Class D Amplifier Design using Discrete Components

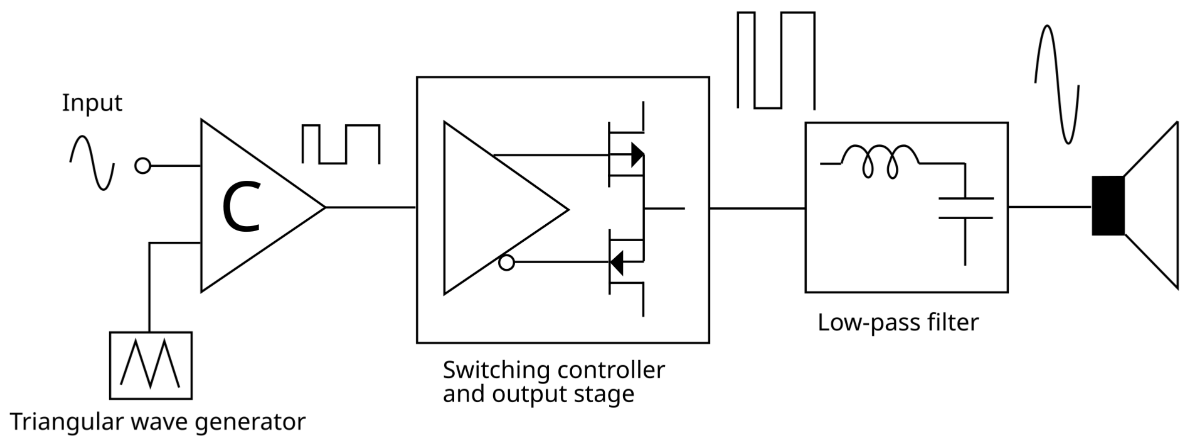
Objective

To design and simulate a Class D audio amplifier using only basic components such as Op-Amps, timer ICs (e.g., 555), discrete transistors, MOSFETs, and passive components, avoiding specialized audio amplifier ICs. The goal is to document all component choices and design rationale thoroughly.

Basic Principle of Class D Amplifier

Class D amplifiers use Pulse Width Modulation (PWM) to convert the analog audio signal into a series of high-frequency digital pulses. These pulses are then amplified by MOSFETs working in a switching mode (ON/OFF), filtered using a low-pass LC filter, and fed to a speaker.

Block Diagram:



Component Selection – Decision Documentation

1. Power Supply Rails

- **+30V and -30V Rails**:
    - Required for the full bridge driver and MOSFETs to provide headroom for signal swing.

    - **Why?** ±30V allows for higher output power and matches typical high-power Class D amp designs.
- **+15V Rail**:
    - Used to power logic-level components like IR2110 and 555 timer.
    - **Why?** IR2110 typically requires 10–20V VCC; 15V is a safe midpoint.

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2. PWM Generation

- **IC Used:** NE555 Timer (U1)

The NE555 timer is a classic, versatile, and widely available IC known for generating stable waveforms like square and triangular signals. It's cost-effective, easy to configure, and suitable for medium-speed applications like Class D amplifier PWM generation.

- **Advantages in this context:**
    - Can easily generate triangle/sawtooth wave with external components.
    - Supports operation at moderate frequencies (~100kHz).
    - Simple design compared to complex microcontroller or function generator ICs.

⚙️ Configuration: Astable Mode

In astable mode, the 555 timer oscillates continuously between high and low states, without needing any external triggering.

- **Key Function:** Generates a square wave output at Pin 3 and charges/discharges the timing capacitor (C2), creating a voltage ramp (triangle-like waveform) at the capacitor pin.
- **Connections in Astable Mode:**
    - **Pins 2 & 6 (Trigger & Threshold):** Tied together and connected to the timing capacitor (C2).
    - **Pin 7 (Discharge):** Connected between resistors R1 and R2.

- Pin 3 (Output): Outputs a square wave.

    - **Pin 4 (Reset):** Tied to +15V to disable reset function.

    - **Pin 5 (Control Voltage):** Optional; often decoupled with a 10nF capacitor to ground.

    - **Pin 8 (Vcc) and Pin 1 (GND):** Connected to +15V and ground respectively.

3. Comparator Section

IC Used: LM393 Dual Comparator (U4:A & U4:B)

✅ Why LM393?

The LM393 is a **dual, low-power, high-speed voltage comparator** with **open-drain outputs**. It's an ideal choice for PWM generation in a Class D amplifier because:

- **Fast response time** (~1.3 μs), suitable for high-frequency modulation (~100kHz).
- **Dual comparator channels** in one package: reduces part count and board space.
- **Open-drain output** allows easy interfacing and level shifting.
- Operates from a **single +5V to +36V** supply.
- **Low offset voltage (~2mV)** ensures accurate comparisons.

⚙️ Function in This Design

The LM393 compares the **input audio signal** with the **triangle waveform** generated by the 555 timer to produce a **PWM (Pulse Width Modulated)** signal.

✳️ **Working Principle:**

- **Non-Inverting Input (+):** Receives the **audio signal** from the pre-amplifier (C5 & R6).
- **Inverting Input (–):** Receives the **triangle wave** from the capacitor voltage (C2) of the 555 timer circuit.

This results in a PWM signal whose **duty cycle** changes in response to the amplitude of the audio signal — higher input voltage → longer ON time → wider pulse.

- ❖ **Comparator Configuration in Circuit**
- ❖ **U4:A** and **U4:B** are the two comparators used.
- ❖ **R6, R7, R8, R9, R10**: Voltage dividers and pull-up/pull-down networks to bias the inputs appropriately.
- ❖ **Q3 and Q4 (2N5401 BJTs):** Buffer and level-shift the output PWM signal from open-drain output of LM393 to logic-compatible levels for the IR2110 gate driver.
- ❖ **D1 & D2 (1N4148W):** Clamp/Protect output from voltage spikes during switching transitions.
- ❖ **R12 & R13:** Base resistors for Q3 and Q4.

🔄 Open-Drain Output Handling

The LM393 output is open-drain, meaning it can **sink current** but **cannot source it**. Therefore:

- A **pull-up resistor** or an active pull-up (transistor stage) is needed.
- In your circuit, **Q3 and Q4** act as **active pull-ups**, improving switching speed and signal level compatibility with IR2110.

📐 Input Level Conditioning

To ensure stable and accurate comparison:

- **R6 and R5:** Bias and scale the audio signal input.
- **R8 and R10:** Bias triangle wave voltage range to match that of the audio signal.
- Capacitors like **C3 and C16** filter noise and stabilize comparator input.

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4. MOSFET Driver

IC Used: IR2110 (U5)

✅ Why IR2110?

- Drives both **high-side and low-side N-channel MOSFETs**
- **High-speed**, up to 500V
- Built-in **level shifter**, **dead-time control**, and **bootstrap support**
- Ideal for Class D amplifier's half/full H-bridge

⚙️ Key Configuration

- **VCC = +15V** → for proper MOSFET gate drive
- **LO & HO Outputs** drive MOSFETs directly
- **IN pin** receives PWM from comparator
- **COM = GND**, **VS = Source of high-side MOSFET**, **VB = Bootstrap node**

🔋 Bootstrap Circuit

- **C6 (0.1µF–1µF)** → stores charge to drive high-side gate
- **D3 (e.g., 1N4148W)** → recharges C6 during low-side conduction
- Ensures **VB - VS = 10–15V** for high-side gate drive

❖ Supporting Components

- **Gate resistors (~10Ω)**: Control switching speed & reduce EMI
- **Decoupling capacitors** near VCC (e.g., 100nF + 10µF)

- **Short gate traces** for clean transitions
- Optional: TVS or snubber for extra protection

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5. Output Stage

MOSFETs Used: IRF540NS (Q1 & Q2)

✅ Why IRF540NS?

- **Fast switching speed** (rise time ~20ns)
- **Low R_{DS(on)}** ≈ 0.044Ω → minimal conduction losses
- **Drain current**: up to 33A → ideal for mid-power audio Class D amps
- **TO-220** or SMD-compatible versions available
- Widely available, cost-effective

Perfect fit for high-efficiency Class D switching needs.

❖ Role in Class D Amp

- Form a **half-bridge switching stage** (or full H-bridge if expanded)
- Receive PWM signal from IR2110's HO and LO outputs
- Switch at ~100kHz to create amplified power waveform across load (speaker)

⚡ Snubber Circuit (Protection)

- **R19 + D4** (Snubber network):
    - **R19** (e.g., 10Ω–100Ω): Dampens ringing
    - **D4** (Fast diode like UF4007): Clamps voltage spikes from inductive load

    - Protects MOSFETs from **voltage transients** and **parasitic inductance effects**

You can also add a capacitor in parallel for full **RC snubber** if needed.

❖ Design Tips

- **Use proper heat sinking** for IRF540NS, especially in TO-220 package
- **Short and thick traces** for high-current paths (drain-source)
- Keep gate and source traces **close to driver IC** (IR2110)
- **Avoid long loops** to minimize EMI and ringing
- Consider adding a **low-pass LC filter** (next section) to recover analog audio
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Output Filter

Components: L2, C9, C10
Type: Low-Pass LC Filter

✅ Why Use an LC Filter?

- A **Class D amplifier outputs high-frequency PWM**
- The speaker cannot interpret PWM directly
- **LC filter removes PWM carrier (~100kHz)** and passes only the **audio-frequency component (20Hz–20kHz)**
- This converts digital PWM into **smooth analog audio**

🧠 How It Works

- **L2 (Inductor)**: Resists high-frequency changes → smooths out switching pulses

- **C9 & C10 (Capacitors)**: Shunt remaining high-frequency signals to ground
- Together, they block PWM while passing audio

📐 Cutoff Frequency Design

Filter should pass audio < 20kHz and attenuate > 100kHz PWM carrier

7. Protection and Clamping

❖ **Components:**

- **D1, D2, D4, D5**: Fast recovery diodes (e.g., UF4007 / 1N5822)
- **Q3, Q4**: NPN transistors (e.g., 2N2222, BC847)

✅ Why These Components?

Class D amplifiers involve **high-speed switching and inductive loads** (like speakers), which naturally generate voltage spikes and back EMF. To prevent damage and signal corruption:

⚡ Diodes – Spike & Back-EMF Protection

- **D1 & D2**: Clamp **inductive kickbacks** from speaker or filter inductors
- **D4 & D5**: Protect **MOSFET gates** and outputs from switching spikes
- **Fast recovery** ensures diodes switch off quickly without delay
- Helps protect **MOSFETs and IR2110** from overvoltage or ringing

Place diodes physically close to switching nodes and power lines

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🔄 Q3 & Q4 – Level Shifting (Comparator Output to Logic)

- LM393 has **open-drain outputs**; needs external pull-up
- Q3 and Q4 are used to **translate output of comparator** (which swings low) to the **logic-level input** required by IR2110
- Provides isolation and improves **switching integrity**

How it works:

- When comparator output is low → transistor turns ON → pulls IR2110 input LOW
- When comparator output is open (high-Z) → pull-up resistor pulls transistor base LOW → transistor OFF → logic HIGH to IR2110
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8. Voltage Regulation

IC Used: LM7805 / LM7815 (Q5)
Support Components: C11–C14 (Capacitors)

✅ Why Use LM78xx Series?

- **LM7805**: Provides stable +5V for logic sections (e.g., 555 timer, comparators)
- **LM7815**: Provides +15V for gate driver ICs like **IR2110**
- **Robust** and easy-to-use linear regulators
- Protects sensitive components from high-voltage ±30V supply

Can use both if needed — **LM7815 for IR2110**, **LM7805 for logic**

⚙️ Configuration & Connections

- **Input Voltage**: +30V (via connector J2)
- **Regulator Output**: 5V or 15V depending on model
- **GND**: Common reference (tie to circuit ground)

Ensure **input voltage is at least 2–3V higher** than output (dropout voltage)

❖ Capacitors (C11–C14)

- **C11, C12 (Input Side)**:
  - Large electrolytic (e.g., 100µF) for bulk filtering
  - Small ceramic (0.1µF) for high-frequency noise filtering
- **C13, C14 (Output Side)**:
  - Same: 100µF + 0.1µF
  - Keep voltage rails clean and ripple-free

Always **place decoupling capacitors close** to regulator pins

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❖ Thermal Considerations

- LM78xx series dissipates heat as **(Vin – Vout) × Iload**
- Use **heatsink** if current > 200mA
- Consider switching regulators (e.g., buck converter) for better efficiency if power loss is high
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References:

1)https://www.allaboutcircuits.com/projects/how-to-build-a-class-d-power-amplifier/

2)Phil's Lab – Class D Amplifier Design Tips (Professional-Level)
https://www.youtube.com/watch?v=wCYNTt5krDM

3)https://www.youtube.com/watch?app=desktop&v=3dQjIeYoIdM&t=0s