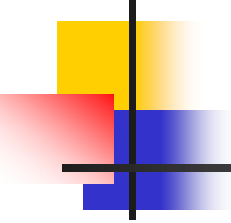


PCB的电磁兼容设计

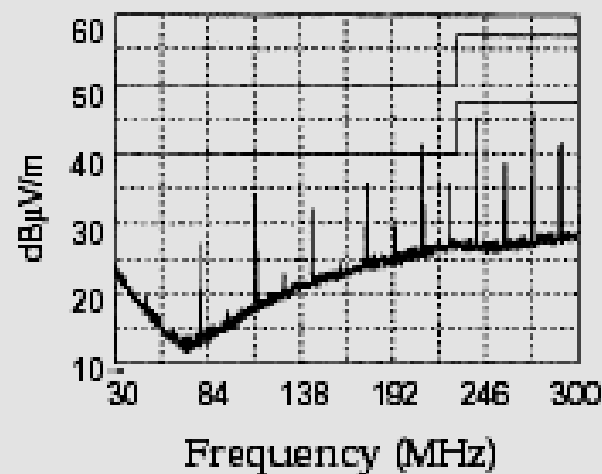
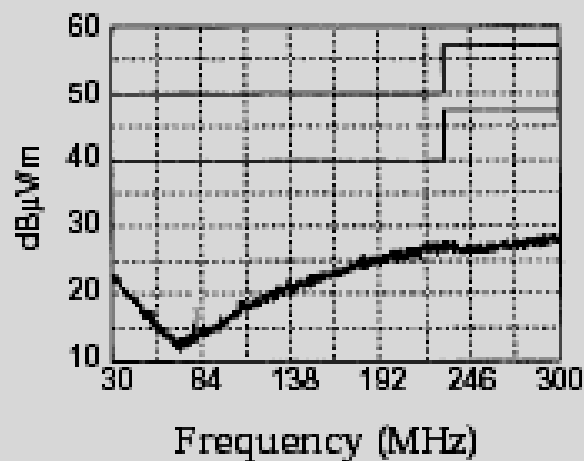
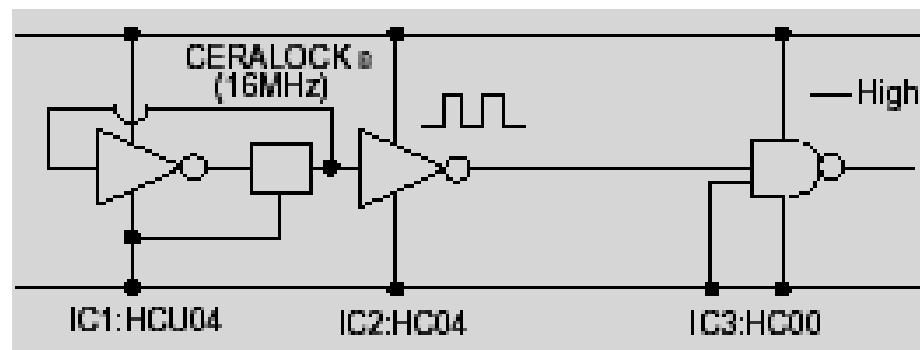
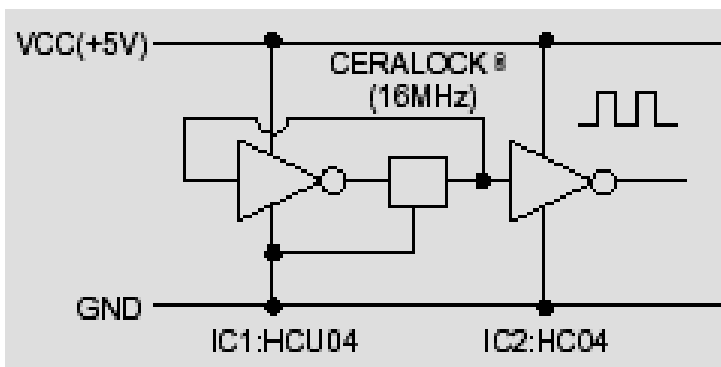
杨继深 2004年5月
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线路板上的电磁兼容问题

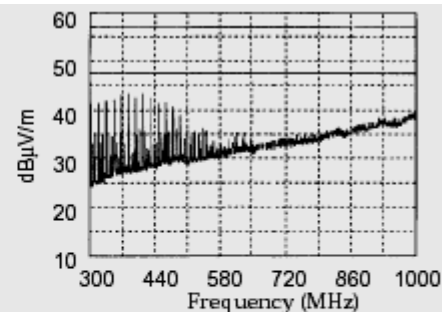
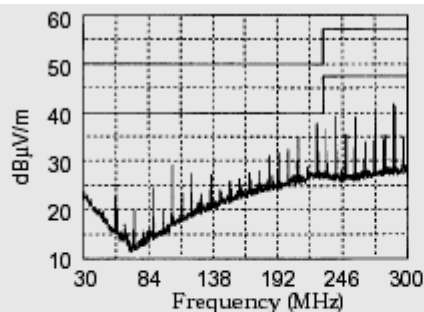
- 线路板的辐射
- 外界电磁场对线路板的干扰
- 地线和电源线噪声
- 地线引起的公共阻抗耦合
- 走线之间的串扰

走线是主要辐射源

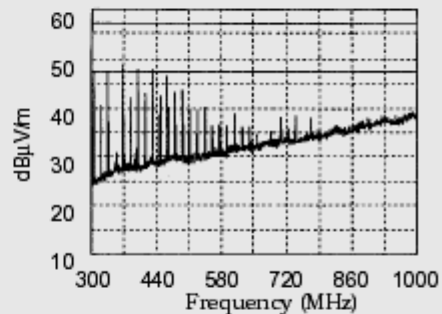
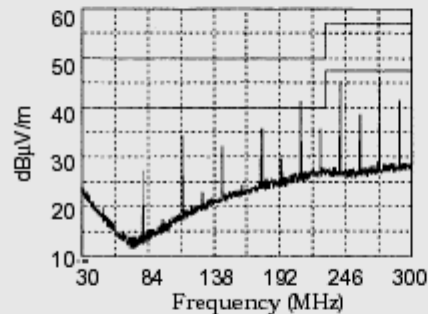


时钟频率越高辐射越强

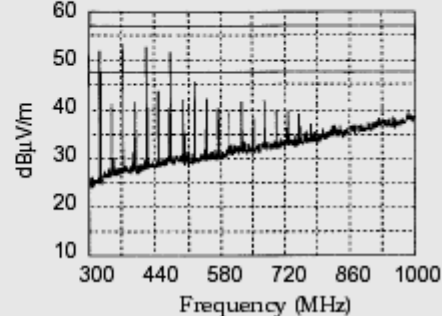
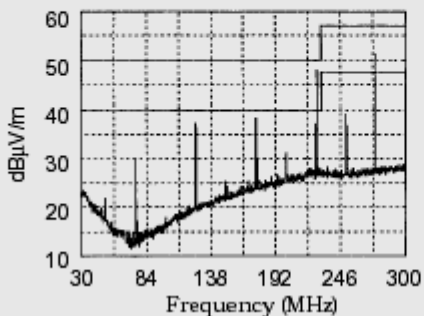
8MHz



16MHz



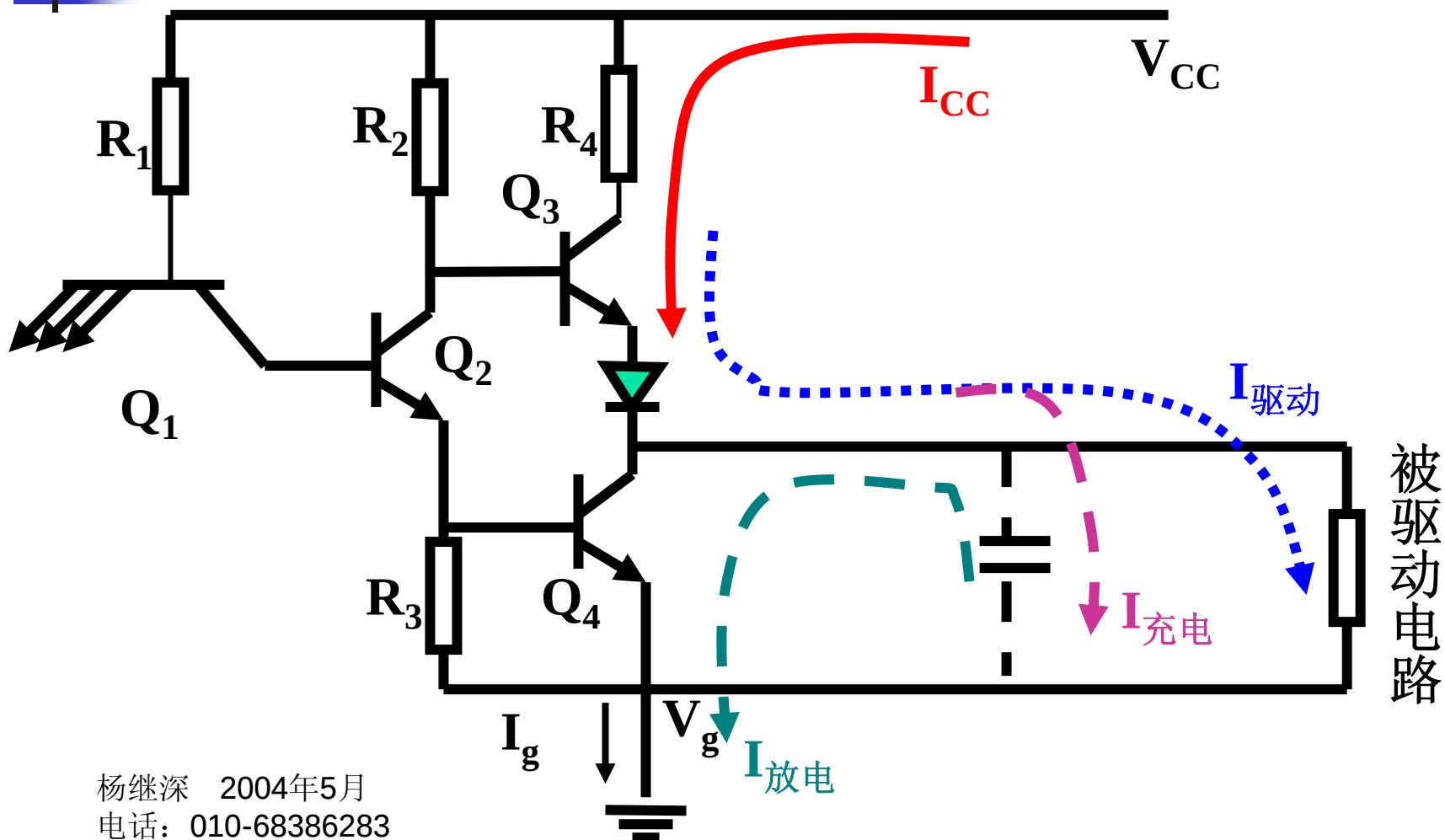
25MHz



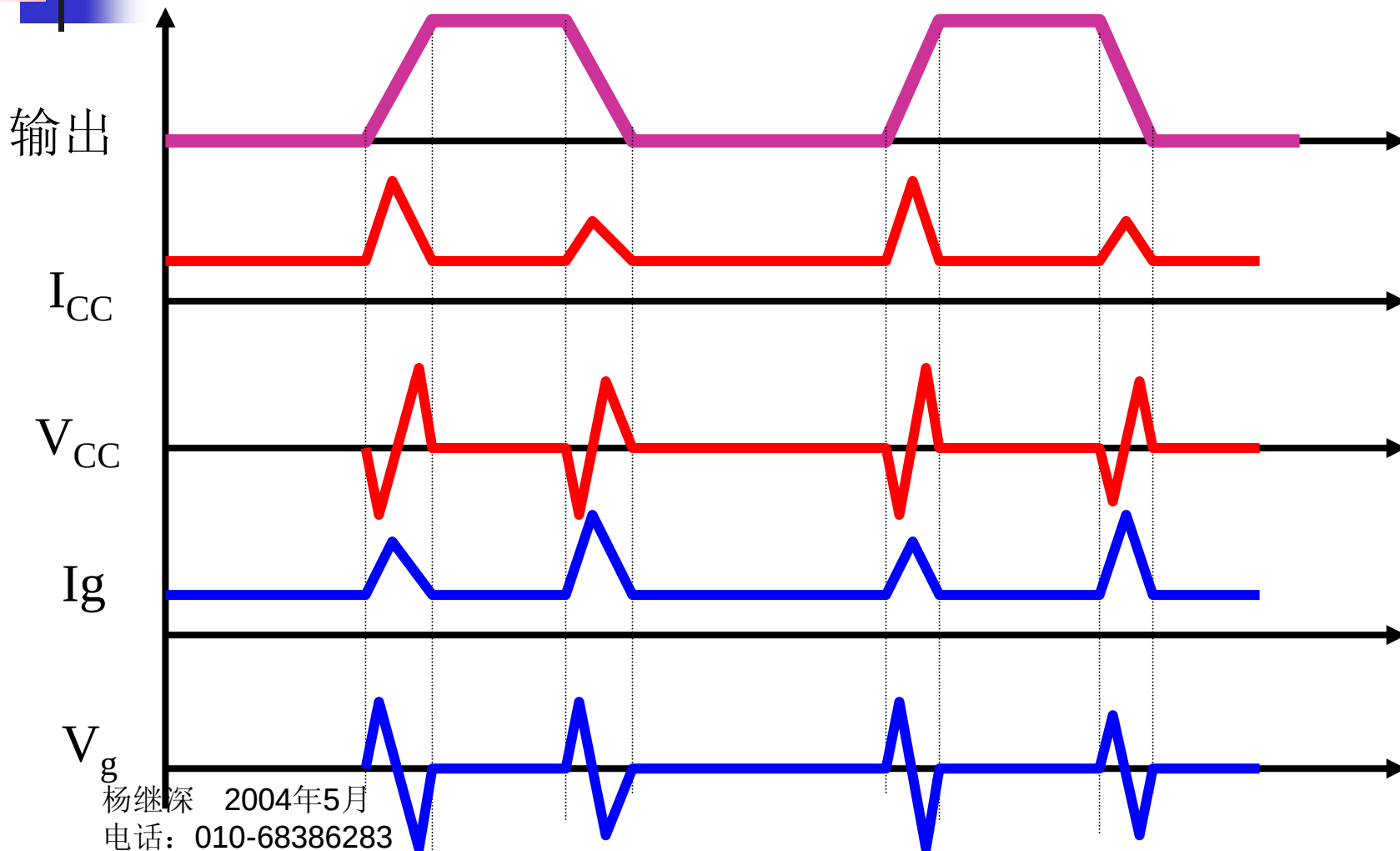
杨继深

电话: 010-68386283

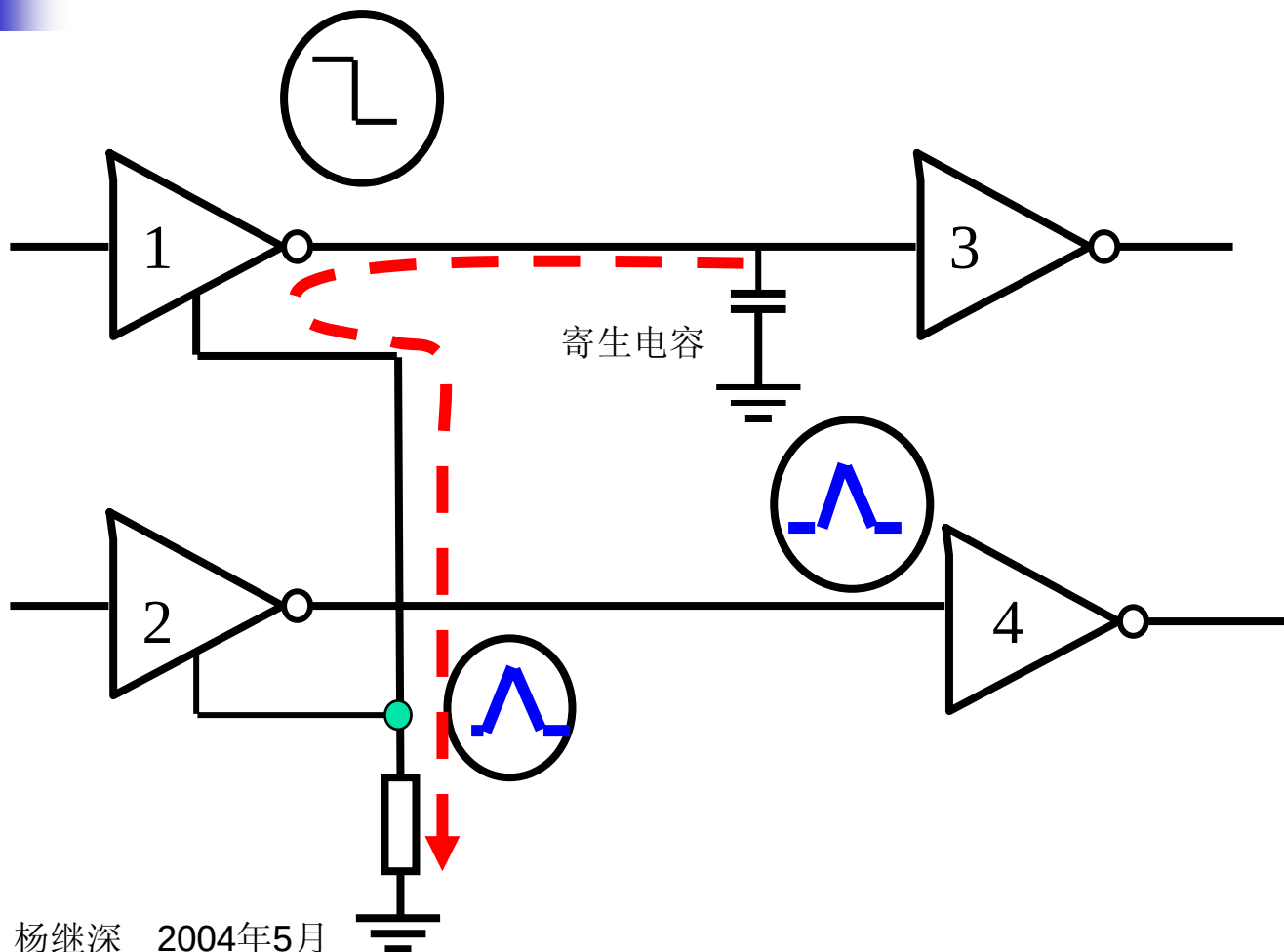
地线和电源线上的噪声



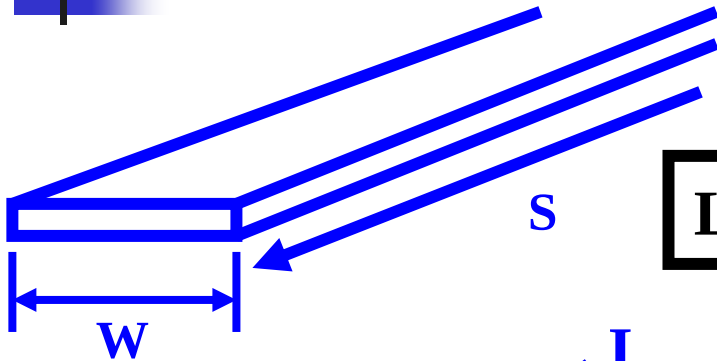
电源线、地线噪声电压波形



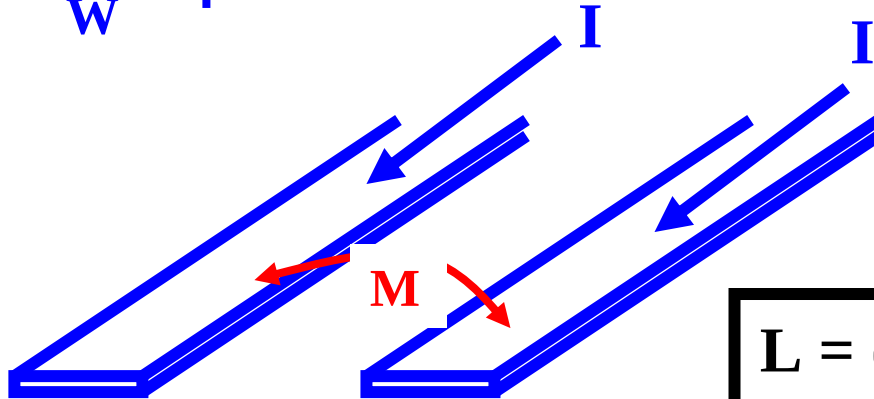
地线干扰对电路的影响



线路板走线的电感



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

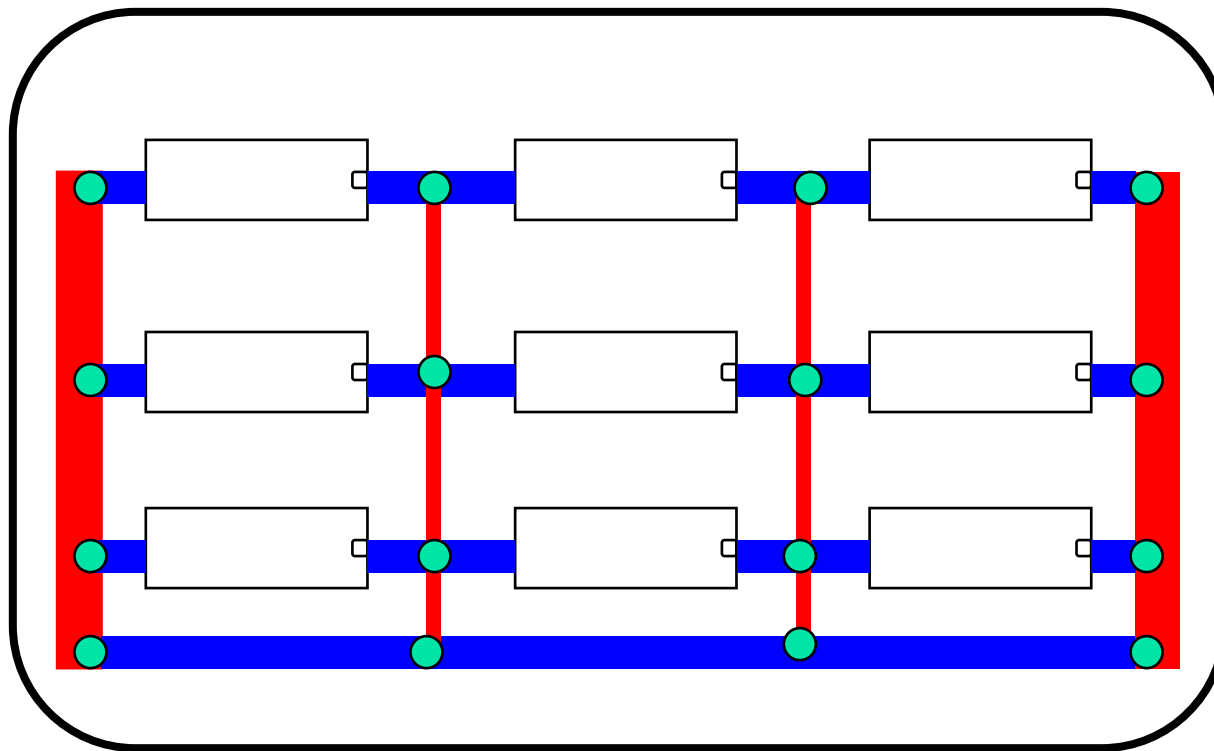


$$L = (L_1 L_2 - M^2) / (L_1 + L_2 - 2M)$$

若: $L_1 = L_2$

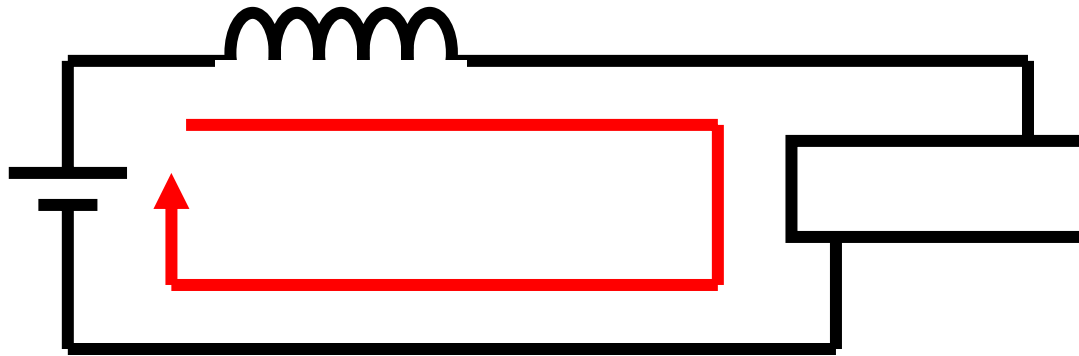
$$L = (L_1 + M) / 2$$

地线网格

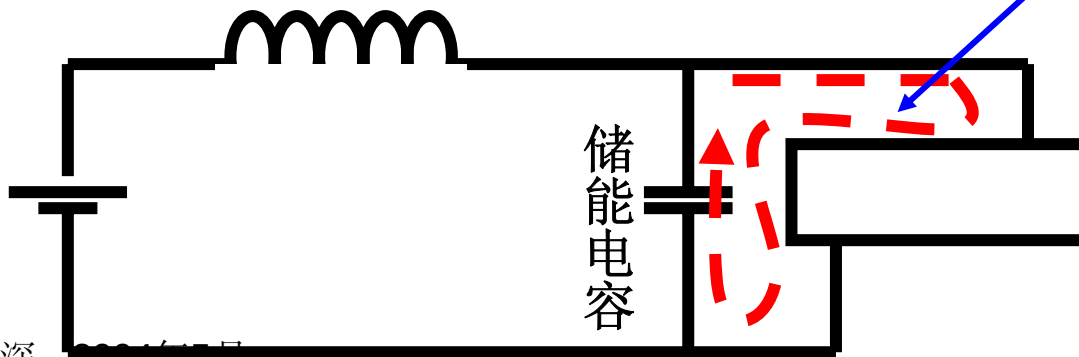


电源线噪声的消除

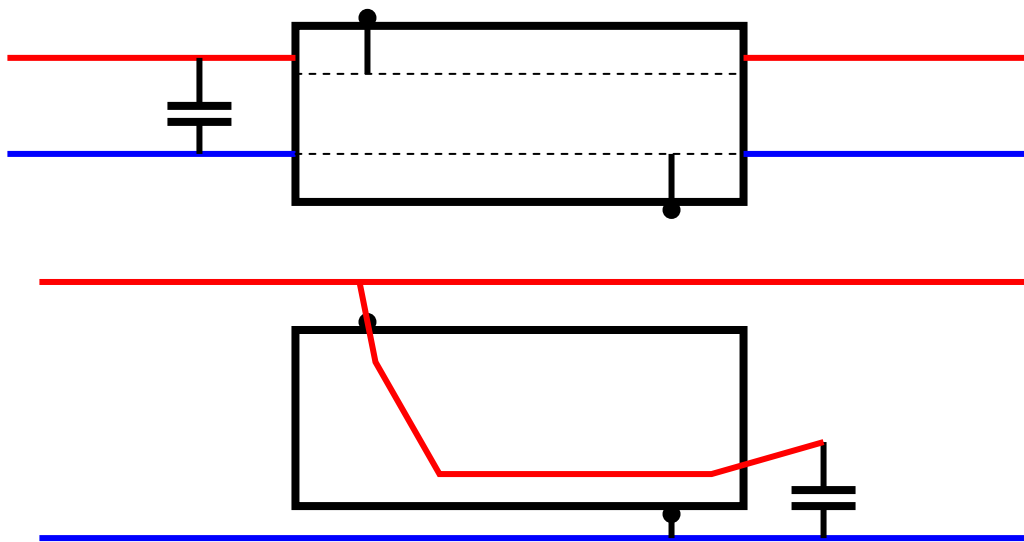
$$V = L(di/dt)$$



这个环路尽量小



电源解耦电容的正确布置



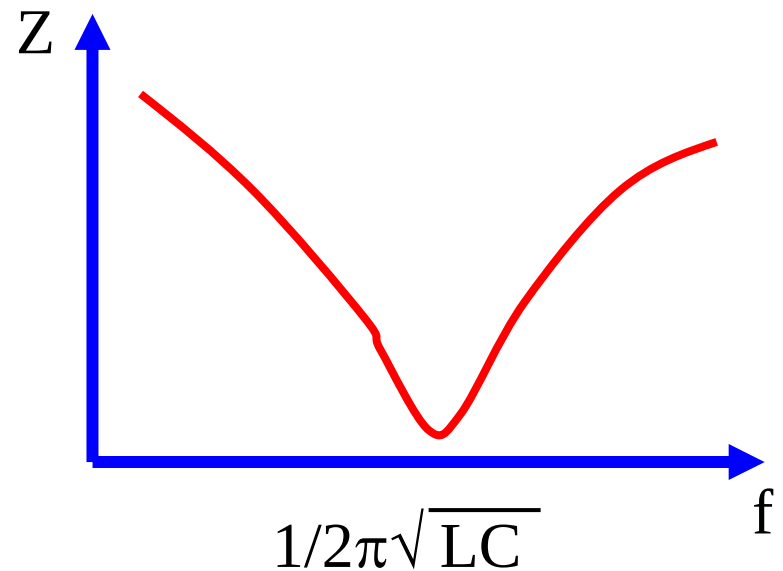
尽量使电源线与地线靠近

解耦电容的选择

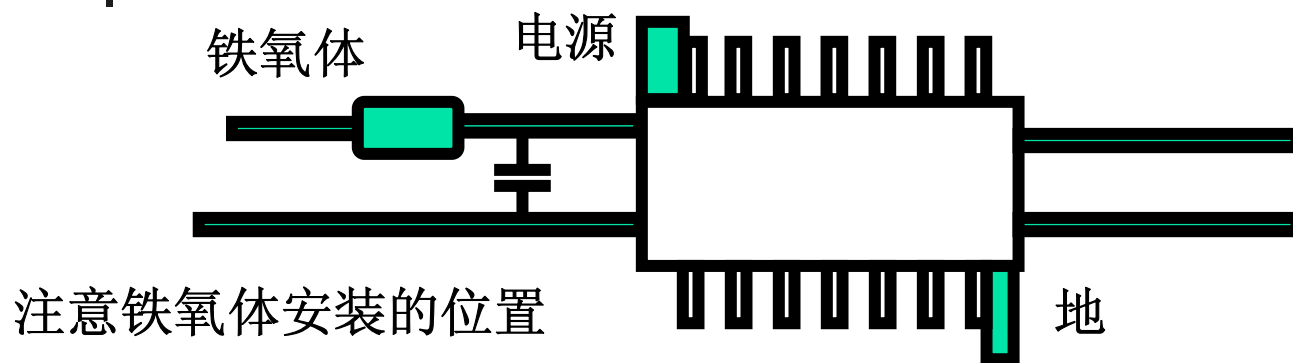
$$C = \frac{dI \, dt}{dV}$$

各参数含义：

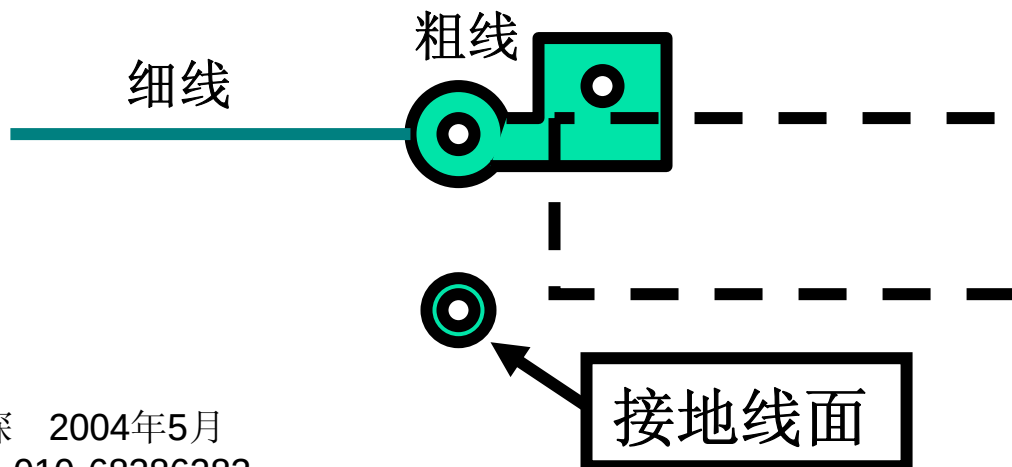
在时间 dt 内，电源线上出现了瞬间电流 dI ， dI 导致了电源线上出现电压跌落 dV 。



增强解耦效果的方法

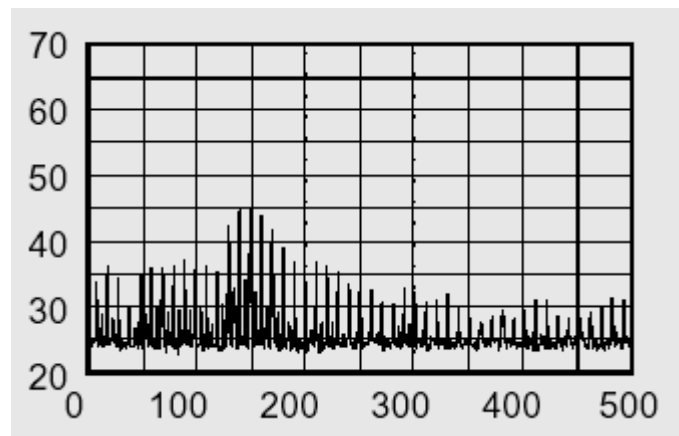
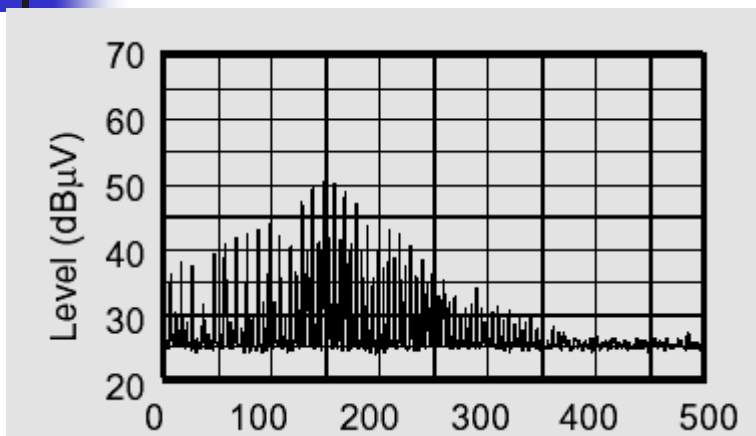


用铁氧体增加
电源端阻抗



用细线增加电
源端阻抗

有效滤波的例子



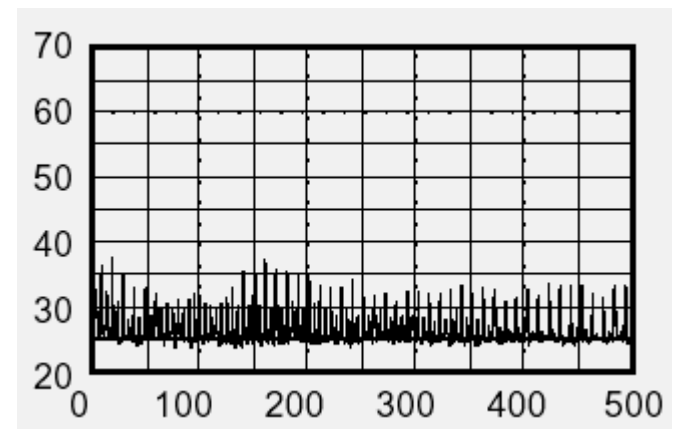
普通电容 (1μ)



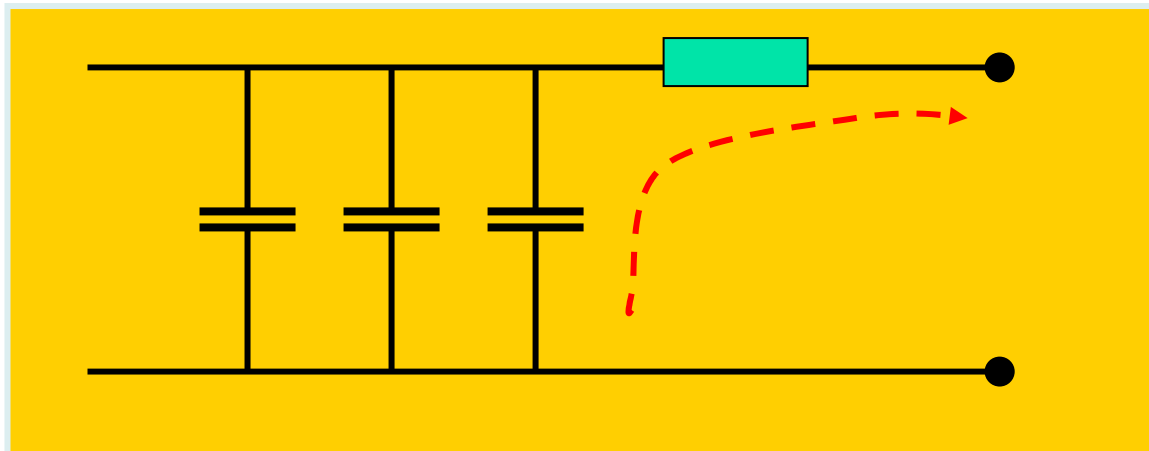
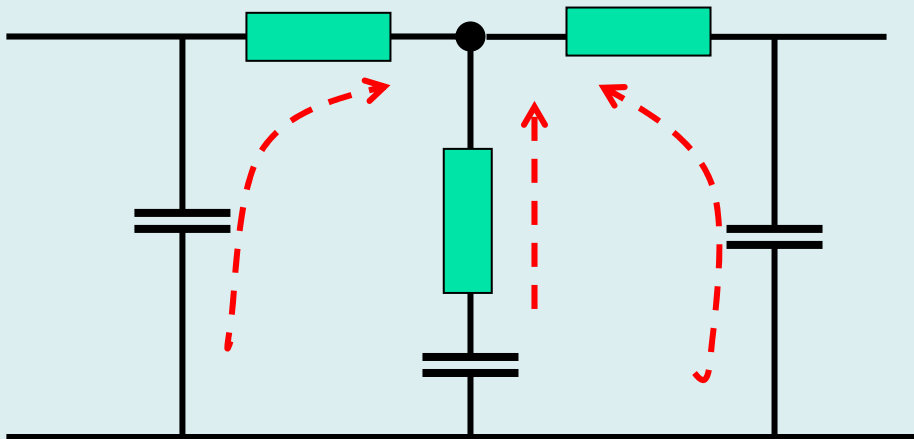
三端电容
(0.1μ)



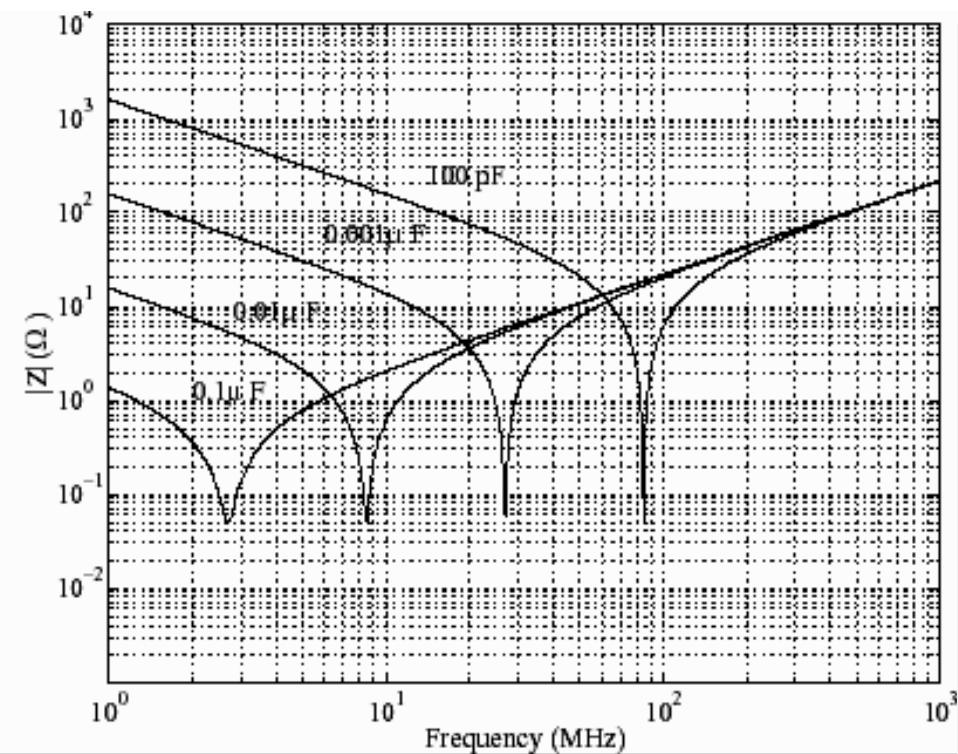
三端电容 + 铁氧体



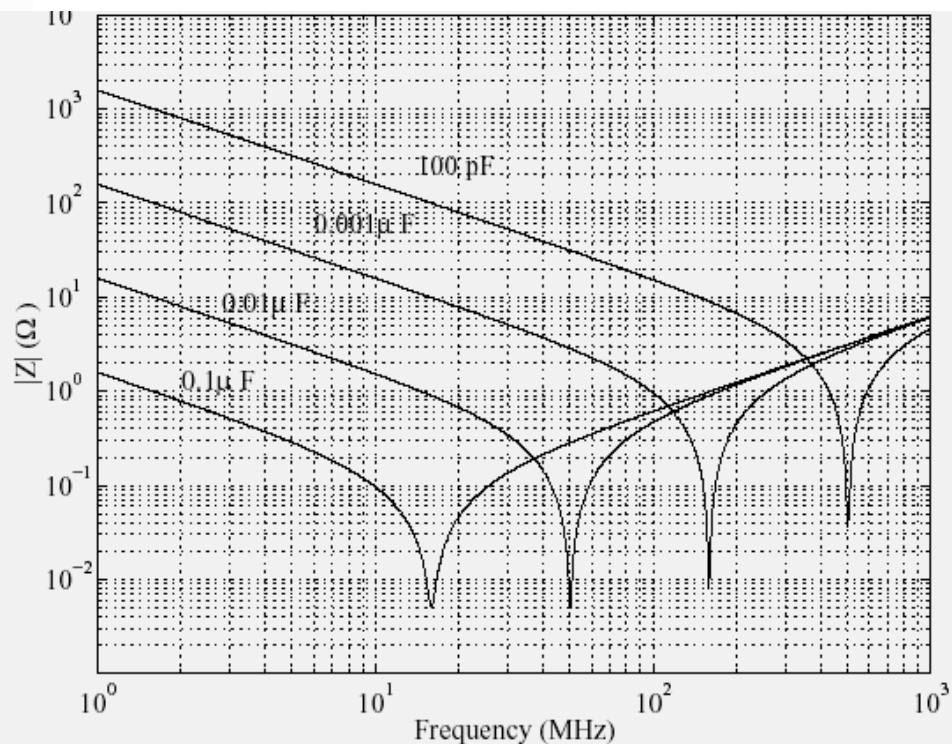
多个电容改善解耦效果



选择合适的电容种类

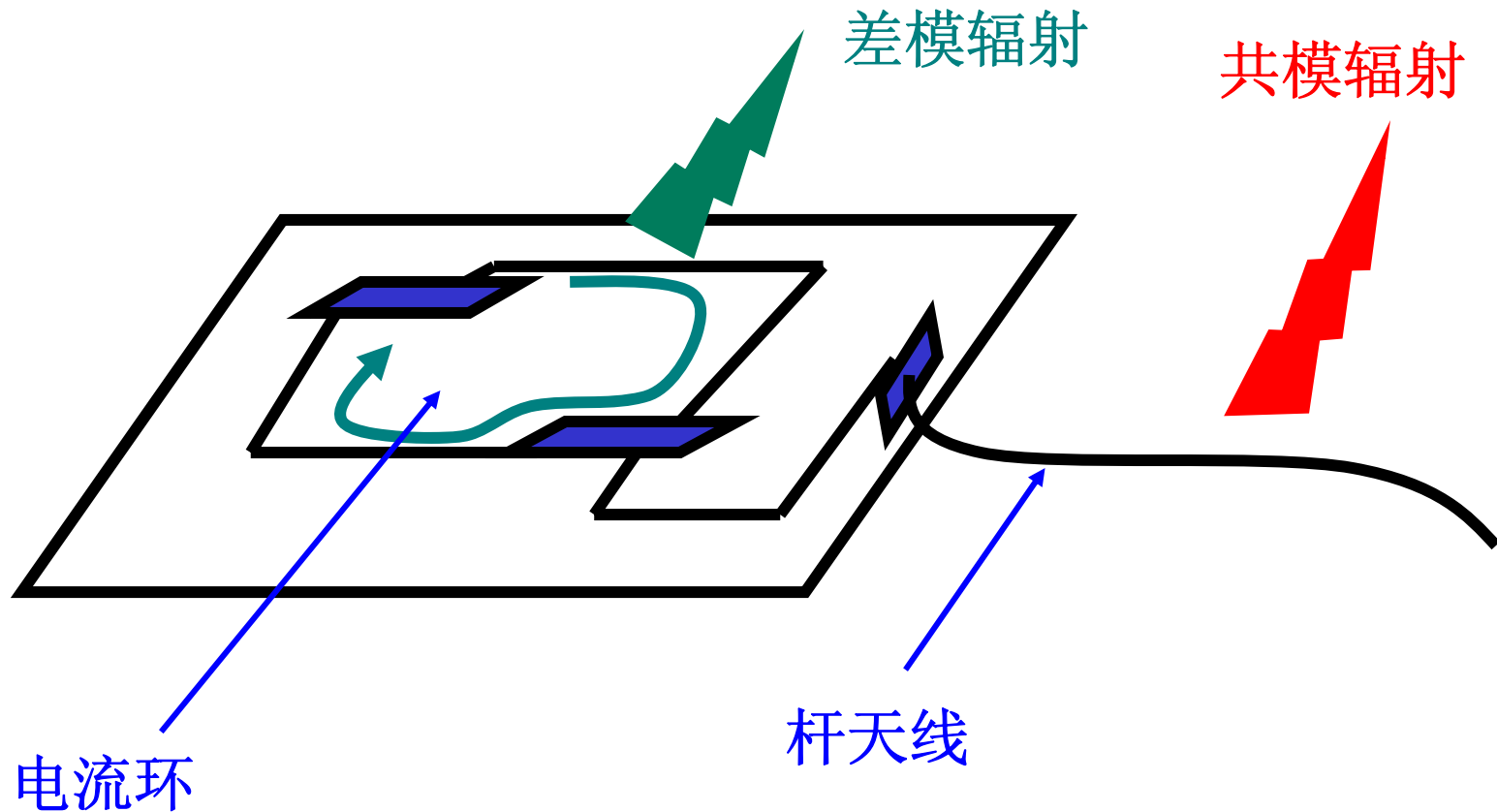


插线电容

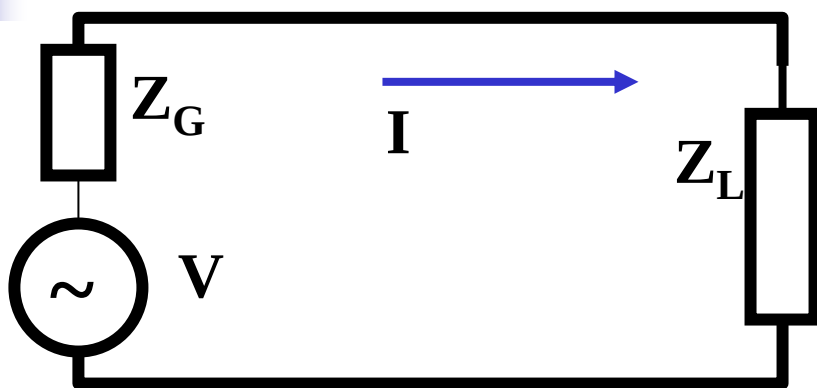


表贴电容

线路板的两种辐射机理



实际电路的辐射



$$Z_C = Z_G + Z_L$$

环路面积 = A

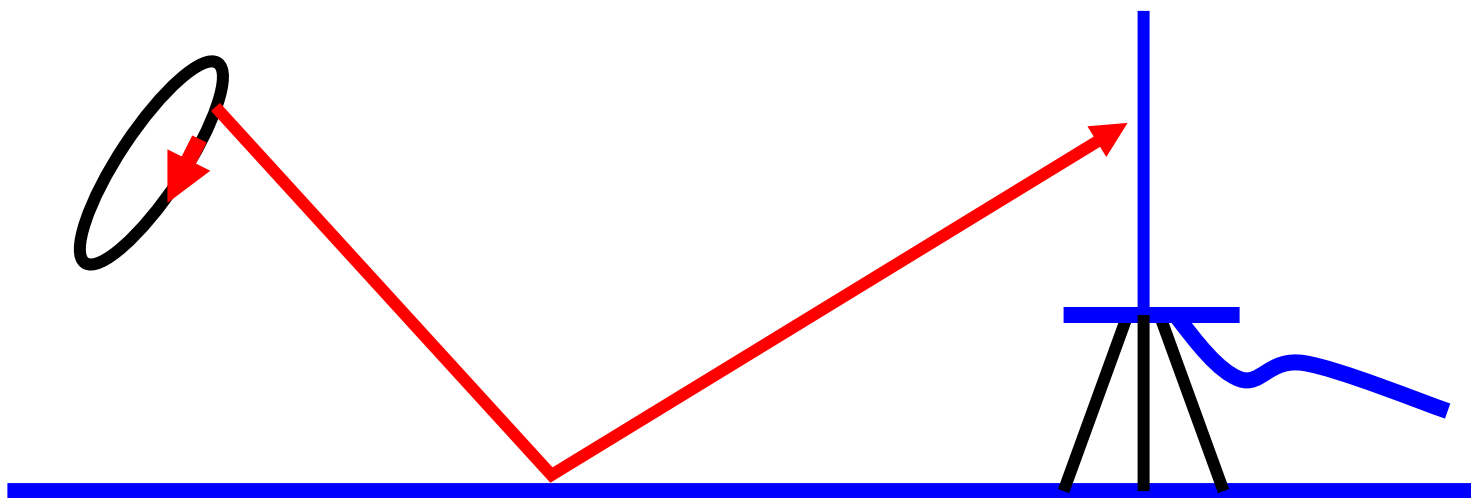
近场:

$$Z_C \geq 7.9 D f \quad E = 7.96 V A / D^3 \quad (\mu V/m)$$
$$Z_C \leq 7.9 D f, \quad E = 63 I A f / D^2 \quad (\mu V/m)$$
$$H = 7.96 I A / D^3 \quad (\mu A/m)$$

远场:

$$E = 1.3 I A f^2 / D \quad (\mu V/m)$$

常用的差模辐射预测公式



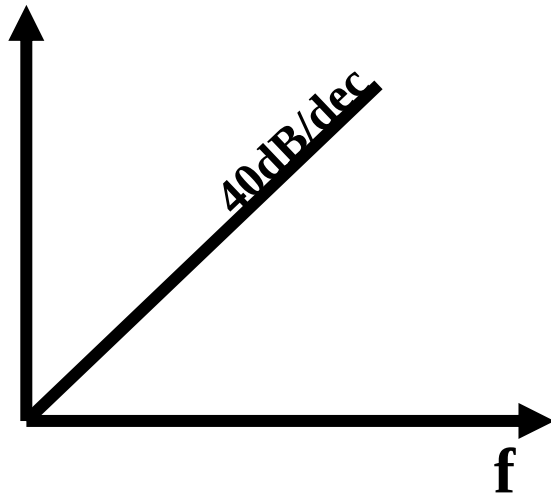
考虑地面反射时：

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

$$(\mu \text{ V/m})$$

脉冲信号差模辐射的频谱

差模辐射频率特性线

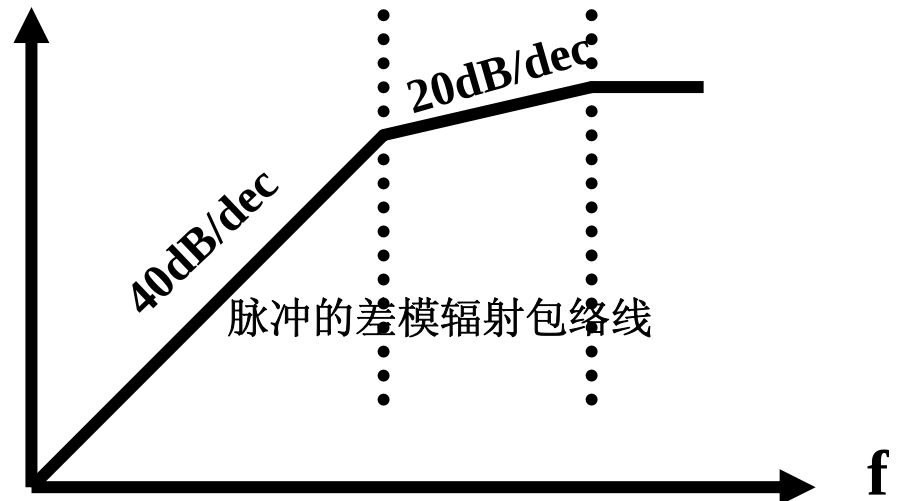
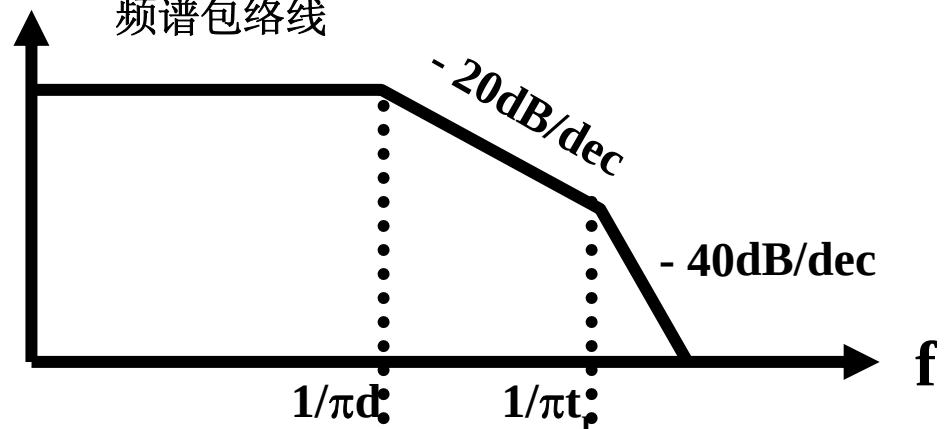


$$E = 2.6 I A f^2 / D$$

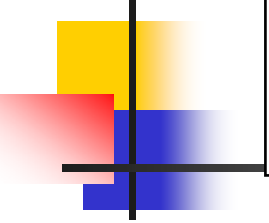
$$E_{\text{dB}} = 20\lg (2.6 I A / D)$$

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频谱包络线



脉冲的差模辐射包络线



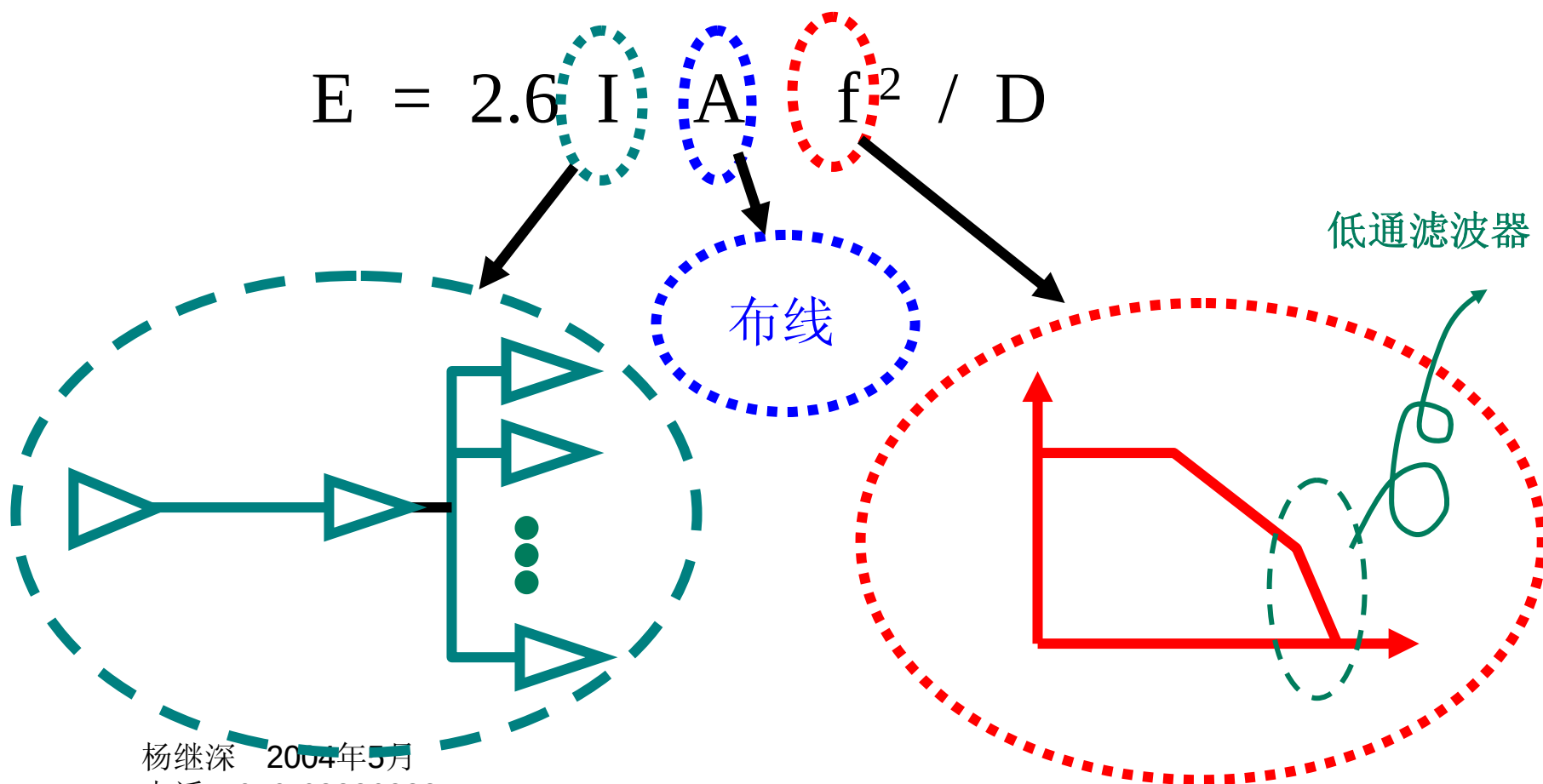
不同逻辑电路为了满足EMI指标要求 所允许的环路面积

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

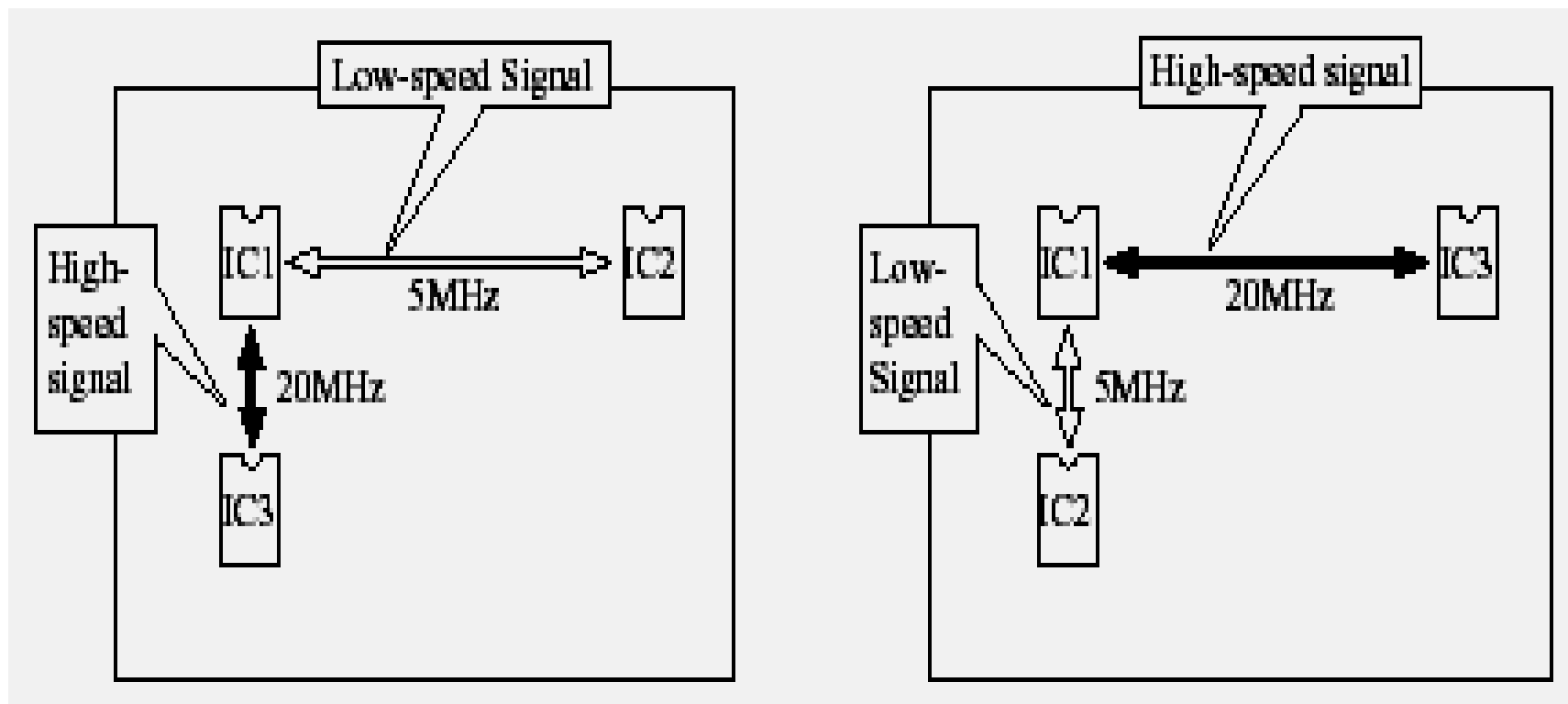
仅代表了一个环路的辐射情况，若有N个环路辐射，
乘以 $\sqrt{N}$ 。因此，可能时，分散时钟频率。

减小差模辐射的方法

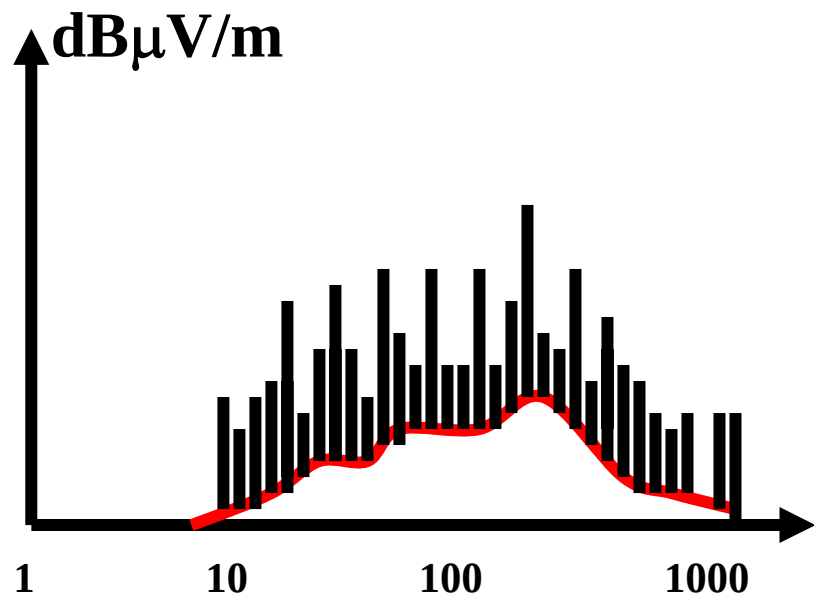
$$E = 2.6 I A f^2 / D$$



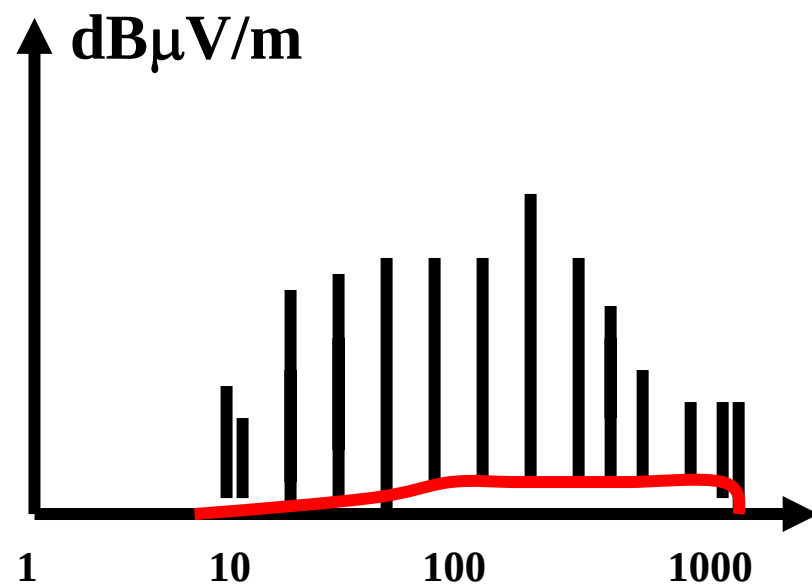
控制高频信号的回路



电路中的强辐射信号

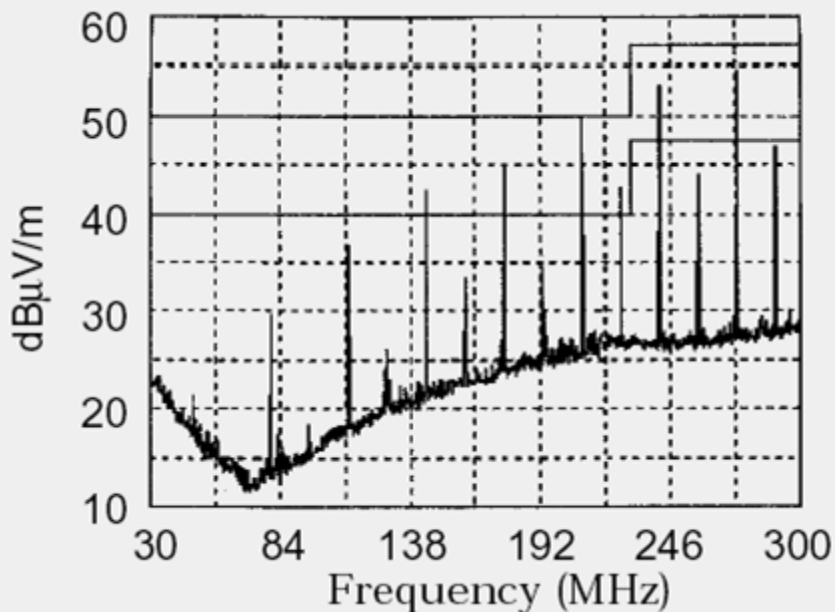
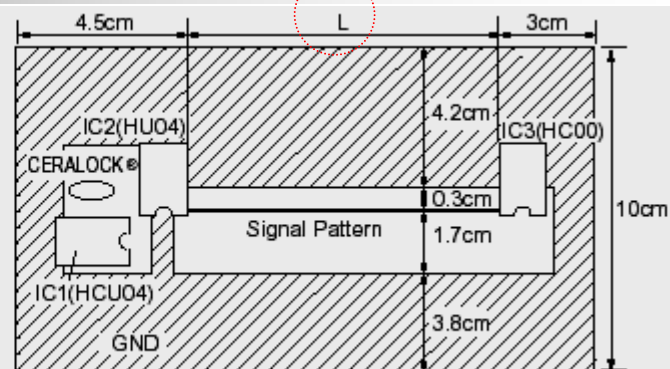
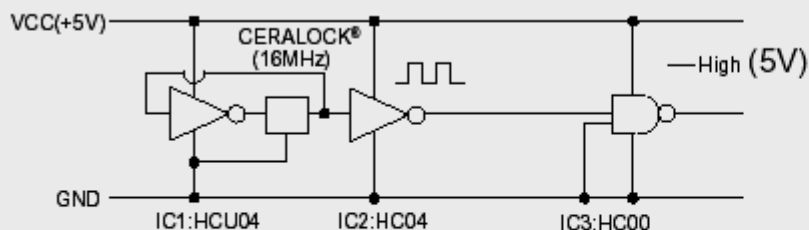


所有电路加电工作

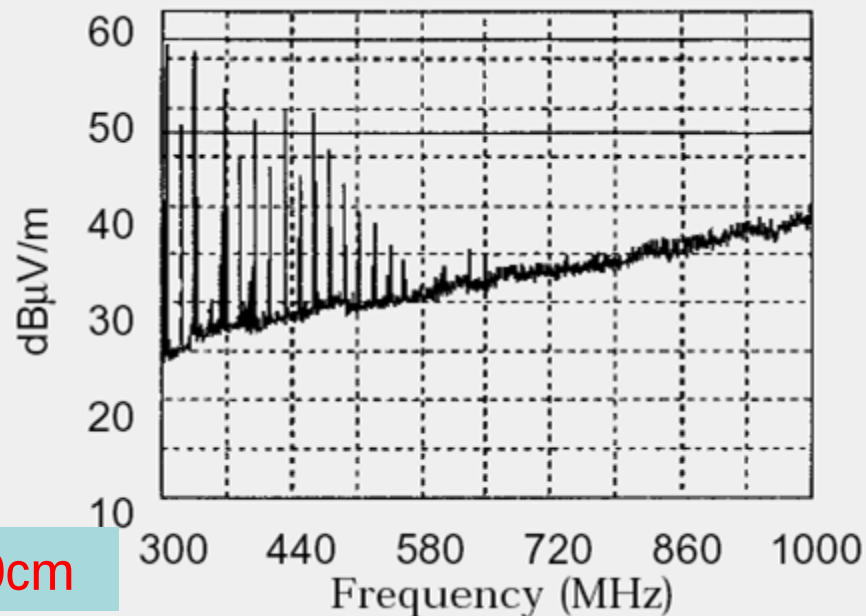


只有时钟电路加电工作

控制回路面积是布线的主要目的

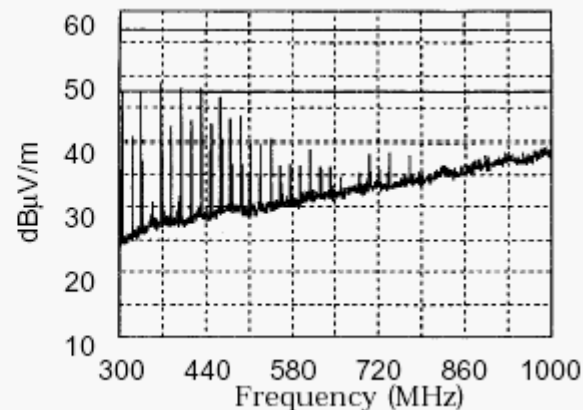
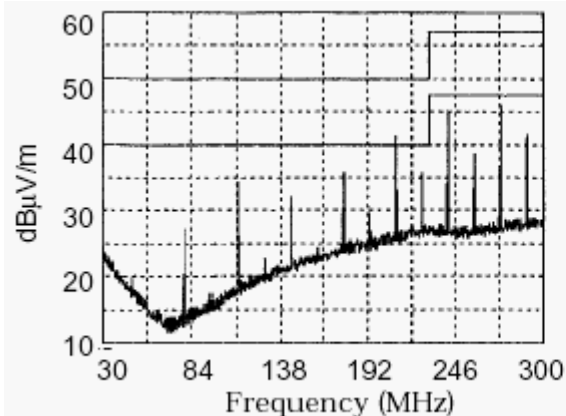


L=20cm

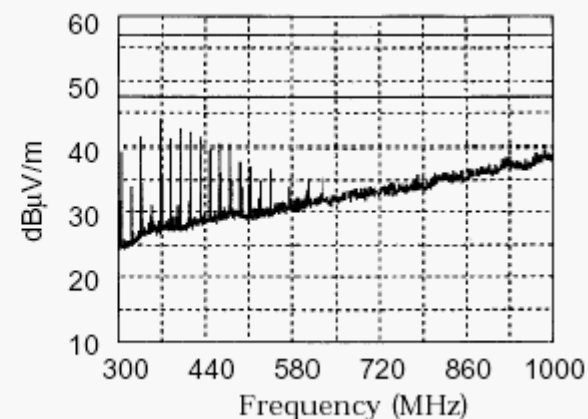
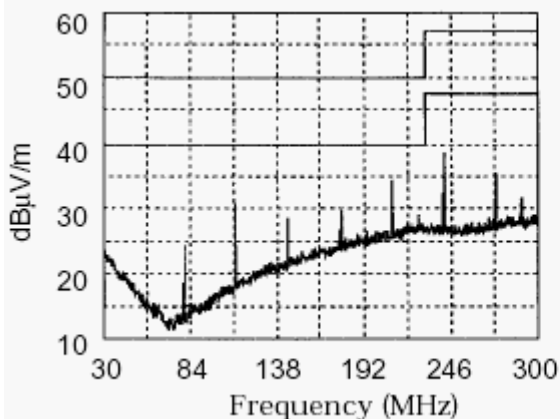


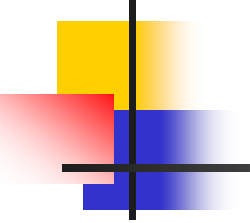
减小面积降低辐射

$L=10\text{cm}$

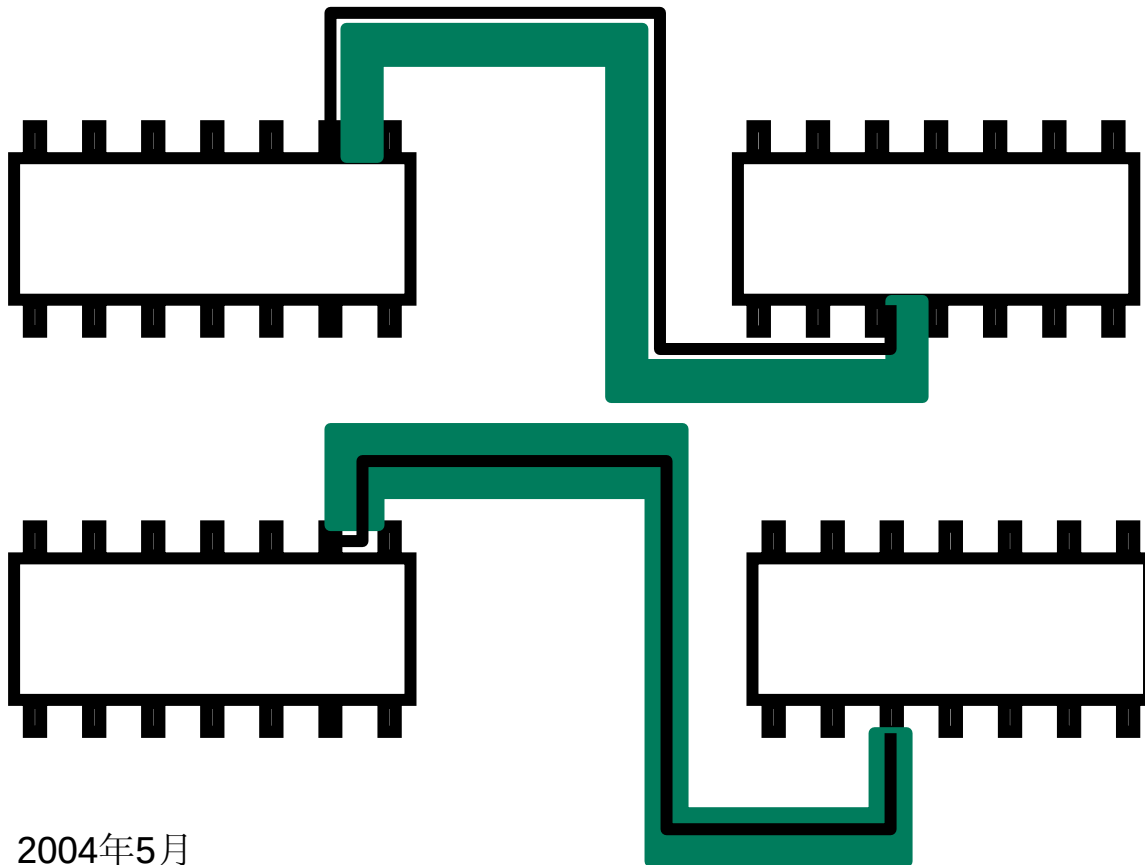


$L=5\text{cm}$

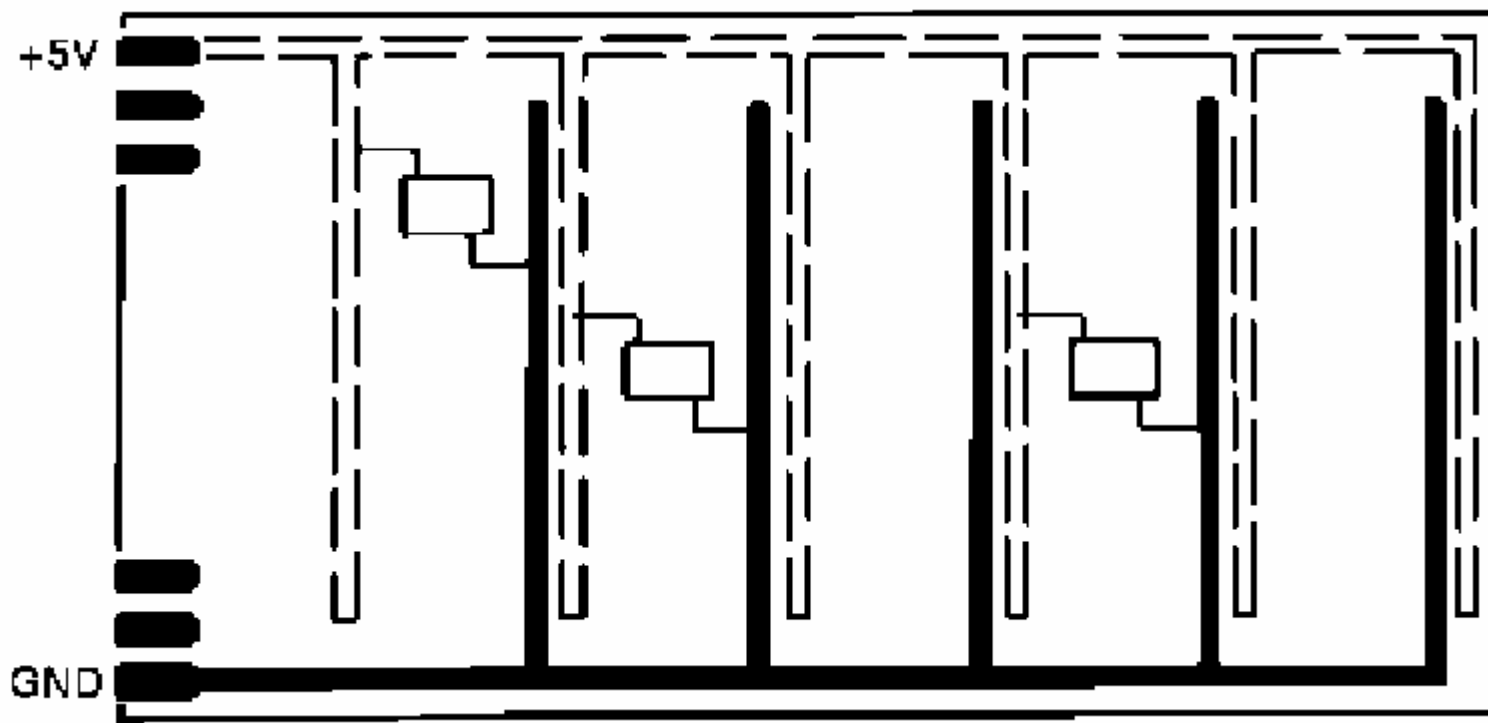




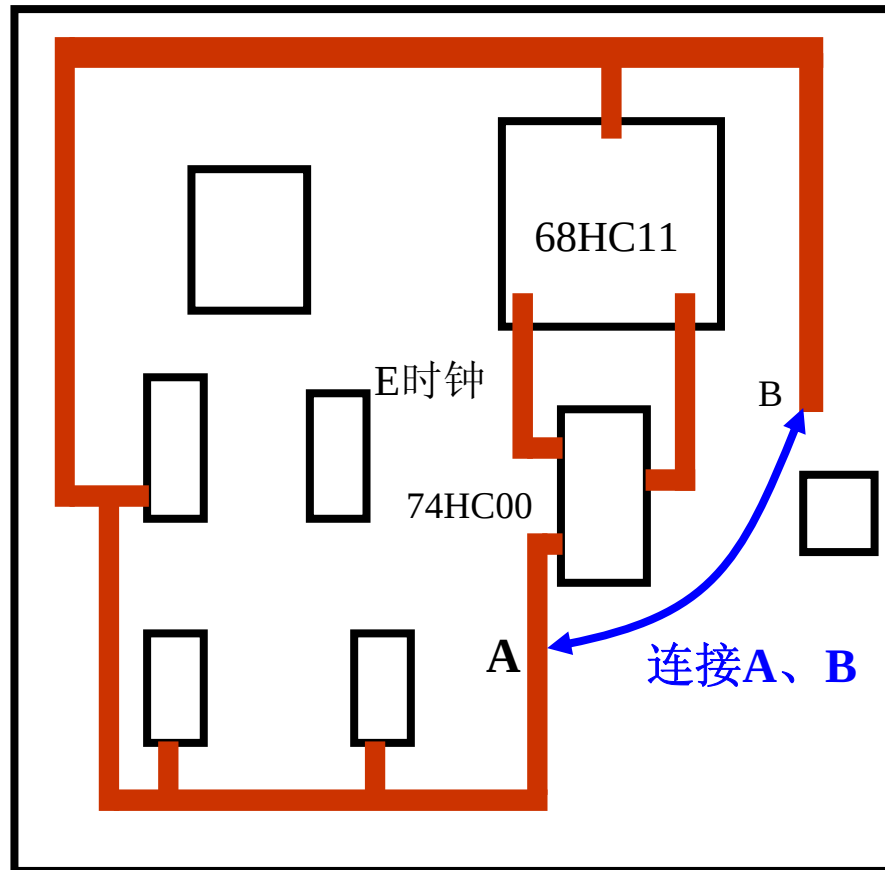
单层或双层板如何减小环路的面积

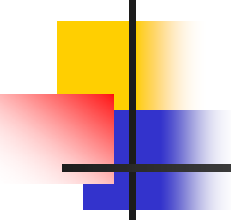


不良布线举例一

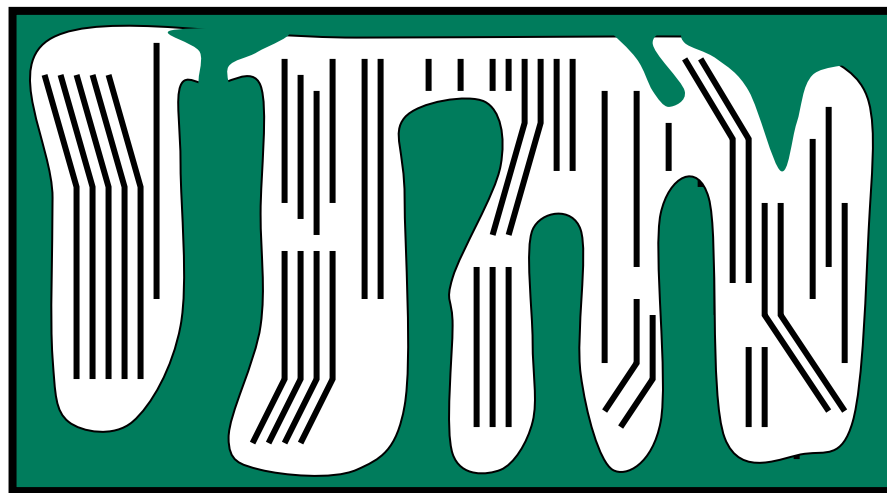
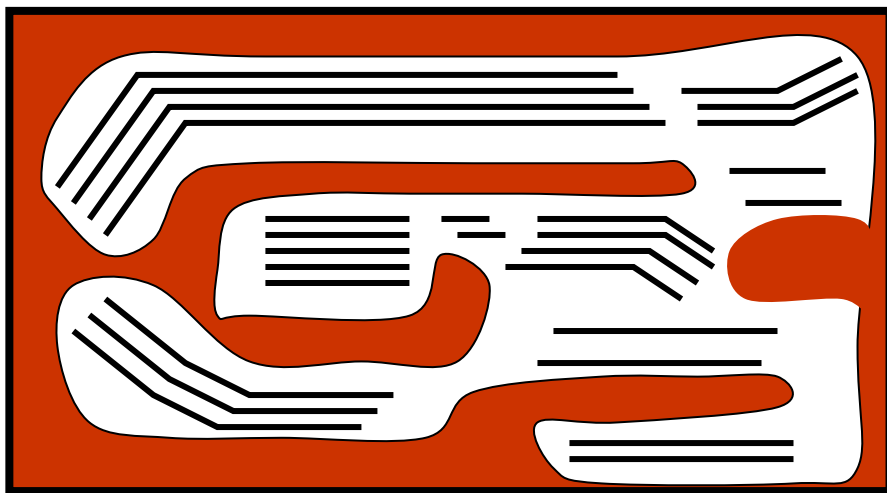


不良布线举例二





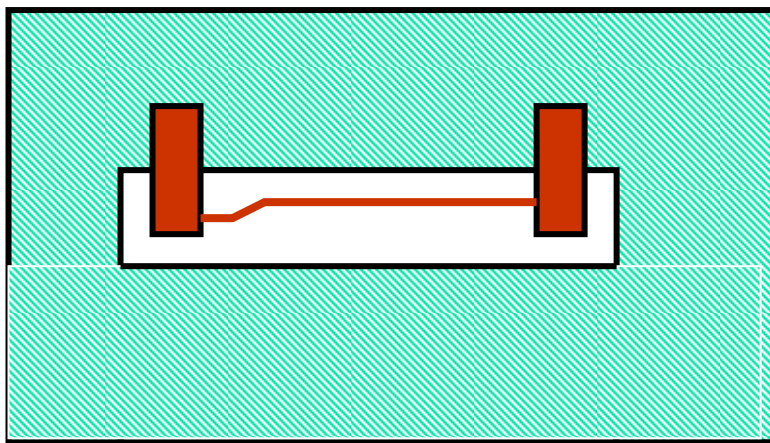
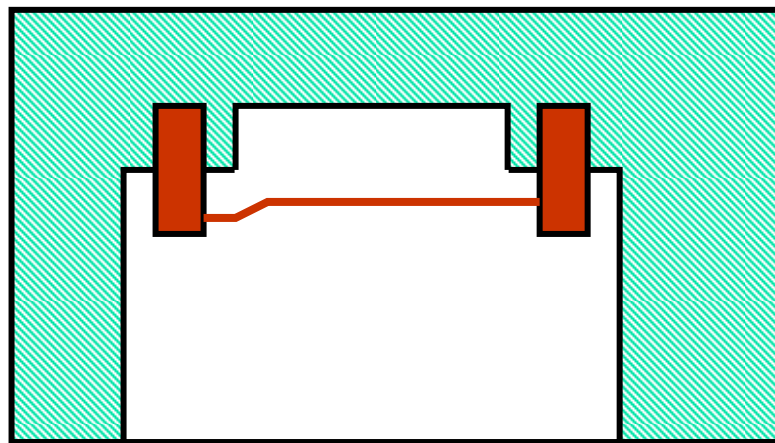
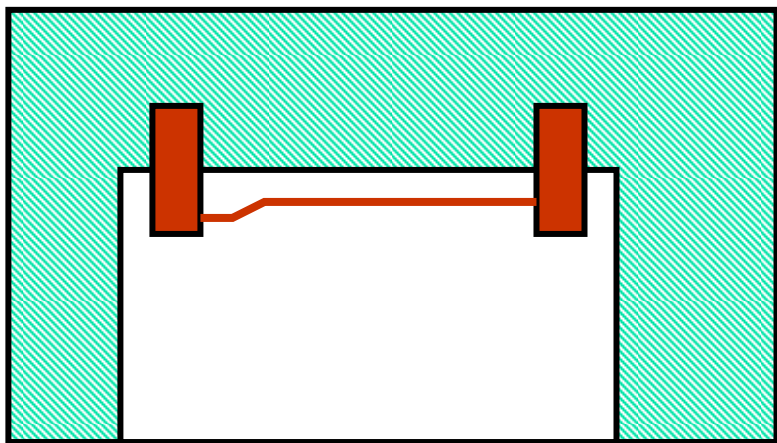
随便设置的地线没有用



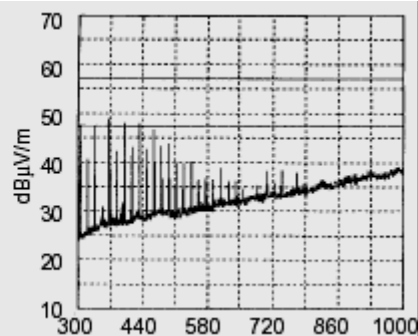
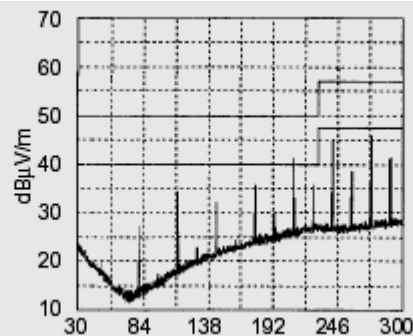
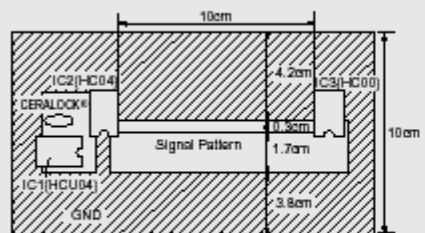
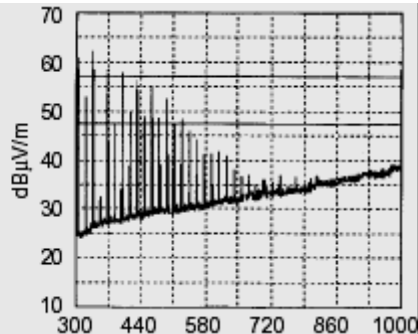
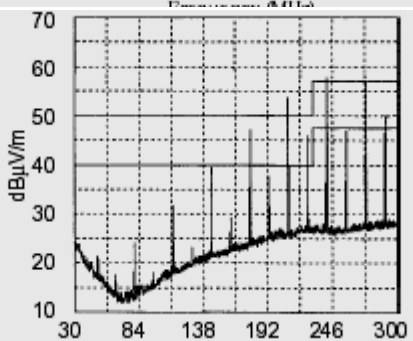
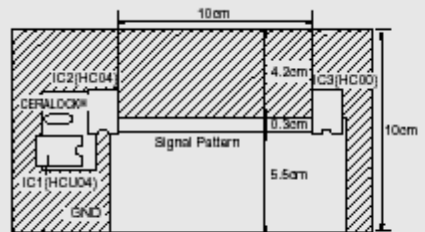
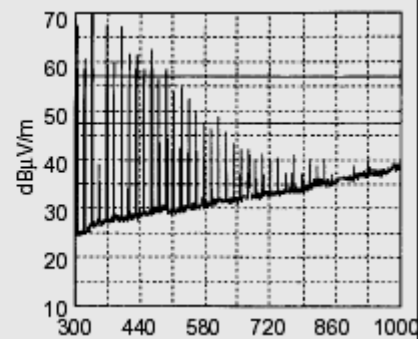
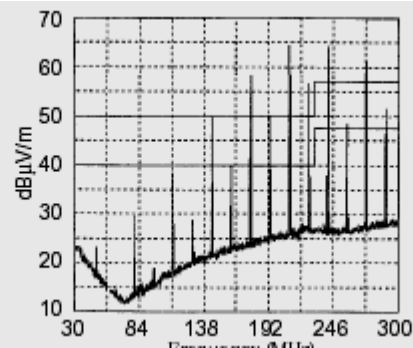
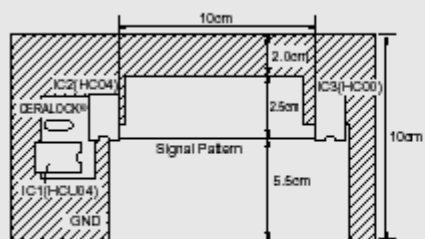
在线路板上没有布线的地方全部铺上地线是**EMC**设计吗？

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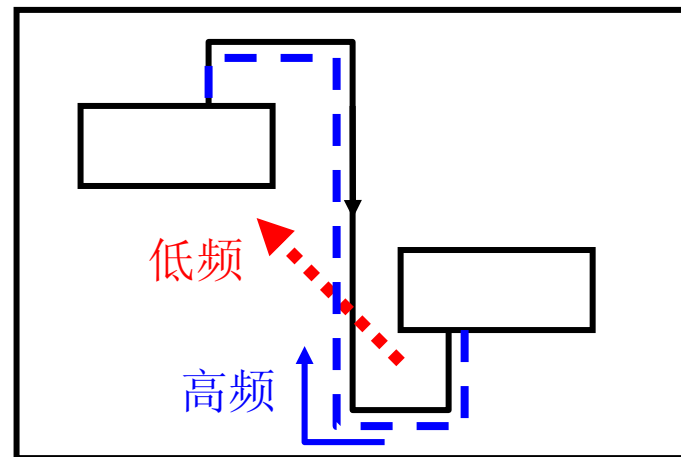
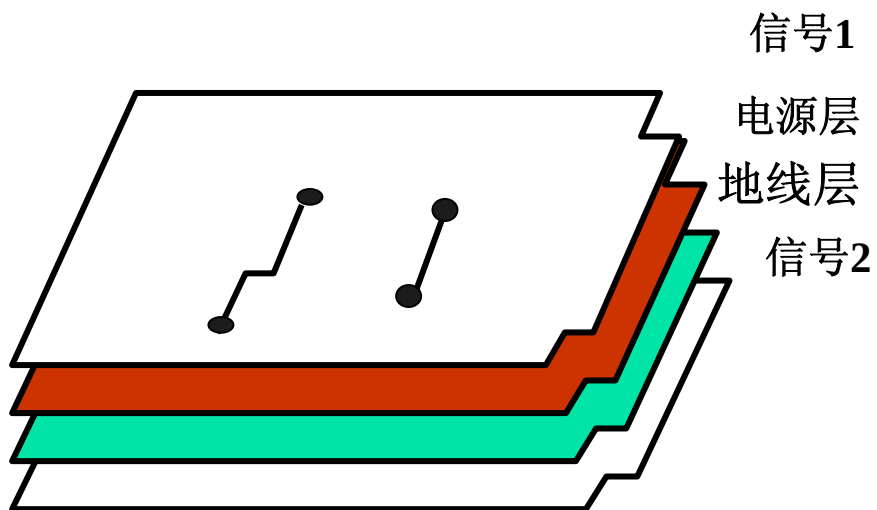
地线对辐射的影响



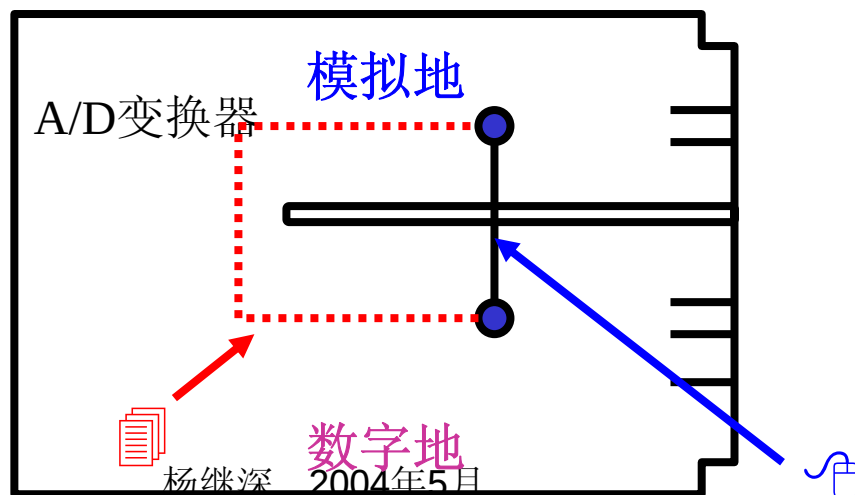
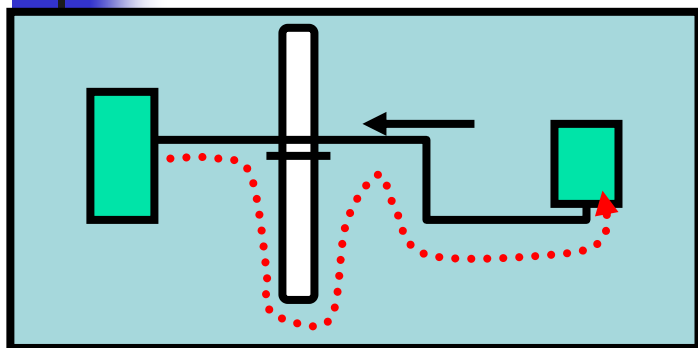
地线对辐射的影响



多层板能减小辐射

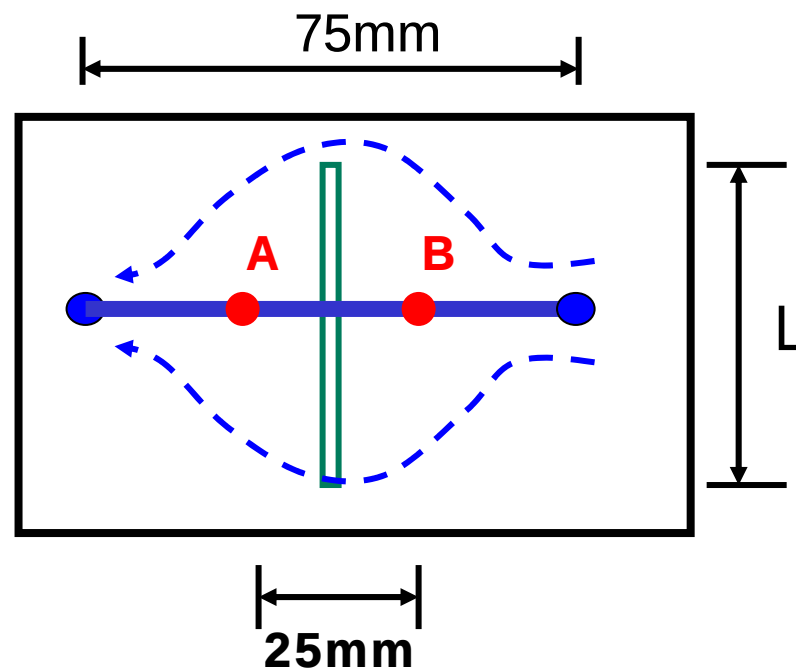


地线面上的缝隙的影响



杨继深 2004年5月

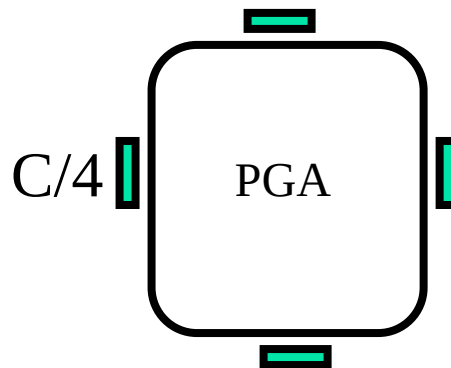
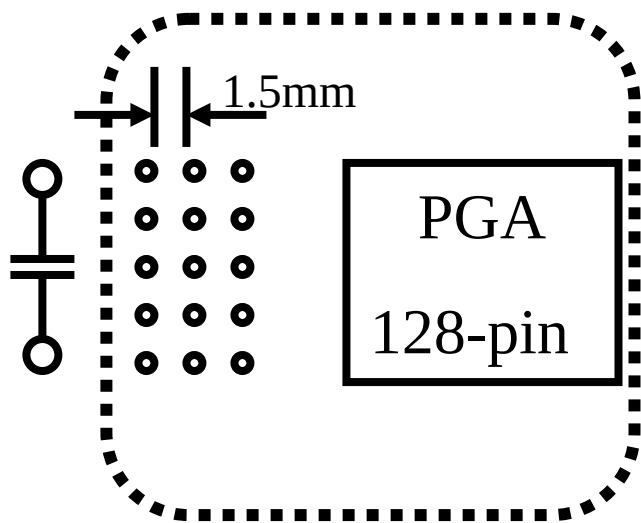
电话: 010-68386283



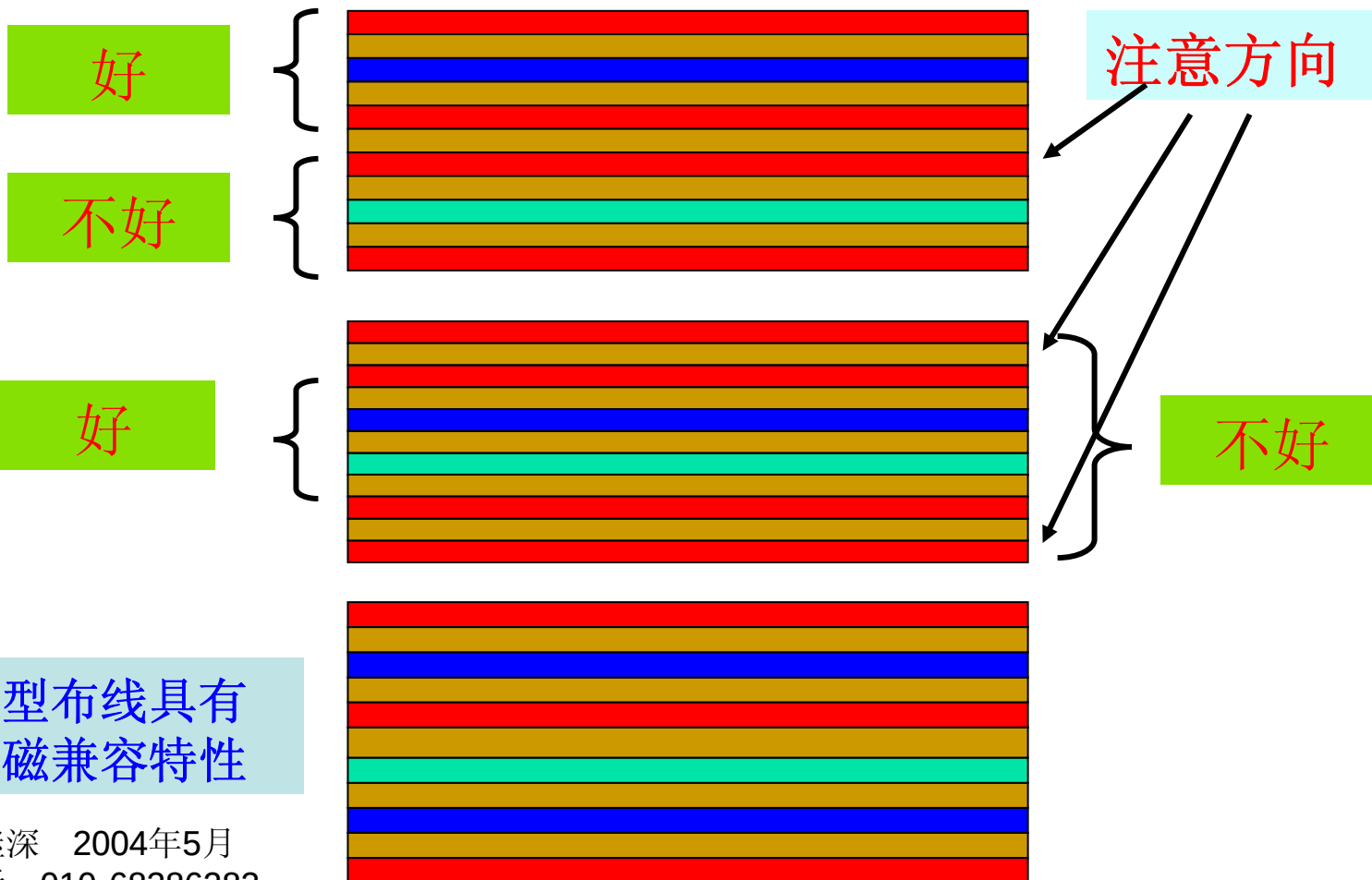
L : 0 ~ 10cm

V_{AB} : 15 ~ 75mV

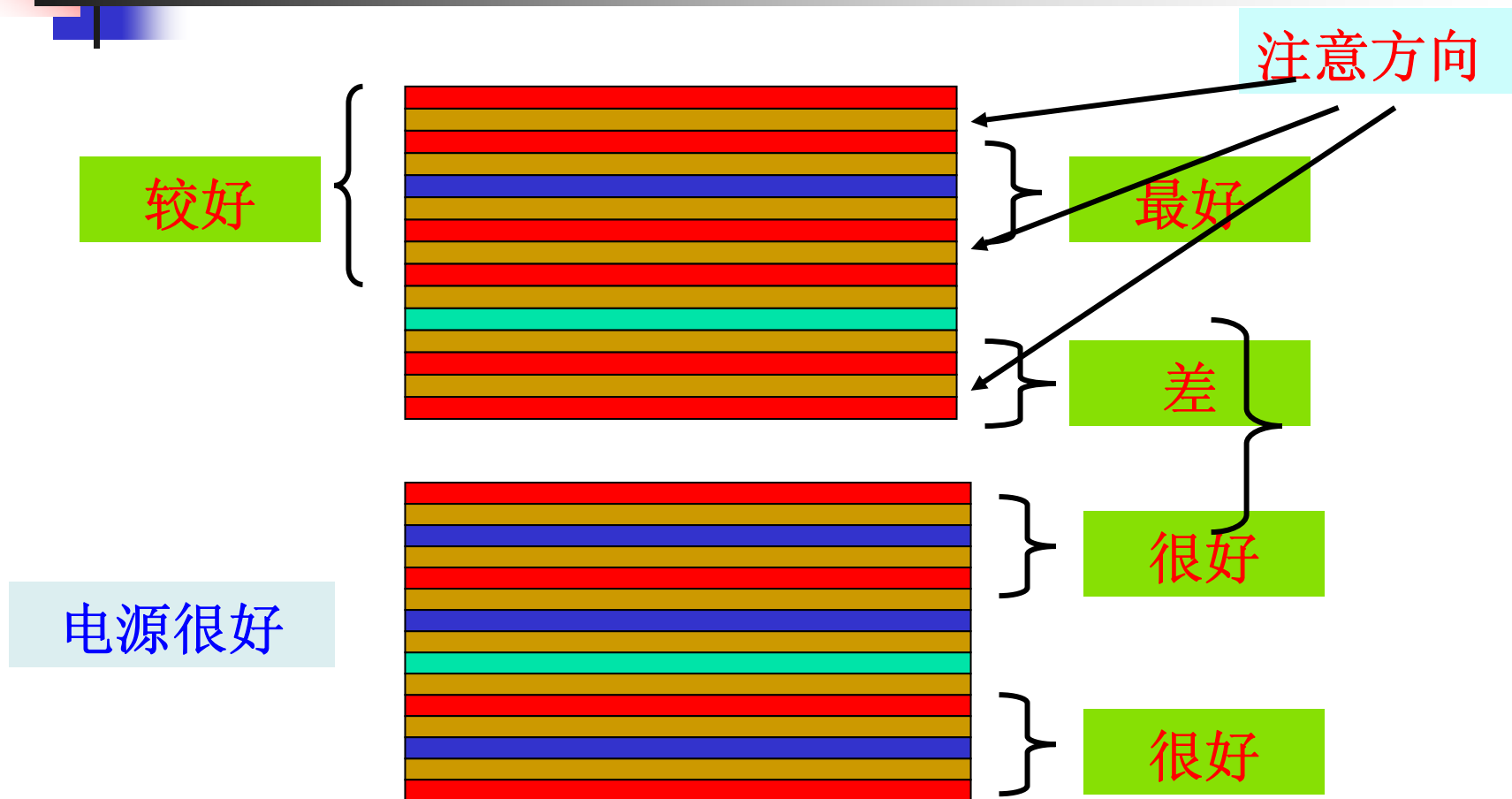
注意过孔的阻抗



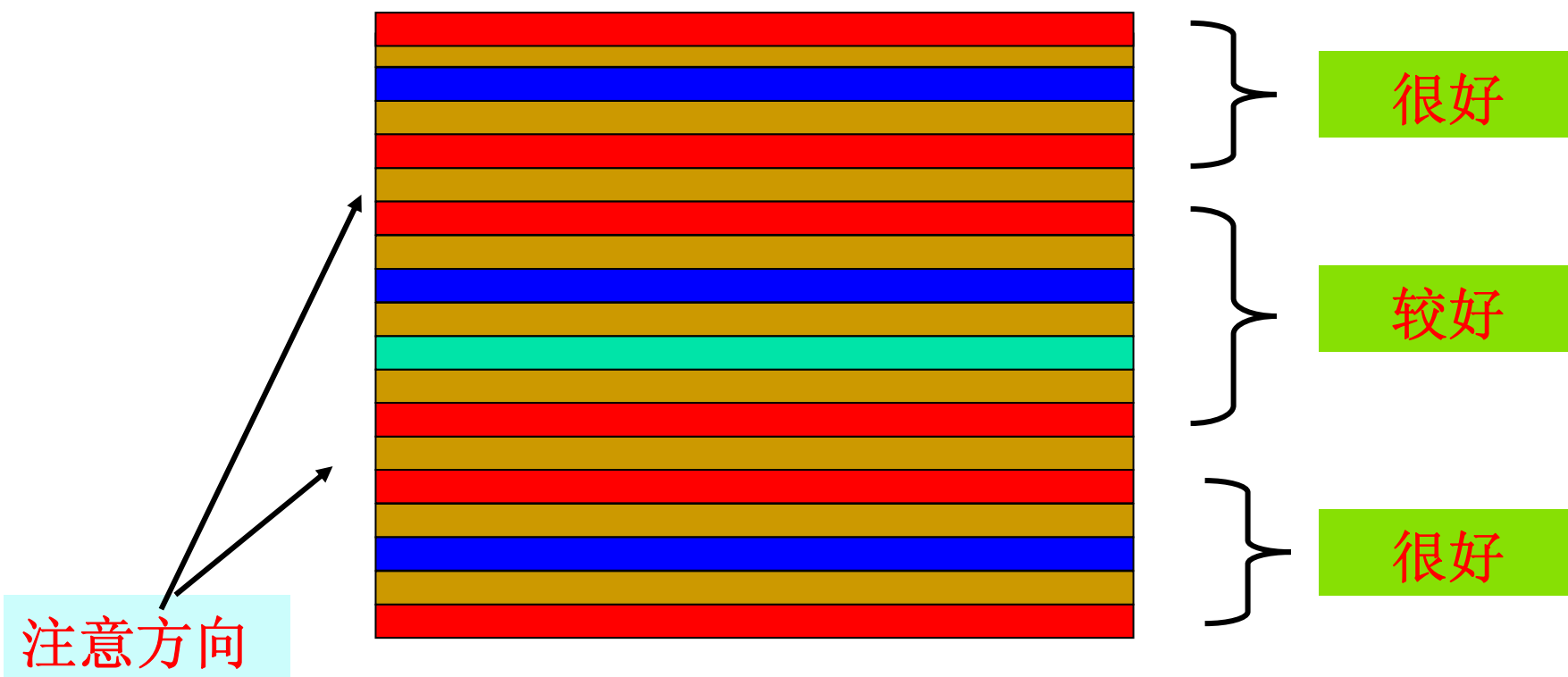
六层板的设计



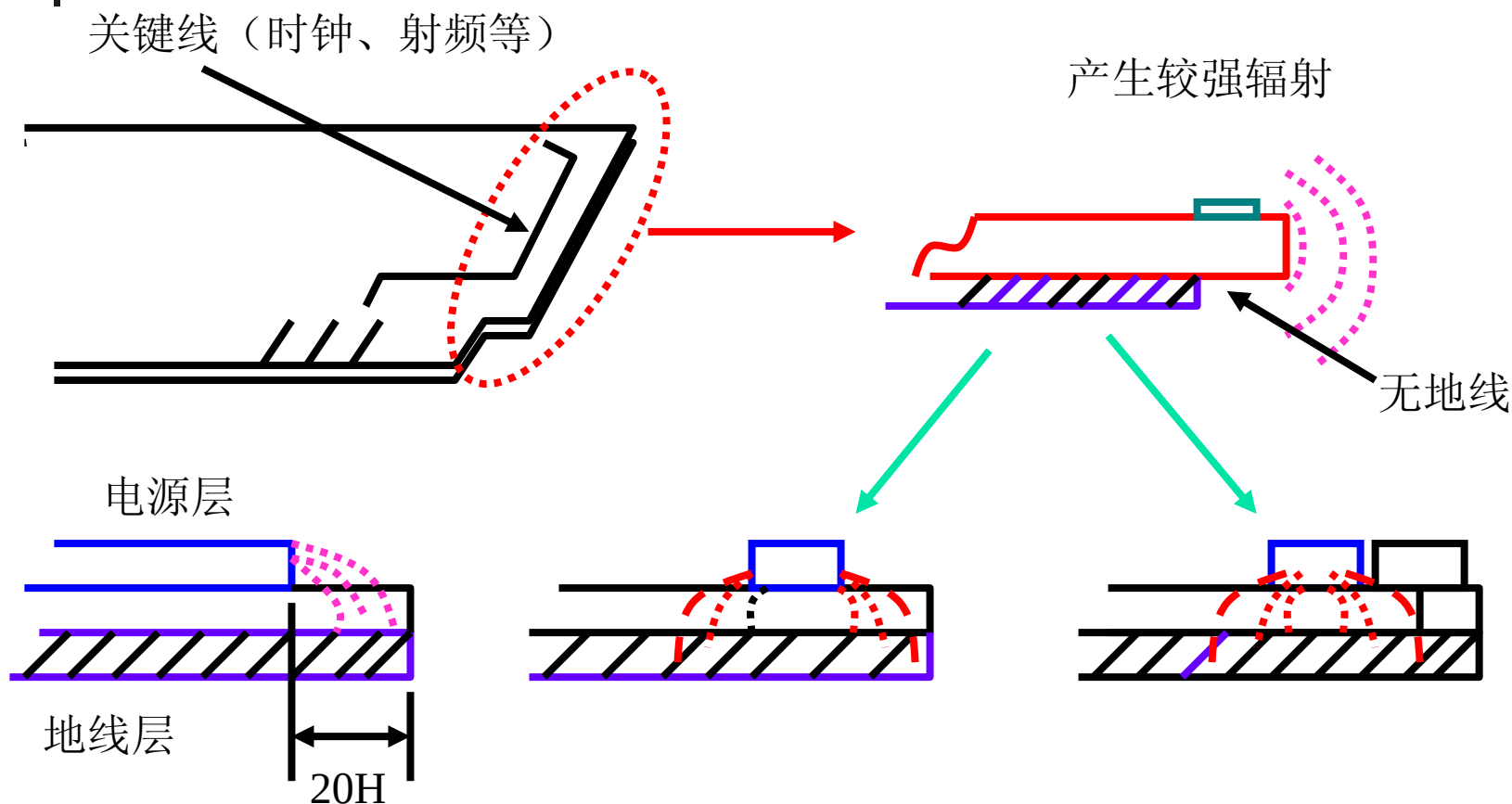
八层板的设计



十层板的设计



线路板边缘的一些问题



扁平电缆的使用

最好



较好



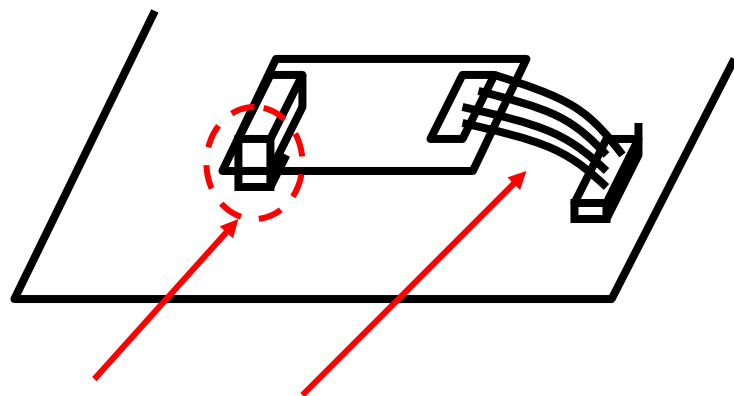
差



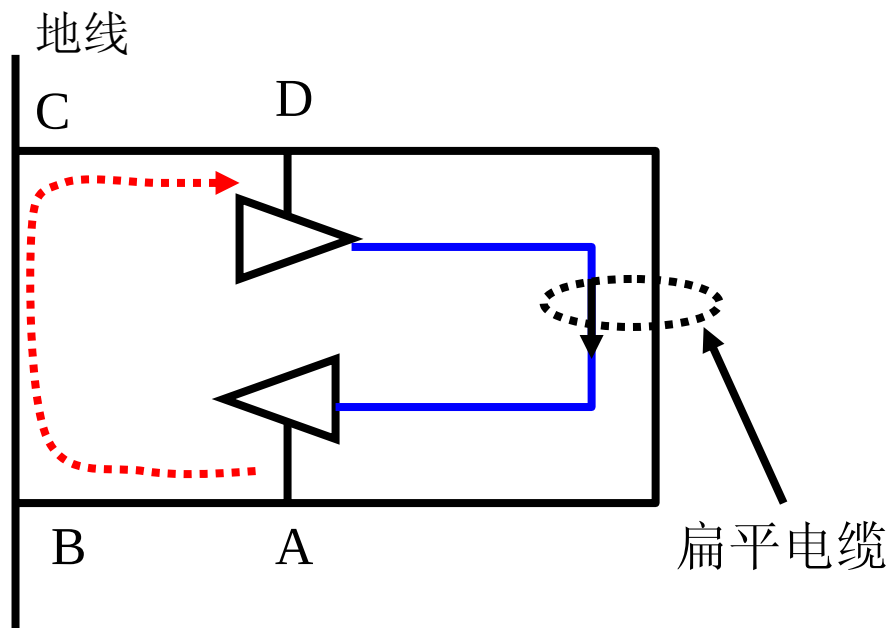
较好，但端接困难



避免面积较大的地线回路

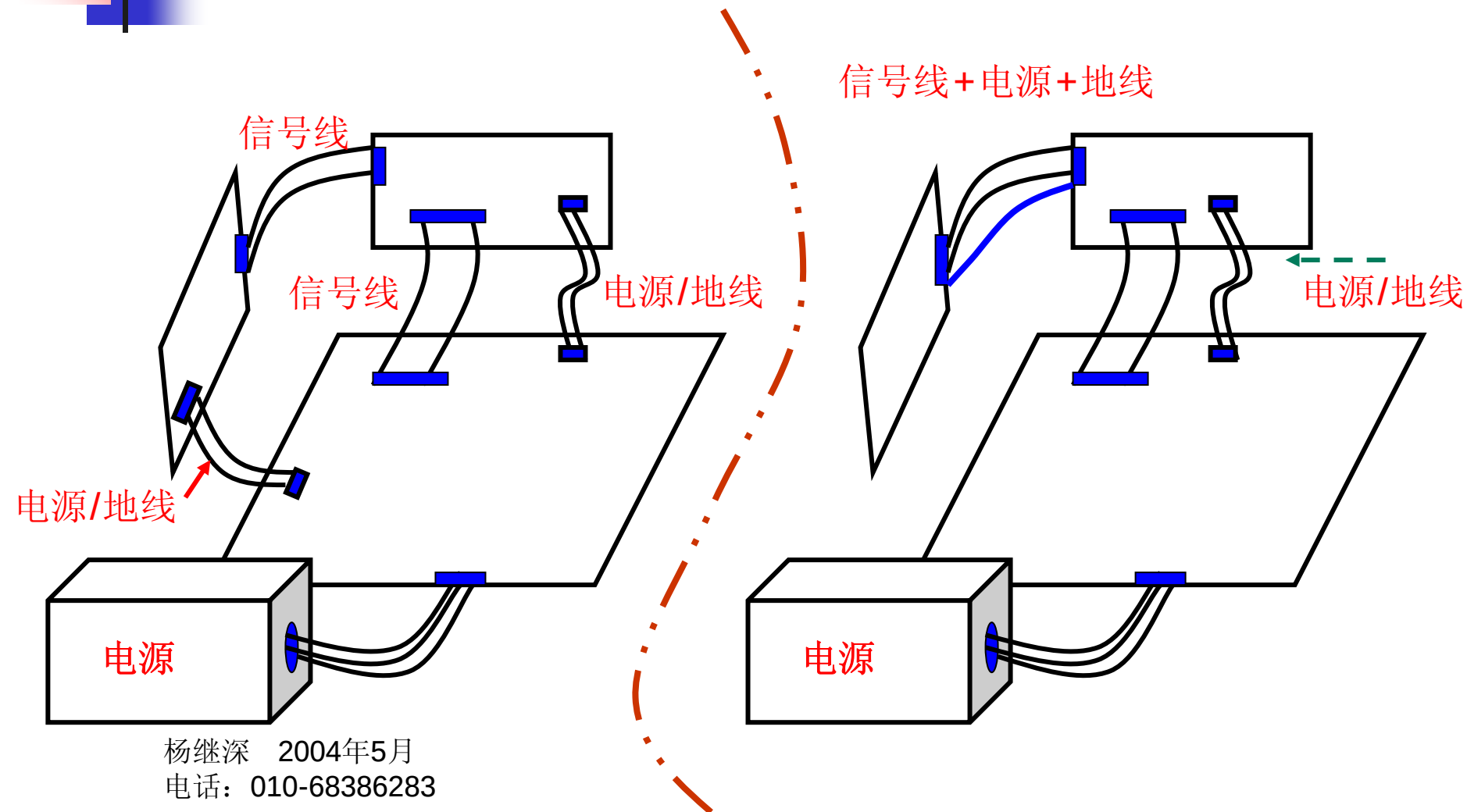


这两处都有地线

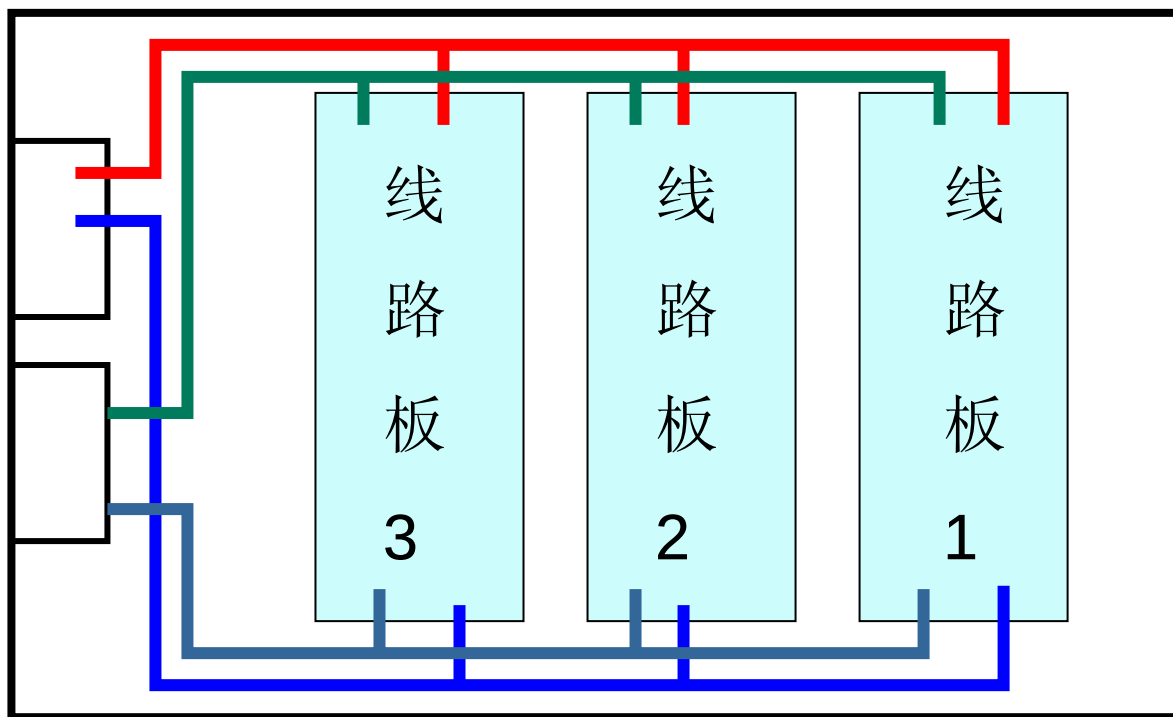


一部分信号回流经过ABCD

注意隐蔽的辐射环路

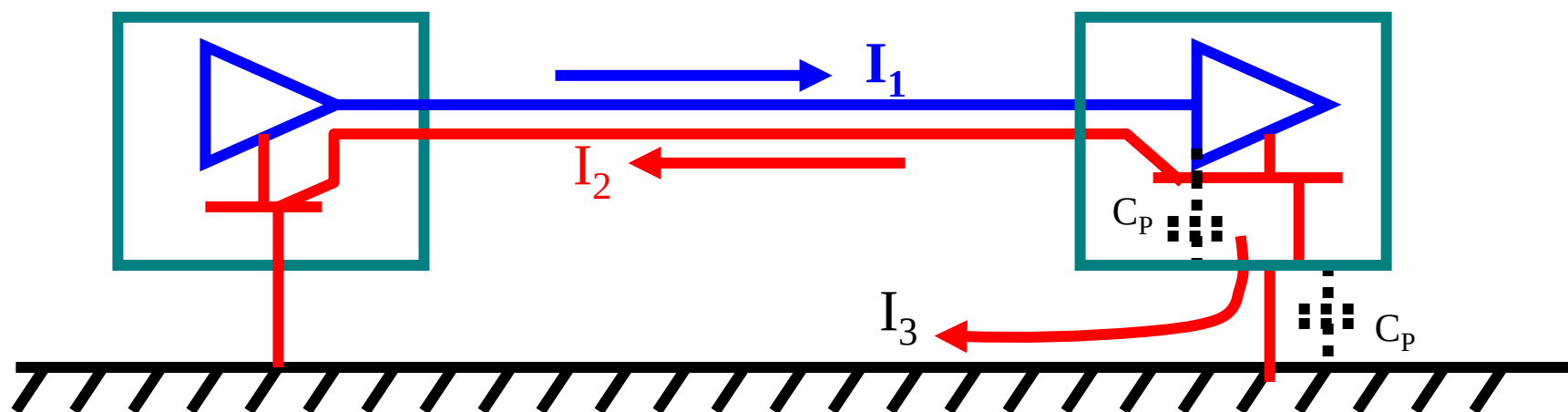


直流线的辐射



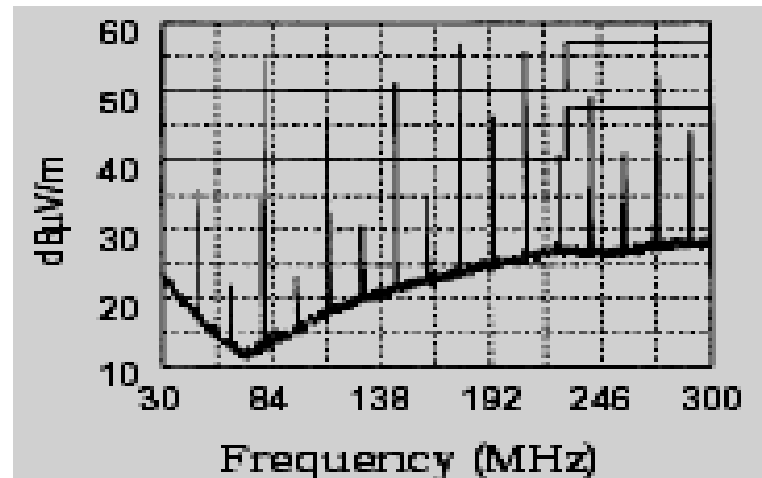
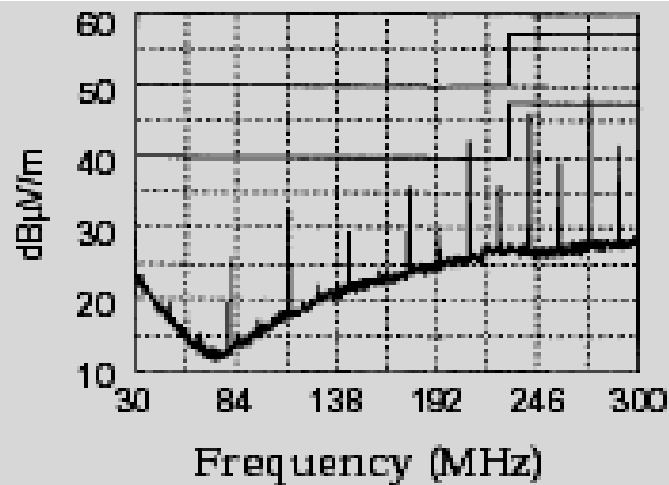
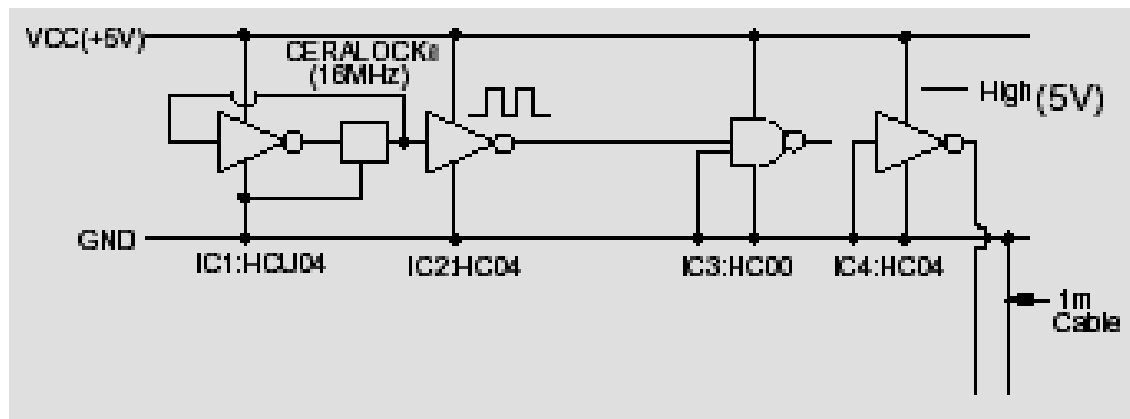
直流线也会产生射频辐射

外拖电缆的共模辐射

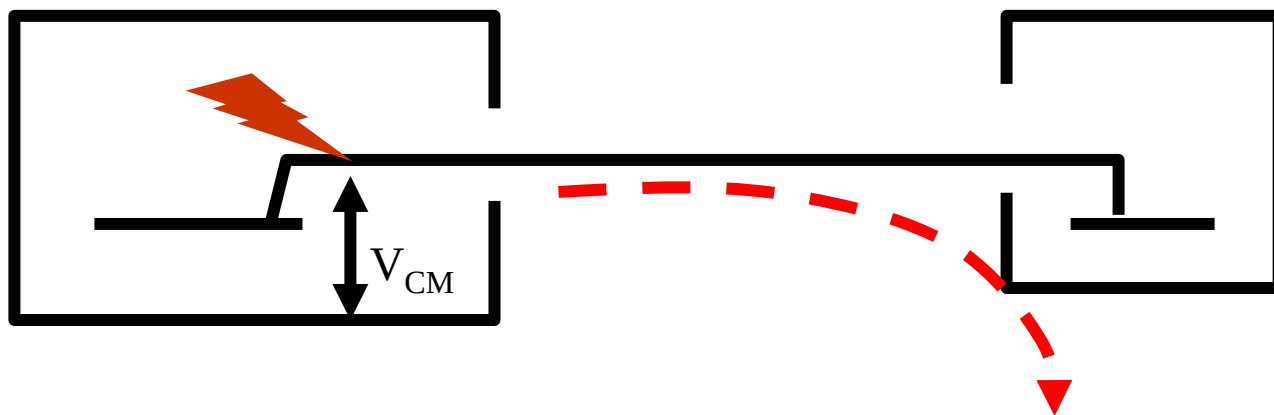


尽管共模成份的比例很小，但是由于辐射环路大，
仍然是主要的辐射因素

“无关”的电缆也辐射

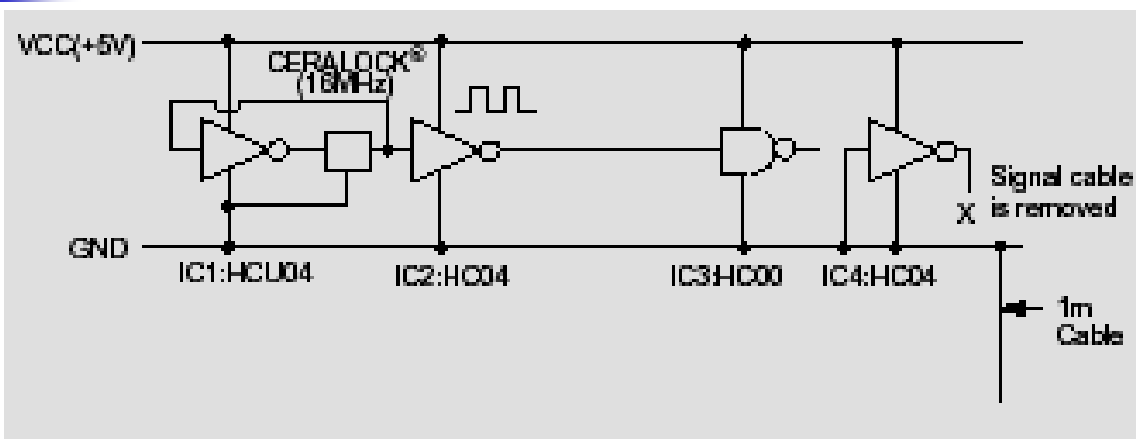


无关电缆辐射机理



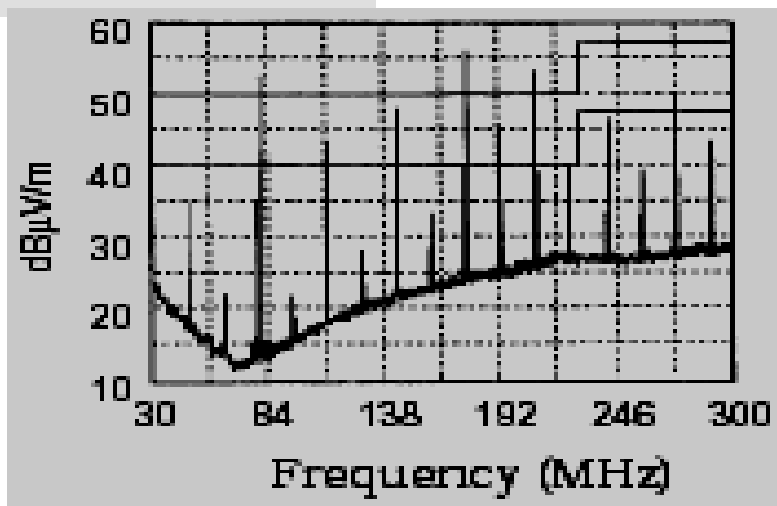
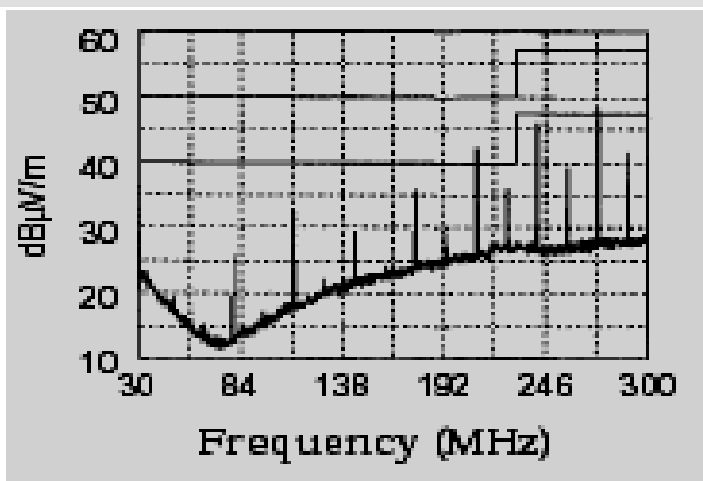
机箱内的所有信号都会通过
电缆辐射！

地线也辐射



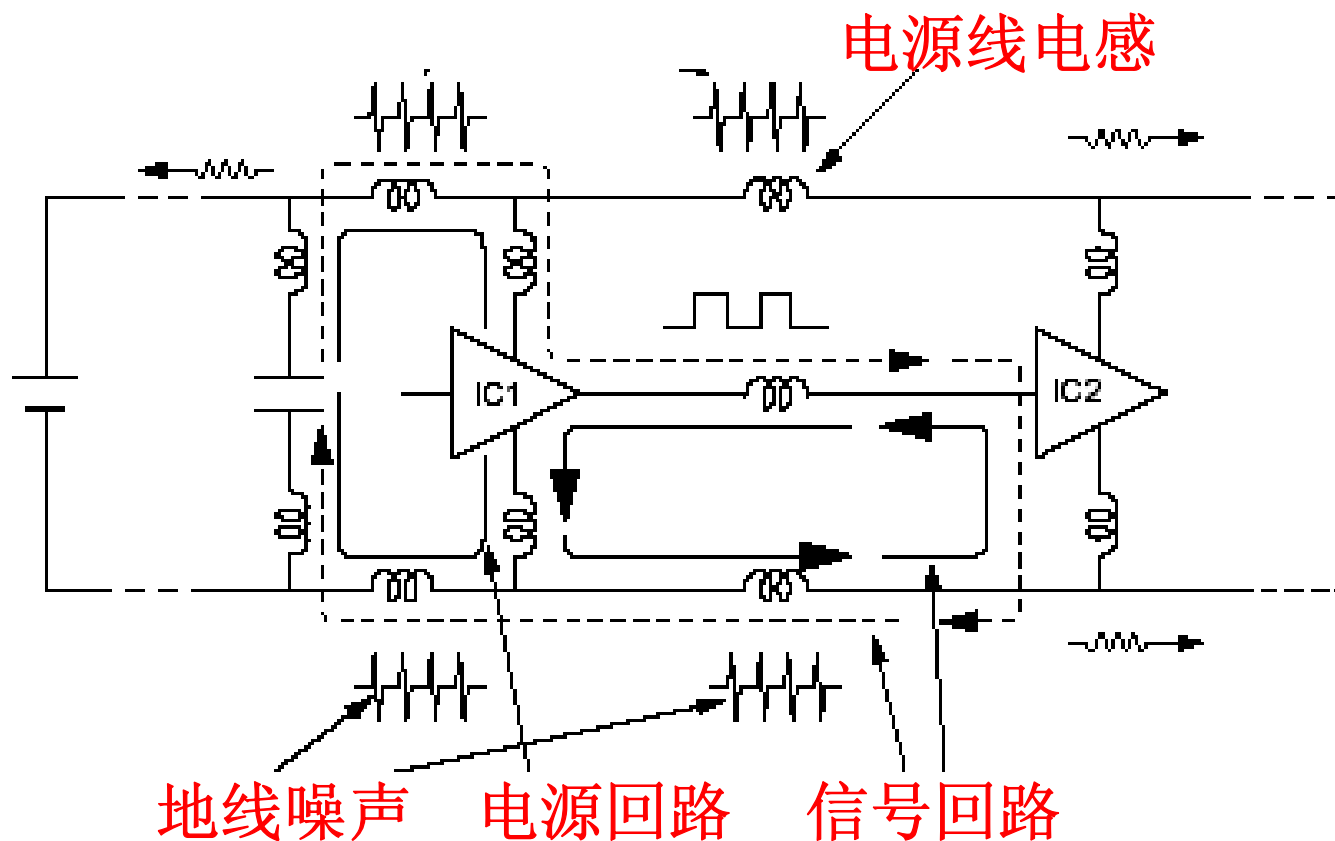
你喜欢 - - - -
电缆屏蔽层接地吗？

不接地线

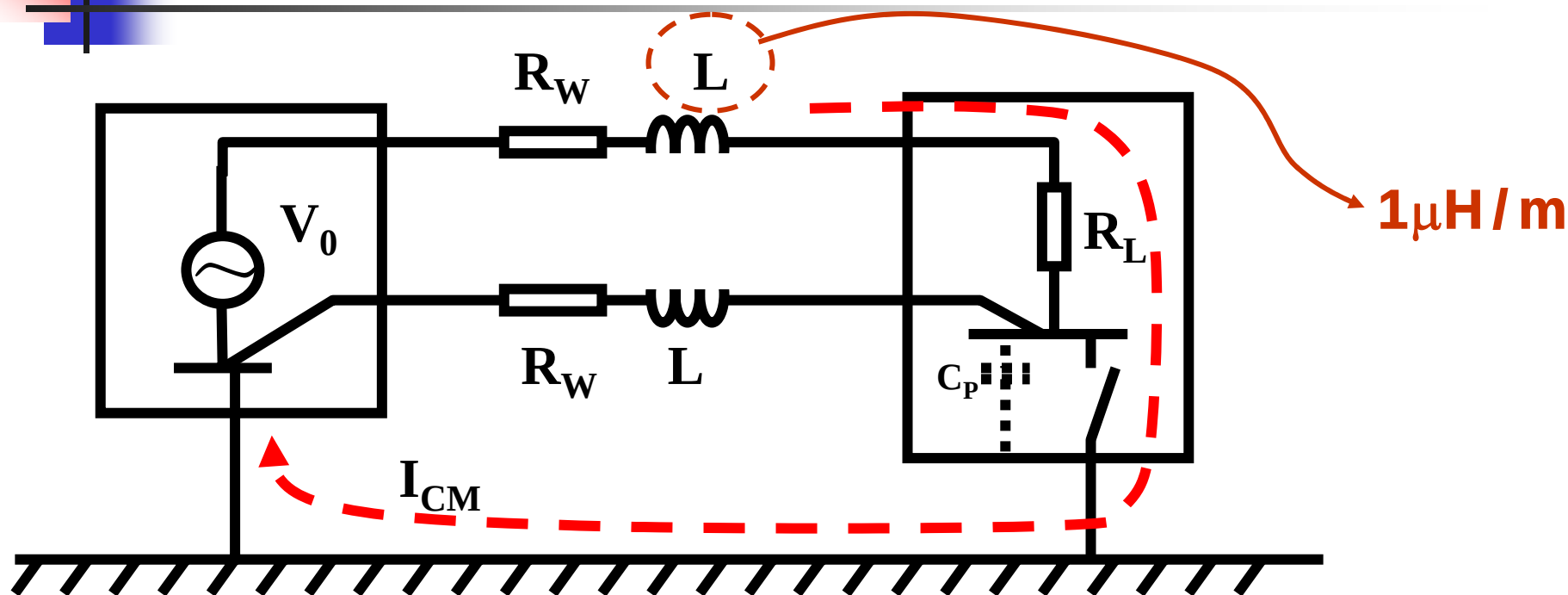


接上地线

地线辐射产生的原因



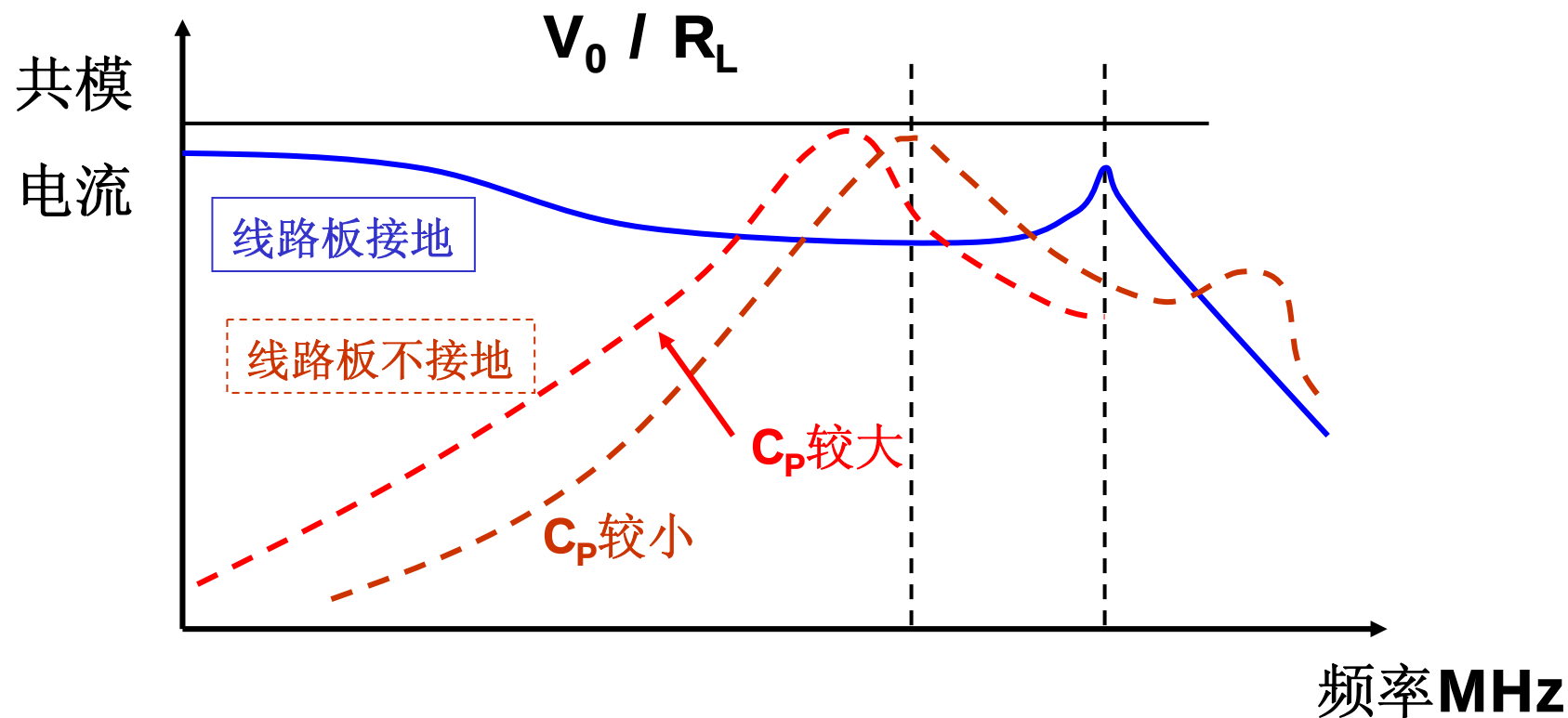
共模电流估算（两端设备都接地的情况）



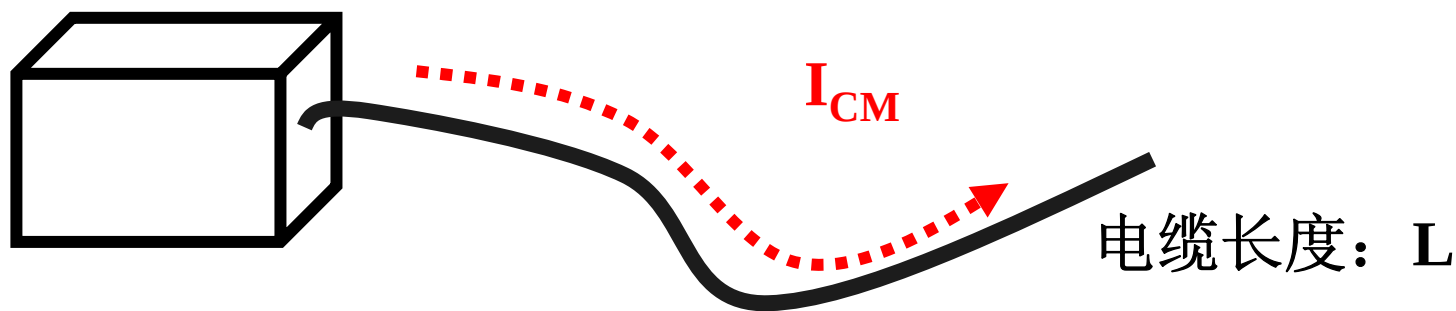
线路板接地: $Z_{CM} = R_W + j\omega L + R_L$

线路板不接地: $Z_{CM} = R_W + j\omega L + R_L + 1/j\omega C$

共模电流主要由寄生电容产生



悬浮电缆



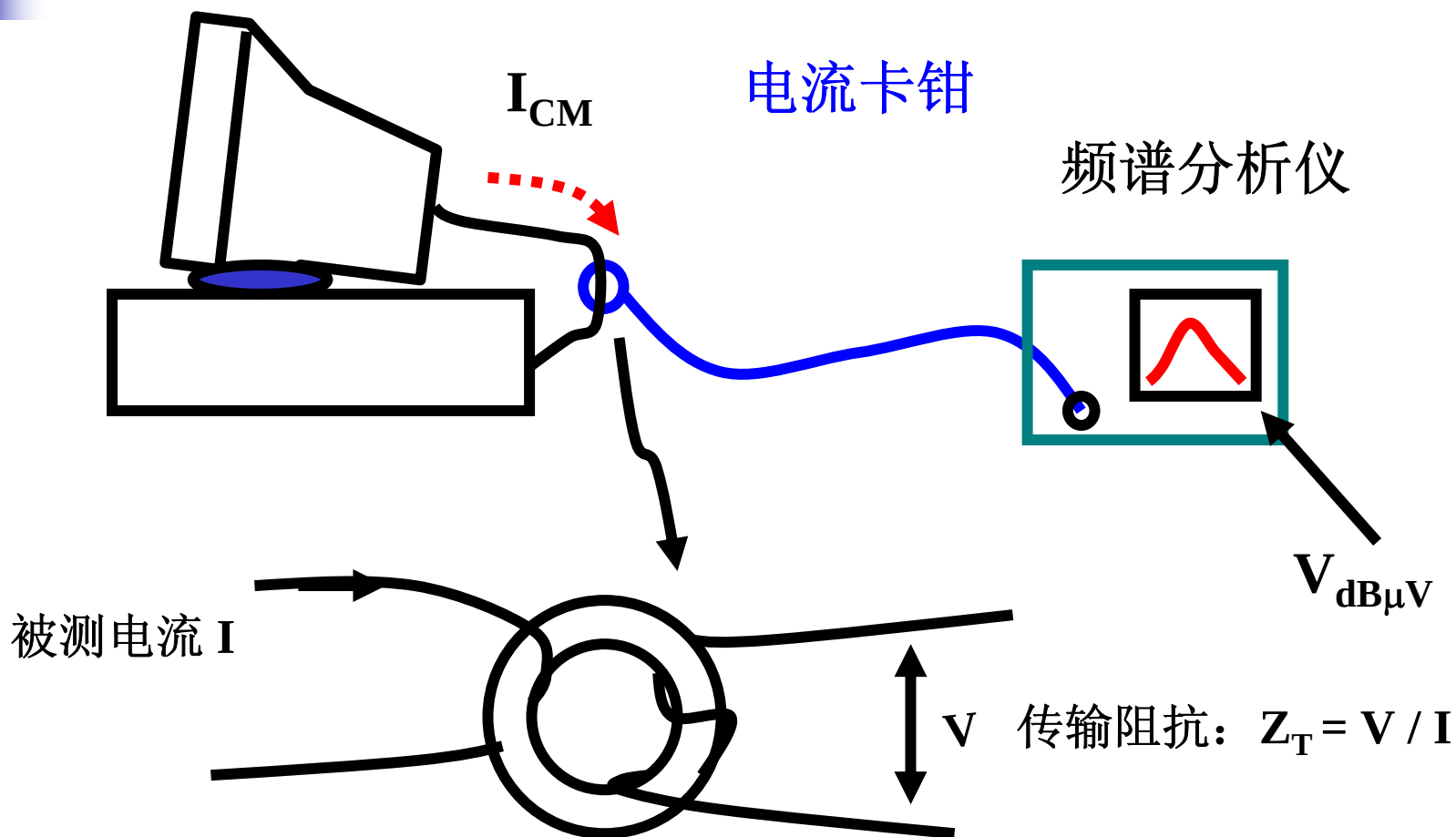
近场区内: $E = 1430 I L / (f D^3)$ $\mu V/m$

远场区内: $E = 0.63 I L f / D$ $\mu V/m$

考虑地面反射: $E = 1.26 I L f / D$ $\mu V/m$

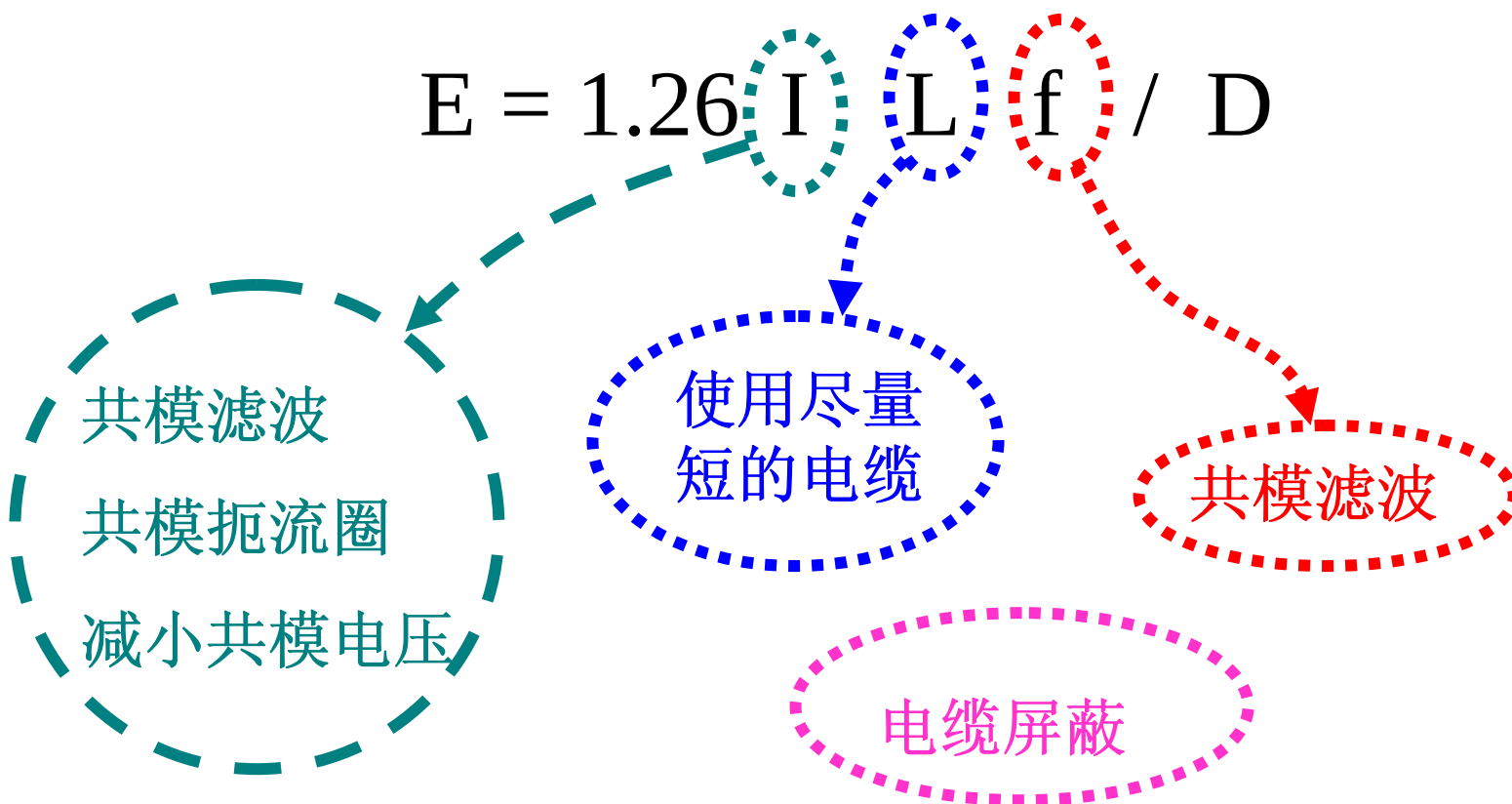
$L > \lambda/2$ 或 $\lambda/4$ 时: $E = 120 I / D$ $\mu V/m$

共模电流的测量

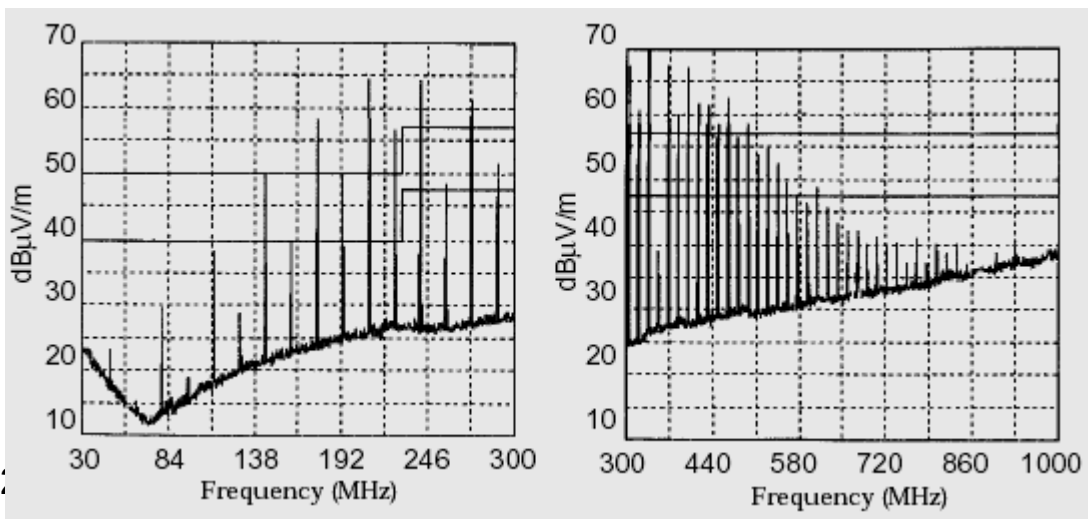
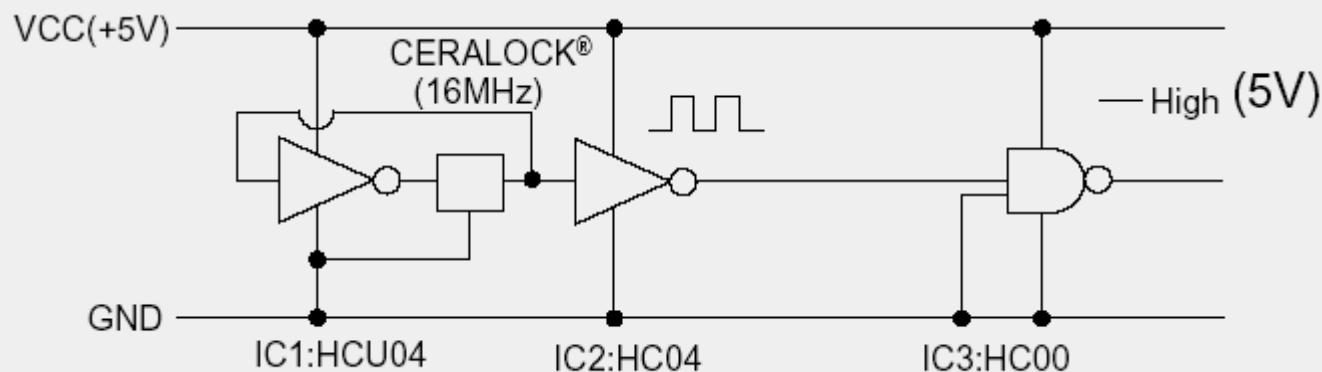


怎样减小共模辐射

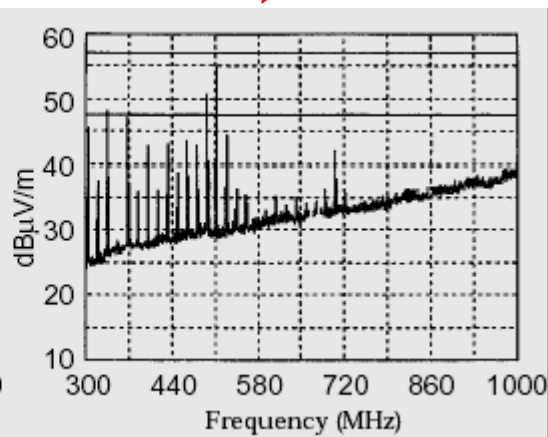
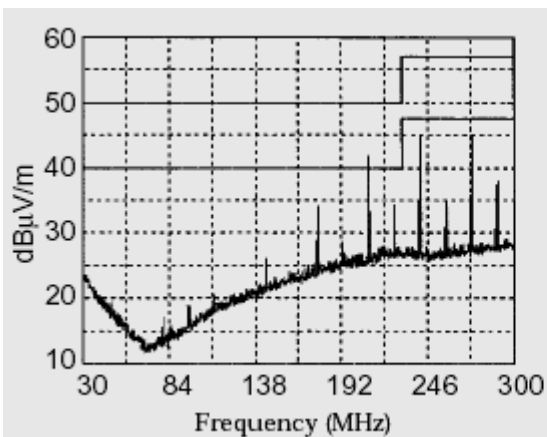
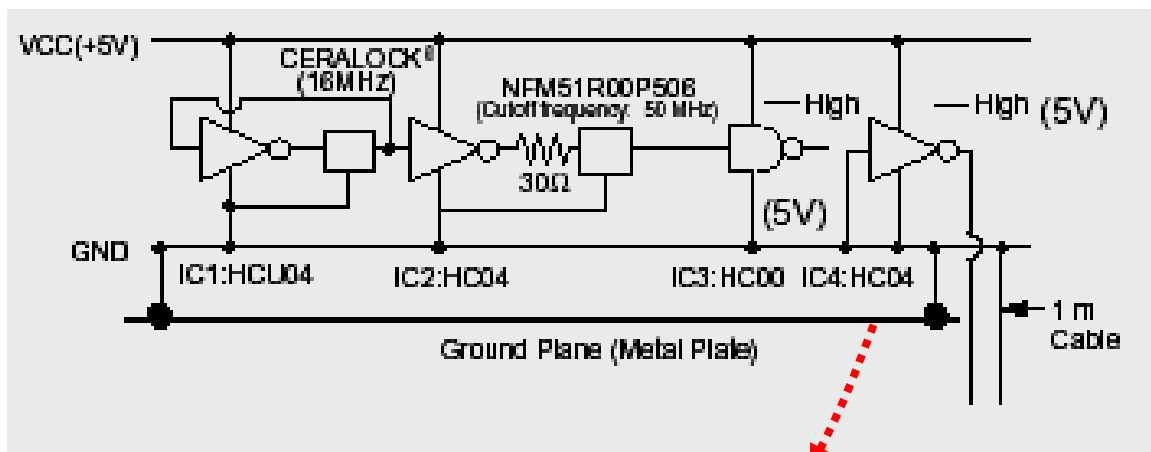
$$E = 1.26 I L f / D$$



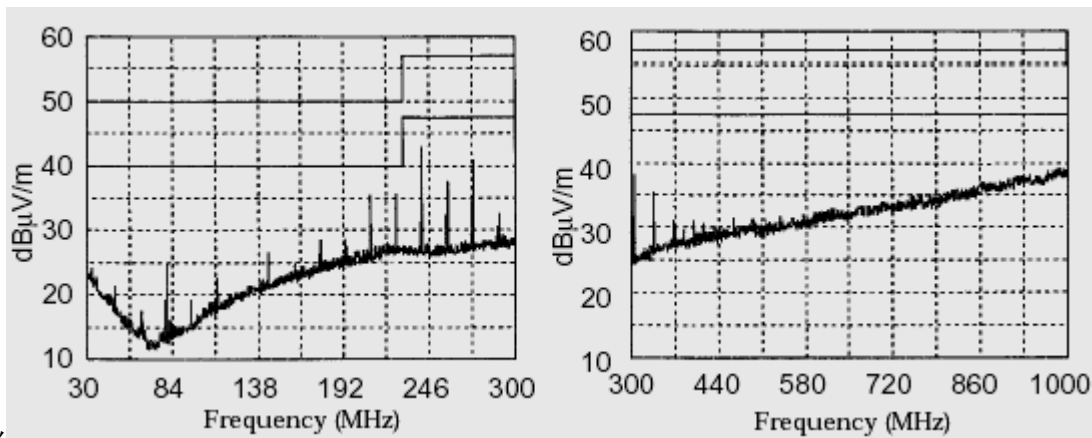
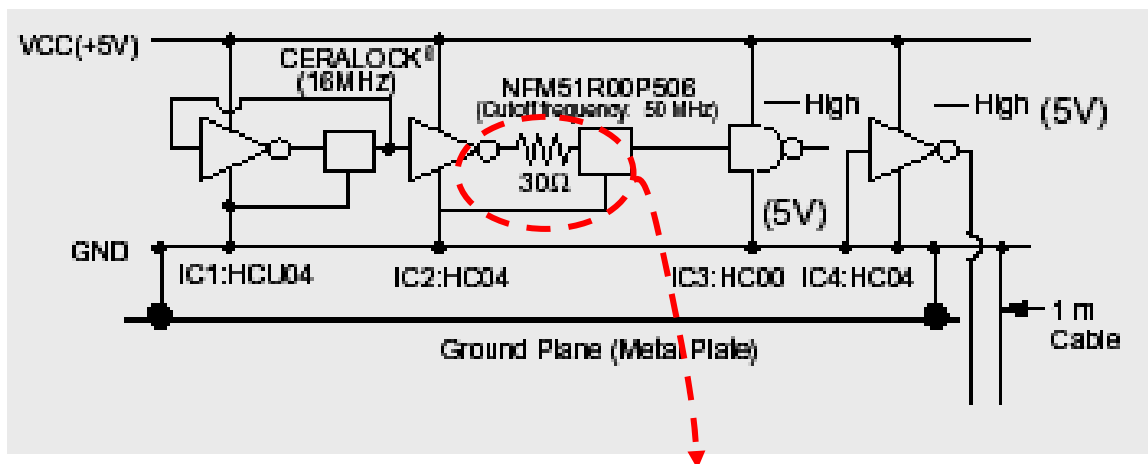
实验电路的辐射



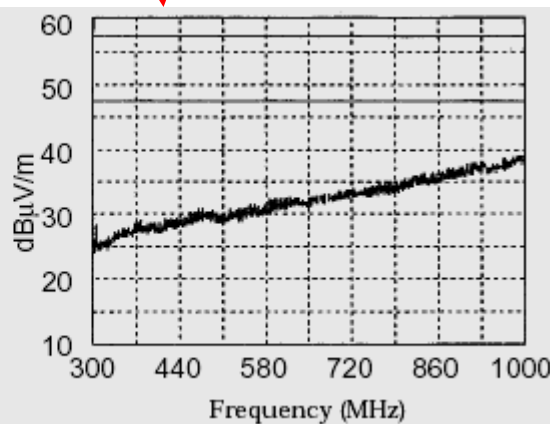
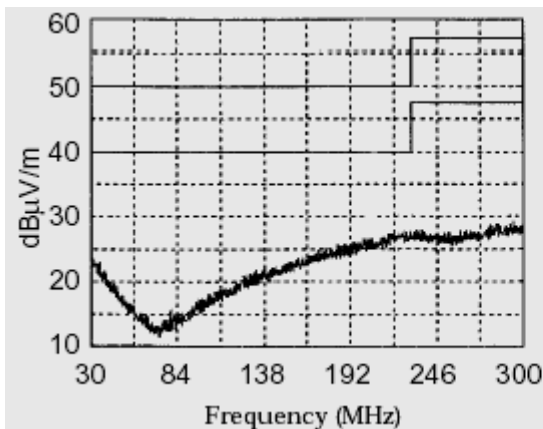
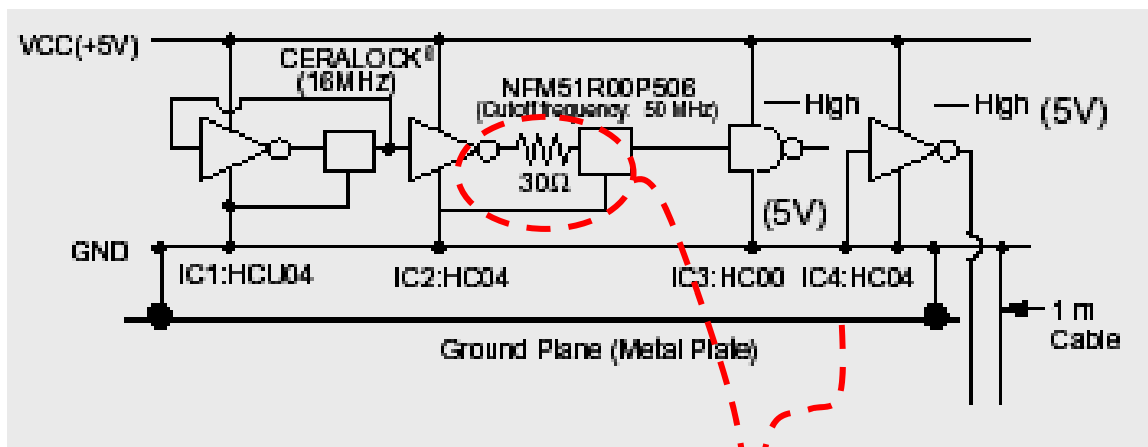
改善地线减小共模电压



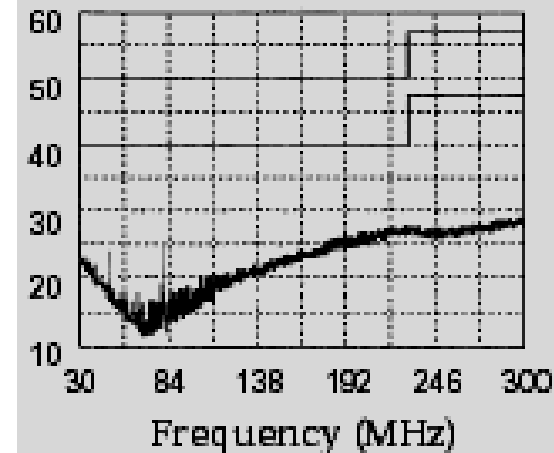
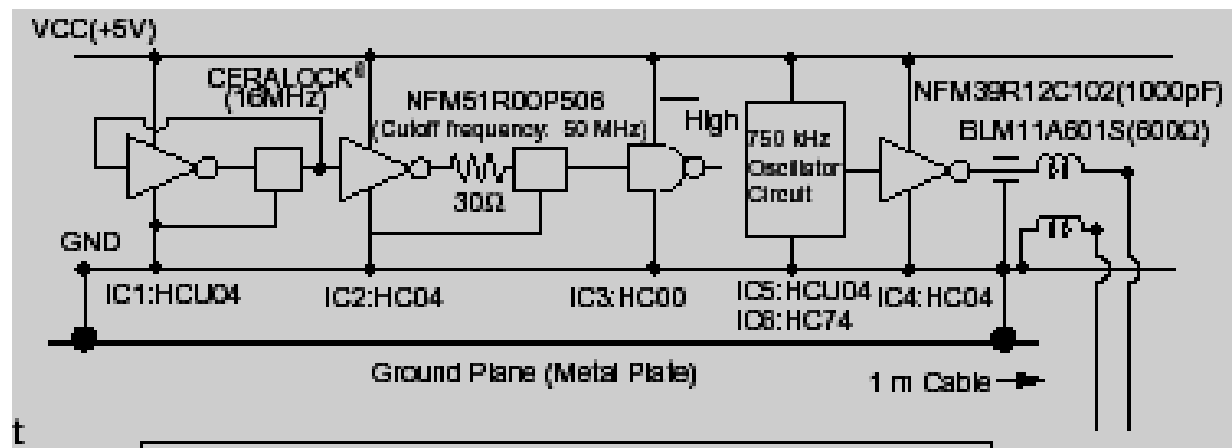
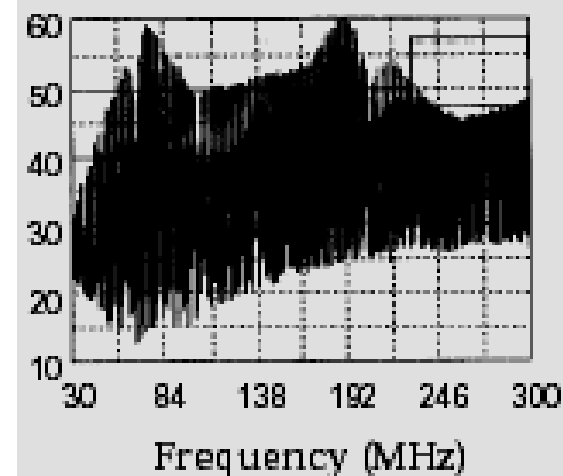
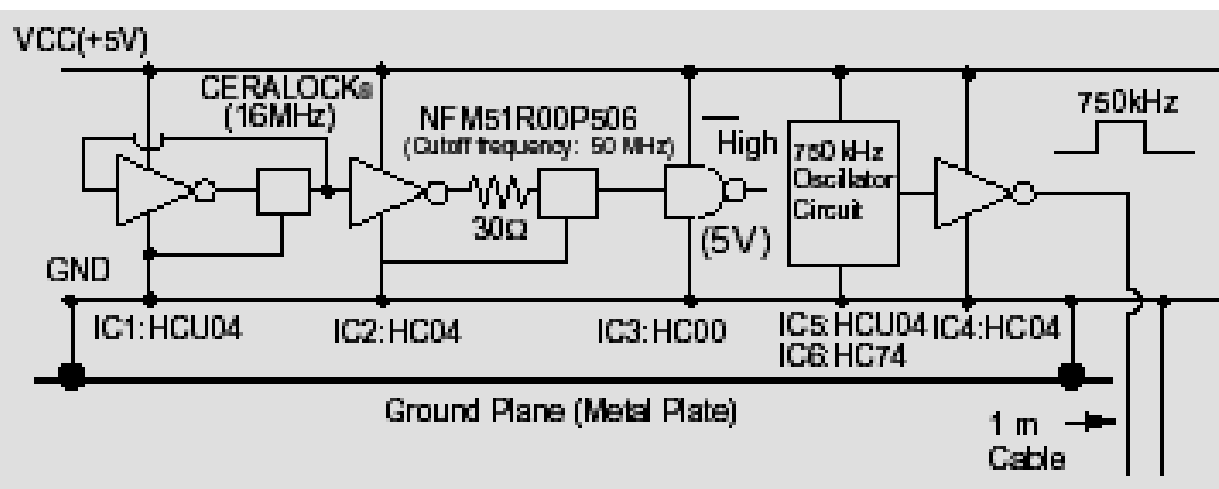
减小空间感应的共模电压



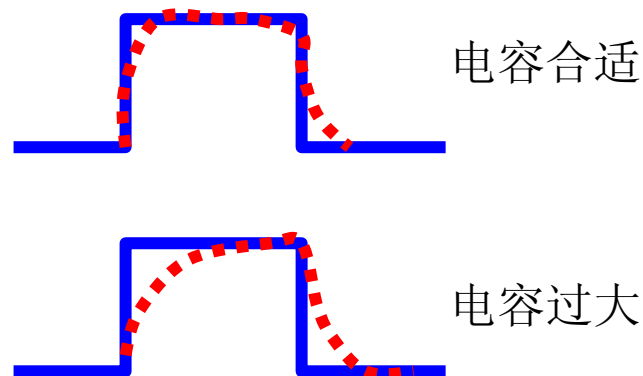
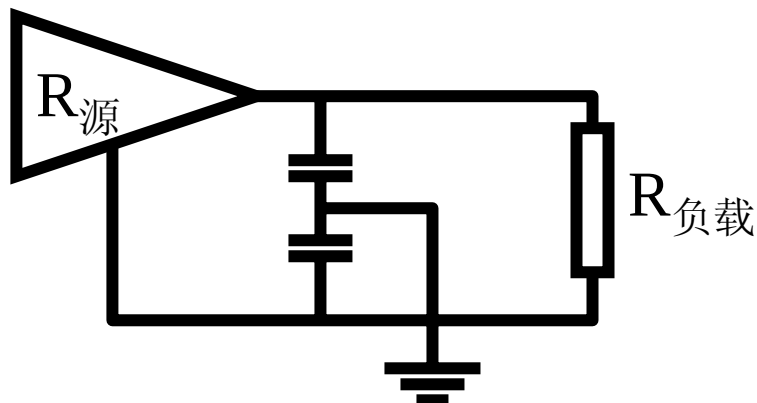
两个措施同时采取



滤波器滤除高频成份

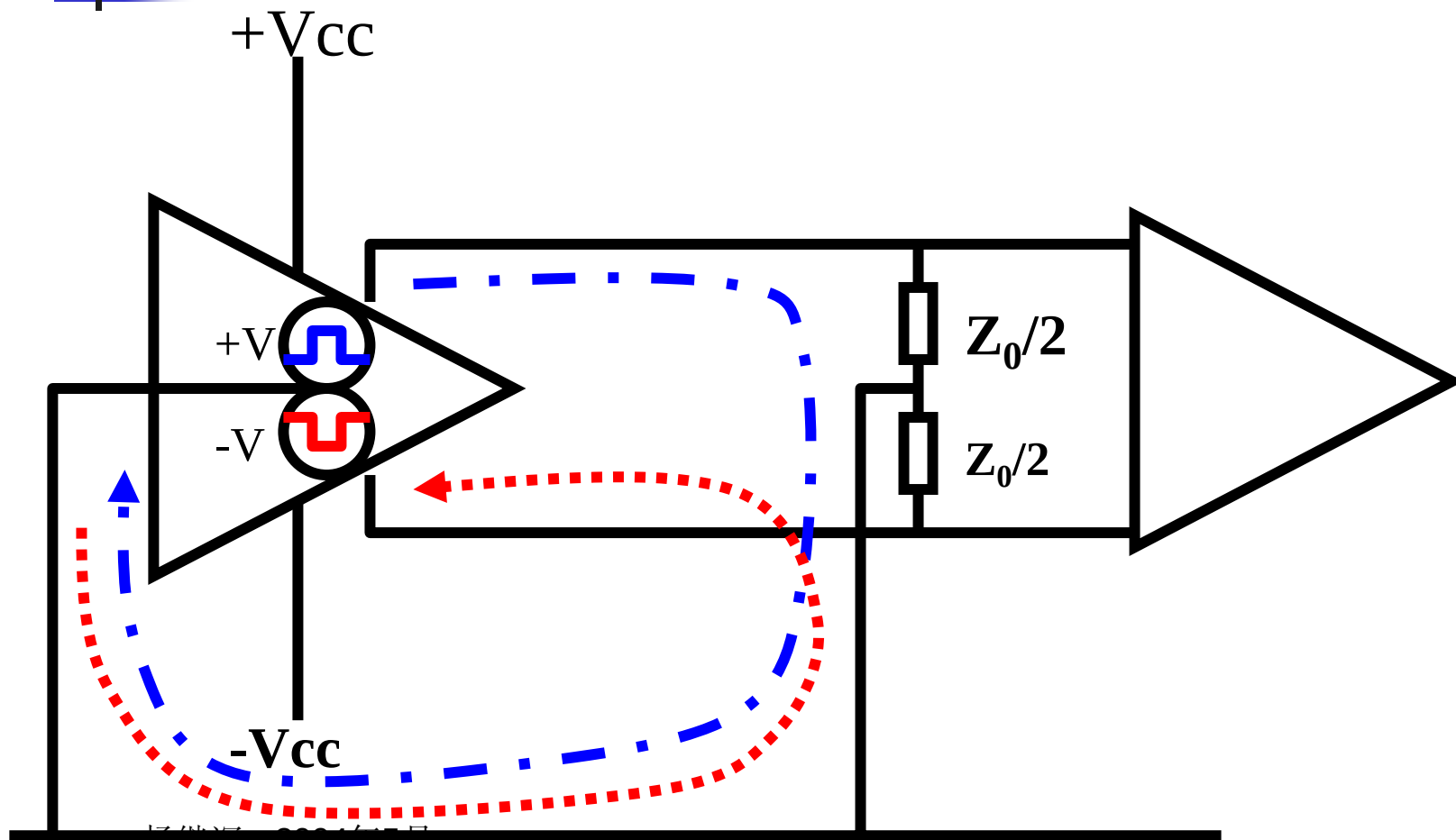


滤波器电容量的选择

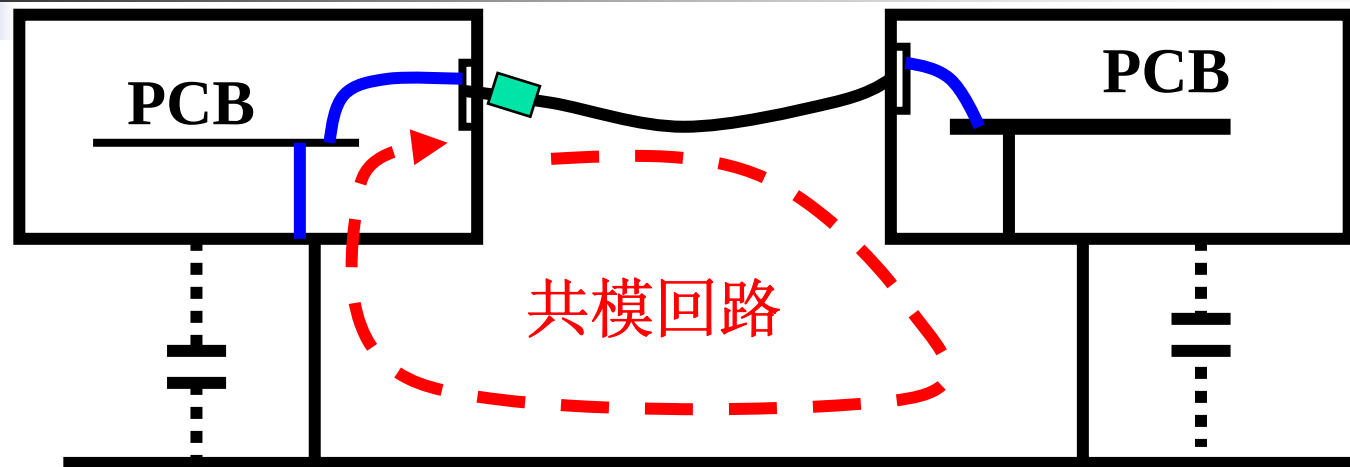


	低速接口 10 ~ 100kB/s	高速接口 2MB/s	低速CMOS	TTL
上升时间 t_r	0.5~1 μ s	50ns	100ns	10ns
带宽 BW	320kHz	6MHz	3.2MHz	32MHz
总阻抗 R	120 Ω	100 Ω	300 Ω	100~150 Ω
最大电容 C	2400pF	150pF	100pF	30pF

平衡接口电路

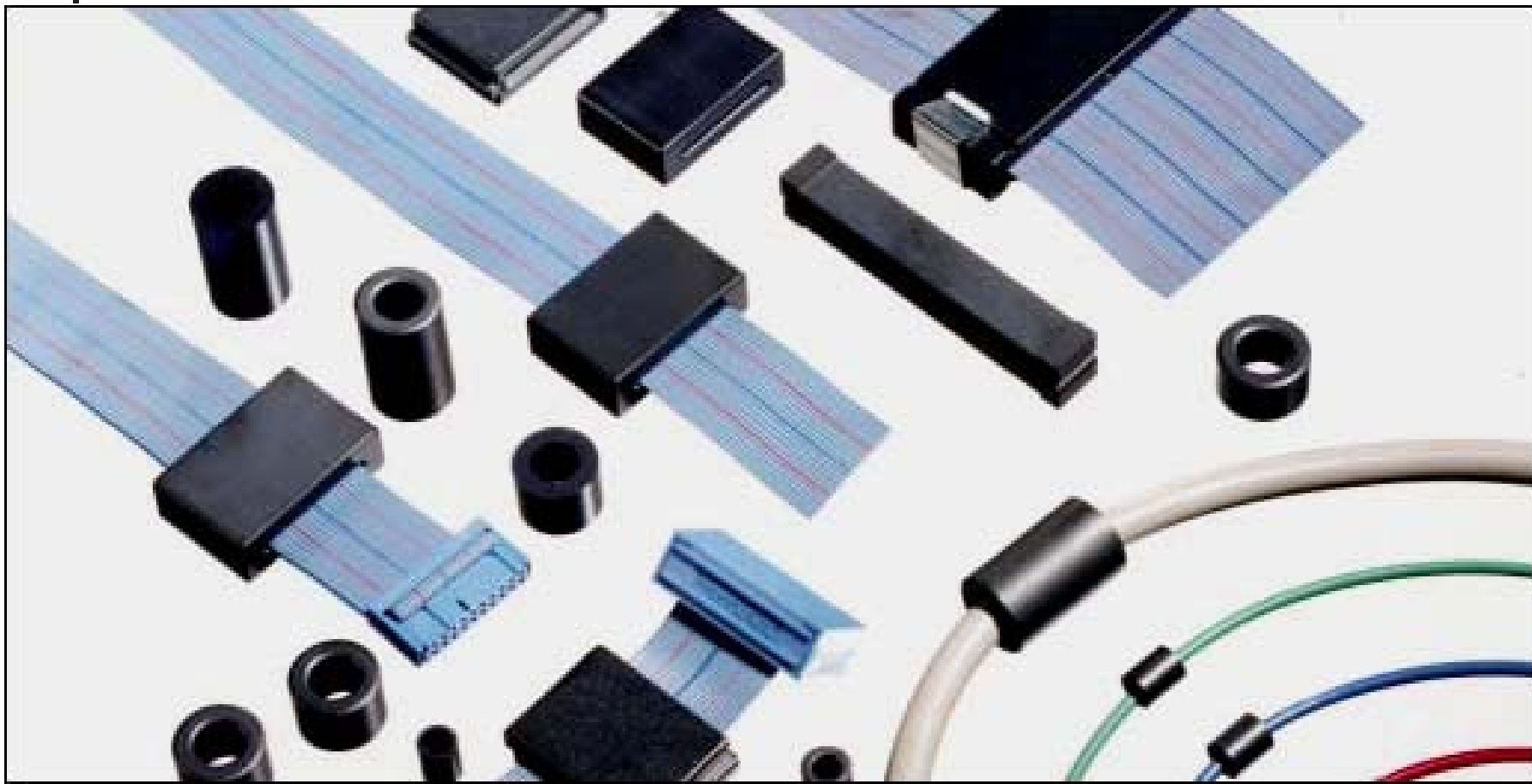


增加共模回路的阻抗



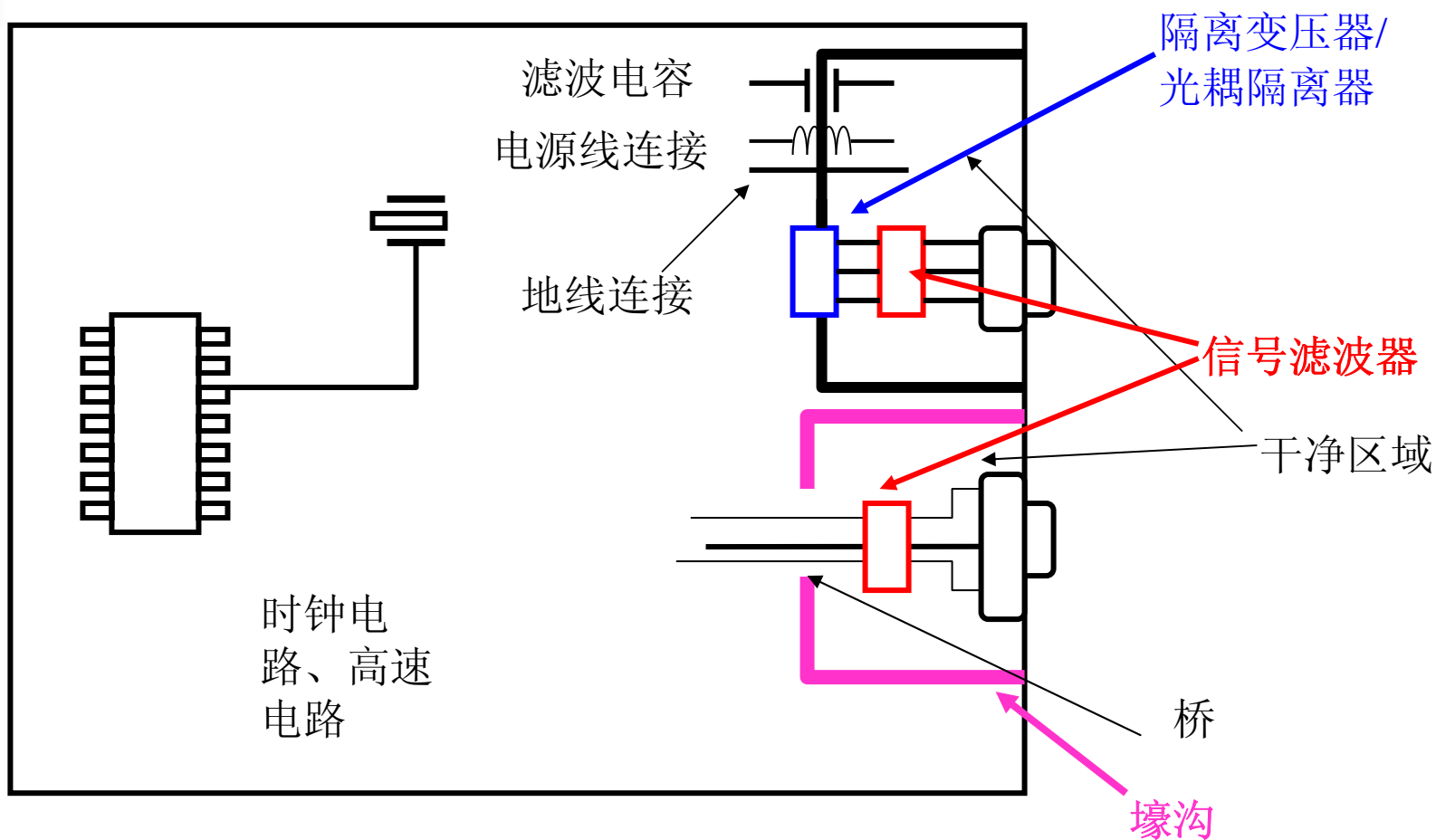
$$\begin{aligned}\text{改善量} &= 20\lg(E_1 / E_2) = 20\lg(I_{CM1} / I_{CM2}) \\ &= 20\lg[(V_{CM} / Z_{CM1}) / (V_{CM} / Z_{CM2})] \\ &= 20\lg(Z_{CM2} / Z_{CM1}) \\ &= 20\lg(1 + Z_L / Z_{CM1}) \quad \text{dB}\end{aligned}$$

铁氧体磁环

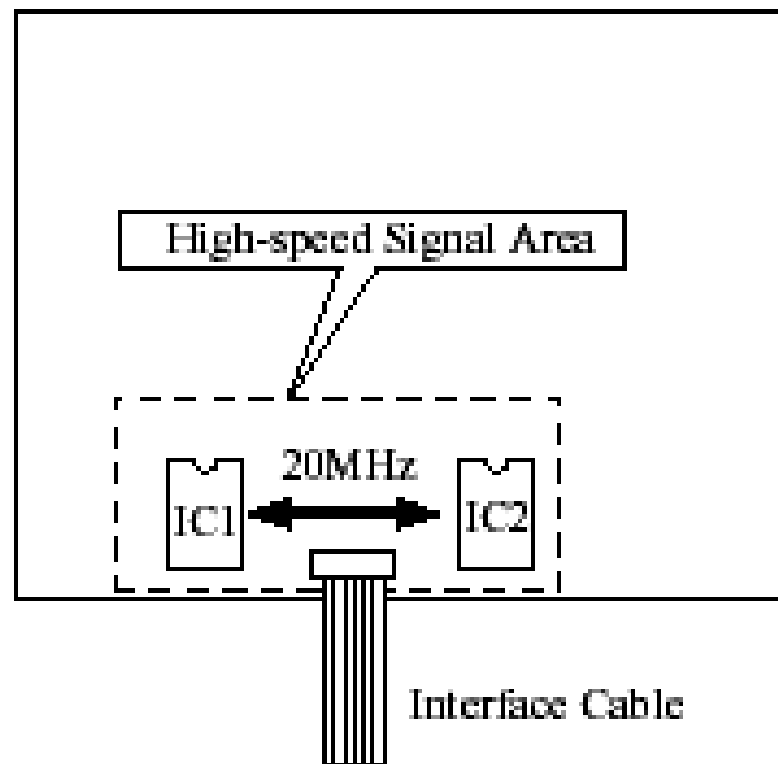
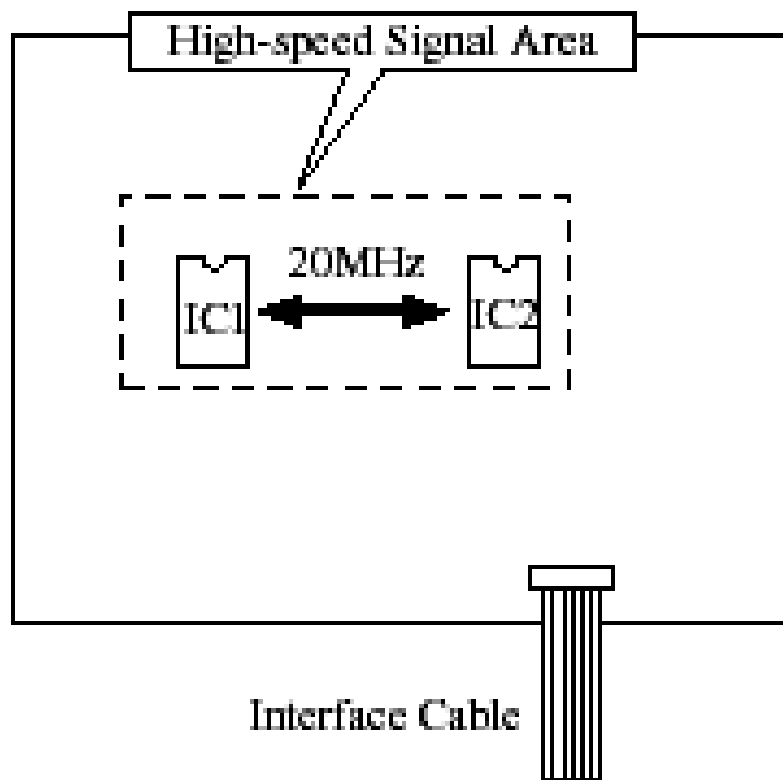


物磁环 2004年5月
电话: 010-68386283

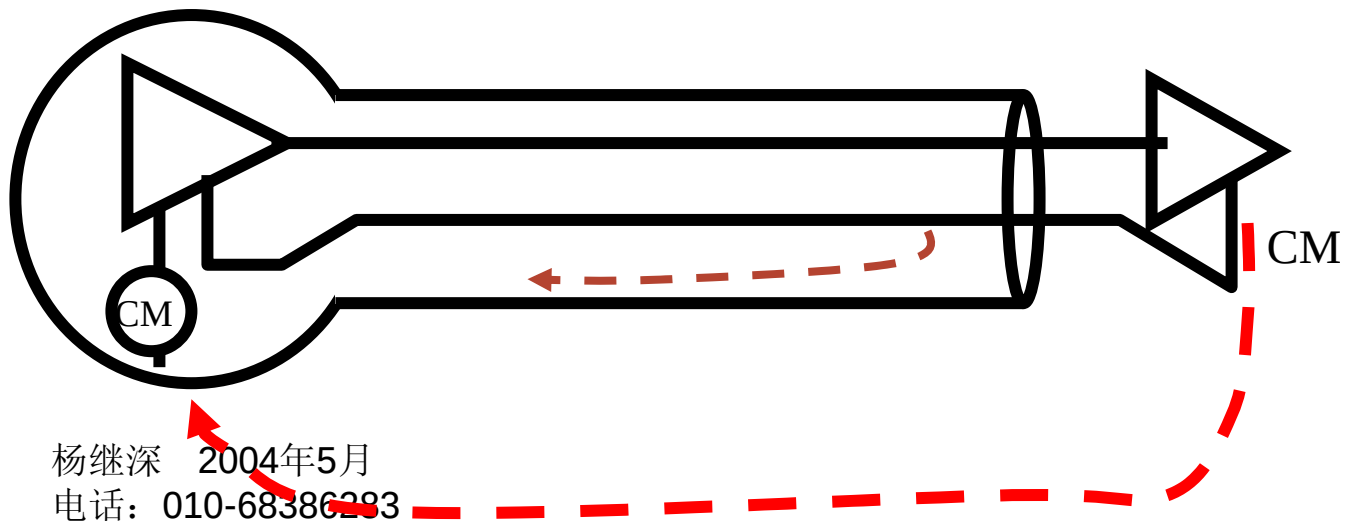
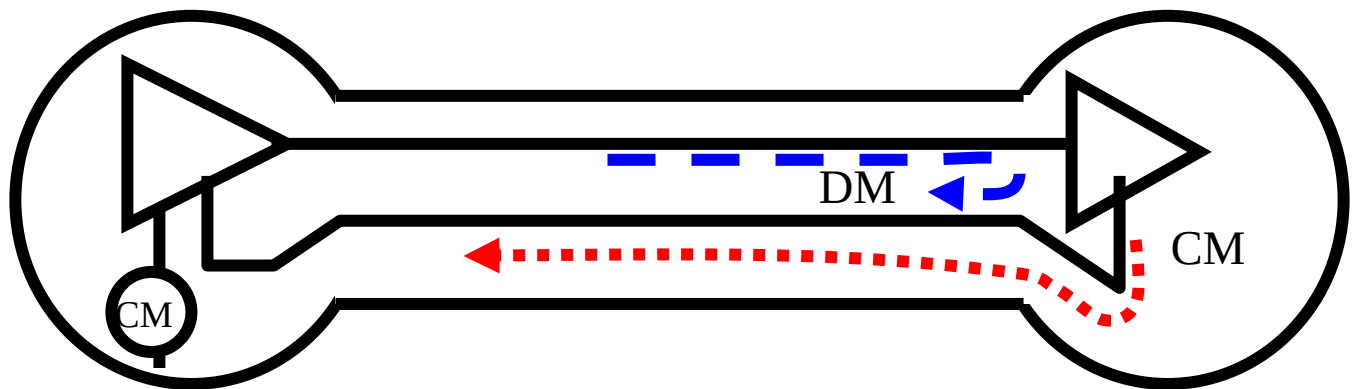
I/O接口布线的一些要点



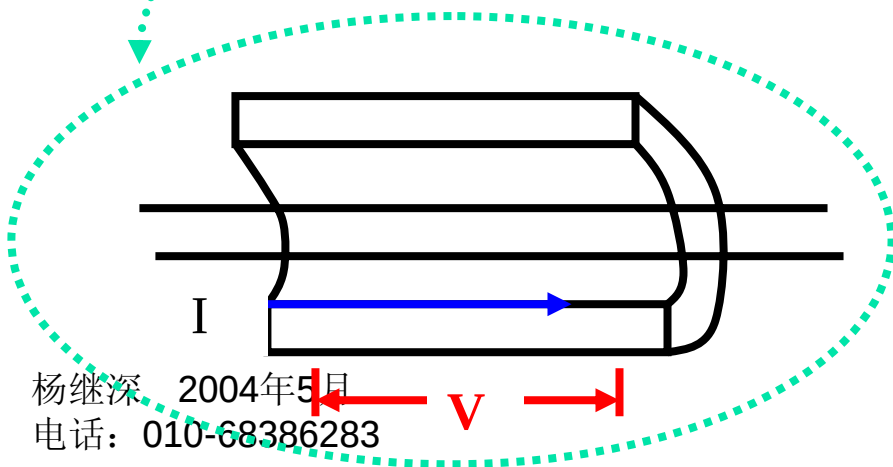
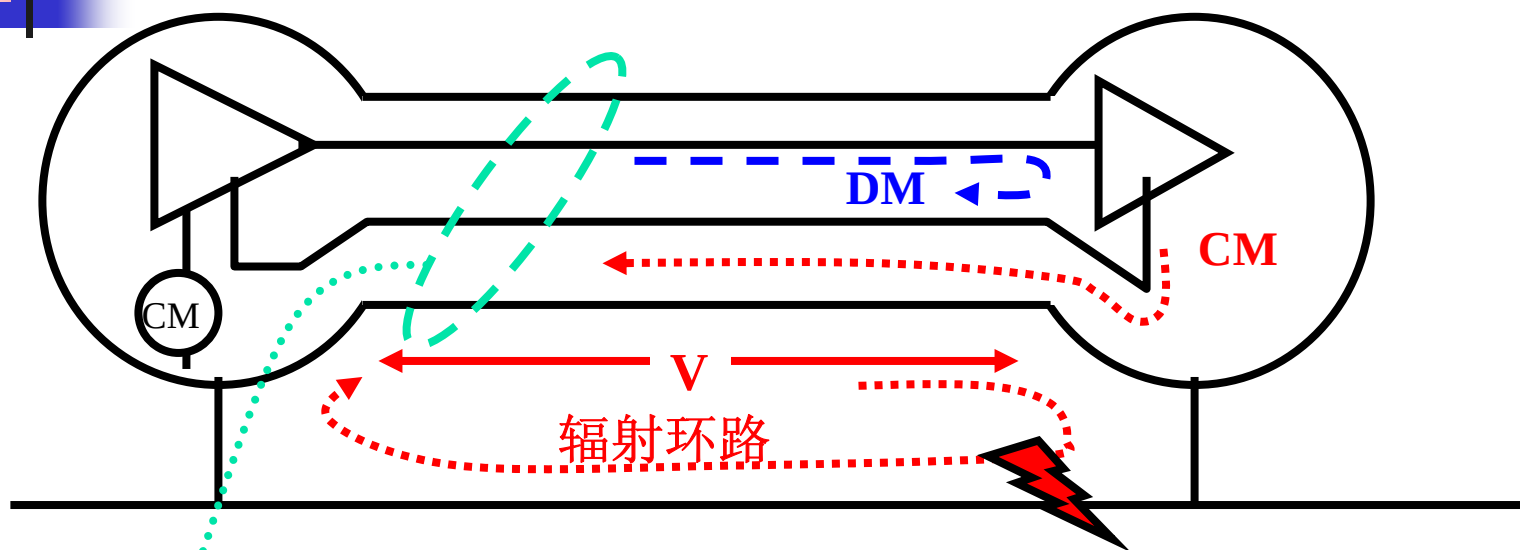
时钟信号远离电缆接口



用屏蔽电缆抑制共模辐射

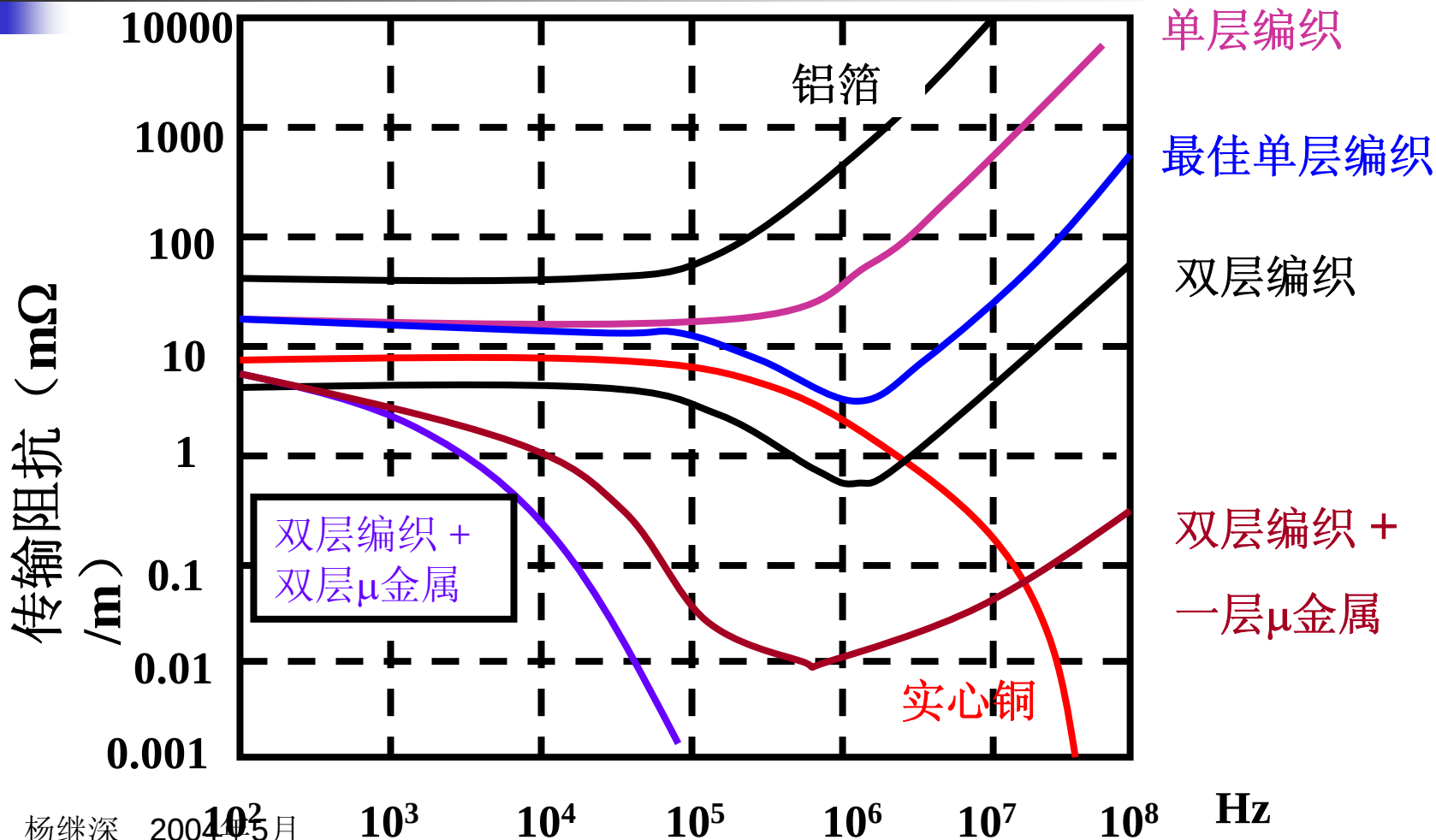


屏蔽电缆的评估

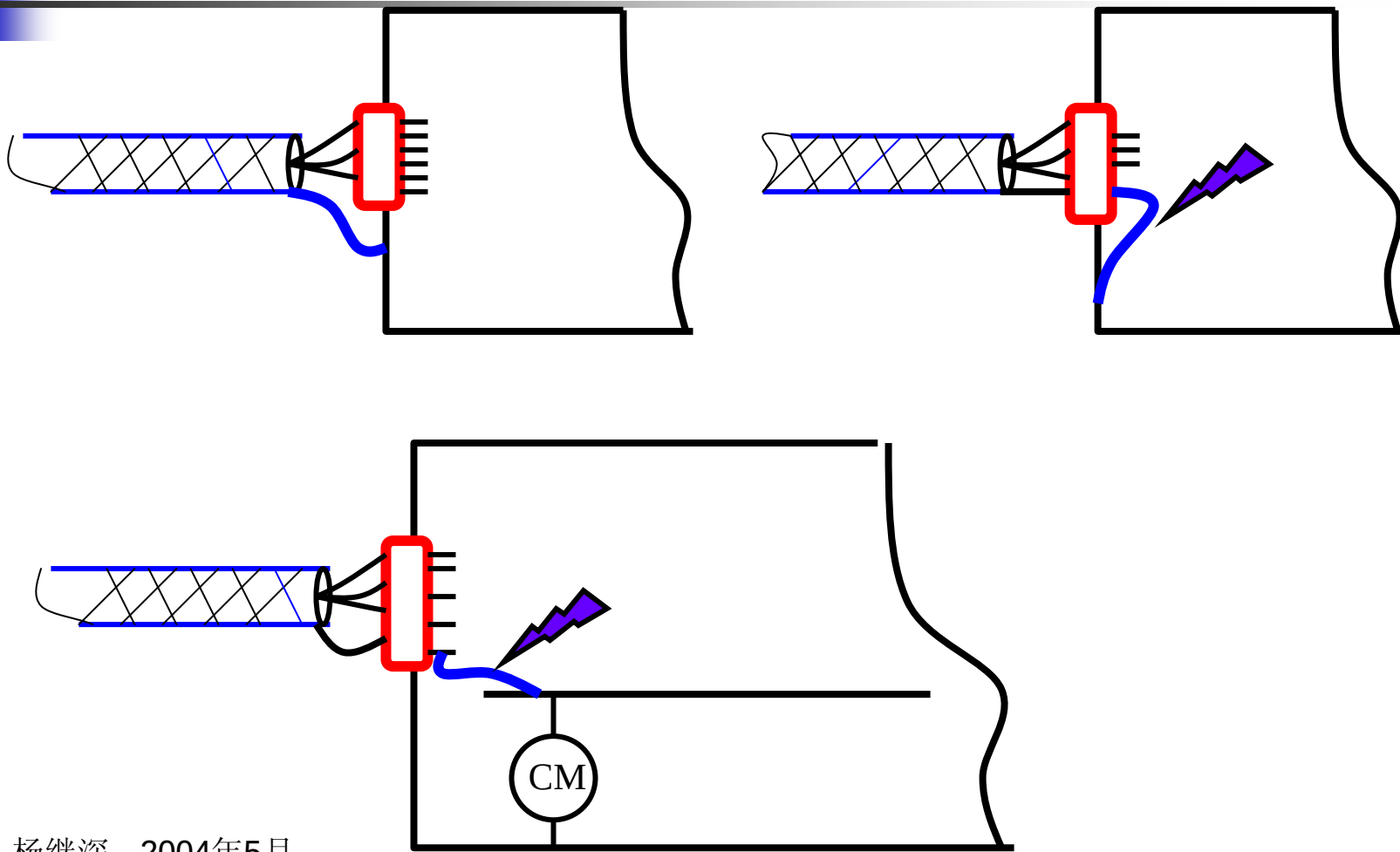


$$Z_T = V / I$$

不同屏蔽层的传输阻抗

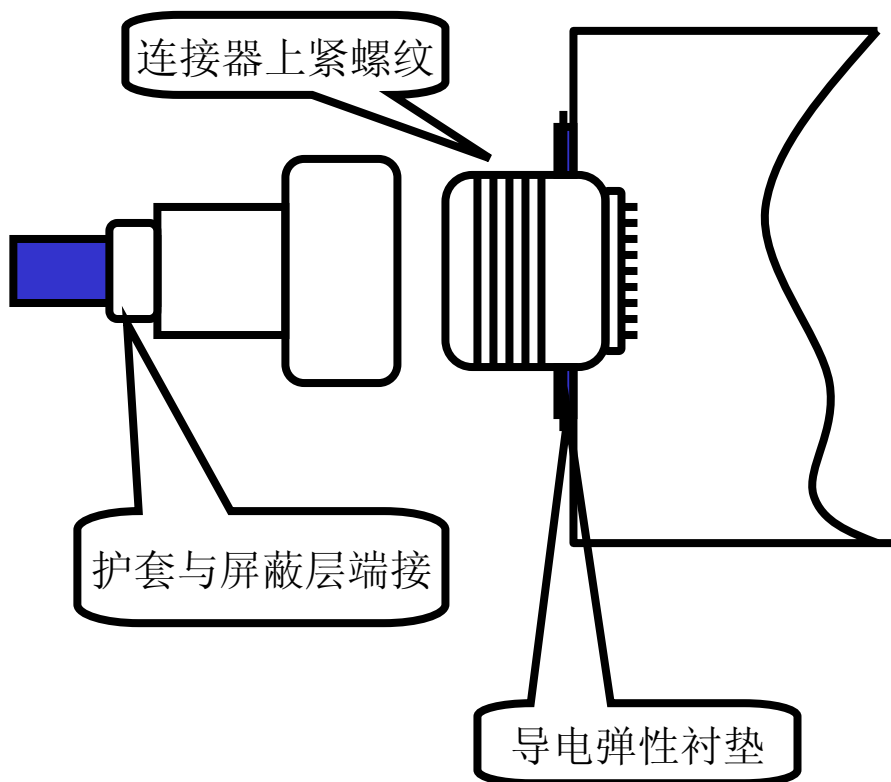


屏蔽层的错误接法

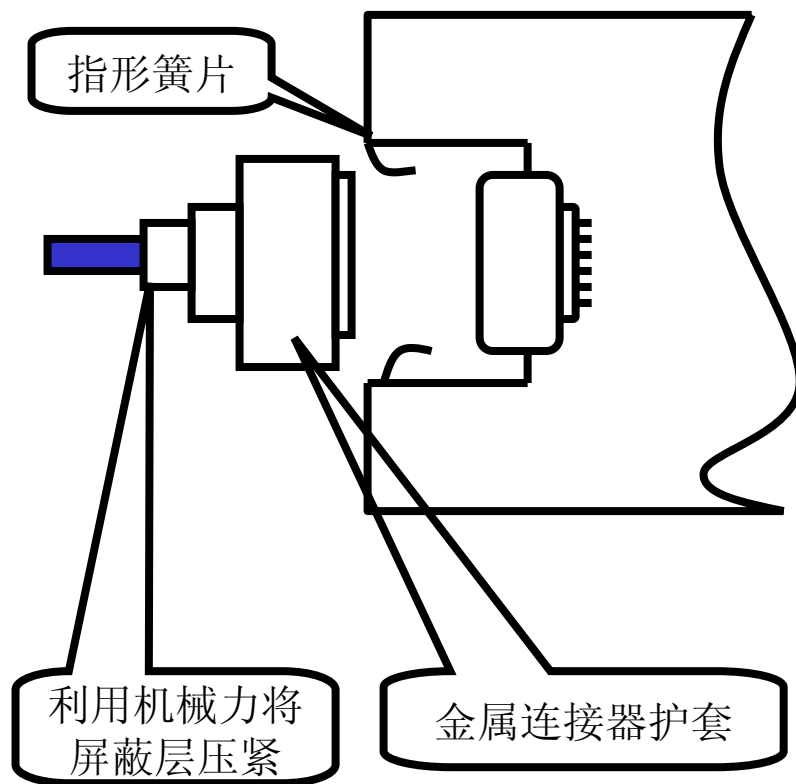


电缆屏蔽层的正确端接

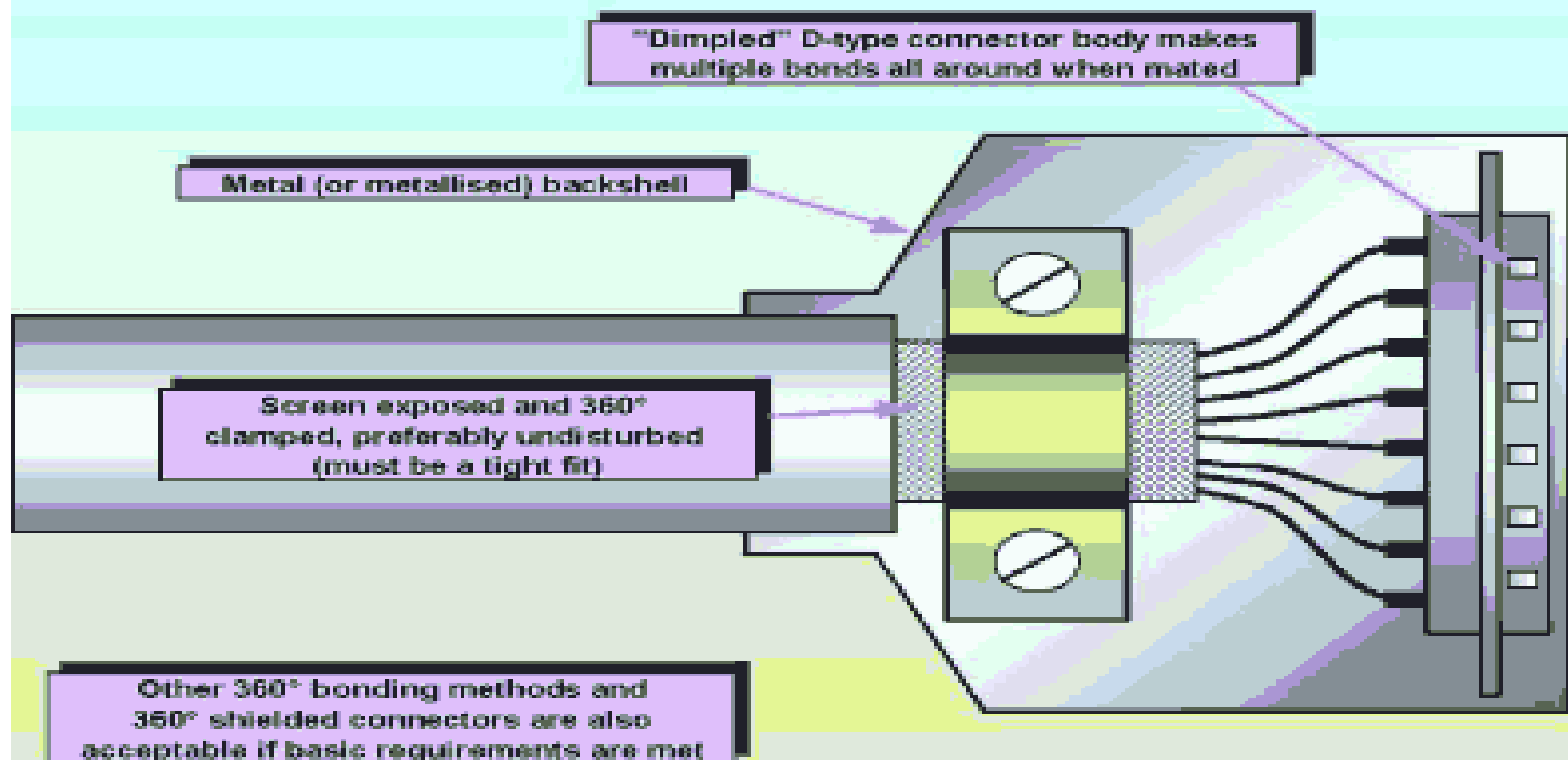
航空连接器



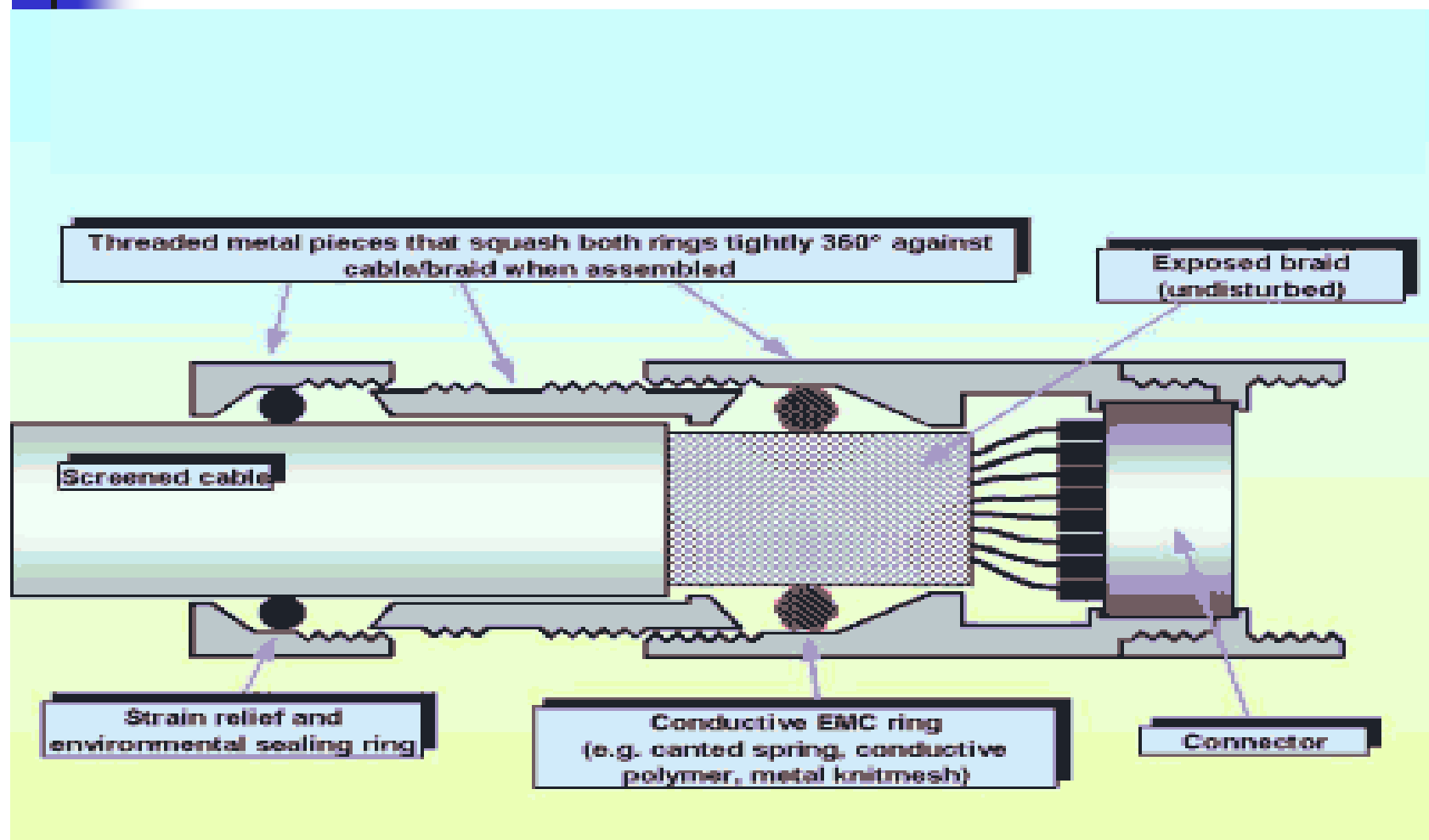
D形连接器



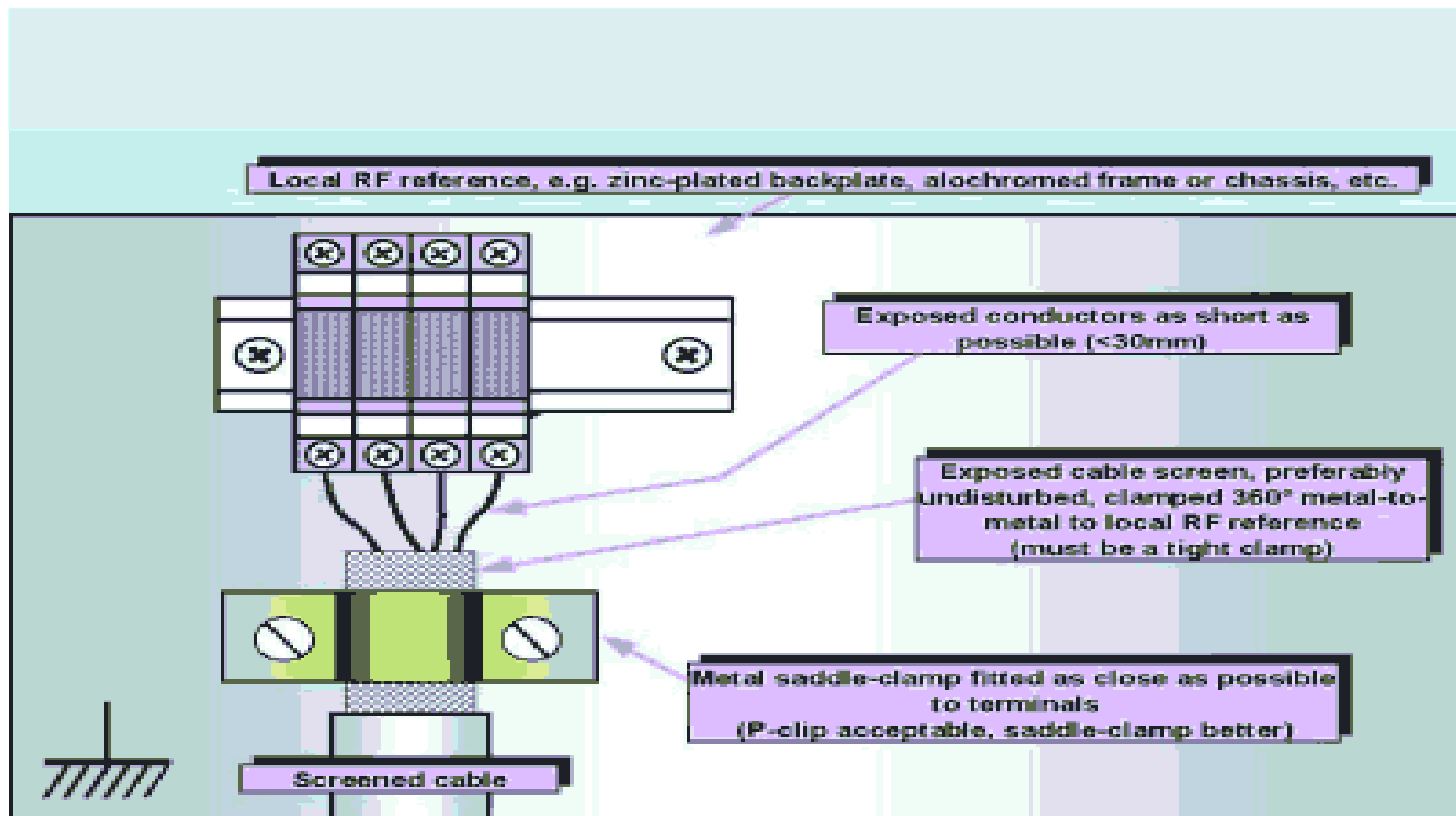
D型连接器的屏蔽层搭接

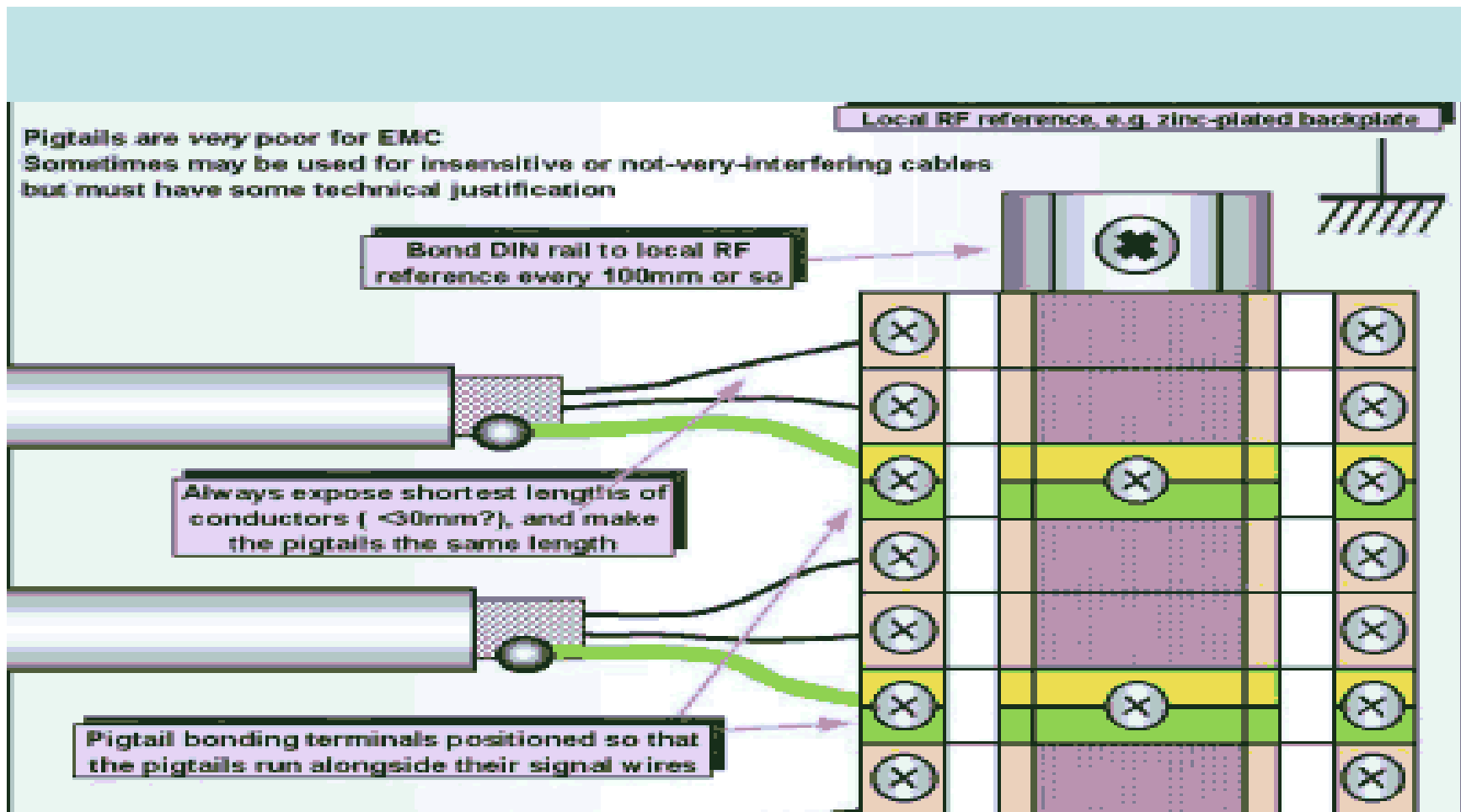


圆形连接器屏蔽层搭接



接线端子上的屏蔽电缆





线路板上的局部屏蔽

