

FUNDAMENTALS OF AI-AUGMENTED ENGINEERING

CHAPTER 8 / LAB-8: Engineering Lab (165 Minutes)

Linear Systems and Matrix-Based Engineering Computation

Breadboard resistor network · Kirchhoff's Current Law · $A \backslash b$ · residuals · validation

Predict every node voltage with a matrix — then let the real circuit answer.

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Authors

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Problem

>

Model

>

Compute

>

Analyze

>

Validate

>

Improve

The engineering workflow you will use throughout this book



From matrix predictions to physical evidence

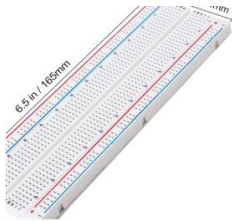
Can a matrix model, built from Ohm's law and conservation of current, predict the voltages of a real circuit?

- Build one resistor network on a breadboard and grow it in stages: a divider (Stage A), two unknown nodes (Stage B), three unknown nodes (Stage C).
- At every stage: measure the real component values, **predict** the node voltages with your matrix model, **then** measure them.
- Solve with MATLAB $A \setminus b$ and check the numerical residual — then test the model against the measurements.
- When prediction and measurement disagree, decide with evidence: modelling error, wiring mistake, component variation, or measurement uncertainty?
- Your job is not to make the numbers match. Your job is to predict, measure, compare, and explain.

AstroAI DM130B
multimeter + leads



830-point
breadboard



power module
(5 V / 3.3 V)



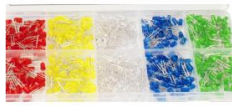
pre-cut jumper wires



1 % metal-film
resistors (kit)



5 mm LEDs
(Stage 0 only)



9 V battery +
clip with
barrel plug
(not pictured)

laptop with
MATLAB
(≥ 1 per
station)

Your station kit (manufacturer product images). 9 V battery supplied separately.

PREDICT › BUILD › MEASURE › MODEL › COMPARE › INVESTIGATE

Problem

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Learning objectives & tools

BY THE END OF THIS LAB, YOU CAN

- Measure resistance, supply voltage and node voltages correctly with a digital multimeter
- Build a circuit on a breadboard from a schematic and verify it against a connection list
- Derive 2×2 and 3×3 nodal systems from KCL and Ohm's law, with MEASURED component values
- Solve and verify the system in MATLAB: $V = A \backslash b$ and $r_num = A * V - b$
- Test the model against measurements (dV, r_meas) and investigate differences with evidence
- Use AI to help write or debug code — and independently verify what it produces

TOOLS YOU WILL USE

- 830-point breadboard + power module (5 V)
- 9 V battery + clip
- AstroAI DM130B multimeter, leads + alligator clips
- 1 % resistors R1–R6 (+ 1 k Ω and an LED for Stage 0)
- MATLAB — your pre-lab script
- Lab8_Report_Template_Final.docx
- Your engineering judgment

THE MODEL PREDICTS. THE CIRCUIT ANSWERS. YOU EXPLAIN THE DIFFERENCE.

Problem



Model



Compute



Analyze



Validate

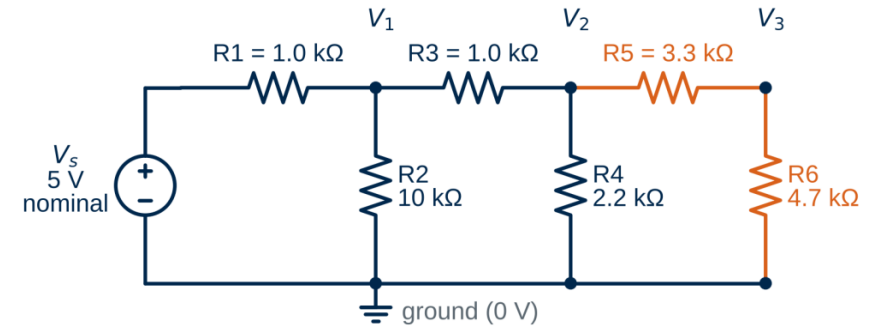


Improve



What you will do — step by step

- 1 **BEFORE LAB** — derive the KCL equations · write and self-test your MATLAB script · commit predictions
- 2 **STAGE 0** — seat the power module · LED rail check · meter check
- 3 **MEASURE** — every resistor, out of the board, power OFF — before it is installed
- 4 **STAGE A** — voltage divider: measure $V_s \rightarrow$ predict $V_1 \rightarrow$ measure V_1
- 5 **STAGE B** — add R_3, R_4 : two unknown nodes · 2×2 model · $A \backslash b$ · compare
- 6 **STAGE C** — add R_5, R_6 : three unknown nodes · 3×3 model · compare
- 7 **EVIDENCE** — residuals · sensitivity probe · investigate any real discrepancy
- 8 **SIGN-OFF** — TA check · photo · every member copies the data · power down
- 9 **REPORT** — one group report with contribution and AI-use records
- 10 **EXTENSION** — optional, individual, computational: Stage D — the bridging resistor



The complete Stage C circuit — built one stage at a time.

Would you trust a matrix that MATLAB solved perfectly for a circuit nobody measured? Today you will decide — after the circuit has had its say.

Problem

Model

Compute

Analyze

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Improve



Pre-lab — do the mathematics before you arrive

P1 · THINK

- Derive the KCL equation at every unknown node for Stage B (V_1, V_2) and Stage C (V_1, V_2, V_3).
- Collect terms into $Ax = b$, symbolically in $G_1 \dots G_6$ and V_s .
- Check: A symmetric? Diagonal = sum of conductances at the node?

P2 · PSEUDOCODE › AI › CODE

- Write 6–10 lines of pseudocode first.
- Turn it into MATLAB from the starter framework. AI may help — from YOUR pseudocode.
- Record your prompt. Explain every line.

P3 · SELF-TEST

- Run your script on the Chapter 8 lecture circuits (next slides).
- If it fails, the error is in the code or the equations — not in the circuit.
- Fix it BEFORE lab.

THE PRE-LAB IS INDIVIDUAL AND DUE AT THE START OF THE SESSION. The TA initials it before Stage 0.

Problem ›

Model ›

Compute ›

Analyze ›

Validate ›

Improve



One rule at every unknown node

At each unknown node, the currents defined as **leaving** the node add up to zero. Current through a resistor = (voltage difference) / R = (voltage difference) · G.

Stage A — worked example (1 × 1): $(V1 - Vs) \cdot G1 + V1 \cdot G2 = 0 \rightarrow (G1 + G2) \cdot V1 = G1 \cdot Vs$

$A = [G1 + G2] \text{ (mS)} \cdot x = [V1] \text{ (V)} \cdot b = [G1 \cdot Vs] \text{ (mA)} \rightarrow V1 = Vs \cdot R2 / (R1 + R2)$, the voltage-divider formula

UNITS THAT WORK TOGETHER

- Voltage in **V** · resistance in **kΩ** · conductance $G = 1/R$ in **mS** · current in **mA**
- $k\Omega \times mA = V$ $mS \times V = mA$
- One value typed in ohms (2200 instead of 2.2) silently builds a different circuit.

WHAT TO CHECK IN YOUR MATRIX

- Diagonal entry = sum of all conductances touching that node
- Off-diagonal entry = – (conductance joining two unknown nodes directly)
- Zero entry = no resistor joins those two nodes directly. Stages B and C: you derive them.

 **TALK TO YOUR AI TEAMMATE** "Check my KCL signs at V2 — do not write A."

 **ENGINEER DECIDES** you can derive every entry of your A.

Problem

**Model**

Compute



Analyze



Validate



Improve



Test the code on circuits you already understand

SELF-TEST — CHAPTER 8 LECTURE CIRCUITS

- All resistors 1 k Ω , $V_s = 5$ V:
- **Two-node network (R1–R4):** $V_1 = 2.000$ V, $V_2 = 1.000$ V
- **Three-node network (R1–R6):** $V_1 \approx 1.9231$ V, $V_2 \approx 0.7692$ V, $V_3 \approx 0.3846$ V (25/13, 10/13, 5/13 V)
- **Numerical residual r_{num} :** every entry about 1e-15 mA or smaller
- Your group compares scripts at the station and uses one that passes.
- **Optional — Gauss-Jordan Stepper**
(lab.aifirstengineering.org/numerical-methods/gauss-jordan): enter A and b in Fractions mode; the 3-node case returns exactly 25/13, 10/13, 5/13 V. Different method, same answer.

COMMIT YOUR PREDICTIONS — BEFORE COMPUTING

- **Q1.** In Stage A, V_1 is a divider output. When R3 and R4 are added (Stage B), will V_1 rise, fall, or stay the same? Why?
- **Q2.** When R5 and R6 are added (Stage C), which changes more, V_1 or V_2 — and in which direction? Why?
- Then run your script with the NOMINAL values for Stages A, B, C and record the nominal predictions.
- Do not change Q1 or Q2 afterwards.

A PREDICTION MADE AFTER THE MEASUREMENT IS NOT A PREDICTION. Record it first — keep it even if it turns out wrong.

Problem



Model



Compute



Analyze



Validate



Improve



Measure first — then predict, measure, compare

0:00–0:10		Readiness — kit out, roles assigned, TA checks every pre-lab Pre-lab initialled · group chooses a script that passes the self-test.
0:10–0:25		Stage 0 · STATION CHECK — module, LED rail check, meter LED lit · positive Vs reading · meter set up correctly.
0:25–0:40		MEASURE — all six resistors, power OFF, out of the board Every digit recorded · $\pm 1\%$ band check · parking card.
0:40–0:55		Stage A · DIVIDER — measure Vs → predict → measure First prediction-before-measurement on real hardware.
0:55–1:25		Stage B · TWO NODES — add R3, R4 · 2 × 2 model · A/b Measured inputs in MATLAB · r_num · measure V1, V2 · r_meas.
1:25–1:55		Stage C · THREE NODES — add R5, R6 · 3 × 3 model Predict first · measure V1, V2, V3 · photo of the board.
1:55–2:20		EVIDENCE — sensitivity probe · investigate Agreement or discrepancy — the evidence decides the path.
2:20–2:35		SIGN-OFF — TA check · data copied · power down Every member leaves with the group's measured data.
2:35–2:45		Buffer · start the optional extension Extension is individual and computational — no equipment.





Group roles — everyone builds, measures and models

BUILDER

Places components with the power OFF, following the figure for that stage.

VERIFIER / RECORDER

Traces every connection against the connection list BEFORE power is switched on. Records predictions and measurements in the report template as they happen.

METER OPERATOR

Sets the meter, clips the black lead, takes every reading, reads all digits aloud.

MODELER

Enters measured values in MATLAB, runs the model, reports predictions BEFORE the node voltages are measured.

	Stage A	Stage B	Stage C	Evidence
Student 1	Builder	Modeler	Meter operator	Verifier / Recorder
Student 2	Meter operator	Builder	Modeler	Modeler
Student 3	Modeler	Verifier / Recorder	Builder	Meter operator
Student 4	Verifier / Recorder	Meter operator	Verifier / Recorder	Builder (re-checks)



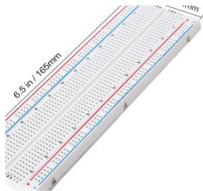


Your station — what each item is for

AstroAI DM130B
multimeter + leads



830-point
breadboard



power module
(5 V / 3.3 V)



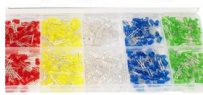
pre-cut jumper wires



1 % metal-film
resistors (kit)



5 mm LEDs
(Stage 0 only)



9 V battery +
clip with
barrel plug
(not pictured)

laptop with
MATLAB
(≥ 1 per
station)

AT EVERY STATION

- 830-point breadboard
- Power module (5 V)
- 9 V battery + clip
- DM130B multimeter + leads
- Alligator-clip tips
- R1–R6
- Extra 1 k Ω + one LED (Stage 0 only)
- Short red and black jumpers

WHY THESE ITEMS

- The module turns the 9 V battery into a regulated 5 V supply.
- The breadboard makes every connection without solder — and every mistake reversible.
- The meter gives the evidence: R, V_s and every node voltage.

Manufacturer product images of the items purchased for this lab.
The 9 V battery and clip are supplied separately.

ONE BOARD FOR THE WHOLE LAB. Stage A $\rightarrow$ B $\rightarrow$ C is cumulative: never dismantle a working stage.

Problem



Model



Compute



Analyze



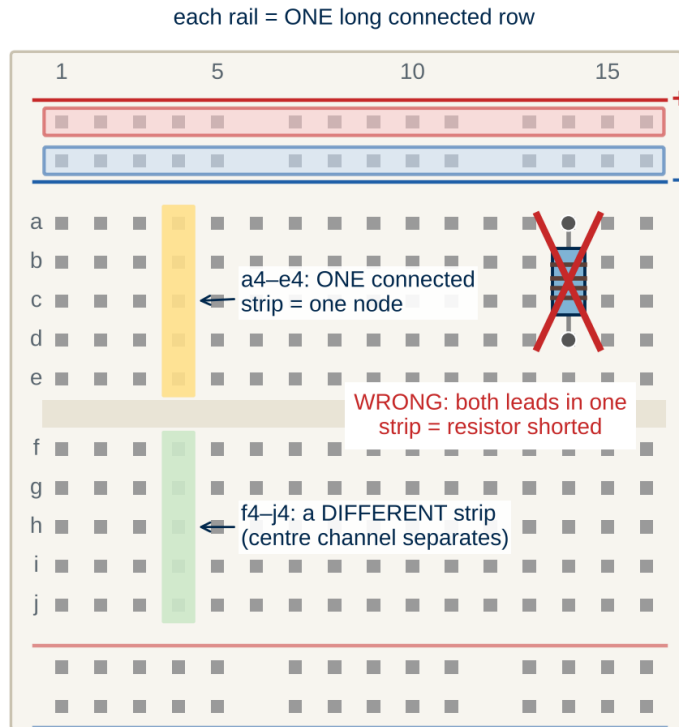
Validate



Improve



The breadboard — one strip is one node



BREADBOARD CONNECTIVITY

- Holes a–e in the same numbered column are connected: **one strip = one electrical node.**
- Holes f–j form a **different** strip — the centre channel separates the halves. Lab 8 uses only a–e.
- Each rail runs along the board: the red-line rail is + (**Vs**), the blue-line rail is – (**ground**).
- Some boards break the rails partway along. Lab 8 uses only columns 1–44, next to the module; Stage 0 confirms the rails are live.
- Both leads of a resistor in the same strip = the resistor is shorted and does nothing.

CHECKPOINT — trace each strip with your finger and name its node before the power goes on.

Problem

Model

Compute

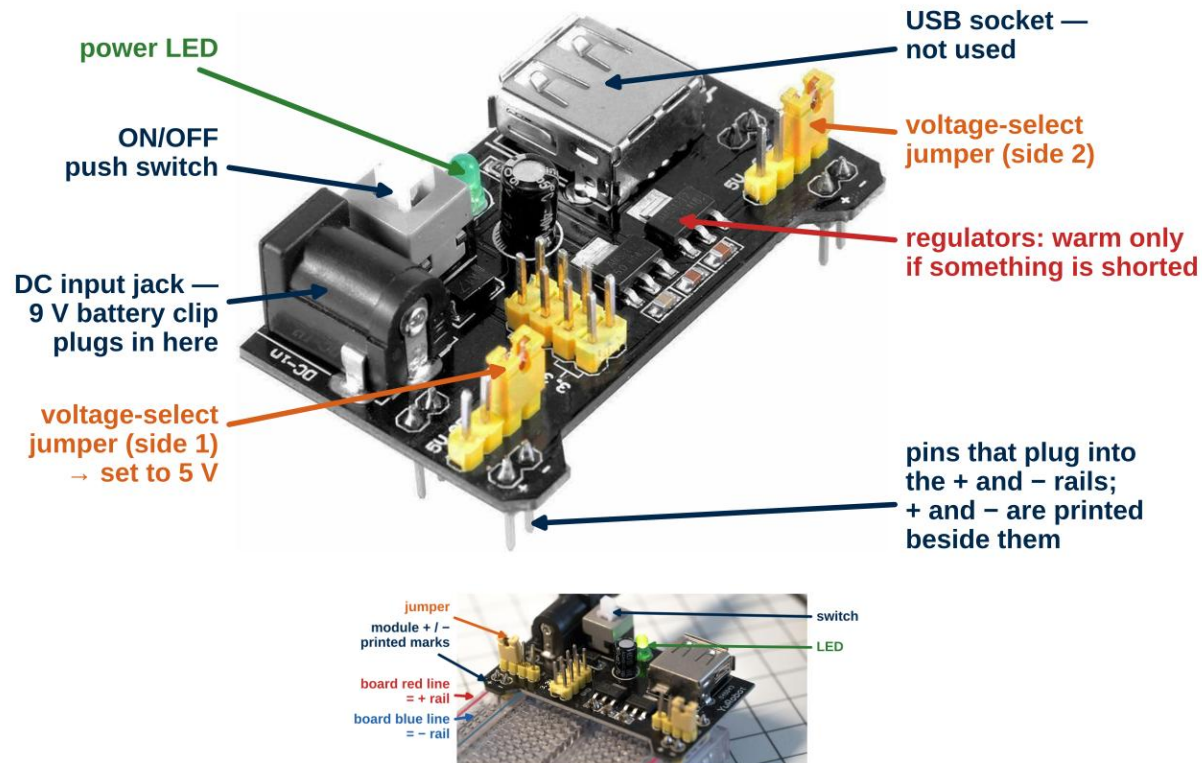
Analyze

Validate

Improve



The power module — a regulated 5 V supply



SET IT UP — POWER OFF

- Seat the module at the **column-1 end** so each pair of pins enters a rail pair.
- The module's + pin must enter the **red-line** rail — Stage 0 checks this with the meter.
- Set the voltage-select jumper on the side you use to **5 V**.
- Clip the 9 V battery to its barrel plug and plug it into the DC input jack. Leave the switch OFF.
- Regulators should never be warm. Warm = short: switch OFF, unclip the battery, call the TA.

REGULATED 5 V ONLY. Never connect the 9 V battery directly to the breadboard.

Problem

Model

Compute

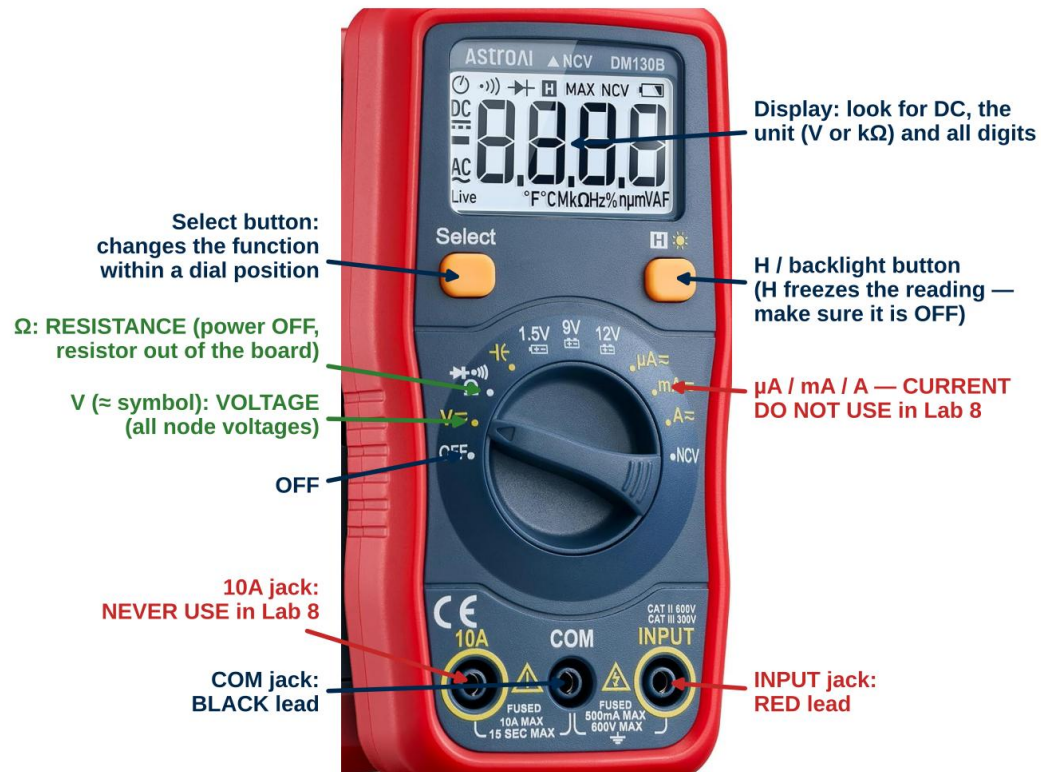
Analyze

Validate

Improve



The multimeter — V and Ω only



USING THE METER

- **Leads:** black in **COM**, red in **INPUT** — for every measurement in this lab.
- **Voltage:** dial to **V**. Check that DC and V appear on the display; if AC appears, press **Select**.
- **Resistance:** dial to **Ω** . The display must show Ω or k Ω ; if a diode or beep symbol shows, press **Select**.
- **H** freezes the display — make sure it is off. Record **every digit** and the unit.
- Never use μ A, mA or A, and never the 10A jack.

NODE VOLTAGE = black probe on ground (– rail), red probe on that node's strip — the Chapter 8 reference.

Problem

Model

Compute

Analyze

Validate

Improve



Low voltage — but real hazards and real mistakes

BEFORE THE POWER GOES ON

- **Power OFF** (module switch) before inserting, removing or moving any wire or component.
- The Verifier checks that **no bare lead touches both rails** — a + to – short heats the regulator and battery.
- Use only the module's regulated output.
- Measure resistance only with the resistor **out of the board** and the power OFF.

IF SOMETHING IS WRONG

- Anything **warm**, a smell, or the module LED going out unexpectedly: switch OFF, unclip the battery, call the TA. Do not touch the regulator.
- Meter on **V** and **Ω** only. Leads in **COM** and **INPUT** — never the 10A jack.
- Unclip the battery whenever the station is idle, and at the end of the session.

POWER OFF BEFORE EVERY CHANGE. Verifier checks · then power ON · then measure.

Problem

**Model**

Compute



Analyze



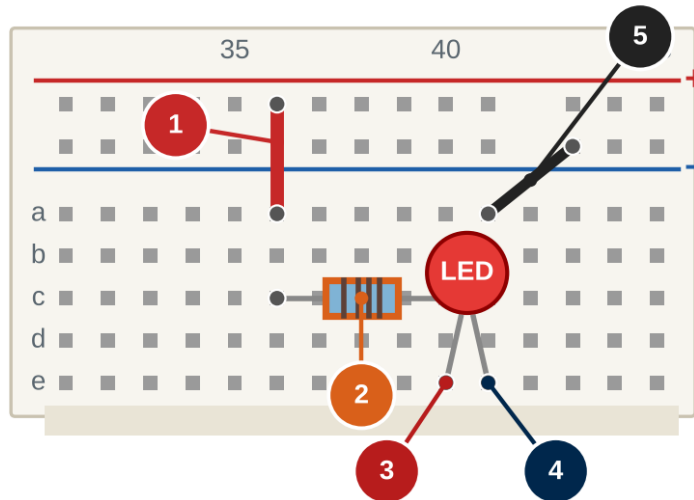
Validate



Improve



Prove the rails are live — before you trust any reading



← power module is at column 1 (off to the left)

- 1 red jumper + → a36
- 2 extra 1 kΩ c36 → c40
- 3 LED long leg (+) e40
- 4 short leg (-) e41
- 5 black jumper a41 → - rail

SEAT + SET

1

Kit check · module at column 1 · jumper at 5 V · battery clipped · switch OFF.

BUILD THE LED CHECK (POWER OFF)

2

Red jumper + → a36 · 1 kΩ c36 → c40 · LED long leg e40, short leg e41 · black jumper a41 → -.

POWER ON — LED LIGHTS?

3

Verifier checks first. A lit LED: the rails are live and the polarity is right.

METER CHECK → Vs (STAGE 0)

4

Dial V. Black clip on the LED's short leg; red tip on the 1 kΩ lead in strip 36. Then switch OFF and remove all four parts.

CHECKPOINT — LED lit and a POSITIVE reading of about 5 V before Stage A.

Problem

Model

Compute

Analyze

Validate

Improve



What the Stage 0 readings mean

What you see	Most likely meaning	What to do
LED lit, meter reads about +5 V	Rails live, polarity correct	Continue
Meter reads a negative voltage	+ and – rails are the reverse of the printed lines	Switch OFF; call the TA
Meter reads about 3.3 V	Voltage-select jumper not at 5 V	Switch OFF; move the jumper; re-check
LED dark, meter reads about 0 V	Switch off, battery flat, clip loose, or wrong rail	Check each; ask the TA
LED dark, meter reads about 5 V	LED reversed, or a lead not in its strip	Switch OFF; re-seat the LED

 **TALK TO YOUR AI TEAMMATE** "My Stage 0 reading is –4.9 V. Why?"

 **ENGINEER DECIDES** the TA approves the station before Stage A.

Problem



Model



Compute

**Analyze**

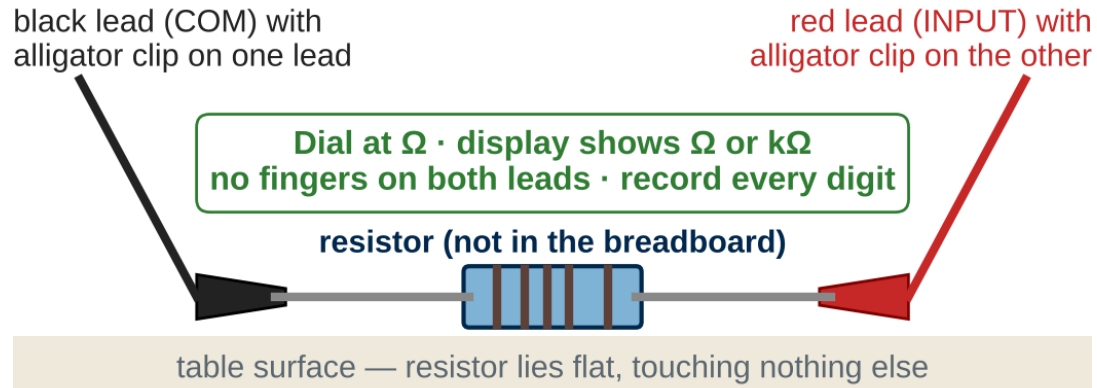
Validate



Improve



Measure every resistor first — out of the breadboard



WHY NOT IN THE CIRCUIT?

Once a resistor is in the board, the meter also measures every other path between its leads — for R2 in the finished circuit it would read far below 10 k Ω .

1 IDENTIFY

Colour bands → nominal value. Then CONFIRM with the meter.

2 CLIP + READ

Resistor on the table, one lead in each clip, no fingers. Every digit, in k Ω .

3 BAND CHECK

Nominal $\pm 1\%$? Far outside = wrong resistor: swap it and re-measure.

4 PARK IT

Place it on the parking card (R1–R6) so the parts cannot be mixed up.

MEASURED, NOT NOMINAL. Every model you run today uses the meter's values, not the colour code.

Problem

Model

Compute

Analyze

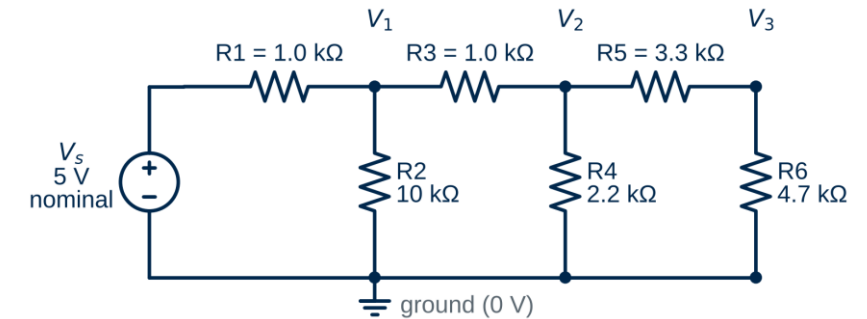
Validate

Improve



One connection list for the whole lab

Element	Connected between	Nominal	Breadboard	Stage
Vs	+ rail and Vs strip	5 V	red jumper + $\rightarrow$ a4	A
R1	Vs strip and node V1	1.0 k Ω	c4 $\rightarrow$ c10	A
R2	node V1 and ground	10 k Ω	a10 $\rightarrow$ - rail	A
R3	node V1 and node V2	1.0 k Ω	d10 $\rightarrow$ d17	B
R4	node V2 and ground	2.2 k Ω	a17 $\rightarrow$ - rail	B
R5	node V2 and node V3	3.3 k Ω	c17 $\rightarrow$ c24	C
R6	node V3 and ground	4.7 k Ω	a24 $\rightarrow$ - rail	C



Nominal values are design labels. The model always uses your MEASURED resistances and your MEASURED Vs.

NODES: Vs strip = column 4 · V1 = column 10 · V2 = column 17 · V3 = column 24 · ground = - rail

Problem

Model

Compute

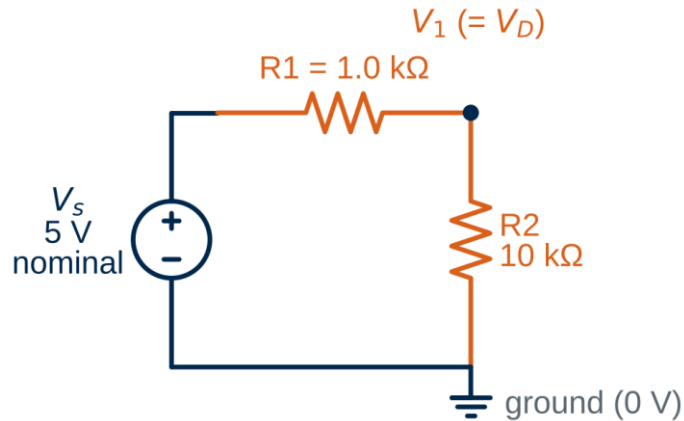
Analyze

Validate

Improve

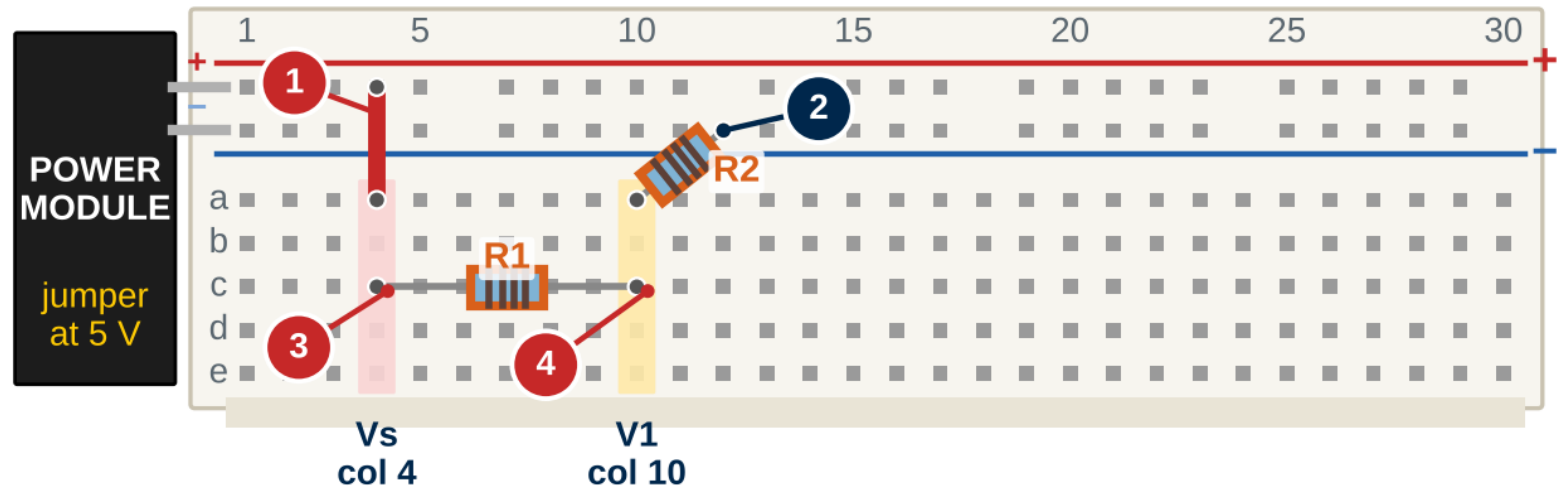


Stage A — build the voltage divider



BUILD — POWER OFF

- Red jumper + → a4
- R1: c4 → c10
- R2: a10 → - rail



1 red jumper + → a4 (makes column 4 the V_s strip) · 2 BLACK clip on R2's lead where it enters the - rail (ground)
 3 RED tip on R1's lead in the V_s strip → V_s · 4 RED tip on a lead in the V_1 strip → V_1

VERIFIER FIRST. Trace both resistors against the connection list, then power ON.

Problem

Model

Compute

Analyze

Validate

Improve



Measure Vs, predict V1 — then measure V1

MEASURE Vs (A)

1 Power ON. Black clip on ground; red tip on R1's lead in the Vs strip (column 4).

PREDICT V1

2 $V1 = V_s \cdot R2 / (R1 + R2)$ with MEASURED Vs, R1, R2. Record it BEFORE the next step.

MEASURE V1

3 Red tip on a lead in the V1 strip (column 10). Record every digit.

COMPARE

4 $dV = V_{\text{meas}} - V_{\text{pred}}$. Then switch OFF and leave R1 and R2 exactly where they are.

QUICK CHECK

Is your dV a few millivolts — or hundreds?

Decide now whether your build is trustworthy. A Stage A problem carries into every later stage.

If $|dV|$ is large, use the troubleshooting ladder before adding anything.

✓ **ENGINEER DECIDES** the prediction is written down before the meter touches V1.

Problem



Model



Compute



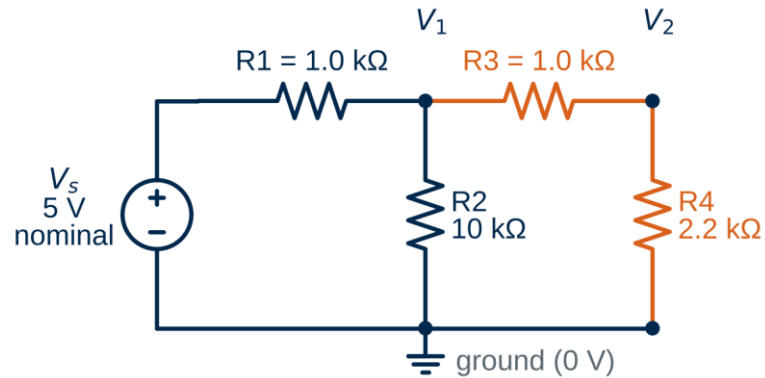
Analyze

**Validate**

Improve

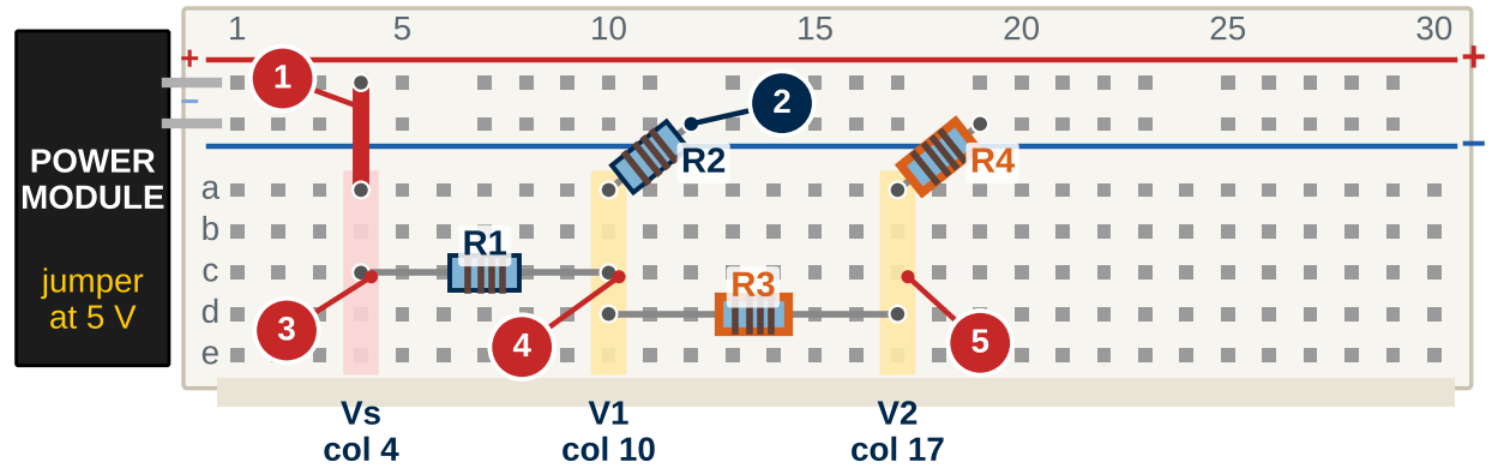


Stage B — add R3 and R4



BUILD — POWER OFF

- R3: d10 → d17
- R4: a17 → - rail
- Do not move R1 or R2



Callouts 1–4 as in Stage A · 5 RED tip on a lead in the V2 strip (column 17) → V2

Measure Vs (B) just before the node voltages — the battery can sag slowly.

CUMULATIVE BUILD. Stage A stays in place; only the orange parts are new.

Problem

Model

Compute

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Build A and b from KCL — then solve with $A \backslash b$

```
% Lab 8 - Stage B model (two unknown node voltages)
% Units: R in kOhm, G in mS, V in V, current in mA
Vs = ____; % measured, this stage
R1 = ____; R2 = ____; R3 = ____; R4 = ____; % measured
G1 = 1/R1; G2 = 1/R2; G3 = 1/R3; G4 = 1/R4;

% one row per node: currents LEAVING sum to zero
A = [ ____ , ____ ;
      ____ , ____ ]; % mS
b = [ ____ ; ____ ]; % mA

V_pred = A\b % predicted [V1; V2]
r_num = A*V_pred - b % numerical residual
V_meas = [ ____ ; ____ ]; % after measuring
dV = V_meas - V_pred
r_meas = A*V_meas - b
```

IN THIS ORDER

- Modeler enters **Vs (B)** and **measured R1–R4**, runs the script.
- Record V_{pred} and r_{num} **before** any node voltage is measured.
- Compare with your pre-lab **Q1**: did V1 move as predicted?
- Measure V1 and V2. Enter V_{meas} ; record dV and r_{meas} .
- Solve with $A \backslash b$ — never $\text{inv}(A) * b$.

TALK TO YOUR AI TEAMMATE "Why must b be a column? Do not fill in A."

ENGINEER DECIDES every entry of A matches your own KCL.

Problem



Model

**Compute**

Analyze



Validate



Improve



Two residuals — two different questions

$$r_num = A \cdot V_pred - b$$

- Checks the **computation**: does MATLAB's answer satisfy the equations you typed?
- Should be about 1e-15 mA.
- Says **nothing** about the real circuit.

$$r_meas = A \cdot V_meas - b$$

- Puts the **measured** voltages into the same equations.
- Each entry is a current (mA) at one node: how far the measurements are from the model's balance.
- $r_meas = r_num + A \cdot dV \approx A \cdot dV$

WHAT IT DOES NOT MEAN

- A nonzero r_meas is **not** a failure of KCL — charge is conserved in the real circuit.
- It means the model, its measured inputs and the measurements do not agree exactly.
- Your job: explained by uncertainty — or a real problem?

A SMALL RESIDUAL IS NOT EXPERIMENTAL VALIDATION. r_num verifies arithmetic; only the measurements can test the model of THIS circuit.

 **TALK TO YOUR AI TEAMMATE** "Quiz me on what r_meas means."

 **ENGINEER DECIDES** you decide what the difference means.

Problem



Model



Compute



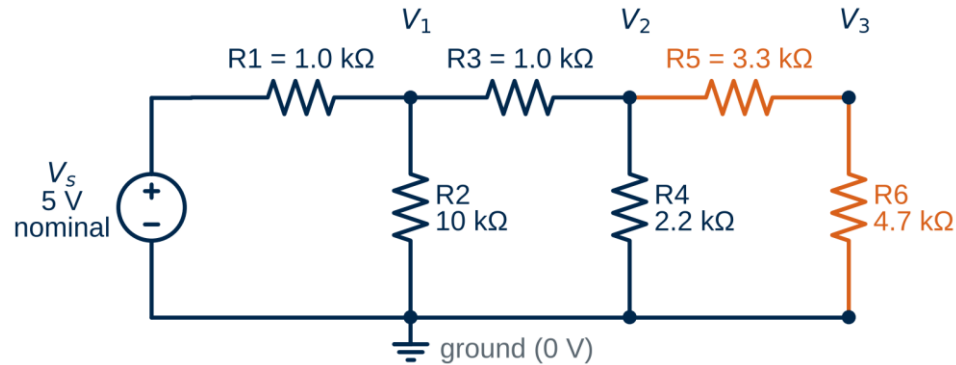
Analyze

**Validate**

Improve

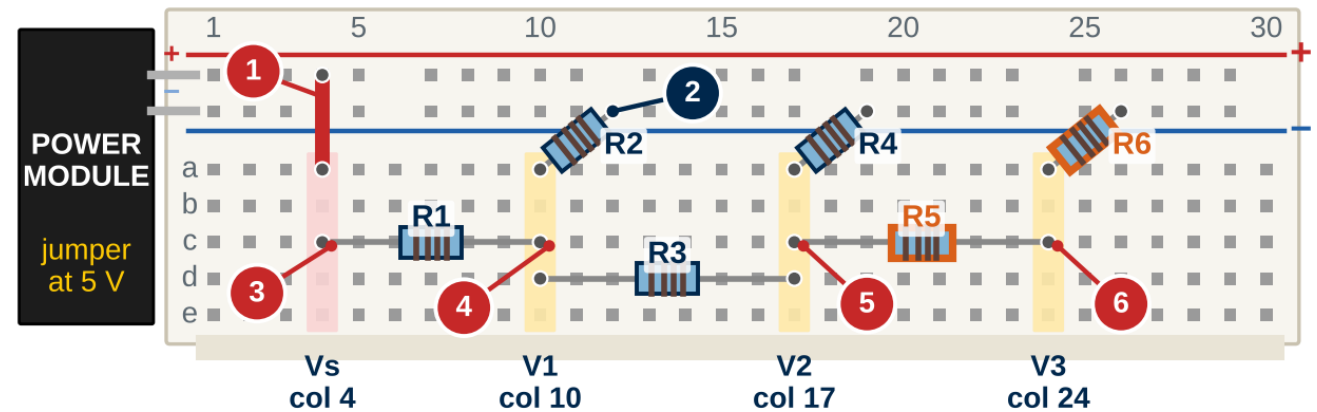


Stage C — add R5 and R6: predict first



PREDICT FIRST — GROUP, 2 MIN

Look back at pre-lab Q2. Which of V1 and V2 will change more when R5 and R6 are added — and in which direction? Record it before building.



Callouts 1–5 as before · 6 RED tip on a lead in the V3 strip (column 24) → V3

BUILD — POWER OFF

R5: c17 → c24 · R6: a24 → – rail · Verifier check · then measure Vs (C)

PHOTO — photograph the finished board with the Vs, V1, V2, V3 strips labelled.

Problem

Model

Compute

Analyze

Validate

Improve



Three unknowns — the matrix grows

```
% Lab 8 - Stage C model (three unknowns)
Vs = ____; % measured
R = [ ____ ____ ____ ____ ];
G = 1./R; % mS
A = [ ____ , ____ , ____ ;
      ____ , ____ , ____ ;
      ____ , ____ , ____ ]; % mS
b = [ ____ ; ____ ; ____ ]; % mA
V_pred = A\b
r_num = A*V_pred - b
V_meas = [ ____ ; ____ ; ____ ];
dV = V_meas - V_pred
r_meas = A*V_meas - b
```

ANSWER IN THE REPORT

- Measure V1, V2, V3; record dV and r_meas.
- **Coupling:** compare Stage C with Stage B. Which changed more, V1 or V2? Was the prediction right?
- **Structure:** why are entries (1,3) and (3,1) of A zero — while V3 still depends on V1?
- Keep the circuit until the evidence section is done.



TALK TO YOUR AI TEAMMATE "Is my 3×3 A symmetric? Show me where not."



ENGINEER DECIDES a zero in A is a statement about the wiring.

Problem



Model



Compute



Analyze



Validate



Improve



How big is "big"? — a sensitivity probe

There is **no universal pass/fail tolerance** in this lab. Find out how much your prediction moves when one input changes by a small, realistic amount.

ONE INPUT +1 %

- 1 In MATLAB, $R4 = 1.01 \cdot R4$ (for example). Re-solve Stage C; record each ΔV in mV. Restore. Repeat for R1–R6.

ONE DISPLAY DIGIT ON Vs

- 2 Change Vs by one step of its last displayed digit; record the effect.

COMPARE

- 3 Set these changes beside your measured dV and the meter's last digit.

THEN DECIDE

- Which input does each node depend on most?
- Is your largest $|dV|$ comparable to what realistic input uncertainties produce — or clearly larger?
- That answer chooses your path (next slide).

 **TALK TO YOUR AI TEAMMATE** "Loop over R1–R6 at +1 % — I will test it."

 **ENGINEER DECIDES** the comparison scale comes from your own model.

Problem



Model



Compute

**Analyze**

Validate



Improve



Investigate — choose the path your evidence supports

PATH 1 — DIFFERENCES ARE SMALL

- State the evidence for agreement.
- Which input limits your confidence most?
- What would you need to detect a smaller error?
- **Do not invent a discrepancy.**

PATH 2 — CLEARLY LARGER AT A NODE

- Follow the troubleshooting ladder (next slide).
- **THINK:** write your own top two suspected causes first.
- **AI:** ask for ranked causes and the measurement that separates them.
- **DECIDE:** make ONE discriminating measurement; record the result.

GROUP DISCUSSION — ANSWER IN THE REPORT

What did r_num establish, and what not? · What did the measurements establish about THIS circuit? · One specific improvement.

 **TALK TO YOUR AI TEAMMATE** "Here are my data — rank the likely causes."

 **ENGINEER DECIDES** only a measurement decides.

Problem



Model



Compute



Analyze



Validate



Improve



Troubleshooting ladder — power OFF first

Symptom	Check, in this order
All readings 0 V	Module ON? Battery clipped and charged? Black clip really on ground? Meter on V, leads in COM / INPUT?
Vs about 3.3 V, or negative	Jumper at 5 V? + pin in the red-line rail (Stage 0)?
One node equals its neighbour	A resistor between them has both leads in one strip, or is missing from its strip.
A node reads 0 V but should not	The resistor feeding it is not in that node's strip, or the node is shorted to –.
A node far above prediction	Its resistor to ground is not in the – rail (check R2, R4, R6 seating).
Every node off by a similar fraction	Vs in the model differs from the real Vs — re-measure Vs and re-run.
Readings drift while you watch	Loose lead or probe contact · battery sagging · H (hold) accidentally on.
Model and measurement differ at one node	That node's resistors: seating, correct strip, value entered correctly in MATLAB.

Problem



Model



Compute



Analyze



Validate



Improve



The model is a claim — validate the claim

WHAT YOU PREDICTED

- V_{pred} from measured inputs, recorded before measuring.
- Keep it — even when it is not close.

WHAT WAS MEASURED

- V_{meas} from the meter, every digit.
- Measurements are never edited, rounded to agree, or replaced.

WHAT YOU EXPLAIN

- dV , r_{meas} , the sensitivity scale.
- Why did the model perform as it did — and how far can it be trusted?

VALIDATION DOES NOT MEAN "THE NUMBERS MATCH." It means you compared a claim with evidence — and explained what you found.



TALK TO YOUR AI TEAMMATE "Organise this — do not change either column."



ENGINEER DECIDES the AI helps you say it; you decide what it means.

Problem



Model



Compute



Analyze

**Validate**

Improve



Before you leave the station

TA SIGN-OFF

- Stage C circuit shown working; Stage A–C tables complete in the report template.
- Stage C photo taken, strips labelled.
- **Every member** has a copy of the group's measured R1–R6, Vs (C) and measured V1–V3.
- Power OFF · battery unclipped · components returned · board cleared · station tidy.

WHY THE DATA COPY?

The optional extension uses YOUR group's Stage C data — and there is no second chance to measure.

Members who leave without the data must use the nominal reference dataset instead.

NO SIGN-OFF, NO DEPARTURE. The TA checks the station, the data and the photo.

Problem



Model



Compute



Analyze



Validate



Improve



What evidence belongs in the report?



MEASURED RECORD

- Committed predictions (pre-lab)
- Station checks (Stage 0)
- Measured R1–R6, band check
- Vs per stage
- V_meas for Stages A, B, C
- Stage C photo



MODEL + COMPUTATION

- KCL equations, Stages B and C
- Numeric A and b with units
- V_pred, r_num
- Why $A(1,3) = A(3,1) = 0$
- MATLAB script (.m)



EVIDENCE + INTERPRETATION

- $dV, r_{\text{meas}} = r_{\text{num}} + A \cdot dV$
- Coupling $A \rightarrow B \rightarrow C$
- Sensitivity table
- Path 1 or Path 2, with evidence
- AI use + one verified AI claim
- Verification vs validation · improvement

ONE GROUP REPORT, ONE CONTRIBUTION RECORD. Use Lab8_Report_Template_Final.docx — every section maps to one of these three columns.

Problem



Model



Compute



Analyze



Validate



Improve



Submission checklist

SUBMIT TOGETHER

- Completed Lab 8 group report, with the contribution record initialled by every member
- MATLAB script(s) (.m) that reproduce the Stage B, Stage C and sensitivity results
- Stage C photo with the strips labelled
- Every member's pre-lab (P1–P4), including the AI-use note
- TA sign-off recorded

FINAL CHECK

Can another engineer trace every prediction back to measured inputs?

Did you record each prediction before the matching measurement?

Did you explain disagreement instead of hiding it?

Did you keep verification (r_num) separate from validation?

AI MAY HELP YOU MODEL, CODE AND COMMUNICATE. IT MAY NOT INVENT, REPLACE, OR ADJUST YOUR MEASUREMENTS.

Problem



Model



Compute



Analyze



Validate

**Improve**



Lab Extension — Stage D: the bridging resistor

WHY A BRIDGE?

Your Stage C network has no direct connection between V1 and V3 — that is why $A(1,3) = A(3,1) = 0$.

Add **R7 directly between V1 and V3** and the matrix gains new coupling. Choose R7 well and the current through R5 becomes zero.

Same model, new connectivity: predict what changes before you compute.

THE CHALLENGE — INDIVIDUAL

- Optional, individual, separately graded.
- **Computational only:** MATLAB and your group's Lab 8 Stage C data. No breadboard, meter or new measurements.
- Predict → update the model → sweep R7 → choose a standard value → verify → assess robustness.
- Use Lab8_Extension_Manual_Final.docx and the extension report template.



ENGINEER DECIDES the bridged design is a model prediction — it is not built or measured in this lab.

Problem

**Model**

Compute



Analyze



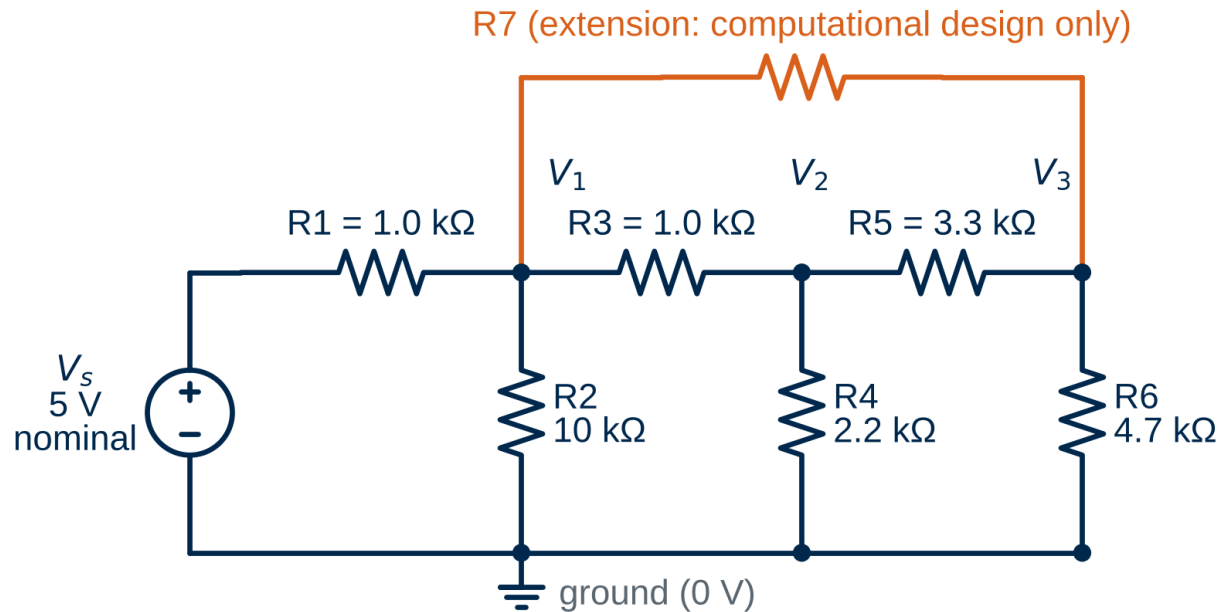
Validate



Improve



Balance the bridge — make the current in R5 zero



R7 joins V_1 and V_3 . Nominal values shown; you use your group's measured $R1$ – $R6$.

WHAT THIS IS — AND IS NOT

- A **design study on a model**: every result is a prediction from the nodal model you tested in Lab 8.
- **Not experimentally validated**. Your report must not call the design tested or confirmed.
- Lab 8 data tell you how well the **unbridged** model matched the real circuit — useful evidence, but not a measurement of the bridged design.

DESIGN GOAL: choose $R7$ so that $V_3 = V_2$, i.e. $I_5 = (V_2 - V_3)/R_5 = 0$.

Problem

Model

Compute

Analyze

Validate

Improve



Predict, update the model, test the reference design

PART A — PREDICT (BEFORE ANY CODE)

1

Direction of current in R7? Will V1 and V3 rise or fall? Which entries of A change? Should R7 be smaller or larger than 4.7 k Ω ?

PART B — UPDATE THE MODEL

2

KCL at V1 and V3 with $G7 = 1/R7$. Write the bridged A and b; mark every changed entry and explain its sign. Why is the V2 row unchanged?

PART C — R7 = 4.7 k Ω

3

Solve unbridged and bridged models; r_{num} for both; I7 and I5; KCL check at V3; compare with Part A.

KEEP LAB 8'S UNITS

- R in k Ω · G in mS · V in V · I in mA
- I5 is often small here — report it in μA
- The new A must still be symmetric — check it.



TALK TO YOUR AI TEAMMATE "Check my bridged KCL at V3 — not the answer."



ENGINEER DECIDES predictions are written before the first solve.

Problem



Model



Compute



Analyze



Validate



Improve



Sweep, choose — then verify independently

```
R7s = logspace(log10(0.5), log10(20), 400);  
I5s = zeros(size(R7s));  
for k = 1:numel(R7s)  
    Vk = ____;           % bridged solve  
    I5s(k) = ____;       % (V2 - V3)/R5  
end  
semilogx(R7s, 1000*I5s), grid on
```

PART D — SWEEP AND CHOOSE

- ≥ 200 log-spaced values, 0.5–20 k Ω · plot I5 (μA) against R7
- Find R7* (I5 = 0) to 4 significant figures
- Choose an E12 value; justify it with the candidates on both sides of R7*

PART E — VERIFY INDEPENDENTLY

- **By hand:** with I5 = 0, R5 can be removed. Write V2 and V3 as dividers of V1, set V2 = V3, solve for R7. Compare with R7*.
- Which resistors do NOT appear in your result — and why?
- **Limits:** R7 $\rightarrow \infty$ and R7 very small. Does the sweep approach them?
- **Conservation:** KCL at all three nodes for your chosen R7.

 **TALK TO YOUR AI TEAMMATE** "After I derive the balance condition, derive it too — then we compare. If we differ, I find out why."

Problem



Model



Compute



Analyze



Validate



Improve



Robustness, limits — and what you may claim

PART F1 — TOLERANCE

- Change R3, R4, R6, R7 one at a time by $\pm 1\%$; record I5.
- Does the sign of I5 change? Explain with your balance result.
- Optional: $\pm 1\%$ Monte Carlo.

PART F2–F4 — LIMITS

- What do your Lab 8 measurements say about trusting this model — and what NOT?
- Write a bench validation plan. Do not carry it out; do not invent results.
- List three model assumptions.

PART G — AI + REPORT

- Record AI use; verify one substantive AI claim independently.
- Recommendation memo: R7, expected I5, sensitivity, evidence, what is not yet shown.
- Individual report + .m files.

A MODEL-ONLY DESIGN IS A RECOMMENDATION, NOT A RESULT. Never present a prediction as a measurement.

✓ **ENGINEER DECIDES** integrity statement signed · Lab 8 data never altered · AI use fully recorded.

Problem



Model



Compute



Analyze



Validate



Improve

LAB 8 · LINEAR SYSTEMS AND MATRIX-BASED ENGINEERING COMPUTATION

You built a circuit one node at a time.
You predicted it with a matrix.
You measured what it actually did.
You explained the difference.

The important question is not whether MATLAB produced a solution.
It is whether that solution describes the circuit on your bench.

PREDICT › BUILD › MEASURE › VALIDATE › IMPROVE

Problem

›

Model

›

Compute

›

Analyze

›

Validate

›

Improve