AC-coupled transimpedance amplifier circuit

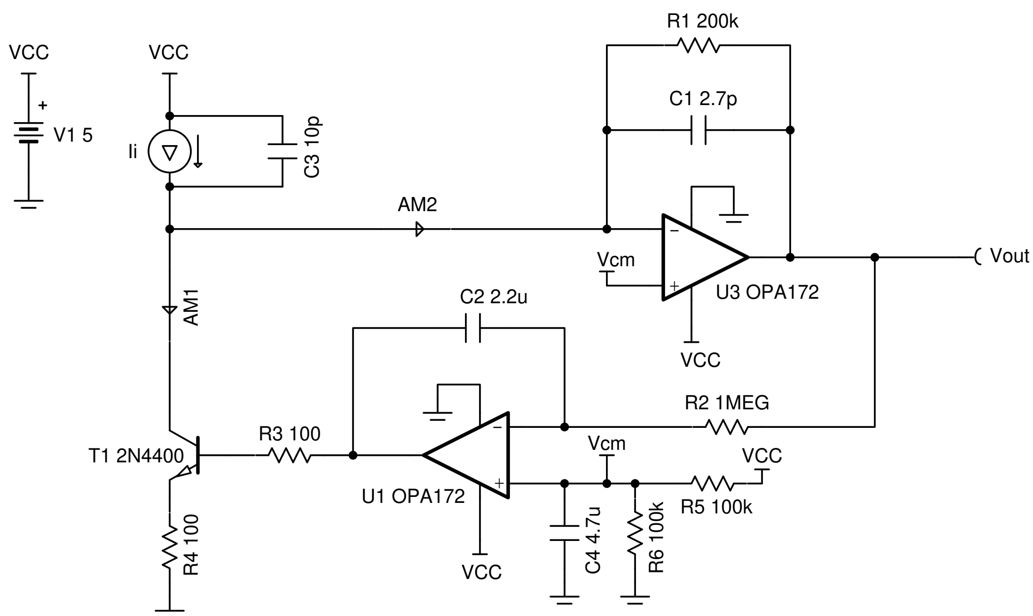
Amplifiers

Design Goals

Input Current		Ambient light current	Output voltage		Target Bandwidth	Supply	
I_{iMin}	I_{iMax}		V_{oMin}	V_{oMax}		V_{cc}	V_{ee}
–10µA	10µA	100µA	0.5V	4.5V	300kHz	5V	0V

Design Description

This circuit uses an op amp configured as a transimpedance amplifier to amplify the AC signal of a photodiode (modeled by I_i and C_3). The circuit rejects DC signals using a transistor to sink DC current out of the photodiode through the use of an integrator in a servo loop. The bias voltage applied to the non-inverting input prevents the output from saturating to the negative supply rail in the absence of input current.



Design Notes

1. Use a JFET or CMOS input op amp with low-bias current to reduce DC errors.
2. A capacitor placed in parallel with the feedback resistor will limit bandwidth, improve stability and help reduce noise.
3. The junction capacitance of photodiode changes with reverse bias voltage which will influence the stability of the circuit.
4. Reverse-biasing the photodiode can reduce the effects of dark current.
5. A resistor, R_3, may be needed on the output of the integrator amplifier.
6. An emitter degeneration resistor, R_4, should be used to help stabilize the BJT.
7. Use the op amp in a linear operating region. Linear output swing is usually specified under the A_{OL} test conditions.

Design Steps

The transfer function of the circuit is:

$$V_{out} = -I_i \times R_1$$

1. Calculate the value of the feedback resistor, R_1, to produce the desired output swing.

$$R_1 = \frac{V_{oMax} - V_{oMin}}{I_{iMax} - I_{iMin}} = \frac{4.5V - 0.5V}{10\mu A - (-10\mu A)} = 200k\Omega$$

2. Calculate the feedback capacitor to limit the signal bandwidth.

$$C_1 = \frac{1}{2\pi \times R_1 \times f_p} = \frac{1}{2\pi \times 200k\Omega \times 300kHz} = 2.65pF \approx 2.7pF\ (\text{Standard Value})$$

3. Calculate the gain bandwidth of the amplifier needed for the circuit to be stable.

$$GBW = \frac{C_i + C_1}{2\pi \times R_1 \times C_1^2} = \frac{23pF + 2.7pF}{2\pi \times 200k\Omega \times (2.7pF)^2} = 2.97MHz$$

   Where:

$$C_i = C_{pd} + C_b + C_d + C_{cm} = 10pF + 5pF + 4pF + 4pF = 23pF$$

   Given:

   - C_{pd}: Junction capacitance of photodiode
   - C_b: Output capacitance of BJT
   - C_d: Differential input capacitance of the amplifier
   - C_{cm}: Common-mode input capacitance of the inverting input

4. Set the cutoff frequency of the integrator circuit, f_I, to 0.1Hz to only allow signals near DC to be subtracted from the photodiode output current. The cutoff frequency is set by R_2 and C_2. Select R_2 as 1MΩ.

$$C_2 = \frac{1}{2\pi \times R_2 \times f_I} = \frac{1}{2\pi \times 1M\Omega \times 0.1Hz} = 1.59\mu F \approx 2.2\mu F\ (\text{Standard Value})$$

5. Select R_3 as 100Ω to isolate the capacitance of the BJT from op amp and stabilize the amplifier. For more information on stability analysis, see the Design References section [2].
6. Bias the output of the circuit by setting the input common mode voltage of the integrator circuit to mid-supply. Select R_5 and R_6 as 100kΩ.

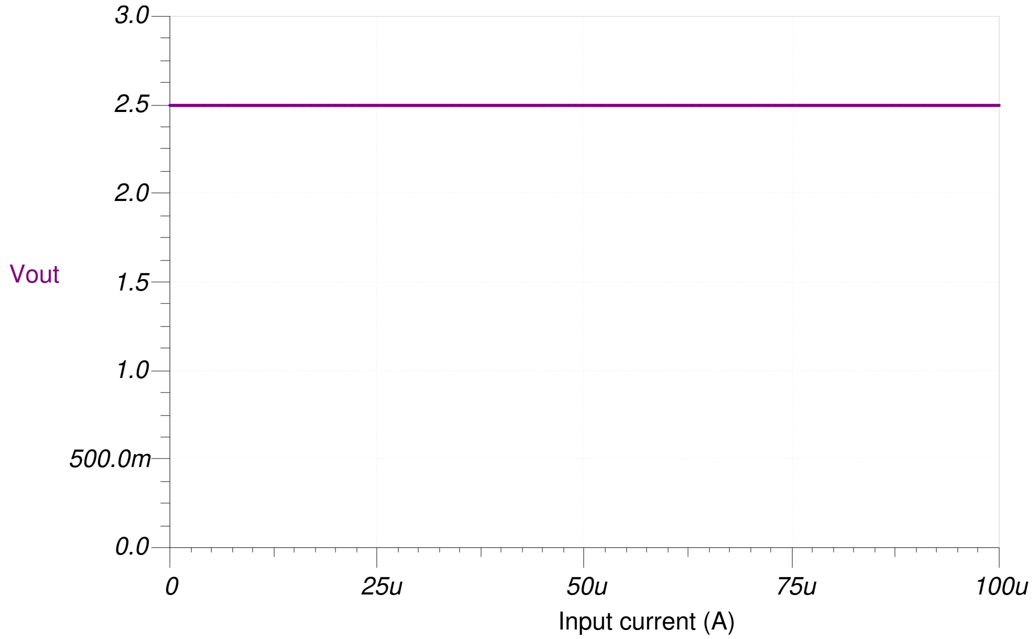
$$Vcm = \frac{R_6}{R_5 + R_6} \times Vcc = \frac{100k\Omega}{100k\Omega + 100k\Omega} \times 5V = 2.5V$$

7. Calculate capacitor C_2 to filter the power supply and resistor noise. Set the cutoff frequency to 1Hz.

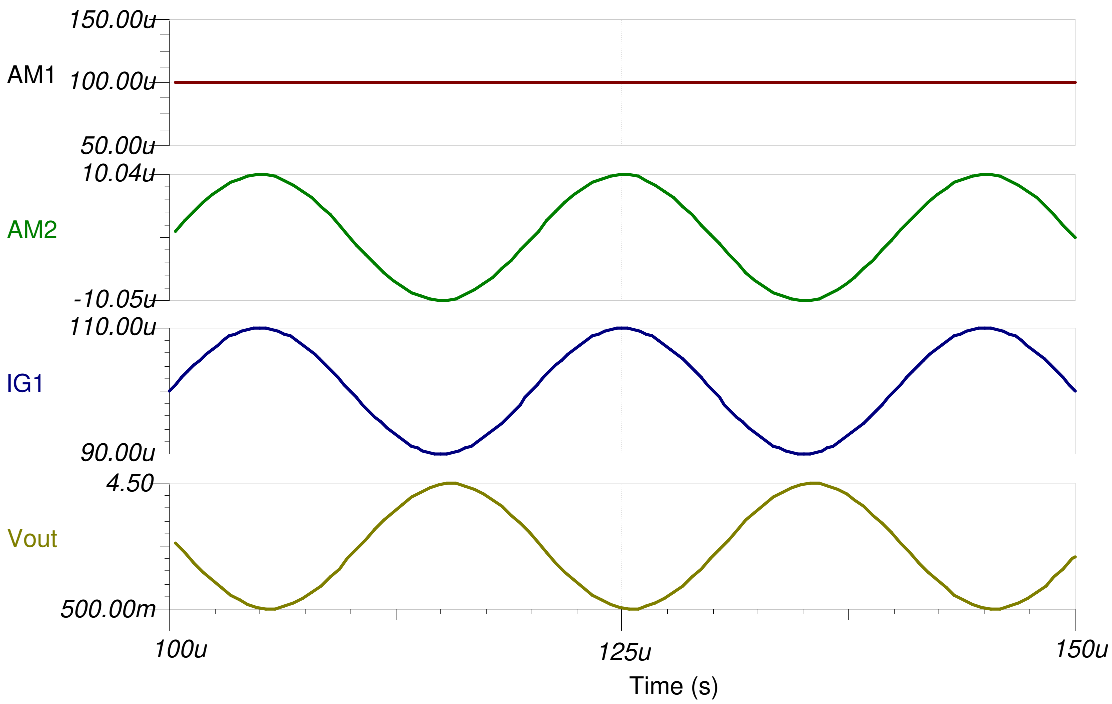
$$C_2 = \frac{1}{2\pi \times (R_2 || R_3) \times 1Hz} = \frac{1}{2\pi \times (100k\Omega\ ||\ 100k\Omega) \times 1Hz} = 3.183\mu F \approx 4.7\mu F$$

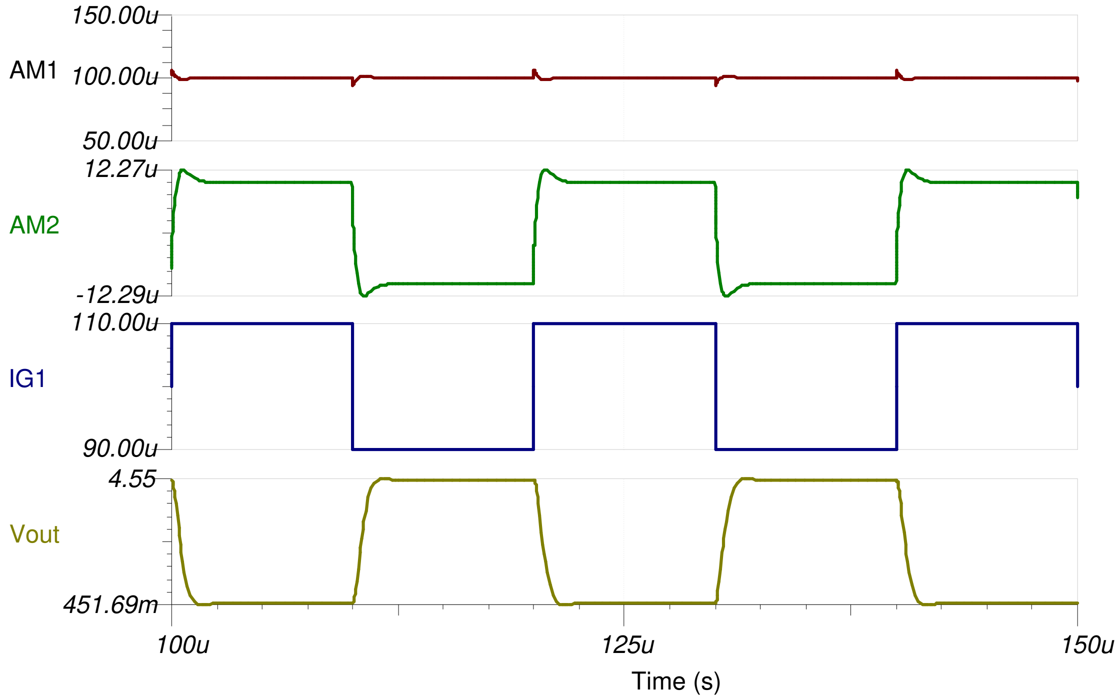
Design Simulations

DC Simulation Results

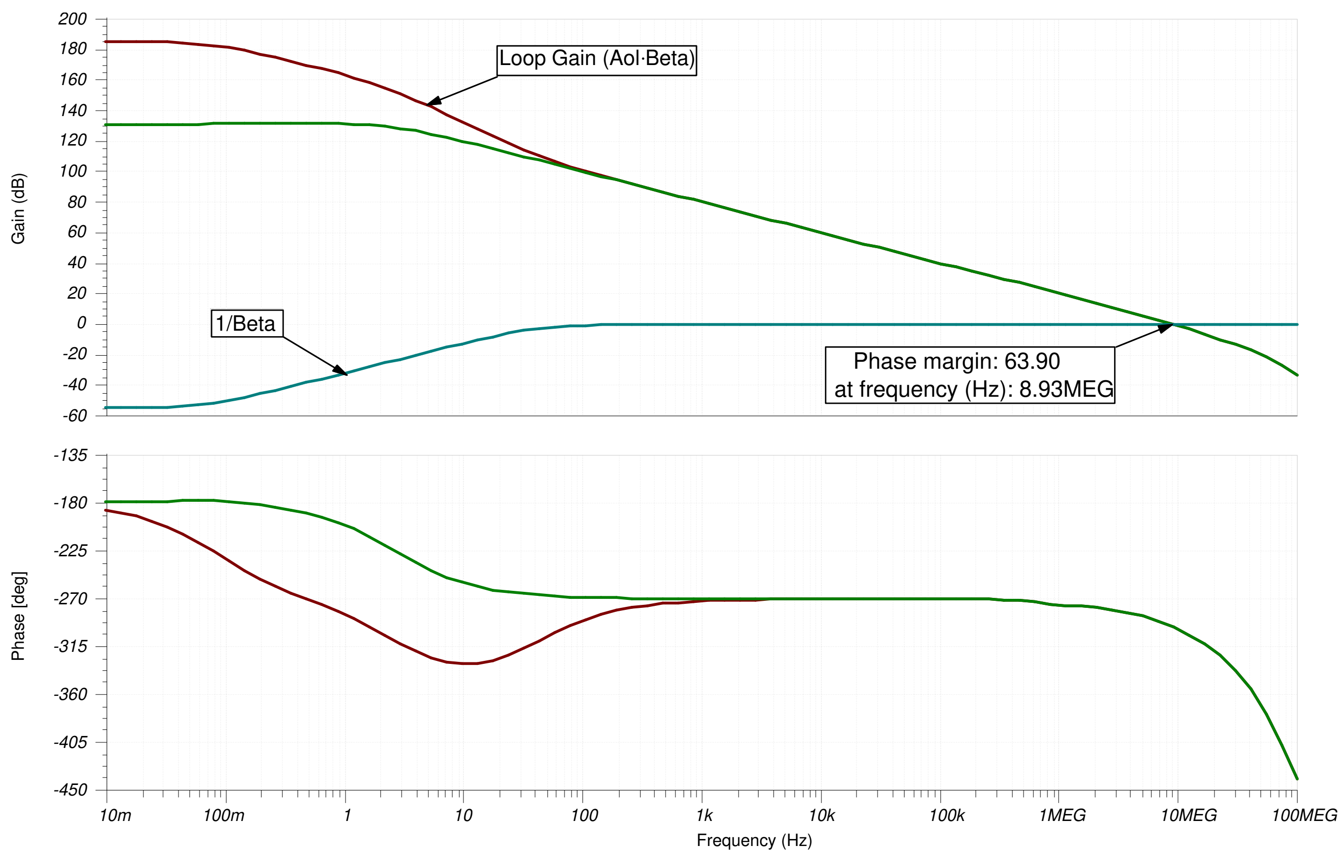


Transient Simulation Results

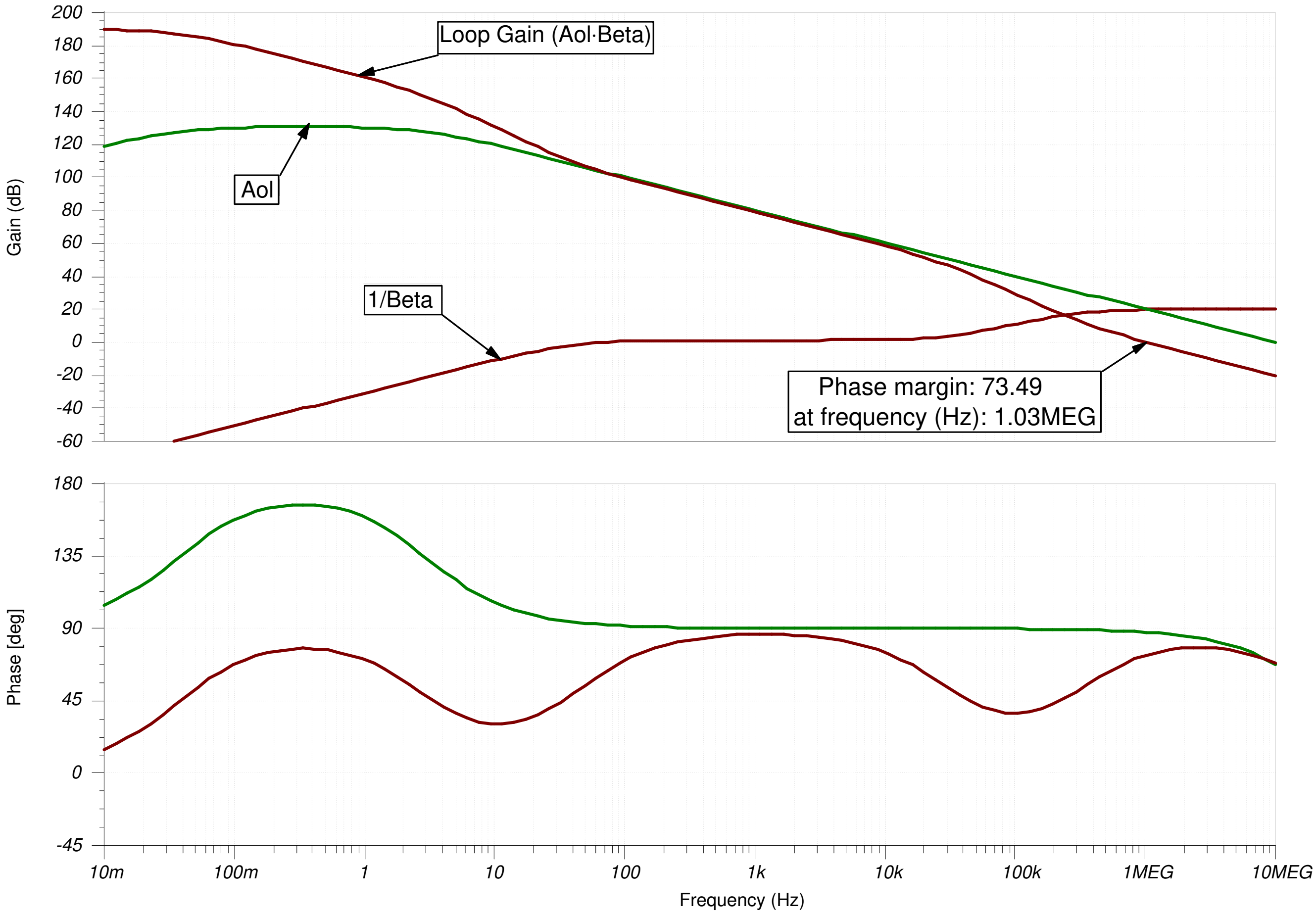




Integrator Open Loop Stability



TIA Stability Results



Design References

1. See Analog Engineer's Circuit Cookbooks for TI's comprehensive circuit library.
2. TI Precision Labs

Design Featured Op Amp

OPA172	
V_{cc}	±2.25V to ±18V, 4.5V to 36V
V_{inCM}	(V–) – 0.1V to (V+) – 2V
V_{out}	Rail-to-rail
V_{os}	0.2mV
I_q	1.6mA
I_b	8pA
UGBW	10MHz
SR	10V/µs
#Channels	1,2,4
www.ti.com/product/OPA172	

Design Alternate Op Amps

	OPA2991	TLV9042
V_{ss}	±1.35V to ±20V, 2.7V to 40V	±0.6V to ±2.75V, 1.2V to 5.5V
V_{inCM}	Rail-to-rail	Rail-to-rail
V_{out}	Rail-to-rail	Rail-to-rail
V_{os}	125µV	0.6mV
I_q	560µV	10uA
I_b	1pA	1pA
UGBW	4.5MHz	350kHz
SR	20V/µs	0.2V/us
#Channels	1, 2, 4	1, 2, 4
	www.ti.com/product/OPA2991	www.ti.com/product/TLV9042