



InterOcean EMC Technology Corp.

EM干擾探討及認證測試

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宇海科技股份有限公司

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InterOcean EMC Technology Corp.



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- 無線產品之EMC測試認證
- EMI耦合探討
- 『 di/dt 』電流路徑觀察



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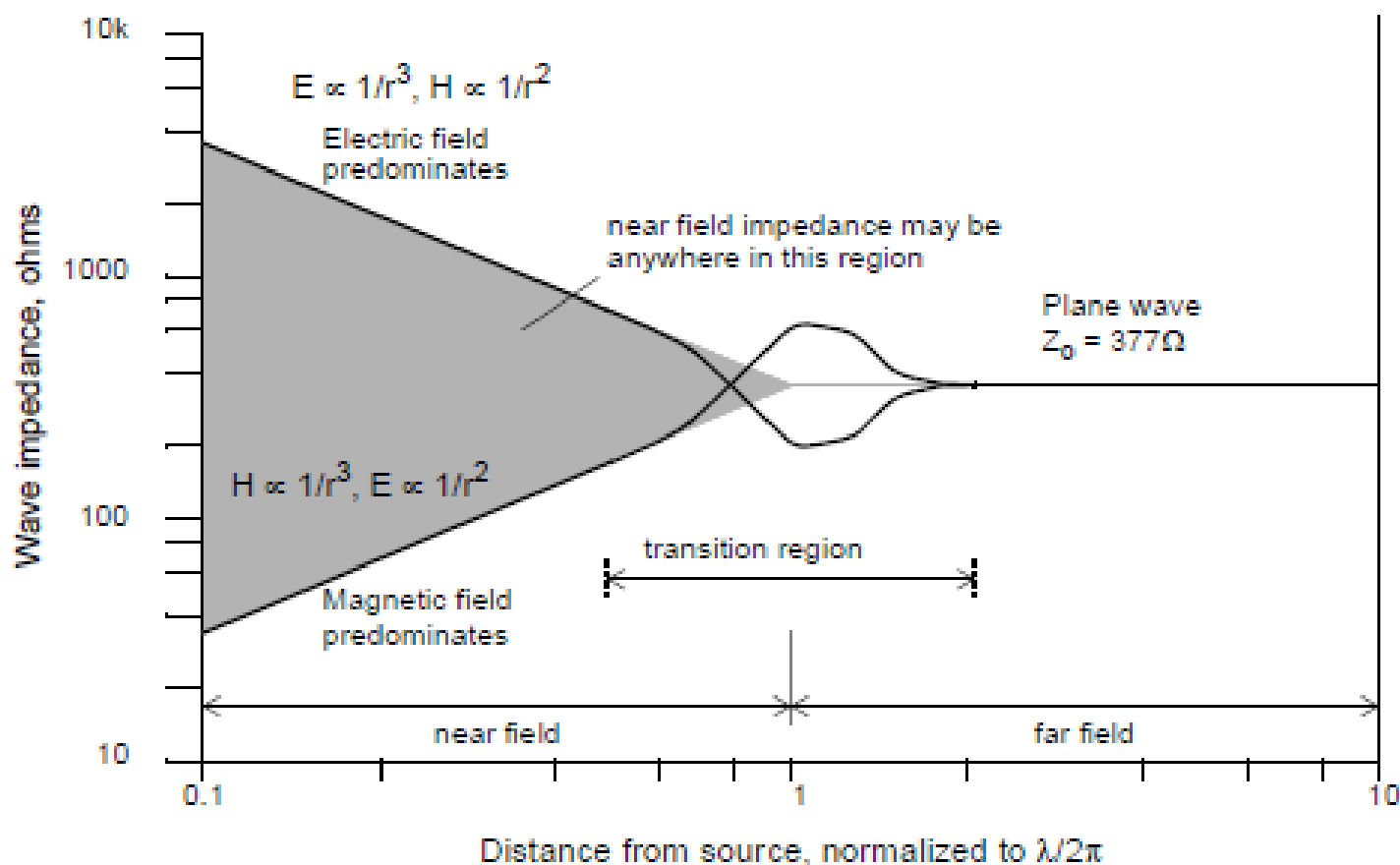
- 無線產品之**EMC**測試



電波阻抗 $Z = \frac{E_0^-}{H_0^-} = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}} = \sqrt{\frac{\mu}{\epsilon}}$

In free space, $\mu = 4\pi \times 10^{-7}$ H/m $\epsilon \approx 8.854 \times 10^{-12}$ F/m

$$Z_0 \approx 377 \Omega \approx 120\pi \Omega$$





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遠場距離定義

Frequency	Maximum dimension D (m)	Maxwell $l = \lambda/2\pi$ (m)
10MHz	1	4.77
	3	
30MHz	1	1.59
	3	
100MHz	0.3	0.477
	1	
	3	
300MHz	0.3	0.159
	1	
1GHz	0.3	0.0477
	1	

By JT Chen



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Bluetooth 規格簡介

- FHSS
- GFSK, $\pi/4$ DQPSK, 8 DPSK
- 2402MHz ~ 2480MHz
- 79 channels
- EDR (enhance data rate)





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Wi-Fi 產品規格簡介

- DSSS, OFDM
- DBPSK, DQPSK, CCK, BPSK, QPSK, 16QAM, 64QAM



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802.11b/g/n 使用頻帶

802.11b	Freq.(MHz)	Channel No.
CE	2412~2472	Ch1~Ch13
Japan	2412~2472, 2484~2497	Ch1~Ch13, Ch14
FCC / IC / NCC	2412~2462	Ch1~Ch11
802.11g/ 11n(20MHz)	Freq.(MHz)	Channel No.
CE / Japan	2412~2472	Ch1~Ch13
FCC / IC / NCC	2412~2462	Ch1~Ch11
802.11n(40MHz)	Freq.(MHz)	Channel No.
CE / Japan	2422~2462	Ch3~Ch11
FCC / IC / NCC	2422~2452	Ch3~Ch9

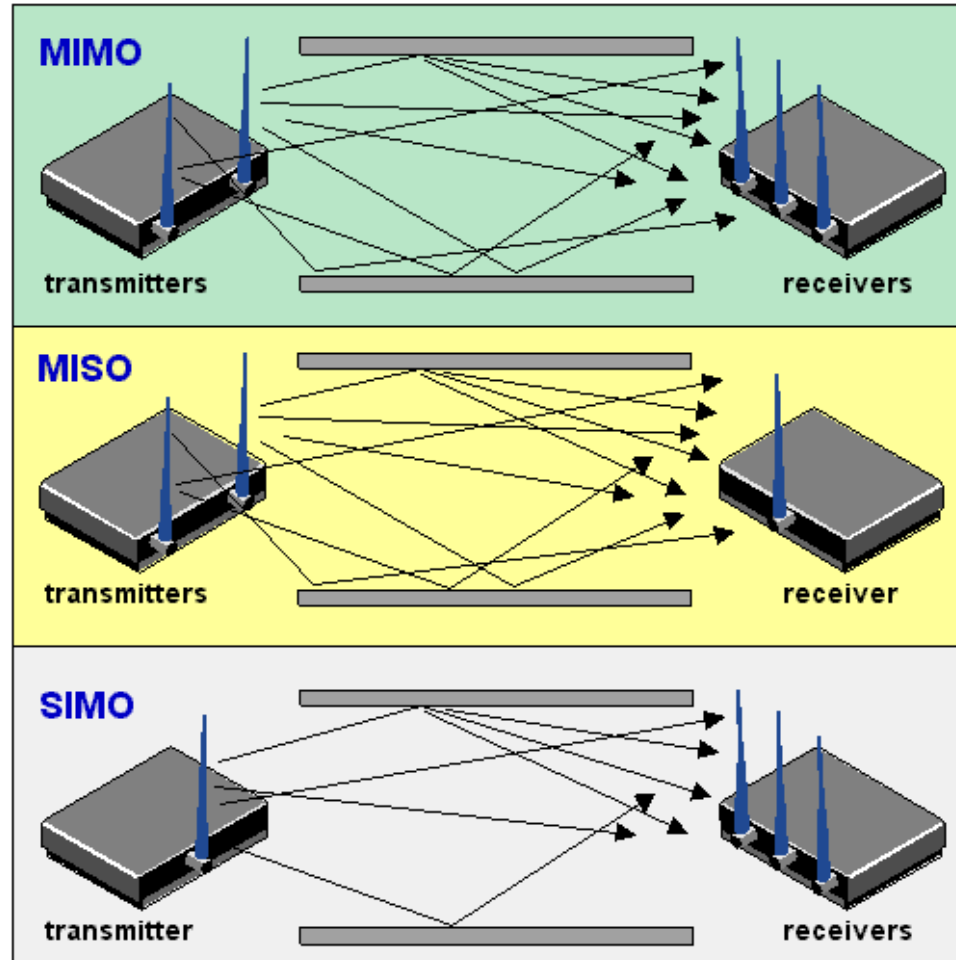


802.11a 使用頻帶

Freq. (MHz)	5150~5250	5250~5350	5470-5725	5725~5825
CE	○	○	○	×
Japan	○	○	○	×
FCC/IC	○	○	○	○
NCC	×	○	○	○



What is MIMO ?



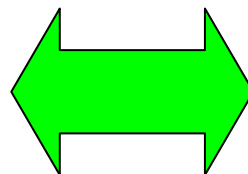
MIMO: Multiple-input multiple-output

By JH Chen



Test Mode 評估

- 802.11b
- 802.11g
- 802.11a
- 802.11n 20MHz BW
- 802.11n 40MHz BW



- Single Tx
- Dual Tx
- Triple Tx
- ⋮





Test case for conducted item

Example: 802.11a/b/g/n 2Tx MIMO WLAN device (FCC)

Test Item:

- Power
- Power density
- Frequency Range
- Bandwidth
- Conducted spurious

Mode	Single Tx		Dual Tx
	Chain A	Chain B	Chain AB
802.11a CH149,157,165	Y	Y	N/A
802.11b CH01,06,11	Y	Y	N/A
802.11g CH01,06,11	Y	Y	N/A
802.11n (20MHz) @2.4GHz band CH01,06,11	Y	Y	●
802.11n (20MHz) @5.8GHz band CH149,157,165	Y	Y	●
802.11n (40MHz) @5.8GHz band CH151,159	Y	Y	●

● : Power , Power density need

Y : all test needed



Test case for Radiated Spurious

Example: 802.11a/b/g/n 2Tx MIMO WLAN device (FCC)

Mode	Single Tx		Dual Tx
	Chain A	Chain B	Chain AB
802.11a CH149,157,165	Y	Y	N/A
802.11b CH01,06,11	Y ●	Y ●	N/A
802.11g CH01,06,11	Y ●	Y ●	N/A
802.11n (20MHz) @2.4GHz band CH01,06,11	Y ●	Y ●	Y ●
802.11n (20MHz) @5.8GHz band CH149,157,165	Y	Y	Y
802.11n (40MHz) @5.8GHz band CH151,159	Y	Y	Y

Y : Spurious needed

● : Band Edge needed

By JT Chen



Test Standard

802.11 b/g/n and Bluetooth (2.4GHz)

- CE
ETSI EN 300 328
- FCC
FCC Part 15.247
- NCC
LP0002 3.10.1/ RTTE01
- Japan
ARIB STD-T66 (CH1~13)
RCR STD-33 (CH14)

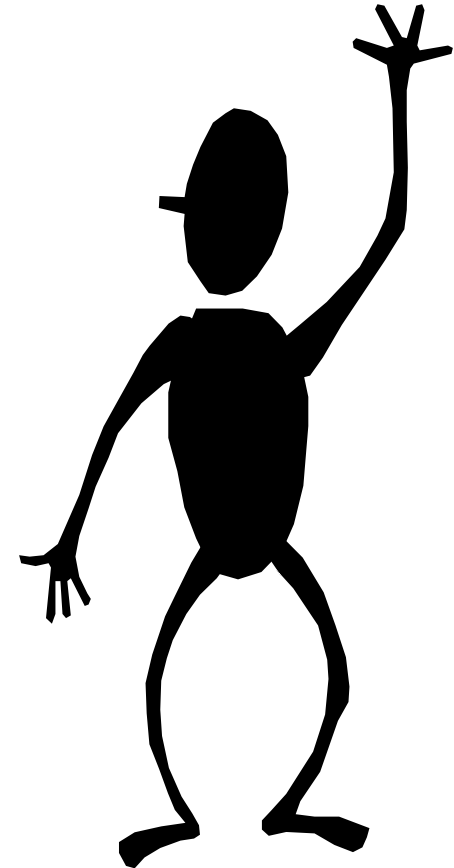
802.11a/n (5GHz)

- CE
ETSI EN 301 893
- FCC
FCC Part 15 subpart E
- NCC
LP0002 4.7
- Japan
ARIB STD-T71



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FCC 之認證





Types for FCC Certify

- FCC 2.902 Verification
- FCC 2.906 Declaration of Conformity
- FCC 2.907 Certification

[http://wireless.fcc.gov/index.htm?job=rules and regulations](http://wireless.fcc.gov/index.htm?job=rules_and_regulations)



Type of device	Equipment authorization required
TV broadcast receiver	Verification.
FM broadcast receiver	Verification.
CB receiver	Declaration of Conformity or Certification.
Superregenerative receiver	Declaration of Conformity or Certification.
Scanning receiver	Certification.
Radar detector	Certification.
All other receivers subject to part 15	Declaration of Conformity or Certification.
TV interface device	Declaration of Conformity or Certification.
Cable system terminal device	Declaration of Conformity.
Stand-alone cable input selector switch	Verification.
Class B personal computers and peripherals	Declaration of Conformity or Certification. ¹
CPU boards and internal power supplies used with Class B personal computers.	Declaration of Conformity or Certification. ¹
Class B personal computers assembled using authorized CPU boards or power supplies.	Declaration of Conformity.
Class B external switching power supplies	Verification.
Other Class B digital devices & peripherals	Verification.
Class A digital devices, peripherals & external switching power supplies.	Verification.
Access Broadband over Power Line (Access BPL)	Certification.
All other devices	Verification.



Building FCC ID

FCC ID: **AAAXXXXXXXXXXXXXXXXXX**

- Grantee Code (**AAA**): 3 characters only, unique code, assigned permanently by FCC
- Equipment product code (XXXXXXXXXXXXXXXXXX): **14 char max.**, Arabic numerals, capital letters or a combination thereof. May include the Dash or hyphen (-)



Permissive Change of FCC

2.1043

- **Class I**

No filing with the Commission is required for a Class I permissive change

- **Class II**

Class II permissive change shall be accepted by FCC

- **Class III**

Class III changes are permitted only for equipment in which no Class II changes have been made from the originally approved device





Organization of Part 15 Rules

- Rules Subpart A

All general rules including measurement procedures, label requirements, etc. are located in 15.xx

- Rules Subpart B

Specify all Unintentional Radiators

- All Intentional Radiators are located in the Subpart C (15.2xxsections) ;15D (unlicensed PCS), 15E (UNII) and 15F (UWB)

- 15G Access Broadband Over Power Line (Access BPL)



Intentional Radiator Requirements

- 15.203 Antenna Requirements
- 15.204 Amplifiers
- 15.205 Restricted Bands
- 15.207 Conducted Requirements
- 15.209 Radiated Requirements



Part 15C Intentional Radiators

- All Part 15 Intentional radiators must show compliance with Class B limits whenever out-of-band unless specifically excluded in the rules

FCC 15.207

FCC 15.209



15.203 Antenna Requirements

- An intentional radiator shall be designed to ensure that no antenna other than that furnished by the responsible party shall be used with the device.
- For Part 15E device, 802.11a, “integral antenna” requirement has been removed, but “unique connector” requirement remain



FCC module approval

- The device must be a complete RF transmitter
- Construction of Transmitter must meet conditions:
 - * It must be RF shielded
 - * It must have individual power regulator
 - * Data lines must be buffered
 - * Built-in antenna
 - * The only connectors should be power supply and modulated data inputs.



FCC module approval

Must be tested independent

- RF module must be tested in host independent (outside of any host) or,
- Must be tested in stand-alone configuration (the module must not be inside another device during testing).
- Antenna must either be permanently attached or employ a “unique” antenna coupler



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Limited Modular Approval

- Limited Modular Approval (LMA) transmitters have been defined by FCC Public Notice DA 00-1407.

<F:\My Documents\FCC\Modular Approval Requirements DA-00-1407A1.pdf>



待測物需量測之頻率數

作業頻率範圍	待測頻率數	待測頻率在作業範圍內之位置
$\leq 1\text{MHz}$	1	Middle
1~10MHz	2	Low , High
$> 10\text{MHz}$	3	Low , Middle , High



FCC 15.33(a) (LP0002 5.14)

➤ Frequency range of radiated spurious measurement

Radiator operates frequency	Frequency range of radiated measurement
Below 10GHz	9kHz to 10 th harmonic or 40GHz , which is lower
10GHz ~ 30GHz	9kHz to 5 th harmonic or 100GHz , which is lower
above 30GHz	9kHz to 5 th harmonic or 200GHz , which is lower



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FCC 15.227 (LP0002 3.3)

- 工作頻率: 26.29至27.28 MHz
- Test Item:
 1. Fundamental field strength @ 3m \leq 80 dBuV/m
(average)
 2. Radiated spurious



FCC 15.231 (LP0002 3.4)

- 器材型式：間歇性或周期性(periodic)發射之器材
- 工作頻率: 40.66 - 40.70 MHz and above 70 MHz
- 此頻段限用於傳送控制訊號(ex:alarm systems, door openers, remote switches),但不得用於連續性傳輸
- Test Item:
 1. Fundamental field strength@ 3m (dependent on fundamental freq.)
 2. Radiated spurious
 3. 手動發射器須有一開關，按下此開關後5秒內自動停止發射
 4. 具自動控制裝置使每次發射時間少於5秒之週期性發射



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FCC 15.239 (LP0002 3.7)

- **工作頻率: 88至108 MHz**
- **Test Item:**
 1. **Fundamental field strength @ 3m \leq 48 dBuV/m (average)**
 2. **Radiated spurious**
 3. **Bandwidth < 200kHz**
 4. **The 200 kHz band shall lie wholly within the frequency range of 88-108 MHz.**



FCC 15.247 (LP0002 3.10.1)

FHSS

- Conduction
- Radiated spurious
- No. of hopping channel
- 20dB Bandwidth
- Carrier frequencies separation
- Dwell time (DH1, DH3, DH5)
- Maximum peak output power
- Band-edge
- Antenna requirement
- MPE/SAR

DSSS / OFDM

- Conduction
- Radiated spurious
- 6dB Bandwidth
- Maximum peak output power
- Peak power spectral density
- Band-edge
- Antenna requirement
- MPE/SAR



FCC 15.249 (LP0002 3.10.2)

- 工作頻率:

FCC: 902 - 928 MHz, 2400 - 2483.5 MHz, 5725 - 5875 MHz, and 24.0 - 24.25 GHz.

NCC: 2400 - 2483.5 MHz, 5725 - 5875 MHz and 24.0 – 24.25 GHz.

器材型式：

analog modulated

digital modulated (小功率產品)

Test Item:

1. Fundamental field strength @ 3m
2. Radiated spurious



FCC 15.407 (LP0002- 4.7)

工作頻率: (802.11a device)

5150-5250; 5250 – 5350; 5470-5725; and 5725-5825**MHz.**

26dB Bandwidth

- Peak output power
- Power Spectrum Density
- Peak excursion to average ratio
- Radiated emission (FCC 15.209)
- Band edge test
- Radiated spurious emission
- RF antenna conducted spurious emission
- AC Power Line Conducted Emission
- Dynamic Frequency Selection (DFS)
- MPE / SAR



FCC 15.205 Restricted band

only spurious emissions are permitted in any of the frequency bands listed below:

MHz	MHz	MHz	GHz
0.090 - 0.110	16.42 - 16.423	399.9 - 410	4.5 - 5.15
¹ 0.495 - 0.505	16.69475 - 16.69525	608 - 614	5.35 - 5.46
2.1735 - 2.1905	16.80425 - 16.80475	960 - 1240	7.25 - 7.75
4.125 - 4.128	25.5 - 25.67	1300 - 1427	8.025 - 8.5
4.17725 - 4.17775	37.5 - 38.25	1435 - 1626.5	9.0 - 9.2
4.20725 - 4.20775	73 - 74.6	1645.5 - 1646.5	9.3 - 9.5
6.215 - 6.218	74.8 - 75.2	1660 - 1710	10.6 - 12.7
6.26775 - 6.26825	108 - 121.94	1718.8 - 1722.2	13.25 - 13.4
6.31175 - 6.31225	123 - 138	2200 - 2300	14.47 - 14.5
8.291 - 8.294	149.9 - 150.05	2310 - 2390	15.35 - 16.2
8.362 - 8.366	156.52475 - 156.52525	2483.5 - 2500	17.7 - 21.4
8.37625 - 8.38675	156.7 - 156.9	2655 - 2900	22.01 - 23.12
8.41425 - 8.41475	162.0125 - 167.17	3260 - 3267	23.6 - 24.0
12.29 - 12.293	167.72 - 173.2	3332 - 3339	31.2 - 31.8
12.51975 - 12.52025	240 - 285	3345.8 - 3358	36.43 - 36.5
12.57675 - 12.57725	322 - 335.4	3600 - 4400	(²)
13.36 - 13.41			

the field strength of emissions appearing within these frequency bands shall not exceed the limits shown in Section 15.209



LP0002 2.7 Restricted band

頻率(兆赫)	頻率(兆赫)	頻率(兆赫)	頻率(兆赫)
0.090 - 0.110	37.475 - 38.275	1435.0 - 1626.5	8025.0 - 8500.0
0.490 - 0.510	73.500 - 75.400	1660.0 - 1755.0	9000.0 - 9200.0
2.172 - 2.198	108.00 - 138.00	1805.0 - 1850.0	9300.0 - 9500.0
3.013 - 3.033	149.90 - 150.05	2200.0 - 2300.0	10600 - 12700
4.115 - 4.198	156.70 - 156.90	2310.0 - 2390.0	13250 - 13400
5.670 - 5.690	162.01 - 167.17	2483.5 - 2500.0	14470 - 14500
6.200 - 6.300	167.72 - 173.20	2655.0 - 2900.0	15350 - 16200
8.230 - 8.400	240.00 - 285.00	3260.0 - 3267.0	17700 - 21400
12.265 - 12.600	322.00 - 335.40	3332.0 - 3339.0	22010 - 23120
13.340 - 13.430	399.90 - 410.00	3345.8 - 3358.0	23600 - 24000
14.965 - 15.020	608.00 - 614.00	3500.0 - 4400.0	31200 - 31800
16.700 - 16.755	825.00 - 915.00	4500.0 - 5250.0	36430 - 36500
19.965 - 20.020	935.00 - 1240.0	5350.0 - 5460.0	38600 以上
25.500 - 25.700	1300.0 - 1427.0	7250.0 - 7750.0	



SAR / MPE

- Mobile device – MPE evaluation
- Portable device – MPE evaluation or SAR testing

(SAR test threshold: $60/f(\text{GHz}) \text{ mW}$)

SAR: Specific Absorption Rate

MPE: Maximum Permissible Exposure

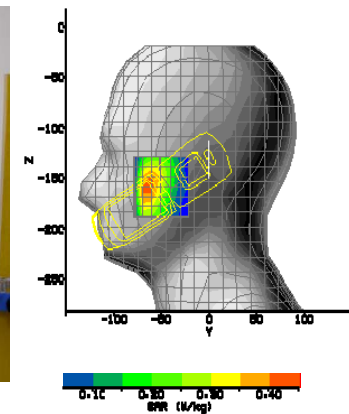
$S = PG / (4 \pi R^2)$ Where

S = Maximum power density (mW/cm^2)

P = Power input to the antenna (mW).

G = Numeric power gain of the antenna

R = Distance to the center of the radiation of the antenna (20cm = limit for MPE)





歐盟 R&TTE

- Article 3.1.a. LVD & RF Explosive
- Article 3.1.b. EMC
- Article 3.2 Radio Spectrum

<http://ec.europa.eu/enterprise/rtte/faq.htm>





R&TTE

- For wired and wireless telecommunications equipment

- Covers the following aspects:
 - Efficient use of spectrum
 - EMC
 - Safety

- Includes EMC and Low Voltage Requirements



Harmonized or Non-harmonized

- Harmonized standard + Harmonized frequency

CE mark



or CE mark + Notified body number (if obtain NB's opinion)

- Harmonized standard +  Non-harmonized frequency

CE mark + "alert" sign



or CE mark + Notified body number + "alert" sign



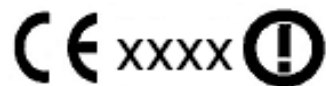


Harmonized or Non-harmonized (cont.)

- Non-harmonized standard + Harmonized frequency
CE mark + Notified body number



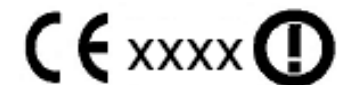
- Non-Harmonized standard + Non-harmonized frequency
CE mark + Notified body number + "alert" sign





Notified Body Opinion

- For new technologies WITHOUT harmonized standards
- Notified Body Opinion





Notification

- Applies to radio equipment using a non-harmonized frequency
- If non-harmonized frequency band, the manufacturer must determine if the frequency is available for use in a particular member state
- Notify each member state where the equipment is to be sold
- One-Stop-Notification (OSN)
 - <http://ec.europa.eu/enterprise/rtte/osn.htm>
 - <http://webgate.ec.europa.eu/enterprise-portal>
- Must be made 4 weeks prior to the equipment being offered to sale.



R&TTE EMC Requirement

- ETSI EN 301 489 series
 - Part 1: Common technical requirement on EMC)
 - Part 2 ~ Part 32: Harmonized standard for different type of radio equipment
 - Part 3: 9kHz - 40GHz Short Range Device (SRD)
 - Part 17: 2.4GHz & 5GHz Wideband transmission systems
 - Part 24: IMT-2000 CDMA Direct Spread (UTRA) for Mobile and portable (UE) radio equipment



ETSI EN 300 328

For 2.4GHz Device : Bluetooth, WLAN

- Maximum transmit Power
- Maximum e.i.r.p spectral density
- Frequency Range
- Transmitter spurious emissions
- Receiver spurious emissions



EN 301 893: 5GHz Radio LAN

- Carrier frequencies
- Nominal Channel Bandwidth and Occupied Channel Bandwidth
- RF output power, Transmit Power Control (TPC)
- Power density
- Transmitter unwanted emissions
 - outside the 5GHz RLAN bands
 - within the 5GHz RLAN bands
- Receiver spurious emissions
- Dynamic Frequency Selection (DFS)



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ETSI EN 300 220

Short Range devices (SRD) used in the range 25 MHz to 1000MHz; power level up to 500mW

(常見產品: 433.92MHz remote controller)

Part 1 : Technical requirement

Part 2 : Harmonized standard of R&TTE Directive



ETSI EN 300 220

Short Range devices (SRD) : 25MHz to 1GHz

Transmitter requirements

- Frequency error & frequency drift
- Frequency stability under low-voltage conditions
- Frequency deviation / Amplitude deep
- Carrier power (conducted)
- Effective radiated power
- Transient power
- Adjacent Channel power
- Modulation BW for wide band equipment (>200kHz)
- Spurious emissions
- Duty cycle
- Listen Before Talk (LBT)
- Types of spread spectrum modulation

Receiver requirements

- Maximum usable sensitivity (conducted)
- Receiver LBT threshold and transmitter max on-time
- Adjacent channel selectivity
- Blocking or desensitization
- Inter modulation response rejection
- Spurious response rejection
- Spurious radiations



ETSI EN 300 440

Short Range devices (SRD) : **1GHz to 40GHz**

- Equivalent isotropic radiated power (**EIRP**)
 - Permitted range of operating frequencies (Transmitter)
 - Radiated Spurious emission (Tx, Rx & Stand by)

<http://www.csgnetwork.com/antennaecalc.html>



ARIB STD-T66 and RCR STD-33 (2.4GHz)

- Frequency Tolerance
- Occupied Band Width
- Spread Band Width
- Output Power
- ERP
- Output Power Tolerance
- Spurious Emission
- Emitted RF wave Strength
- Dwell Time (for FHSS only)
- Carrier Sense



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ARIB STD-T71 (5GHz)

- Frequency Tolerance
- Occupied Band Width
- Spread Band Width
- Output Power
- EIRP
- Output Power Tolerance
- Spurious Emission
- Adjacent Channel Emitted Power
- Out-Band Leakage Power
- Emitted RF wave Strength
- Transmission Burst Length
- DFS/TPC/Carrier Sensing

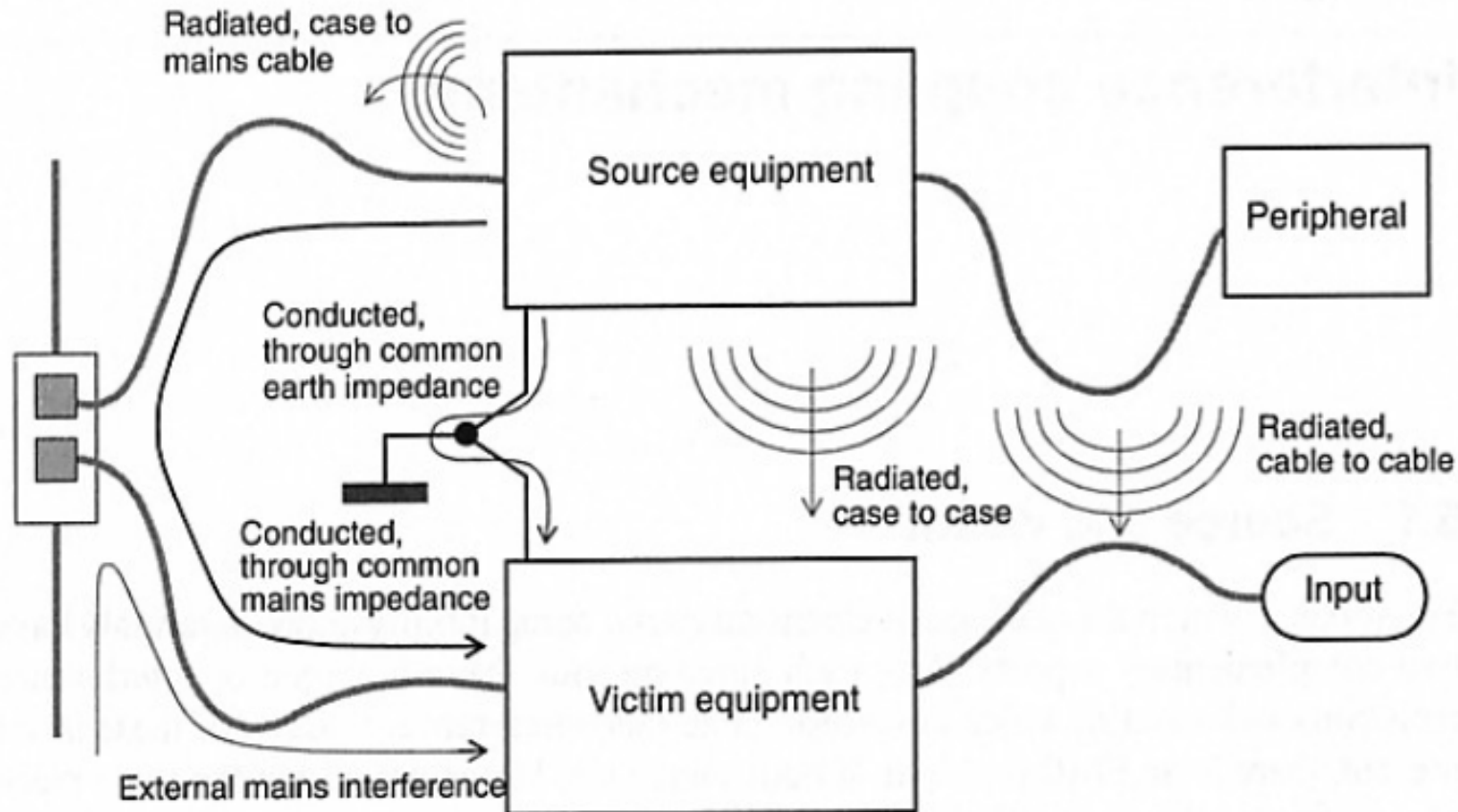


- 結語：
- 產品測試認證是上市前必須程序。
- **Design in**的觀念就是把測試可能出現的問題預先作防範設計。
- 在設計前先瞭解法規標準及測試要求，有助於產品設計過程及週期管控。



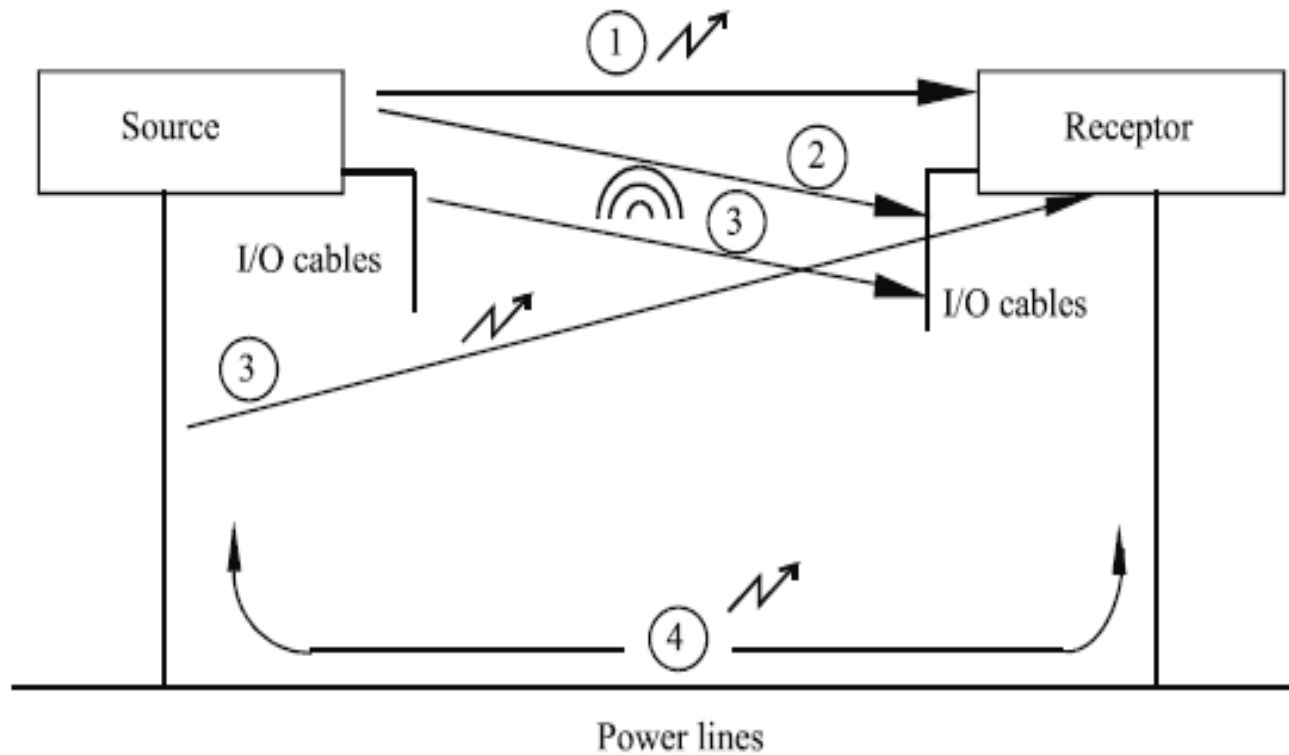
Coupling Path

- 耦合途徑（coupling path）：電磁能量從信號源傳到另一電路或裝置所經的途徑。



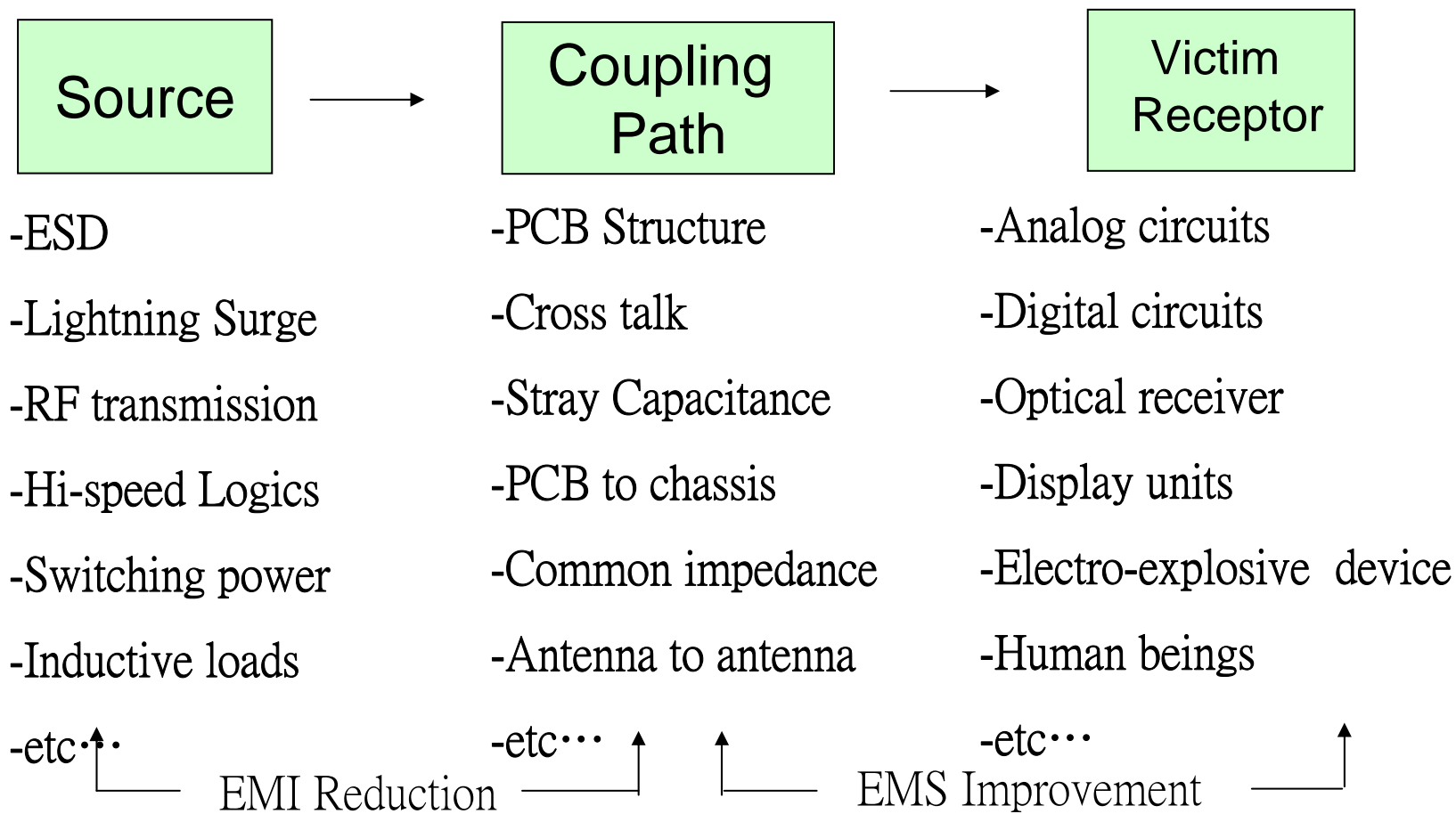


EMI干擾耦合路徑





電磁耦合機製





Coupling types

- **Conducted coupling** occurs when the source and receptor are connected via power or data cabling.
- **Inductive coupling** occurs across a magnetic field surrounding a conductor
- **Capacitive coupling** can occur across an electrostatic field surrounding conductors
- **Common impedance coupling** occurs when there is a shared wire or path between the source and the receiver.

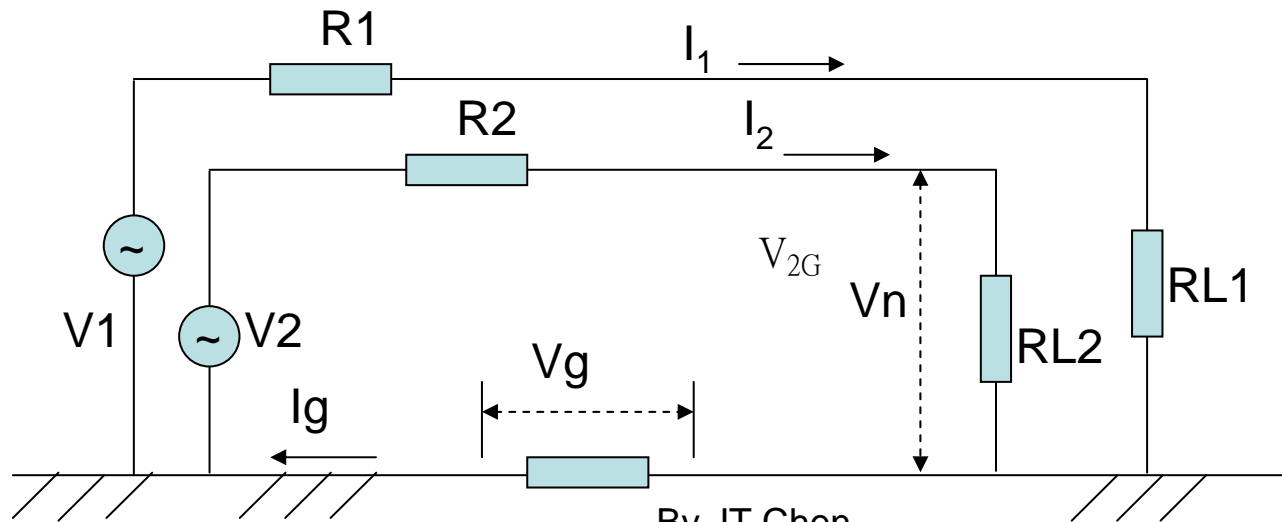
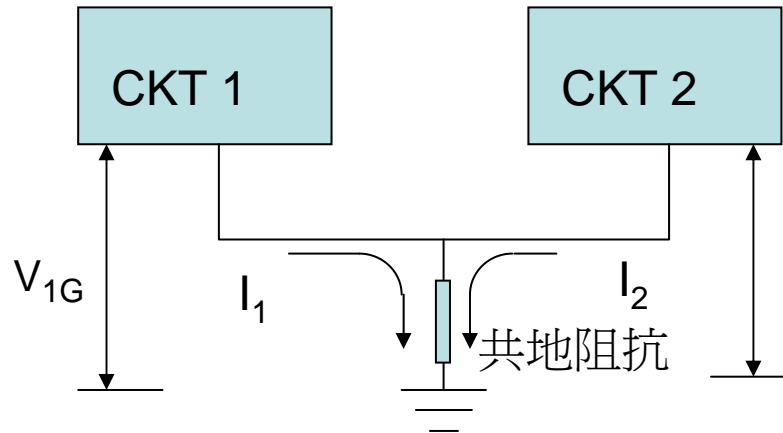


雜訊耦合型態

- 傳導耦合 (Conducted coupling)
- 共阻抗耦合 (Common Impedance coupling)
- 電磁場耦合 (Field coupling)
 - 一 電容性耦合 (E-Field Coupling)
 - 一 電感性耦合 (H-Field Coupling)



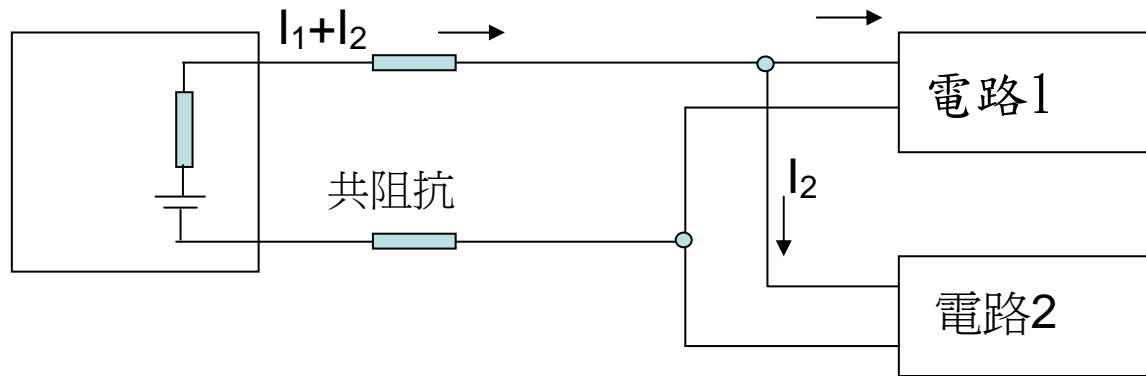
共阻抗耦合 1



By JT Chen



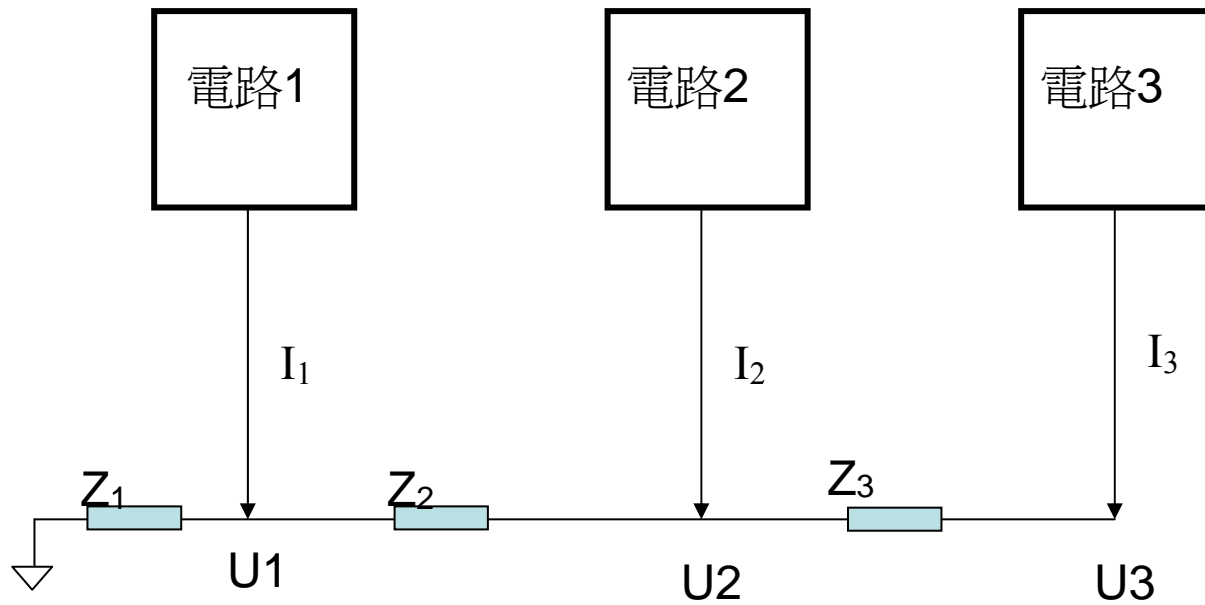
共阻抗耦合 2



兩個電路使用共電源時的共阻抗



共阻抗耦合 3

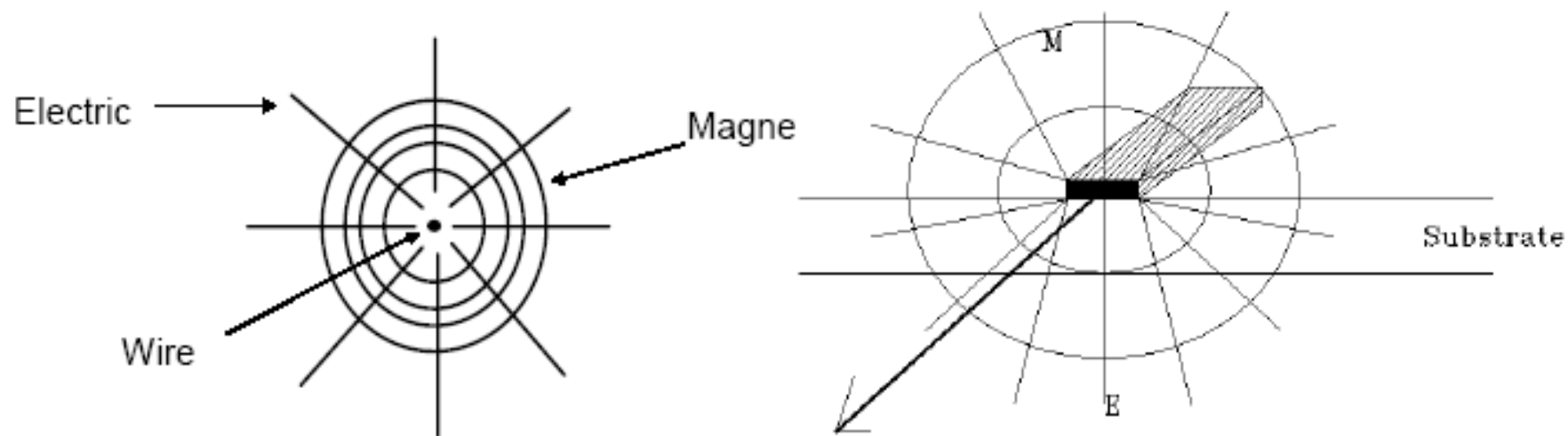


串連地阻抗耦合電路



電場與磁場

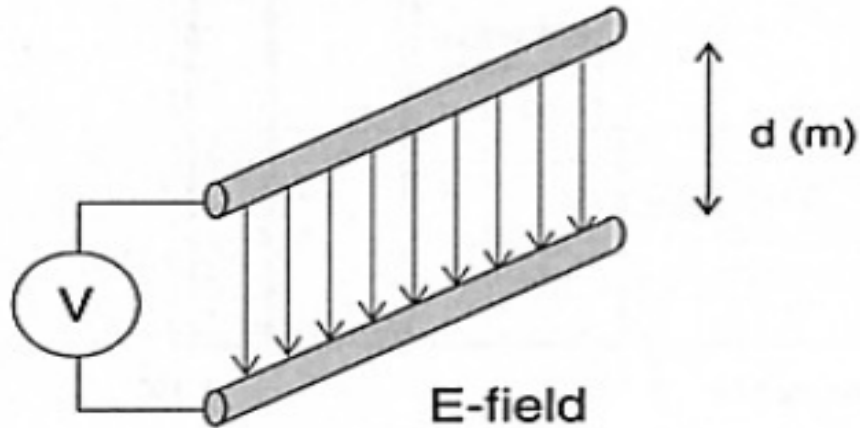
導體當有電流透過，在導體周遭會產生電場和磁場。



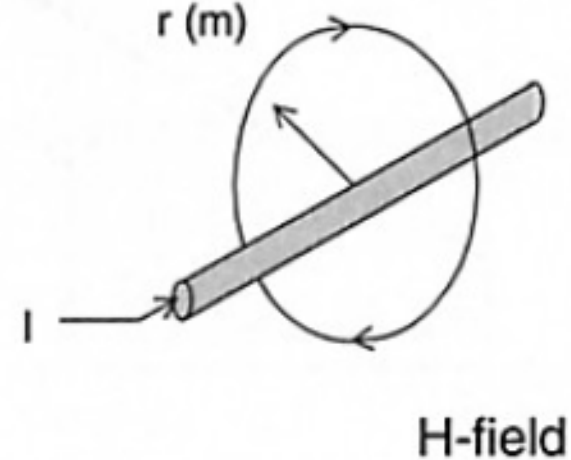
around current in conductor
generate magnetic field



電場磁場耦合



- E field create mutual capacitive between two conductors;



- Magnetic field generate inductive coupling energy.

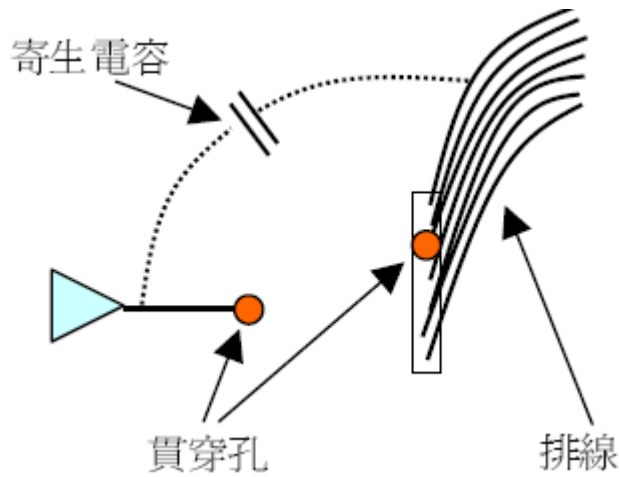
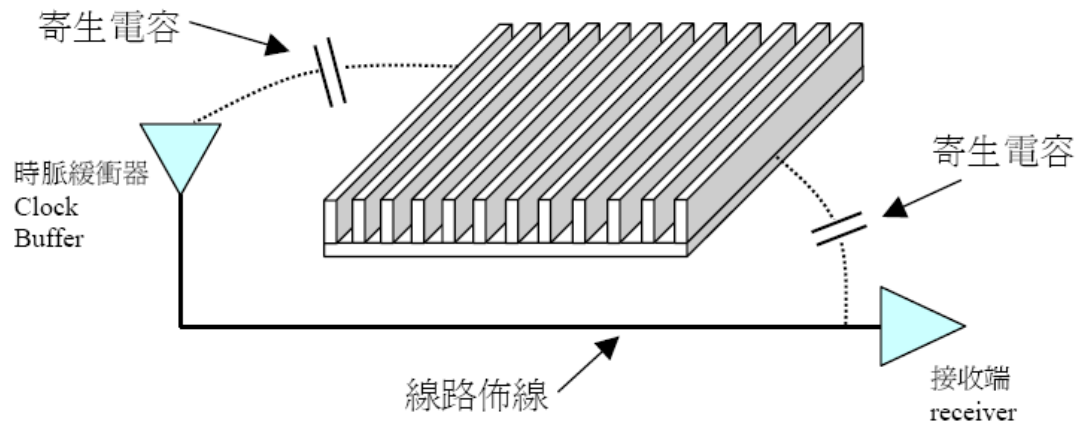


電場耦合

- 電場耦合是因爲電容性效應而產生。
- 在電路板架構會有一種自然形成的寄生電容，提供一個較設計回路更低阻抗的路徑。某些瞬間改變的信號(di/dt)會自己選擇經此路徑。
- 這種因電磁場變化帶出的耦合電流稱爲『位移電流』，它會選由『寄生電容 電感』做回流路徑。



PCB 內位移電流

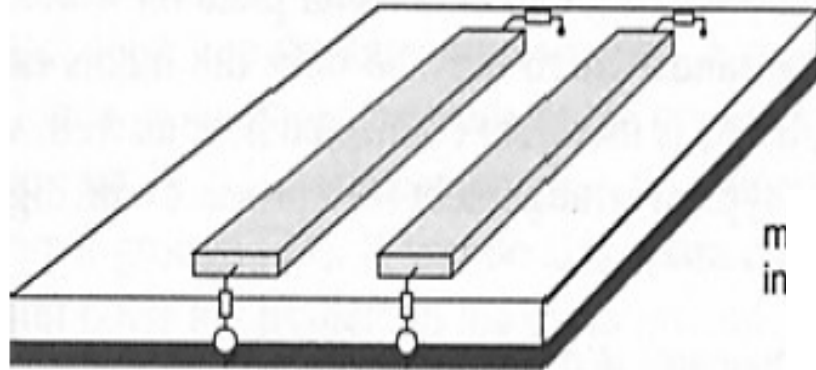
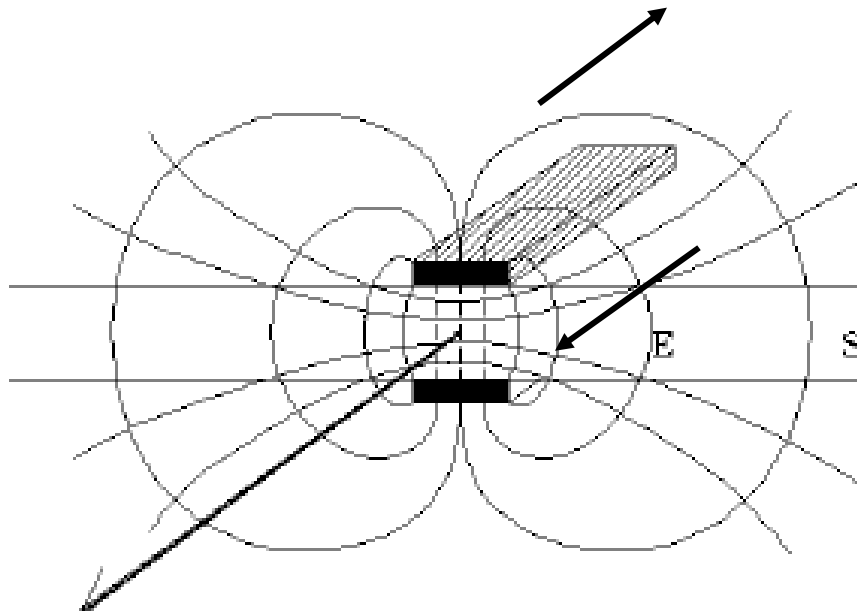


位移電流經由寄生電容迴返路徑



電容性耦合

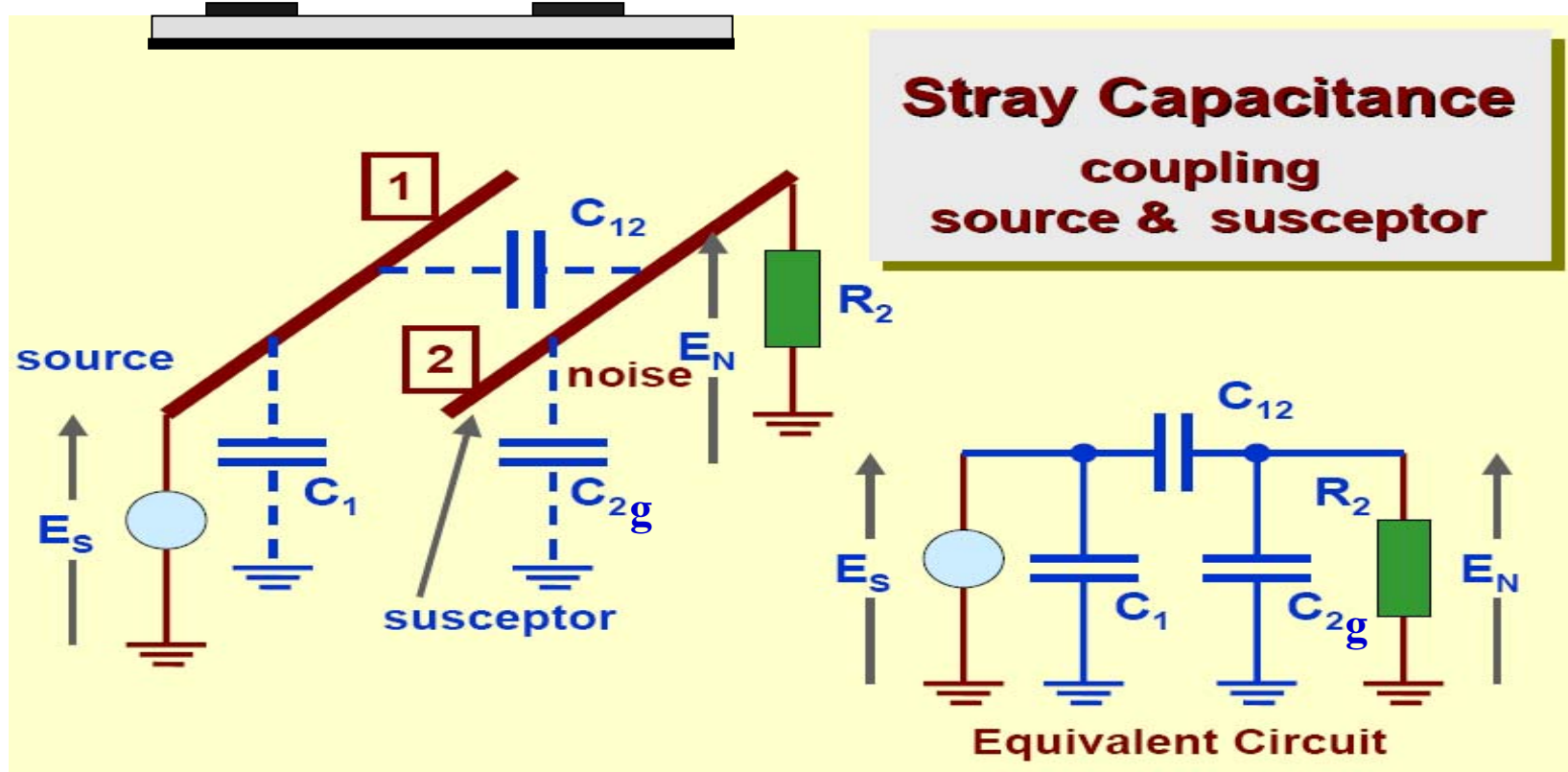
- Two circuits with mutual capacitance, Voltages in one circuit create electric fields which affect the second circuit.





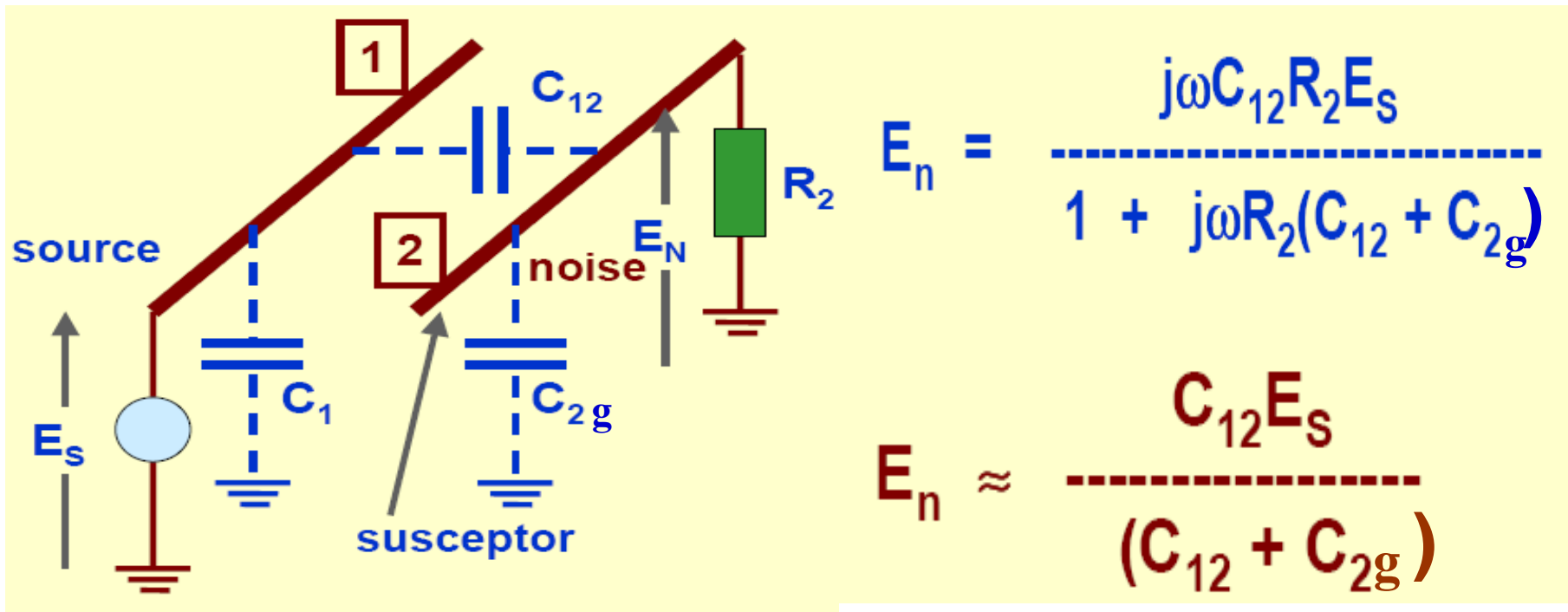
電場耦合

C_{12} = parasitic capacitance between conductor 1 & 2



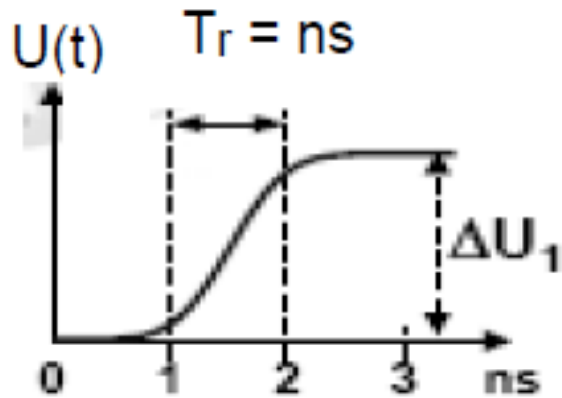


電場耦合





電場耦合 Time domain



Max dv/dt driving wave form:

$$\frac{dU_1}{dt} = \frac{\Delta U_1}{T_r}$$



Injected current in circuit 2:

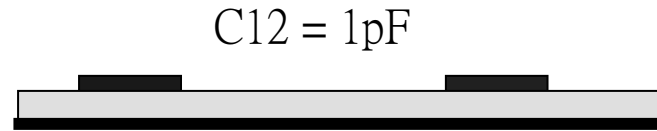
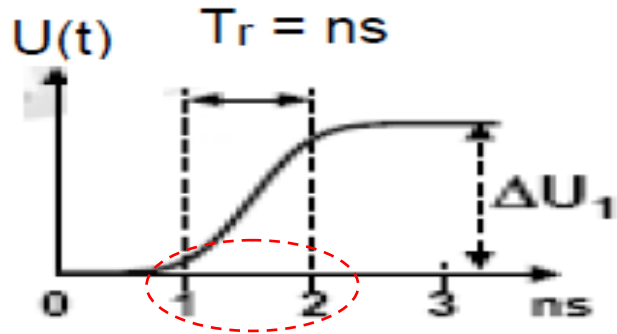
$$I_c = C_{12} \frac{\Delta U_1}{T_r}$$



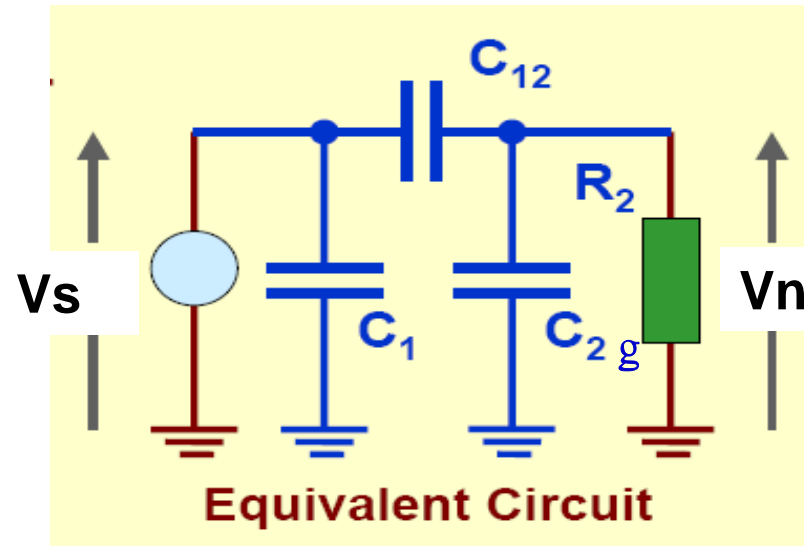
$$\text{Crosstalk} = \frac{U_{2N}}{\Delta U_1} = \frac{RC_{12}}{T_r}$$



電場耦合 Time domain



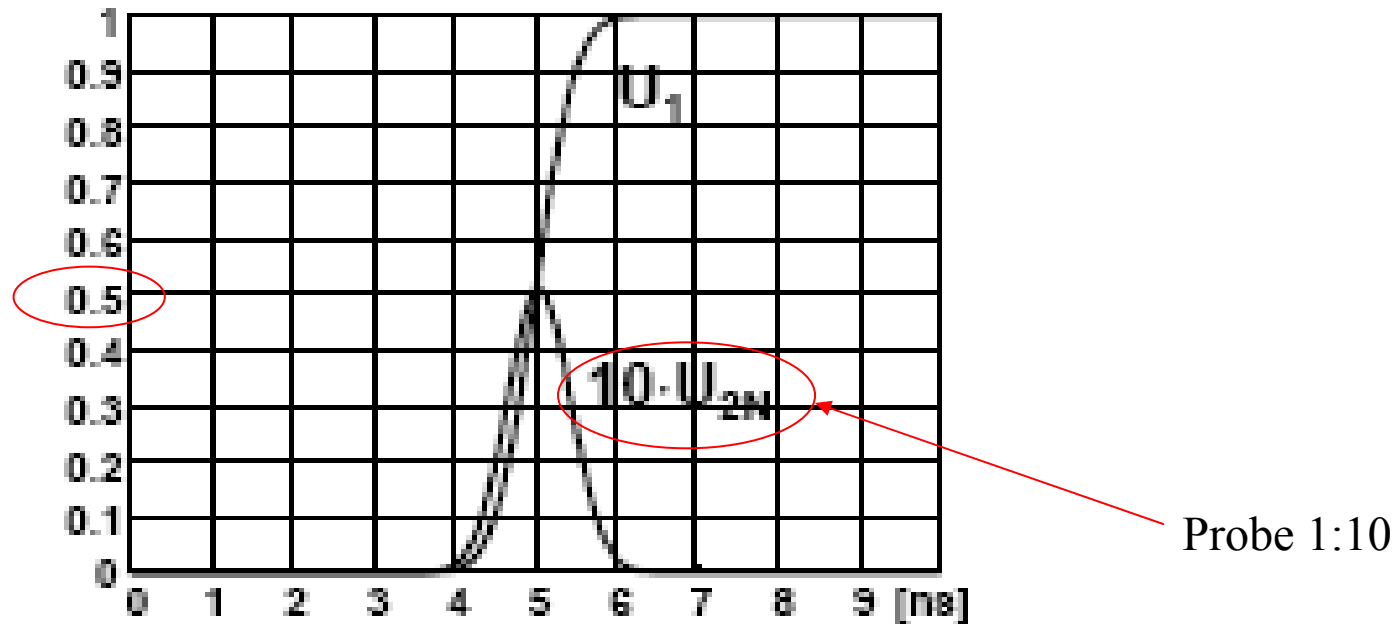
- Example: 依據前頁波形
 $\Delta V_s = 1V$, $T_r = 1ns$,
 $C_{12} = 1pF$, $R = 50 \Omega$



$$\text{Cross talk} = V_N / \Delta V_s = RC_{12} / T_r = 0.05$$



電場耦合

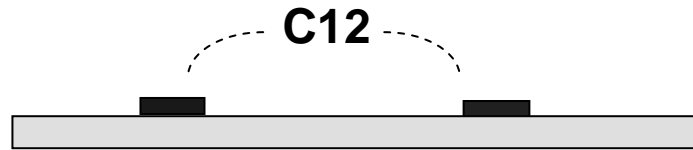


**Crosstalk of C_{12} from measured noise voltage with 1 pF,
Ratio of coupling = $V_n \text{ peak} / \Delta V_s = 0.0508$**

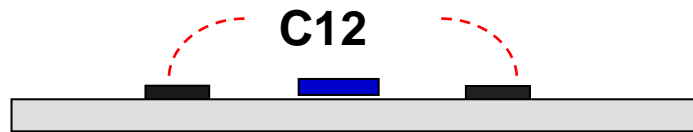


用接地面降低耦合

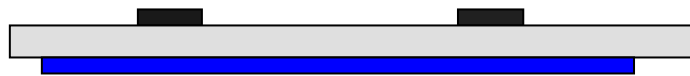
$$V_n = \frac{C_{12}}{C_1 + C_{2g}} V_1$$



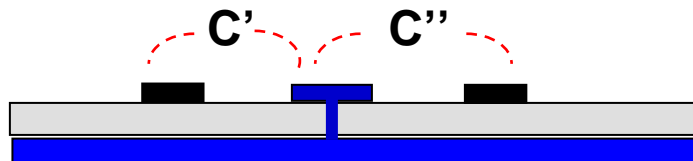
C_{12} ; $C_{2g} = 0$



$C_{12} ?$; $C_{2g} = 0$



C_{12} ; $C_{2g} \uparrow$



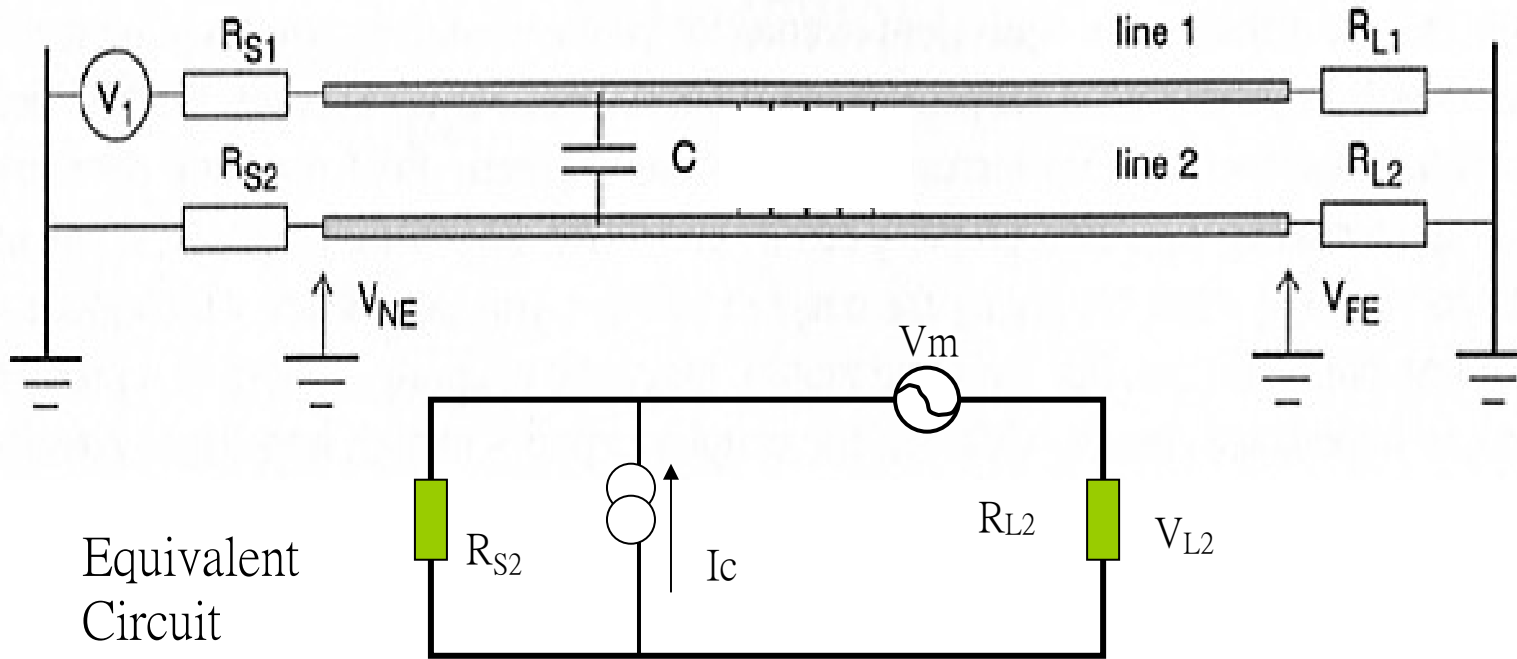
$C_{12} \downarrow$; $C_{2g} \uparrow$

Though hole
to ground

By JT Chen



導線之電場耦合

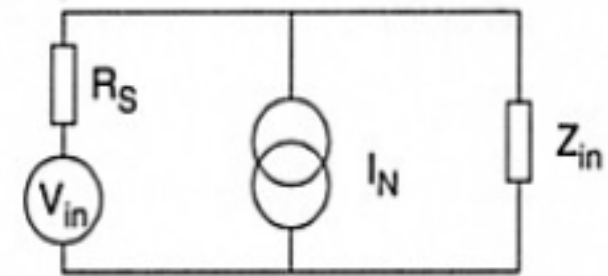
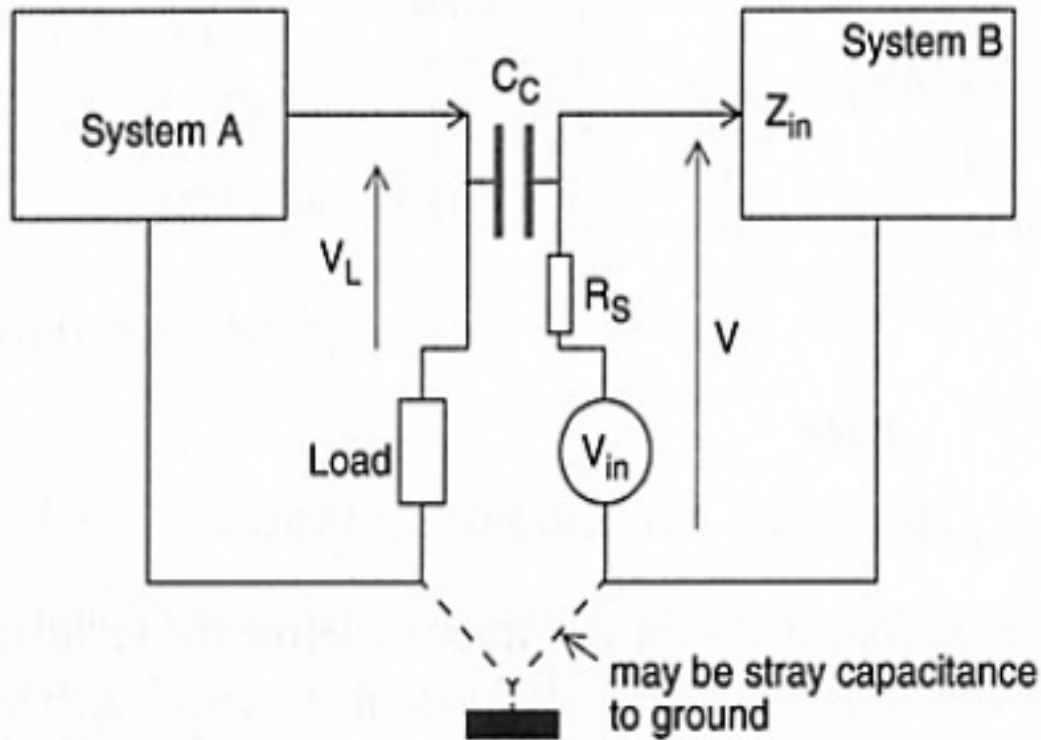


$$V_{s2} (\text{近端}) = V_{L2} (\text{遠端}) = I_c (R_{S2} // R_{L2})$$



電場耦合干擾對策

- 降低組抗以減低電場耦合干擾



equivalent circuit – electric coupling

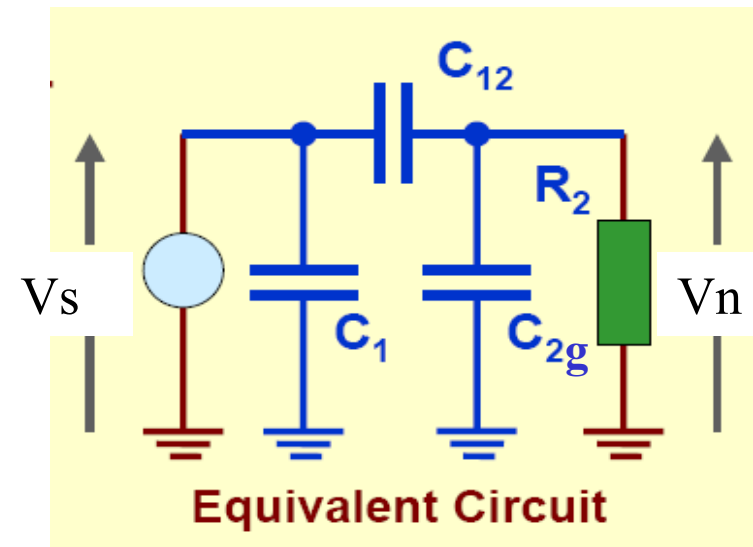


電場耦合干擾對策

- Reduce Stray Capacitance effect.
- - Coupling voltage

$$V_n \doteq j\omega \cdot R_2 \cdot C_{12} \cdot V_s$$

- Reduce E-Field coupling by:
 - Lower down V_s .
 - reduce R_2 of Victim
 - Increasing Capacitance C_2 to GND





磁場耦合

電感 $L = \Phi / I$

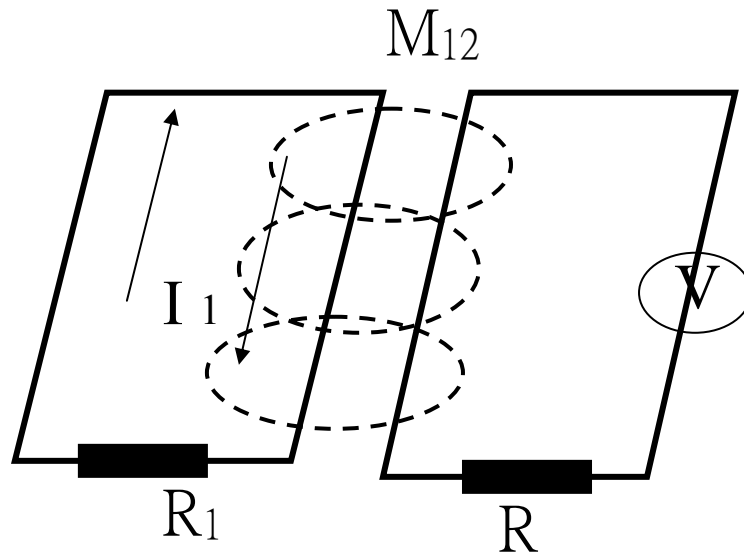
$$\Phi = L \times I$$

互感 $M_{12} = \Phi_{12} / I_1$

耦合電壓 $V_n = j \omega M_{12} I_1$

$$= M_{12} (di/dt)$$

$$= j \omega B A \cos \theta$$



A : 面積

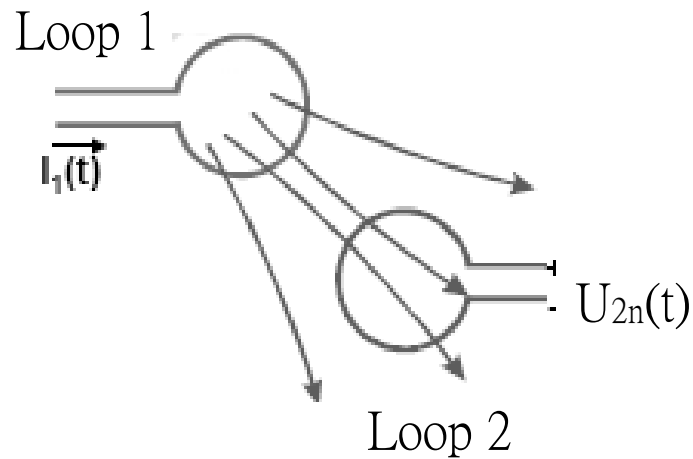
$B = \mu H$ (磁通);

$$\mu = 4 \pi \cdot 10^{-7}$$



磁場耦合

Inductive coupling



Faraday's law:

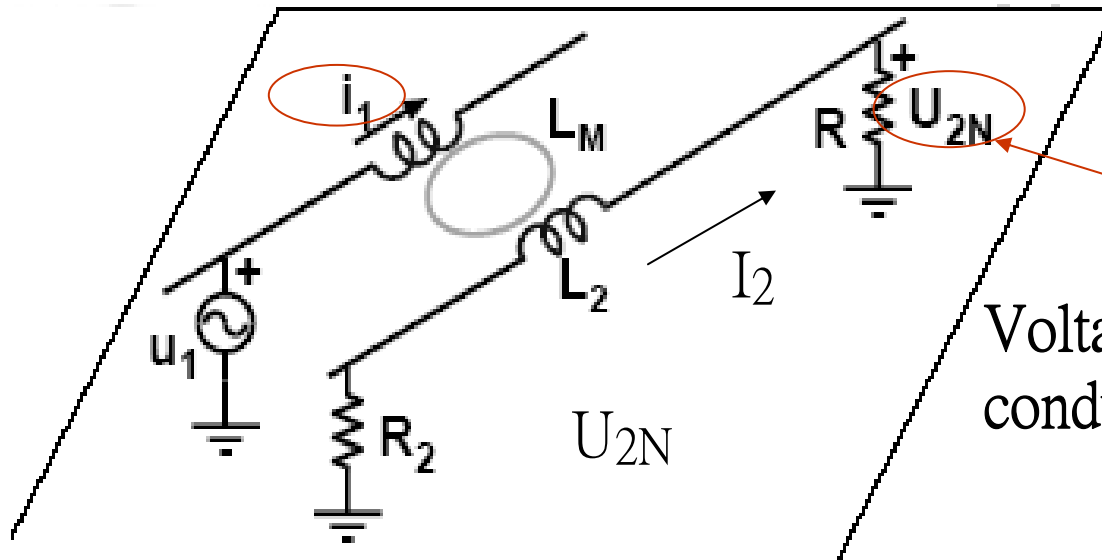
$$U_{2N}(t) = -\frac{d\phi_{12}}{dt} = -\frac{d}{dt} \int_{\text{area2}} \vec{B} \cdot d\vec{s}$$

Mutual inductance:

$$U_{2N}(t) = L_M \frac{di_1}{dt} \quad \left\{ \begin{array}{l} L_M = \frac{\phi_{12}}{I_1} \\ \leftarrow \end{array} \right.$$



Inductive Coupling



Voltage noise U_{2N} induced into conductor 2

$$U_{2N} = j\omega L_2 I_2 + j\omega L_M I_1$$

$$I_2 = -\frac{U_{2N}}{R_2 + R} = -\frac{U_{2N}}{R_T}$$

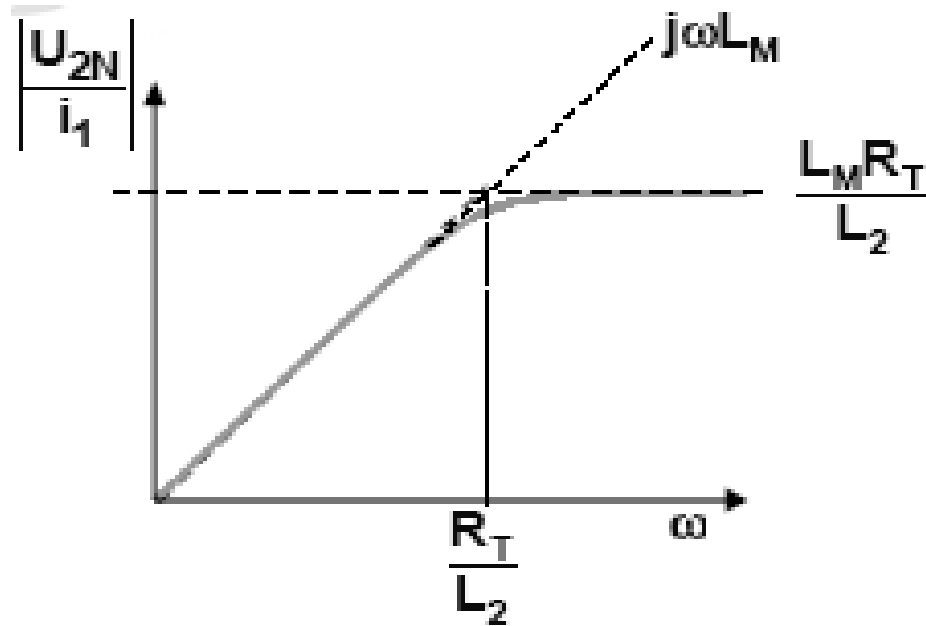


$$U_{2N} = \frac{j\omega L_M}{1 + j\omega \frac{L_2}{R_T}} I_1$$

(R_T total)



Inductive Coupling



Frequency response

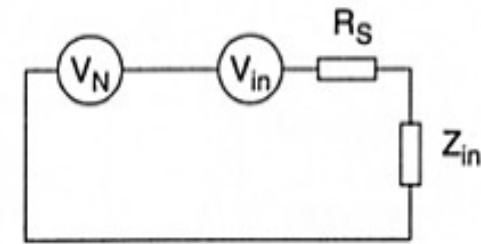
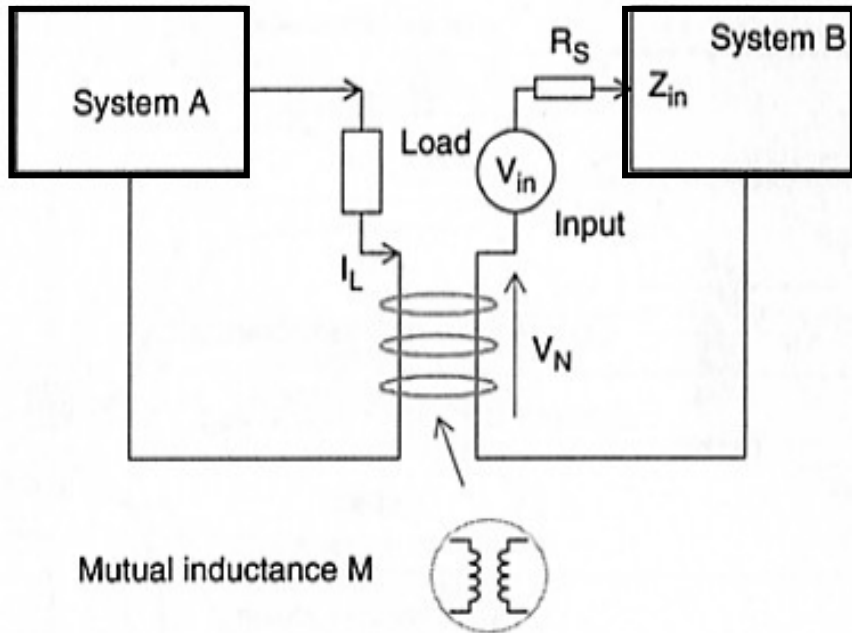
$$U_{2N} = \frac{j\omega L_M}{1 + j\omega \frac{L_2}{R_T}} I_1$$

$$R_T: R+R_2$$

$$\text{High Frequency : } U_{2N} \doteq \frac{L_M R_T}{L_2} I_1$$



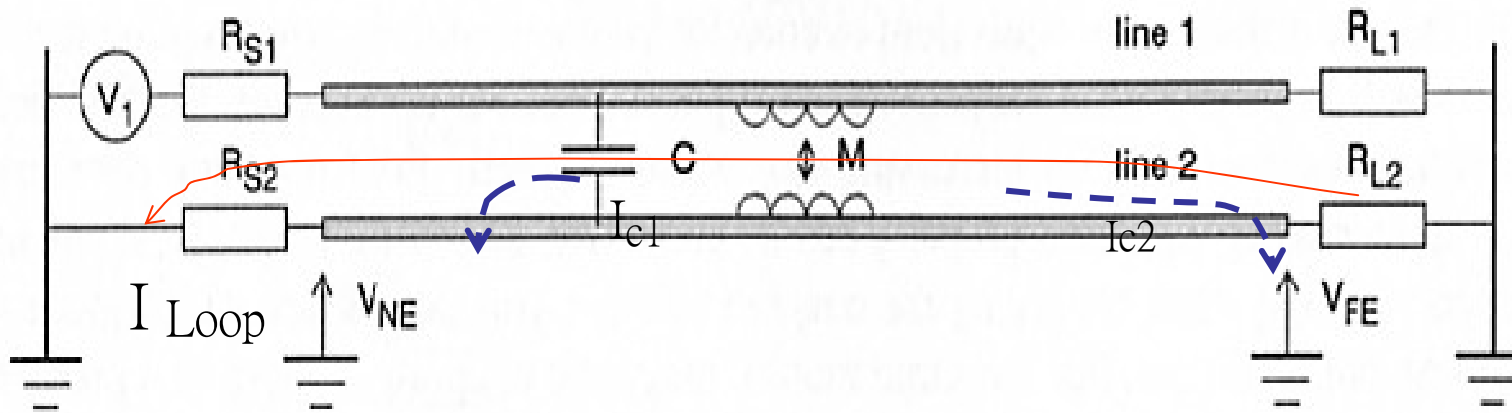
磁場耦合



equivalent circuit – magnetic coupling



磁場耦合

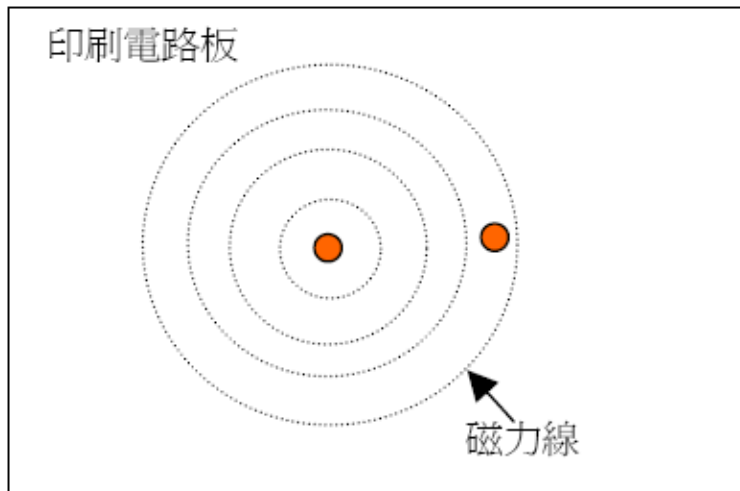
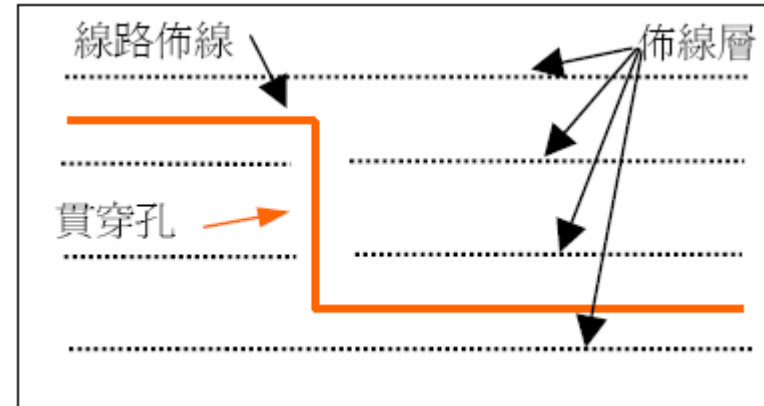
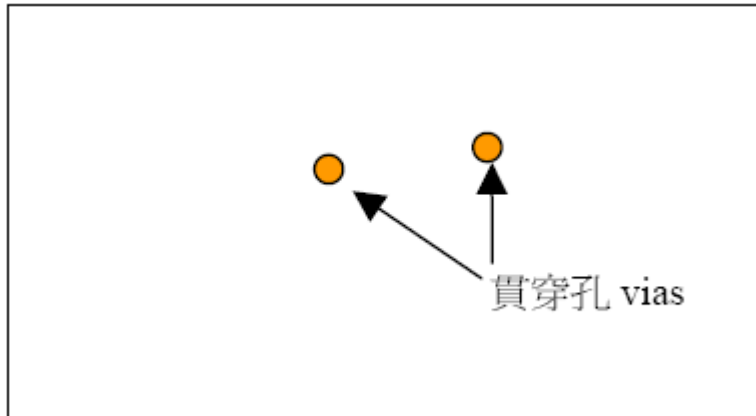


磁場; V_{ns2} (近端) = $(I_{c1} + I_{Loop}) R_{S2} / (R_{L2} + R_{S2})$

V_n (遠端) = $(I_{c2} - I_{Loop}) R_{L2} / (R_{L2} + R_{S2})$ out of phase



Magnetic field coupling on PCB



- 圖左上：印刷電路板上之貫穿孔
- 圖右上：印刷電路板上之貫穿孔(內部)
- 圖左下：印刷電路板貫穿孔磁力線

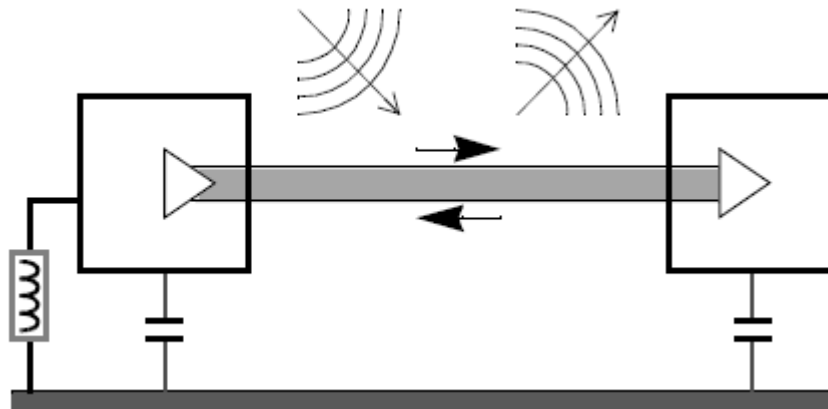


電磁場耦合的模式

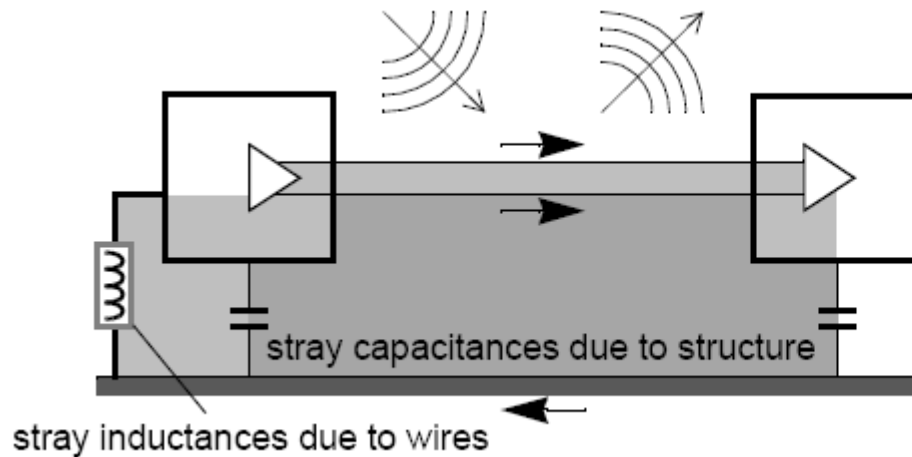
- Differential mode
- Common mode
- Antenna mode



Differential mode & Common Mode



Differential mode

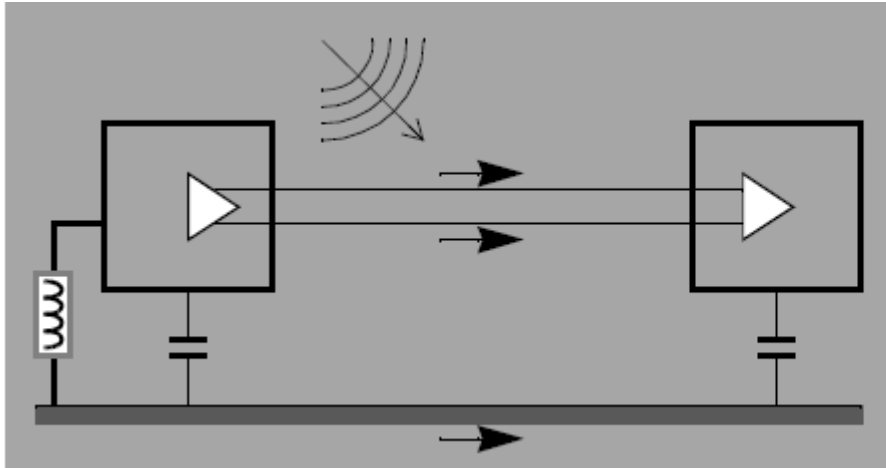


Common mode

(Shaded areas indicate part of circuit that couples with external fields)



Antenna Mode coupling



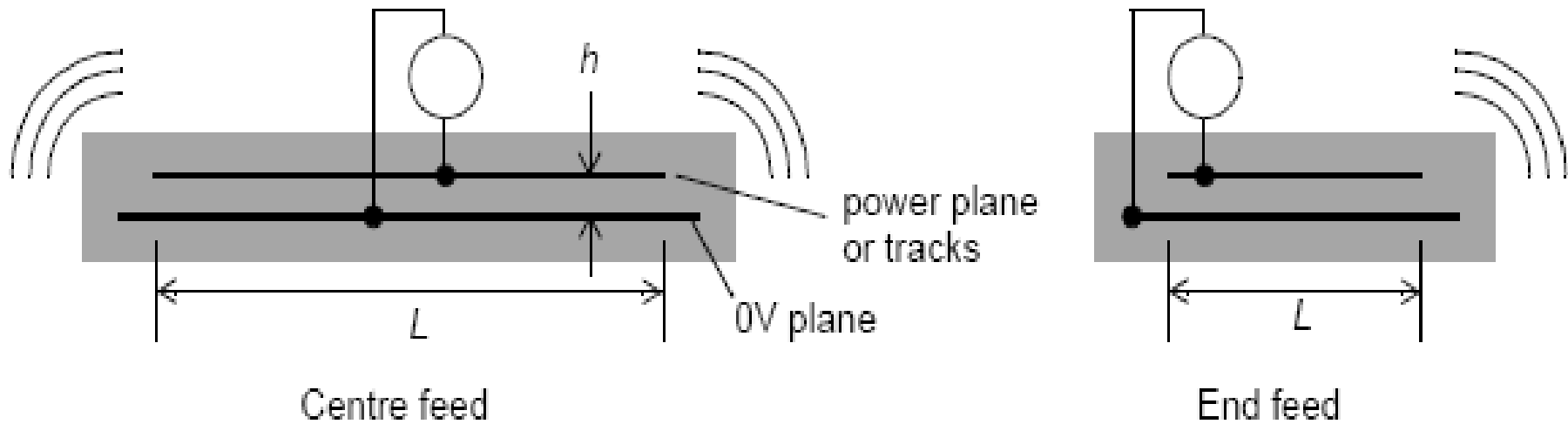
連接線束會有天線效應
挾帶著感應電流，形成
EMS問題

Antenna mode

天線模式對導線及接地平面耦合的感應電流方向是相同的,天線模式的耦合僅對RS輻射場強照射時，會在自己電路系統差模的路徑阻抗變化產生感應電流後再轉變為共模及差模的耦合電流。



PCB as Patch Antenna

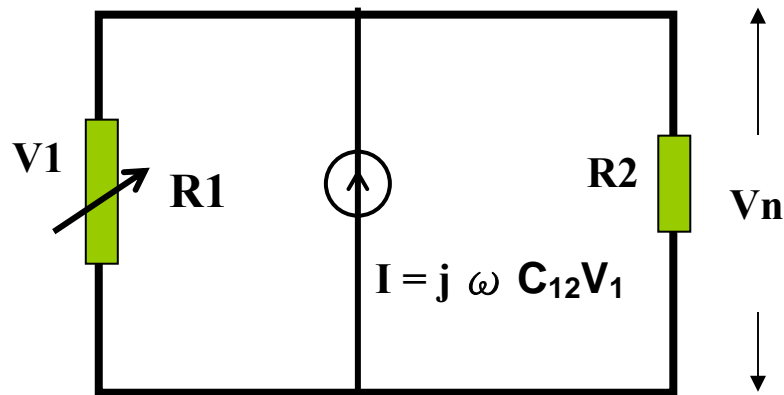


PCB邊緣輻射增加隨 h 而增加，當 $L = n / 2$ 或者 $n / 4$ 時最大化

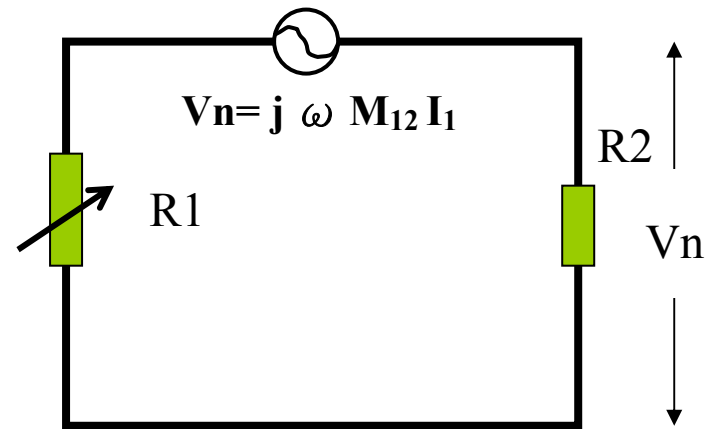


阻抗影響電場與磁場耦合

電場耦合模型



磁場耦合模型





Summary of Field coupling

- 耦合發生的兩種機制是：電場耦合與磁場耦合
- 從雜訊源耦合到『有效』的輻射天線之機制可能是電場、可能是磁場耦合，也可能是兩者皆有。
- 高速信號升降(rise and fall)時間越快，會增加電容性和電感性雜訊的串音(Cross talk)耦合。



Summary of Field coupling

- 磁場耦合程度取決於環路面積所產生的互感大小.
- 電場耦合會將雜訊電流注入到受干擾的電路.
- 磁場耦合是信號雜訊電壓進入受干擾的電路
- 鄰近導體之間存在互感耦合效應，會產生 crosstalk 的感應電壓，電流方向和原信號方向相反.
- 電路對地阻抗越高，越容易遭受電場耦合干擾.



Summary of Field coupling

- 電感性耦合是由信號雜訊電壓進入受干擾的電路
- 鄰近導體之間存在互感耦合效應，會產生 crosstalk 的感應電壓，極向流向和原趨動信號相反
- 用導體特性阻抗相近的阻值作端點，可減低耦合的敏感程度。
- 電場耦合模式有 Differential mode Common mode Antenna mode 三種。

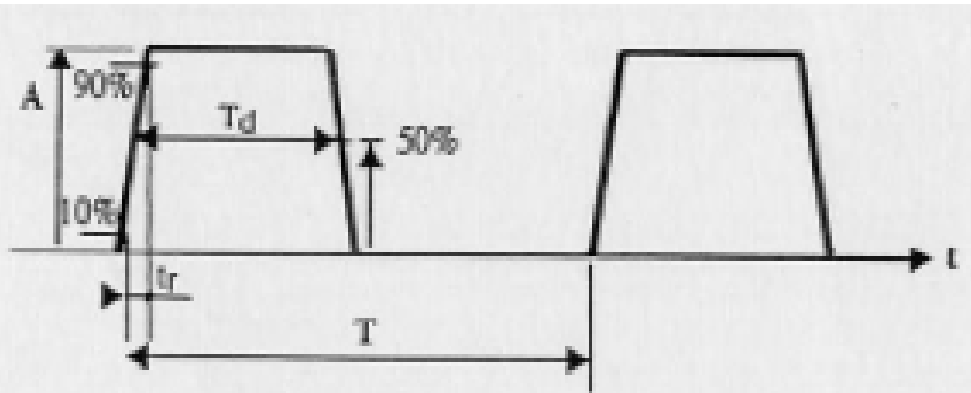


信號頻譜(Signal Spectra)

- 信號之諧波頻譜在EMC設計考慮中是一個很重要的項目。
- 基頻(Fundamental frequency)很少直接造成問題的頻率。大多數之EMC問題是來自於較高之頻率諧波。



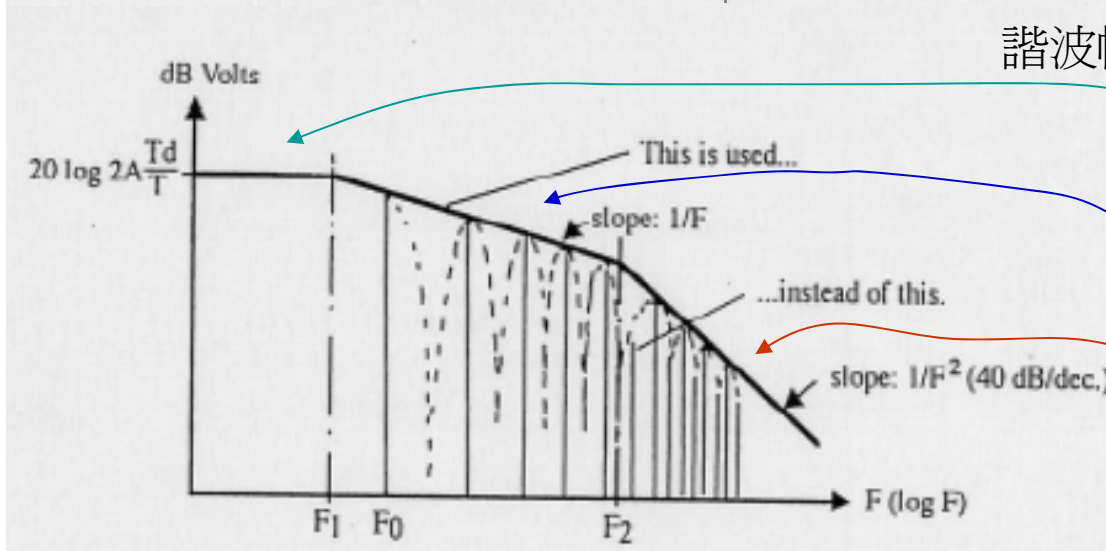
脈波信號的頻譜



$$F1 = \frac{1}{\pi Td}$$

$$F0 = \frac{1}{T}$$

$$F2 = \frac{1}{\pi Tr}$$



諧波幅度 (電壓或電流)

$$V(\text{ or } I) = 2 A (Td+tr) / T$$

$$V(\text{ or } I) = 0.64A / T f$$

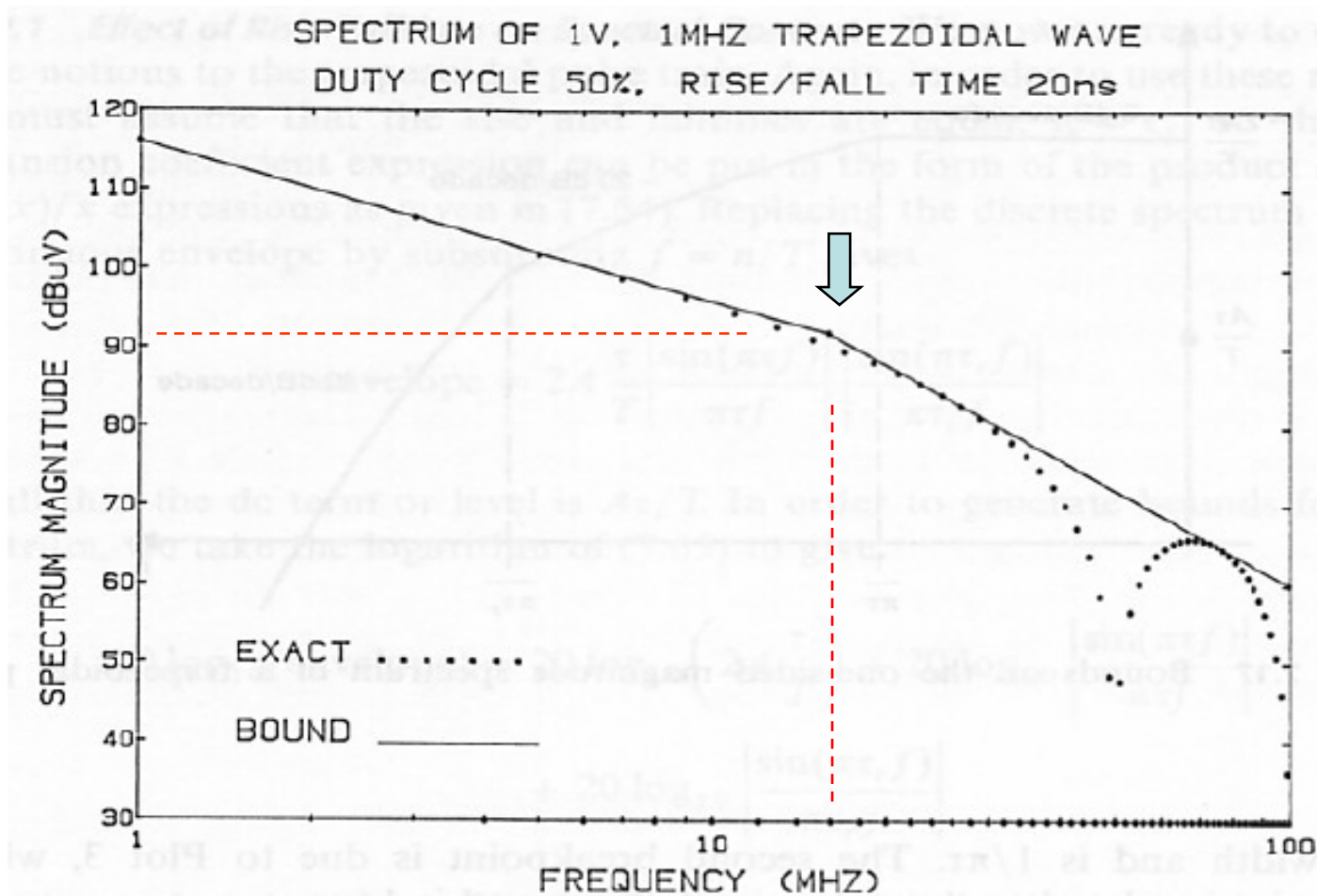
$$V(\text{ or } I) = 0.2A / T tr f^2$$

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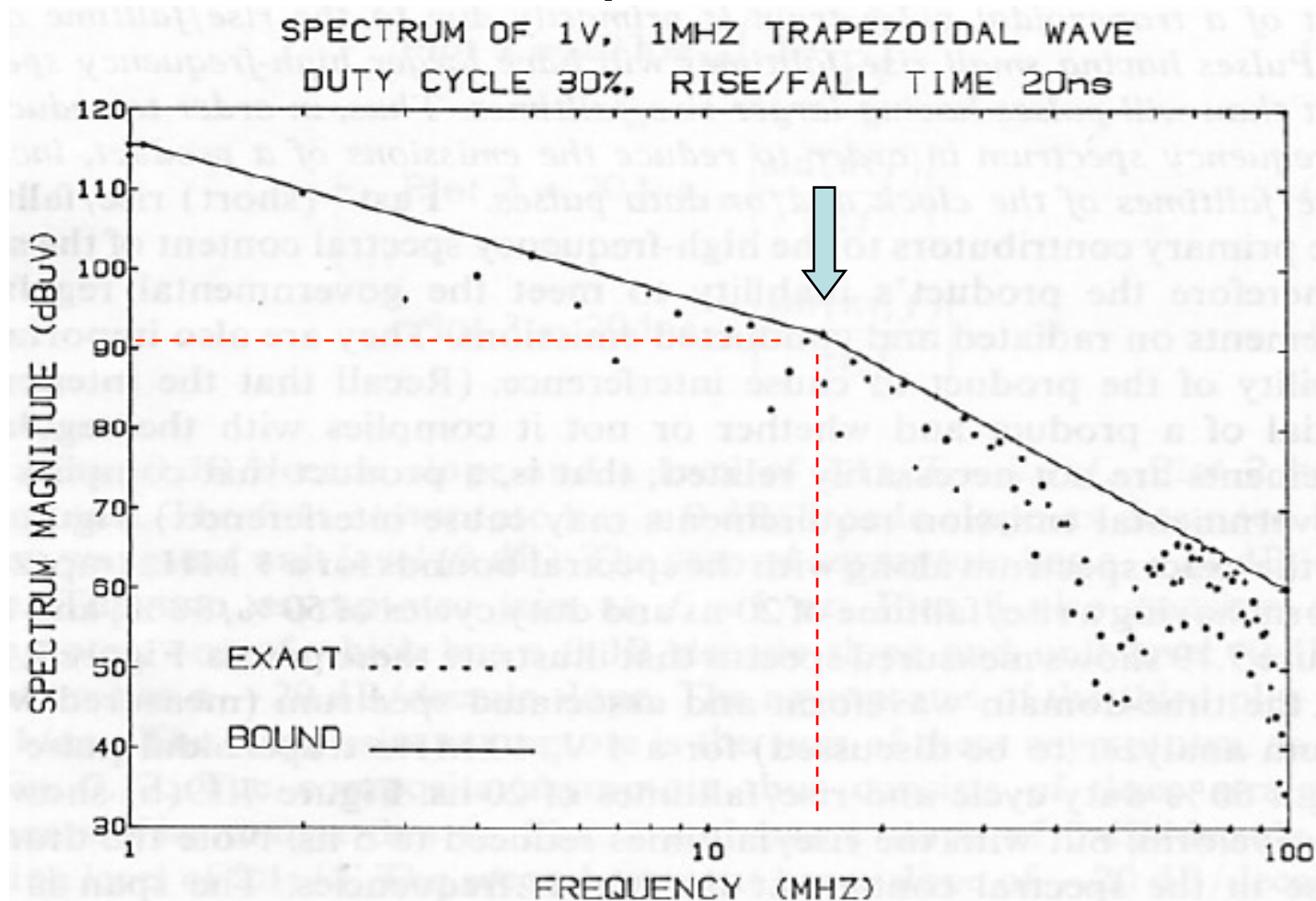
Interocean EMC Technology Corp.

Spectral for 50% duty cycle trapezoidal pulse



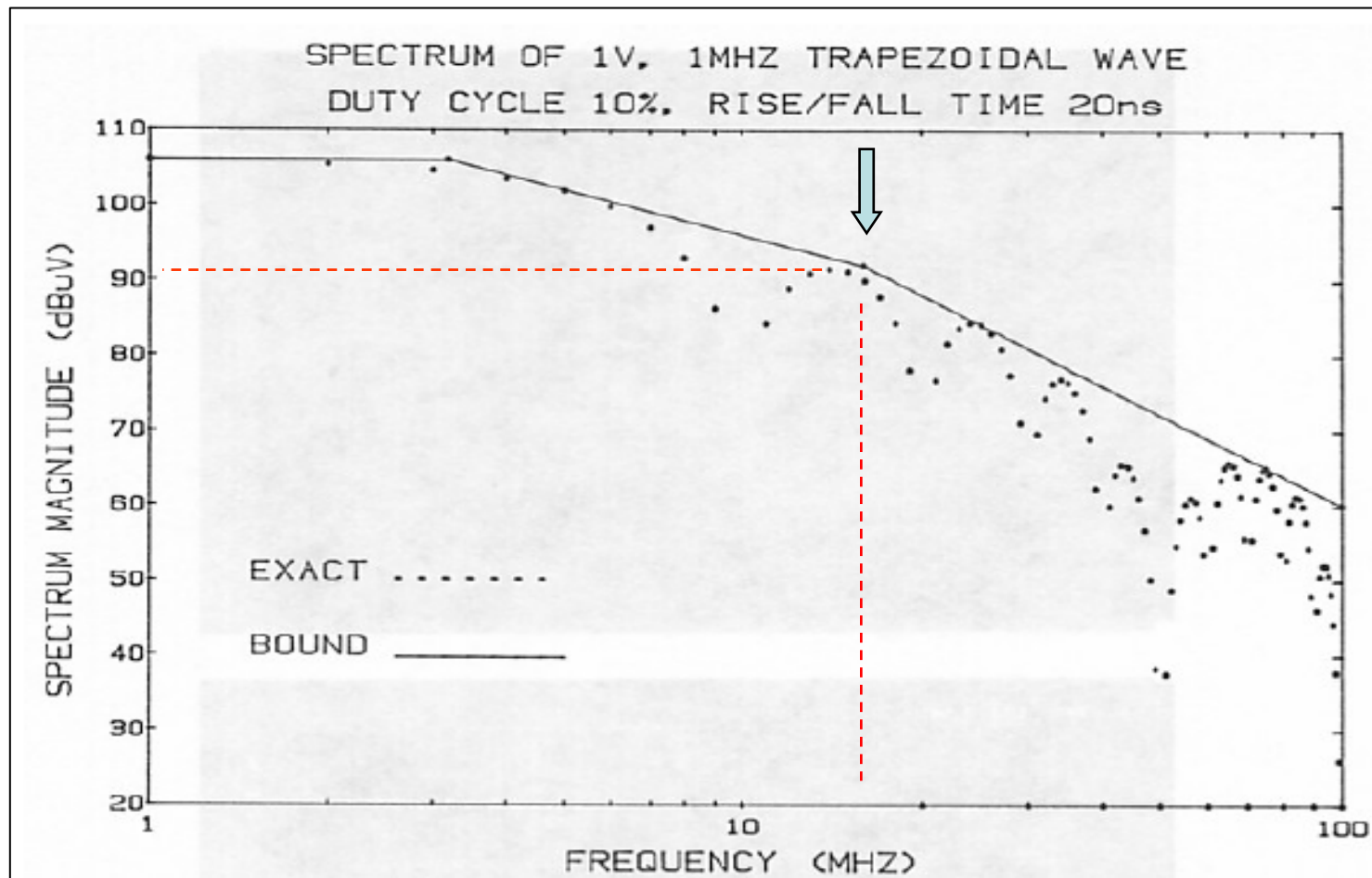


Spectral for 30% duty cycle trapezoidal pulse





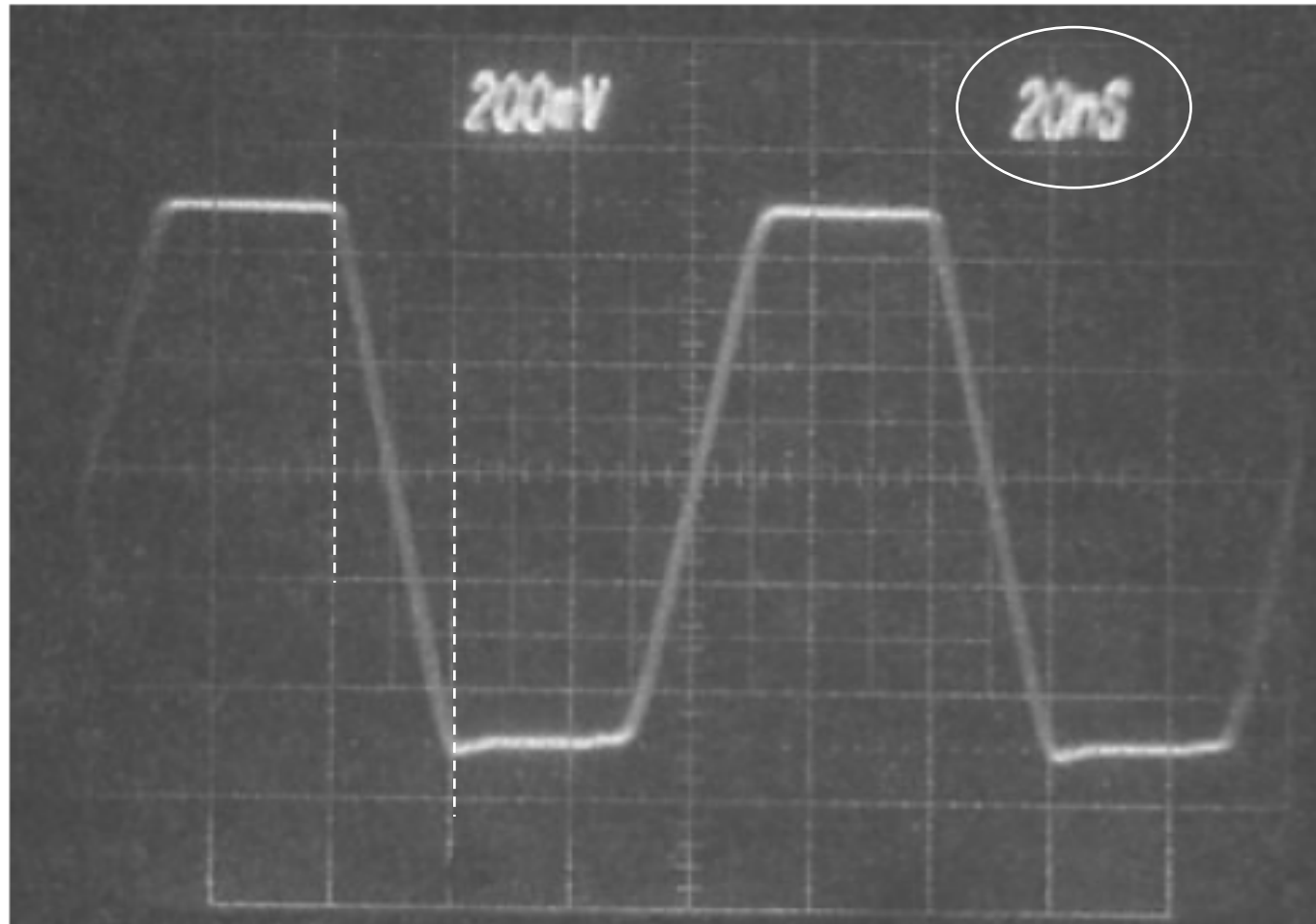
Spectral for 10% duty cycle trapezoidal pulse





Interocean EMC Technology Corp.

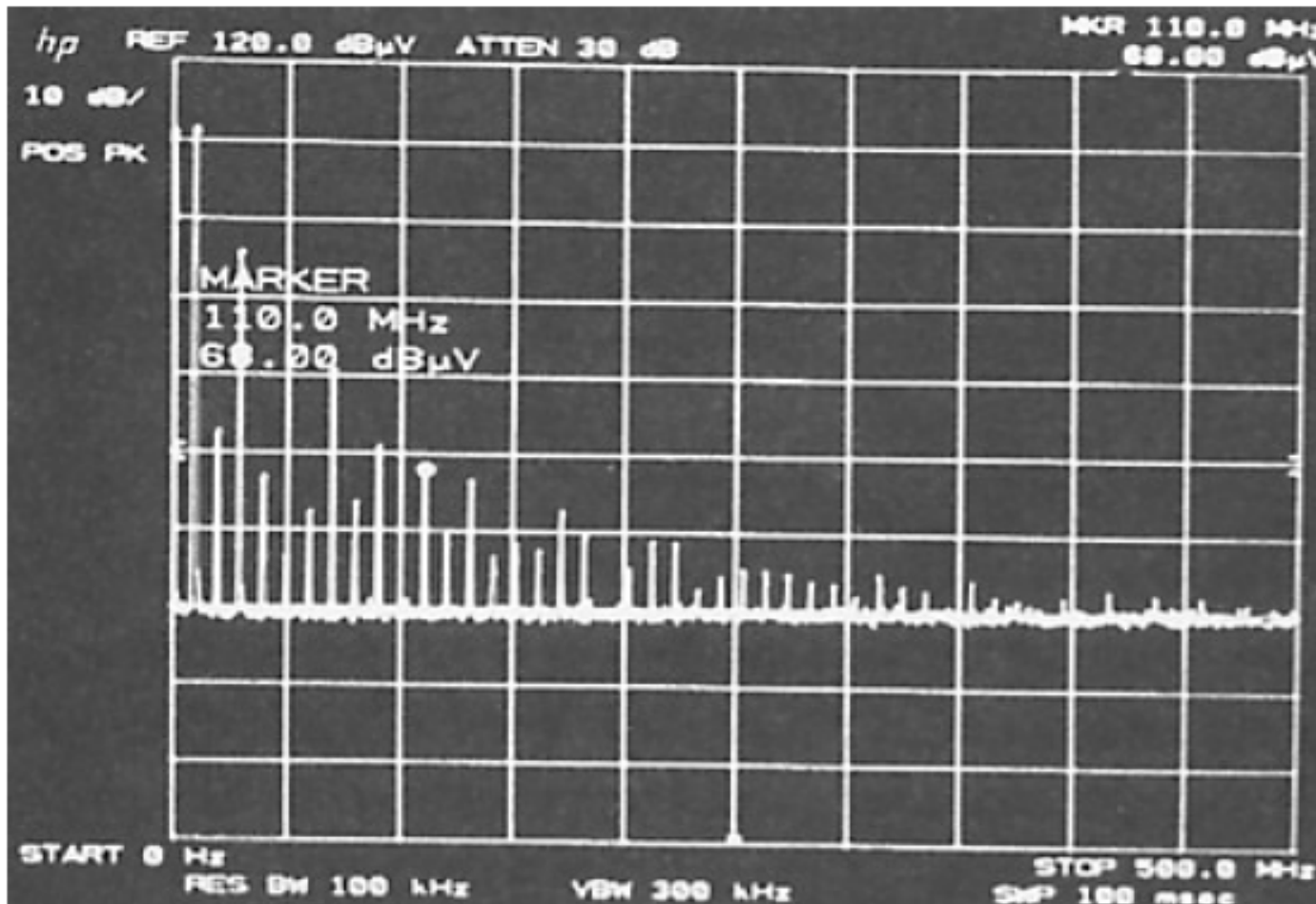
Pulse train of 1V, 10 MHz, 50% duty cycle
for **20ns** rise/fall time





Interocean EMC Technology Corp.

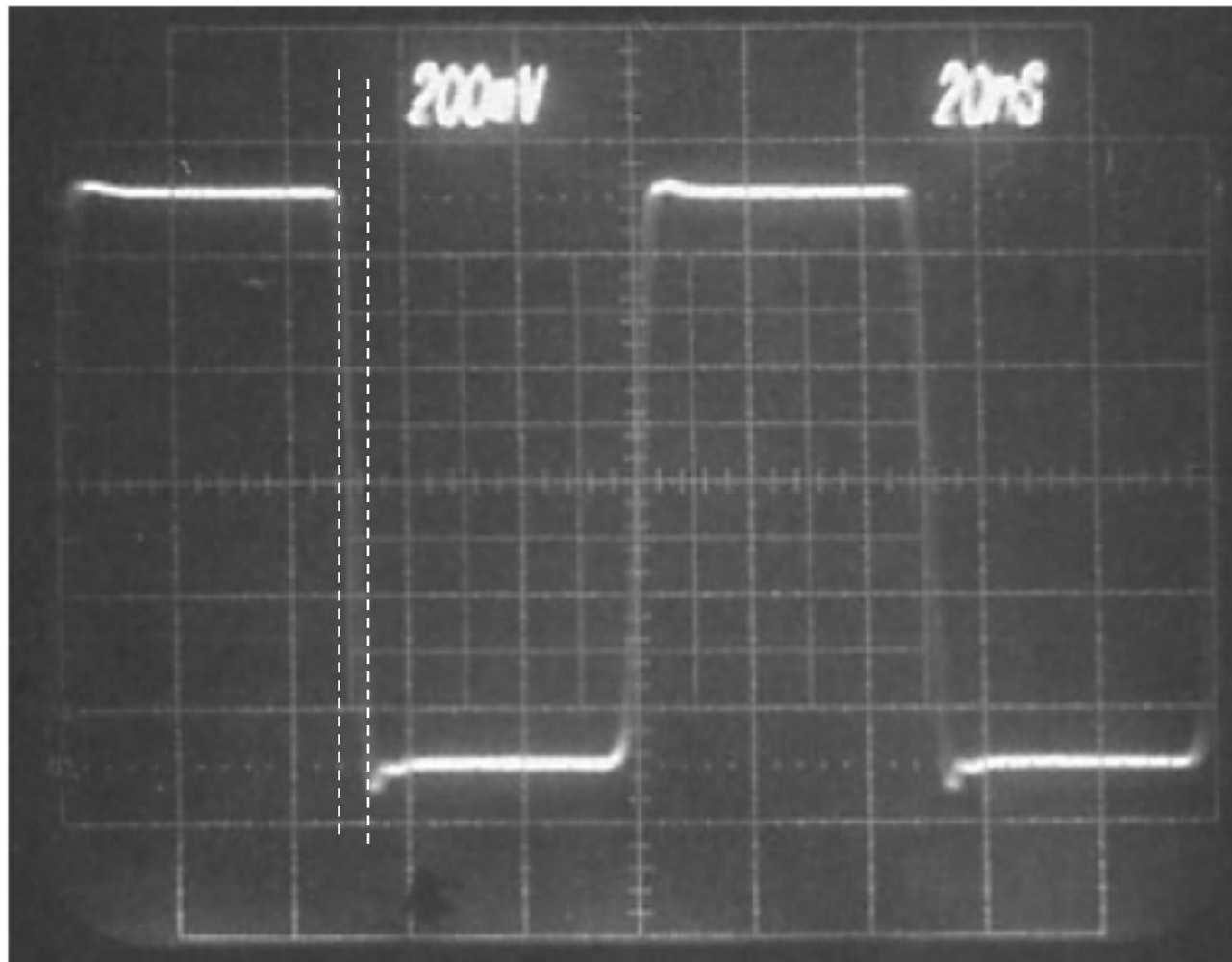
Measured spectral of pulse train (20 ns rise/fall time)





Interocean EMC Technology Corp.

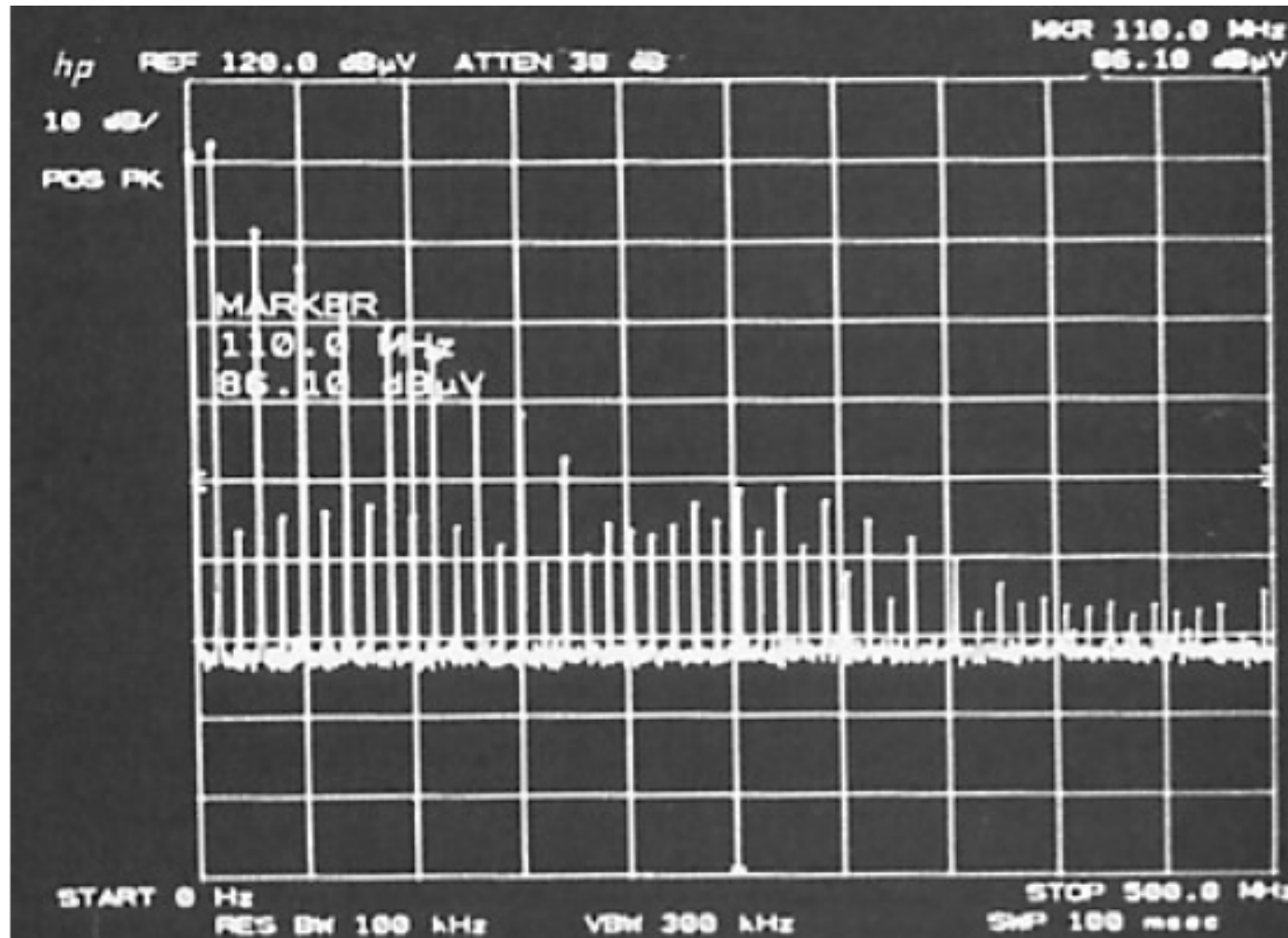
Pulse train of 1V, 10 MHz, 50% duty cycle
for 5 ns rise/fall time





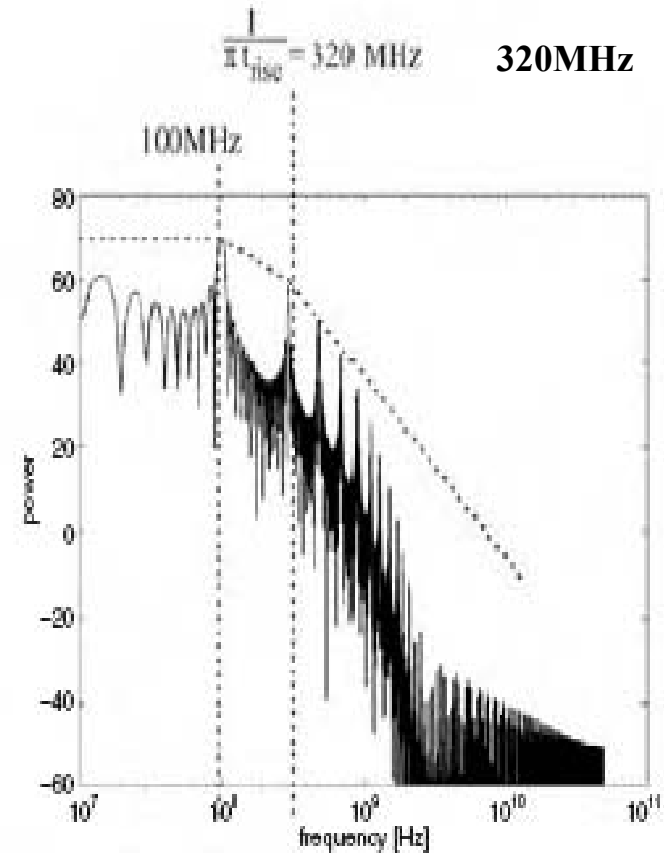
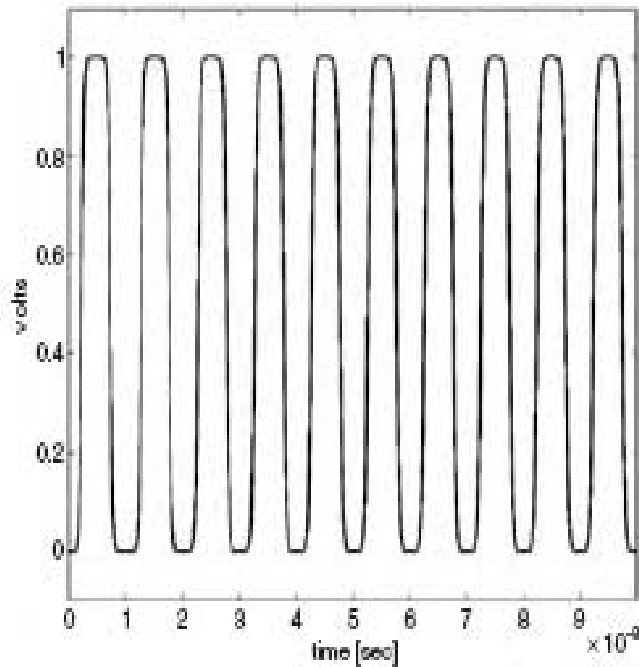
Interocean EMC Technology Corp.

Measured spectral of pulse train (5 ns rise/fall time)





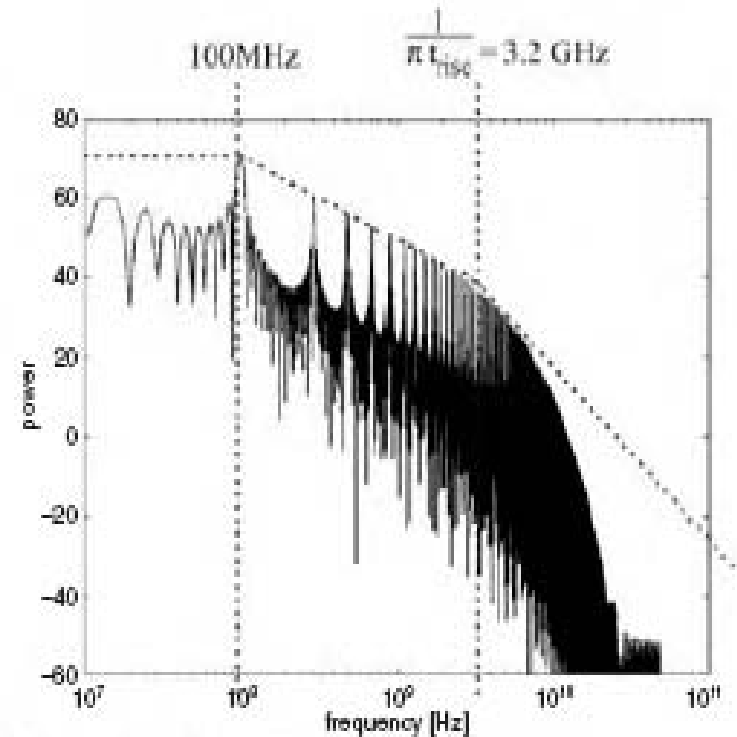
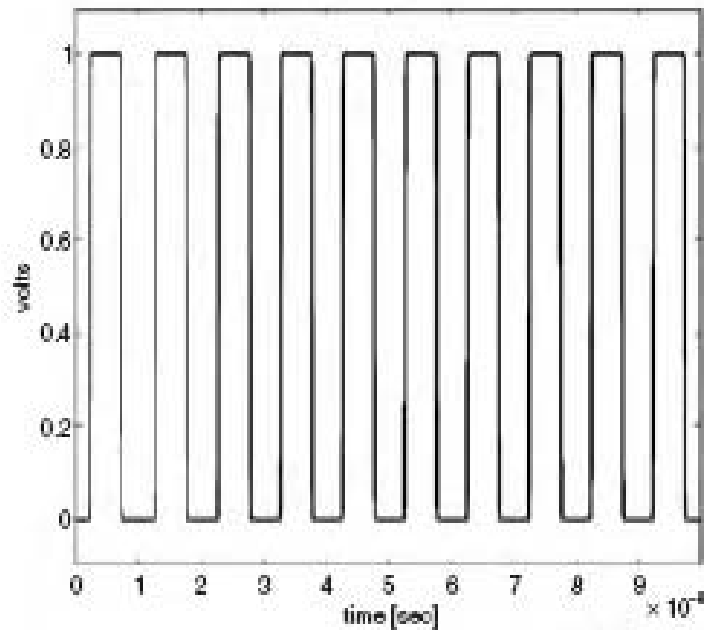
The rise time determines how fast the harmonics decay



100 MHz signal with 1nsec rise time



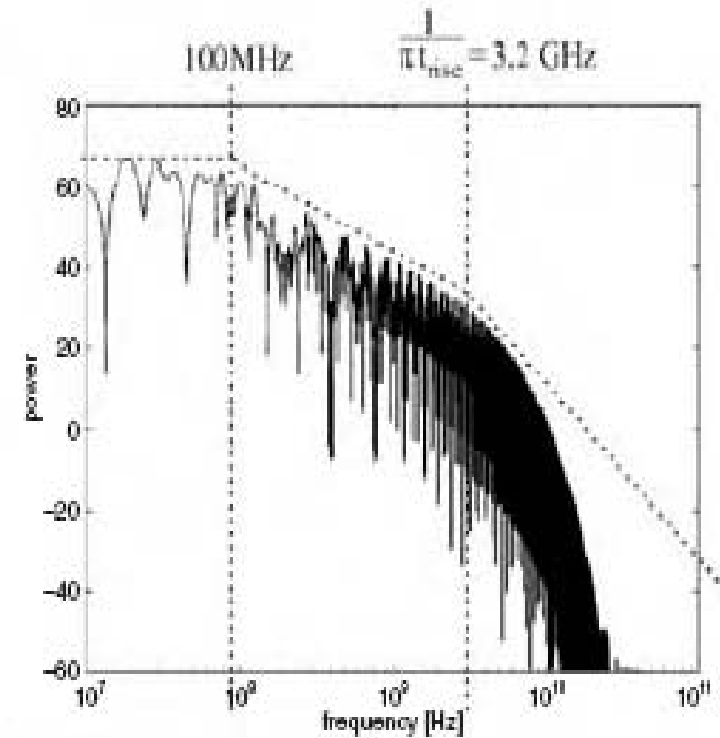
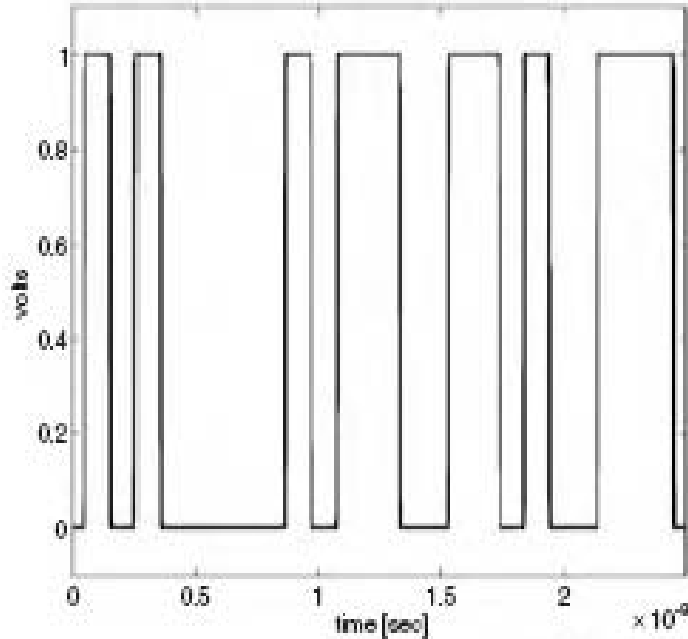
The rise time determines how fast the harmonics decay



100 MHz signal with 100psec rise time



The rise time determines how fast the harmonics decay



arbitrary data signal with 100psec rise time



Fourier 分析

- 一個簡單方波之諧波頻率成分包含有基頻以及所有的奇次諧波(Odd harmonics)。每一個別諧波之

振幅大小為 $A_n = \frac{1}{n}$

$n =$ 奇數諧波 (1,3,5,7...)

$A_n =$ 諧波之振幅

- 在真實環境中極少有duty cycle 剛好是50%，並且此一方波之上升時間與下降時間是相等的，這種Duty cycle 的一點小小變動就會造成很大的偶數諧波。

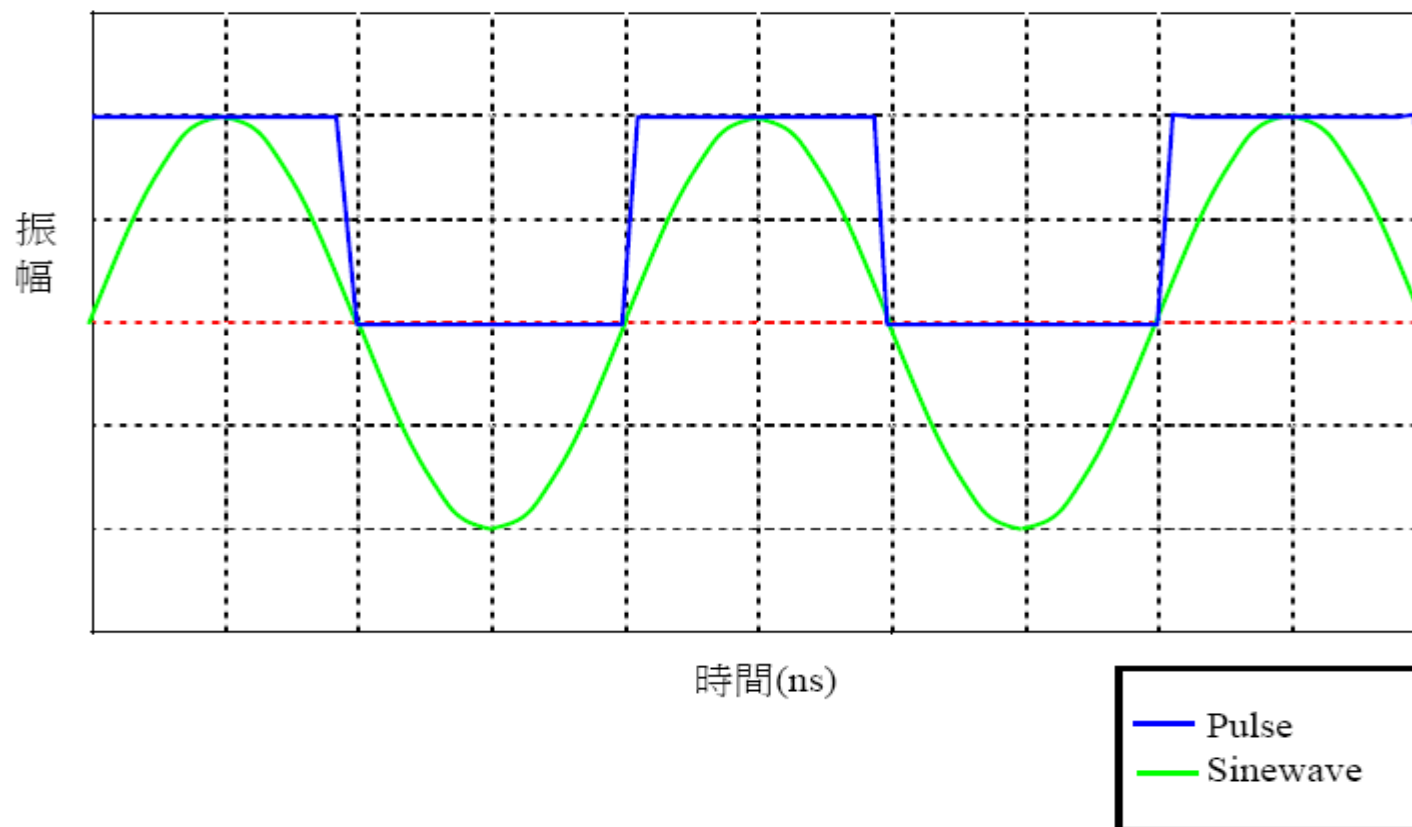


『 Hertz 』 & 『 Bits-per-Second 』

- 有時我們對於(例如)50M bit/秒 之信號及 50MHz 信號之間會有些混淆。
- 50M bit/秒 信號之基頻並不是50MHz。
- 50M bit/秒 之方波以及一個25MHz 之 Sine 波。事實上，方波之資料速率只是根據一個位元寬度來決定的，也就是整個弦波週期的一半。



25MHz 之Sine 波與50Mbit/秒方波之比較



圖中顯示一個50M bit每秒之方波，以及一個25MHz 之Sine 波；此意味著100M bit/秒 之方波其奇數諧波會在50MHz、150MHz、250MHz、350MHz、等等。



諧振效應

- 諧振是一與實體空間大小有關之物理現象，與導體之尺寸大小有關。
- 與電路相關的諧振是由於電容性與電感性阻抗元件大小相等且方向相反。能量反覆地在電容器與電感器之間振盪儲能。
- 諧振會增加輻射之強度，因為它會讓輻射器更有效率發射。



空間諧振(Cavity Resonance)

- 空的矩形體，其空間諧振點頻率為：

$$f_{mnp} = \frac{1}{2\sqrt{\epsilon\mu}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2}$$

此處： a, b 及 $c =$ 此空間之三邊長度

m, n 及 $p =$ 整數 (一次只有其中的一個可以為零)

一個矩形空間中，只要其內部之任一尺寸等於半波長之整數倍，就會造成駐波的諧振。



諧振效應影響

- 例:過去在設計時常會故意不將每一個螺絲接地孔接到PCB之接地平面。通常在PCB預留焊點，在稍後測試時若發生問題時再依狀況加上電容、零歐姆電阻、或是ferrite bead。
- 不幸的是，這樣會製造出比其解決掉的還要多的問題出來。因為即使是零歐姆電阻都會增加其電感(阻抗)而使得在高頻時接觸不良。
- 傳統上，工程師會試用不同數值之電容、ferrite，等之組合元件電路元件去微調，某個信號降低了，但是另一個信號頻率反而升高。

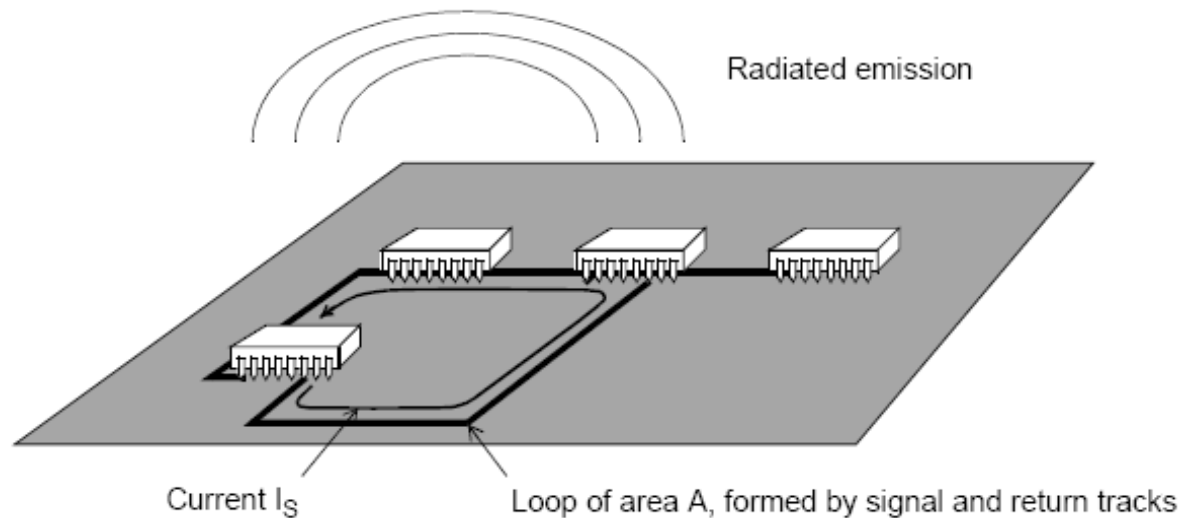


潛在的干擾源

- 非屏蔽外殼產品：
來自PC板的輻射能量必須細心處理，耦合到散熱片及外部線路佈線之能量都可能造成輻射源。
- 屏蔽之產品：
 - 雜訊可以由金屬外殼之開孔輻射出去或是經由外殼之I/O導線傳導出去。但某些輻射並不一定是由縫隙、開孔等輻射，而是經整體外部系統諧振。
 - I/O導線可以直接傳遞信號至機殼之外，故也常會有不必要的信號耦合至I/O導線或連接器之信號腳之上傳到了外部的導線。



Radiated emission from PCB



A: 回路面積 Cm^2
f: 頻率MHz
I_s: 回路電流mA

$$E = 263 \cdot 10^{-12} (f^2 \cdot A \cdot I_s) \text{ volts per metre}$$

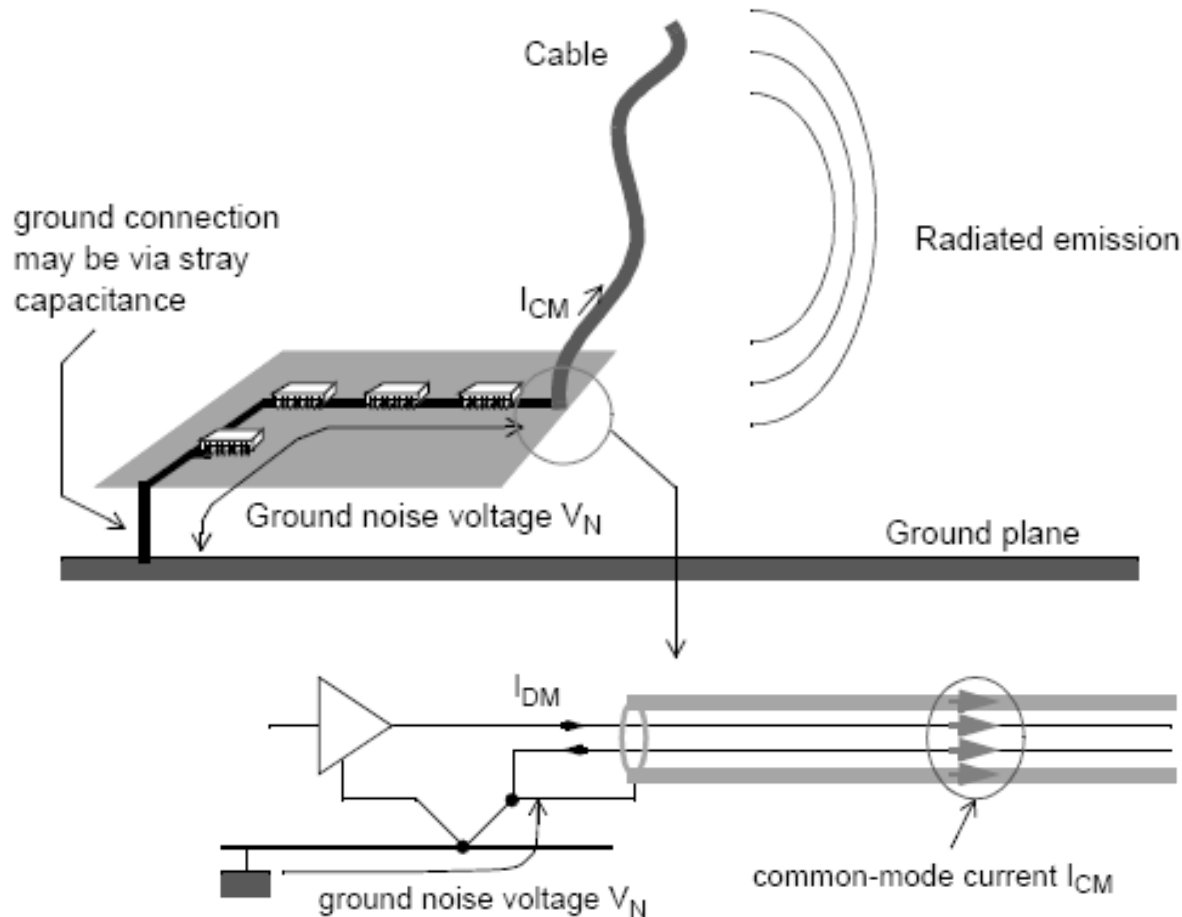
Example: If PCB loop area $A = 10\text{cm}^2$, $I_s = 20\text{mA}$,
 $f = 50\text{MHz}$; then the field strength E at 1 meter
distance is $42\text{dB}\mu\text{V/m}$



Radiation from cables

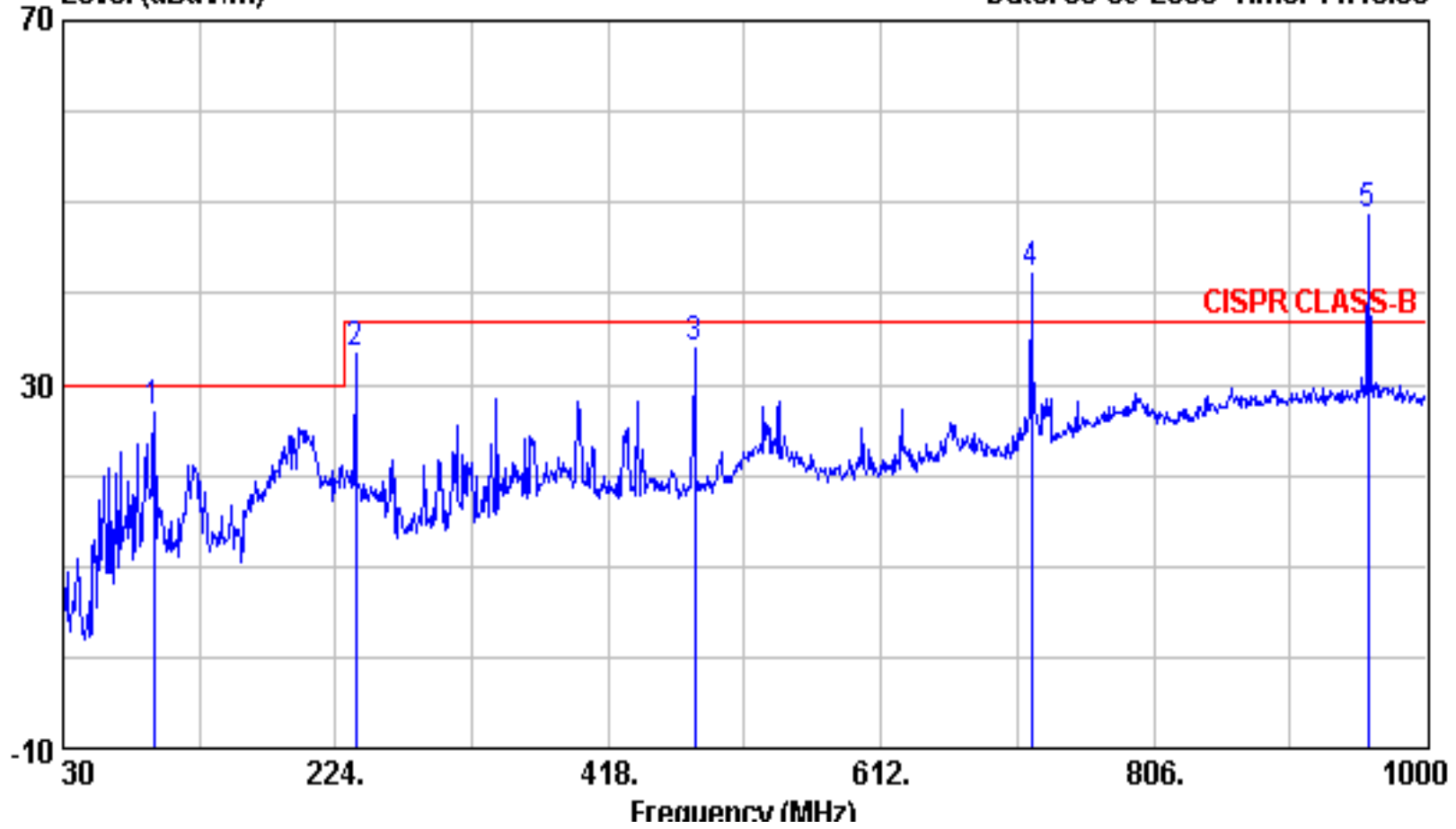
- $E = 1.26 \times 10^{-4} (f \times L \times I_{CM}) \quad \text{V/m}$

L: Cable length (m); I_{CM} : CM Current (mA) . At f MHz





Data: 5 File: C:\Program Files\3\2005年5月\旭邦.EMI (142) Date: 05-09-2005 Time: 14:48:00





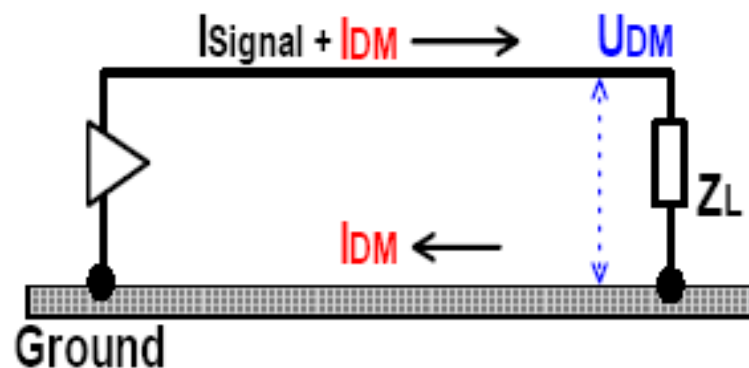
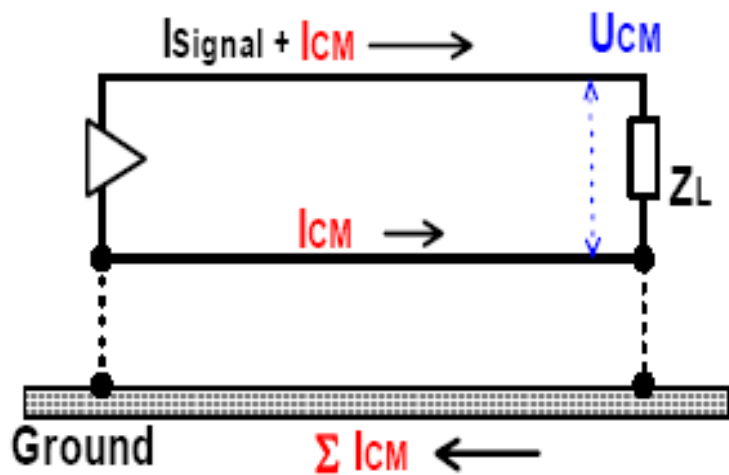
準峰值檢波(QP)

- 準峰值檢波 (quasi-peak detector)
依據規定的電氣時間常數積分的檢波器。當輸入規則性的等幅脈波時，輸出電壓是脈波峰值的分數，且此分數隨脈波重複率遞增，若重複率愈高QP值與輸入信號的Coherence function 趨向=1。



共模與差模

- 差模電壓 (differential mode voltage) : 一組規定的帶電導體任意兩根之間的電壓。
- 共模電壓 (common mode voltage) : 每個導體與規定參考點 (通常是機殼或地) 之間的電壓。

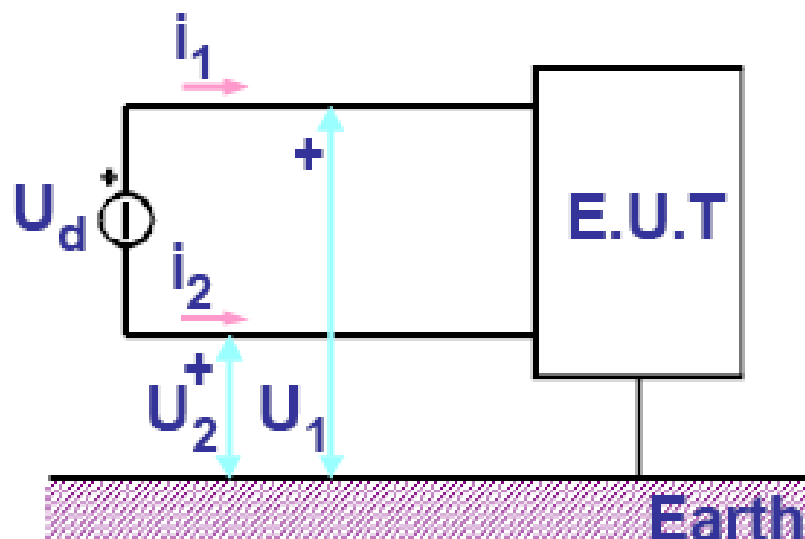




共模與差模電壓

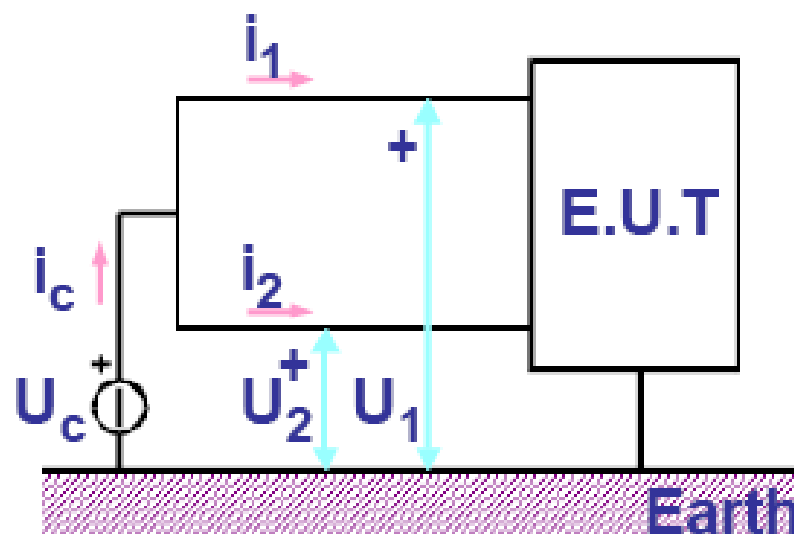
Differential mode

$$U_d = U_1 - U_2, \quad I_d = \frac{I_1 - I_2}{2}$$



Common mode

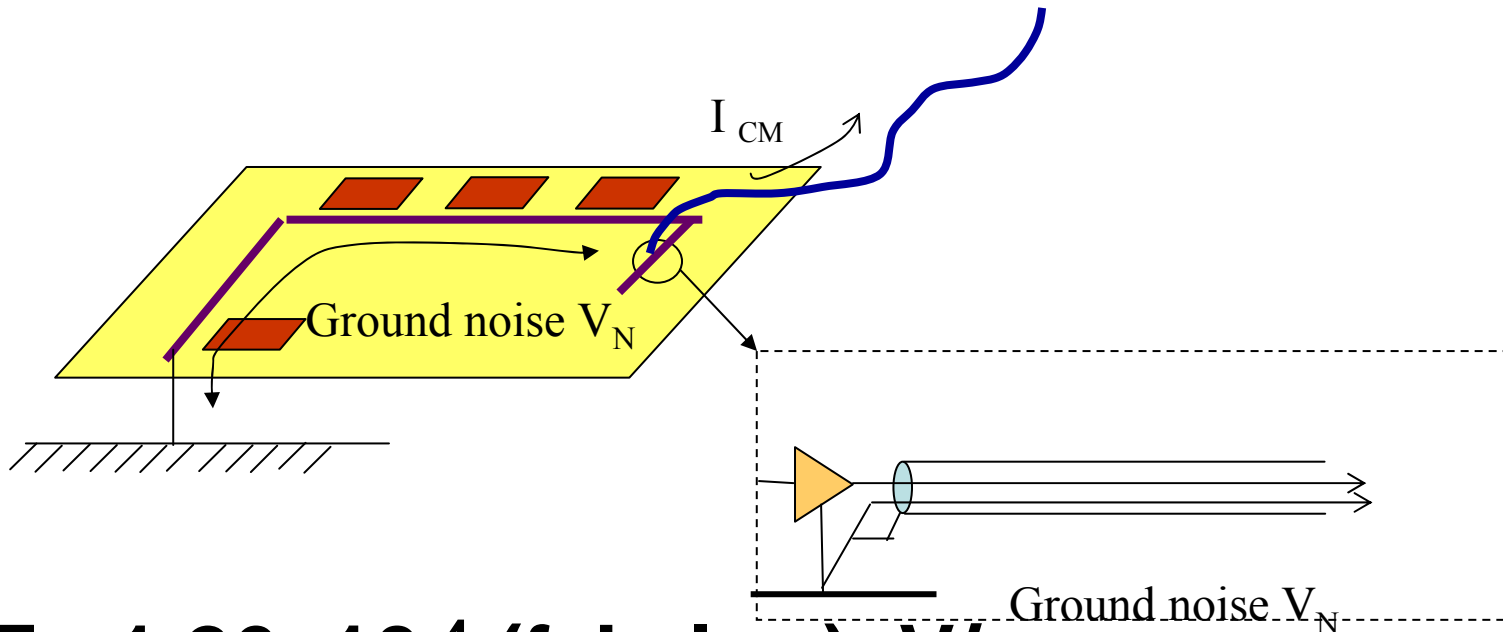
$$U_c = \frac{U_1 + U_2}{2}, \quad I_c = I_1 + I_2$$





Common mode Radiated emission

- Common mode Field strength



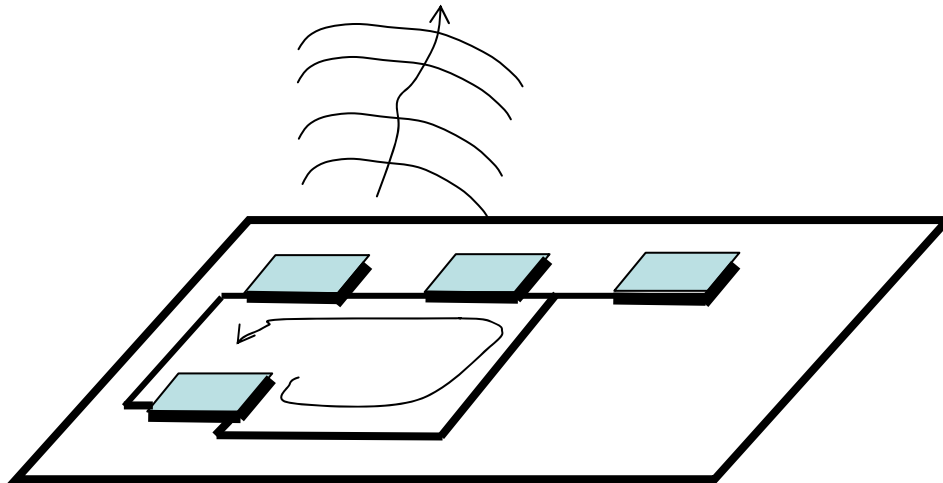
$$E = 1.26 \times 10^{-4} (f \cdot L \cdot I_{CM}) \text{ V/m}$$



Differential Mode Radiated emission

➤ Differential mode field strength

$$E = 263 \cdot 10^{-12} (f^2 \cdot A \cdot I_s)$$



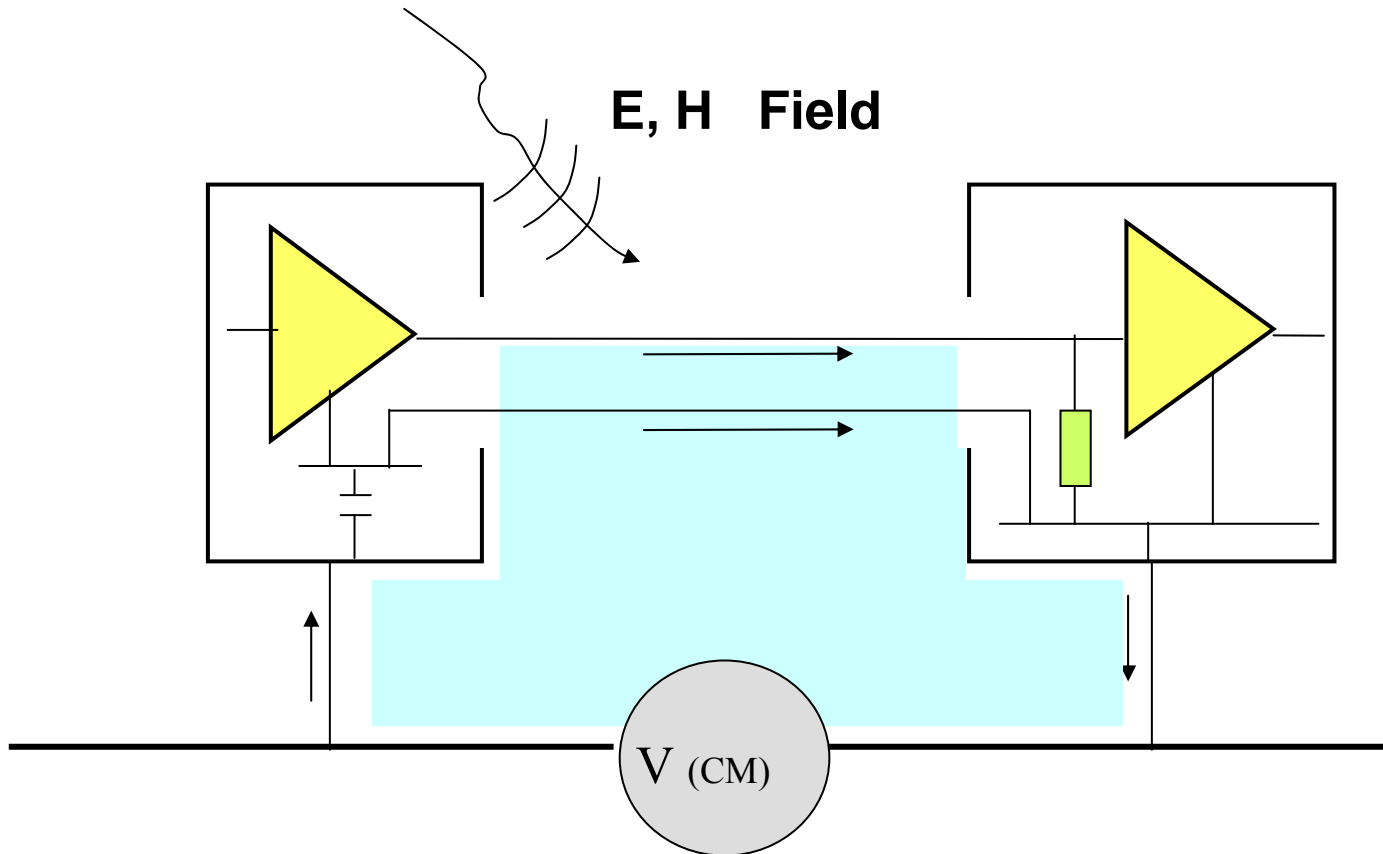
A: loop area

f : frequencies

I_s: Current of each freq.



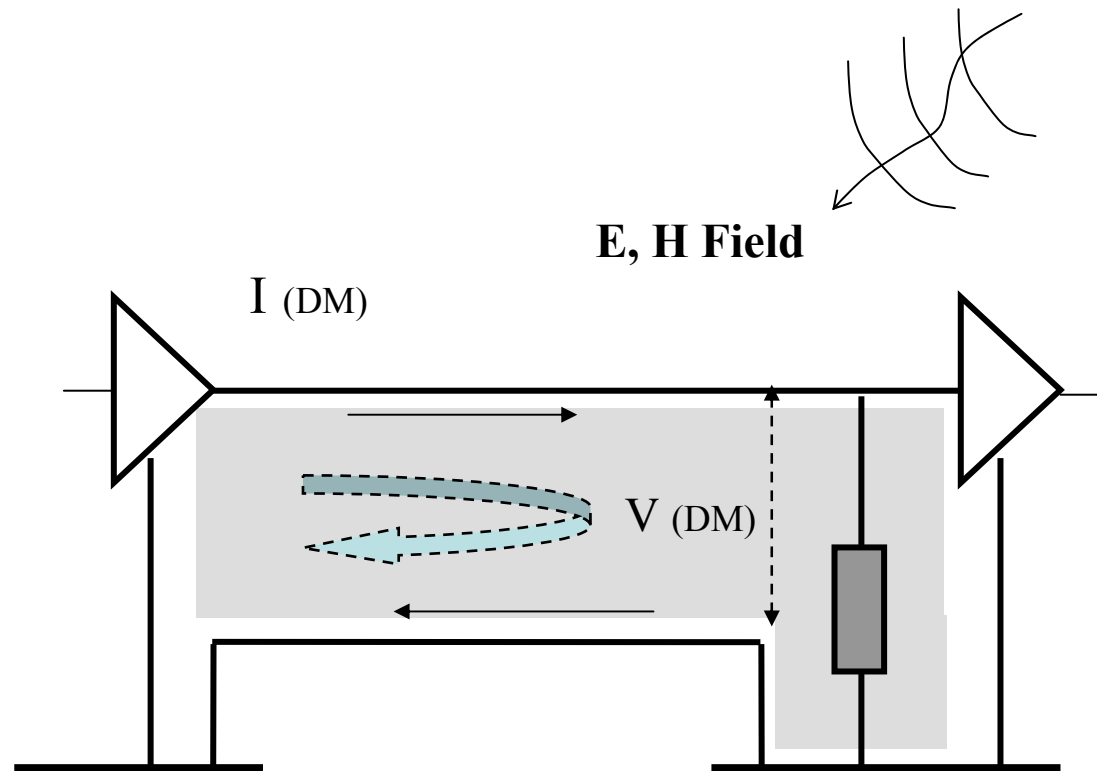
Common mode field loop coupling





- **Field to loop coupling**

Differential mode





輻射電磁場

抗擾性不足的電子產品，如受到輻射電磁場照射會產生共模與差模的耦合干擾。



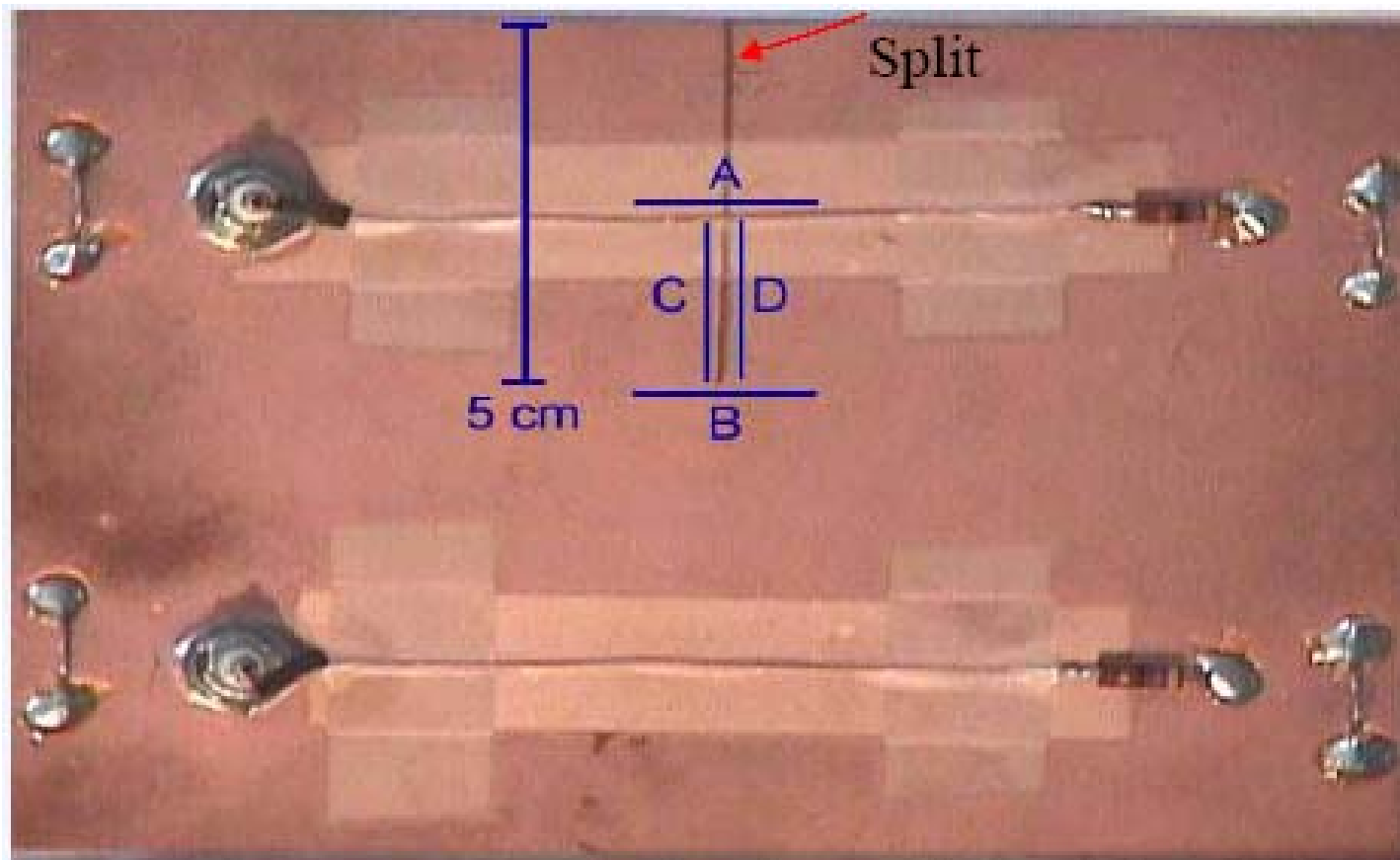


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觀察PCB的Emission

➤ Observation:

Split a 5cm slot on PCB ground plan





Emission on PCB splits

- Effect of slots on PCB Ground plane 1k volt ESD injected onto PCB with and without split

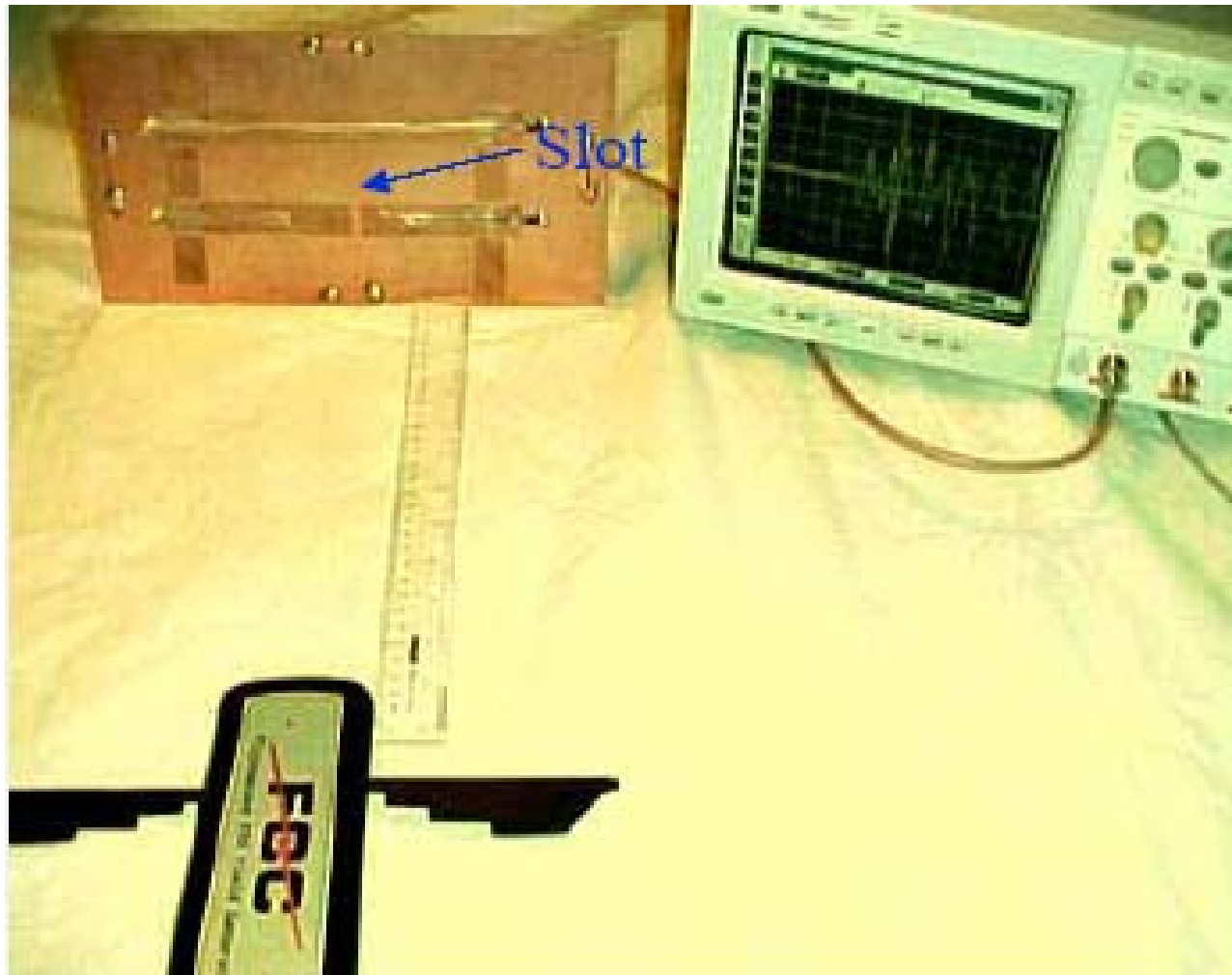


Overall Test Setup... Front View



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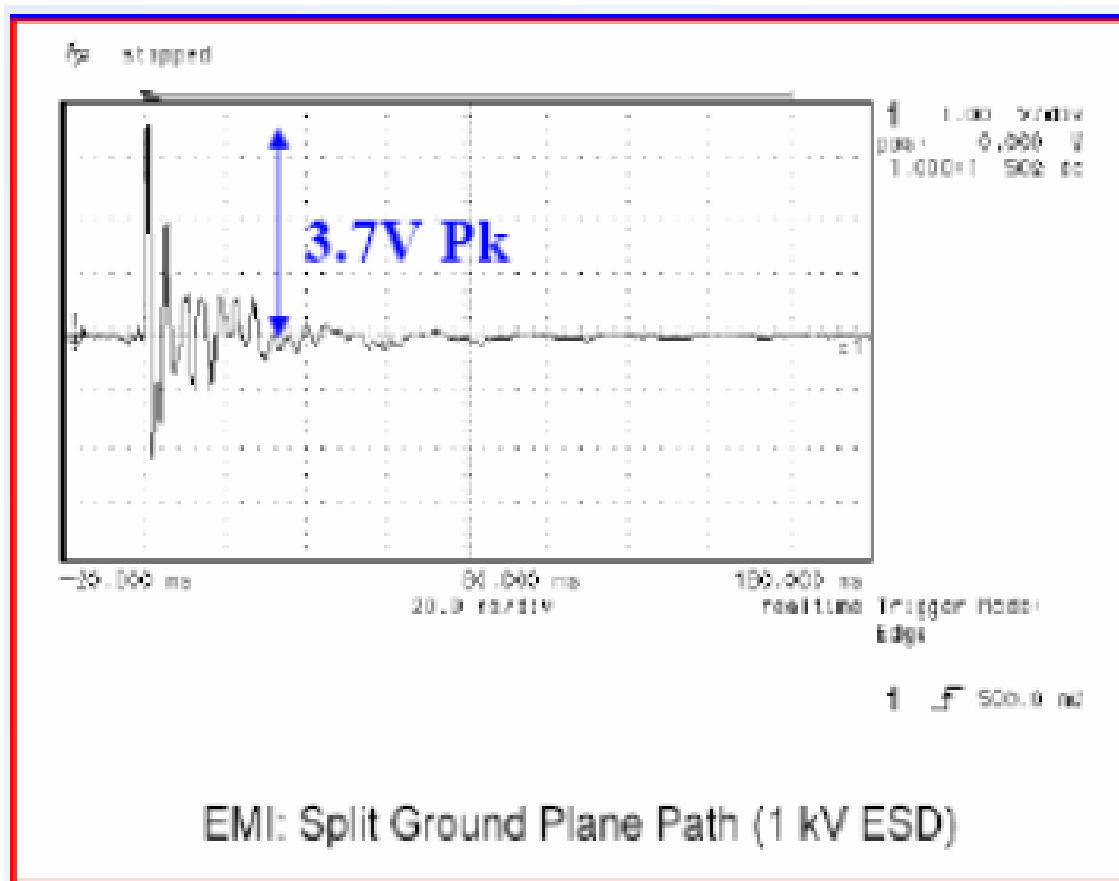
Measurement PCB Emission





Emission of slots on PCB (1)

➤ 跨過切縫的導線輻射

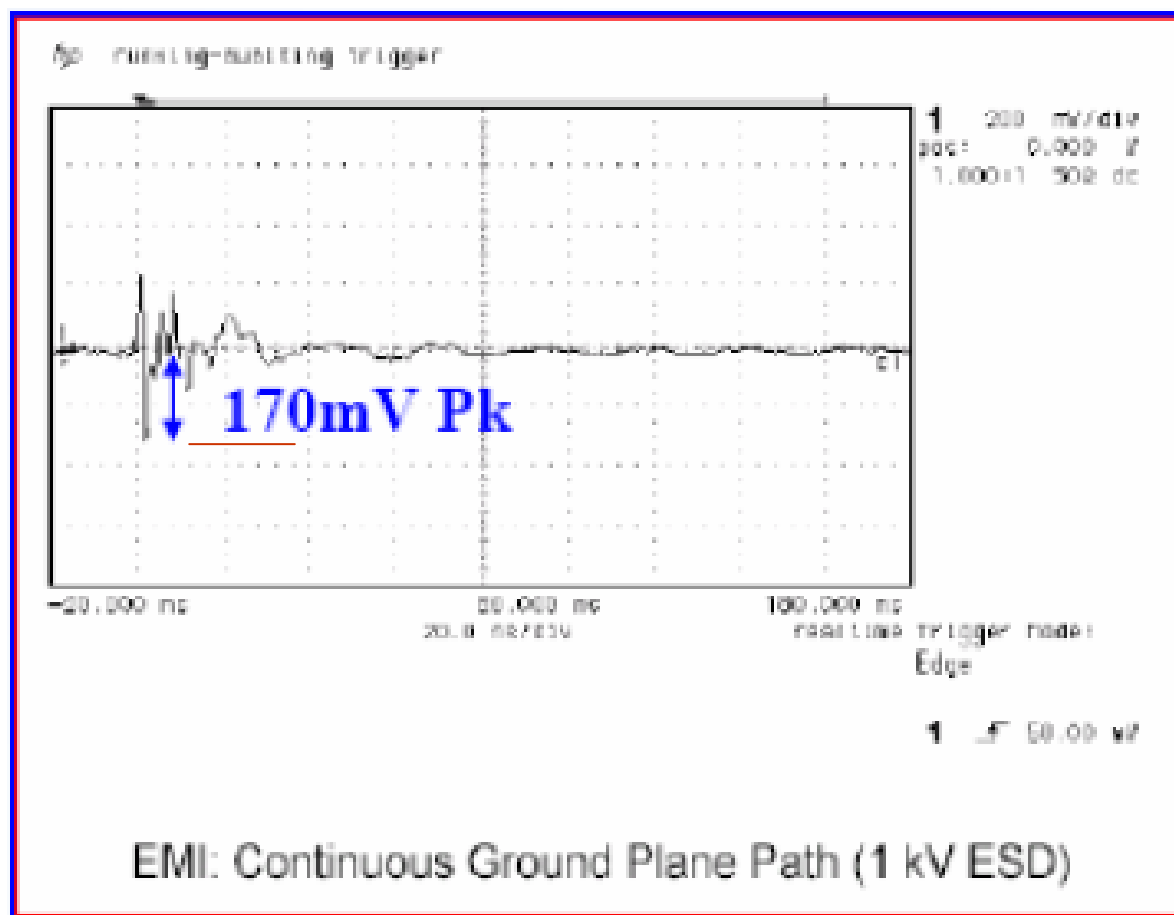


Max. Peak = 3.7V



Emission of slots on PCB (2)

➤ 未跨過切縫的導線輻射



Max. Peak = 170mV

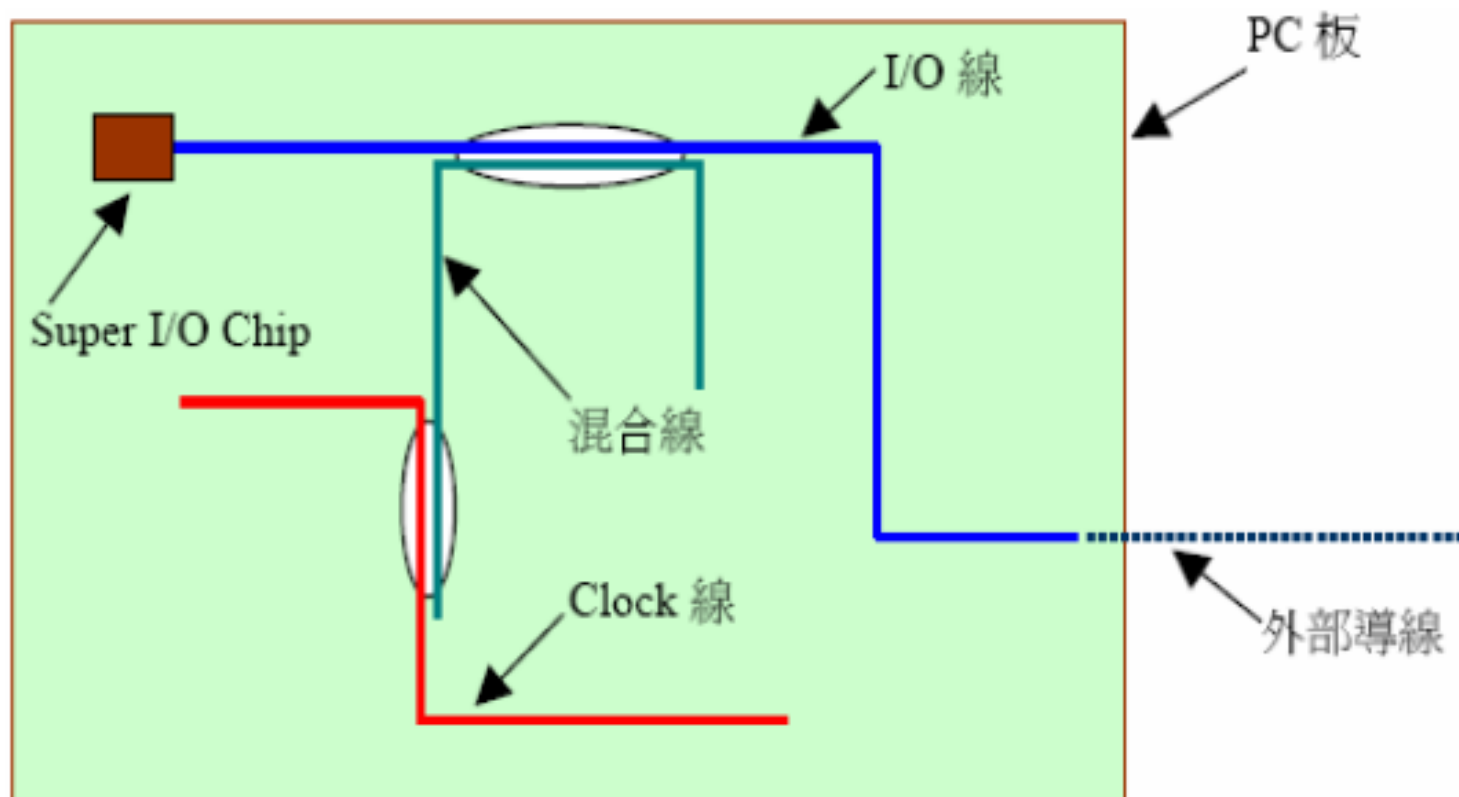


觀察的結論

- 跨越切割縫隙的導線所帶出來的輻射能量遠大於為經過縫隙導線的輻射。
- **di/dt caused EMI**
由於電子設備之電路元件工作時瞬間電流改變『di/dt』，未做處治而導致雜訊散射干擾。



這種佈局勢必產生很多的Emission





Antenna Factor (AF)

- 天線因素(Antenna Factor)

$AF = E / V$; (E 電場 V/m, V 天線端電壓)

$AF_{dB} = 20 \log (E/V) = E_{dB} - V_{dB}$

$$AF = \frac{9.73}{\lambda \sqrt{g}} \quad ; \quad g \text{ 表示線性增益}$$

- Antenna Gain & AF in 50 Ω system

$$G_{dB} = 20 \log (f_{MHz}) - AF_{dB(m^{-1})} - 29.79$$



- 結語：
- 產品測試認證是上市前必須程序。
- **Design in**的觀念就是把測試可能出現的問題預先作防範設計。
- 在設計前先瞭解法規標準及測試要求，有助於產品設計過程及週期管控。



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Q & A



By JT Chen



RF Capability

- ❑ ARIB STD-T66, ARIB STD-T71(日本無線區域網路、藍芽產品測試)
- ❑ DGT LP0002 (台灣低功率射頻產品測試)
- ❑ EN 300 220(短距離低功率射頻產品測試(其操作頻率介於25MHz to 1000 MHz))
- ❑ EN 300 328(2.4 GHz展頻調變技術產品測試)
- ❑ EN 300 330(短距離低功率射頻產品測試(其操作頻率介於9 kHz to 25 MHz))
- ❑ EN 300 422(無線麥克風產品測試(其操作頻率介於25 MHz to 3 GHz))
- ❑ EN 300 440(短距離低功率射頻產品測試(其操作頻率介於1 GHz to 40 GHz))
- ❑ EN 301 893(5 GHz無線區域網路產品測試)
- ❑ EN 301 489-1&-3& 4 & 7 & 9& 17 & 24(射頻產品共同技術要求電磁相容檢測)
- ❑ FCC Part 15 Subpart C & E,and 加拿大 RSS-210... 等(意圖輻射裝置測試)





InterOcean EMC Technology Corp.

Automobile (ESA) Testing Lab.

宇海科技在EMC領域具有多年認證測試及申請經驗，可協助汽機車零組件直接在臺灣測試，節省遠赴國外測試之費用，提升產品快速上市競爭力，特別是產品需修改時，宇海超過20年之EMC修改技術團隊更可協助找出EMC問題。

服務項目：

- 歐盟E/e Mark: R10.2 & EU Directive 2004/104/EC測試認證。
- 國際及各國法規測試服務：
CISPR 12; CISPR 25; ISO-7637;
ISO-11452; ISO-10605; SAE; JASO; D001。
- 各大車廠法規測試服務: 28400NDS;
28401NDS02; ES_X82010;
ES-XW7T-1A278-AB; GMW3097
GMW3100; GS95002...等

❖ 盧森堡交通部E/e 13 及 TUV Nd E/e4 認可實驗室
By JT Chen





InterOcean EMC Technology Corp.

宇海科技股份有限公司

- 如果您有任何法規認證申請或產品測試修改技術上的相關問題，歡迎與我們聯繫：

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業務人員：分機239 Peter 倪孔光

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