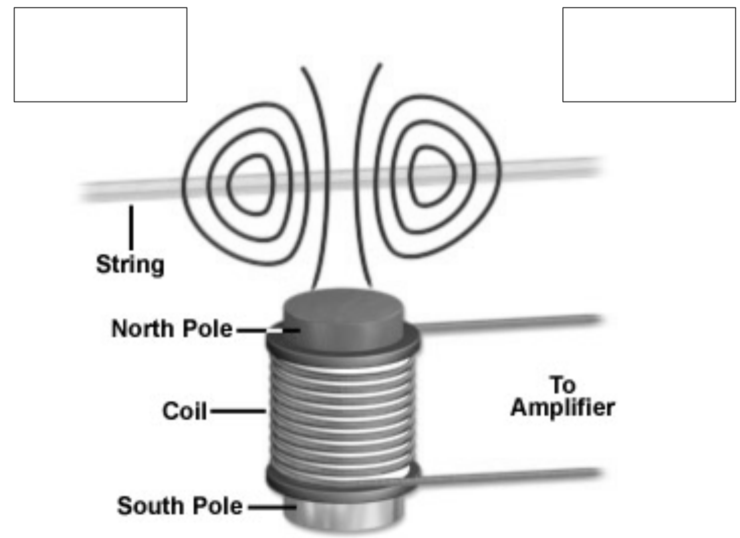
Introduction to Audio and Music Engineering

Lecture 17

Topics:

- Guitar pickups
- Guitar tone and volume controls
- Wah pedal – variable bandpass filter
- Amplfier project
- Tone control
- Gain control – distortion
- Speaker cabinet

Guitar Pickups



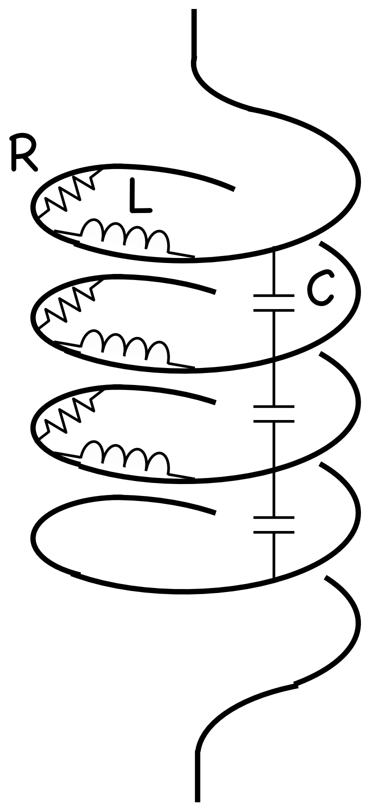
http://www.magnet.fsu.edu/education/tutorials/java/guitarpickup/

$$V = -N \frac{d\Phi_B}{dt}$$

5,000 → 6,000 turns of 44 AWG wire

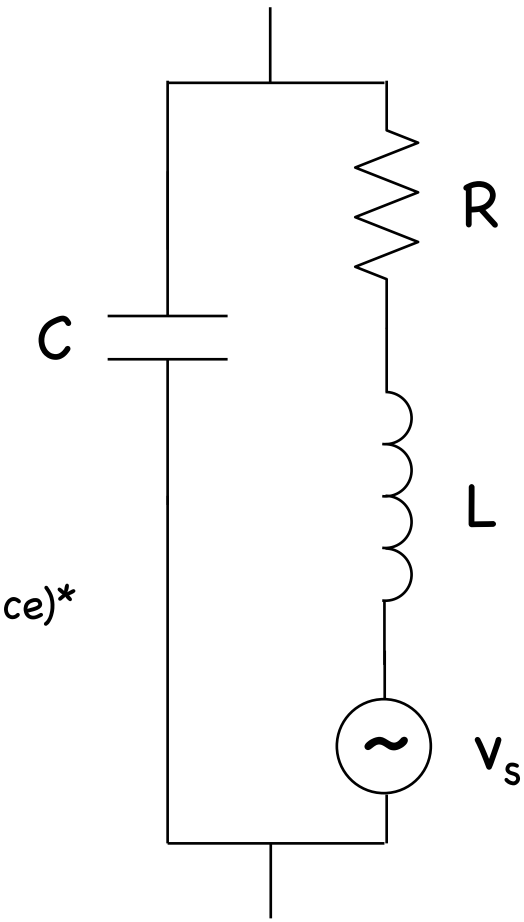
44 AWG ≈ 0.05 mm (2x dia of human hair)

Electrical model of a guitar pickup



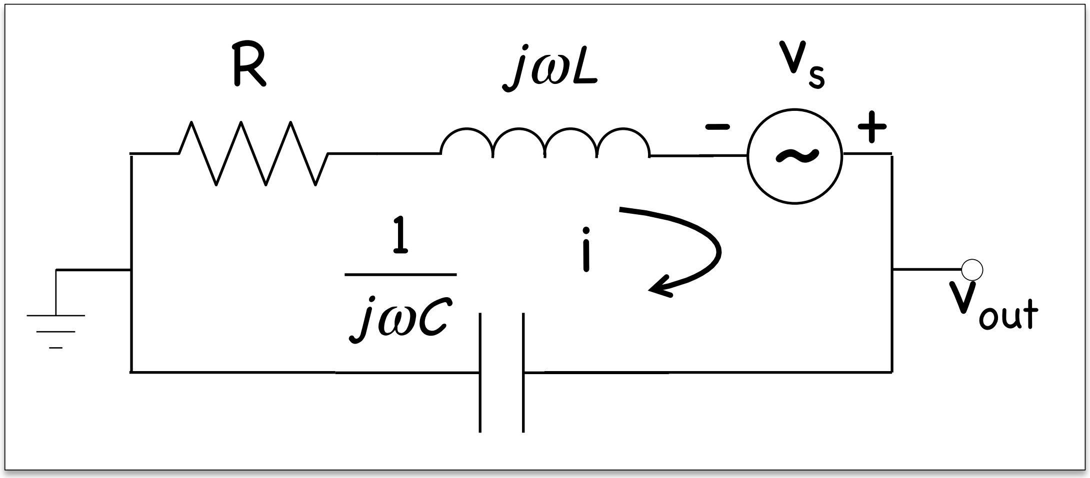
6000 turns
$L \approx 2$ Henry
$C \approx 120$ pF
$R \approx 5{,}000\ \Omega$ (DC resistance)*

v_s = voltage signal
induced in coil
from string motion



* Effective resistance at audio frequencies ≈ 10x DC resistance due to losses in the magnets

Guitar pickup analysis: Find the output voltage, v_{out}



Resonant frequency

$$\omega_r^2 = \frac{1}{LC}$$

"Q" quality factor

$$Q = \frac{1}{\omega_r RC} = \frac{1}{2\pi}\frac{T}{RC}$$

T is the period of the resonance of the circuit

Apply KVL:

$$-iR - j\omega L i + v_s - \frac{1}{j\omega C} i = 0$$

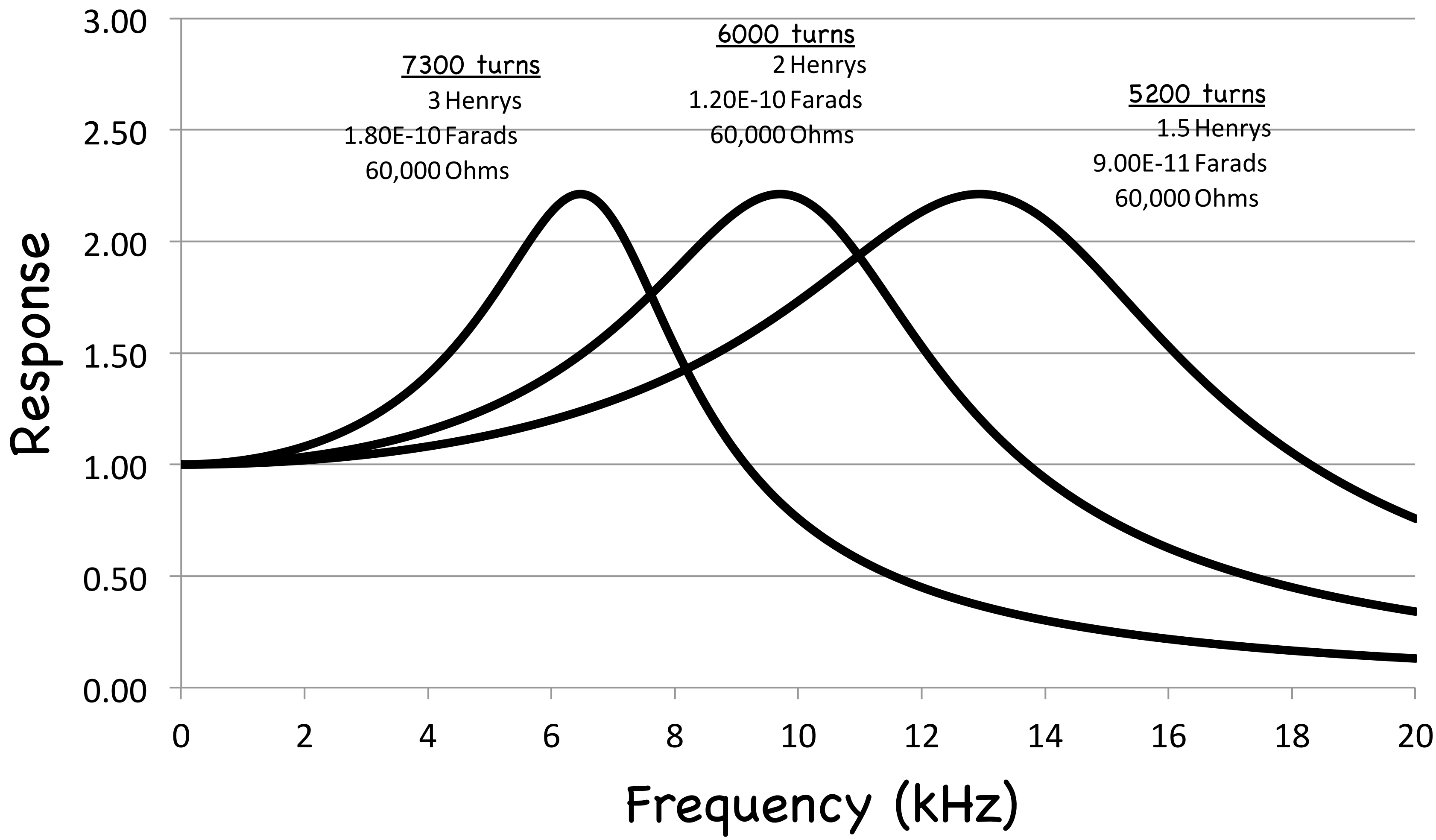
$$i = \frac{v_s}{R + j\omega L + \dfrac{1}{j\omega C}}$$

$$v_{out} = i\frac{1}{j\omega C} = v_s \frac{\dfrac{1}{j\omega C}}{R + j\omega L + \dfrac{1}{j\omega C}}$$

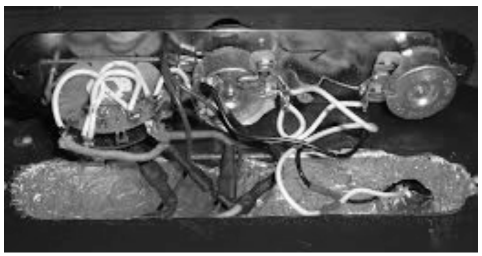
$$v_{out} = v_s \frac{1}{1 - \omega^2/\omega_r^2 + j\,\omega/(\omega_r Q)}$$

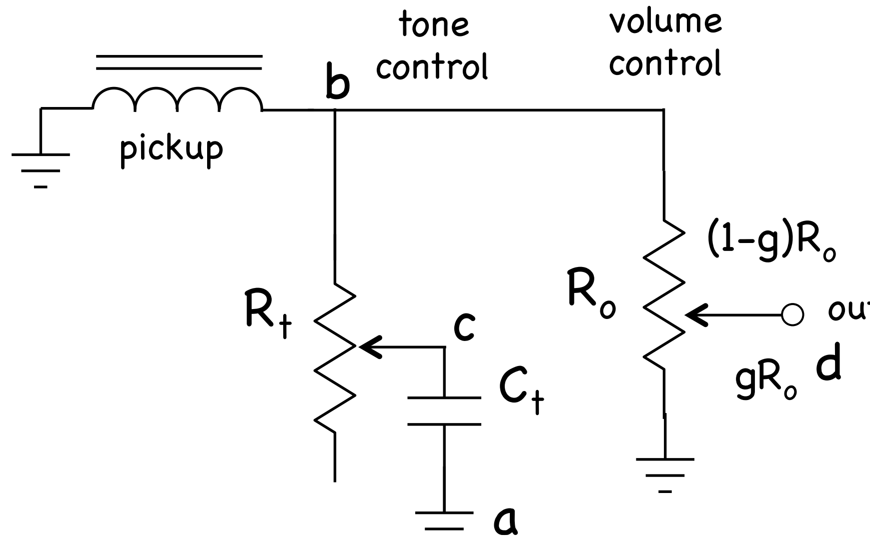
$$\left|v_{out}\right| = v_s \frac{1}{\left[(1 - \omega^2/\omega_r^2)^2 + \omega^2/(\omega_r^2 Q^2)\right]^{1/2}}$$

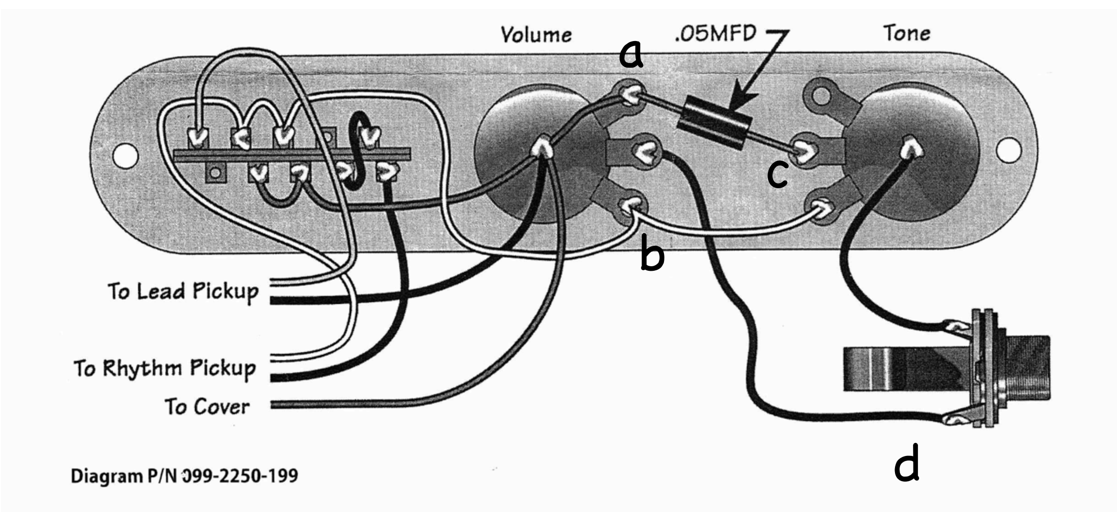
Frequency response of pickups

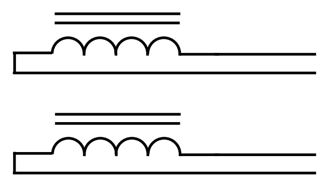


Guitar tone & volume control circuit







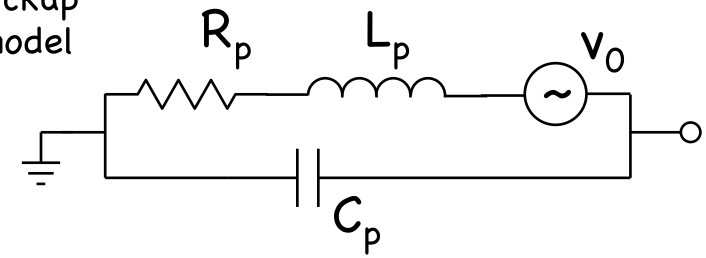


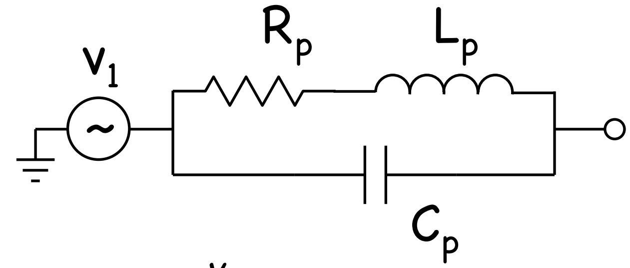
4-way Selector switch

1) Bridge (lead) pickup
2) Neck (rhythm) pickup
3) Parallel combination
4) Series combination

Analysis of pickup and control circuit …

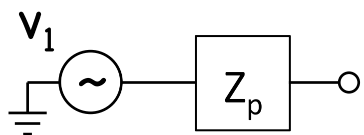
Pickup model



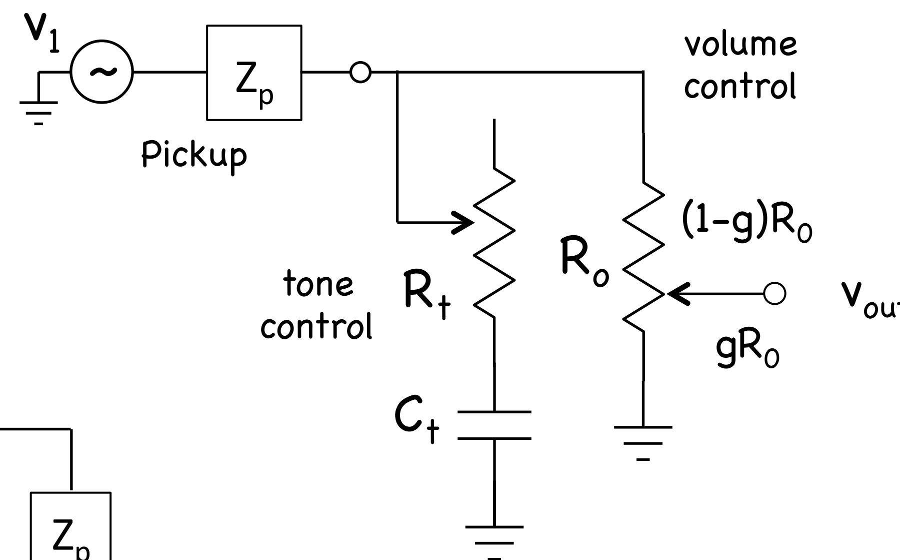


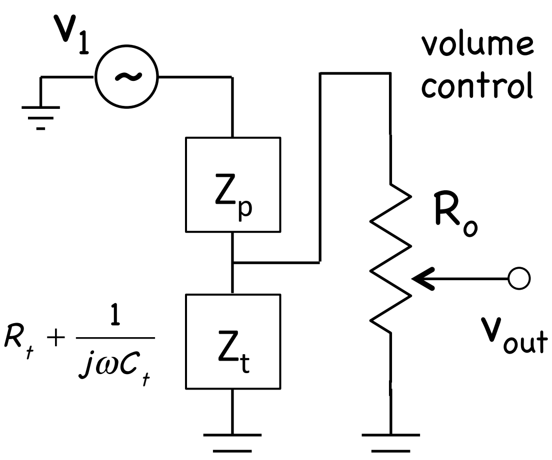
$$v_1 = \frac{v_0}{1 - \omega^2 L_p C_p + j\omega R_p C_p}$$

… to assure same open circuit voltage

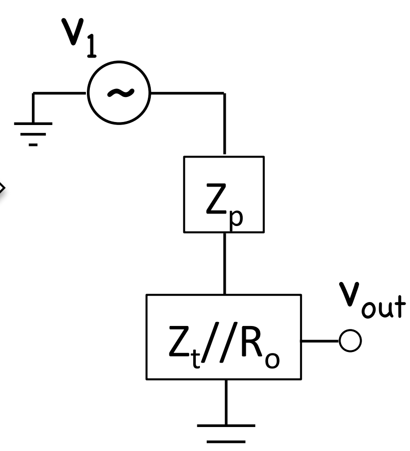


$$Z_p = \frac{\left(j\omega L_p + R_p\right)\frac{1}{j\omega C_p}}{j\omega L_p + R_p + \frac{1}{j\omega C_p}} = \frac{j\omega L_p + R_p}{1 - \omega^2 L_p C_p + j\omega R_p C_p}$$



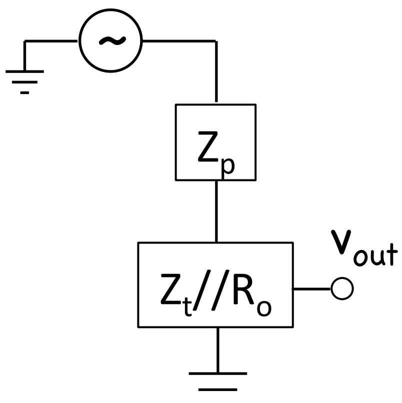


$$Z_t = R_t + \frac{1}{j\omega C_t}$$

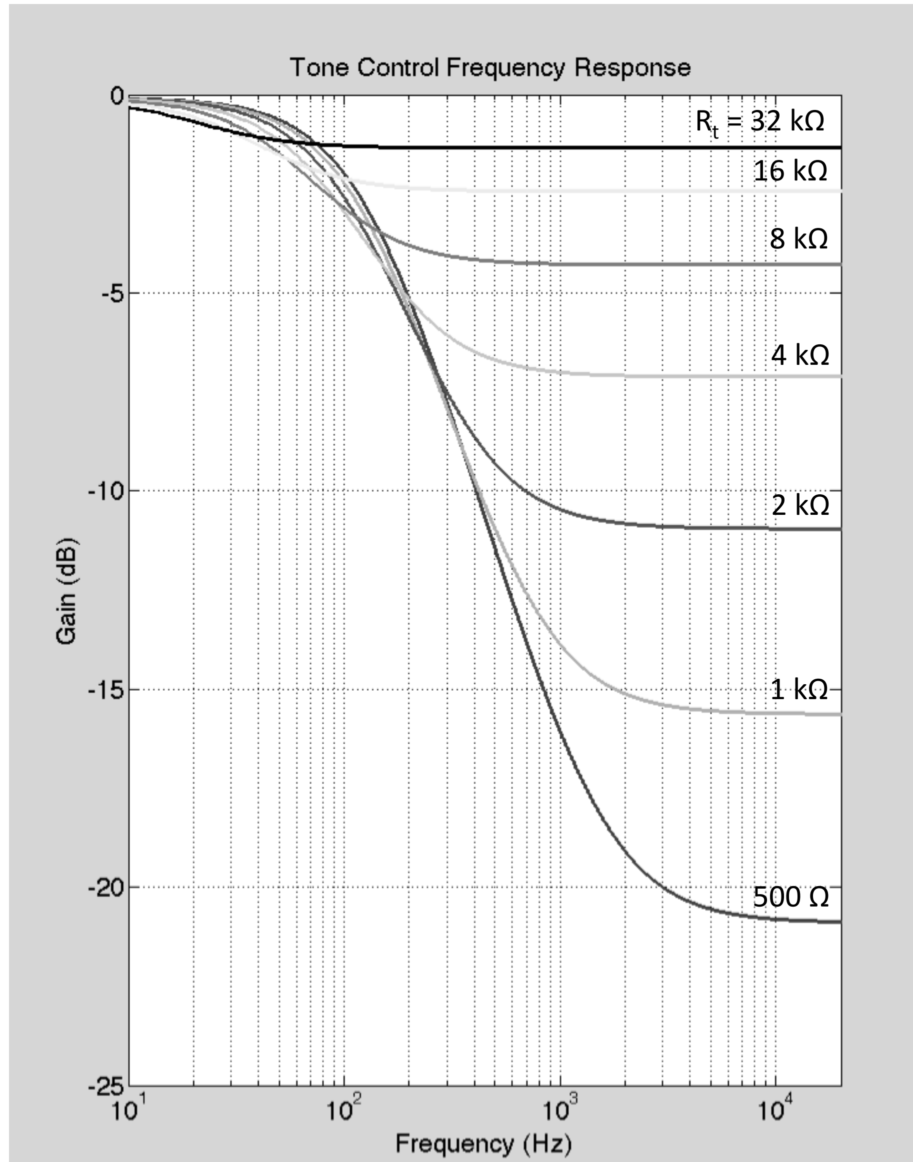


$$v_{out} = v_1 \cdot g \frac{Z_t // R_O}{Z_p + Z_t // R_O}$$

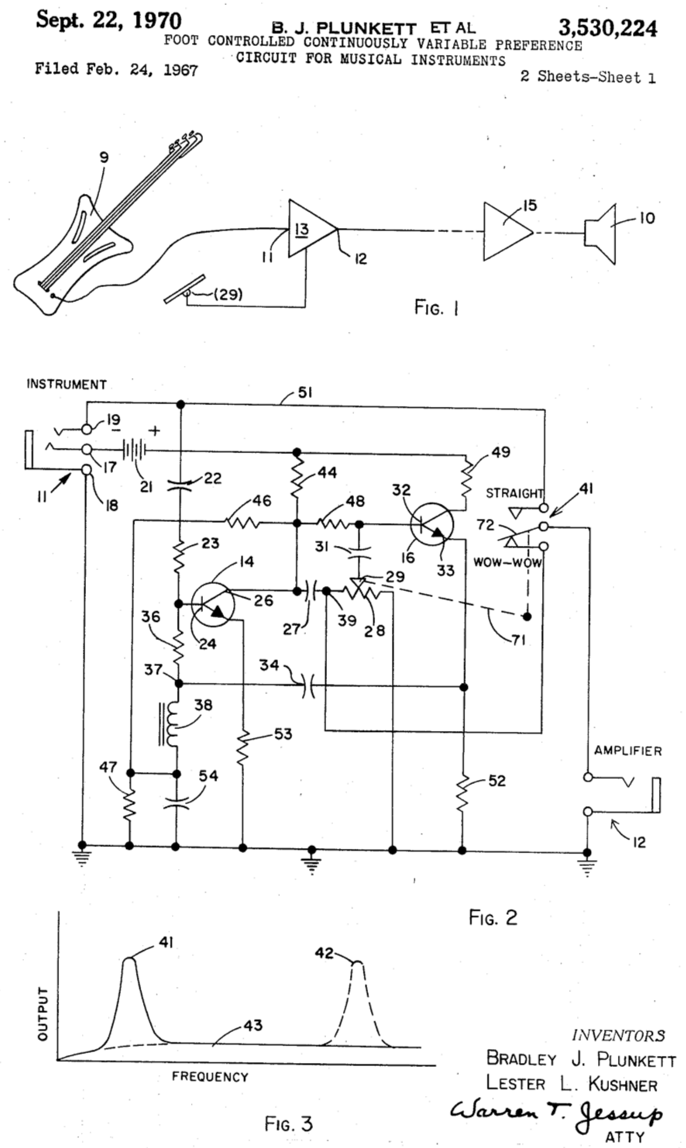
Tone control frequency response …



$$v_{out} = v_1 \cdot g \frac{Z_t // R_O}{Z_p + Z_t // R_O}$$

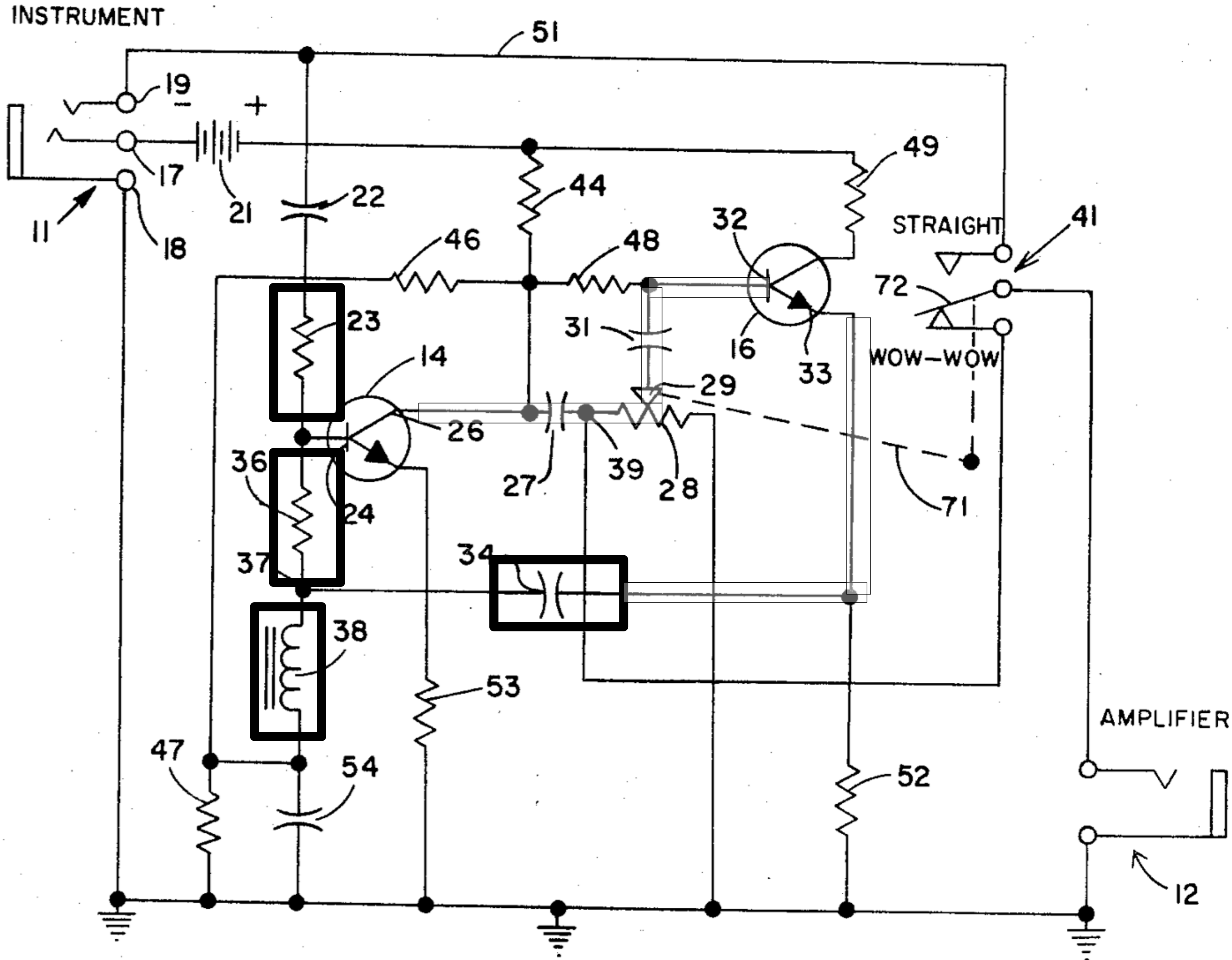


Wah Pedal



https://www.youtube.com/watch?v=kMqGuF8VoRo

http://www.youtube.com/watch?v=HyfKQhTRwkU



INSTRUMENT
51
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48
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STRAIGHT
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72
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WOW–WOW
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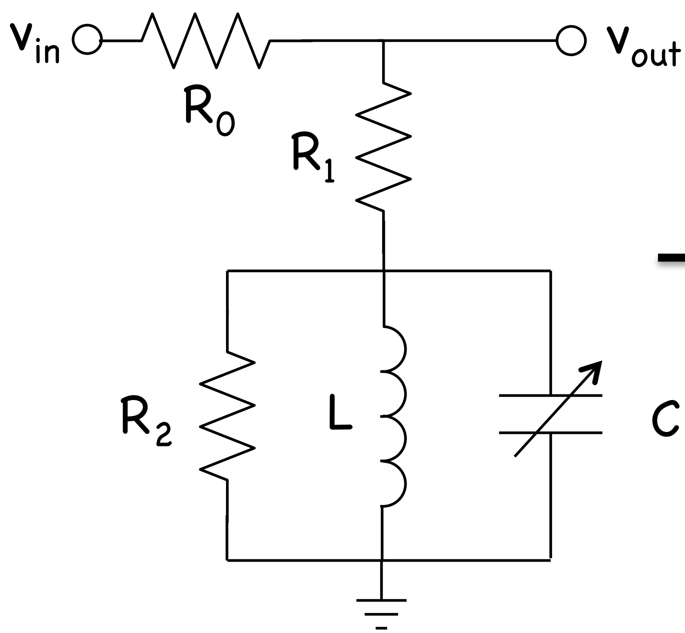
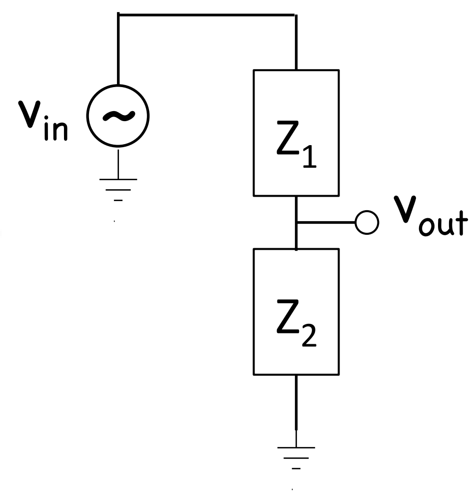
AMPLIFIER
47
54
52
12

FIG. 2

Wah Pedal - Variable Bandpass Filter

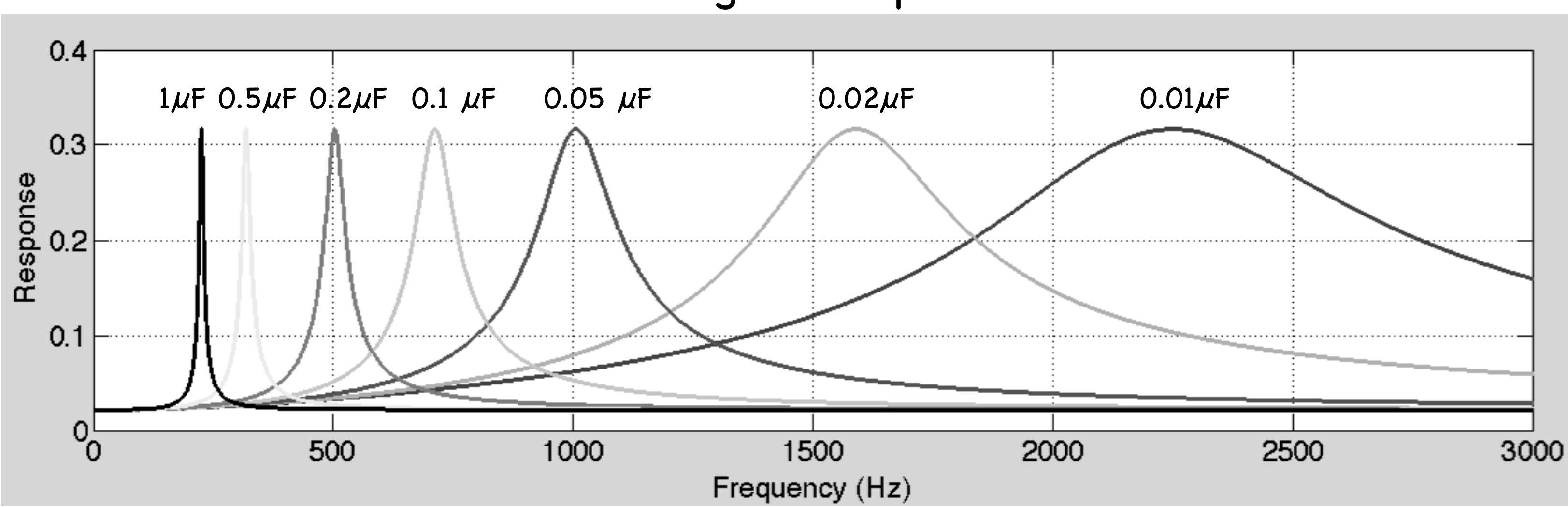




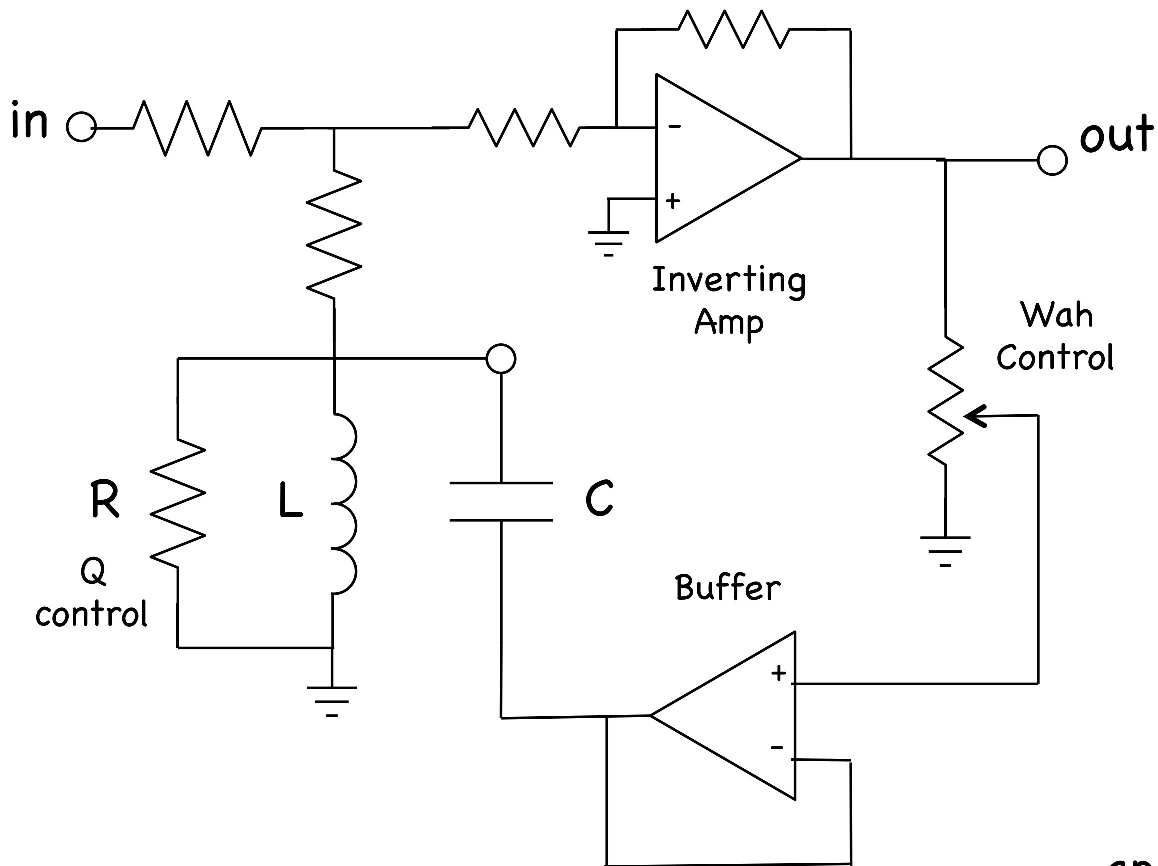
<u>Typical Values</u>

R0 = 68 kΩ
R1 = 1.5 kΩ
R2 = 33 kΩ
L = 0.5 H
C = 0.01 μF → 1 μF

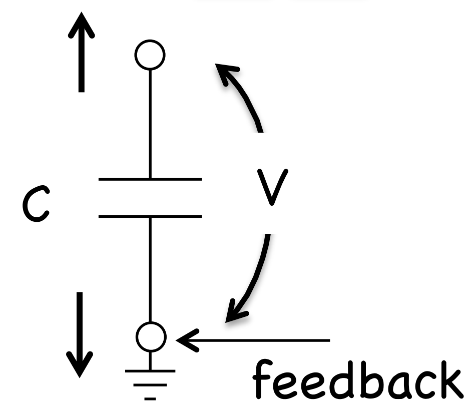
"shelving" band-pass filter



Op Amp Wah Pedal



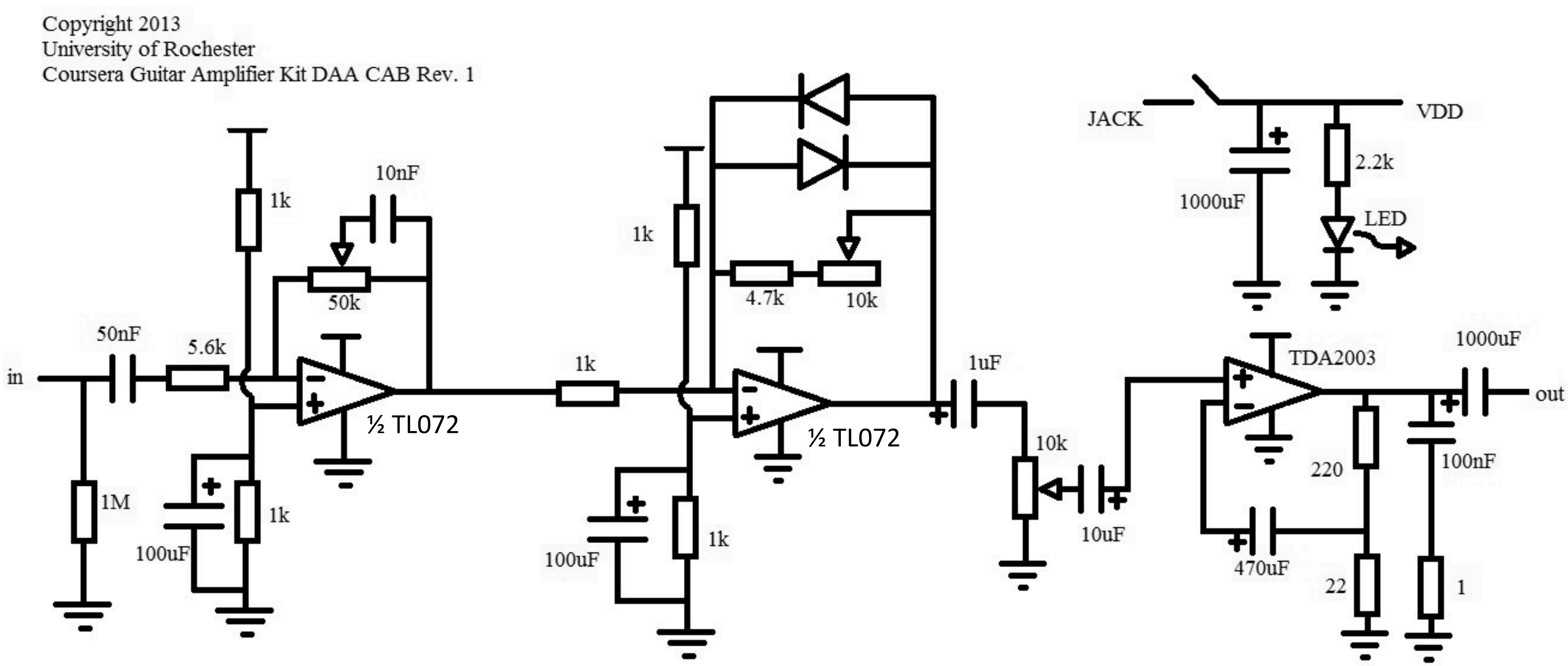
$$I = j\omega \boxed{C} \cdot \boxed{V}$$



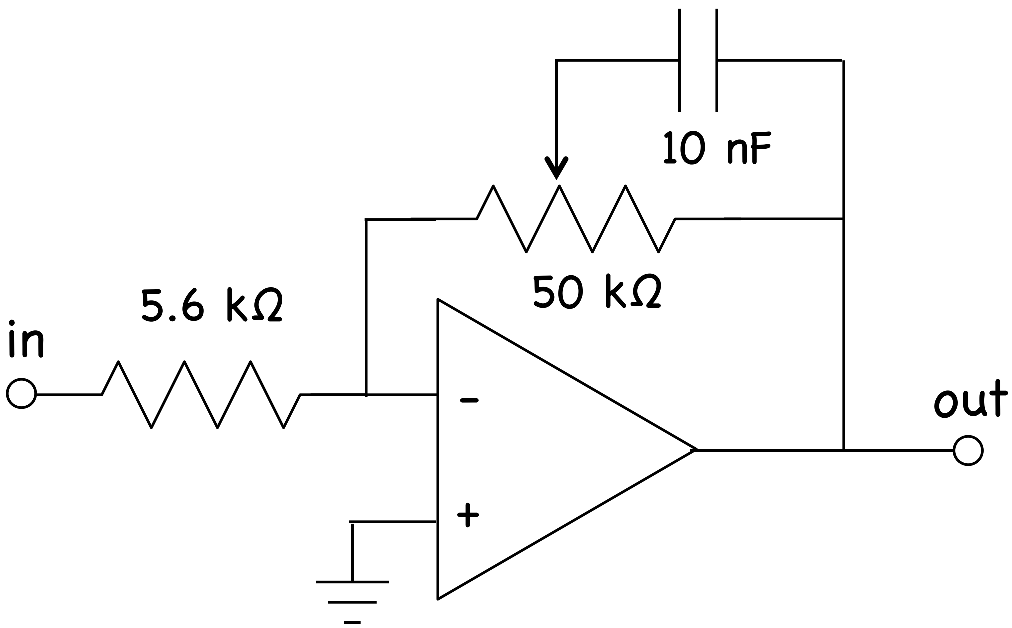
Feedback changes the <u>apparent</u> size of C, thereby shifting the resonant frequency

Full Schematic

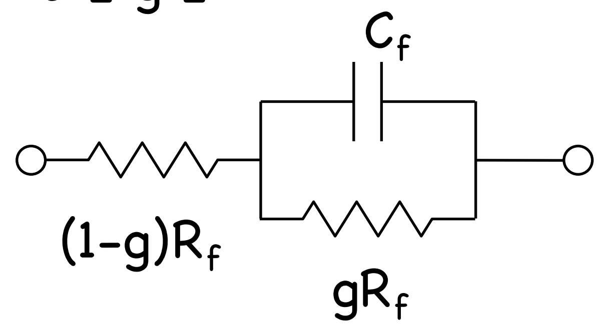
Tone Gain Volume



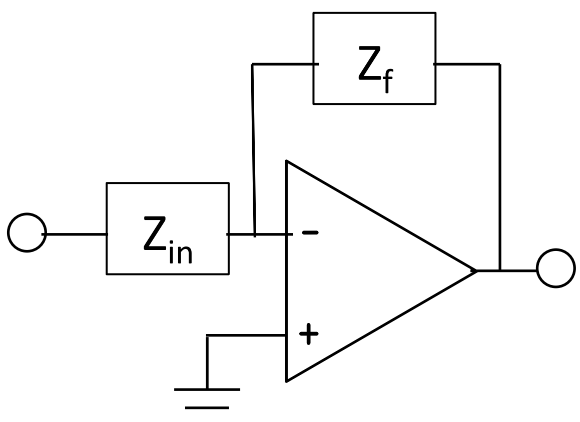
Tone control circuit



$0 \le g \le 1$



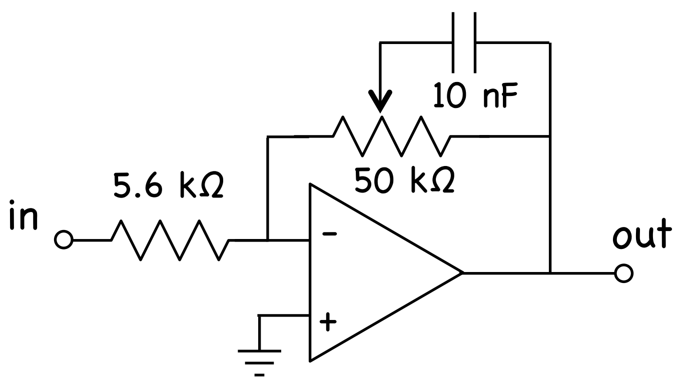
$$Z_f = (1-g)R_f + \frac{\frac{1}{j\omega C_f} \cdot gR_f}{\frac{1}{j\omega C_f} + gR_f}$$



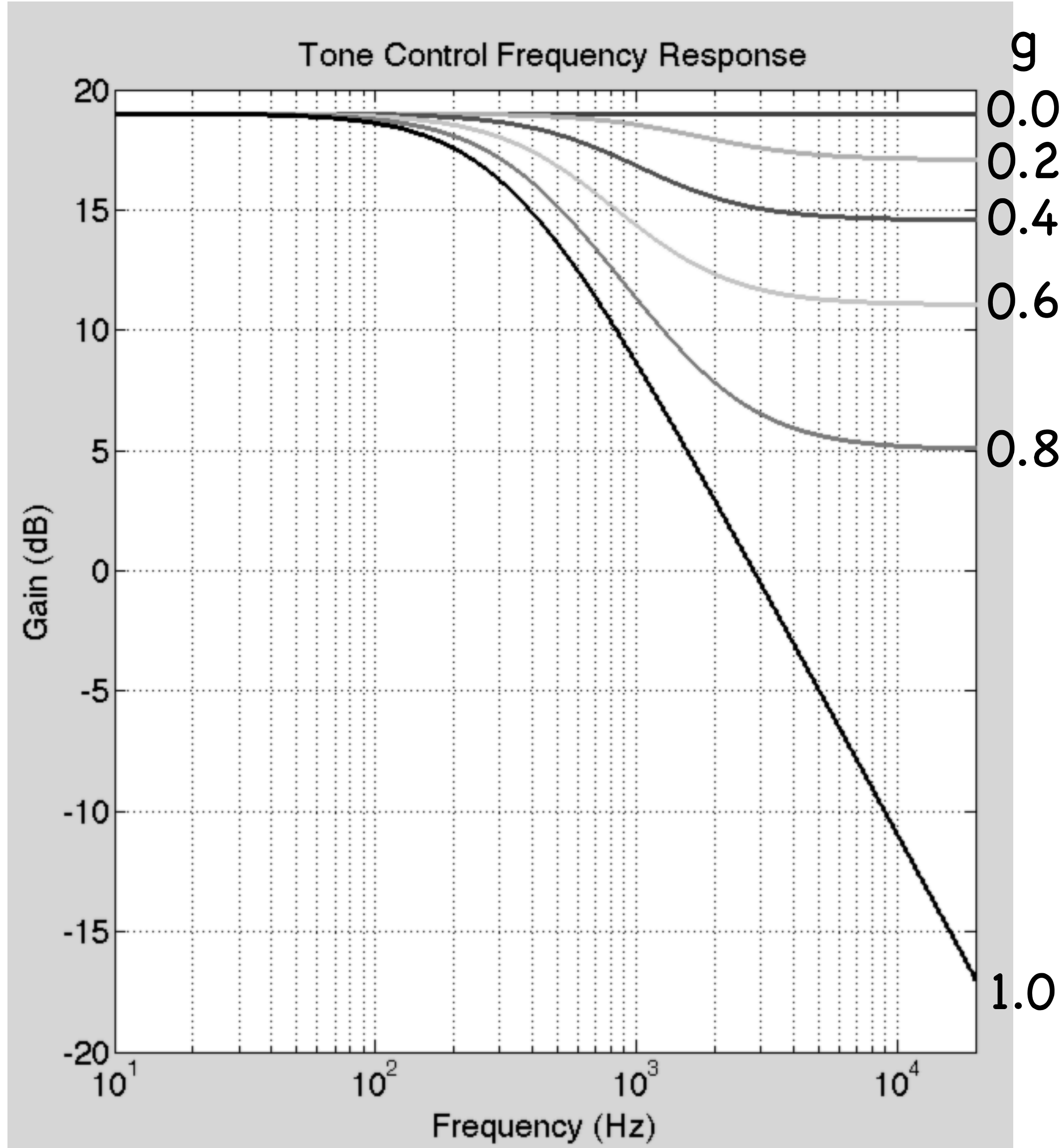
$$|G| = \left|\frac{Z_f}{Z_{in}}\right|$$

$$|G| = \frac{1}{R_{in}}\left|(1-g)R_f + \frac{gR_f}{1 + jg\omega R_f C_f}\right|$$

Frequency response versus tone pot setting

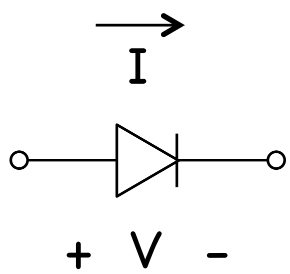


$$\left|G\right| = \frac{1}{R_{in}}\left|(1-g)R_f + \frac{gR_f}{1+jg\omega R_f C_f}\right|$$



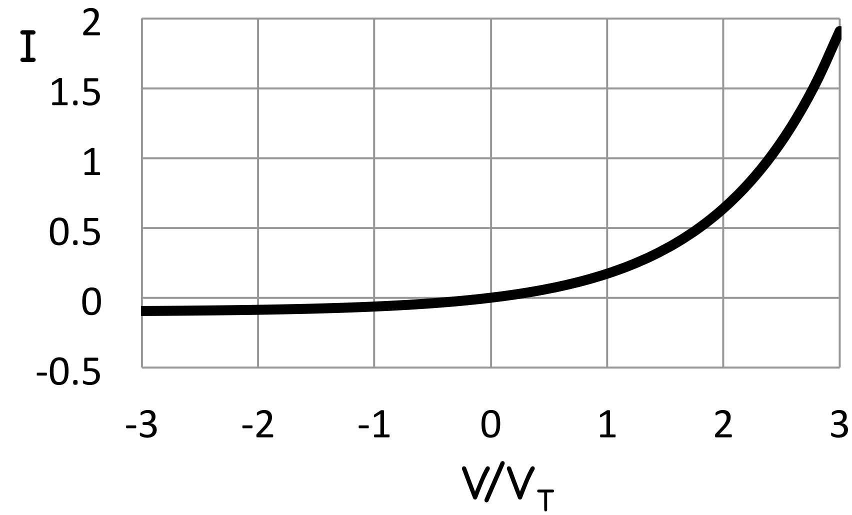
Gain control - distortion

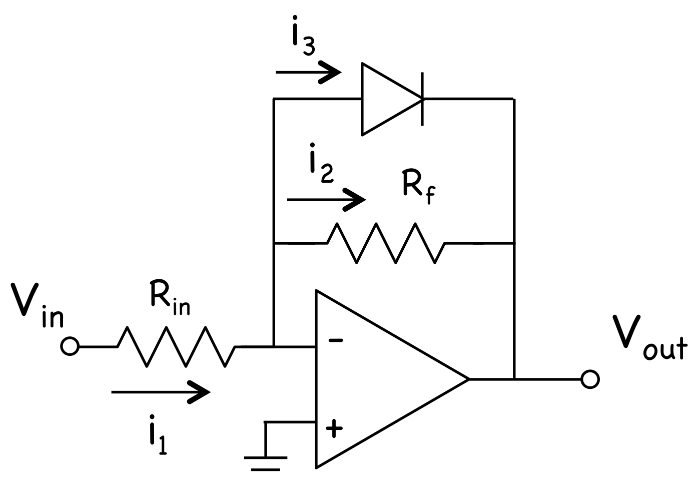
Diode



$$I = I_0\left(e^{V/V_T} - 1\right)$$

$V_T \approx 0.026$ V





KCL: $i_1 = i_2 + i_3$

$$\frac{V_{in} - 0}{R_{in}} = \frac{0 - V_{out}}{R_f} + I_0\left(e^{(0-V_{out})/V_T} - 1\right)$$

$$V_{in} = R_{in}\left[I_0\left(e^{\frac{-V_{out}}{V_T}} - 1\right) - \frac{V_{out}}{R_f}\right]$$

Can't solve analytically for V_{out} but we can use a graphical technique

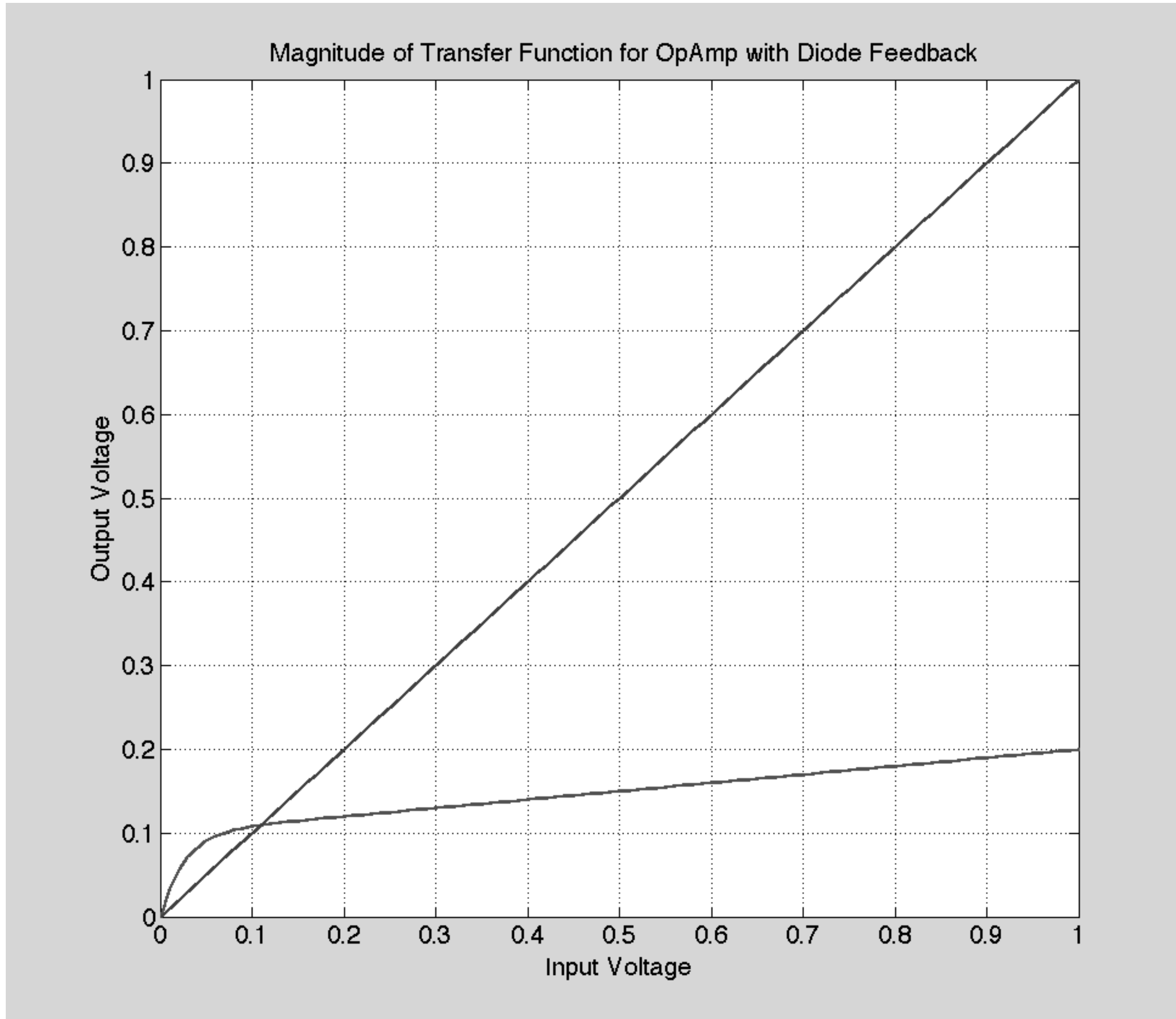
Graphical solution for V_{out} vs. V_{in}

$$V_{in} = R_{in}\left[I_0\left(e^{\frac{-V_{out}}{V_T}} - 1\right) - \frac{V_{out}}{R_f}\right]$$

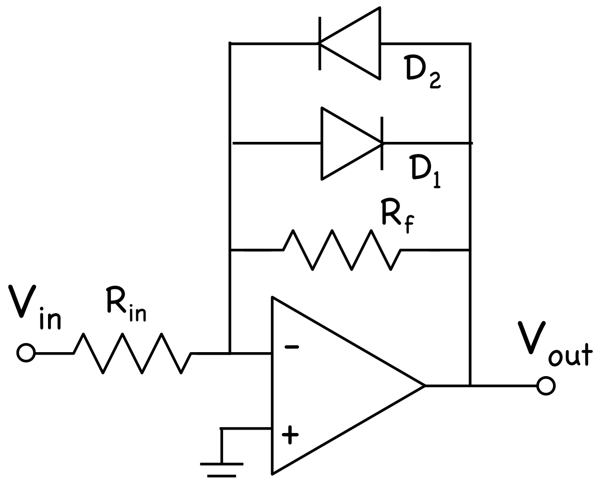
Find V_{in} as a function of V_{out} but then plot it as V_{out} vs. V_{in}

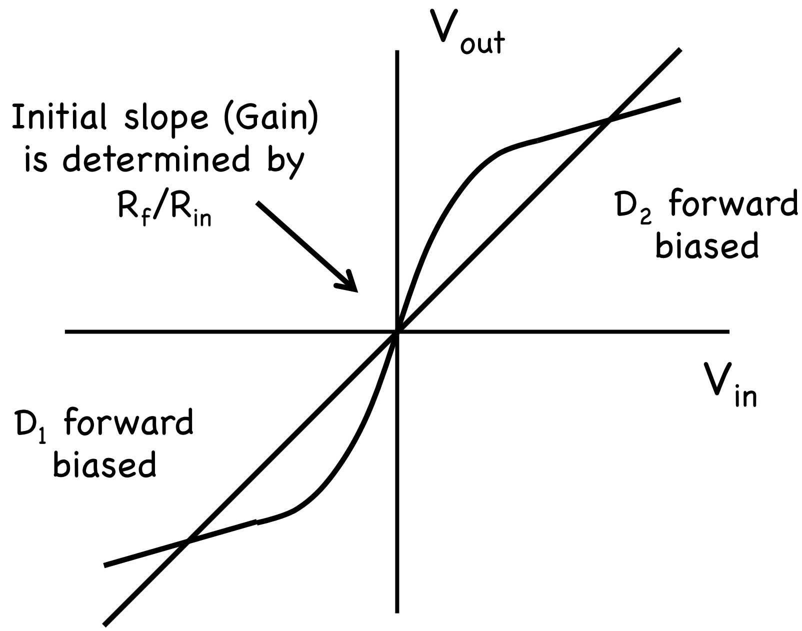
But don't forget that this is an inverting amplifier configuration!

That's why we plotted the <u>magnitude</u> of the transfer function.



Making the transfer function symmetrical





D_1 conducts for $V_{in} > 0$,
(V_{out} will be negative)

D_2 conducts for $V_{in} < 0$,
(V_{out} will be positive)

Speaker Cabinet Design

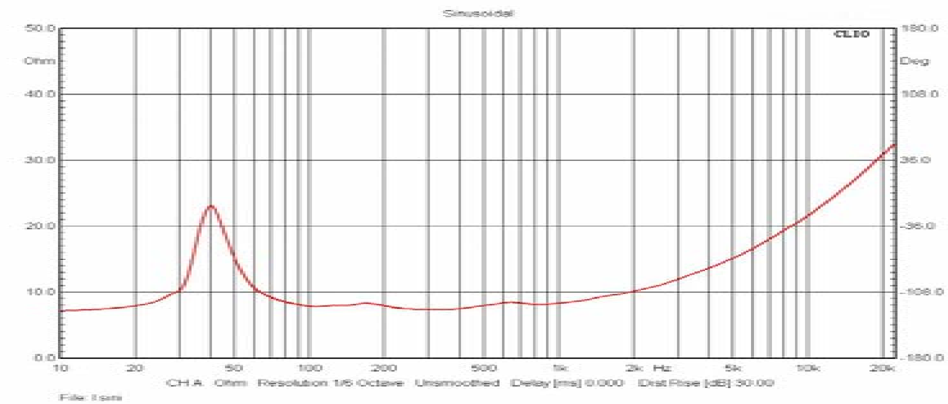
- Guitar amplifiers normally have an open back so the cabinet has little acoustical effect

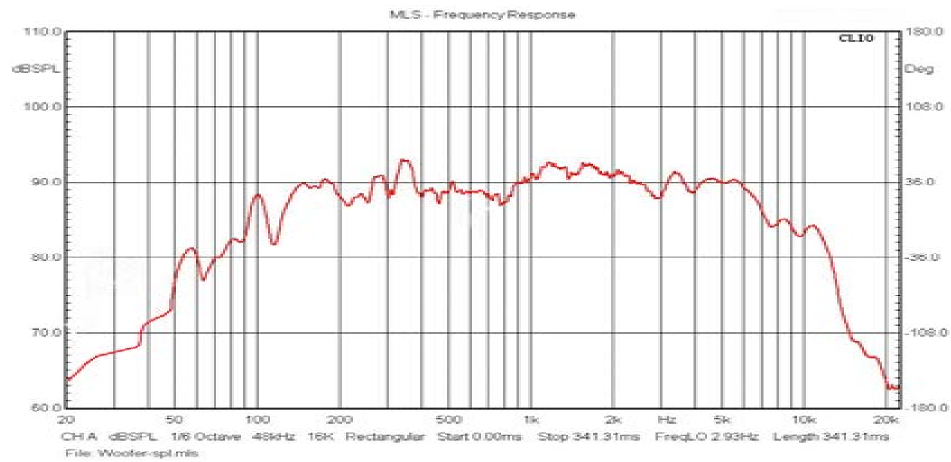
- Bass cabinet design – to obtain better bass response from the amplifier the cabinet should be properly sized.

Thiele-Small parameters for project speaker

SPEAKER SPECIFICATIONS

Model Number:	55-2970	
GENERAL SPECIFICATIONS		
Nominal Diameter:	6.5 inch	
Rated Lmpedance:	8 ohms	
Operating Bandwidth:	60-8k hz(-3dB)	
Power Handling Capacity:	50 Watts	
Sensitivity (1W/M):	88 dB(+-3dB)	
Voice Coil Diameter:	1 inch	
THIELE-SMALL PARAMRTERS		
Resonance Frequency	Fs:	40 HZ
DC Resistance	Re:	7.2 ohm
Mechanical Q Factor	Qms:	3.66
Electrical Q Factor	Qes:	0.4796
Total Q Factor	Qts:	0.424
Equivalent Cas air load	Vas:	26.93 L
Surface Area of Cone	Sd:	0.0139 m2
Efficiency Bandwidth Product	EBP	83.4
Voice Coil Over Hang	X-max	3.5 mm
Voice Coil Inductance	Le	0.3875mH
PHYSICAL INFORMATION		
Basket:	Pressed steel chassis	
Magnet Type:	16.6 OZ	
Cone Material:	PP	
Surround:	Rubber	
Dust Cap:	PP	
Damper:	cloth	





Date: 2010/6/28

Following Rob's Week 5 Lecture 1 example …

f_s = 40 Hz
Q_{ts} = 0.424
V_{AS} = 26.93 liters

Choose Q_{cb} = 1 so Q_{cb}/Q_{ts} = 2.36

$$\frac{V_{as}}{V_{box}} = \left(\frac{Q_{cb}}{Q_{ts}}\right)^2 - 1 \qquad \frac{V_{as}}{V_{box}} = (2.36)^2 - 1 = 4.57$$

$$V_{box} = \frac{V_{AS}}{4.57} = \frac{26.93}{4.57} = 5.89 \ liters = 5890 \ \text{cm}^3$$

Using the ratio, 0.618 : 1 : 1.618
…we find approximately
11 cm x 18 cm x 29 cm