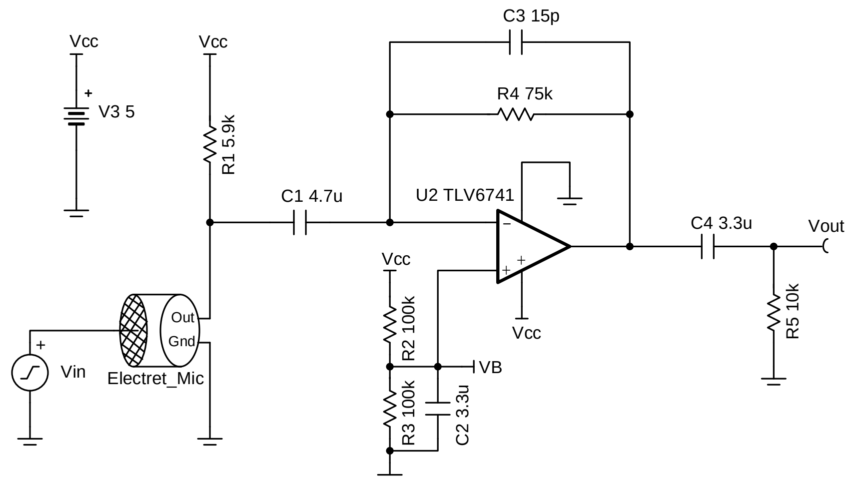
TIA microphone amplifier circuit

Design Goals

Input pressure (Max)	Output Voltage (Max)	Supply		Frequency Response Deviation	
		V_{cc}	V_{ee}	@ 20Hz	@20kHz
100dB SPL(2Pa)	1.228V_{rms}	5V	0V	–0.5dB	–0.1dB

Design Description

This circuit uses an op amp in a transimpedance amplifier configuration to convert the output current from an electret capsule microphone into an output voltage. The common mode voltage of this circuit is constant and set to mid–supply eliminating any input–stage cross over distortion.



Design Notes

1. Use the op amp in the linear output operating range, which is usually specified under the A_{OL} test conditions.

2. Use low–K capacitors (tantalum, C0G, etc.) and thin film resistors help to decrease distortion.

3. Use a battery to power this circuit to eliminate distortion caused by switching power supplies.

4. Use low value resistors and low noise op amp to achieve high performance low noise designs.

5. The voltage connected to R_1 to bias the microphone does not have to match the supply voltage of the op amp. Using a larger microphone bias voltage allows for a larger value or R_1 which decreases the noise gain of the op amp circuit while still maintaining normal operation of the microphone.

6. Capacitor C_1 should be large enough that its impedance is much less than resistor R_1 at audio frequency. Pay attention to the signal polarity when using tantalum capacitors.

Design Steps

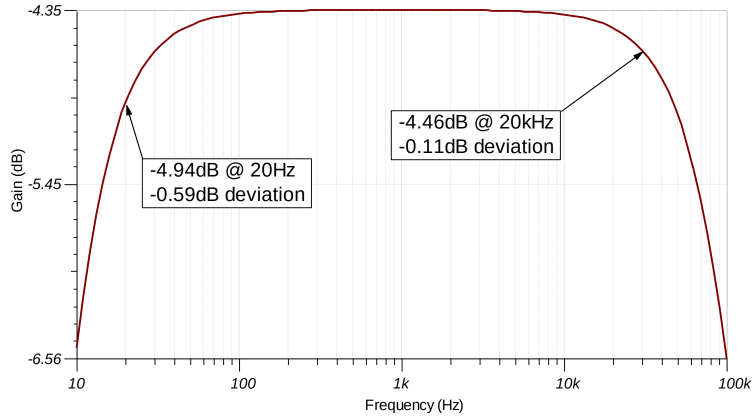
The following microphone is chosen as an example to design this circuit.

Microphone parameter	Value
Sensitivity @ 94dB SPL (1 Pa)	–35 ± 4 dBV
Current Consumption (Max)	0.5mA
Impedance	2.2kΩ
Standard Operating Voltage	$2V_{dc}$

1. Convert the sensitivity to volts per Pascal.
   $$10^{\frac{-35dB}{20}} = 17.78\ mV / Pa$$
2. Convert volts per Pascal to current per Pascal.
   $$\frac{17.78mV / Pa}{2.2k\Omega} = 8.083\ \mu A / Pa$$
3. Max output current occurs at max sound pressure level of 2Pa.
   $$I_{Max} = 2Pa \times 8.083\ \mu A / Pa = 16.166\ \mu A$$
4. Calculate the value of resistor R_4 to set the gain
   $$R_4 = \frac{V_{max}}{I_{max}} = \frac{1.228V}{16.166\mu A} = 75.961\ k\Omega \approx 75k\Omega\ (\text{Standard value})$$
   The final signal gain is:
   $$\text{Gain} = 20 \times \log \frac{V_{out}}{V_{in}} = 20 \times \log \frac{16.166\mu A \times 75k\Omega}{2V} = -4.347\ dB$$
5. Calculate the value for the bias resistor R_1. In the following equation, Vmic is the standard operating voltage of the microphone
   $$R_1 = \frac{V_{cc} - V_{mic}}{I_s} = \frac{5V - 2V}{0.5mA} = 6k\Omega \approx 5.9\ k\Omega\ (\text{Standard value})$$
6. Calculate the high frequency pole according to the allowed deviation at 20 kHz. In the following equation, G_pole1 is the gain at frequency "f".
   $$f_p = \frac{f}{\sqrt{\left(\frac{1}{G\_pole1}\right)^2 - 1}} = \frac{20kHz}{\sqrt{\left(\frac{1}{10^{\frac{-0.1}{20}}}\right)^2 - 1}} = 131.044\ kHz$$
7. Calculate C_3 based on the pole frequency calculated in step 6.
   $$C_3 = \frac{1}{2\pi \times f_p \times R_4} = \frac{1}{2\pi \times 131.044kHz \times 75k\Omega} = 16.194\ pF \approx 15pF\ (\text{Standard value})$$
8. Calculate the corner frequency at low frequency according to the allowed deviation at 20 Hz. In the following equation, G_pole2 is the gain contributed by each pole at frequency "f" respectively. There are two poles, so divided by two.
   $$f_c = f \times \sqrt{\left(\frac{1}{G\_pole2}\right)^2 - 1} = 20Hz \times \sqrt{\left(\frac{1}{10^{\frac{-0.5/2}{20}}}\right)^2 - 1} = 4.868\ Hz$$
9. Calculate the input capacitor C_1 based on the cut off frequency calculated in step 8.
   $$C_1 = \frac{1}{2\pi \times R_1 \times f_c} = \frac{1}{2\pi \times 5.9k\Omega \times 4.868Hz} = 5.541\ \mu F \approx 4.7\ \mu F\ (\text{Standard value})$$
10. Assuming the output load R_5 is 10kΩ, calculate the output capacitor C_4 based on the cut off frequency calculated in step 8.
    $$C_4 = \frac{1}{2\pi \times R_5 \times f_c} = \frac{1}{2\pi \times 10k\Omega \times 4.868Hz} = 3.269\ \mu F \approx 3.3\ \mu F\ (\text{Standard value})$$
11. Set the amplifier input common mode voltage to mid–supply voltage. Select R_2 and R_3 as 100kΩ. The equivalent resistance equals to the parallel combination of the two resistors:
    $$R_{eq} = R_2 || R_3 = 100k\Omega || 100k\Omega = 50k\Omega$$
12. Calculate the capacitor C_2 to filter the power supply and resistor noise. Set the cutoff frequency to 1Hz.
    $$C_2 = \frac{1}{2\pi \times (R_2 || R_3) \times 1Hz} = \frac{1}{2\pi \times (100k\Omega || 100k\Omega) \times 1Hz} = 3.183\ \mu F \approx 3.3\ \mu F\ (\text{Standard value})$$

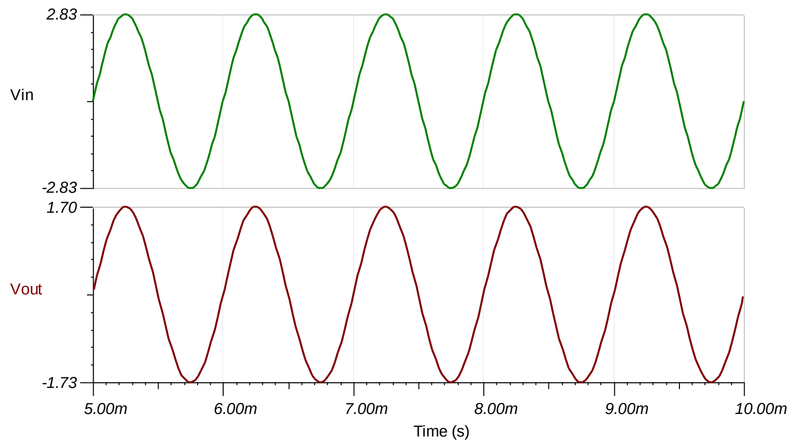
Design Simulations

AC Simulation Results



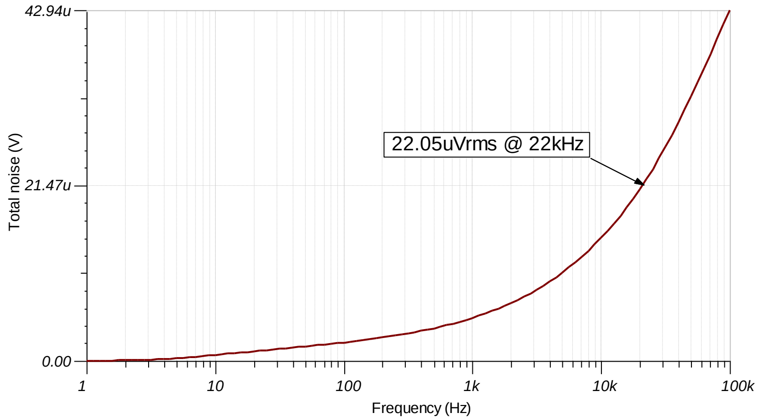
Transient Simulation Results

The input voltage represents the SPL of an input signal to the microphone. A 2 V_{rms} input signal represents 2 Pascal.



Noise Simulation Results

The following simulation results show 22.39µV_{rms} of noise at 22kHz. The noise is measured at a bandwidth of 22kHz to represent the measured noise using an audio analyzer with the bandwidth set to 22kHz.



References:

1. Analog Engineer's Circuit Cookbooks
2. SPICE Simulation File SBOC526
3. TI Precision Designs TIPD181
4. TI Precision Labs

Design Featured Op Amp

TLV6741	
V_{ss}	1.8V to 5.5V
V_{inCM}	V_{ee} to V_{cc}–1.2V
V_{out}	Rail–to–rail
V_{os}	150µV
I_q	890µA/Ch
I_b	10pA
UGBW	10MHz
SR	4.75V/µs
#Channels	1
www.ti.com/product/tlv6741	

Design Alternate Op Amp

	OPA172	OPA192
V_{ss}	4.5V to 36V	4.5V to 36V
V_{inCM}	V_{ee}–0.1V to V_{cc}–2V	V_{ee}–0.1V to V_{cc}+0.1V
V_{out}	Rail–to–rail	Rail–to–rail
V_{os}	±200µV	±5µV
I_q	1.6mA/Ch	1mA/Ch
I_b	8pA	5pA
UGBW	10MHz	10MHz
SR	10V/µs	20V/µs
#Channels	1, 2, 4	1, 2, 4
	www.ti.com/product/opa172	www.ti.com/product/opa192

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