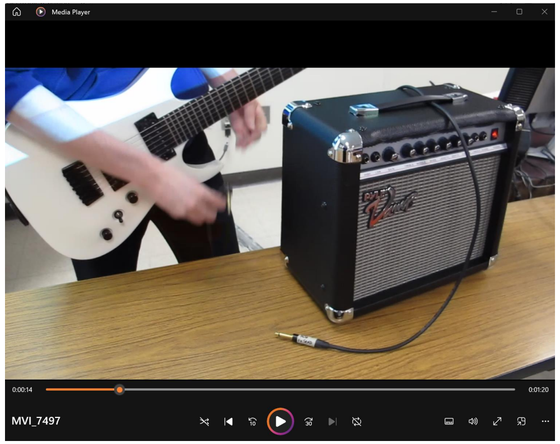
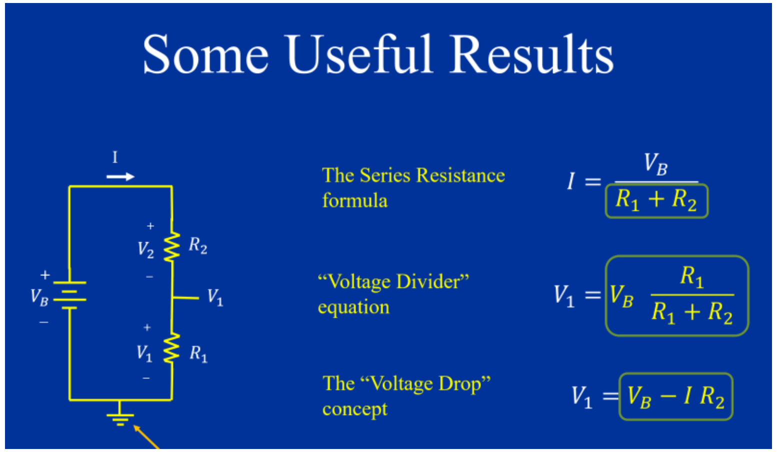
ECE Topics #3 - Circuit Analysis –
From Theory to Applications

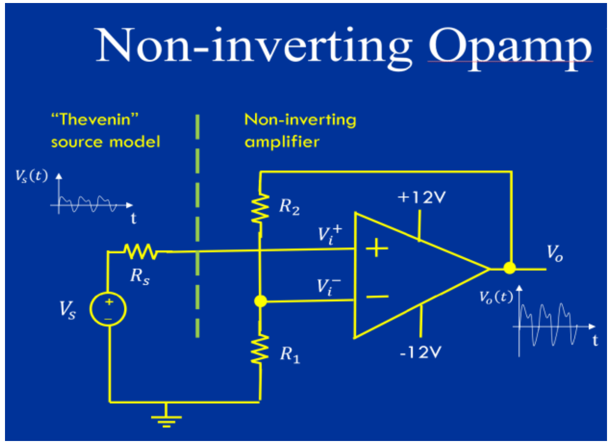
Slides downloaded from: https://ecefiles.org/ece-topics/

Companion video at: https://www.youtube.com/watch?v=8UBXjlilkeU

This video focuses on how fundamental theory like Kirchoff's Laws are used to analyze, understand, and design real-world products. Basic topics include Ohm's Law, KVL, KCL, Nodal Analysis, the ubiquitous voltage divider circuit, and more. But the main theme is how these give way to analysis using common subcircuits, leveraging known results. While a guitar amp and DSP reverb are used in demos, the topics covered are essential to all analog circuit analysis. The design of a voltage amplifier built using an opamp is also discussed.



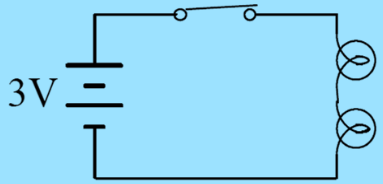




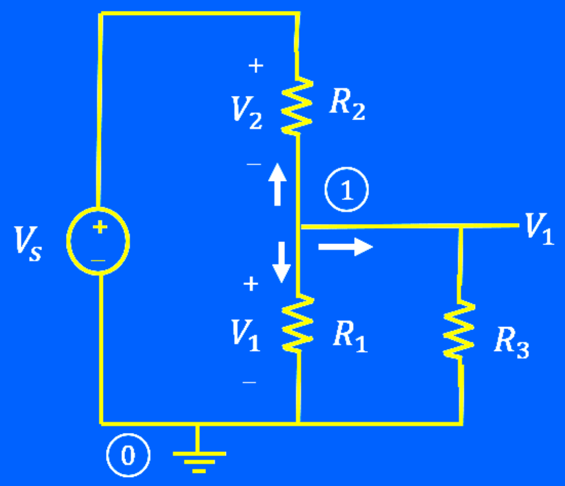
Topics in ECE #3

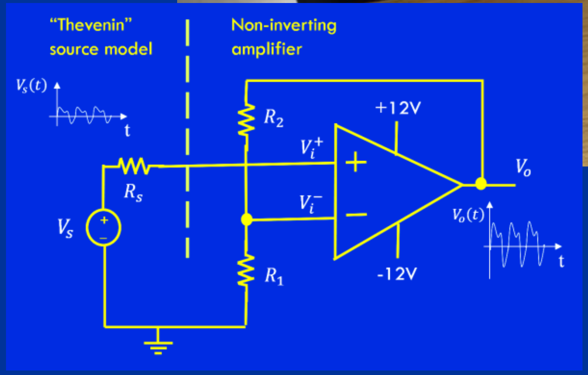
Circuit Analysis

Theory and Applications

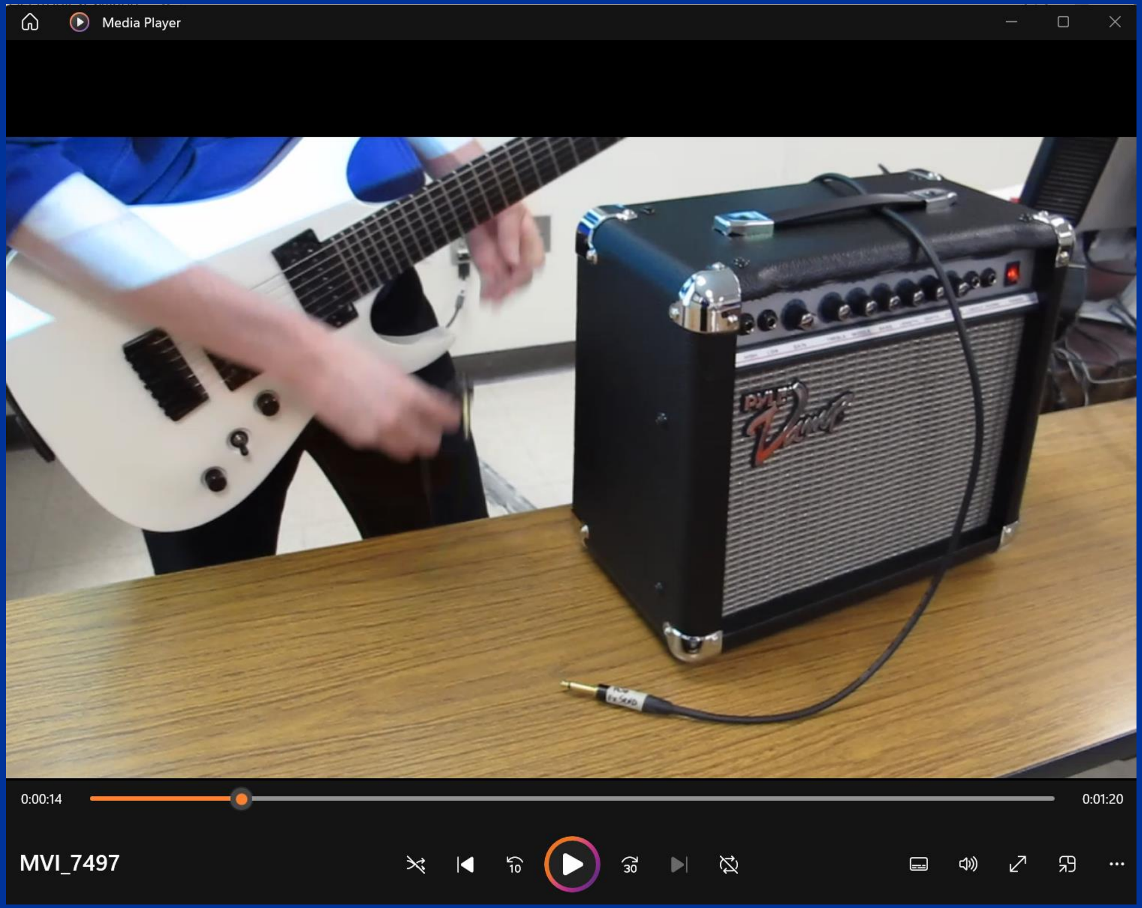


Schematic 3
KVL Demo





Demo in Lecture Class



CAUTION !
120 VAC

Typical Undergrad EE Curriculum

Freshman year

Fall semester (16 credit hours)

- CHM 210 - Chemistry I **Credits:** (4)
- COMM 105 - Public Speaking IA **Credits:** (2)
- ECE 015 - New Student Assembly **Credits:** (0)
- ECE 210 - Introduction to Electrical Engineering **Credits:** (3)
- ENGL 100 - Expository Writing I **Credits:** (3)
- MATH 220 - Analytic Geometry and Calculus I **Credits:** (4)

Spring semester (17 credit hours)

- BIOL 198 - Principles of Biology **Credits:** (4)

or

- CHM 230 - Chemistry II **Credits:** (4)
- ECE 115 - New Student Design Project **Credits:** (1)
- ECON 110 - Principles of Macroeconomics **Credits:** (3)
- MATH 221 - Analytic Geometry and Calculus II **Credits:** (4)
- PHYS 213 - Engineering Physics I **Credits:** (5)

Sophomore year

Fall semester (17 credit hours)

- CHE 354 - Basic Concepts in Materials Science and Engineering **Credits:** (1)
- CHE 356 - Fundamentals of Electrical Properties **Credits:** (1)
- ECE 241 - Introduction to Computer Engineering **Credits:** (3)
- ECE 410 - Circuit Theory I **Credits:** (3)
- MATH 240 - Elementary Differential Equations **Credits:** (4)
- PHYS 214 - Engineering Physics II **Credits:** (5)

Spring semester (16 credit hours)

- CIS 209 - C Programming for Engineers **Credits:** (3)
- ECE 511 - Circuit Theory II **Credits:** (3)
- ECE 525 - Electronics I **Credits:** (3)
- MATH 222 - Analytic Geometry and Calculus III **Credits:** (4)
- STAT 510 - Introductory Probability and Statistics I **Credits:** (3)

Junior year

Fall semester (16 credit hours)

- **Humanities/Social Science Elective **Credits:** (3)
- ECE 431 - Microcontrollers **Credits:** (3)
- ECE 526 - Electronics II **Credits:** (3)
- ECE 540 - Applied Scientific Computing for Engineers **Credits:** (3)
- ECE 557 - Electromagnetic Theory I **Credits:** (4)

Spring semester (17 credit hours)

- **Humanities/Social Science Elective **Credits:** (3)
- ECE Technical Electives **Credits:** (3)
- ECE 502 - Electronics Laboratory **Credits:** (2)
- ECE 512 - Linear Systems **Credits:** (3)
- ECE 581 - Energy Conversion I **Credits:** (3)
- ENGL 415 - Written Communication for Engineers **Credits:** (3)

Senior year

Fall semester (15 credit hours)

- ***Technical electives **Credits:** (6)
- CE 530 - Statics and Dynamics **Credits:** (3)
- ECE 530 - Control Systems Design **Credits:** (3)
- ECE 590 - Senior Design Experience **Credits:** (3)

Spring semester (15 credit hours)

- ***Technical electives **Credits:** (9)
- **Humanities/Social Science Elective **Credits:** (3)
- ME 513 - Thermodynamics I **Credits:** (3)

Electrical engineering options

General option

Intro EE and Electronics

Introduction to Electrical Engineering Syllabus

Prerequisites: **Good background in algebra.** Some calculus and complex number experience is handy, but we'll introduce these as needed.

Course Description:

Classically, ECE students had to wait till the 2nd semester of their Sophomore year to take circuit theory, and till their *Junior year* to get into an EE lab. This course changes all that, giving incoming students a chance to experience electrical engineering in their first year.

It is a moderately rigorous course designed as an introduction to fundamental electrical engineering concepts that you will use for the rest of your life. In it you will learn the basics of EE as well as practical knowledge about the world's electrical infrastructure and modern electronic products.

Course Topics:

- AC and DC voltages, currents, power, and essential circuit theory concepts.
- Oscilloscopes, function generators, and meters.
- Circuit fabrication techniques, including breadboard construction and soldering.
- Opamps, transistors, and integrated circuit fundamentals and applications.
- Lab experiments including covering real-world applications including, batteries, switches, microphones and loudspeakers, motors and generators, amplifiers, etc.

Labs: **Labs meet once per week (nominally)**
This is an integral part of the course, and accounts for a major part of your grade.

Lab Kit: You will need to purchase a lab kit (approx. $40) that contains the core components required to complete the projects. ***<u>This must be purchased by the second week of the semester.</u>***

Tools: As you begin your Electrical Engineering career, you should begin to collect some basic tools. These include wire cutters, strippers, needle-nose pliers, a soldering iron, etc. Your professor or lab instructor can give you information on where and how to purchase these. (Purchase is somewhat optional, but strongly encouraged).

Electronics II Syllabus

Prerequsites: Electronics I and Circuit Theory II

Required Text: A.S. Sedra & K.C. Smith, **Microelectronic Circuits**, Oxford, 2010.

Resources: **Practical Electronics for Inventors**, Paul Scherz and Simon Monk, Copyright 2016, McGraw Hill. This is an amazing book for the money. It contains a wealth of schematics and reference information that is complementary to the deeper theoretical info in our course text.

Course Description:

This course builds on previous circuits and electronics courses, providing the theory needed to understand and design practical circuits/systems of moderate complexity.

While the textbook concentrates on classic low-level design, we will also cover topics not in that book, including switch-mode power supplies, modern IC components, and interfacing to and from microprocessors with analog-to-digital and digital-to-analog converters.

Part I (The big picture)

- Review of amplifier models, including gain, Rin, Rout, loading, and frequency response
- Frequency domain characterization of real-world signals with examples (Fourier theory)
- Opamps, including modern single-supply circuits, low-voltage, low-power ICs, and data-sheets
- Additional analog ICs (comparitors, switches, regulators, ADCs/DACs, etc.)
- Example systems that include amplifiers, ADCs, DACs, and digital signal processing (DSP).
- Circuit board layout, including power and signal integrity, and EM compatibility issues

Part 2 (Elaboration of discrete devices and common sub-circuits used in designing analog and digital ICs)

- Diodes, classic power supplies, and modern switching supplies
- Review of MOSFET structure and operation with switching and amplifier circuit examples
- Amplifier configurations (e.g. CS, CG, CD, and high-frequency behavior)
- Multi-transistor amplifiers, Miller's theorem, and cascoding/buffering to improve frequency response.
- Comparison of MOSFETs and BJTs.
- Power dissipation and heat-sinking
- Differential amplifiers, power-amp stages, and basics of op-amp internal designs
- Feedback, and stability

Additional topics will be interwoven as time permits (e.g. Simulators, filter design, IC design, etc.)

Homework: There will be approximately 8 to 10 homework assignments throughout the semester, most of which will be collected and graded.

Today’s Topics

- Quick review from Episode 1
- Using Kirchhoff’s Laws
- Analysis using Equivalent Circuits
- Subcircuit recognition and understanding

Ohm's and Kirchhoff's Laws…

Ohm's Law

$$I = \frac{V}{R}$$

$$V = IR$$

$$R = \frac{V}{I}$$

Kirchoff's Current Law

At a "node":

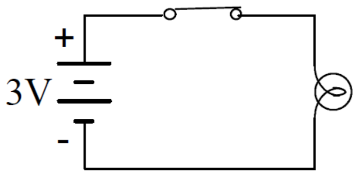
$$\sum I_{entering} = \sum I_{leaving}$$

Kirchoff's Voltage Law

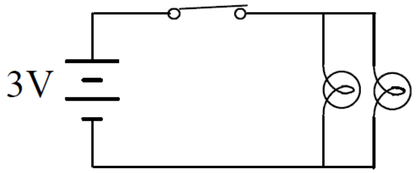
Around a loop:

$$\sum V_{rises} = \sum V_{drops}$$

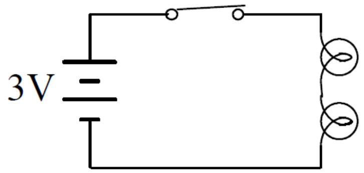
In this lab, we will build 3 simple circuits, shown in the 3 schematics below.



Schematic 1
Ohm's Law Demo

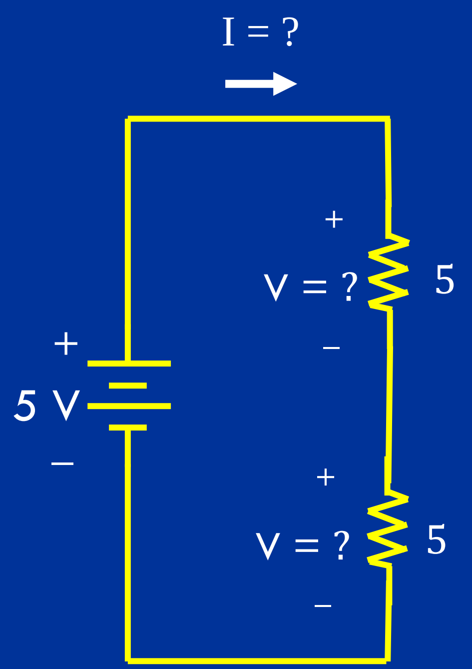


Schematic 2
KCL Demo

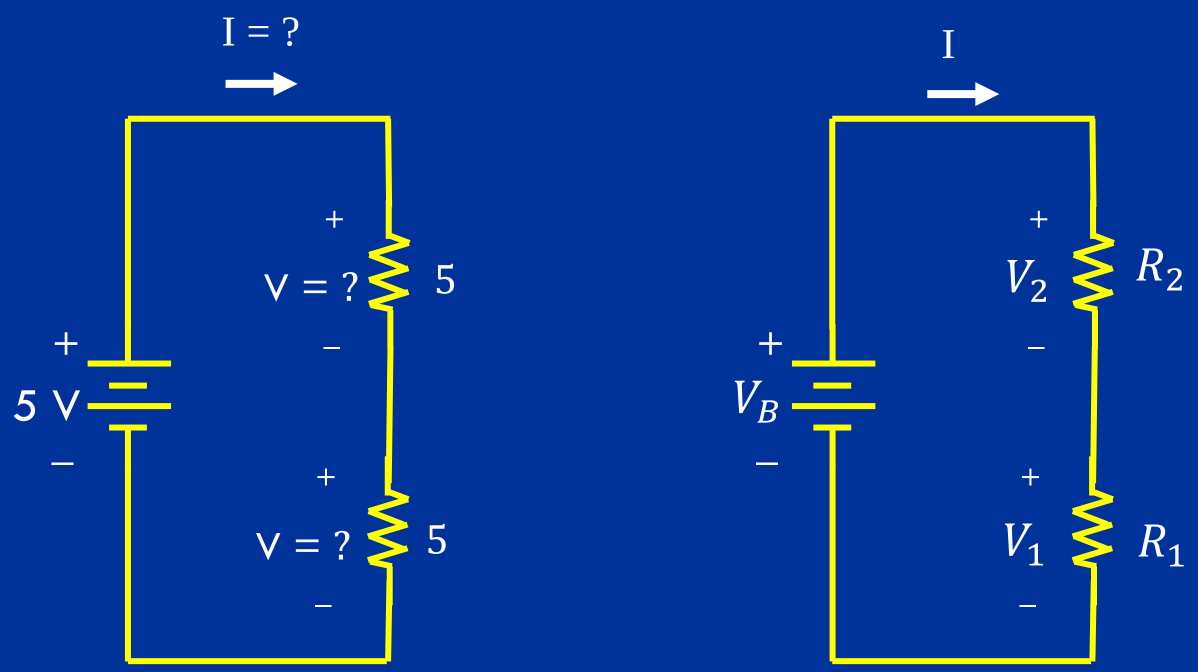


Schematic 3
KVL Demo

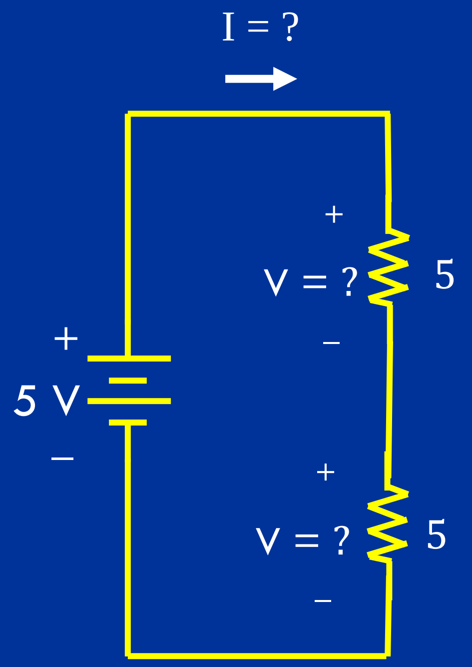
A Simple Example with 2 Resistors

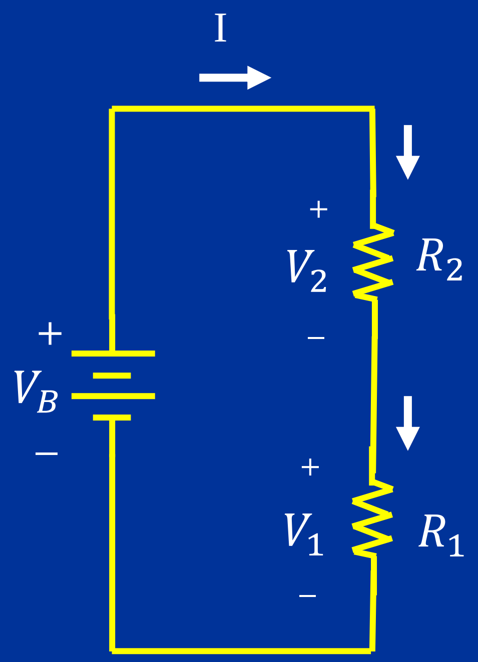


Generalizing the Problem



Applying the Laws





KVL : $V_B = V_2 + V_1$

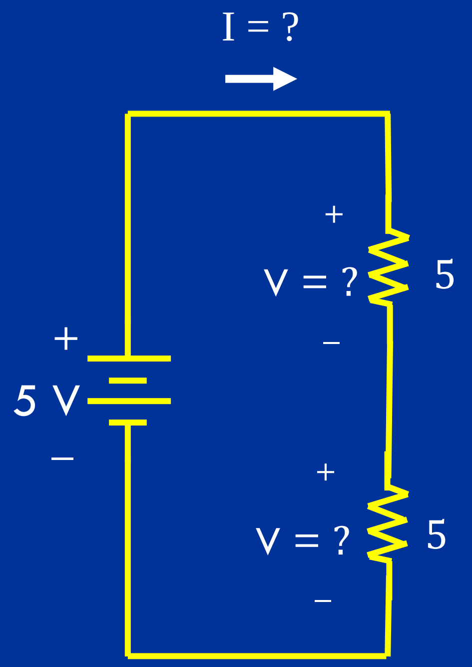
Ohm's Law : $V_2 = I_2 R_2$

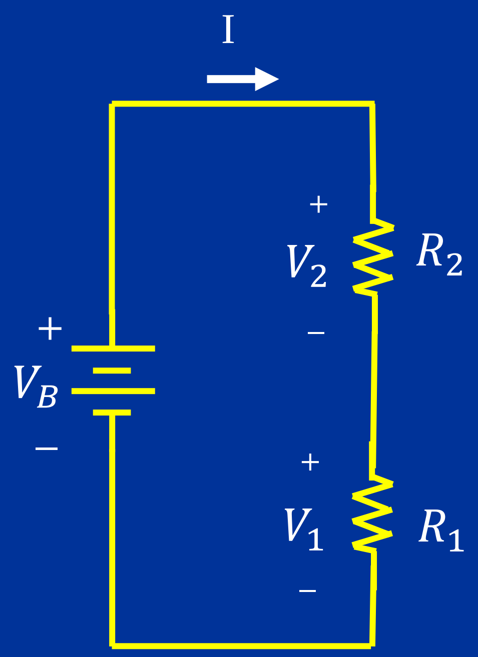
$V_1 = I_1 R_1$

KCL : $I = I_2 = I_1$

I_1

Solving the Equations





KVL : $V_B = V_2 + V_1$

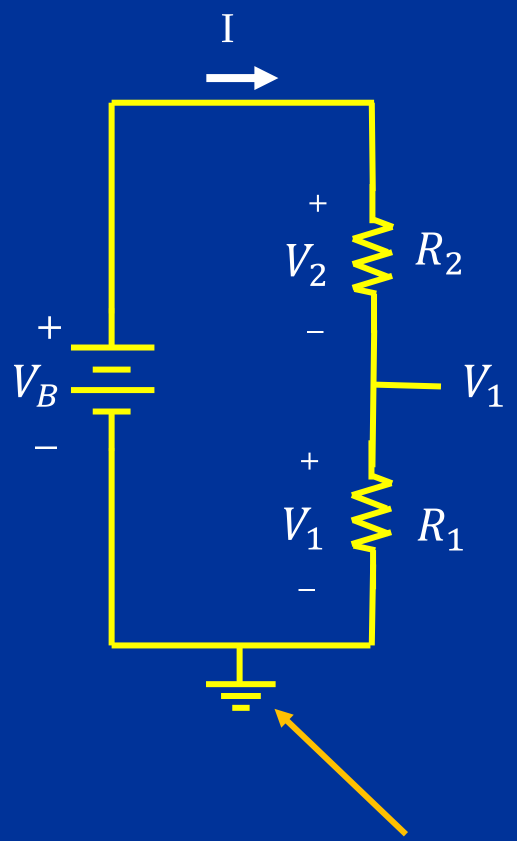
Ohm's Law : $V_2 = I_2 R_2$

$V_1 = I_1 R_1$

KCL : $I = I_2 = I_1$

Solve to get : $I = \dfrac{V_B}{R_1 + R_2}$ = 0.5 A $\qquad V_1 = V_B \dfrac{R_1}{R_1 + R_2}$ = 2.5 V $\qquad V_2 = V_B - V_1$ = 2.5 V

Some Useful Results



Ground (aka Reference-node)

The Series Resistance formula

$$I = \frac{V_B}{R_1 + R_2}$$

"Voltage Divider" equation

$$V_1 = V_B \frac{R_1}{R_1 + R_2}$$

The "Voltage Drop" concept

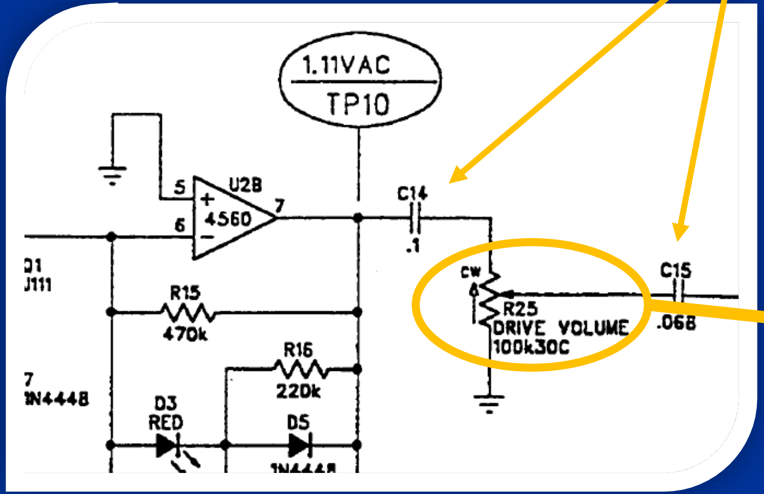
$$V_1 = V_B - I\,R_2$$

Potentiometer (Voltage-Divider)

Classic Volume Control

https://reverb.com/p/fender-champion-30-2-channel-30-watt-1x10-guitar-practice-amp-1999-2002

AC coupling capacitors (aka DC blocks)



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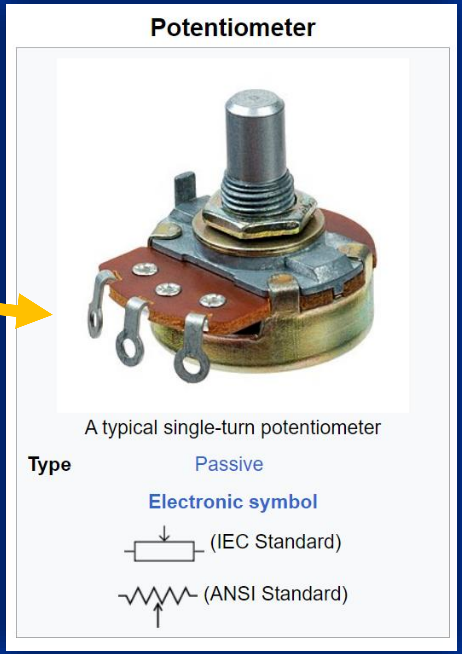
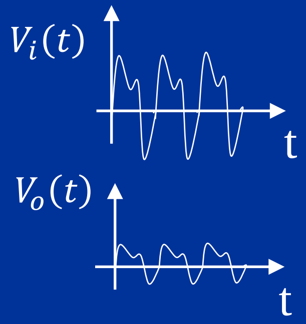
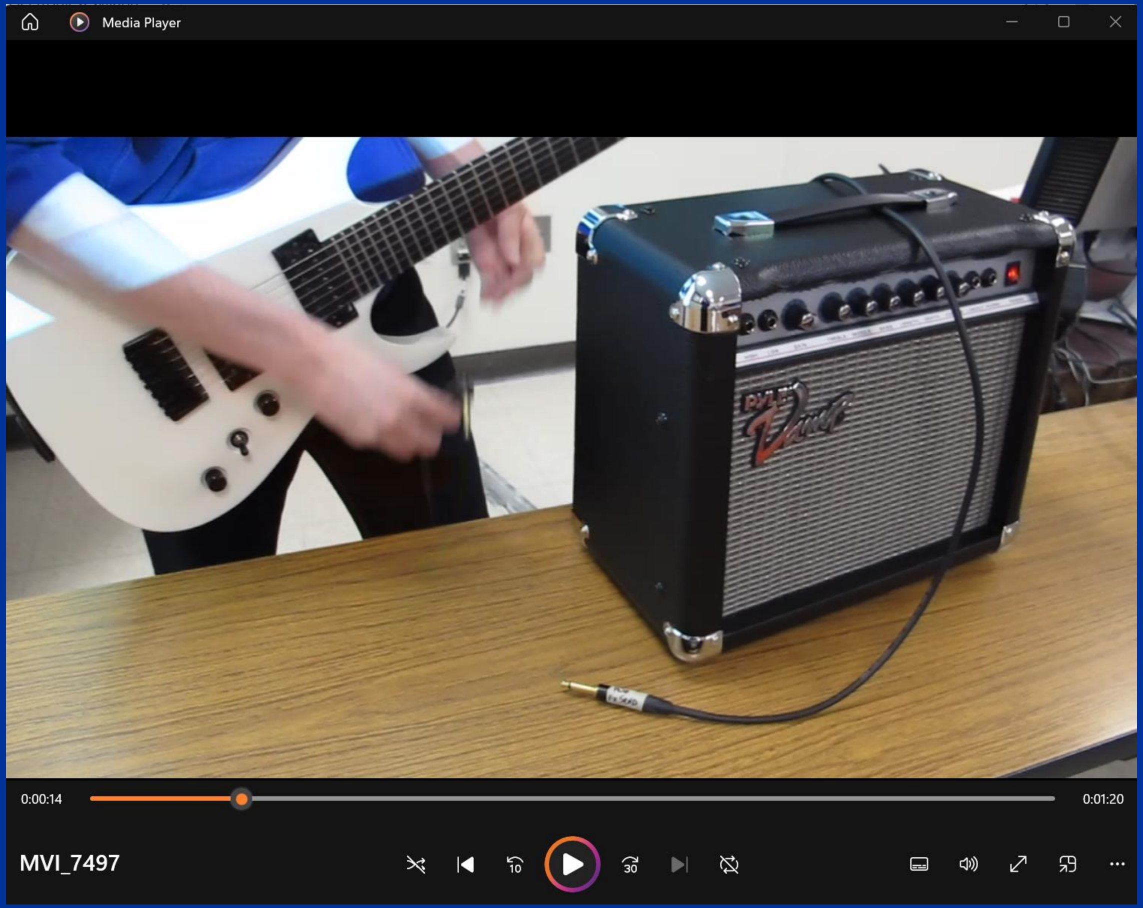




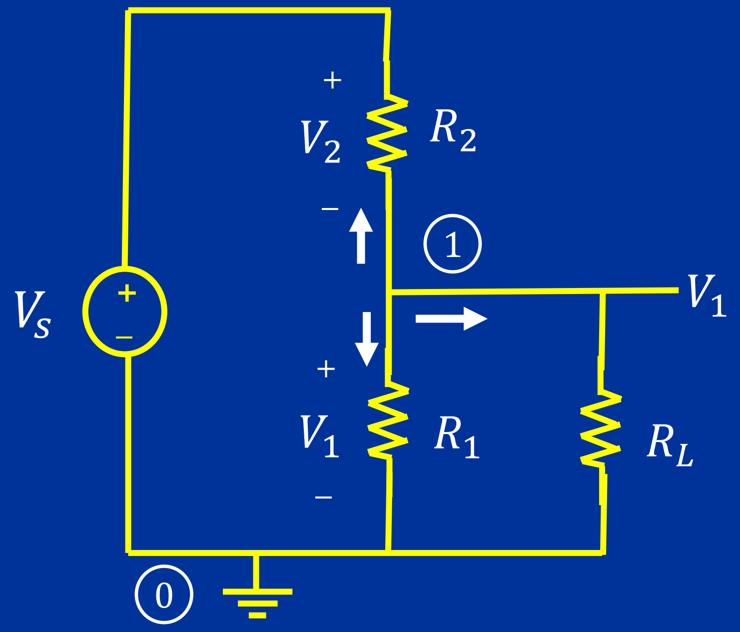
https://en.wikipedia.org/wiki/Potentiometer

Pots Used for Reverb and Tone Adjust Too



A More Complicated Example
(Loaded voltage-divider)

KCL-based "Nodal Analysis" at node 1 : $\sum I_{leaving-node-1} = 0$



$$(V_1 - V_s)\frac{1}{R_2} + V_1\left(\frac{1}{R_1} + \frac{1}{R_L}\right) = 0$$

$$\Rightarrow \boxed{V_1 = V_s \frac{1}{1 + \frac{R_2}{R_1} + \frac{R_2}{R_L}}}$$

Checks:

$R_2 \to 0 \;\Rightarrow\; V_1 = V_s$ ✓

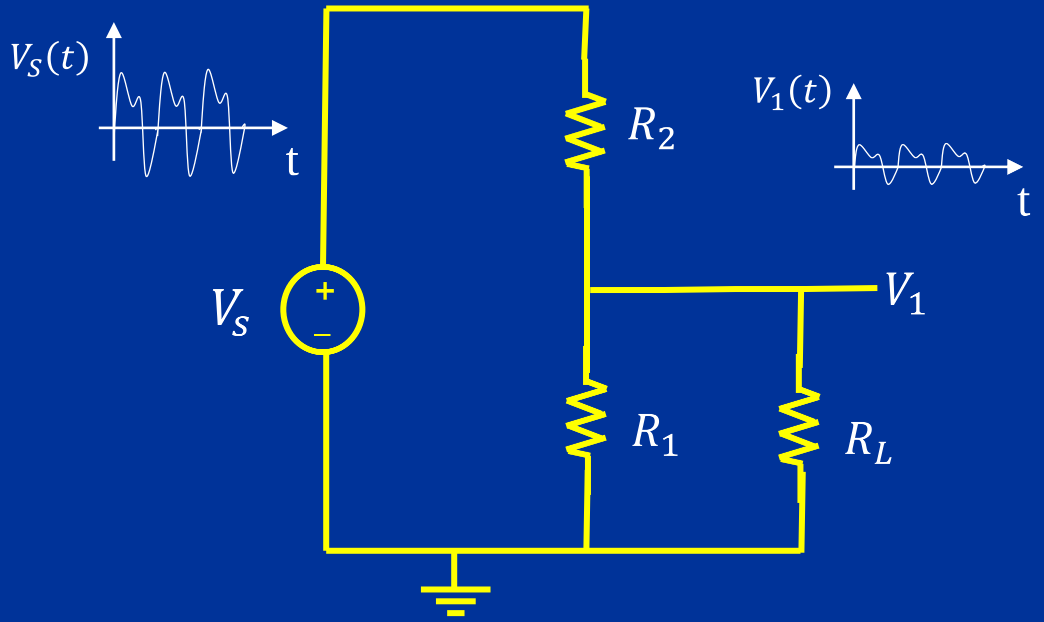
$R_L \to \infty \;\Rightarrow\; V_1 = V_s \frac{1}{1+\frac{R_2}{R_1}} = V_s \frac{R_1}{R_1+R_2}$ ✓

NOTE: Simulators such as SPICE handle large circuits using "Modified Nodal Analysis" and solve simultaneous equations using matrix math

But this isn't the most human-friendly, or insightful approach …

A "Better" Approach ☺

Leverage already known V-divider and Parallel-R results…



$$V_1 = V_S \frac{R_{eq}}{R_{eq} + R_2}$$

where $R_{eq} = R_1 \parallel R_L = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_L}\right)}$

NOTE: if $R_L \gg R_1$ then $R_{eq} \approx R_1$

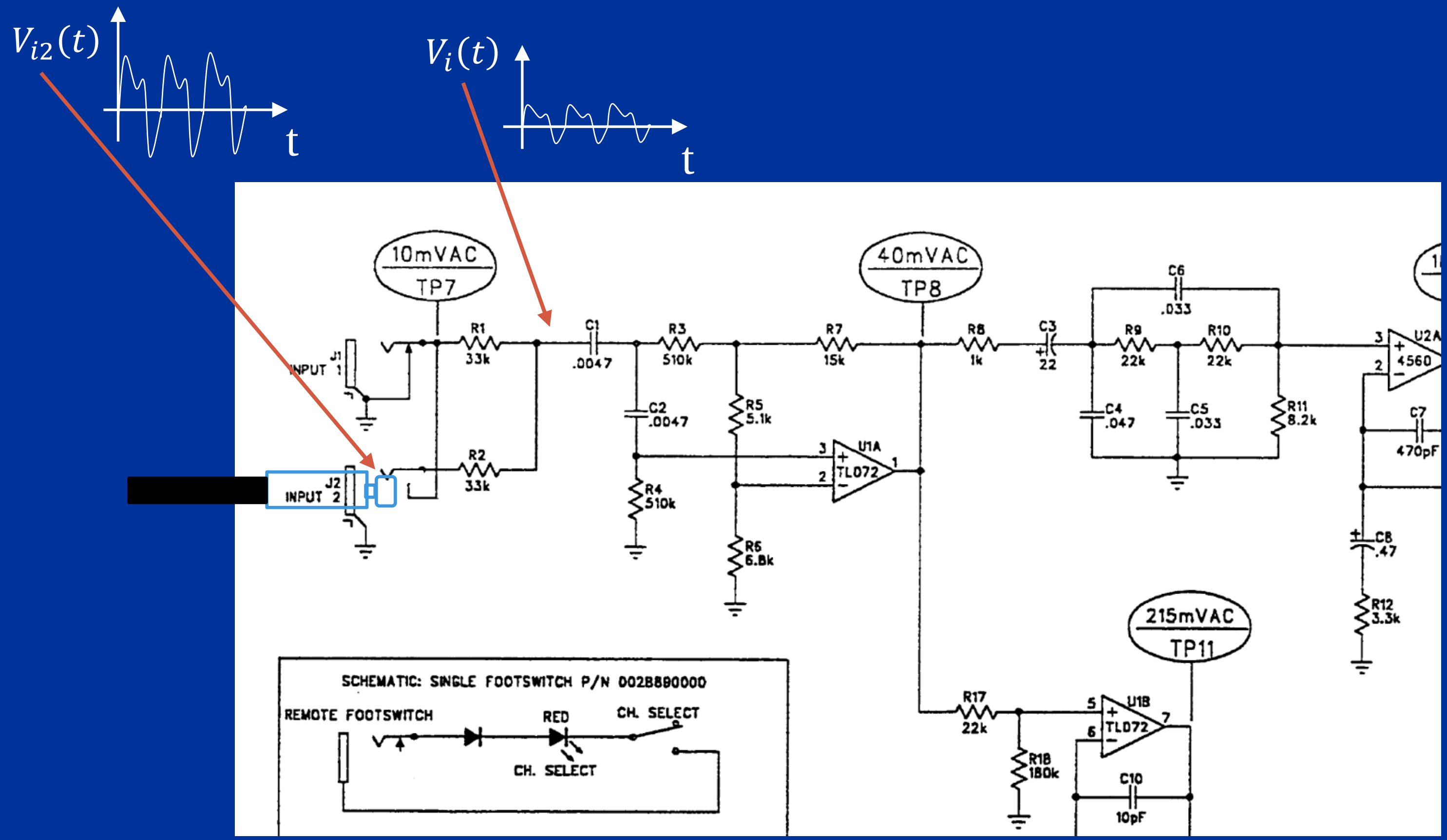
An important simplification !

These are additional results we can now add to our mental circuits catalog !

Real-World Circuits

Example: Fender "Champion 30" Guitar Amp

https://reverb.com/p/fender-champion-30-2-channel-30-watt-1x10-guitar-practice-amp-1999-2002



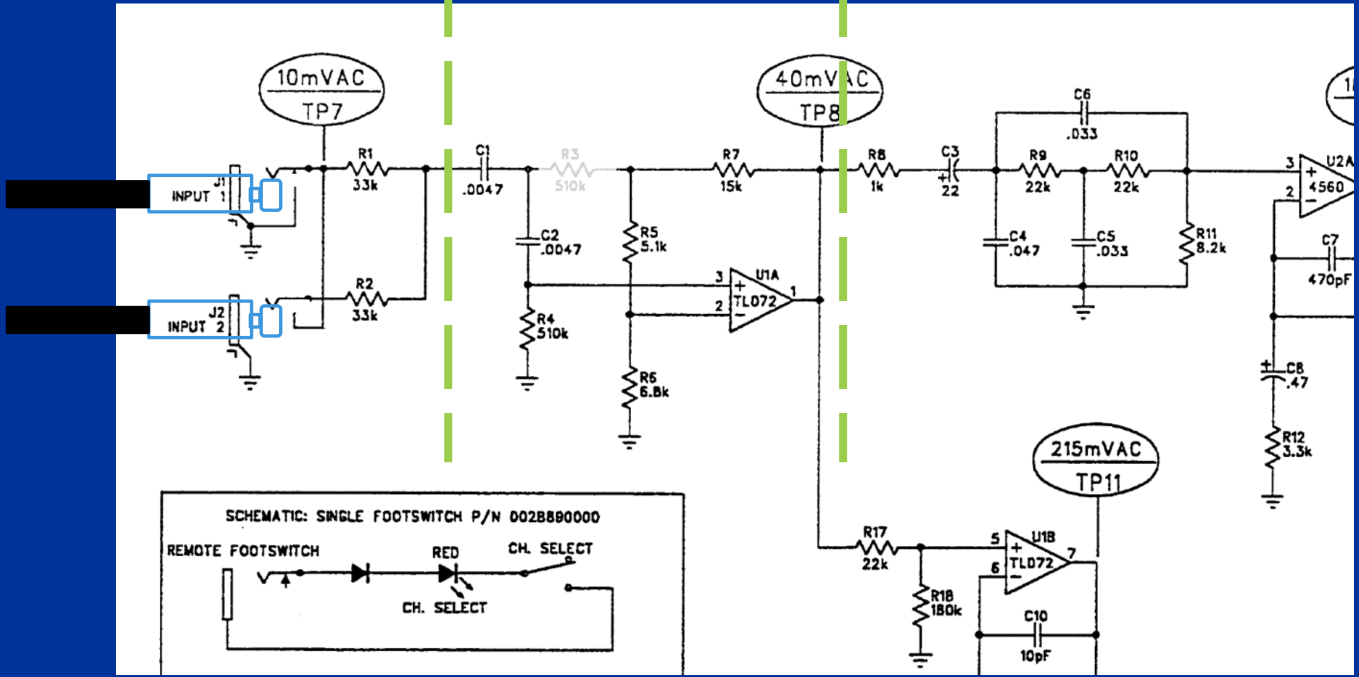
https://music-electronics-forum.com/filedata/fetch?id=832608

Parsing and *Understanding* Circuits

Example: Fender "Champion 30" Guitar Amp

https://reverb.com/p/fender-champion-30-2-channel-30-watt-1x10-guitar-practice-amp-1999-2002

Signal-Summing Circuit | Opamp-based Voltage amplifier | Frequency Response Shaping



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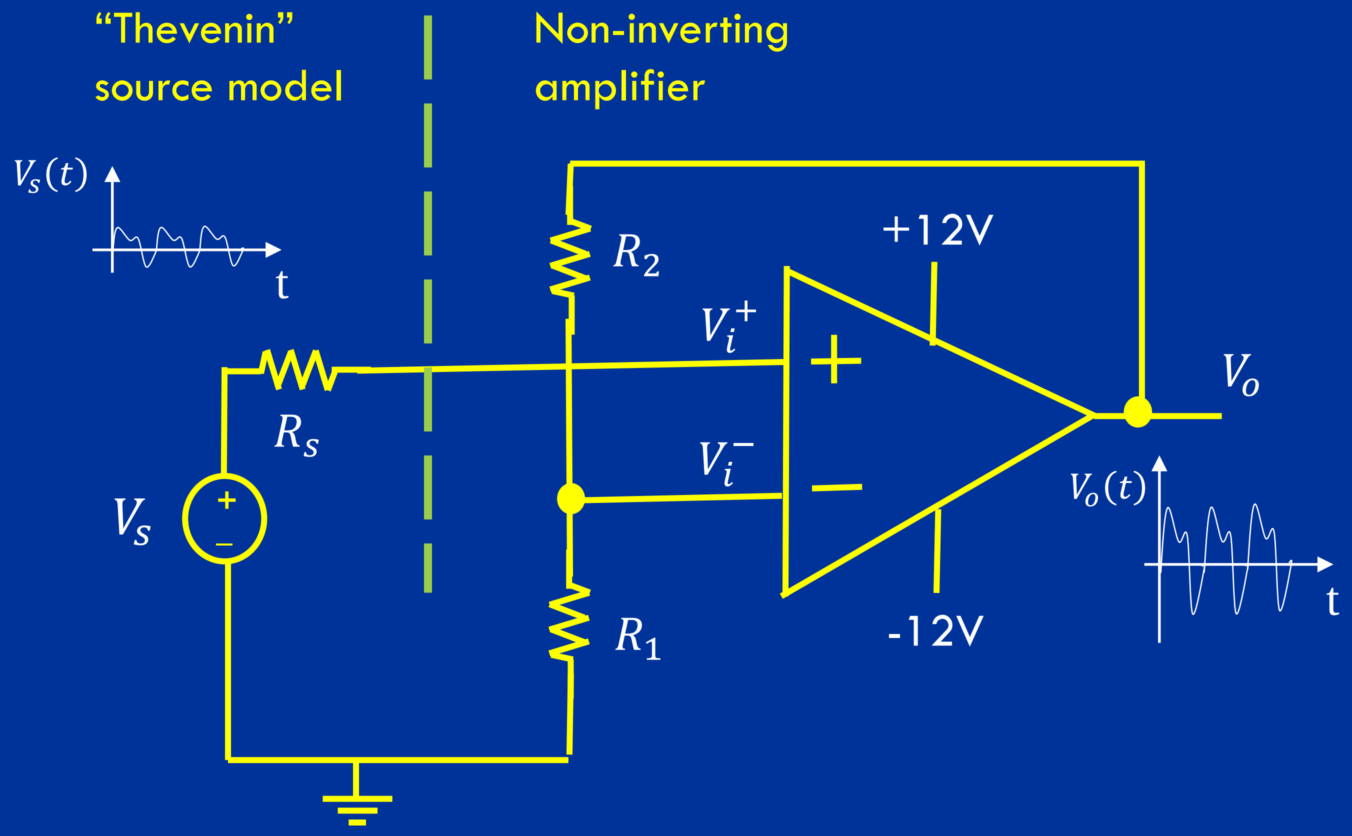
Non-inverting Opamp Voltage Gain Stage



Use known V-divider, $V_i^- = V_o \dfrac{R_1}{R_1 + R_2}$

and near-infinite "open-loop" gain approximation… $V_i^- \approx V_i^+$

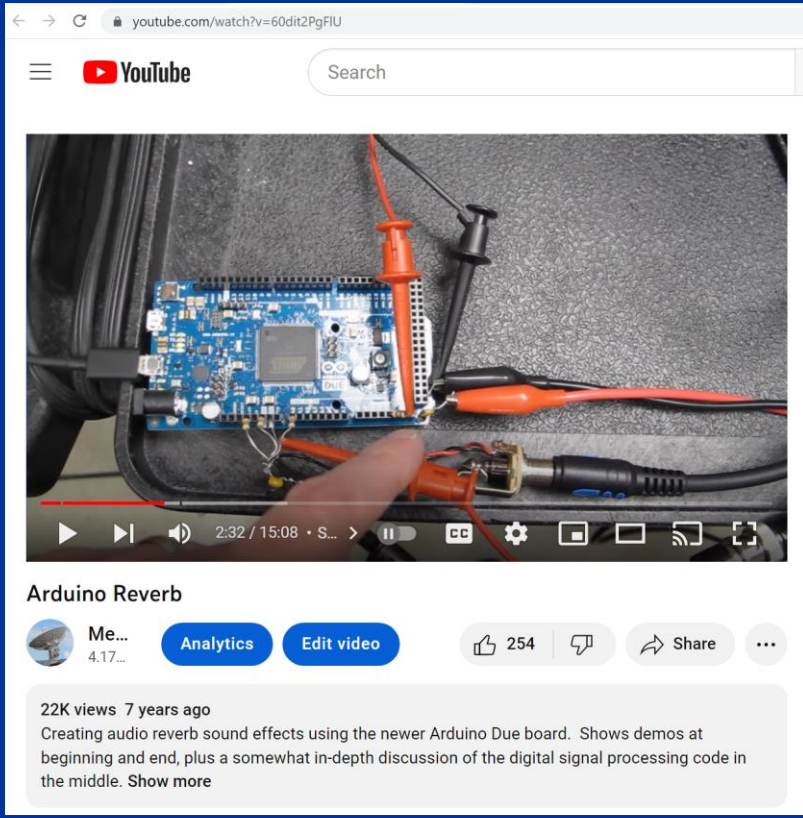
To find output, $\Rightarrow \quad V_o = V_i^+ \left(\dfrac{R_1 + R_2}{R_1}\right)$

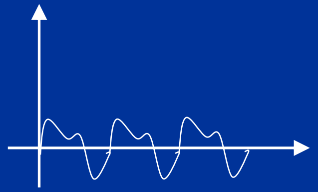
and "closed-loop" voltage gain: $\Rightarrow \quad A_v = \dfrac{V_o}{V_i} = \boxed{1 + \dfrac{R_2}{R_1}}$

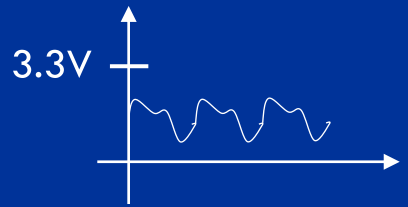
This is another common circuit, used in the amplifier example, with embellishment…

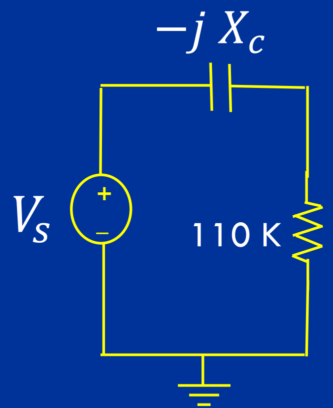
Designing New Circuits

Example: Audio Input Level-Shifter for Arduino





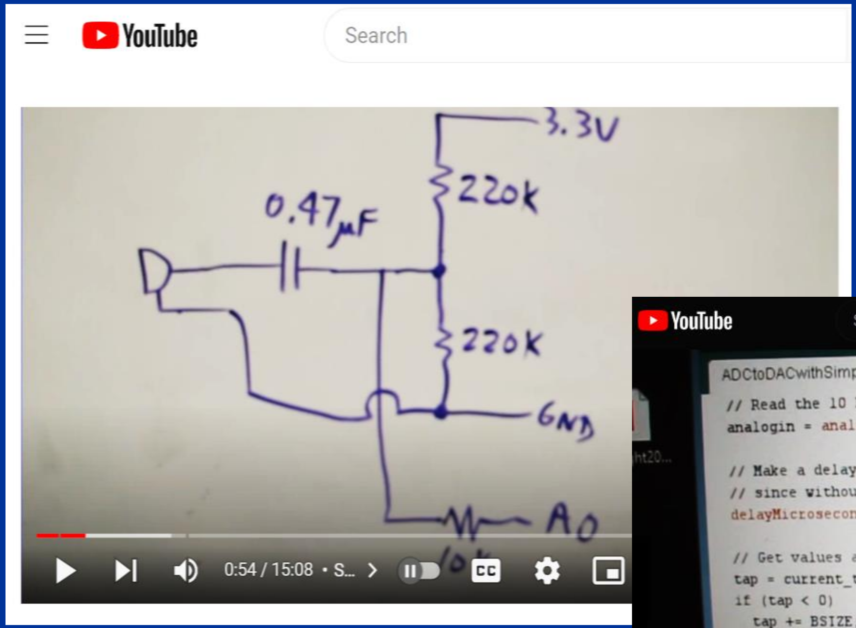


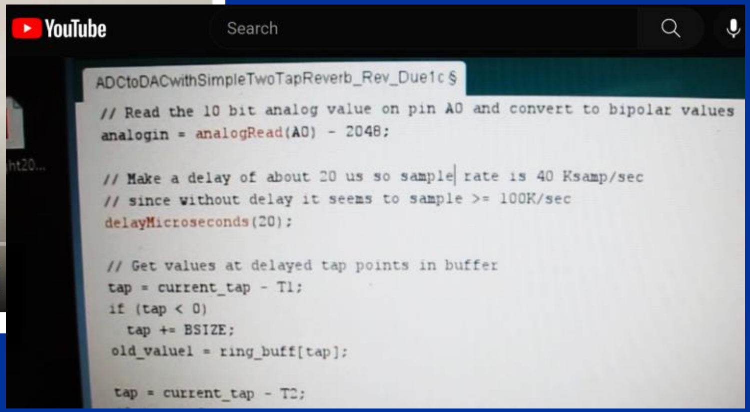


$$X_c = \frac{1}{2\pi f C}$$

$$f_c = \frac{1}{2\pi RC}$$

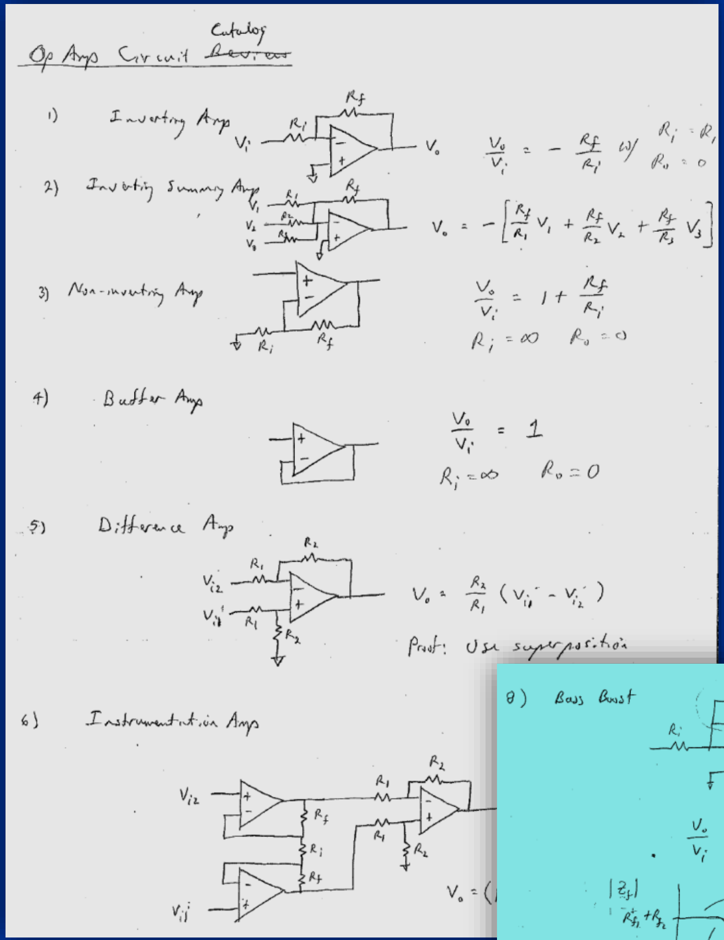
$$= 3 \text{ Hz}$$

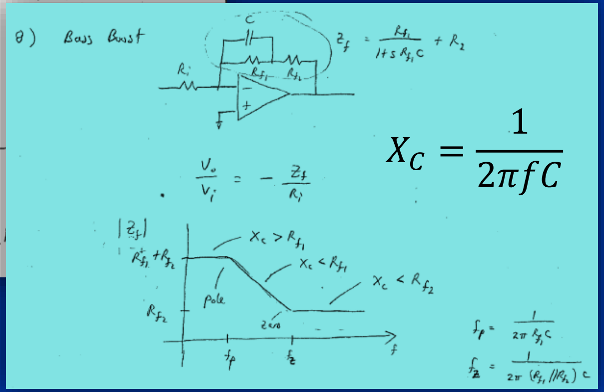




Possible Future Videos

- More circuit analysis techniques (e.g. Thevenin circuits and linearity)
- Opamp circuit catalog
- DC vs midband (AC) circuit analysis
- Complex impedances, frequency response, and Fourier analysis
- Power amps
- Power supplies, …





THANKS FOR WATCHING !