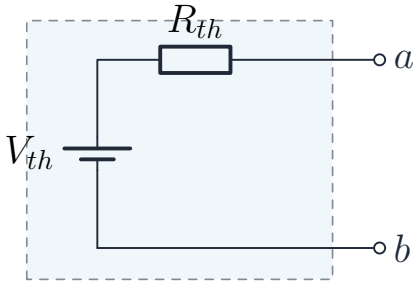
Exercise walk-through

1.7
First-order RC and RL response

University Electrical Engineering

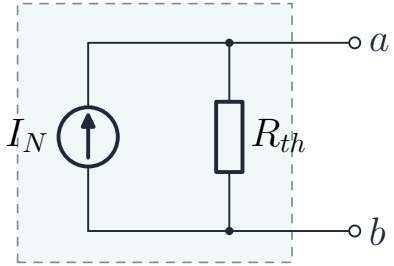
Every linear one-port is one source and one resistance

Thévenin: series form



same port ⟷

Norton: parallel form



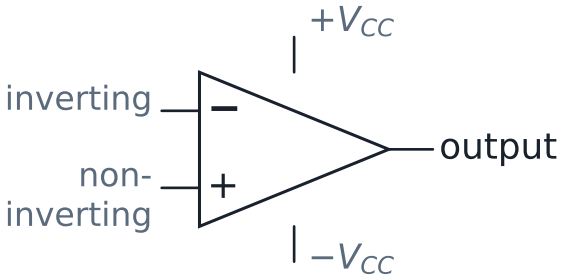
V_{th}: open-circuit voltage at a–b
R_{th}: resistance at a–b, sources set to zero

$I_N = V_{th}/R_{th}$,
the short-circuit current at a–b

> Measure the **open-circuit voltage** and the zeroed-source resistance; the whole network folds into Vth in **series** with Rth, or IN in **parallel**.

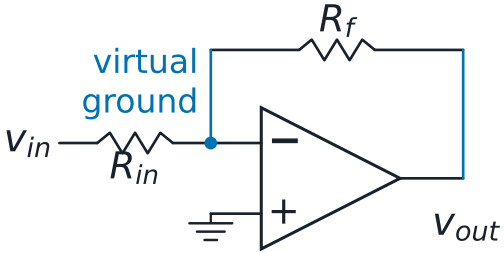
Five terminals and one taming trick

Five terminals



ideal: infinite gain,
infinite input resistance

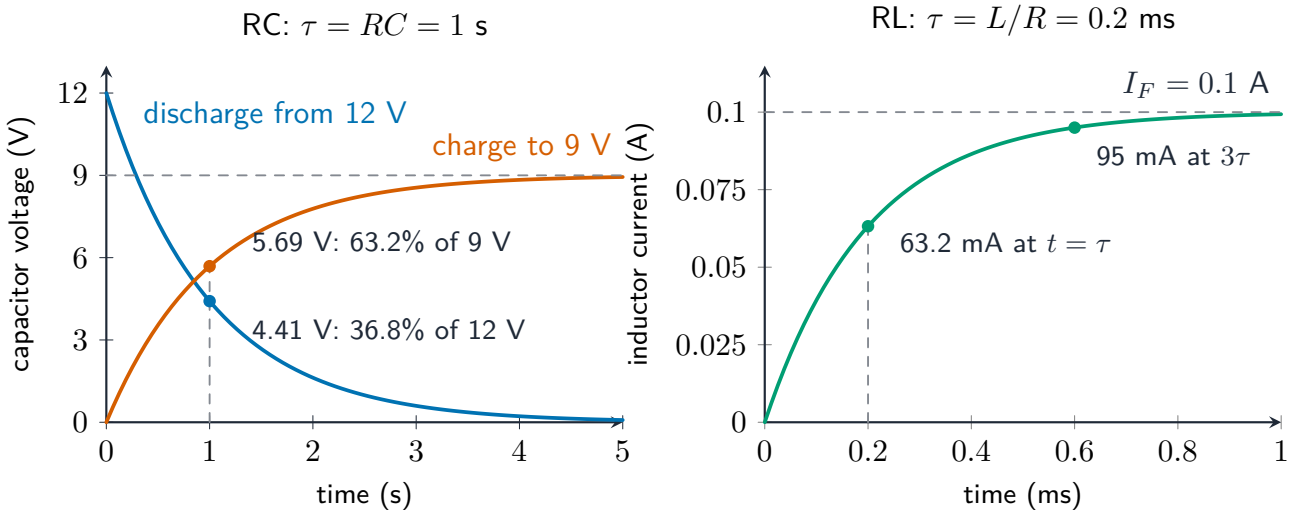
Inverting amplifier



the − node sits at 0 V, so
all of v_{in}/R_{in} flows through R_f

The triangle has two inputs, one output and two supply rails; **negative feedback** pins the minus node to the plus node - the **virtual ground** that makes gain exact.

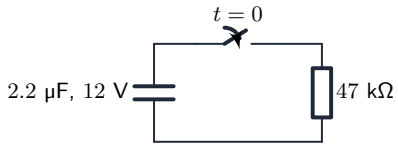
The same shape, capacitor or inductor



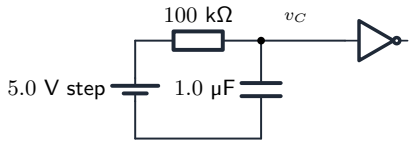
Charge and discharge share one curve family; τ marks the 63.2% point.

Exercises 2.1·2.2

2.1 A 2.2 µF capacitor charged to 12 V discharges through 47 kΩ from $t = 0$. Find τ and v_C at $t = 0.20$ s. [3]

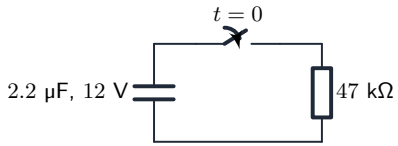


2.2 An RC delay uses $R = 100$ kΩ and $C = 1.0$ µF from a 5.0 V step, starting uncharged. A logic input switches when v_C reaches 2.5 V. Find the delay. [3]



Exercises 2.1·2.2

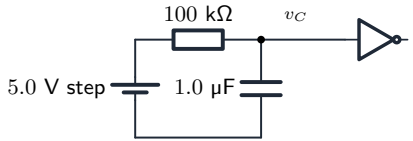
2.1 A 2.2 µF capacitor charged to 12 V discharges through 47 kΩ from $t = 0$. Find τ and v_C at $t = 0.20$ s. [3]



2.1

$\tau = 47 \times 10^{3} \times 2.2 \times 10^{-6} = \mathbf{103\ ms}$; $v_C = 12e^{-0.20/0.1034} = \mathbf{1.73\ V}$

2.2 An RC delay uses $R = 100$ kΩ and $C = 1.0$ µF from a 5.0 V step, starting uncharged. A logic input switches when v_C reaches 2.5 V. Find the delay. [3]

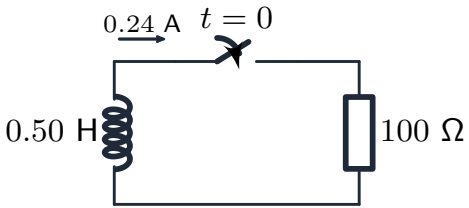


2.2

$\tau = 0.10$ s; $t = \tau \ln \dfrac{0 - 5.0}{2.5 - 5.0} = \tau \ln 2 = \mathbf{69\ ms}$

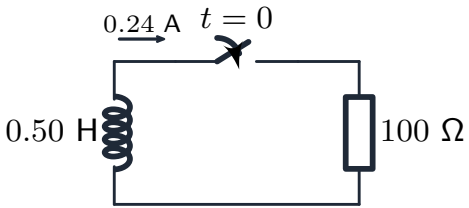
Exercise 2.3

2.3 A current of 0.24 A flows in a 0.50 H inductor. At $t = 0$ the current is diverted into a 100 Ω resistor. Find τ, i at $t = 10$ ms, and the voltage across the resistor at $t = 0^+$. [3]



Exercise 2.3

2.3 A current of 0.24 A flows in a 0.50 H inductor. At $t = 0$ the current is diverted into a 100 Ω resistor. Find τ, i at $t = 10$ ms, and the voltage across the resistor at $t = 0^+$. [3]

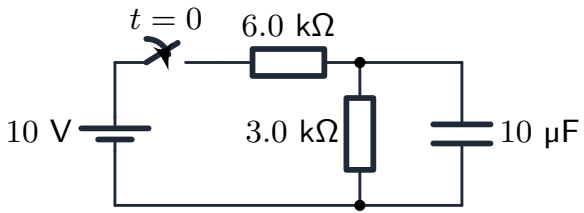


2.3

$\tau = \dfrac{0.50}{100} = \mathbf{5.0\ ms}$; $i = 0.24e^{-2} = \mathbf{32\ mA}$; i_L cannot jump, so $v_R(0^+) = 0.24 \times 100 = \mathbf{24\ V}$

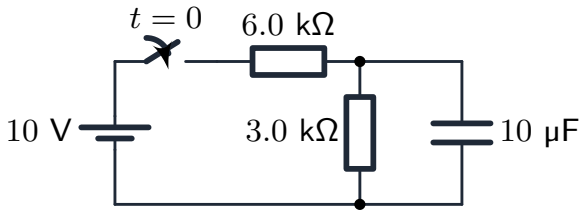
Exercise 2.4

2.4 At $t = 0$ a 10 V source is switched onto 6.0 kΩ in series, with 3.0 kΩ and an uncharged 10 µF capacitor both across the output. Find $v_C(\infty)$, τ and v_C at $t = 20$ ms. [3]



Exercise 2.4

2.4 At $t = 0$ a 10 V source is switched onto 6.0 kΩ in series, with 3.0 kΩ and an uncharged 10 µF capacitor both across the output. Find $v_C(\infty)$, τ and v_C at $t = 20$ ms. [3]



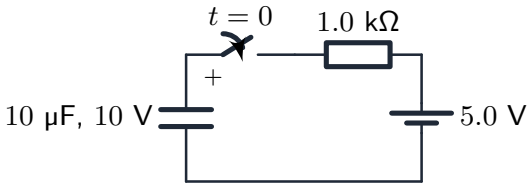
2.4

$v_C(\infty) = 10 \times \frac{3}{9} = \mathbf{3.33\ V}$; $R_{Th} = 6 \parallel 3 = 2.0\,\text{k}\Omega$, $\tau = \mathbf{20\ ms}$; $v_C(20\ \text{ms}) = 3.33(1-e^{-1}) = \mathbf{2.11\ V}$

Exercise 3.1

3.1 A 10 µF capacitor has been charged to 10 V. At $t = 0$ a switch connects it, through 1.0 kΩ, to a 5.0 V source.

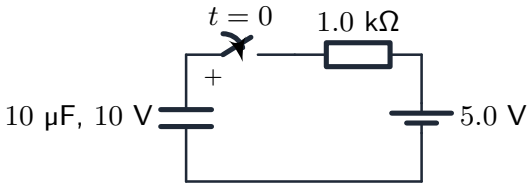
Find $v_C(t)$, the current at $t = 0^+$ with its direction, and the time for v_C to fall to 6.0 V. [5]



Exercise 3.1

3.1 A 10 µF capacitor has been charged to 10 V. At $t = 0$ a switch connects it, through 1.0 kΩ, to a 5.0 V source.

Find $v_C(t)$, the current at $t = 0^+$ with its direction, and the time for v_C to fall to 6.0 V. [5]



3.1

$v_C(0^+) = 10$ V, $v_C(\infty) = 5.0$ V; $\tau = 1.0\ \text{k} \times 10\ \mu\text{F} = 10$ ms, $v_C = 5.0 + 5.0e^{-t/10\ \text{ms}}$ V

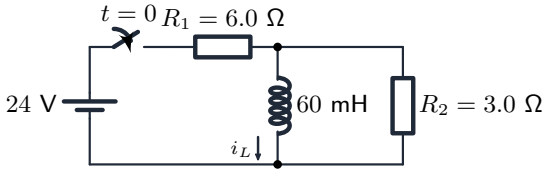
$i(0^+) = \dfrac{10 - 5.0}{1.0\ \text{k}} = \mathbf{5.0\ mA}$, flowing out of the capacitor into the source

$t = 10 \ln \dfrac{10 - 5}{6 - 5} = \mathbf{16.1\ ms}$

Exercise 3.2

3.2 At $t = 0$ a switch connects 24 V to $R_1 = 6.0\ \Omega$ in series. After R_1, an inductor $L = 60$ mH and $R_2 = 3.0\ \Omega$ are in parallel. The inductor current is zero before the switch closes.

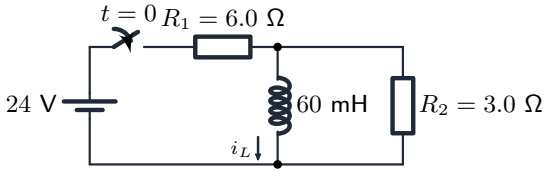
Find $i_L(t)$, and the source current just after closing and after a long time. Check your τ from the starting slope of i_L. [5]



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Find $i_L(t)$, and the source current just after closing and after a long time. Check your τ from the starting slope of i_L. [5]



3.2

$i_L(\infty) = \dfrac{24}{6.0} = 4.0$ A (L shorts R_2); $R_{Th} = 6 \parallel 3 = 2.0\ \Omega$, $\tau = \dfrac{0.060}{2.0} = 30$ ms: $i_L = 4.0(1 - e^{-t/30\ \text{ms}})$ A

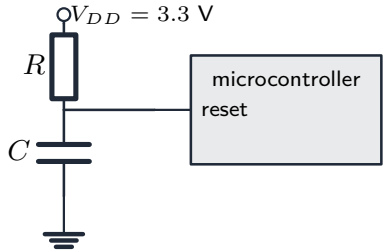
source current: $t = 0^+$, $i_L = 0$: $\dfrac{24}{9.0} = \mathbf{2.67\ A}$; long after: $\mathbf{4.0\ A}$

check: $v_L(0^+) = 2.67 \times 3.0 = 8.0$ V, so $\dfrac{di_L}{dt} = \dfrac{8.0}{0.060} = 133$ A/s; $\dfrac{i_L(\infty)}{\tau} = \dfrac{4.0}{0.030} = 133$ A/s

Exercise 3.3 (a)

3.3 A microcontroller has a **power-on reset** pin. An RC circuit (R from $V_{DD} = 3.3$ V to the pin, C from the pin to ground) holds the pin low after power-up. The chip leaves reset when the pin reaches kV_{DD}. The chip needs at least 10 ms of reset, and at most 50 ms.

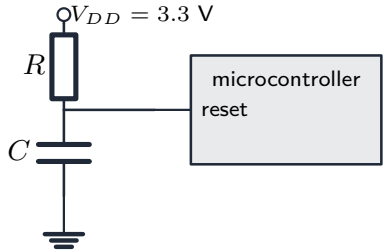
(a) Show that the reset time is $t = RC \ln \dfrac{1}{1-k}$, and find it for $R = 10$ kΩ, $C = 1.0$ µF, $k = 0.70$. [3]



Exercise 3.3 (a)

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(a) Show that the reset time is $t = RC \ln \dfrac{1}{1-k}$, and find it for $R = 10$ kΩ, $C = 1.0$ µF, $k = 0.70$. [3]



(a) $v = V_{DD}(1 - e^{-t/RC}) = kV_{DD}$ gives $e^{-t/RC} = 1 - k$, so $t = RC \ln \dfrac{1}{1-k}$; $t = 10\ \text{ms} \times \ln \dfrac{1}{0.30} = \mathbf{12.0\ ms}$; meets 10 ms with a small margin

Exercise 3.3 (b)

3.3 A microcontroller has a **power-on reset** pin. An RC circuit (R from $V_{DD} = 3.3$ V to the pin, C from the pin to ground) holds the pin low after power-up. The chip leaves reset when the pin reaches kV_{DD}. The chip needs at least 10 ms of reset, and at most 50 ms.

(b) The capacitor has a tolerance of $\pm 20\%$ and k can be anywhere from 0.60 to 0.80. Find the worst-case shortest reset time. Does it pass? [2]

Exercise 3.3 (b)

3.3 A microcontroller has a **power-on reset** pin. An RC circuit (R from $V_{DD} = 3.3$ V to the pin, C from the pin to ground) holds the pin low after power-up. The chip leaves reset when the pin reaches kV_{DD}. The chip needs at least 10 ms of reset, and at most 50 ms.

(b) The capacitor has a tolerance of $\pm 20\%$ and k can be anywhere from 0.60 to 0.80. Find the worst-case shortest reset time. Does it pass? [2]

(b) $C = 0.80$ µF, $k = 0.60$: $t = 8.0$ ms $\times \ln 2.5 =$ **7.3 ms**: it **fails** the 10 ms minimum

Exercise 3.3 (c)

3.3 A microcontroller has a **power-on reset** pin. An RC circuit (R from $V_{DD} = 3.3$ V to the pin, C from the pin to ground) holds the pin low after power-up. The chip leaves reset when the pin reaches kV_{DD}. The chip needs at least 10 ms of reset, and at most 50 ms.

(c) Choose a standard capacitor (E6 series: 1.0, 1.5, 2.2, 3.3 µF) that meets the 10 ms minimum in the worst case. Check it against the 50 ms maximum. [3]

Exercise 3.3 (c)

3.3 A microcontroller has a **power-on reset** pin. An RC circuit (R from $V_{DD} = 3.3$ V to the pin, C from the pin to ground) holds the pin low after power-up. The chip leaves reset when the pin reaches kV_{DD}. The chip needs at least 10 ms of reset, and at most 50 ms.

(c) Choose a standard capacitor (E6 series: 1.0, 1.5, 2.2, 3.3 µF) that meets the 10 ms minimum in the worst case. Check it against the 50 ms maximum. [3]

(c) need $RC_{\min} \ln 2.5 \geq 10$ ms: $RC_{\min} \geq 10.9$ ms, $C_{\text{nom}} \geq \dfrac{10.9 \text{ ms}}{0.80 \times 10 \text{ k}\Omega} = 1.36$ µF, so 1.5 **µF**

longest: $C = 1.8$ µF, $k = 0.80$: 18 ms $\times \ln 5 =$ **29 ms**, below 50 ms, so the design passes