Report

TITLE: Reproduction of a Self-Oscillating Class-D Audio Amplifier with Hysteretic Comparator and Post-Filter Feedback in eSim

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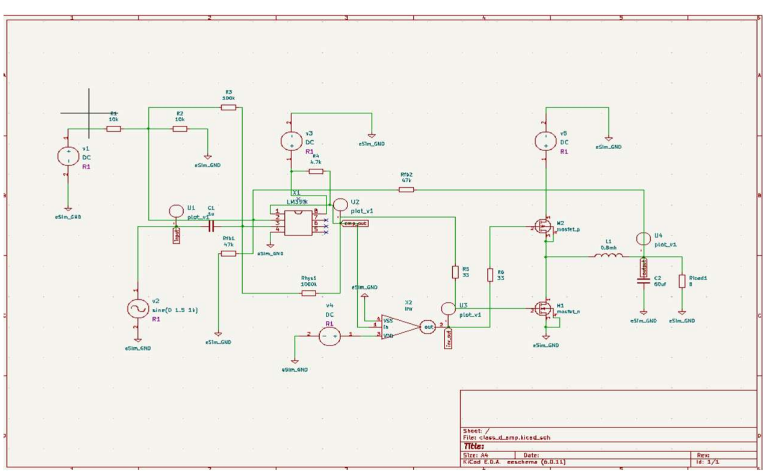
Theory/Description

Class-D amplifiers are highly efficient switching amplifiers that use pulse-width modulation (PWM) or self-oscillating topologies to reproduce analog signals. The design implemented here focuses on a **self-oscillating Class-D amplifier** using a **hysteretic comparator** and **post-filter feedback**, which stabilizes the loop and improves linearity.

- **Self-Oscillating Mechanism:**
  The system uses the natural oscillation generated by the comparator and feedback loop, eliminating the need for an external clock.
- **Hysteretic Comparator:**
  Introduces a hysteresis window, preventing unwanted switching due to noise and ensuring clean transitions in the switching waveform.
- **Post-Filter Feedback:**
  Feedback is taken after the LC low-pass filter, allowing the amplifier to compensate for non-linearities and improve the fidelity of the reproduced audio signal.

This topology is widely used in modern audio amplifiers for its **high efficiency (up to 90% or more)**, **low distortion**, and **compact design**.

Circuit Diagram



1. LM393 (Comparator)

- **Purpose:** The LM393 is a dual comparator.
- In your circuit, it is used as the **hysteretic comparator** that compares the input signal (after being conditioned by resistors and capacitor) with the feedback signal.
- It generates a **PWM (pulse-width modulated) switching signal**, which drives the MOSFET half-bridge.
- The hysteresis (Rhys1 resistor) avoids false triggering due to noise and ensures stable oscillation.

🔹 **2. MOSFETs (M1 = n-channel, M2 = p-channel)**

- **Purpose:** These form a **half-bridge power stage**.
- They act as **switches** that alternately connect the output node either to supply (Vdd) or ground, depending on the comparator output.
- This converts the low-power comparator signal into a **high-power switching waveform** that can drive the load after filtering.

🔹 **3. Voltage Dividers (R1–R3, Rfb1, Rfb2, etc.)**

- **Purpose:**
  - **R1, R2, R3**: Create reference voltages and biasing points for the comparator input.
  - **Rfb1, Rfb2**: Form the **post-filter feedback network**, feeding a scaled version of the filtered output signal back to the comparator for stability and linearity.
- In essence, voltage dividers **set thresholds and feedback scaling** for the self-oscillating control loop.

🔹 **4. LC Filter (L1 = 0.8 mH, C2 = 60 µF)**

- **Purpose:** This is the **low-pass output filter**.
- It removes the high-frequency switching components from the PWM waveform, leaving behind the **clean amplified audio signal** across the load (Rload).
- Without the LC filter, the speaker/load would see a high-frequency square wave instead of the desired audio waveform.

◆ **5. Input Signal Source (V2, sine)**

- Provides the **audio input** (in your case, 1 kHz sine wave).
- This is what gets amplified.

◆ **6. DC Supplies (V1, V3, V4, V5)**

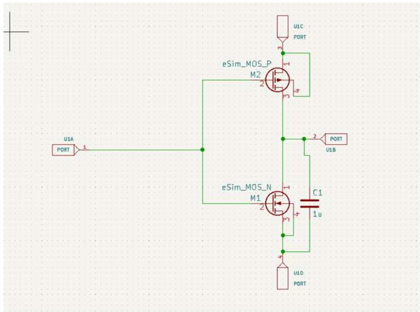
- Provide the operating voltages for comparator and MOSFETs.
- Example:
  - V1: Biasing/reference supply
  - V3 & V4: Supply rails for comparator and MOSFETs
  - V5: Logic-level supply for inverter (X1).

◆ **7. Inverter (X1)**

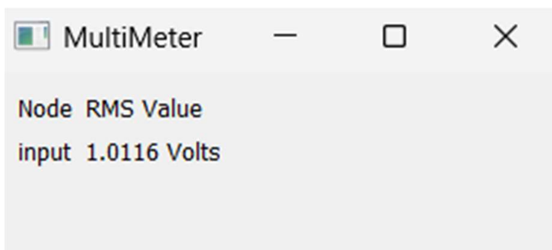
- Ensures proper gate drive by inverting one comparator output.
- This way, M1 and M2 switch alternately, preventing shoot-through current.

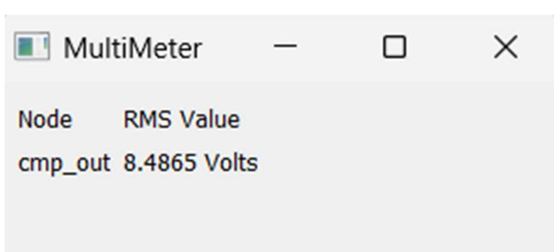
Sub-circuit

- The default invcmos symbol in eSim doesn't explicitly expose the power rails (VDD and VSS).
- By adding them, you make the subcircuit more **modular and reusable**, because now the same inverter can be used in designs with **different supply voltages**.
- It also makes the circuit **clearer**, since the inverter's supply connections are explicitly shown in your schematic instead of being hidden inside the model.

- 

Output:

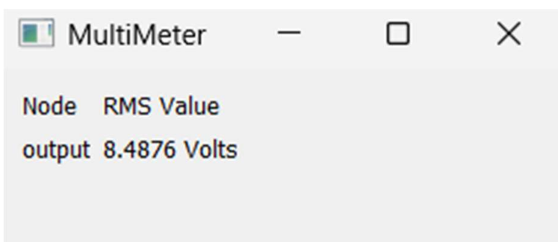
- INPUT RMS:
    - Confirms the **strength of the test signal** applied to the amplifier.
    - 

- **CMP Out RMS:**
    - RMS of the **PWM signal** generated by the comparator.
    - Not equal to the input RMS, since it's a high-frequency square wave with varying duty cycle.
    - Helps verify correct modulation (duty cycle proportional to input signal).
    - 

    - Confirms **proper half-bridge switching**.
    -

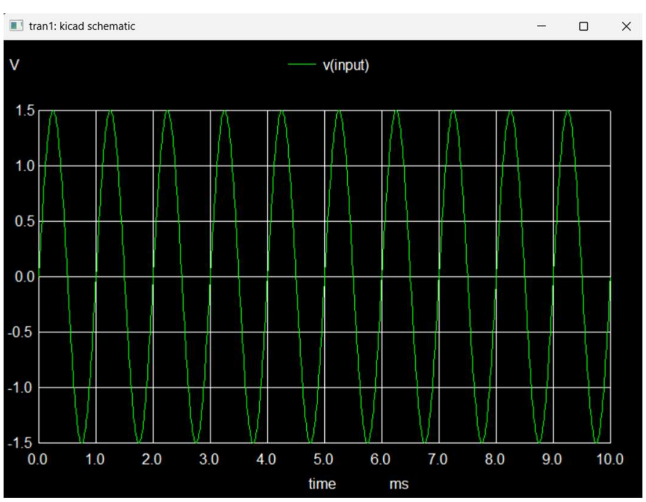
Amplifier Output RMS (after LC filter):

- The **main performance metric** → represents the amplified version of the input sine wave.
- Comparing **Output RMS vs Input RMS** gives the **gain** of your amplifier.
- Also, distortion can be checked if the RMS does not scale linearly with input.

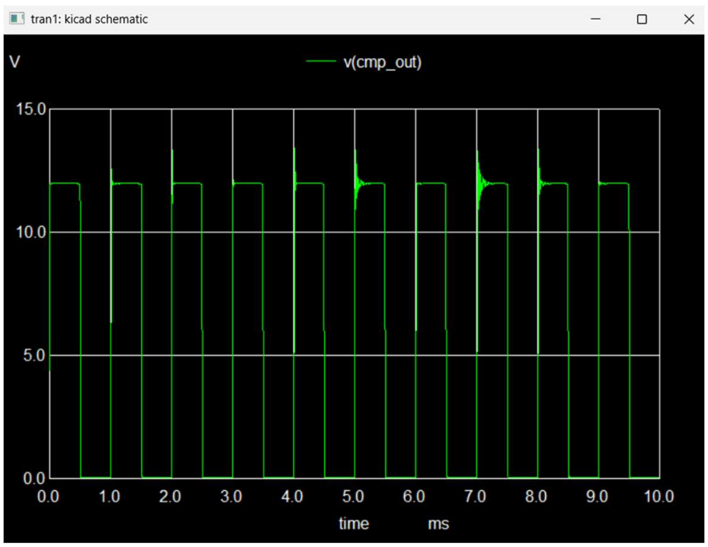


OUTPUT WAVEFORM:

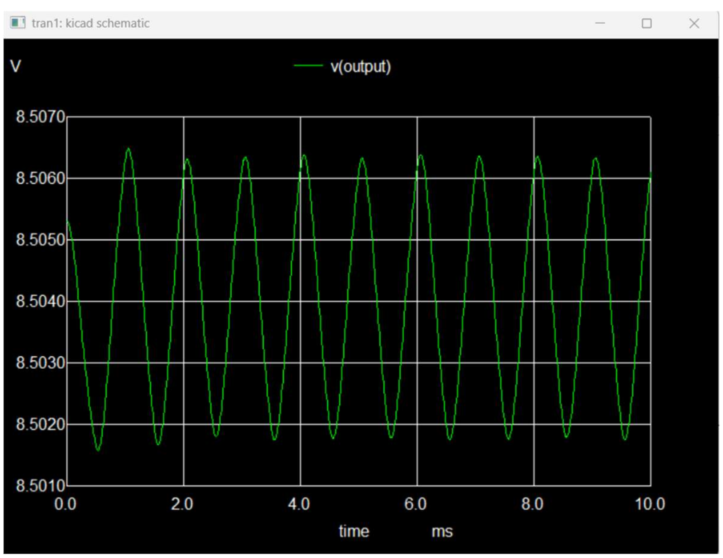
INPUT:



COMPARATOR OUTPUT:



OUTPUT:



ANALYSIS:

Input vs Output Analysis

- **Input (Vin):**
  A clean low-frequency sine wave (e.g., 1 kHz) was applied to the comparator stage as the reference audio signal.
- **Comparator Output (CMP_OUT):**
  The sine input was converted into a **PWM square wave**, where the duty cycle of the high-frequency switching signal varied in proportion to the instantaneous amplitude of the input sine wave.
- **Inverter Output (INV_OUT):**
  Produced the complementary PWM signal (180° out of phase with CMP_OUT) to drive the other MOSFET in the half-bridge.
- **Switch Node (SW):**
  At the MOSFET half-bridge output, a full **0–12 V PWM waveform** was observed. Its duty cycle followed the input sine, confirming correct switching operation.
- **LC Filter + Load Output (Vout):**
  The PWM carrier frequency components were attenuated by the LC low-pass filter, and the waveform was reconstructed into an **approximate sine wave** that resembles the original input signal. Ripple and distortion depended on the filter tuning and load.

RESULT:

The circuit successfully demonstrated the working of a **self-oscillating Class-D amplifier** — efficiently converting a sine input into PWM, switching it through MOSFETs, and reconstructing it back into a sine output using an LC filter.

Reference: Lu, J., & Gharpurey, R. (2011):
https://ieeexplore.ieee.org/document/5986758

Analog Devices :
https://www.analog.com/media/en/technicaldocumentation/application-notes/AN-1071.pdf