Earth Testing

Earth Testing Pioneer

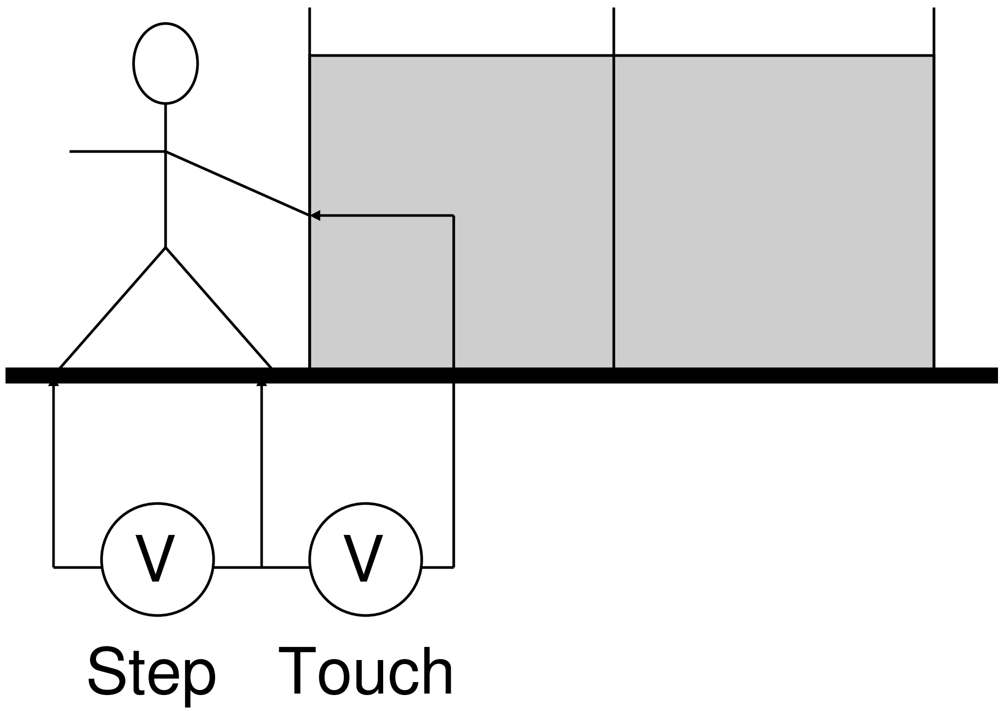
- Dr George Tagg pioneered earth testing at Megger
- Designing, manufacturing and selling for well over 50 years

Earthing System Resistance

- **Purpose**: Measure resistance of earthing system to Earth - ascertain that prospective fault current can be conducted safely to Earth and thus limit "touch voltage".

- **Methods**:
  - 3-pole: Fall of Potential
  - 2-pole: Direct measurement
  - 3-pole:Slope Method
  - 3-pole with clamp
  - Stakeless measurements: Earth Clamp.
- **Note:**
  - The earth electrode under test must be disconnected from the system it is earthing (apart from clamp & stakeless measurements)

Step and touch voltages



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Resistance and GPR from earth electrode

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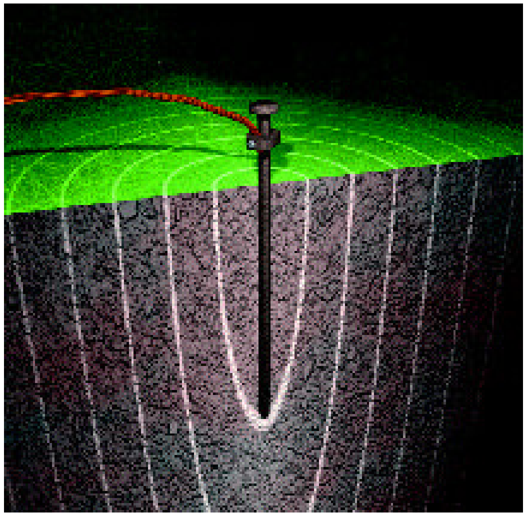
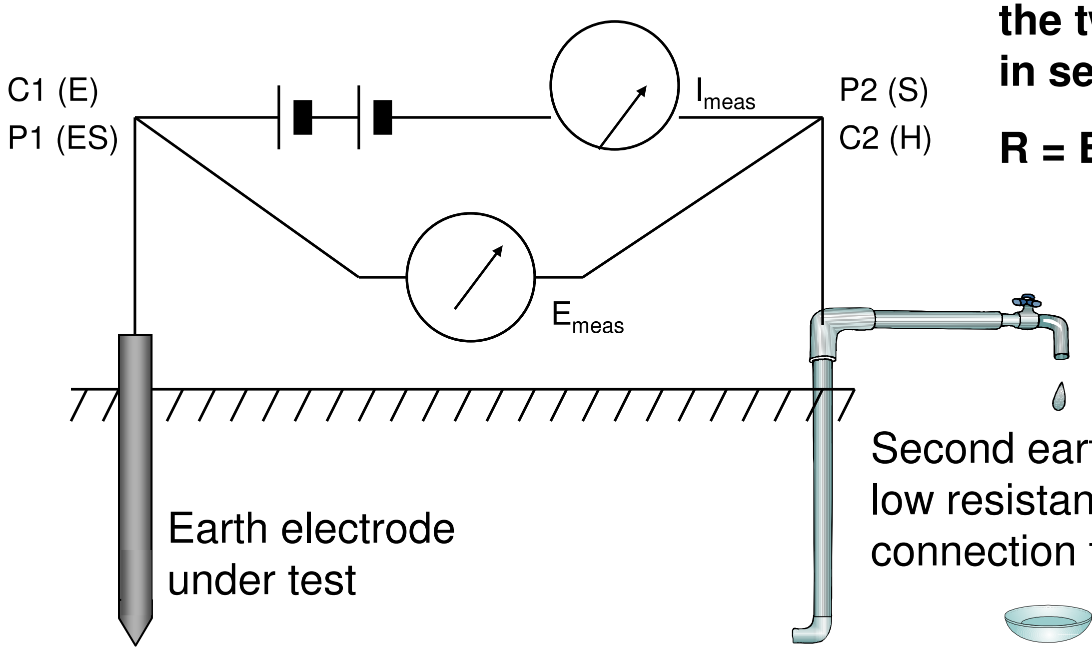
Earth sphere of influence



- Resistance of an earth electrode
  - 1 – Resistance of the electrode and the connections to it (low)
  - 2 – Contact resistance of the surrounding soil to the electrode (should be low)
  - 3 – Resistance of the surrounding body of earth around the electrode – these can be thought of as "shells" and create a sphere of influence (varies)

2-pole: Direct measurement

- Measure "coupling" between two earth points; measure resistance of earth electrode to Earth.



Measures resistance of the two Earth electrodes in series.

$R = E_{meas}/I_{meas}$

2-pole Method – Advantages

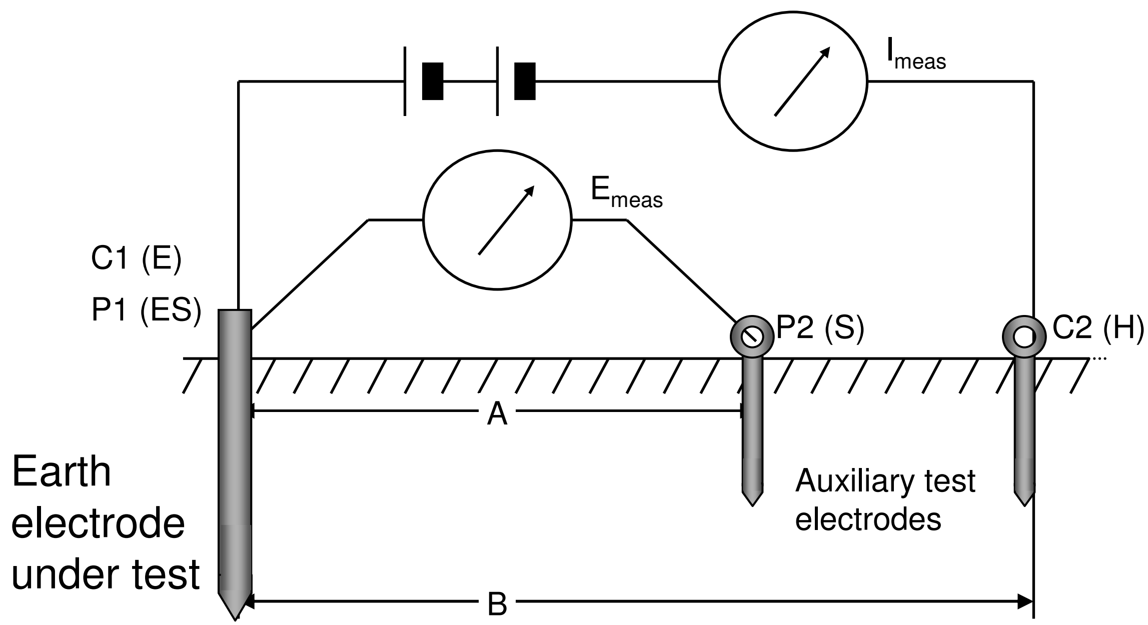
- Quick and easy
- Better than a continuity measurement with a multimeter because of noise rejection

2-pole Method – Disadvantages

- Result is a loop resistance, not just the electrode we want to measure but the return path as well
- Only OK if we have a good known low value return path and a high resistance electrode under test
- Interfering spheres of influence can give incorrect results

3-pole: Fall of Potential (full method)

- Classic method for measuring resistance of a single earthing electrode, or of a system of electrodes to Earth.



$$R = E_{meas}/I_{meas}$$

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Fall of Potential - Full Method

- Vary location of P2 (Potential) spike by regular steps along a straight line between the electrode under test and the C2 (Current) electrode.

- Take resistance $R = E_{meas}/I_{meas}$ at each step and plot a graph of R versus distance.

- Resistance of system taken where slope is flat.

- NB The C spike must be outside the sphere of influence to achieve a viable reading

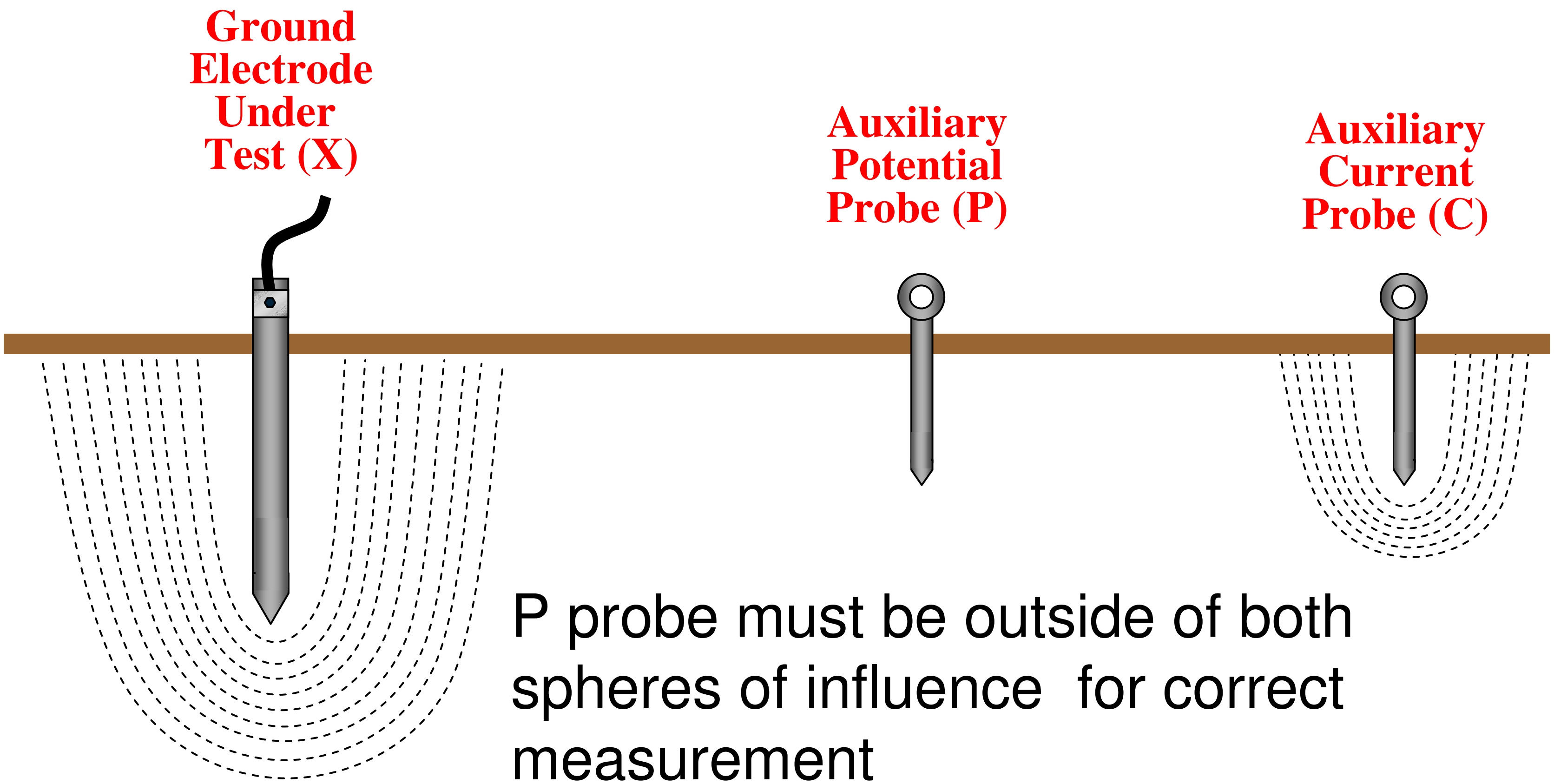
Fall of Potential Method – Advantages

- Can always make an accurate measurement of earth resistance
- Measures the overall system resistance at this point, to calculate earth fault current
- Test leads & contact resistance are not included in the measurement (may want to use 4 terminals)
- Can check by testing in a different direction or distance

Fall of Potential Method – Disadvantages

- Extremely time consuming and labour intensive.
  - Temporary probes must be placed.
  - Cables must be run to make connections.
- Space constraints can make it hard to place remote probes.
- Must disconnect individual ground electrodes to measure them.

Fall of potential - Current Probe Sphere of Influence



P probe must be outside of both spheres of influence for correct measurement

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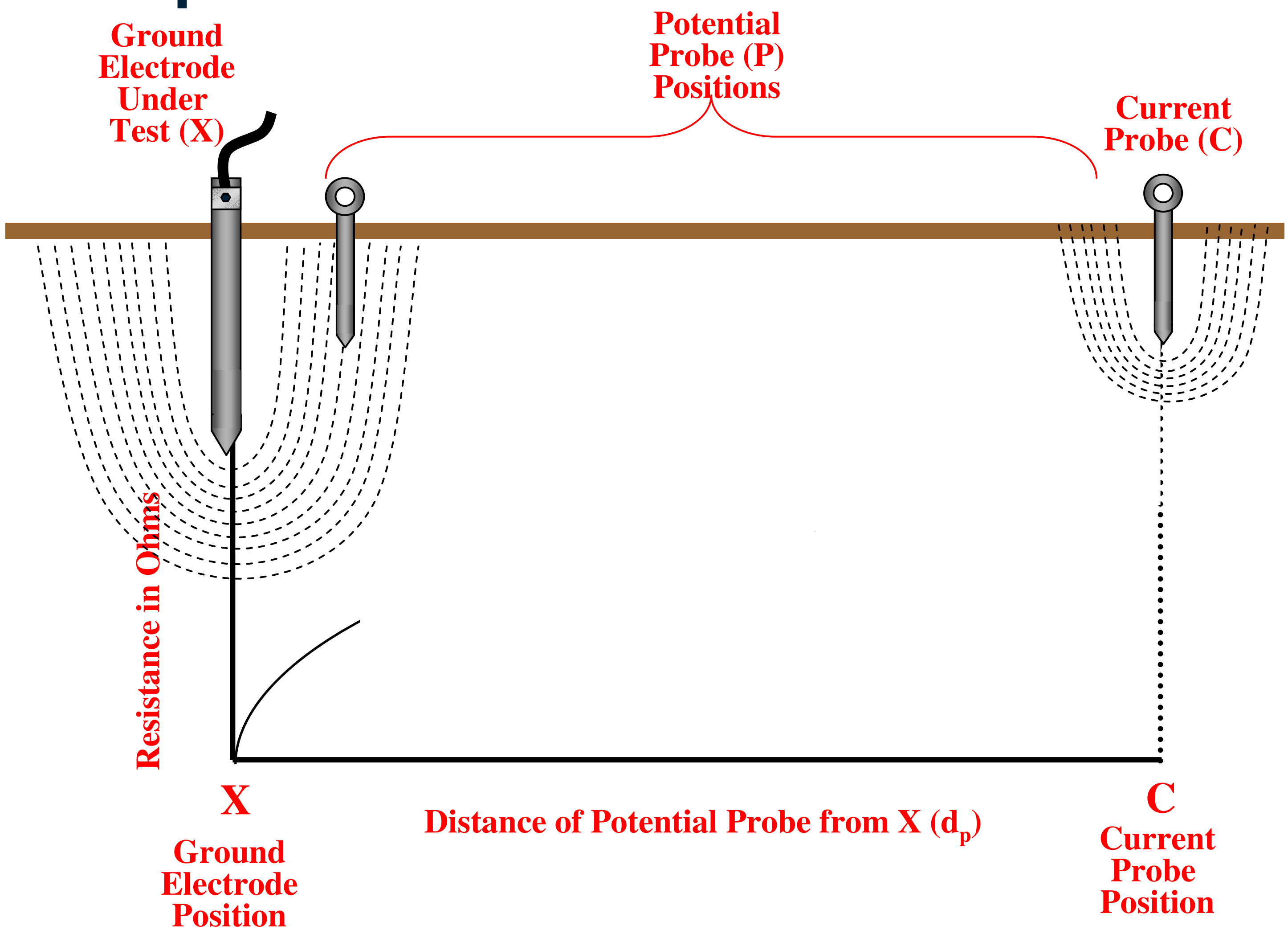
Fall of potential – test and result



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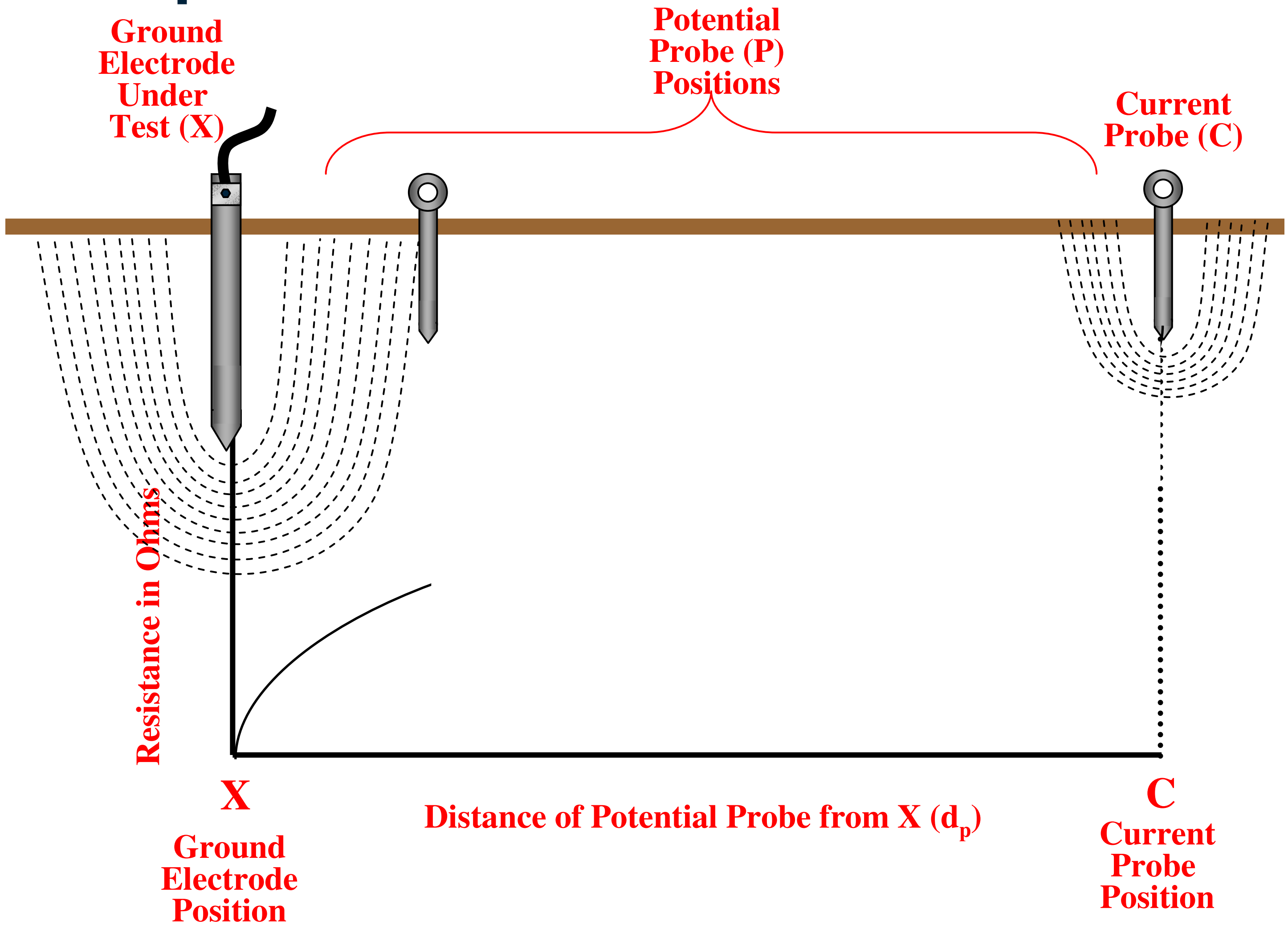
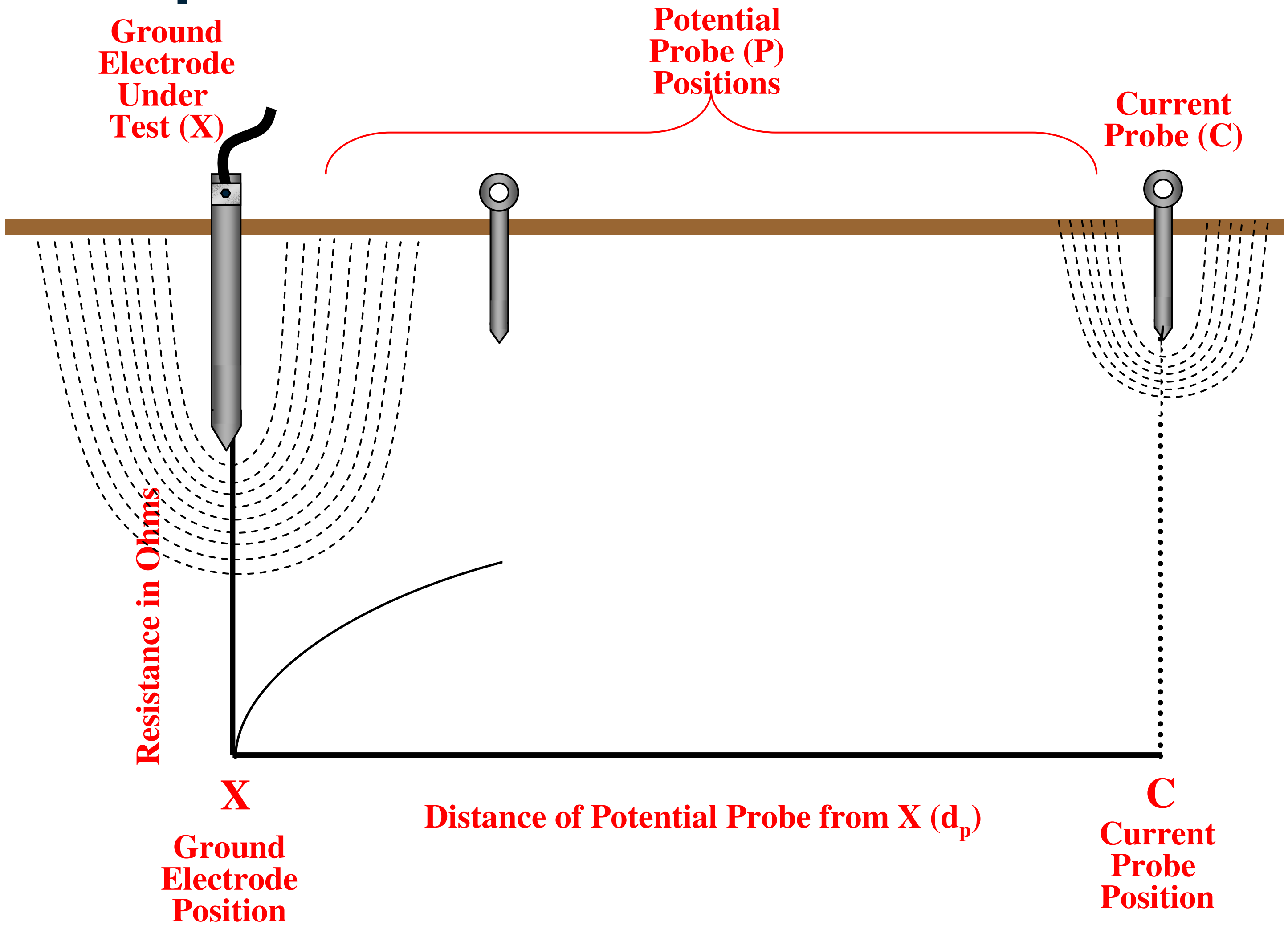
Fall of potential – test and result



Fall of potential – test and result



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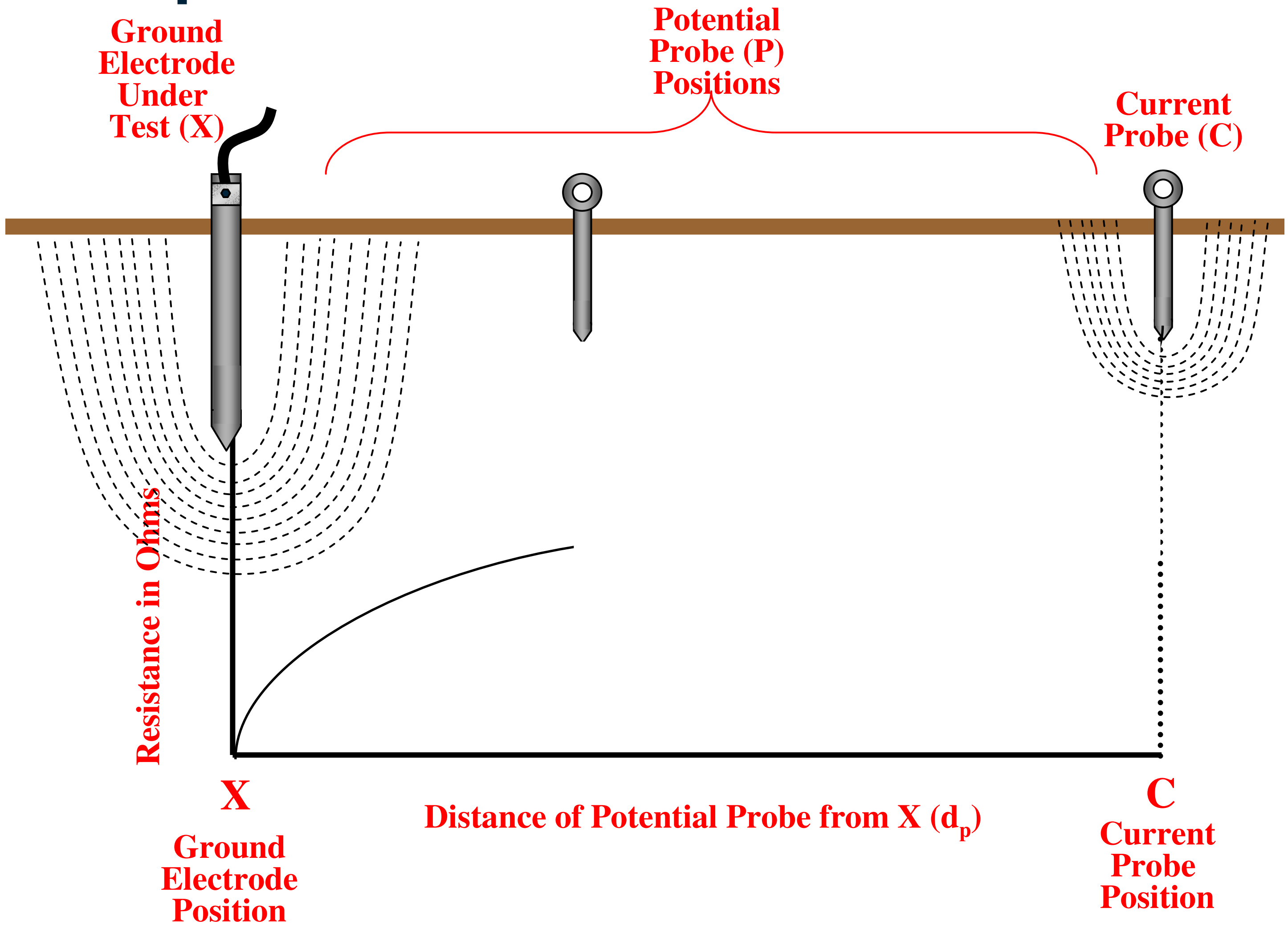

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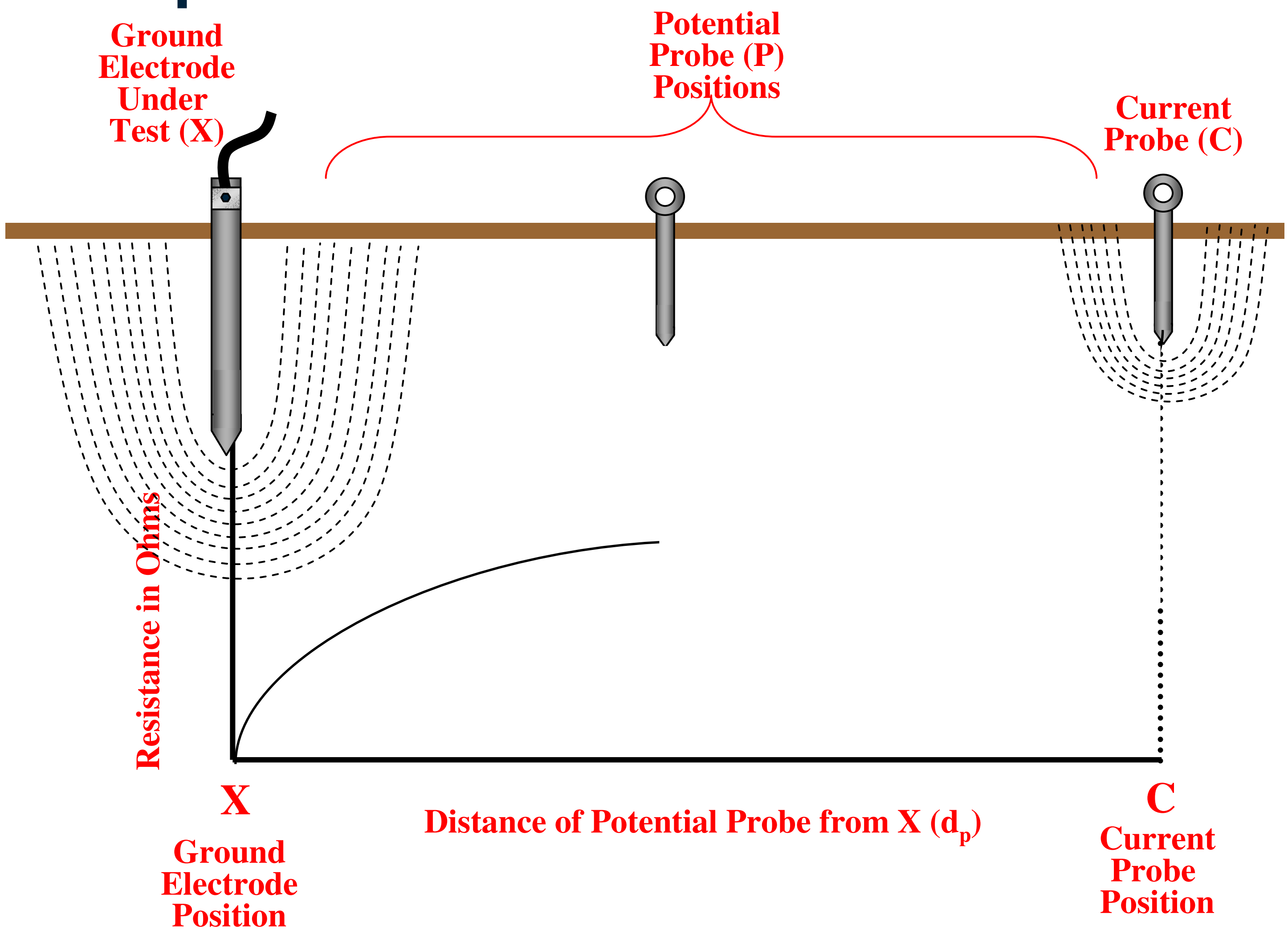

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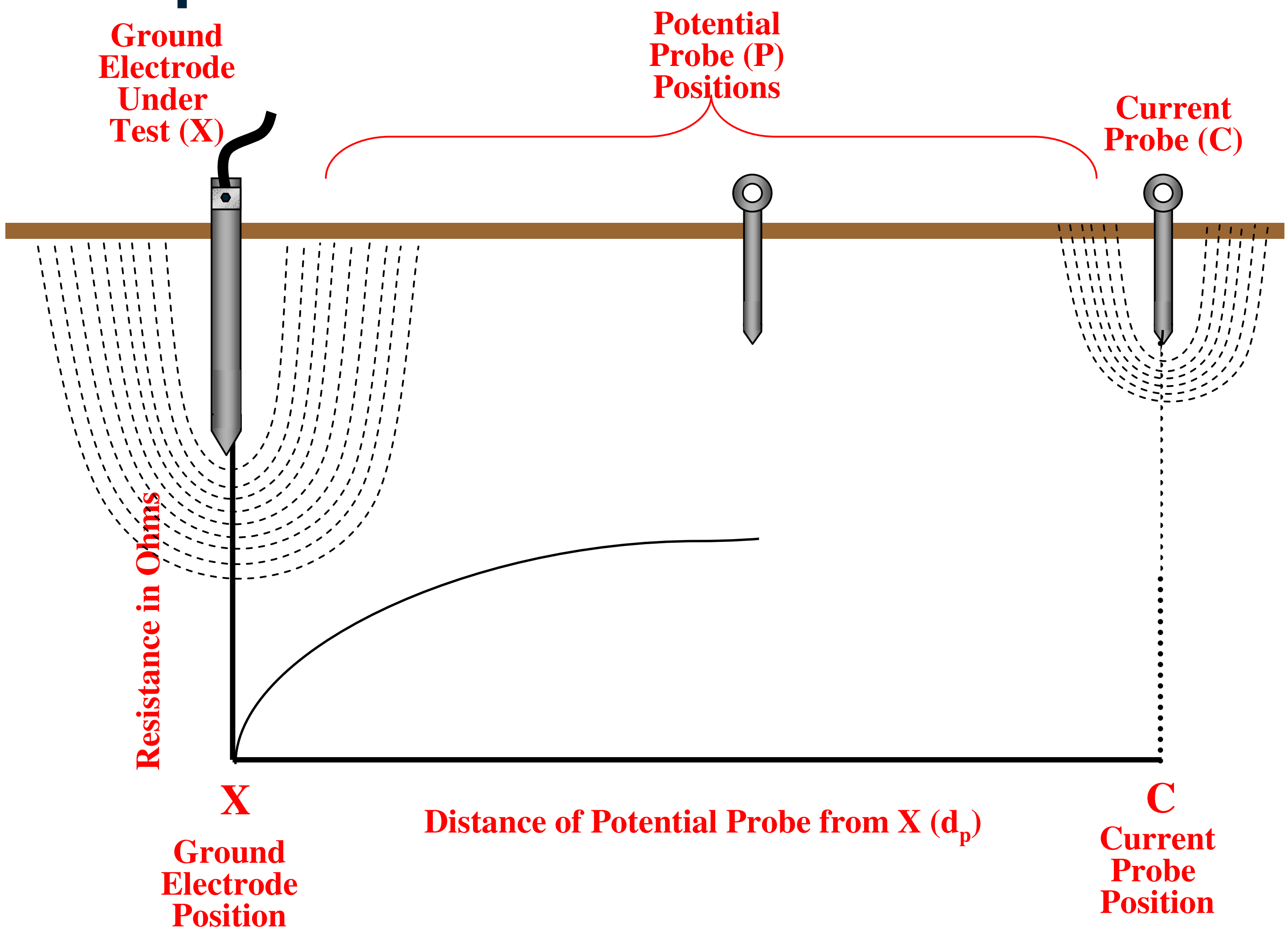

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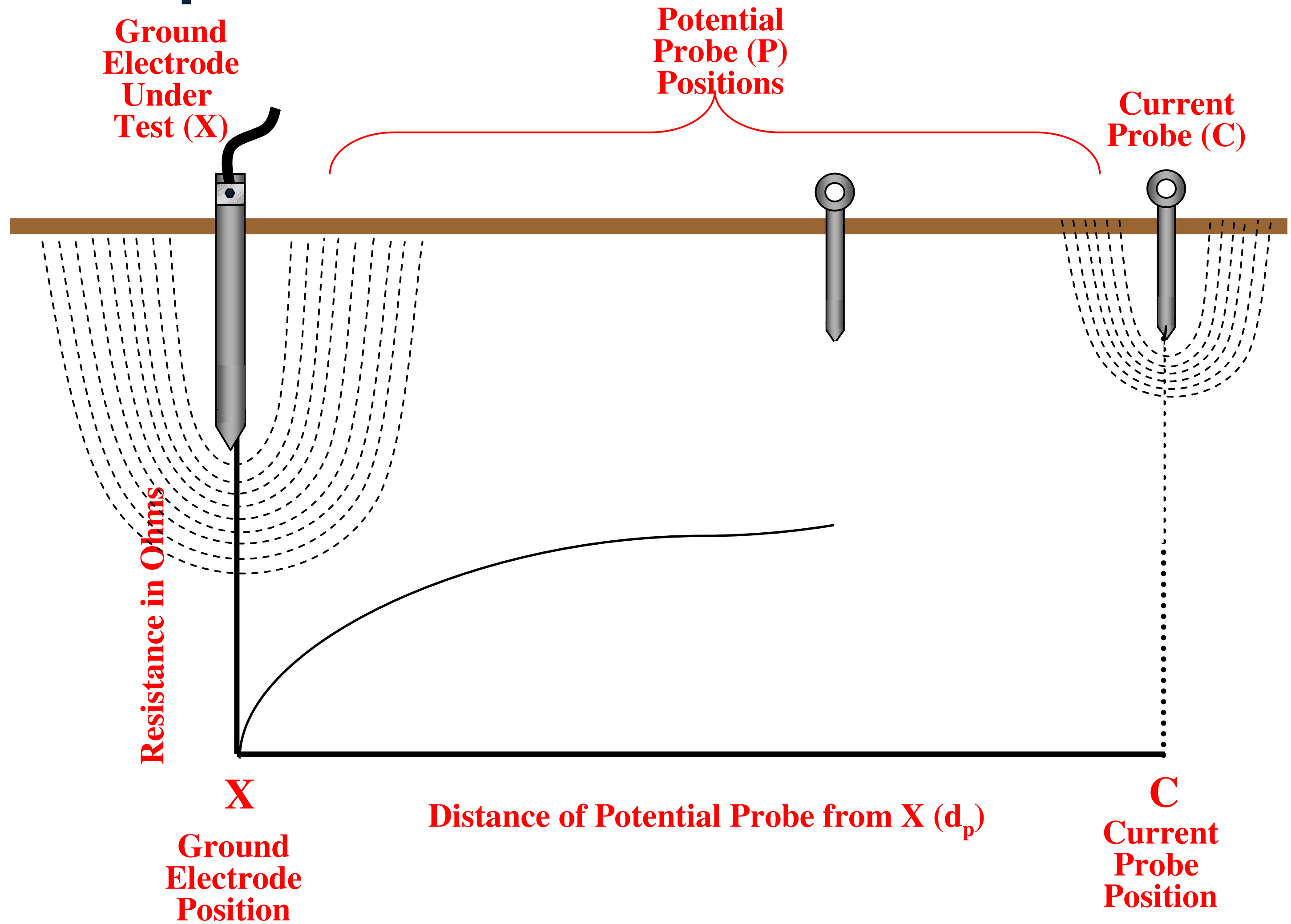

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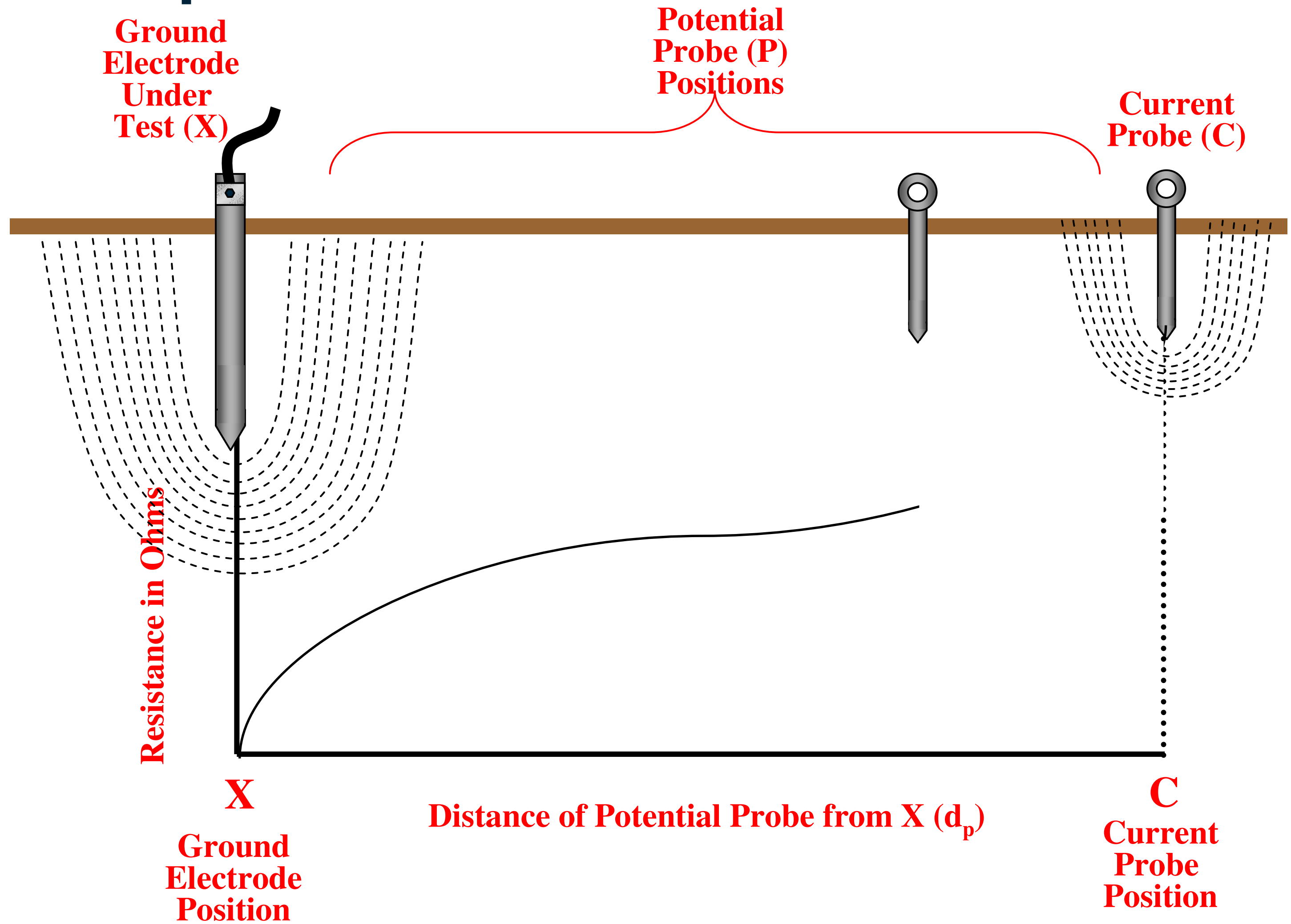

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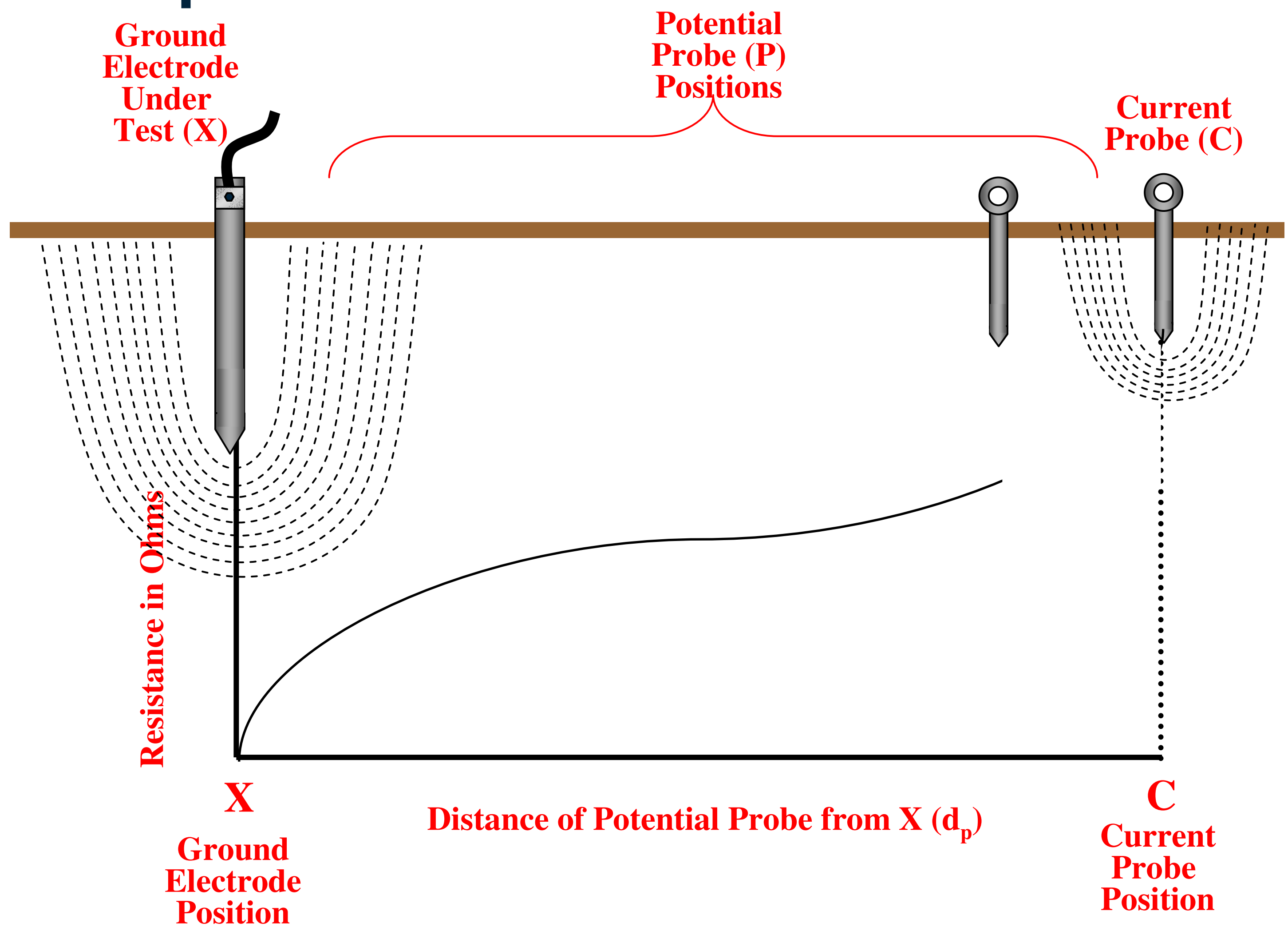

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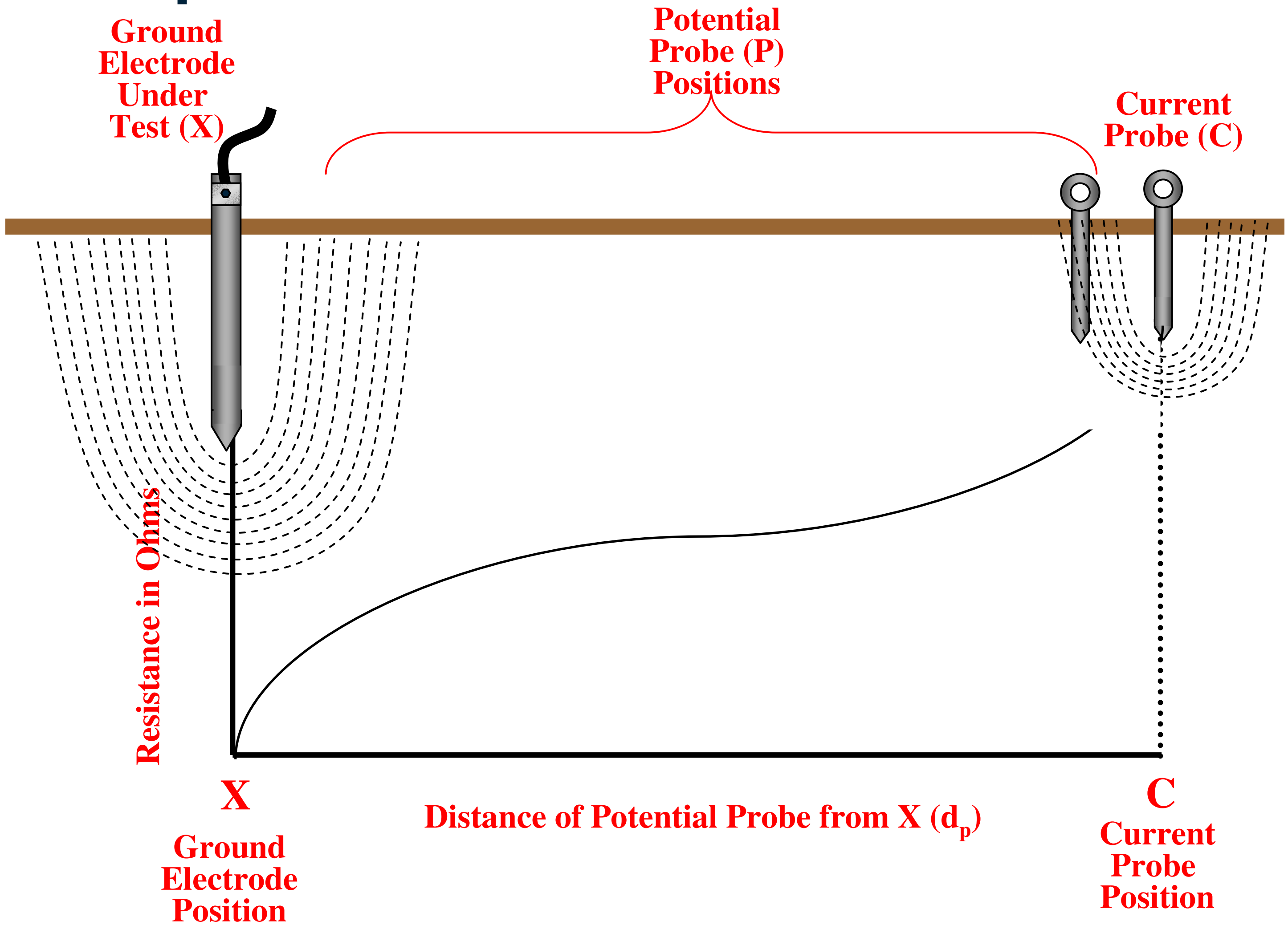

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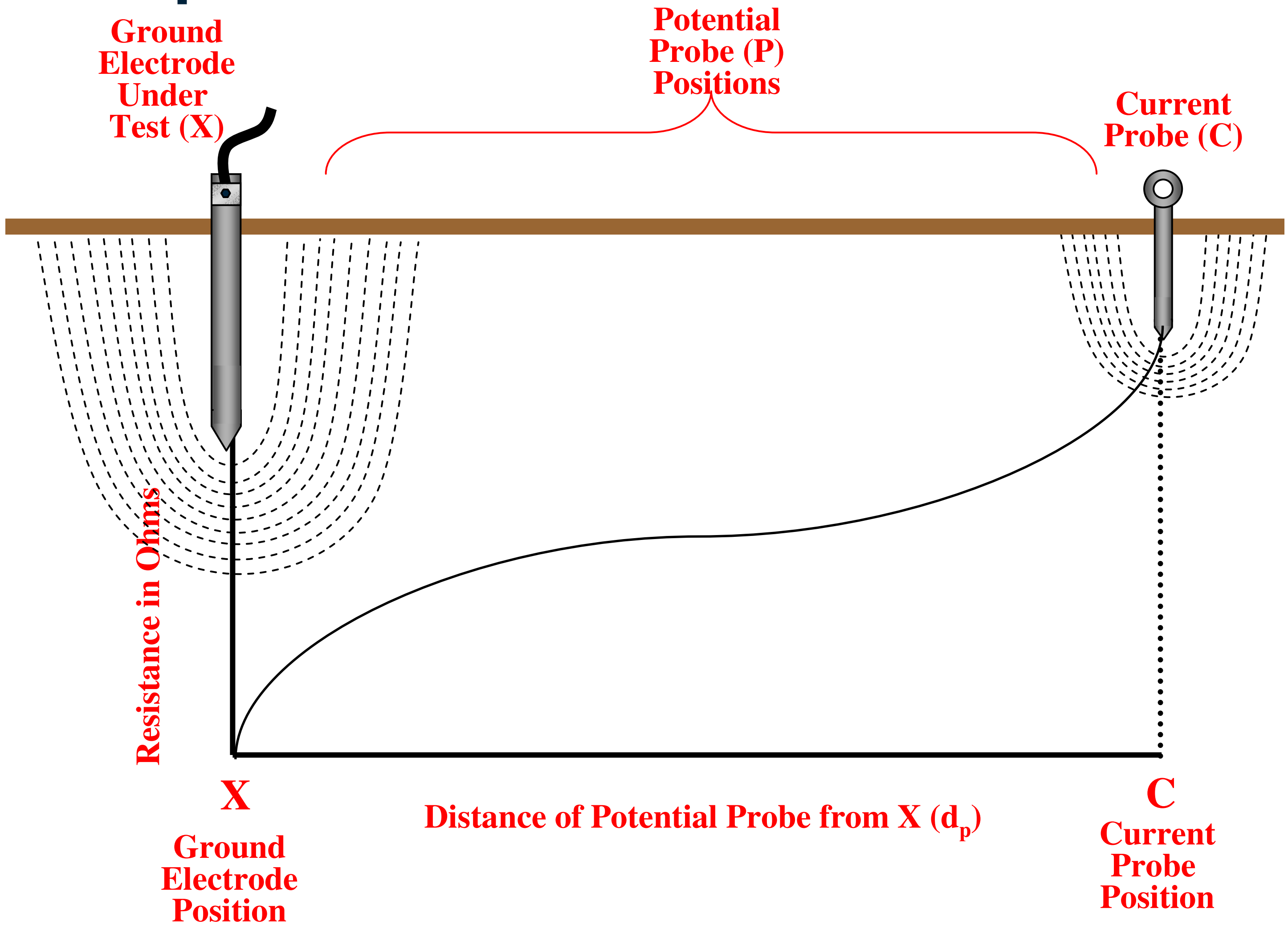

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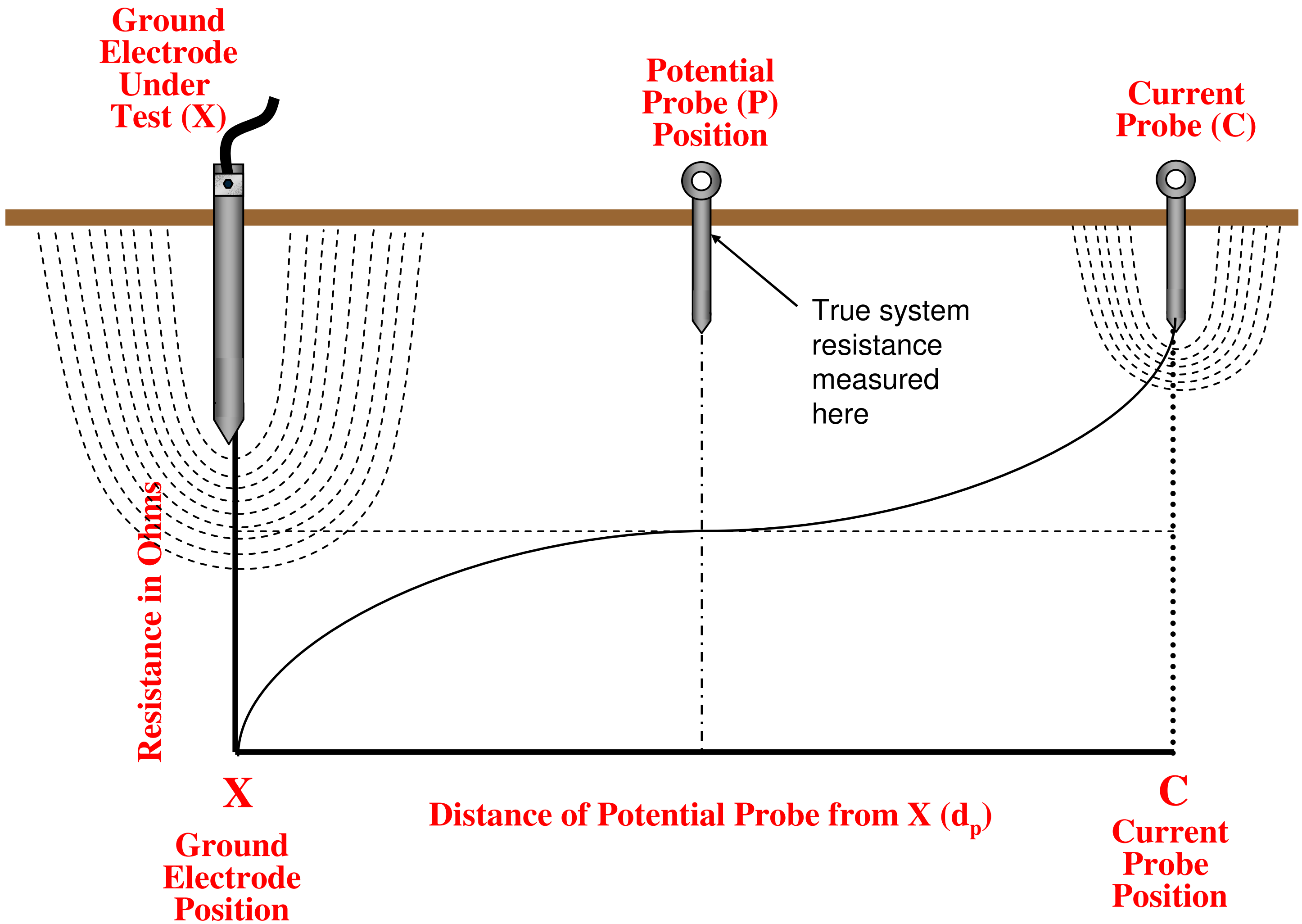

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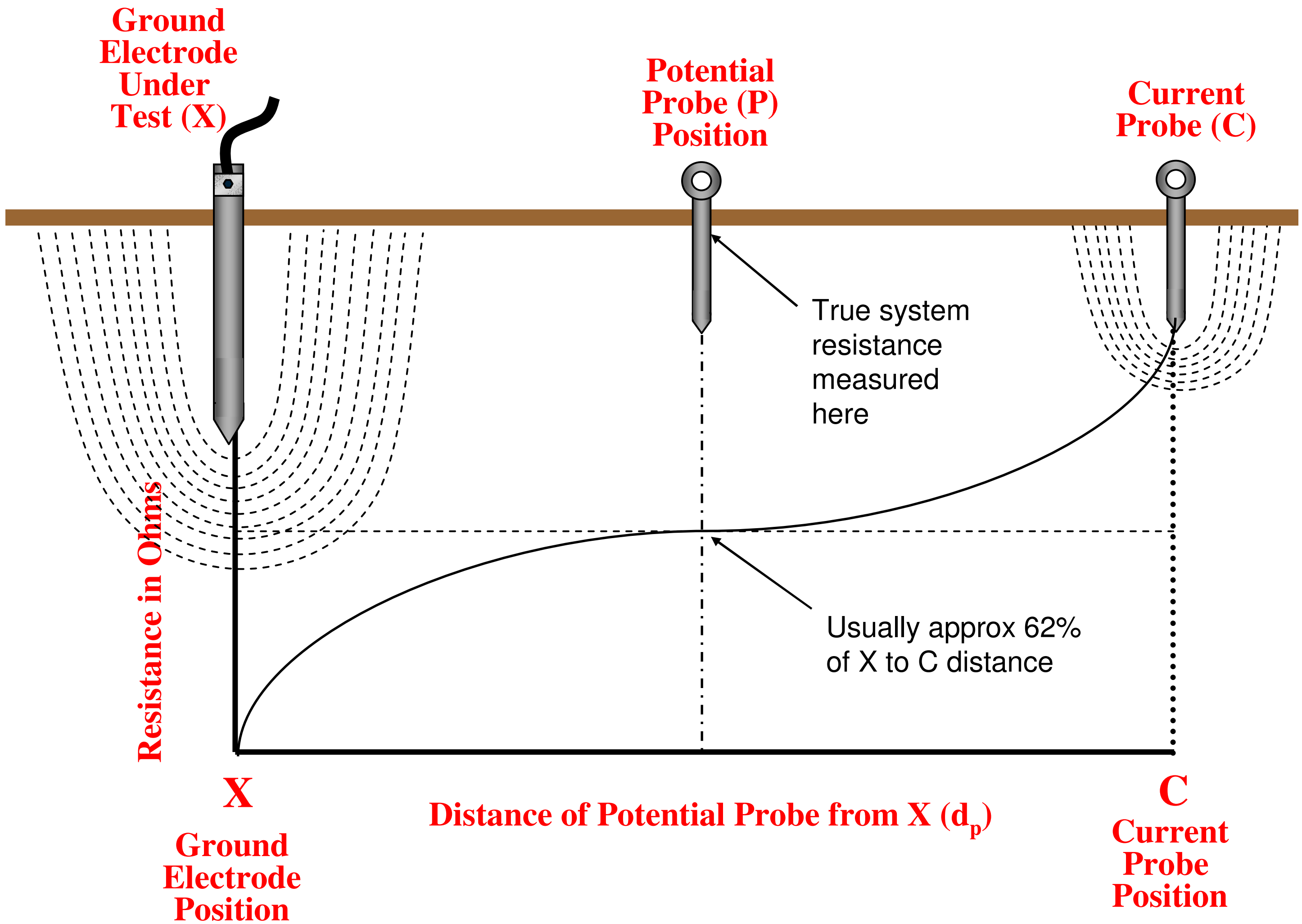

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For deeper spikes -Readings are taken further apart

Guidelines for setting test probes are based on the depth of the electrode under test.

2m depth	p spike 15.5m	c spike 25m
3m depth	p spike 18.5m	c spike 30m
6m depth	p spike 25m	c spike 40m
10m depth	p spike 31m	c spike 50m

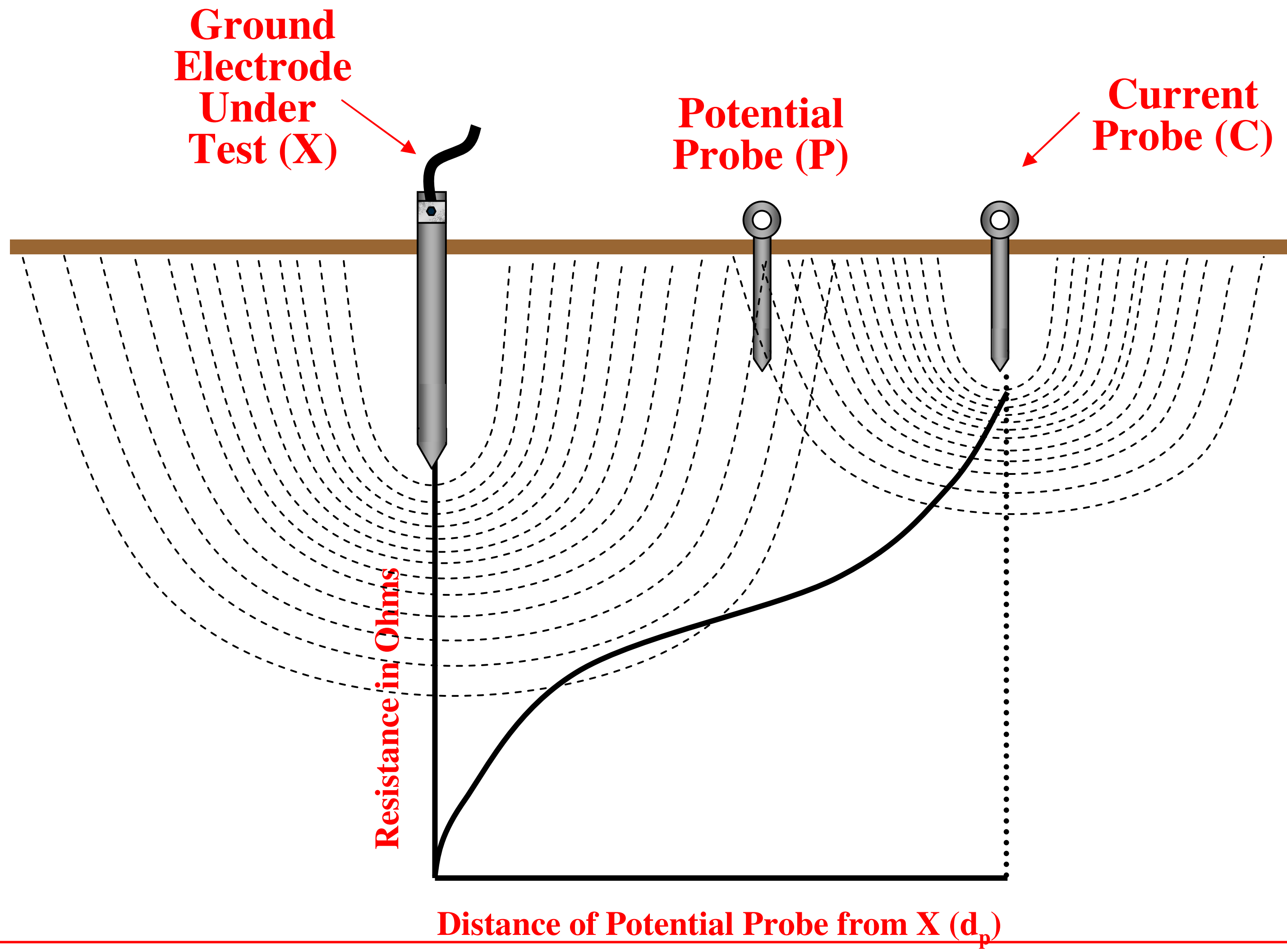
3-pole: Fall of Potential (short method)

- **Site P2 (Potential) spike at 62% of B and take resistance measurement R_a[R = E_{meas}/I_{meas}].**

- **Locate P2 ± 0.1B around the 62% point and take additional resistance readings, R_b and R_c.**

- **If the three readings are within an agreed accuracy limit, the system resistance is the average.**

The Problem of Limited Distance/Space



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The Slope Method

- Based on the theory behind the Fall of Potential method:
  - for complex grounding systems and/or
  - situations where lead lengths prohibitive
- This method allows measurement of the earth system resistance without finding the flat portion of the curve, reducing the test distances
- Use three measurements in calculation; can take more
- Advantage: Provides an approach for dealing with complex systems
- Disadvantage: Less accurate; requires more maths

3-pole: Slope Method

- Tables of values for the co-efficient of slope against actual P spike distance is published in the instrument user guide

- Take calculated value of μ and look up ideal distance of the voltage spike (P2) for measuring the electrode resistance

3-pole: Slope Method

- Vary location of P2 (Potential) spike by regular steps along a straight line between the electrode under test and the C2 (Current) electrode
- Measure resistance at each step and plot a graph of R versus distance.
- Measure resistance at 0.2B, 0.4B and 0.6B: R1, R2 and R3.
- Slope coefficient, $\mu = (R3-R2)/(R2-R1)$ relates distance B and ideal distance of the voltage spike (P2) for measuring the resistance.

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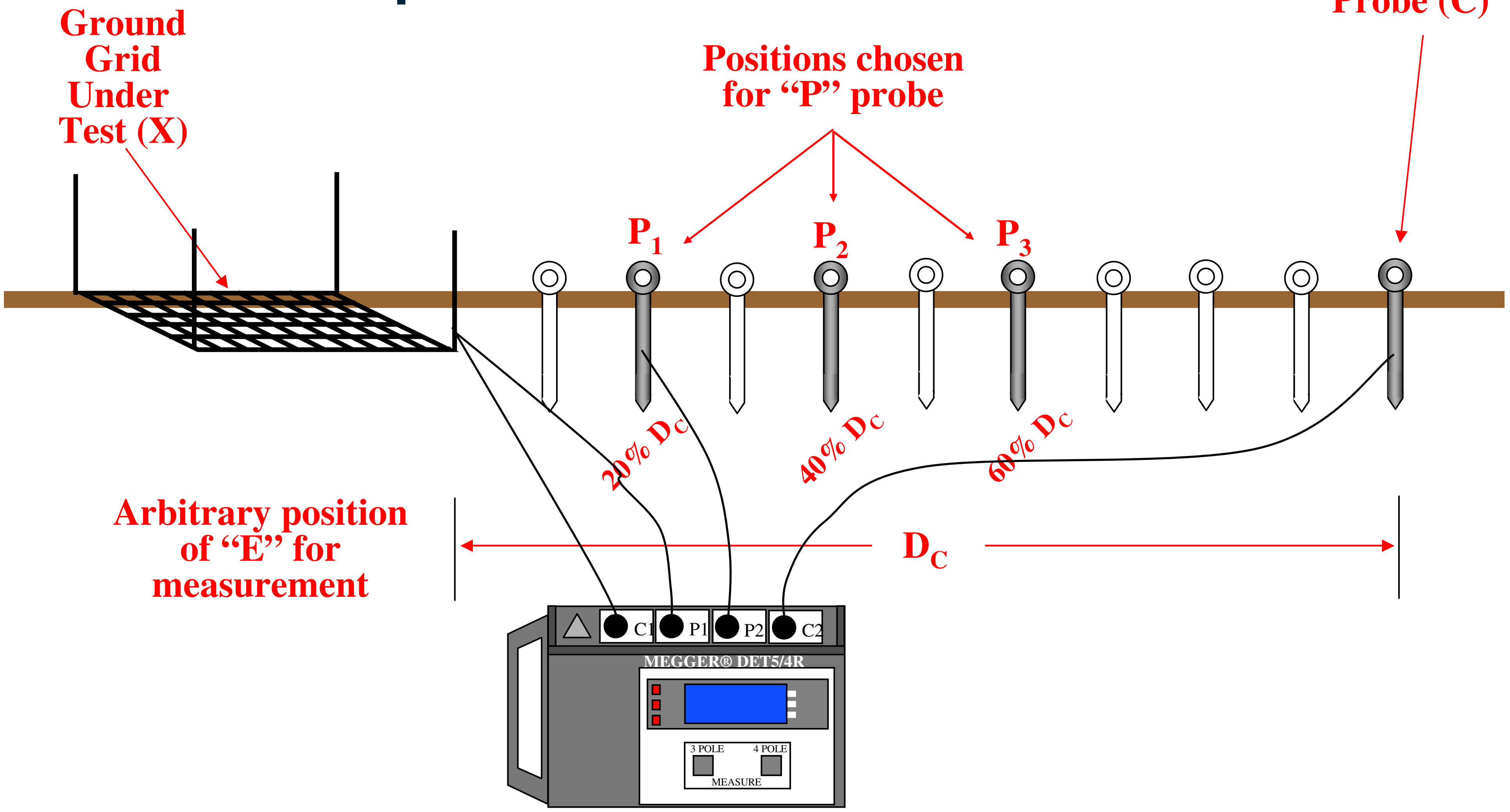
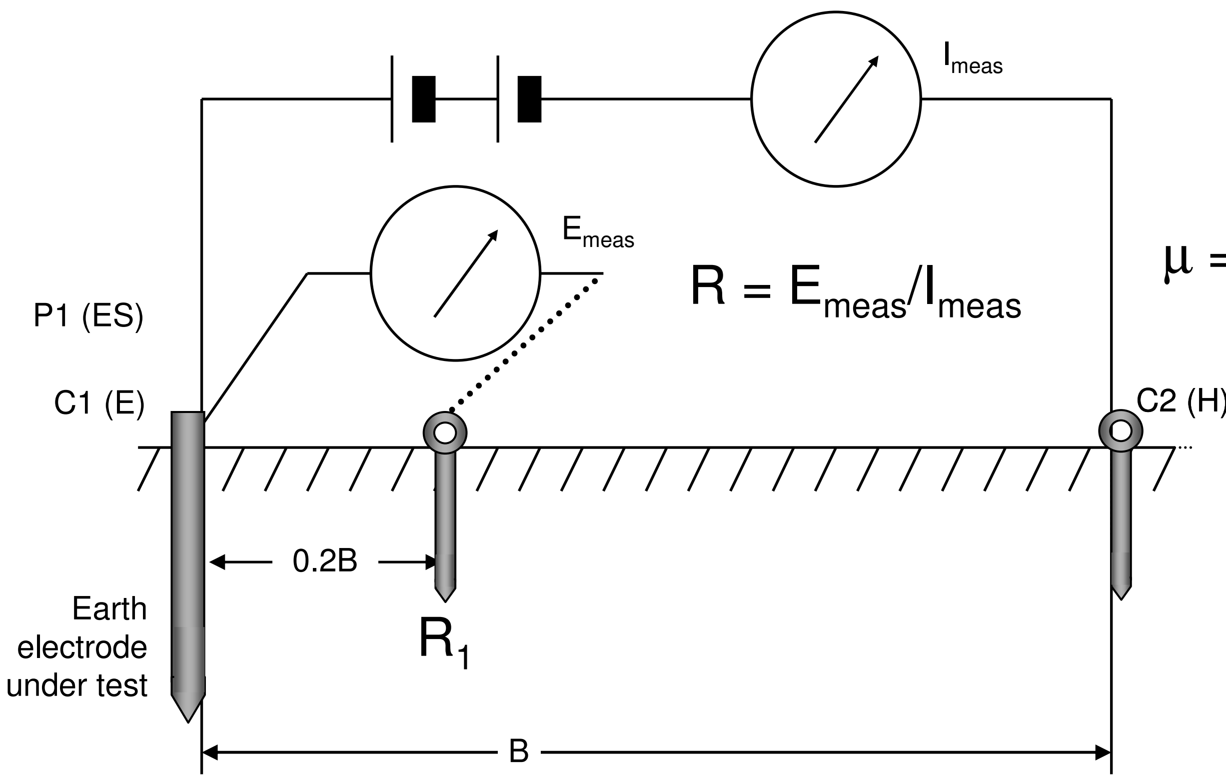
The Slope Method



3-pole: Slope Method

- Measure R1 at 20% distance to C2



$$R = E_{meas}/I_{meas}$$

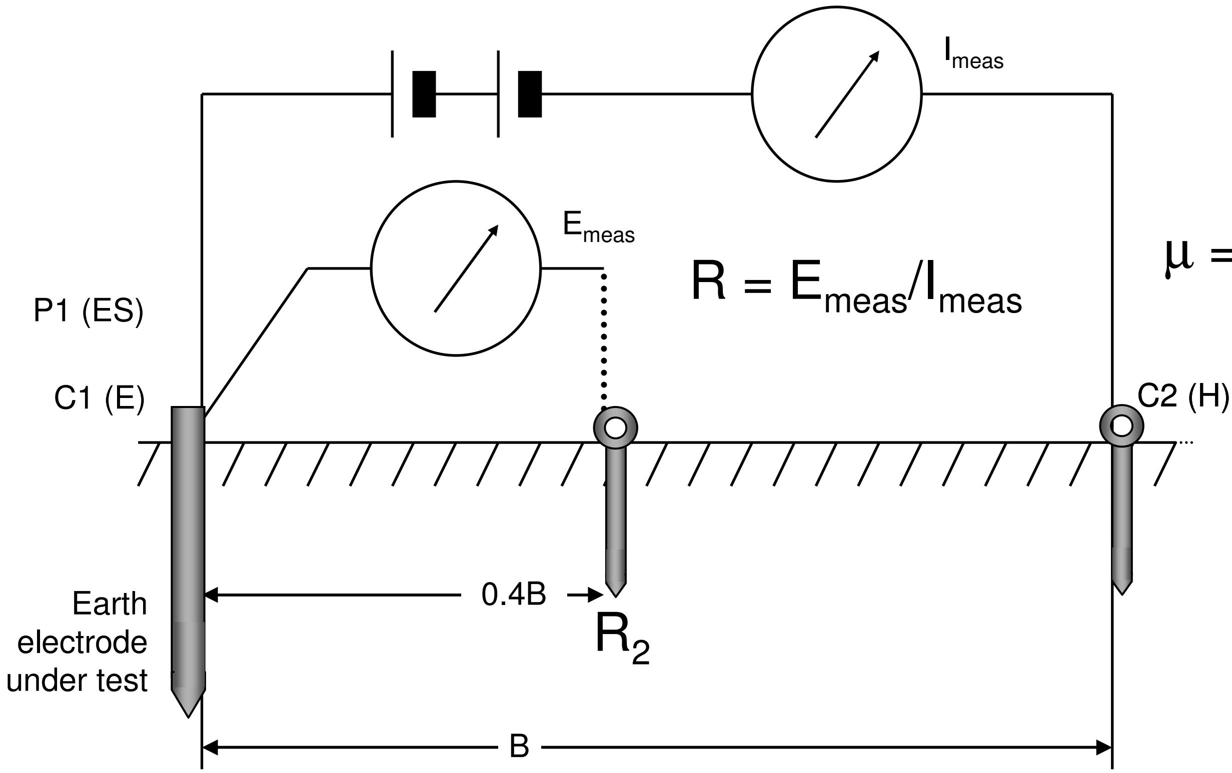
$$\mu=(R_3-R_2)/(R_2-\mathbf{R_1})$$

$$\mu = (R_3-R_2) / (R_2 - \mathbf{9.3})$$

R_1= 9.3 ohm

3-pole: Slope Method

- Measure R2 at 40% distance to C2



$\mu=(R_3-R_2)/(R_2-R_1)$

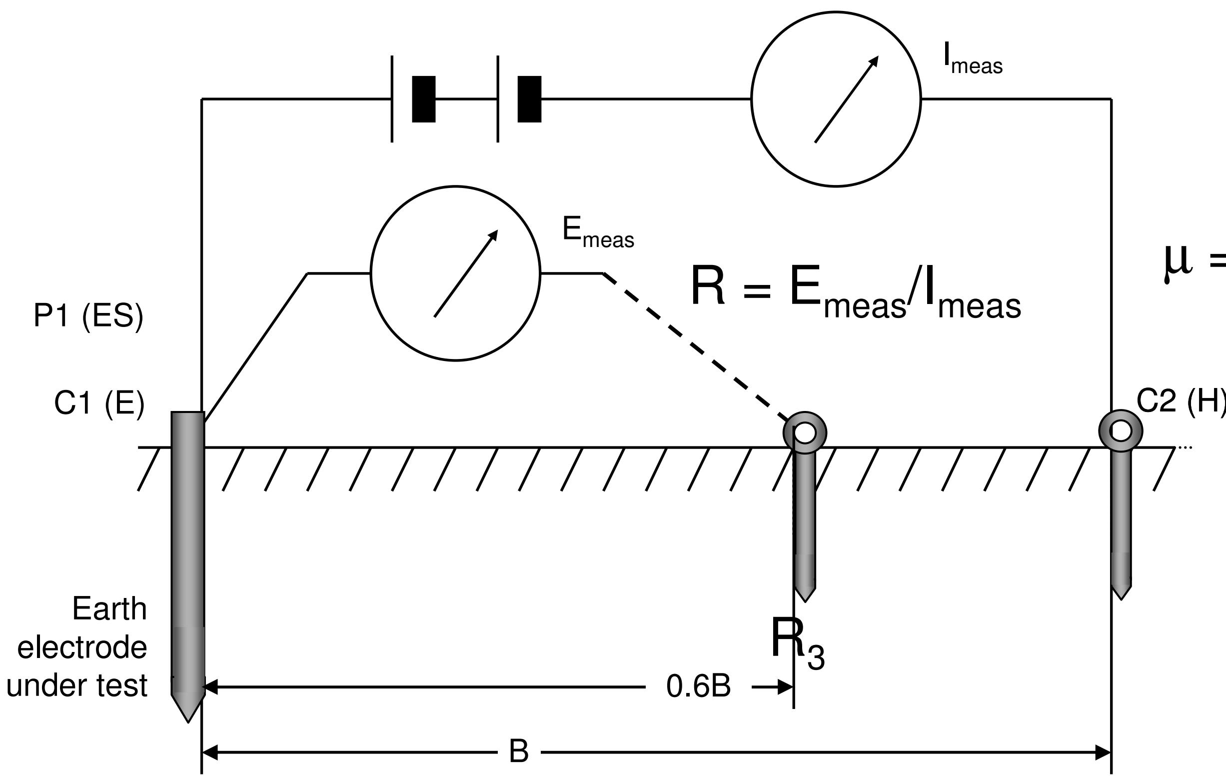
$\mu = (R_3 - 16) / (16 - 9.3)$

$R_1 = 9.3$ ohm

$R_2 = 16$ ohm

3-pole: Slope Method

- Measure R3 at 60% distance to C2



$\mu = (R_3 - R_2)/(R_2 - R_1)$

$\mu = (19.2 - 16) / (16 - 9.3)$

$R_1 = 9.3$ ohm

$R_2 = 16$ ohm

$R_3 = 19.2$ ohm

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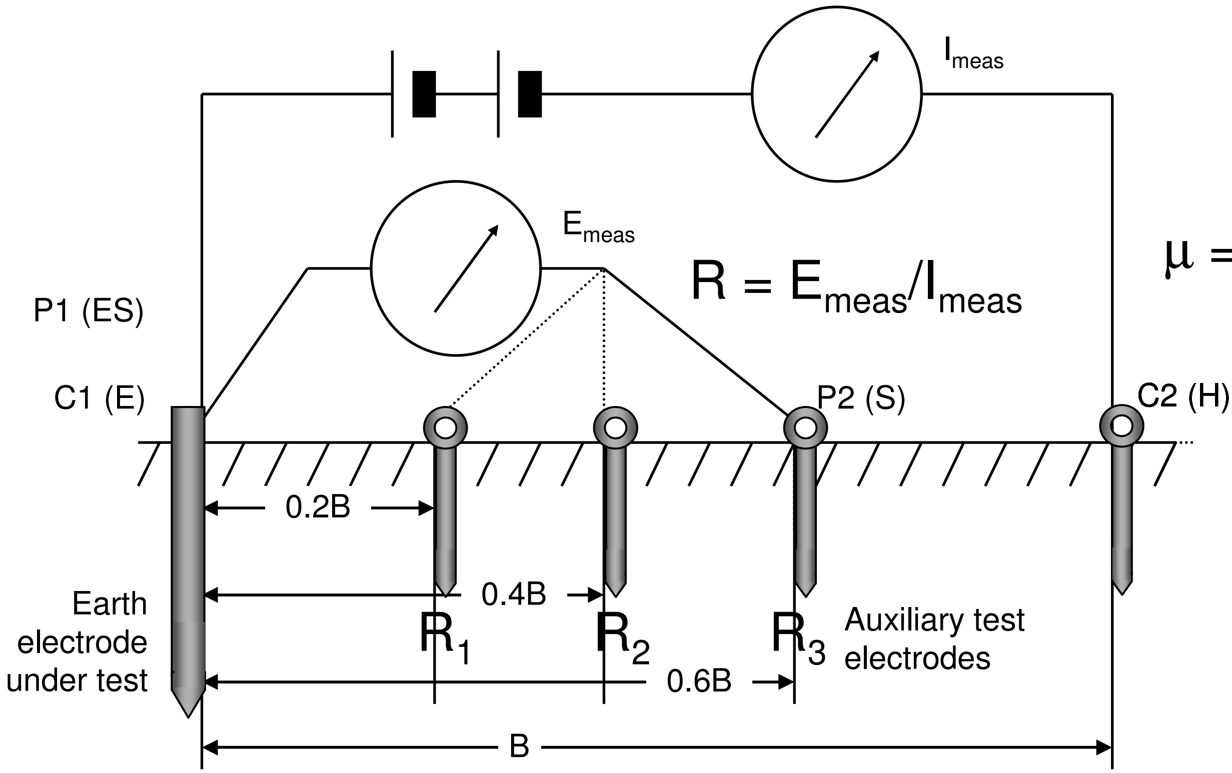
3-pole: Slope Method

- Calculate value of μ



$\mu=(R_3-R_2)/(R_2-R_1)$

$\mu = (19.2 – 16) / (16 – 9.3)$

μ =0.478

3-pole: Slope Method

μ =0.478

Chart for use with the Slope Method

Values of $P_{t/EC}$ for Values of μ

μ	0	1	2	3	4	5	6	7	8	9
0.40	0.6432	0.6431	0.6429	0.6428	0.6426	0.6425	0.6423	0.6422	0.6420	0.642
0.41	0.6418	0.6417	0.6415	0.6414	0.6412	0.6411	0.641	0.6408	0.6407	0.6405
0.42	0.6404	0.6403	0.6401	0.64	0.6398	0.6397	0.6395	0.6394	0.6393	0.6391
0.43	0.639	0.6388	0.6387	0.6385	0.6384	0.6383	0.6381	0.638	0.6378	0.6377
0.44	0.6375	0.6374	0.6372	0.6371	0.637	0.6368	0.6367	0.6365	0.6364	0.6362
0.45	0.6361	0.6359	0.6358	0.6357	0.6355	0.6354	0.6352	0.6351	0.6349	0.6348
0.46	0.6346	0.6345	0.6344	0.6342	0.6341	0.6339	0.6338	0.6336	0.6335	0.6333
0.47	0.6332	0.633	0.6329	0.6328	0.6326	0.6325	0.6323	0.6322	0.632	0.6319
0.48	0.6317	0.6316	0.6314	0.6313	0.6311	0.631	0.6308	0.6307	0.6306	0.6304
0.49	0.6303	0.6301	0.63	0.6298	0.6297	0.6295	0.6294	0.6292	0.6291	0.6289
0.50	0.6288	0.6286	0.6285	0.6283	0.6282	0.628	0.6279	0.6277	0.6276	0.6274

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The Slope Method

- $R_1 = 0.2 \times D_C$; $R_2 = 0.4 \times D_C$; $R_3 = 0.6 \times D_C$
- Calculate the value for μ using the following equation:

$$\frac{R_3 - R_2}{R_2 - R_1}$$

- The value for μ corresponds to a value for P_T/C.
  - P_T: potential probe position where True Resistance found.
  - % of distance P_T is of D_C.
  - Table of values in "Getting Down to Earth"
- Measure the resistance at P_T.
- Repeat the process for a larger value of C.

Factors Affecting Resistance…… Variation

Type of ground composition beneath the site	Large 10/1
Moisture content of soil (tides, rainfall, season)	60%
Quantity and type of electrolytes added to the soil Adjacent conductors if any	< 10 x lower
Temperature of the earth	½ ?
Electrode *depth* Electrode *diameter*	+ 20% for - 10º (ICE is very high)
Electrode(s) *spacing*	- 40% (x2 in depth)
	Twice diameter = - 20%
	See 62% rule

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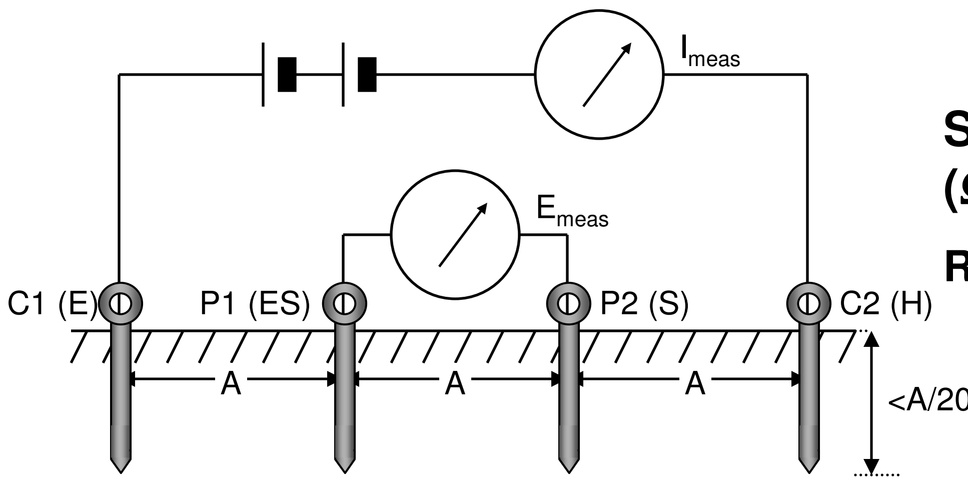
Soil Resistivity/ Wenner Method

- Purpose: **Survey a site for the lowest resistance connections for Earth.**



Soil resistivity, $\rho = 2\pi AR$ (Ωcm)

$R = E_{meas}/I_{meas}$

Soil Resistivity

- Purpose of this test:
  - Find lowest possible resistance in a location
  - Obtain the values needed to design the earth system
- Factors affecting soil resistivity
  - Soil composition
  - Moisture in the ground
  - Temperature
- Consider
  - Resistivity will vary through the year
  - Moisture more constant at water table
  - Stable temperature below the frost line

Soil Resistivity typical values (Ohm-cm)

Surface soils, loam etc.	100 – 5000
Clay	200 – 10000
Sand & gravel	5000 – 100000
Surface limestone	10000 – 1000000
Shales	500 – 10000
Sandstone	2000 – 200000
Granites, basalts etc	100000
Slates etc	1000 – 10000

What Can Be Done to Improve Earth Resistance?

- Lengthen earth electrode
- Increase the rod’s diameter
- Use multiple electrodes bonded together
- Treat the surrounding soil chemically

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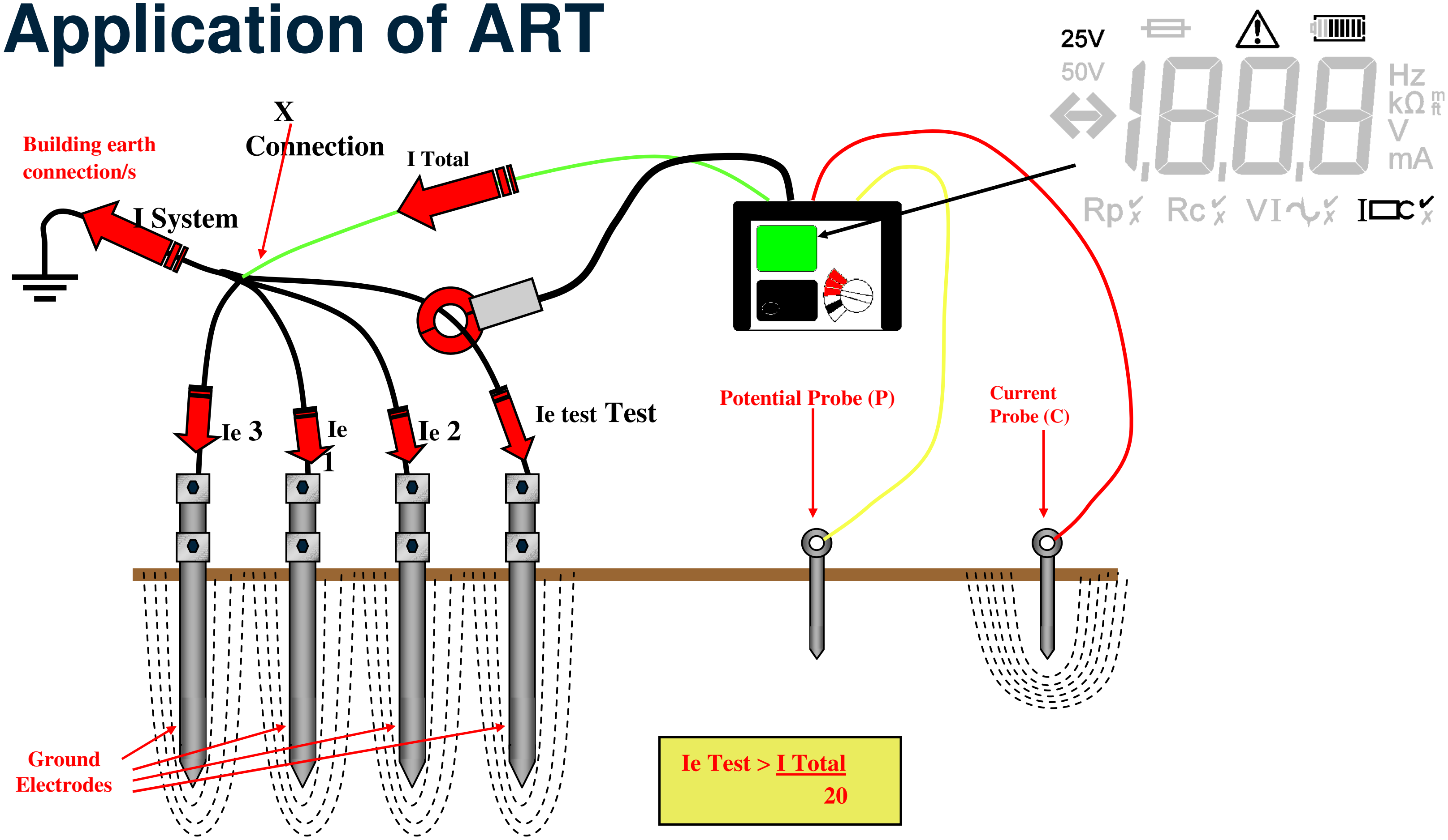
Application of ART



Ie Test > I Total
20

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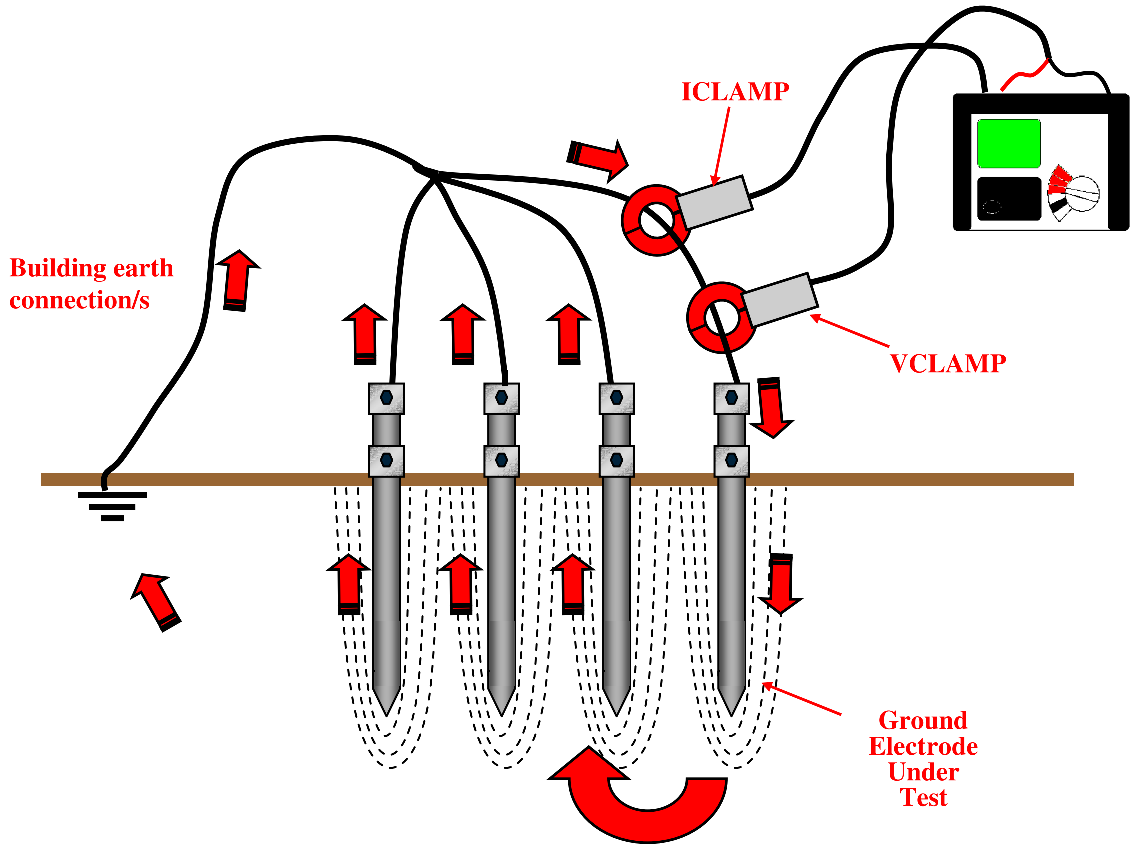
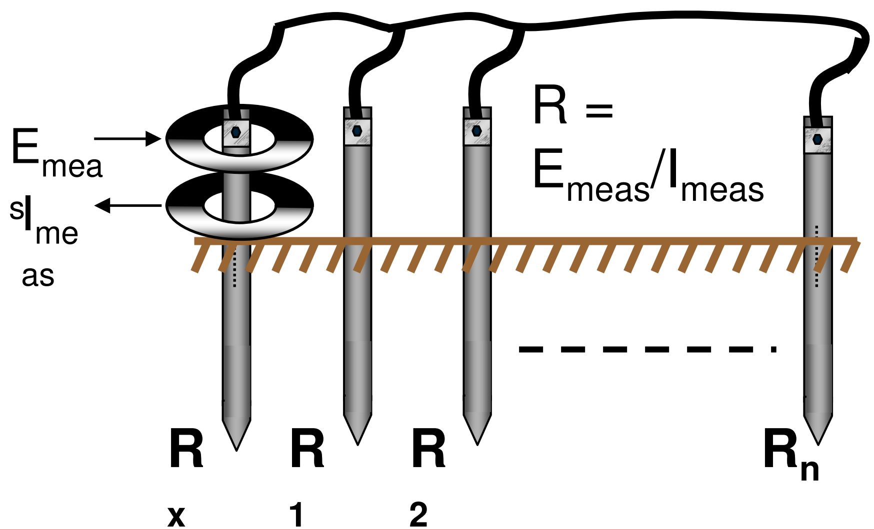
Clamp-On / Stakeless Methodology



"Stakeless" Measurements for earth system resistance (DET10/20C)

- A method that does not need the earth electrode to be disconnected



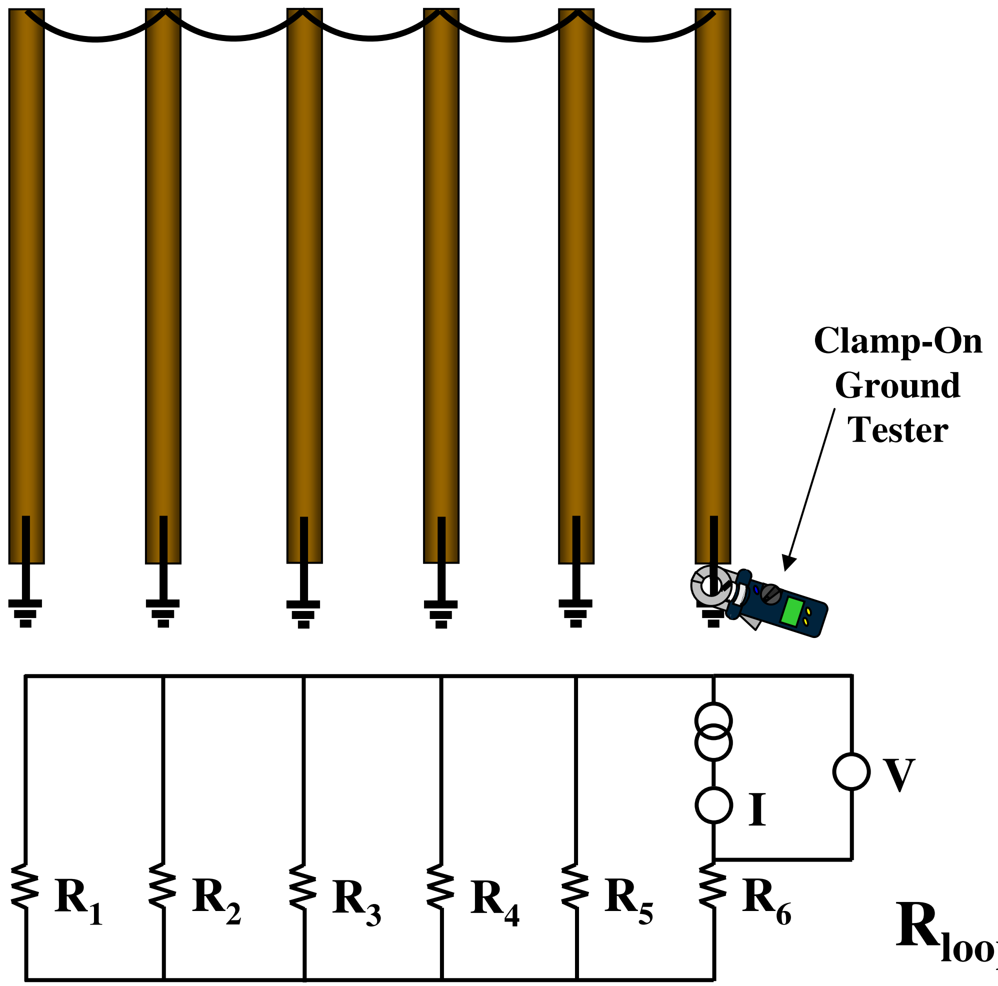
Clamp-On Method

- Includes the bonding and overall connection resistance (not available with Fall of Potential).
- Can measure the leakage current flowing through the system.
- Effective only in situations with multiple grounds in parallel (pole grounds).
- Cannot be used on isolated grounds (no return path)
- Cannot be used if an alternative lower resistance return exists not involving the soil

Clamp-On/Stakeless Methodology

- In a multiple ground system the circuit can be considered a loop comprising:
  - The individual ground electrode.
  - A return path via all other electrodes.
  - The mass of earth.
- The single electrode will have a higher resistance than the remainder of grounds connected in parallel.
- Inject a voltage and measure the resultant current produced in a “single turn” ground loop.

Clamp-On/Stakeless Methodology



$$R_{loop} = V_{loop} / I_{loop}$$

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Clamp-On/Stakeless Methodology

- $R_{loop} = R_6 + (1/(1/R_1 + 1/R_2 + 1/R_3 + 1/R_4 + 1/R_5))$
- For 6 similar electrodes with a resistance of 10Ω:
  R_{loop} = 10Ω + 2Ω = 12Ω
- If one electrode has a resistance of 100Ω:
  R_{loop} = 100Ω + 2Ω = 102Ω (measuring the bad electrode)
  R_{loop} = 10Ω + 2.4Ω = 12.4Ω (on the other electrodes)

- For 60 similar electrodes with a resistance of 10Ω:
  R_{loop} = 10Ω + 0.17Ω = 10.17Ω
- If one electrode has a resistance of 100Ω:
  R_{loop} = 100Ω + 0.17Ω = 100.2Ω (measuring the bad electrode)
  R_{loop} = 10Ω + 0.17Ω = 10.17Ω (on the other electrodes)

Clamp-On Method - Advantages

- Test is quick and easy:
  - No disconnecting the ground rod from the system.
  - No probes need to be driven/cables connected.
- Includes the bonding and overall connection resistance (not available with Fall of Potential).
- Can measure the leakage current flowing through the system.

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Clamp-On Method - Disadvantages

- Effective only in situations with multiple grounds in parallel (pole grounds).
- Cannot be used on isolated grounds (no return path):
  - Not applicable for installation checks/commissioning new sites
- Cannot be used if an alternate lower resistance return exists not involving the soil:
  - Cellular towers
  - Substations
- Subject to influence if another part of the ground system is in "resistance area":
  - Result will be lower than true resistance.
- Test is carried out at a high frequency (enables the transformers to be small):
  - Less representative of a fault at power frequency but easier to filter out noise

Clamp-On Method - Disadvantages

- Requires a good return path:
  - Poor return path may give high readings.
- Connection must be on the correct part of the loop for the electrode under test:
  - Requires thorough understanding of the system.
  - Wrong connection can give a faulty result.
- Susceptible to noise from nearby substations and transformers (no reading).
- No basis for the test in standards – no objective reference for the test results
- Less effective for very "low" grounds:
  - Extraneous elements in reading become comparatively large.

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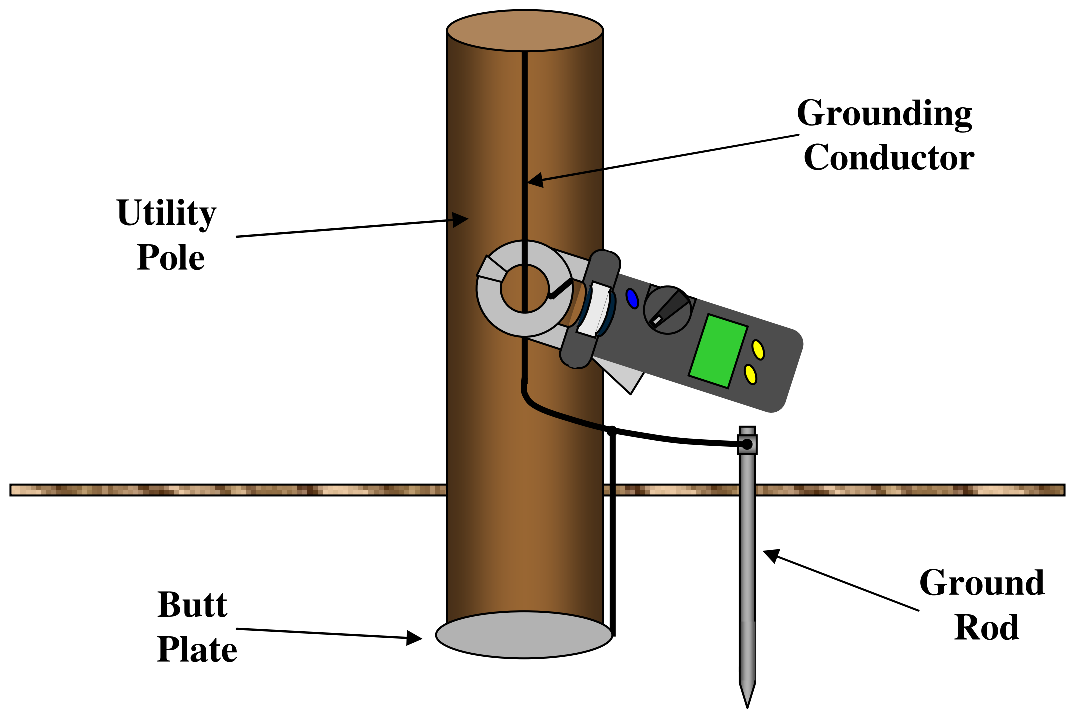
Clamp-On Method - Recommendations

- Should not use as the only test instrument unless the earth system architecture is known and understood
- Is an important part of the ground testing tool kit.
  - Should also have a Fall of Potential tester.
- Use the Clamp-On to identify potential problems quickly; confirm with a Fall of Potential tester:
  - Saves time.
  - Ensures accuracy
  - No disturbance of connections or re-connection risks

Applications – Pole Grounds



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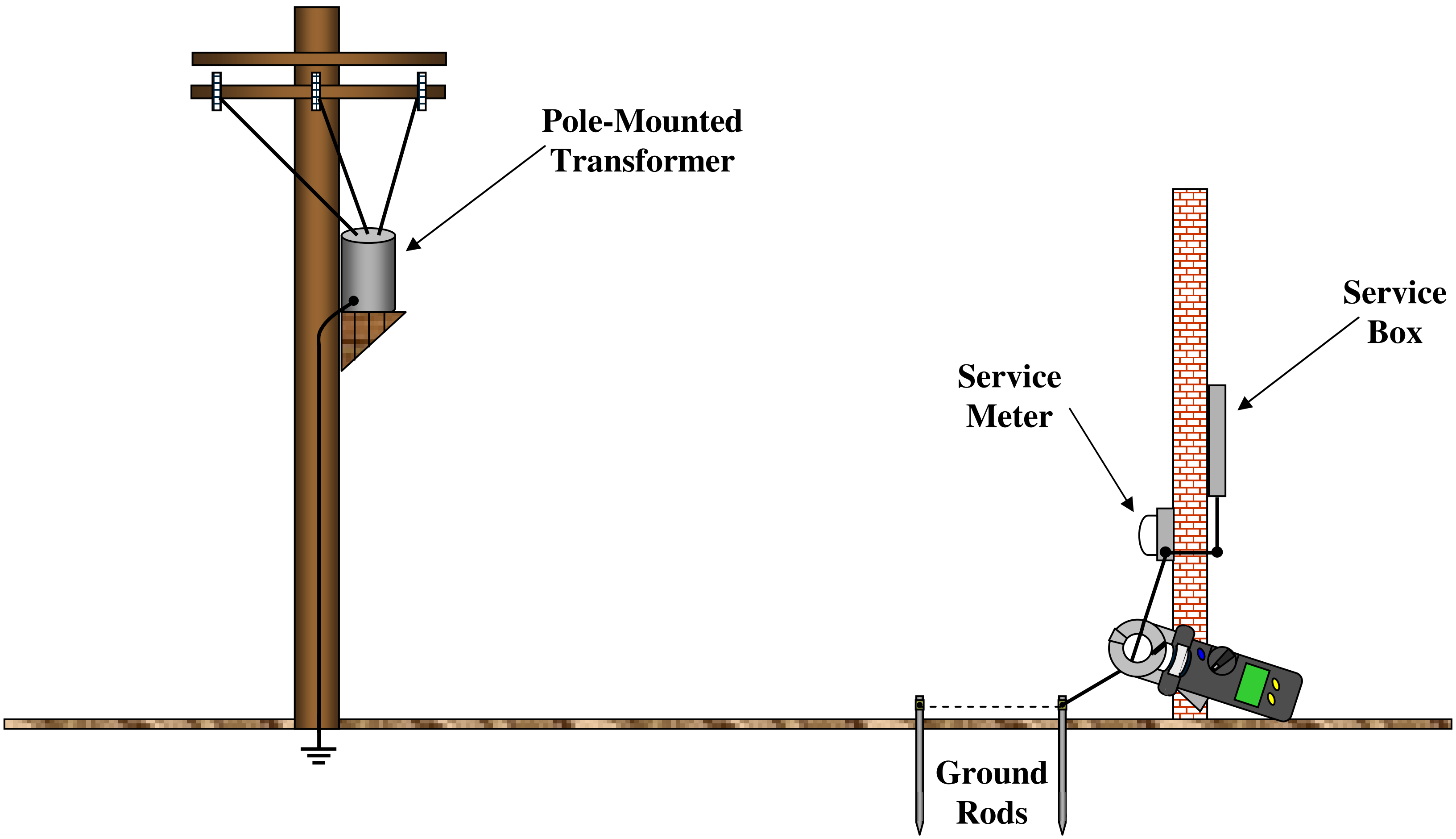
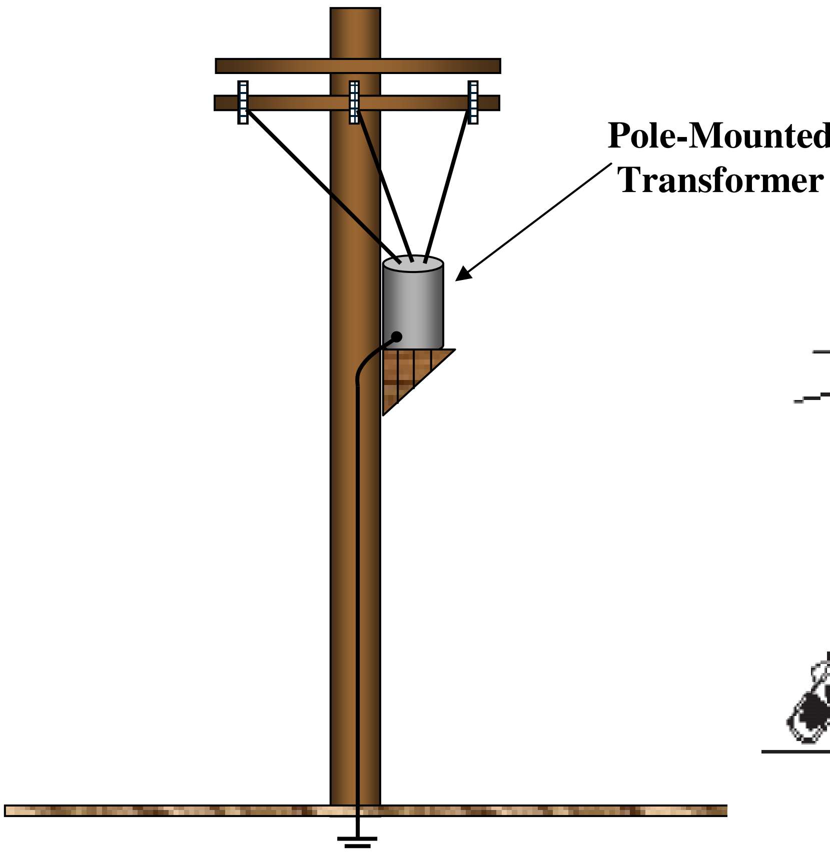
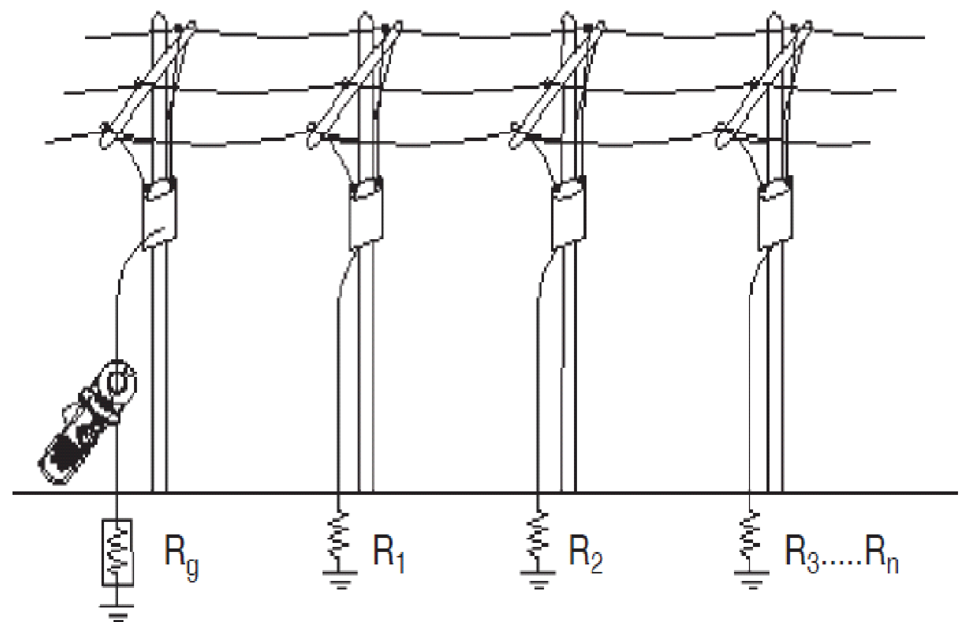
Applications – Service Entrance/Meter



Applications – Service Entrance/Meter





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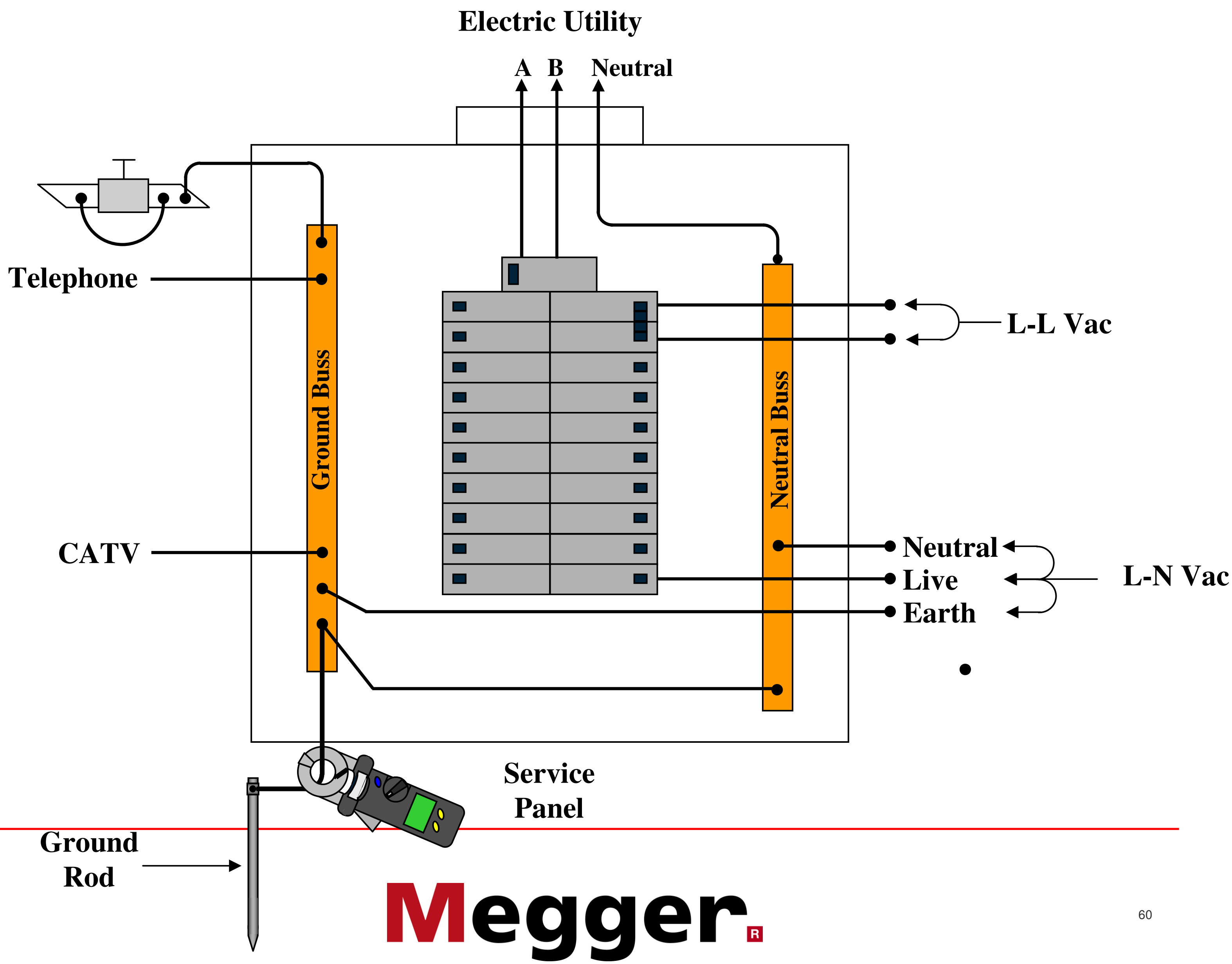
Applications – Service Panel



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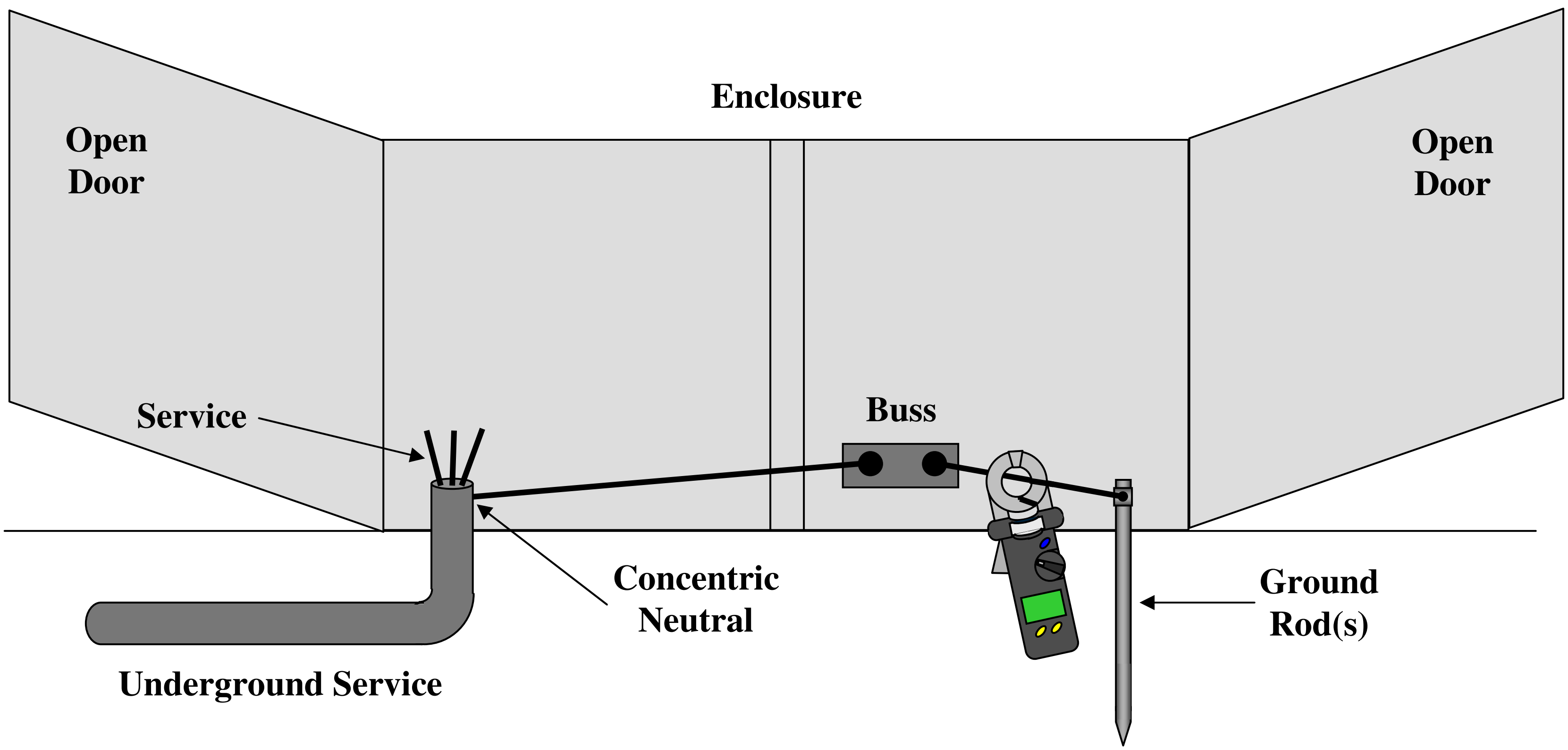
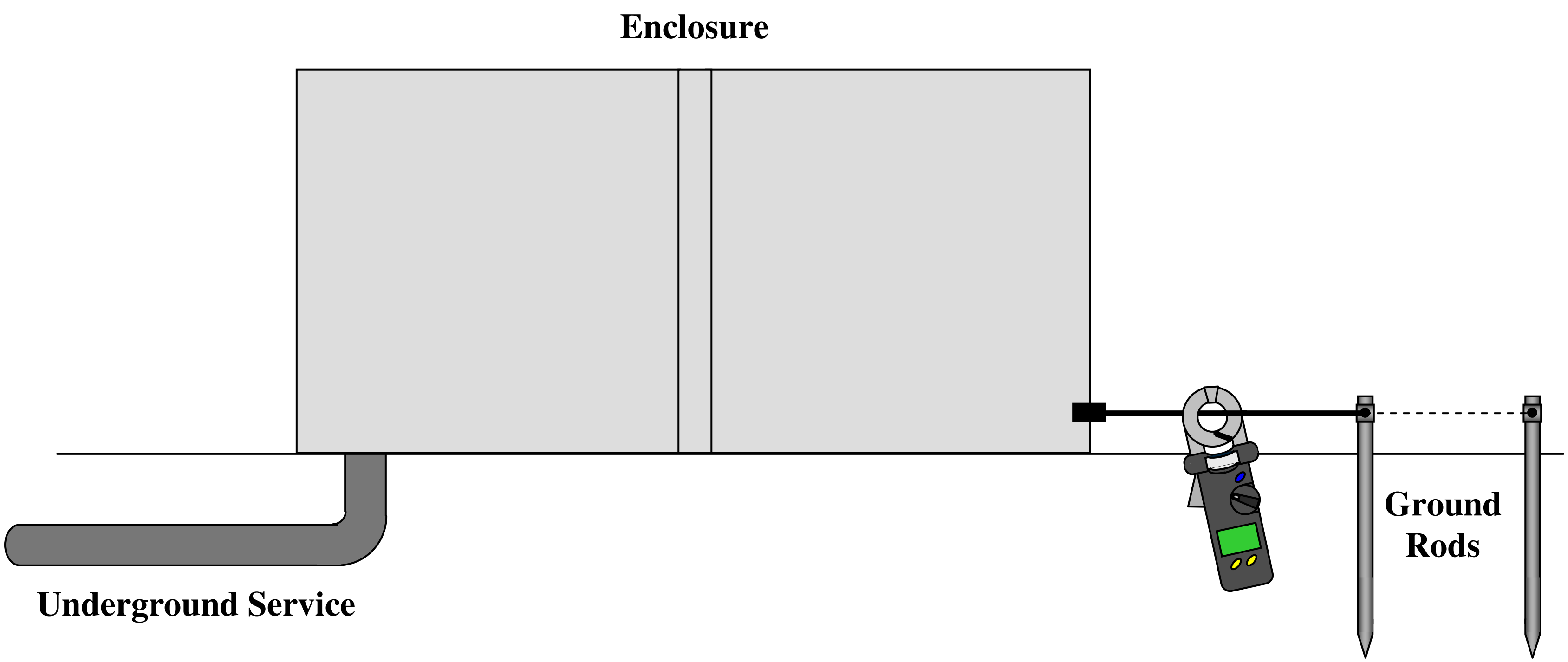
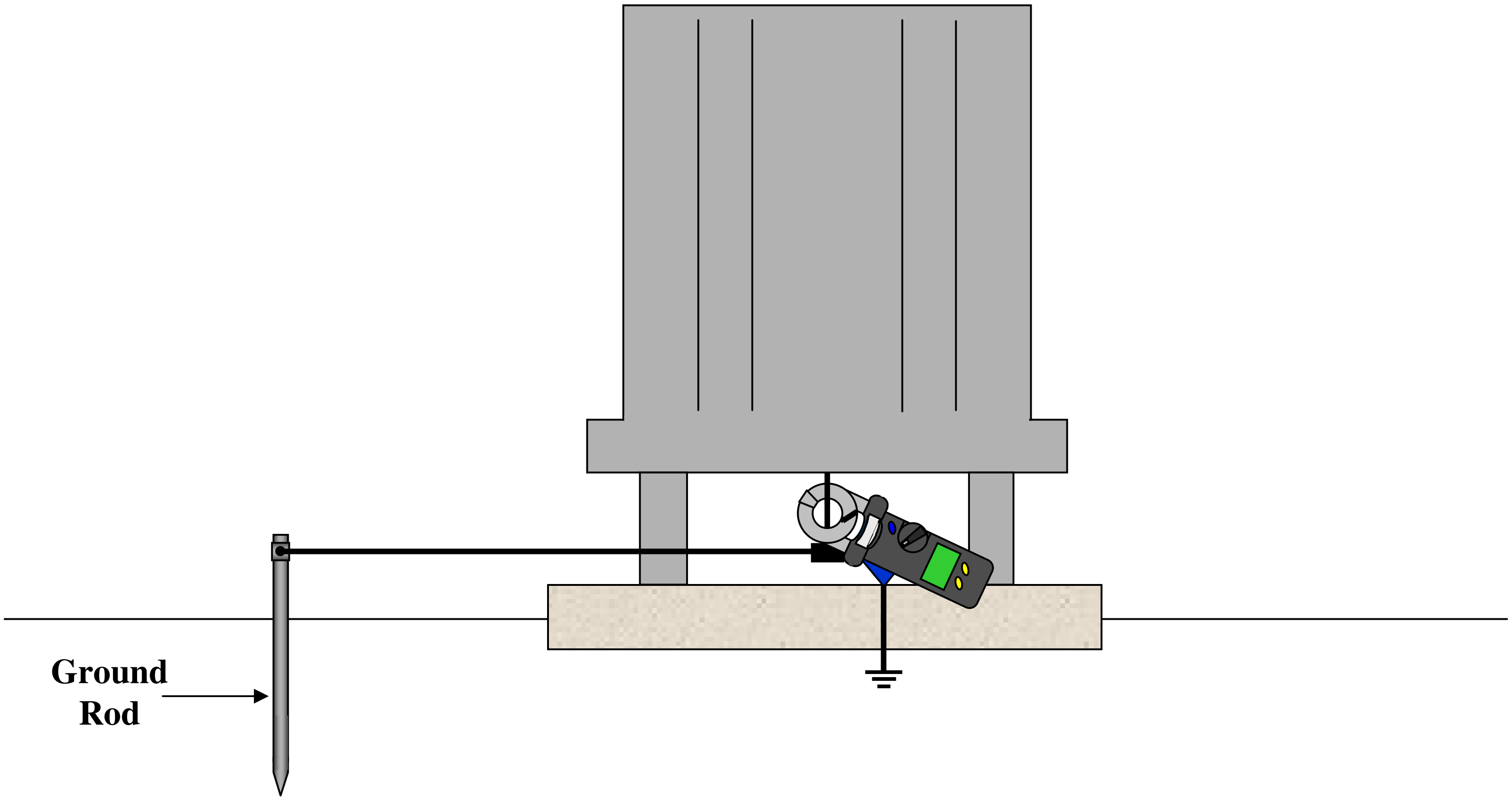
Applications – Pad Mount Transformer



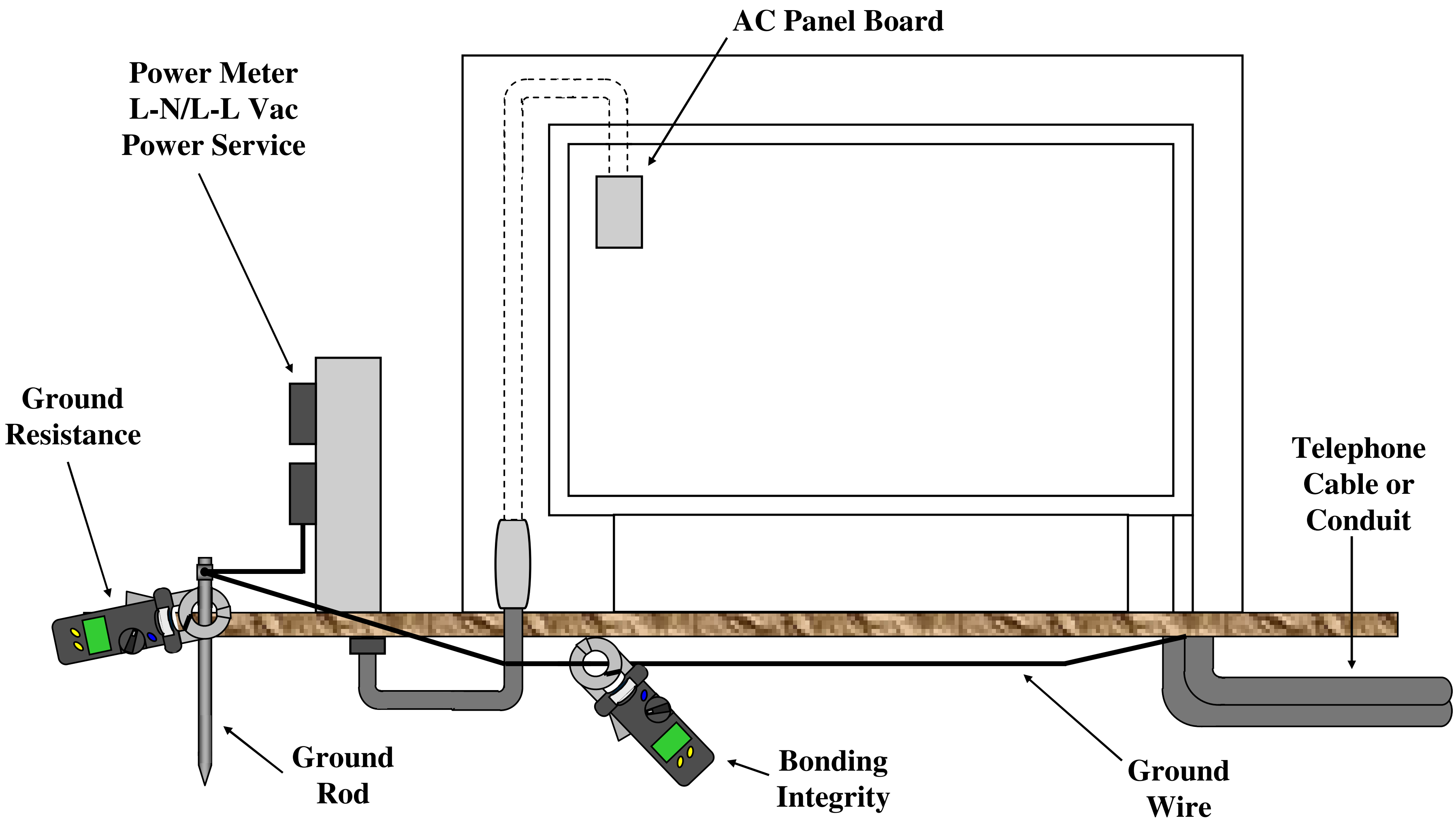
Applications – Pad Mount Transformer



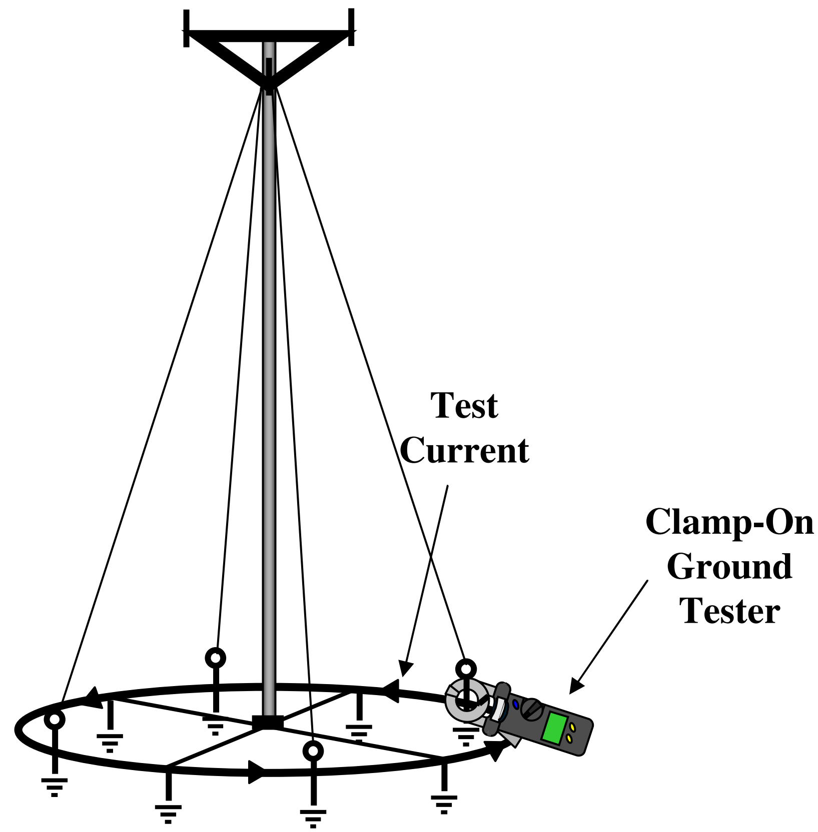
Applications – Transmission Towers



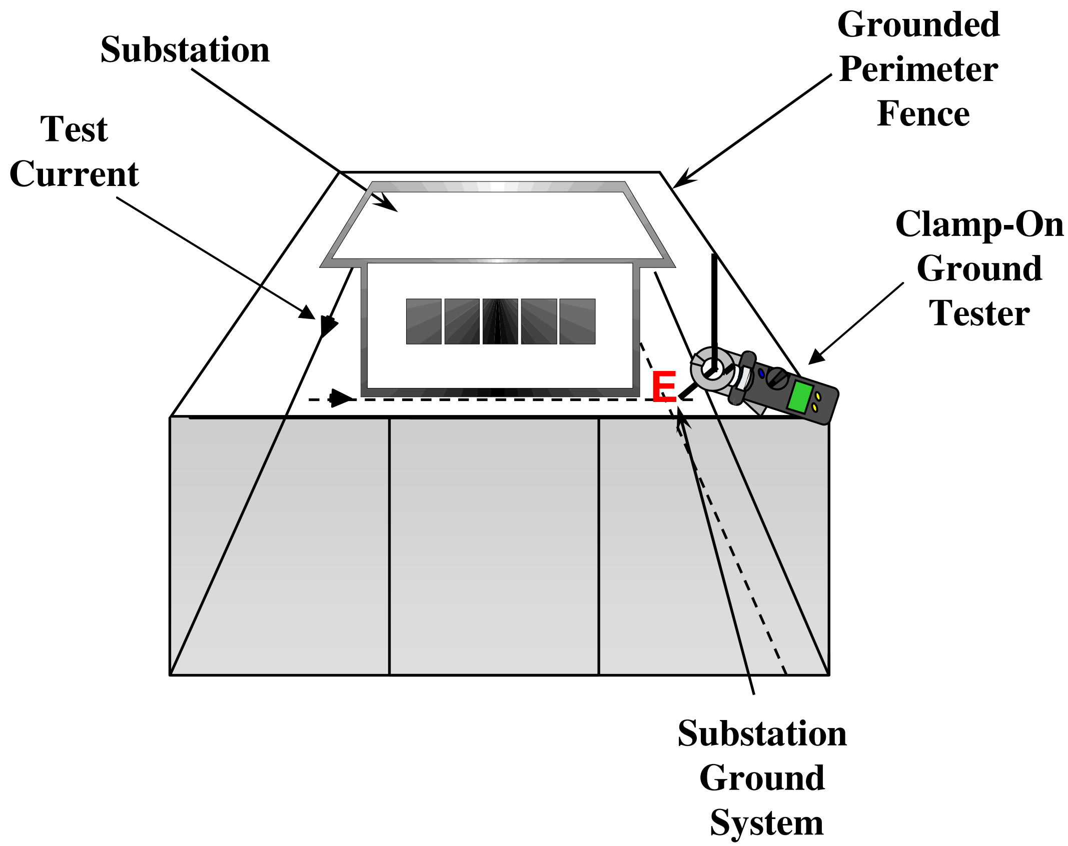
Applications – Telephone Cabinets



Misuses – Cellular Sites



Misuses – Substations



ERROR: undefined
OFFENDING COMMAND: f‘~

STACK: