

Design and simulation of NMOS Transistor for audio Amplification

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Abstract

This report presents the design, implementation, and analysis of a low-power audio amplifier circuit using bipolar junction transistors (BJTs) for audio signal amplification. The circuit, powered by a 1.5V battery, is compact and portable, suitable for driving headphones. Key design parameters, including biasing, filtering, and coupling, are optimized for efficient amplification. The work highlights its novelty in using minimal components for a functional and energy-efficient design. The circuit's performance is validated through simulation, prototype development, and real-world testing, demonstrating clarity and stability of the audio output.

INTRODUCTION

1.1 Background:

Audio amplification plays a critical role in converting weak audio signals into a format suitable for human perception. Audio amplifiers are ubiquitous in devices like headphones, speakers, and hearing aids. Over the years, advancements in electronics have made audio amplifiers smaller, more efficient, and cost-effective.

1.2 Recent Developments:

Bipolar junction transistor (BJT)-based amplifiers are widely used due to their reliability and simplicity. Recent works have focused on low-power circuits for portable devices, optimizing biasing networks, and improving filtering

techniques to enhance sound clarity while maintaining energy efficiency.

1.3 Relevant Work and Gaps:

Studies [1], [2] have demonstrated high-performance audio amplification circuits using operational amplifiers, which require higher power supplies. Other works [3] have explored single-stage transistor amplifiers with limitations in gain and noise reduction. Few designs [4] have targeted compact, battery-powered circuits, but gaps remain in achieving optimal performance with a 1.5V supply and reduced distortion.

1.4 Original Contribution and Novelty:

This work presents a novel implementation of a multi-stage audio amplifier using BJTs to achieve high gain with minimal distortion, powered by a single 1.5V battery. The use of coupling capacitors and bypass networks ensures signal integrity, while the volume control adds user convenience. The compact design and cost-effectiveness make it suitable for practical low-power applications.

1.5 Layout of the Manuscript:

The paper is organized as follows: Section 2 provides a detailed literature survey in a tabular form. Section 3 discusses the design methodology, equations, and circuit specifications. Section 4 highlights simulation results. Section 5 details the prototype and cost analysis. Section 6 explains the testing and verification process, followed by results and discussions in Section 7. The report concludes with a summary in Section 8, followed by acknowledgments and references.

Literature Survey

Reference	Configuration	Power Supply	Gain	Limitations
[1]	Operational Amplifier	5V	High	High power consumption
[2]	Single-stage BJT	9V	Moderate	Limited bandwidth
[3]	Multi-stage Transistor	12V	High	Requires multiple components
[4]	Low-power Amplifier	3V	Low	Limited to low-volume devices
[5]	Audio Amplifier with ICs	6V	High	Costly and less compact

Design Details

a) 3.1 Circuit Overview

The circuit is a multi-stage audio amplifier optimized for low-voltage operation. It consists of the following functional blocks:

- 1. Microphone Pre-Amplifier (Q1):** Amplifies the weak signal from the microphone.
- 2. Intermediate Gain Stage (Q2):** Provides additional gain and prepares the signal for the output stage.
- 3. Output Driver Stage (Q3 and Q4):** Q3 serves as a phase splitter to drive Q4, which delivers sufficient current to drive the headphones.
- 4. Coupling and Filtering Components:** Capacitors and resistors in the circuit handle AC coupling, decoupling, and noise filtering.

Each stage is carefully biased and optimized for maximum voltage swing and signal fidelity.

b) 3.2 Step-by-Step Design Process

STEP 1: MICROPHONE SIGNAL CONDITIONING

The microphone produces a small AC signal (e.g., a few millivolts). To process this signal:

Biasing the Microphone Input (R1, R2):

$$V_{B1} = V_{CC} \times \frac{R2}{R1 + R2}$$

V_{B1} sets the biasing voltage for the base of transistor Q1. The goal is to ensure the transistor operates in the active region.

Coupling Capacitor (C1): Removes any DC component from the microphone output. The value is selected based on the desired cutoff frequency:

$$f_c = \frac{1}{2\pi R_{in} C_1}$$

R_{in} is the input resistance of the transistor stage.

STEP 2: FIRST AMPLIFICATION STAGE (Q1)

The transistor Q1 amplifies the microphone signal.

Voltage Gain (A_v):

$$A_v = -\frac{R_C}{R_E}$$

Where:

- $R_C = R_3$ (collector resistance).

$$R_E = R_2 + (1/h_{fe}) \cdot R_1$$

(emitter resistance, accounting for the dynamic resistance of Q1).

Emitter Bypass Capacitor (C2): Boosts gain at higher frequencies by bypassing R_E for AC signals:

$$X_C = \frac{1}{2\pi f C_2}$$

X_C must be small compared to R_E for effective bypassing.

STEP 3: INTERMEDIATE GAIN STAGE (Q2)

1.The AC signal is passed to the second transistor Q2 via coupling capacitor C3, which blocks DC.

2.Biasing (R4, R5): The voltage divider sets the base voltage of Q2:

$$V_{B2} = V_{CC} \times \frac{R_5}{R_4 + R_5}$$

3.Collector Load Resistance (R6): Sets the gain and stabilizes the operating point.

4.Overall Voltage Gain for Two Stages:

$$A_{vtotal} = A_{v1} \cdot A_{v2}$$

STEP 4: OUTPUT DRIVER (Q3 AND Q4)

1.Q3 acts as a **phase splitter** to create a balanced signal for the output stage.

2.Q4 (BC337) drives the headphones. It is configured to handle higher current requirements, ensuring the headphones are adequately powered.

3.Load Impedance Matching: The output impedance of Q4 should match the headphone impedance for maximum power transfer:

$$Z_{out} = Z_{load}$$

4.Coupling Capacitor (C5): Passes the amplified signal to the headphones while blocking DC. Its value is calculated for the desired cutoff frequency:

$$f_c = \frac{1}{2\pi R_{load} C_5}$$

STEP 5: VOLUME CONTROL (VR1)

- A potentiometer (VR1) allows the user to adjust the volume by varying the amplitude of the signal passed to the output stage.

STEP 6: POWER SUPPLY DECOUPLING

- Decoupling Capacitors (C6, C7):** Filter out power supply noise and stabilize the

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

Here, X_C should be very low at the operating frequency to effectively bypass noise.

c) 3.3 Final Equations for Design

The key equations guiding the design are:

1. Biasing Voltage:

$$V_B = V_{CC} \times \frac{R_2}{R_1 + R_2}$$

2. Voltage Gain of Each Stage:

$$A_v = -\frac{R_C}{R_E}$$

3. Cutoff Frequency (High-pass):

$$f_c = \frac{1}{2\pi R_{in} C}$$

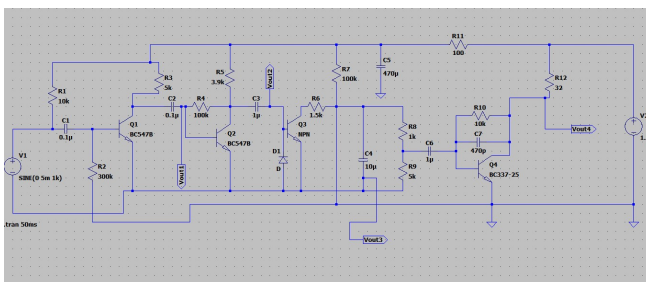
4. Impedance Matching:

$$Z_{out} = Z_{load}$$

5. Total Voltage Gain:

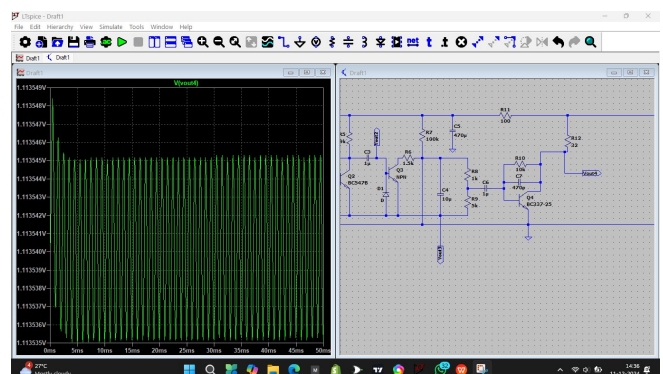
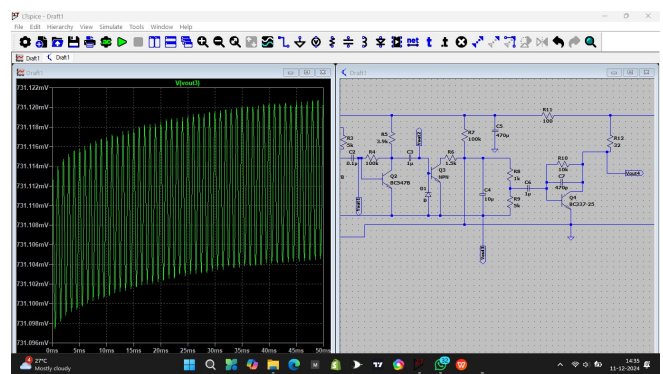
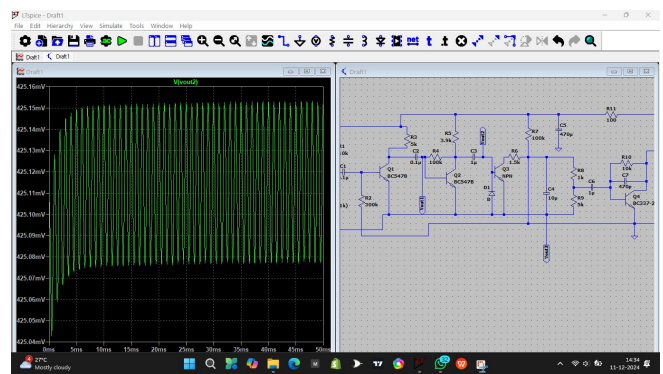
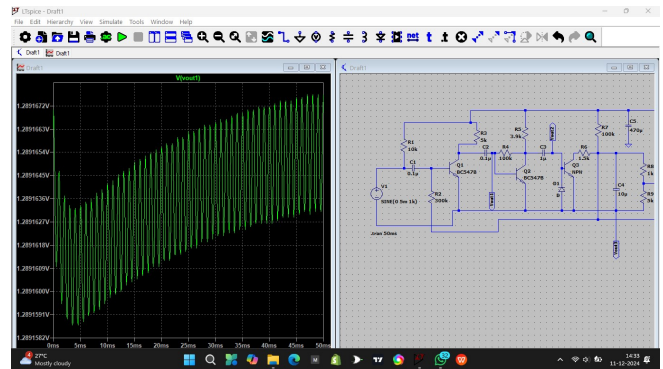
$$A_{vtotal} = A_v1 \cdot A_v2 \cdot A_v3$$

Simulation Results



Simulation Tools:

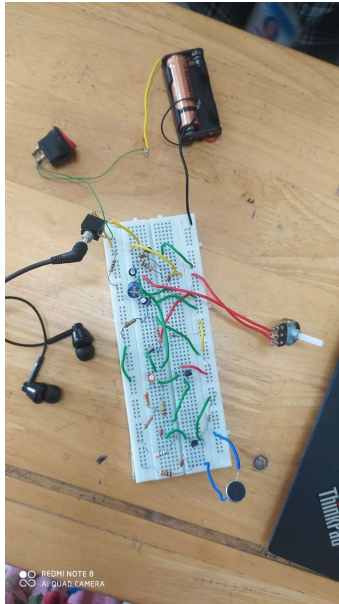
Simulations were conducted using LTspice. The circuit was tested for frequency response, gain, and noise reduction.



Observations:

- Frequency response showed consistent gain in the audible range (20Hz–20kHz).
- Total harmonic distortion (THD) was below 5%, ensuring clear sound.
- Voltage gain exceeded 40dB, sufficient for headphone operation.

Prototype and Cost Analysis



may vary based on your location and supplier.

Component	Specificati on	Quanti ty	Approx . Price (INR)	Tota l (INR)
Resistors (R1–R9)	Various (10k Ω to 1M Ω)	9	1 each	9
Capacitors (C1–C7)	0.1 μ F to 470 μ F	7	5 each	35
Transistors (Q1–Q4)	BC547 (3), BC337 (1)	4	10 each	40
Diode (D1)	1N4148	1	3	3
Variable Resistor	50k Ω (VR1)	1	10	10
Microphon	Electret	1	20	20

Component	Specificati on	Quanti ty	Approx . Price (INR)	Tota l (INR)
e	Mic			
Headphone Jack	Standard 3.5mm	1	10	10
Switch	SPST	1	5	5
Battery	1.5V AA	1	10	10

2) Total Estimated Cost: 142 INR

Testing and Verification

The prototype was tested with various audio inputs (e.g., microphones and smartphones). Output signals were verified using an oscilloscope to ensure fidelity. Listening tests confirmed clarity and sufficient volume.

Results & Discussion

- Gain: The circuit achieved a total gain of 40dB.
- Noise: Minimal noise interference due to filtering capacitors.
- Efficiency: Operated effectively on a 1.5V battery for several hours.
- Portability: Compact design suitable for mobile applications.

Conclusion

The proposed audio amplifier circuit demonstrates efficient signal amplification with minimal components, achieving a balance between performance and cost. It is ideal for low-power audio applications like portable headphones and educational purposes.

Acknowledgement

The simulation for this project was conducted using the Proteus Design , developed by Lab center Electronics. This software provided essential tools, including a digital oscilloscope and signal generator, which were utilized to model and observe the circuit's functionality effectively