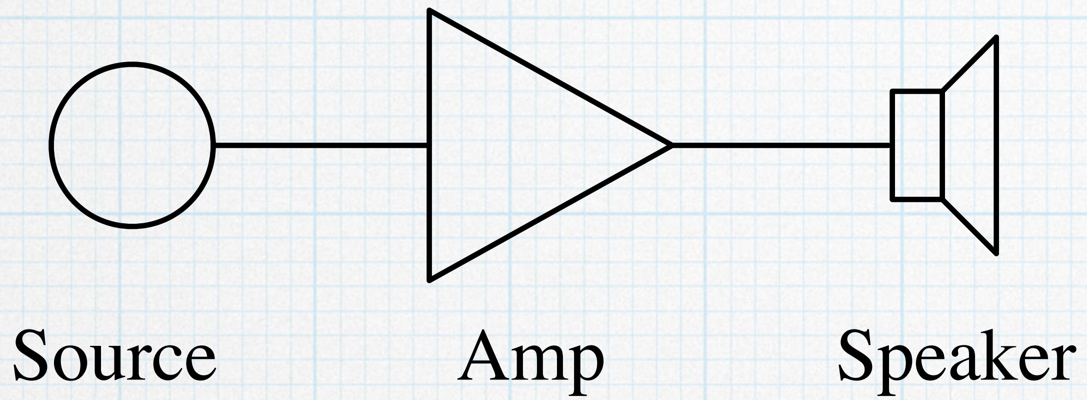
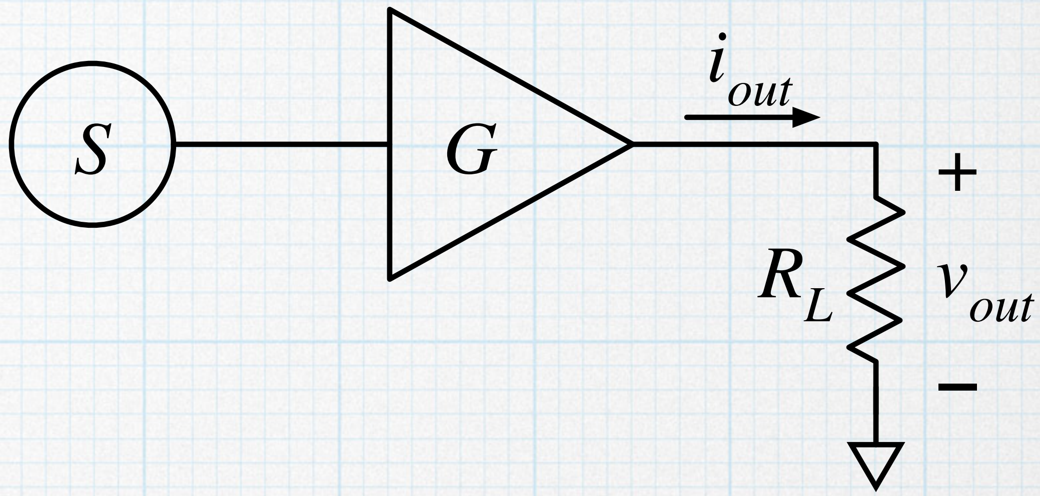
# Amplifier basics




- Power
- Frequency response
- Distortion
- Efficiency
- Thermal control
- Noise
- Cost

# Power

In an audio system, the amplifier is probably delivering power to a speaker. Typical speakers have voice coils with either 4-Ω or 8-Ω resistance. (We will use 4 Ω as a standard.)




The resistive nature of the speaker imposes constraints on power.

$$P = v_o \cdot i_o$$

$$v_o = i_o \cdot R_L$$

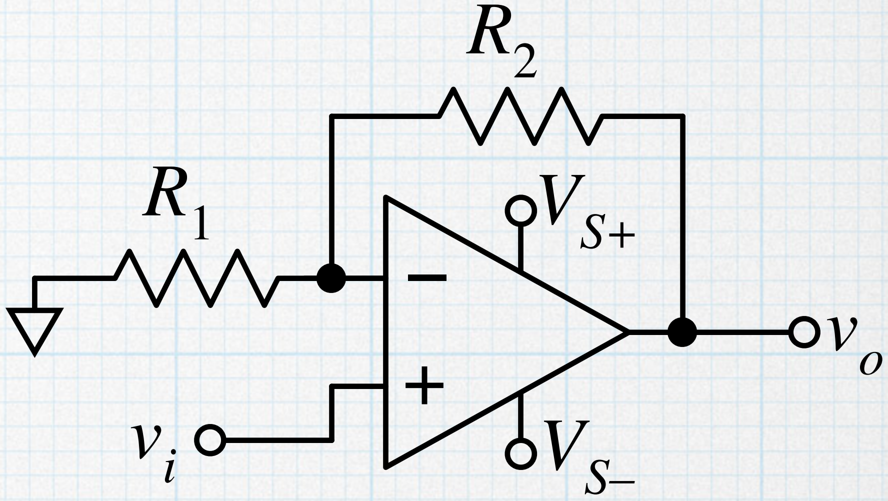
$$P = \frac{v_o^2}{R_L} = i_o^2 \cdot R_L$$

For a 4-Ω speaker: (RMS quantities)

| $P$ | $v_o$ | $i_o$ |
|---|---|---|
| 0.1 W | 0.632 V | 0.158 A |
| 1 W | 2 V | 0.5 A |
| 10 W | 6.32 V | 1.58 A |
| 100 W | 20 V | 5 A |

DC supplies must be able to supply the corresponding voltage and current!

# Non-inverting amp




A nice starting point is the simple non-inverting op-amp circuit, right out of EE 201.

The gain is easily to set: $G = \frac{v_o}{v_i} = 1 + \frac{R_2}{R_1}$.

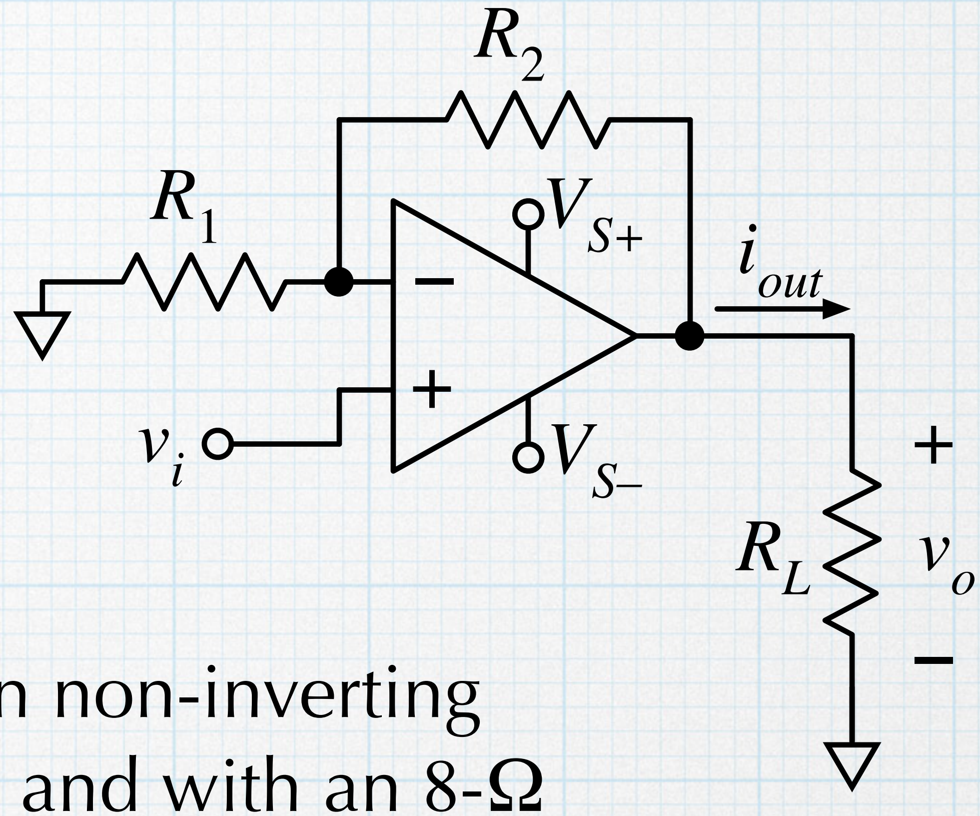
Gain of 10 to 20 is usually adequate.

With $R_2$ = 15 kΩ and $R_1$ = 1 kΩ, $G$ = 16. (or 150 kΩ and 10 kΩ)

For low-power applications, this may be all that is needed.

# Low output current

However, problems come up when the op amp is trying to deliver higher power. Most conventional op amps have maximum output current limits of 50 mA or less.




Below are the outputs of a TL082 op-amp in non-inverting configuration with gain of 16, with no load and with an 8-Ω load. Yellow trace is input, green is output. (Note the scales.)

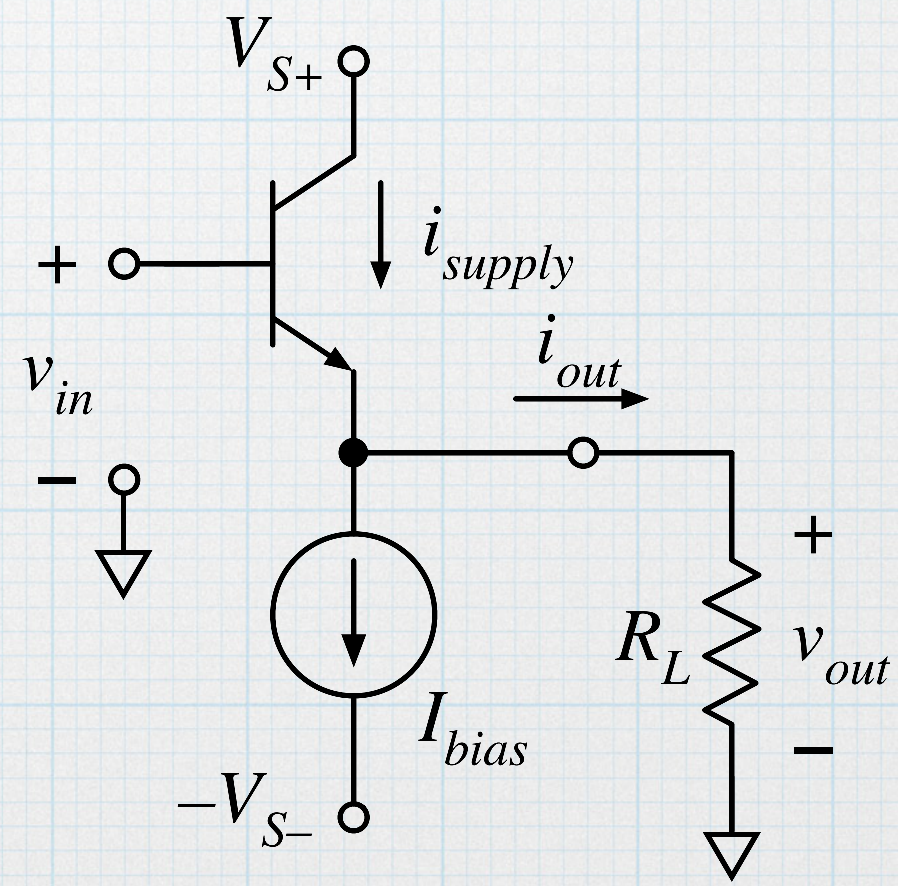
No load. (no output current.)


8-Ω load. Severe current limit.

# Higher currents

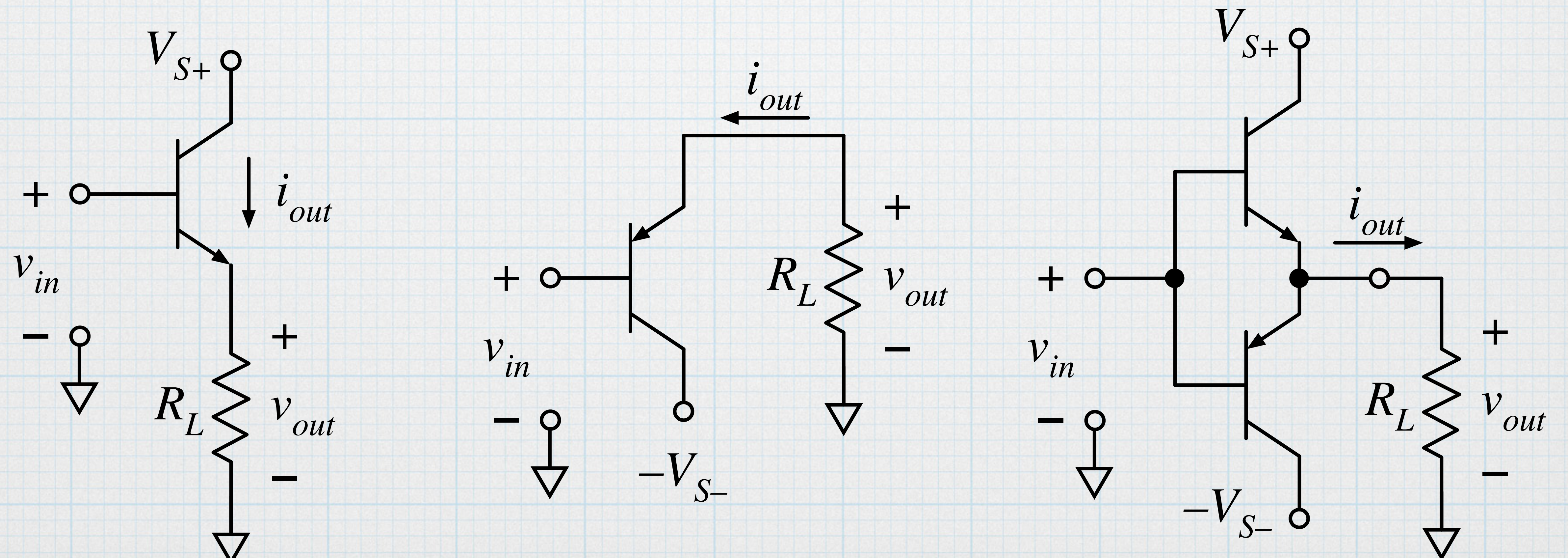
- Op amps are great for providing voltage gain. However, most op amps have very limited current output capability. For example, maximum $i_o$ for a TL082 is about 25 mA. Into a 4-Ω speaker, this would be about 2.5 mW of power. Might be hard to hear.
- So, if using op amps, we will need some sort of current-boosting stage to get to the desired power. (Some op amps are capable of higher currents, eg. Texas Instruments' LM386 or LM3886. (We may make a higher power amp using the LM3886 later.)

- Class A amp. Single transistor (BJT here, but could be a MOSFET). Transistor is biased to have a continuous DC current flowing — transistor is always on.
- No voltage gain, $v_o \approx v_{in}$. It's job is provide bigger output current.
- $I_{bias}$ must be bigger than the magnitude of the output current.
- Very linear.
- Inefficient.



# Class B

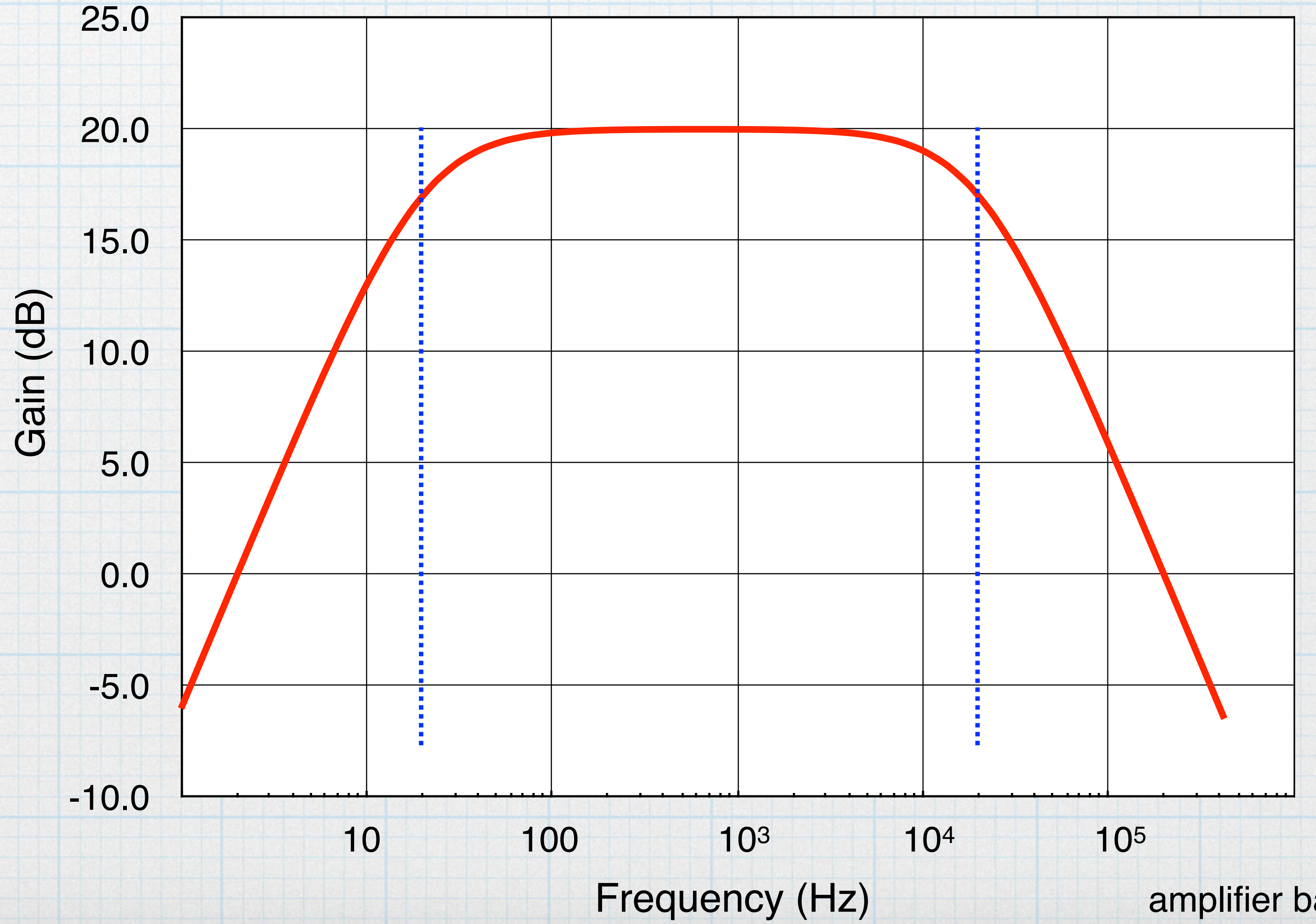
- Similar to Class A, but the *npn* BJT transistor is biased at zero current, meaning that it is off until the input signal is positive enough to turn on the transistor and cause current to flow. (Again, could use an NMOS.)
- As with Class A, no voltage gain, but lots of current when the output goes positive.
- Less loss than Class A, but only works when the signal goes positive.
- Can get the negative half of the signal using *pnp* BJT transistor (or PMOS).
- Put the two together for a *push-pull* configuration to get both positive and negative voltage swings.
- More efficient than Class A, but has some distortion when $v_{in} \approx 0$.



# Frequency response

- Audio singles are made up of sinusoids with frequencies ranging from 20 Hz to 20 kHz. (Fourier analysis)
- The amplifier should boost all frequencies by the same amount. This would be a flat frequency response.
- If some frequencies are amplified more than others, then the information in the audio signal is being changed. Usually, we want the *frequency response* to be flat. But, in some cases, we may intentionally boost or suppress some frequencies.

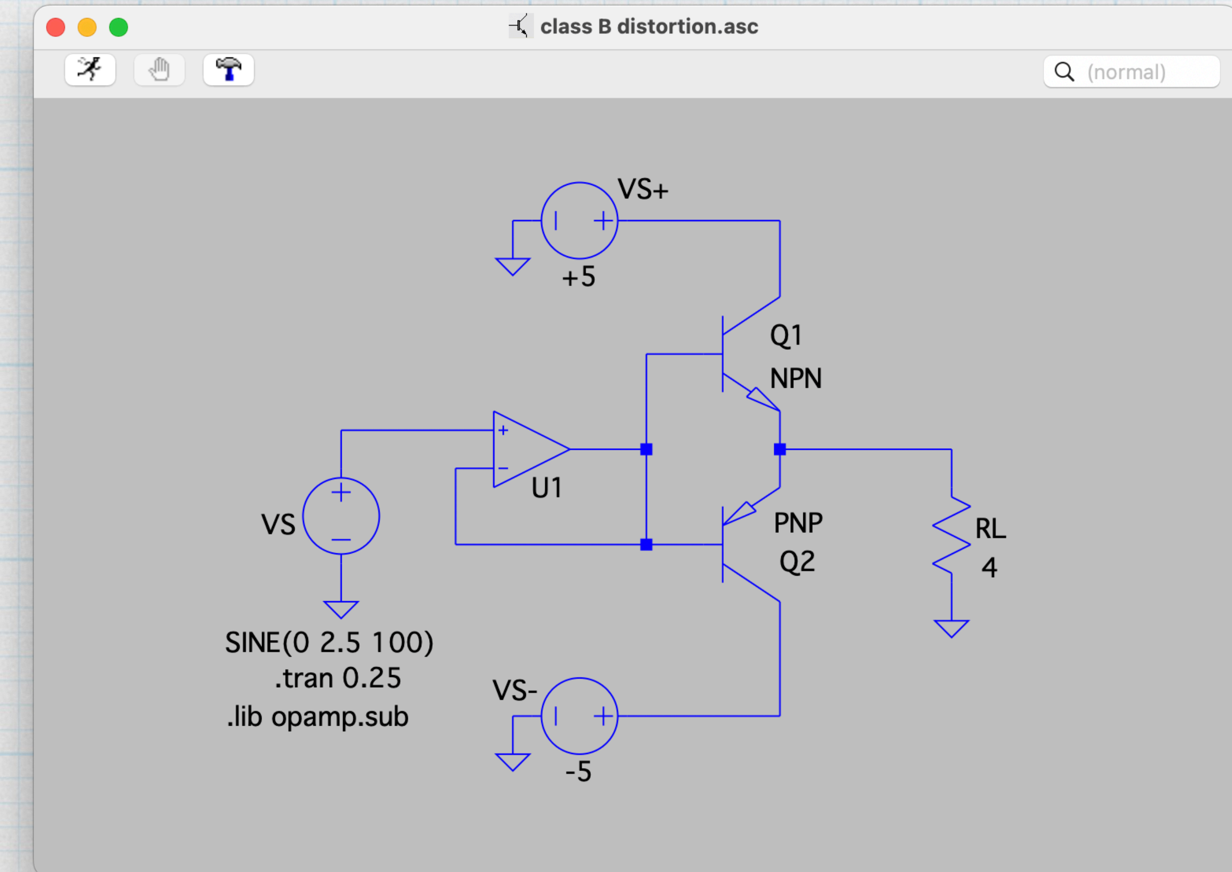
Frequency response plot of an amp with gain of 10 (= 20 dB) between 20 Hz and 20 kHz.

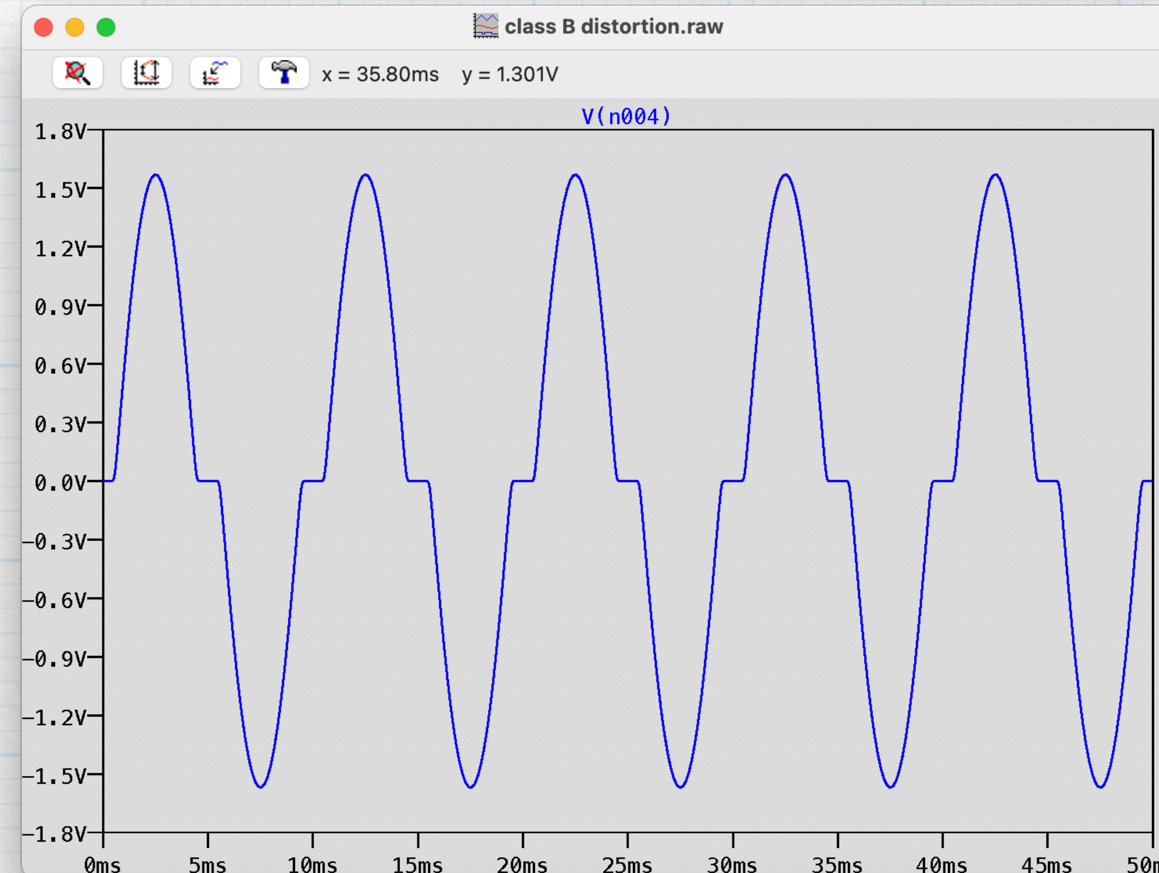


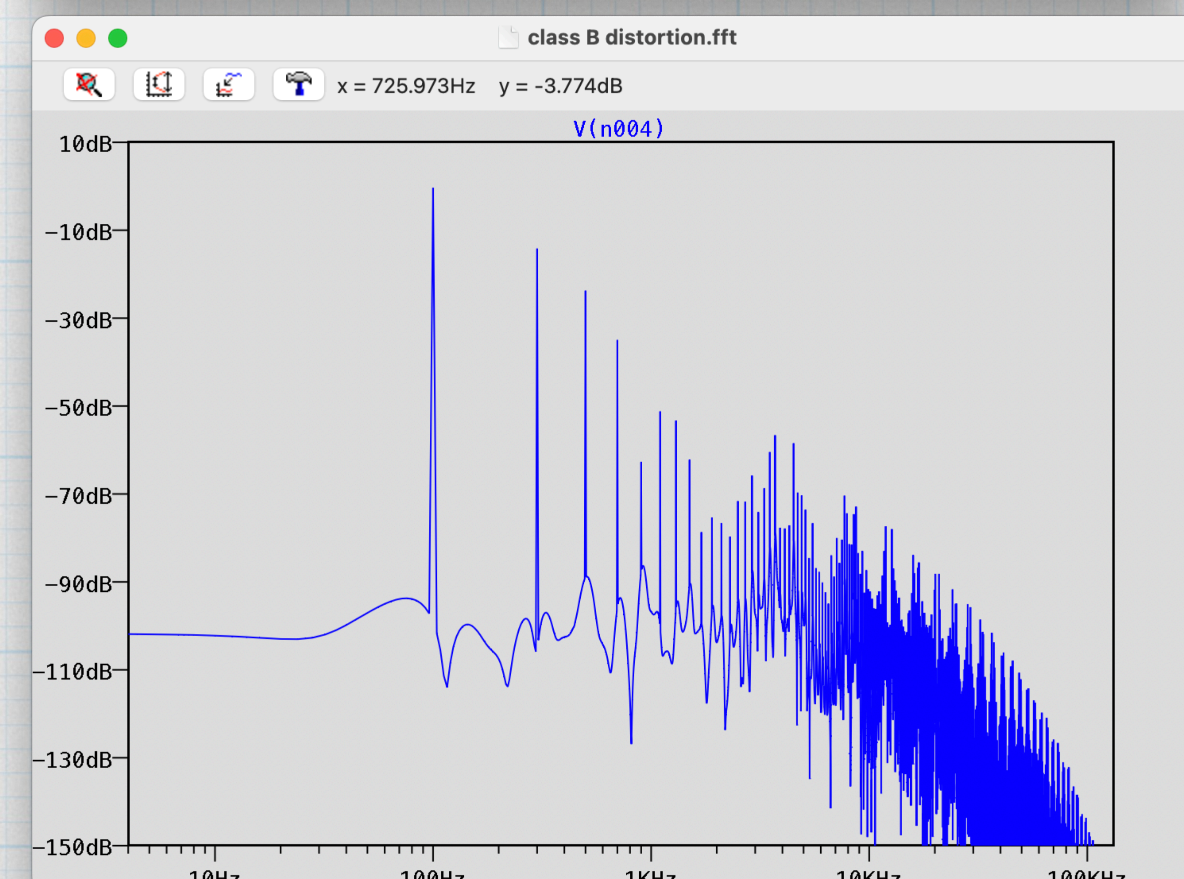
# Distortion

- Another mechanism that changes the information in a signal.
- Changes the shape of the audio waveform due to non-linear effects in the circuit or components.
- Much different than changes due to frequency response.
- Generally makes the audio sound "harsh" or "static-y". Generally want to avoid distortion.
- Introduces new harmonics in the Fourier transform of the signal.
- Characterized by "total harmonic distortion" - THD. This an indication of how much power is in the distortion-induced harmonics. Ideal is 0% (no distortion, no harmonics). Below 0.1% is probably OK. Above 1% is probably becoming noticeable.
- Biggest culprits are clipping (exceeding the power-limits) and cross-over distortion in class B output stages. Other sources are inductor saturation and over-driving speakers.
- Remedies: Feedback and/or filtering.

# Distortion in class B output



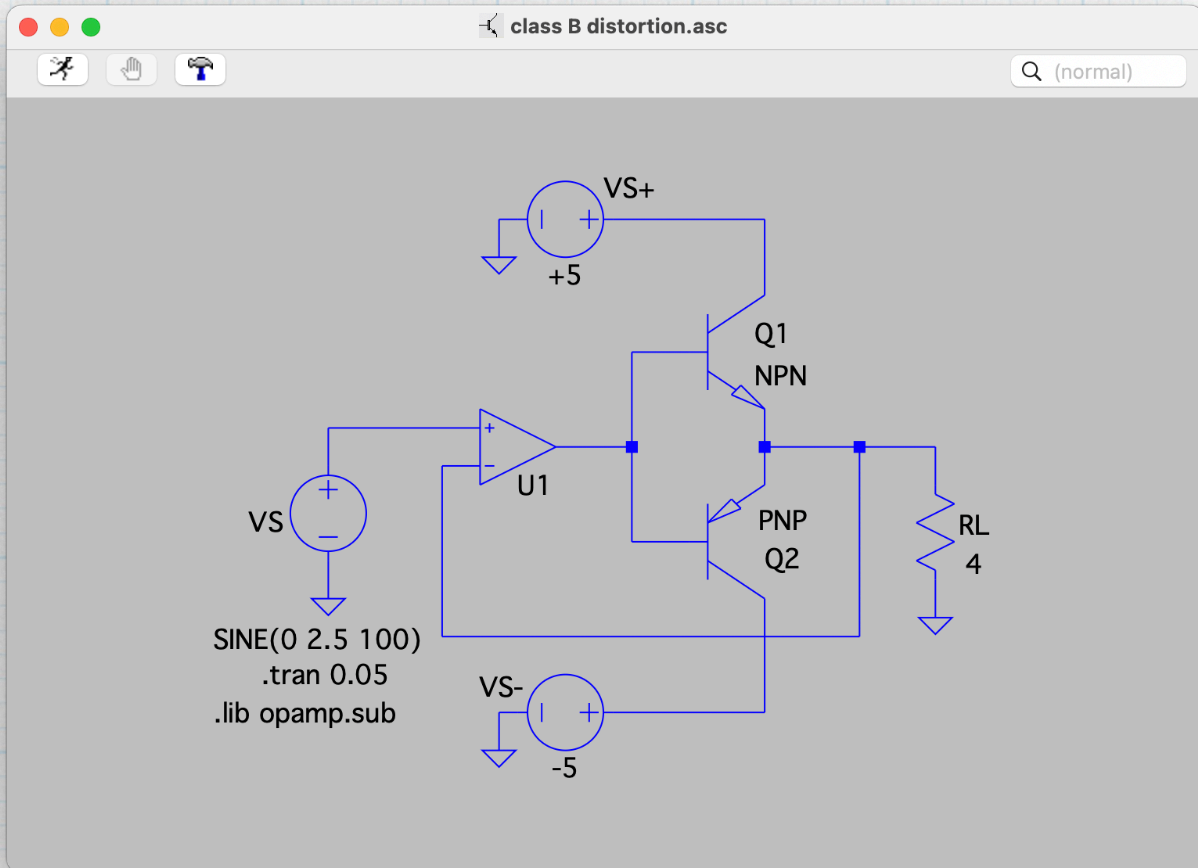



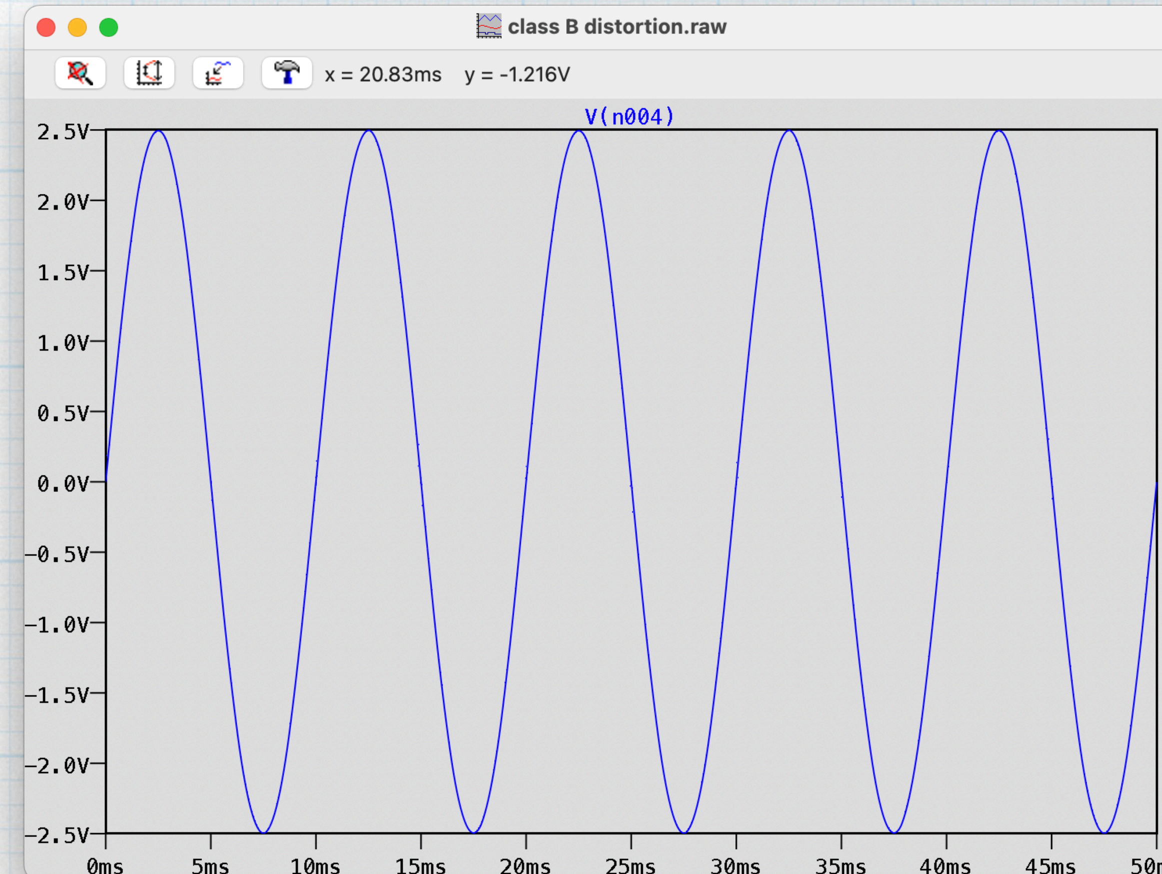

Simple class B push-pull output stage — no correction.

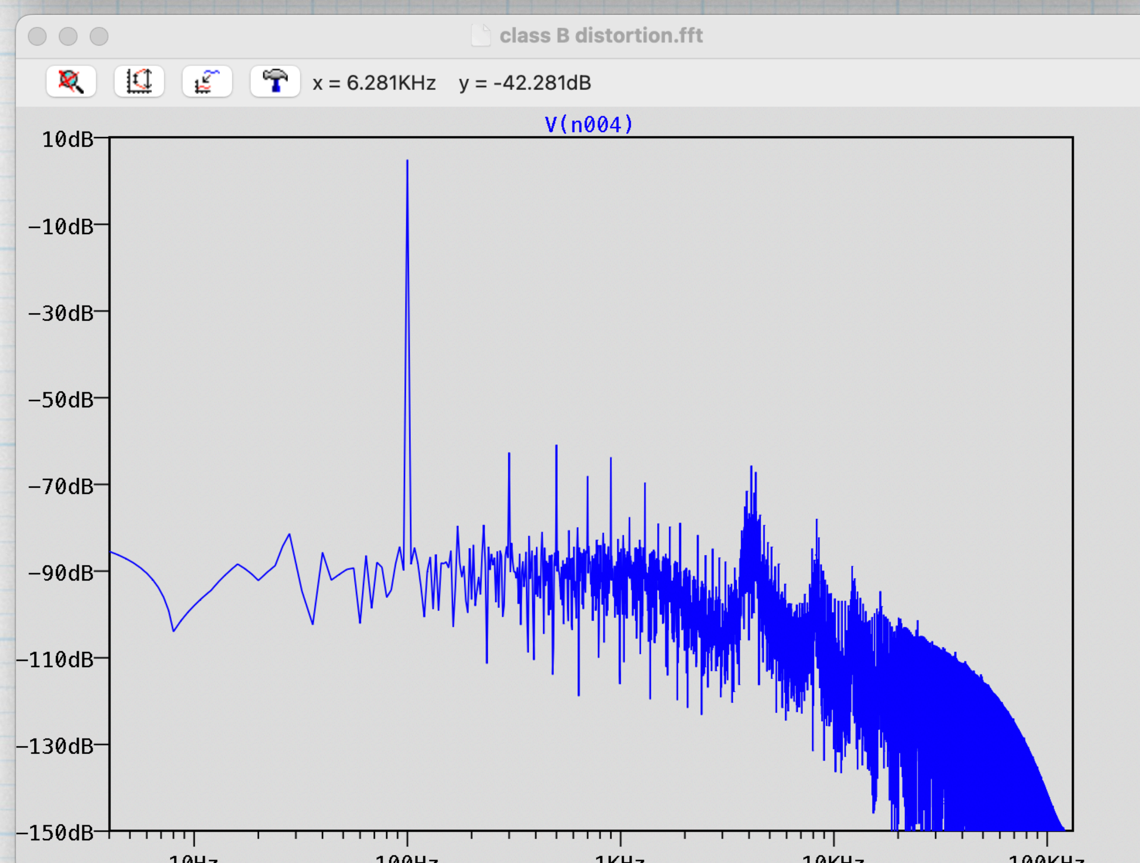
Use LTSpice as a quick method to show the effects distortion.

Class B circuit with no attempt to correct. Cross-over distortion is evident in the waveform. Many strong odd harmonics.

# Distortion in class B output

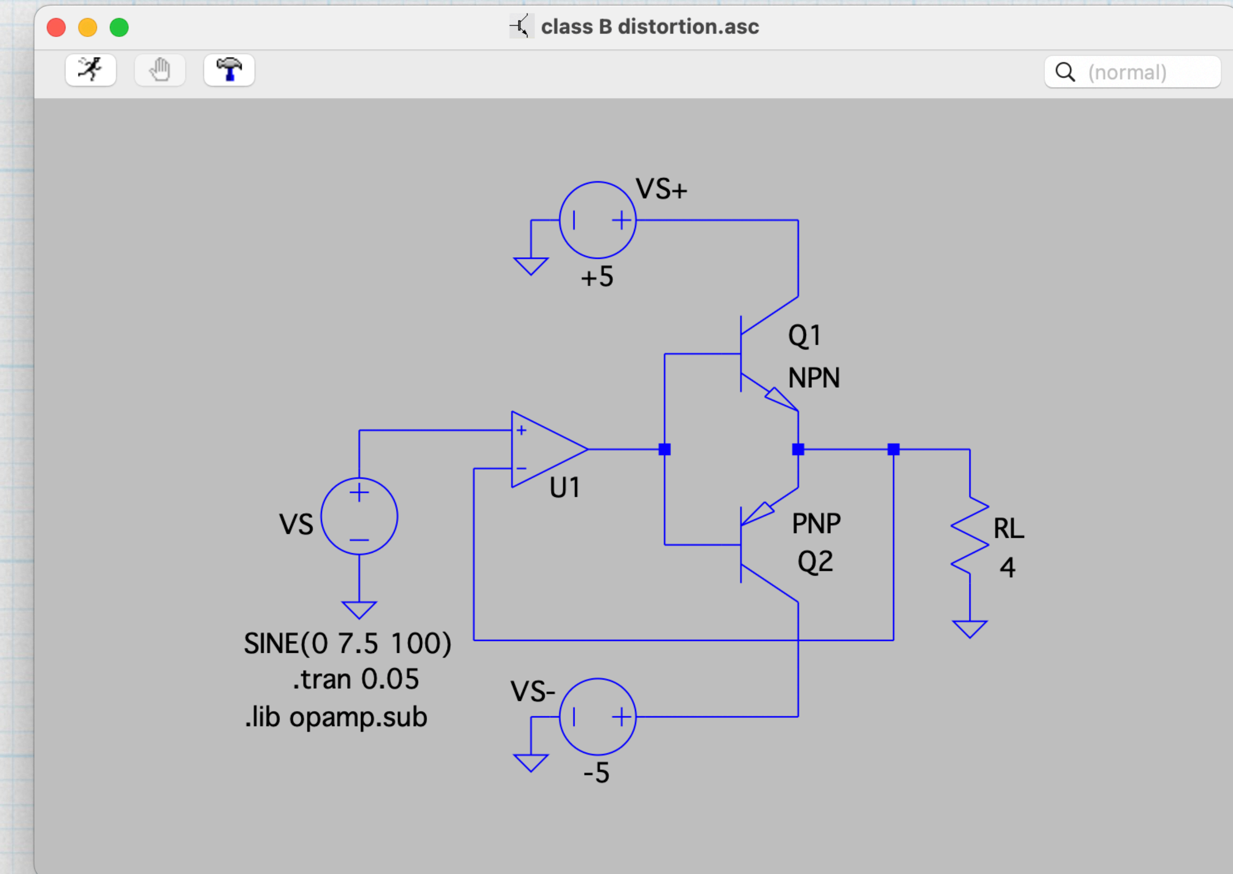


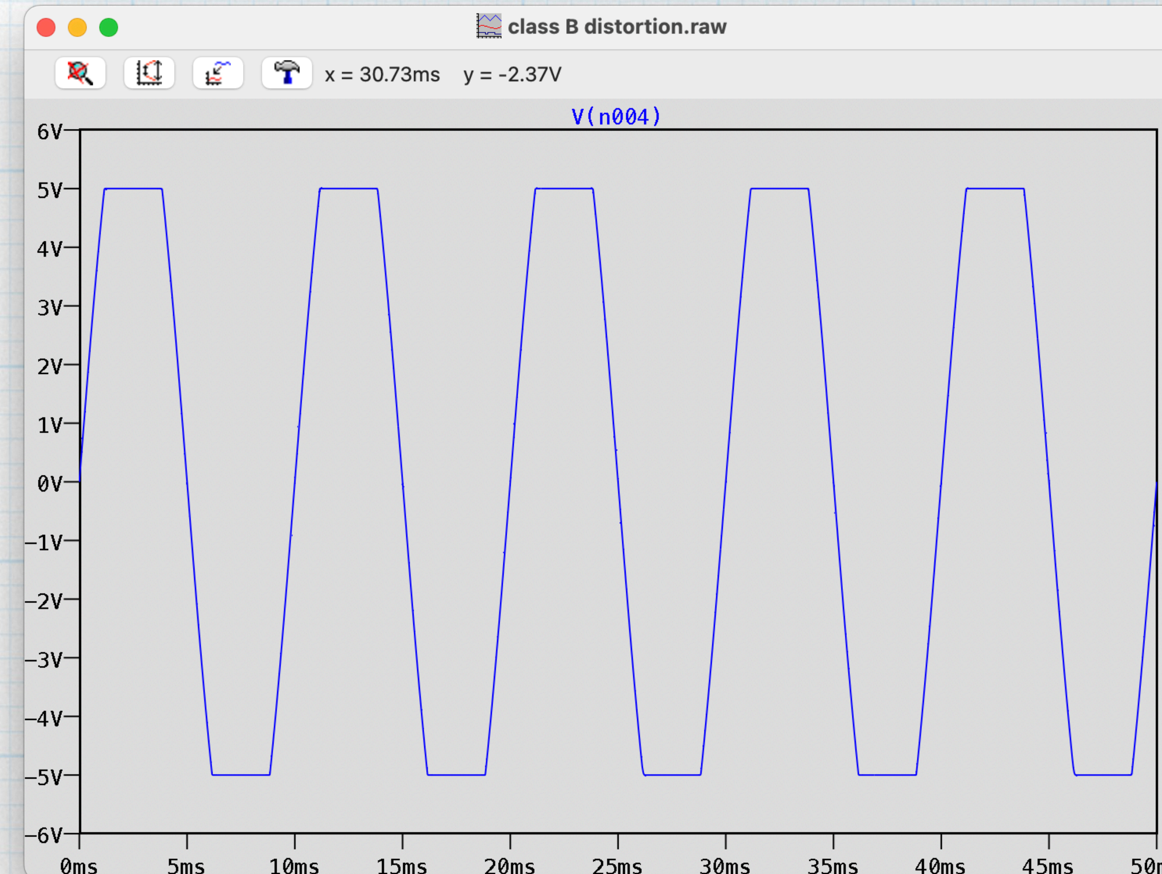



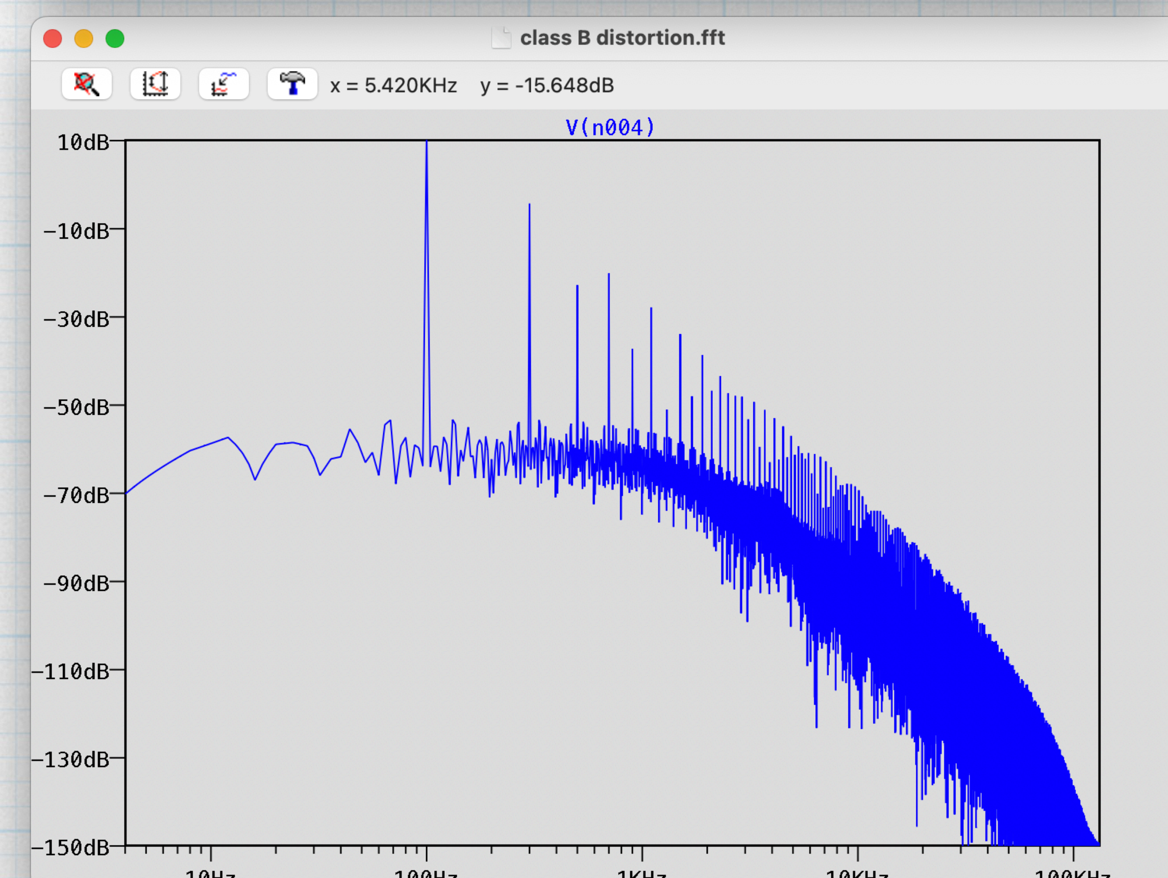




Use feedback to correct. Waveform looks perfect. Harmonics are greatly reduced relative to the signal. (In practice, probably works less well that what SPICE claims.)

# Distortion in class B output

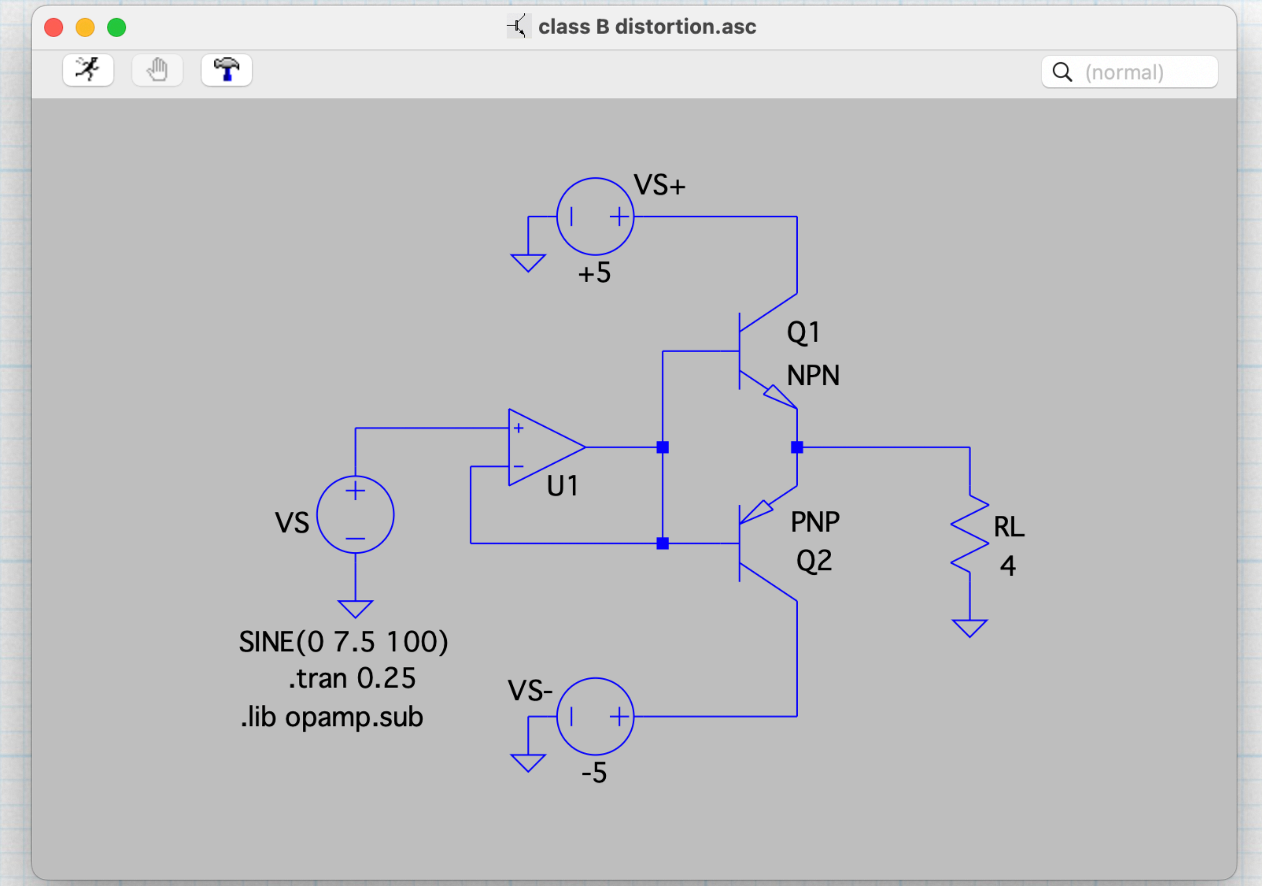


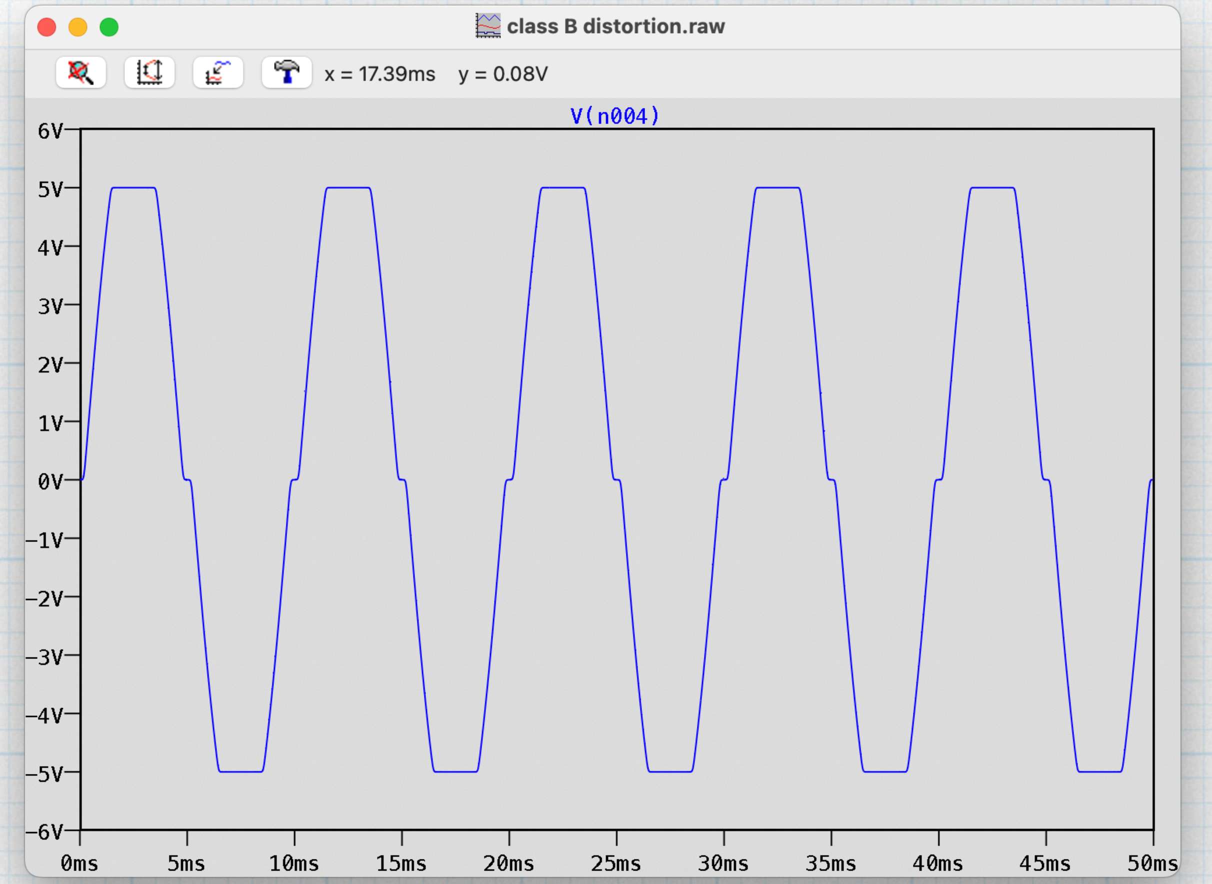



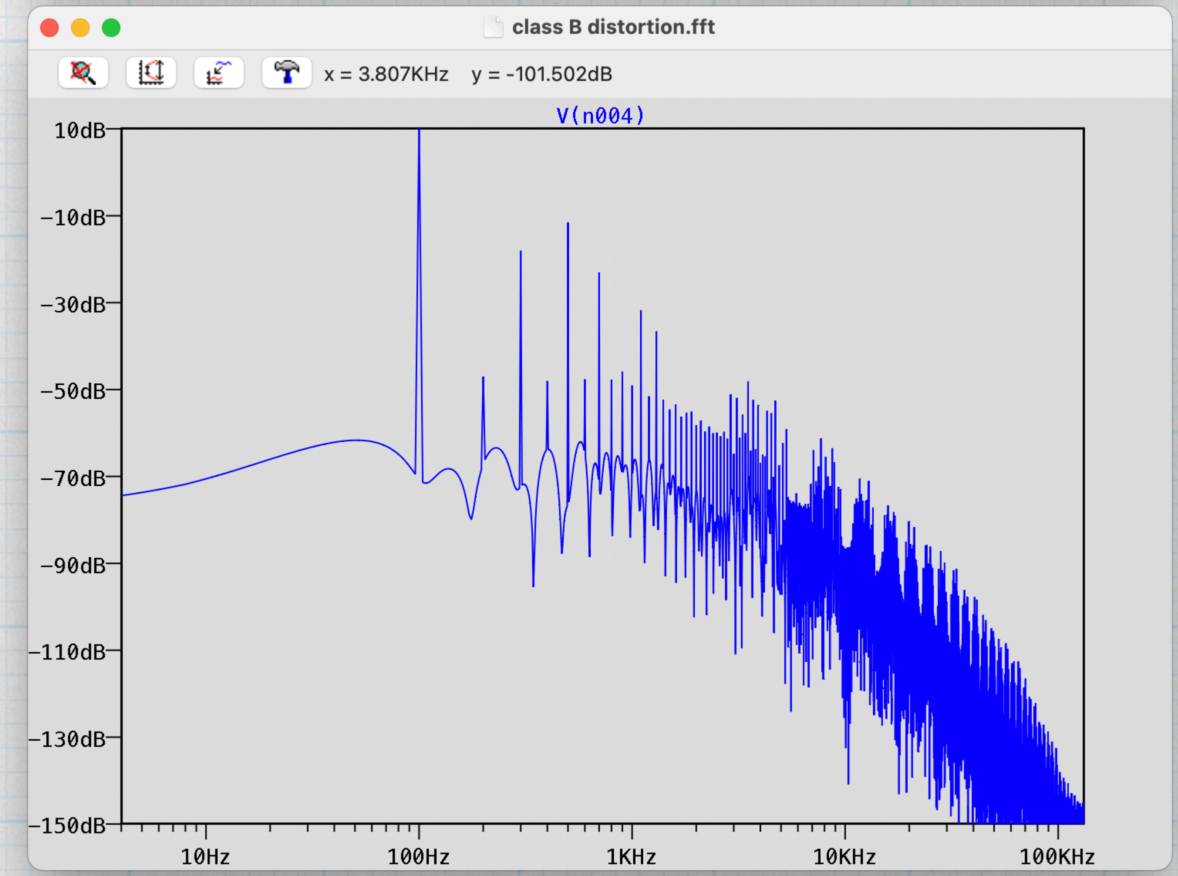

Now drive the level beyond the power supply limits. Severe clipping. Harmonics are back.

# Distortion in class B output




Worst case: clipping + cross-over. Frequency plot is a mess of harmonics. Bleh.



# Efficiency and thermal management

- Efficiency: $\eta = \dfrac{\text{audio power out}}{\text{total power in}}$
- Generally determined by the output stage.
- Class A is worst, may be much less than 50%
- Class B is better, may approach 65%.
- Lost power is dissipated in the output transistors. They will heat up.
- When working at higher powers, it may be necessary to provide cooling for the output stage — heat sinks or even fans.
- Of course, this drives up cost and lowers reliability.
- The primary problem with type A or B stages is that when the transistors are on, they are operating in the active region, meaning that there is both a current flowing through the transistors and a voltage drop across the transistors. $P = v \cdot i$ → power dissipated.
- To improve efficiency, need a radically different approach. Use the transistors as switches. This is is a Class D amp, to be discussed later in Audio Club.