EC-002 · MODULE 2 OF 22

Ohm's Law and Basic Circuit Calculations

$V = I \times R$ — applied to shunts, cables, and CP circuits.
The math you'll reach for at every cabinet, test station, and rectifier check.

EXTERNAL CORROSION TRACK   FOUNDATION TIER   ELECTRICAL BASICS FOR CP   ~30 MINUTES

BY THE END OF THIS MODULE

You'll be able to —

- Apply each rearrangement of Ohm's Law to solve for **voltage**, **current**, or **resistance** when the other two are known.
- Read a calibrated shunt by measuring millivolts and converting the reading to amps using the shunt's resistance.
- Calculate **cable IR drop** from current and cable resistance, and reason about its effect on the system's voltage budget.
- Back out a CP system's **total circuit resistance** from rectifier voltage and current readings, and compare it against design.
- Keep units consistent across calculations — base units or matching prefixes — and avoid the most common multi-order-of-magnitude mistakes.

OUT AT A TEST STATION

You open the lid and find this.

A bond cable runs through a calibrated shunt — labeled **0.1 Ω** on its housing — and continues out to a buried set of magnesium anodes wired to the pipeline. The shunt is there for one reason: to let you measure the bond current without breaking the circuit to do it.

You set the meter to **millivolts DC**. Black lead on one end of the shunt, red on the other. The display settles on **25 mV**.

> **The question.** That number isn't current — it's a voltage drop across a known resistance. To turn it into amps, we need the formula that connects all three quantities together.

THE READING

How many amps is that?

25.0 mV

DMM · MV DC · ACROSS 0.1 Ω SHUNT

Knowns: shunt resistance R = 0.1 Ω · meter reading V = 25 mV
Unknown: bond current I (in mA or A — your call)

It's not a guess. It's a calculation.
Three quantities, one equation, three rearrangements.

WHAT WE'LL COVER

From a meter reading to a defensible number — in five moves.

01
The shunt as a measurement tool
Why we measure mV across calibrated low-Ω resistors

02
Ohm's Law — three forms
V = I × R · I = V ÷ R · R = V ÷ I

03
Unit consistency
mV ÷ Ω = mA · the carry-through pattern

04
Four worked examples
Solve for V, I, and R in CP-flavored scenarios

05
Field meaning
What the calculated number tells you about the system

THREE QUANTITIES, ONE MORE TIME

The vocabulary you'll need

You met these in EC-001. We'll keep the introductions brief because **EC-003** unpacks each one in detail — including how each is measured at a real CP test point.

V

VOLTAGE · VOLTS

Electrical pressure

The driving force that pushes current through a circuit. At the rectifier output, between two test station leads, or across a shunt.

I

CURRENT · AMPERES

Rate of charge flow

What does the actual job in CP — current onto the pipe drives the protective electrochemical reaction.

R

RESISTANCE · OHMS (Ω)

Opposition to flow

Lives in the cable, the anode-to-soil interface, the structure-to-electrolyte interface — and by design, in the calibrated shunt.

THE RELATIONSHIP

Three quantities, one equation.

The relationship between voltage, current, and resistance is **Ohm's Law**:

$$V = I \times R$$

Know any two of them and you can solve for the third. That's not a slogan — it's the move you'll make at every cabinet, every test station, every rectifier check from here forward.

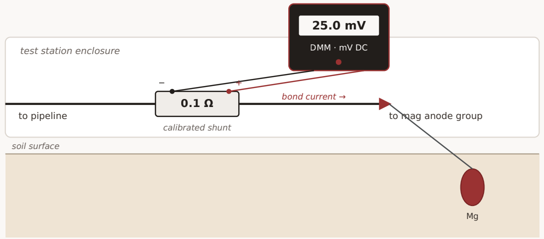
> **Reminder from EC-001:** the *shapes* these three quantities live in (series, parallel, series-parallel) were the subject of the previous module. EC-002 is about the *math* that runs inside those shapes.

SECTION 1 OF 5 · SLIDES 9–13

The shunt — Ohm's Law as a measurement tool.

WHAT A SHUNT DOES

Turn a current measurement into a voltage measurement.



Shunt in a test station bond. Current flows on its normal path; the voltmeter reads the IR drop the shunt makes visible.

WHY WE MEASURE IN MILLIVOLTS

The voltage drops are small — by design.

A shunt is engineered to barely affect the circuit it sits in. Its resistance is small enough that it adds negligible opposition to the current path — but large enough that the voltage drop across it is readable on a meter.

The numbers — a 0.1 Ω shunt at typical test-station currents

1 A through 0.1 Ω → V = 1 × 0.1 = **100 mV**

0.5 A through 0.1 Ω → V = 0.5 × 0.1 = **50 mV**

0.25 A through 0.1 Ω → V = 0.25 × 0.1 = **25 mV**

A meter on the volts scale can't resolve those — they round down to "0 V." Switching to **millivolts** gets you the resolution you need to read the current the shunt was built to measure.

TEST STATION BOND SHUNTS

Sized for the smaller currents in CP test connections.

COMMON · 0.1 Ω

0.1 Ω test-station shunt

0.1 Ω

Galvanic mag-anode bonds, foreign-line bonds, small test connections. Reads cleanly in millivolts at currents from a few mA up to about 1 A.

COMMON · 0.01 Ω

0.01 Ω test-station shunt

0.01 Ω

Larger bond currents — typically 1 A to 10 A — where 0.1 Ω would drop too much voltage. The 10× lower resistance keeps the bond's IR loss negligible.

The move is the same on either: meter on mV across the shunt → divide by the shunt's labeled R → current.

RECTIFIER SHUNTS

Same idea, larger currents — same label format.

RATED · 50 MV = 50 A

"50 mV = 50 A" shunt

0.001 Ω

At its rated current of 50 A, the shunt drops 50 mV. Apply Ohm's Law to the rating: R = 0.050 V ÷ 50 A = 0.001 Ω. Common on impressed-current systems sized at 50 A or below.

RATED · 50 MV = 25 A

"50 mV = 25 A" shunt

0.002 Ω

R = 0.050 V ÷ 25 A = 0.002 Ω. Used on smaller impressed-current rectifiers in the 10–25 A range. Same shunt math, smaller scale.

Rule of thumb on shunt ratings: CP rectifier shunts almost always use the "50 mV = X A" format — 50 mV at the rated full-load current. Divide the rated mV by the rated A to get R in ohms.

SECTION 2 OF 5 · SLIDES 14–18

Ohm's Law — three forms, one relationship.

THE THREE REARRANGEMENTS

Use whichever form lines up with what you know.

FORM 1

$$V = I \times R$$

Use when you know I and R and want V. Cable IR drop calculations live here.

FORM 2

$$I = V \div R$$

Use when you know V and R and want I. Shunt readings live here. Most field calculations live here.

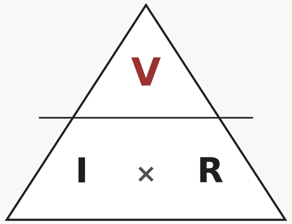
FORM 3

$$R = V \div I$$

Use when you know V and I and want R. Diagnostic work lives here — backing out total circuit R from rectifier readings.

MEMORY AID

The Ohm's Law triangle.



cover the quantity you want · what's left is the operation

Cover V → I × R · Cover I → V over R · Cover R → V over I

However you remember it — triangle, saying, or just "the formula" — the math is the same. Three quantities related by multiplication and division, with the unit relationships baked in.

THE SILENT FAILURE MODE

Unit consistency — the most common Ohm's Law mistake.

The math is simple. The mistakes are almost always about units. Voltages run from microvolts to tens of volts; currents from microamps to tens of amps; resistances from milliohms to thousands of ohms. Mix prefixes carelessly and the answer is off by a factor of 1,000 — and looks plausible enough to act on.

Quantity	Base unit	Common prefixes you'll meet in CP
Voltage	volt (V)	`1 V = 1,000 mV = 1,000,000 µV`
Current	ampere (A)	`1 A = 1,000 mA = 1,000,000 µA`
Resistance	ohm (Ω)	`1 Ω = 1,000 mΩ` · `1 kΩ = 1,000 Ω`

Match your units. *Ohm's Law works in any consistent family — V/A/Ω or mV/mA/mΩ — but it doesn't work mixed. Convert everything into one family before you calculate. Going back to V = I × R in base units is never a bad thing.*

THE MISTAKE TO AVOID

Same numbers. Different units. Three orders of magnitude apart.

✓ RIGHT

Convert to base units first

25 mV → 0.025 V

0.025 V ÷ 0.1 Ω = **0.25 A** (= 250 mA)

Voltage in volts, resistance in ohms, current in amps. Every quantity in the same family. The math is unambiguous and the answer is in matching units.

✗ WRONG

Mixed prefixes

25 µV ÷ 0.1 Ω = ? (µV and Ω don't match)

0.025 V ÷ 100 kΩ = ? (V and kΩ don't match)

If the answer feels three orders of magnitude wrong, the units almost always are. Convert everything to one consistent family before calculating.

SECTION 3 OF 5 · SLIDES 19–28

Four worked examples — V, I, and R in CP-flavored scenarios.

WORKED EXAMPLE A · SOLVE FOR I

The test station shunt — back to the hook.

Shunt R = **0.1 Ω** · meter reading V = **25 mV** · we want the bond current I.

Form 2 of Ohm's Law: I = V ÷ R

```
I = V ÷ R = 25 mV ÷ 0.1 Ω
```

Working in millivolts and ohms, the answer comes out directly in milliamps:

```
I = 250 mA (or 0.25 A)
```

Cross-check in base units: 0.025 V ÷ 0.1 Ω = 0.25 A. Same answer. The math is self-consistent.

Bond current = 250 mA = 0.25 A ✓

FIELD MEANING

What does 250 mA tell you about the system?

A quarter amp of bond current from a small mag-anode group is well within the range you'd expect on a freshly-installed group on a moderately resistive pipeline. **The number alone doesn't say much.** The number plus the design intent does.

If today's reading is 250 mA and the design current is 200–400 mA

System is performing within spec. Log the reading, move to the next station.

If today's reading is 250 mA and 60 days ago this station read 350 mA

Trending downward. Worth watching. Could be soil drying, anode consumption starting, or a connection drift.

If today's reading is 50 mA on a station designed for 250 mA

Underperforming. Anodes likely partially consumed or in soil far drier than design assumed.

If today's reading is 800 mA on a station designed for 250 mA

Higher than expected — could mean unusually wet soil, an additional metallic short to the structure, or coating damage.

SAME CALCULATION · LARGER SCALE

Worked example B
The rectifier shunt

A standard "50 mV = 25 A" rectifier shunt — back out the resistance from the rating, then read the live current with your multimeter.

STEP 1 OF 2

Back out the shunt resistance from its rating.

The rating tells us: at the rated current of 25 A, the shunt drops 50 mV. We want R.

Form 3 of Ohm's Law: R = V ÷ I (applied to the rating itself)

$$R = V_{rated} \div I_{rated} = 50\ mV \div 25\ A$$

Convert to base units to keep the answer clean:

$$R = 0.050\ V \div 25\ A = \mathbf{0.002\ \Omega}$$

The shunt is a **0.002 Ω** resistor — sometimes also written as 2 mΩ. The mV-at-rated-A label is just a friendlier way of expressing the same physical thing.

Shunt resistance = 0.002 Ω = 2 mΩ ✓

STEP 2 OF 2

Read the live current — multimeter shows 40 mV.

Form 2: I = V ÷ R · convert to base units first

```
40 mV → 0.040 V (resistance is already in ohms)
```

```
I = 0.040 V ÷ 0.002 Ω = 20 A
```

Rectifier output current = 20 A · 80% of rated 25 A · in spec ✓

Field-fast sanity check. At 25 A rated, the shunt drops 50 mV. Today it's dropping 40 mV. The ratio: 40 ÷ 50 = 0.8 → so today's current is 0.8 × 25 A = 20 A. The arithmetic agrees with the proportion. This shortcut works on any rated shunt.

MOVE THE UNKNOWN AROUND

Worked example C
Solving for voltage drop

Cable IR drop is the textbook case for solving V = I × R. Every volt the cable eats is a volt that isn't doing work in the soil.

WORKED EXAMPLE C · SOLVE FOR V

How much voltage does a 750-foot header drop at 18 A?

Form 1 of Ohm's Law: V = I × R

Known: cable resistance R = **0.4 Ω** (from a standard sizing table for the gauge and length) · current I = **18 A**.

$$V_{drop} = I \times R = 18\ A \times 0.4\ \Omega = \mathbf{7.2\ V}$$

If the rectifier output is set to 24 V, the junction box at the far end of the cable sees:

$$V_{jct} = 24\ V - 7.2\ V = \mathbf{16.8\ V}$$

Only that 16.8 V is left to push current across the anode-to-soil interface.

Cable IR drop = 7.2 V · Voltage at junction = 16.8 V ✓

Field meaning. The 7.2 V isn't a defect — it's the price of pushing 18 A through 0.4 Ω of conductor. But it's a price you can choose to pay differently: a heavier-gauge cable has lower R, which means lower IR drop, which means more volts available where they actually do work. **Cable sizing is a voltage-budget decision dressed up as a hardware decision.**

THE DIAGNOSTIC REARRANGEMENT

Worked example D Solving for resistance

R = V ÷ I gives a single number that summarizes the whole circuit. Compare today's R to design R and the system tells you whether it's still operating where the design intended.

WORKED EXAMPLE D · SOLVE FOR R

Total circuit R from a rectifier reading.

At the cabinet with your multimeter: output voltage at the terminals = **22 V**, and the shunt reading converts to **12 A** of output current. What total resistance is the rectifier seeing across its output terminals — cable, connections, anode array, soil, and structure return all summed?

Form 3: R = V ÷ I

R_{total} = 22 V ÷ 12 A ≈ **1.83 Ω**

If commissioning had R_{total} = 1.5 Ω, today's system is running 0.33 Ω higher than designed.

R_{total} = 1.83 Ω · ΔR vs design = +0.33 Ω ✓

Where the extra R could be

Anode consumption raises parallel-array R. Drier soil increases anode-to-soil contact. Loose lugs or oxidized splices add series R. Cable damage is rarer but possible.

What the diagnostic does

The single ΔR doesn't say which cause it is. It tells you to go look — and gives you a defensible reason to.

MULTI-STEP CALCULATION CROSS-CHECK

Use what EC-001 already taught — to verify, not re-derive.

EC-001 named two rules tied to the shapes themselves. They aren't new theory in EC-002 — they're the right tools to **check** a multi-step Ohm's Law answer.

FROM EC-001 · SERIES

Kirchhoff's Voltage Law (KVL)

$$\Sigma V_{source} = \Sigma V_{drop}$$

In any closed loop, the source voltages equal the sum of voltage drops across the elements. Use it to check that a chain of cable + connection + anode IR drops adds up to the rectifier output.

FROM EC-001 · PARALLEL

Kirchhoff's Current Law (KCL)

$$\Sigma I_{in} = \Sigma I_{out}$$

At any junction, current in equals current out. Use it to check that branch currents in an anode array add back to the total current at the junction.

If the two numbers don't agree to within a small rounding error, the math broke somewhere — usually a missed unit conversion or a wrong rearrangement. Treat KVL and KCL as the sanity check that runs after the calculation.

CLOSING THE LOOP

Back at the test station.

Shunt 0.1 Ω · meter on mV · reading 25 mV. We ran **I = V ÷ R = 25 ÷ 0.1 = 250 mA**. That's the bond current — the magnesium anodes are putting a quarter amp of protective current onto the pipeline.

That number is what you came for. But what you do with it depends on knowing what to compare it to. **Two questions are worth running every time:**

1. Is the current within the expected range for this anode group, this pipeline, this soil?

A quarter amp from three 32-pound magnesium anodes in moderately moist clay is reasonable. From three 17-pound zinc anodes in dry sand-and-gravel, it's generous. Same number, different stories.

2. How does it compare to the last reading from this station?

250 mA today after 300 mA two months ago is trending — slowly enough that no alarm is warranted, but worth watching. 50 mA today after 300 mA in the spring is something else entirely.

The math gives you a number you can defend. The interpretation is in how that number sits inside the system you're responsible for.

KEY TAKEAWAYS

What you can do now.

- **Ohm's Law connects V, I, R** — V = I × R. Three quantities, three rearrangements. Use whichever lines up with what you know.
- **Shunts turn current measurement into voltage measurement.** Calibrated low-Ω resistor in series · meter on mV across it · I = V ÷ R_{shunt}.
- **Test-station shunts** are typically 0.1 Ω or 0.01 Ω. **Rectifier shunts** are typically 0.001 Ω or 0.01 Ω, often labeled mV-at-A.
- **Unit consistency is the most common failure mode.** Convert to base units before calculating, or stay in matching prefixes throughout. `mV ÷ Ω = mA`.
- **Solve for V (V = IR)** — cable IR drop is the standard case.
- **Solve for I (I = V ÷ R)** — shunt readings, most field calculations live here.
- **Solve for R (R = V ÷ I)** — diagnostic work, comparing today's R against design R.
- **KVL and KCL (from EC-001)** are cross-checks for multi-step calculations — not new theory in EC-002.

WHERE THIS COMES FROM

References & further reading

- **AMPP CP 1 Cathodic Protection Tester Course Manual** — basic electricity foundations including Ohm's Law and resistivity for CP technicians.
- **AUCSC Basic Course** — companion treatment with utility-side examples for CP work.
- **Peabody's Control of Pipeline Corrosion** — A.W. Peabody. CP-specific application of Ohm's Law with practical worked examples.
- **AMPP CP 2 Cathodic Protection Technician Course Manual** — extended CP-1 treatment covering rectifier sizing and ground bed design.
- **Corrosion Basics: An Introduction** — broad textbook context for Ohm's Law in CP design.
- **Corrosion Engineer's Reference Book** — Robert Baboian, ed. General electrical reference covering material resistivities and conductor properties.

UP NEXT IN THIS RUNG

EC-003 — Voltage, Current, and Resistance in DC Systems

The roles of V, I, and R in cathodic protection circuits, including how each one is measured at a real CP test point and what each measurement is actually telling you.