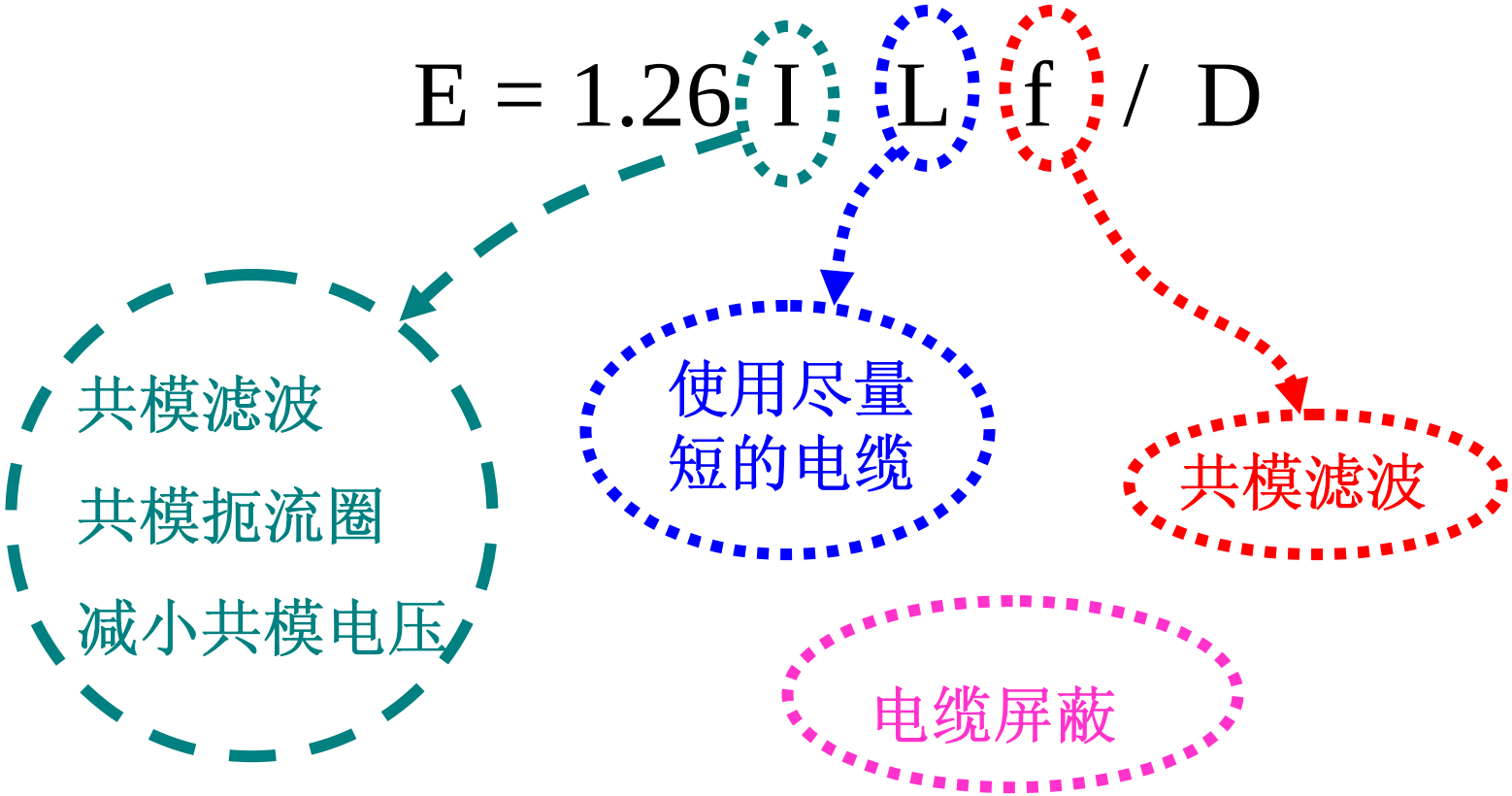
L >λ/2或λ/4时：　$E = 120 I / D$　　μV/m

共模电流的测量

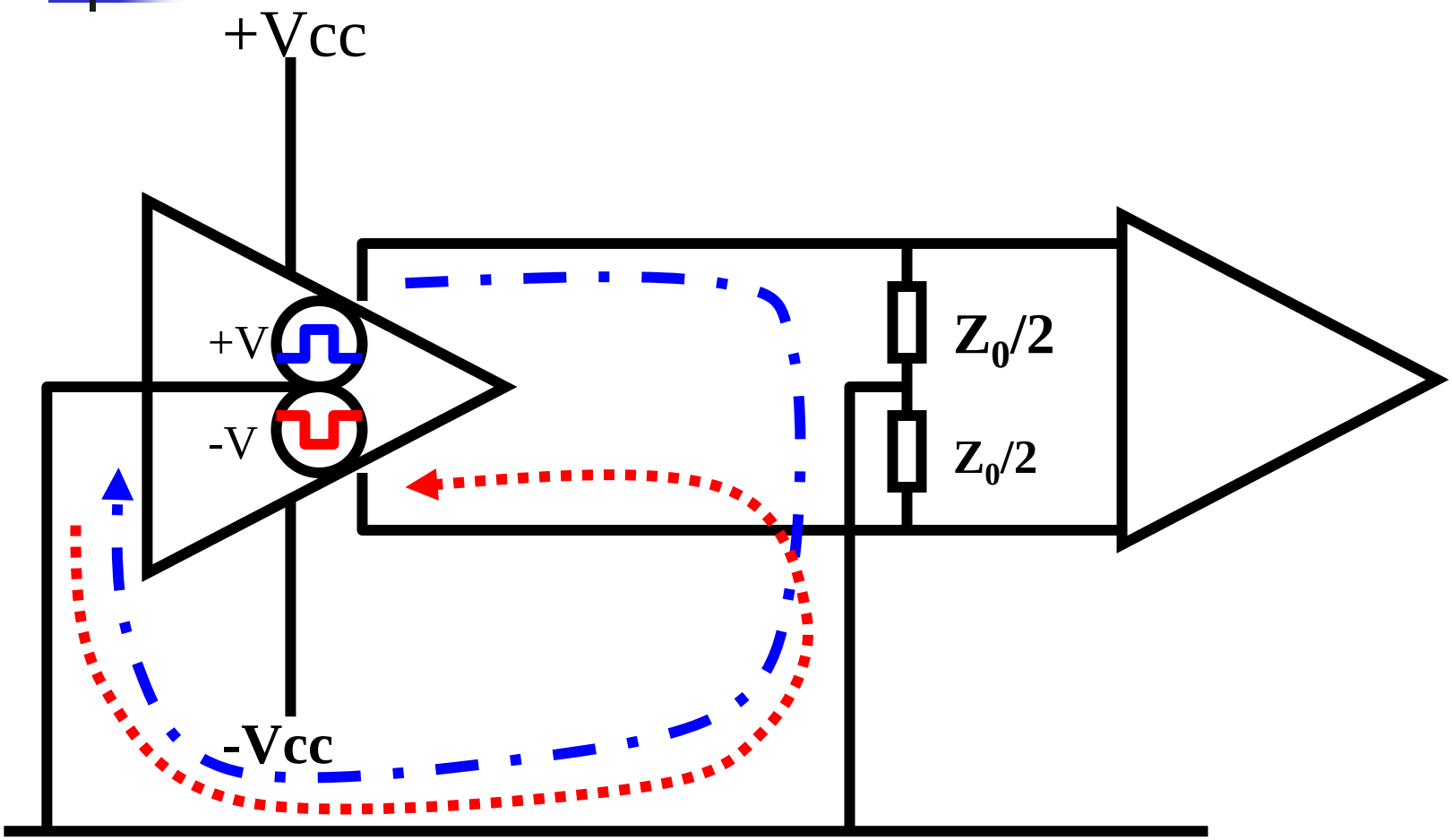


怎样减小共模辐射

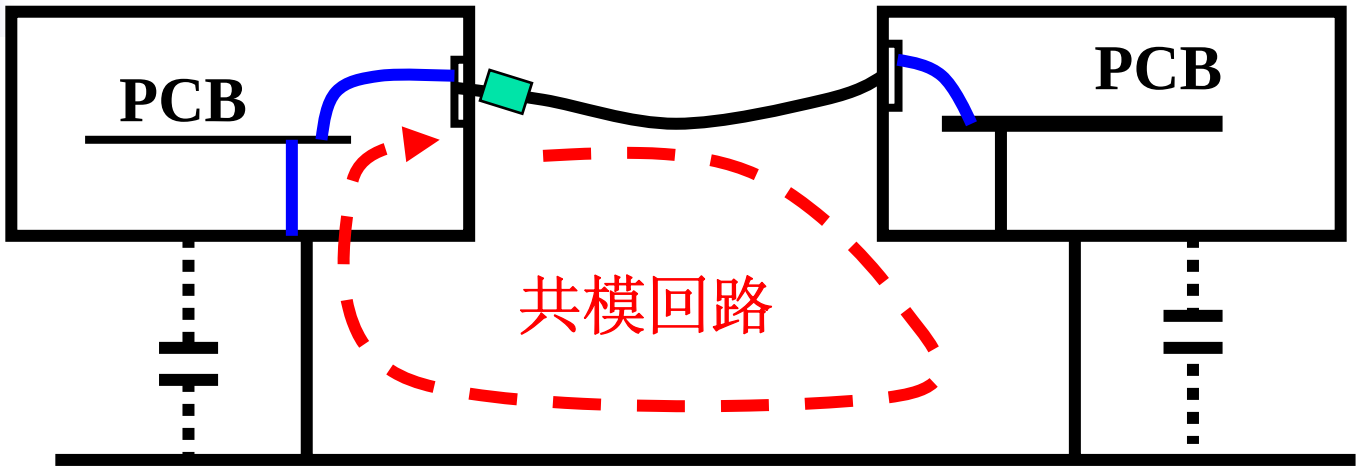
$$E = 1.26\ I\ L\ f\ /\ D$$



平衡接口电路



增加共模回路的阻抗



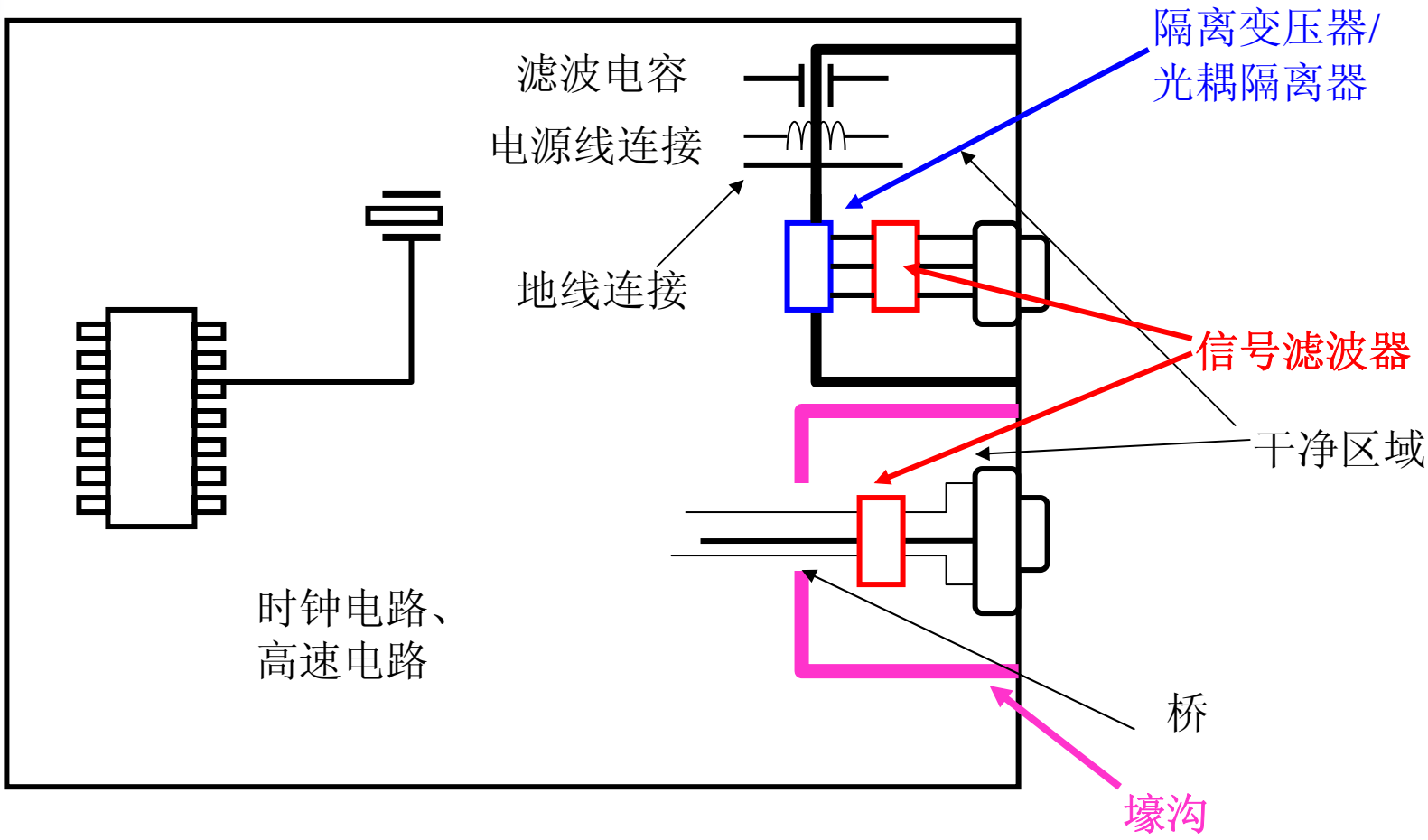
改善量 = $20\lg(E_1 / E_2) = 20\lg(I_{CM1} / I_{CM2})$

$= 20\lg[(V_{CM} / Z_{CM1}) / (V_{CM} / Z_{CM2})]$

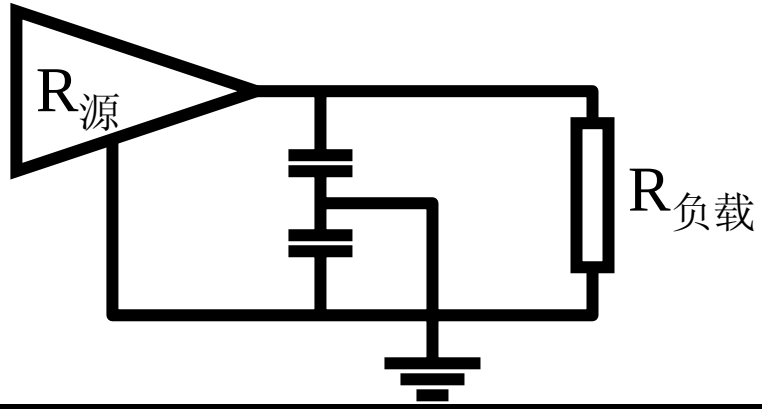
$= 20\lg(Z_{CM2} / Z_{CM1})$

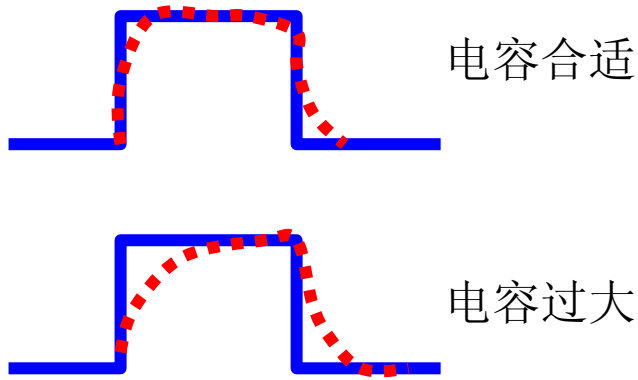
$= 20\lg(1 + Z_L / Z_{CM1})$ dB

I/O接口布线的一些要点



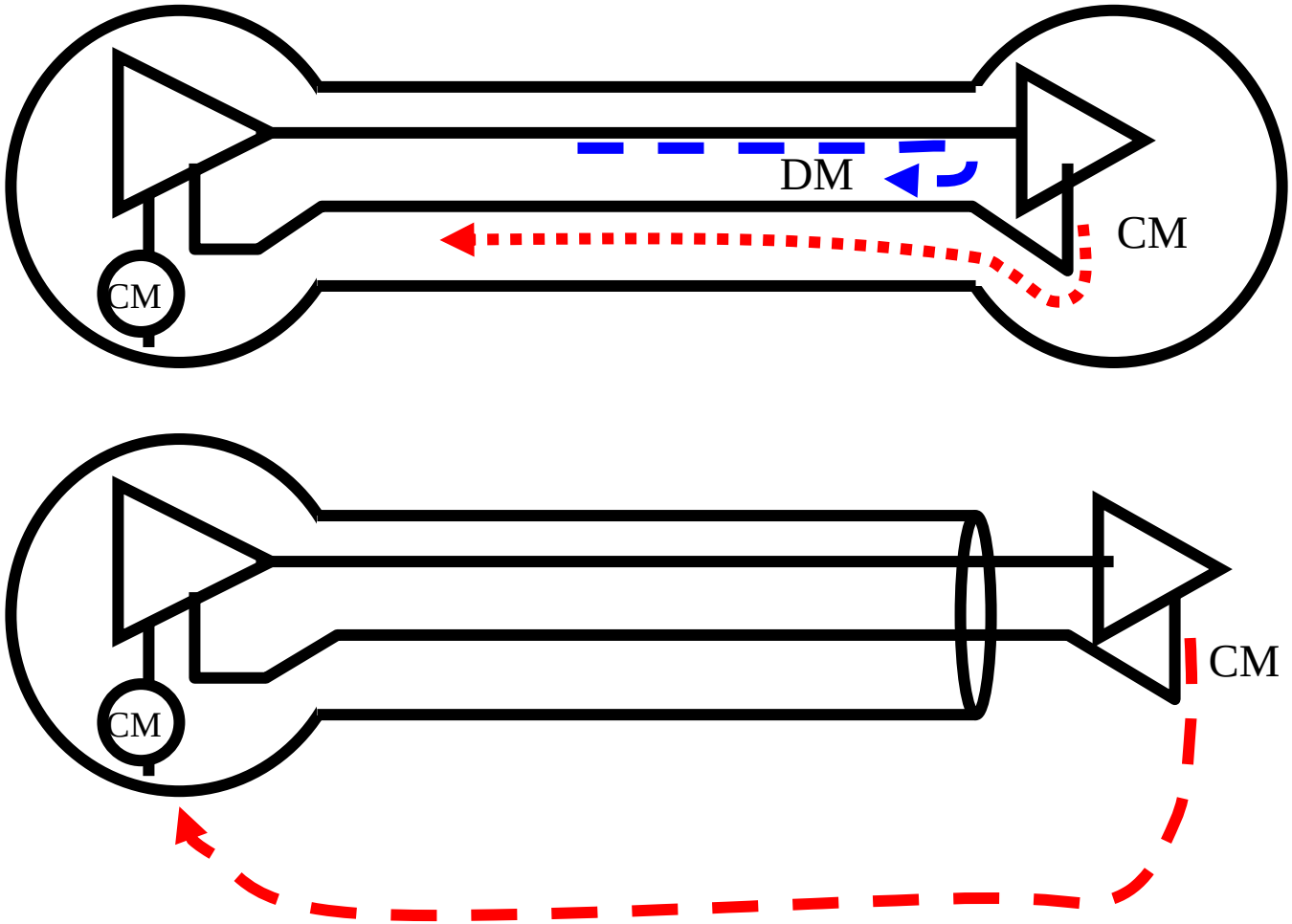
滤波器电容量的选择



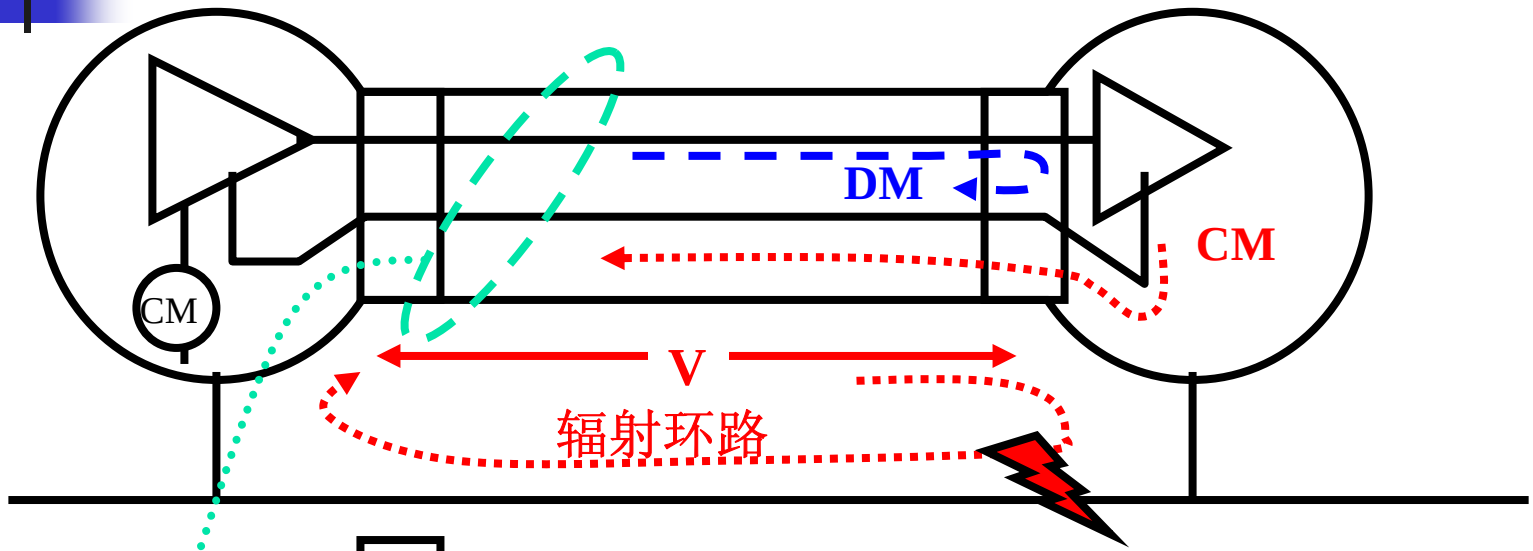


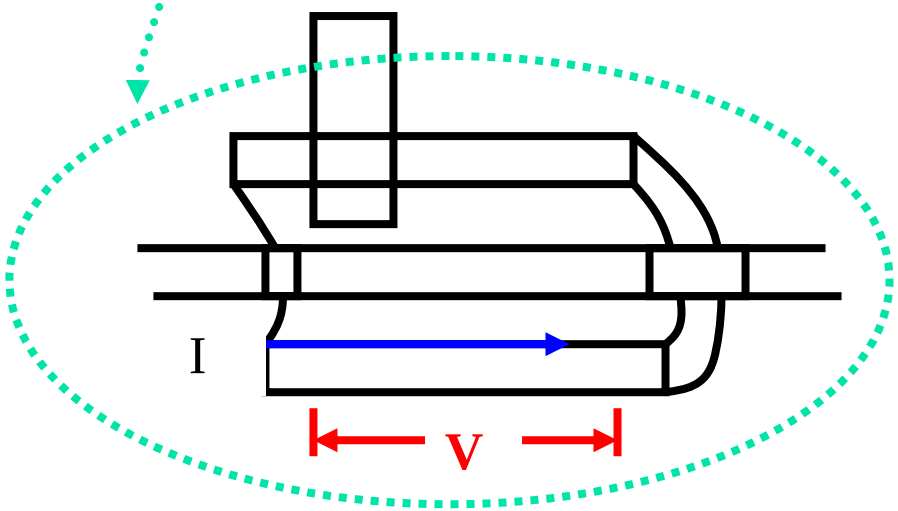
	低速接口 10 ~ 100kB/s	高速接口 2MB/s	低速CMOS	TTL
上升时间 tr	0.5~1μs	50ns	100ns	10ns
带宽 BW	320kHz	6MHz	3.2MHz	32MHz
总阻抗 R	120Ω	100Ω	300Ω	100~150Ω
最大电容 C	2400pF	150pF	100pF	30pF

用屏蔽电缆抑制共模辐射



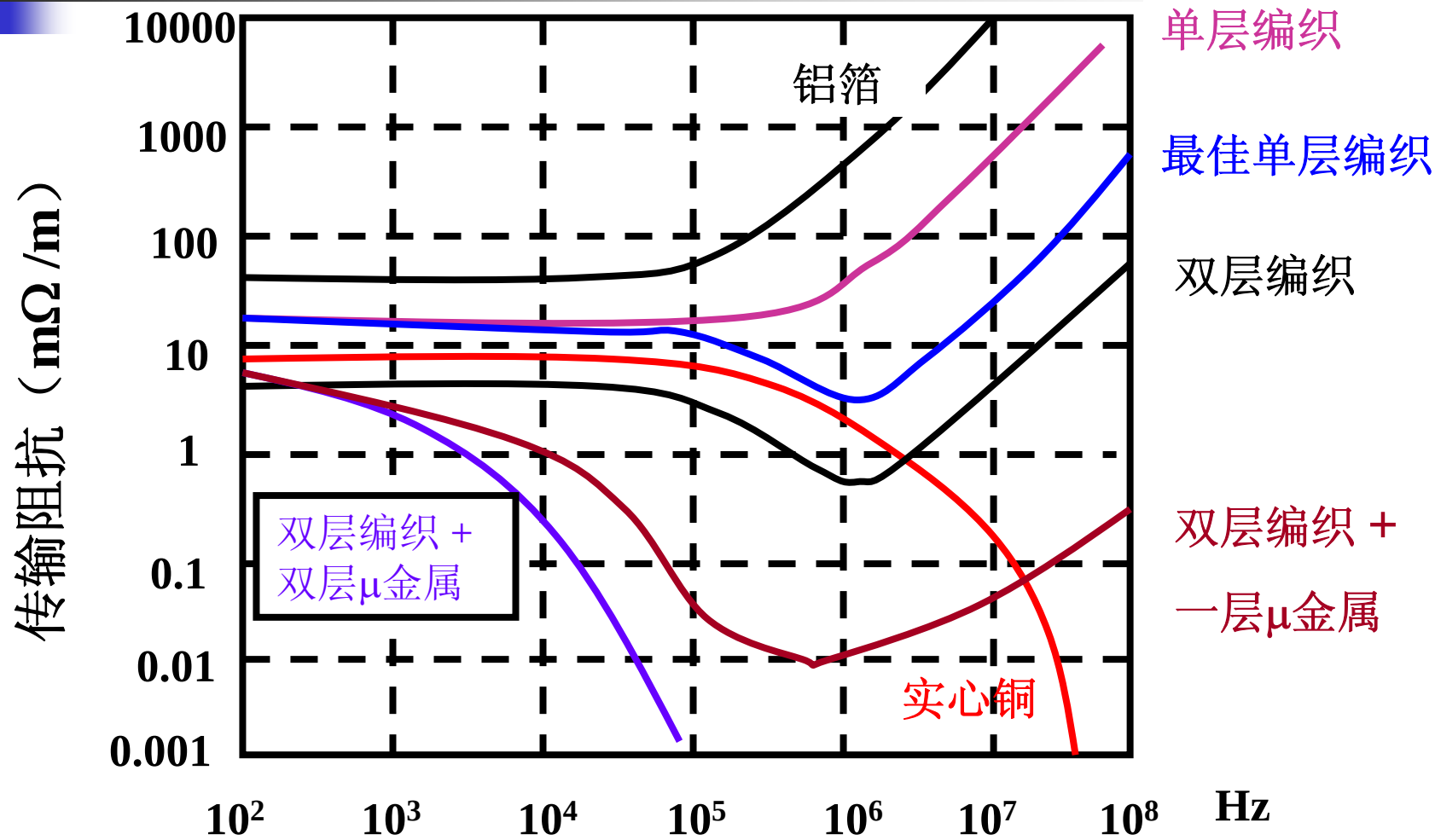
屏蔽电缆的评估



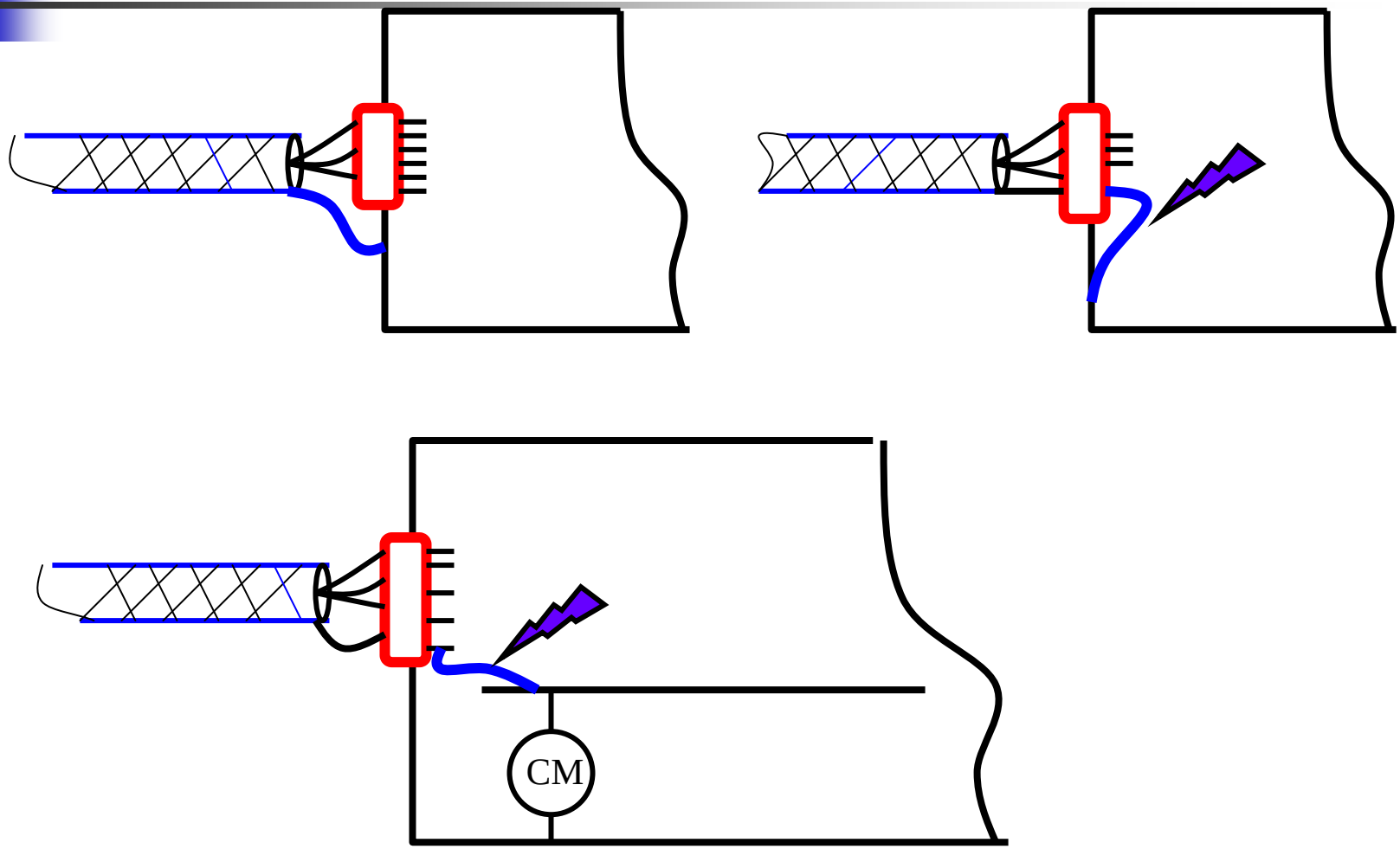


$$Z_T = V / I$$

不同屏蔽层的传输阻抗

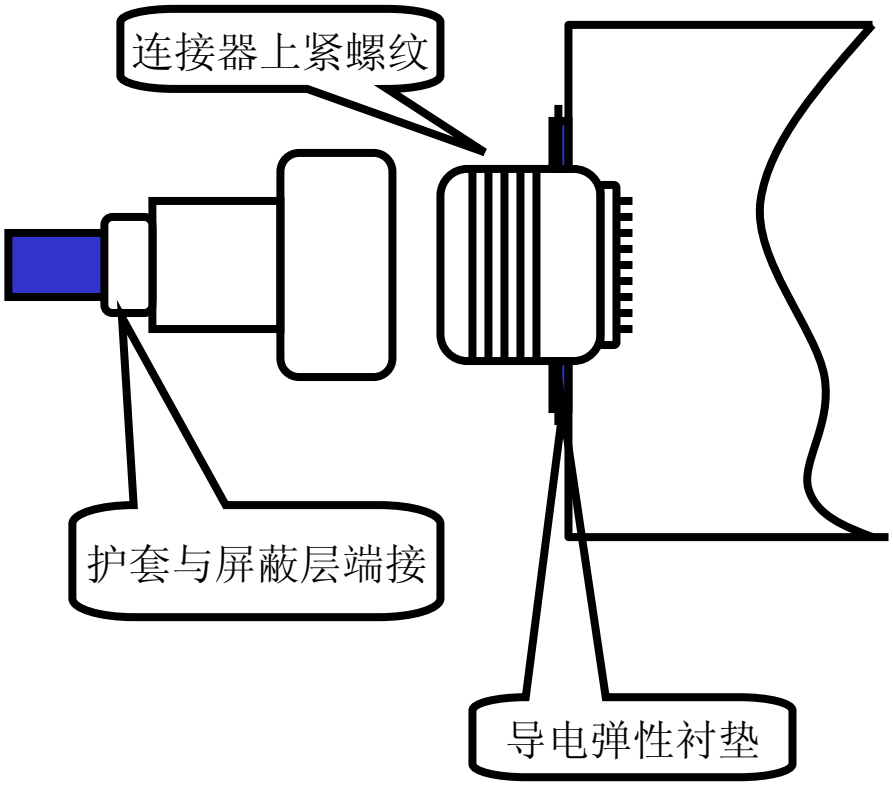

10000
1000
100
10
1
0.1
0.01
0.001
传输阻抗（mΩ /m）
铝箔
双层编织 +
双层μ金属
实心铜
10^2
10^3
10^4
10^5
10^6
10^7
10^8
Hz
单层编织
最佳单层编织
双层编织
双层编织 +
一层μ金属

屏蔽层的错误接法

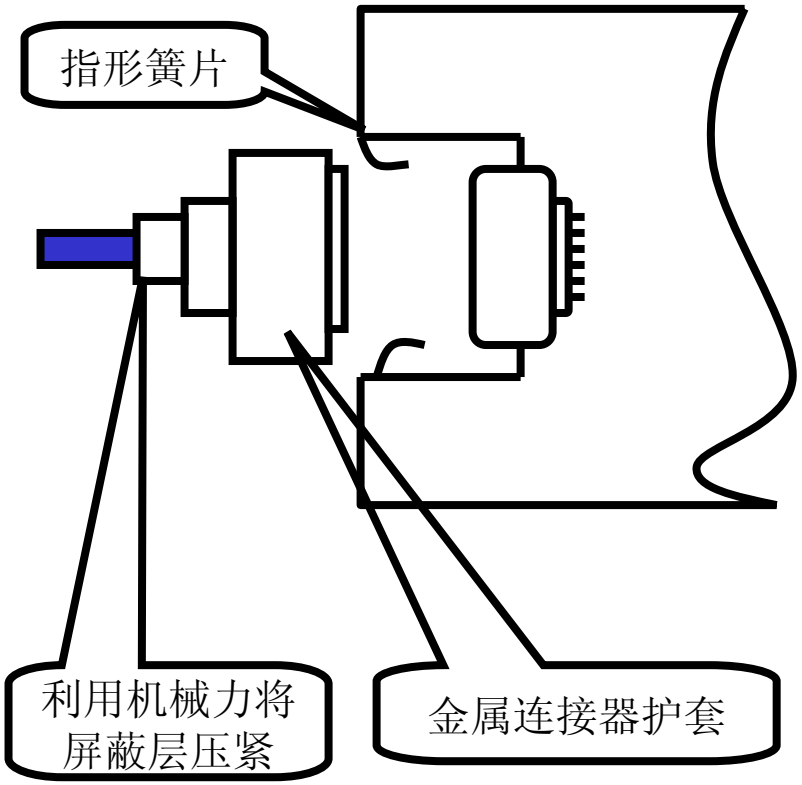


电缆屏蔽层的正确端接

航空连接器



D形连接器



线路板上的局部屏蔽