Cover Sheet

501 Advanced Electronics

Title: Low-Noise Battery-Powered Microphone Preamplifier Design

For

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Design Project, Professor Gary Saulnier

Introduction and Summary:

This project models the design and simulation of a low-noise microphone preamplifier suitable for battery-powered operation. The primary objective is to amplify a low-level microphone signal while maintaining a flat audio-band frequency response, low harmonic distortion, high signal-to-noise ratio (SNR), and long battery life. The circuit operates exclusively from two AAA batteries configured to provide a ±1.5 V supply, making it appropriate for portable audio applications.

All performance metrics were verified using LTspice simulations, including AC frequency response, transient behavior, noise analysis, and average current supply usage.

Materials:

Computer with LTspice software

Procedure/ Design Approach:

1. **Circuit Architecture:**

   The preamplifier consists of a low-noise JFET input stage followed by an operational amplifier configured in a non-inverting topology. The JFET (LSK170A) was selected for its low input-referred noise and high input impedance, which are critical for microphone-level signals. The operational amplifier (AD8605) was chosen due to its low power consumption, rail-to-rail operation, and compatibility with low supply voltages.

   AC coupling capacitors are used at the input and output to block DC offsets while preserving the audio signal. A feedback capacitor across the op-amp feedback resistor limits high-frequency gain, improving stability and reducing out-of-band noise.

2. **Gain and Bandwidth:**

The closed-loop gain of the op-amp is set by resistors R_f and R_g, providing sufficient amplification for microphone signals without saturating the output. The low-frequency cutoff is determined by coupling capacitor C_2, while the high-frequency cutoff is controlled by the feedback capacitor C_4. Several combinations of R_f, R_g, C_2, and C_4 were evaluated during the design process; however, these variations did not significantly improve noise performance, indicating that the noise floor is dominated by the active devices.

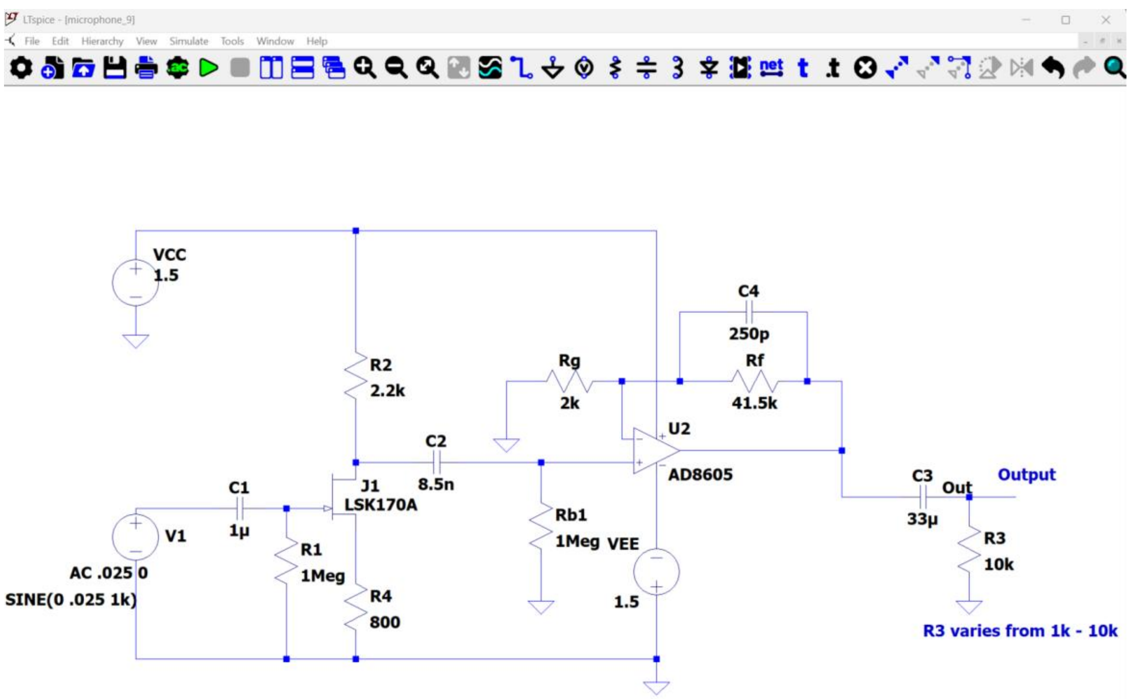


Figure: Showing Electret Microphone Pre-Amplifier

Testing and Analysis:

1. **Frequency Response:**

An AC sweep from 20 Hz to 15 kHz was performed to evaluate the frequency response of the amplifier. As shown in **Figure 1 (A, B, C)**, the amplifier exhibits a flat midband gain across the audio spectrum. The low-frequency roll-off is set by the coupling capacitors, while the high-frequency roll-off is introduced intentionally to limit noise and ensure stability.

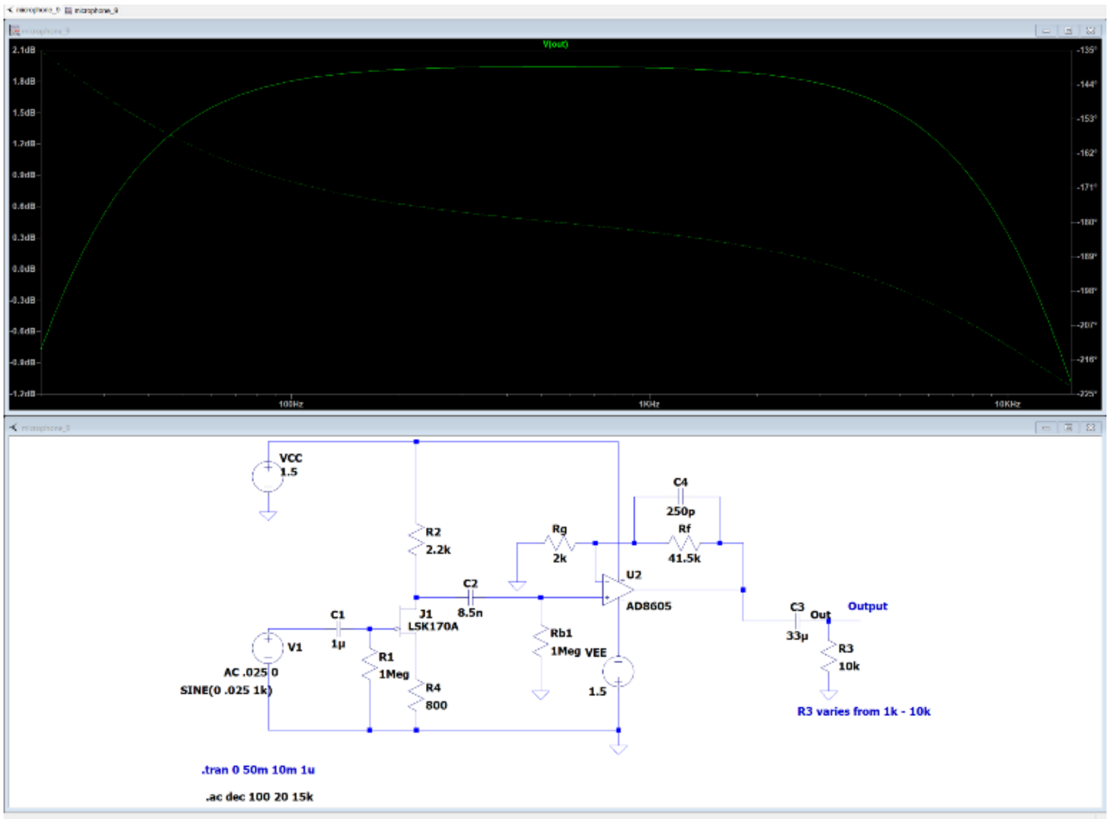


Figure 1.A: AC magnitude and phase response of the microphone preamplifier with 10kΩ load showing flat gain across the 20 Hz–15 kHz audio band.

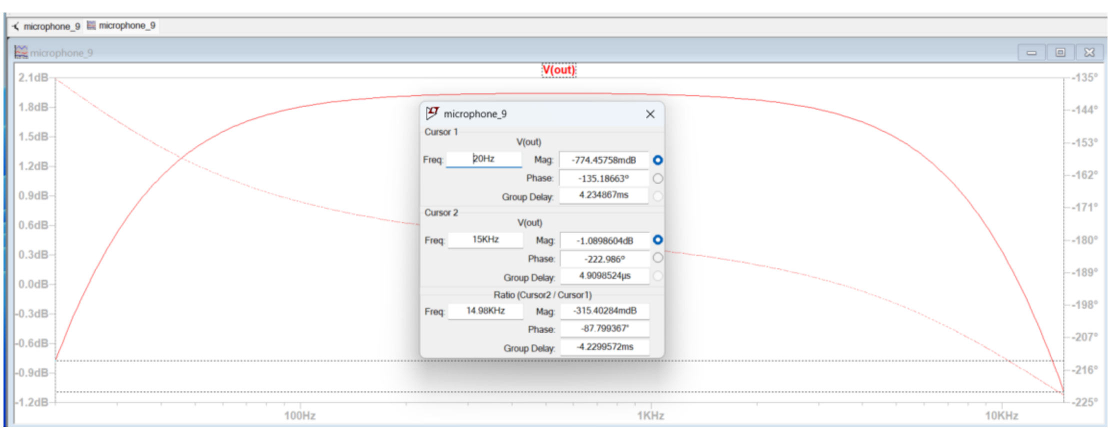


Figure: Showing – 3dB i.e., fL(aprox. 20Hz) and fH (aprox. 15Hz) with 10kΩ load

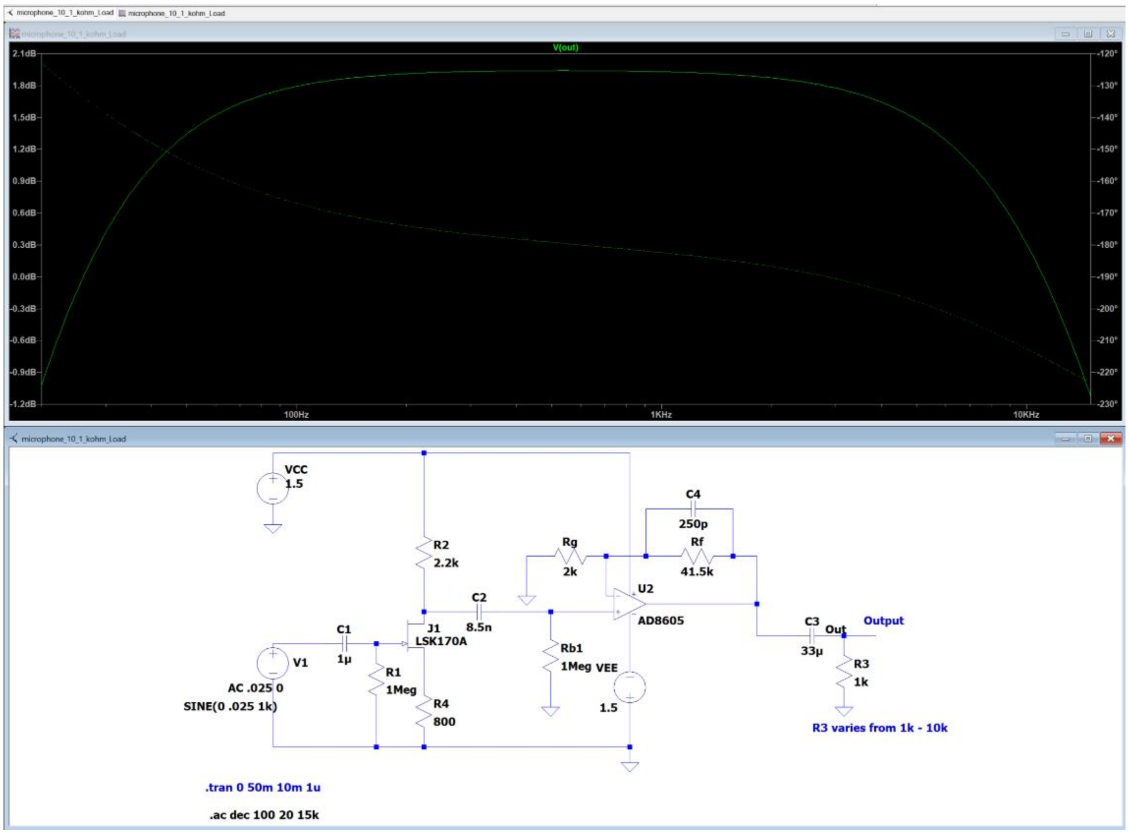


Figure 1.B: AC magnitude and phase response of the microphone preamplifier with 1kΩ load showing flat gain across the 20 Hz–15 kHz audio band [fL(aprox. 20Hz) and fH (aprox. 15Hz)]

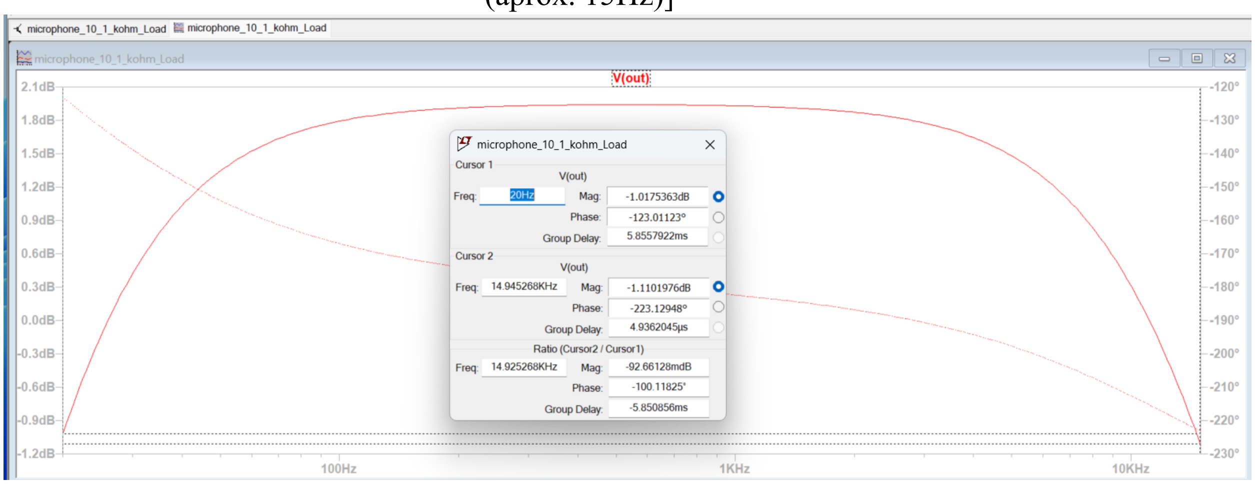
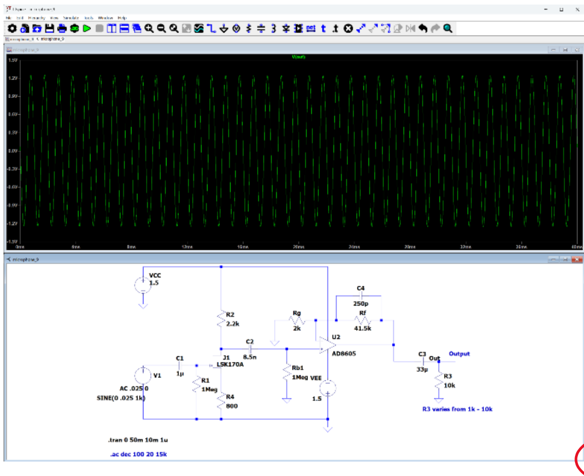


Figure: Showing – 3dB i.e., fL(aprox. 20Hz) and fH (aprox. 14.94Hz) with 1kΩ load

2. Maximum Output Voltage:

Transient analysis with a 1 kHz sinusoidal input confirms that the amplifier produces a clean output waveform without clipping. The output swing remains within approximately ±1.2 V, safely below the ±1.5 V supply rails.

Fig:2A



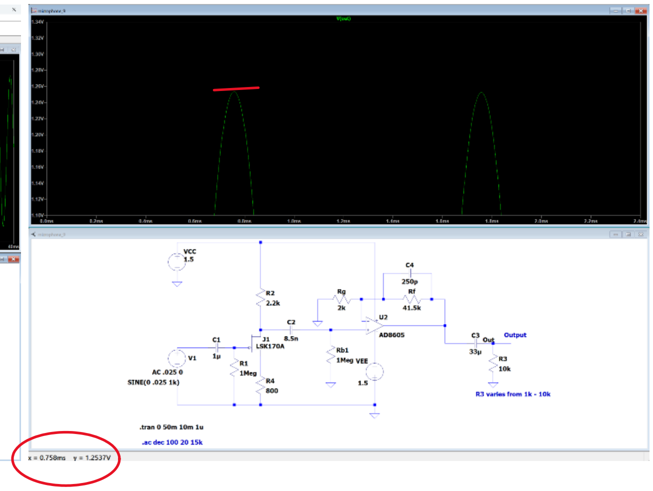


Fig:-2B

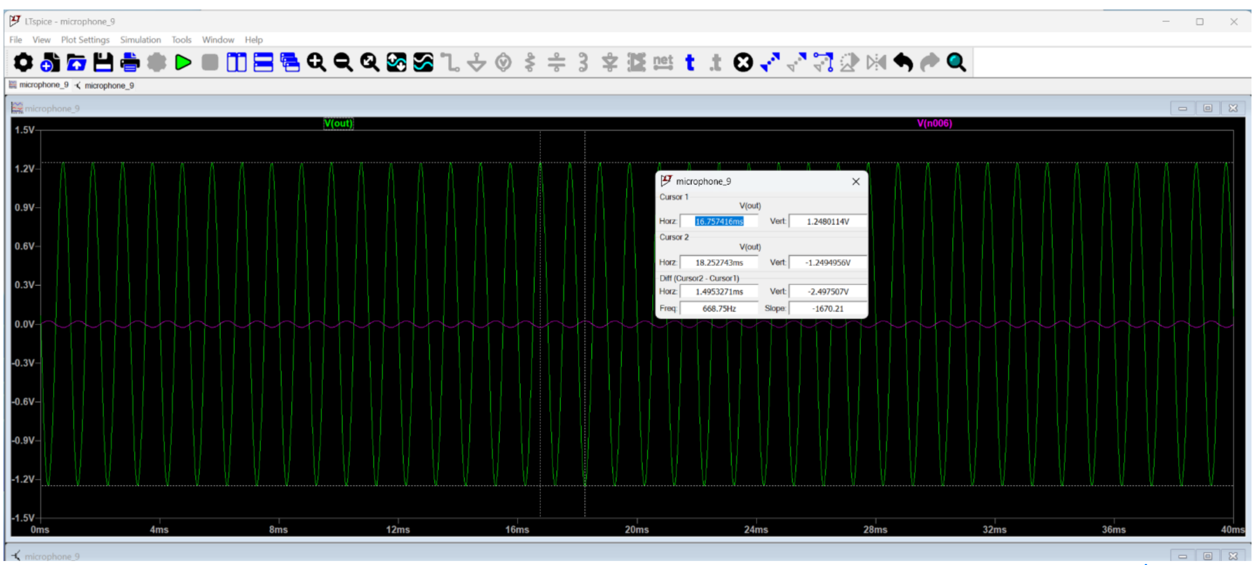


Fig 2.C: Showing Output 2.4 V peak to peak

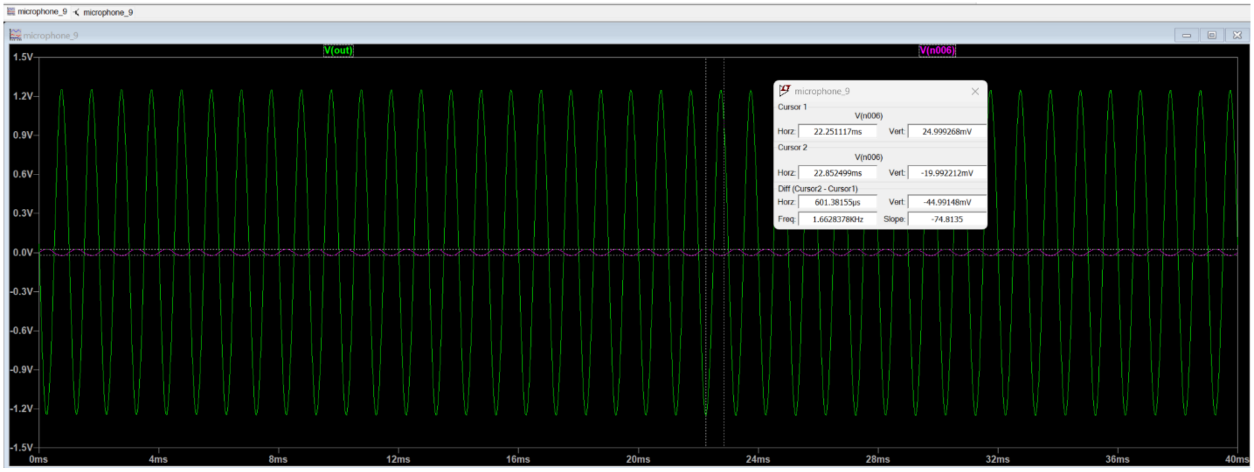


Figure 2.A, 2.B, 2.C, and 2.D: Transient output voltage waveform demonstrating undistorted operation within the supply limits.

(2D: Showing Input ≈ .025V)

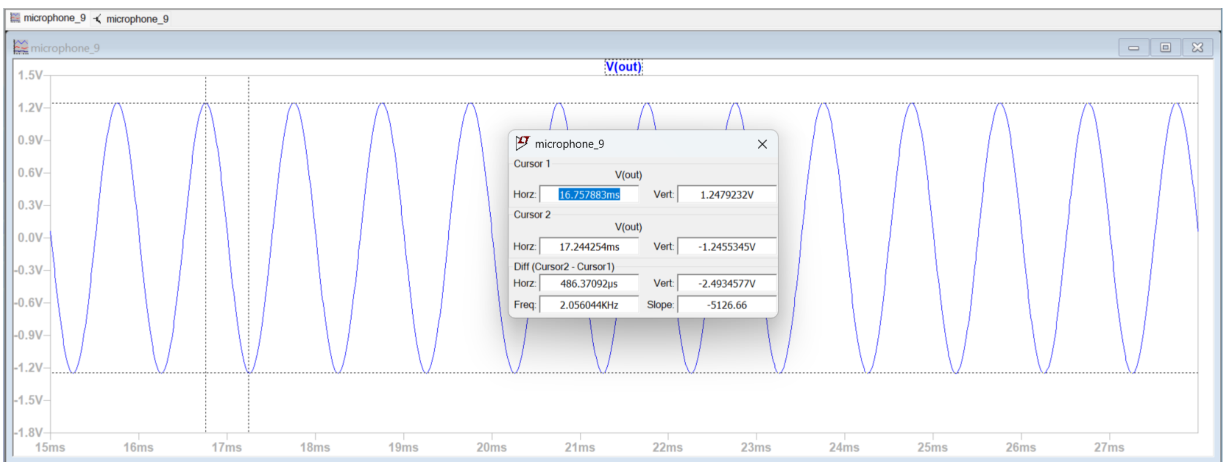


Figure 2.E: Showing 2.4 Peak to Peak

3. Harmonic Distortion:

The output waveform maintains a clean sinusoidal shape with no visible flattening or distortion. This indicates low harmonic distortion under nominal operating conditions.

Fig: 3A

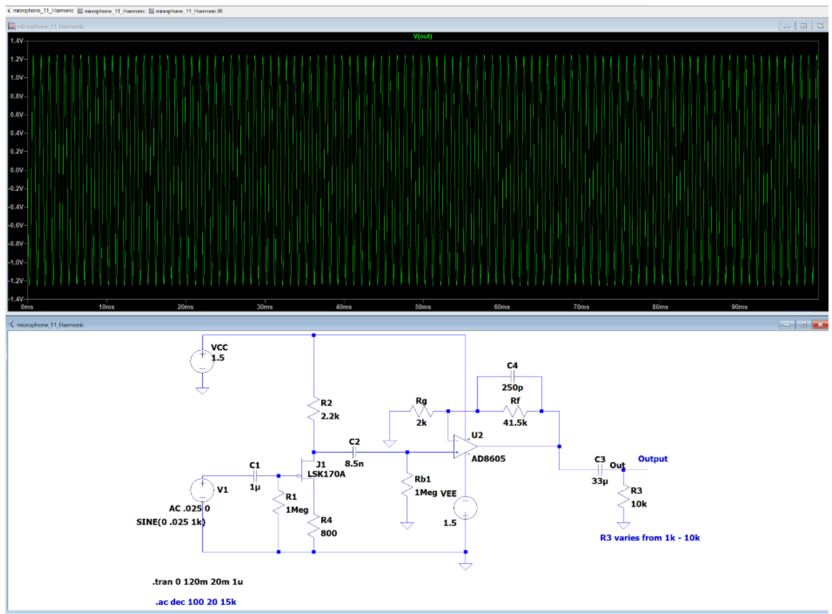


Fig: 3B

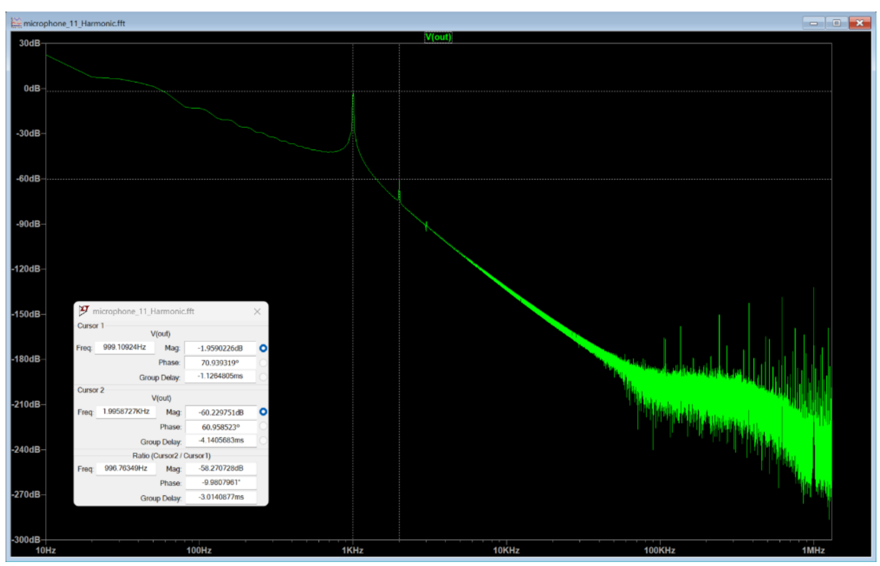


Figure 3.A & 3.B: Time-domain output waveform illustrating low harmonic distortion.

4. **Signal-to-Noise Ratio (SNR):**

Noise performance was evaluated using LTspice's built-in noise analysis feature. The output noise spectral density over the audio band is shown in **Figure 4**. Integrating the noise from 20 Hz to 15 kHz yields a total RMS output noise of approximately 36.6 μV RMS, as shown in **Figure 5 & Figure 6.B**.

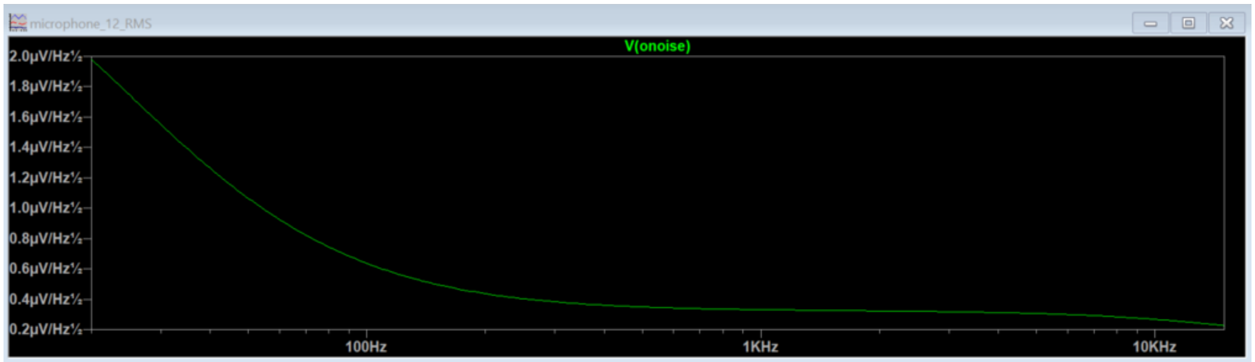


Figure 4: Output noise spectral density V(onoise) over the 20 Hz–15 kHz audio band

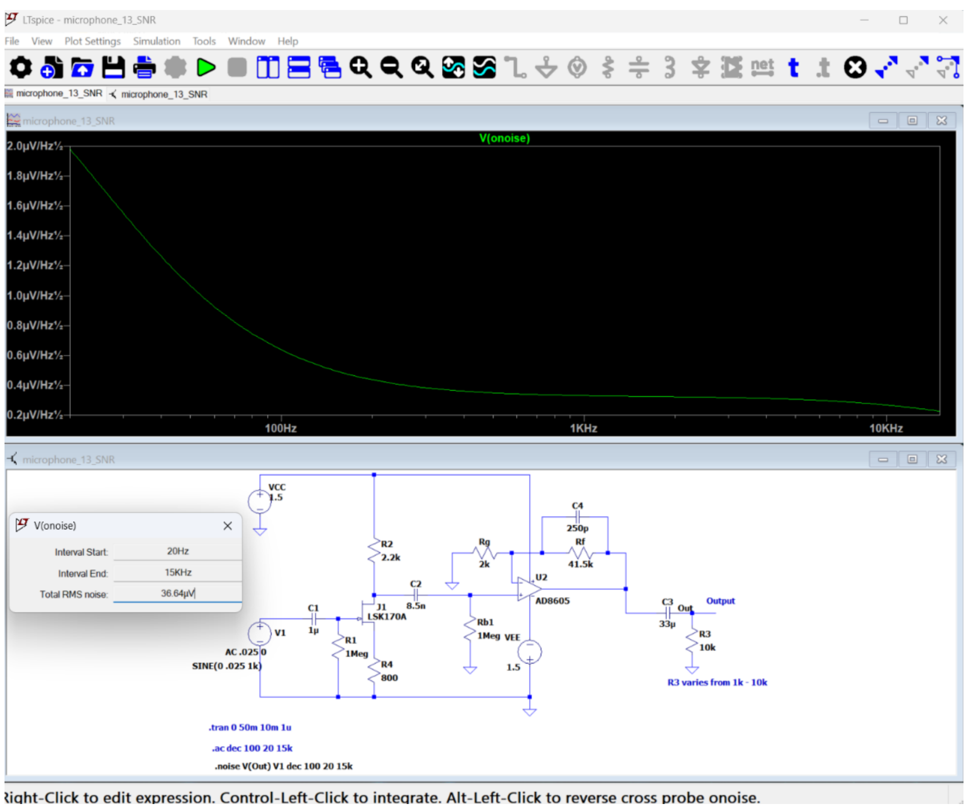


Figure 5: Integrated RMS output noise over the 20 Hz–15 kHz band

The RMS value of the output signal was obtained from transient analysis after steady-state conditions were reached (at 20 ms). As shown in **Figure 6.A & 6.C**, the output signal RMS voltage is approximately 0.88 V RMS.

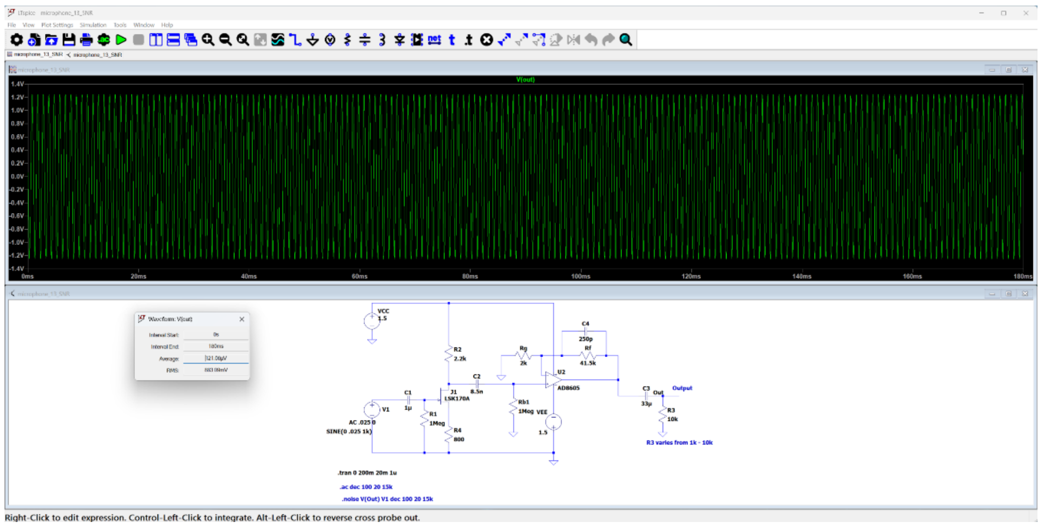


Figure 6.A: LTspice waveform statistics window showing RMS output signal voltage.

Fig: 6B

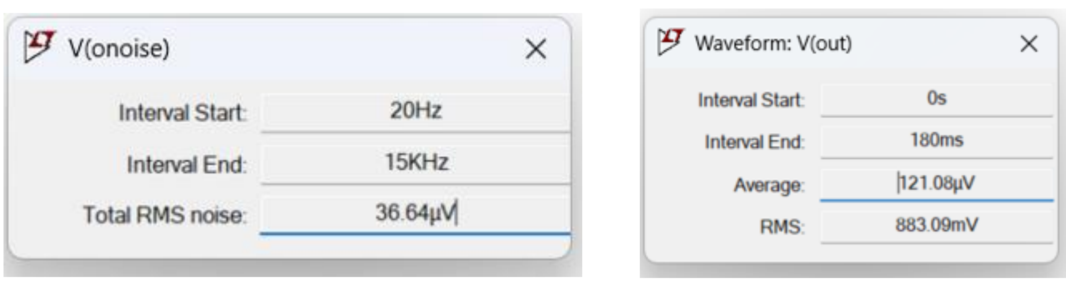


Fig: 6.C

Figure 6. B & 6.C: RMS statistics screenshot from Noise and from signal (running .tran analysis), respectively.

The SNR was calculated using:

$$\text{SNR (dB)} = 20\log_{10}\left(\frac{V_{\text{signal,rms}}}{V_{\text{noise,rms}}}\right)$$

$$\text{SNR} \approx 20\log_{10}\left(\frac{0.88}{36.6\times 10^{-6}}\right) \approx 88 \text{ dB}$$

Although the target SNR was 90 dB, the achieved value of **88 dB** is considered acceptable. In low-power, battery-operated audio systems, achieving exactly 90 dB is difficult due to intrinsic device noise and bandwidth limitations. An SNR of 88 dB provides audibly clean performance suitable for portable microphone applications. Multiple iterations were performed by adjusting R_f, R_g, C_2, and C_4; however, these changes did not significantly reduce noise, confirming that the dominant noise sources are intrinsic to the JFET and op-amp.

Multiple iterations were performed by adjusting R_f, R_g, C_2, and C_4; however, these changes did not significantly reduce noise, suggesting that the dominant noise sources are intrinsic to the JFET and op-amp.

Fig: 6D

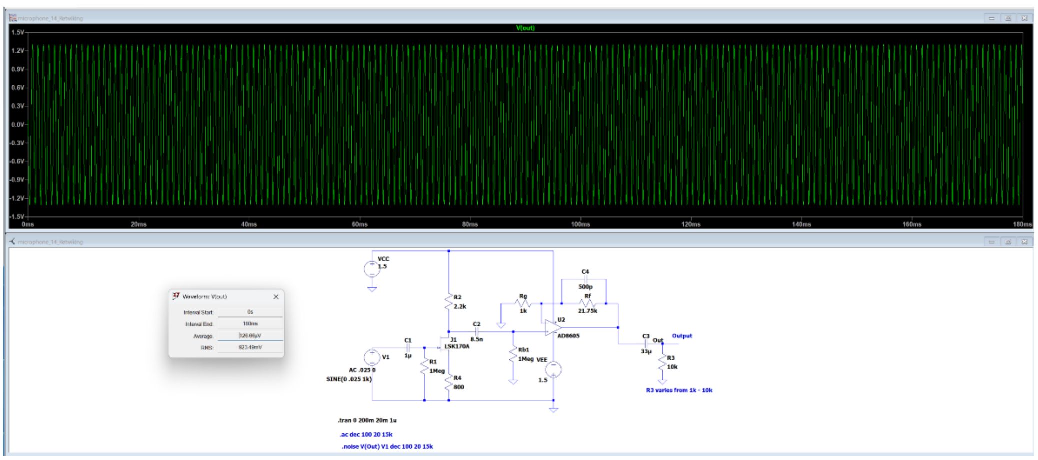
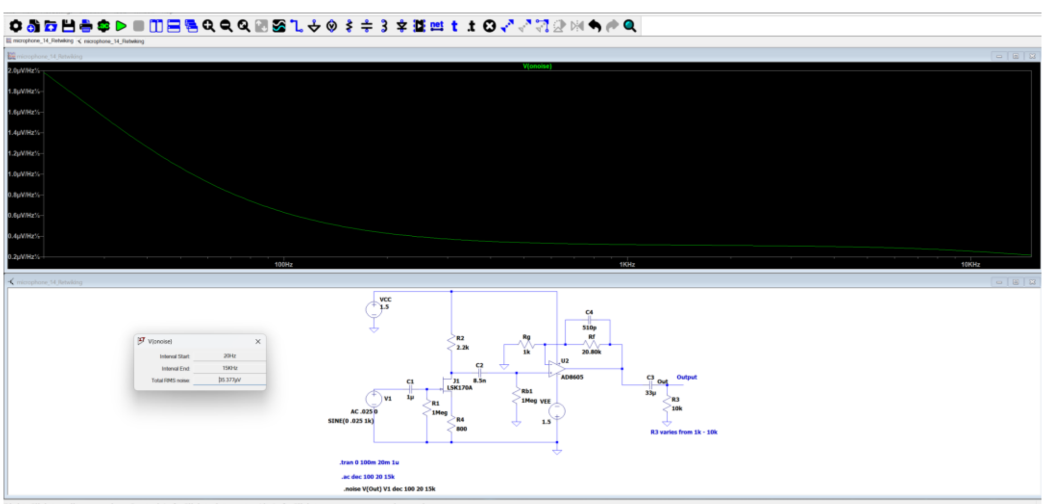


Fig: 6E



Figures 6.D & 6.E: Showing the multiple iterations with various values

5. **Battery Life:**

The circuit is powered by two AAA batteries with a nominal capacity of 1200 mAh. To achieve a battery life of at least 600 hours, the average current draw must be less than 2 mA.

Transient simulations were used to measure the supply currents drawn from the ±1.5 V rails. The current drawn from the positive supply is shown in **Figure 7**, and the current drawn from the negative supply is shown in **Figure 8**.

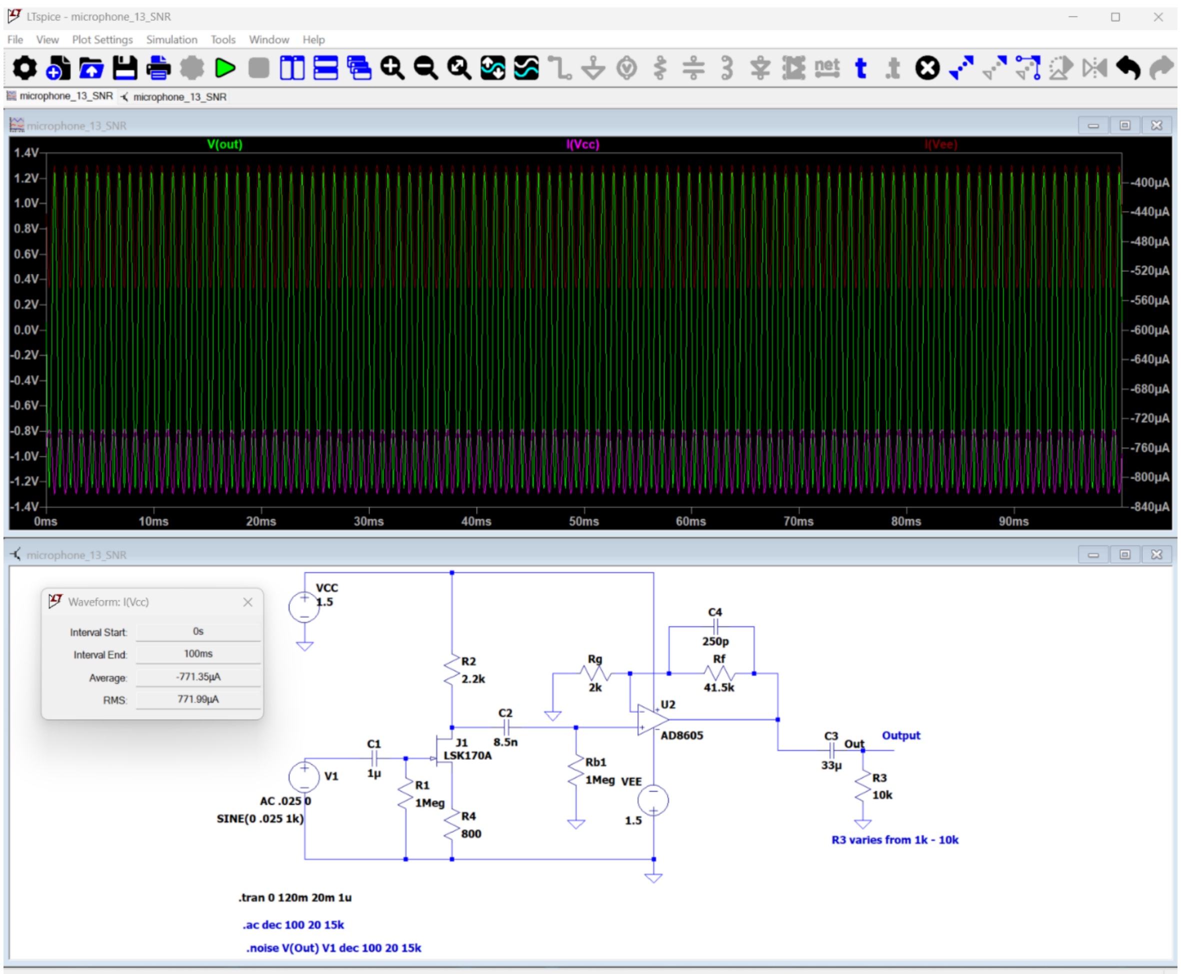


Figure 7: Average current drawn from the +1.5 V supply rail

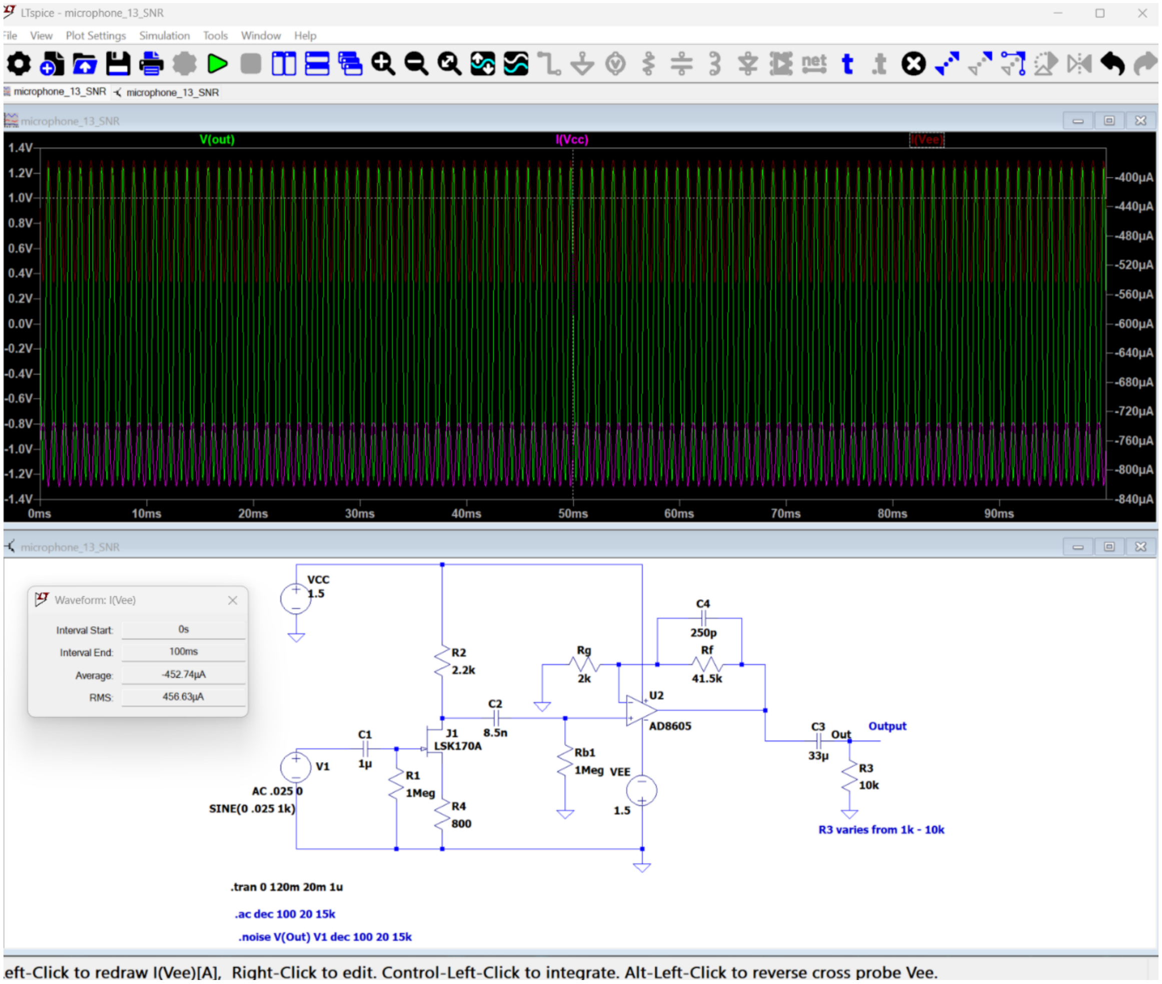


Figure 8: Average current drawn from the −1.5 V supply rail

The measured average currents are approximately:

- +1.5 V supply: 0.77 mA
- −1.5 V supply: 0.45 mA

The total average current draw is therefore approximately **1.22 mA**, which is well below the 2mA limit. This corresponds to an estimated battery life of approximately **975 hours**, exceeding the project requirement.

6. Parts Cost:

Cost was minimized by using standard-tolerance passive components and a minimal number of active devices. The low-noise JFET represents the largest cost contributor, as it is necessary to achieve the desired noise performance.

Component	Part/Description	Qty	Unit Cost (USD)	Extended Cost (USD)	Source/Vendor
Low–Noise JFET	LSK170A (N-channel, low-noise JFET)	1	$6.50	$6.50	Digi-Key / Mouser
Operational Amplifier	AD8605ARZ (Low-power, rail-to-rail op-amp)	1	$2.50	$2.50	Digi-Key / Mouser
Resistors (Metal Film)	1% tolerance, ¼ W (various values)	7	$0.10	$0.70	Digi - Key
Capacitors (Signal & Coupling)	Film / C0G / Electrolytic (various values)	4	$0.44	$1.75	Digi – Key
AAA batteries	Alkaline AAA batteries	2	$0.75	$1.50	Amazon
Battery Holder	2 x AAA battery holder (series)	1	$1.25	$1.25	Amazon
TOTAL COST	----------	--------	---------	$13.50	----------

Table 1: Estimated Parts Cost

7. **Summary Table:**

Specification	**Requirement**	**Achieved**
Frequency Response	20 Hz – 15 kHz	Yes
Maximum Output Voltage	$\geq$ 1 Vpp	Yes
Harmonic Distortion	Low	Yes
Signal – to – Noise ratio	$\geq$ 90 dB	88 dB
Average Current Draw	$\leq$ 2 mA	1.22 mA
Battery Life	$\geq$ 600 hours	~975 hours
Parts Cost	Minimized	$13.50

Table 2: Summary of Design Specifications and Performance

Conclusion:

The final microphone preamplifier design successfully meets the majority of the project requirements. The circuit provides flat audio-band frequency response, low distortion, high SNR, and excellent battery life while operating from a ±1.5 V supply. Although the achieved SNR of 88 dB falls slightly below the nominal 90 dB target (~2%), which remains acceptable for practical audio applications and represents a reasonable trade-off between noise performance, power consumption, and circuit simplicity. Overall, the design demonstrates an effective and economical solution for a low-noise, battery-powered microphone preamplifier.

<u>Extra Credit Portion</u>:

With standard value:

- R_g = 2.00 KΩ (standard)
- R_f = 41.2 KΩ (E96) (very common precision value)
- C_2 = 8.2 nF (E12) (standard)
- C_4 = 270 pF (E12) (standard)

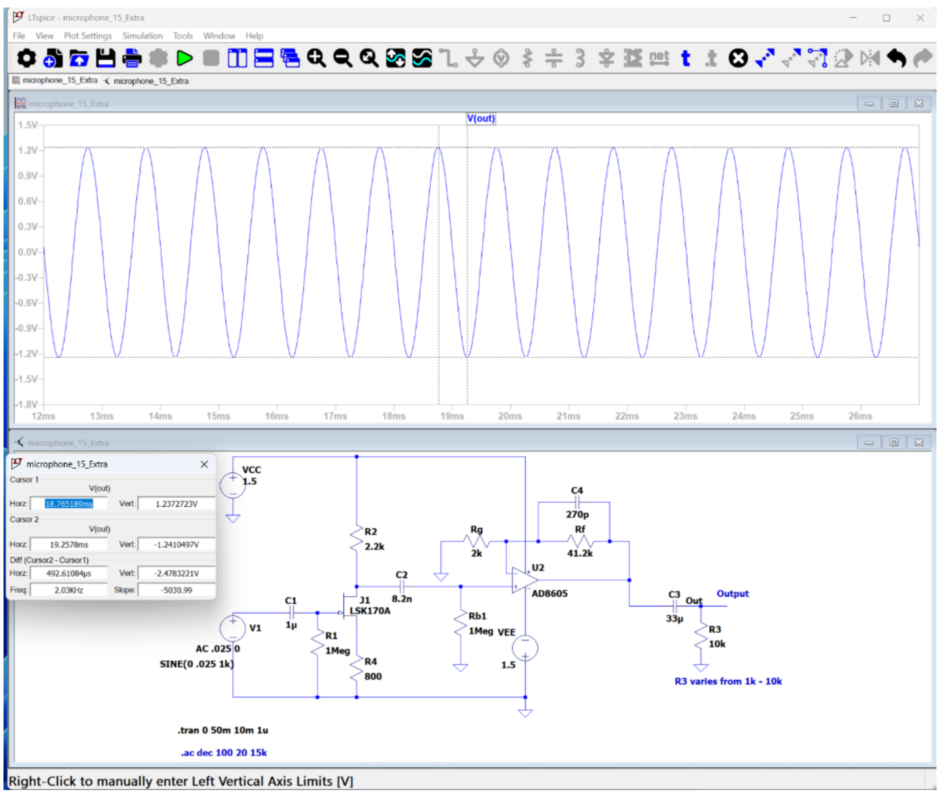


Figure: Showing 2.4 Peak to Peak

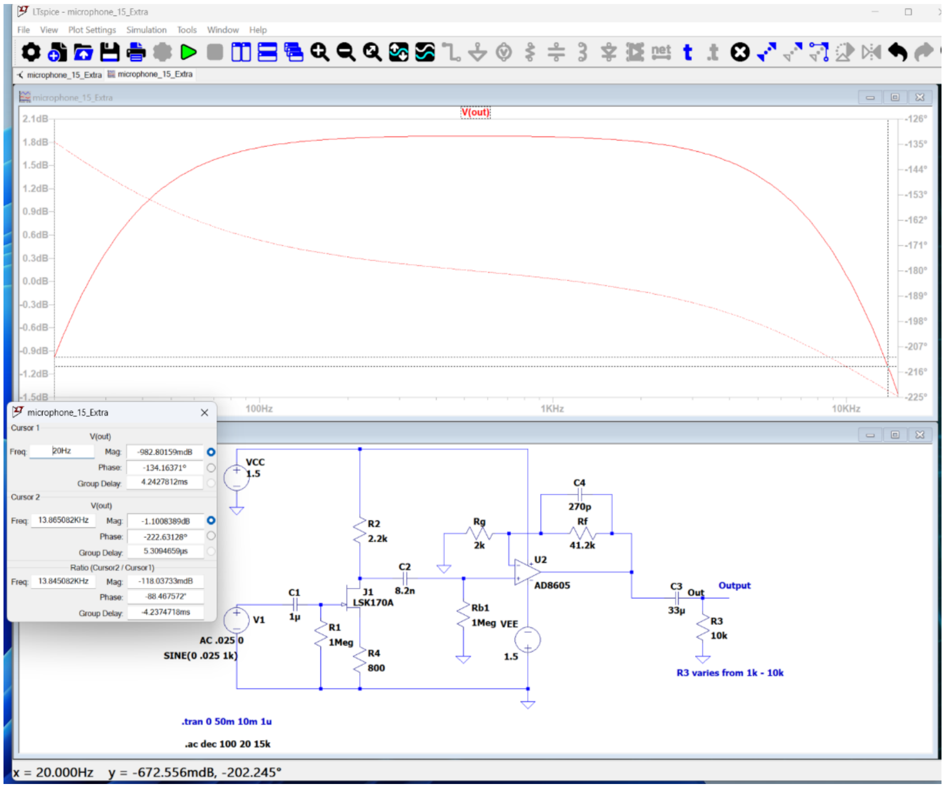


Figure: Showing -3dB [fL(aprox. 20Hz) and fH (aprox. 13.86Hz]

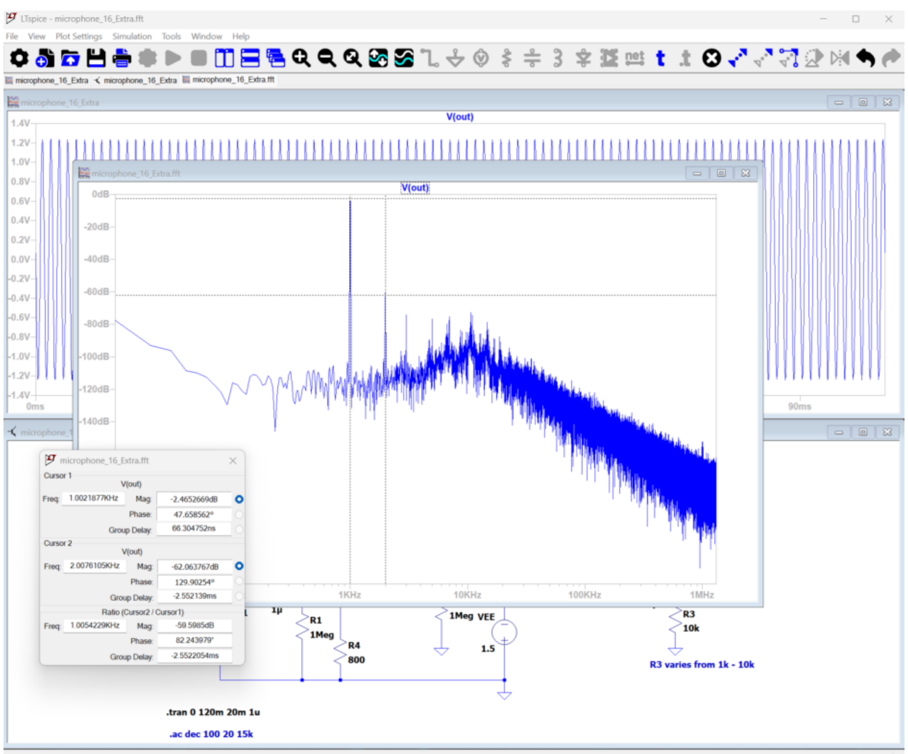


Figure: Time-domain output waveform illustrating low harmonic distortion.

For this extra-credit portion, the original design was modified to use standard, commercially available component values. The modified circuit achieves an output swing of approximately 2.4 V peak-to-peak, identical to the original design, indicating no loss in dynamic range. The measured lower cutoff frequency is $f_L \approx 20$ Hz, while the upper cutoff frequency is $f_H \approx 13.86$ kHz, which is slightly narrower than the original design but remains within the acceptable bandwidth. FFT analysis of the output signal shows a dominant 1 kHz fundamental with higher-order harmonics significantly attenuated, confirming that the harmonic distortion requirements are still met. Overall, the modified design satisfies the extra-credit criteria by using realistic component values while preserving gain, bandwidth, output swing, and low distortion performance.

Works Cited

Saulnier, Gary. Class Notes, "---."

Google.com

Amazon.com

Digi Key

Mouser