Electromagnetic Compatibility (*EMC*)

Introduction about

Earthing and Grounding

Agenda

- *Earthing and Grounding*
  - Safety ground
- Principles and Practice of Earthing
- Precautions(事先注意事項) in Earthing
- Measurement of Ground Resistance
- System Grounding for EMC
- Circuit Ground
- Cable Shield Grounding
- Isolate

Earthing and Grounding

- A ground is normally defined as an equipotential point or plane that serves as a reference for a circuit or system.
  - This definition can’t represent grounds in a practical system because they are not equipotential.
- *A signal ground is a low-impedance path for current to return to the source.*
  - It is “current concept” of a ground that can really show the relationship between grounding and EMC problems.
  - To design a ground, it is important to know how the current flows.

Earthing and Grounding

- An ideal electrical earth is the soil having zero potential in which a rod, or wire of electrically conducting material, is driven to *provide a low (ideally zero) impedance sink for unwanted currents.*

Refer : for the definition of ground resistance

- An ideal electrical ground is *a low-impedance plan at a reference potential* (often 0V with respect to earth) to which all the voltages in systems and circuits can be related.
  - If the ground is connected to the earth through a low impedance path, it may be called an earth ground.

Earthing and Grounding

- *"Grounding" is a technique that provides a low-resistance path* between electrical or electronic equipment and the earth or common reference low-impedance plane to bypass fault current or EMI signal.
  - Safety and EMI concern both

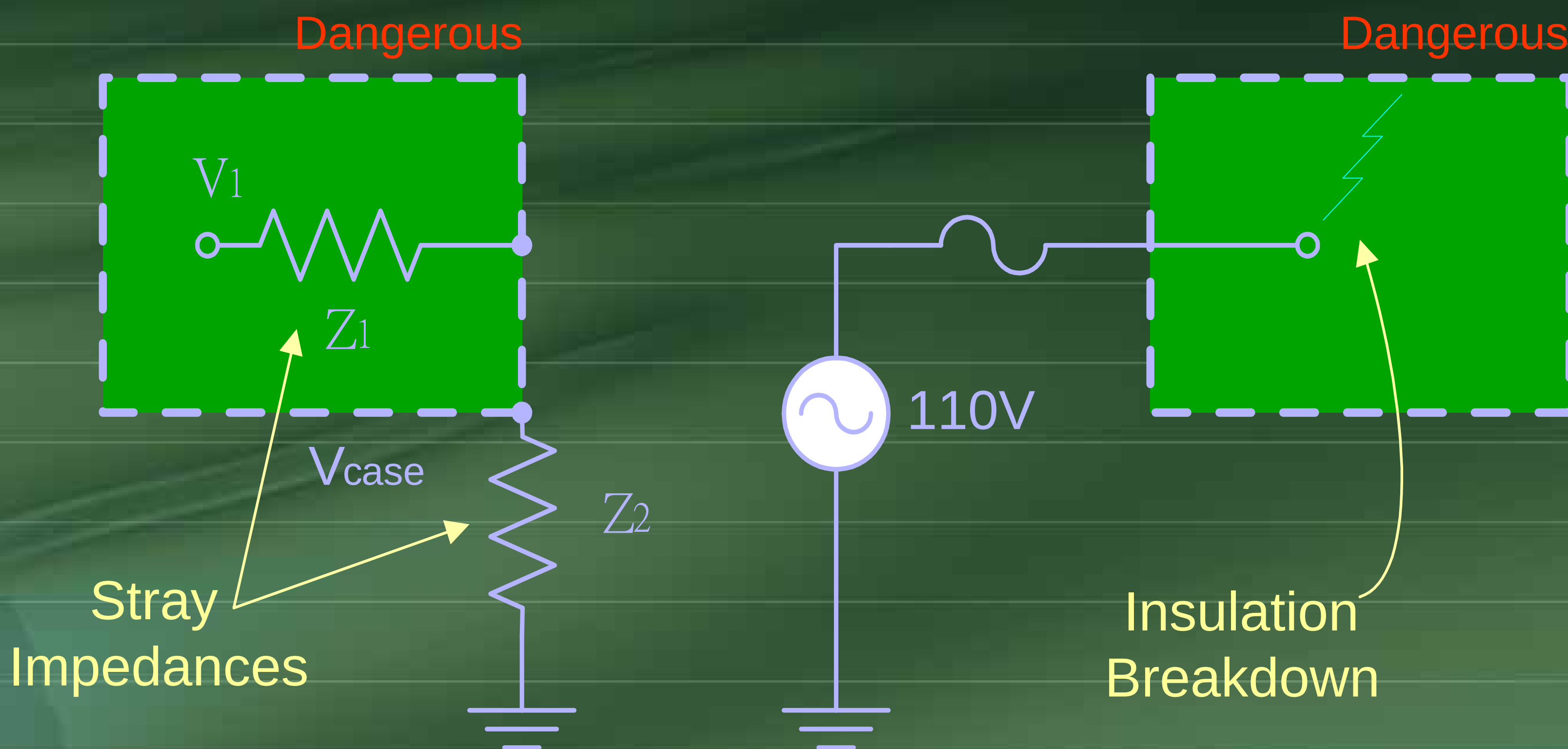
Soil type	Resistivity (Ω/cm)
Wet organic soil	10^3
Moist(微濕的) soil	10^4
Dry soil	10^5
Bedrock (岩床)	10^6

Electric Shock Hazardous(有危險的) Current Level

60 Hz current (mA) AC	Direct current (mA) DC	Effects
0.5 ~ 1.5	0~4	Perception (有感)
1 ~ 3	4~15	Surprise
3 ~ 22	15~88	Reflex action
21 ~ 40	80~160	Muscular inhibition
40 ~ 100	160~300	Respiratory block (呼吸困難)
Over 100	Over 300	Fatal (掛點)

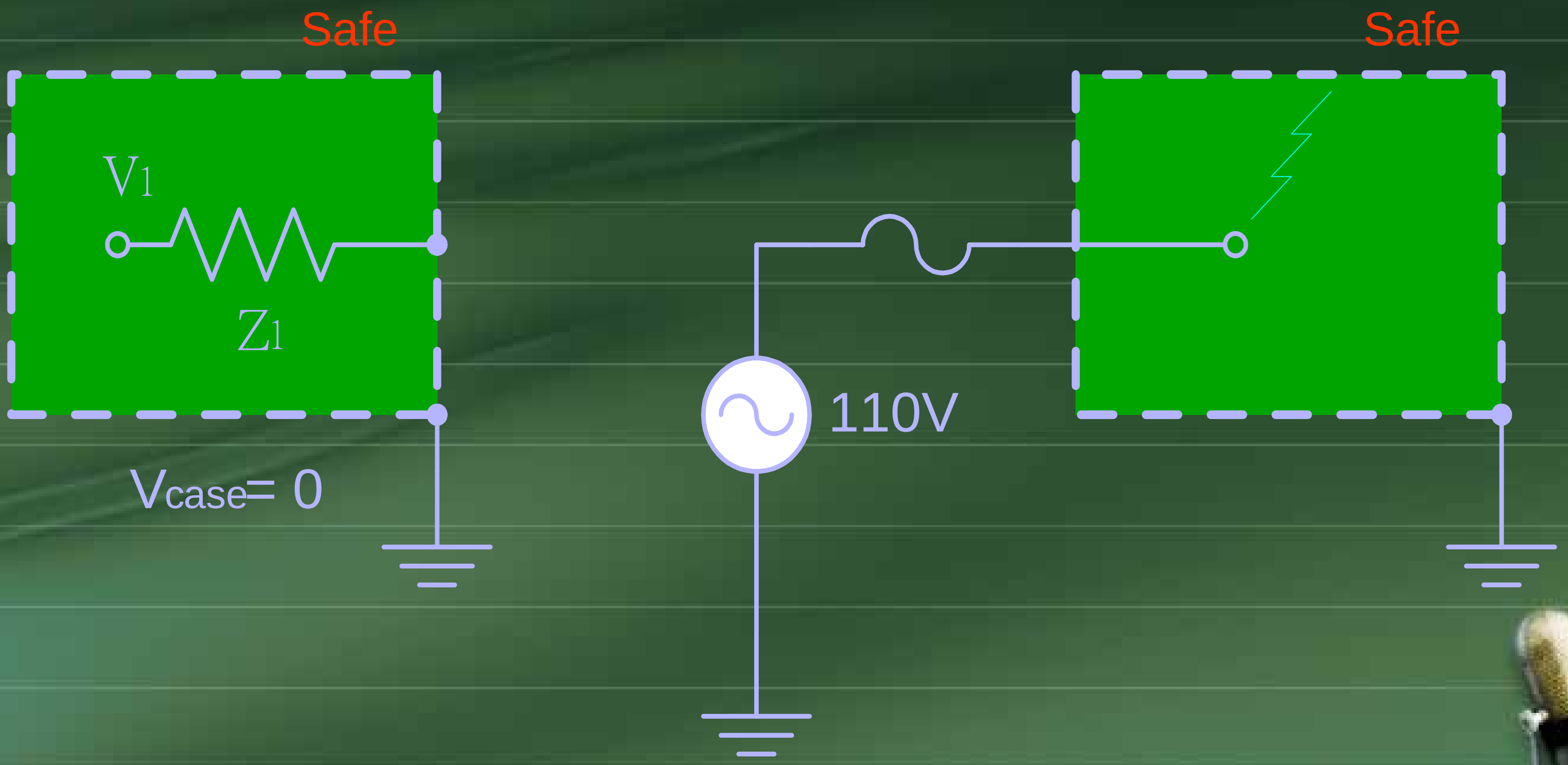
- At frequencies above 300Hz, the current levels required to produce the above effects will increase due to skin effect.

Unsafety Ground

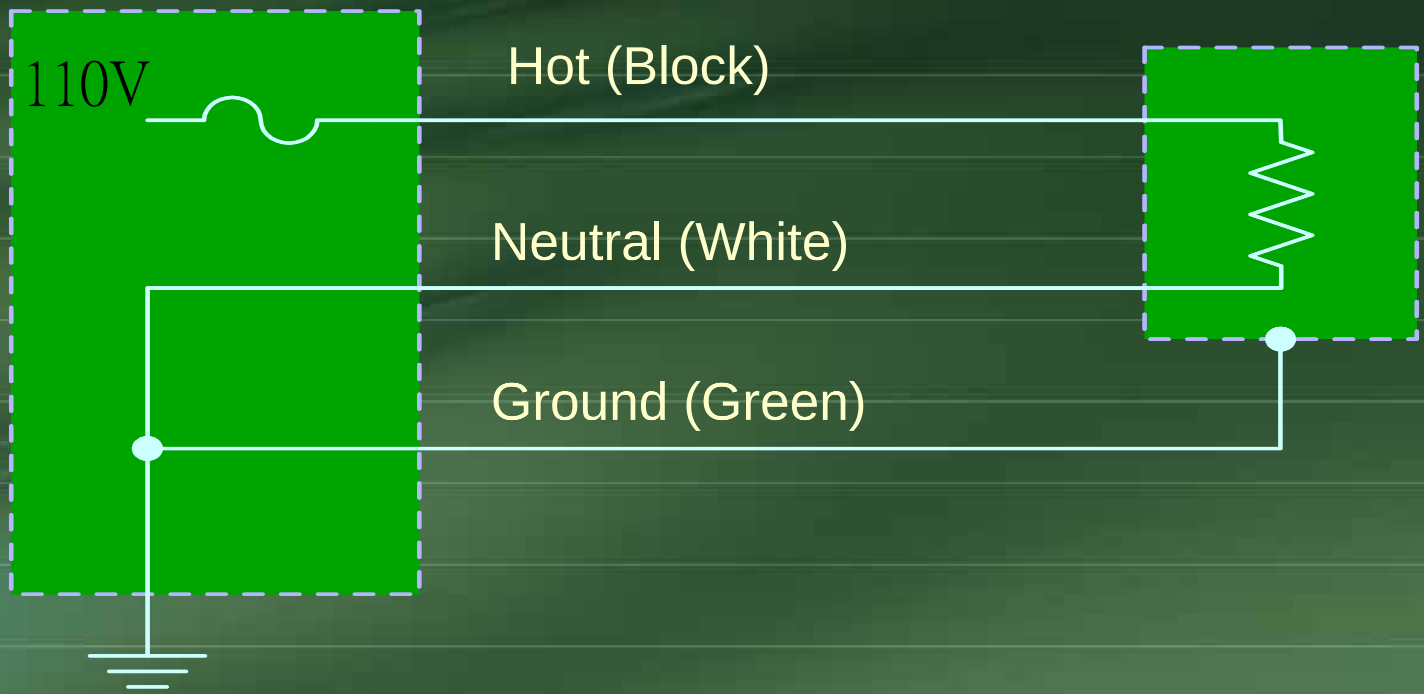


$$V_{case} = \frac{Z_2}{Z_1 + Z_2} \cdot V_1$$

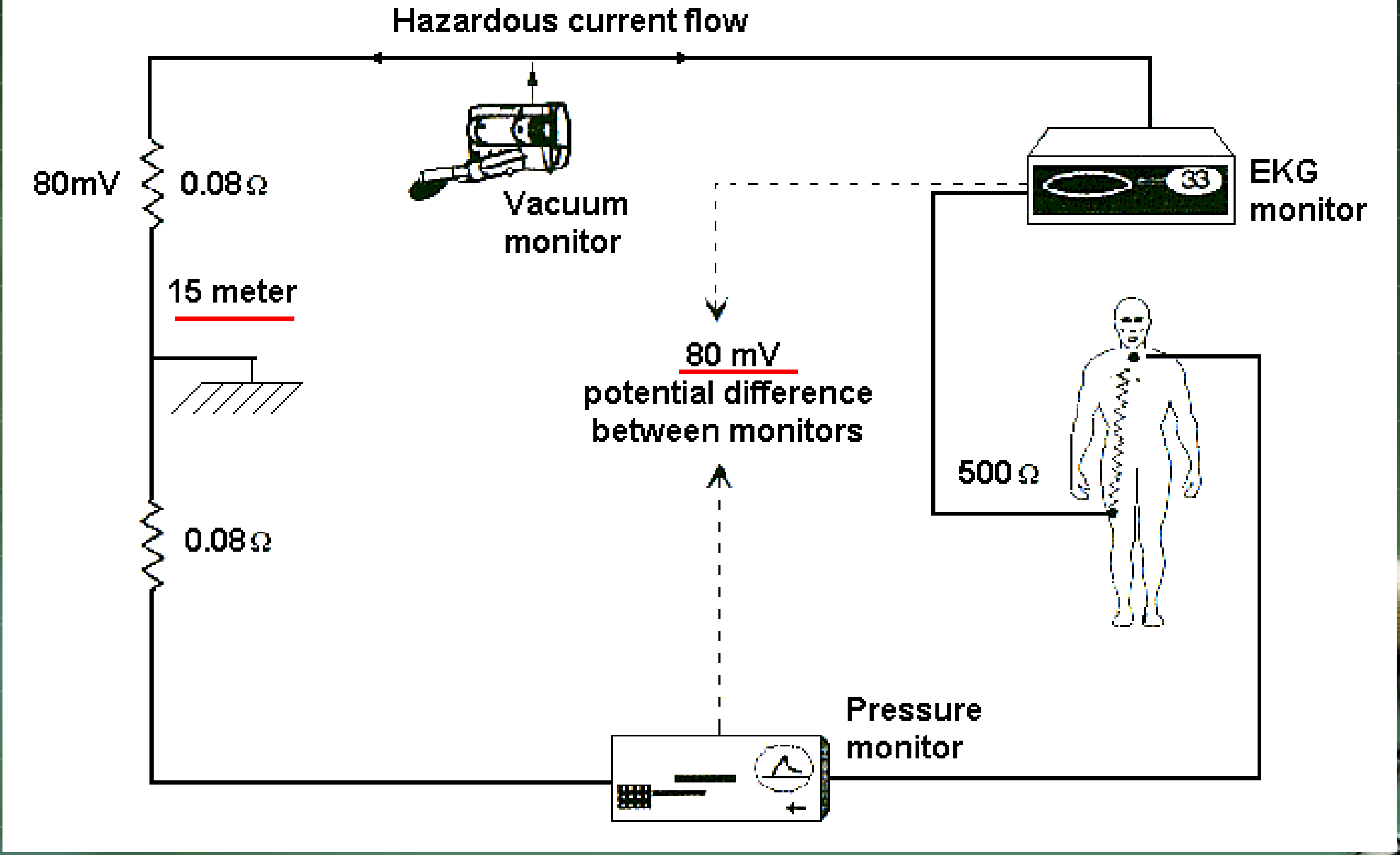
Safety Ground



Safety Ground



Example for Improper Grounding



Agenda

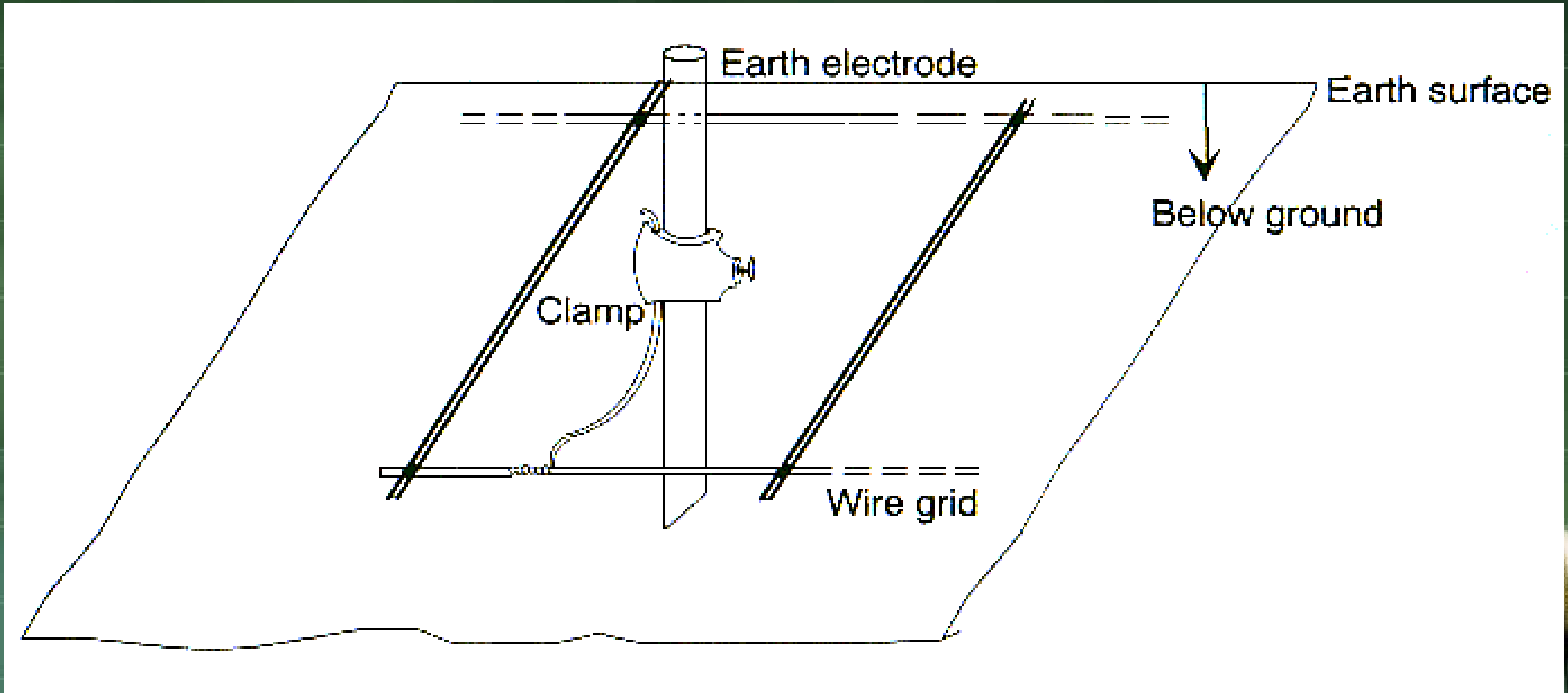
- Earthing and Grounding
- *Principles and Practice of Earthing*
- Precautions in Earthing
- Measurement of Ground Resistance
- System Grounding for EMC
- Circuit Ground
- Cable Shield Grounding
- Isolate

Principles and Practice of Earthing

- The voltage gradient(電壓梯度) near the earth can be reduced by burying a grid beneath (在...之下) the earth, surrounding the earth electrode, and connecting with the ground rod or rods.
  - Wire grids or meshes(網) of large area embedded in the earth at a convenient depth (how deep?)
  - Use enough material in an earth electrode(電極) to prevent excessive local heating when large currents flow

Principles and Practice of Earthing

A combination of buried grid and vertical rod ground



Principles and Practice of Earthing

A technical definition of ground resistance

Current density

$$J = \frac{I}{2\pi \cdot r^2}$$

At point r, the electric field

$$E = \rho \cdot J = \frac{\rho \cdot I}{2\pi \cdot r^2}$$

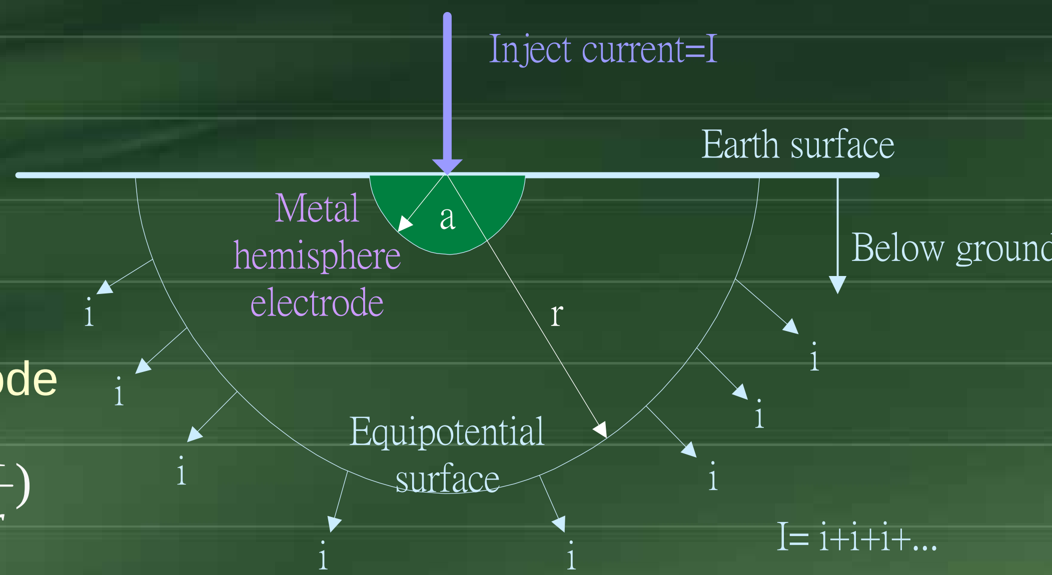
Voltage at the surface of the electrode

$$V = \int_a^r \vec{E} \cdot d\vec{r} = \frac{\rho \cdot I}{2\pi \cdot r}\left(\frac{1}{a} - \frac{1}{r}\right)$$

In the limits $r \to \infty$;

$$V = \frac{\rho \cdot I}{2\pi \cdot a}$$

The ground resistance is $R = \frac{V}{I} = \frac{\rho}{2\pi \cdot a} = \rho \cdot \frac{l}{A}$

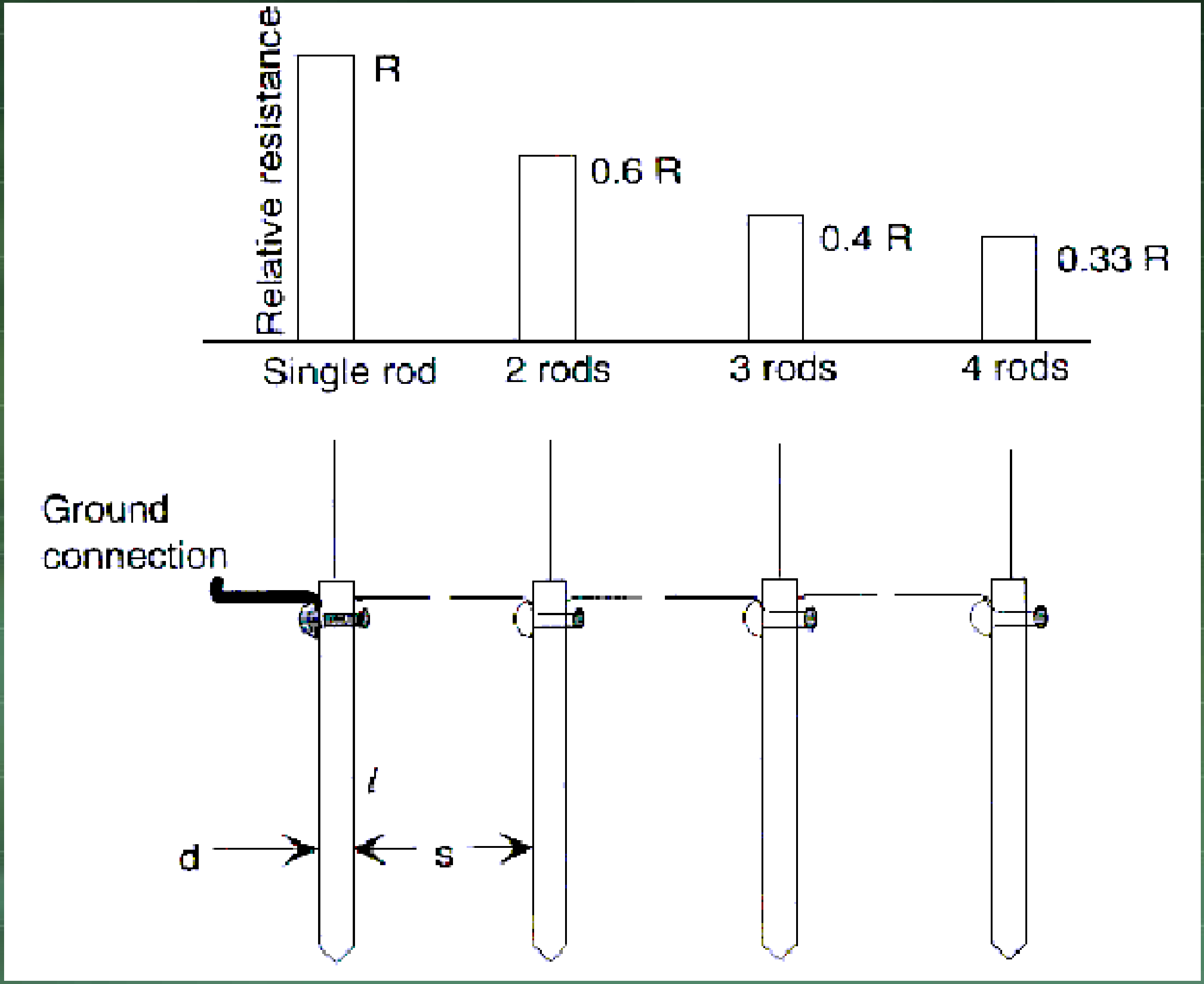


Back

ρ Is the resistivity of the conducting medium

Principles and Practice of Earthing

A linear array of vertical ground rods



Principles and Practice of Earthing

- The resistance to earth of an electrode is directly proportional to soil(土壤) resistivity and inversely proportional to the total area of contact with the soil.

$$R = \frac{V}{I} = \frac{\rho}{2\pi \cdot a}$$

- The most cost-effective method of reducing ground resistance is to reduce soil resistivity, not adding rods or grids.
  - Increase soil moisture(水份) content (typically 30%)
  - Adding ionizable salt(離子鹽) content

Principles and Practice of Earthing

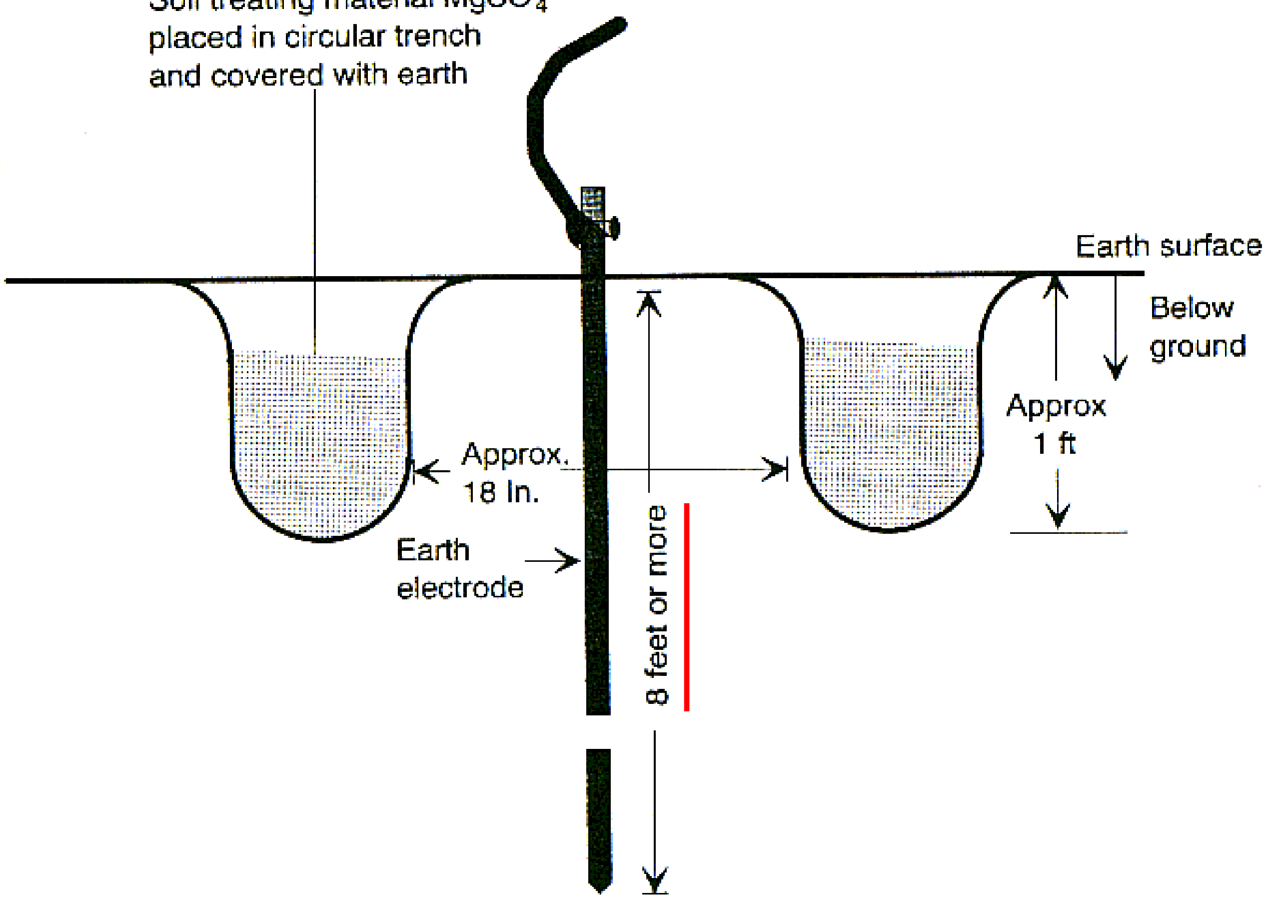
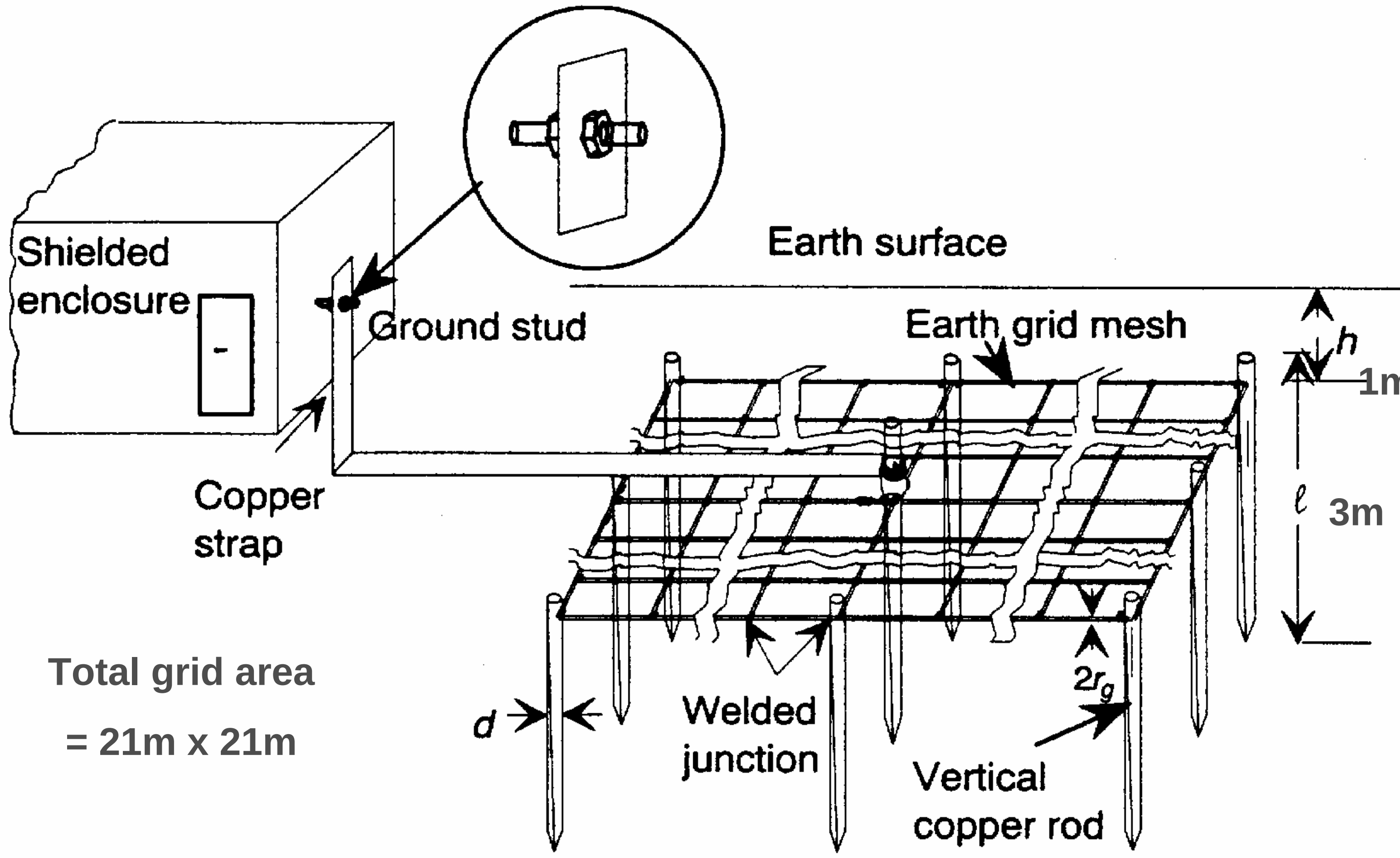


Figure 9-8 Trench method of soil treatment for grounding

Back

Principles and Practice of Earthing

Design Example of a Shielded Chamber



Total grid area

= 21m x 21m

Agenda

- Earthing and Grounding
- Principles and Practice of Earthing
- *Precautions in Earthing*
- Measurement of Ground Resistance
- System Grounding for EMC
- Circuit Ground
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Precautions of Earthing

- Cathode(陰極) protection for corrosion(鏽蝕)
  - Proper power-system ground reduces the current flowing return between ground electrodes.
  - Using metals with low electrochemical activity; it is practical to use plating(鍍層) such as tin over copper.

Metals	EMF(V)
Aluminum	+1.60
Zinc(鋅)	+0.76
Iron	+0.44
Nickel(鎳)	+0.25
Tin(錫)	+0.14
Lead(鉛)	+0.13
Copper(銅)	-0.35
Silver(銀)	-0.80
Gold	-1.50

Measurement of Ground Resistance

- Soil is typically non-homogeneous, the best way to determine the resistivity of soil at a specific location is to measure it.

$$R = \frac{V_{13}}{I_{12}}$$

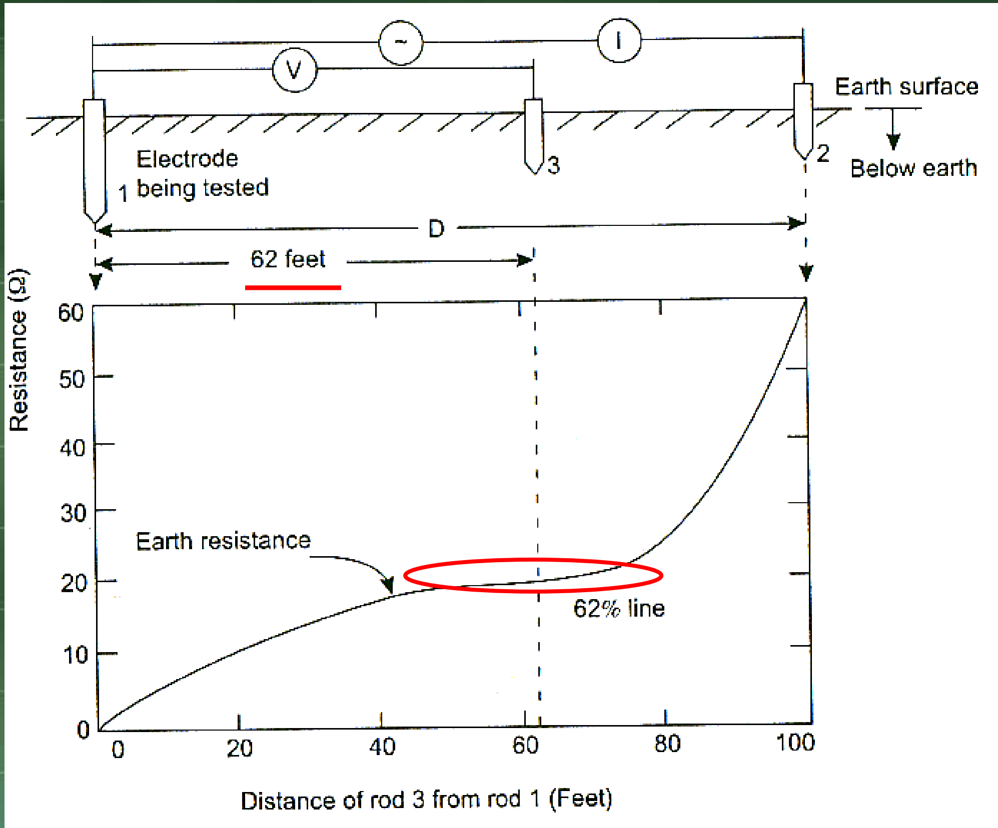


Figure 9-9 Principle of earth resistance test

Measurement of Ground Resistance

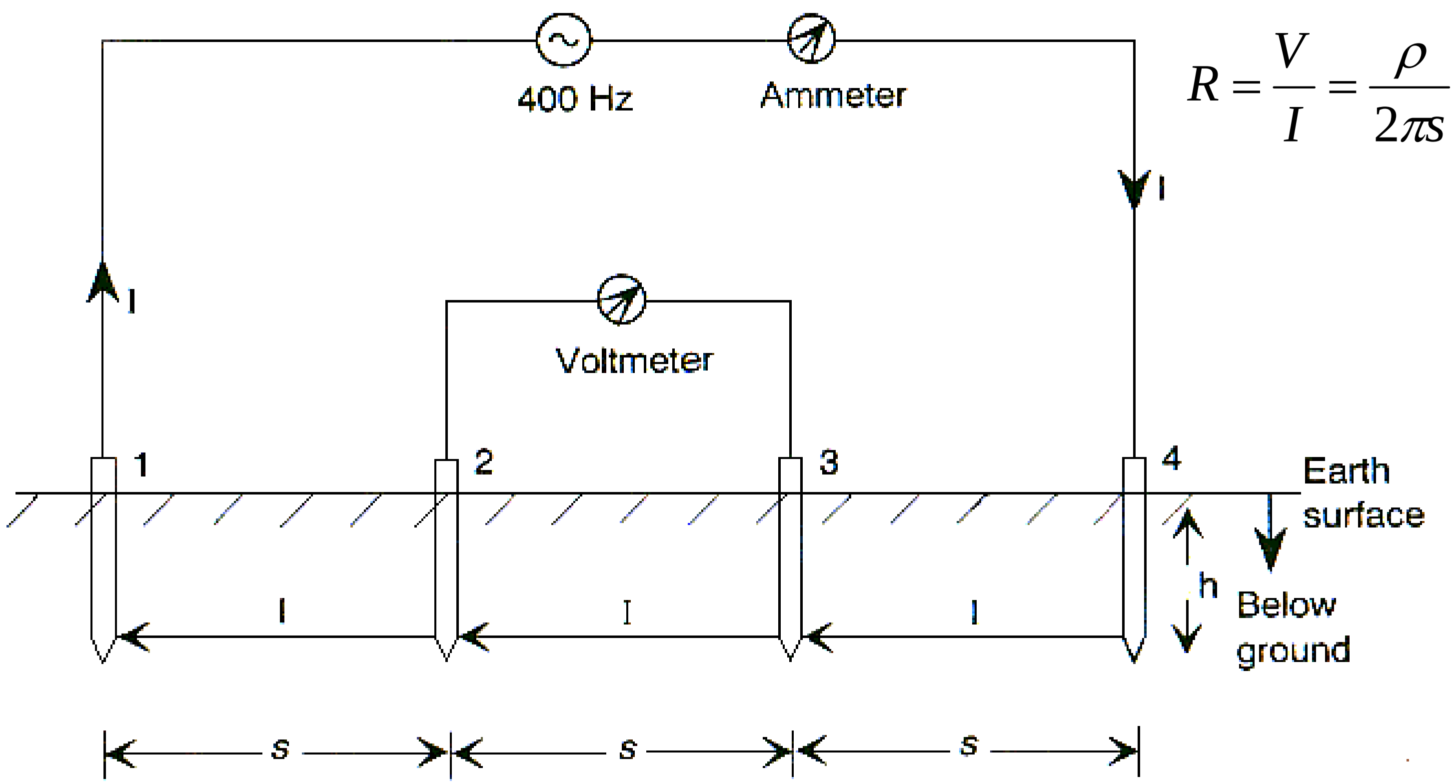


Figure 9-10 Four-terminal method of measuring earth resistivity

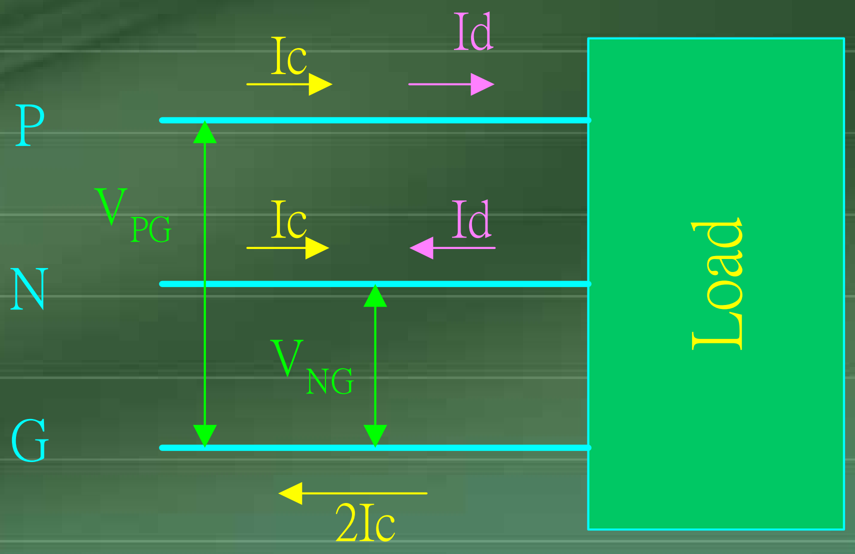
Agenda

- Earthing and Grounding
- Principles and Practice of Earthing
- Precautions in Earthing
- Measurement of Ground Resistance
- *System Grounding for EMC*
  - Impedance of Ground
  - System Grounding Type
  - Guarded Meter
- Circuit Ground
- Cable Shield Grounding
- Isolate

System Grounding for EMC

CM / DM

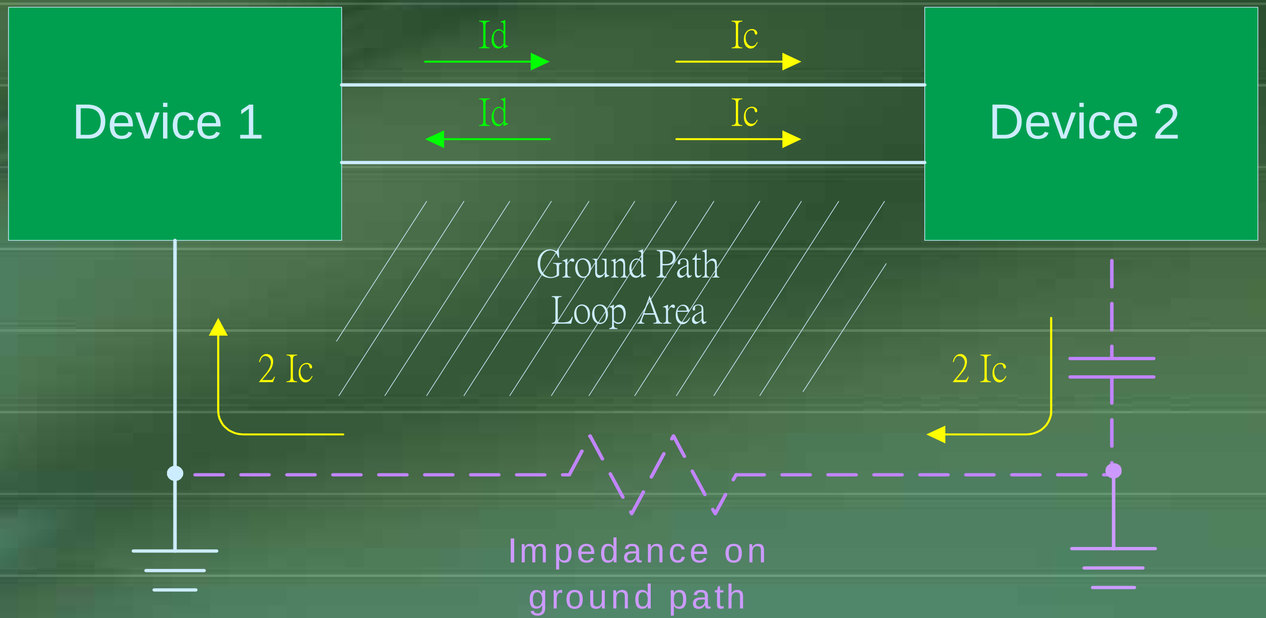
- Common-Mode(CM) – Balance Circuit
  - Cause of ground impedance in design or measurement system
- Differential-Mode(DM) – Unbalance Circuit
  - Cause of internal circuit operation or unbalance



System Grounding for EMC

Impedance of Ground

- The effect of improper grounding
  - Induce "ground bounce" (CM Noise) to the system
    - Larger impedance on grounding path
    - More loop area caused by grounding path



System Grounding for EMC

- EMC grounding techniques are not straightforward because the equipment and system performance is very variable.
- Two levels of concern about grounding are important :
  - Internal circuit level
  - System level

System Grounding for EMC

System Grounding Type

- System Grounding Network
- Single-Point Grounding
  - *Well for low frequencies* (below 1MHz)
- Multipoint Grounding
  - *Well for high frequencies* (above 10MHz)
- Hybrid Grounding
  - *Well for both low and high frequencies*
- Floating Ground

System Grounding for EMC

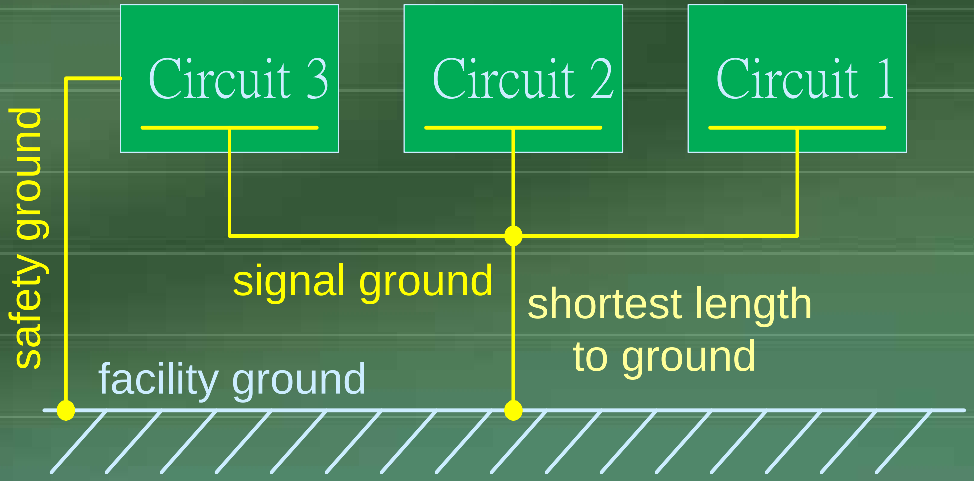
System Grounding Type

- System Grounding Network
  - Selected based on frequency range of intended signals and system configuration
  - Low frequency circuits can be grounded using wires, whereas high-frequency / high-speed logic circuits must have low-impedance interference-free return paths in the form of conducting or coaxial(同軸) cables.

System Grounding for EMC

System Grounding Type

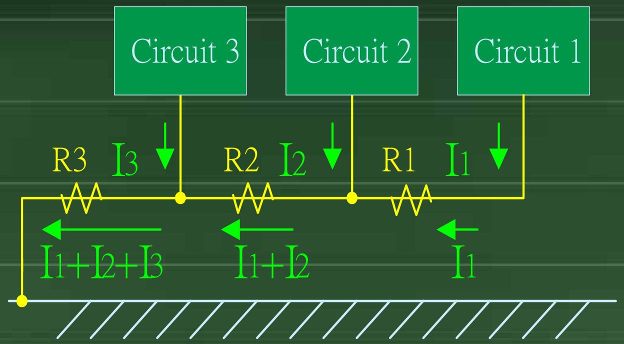
- Single-Point Grounding
  - Each subsystem is grounded to separated ground planes, and these individual ground planes are finally connected by *the shortest path to the system ground point*.
  - The scheme operates better at low frequencies, and it *avoids common-mode impedance coupling*.



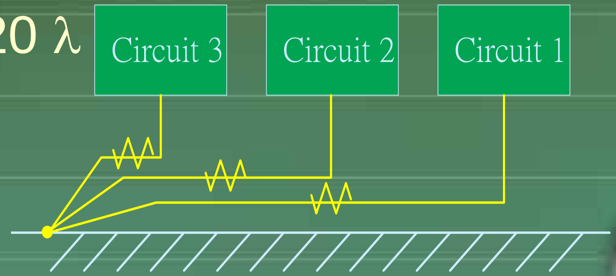
System Grounding for EMC

System Grounding Type

- Single-Point Grounding Example
  - Serial single-point grounding
    - *General worse* methodology
    - R3 should be as less as possible
    - Sensitive circuit or noise source should be placed on circuit 3

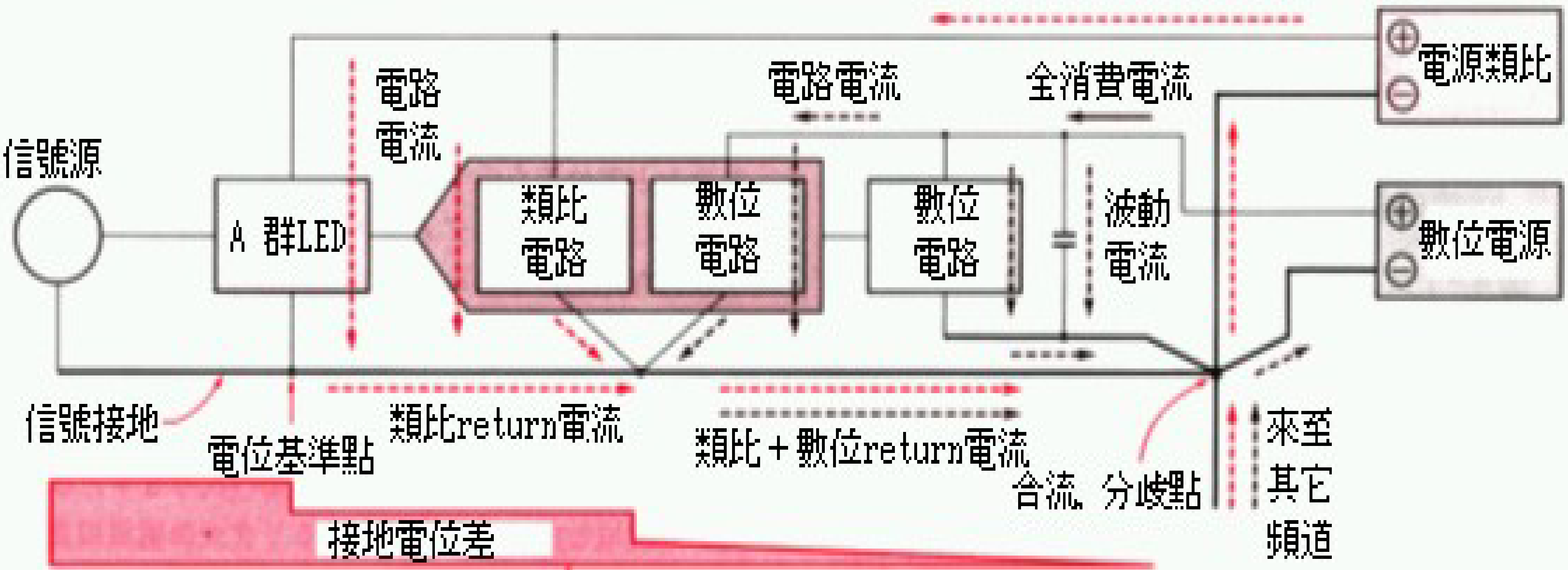


  - Parallel single-point grounding
    - Good methodology for low bandwidth application
    - *Worse for RF application*, because the long wire will induce inductance *(ground impedance)* and *antenna effect*
    - Keep the wire shorter than 1/20 λ



System Grounding for EMC

Serial Single-Point Grounding



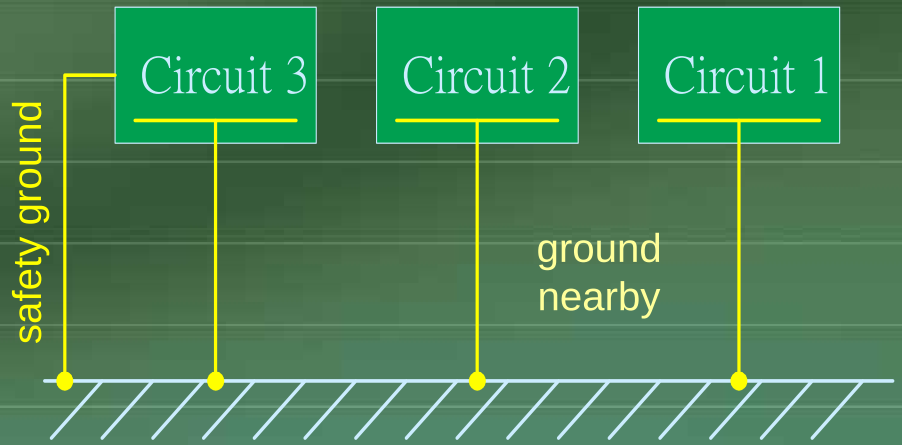
即使接地電位有變化，只要抓取信號的電位基準點與信號線是在相同接地電位上，就可以利用電位差抵銷誤差

這例子雖然堪用於24bit ADC，但不是最理想的數位與類比線路分地配置，用parallel single-point會更好

System Grounding for EMC

System Grounding Type

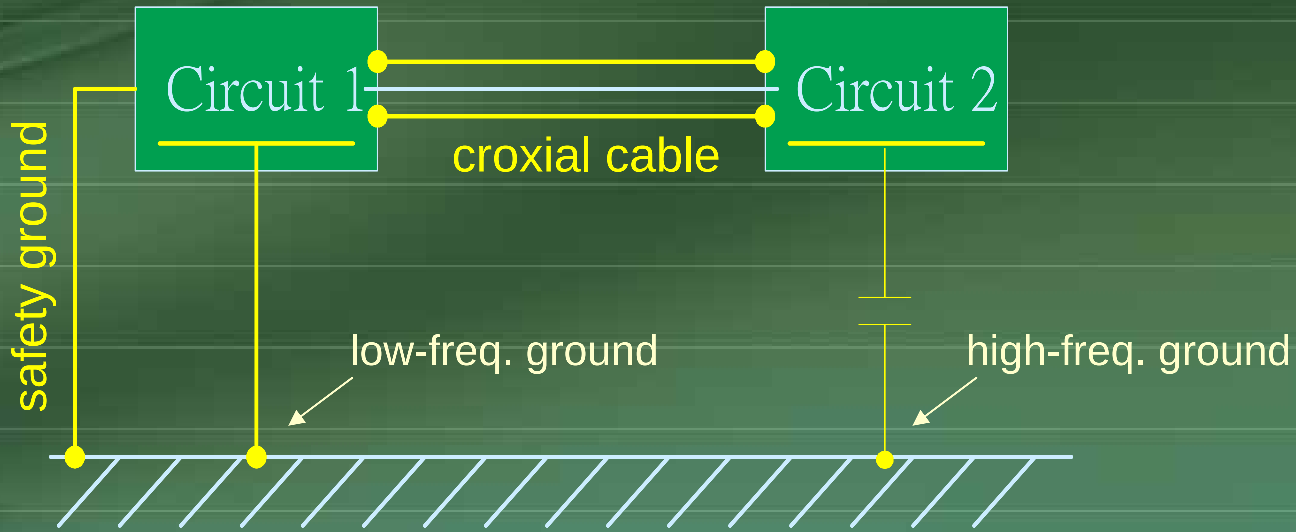
- Multipoint Grounding
  - It behaves well at high frequencies.
  - Each subsystem is grounded nearby and connected to the nearest low-impedance ground.
    - At high frequencies, the parasitic capacitive represents low-impedance paths, and the *bound inductance* of a subsystem to ground results in higher impedances. *Thus, common-mode current may flow*, like signal-point grounding.



System Grounding for EMC

System Grounding Type

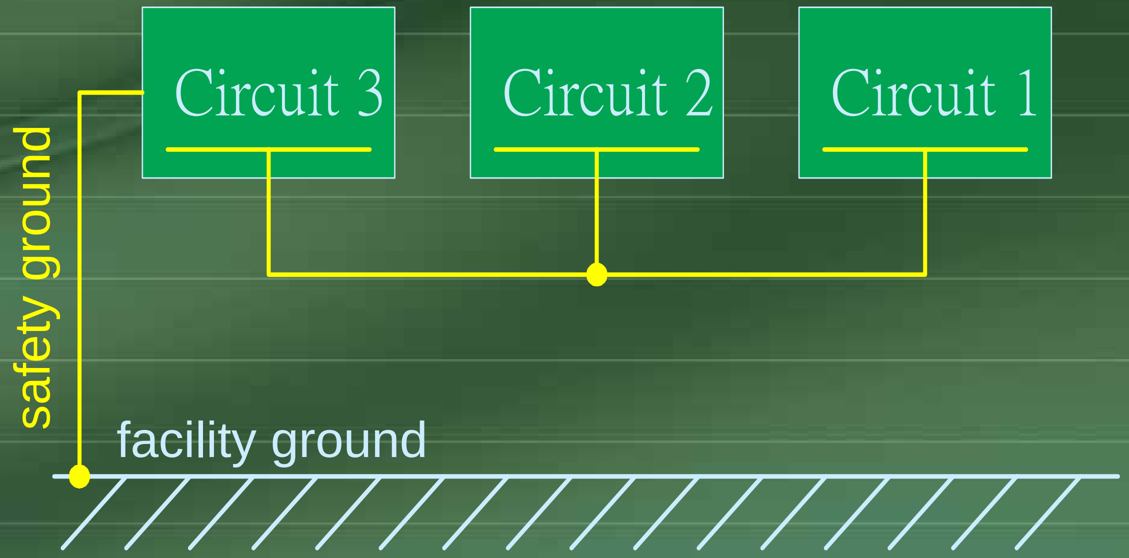
- Hybrid Grounding
  - The ground appears as a single-point ground at low frequencies and a multipoint ground at high frequencies.
  - Well at both high and low frequencies



System Grounding for EMC

System Grounding Type

- Floating Ground
  - Electrical isolation avoids a coupling loop for noise currents present in the ground system.



System Grounding for EMC

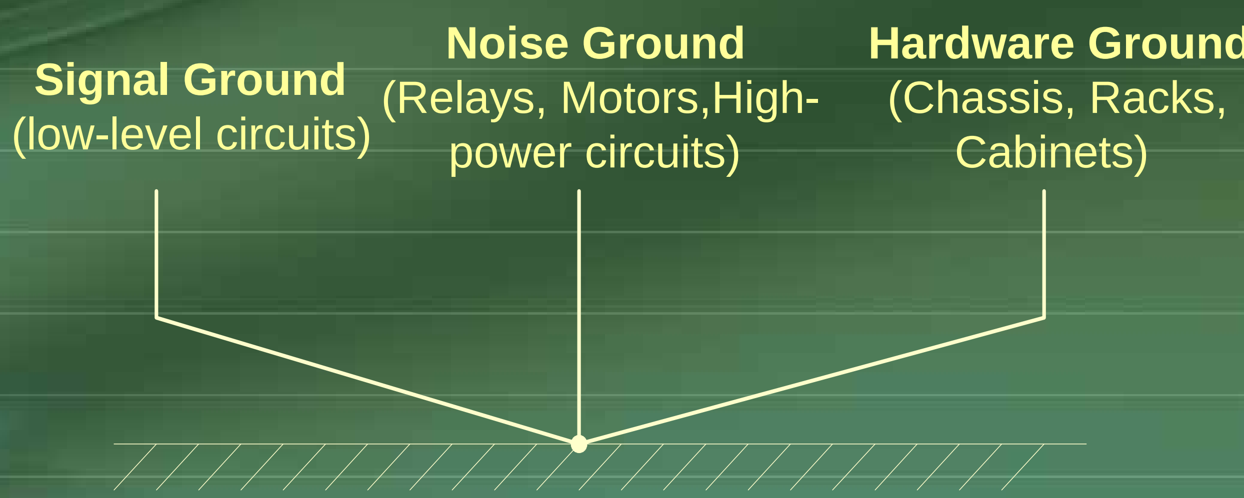
System Grounding Type

- Most practical grounding systems at low-frequencies are combination of the series and parallel single-point ground.
- A digital logic circuit has to be treated as a high-frequency circuit, due to the high frequencies it produces.
  - Multipoint grounding and a ground grid is preferred
- Power supply is low frequency
  - Wired as a single point grounding

System Grounding for EMC

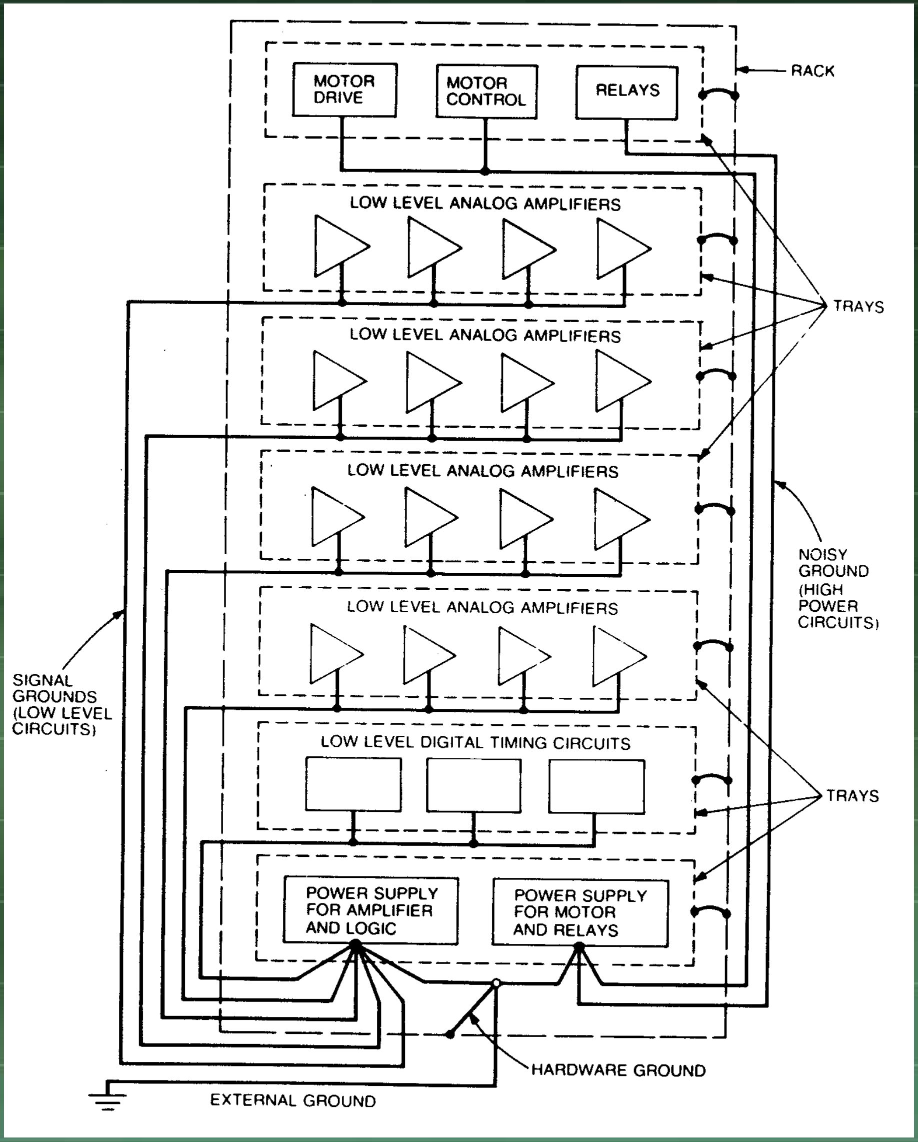
System Grounding

- Grouping ground leads is the key to balance system noise criteria and wiring complexity.
- Most systems require a minimum of three separate ground returns
  - If AC power is distributed throughout the system, the power ground should be connected to the hardware ground.



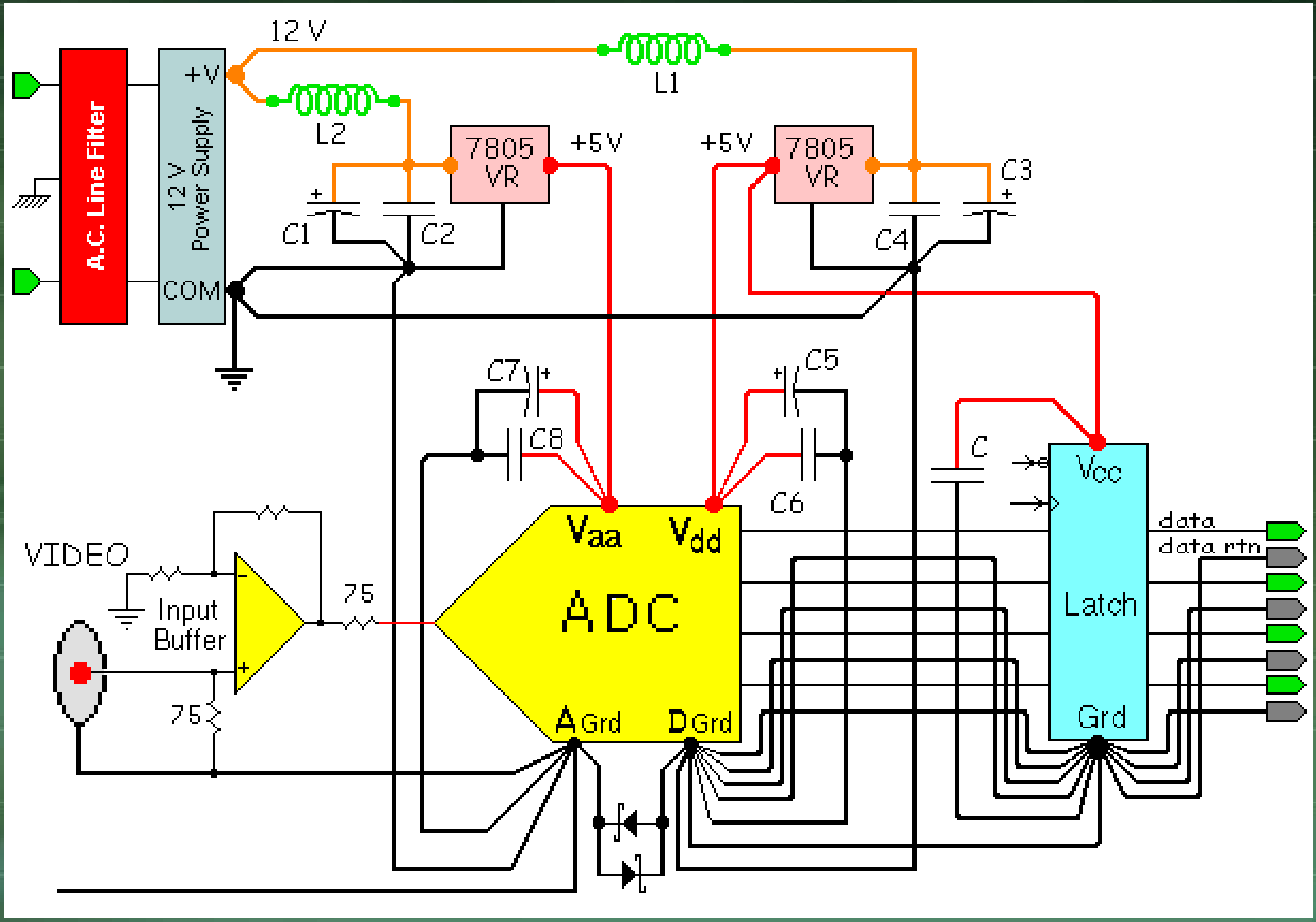
System Grounding for EMC

System Grounding



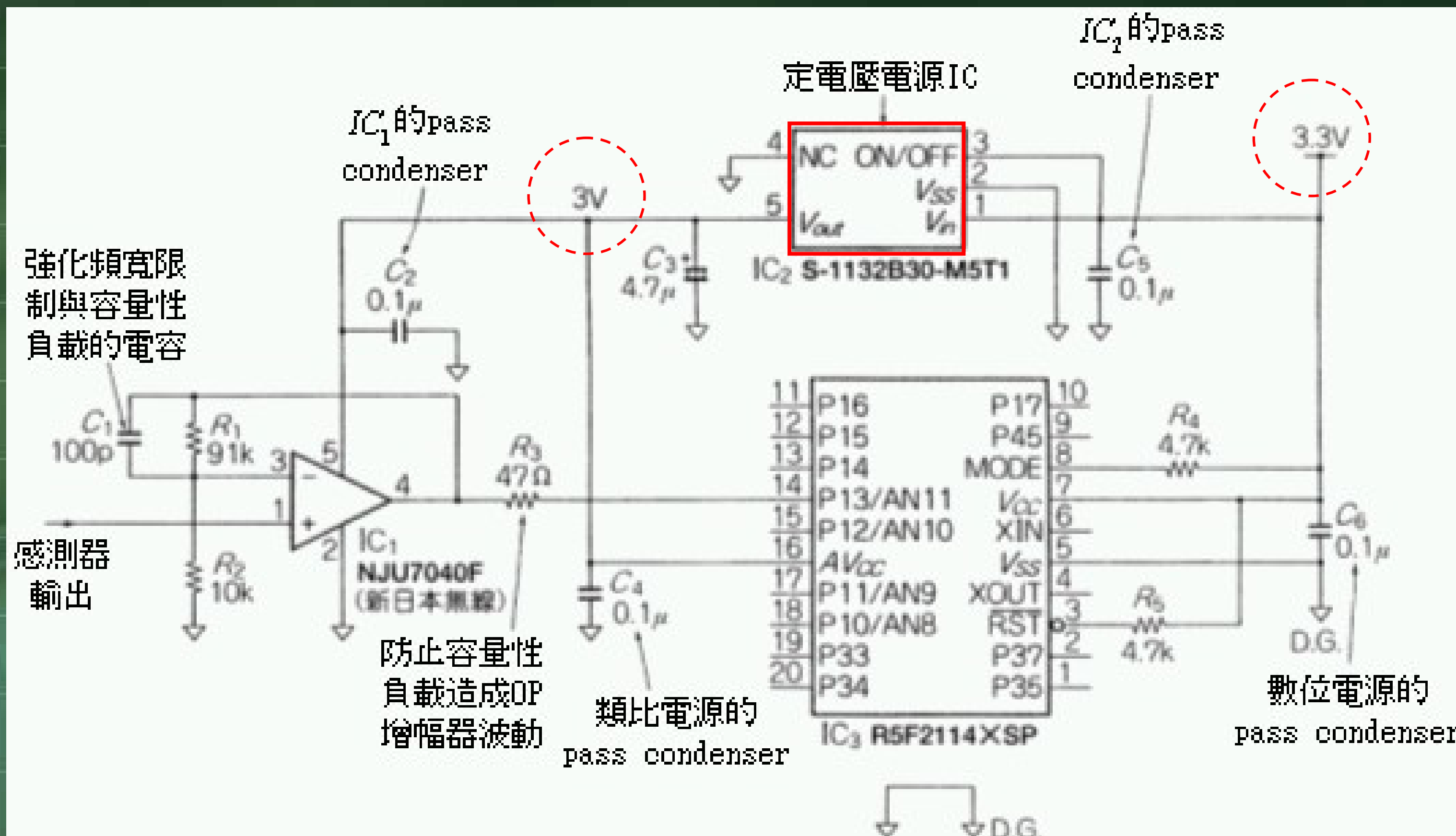
System Grounding for EMC

System Grounding



System Grounding for EMC

System Grounding : case 3

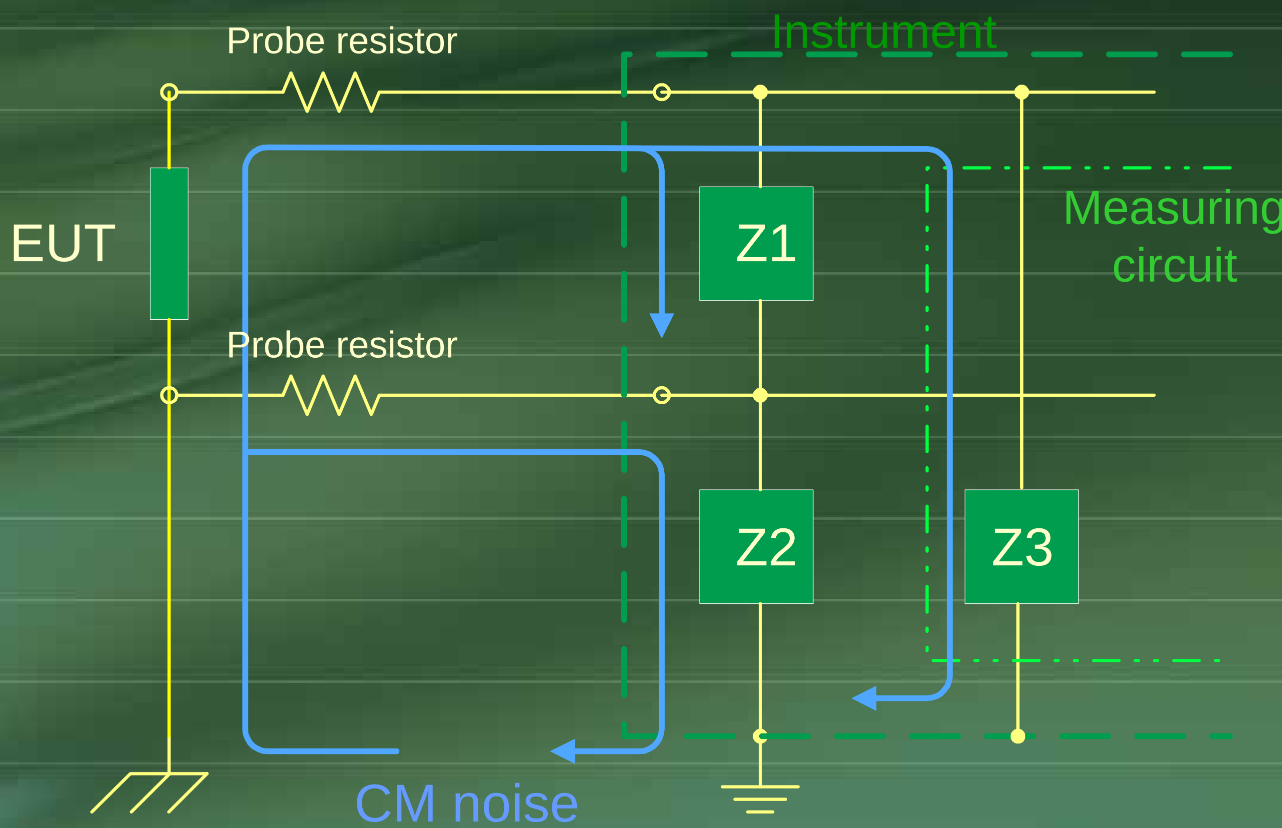


Support clear power to analog circuit by LDO.

System Grounding for EMC

Guarded Meter

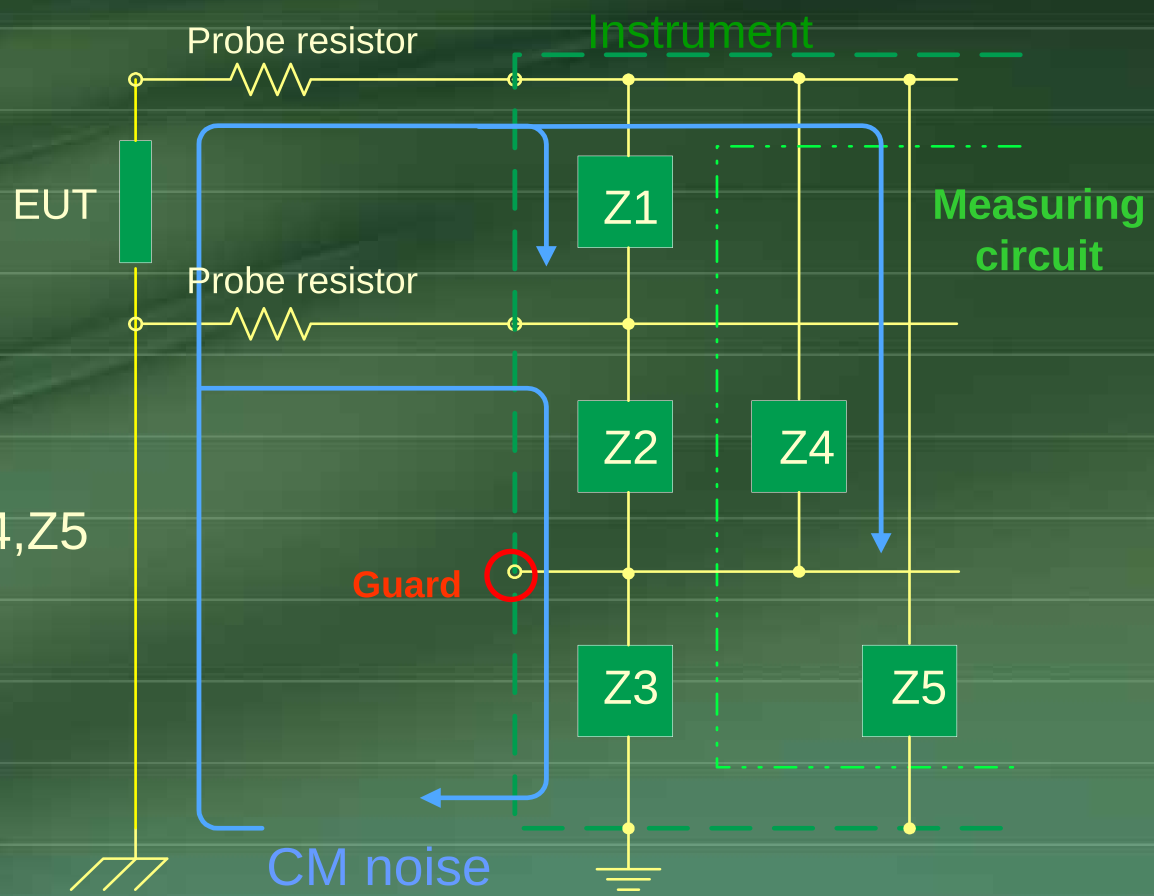
- Floating meter induces common-mode noise



System Grounding for EMC

Guarded Meter

- Measuring instrument with guard terminal



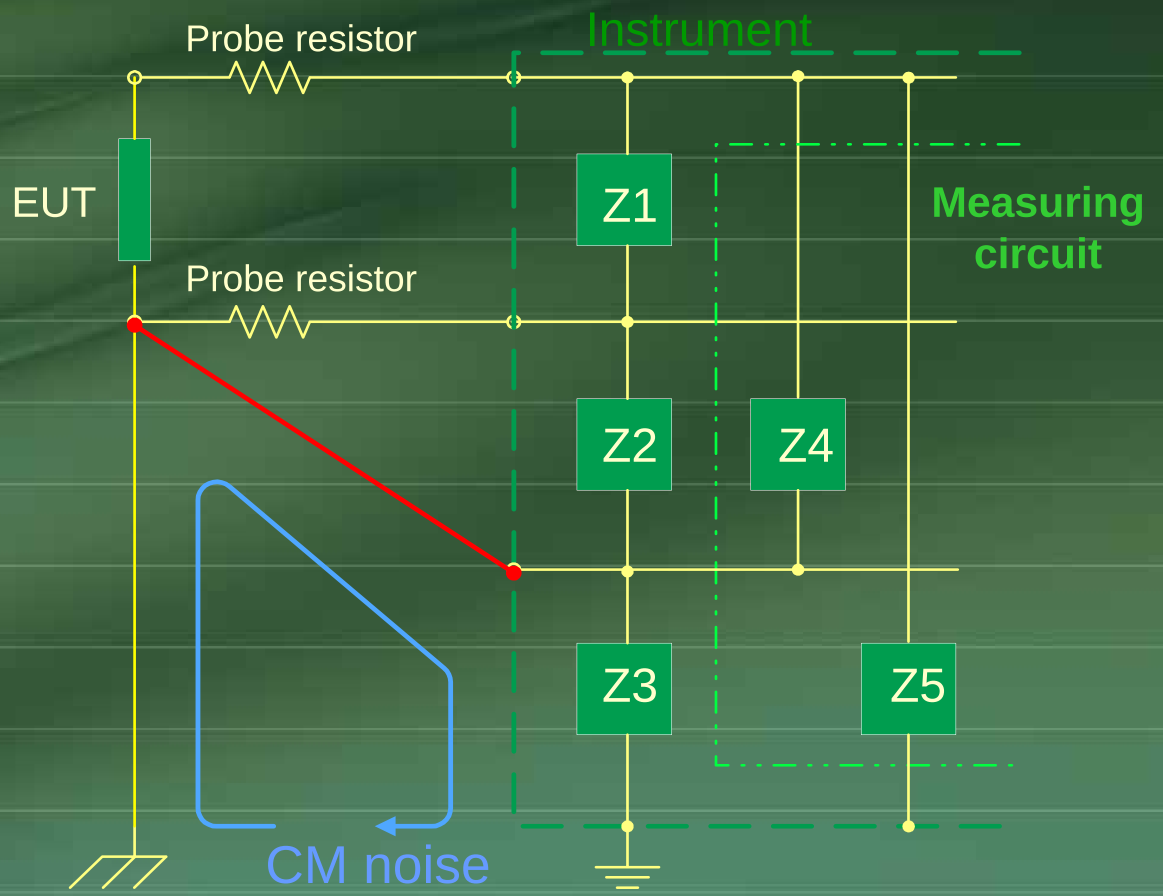
It is designed as

Z3=0<<Z1,Z2,Z4,Z5

System Grounding for EMC

Guarded Meter

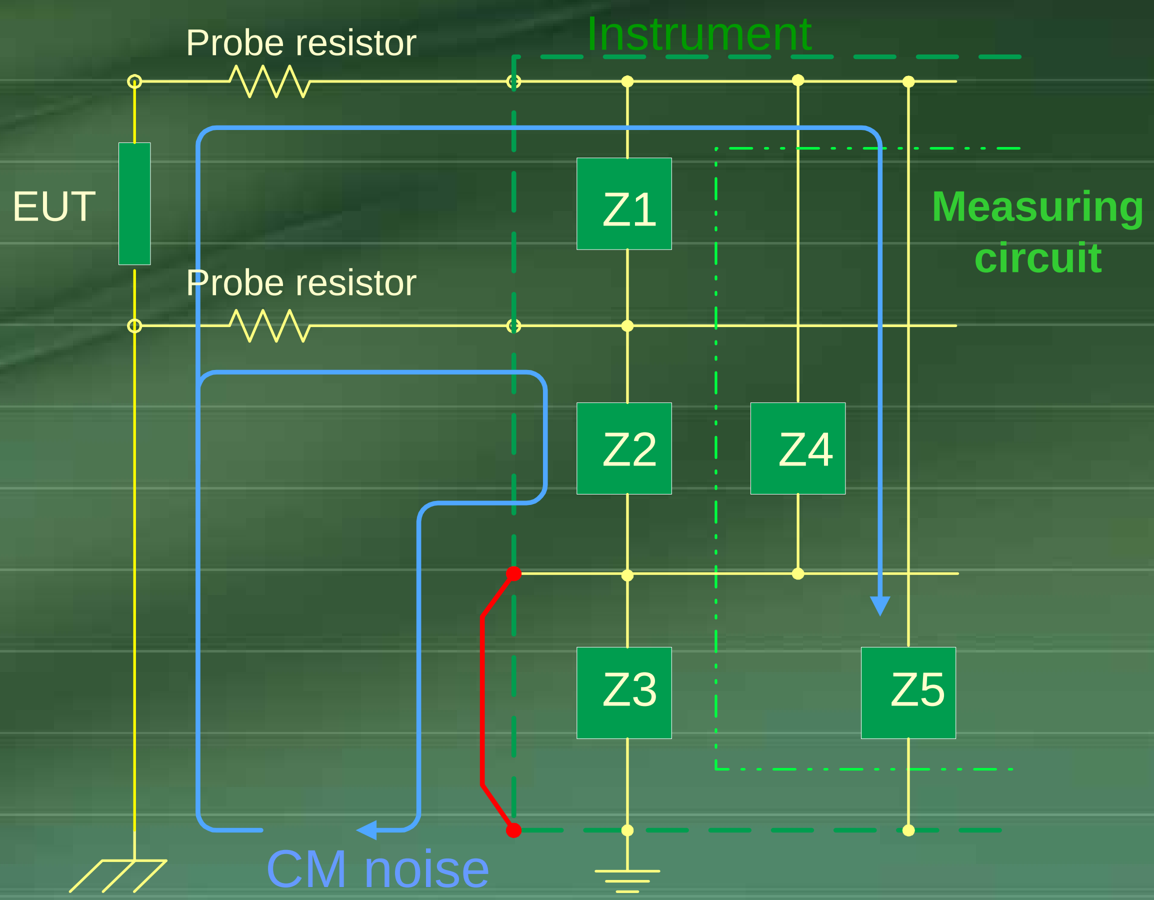
- Measuring instrument with *proper* guard terminal grounded



System Grounding for EMC

Guarded Meter

- Measuring instrument with *improper* guard terminal grounded

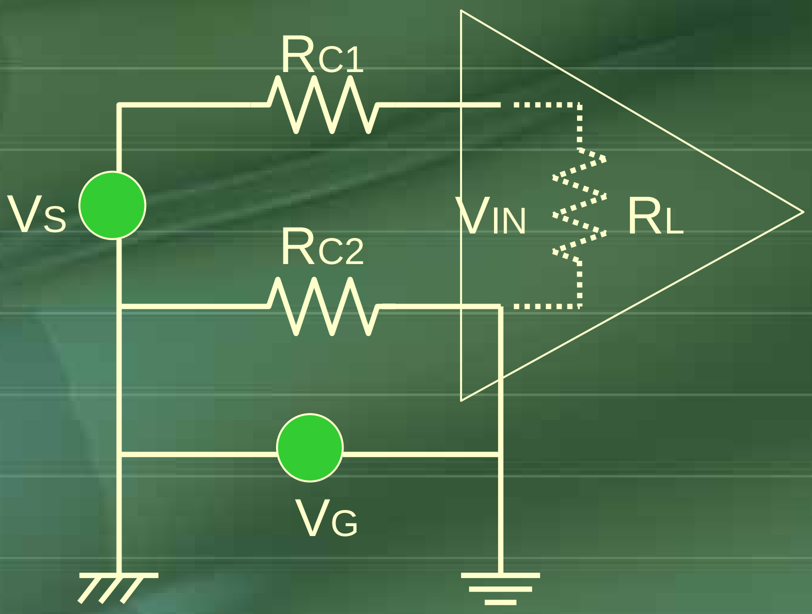


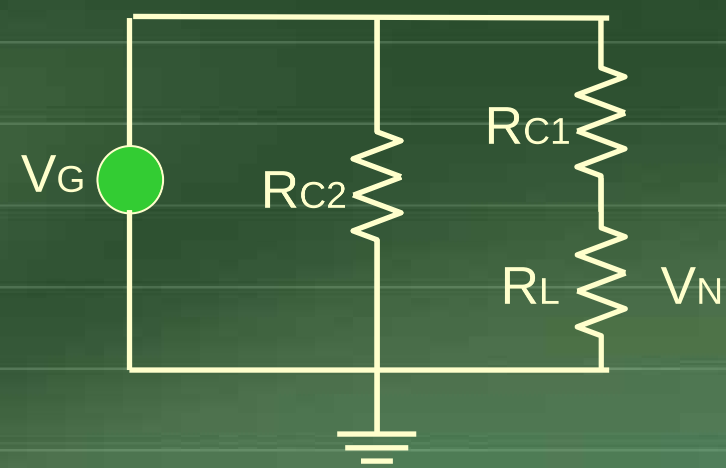
Agenda

- Earthing and Grounding
- Principles and Practice of Earthing
- Precautions in Earthing
- Measurement of Ground Resistance
- System Grounding for EMC
- *Circuit Ground*
- Cable Shield Grounding
- Isolate

Circuit Ground

- Since two ground points are seldom at the same potential, the difference in ground potential V_G will couple into a circuit if it is grounded at more than one point.

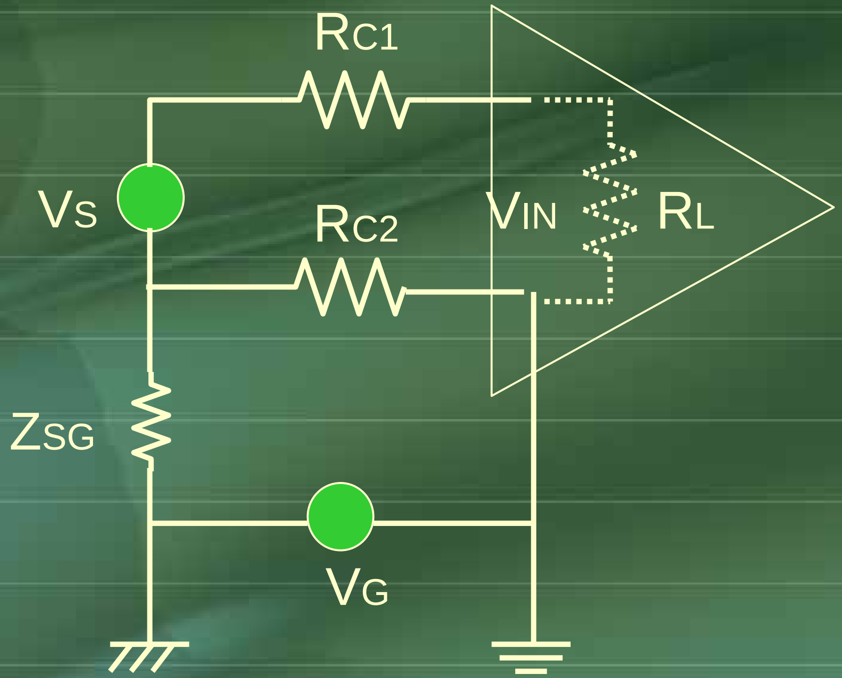


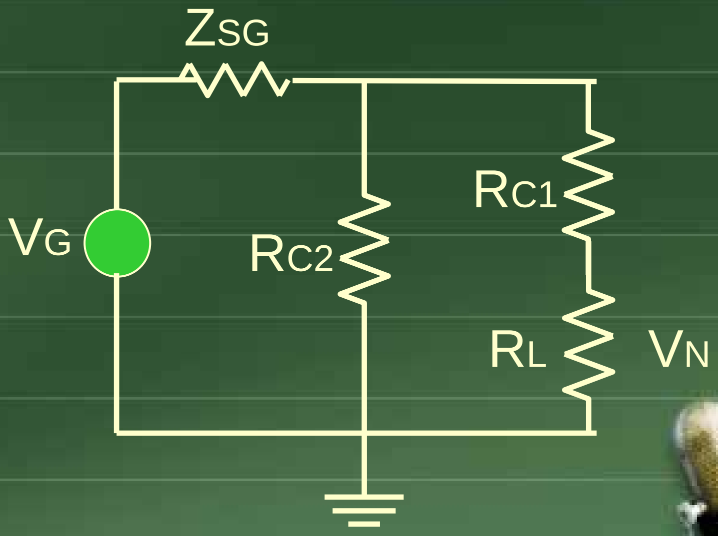


Coupling Noise $V_N = \frac{R_L}{R_{C1} + R_L} \cdot V_G$

Circuit Ground

- Noise source V_G can be isolated from ground by adding the impedance Z_{SG}.
  - If $Z_{SG} \rightarrow \infty$ (isolated), $V_N \rightarrow 0$





$$V_N \approx [\frac{R_L}{R_{C1} + R_{C2} + R_L}] \cdot [\frac{R_{C2}}{Z_{SG}}] \cdot V_G$$

$$as \quad R_L >> R_{C1}, R_{C2}$$

Amplifier Shields

- High-gain amplifiers are often enclosed in a metallic shield to provide protection from electric fields.
- $C_{3S}+C_{1S}$ provide a feedback path from output to input. If it is not eliminated, the amplifier may oscillate.

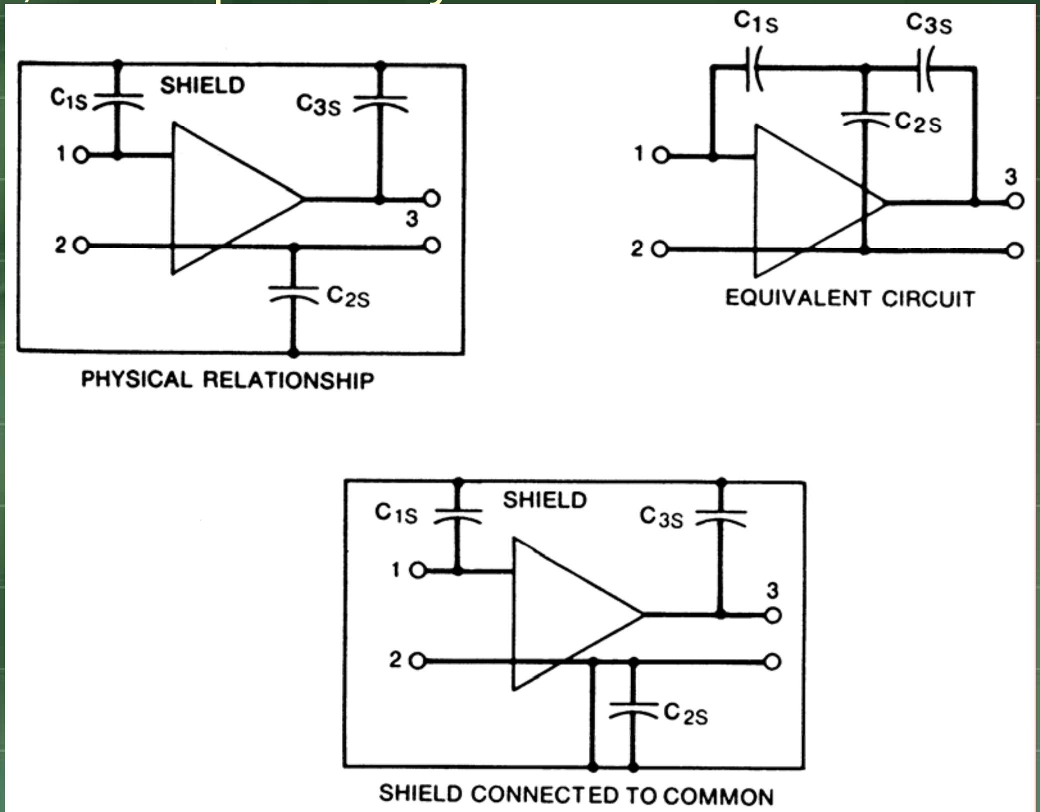


Figure 3-18. *Amplifier shield should be connected to the amplifier common.*

Agenda

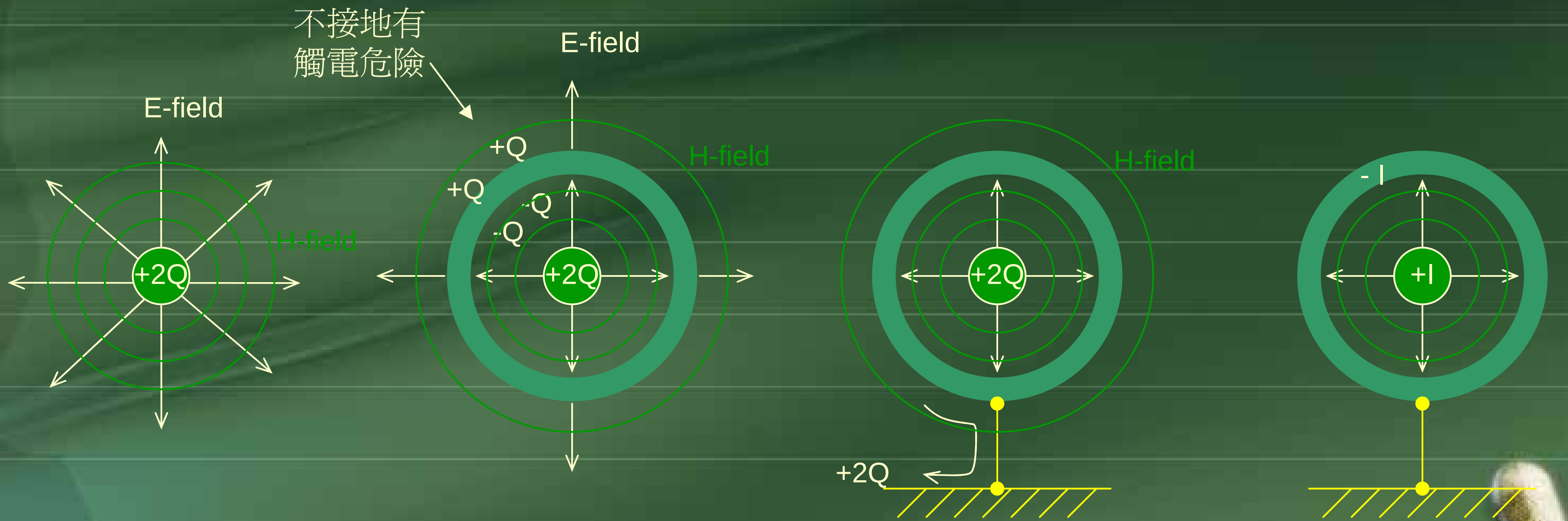
- Earthing and Grounding
- Principles and Practice of Earthing
- Precautions in Earthing
- Measurement of Ground Resistance
- System Grounding for EMC
- Circuit Ground
- *Cable Shield Grounding*
- Isolate

Cable Shield Grounding

- Cable Shield Grounding Type
  - Grounded at one end
    - Eliminate E-field emission
  - Grounded at both ends
    - Eliminate E-field and H-field emission
  - Grounded at intervals along the length of the cable
    - EMI voltage pickup in cable increases with frequency in general
    - As the freq. increases, resonance phenomena produce maximum induced voltages for a cable length l such that
      - Both ends grounded → resonance for $l = k\lambda / 2$
      - One end grounded → resonance for $l = (2k+1)\lambda / 4$

Cable Shield Grounding

- Cable Shield Grounding Type



Connecting wire without shield

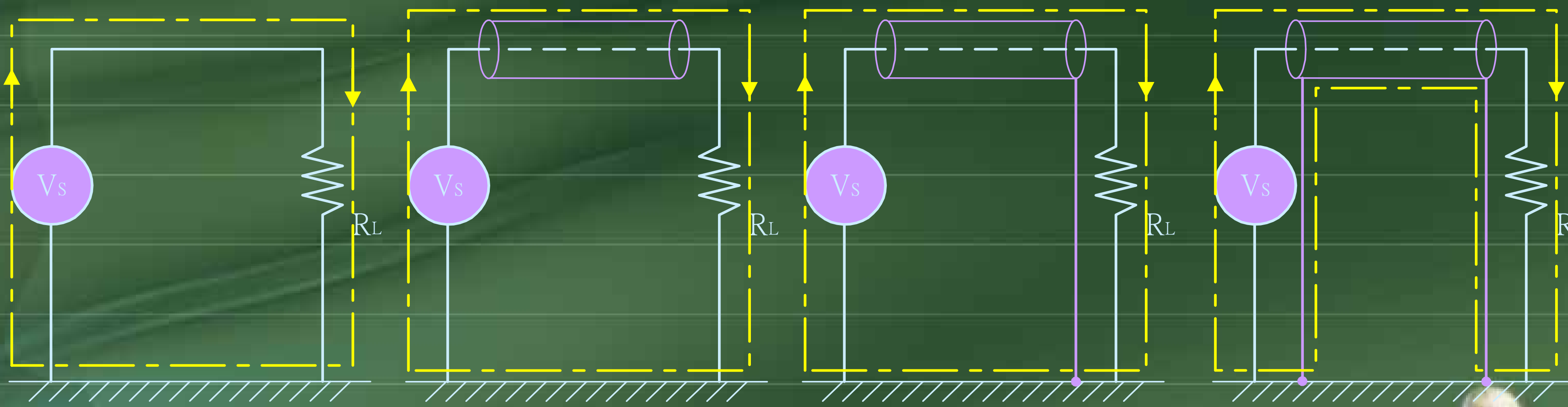
Cable shield without grounding

Cable shield grounded

Cable shield grounded and current in shield

Cable Shield Grounding

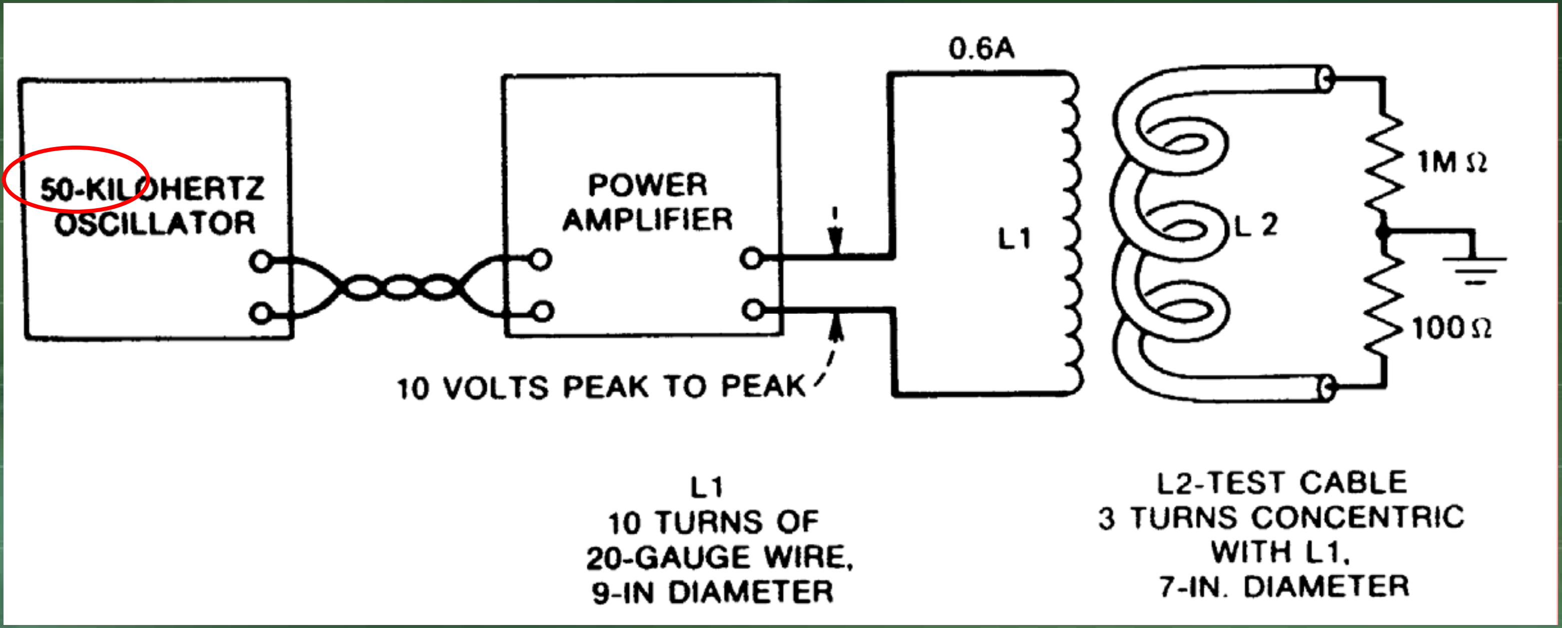
- Cable Shield Grounding Type



Connecting wire without shield | Cable shield without grounding | Cable shield grounded (Grounded at one end) | Cable shield grounded and current in shield (Grounded at two end)

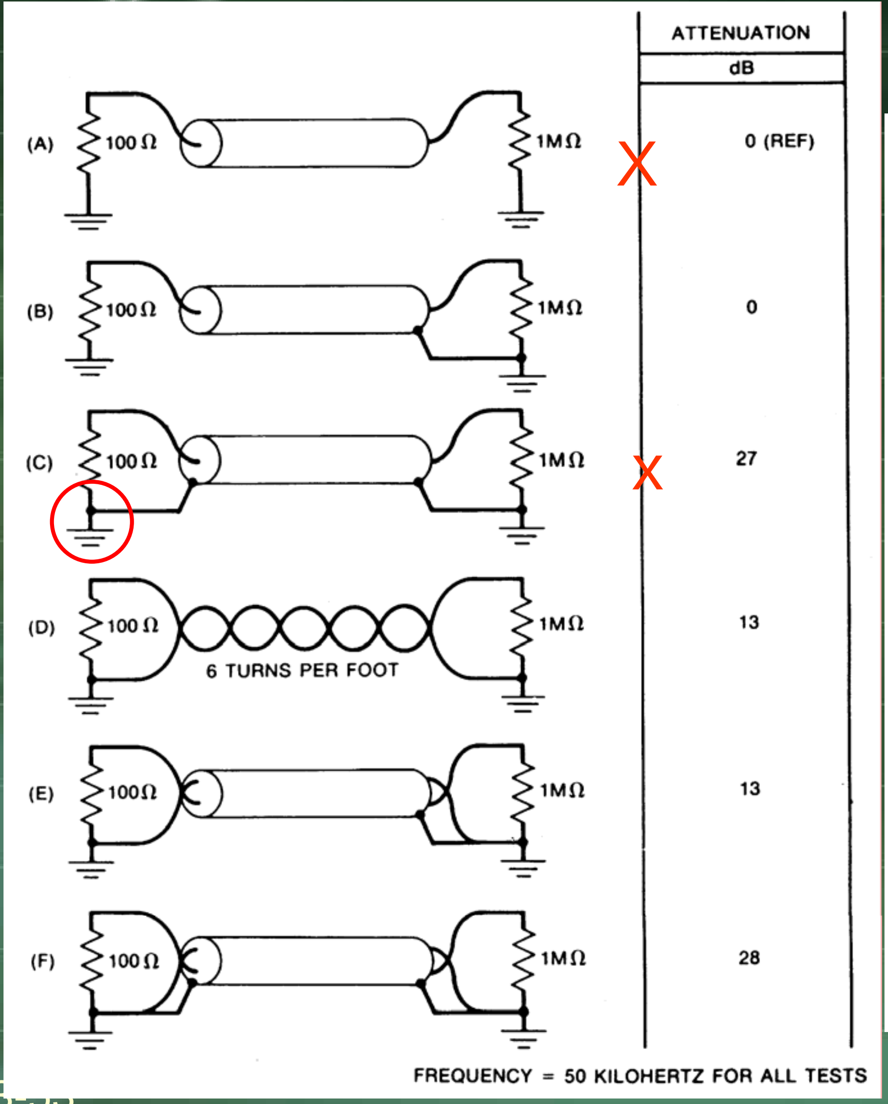
Cable Shield Grounding

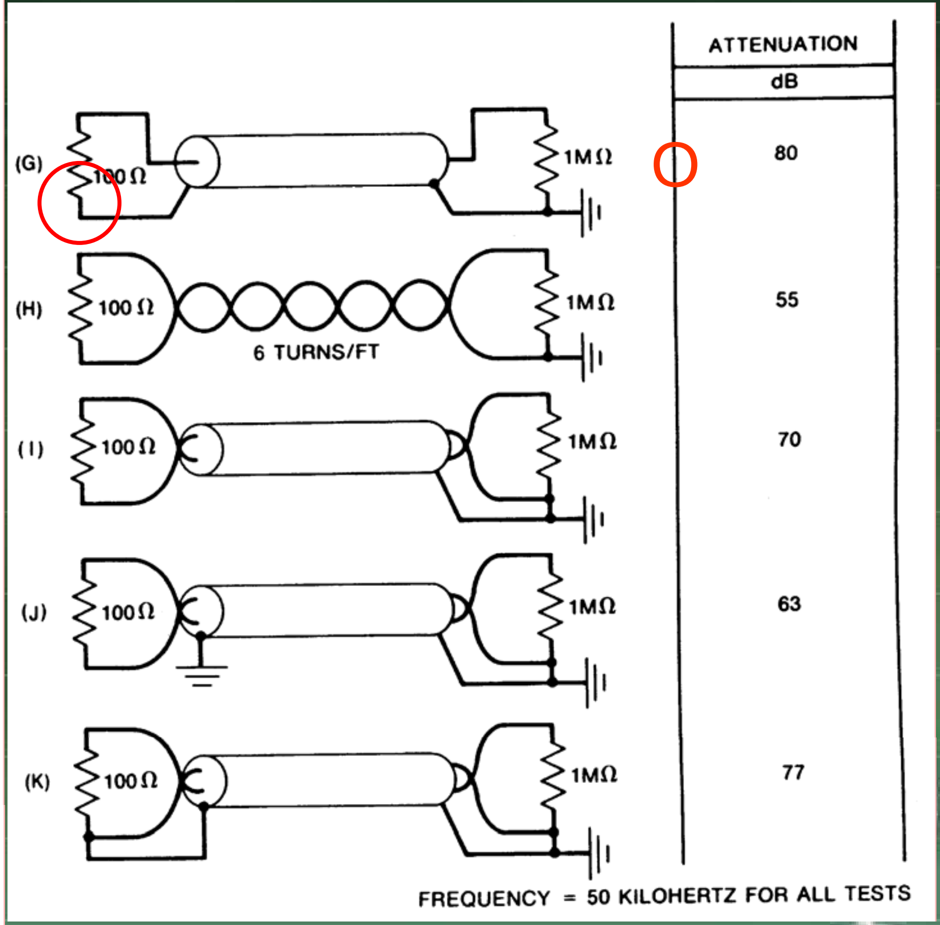
Test setup of Inductive Coupling Experiment



Cable Shield Grounding

Results of Inductive Coupling Experiment

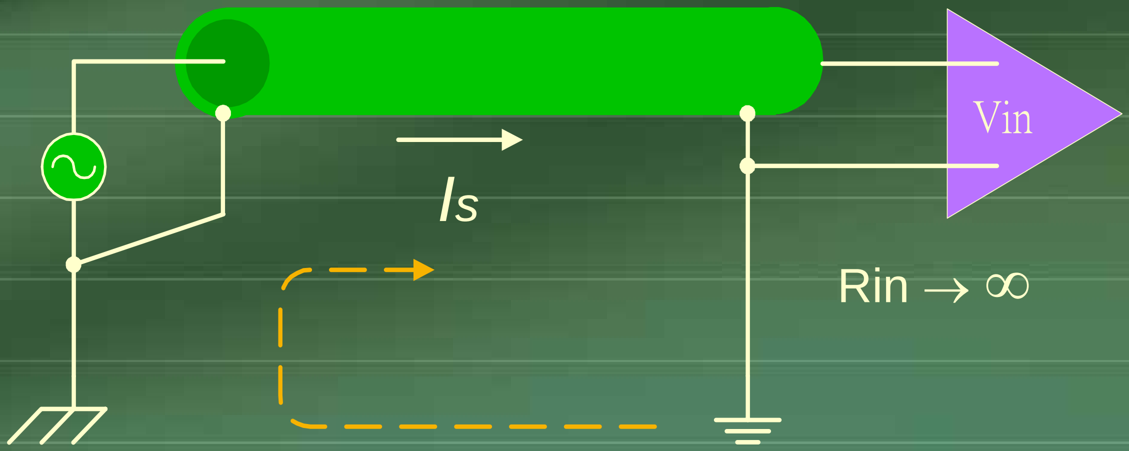




Cable Shield Grounding

At Low Frequencies

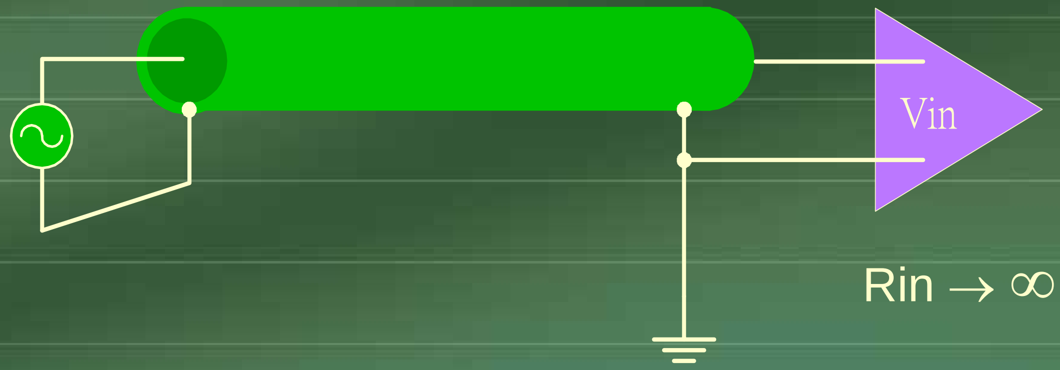
- Even a cable is grounded at both ends, *only a limited amount of magnetic field protection is possible* because of the large noise current induced in the ground loop.
  - *The noise current I_s in the shield is due to a ground differential or to external noise coupling.*



Cable Shield Grounding

At Low Frequencies

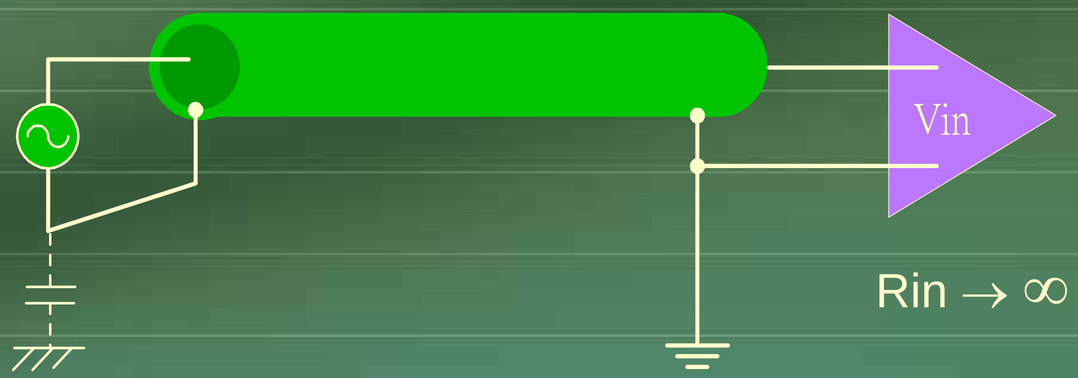
- Therefore,for maximum noise protection *at low frequencies(<1MHz)*, the shield should not be one of the signal conductors, and one end of the cable must be isolated from ground.
  - 低頻下，可不考慮導線屏蔽未接地端的對地雜散電容效應



Cable Shield Grounding

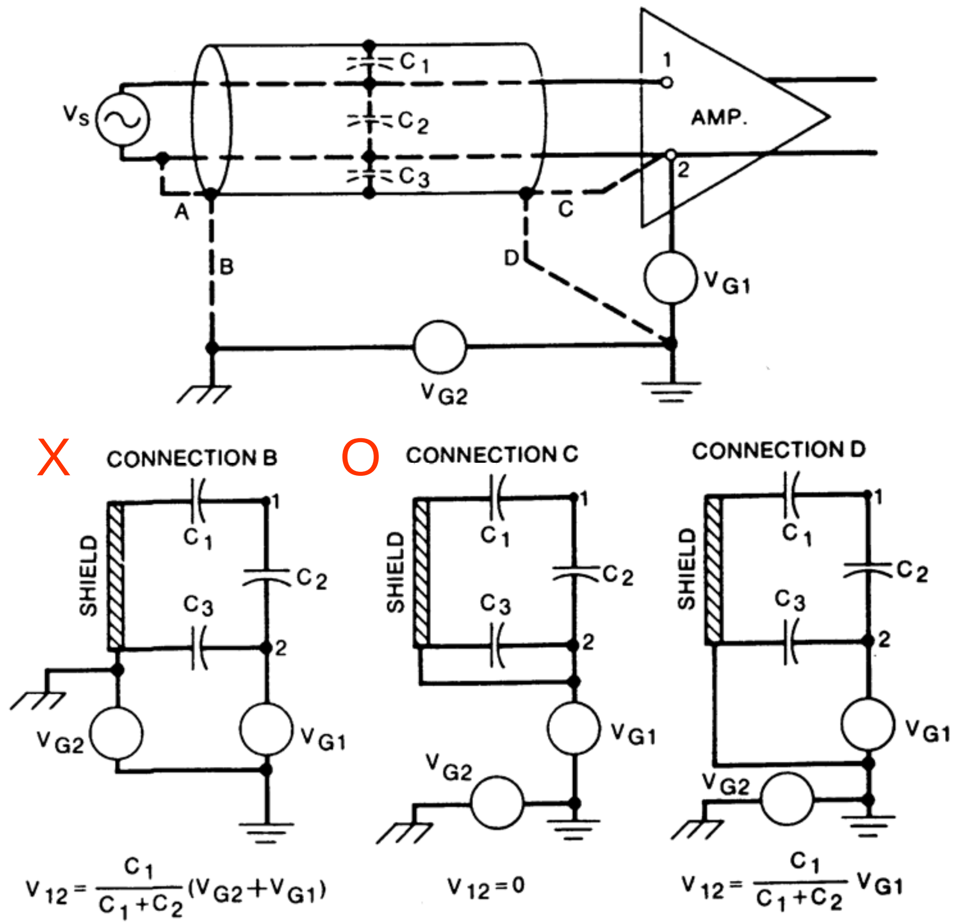
At High Frequencies

- At frequencies above 1MHz or where cable length exceeds 1/20 wavelength, it is often necessary to ground a shield at more than one point to guarantee that it remains at ground potential.
- The stray capacitor makes it difficult to isolation at ungrounded end of shield. It is therefore common practice at high frequencies and digital circuits, to ground cable shield at both ends.



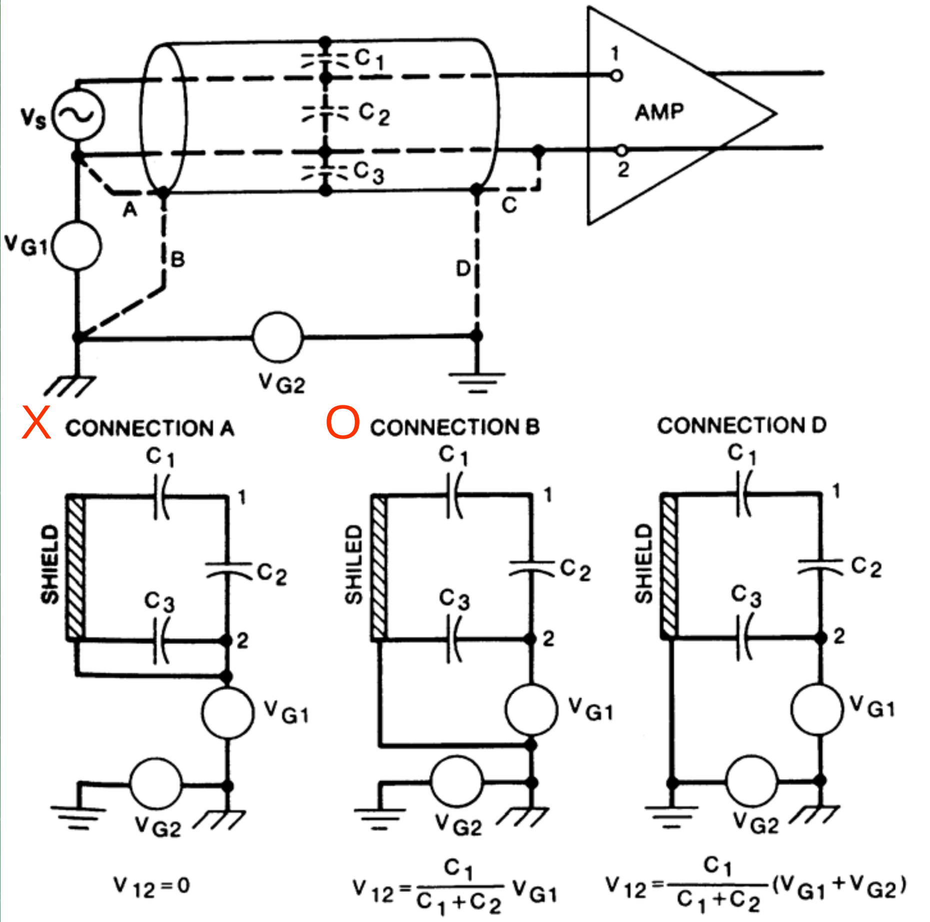
Cable Shield Grounding

- For an ungrounded source and a grounded amplifier, the input shield should be connected to the amplifier common terminal, even if this point is not at earth ground.



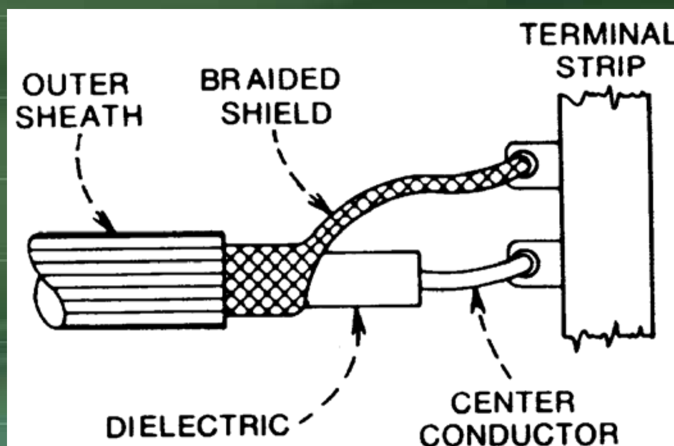
Cable Shield Grounding

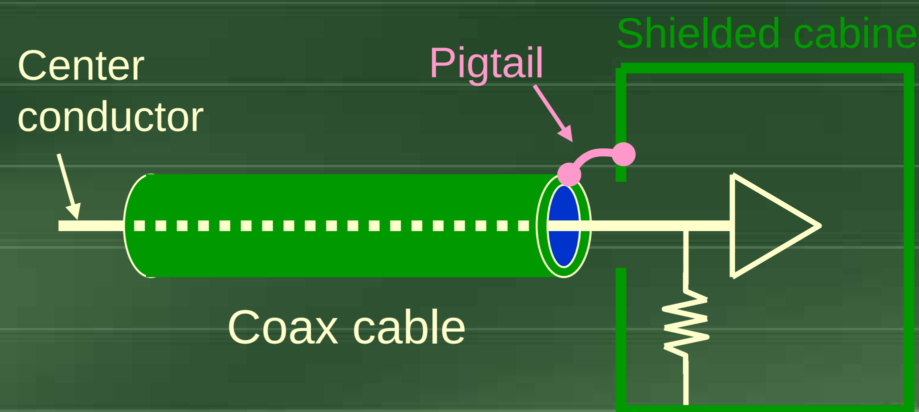
- For a grounded source and an ungrounded amplifier, the input shield should be connected to the source common terminal, even if this point is not at earth ground.



Cable Shield Grounding

- Outer surface of the cable shield must be <u>closed entirely</u> and grounded (a *<u>360º</u>* low-impedance electrical connection) to avoid *Pigtail Effect.*





- The effectiveness of grounding schemes depends on the electromagnetic coupling mode (electric field / magnetic field) and the electrical length、shield、connector of cables used for interconnection.

	電場干擾	磁場干擾	
		高頻磁場	低頻磁場
防治原則	以*高導電性*材料做屏蔽，並接地	利用封閉的金屬屏蔽導體上產生的磁場感應電流，其產生的反向磁通與雜訊源輻射相互抵消；或減少迴路面積避免引入感應電流	以*高導磁性*材料做屏蔽

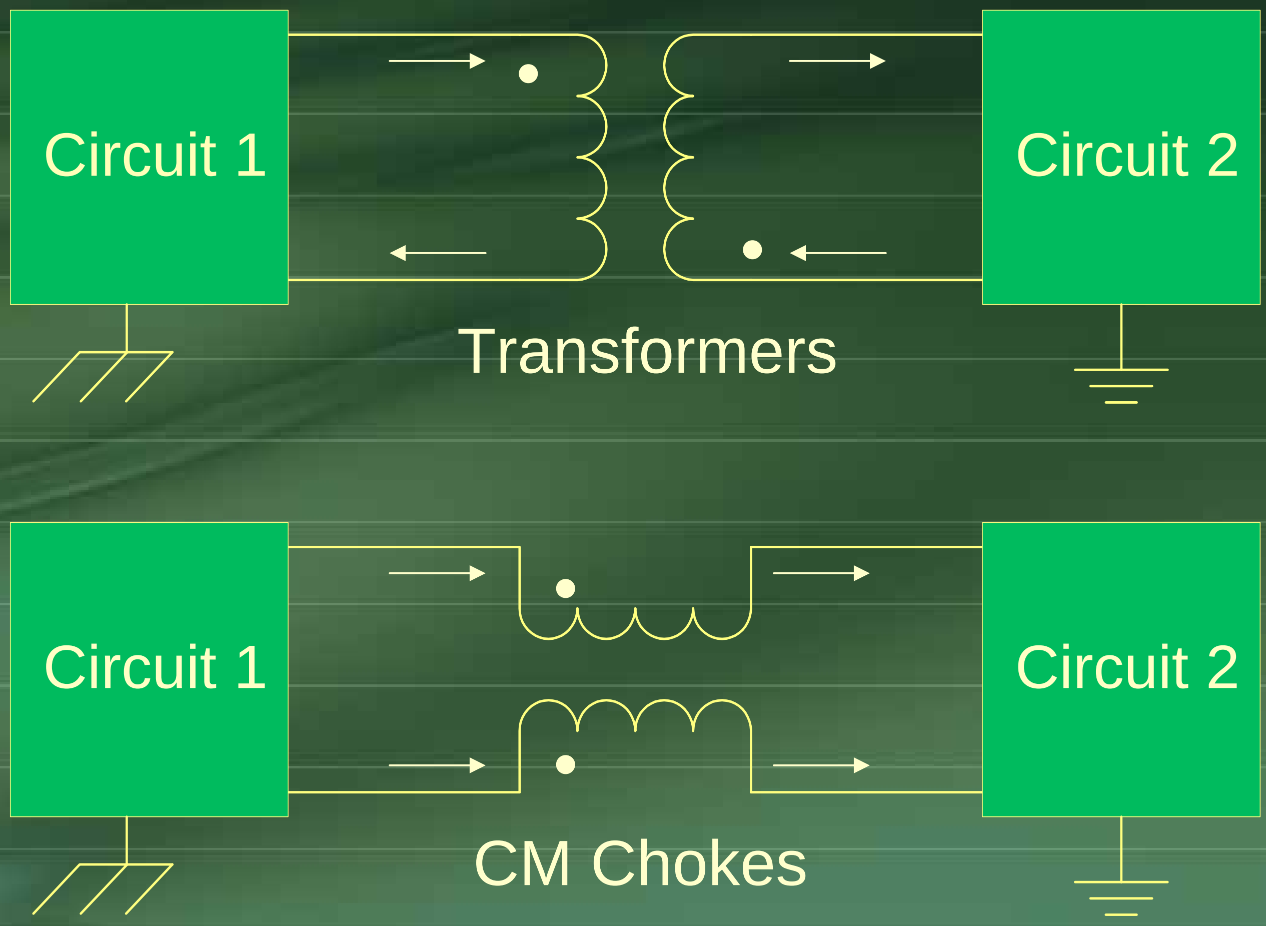
- The inductive current in a electromagnetic field *is direct proportioned to* the high-frequency of electromagnetic field, so it is the conductive material that is used to shield the high-frequency electromagnetic field.
- A high-frequency electromagnetic field will make a high μ_r material saturated, so it is used just under low-frequency electromagnetic field.

Isolate

- Isolation against the ground-path noise
  - Transformers
  - Common-mode chokes
  - Optical couplers
  - Balanced circuitry
  - Frequency-selective (hybrid) grounding

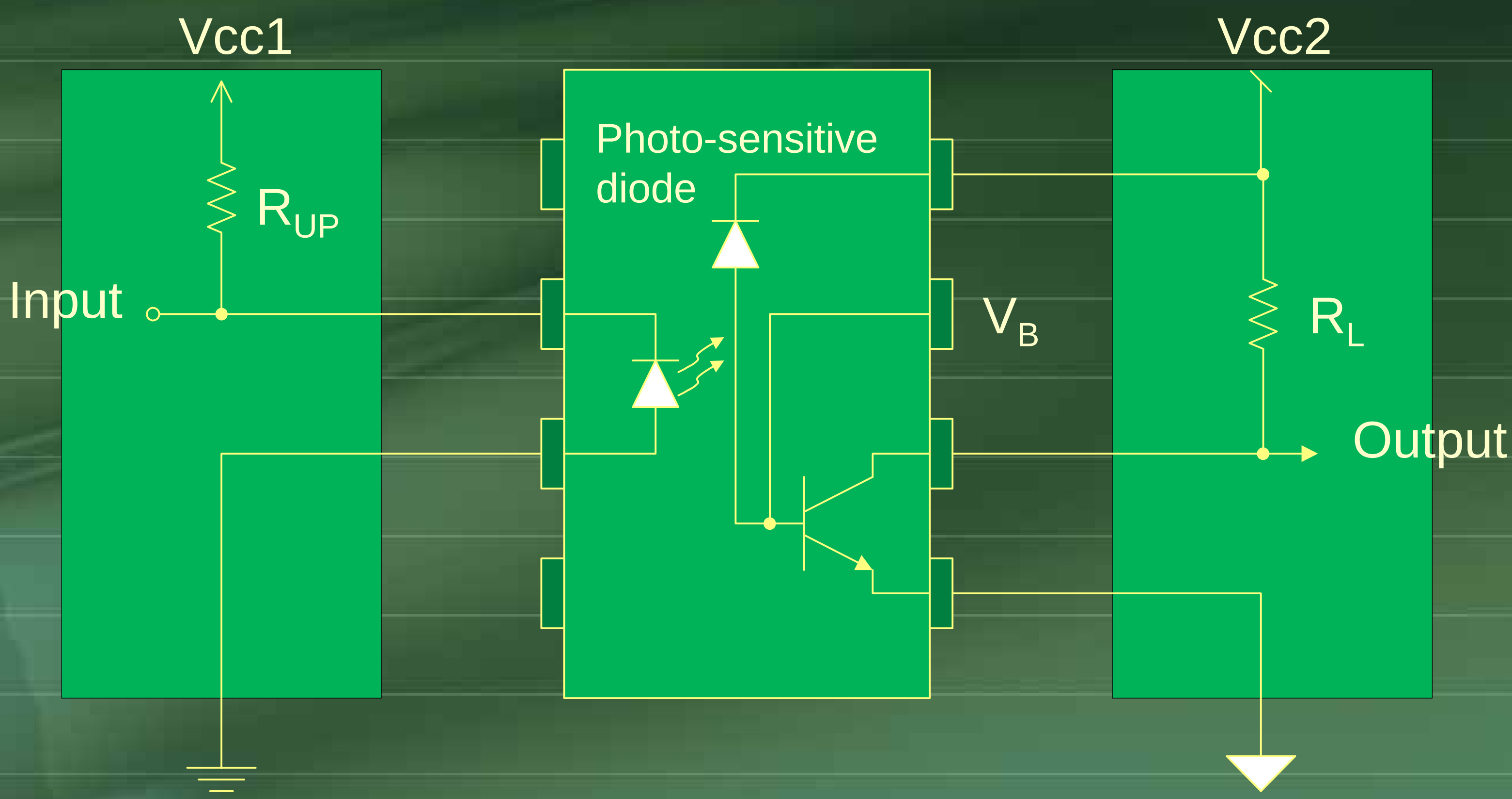
Isolate

Transformers and CM Chokes



Isolate

Optical Couplers



Summary

- Two grounding levels are concerned
  - Internal circuit grounding
  - System grounding
- Improper grounding will induce
  - Common-mode noise
  - Potential difference between subsystems
- At low frequencies a single-point ground system should be used.
- At high frequencies and in digital circuitry a multipoint ground system should be used.
- *Cable shield should always be connected to a noise-free ground at both end.*
- Guard terminal of a instrument should be grounded correctly.
- Proper grounding generally can improve
  - *EMI、ESD、EFT*