ECE Topics #4 and 4A - Circuit Understanding –

From Schematics to Block Diagrams

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

Companion videos at: https://www.youtube.com/watch?v=yn8CaEnt390 (Part 1)

And https://www.youtube.com/watch?v=8oGsBL6CHk4 (Part 2)

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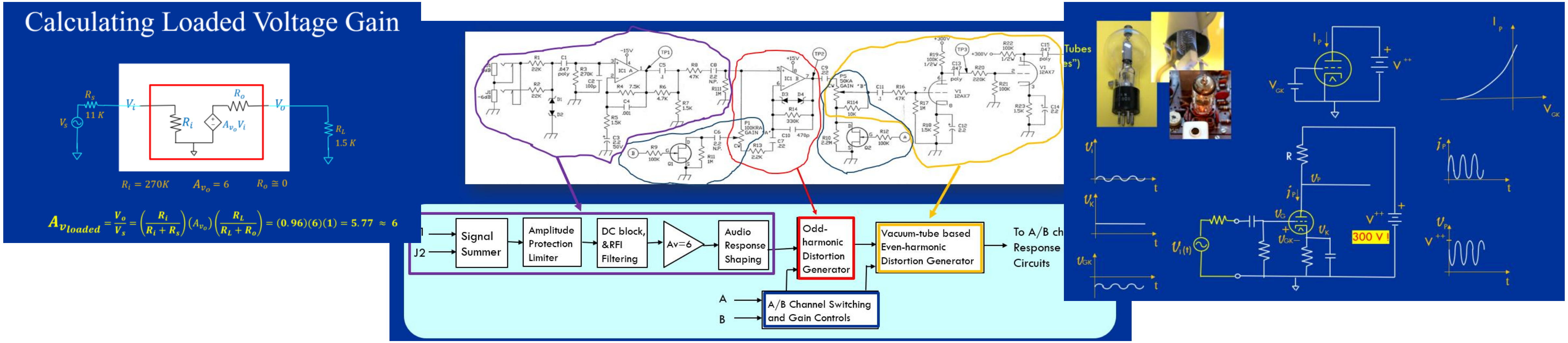
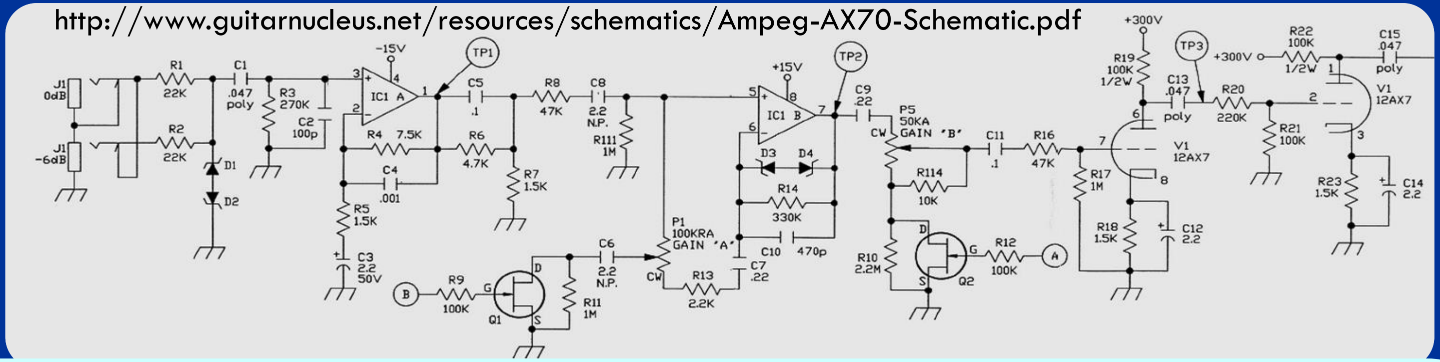
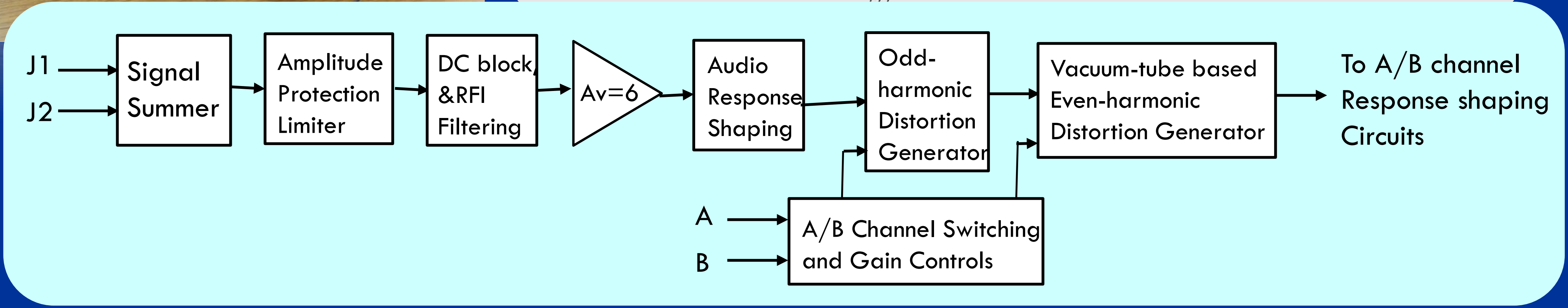
This episode continues our journey through circuit theory and beyond. The goal is to illuminate the key aspects of circuit analysis that practicing engineers use to understand circuits. Linearity and Thevenin's theorem are introduced, but the main focus is on how these can be used to parse analog schematics into block diagrams that show the functions of different parts of the circuit.



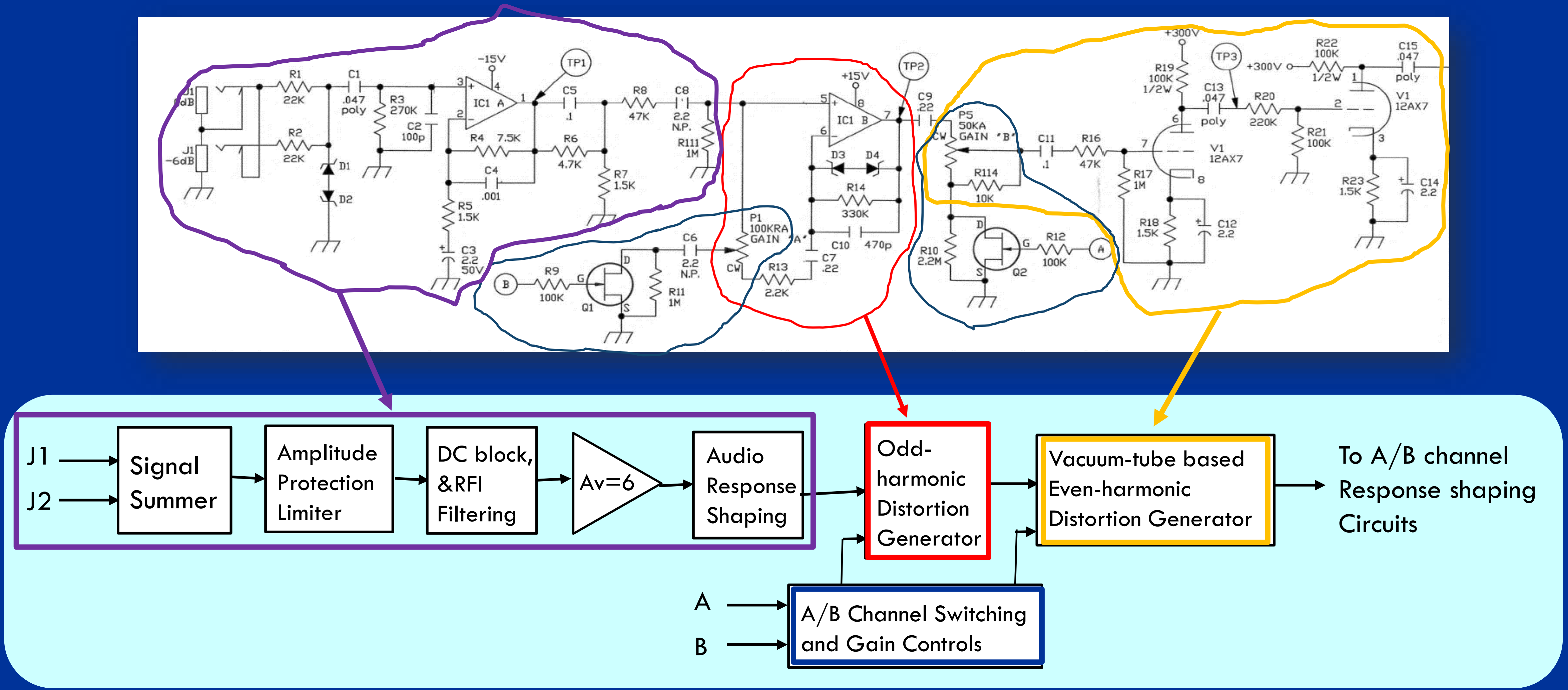
Topics in ECE #4

Understanding Circuits





Parsing Schematics into Block Diagrams

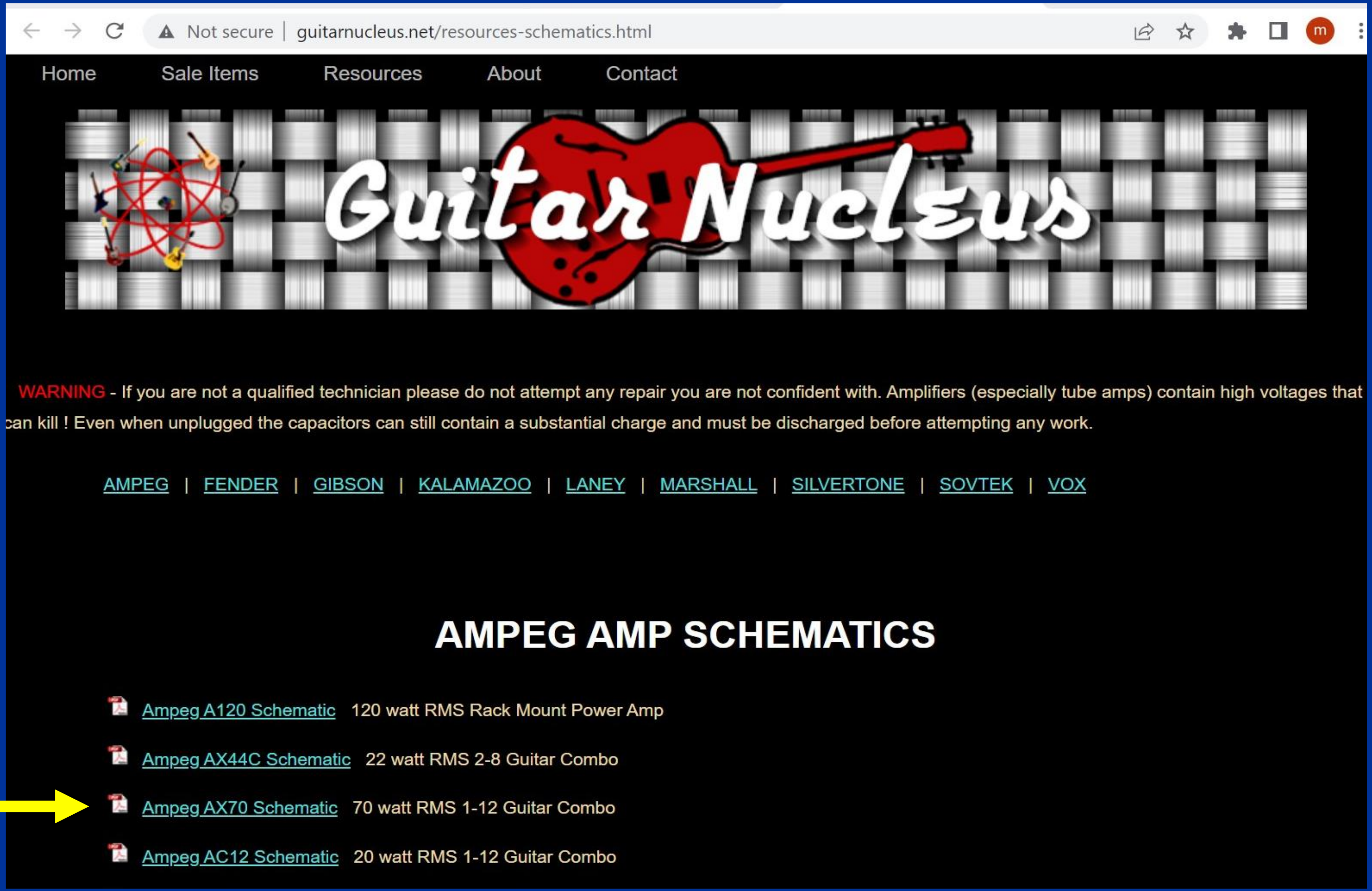


Today's Topics

- Prior Episode Review / Overview
- Linearity and Thevenin Equivalents
- Voltage Amplifiers (R_{in} A_{vo} R_{out} and $A_{v\text{-}loaded}$)
- Parsing Schematics into Block Diagrams
- Some Common Analog Subcircuits (Waveform clipping, RC Circuits, JFET switches, and Tube Amplifiers ☺)

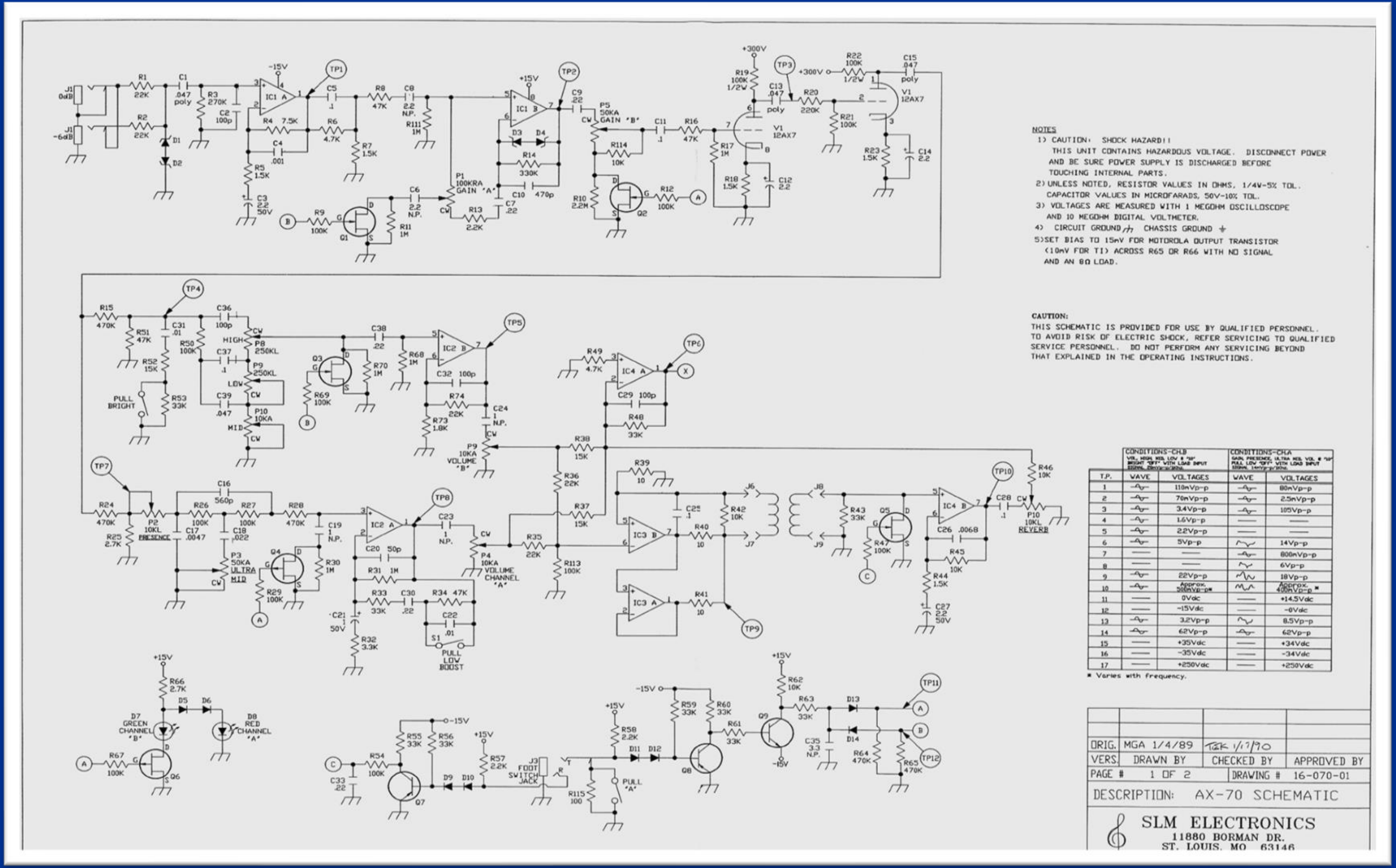
Finding Schematics

https://reverb.com/p/ampeg-ss-70c-2-channel-70-watt-2x10-guitar-combo



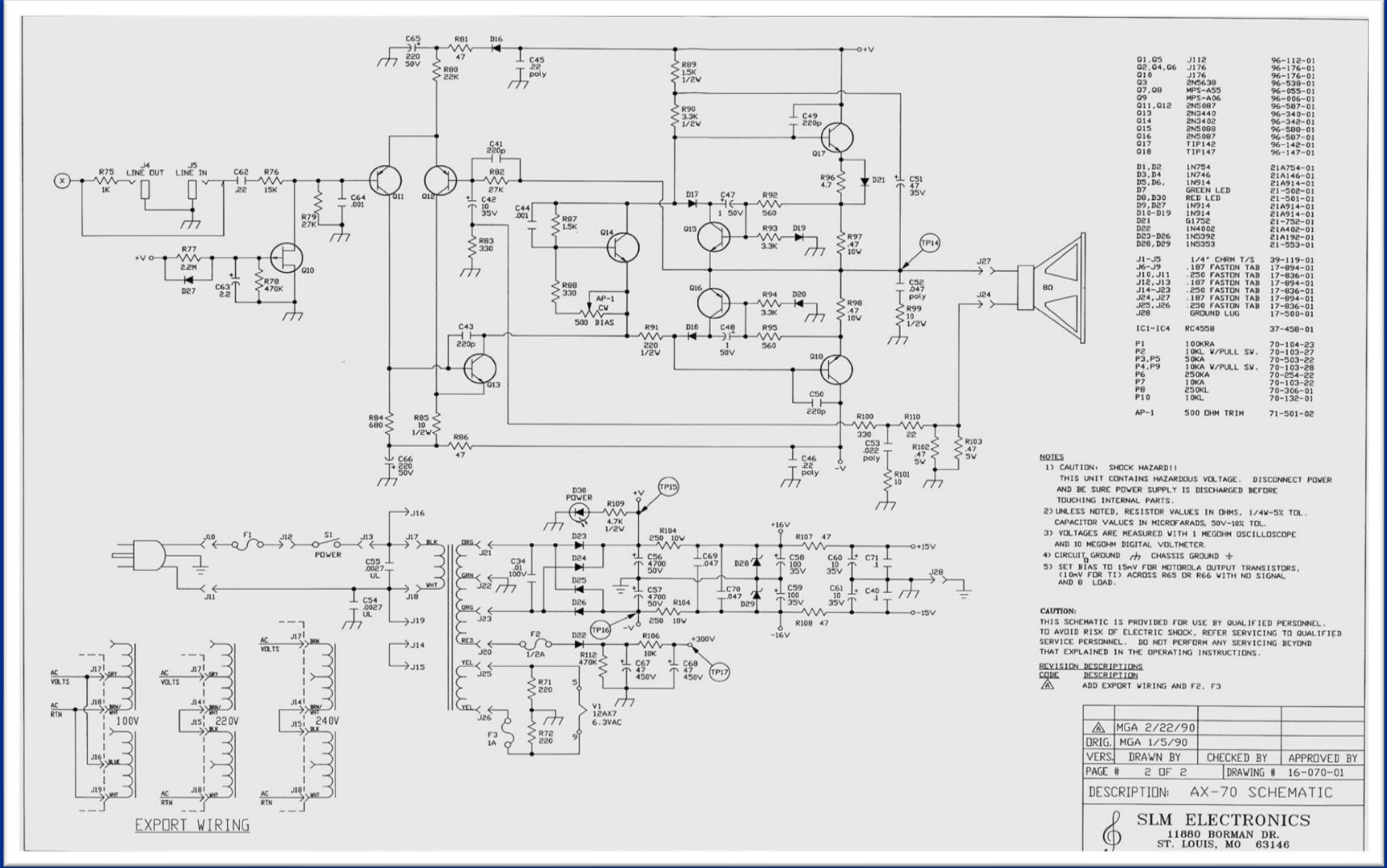
http://www.guitarnucleus.net/index.html

Today's Goal: Understand This One:



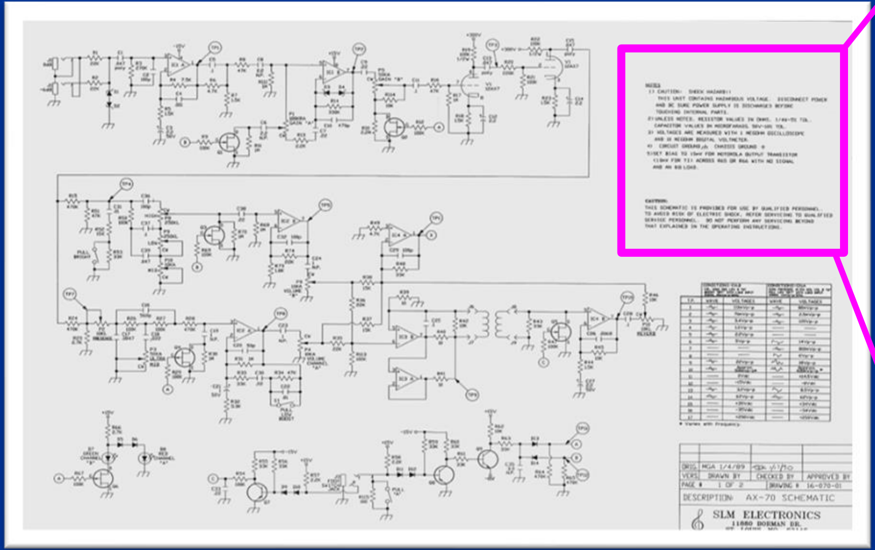
http://www.guitarnucleus.net/resources/schematics/Ampeg-AX70-Schematic.pdf

And This … ?

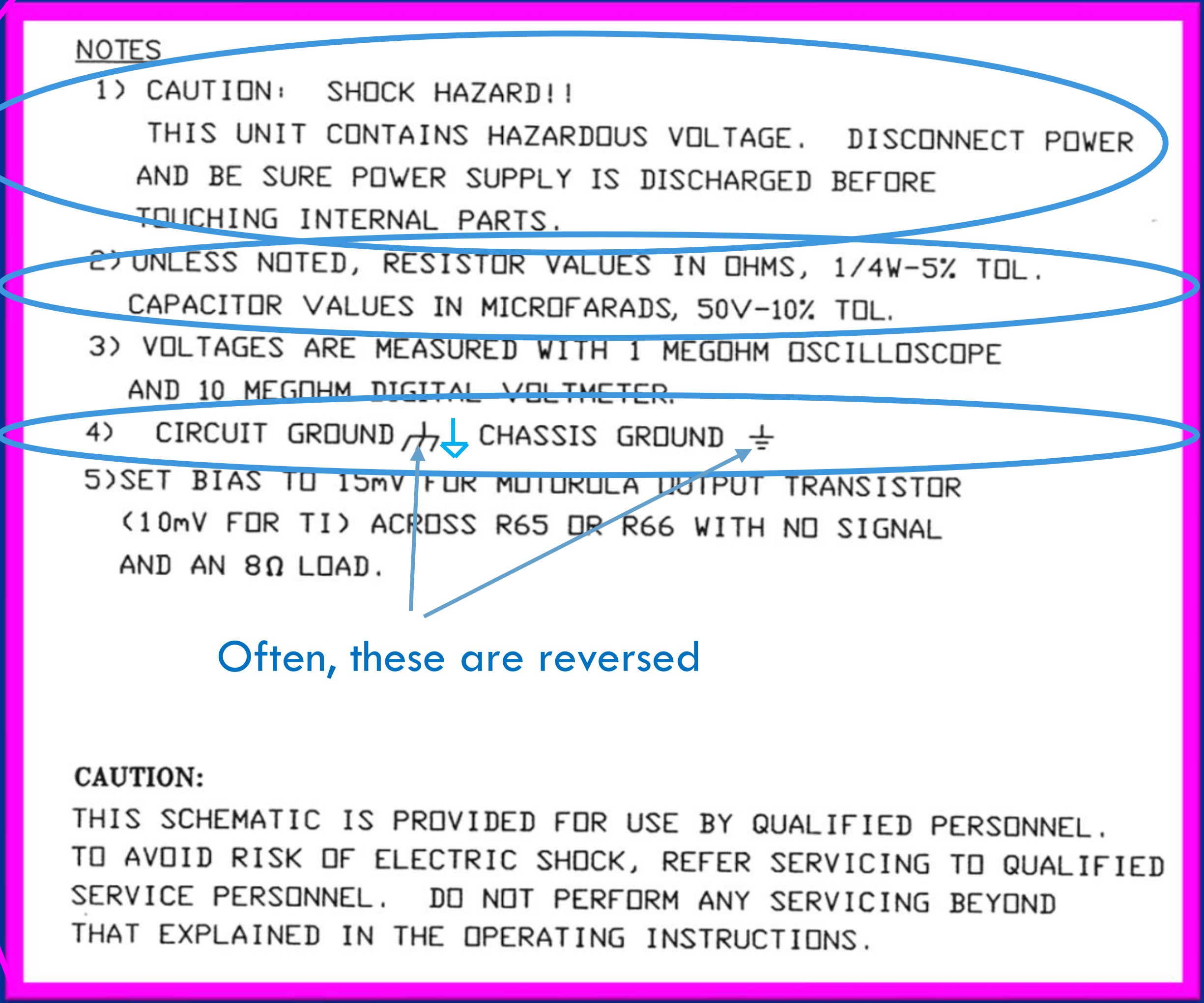


http://www.guitarnucleus.net/resources/schematics/Ampeg-AX70-Schematic.pdf

Important Notes



http://www.guitarnucleus.net/resources/schematics/Ampeg-AX70-Schematic.pdf



NOTES

1) CAUTION: SHOCK HAZARD!!
THIS UNIT CONTAINS HAZARDOUS VOLTAGE. DISCONNECT POWER AND BE SURE POWER SUPPLY IS DISCHARGED BEFORE TOUCHING INTERNAL PARTS.

2) UNLESS NOTED, RESISTOR VALUES IN OHMS, 1/4W-5% TOL.
CAPACITOR VALUES IN MICROFARADS, 50V-10% TOL.

3) VOLTAGES ARE MEASURED WITH 1 MEGOHM OSCILLOSCOPE AND 10 MEGOHM DIGITAL VOLTMETER.

4) CIRCUIT GROUND ⏚ CHASSIS GROUND ⏚

5) SET BIAS TO 15mV FOR MOTOROLA OUTPUT TRANSISTOR (10mV FOR TI) ACROSS R65 OR R66 WITH NO SIGNAL AND AN 8Ω LOAD.

CAUTION:
THIS SCHEMATIC IS PROVIDED FOR USE BY QUALIFIED PERSONNEL. TO AVOID RISK OF ELECTRIC SHOCK, REFER SERVICING TO QUALIFIED SERVICE PERSONNEL. DO NOT PERFORM ANY SERVICING BEYOND THAT EXPLAINED IN THE OPERATING INSTRUCTIONS.

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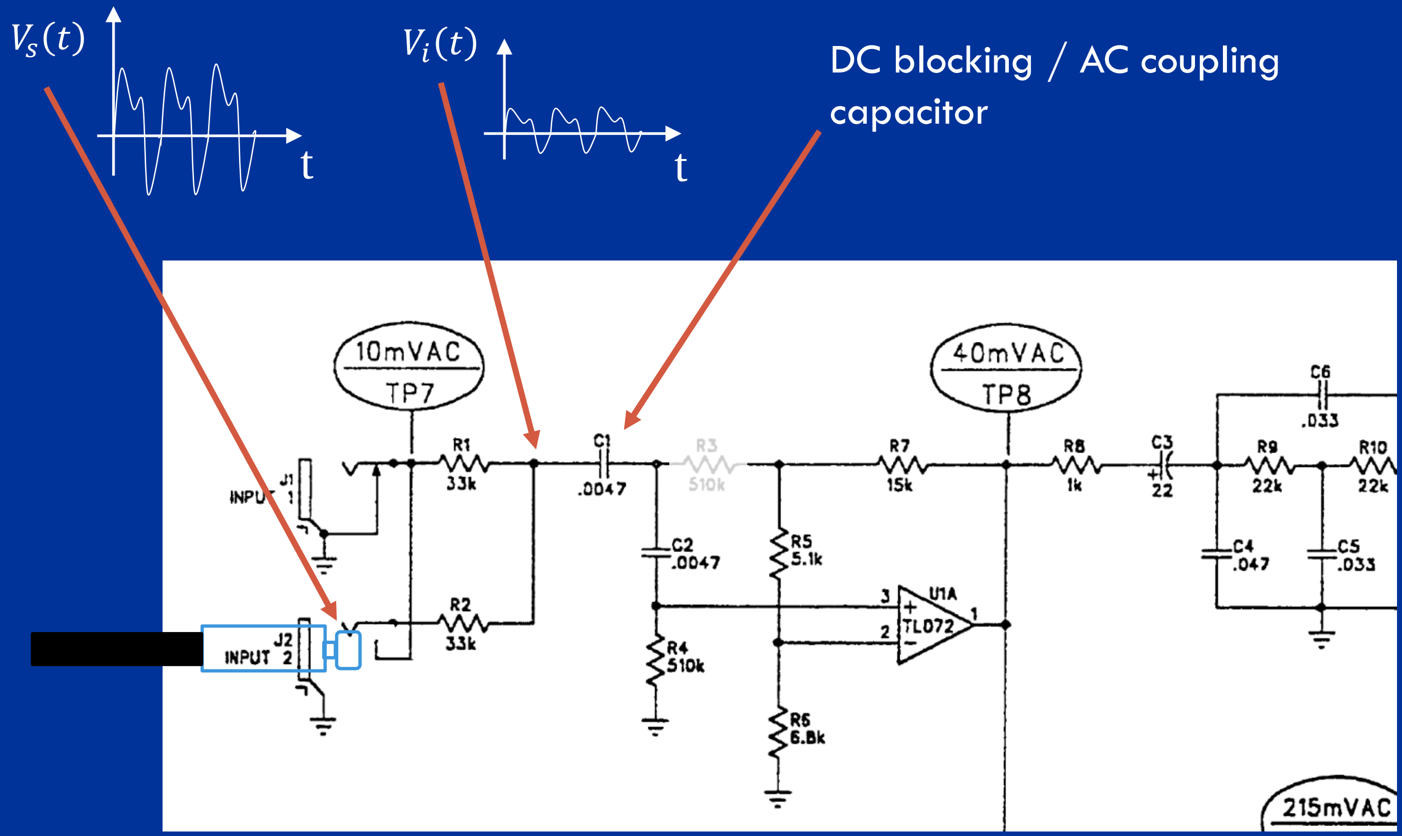
A Quick Review

Example: Fender “Champion 30” Guitar Amp

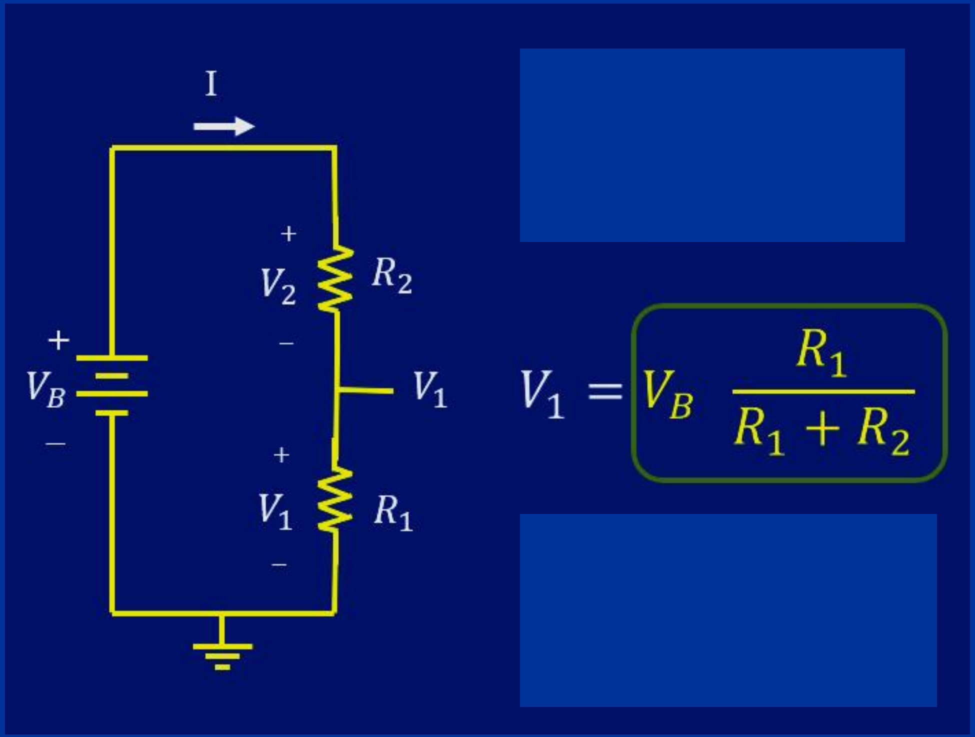
https://reverb.com/p/fender-champion-30-2-channel-30-watt-1x10-guitar-practice-amp-1999-2002



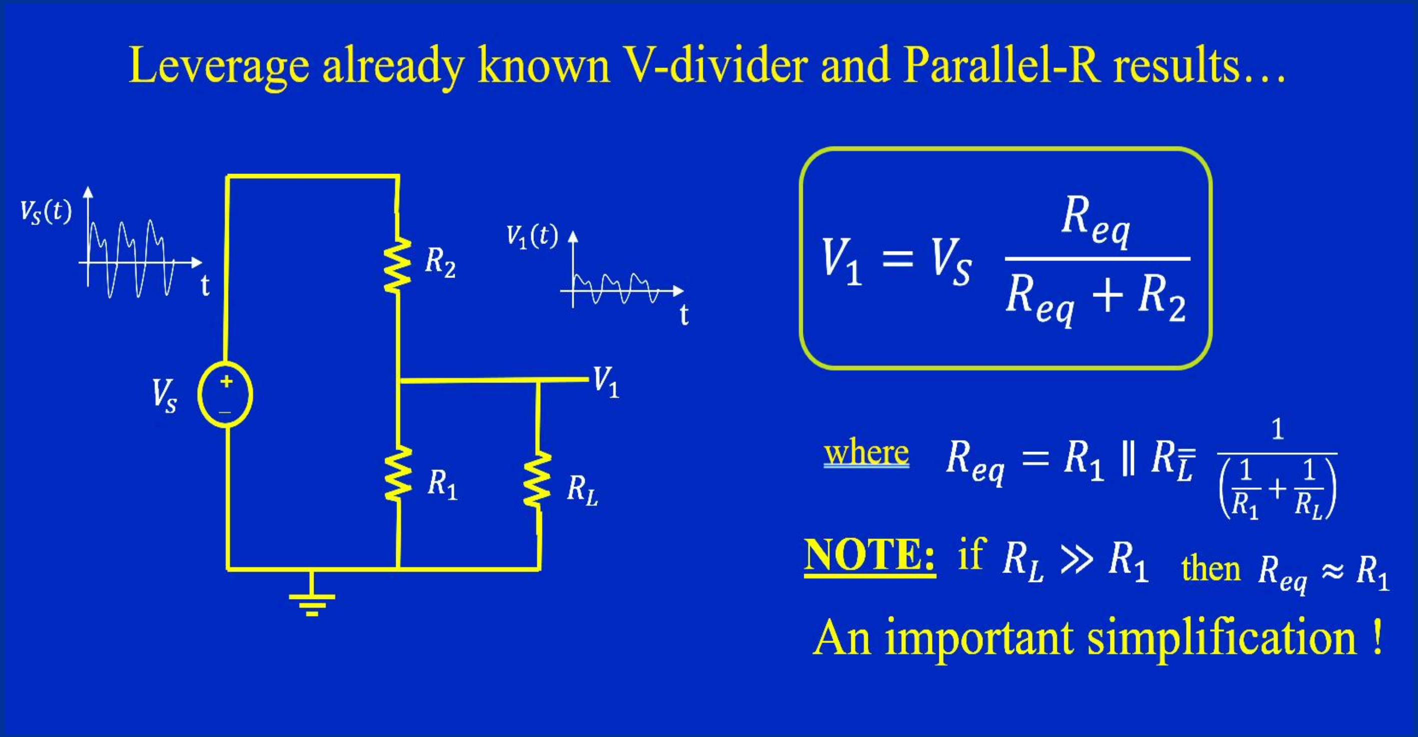
https://music-electronics-forum.com/filedata/fetch?id=832608

Voltage Divider Circuits

Voltage Divider concept



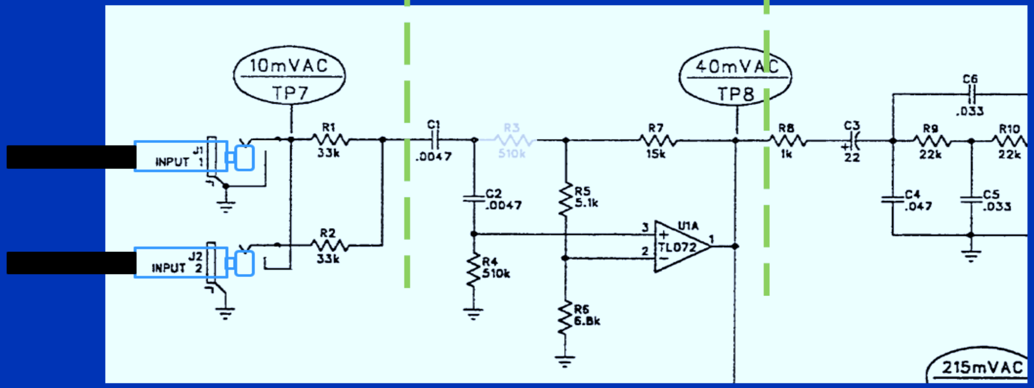
Loaded Voltage Divider, and using engineering approximations in analysis



Parsing into Functional Blocks

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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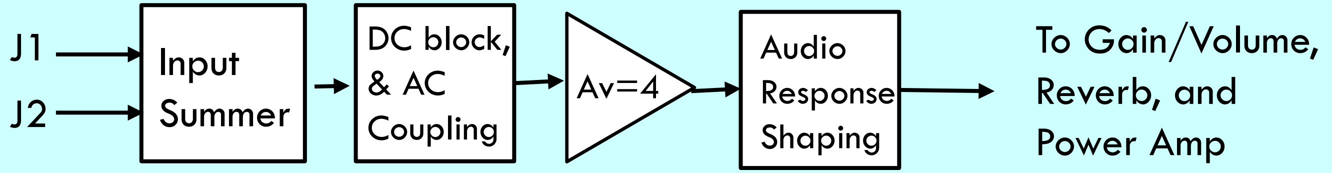

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Linearity and Thevenin Equivalents

For "linear circuits",

Output can be found by …

- Finding output from each individual source, with other source values set to zero
- Adding the individual outputs together

A "Thevenin" equivalent circuit:

- Can replace a complex linear circuit with a simpler one, to help in understanding
- Consists of a voltage source in series with a source impedance

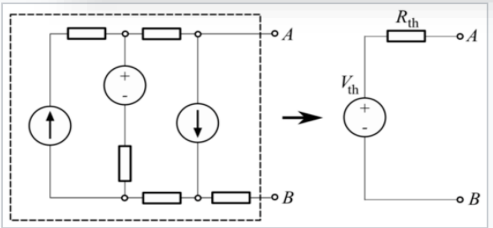
en.wikipedia.org/wiki/Thévenin%27s_theorem

Thévenin's theorem

Article Talk

From Wikipedia, the free encyclopedia

As originally stated in terms of direct-current resistive circuits only, **Thévenin's theorem** states that *"Any linear electrical network containing only voltage sources, current sources and resistances can be replaced at terminals A–B by an equivalent combination of a voltage source V_{th} in a series connection with a resistance R_{th}."*

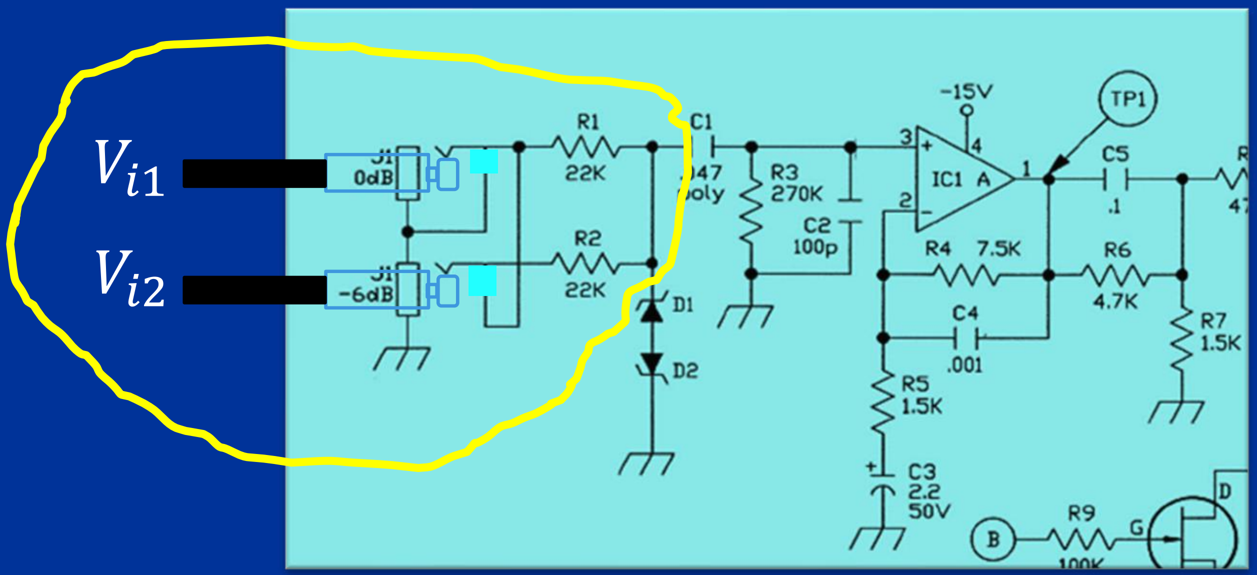


Any black box containing only resistances, voltage sources and current sources, can be replaced by a Thévenin equivalent circuit consisting of an equivalent voltage source in series connection with an equivalent resistance.

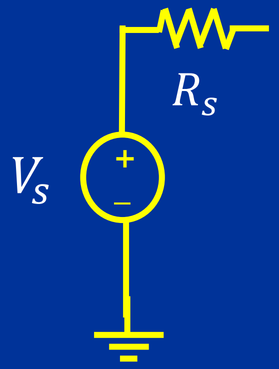
- The equivalent voltage V_{th} is the voltage obtained at terminals A–B of the network with terminals A–B open circuited.
- The equivalent resistance R_{th} is the resistance that the circuit between terminals A and B would have if all ideal voltage sources in the circuit were replaced by a short circuit and all ideal current sources were replaced by an open circuit.

https://en.wikipedia.org/wiki/Th%C3%A9venin%27s_theorem

Linearity and Thevenin Equivalents



"Thevenin" source model of circled section of circuit



$$V_s \cong \frac{1}{2}V_{i1} + \frac{1}{2}V_{i2}$$

$$R_s \cong 11K$$

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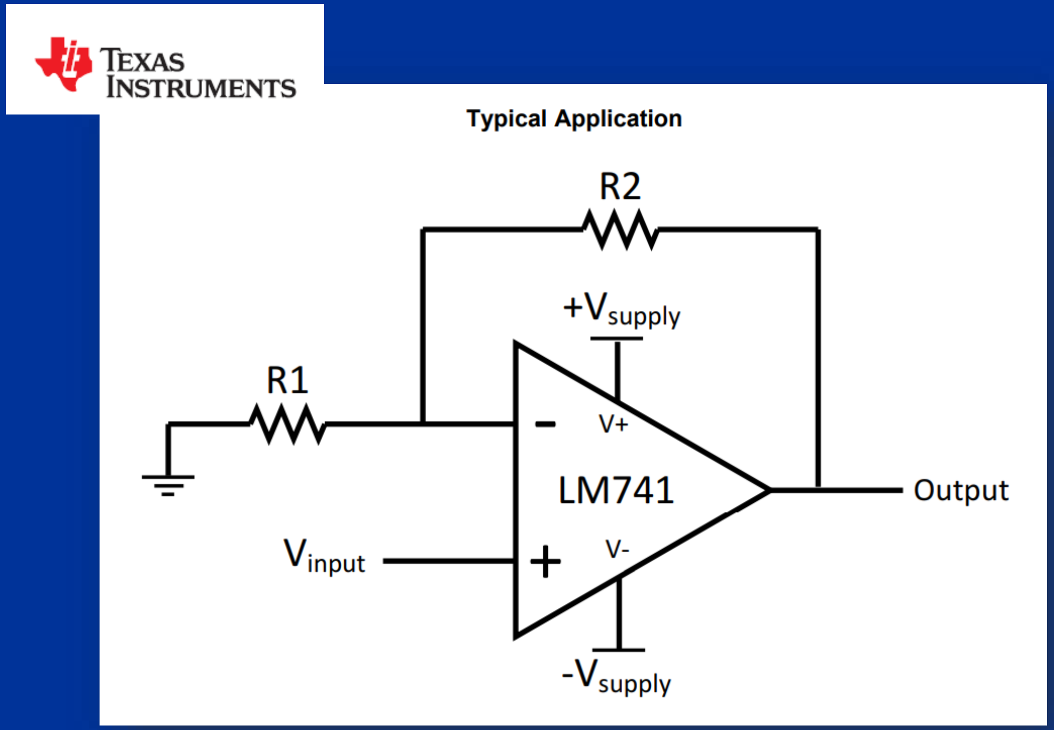
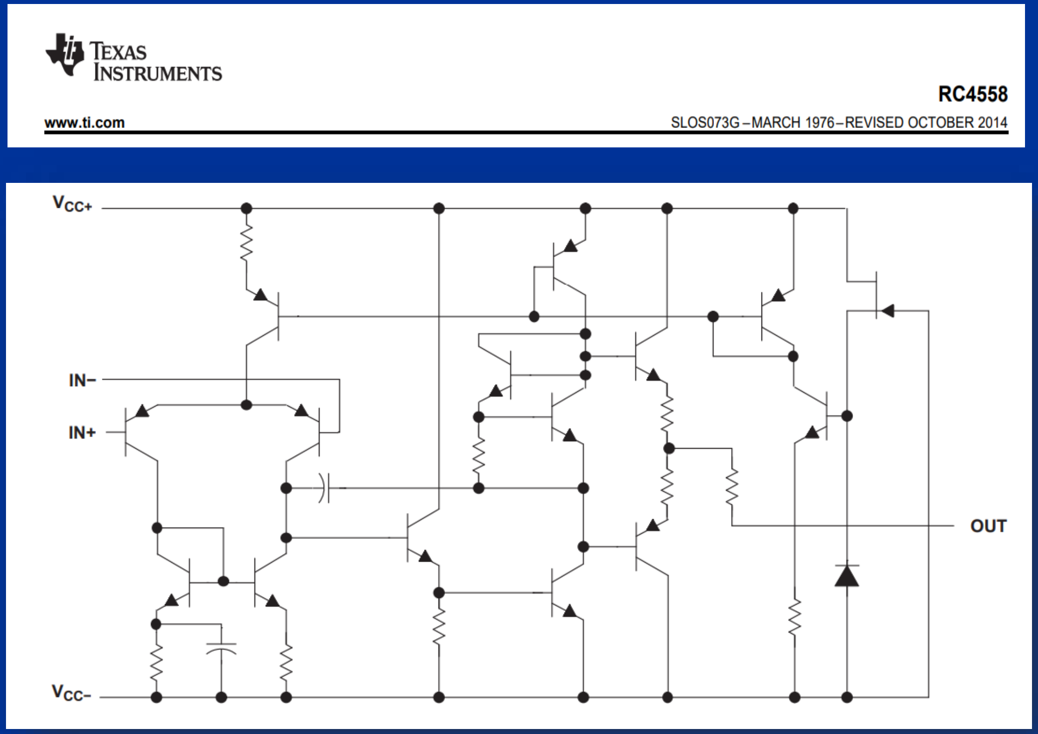
Operational Amplifiers (Opamps)

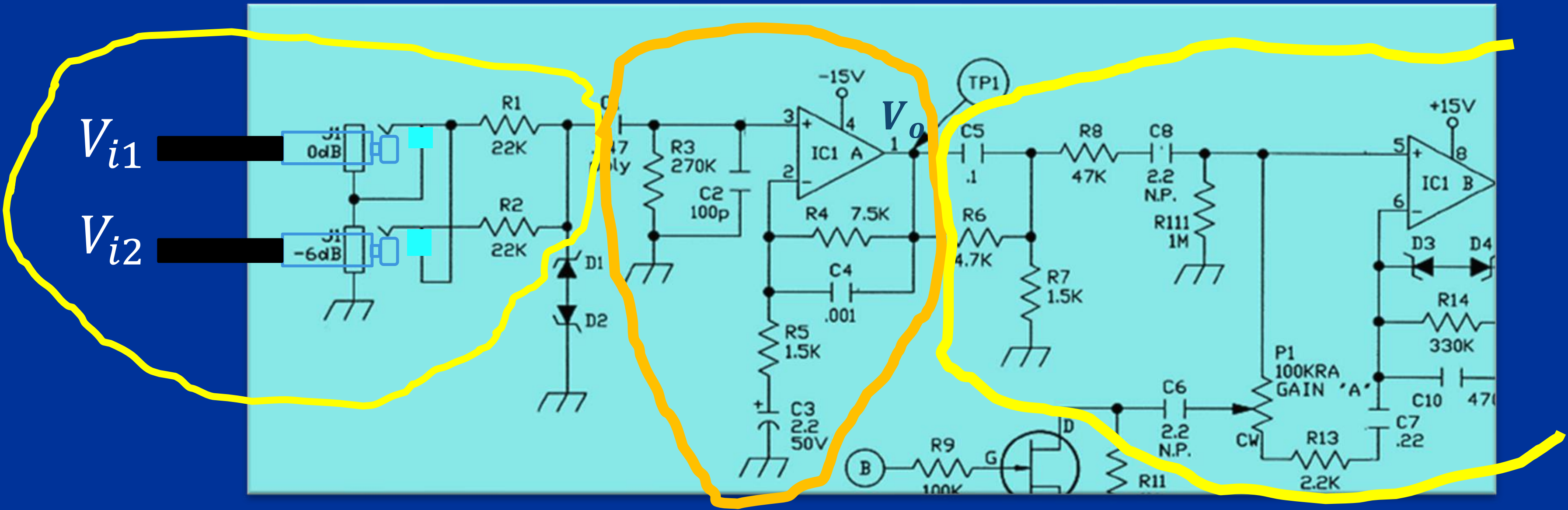


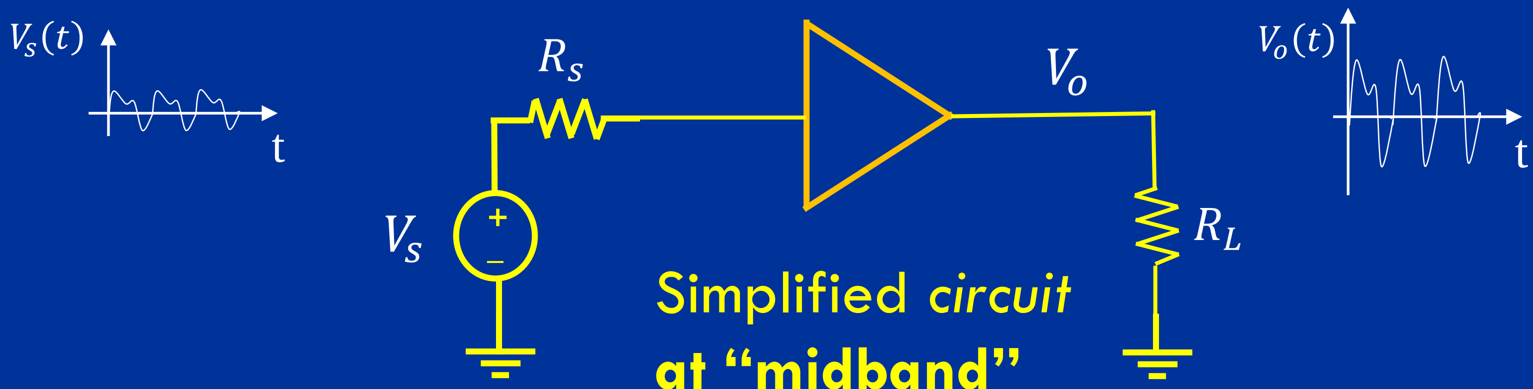


NOTE

- Classic, dual-supply devices shown
- Better performance devices exist today

Amplifier Gain Stage



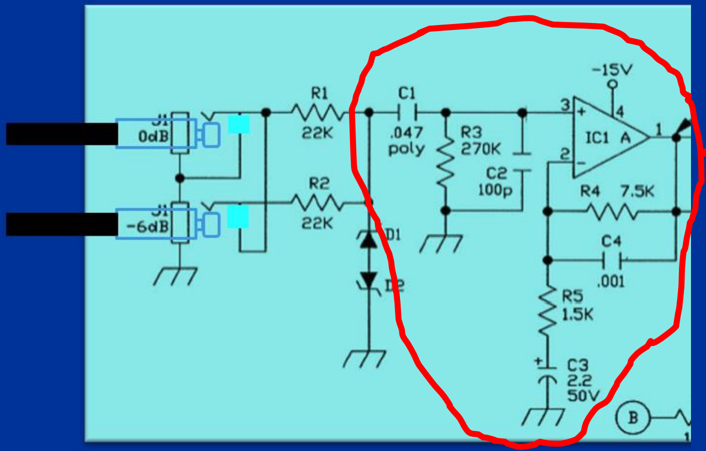


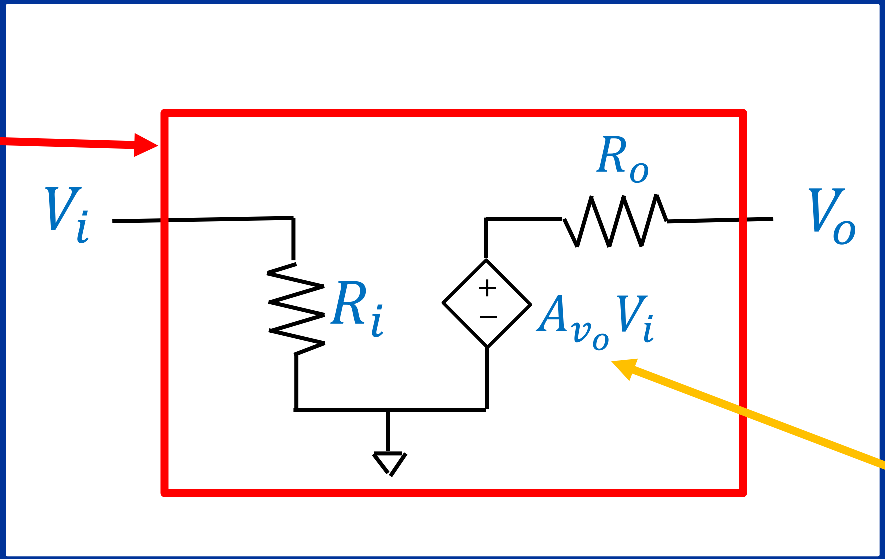
Simplified *circuit*
at "midband"

Gain Stage Equivalent Circuit

V_{i1}

V_{i2}





Simplified *equivalent circuit* **at "midband"**, based on Thevenin's theorem

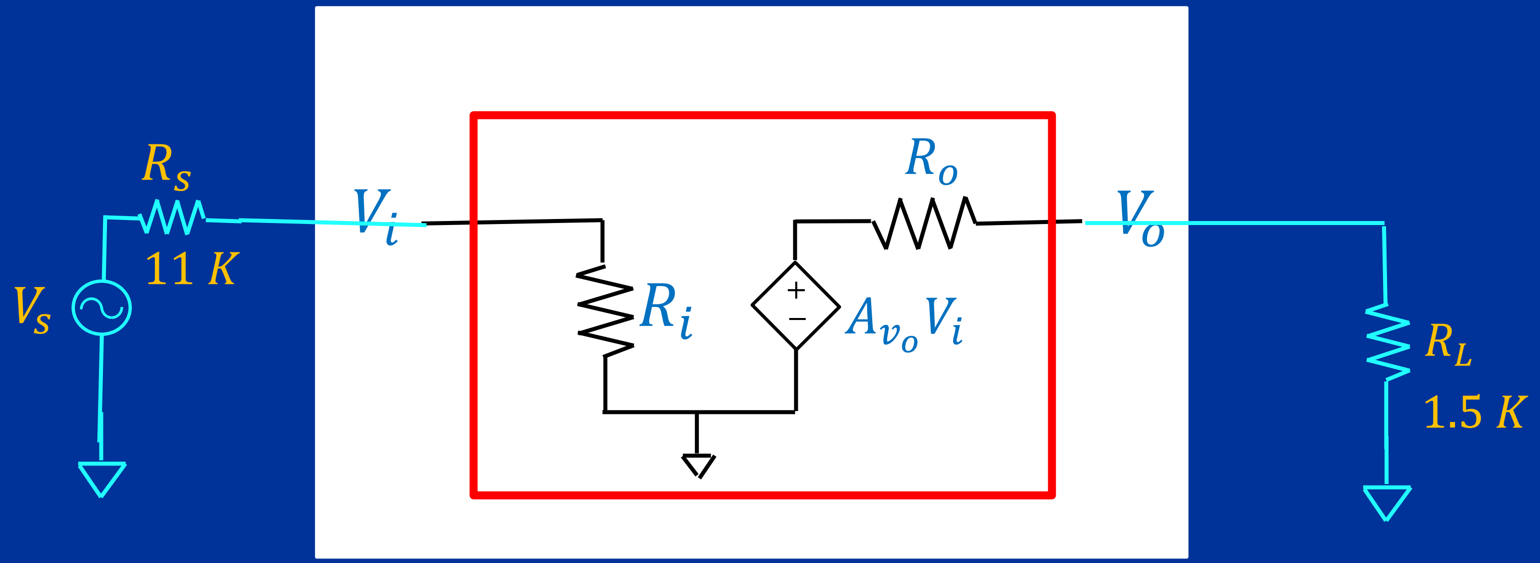
$R_i = 270K$

$R_o \cong 0$

$$A_{v_o} = \frac{V_o}{V_i} = \left(1 + \frac{R_4}{R_5}\right) = 6$$

- In general, R_i, R_o, and A_{vo} depend on amplifier device, circuit configuration, and biasing
- Should use Z_i, Z_o, and complex $A_{vo}(f)$, but this simplified treatment is sufficient **at midband**
- **We typically want R_i large, and R_o small. Why ?**

Calculating Loaded Voltage Gain



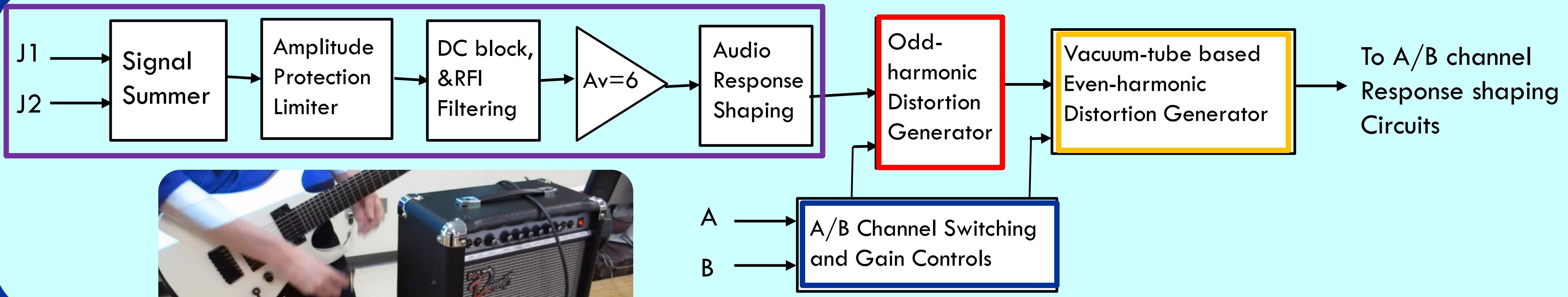
$R_i = 270K$ $\quad A_{v_o} = 6$ $\quad R_o \cong 0$

$$A_{v_{loaded}} = \frac{V_o}{V_s} = \left(\frac{R_i}{R_i + R_s}\right)(A_{v_o})\left(\frac{R_L}{R_L + R_o}\right) = (0.96)(6)(1) = 5.77 \approx 6$$

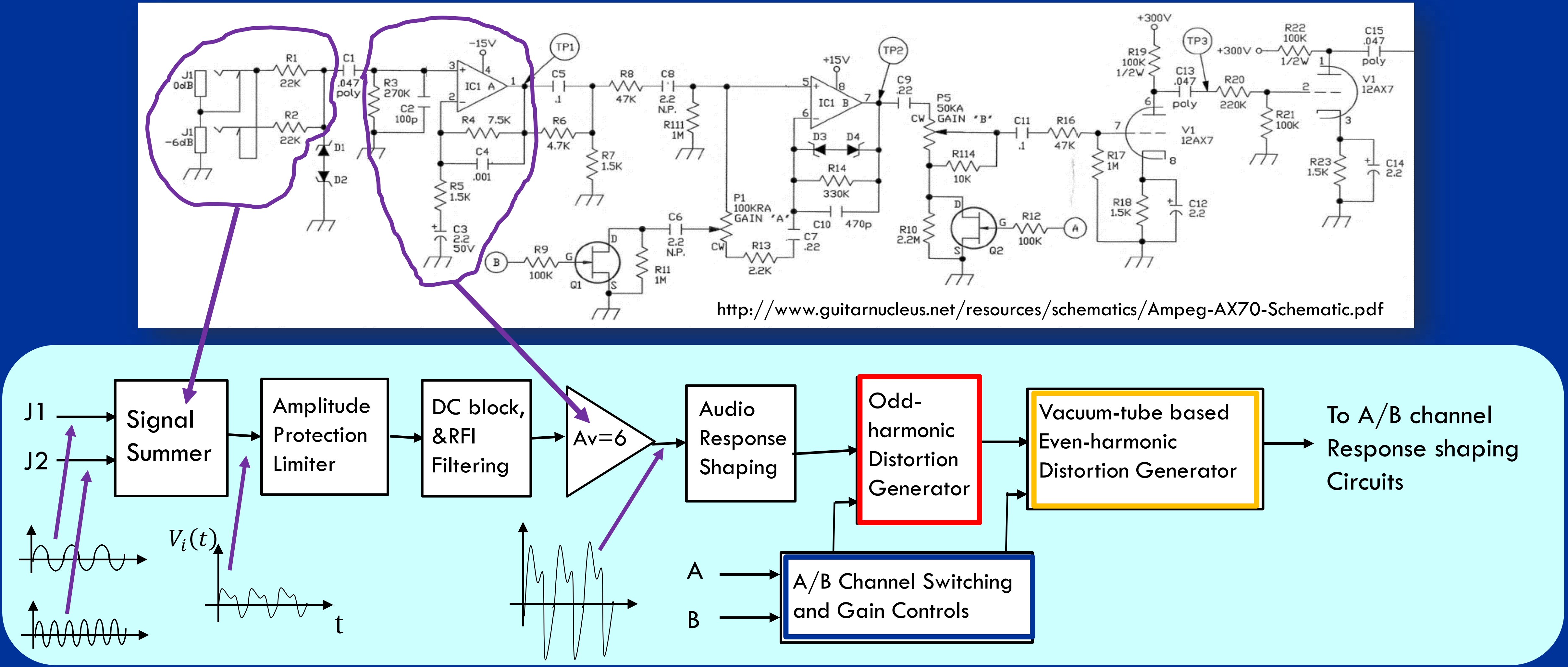
Topics in ECE #4A

Understanding Circuits

(Part 2 – Schematics to Block Diagrams)



Circuits Covered in Part 1

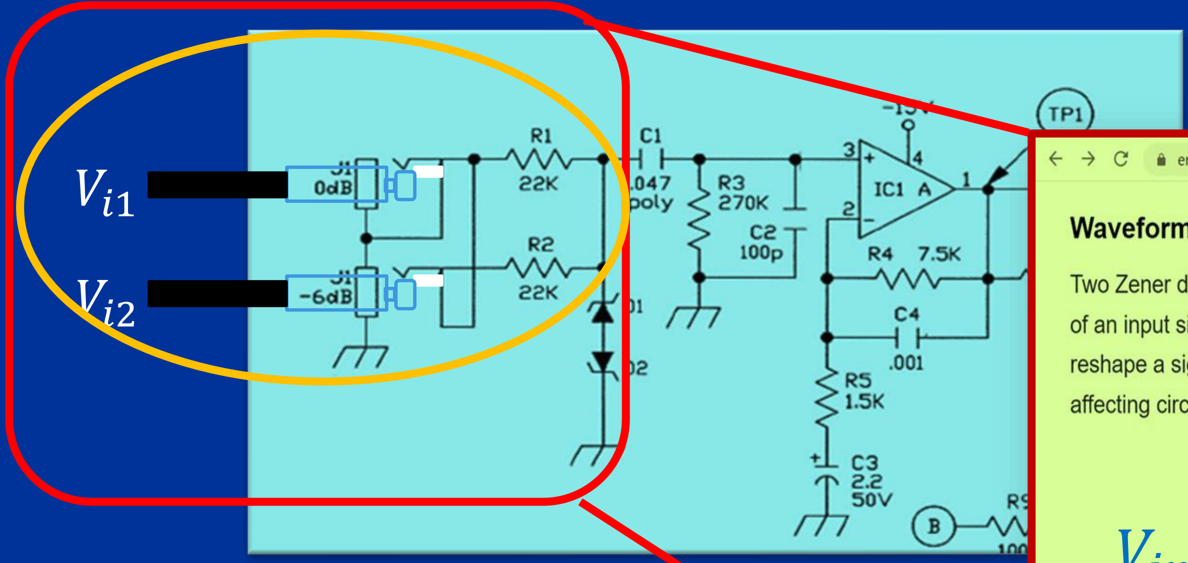


Circuits to be Covered Today

- Zener Diode input over-voltage protection
- AC Coupling (DC Blocking) Capacitors
- Frequency dependent V-dividers – the Math
- Highpass and Lowpass corner frequencies
- JFET analog switches
- Opamp-based clipping amp for distortion
- Vacuum Tube amplifiers

Zener Diode Clipping/Protection Circuit

Thevenin source model



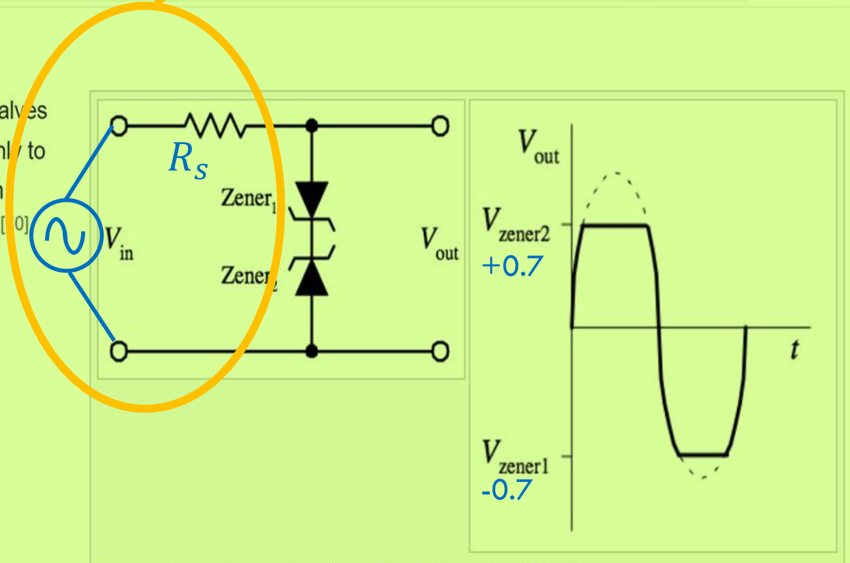
en.wikipedia.org/wiki/Zener_diode

Waveform clipper [edit]

Two Zener diodes facing each other in series clip both halves of an input signal. Waveform clippers can be used not only to reshape a signal, but also to prevent voltage spikes from affecting circuits that are connected to the power supply.[10]

$$V_{in} \cong \frac{1}{2}V_{i1} + \frac{1}{2}V_{i2}$$

$$R_s \cong 11K$$

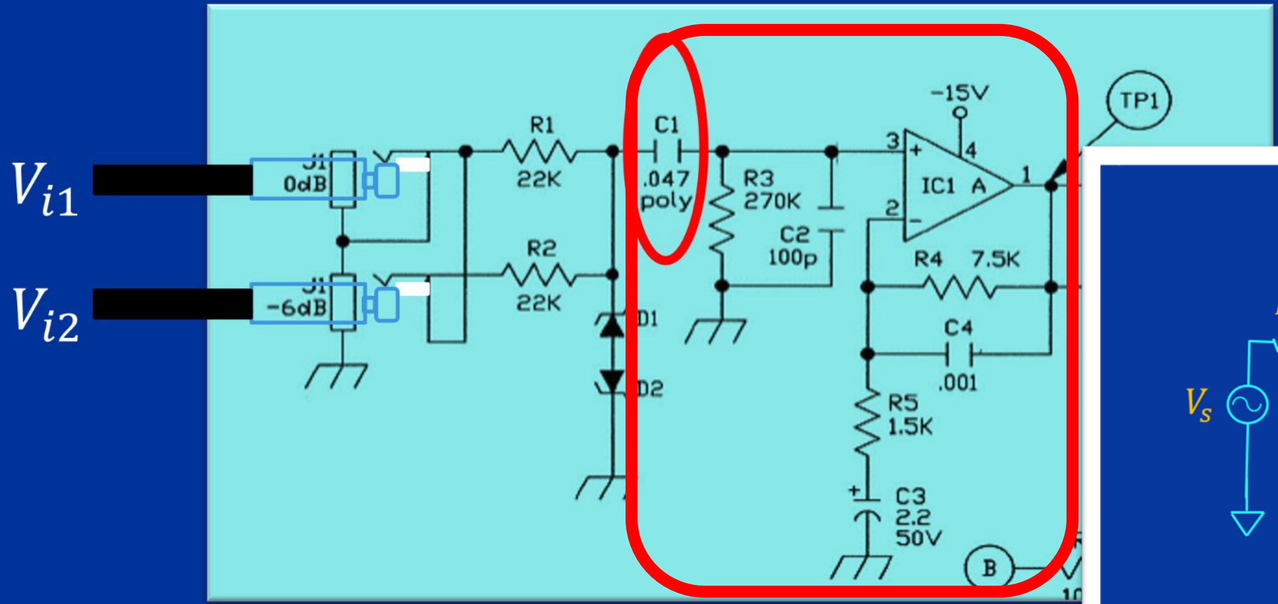


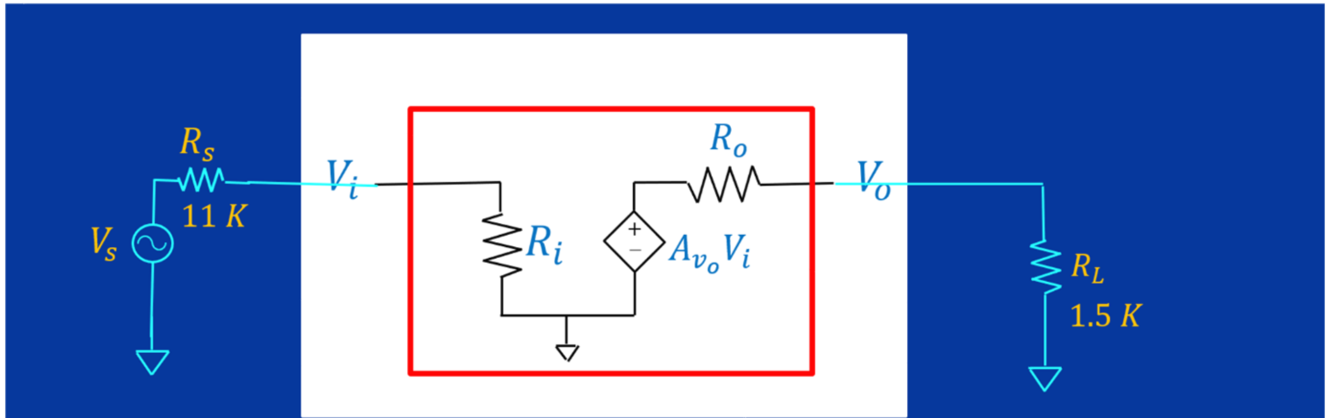
Examples of a waveform clipper (V_{in} polarity is irrelevant)

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

With edits/additions in blue

Amplifier Model at "Midband" (from Part 1)

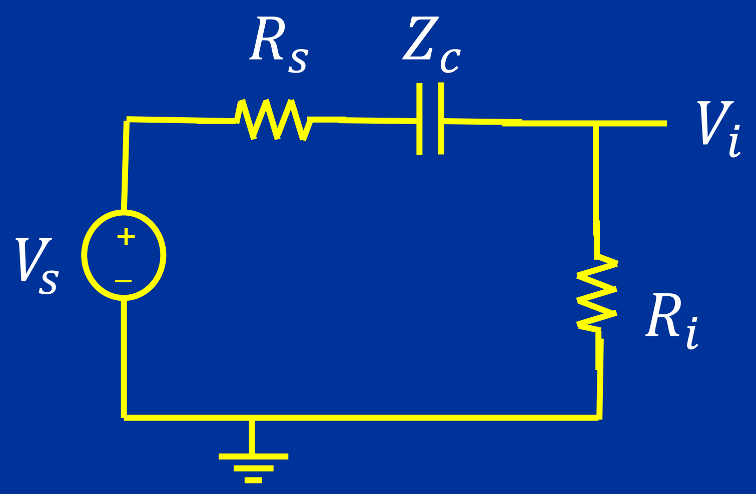




$R_i = 270K \qquad A_{v_o} = 6 \qquad R_o \cong 0$

$$A_{v_{loaded}} = \frac{V_o}{V_s} = \left(\frac{R_i}{R_i + R_s}\right)(A_{v_o})\left(\frac{R_L}{R_L + R_o}\right) = (0.96)(6)(1) = 5.77 \approx 6$$

AC Coupling - The “Complex” Math



$$Z_c = -jX_c$$

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

Full Coupling
(at high frequency)

$$V_i = V_s\left(\frac{R_i}{R_i + R_s}\right)$$

No Coupling
(at DC)

$$V_i = V_s\left(\frac{R_i}{R_i+(-j\infty)+R_s}\right) = 0$$

“OK” Coupling

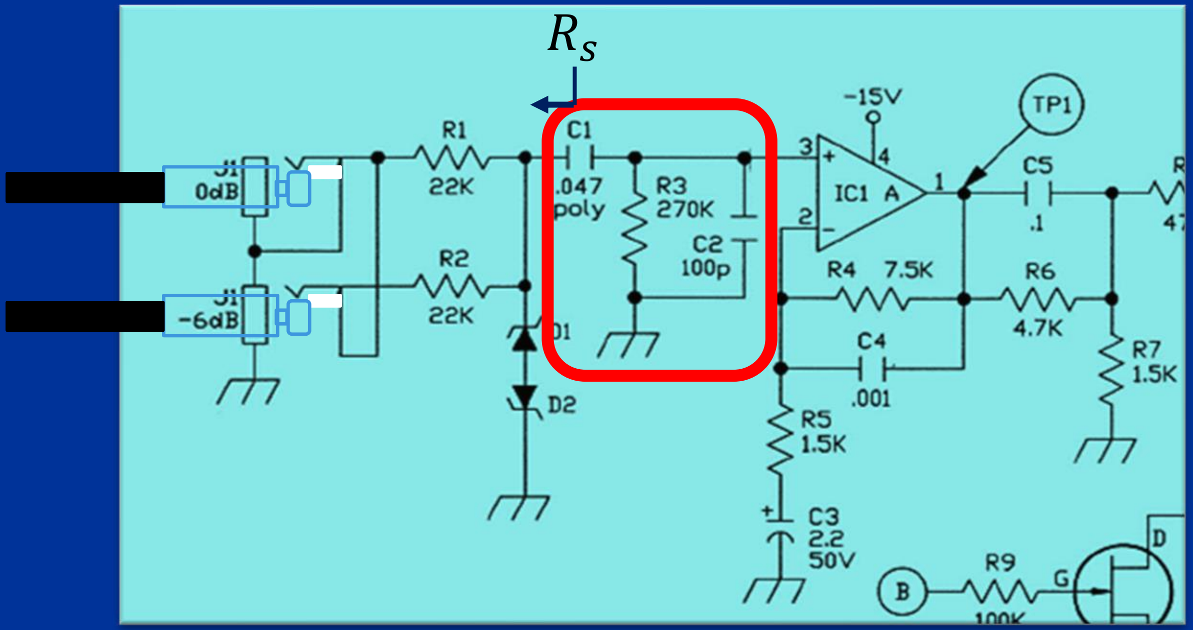
(at “corner frequency” f_c
where $Xc = Ri + Rs$)

$$V_i = V_s\left(\frac{R_i}{R_i+(-jX_c)+R_s}\right)$$

$$= V_s\left(\frac{R_i}{R_i + R_s}\right)\left(\frac{1}{(1\ - j)}\right)$$

$$= V_s\left(\frac{R_i}{R_i + R_s}\right)(0.7071\angle 45^o)$$

More Input Protection



C1 blocks any DC input "offsets" so that amplifier IC1 does not saturate, while "coupling" audio into amplifier

"High-pass" corner frequency is

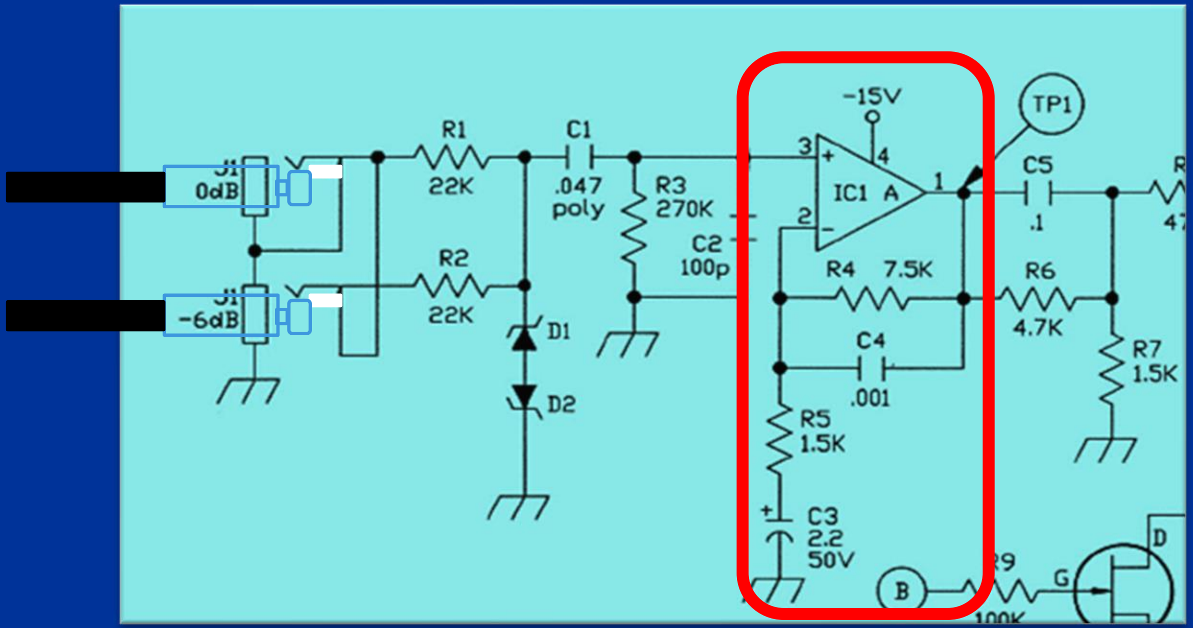
$$f_H \cong \frac{1}{2\pi(R_s + R_3)C_1} = 12\ Hz$$

C2 "shorts" radio frequency interference to ground, so it doesn't disturb amplifier IC1. R_s , C_2 forms a frequency-dependent voltage divider. Here low-pass corner is $f_L \cong \frac{1}{2\pi\ R_s\ C_2} = 150\ kHz$

Recall $$X_C = \frac{1}{2\pi\ f\ C}$$

Corner frequencies occur when Xc = R

Gain Stage (amplifier)



<u>At "Midband"</u> (audio frequencies here), C3 connects R5 to ground, and C4 is nearly an open circuit ☺

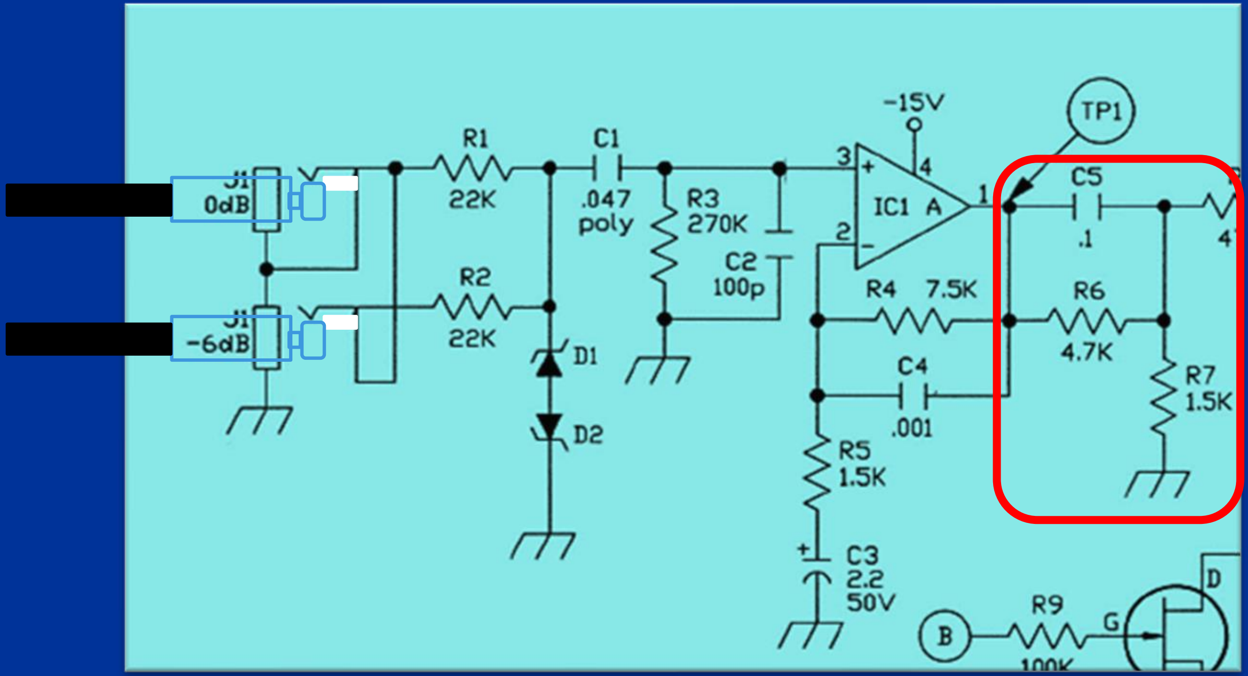
So circuit reduces to a simple amplifier with gain of

$$A_v = \frac{R_4 + R_5}{R_5} = \frac{9K}{1.5K} = 6 \text{ V/V}$$

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

- C4 reduces gain at high frequencies (above 20 kHz).
- C3 reduces gain at low frequencies (below 50 Hz).

Frequency-Response Shaping

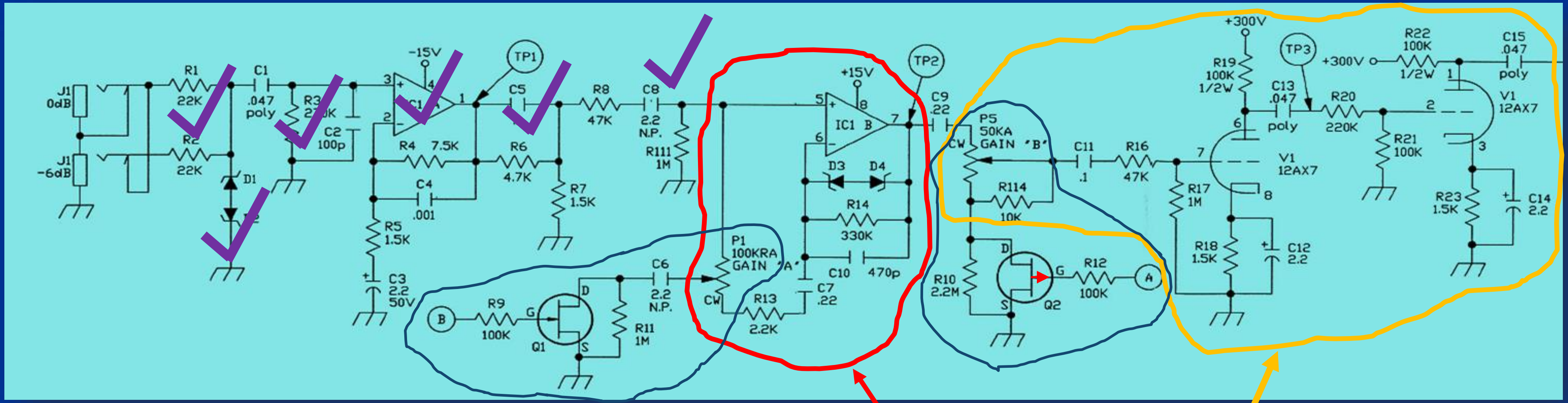


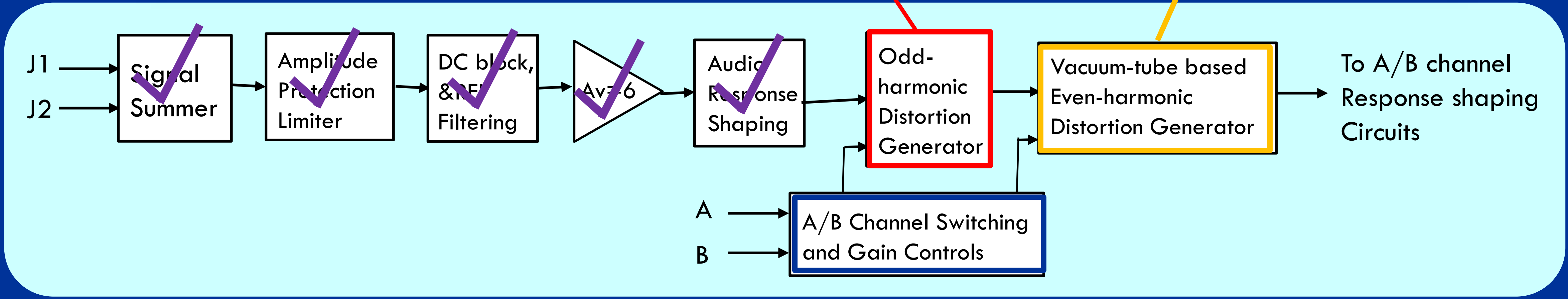
- R6, C5, R7 create a **<u>frequency-dependent voltage divider</u>**
- At low-frequency (<< 340 Hz), X_{C5} >> R6, so division is approx R7/(R7+R6) = 0.24
- At high-frequency (>> 1 kHz), X_{C5} << R7, so not much voltage division. C5 just couples signal to next stage
- Response is 12 dB ***bass-cut, treble-boost***

NOTES :

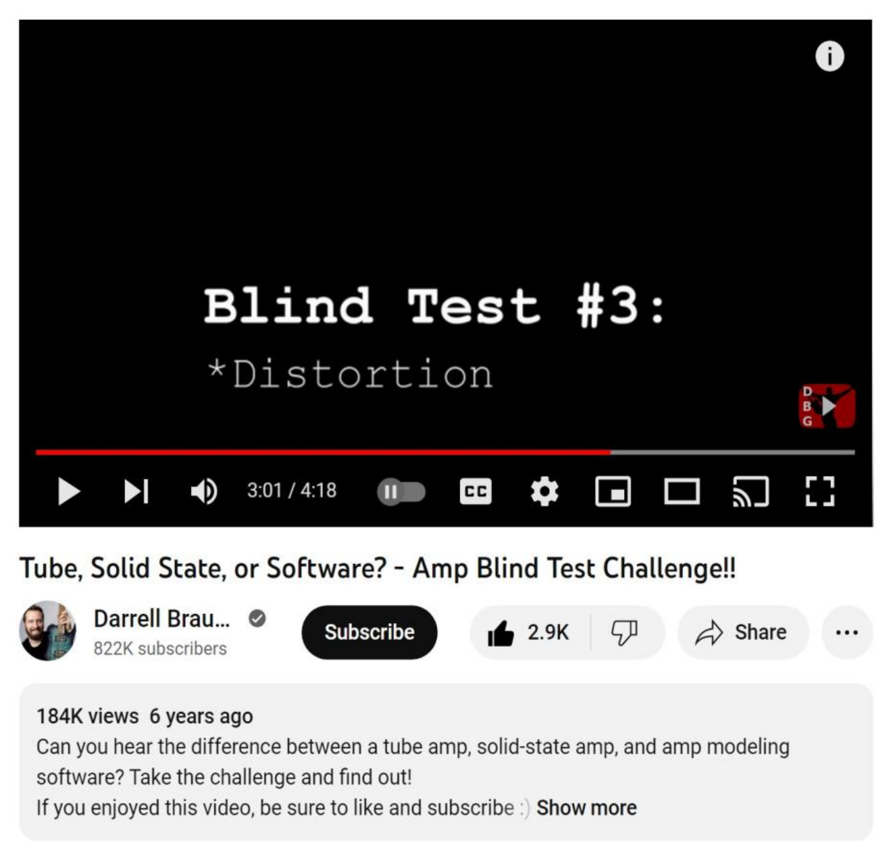
- Voltage division values shown are approximate. Complex math is needed for detailed analysis.
- Loading of next stage should always be considered ! (Here, it is > 1 M Ohm – so we're OK)

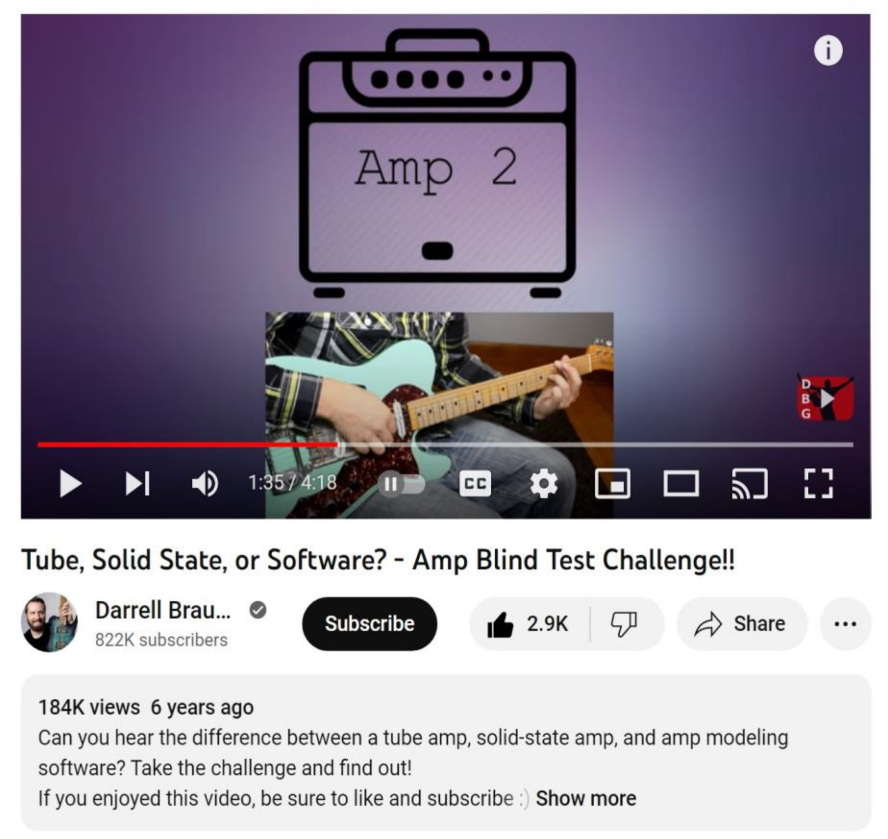
Gain and Distortion Generators





An Interesting YouTube Video …

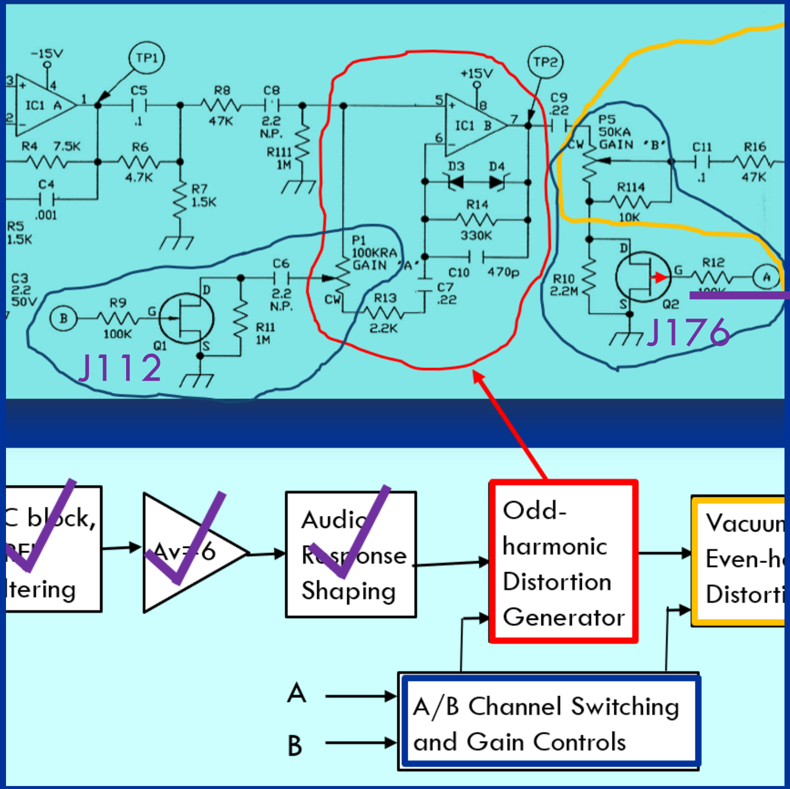


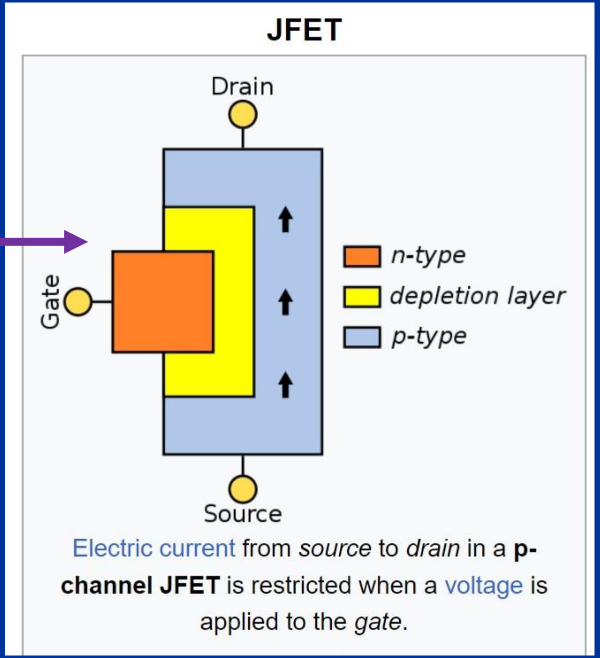


Darrell Braun Guitar https://www.youtube.com/watch?v=qRvRZNg8L0w

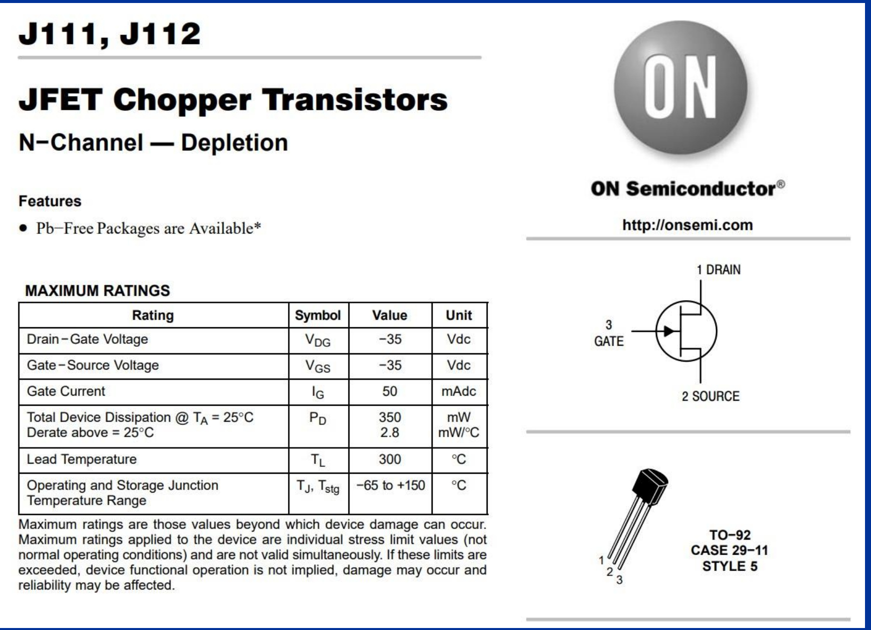
See also: https://producerhive.com/ask-the-hive/odd-vs-even-harmonic-distortion/

JFET Analog Switches





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



J111, J112

JFET Chopper Transistors

N−Channel — Depletion

Features

- Pb−Free Packages are Available*

ON Semiconductor®

http://onsemi.com

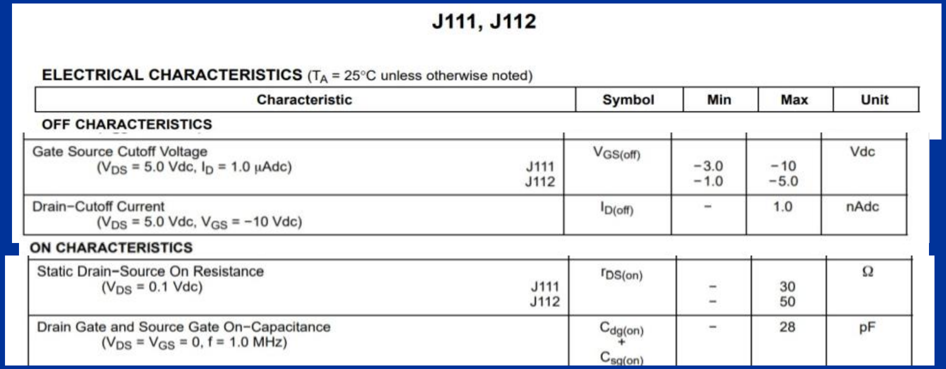
MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Drain−Gate Voltage	V_{DG}	−35	Vdc
Gate−Source Voltage	V_{GS}	−35	Vdc
Gate Current	I_G	50	mAdc
Total Device Dissipation @ T_A = 25°C Derate above = 25°C	P_D	350 2.8	mW mW/°C
Lead Temperature	T_L	300	°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +150	°C

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

1 DRAIN
3 GATE
2 SOURCE

TO−92
CASE 29−11
STYLE 5



J111, J112

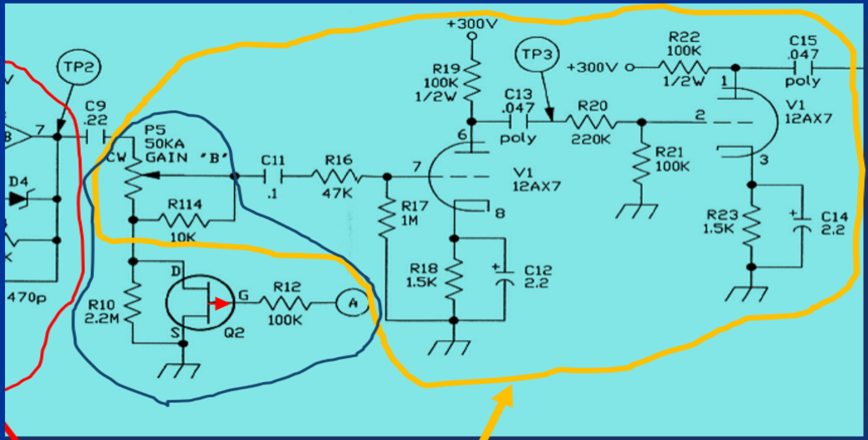
ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

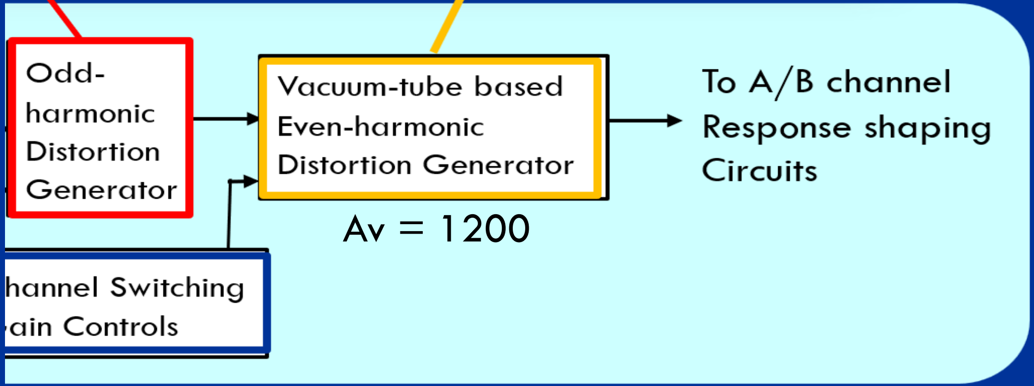
Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Gate Source Cutoff Voltage (V_{DS} = 5.0 Vdc, I_D = 1.0 μAdc)	J111 J112	$V_{GS(off)}$	−3.0 −1.0	−10 −5.0	Vdc
Drain−Cutoff Current (V_{DS} = 5.0 Vdc, V_{GS} = −10 Vdc)		$I_{D(off)}$	–	1.0	nAdc
ON CHARACTERISTICS					
Static Drain−Source On Resistance (V_{DS} = 0.1 Vdc)	J111 J112	$r_{DS(on)}$	– –	30 50	Ω
Drain Gate and Source Gate On−Capacitance (V_{DS} = V_{GS} = 0, f = 1.0 MHz)		$C_{dg(on)}$ + $C_{sg(on)}$	–	28	pF

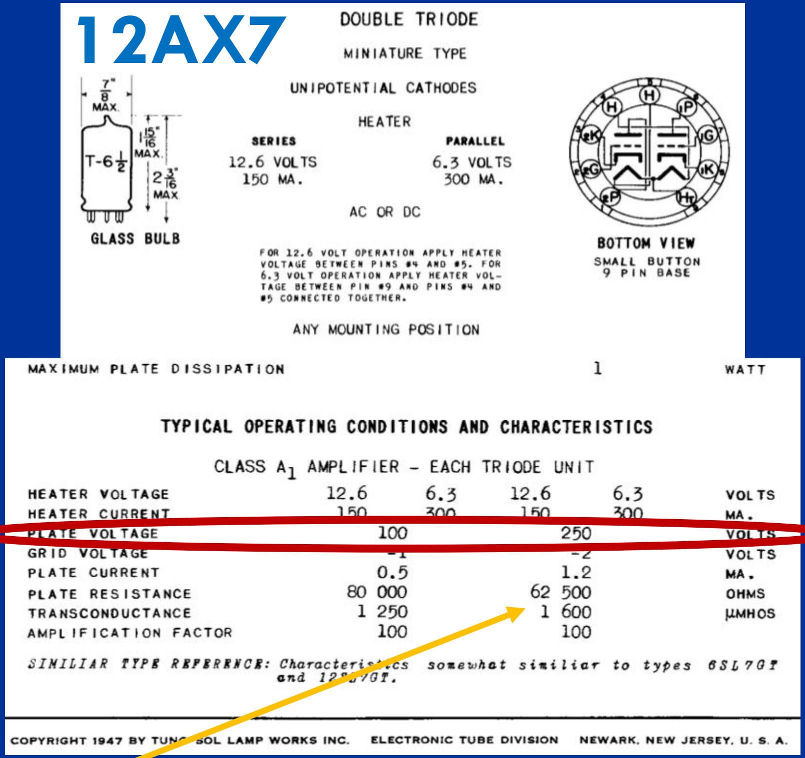
https://www.farnell.com/datasheets/3360937.pdf

Tube Amplifier Subcircuit

DANGER ! HIGH-VOLTAGE !







12AX7

DOUBLE TRIODE

MINIATURE TYPE

UNIPOTENTIAL CATHODES

HEATER

SERIES	PARALLEL
12.6 VOLTS	6.3 VOLTS
150 MA.	300 MA.

AC OR DC

GLASS BULB

FOR 12.6 VOLT OPERATION APPLY HEATER VOLTAGE BETWEEN PINS #4 AND #5. FOR 6.3 VOLT OPERATION APPLY HEATER VOLTAGE BETWEEN PIN #9 AND PINS #4 AND #5 CONNECTED TOGETHER.

BOTTOM VIEW
SMALL BUTTON
9 PIN BASE

ANY MOUNTING POSITION

MAXIMUM PLATE DISSIPATION 1 WATT

TYPICAL OPERATING CONDITIONS AND CHARACTERISTICS

CLASS A_1 AMPLIFIER – EACH TRIODE UNIT

HEATER VOLTAGE	12.6	6.3	12.6	6.3	VOLTS
HEATER CURRENT	150	300	150	300	MA.
PLATE VOLTAGE	100		250		VOLTS
GRID VOLTAGE	-1		-2		VOLTS
PLATE CURRENT	0.5		1.2		MA.
PLATE RESISTANCE	80 000		62 500		OHMS
TRANSCONDUCTANCE	1 250		1 600		µMHOS
AMPLIFICATION FACTOR	100		100		

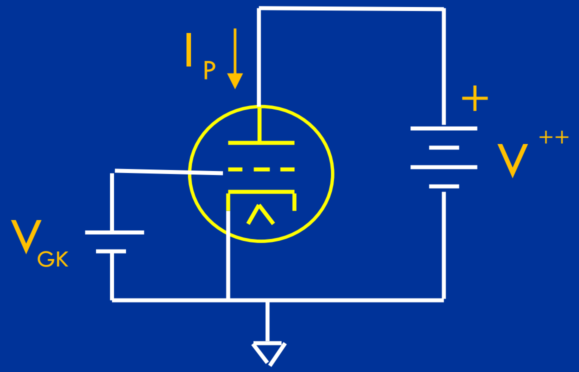
SIMILIAR TYPE REFERENCE: Characteristics somewhat similiar to types 6SL7GT and 12SL7GT.

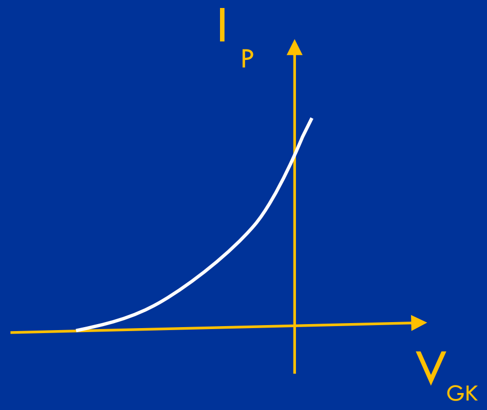
$$A_v = -g_m\,R = -(1600 \times 10^{-6})(62{,}500) = -100$$

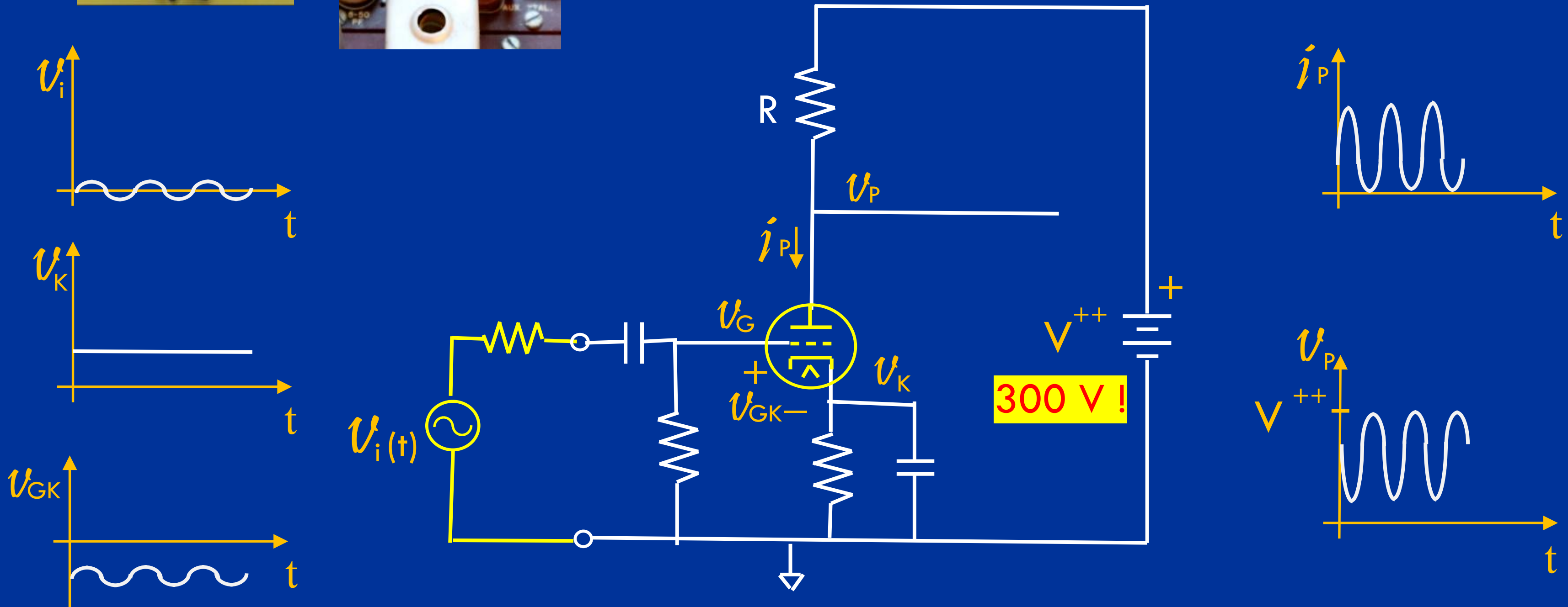
About -60 when 100 K plate resistor included …

Producing Even-Order Distortion

Vaccuum Tubes
(or “Valves”)





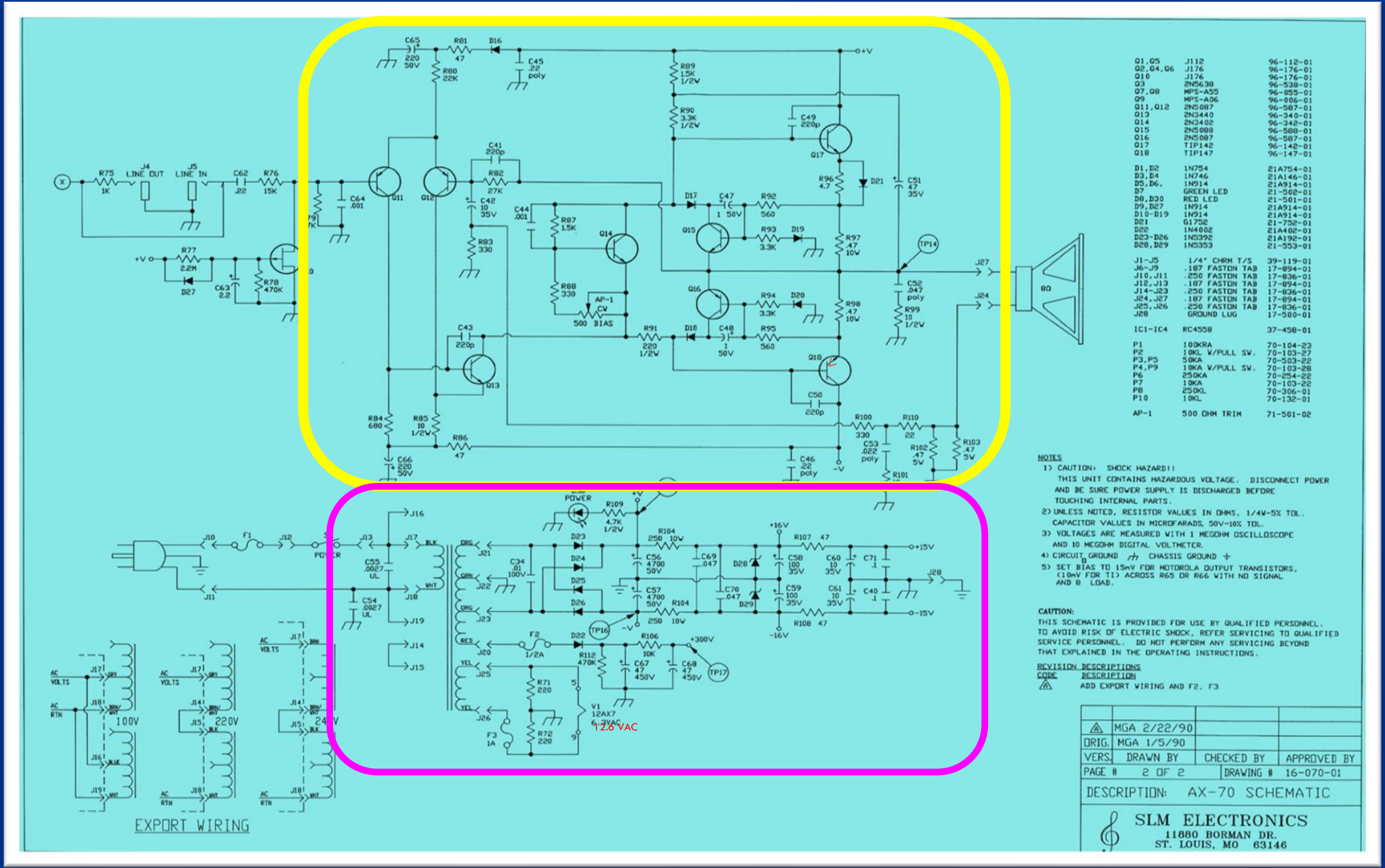


More Circuits to Learn !

Power Amplifier

(Giant, Discrete, High Power "Opamp" circuit)

Power Supply Circuits



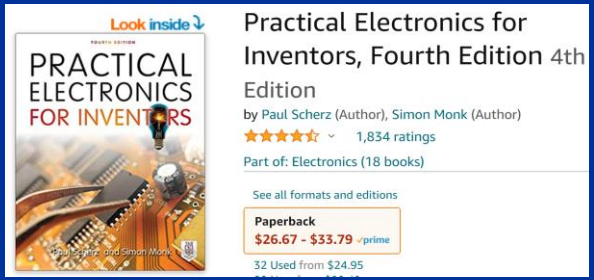
http://www.guitarnucleus.net/resources/schematics/Ampeg-AX70-Schematic.pdf

Different Ways to Learn

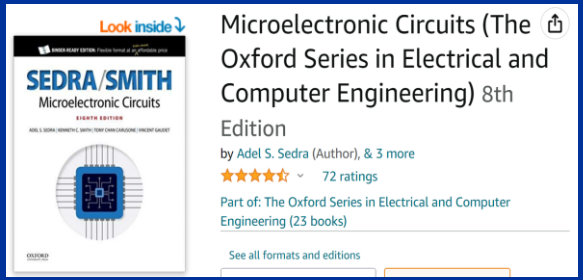
Videos and Websites

- This Video / Playlist / Channel ☺
- Other Videos
- ECEfiles.org
- Other Websites

Books



https://www.amazon.com/Practical-Electronics-Inventors-Fourth-Scherz-dp-1259587541/dp/1259587541/



https://www.amazon.com/Microelectronic-Circuits-Electrical-Computer-Engineering/dp/0190853549/

University Courses

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

Possible Future Videos

- More Opamp circuits
- Real-world opamp limitations (gain-bandwidth product, bias current, output voltage swing, output current limits…)
- Frequency response, complex impedances, and Fourier analysis
- Power amps (including class AB linear, and class D switching designs)
- Modern power supplies (including linear regulators and switch-mode supplies)
- More “big circuit” walkthroughs ☺ …

THANKS FOR WATCHING !