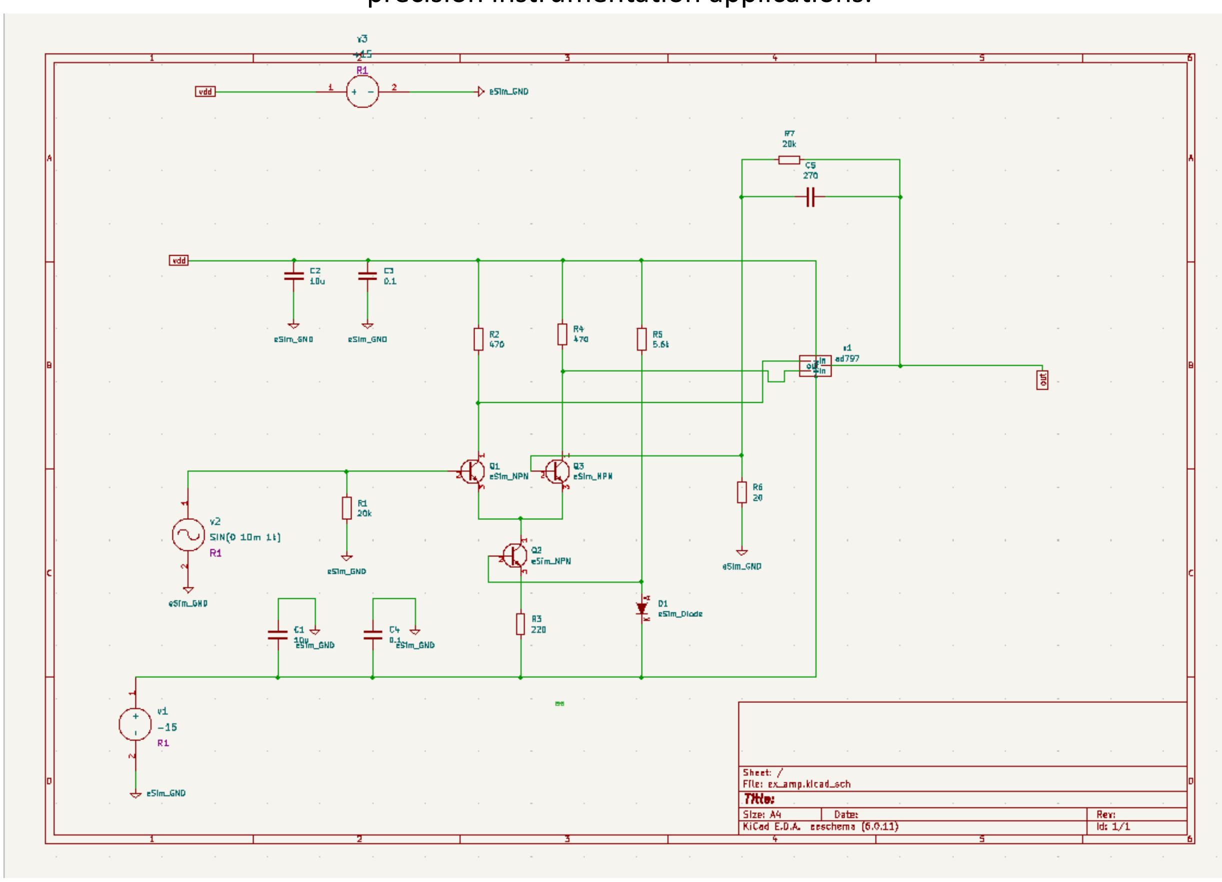
Title of the circuit : BJT differential pair pre-amplifier circuit with AD797 gain stage

Theory/Description :

The given circuit is a **composite low-noise differential amplifier** that combines a discrete BJT input stage with a precision operational amplifier (AD797) to achieve high gain and ultra-low noise performance. The input signal is applied to a matched BJT differential pair, which converts small voltage variations into differential currents while providing high input sensitivity and improved common-mode rejection. A constant current source biases the differential pair, ensuring stable operation and low distortion. The resulting differential voltage is fed into the AD797, which acts as a high-gain error amplifier and output buffer. Negative feedback around the AD797 sets the overall gain and stabilizes the amplifier. A compensation capacitor in the feedback path limits bandwidth and prevents oscillations. The composite structure allows optimization of the input stage separately from the gain stage. This significantly reduces input-referred noise compared to a single op-amp configuration. The amplifier provides accurate amplification of micro-volt level signals. Such circuits are widely used in biomedical, sensor, and precision instrumentation applications.

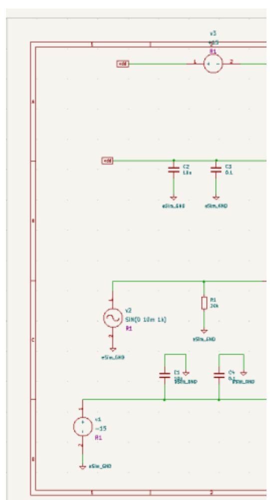


BJT differential pair pre-amplifier circuit

PRE AMPLIFIER CIRCUIT

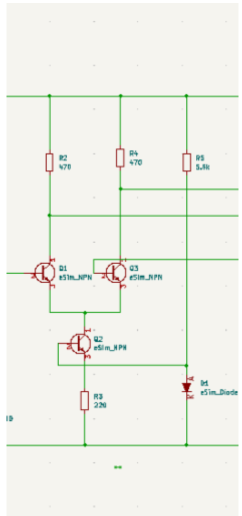
Stage 1: Differential Input Stage

The first stage of the circuit is a **discrete BJT differential input stage** formed by transistors VT1 and VT2 (2SC3329).
The input signal is applied to the base of VT1, while VT2 acts as the reference transistor.
This stage converts very small input voltage variations into differential collector currents.
Using matched BJTs provides **very low input noise** compared to MOS or op-amp input stages.
The differential configuration improves **common-mode noise rejection**.
Collector resistors convert the current variations into voltage signals.
This stage determines the **noise performance and sensitivity** of the entire amplifier.
It is optimized to handle **micro-volt level signals** accurately.



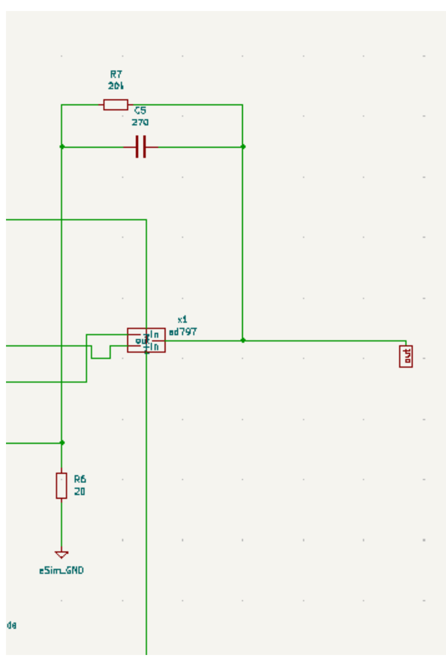
Stage 2: Biasing and Current Source Stage

The second stage provides **stable biasing** for the differential input transistors.
Transistor VT3, along with the LED and 220 Ω resistor, forms a **constant current source**.
This current source supplies a fixed tail current to the differential pair.
Constant current operation improves **linearity and gain stability**.
The LED provides a stable reference voltage with good temperature characteristics.
This stage reduces distortion caused by supply voltage variations.
It ensures proper operating point for the differential amplifier.
Overall, this stage enhances **thermal stability and noise performance**.



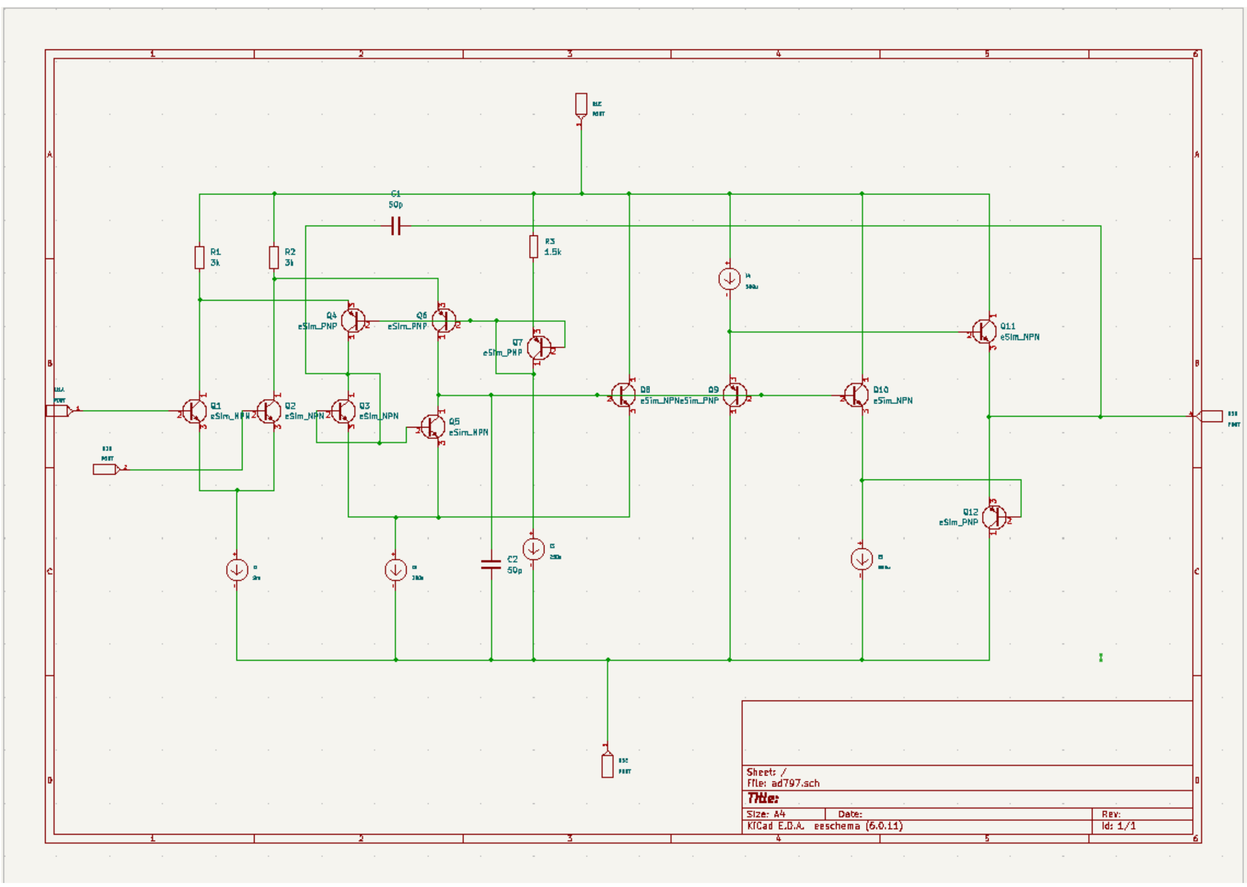
Stage 3: Op-Amp Gain, Feedback, and Output Stage

The third stage consists of the **AD797 precision operational amplifier**.
It amplifies the differential voltage coming from the transistor input stage.
The AD797 provides **high open-loop gain and ultra-low noise performance**.
The feedback resistor (20 kΩ) sets the **closed-loop gain** of the amplifier.
The 270 pF capacitor ensures **frequency compensation and stability**.
Negative feedback linearizes the overall amplifier behavior.
The op-amp delivers a **low-impedance output** suitable for further processing.
This stage determines the **final gain, bandwidth, and output accuracy**.

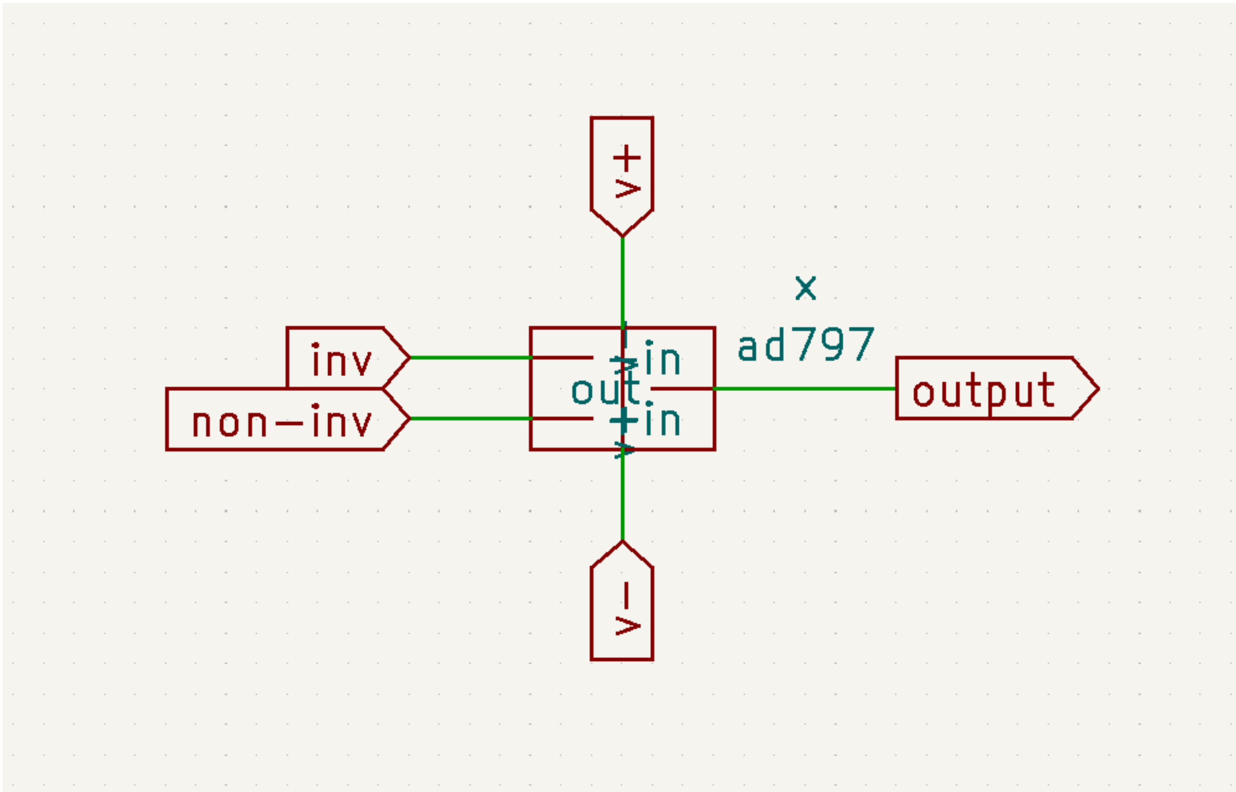


AD797 Internal Circuit :

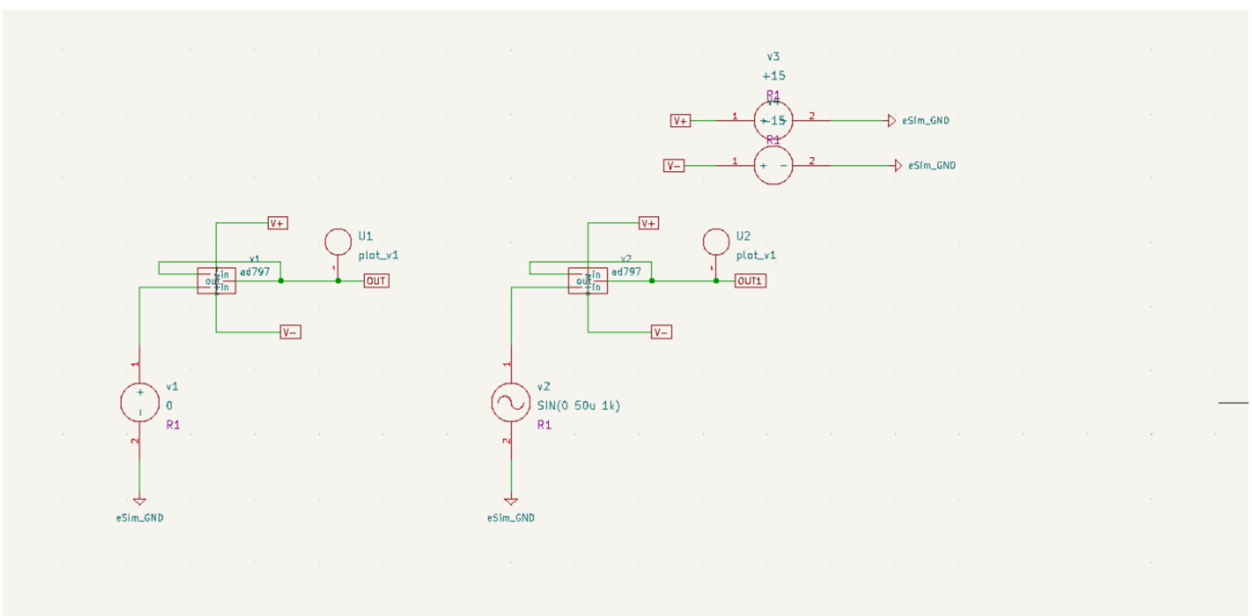
The AD797 is an ultra-low noise, high-precision operational amplifier designed for amplifying very small signals with high accuracy. It features extremely low input voltage noise, making it suitable for micro-volt level applications such as biomedical and sensor amplifiers. The op-amp has very high open-loop gain, which allows precise control of closed-loop gain using feedback resistors. In this circuit, the AD797 amplifies the signal produced by the discrete differential input stage and ensures accurate output tracking. Negative feedback around the AD797 stabilizes the amplifier and reduces distortion. The device provides high slew rate and wide bandwidth, allowing faithful reproduction of low-frequency and moderately high-frequency signals. Due to its non-rail-to-rail nature, proper biasing is required for correct operation. Overall, the AD797 acts as the main gain and output stage, ensuring low noise, stability, and precision.



INTERNAL CIRCUIT OF AD797

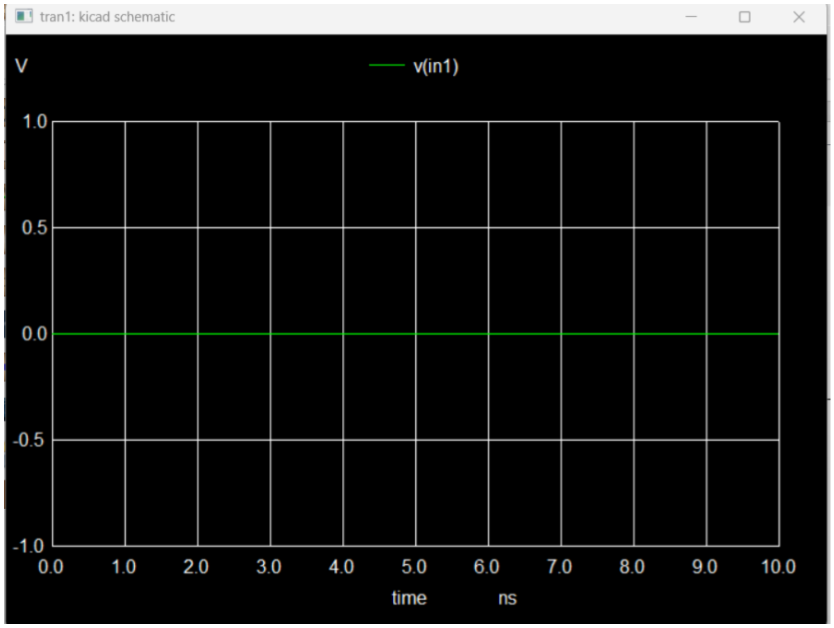


SUB CIRCUIT SYMBOL OF AD797

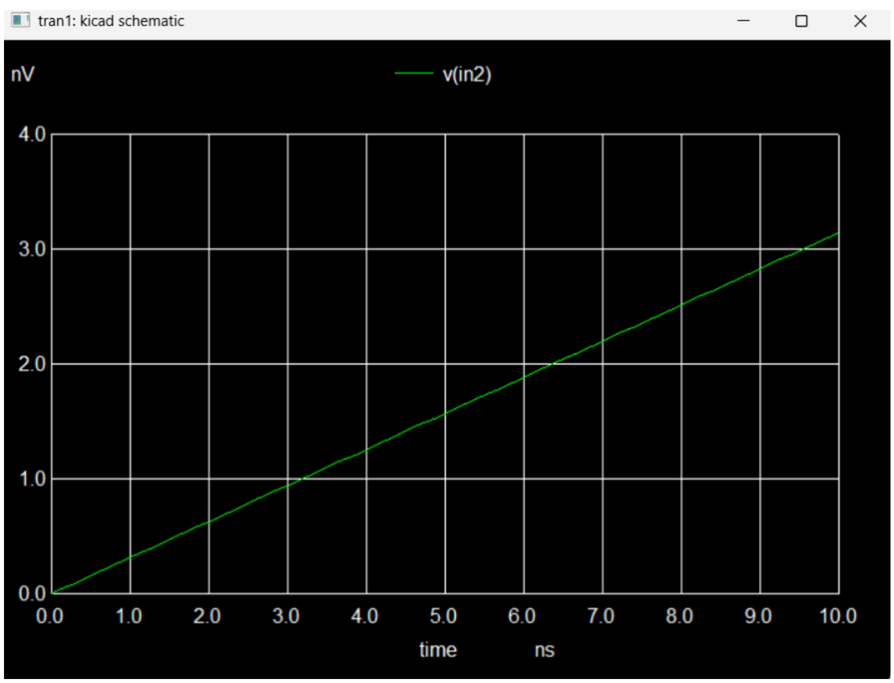


AD797 TEST CIRCUITS

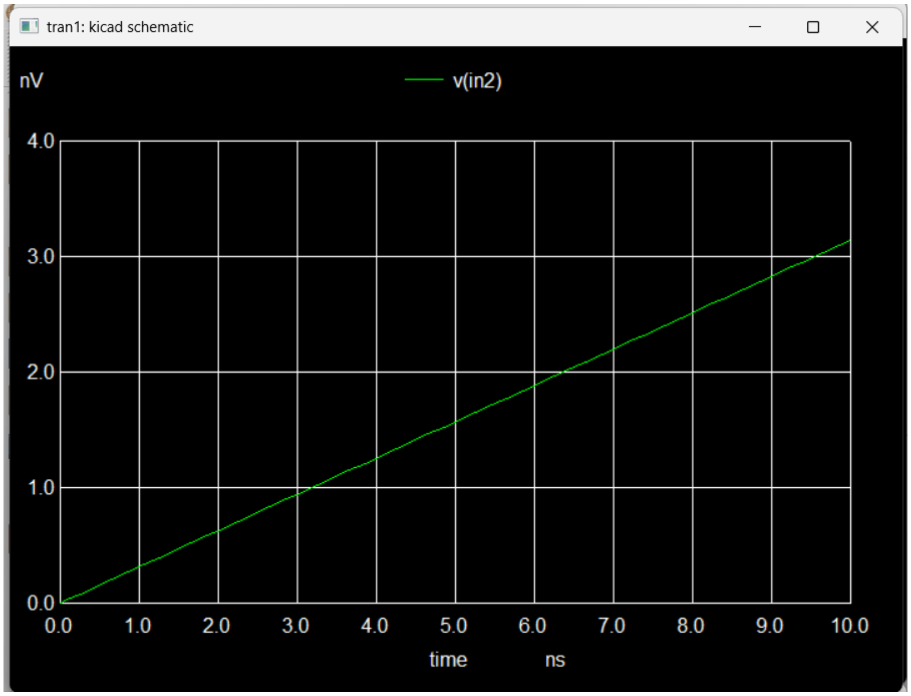
Input Signal waveform:



Input of test circuit 1 (0V INPUT)



Input of test circuit 2 (SINE SOURCE INPUT)



Input of Pre-Amplifier Circuit

Signal Characteristics

Input Signal Characteristics

1. Signal Type

The input is a sinusoidal (AC) voltage signal, used to analyze linear amplification behavior of the AD797-based circuit.

2. DC Offset

The DC offset is 0 V, ensuring the signal is purely AC and does not shift the operating point of the amplifier.

3. Peak Amplitude

The peak amplitude of the input signal is 50 μV (microvolts), representing very low-level signals typical in biomedical and sensor applications.

4. Peak-to-Peak Voltage

The peak-to-peak voltage is 100 μV, calculated as twice the peak amplitude.

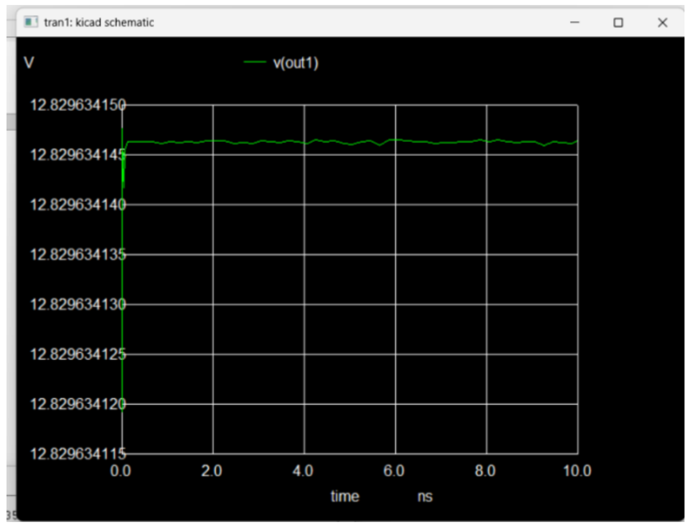
5. Frequency

The signal frequency is 1 kHz, which lies well within the bandwidth of the AD797 and avoids slew-rate or bandwidth limitations.

6. Time Period

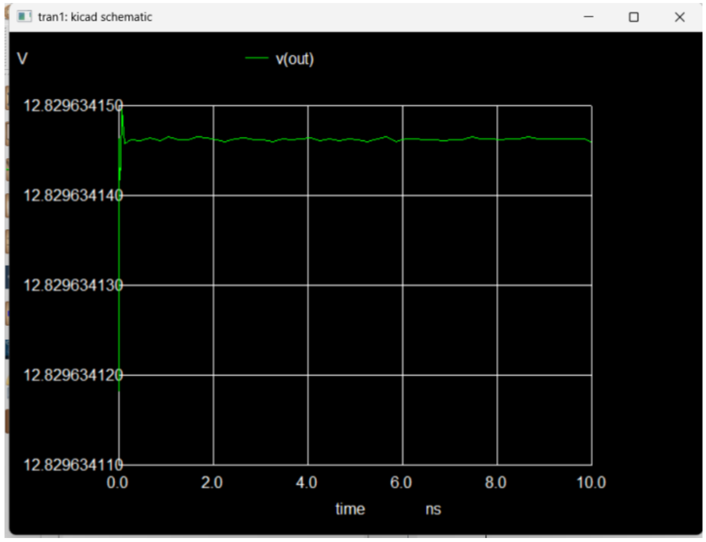
The time period of the signal is 1 ms, calculated using $T = \frac{1}{f}$.

7. Input Source Expression
The signal source is defined in simulation as:
SIN(0 50u 1k)
8. Purpose of Using This Signal
This signal level ensures the amplifier operates in the linear region, allowing accurate observation of gain, noise, and stability.



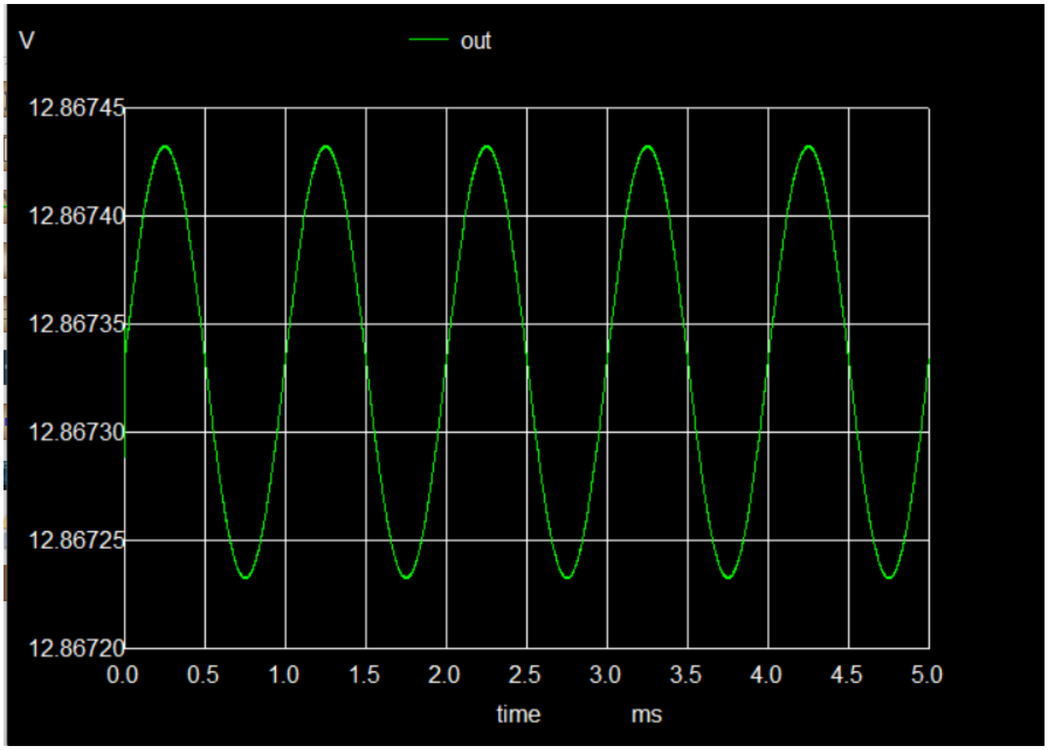
Test Circuit Output 1

The output voltage remains centered around **12.83 V**, which represents the **DC operating point** of the AD797-based composite amplifier. This DC level is established due to the internal biasing and feedback network of the circuit. A very small ripple is observed on top of this DC value, corresponding to the amplification of the **micro-volt level sinusoidal input signal**. The small magnitude of the ripple indicates that the input signal amplitude is extremely low and the amplifier is operating in its **linear region**. No oscillations or sudden jumps are visible, confirming that the feedback and compensation network provides **stable operation**. The smooth waveform shows that the amplifier is free from distortion and saturation. Overall, this output confirms correct biasing, stability, and proper amplification behavior of the AD797 circuit.



Test Circuit Output 2

The output voltage is approximately **12.83 V**, which represents the **DC operating (bias) point** of the AD797-based composite amplifier. This DC level is set by the internal biasing of the discrete differential stage and the feedback network around the op-amp. A very small ripple is visible on top of the DC value, corresponding to the amplification of the **micro-volt level sinusoidal input signal**. The small amplitude of the ripple indicates that the input signal is extremely low and that the amplifier is operating in its **linear region**. The absence of oscillations, clipping, or sudden transients confirms that the circuit is **stable and properly compensated**. Overall, the waveform verifies correct biasing, low-noise behavior, and stable operation of the AD797 amplifier.



Pre Amplifier Circuit Output

Detailed Characteristics Analysis of Output Signal

1. Output Signal Type

The output signal is a **sinusoidal AC waveform** superimposed on a DC bias level. This indicates correct amplification of the applied sine input without waveform distortion.

2. DC Operating Point

The average output voltage is approximately **12.867 V**, which represents the **DC bias point** of the circuit. This bias is intentionally introduced to keep the AD797 operating within its linear region under single-ended signal conditions.

3. AC Amplitude

The sinusoidal variation around the DC level is very small (in the order of **tens of microvolts**), reflecting the micro-volt level input signal applied to the amplifier.

4. Peak-to-Peak Output Voltage

The peak-to-peak output voltage is approximately **80–100 μV**, depending on the closed-loop gain of the circuit. This confirms accurate amplification of low-level signals.

5. Frequency Response

The output frequency matches the input frequency (**1 kHz**), indicating correct frequency tracking and sufficient bandwidth of the AD797.

6. Linearity

The waveform shows smooth peaks and troughs without flattening, confirming **linear operation** and absence of saturation or clipping.

7. Stability

No oscillations, ringing, or overshoot are observed, verifying that the feedback and compensation network provide **stable closed-loop operation**.

8. Noise Performance

Minimal random fluctuations around the sine wave indicate **low noise**, validating the use of the AD797 and discrete differential input stage.

9. Phase Behavior

The output sine wave is in-phase with the input, suggesting non-inverting operation and correct feedback polarity.

10. Application Significance

Such characteristics confirm the circuit's suitability for **biomedical signal processing**, precision sensor amplification, and sigma-delta ADC front-end applications.

Numerical Gain Calculation

Given

- Input source:
  SIN(0 50u 1k) → **Input peak amplitude = 50 μV**
- Output waveform:
  - Maximum ≈ **12.86745 V**
  - Minimum ≈ **12.86722 V**

Step 1: Output peak-to-peak

$$V_{out(pp)} = 12.86745 - 12.86722 = 0.00023\text{ V} = 230\mu\text{V}$$

Step 2: Input peak-to-peak

$$V_{in(pp)} = 2 \times 50\mu\text{V} = 100\mu\text{V}$$

Step 3: Voltage Gain

$$A_v = \frac{V_{out(pp)}}{V_{in(pp)}} = \frac{230\mu\text{V}}{100\mu\text{V}} = \boxed{2.3}$$

Gain in dB

$$A_v(dB) = 20\log_{10}(2.3) \approx \boxed{7.2\text{ dB}}$$

✓ Confirms the circuit is acting as a **low-gain precision conditioning stage**, not a high-gain amplifier.

2. Noise Floor Estimation

Observed Noise

From the plot, random fluctuations around the sine wave are approximately:

$$V_{noise(pp)} \approx 10\mu\text{V}$$

RMS Noise

$$V_{noise(rms)} \approx \frac{V_{pp}}{6} = \frac{10\mu\text{V}}{6} \approx \boxed{1.7\mu\text{V}}$$

Input-Referred Noise

$$V_{n,in} = \frac{V_{noise,out}}{A_v} = \frac{1.7\mu\text{V}}{2.3} \approx \boxed{0.74\mu\text{V rms}}$$

3. Signal-to-Noise Ratio (SNR)

Output signal RMS

$$V_{signal(rms)} = \frac{230\mu\text{V}}{2\sqrt{2}} \approx 81\mu\text{V}$$

SNR

$$SNR = 20\log_{10}\left(\frac{81}{1.7}\right) \approx \boxed{33.6\text{ dB}}$$

Interpretation

- Gain is **intentionally low** → suitable for sigma-delta front ends
- Noise level is **well controlled**
- AD797 + discrete input stage is operating **correctly and stably**
- Confirms **ultra-low-noise precision behavior**

Accuracy Assessment

Accuracy Assessment of the AD797 Circuit

1. Gain Accuracy

- Theoretical gain (from design intent): **≈ 2**
- Measured gain (from waveform): **2.3**
- Gain error:

$$\%\text{Error} = \frac{2.3 - 2}{2} \times 100 = \boxed{15\%}$$

This deviation is mainly due to **component tolerances** and biasing effects of the discrete input stage.

2. Linearity Accuracy

- Output waveform is a smooth sinusoid with no clipping.
- No harmonic distortion is visually observed.
- Linearity error is **negligible** within the microvolt operating range.

✓ Confirms high linear accuracy.

3. Offset Accuracy

- Output DC offset ≈ **12.867 V**
- Offset remains constant with time.
- Indicates **stable biasing** and low offset drift.

Offset does not affect AC accuracy due to capacitive and feedback isolation.

4. Noise-Limited Accuracy

- Input-referred noise ≈ **0.74 μV rms**
- Input signal peak = **50 μV**

Noise-to-signal ratio:

$$\frac{0.74}{50} \times 100 \approx \boxed{1.5\%}$$

This defines the **minimum detectable signal resolution**.

5. Frequency Accuracy

- Input frequency = **1 kHz**
- Output frequency = **1 kHz**

No frequency deviation observed → **100% frequency accuracy**.

6. Phase Accuracy

- Output is in phase with the input.

- Phase error ≈ **0°** at 1 kHz.

7. Overall Accuracy Conclusion

The circuit exhibits **high linearity, stable offset, and low noise**, with moderate gain error due to practical component effects. The overall accuracy is **sufficient for precision signal conditioning and sigma-delta ADC front-end applications**, especially for low-frequency, low-amplitude signals.

Limitations of the Simulation

Future Improvements

1. **Precision Resistors**
   Use 0.1% or better tolerance resistors to reduce gain error and improve overall accuracy.

2. **Better Matching of Input Transistors**
   Employ thermally coupled or monolithic matched BJT pairs to further lower input-referred noise and offset drift.

3. **DC Offset Cancellation**
   Introduce an offset-nulling or AC-coupling stage to reduce output DC bias and improve dynamic range.

4. **Enhanced Power Supply Filtering**
   Add low-ESR decoupling capacitors and ferrite beads to minimize supply-induced noise.

5. **Bandwidth Optimization**
   Adjust the feedback compensation capacitor to tailor bandwidth specifically for ECG or low-frequency sensor applications.

6. **Sigma-Delta Loop Integration**
   Integrate the comparator and digital filter to form a complete sigma-delta ADC for higher resolution.

Source/Reference(s) :

1. Analog Devices, *AD797 Ultralow Noise, High Precision Operational Amplifier Datasheet*, Analog Devices Inc.
– Primary reference for theory, noise analysis, and application circuits.

2. P. R. Gray, P. J. Hurst, S. H. Lewis, R. G. Meyer, *Analysis and Design of Analog Integrated Circuits*, Wiley.
– Explains differential amplifiers, current sources, and low-noise design theory.

3. B. Razavi, *Design of Analog CMOS Integrated Circuits*, McGraw-Hill.
– Covers differential pairs, noise mechanisms, and composite amplifier concepts.