## Lecture 5

- Series and Parallel Resistors
- Voltage and Current Divider
- Ammeters and Voltmeters
- Series and Parallel Capacitors
-2-Capacitor Circuit
- Useful insights and tips to avoid dumb mistakes


## SERIES ELEMENTS

KCL tells us that all of the elements in a single branch carry the same current.

We say these elements are in series.


Current entering node $=$ Current leaving node

$$
\mathrm{i}_{1}=\mathrm{i}_{2}
$$

## RESISTORS IN SERIES

Circuit with several resistors in series: Find "equivalent resistance"


Thus, equivalent resistance of resistors in series is the sum

Circuit with several resistors in series

-We know
$\mathrm{I}=\mathrm{V}_{\mathrm{SS}} /\left(\mathrm{R}_{1}+\mathrm{R}_{2}+\mathrm{R}_{3}+\mathrm{R}_{4}\right)$

- Thus,
$V_{1}=\frac{R_{1}}{R_{1}+R_{2}+R_{3}+R_{4}} \cdot V_{S S}$ and
$V_{3}=\frac{R_{3}}{R_{1}+R_{2}+R_{3}+R_{4}} \cdot V_{S S}$ etc...


## WHEN IS VOLTAGE DIVIDER FORMULA CORRECT?



Correct if nothing else connected to nodes

because $\mathrm{R}_{5}$ removes condition of resistors in series $\mathrm{I}_{3} \neq 1$

## MEASURING CURRENT

To measure current in a circuit, insert DMM (in current mode) into circuit, in series with measured element.

But ammeters change the circuit. Ammeters are characterized by their "ammeter input resistance," $\mathrm{R}_{\text {in }}$. Ideally this should be very low. Typical value $1 \Omega$.


## MEASURING CURRENT

Potential measurement error due to non-zero input resistance:

undisturbed circuit

$$
I=\frac{V}{R_{1}+R_{2}}
$$



Example: $\mathrm{V}=1 \mathrm{~V}, \mathrm{R}_{1}=\mathrm{R}_{2}=500 \Omega, \mathrm{R}_{\text {in }}=1 \Omega$

$$
I=\frac{1 \mathrm{~V}}{500 \Omega+500 \Omega}=1 \mathrm{~mA}, \quad I_{\text {meas }}=\frac{1 \mathrm{~V}}{500 \Omega+500 \Omega+1 \Omega} \cong 0.999 \mathrm{~mA}_{13}
$$

## PARALLEL ELEMENTS

KVL tells us that any set of elements which are connected at both ends carry the same voltage.
We say these elements are in parallel.


## RESISTORS IN PARALLEL

Resistors in parallel can be made into one equivalent resistor


$$
R_{e q}=\left(R_{1}^{-1}+R_{2}^{-1}+R_{3}^{-1}+\ldots\right)^{-1} \quad \text { Special case: } R_{\text {eq }}=\frac{R_{1} R_{2}}{R_{1}+R_{2}}
$$

- For resistors in series:
- Current through $R_{\text {eq }}$ is equal to the current through each of the original resistors (all have same current)
- Voltage over $R_{\text {eq }}$ is the sum of the voltages over the original resistors
- For resistors in parallel:
- Current through $R_{\mathrm{eq}}$ is equal to the sum of the currents through each of the original resistors
- Voltage over $R_{\text {eq }}$ is equal to the voltage over the original resistors (all have same voltage)


## CURRENT DIVIDER

There is a simple equation for the way current splits between
two parallel resistors:

X


REAL VOLTMETERS
How is voltage measured? Digital multimeter (DMM) in parallel with measured element.

Connecting a real voltmeter across two nodes changes the circuit. The voltmeter may be modeled by an ideal voltmeter (open circuit) in parallel with a resistance: "voltmeter input resistance," $\mathrm{R}_{\text {in }}$. Typical value: $10 \mathrm{M} \Omega$


## REAL VOLTMETERS



## CAPACITORS IN PARALLEL



Equivalent capacitance defined by

$$
\begin{gathered}
i(t)=C_{e q} \frac{d V}{d t} \\
i(t)=C_{1} \frac{d V}{d t}+C_{2} \frac{d V}{d t} \\
C_{e q}=C_{1}+C_{2}
\end{gathered}
$$

DIGITAL CIRCUIT: DRAM


