# Earth Testing

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# What is a Ground?

- "A ground is a conducting connection by which an electrical circuit or equipment is connected to the earth or some conducting body."

  Source: IEEE Standard 81

- Low impedance conductor used to provide a safe path for the dissipation of:
  - fault currents
  - lightning strikes
  - static charges
  - EMF/RFI signals

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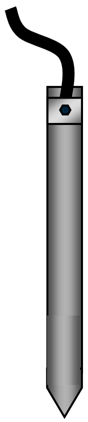
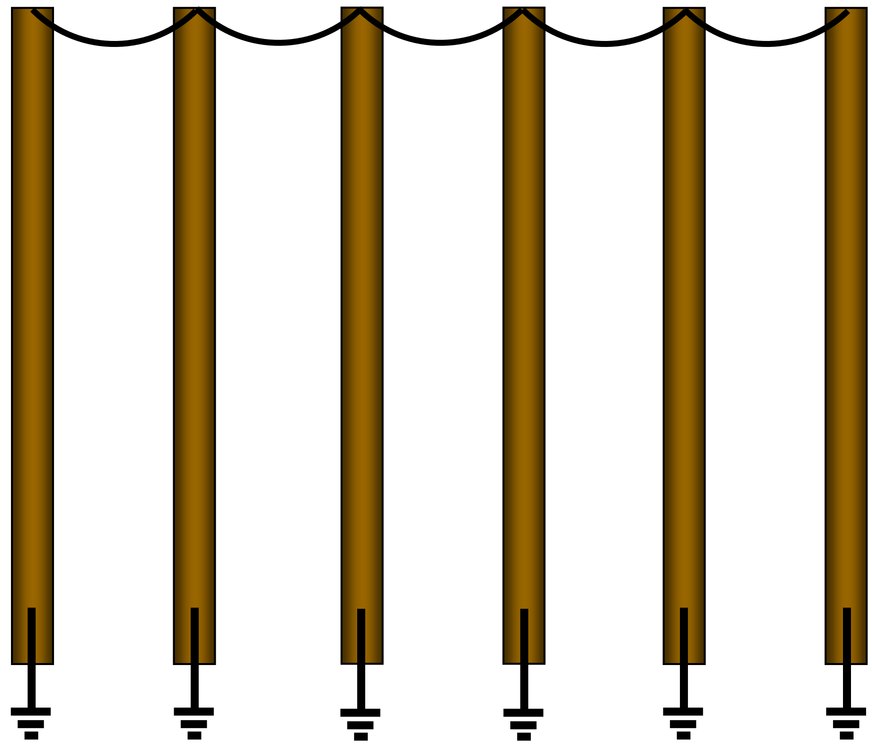
# Types of Grounding Systems

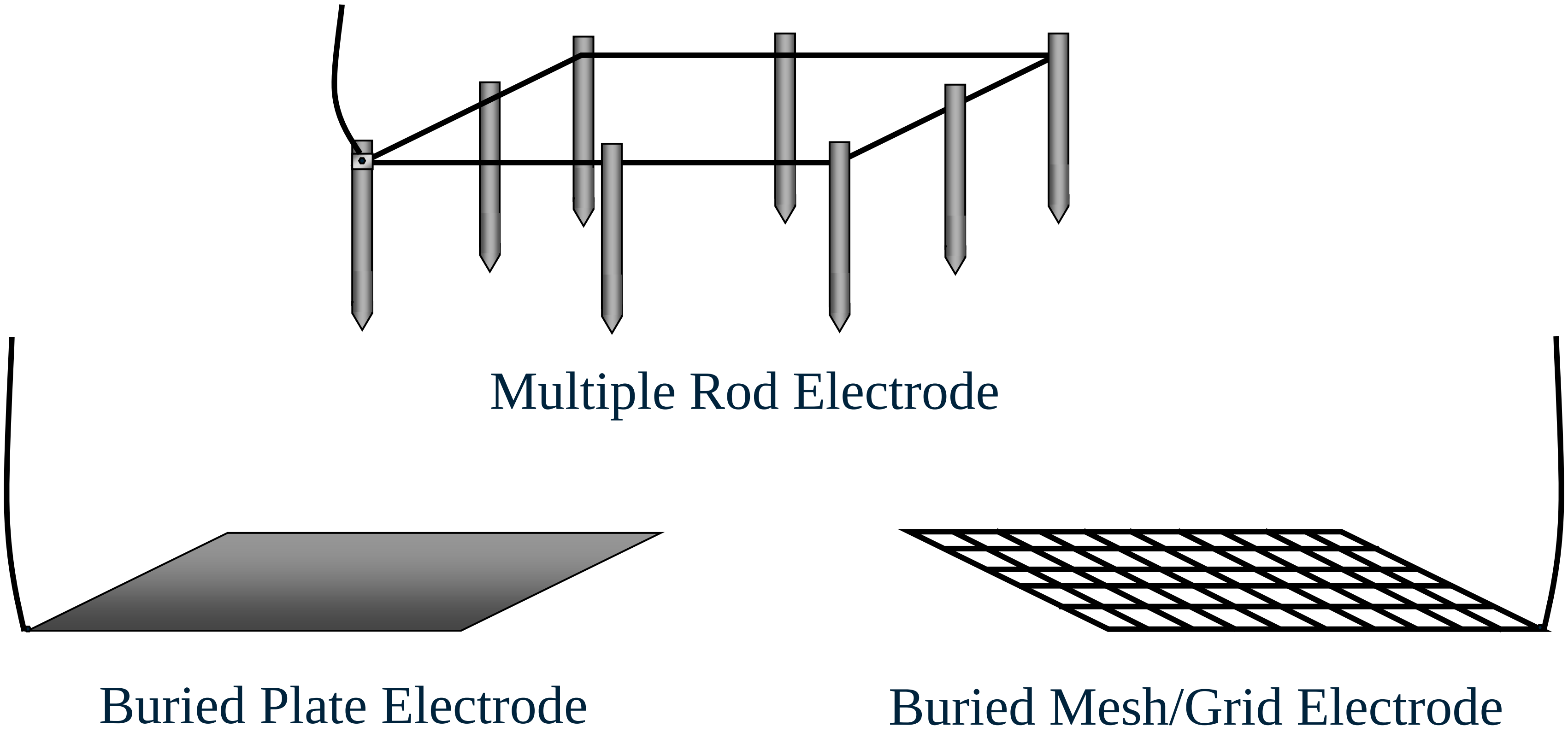


Single Rod Electrode



Multiple Pole Grounds

# Types of Grounding Systems

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# Benefits of Proper Grounding

- Lessens the chance of injury due to faulty insulation.
- Reduces the likelihood of damage from lightning strikes and induced voltages.
- Improves the performance of computer, communication, and other sensitive equipment.

# Benefits of Proper Grounding

- Protects electric, communications and process control circuits.
- Protects against static electricity from friction.
- Limits to definite values the voltage to earth of the entire electrical system.

# Causes of Ground System Deterioration

- Corrosion and weather influences exert mechanical strain on ground rods and cause metallic corrosion over time.
- Catastrophic events like lightning strikes or large fault currents can cause instant degradation.
- Soil resistivity can change over time due to environmental conditions.
- Electrical facility/plant expansion can create different needs in the ground system.

# Risks from Ground System Deterioration

- Potentially deadly electrical shock situations.
- Plant-wide equipment damage.
- Disruption in the performance of sensitive equipment with tight voltage parameters.
- Heat build-up on a single piece of electrical equipment and, eventually, fire.

# Ground Resistance vs. Earth Resistivity

- Ground Electrode Resistance: The resistance of the electrode system (in ohms); resistance must be low enough to dissipate all fault currents, lightning strikes, etc. into the earth.
- Earth Resistivity: The electrical properties of the soil for conducting current (measured in ohm-cm.).

# Why Measure Earth Resistance Periodically?

- To determine the effectiveness of ground rods, ground grids and connections.
- To check that standards set by statutory requirements/codes of practice have been met.
- To check that specific design parameters have been met.
- To check that the grounding electrodes are still present.

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# Why Measure Earth Resistivity Periodically?

- To prospect for low resistance ground locations.
- To gather sufficient information to allow the grounding requirements to be designed.
- To check that climatic conditions have not affected the ground such that it no longer meets the requirements.
- To check for seasonal variations.

# Choose the Proper Instruments:

- Use a dedicated ground tester (designed to make this measurement).
- Don’t make the measurement with a generalized ohmmeter or multimeter - results will be erroneous.
- Don’t use an insulation tester.

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# Maximum Earth Resistance Values:

- Varies depending on the standard used:
  - some call for 5 Ω maximum
  - some call for a fraction of an ohm
- Typical values from an insurance company:
  - Industrial plant: 5 Ω
  - Chemical plant: 3 Ω
  - Computer system: 3 Ω
- Typical values for a power company:
  - Generating station: 1 Ω maximum
  - Large sub-station: 1 Ω maximum
  - Small sub-station: 5 Ω maximum
- Water pipe ground should be less than 3 Ω and frequently less than 1 Ω.

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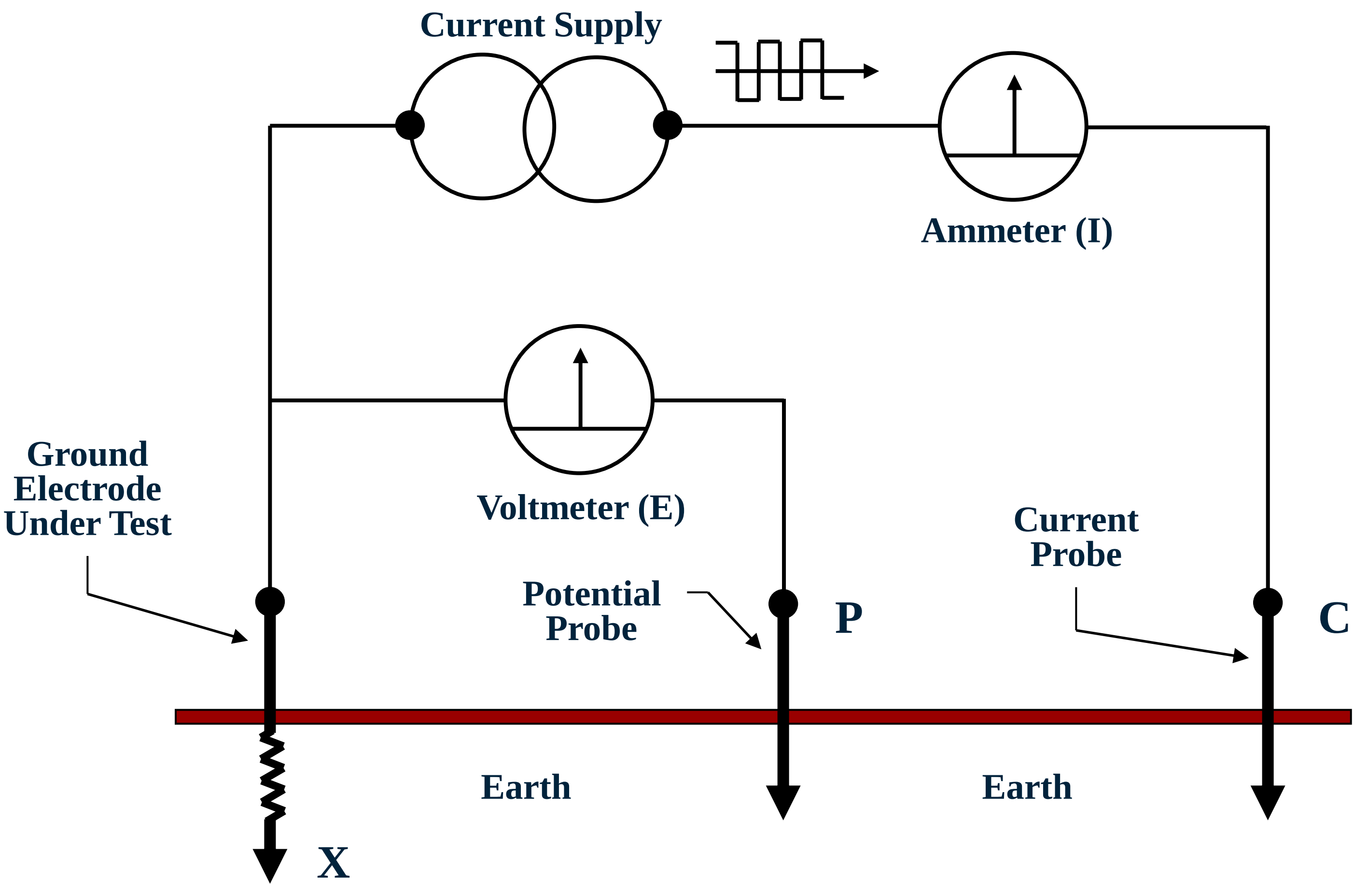
# 3-Terminal Earth Tester

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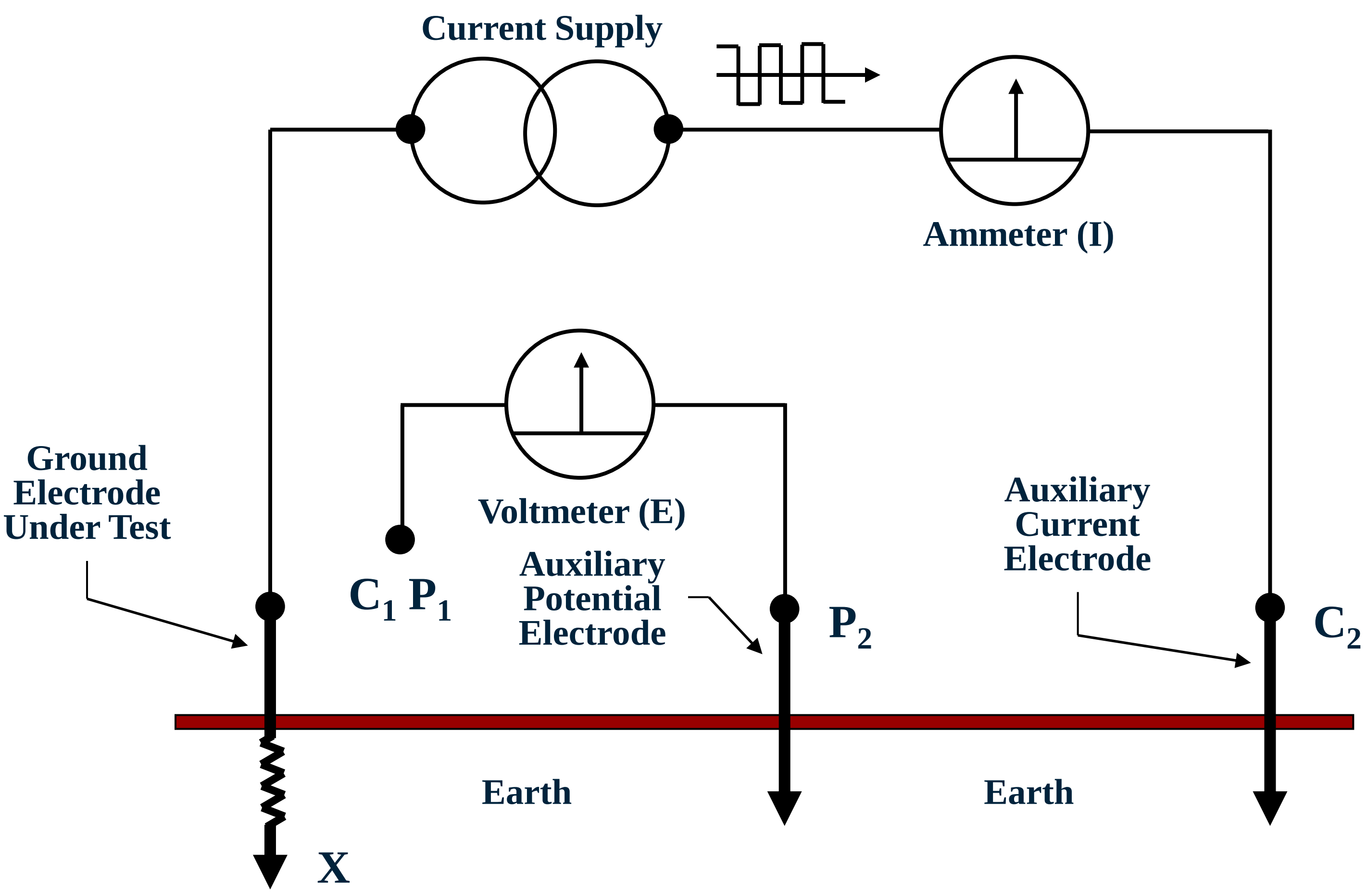
# 4-Terminal Earth Tester

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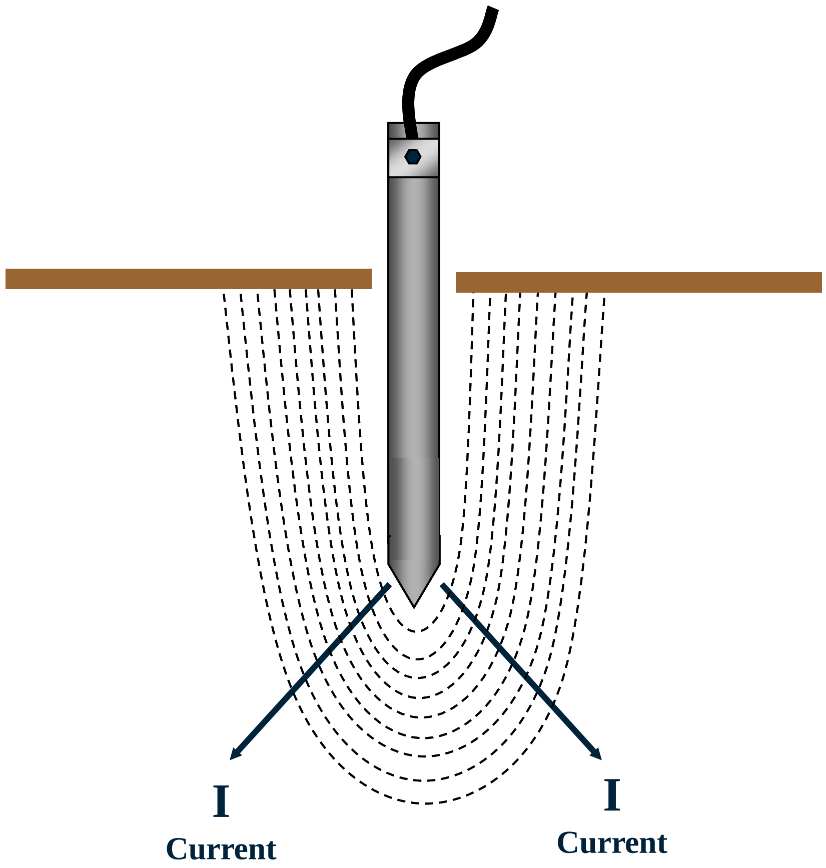
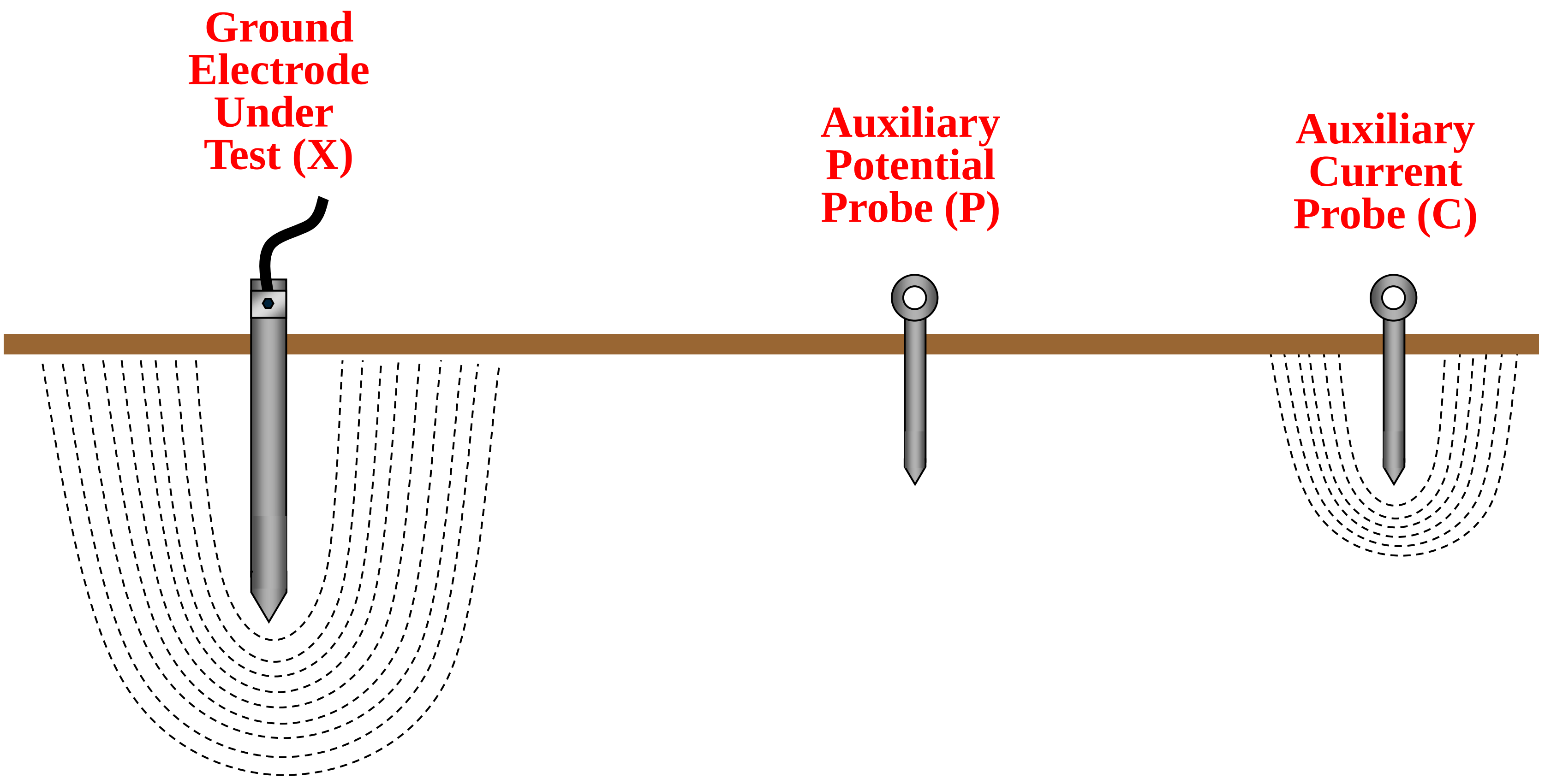
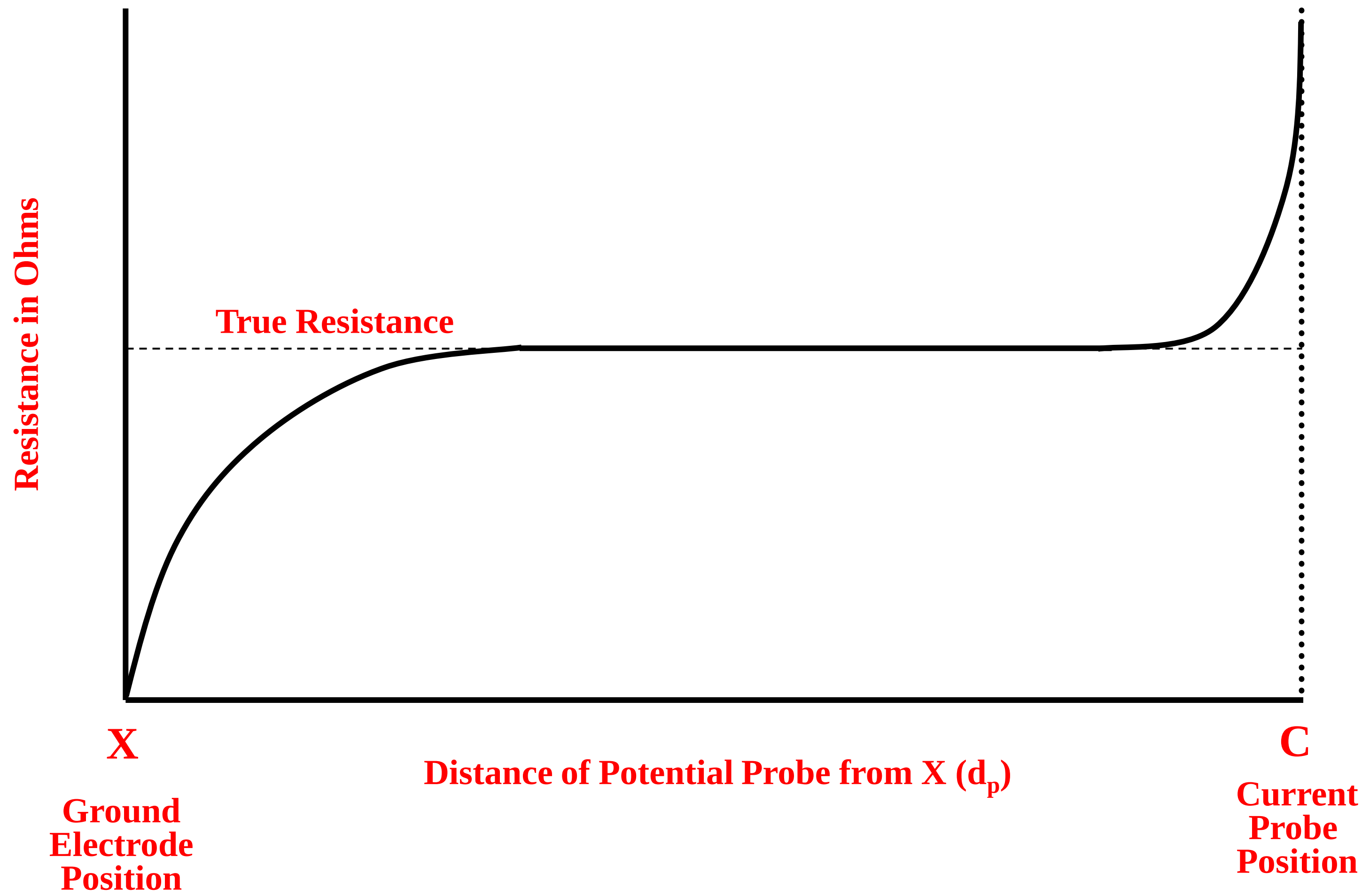
# Theoretical Background - Ground Rod Sphere of Influence



# Theoretical Background - Current Probe Sphere of Influence



# Theoretical Background - Resistance Curve

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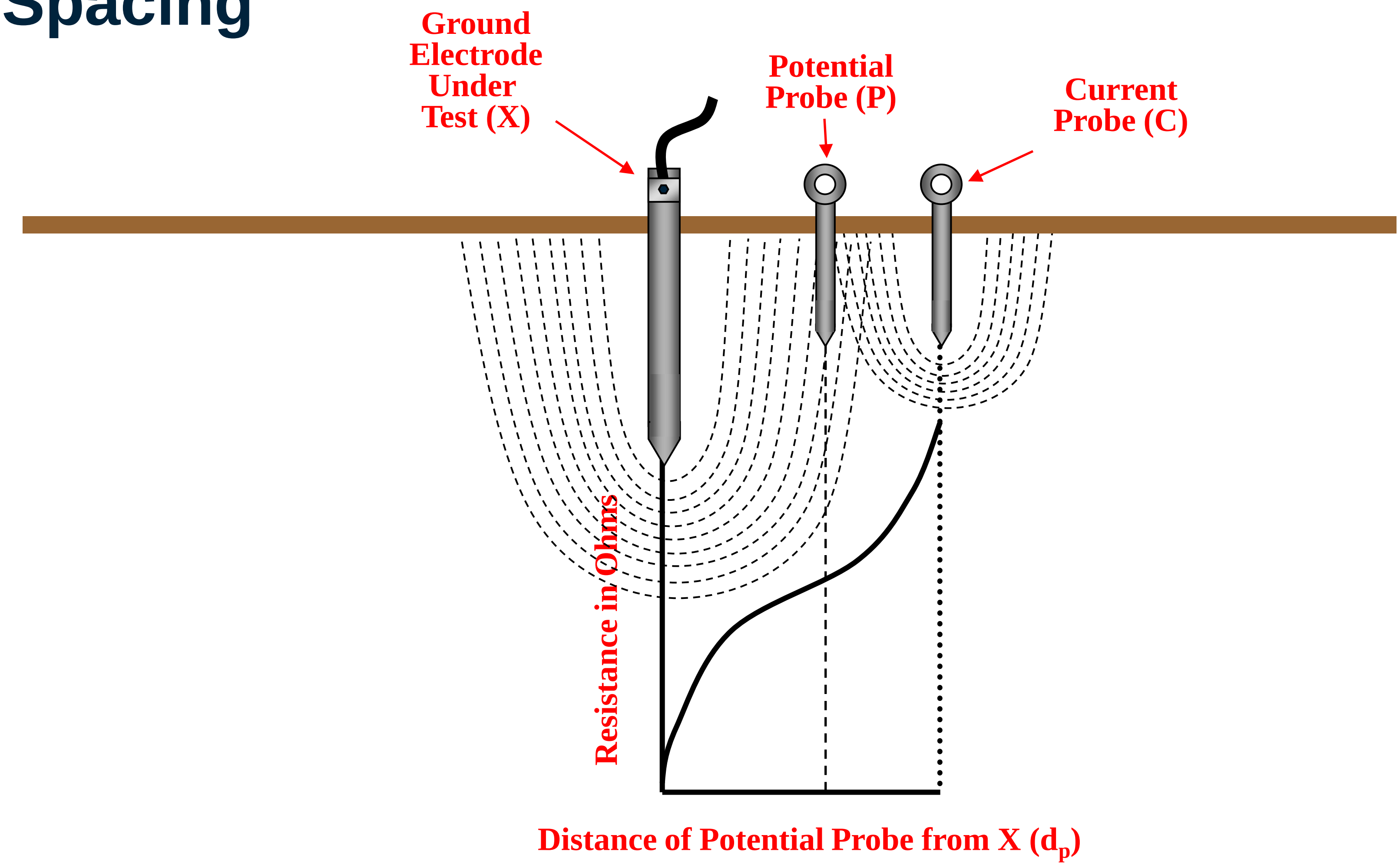
# Theoretical Background - Insufficient Probe Spacing



# Test Methods Serve Two Primary Purposes:

- Verify that correct spacing is being used to assure reliable results.
- Provide specific shortcuts to reduce testing time.

# Ground Testing Methods

- Fall of Potential Method
- 61.8% Rule/Method
- Four Potential Method
- Intersecting Curves Method
- Slope Method
- Dead Earth Method
- Star-Delta Method

# Fall of Potential Method

- Advantage: Extremely reliable.
- Disadvantage: Extremely time consuming and labor intensive.

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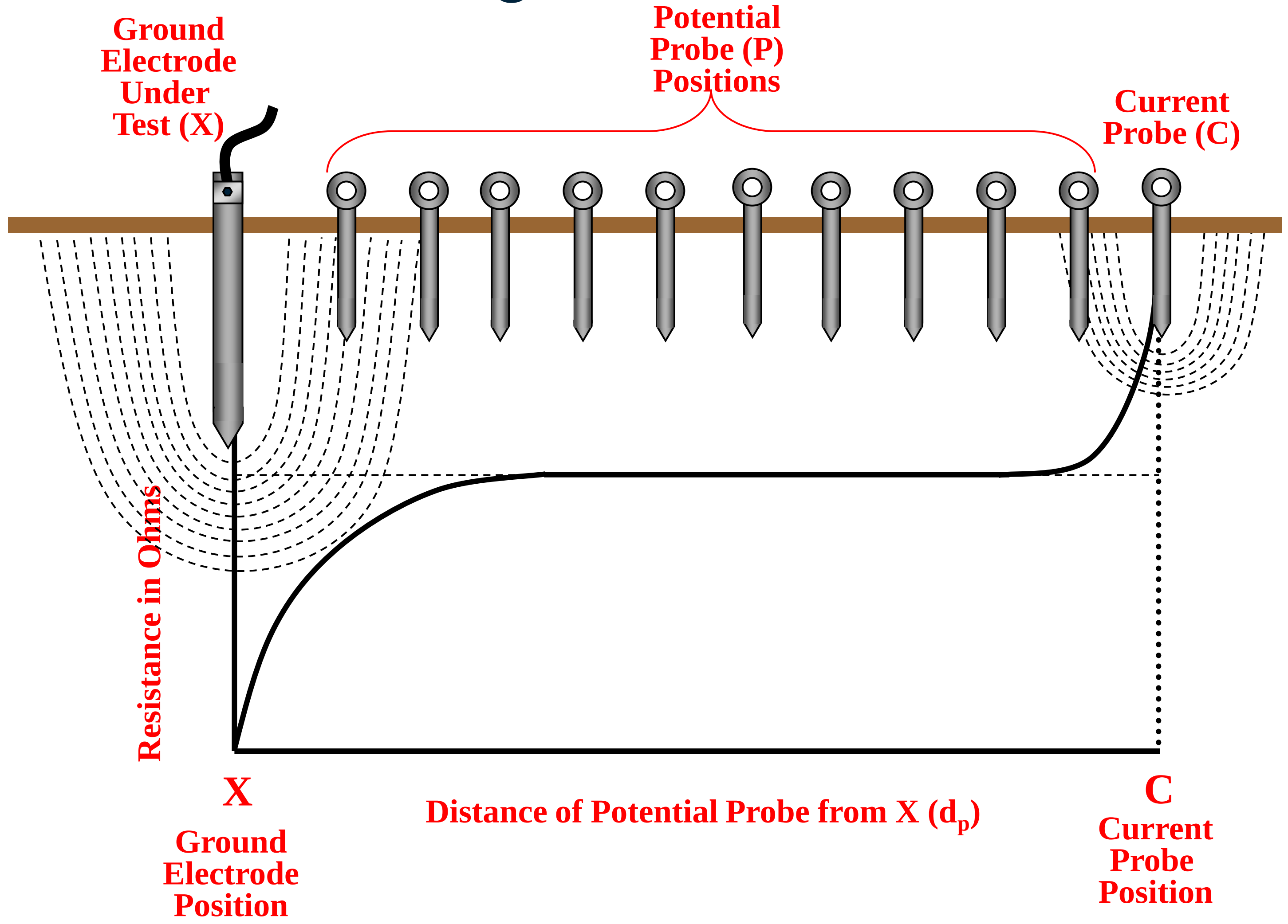
# Theoretical Background - Fall of Potential

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# Advantages of Fall of Potential Testing

- Conforms to IEEE 81; only approved method.
- Operator has complete control of the test set-up.
- Far more accurate:
  - 4-wire configuration/no additional loop resistances included.
  - Significant for low resistance (1-2Ω) grounds

# Simplified Fall of Potential Method

- Based on the theory behind the full Fall of Potential method.
- Take measurements at three points.

# Simplified Fall of Potential Method

- Advantage: Much faster than full Fall of Potential method.
- Disadvantage: Less reliable since fewer measurements being made.

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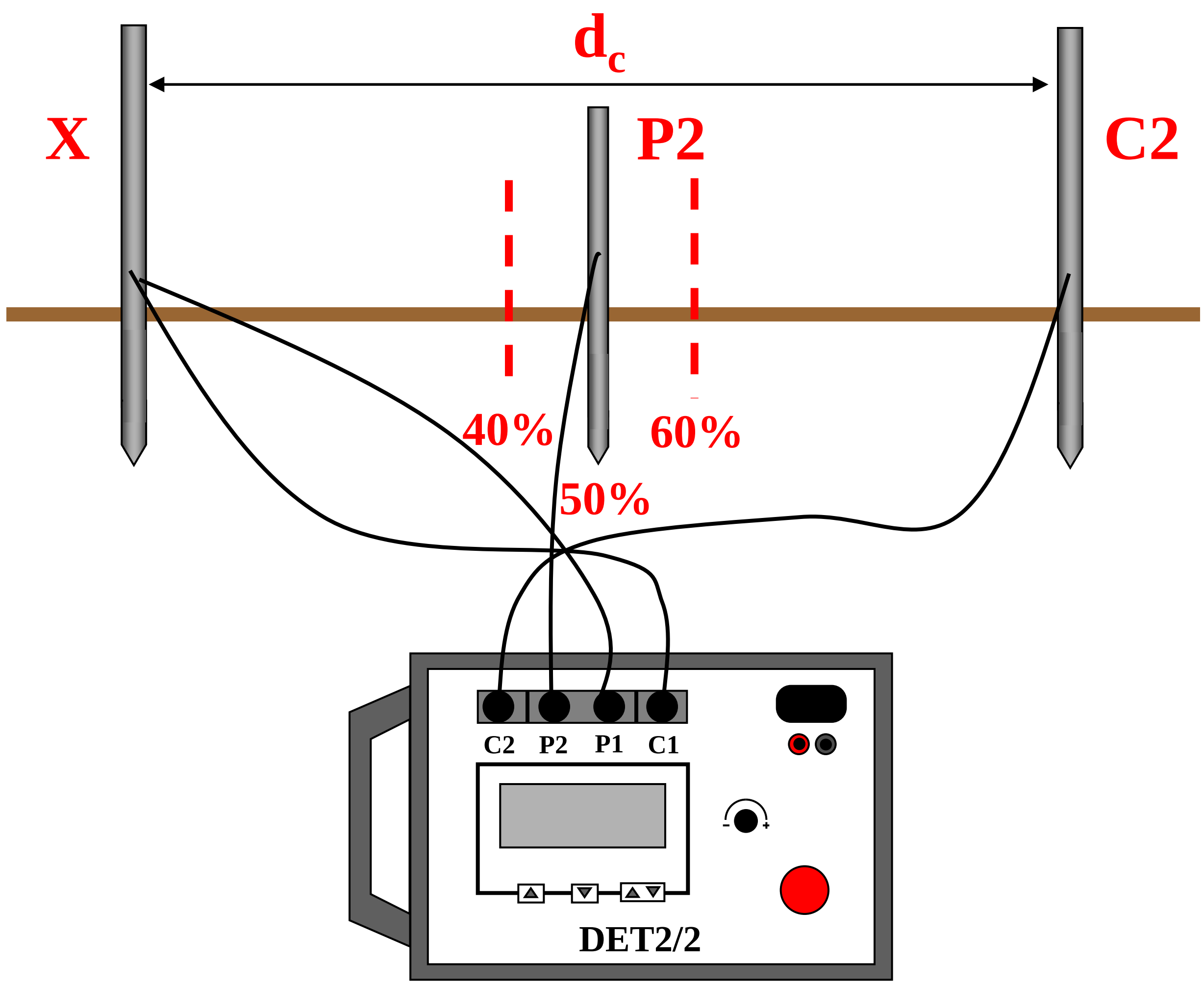
# Simplified Fall of Potential Method

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# Simplified Fall of Potential Method

- $R_A = \frac{R_1 + R_2 + R_3}{3}$
- $R_{Max\ Deviation} = R_A - R_X$
  *($R_X$ is furthest R value from $R_A$)*
- $\%\ deviation = \frac{(R_{Max\ Deviation})}{R_A} * 100$
- If (% deviation)*1.2 > 10%; C2 must be moved further away

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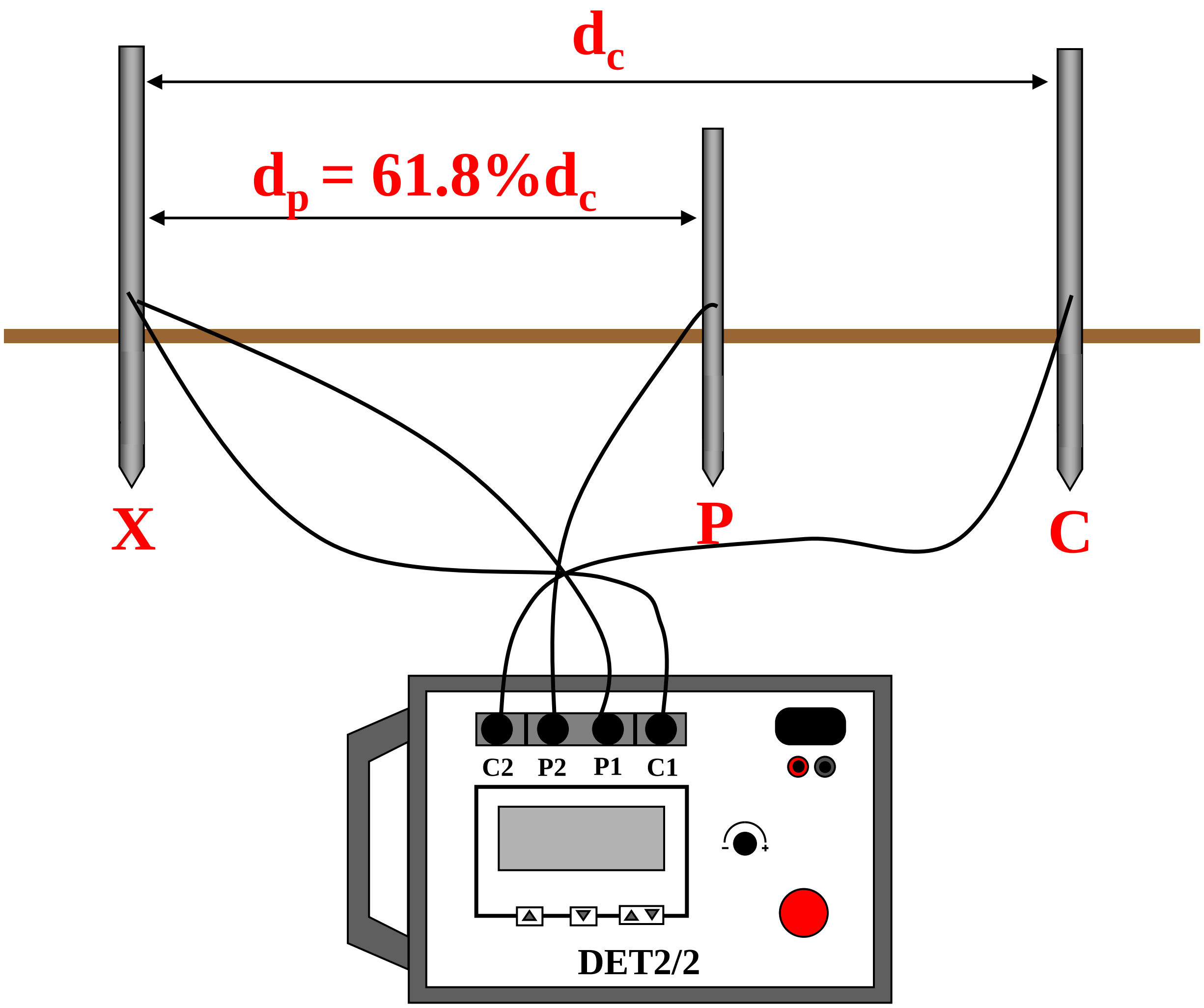
# 61.8% Rule/Method

- Based on the theory behind the full Fall of Potential method.
- Take measurement at only one point.

# 61.8% Rule/Method

- Advantage: Extremely quick and easy.
- Disadvantage: Assumes that conditions are perfect (adequate probe spacing and soil homogeneity).

# 61.8% Rule/Method

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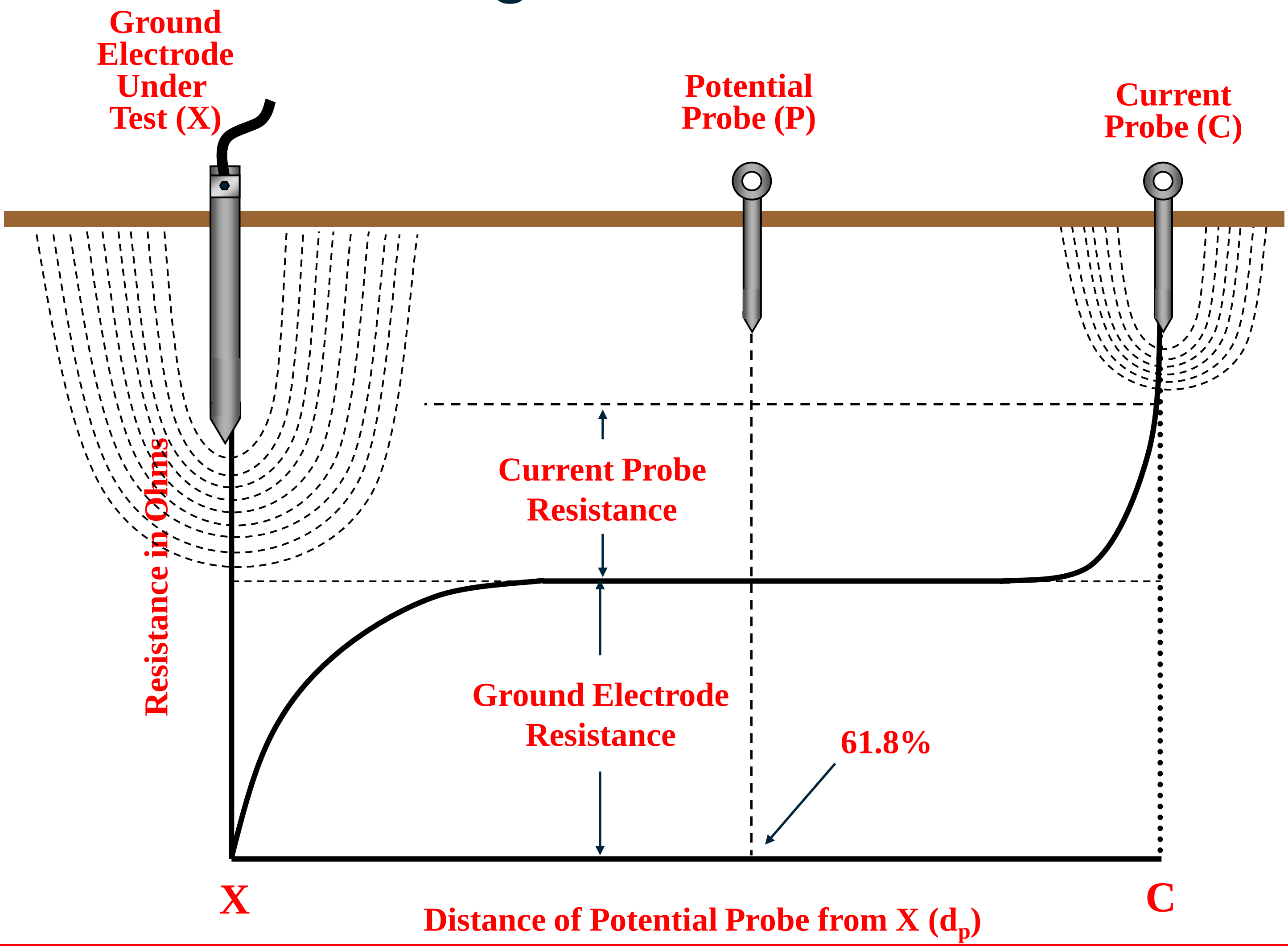
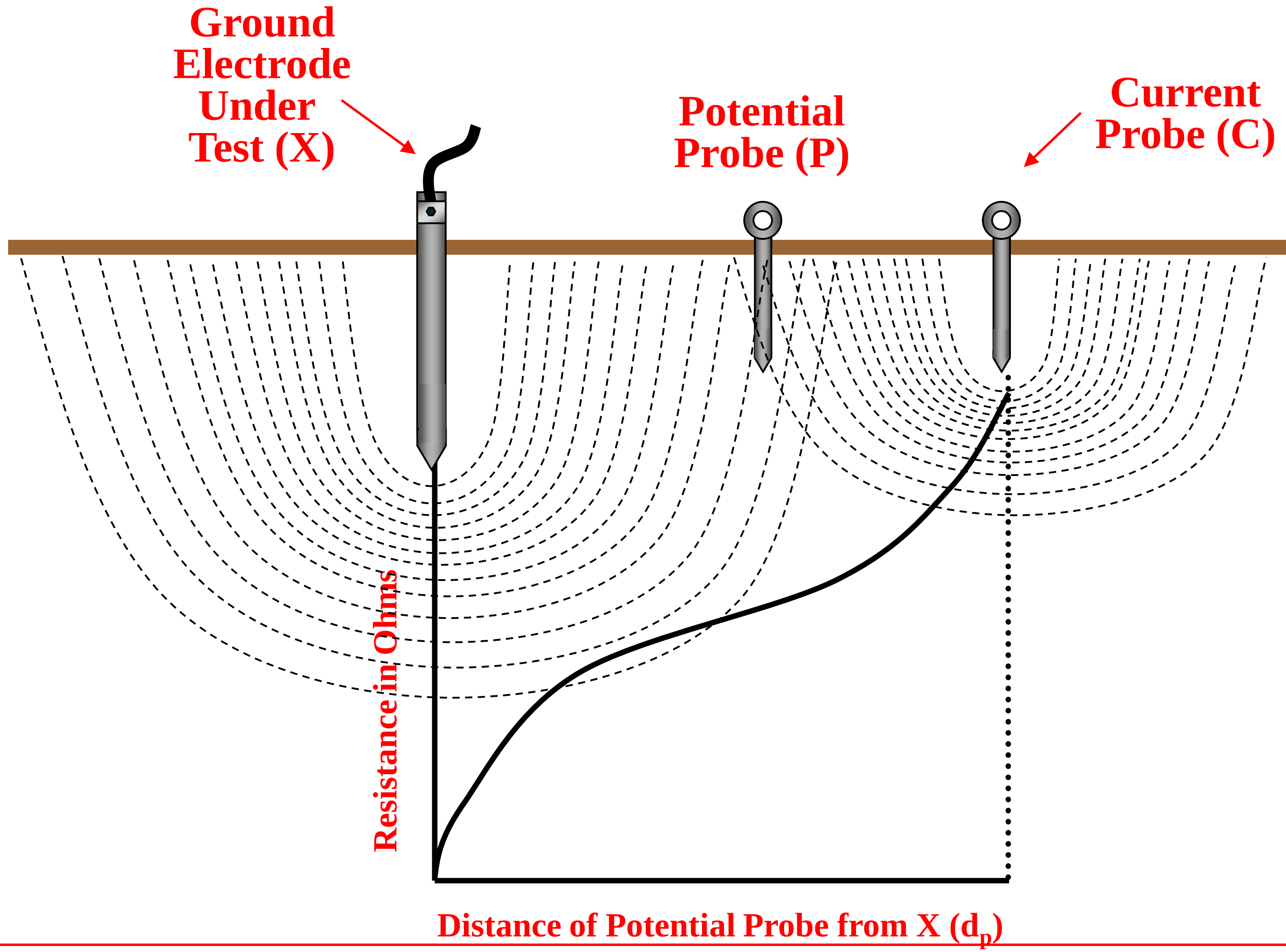
# Theoretical Background - 61.8% Rule



# The Problem of Limited Distance/Space

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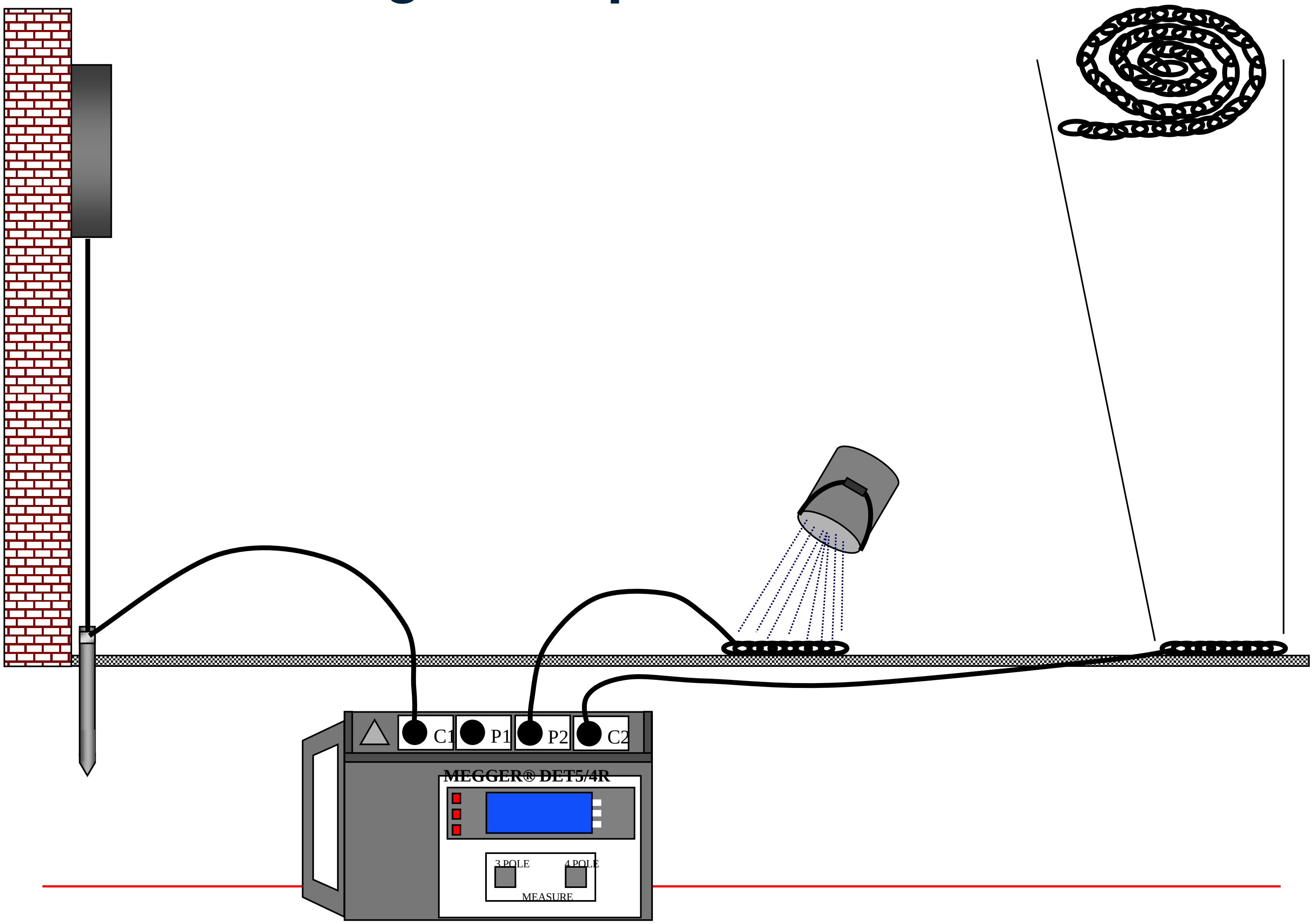
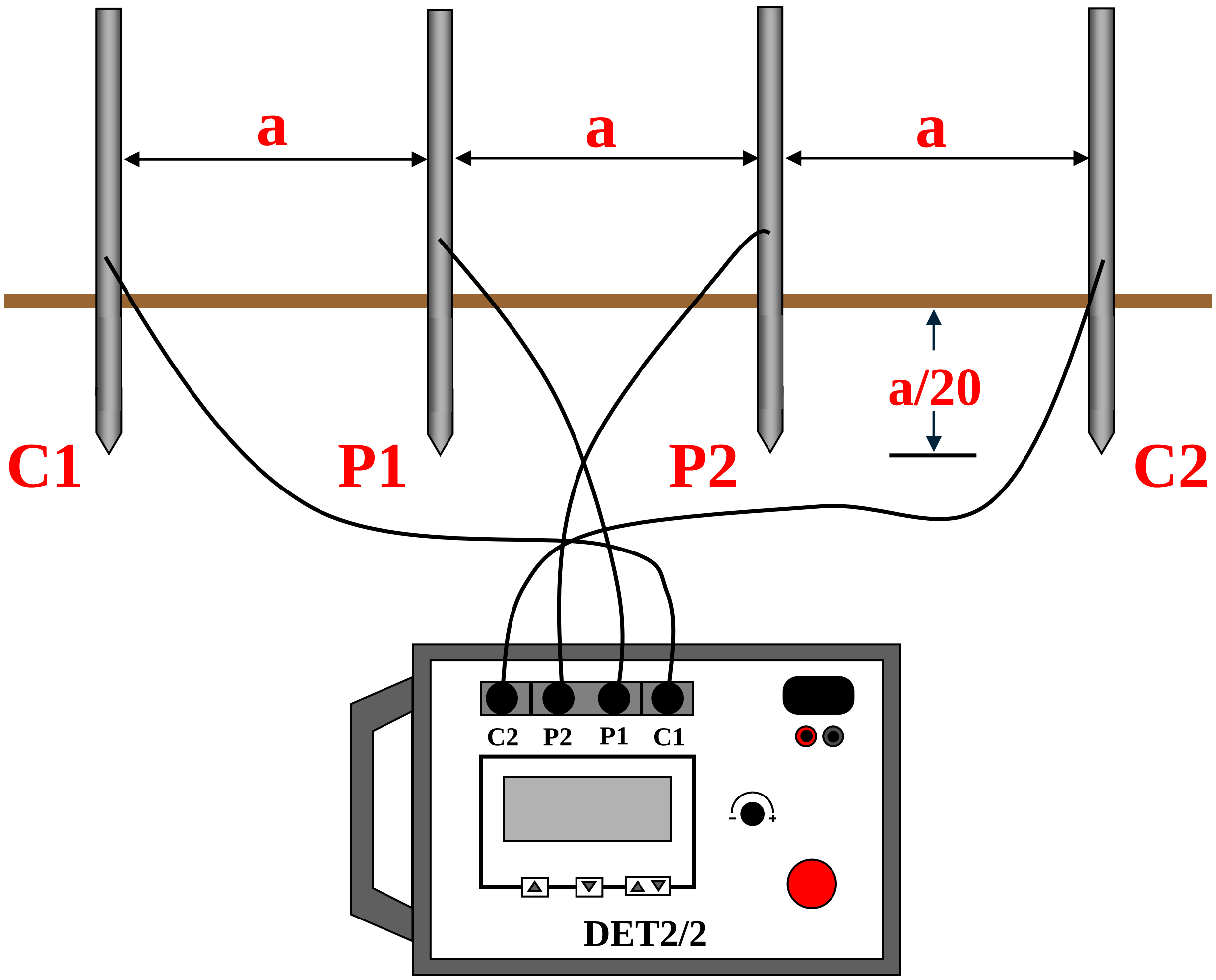
# Earth Testing on Asphalt



# Measuring Earth Resistivity

- Use a 4-terminal ground tester.
- Space the electrodes an equal distance “a” apart.
- Insert the electrodes a distance of a/20 into the ground.
- Measures the average soil resistivity to a depth equal to the electrode separation.

# Measuring Earth Resistivity

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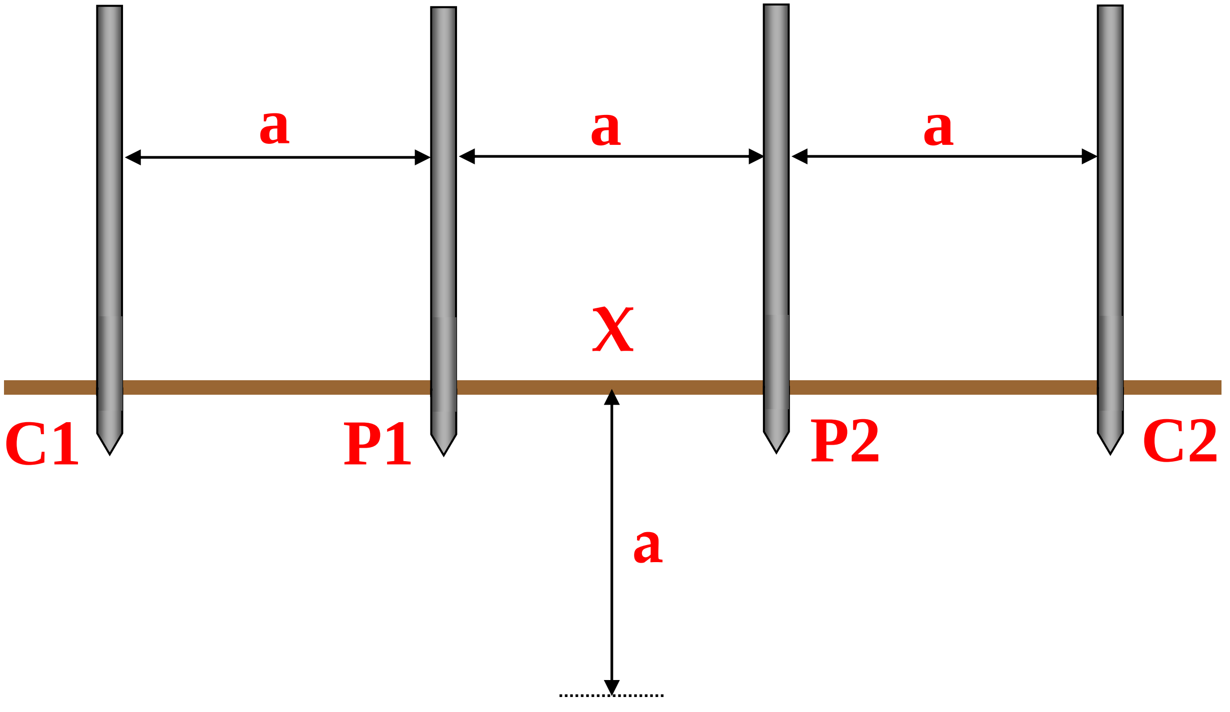
# Measuring Earth Resistivity

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# Measuring Earth Resistivity

**Soil Resistivity = $2\pi$ aR**

## Where:

- a = Probe spacing given in centimeters.
- R = Measured resistance given in ohms.
- Soil resistivity calculated to average depth of probe spacing.

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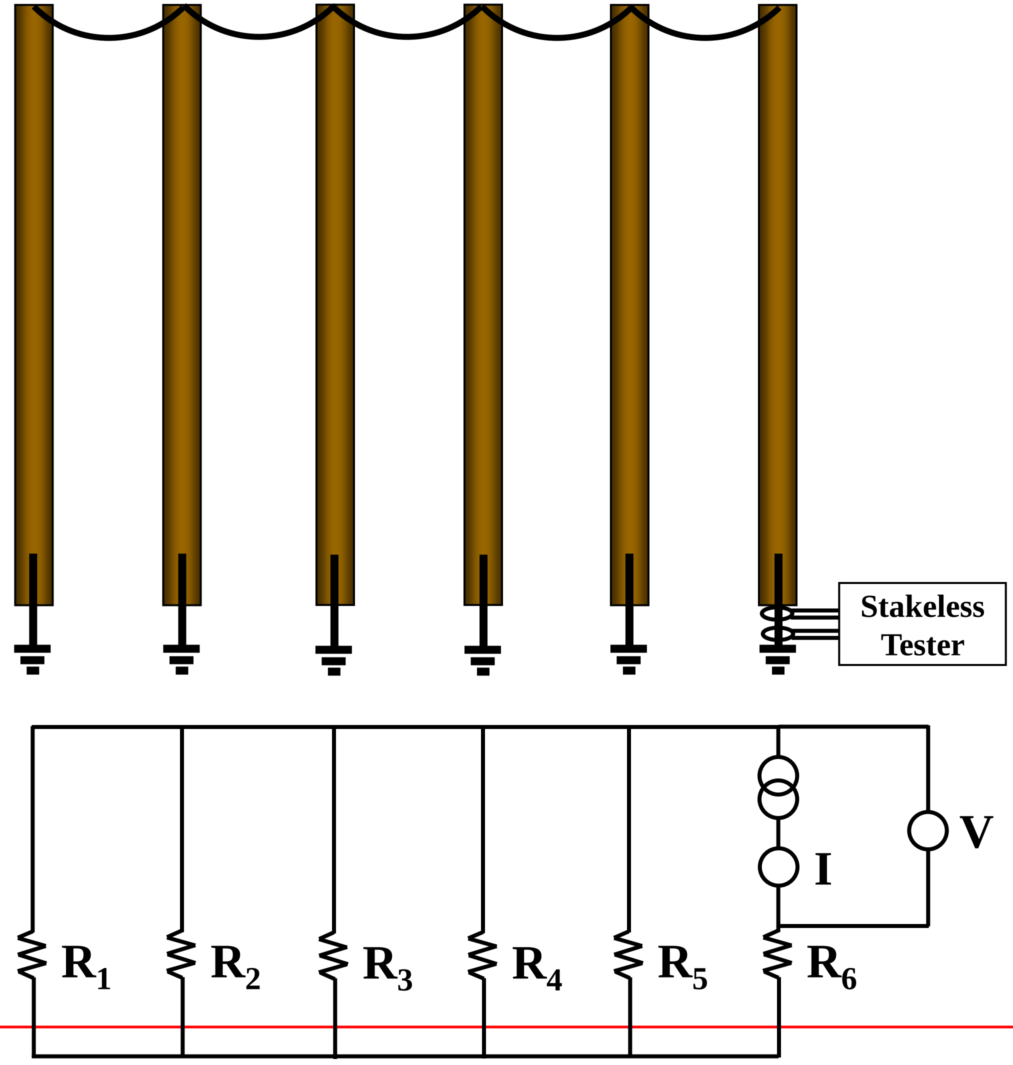
# Stakeless/Clamp-On Method

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# Disadvantages of the - Stakeless/Clamp-On Method

- 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 alternate lower resistance return exists not involving the soil.
  - Cellular towers
  - Substations

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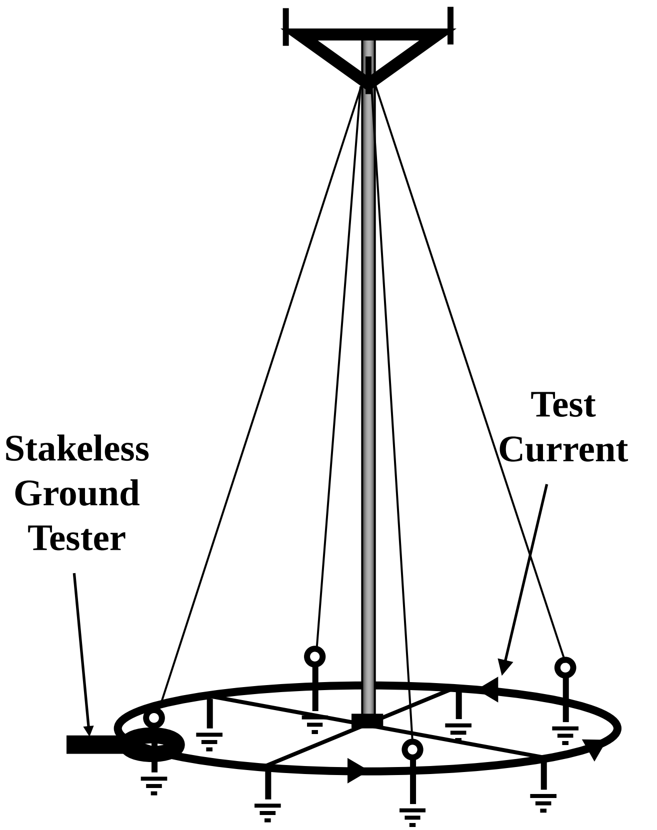
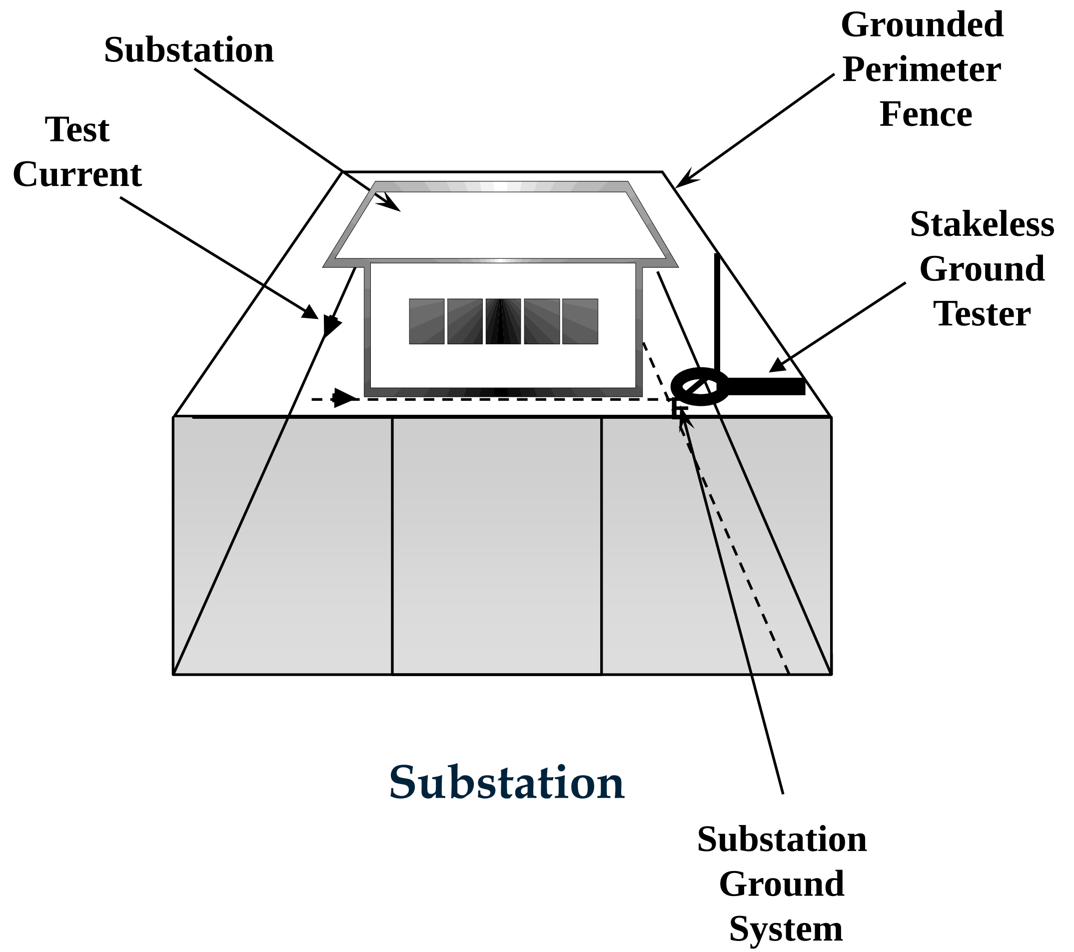
# Disadvantages of the - Stakeless/Clamp-On Method

- Subject to influence if another part of the ground system is in “resistance area”.
- Test is less representative of a fault at power frequency.
- Accuracies are greatly reduced.

# Misuses of the Stakeless/Clamp-On Method




Cell Tower




Substation

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# Addressing Ground System Problems

- Use longer ground rods.
- Use multiple ground rods.
- Chemically treat the soil.
- Place the system in lower resistivity soil.

# Questions to Consider:

- Are you measuring the resistance of an already existing ground system?
- Are you prospecting for the best location for a ground system?
- Are you working in an active substation environment?

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# Attached Rod Technique Goal

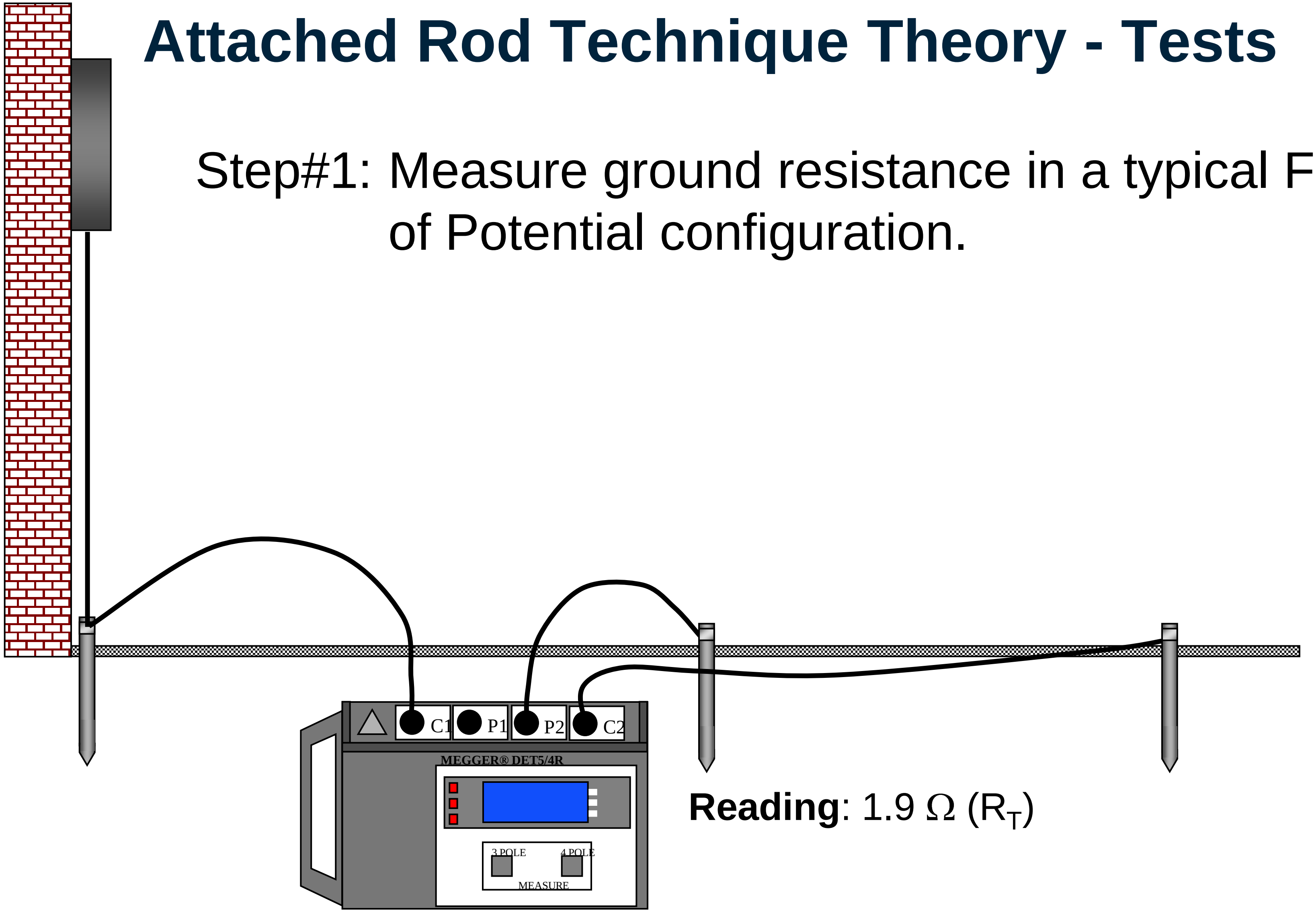
- To combine some of the time saving benefits of the Clamp-On technique with the accuracy and repeatability of the Fall of Potential technique.

# Attached Rod Technique Theory

- Uses Fall of Potential.
- Involves the use of a milliammeter to measure leakage currents.
- Uses Ohm's Law to convert Fall of Potential readings and leakage current readings to the resistance of the ground rod.

# Attached Rod Technique Theory - Tests

Step#1: Measure ground resistance in a typical Fall of Potential configuration.

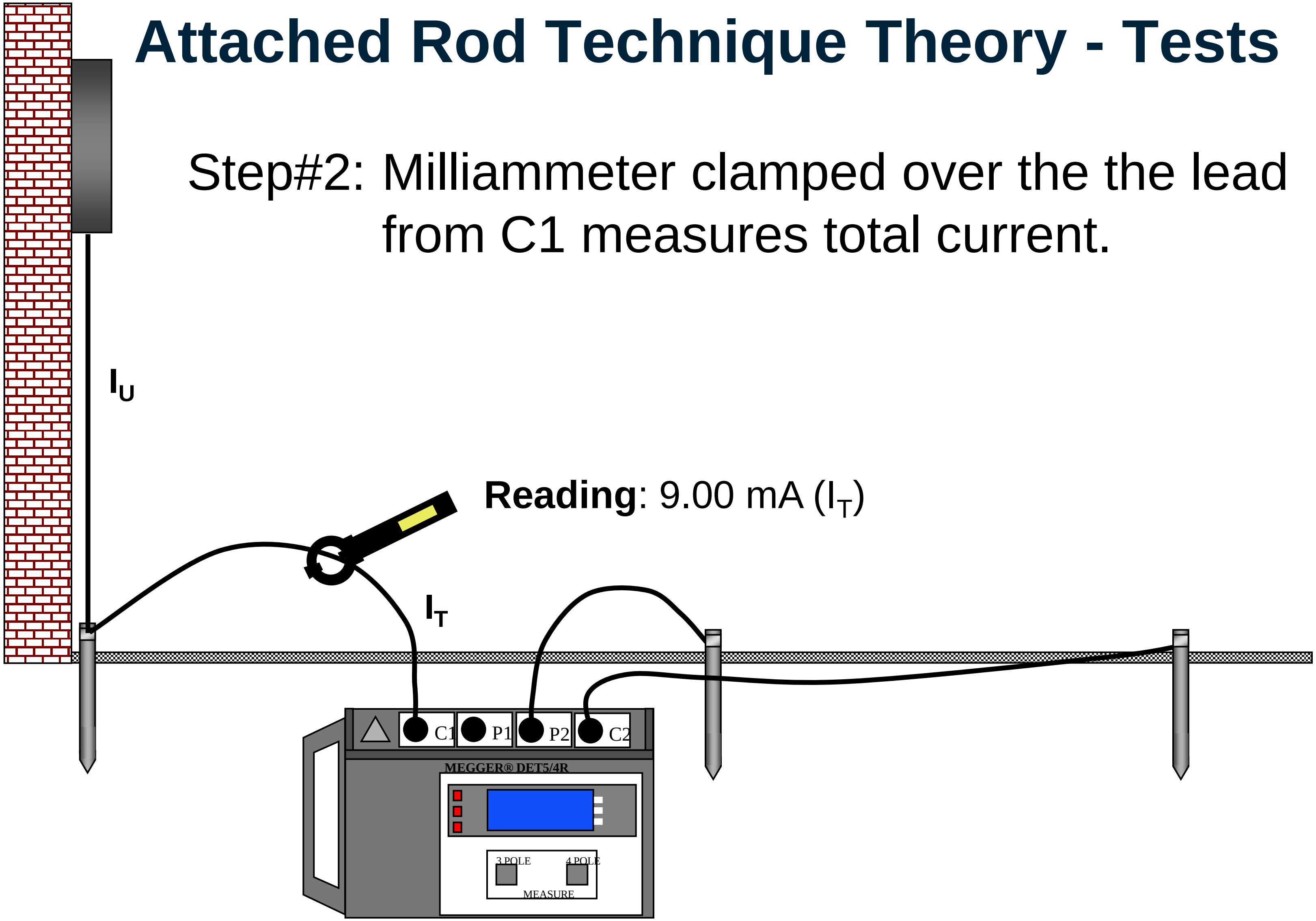



**Reading**: 1.9 Ω ($R_T$)

# Attached Rod Technique Theory - Tests

Step#2: Milliammeter clamped over the the lead from C1 measures total current.

**Reading**: 9.00 mA ($I_T$)

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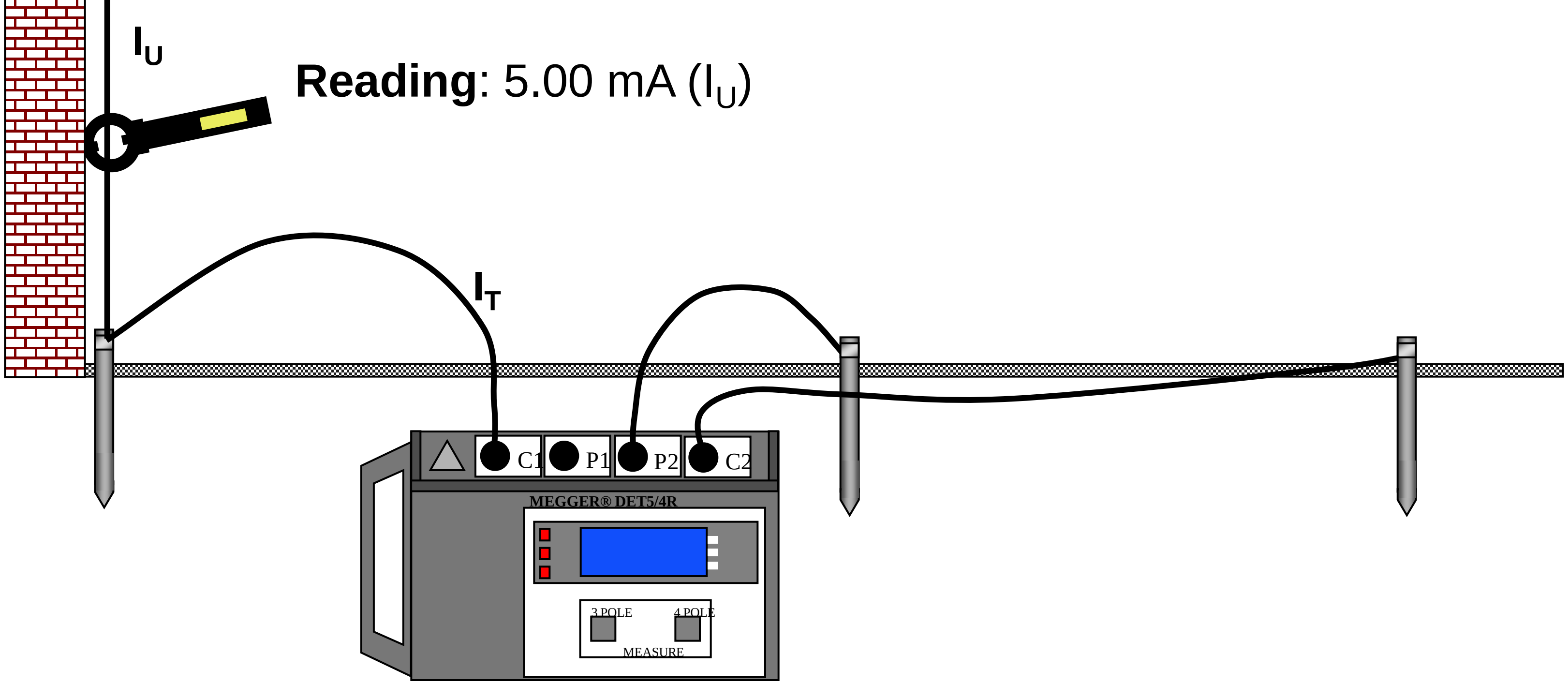
# Attached Rod Technique Theory - Tests

Step#3: Milliammeter clamped over the ground conductor from the service entrance measures current to the service.

**Reading**: 5.00 mA ($I_U$)

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# Attached Rod Technique Theory - Math

- Determine the voltage drop from the selected volume of soil to the point of the P2 probe (from the resistance of the the soil around the ground electrode).

$$V = I_T R_T$$

$$V = 0.009\ A \times 1.9\ \Omega$$

$$V = 0.017\ V$$

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# Attached Rod Technique Theory - Math

- Determine the current through the ground electrode.

$$I_G = I_T - I_U$$

$$I_G = 9.00\text{ mA} - 5.00\text{ mA}$$

$$I_G = 4.00\text{ mA}$$

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# Attached Rod Technique Theory - Math

- Determine the resistance of the ground electrode.

$$R_G = V \div I_G$$

$$R_G = 0.017\ V \div 0.004\ A$$

$$R_G = 4.25\ \Omega$$

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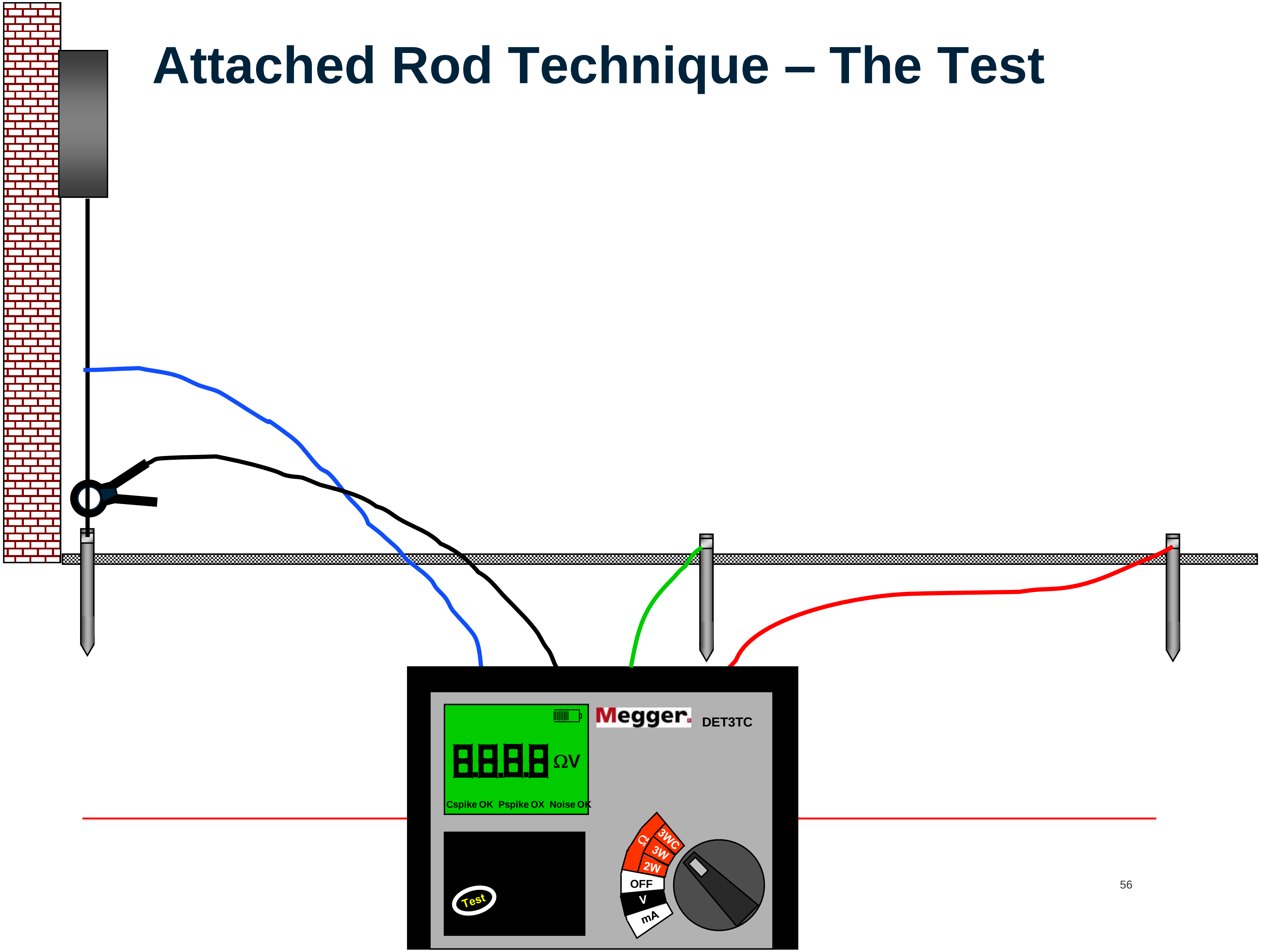
# Attached Rod Technique Theory - Limitations

- Theoretical approach requires perfect conditions.
- Any additional current flowing from the service to the ground rod would reduce the accuracy.
- The milliammeter would have to filter out all but the current generated by the instrument through C1.
- Vulnerable to stray electrical noise.
- Multiple mathematical calculations are required.

# Attached Rod Technique – Special Instrument Design

- Fall of Potential tester.
- Includes an integrated current clamp.
- Includes noise protections.
- Filters out all currents except that produced by the instrument.
- Includes an integrated circuit to make the required calculations.

# Attached Rod Technique – The Test



# Attached Rod Technique - Advantages

- Extremely reliable:
  - Results can be checked by testing at different probe spacings.
- Conforms to IEEE 81; only approved method.
- Operator does not have to disconnect the ground rods to measure them.
- Operator has complete control of the test set-up.
- Can be used to test any size system.
- Highly accurate:
  - 4-wire configuration/no additional loop resistances included.
  - Significant for low resistance (1-2Ω) grounds.

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# Attached Rod Technique – Disadvantages

- Time consuming and labor intensive:
  - Temporary probes must be placed.
  - Cables must be run to make connections.
- Space constraints can make it hard to place remote probes.