ABSTRACT

Title: Design and Simulation of Anti-logarithmic Amplifier using Operational Amplifier

Theory/Description: An anti-logarithmic (or exponential) amplifier is a non-linear analog circuit that produces an output voltage proportional to the anti-logarithm (exponential) of the applied input voltage. The circuit is typically implemented using an operational amplifier with a non-linear semiconductor device, such as a diode or the base-emitter junction of a Bipolar Junction Transistor (BJT) connected to its inverting input, and a linear resistor in the negative feedback loop.

When a diode is used at the input, the non-inverting terminal is grounded, making the inverting terminal a virtual ground. The current flowing through the forward-biased diode is governed by the Shockley diode equation:

$$I_f = I_s e^{\frac{V_{in}}{\eta V_T}}$$

where 'Is' is the reverse saturation current, 'Vin' is the input voltage across the diode, 'eta' is the ideality factor, and 'VT' is the thermal equivalent voltage. Because this exact current 'If' flows through the feedback resistor 'Rf', the output voltage 'Vo' is given by:

$$V_o = -R_f I_s e^{\frac{V_{in}}{\eta V_T}}$$

This demonstrates that the output voltage is exponentially proportional to the input voltage, accompanied by a 180-degree phase inversion.

Explanation:

1. The diode is connected in series between the input voltage source and the inverting terminal of the op-amp, with its anode at the input and cathode at the virtual ground node.
2. The feedback resistor Rf is connected between the output and the inverting terminal. The non-inverting terminal is directly grounded.
3. When a positive input voltage is applied, the diode becomes forward-biased and conducts exponentially. The resulting current flows through Rf, producing a negative exponential output voltage.
4. When the input is negative or zero, the diode is reverse-biased, no appreciable current flows, and the output remains near zero.
5. The output magnitude grows exponentially with increasing input, and the circuit saturates when Vo approaches the op-amp's supply rails, defining the usable dynamic range.

Working:

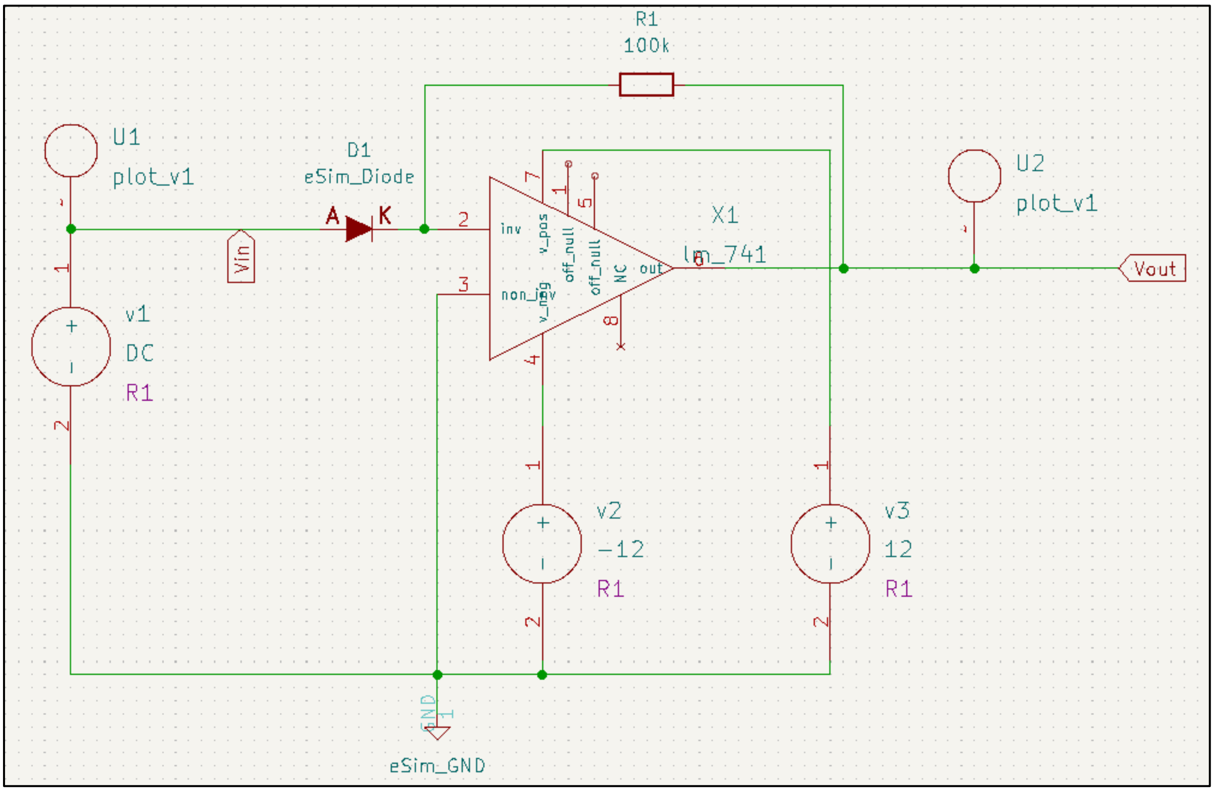
- **Transient Analysis:** A sinusoidal input (cyan waveform) with a peak amplitude of 10 V is applied over a time span of 0 to 5 s. The output (magenta) waveform exhibits a clipped, near-square-wave shape, which is consistent with the expected exponential behaviour of the anti-logarithmic amplifier. During the negative half-cycles of the input, the diode is reverse-biased and the output is clamped near 0 V. During the positive half-cycles, the diode conducts and the exponential current through R_f drives the output sharply to approximately -10.8 V, saturating at the op-amp's negative supply rail. The abrupt switching between near-zero and saturated negative voltage confirms that the circuit operates as a half-wave exponential converter, with the output magnitude limited by the supply voltage rather than by a gradual exponential curve, demonstrates the extreme sensitivity of the anti-log function even for moderate input swings.

- **DC Analysis:** The DC sweep varies the input from -12 V to +12 V. For negative input voltages, the diode remains reverse-biased, no current flows through Rf, and the output (black curve) stays clamped near 0V. As the input just crosses zero into positive territory, the diode becomes forward-biased and conducts exponentially. The resulting current through Rf drives the output, sharply to approximately -10.5 V, where it saturates at the op-amp's negative supply rail. This steep transition at Vin = 0 V confirms the high sensitivity of the exponential diode characteristic, and the flat saturation region for positive inputs demonstrates the bounded dynamic range imposed by the supply voltage, both consistent with the theoretical anti-logarithmic transfer function.

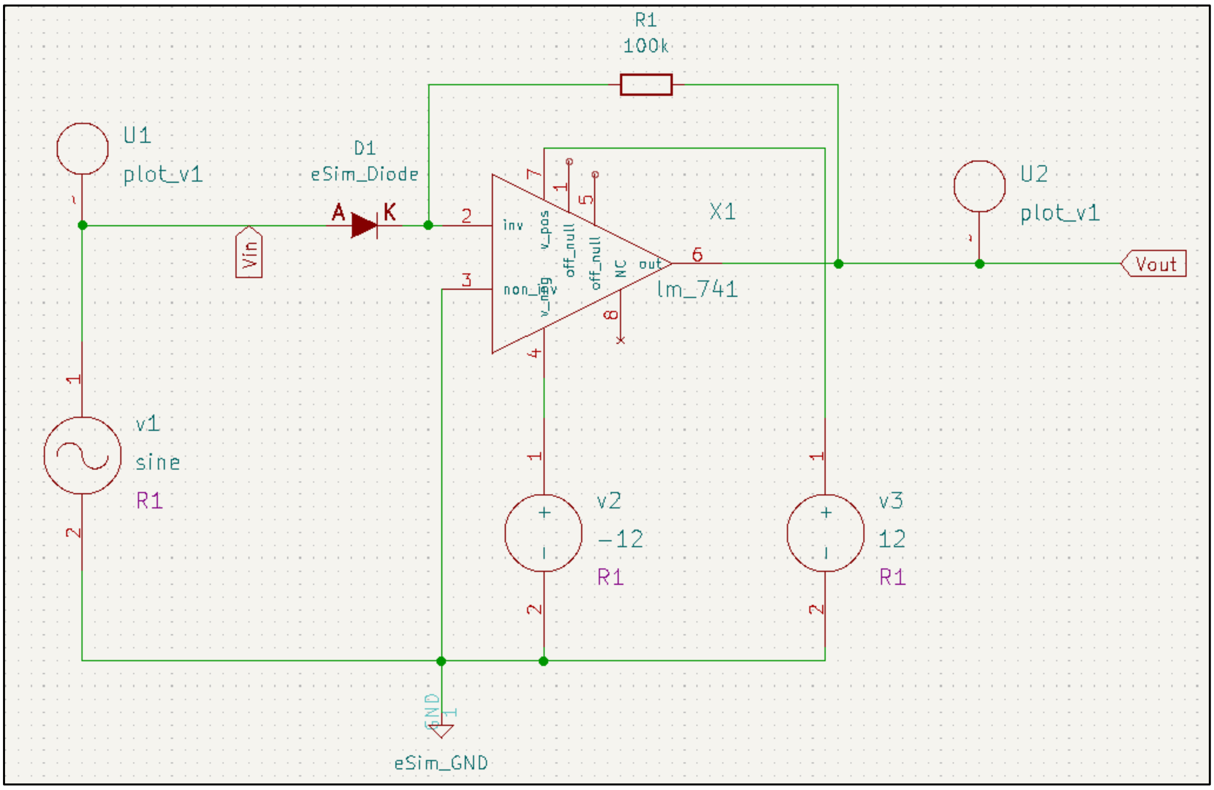
Applications:

1. Anti-logarithmic amplifiers are a core building block in analog computation circuits, used in combination with log amplifiers to implement analog multipliers, dividers, and power-law functions in real time.
2. They are widely used in audio signal processing systems, where the exponential transfer function is used to restore compressed audio signals to their original dynamic range.

Circuit Diagram(s):



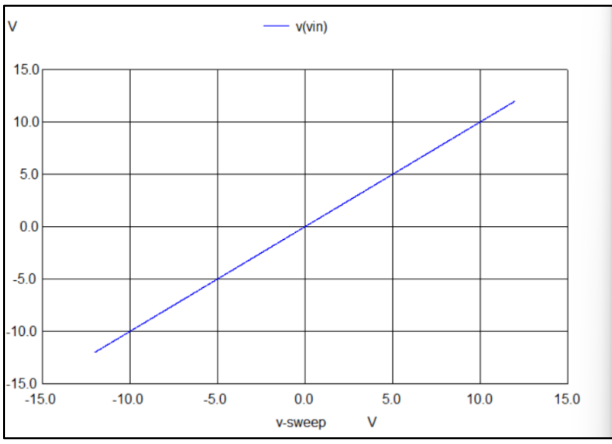
Schematic For DC Analysis (DC Source)



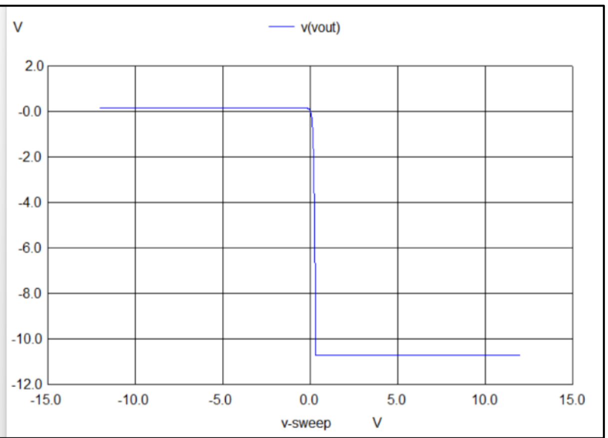
Schematic For Transient Analysis (Sine Source)

Results / Outputs (Ngspice and/or Python plots):

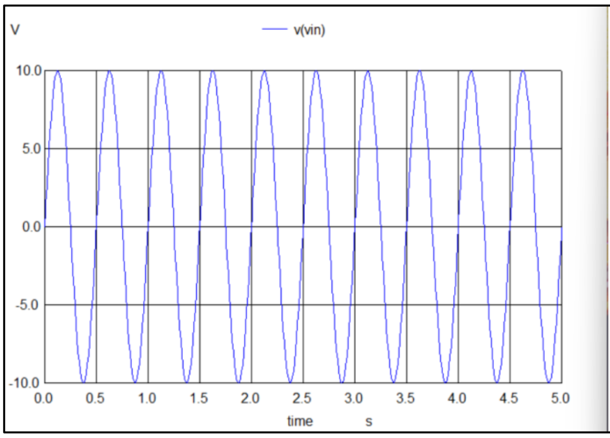
Ngspice Plots:

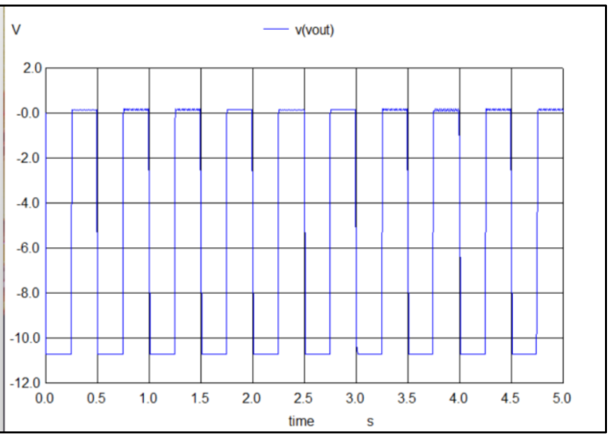


DC Input (-12V to 12V)



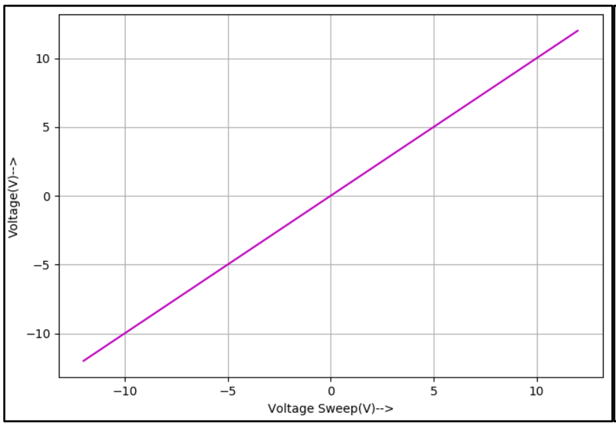
DC Output

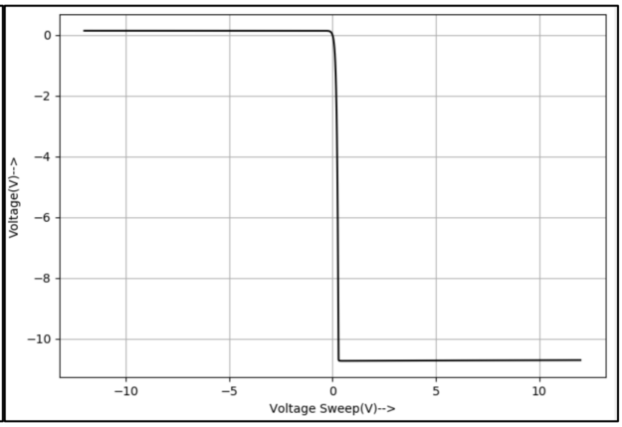




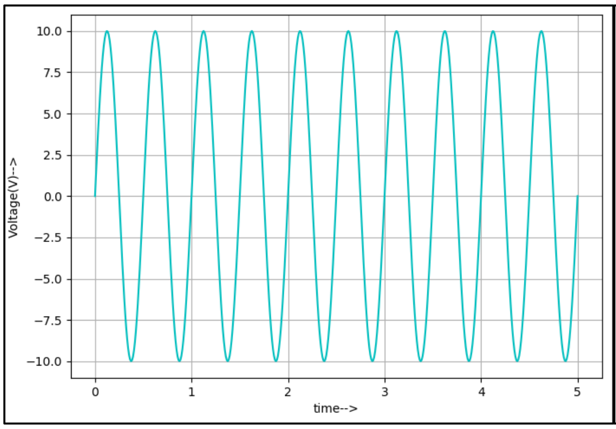
Transient Input (Sine Wave) **Transient Output**

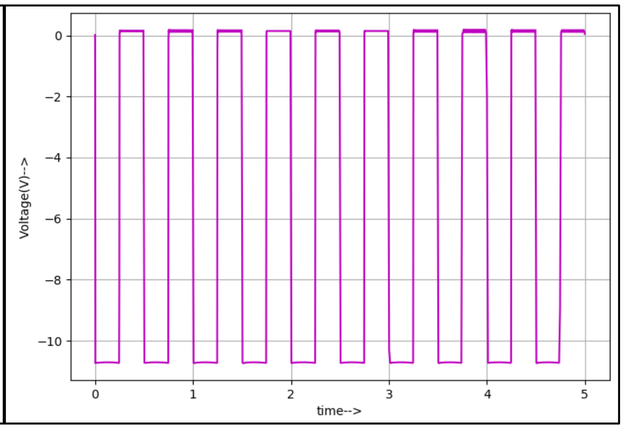
Python Plots:





DC Input (-12V to 12V) **DC Output**





Transient Input (Sine Wave) **Transient Output**

References:

- Virtual Labs, "Log and Antilog amplifiers," IIT Roorkee.
- https://www.tutorialspoint.com/linear_integrated_circuits_applications/linear_integrated_circuits_applications_log_and_anti_log_amplifiers.htm

Journal:

- **Title:** Probabilistic Operational Amplifier
- **Link:** https://www.ijrar.org/papers/IJRAR19J2993.pdf