Op-amps

Op-amp Information

- https://mysite.du.edu/~etuttle/electron/elect3.htm
- https://bjpcjp.github.io/pdfs/cmos_layout_sim/ch24-op-amps.pdf
- https://www.allaboutcircuits.com/technical-articles/negative-feedback-part-1-general-structure-and-essential-concepts/

Bandwidth Measurement

Measuring the bandwidth of an operational amplifier (op-amp) means determining the frequency range over which it can amplify signals accurately. Bandwidth is typically defined as the frequency at which the gain drops by 3 dB compared to its low-frequency value. There are two closely related bandwidth concepts:

- **Small-signal (linear) bandwidth**: The frequency at which the gain drops by 3 dB (to 0.707 of its mid-band value).
- **Gain-Bandwidth Product (GBW)**: For most voltage-feedback op-amps, the product of closed-loop gain and bandwidth is approximately constant.

```
Bandwidth = GBW / Closed-loop gain
```

Step-by-step Procedure:

1. Configure the op-amp in a non-inverting amplifier configuration with a moderate gain (e.g., 5 or 10).
2. Apply a small-amplitude sine wave (typically 50–100 mVpp) at a low starting frequency, such as 1 kHz.
3. Measure the mid-band gain (Vout/Vin) and use this as the reference gain.
4. Sweep the input frequency upward while monitoring the output amplitude.
5. Identify the frequency at which the output amplitude falls to 0.707 of the mid-band value. This frequency is the closed-loop bandwidth.

Measuring Unity-Gain Bandwidth (GBW)

To measure the GBW directly, configure the op-amp as a voltage follower (gain = 1). Sweep the frequency and find the −3 dB point. This frequency approximates the unity-gain bandwidth. Note: Always verify that the op-amp is unity-gain stable before using this method.

Common Measurement Pitfalls

- Slew-rate limitation is a frequent error. If the output waveform becomes triangular at high frequency, the op-amp is slew-rate limited and the measurement is invalid. Reduce the input amplitude to correct this.
- Additionally, avoid excessive output loading and use a high-impedance oscilloscope probe (10×) to reduce measurement errors.
- Ensure proper power-supply decoupling and watch for instability or oscillations caused by capacitive loads.

Input Offset Voltage (Vos) Measurement

The input offset voltage (Vos) of an operational amplifier is the small differential DC voltage that must be applied between the inputs to force the output to exactly zero. Measuring Vos is an important step when evaluating DC accuracy, especially for precision, instrumentation, or low-level signal applications. Typical input offset voltage ranges:

- General-purpose op-amps: 0.5 mV to 5 mV
- Precision op-amps: 1 µV to 100 µV
- Chopper / auto-zero op-amps: < 1 µV

Measurement Method (Non-Inverting Amplifier)

The most reliable way to measure Vos is to amplify it using a high closed-loop gain and then calculate it back from the measured output voltage. Test Configuration:

- Configure the op-amp as a non-inverting amplifier
- Connect the non-inverting (+) input to ground
- Use a resistive feedback network to set a high gain (e.g. 100–1000)
- Power the op-amp with normal operating supply voltages.
- Allow the circuit to thermally stabilize (5–15 minutes recommended).
- Ensure no signal is applied to the input.
- Measure the DC output voltage using a high-resolution DMM.
- Calculate Vos using the formula below.

```
Vos = Vout / Gain
```

Compensation for Input Bias Current

Input bias currents flowing through source resistances introduce additional offset voltage. To cancel this effect, add a bias compensation resistor. Bias compensation resistor:

```
Rcomp = Rf || Rg
```

Place Rcomp between the non-inverting input and ground.

Special Considerations for Chopper and Auto-Zero Op-Amps

Chopper and auto-zero op-amps have extremely low Vos but may exhibit output ripple due to internal switching. Use output filtering or averaging measurements to obtain a stable DC reading.

Temperature Effects

Input offset voltage drifts with temperature, typically specified in µV/°C.
For accurate results, maintain a stable ambient temperature and avoid airflow or direct heat sources.

Measurement Best Practices

- Use short, symmetric input wiring
- Avoid thermoelectric junctions and touching nodes during measurement
- Use proper supply decoupling capacitors

Op-amp Stability

- https://www.ti.com/lit/an/slyt087/slyt087.pdf?ts=1687347593525&ref_url=https%253A%252F%252Fwww.google.com%252F
- https://www.k-state.edu/edl/docs/pubs/technical-resources/Technote9.pdf
- https://electronics.stackexchange.com/questions/530698/whats-the-need-for-a-small-capacitor-in-the-negative-feedback-parallel-to-a-fee
- https://electronics.stackexchange.com/questions/390986/non-inverting-op-amp-configuration-with-capacitor
- https://www.edn.com/the-impact-of-input-capacitance-on-op-amp-stability/
- https://www.analog.com/en/analog-dialogue/articles/techniques-to-avoid-instability-capacitive-loading.html
- https://www.eevblog.com/forum/projects/compensation-methods-in-current-sink-circuits/
- https://www.eevblog.com/forum/projects/dynamic-electronic-load-project/msg462562/#msg462562