Power Supply Systems

EE 334 Power Systems
Prof. A. M. Kulkarni

Safety
Three-Phase Neutral and Earthing Connections
Equipment Classes
Switches

Earthing

- What is Earthing ?
- Can the earth be used as a return path?
- Is the earth an equipotential surface?

Ground Path (Earthing)

- A **ground** is a return path for current
  - Path can be **intended** or
  - **unintended** (parasitic branches).

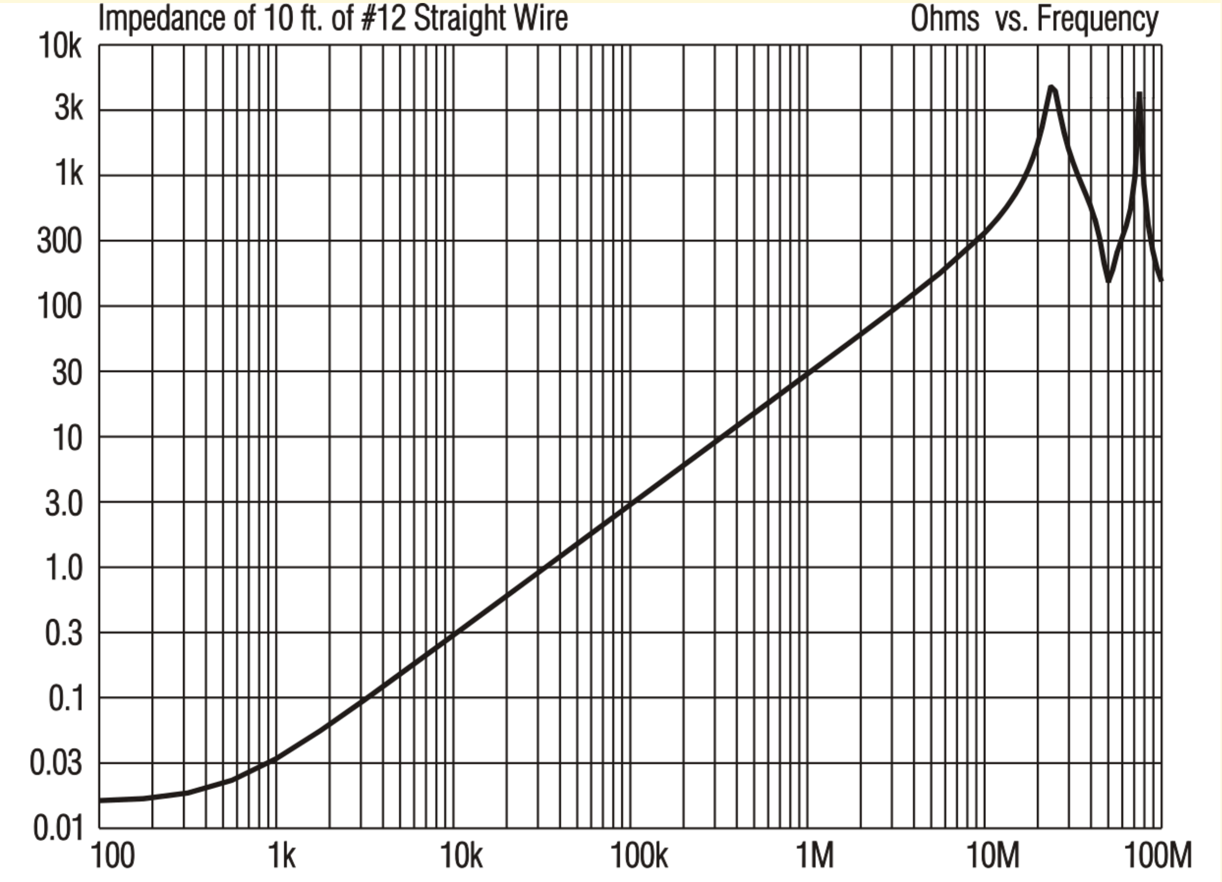
- A **ground** is also a point to which circuits may be referenced
  - No **guarantee** that any two points will stay at the same voltage.

Ref: Daryl Gerke, "**MYSTERIES OF GROUNDING**", Rocky Mountain Chapter EMC Society, September 2002.

Myths of Earthing

● **Earth grounds are all at zero volts** - ‘presumably with respect to each other and to some “mystical absolute” reference point’.

● **Wires have zero impedance.**



Ref: Bill Whitlock, “**UNDERSTANDING, FINDING, & ELIMINATING GROUND LOOPS**”, CEDIA Class EST016.

Material Characteristics (20^oC)

Material	Resistivity (Ω m)	Temp. Coeff. ($^o K^{-1}$)
Copper	1.7×10^{-8}	0.004
Aluminium	2.65×10^{-8}	0.0039
Iron	9.7×10^{-8}	0.005
Nichrome	1.1×10^{-6}	0.0004
Sea Water	2×10^{-1}	
Drinking Water	2×10^{1} to 2×10^{3}	
Deionized Water	1.8×10^{7}	
Alluvial Soil	5	
Granite	1000	
Wood (damp)	10^{3} to 10^{4}	
Wood (oven dry)	10^{14} to 10^{16}	
Air	10^{9} to 10^{15}	
Silicon	6.4×10^{2}	-0.075

Soil resistivity

Types of Soil	Climatic Condition			
	Normal and high rainfall (eg: > 500 mm an year)	Low rainfall and desert condition (eg: < 250 mm an year)		Underground waters (Saline)
	Probable value (Ωm)	Range of values encountered (Ωm)	Range of values encountered (Ωm)	Range of values encountered (Ωm)
(1)	(2)	(3)	(4)	(5)
Alluvium and lighter clays	5	*	*	1-5
Clays (excluding alluvium)	10	5-20	10-100	
Marls	20	10-30	50-300	
Porous limestone	50	30-100		
Porous sandstone	100	30-300		
Quartzites, compact and crystalline limestone	300	100-1000		
Clay slates and slatey shales	1000	300-3000	>1000	30-100
Granite	1000			
Fossile slates, igneous rocks	2000	>1000		

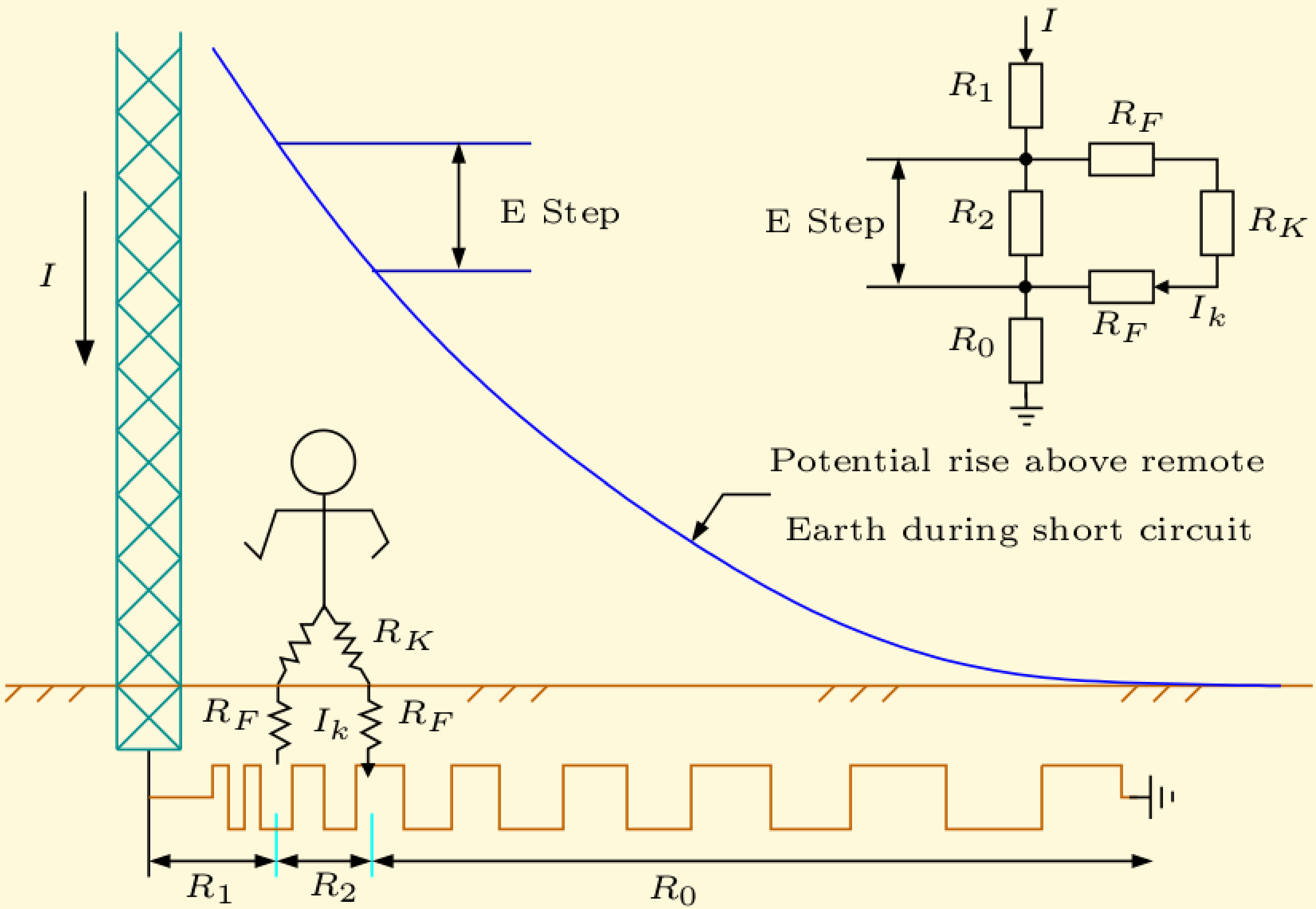
Adapted from: Indian Standard 3043 – 1987.

* depends on water level of locality

Can ground be a regular current path?

- Not generally used in practice.
- Current can flow through ground during short-circuits.
- A **few** single-wire earth return systems are used in the world.
- For high voltage DC transmission, earth/sea are used as ground returns for short durations.

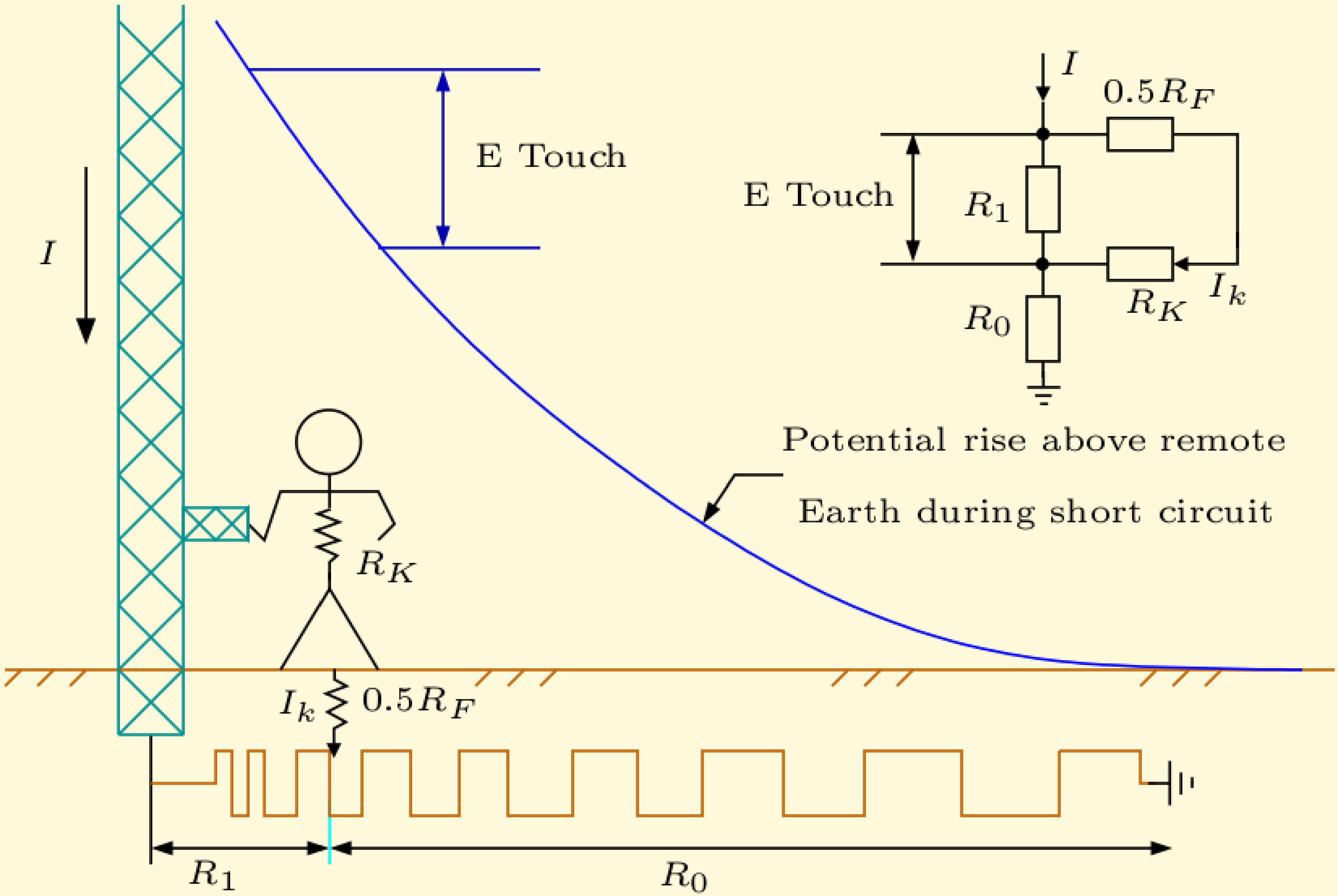
Step Voltage (under short circuit condition)



Step voltage at a grounded structure

Adapted from: Indian Standard 3043 – 1987.

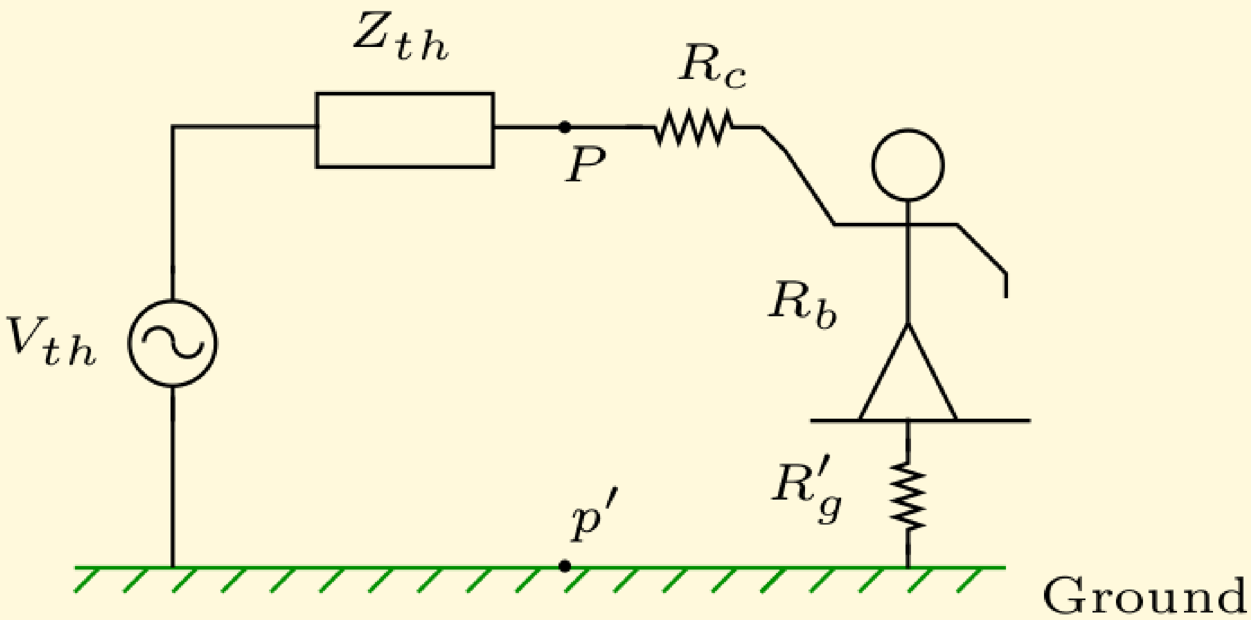
Touch Voltage (under short circuit condition)



Touch voltage at a grounded structure

Adapted from: Indian Standard 3043 – 1987.

Safety



Z_{th} = Equivalent Impedance

$V_{th} = V_{\text{open-circuit}}$ at $P\,p'$

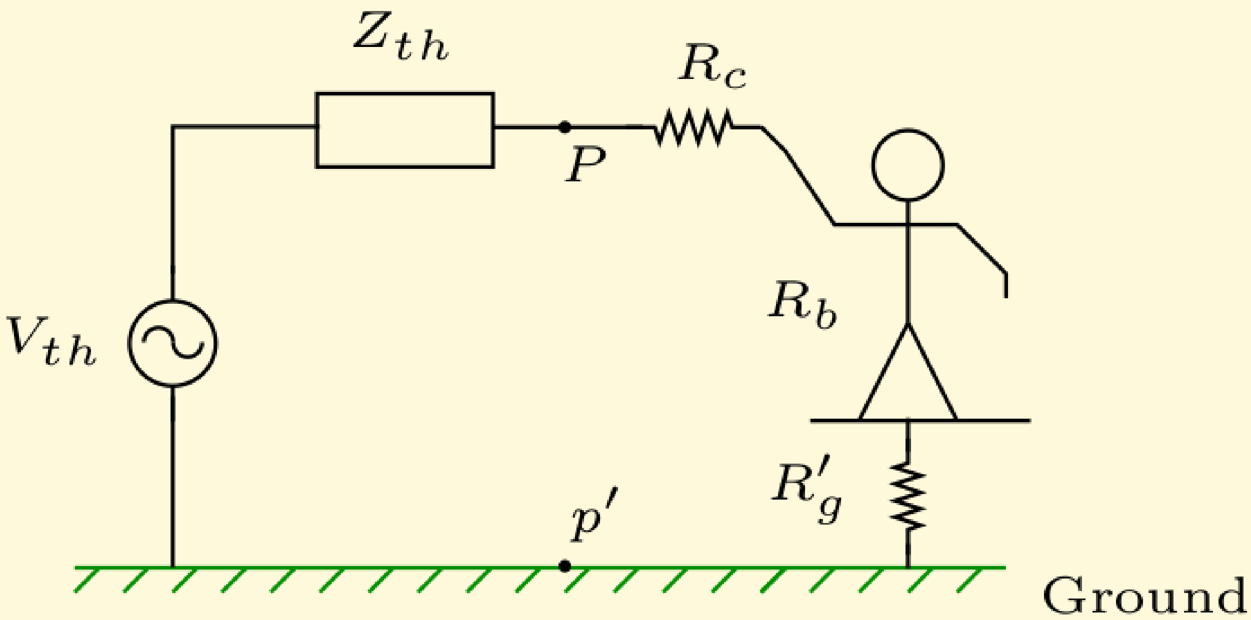
$R_c = R_{\text{contact}} \approx 500\,\Omega$

$R_b = R_{\text{body}} \approx 1000\,\Omega$

$R'_g = R_{\text{ground}} \approx 600\,\Omega$

Source: Walter Weeks, *Transmission and Distribution of Electrical Energy*, Harper & Row Publishers 1980.

Safety



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Dalziel's electrocution formula
(fatal current for an average human at 60 Hz):

$$I = \frac{0.165}{\sqrt{t}}$$

'*I*' is in ampere
'*t*' is time in s

Source: Walter Weeks, *Transmission and Distribution of Electrical Energy*, Harper & Row Publishers 1980.
Source: C. F. Dalziel and W. R. Lece, "Lethal Electric Current", *IEEE Spectrum 6*, 44-51 (Feb.-1969).

Typical effects of currents on People

Sr No.	Effect	Current (mA)			
		Direct Current		60 Hz rms	
		Men	Women	Men	Women
1.	No sensation on hand	1	0.6	0.4	0.3
2.	Slight tingling. Perception threshold	5.2	3.5	1.1	0.7
3.	Shock- not painful but muscular control not lost	9	6	1.8	1.2
4.	Painful shock- painful but muscular control not lost	62	41	9	6
5.	Painful shock- let go threshold	76	51	16.0	10.5

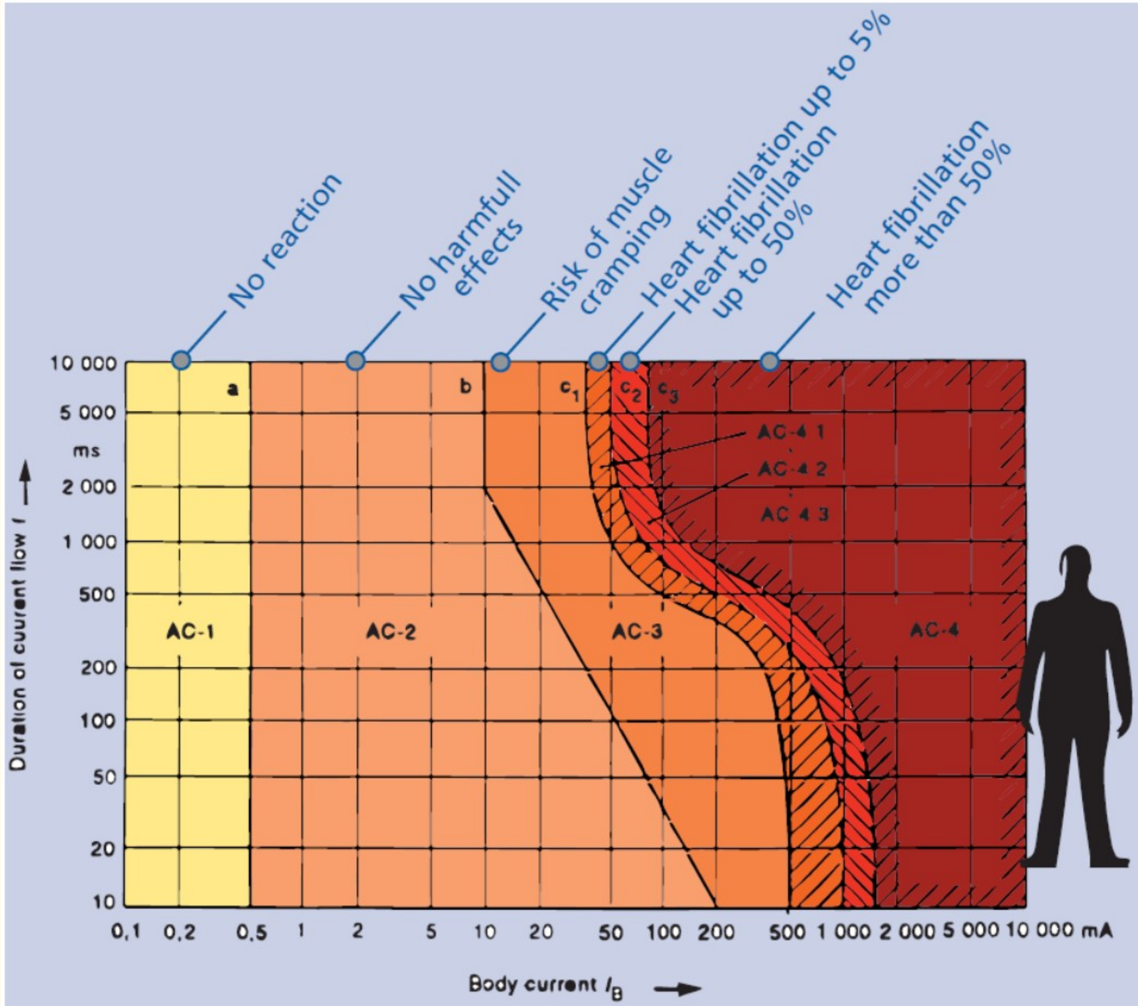
Threshold for 50% of males and females tested.

Typical effects of currents on People ...

Sr No.	Effect	Current (mA)			
		Direct Current		60 Hz rms	
		Men	Women	Men	Women
6.	Painful and severe shock, muscular contractions, breathing difficult	90	60	23	15
7.	Possible ventricular fibrillation from short shocks:				
(a)	Shock duration 0.03 s	1300	1300	1000	1000
(b)	Shock duration 3 s	500	500	100	100
(c)	Almost certain ventricular fibrillation (if shock duration is over one heart beat interval)	1375	1375	275	275

Threshold for 50% of males and females tested.

Effects of current



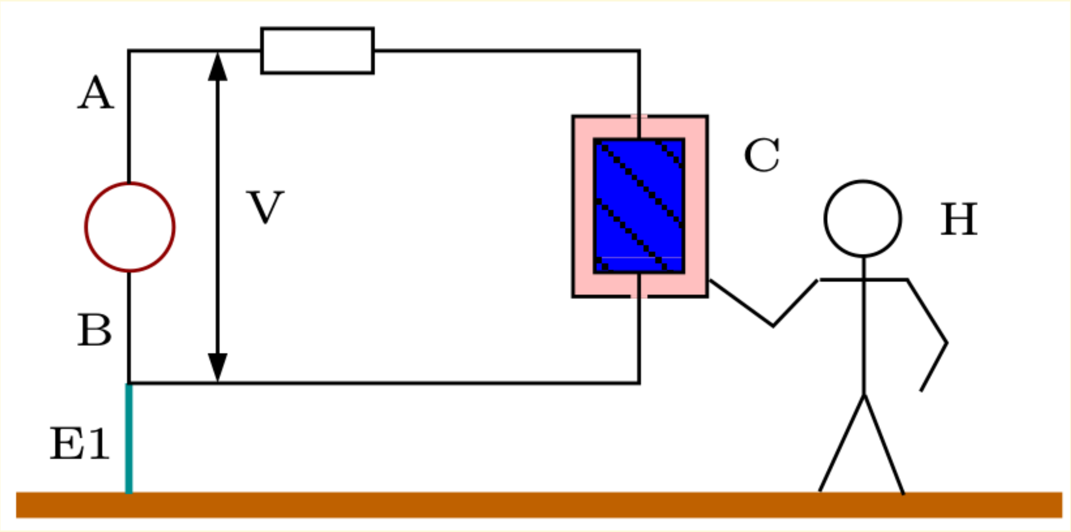
Source: IEC 60479-1 Technical Report - Effects of current on human beings and livestock

Factors which affect earthing scheme

- Safety
- Service Continuity
- Abnormal Voltage Hazards
- Multiple Faults to Ground
- Location of Faults
- Cost.

- Numerical Examples

Case-1: Source grounded, Equipment ungrounded



R_C = equipment load resistance = 58 Ω

R_I = equipment insulation resistance.

Adapted from: K. Rajamani, *Application Guide for Power Engineers, Part-1 Earthing and Grounding of Electrical Systems,* Notion Press Publisher, (2018).

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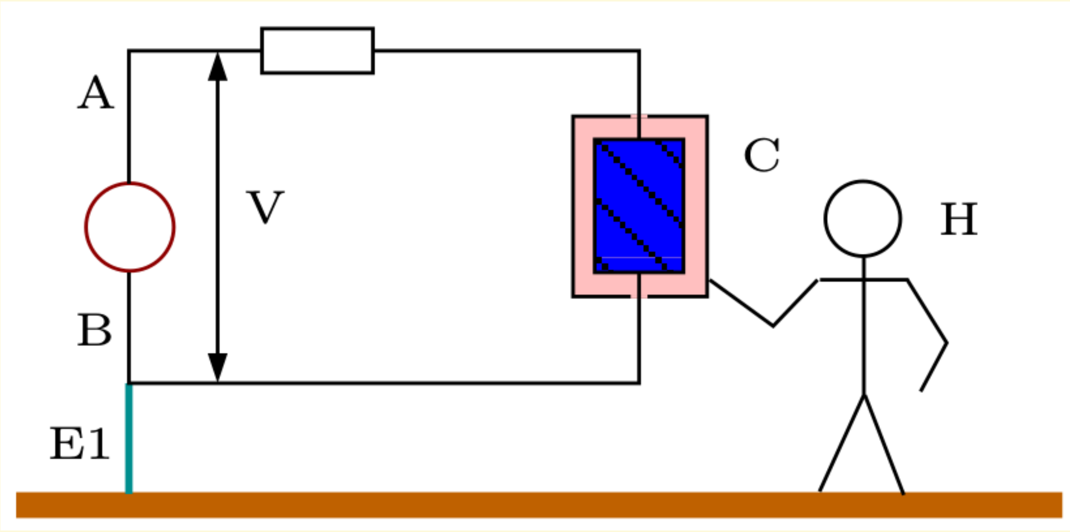

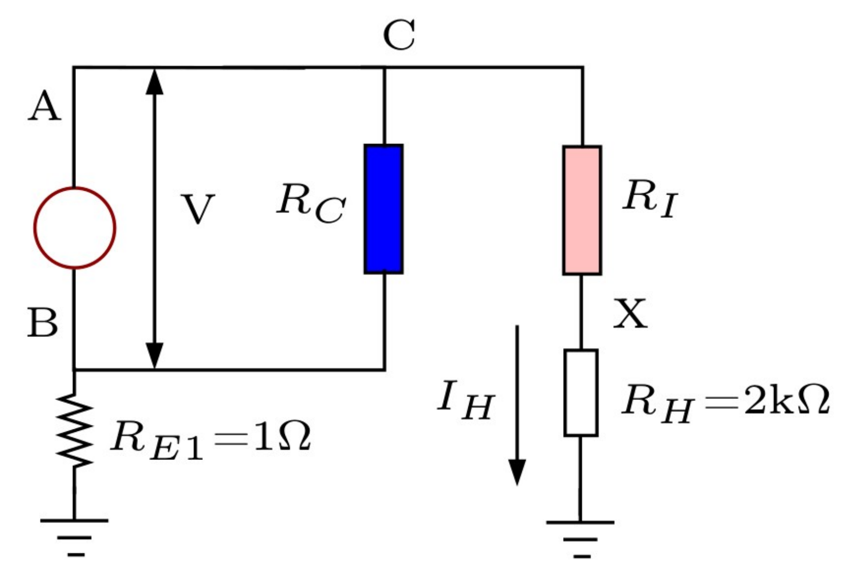

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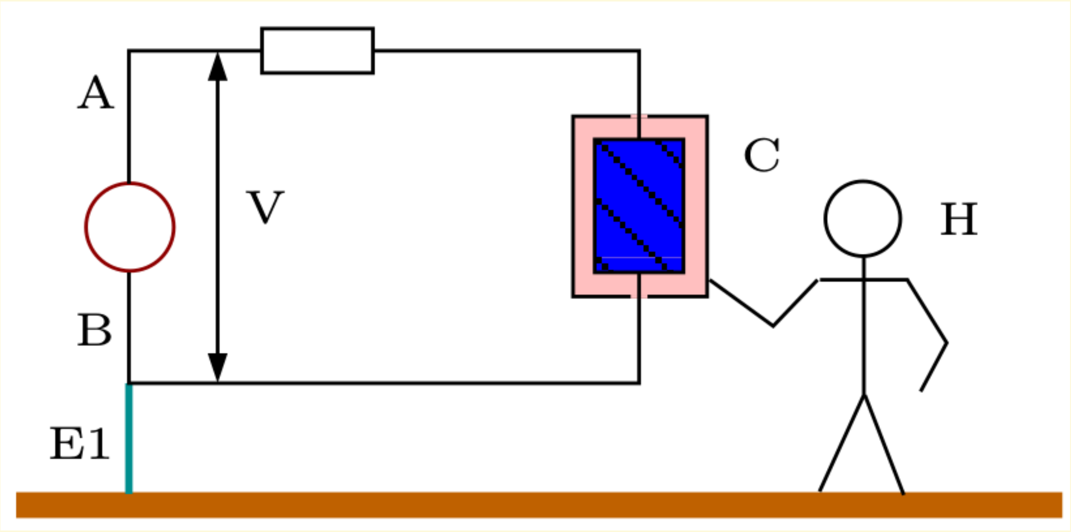
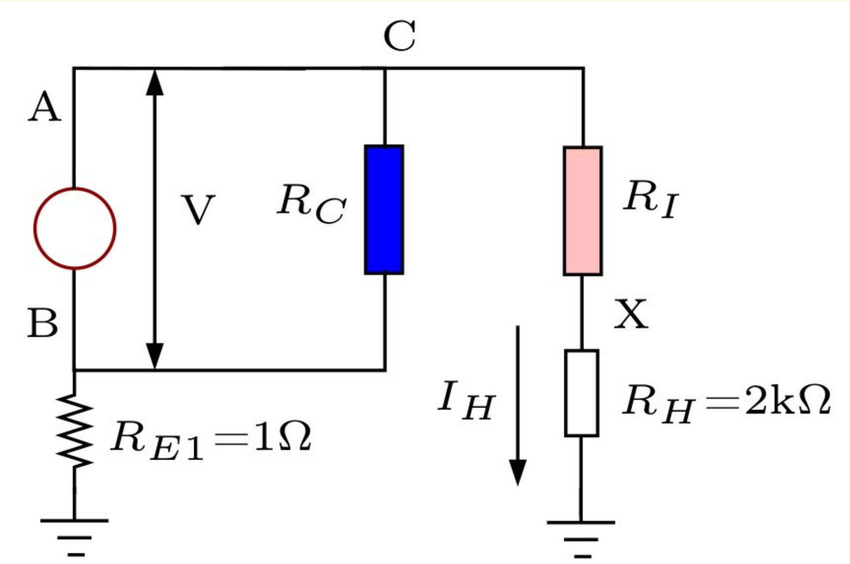




R_C = equipment load resistance = 58 Ω

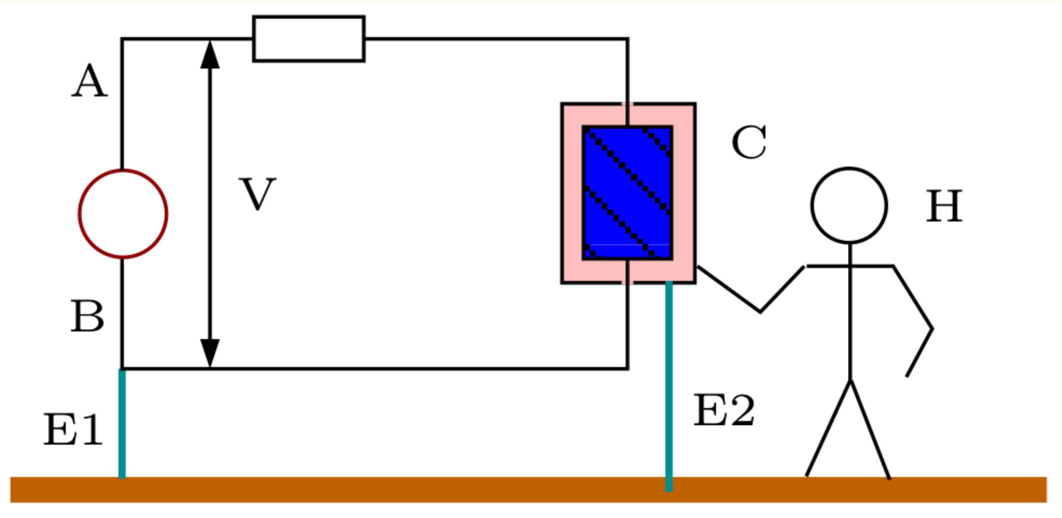
R_I = equipment insulation resistance.

The current through the person during insulation failure (R_I = 0 Ω)

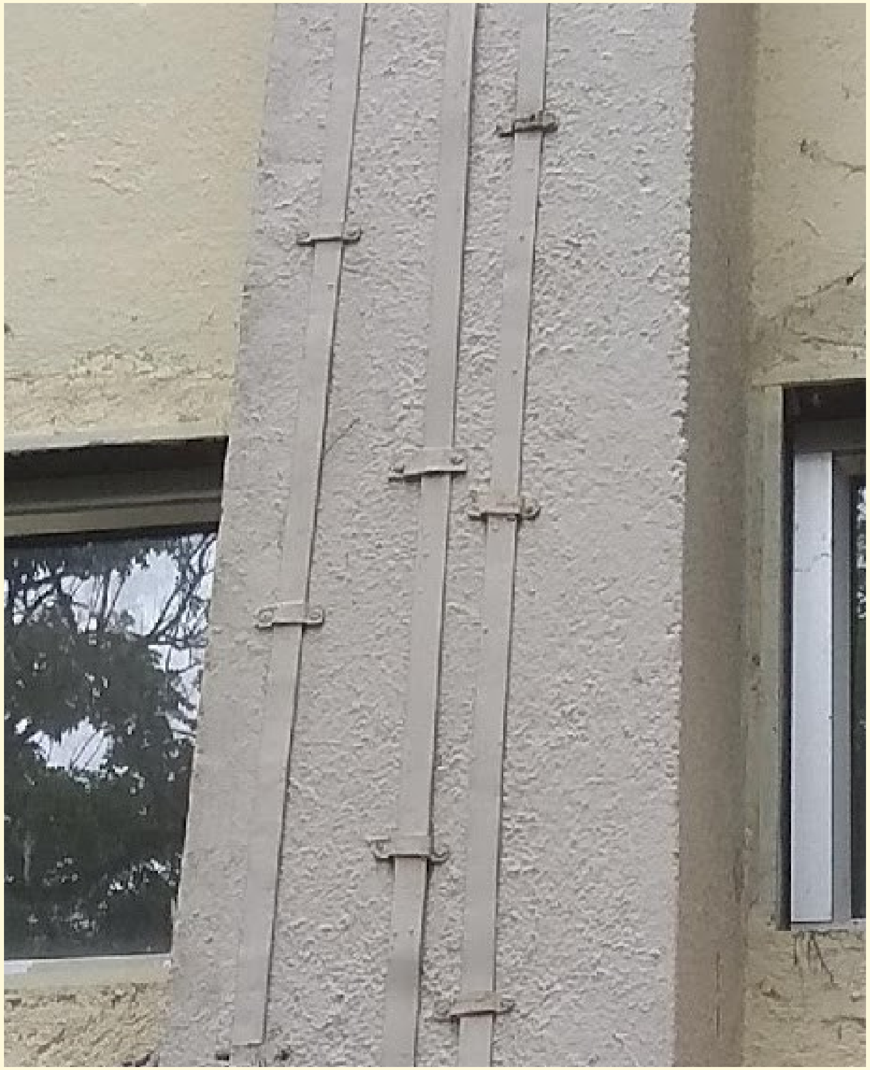
$$I_H = \frac{V}{R_H + R_{E1}} = \frac{240}{2000 + 1} \approx 120 \text{ mA}$$

Adapted from: K. Rajamani, *Application Guide for Power Engineers, Part-1 Earthing and Grounding of Electrical Systems,* Notion Press Publisher, (2018).

Case-2: Source grounded, Equipment grounded



Earthing



Earthing

Earthing

Earthing

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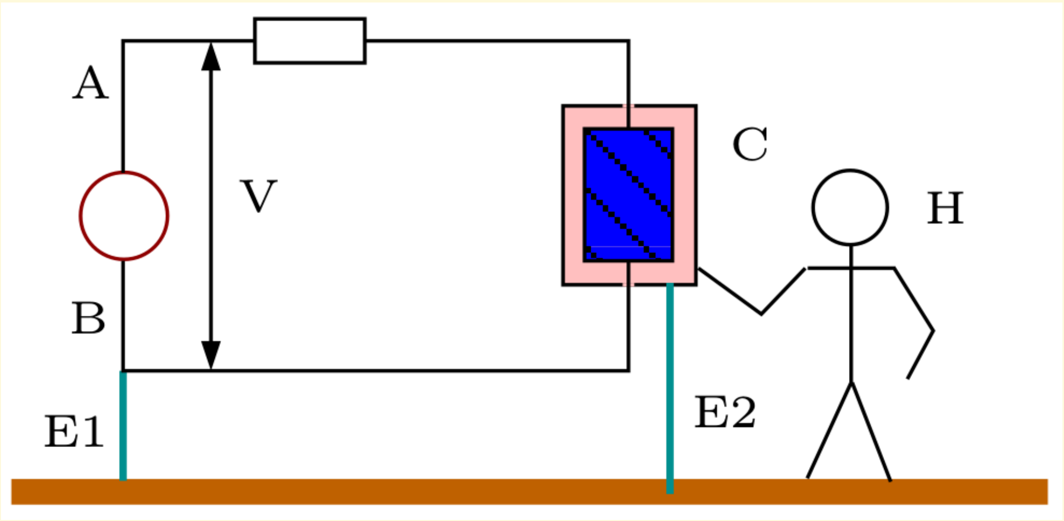
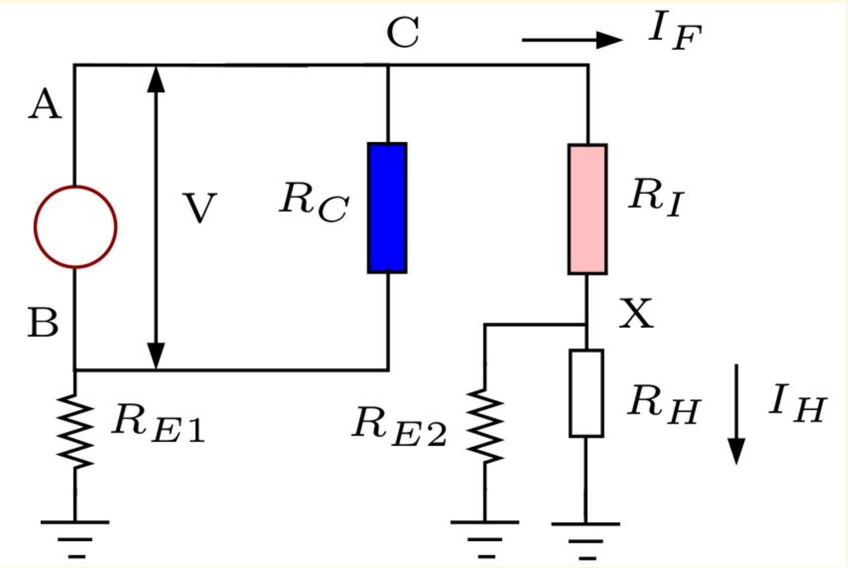
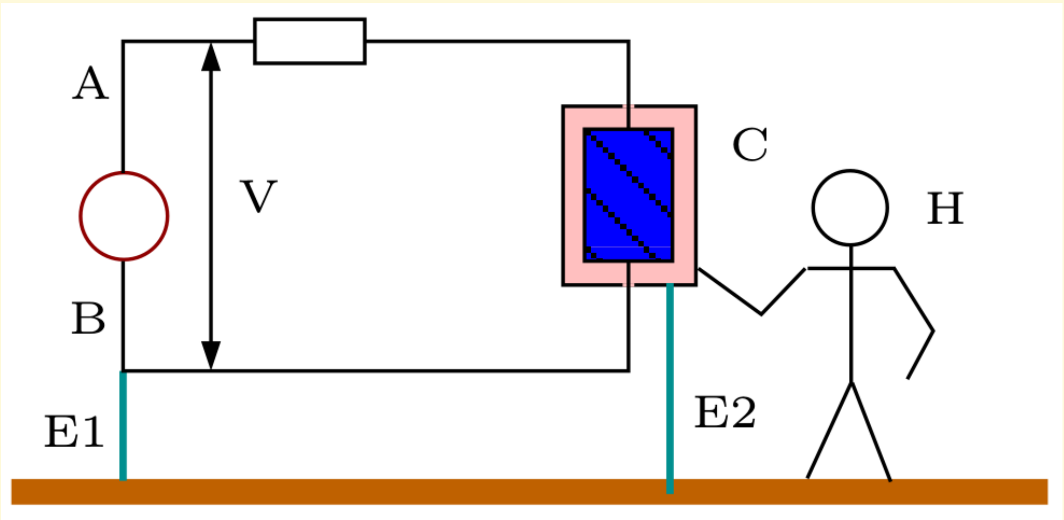
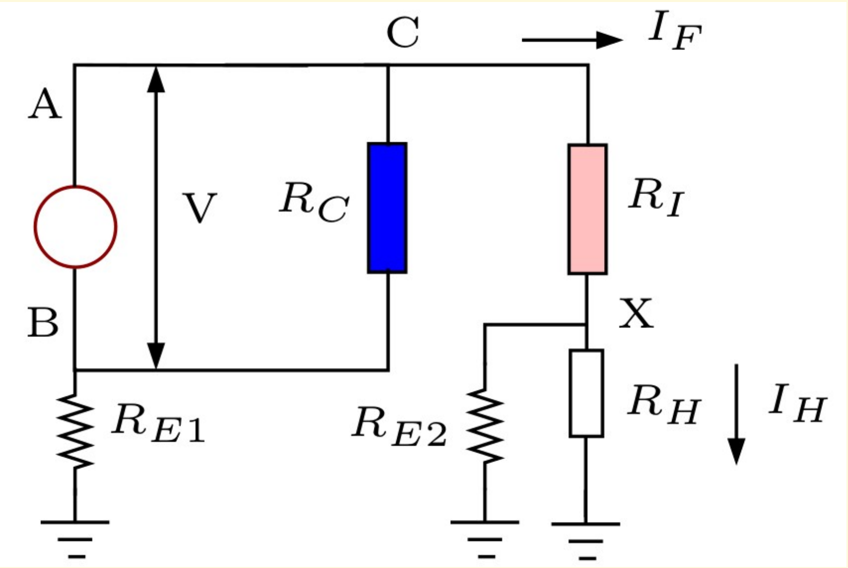




$$R_{EQ} = R_{E2} || R_H \approx 1\,\Omega$$

Case-2: Source grounded, Equipment grounded



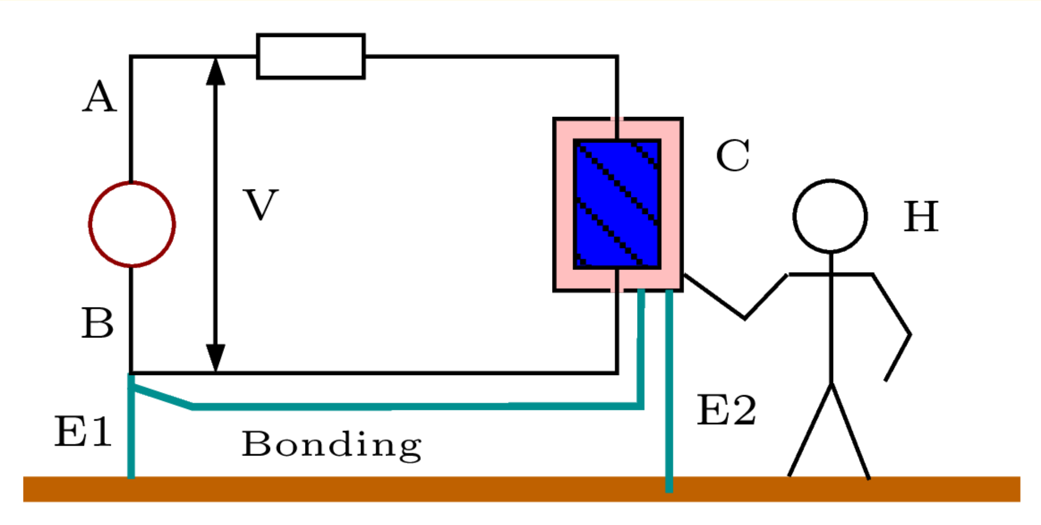


$$R_{EQ} = R_{E2} || R_H \approx 1\ \Omega$$

$$I_F = \frac{V}{R_{EQ} + R_{E1}} = \frac{240}{1+1} = 120\ \mathrm{A}$$

$$I_H = \frac{1}{(1+2000)} 120 = 60\ \mathrm{mA}$$

Case-3: Source grounded, Equipment grounded with **bonded conductor**



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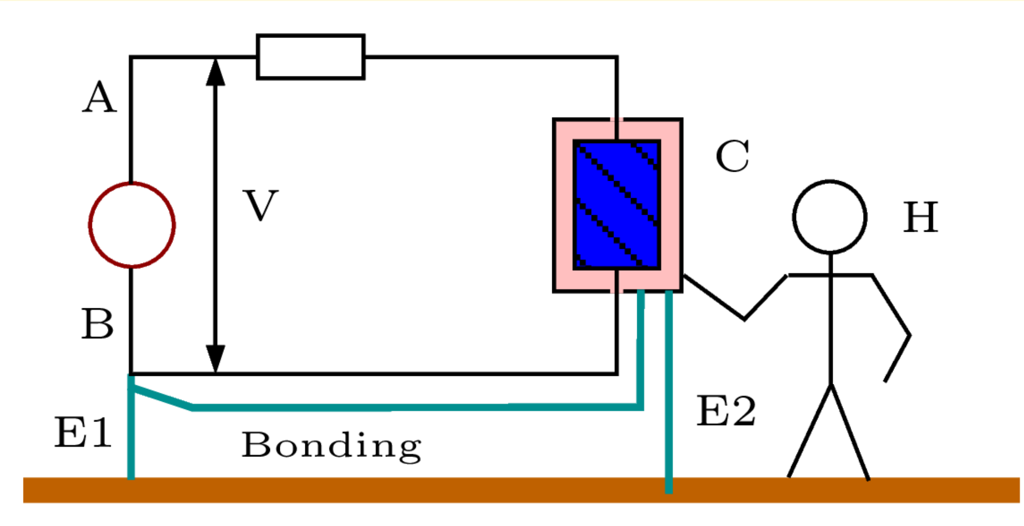

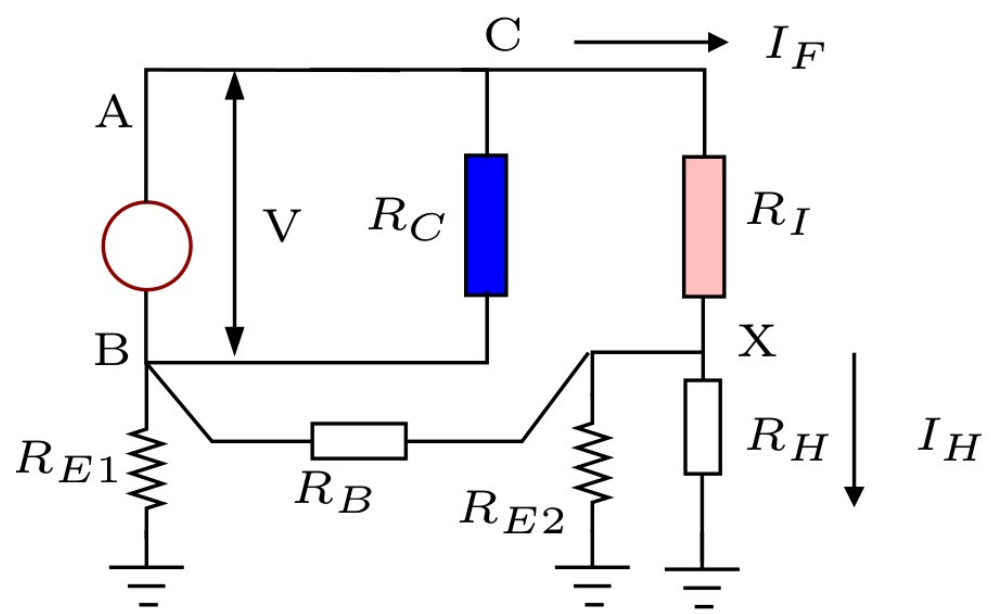

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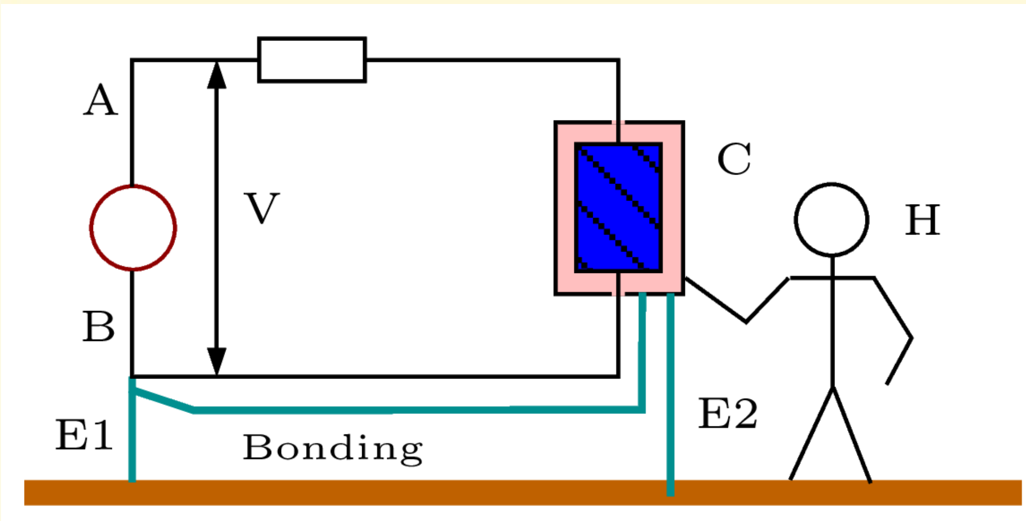
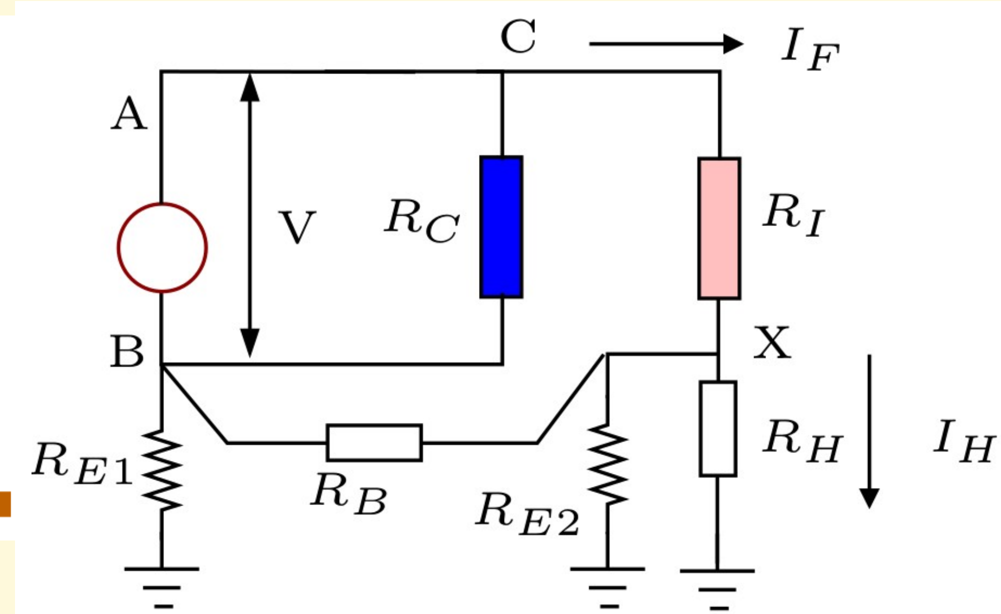
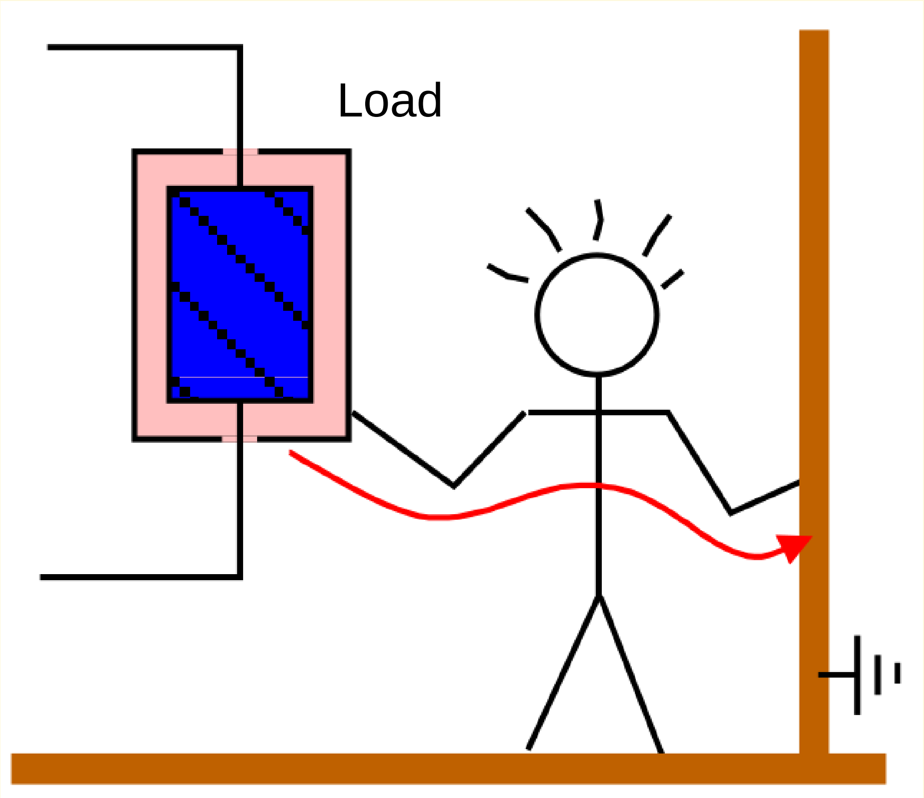




$$I_F = \frac{V}{R_B} = \frac{240}{1} = 240 \text{ A}$$

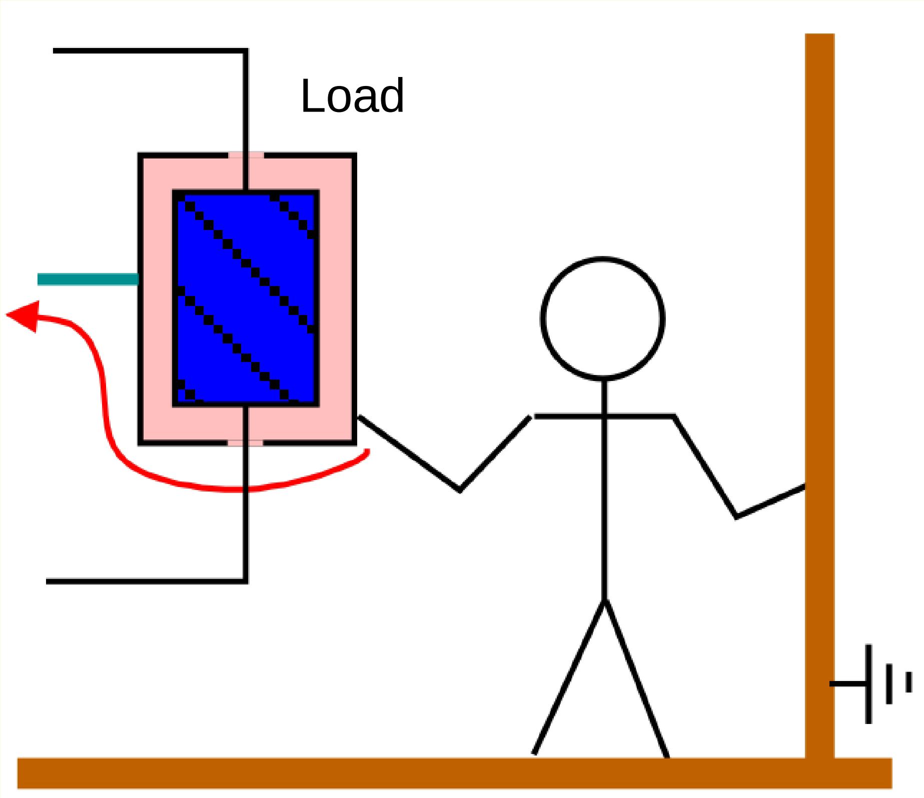
$$I_H \approx 0 \text{ mA}$$

Two-pin wiring



Unsafe Earthing
No Earth Continuity Conductor

Three-pin wiring

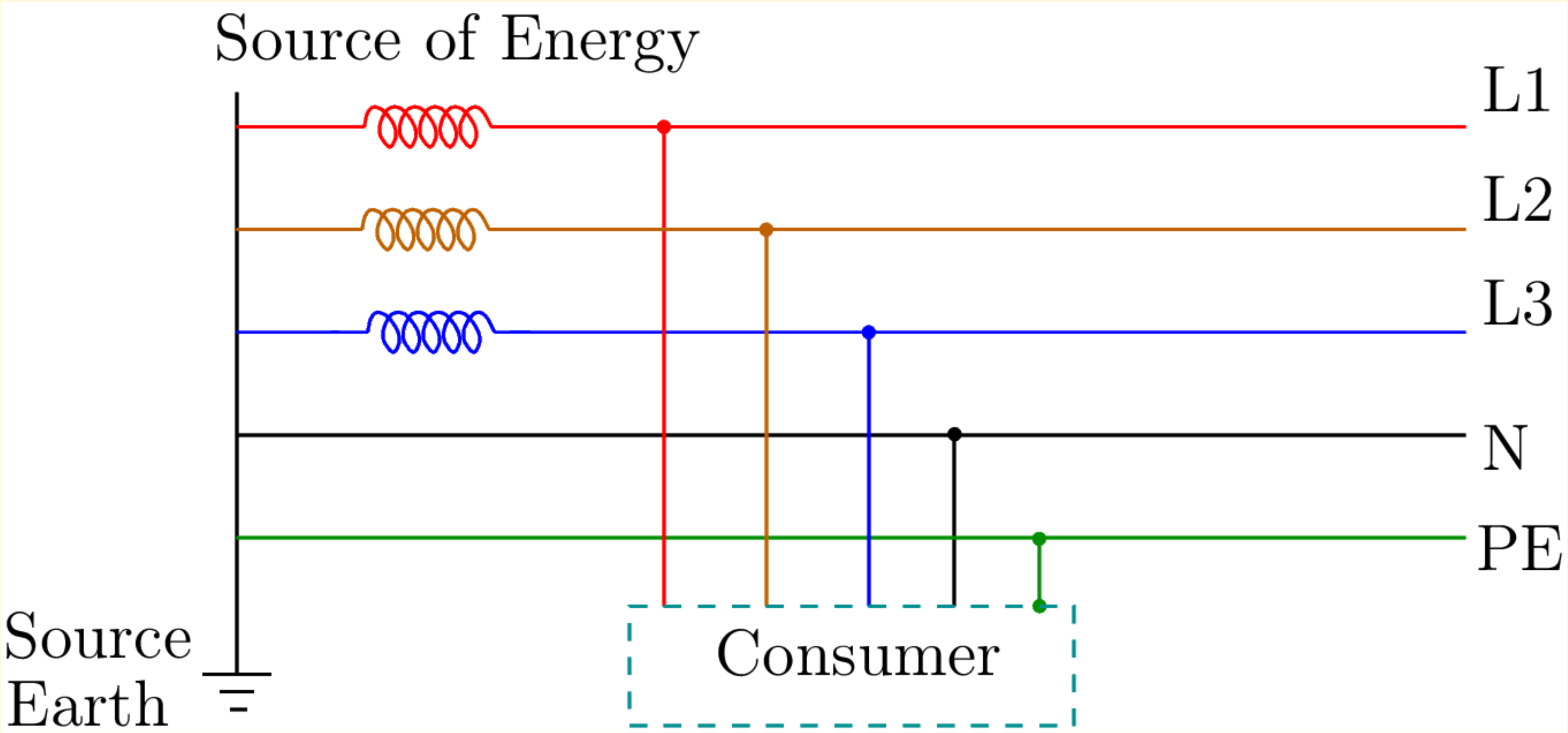


Safe Earthing
With Earth Continuity Conductor

Standards

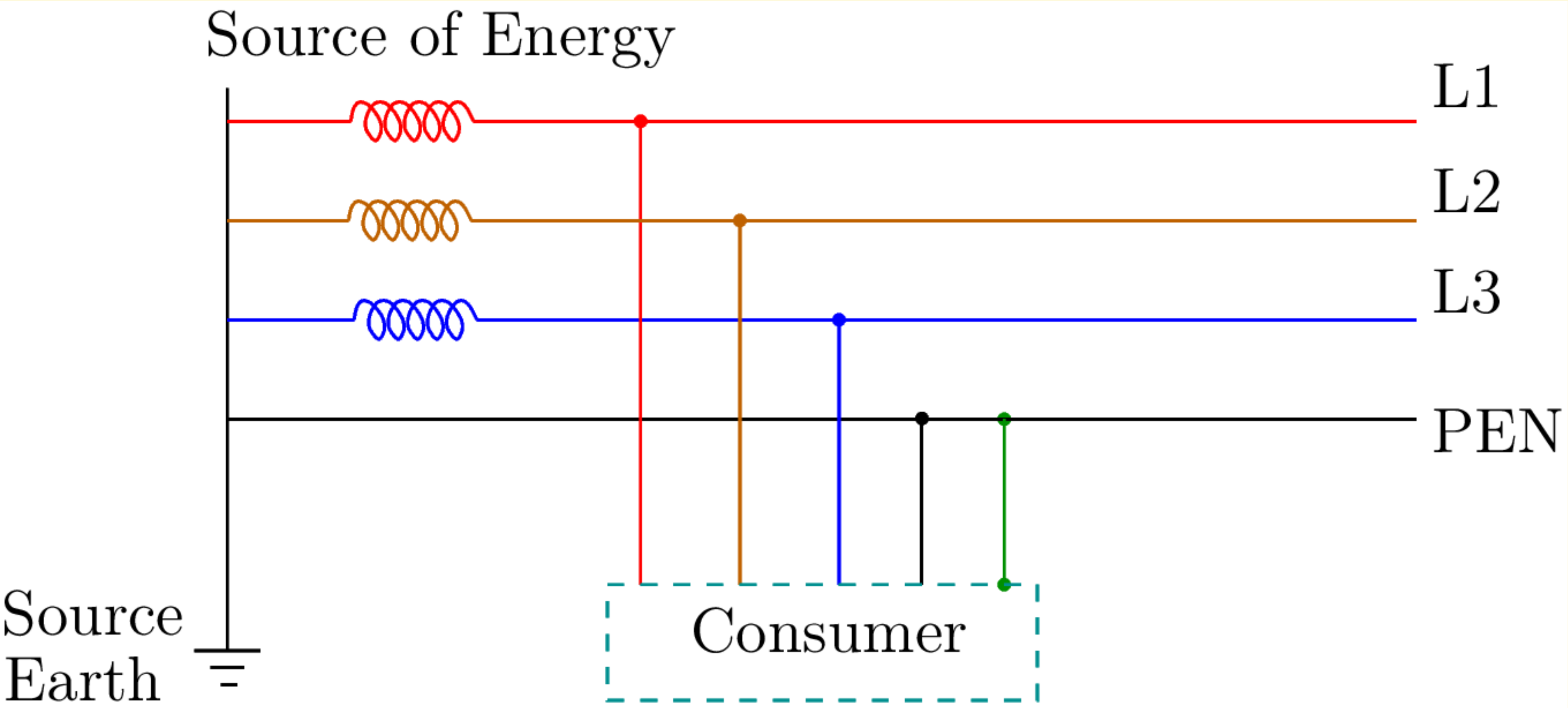
- Indian Standard
- Code of Practice for Earthing
- (Second Reprint, February 1998)
- **IS: 3043 - 1987**

Type of Connection: TN-S



Adapted from Wikipedia on earthing systems

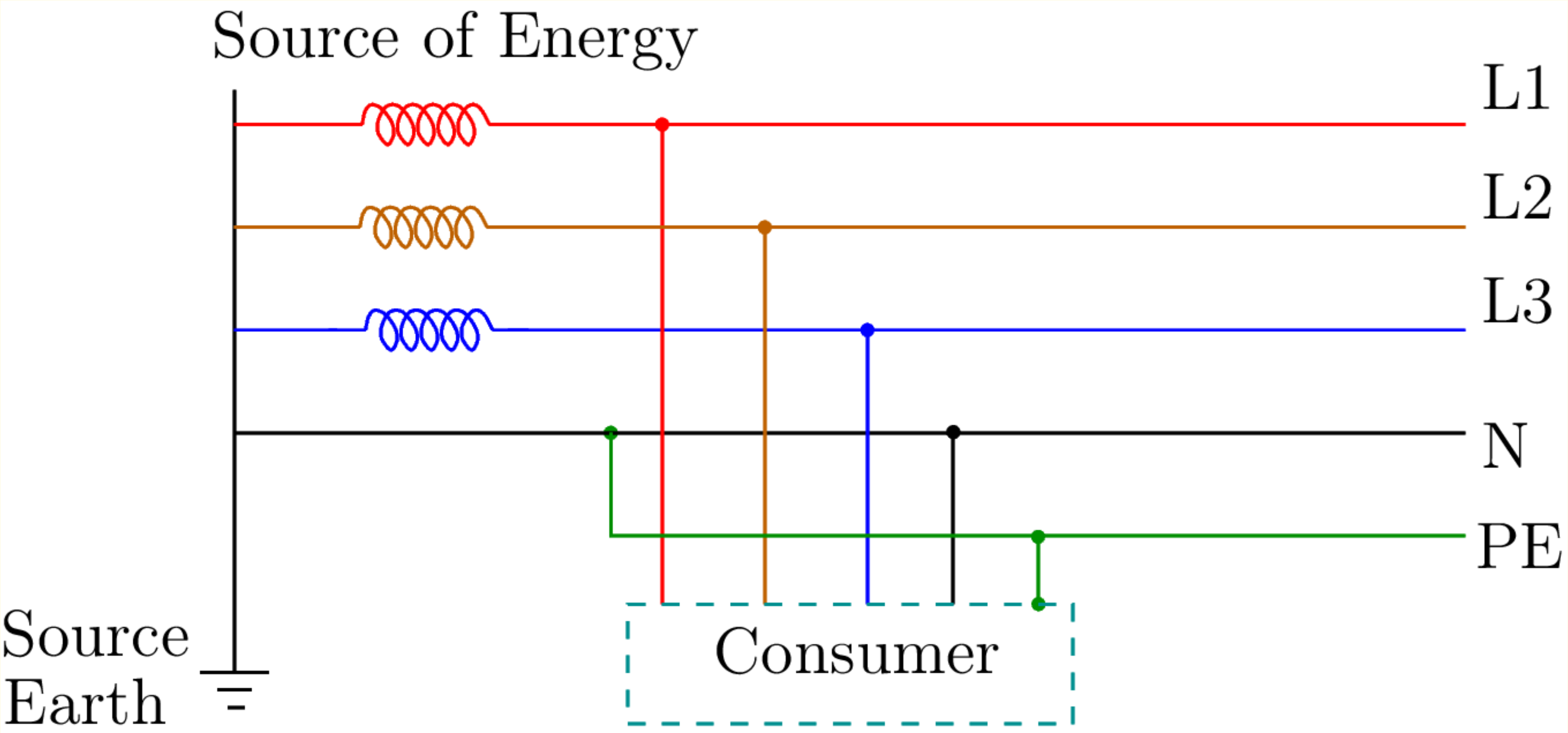
Type of Connection: **TN-C**



Neutral and protective functions combined

in a single conductor throughout the system.

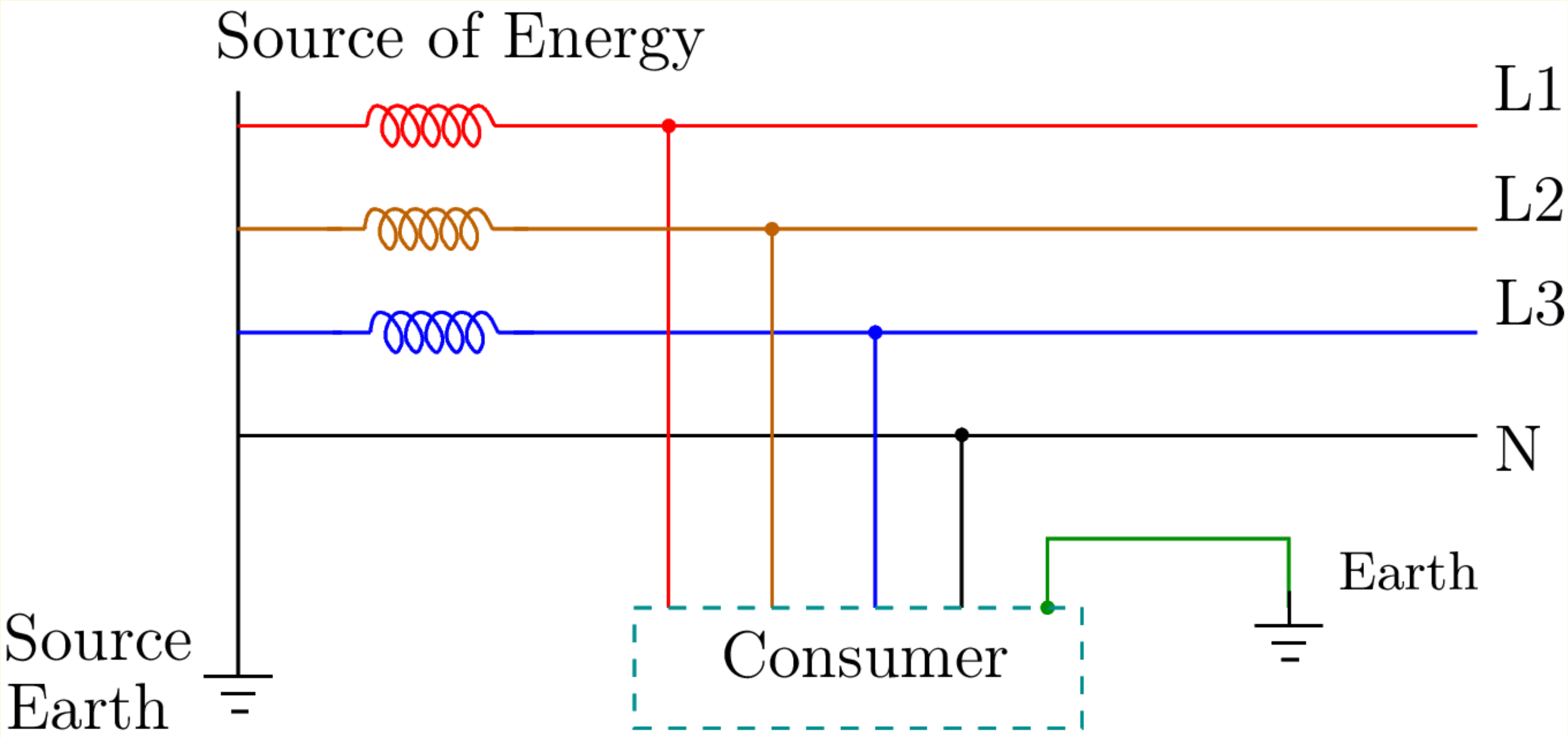
Type of Connection: TN-C-S



Neutral and protective functions combined

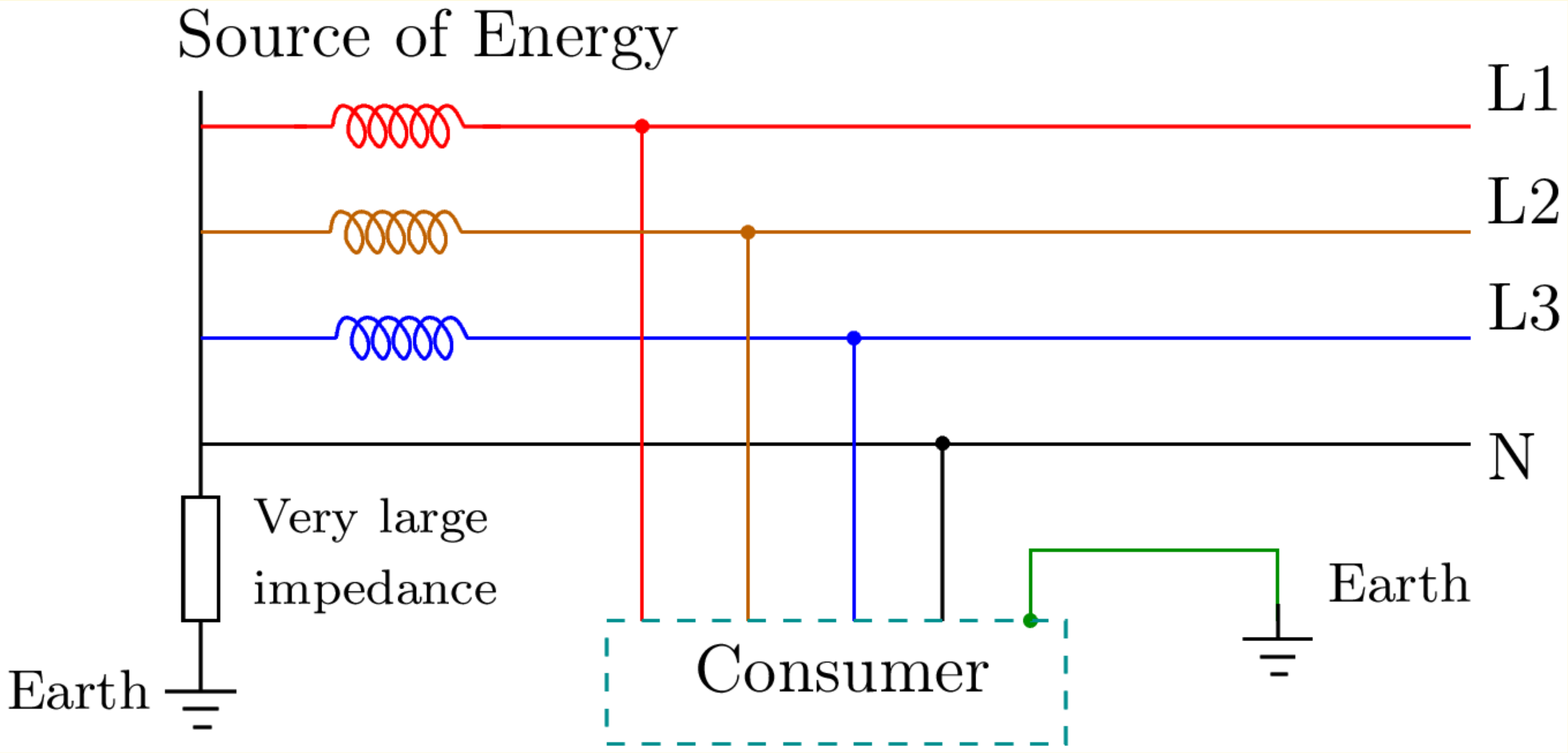
in a single conductor in a part of the system.

Type of Connection: **TT**



TT systems (all exposed conductive parts of the installations are connected to the earth electrode).

Type of Connection: **IT**



IT systems (all exposed conductive parts of the installations are connected to the earth electrode). The source is either isolated or connected from earth through an earthing impedance.

Comparison of Earthing systems

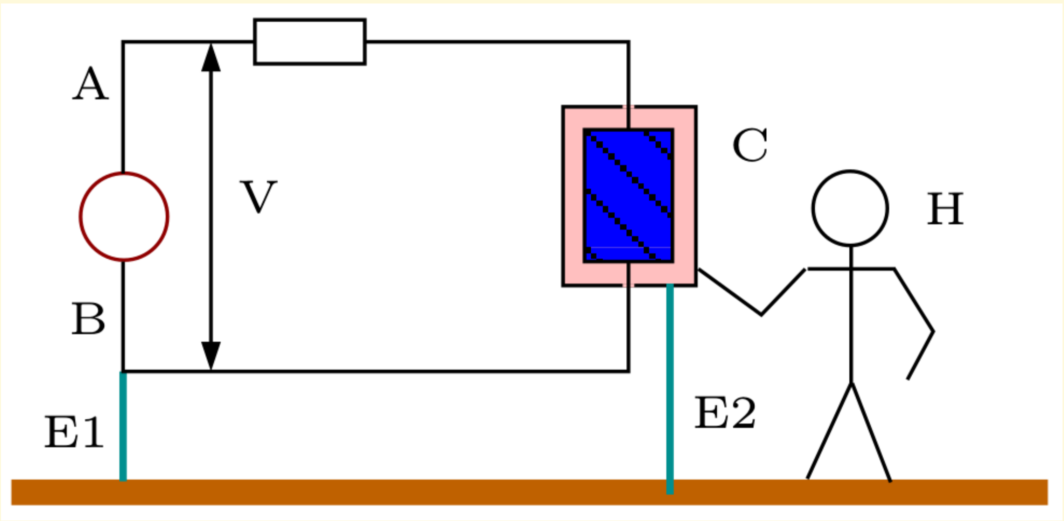
	TT	IT	TN-S	TN-C	TN-C-S
Earth fault loop impedance	High	Highest	Low	Low	Low
RCD preferred?	Yes	N/A	Optional	No	Optional
PE conductor cost	Low	Low	Highest	Least	High
Safety	Safe	Less Safe	Safest	Least Safe	Safe
Safety risks	High loop impedance (step voltages)	Double fault, overvoltage	Broken PE	Broken neutral	Broken neutral
Advantages	Safe and reliable	Continuity of operation, cost	Safest	Cost	Safety and cost

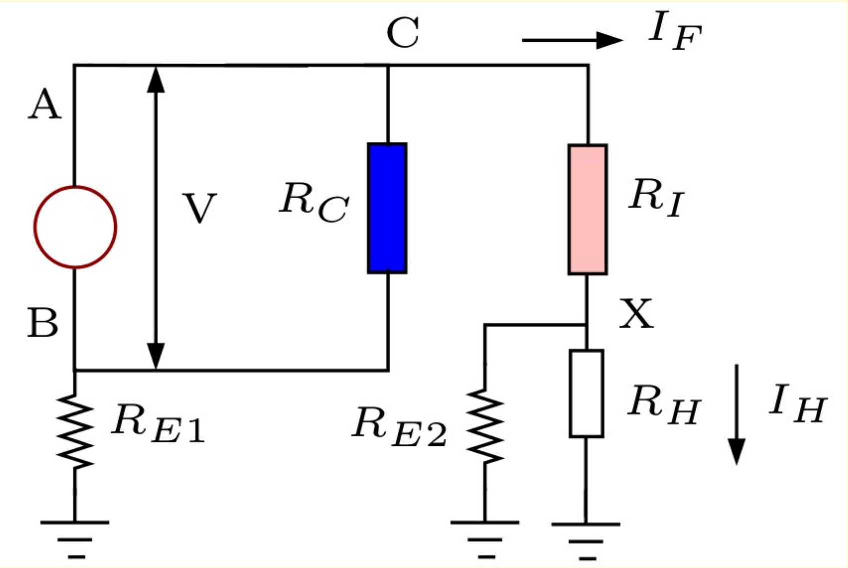
Adapted from: Wikipedia on earthing systems.

Residual Current Devices (RCD)

A case revisited

Case-2: Source grounded, Equipment grounded





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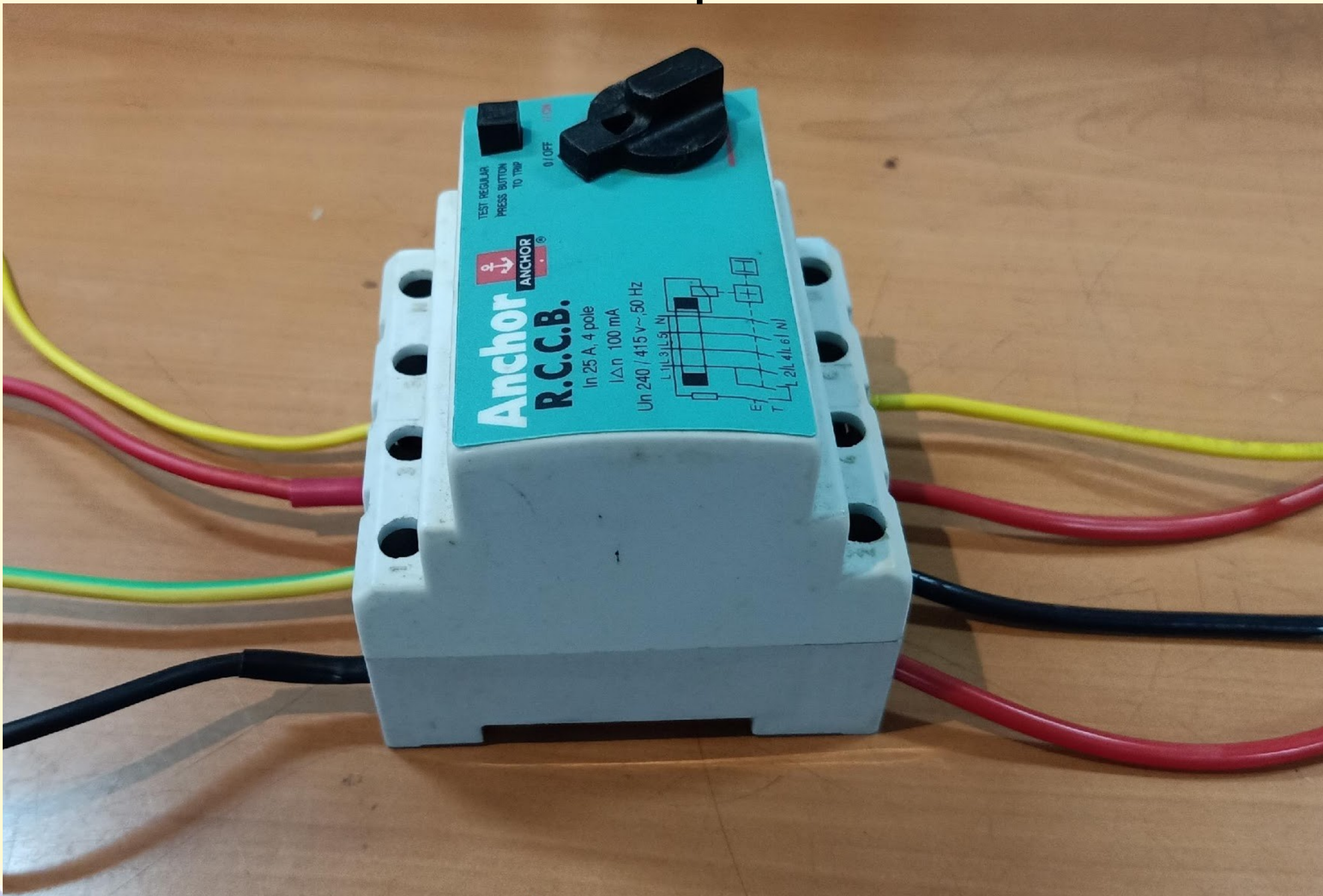
100 mA three-phase RCD

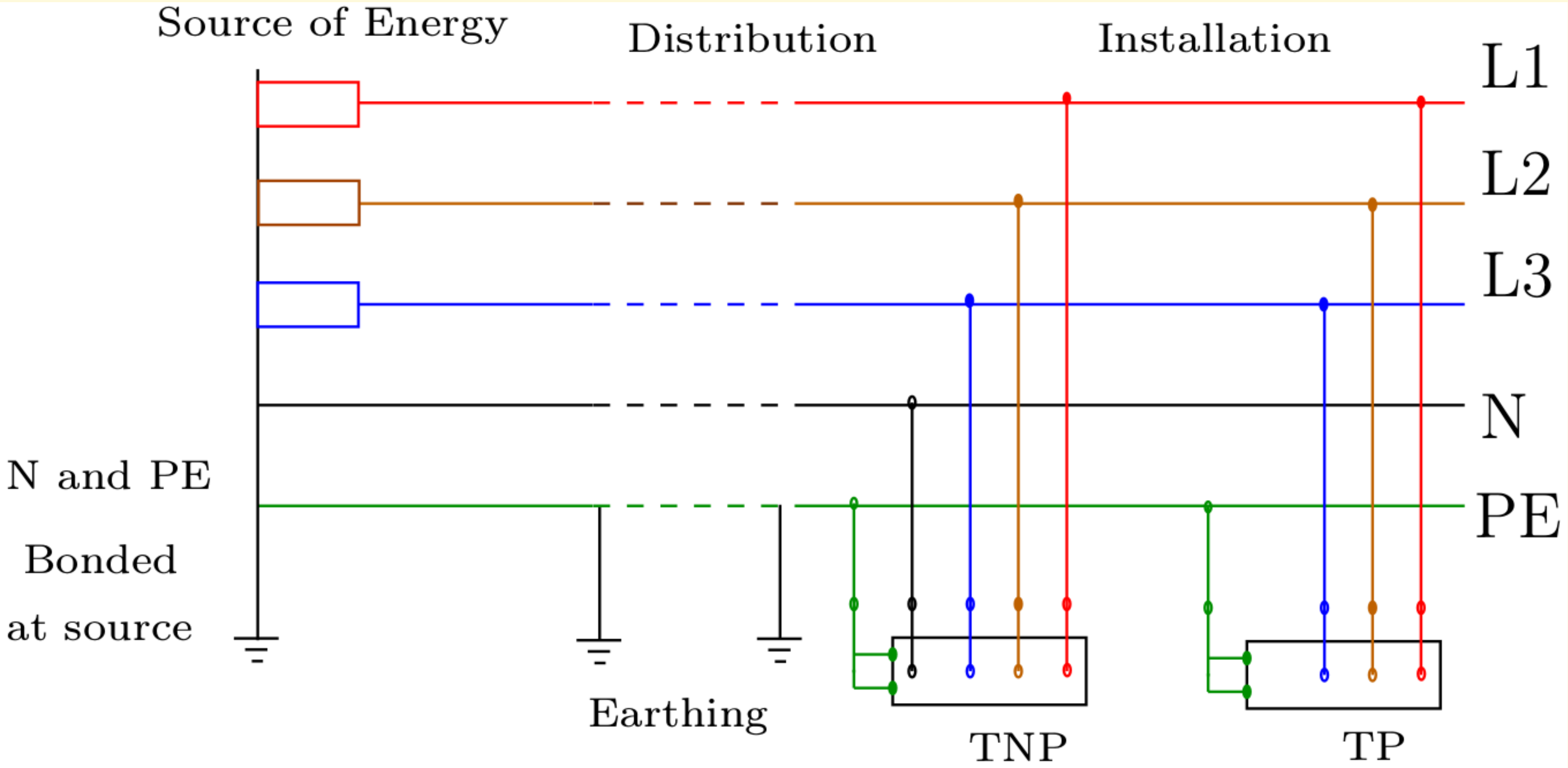


Experimental demo

A person (resistors used) with body resistance around 2.3 kΩ directly touching a live point of a 415 V (rms) three-phase circuit.

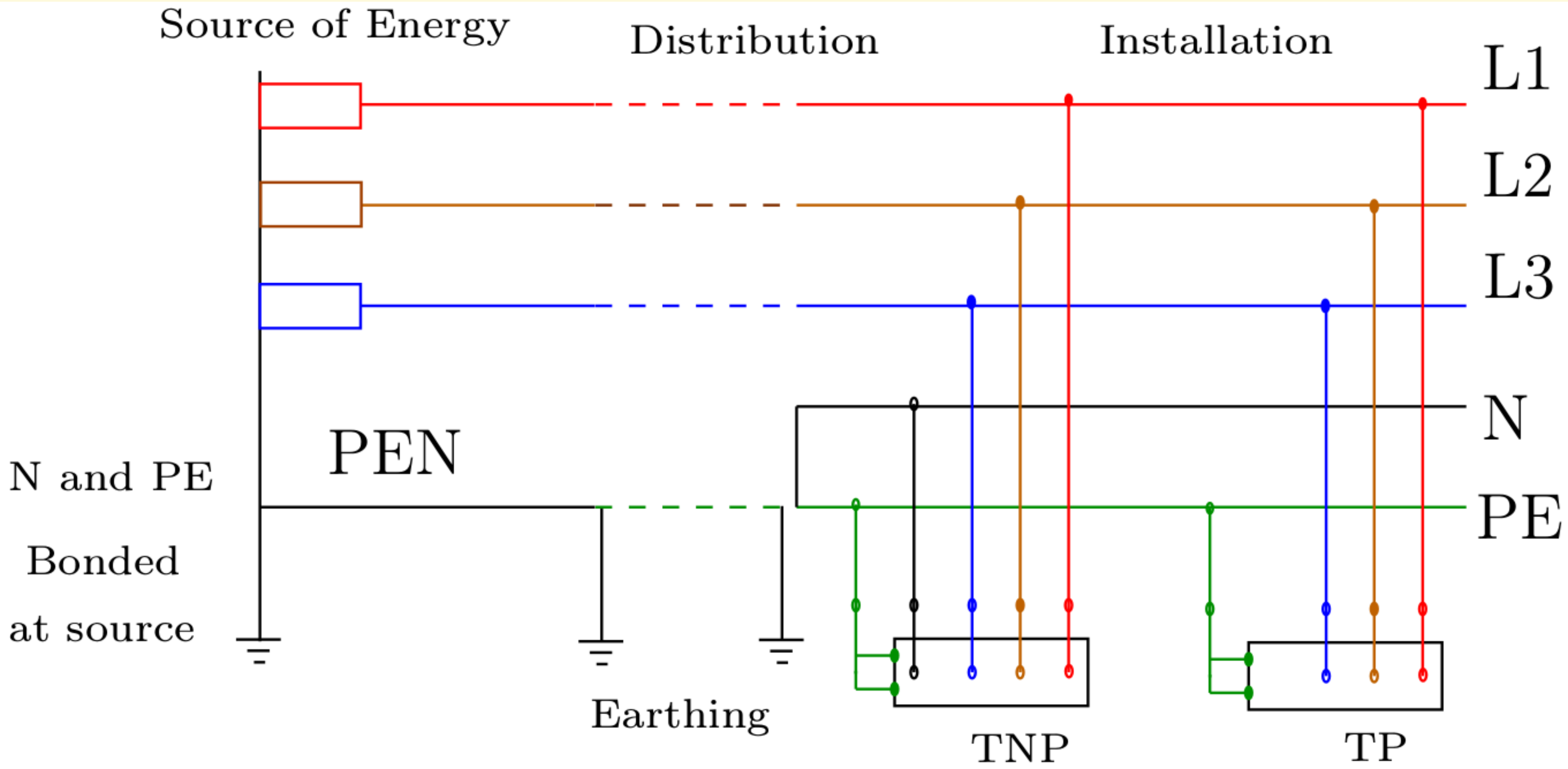
Other types of connections ...

Type of connection: **TNS**

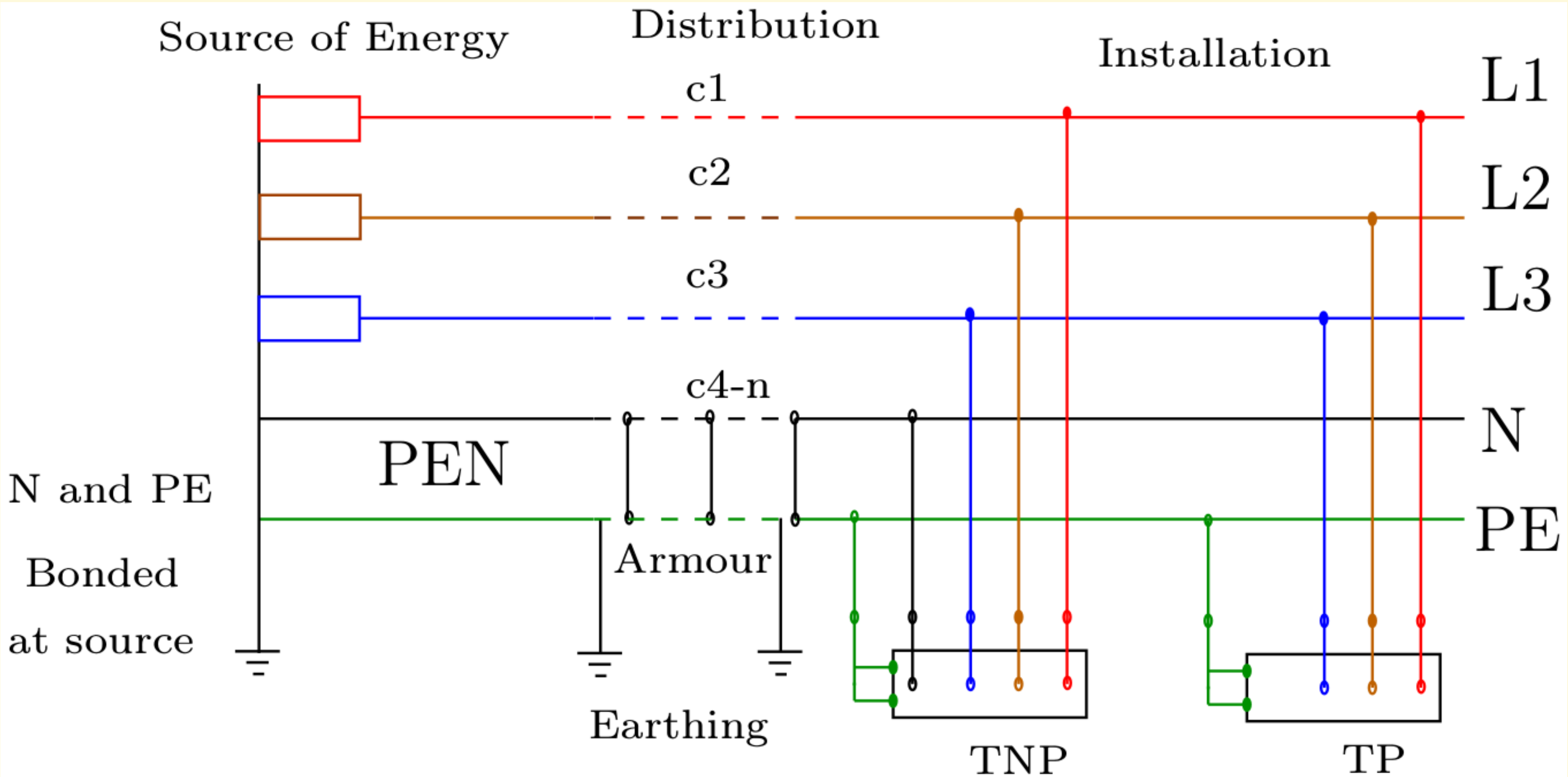


Adapted from: K. Rajamani, *Application Guide for Power Engineers, Part-1 Earthing and Grounding of Electrical Systems,* Notion Press Publisher, (2018).

Type of connection: **TNCS-PME**

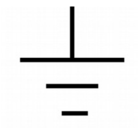


Type of connection: **Modified TNCS**



Earth Conductor

Marking of conductors

Designation of Conductors	Identification by		Colour
	Alphanumeric Notation	Graphical Symbol	
Earth	E		No colour other than the colour of the bare conductor
Protective conductor	PB		Green and yellow

Classification of Equipment

	Class 0	Class I	Class II	Class III
Principal characteristics of equipment	No means of protective earthing	Protective earthing means provided	Additional insulation and no means for protective earthing	Designed for supply at safety extra low voltage
Precautions for safety	Earth free environment	Connection to the protective earthing	None necessary	Connection to safety extra low voltage

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Specialist Equipment Only (Risky)

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Kettles, Irons, Washing Machines, Toasters, Microwaves, Electric Heaters, Fridges, Freezers and Tumble Dryers

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Hair Dryers, DVD Players, TVs and Lamps

Chargers

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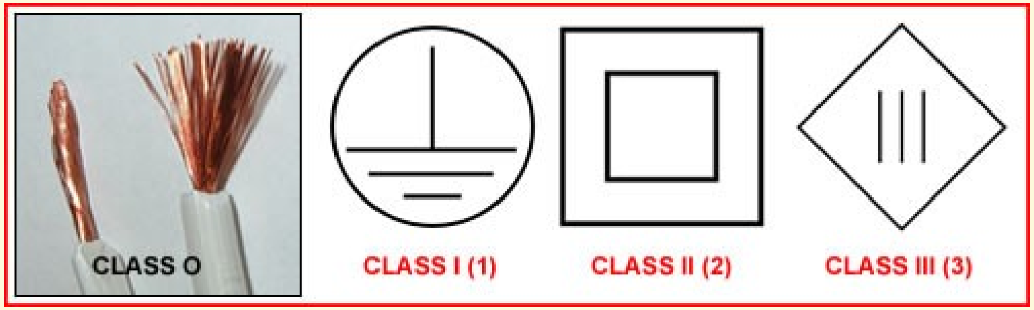
Hair Dryers, DVD Players, TVs and Lamps

Chargers

Mobile Phones, Laptops and Low Energy Light Bulbs (torch), Cameras. Run Independent of Power Supply (<50 Vac normally Below 24 V ac)

Note:
Chargers are Class I/II

Equipment



Class ?

Does Appliance Have a Rating Plate

NO

Investigate

YES

Double Box Mark

NO

Class I

YES

Class II

Equipment

Fig 4.11: Electric fan: rating plate

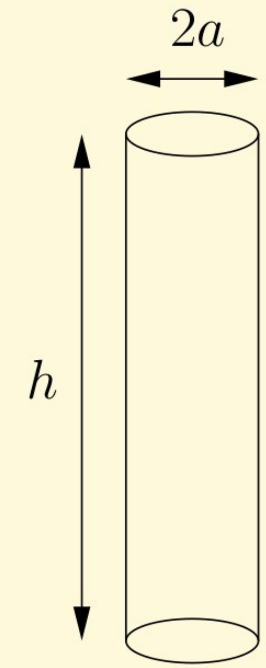
Fig 4.10: Plastic table lamp: rating plate

Earthing

- Low Resistance to Ground
- Electrode – Contact Resistance
- Ground Conductor Pipes/Rods/Strip/Conductor
- Water Piping? Non Conducting Pipe/Joints
- Structural Steel Work ? Resistance Needs to be checked
- Cable Sheath/Armour

Earthing

The most common electrode is cylindrical rod (as shown)



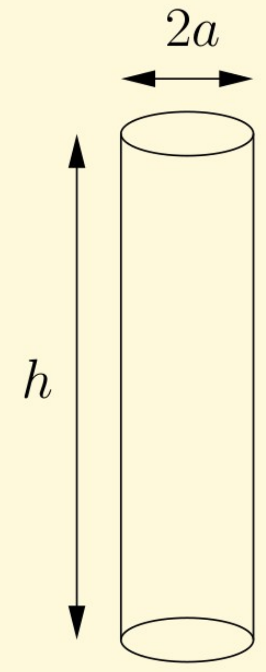
Earthing

The most common electrode is cylindrical rod (as shown)

The grounding resistance is given by

$$R = \frac{\rho}{2\,\pi\,h}\,\left[\log_e\left(\frac{4\,h}{a}\right) - 1\right]$$

ρ : Resistivity of the ground



Source: E. D. Sunde, Earth Conduction Effects in Transmission Systems (New York, Dover, 1968).

Fault-Current Interruption (Circuit Breakers)

Moulded Case Circuit Breaker
(fault current interruption
Large rating)

Miniature Circuit Breaker
(fault current interruption
Smaller ratings)

Switch Fuse Unit

Other Switches

1) A **disconnector switch** or **isolator** switch (for service or maintenance). Do not have fault current interruption capability.

2) Electrically / Electronically operated switch in a low power circuit is called a **relay**. Digital relays can provide complex logic.

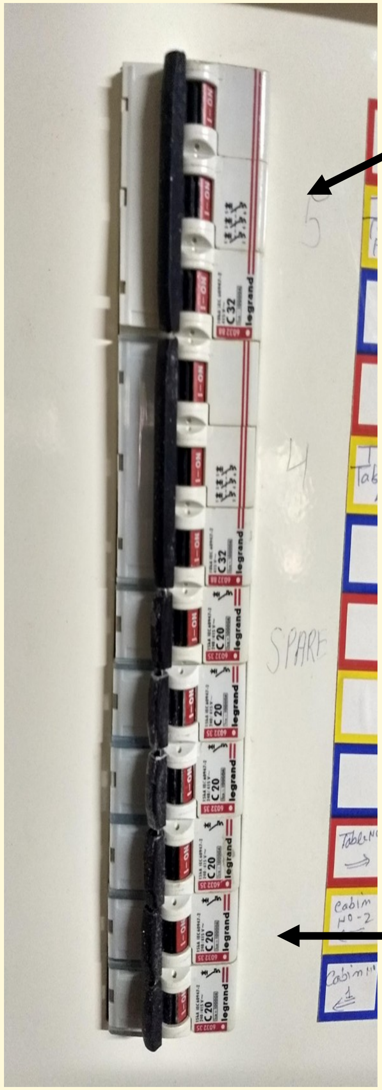
3) Devices switching more than **15 A** or in circuits rated more than a few kilowatts are usually called **contactors**.

   a) Unlike relays, contactors are designed to be directly connected to high-current load devices.

   b) Cannot interrupt large fault (short circuit) currents.

   c) Used for motor control, heating loads etc (switching in and out).

Distribution Board



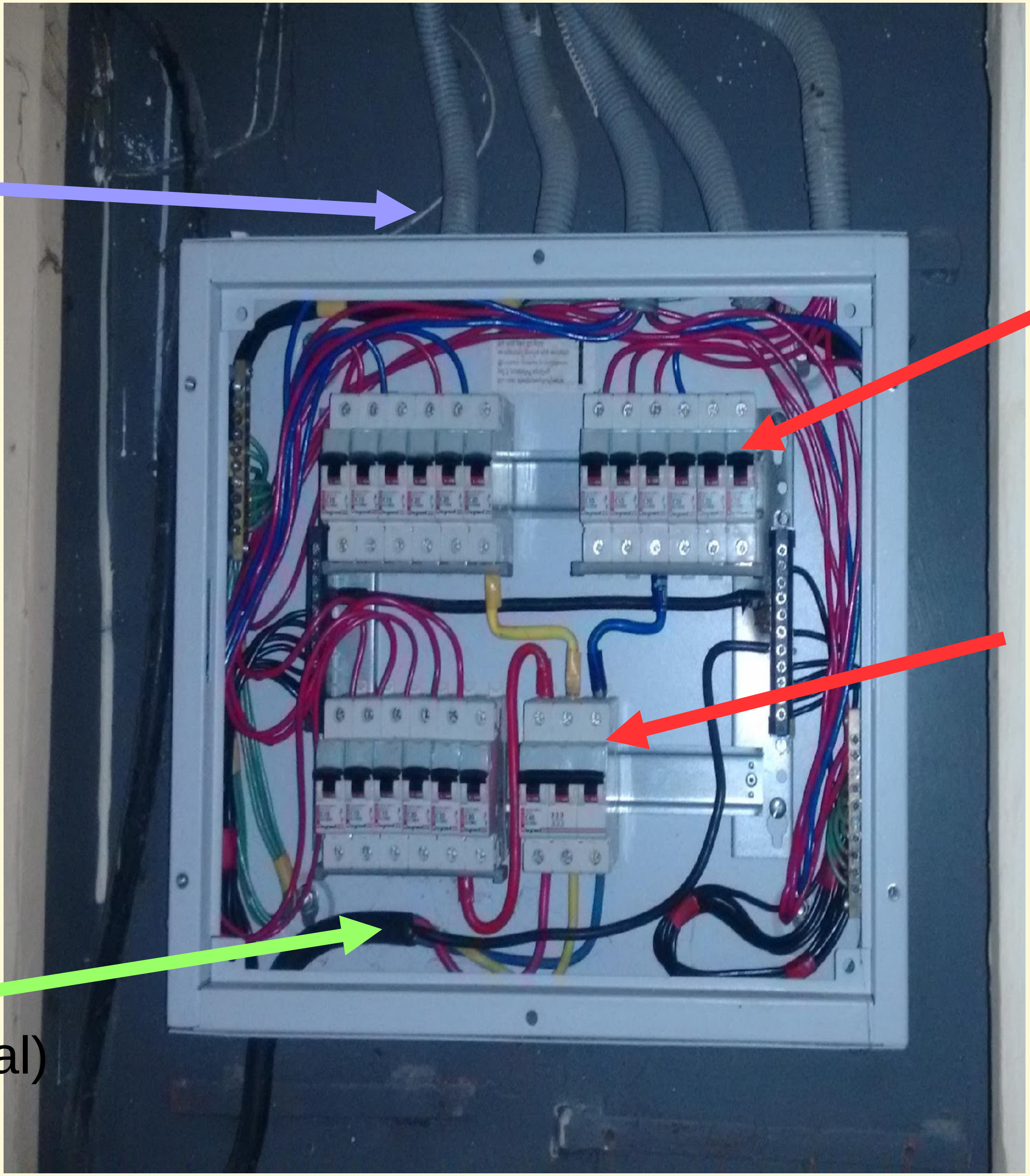
Three Pole MCB (for 3 phase loads)

Single Pole Switch

For single phase loads

Earth conductor

Distribution Board



Earth wire
(bare)

Single Pole
MCB

3-pole MCB

Input
(3 phase+Neutral)