Component selection



Noise:
$$R_b < 600\Omega,$$

 $R_c \gg 600\Omega,$
 $\frac{1}{2\pi f C_C} \ll R_s,$
 $S_{V_n} < 3.15 \frac{nV}{\sqrt{Hz}}$
 $S_{I_n} < 5.25 \frac{pA}{\sqrt{Hz}}$ Bandwidth: $\frac{1}{2\pi f_{low}C_A} \leq R_b$
 $GB > 45 MHz$
 $\frac{1}{2\pi f_{low}C_A} \leq R_b$ Accuracy: $R_a \gg R_a$

curacy: $R_c \gg R_s$ $A_0 \gg 33 \times 90 \approx 3000$

- Drive capability:

 $I_{\text{source,sink}} > 5 \text{ mA}$ SR > 1.5 V/ μ s $V_{\text{sat}} < 0.25 \text{ V}$

Component selection



Noise:
$$R_b < 600\Omega$$
,
 $R_c \gg 600\Omega$,
 $\frac{1}{2\pi f C_C} \ll R_s$,
 $S_{V_n} < 3.15 \frac{nV}{\sqrt{Hz}}$
 $S_{I_n} < 5.25 \frac{pA}{\sqrt{Hz}}$
Bandwidth: $\frac{1}{2\pi f_{low}C_A} \le R_b$
 $GB > 45 \text{ MHz}$
 $\frac{1}{2\pi f_{low}C_A} \le R_b$
Accuracy: $R \gg R$

- Accuracy: $R_c \gg R_s$ $A_0 \gg 33 \times 90 \approx 3000$

- Drive capability:

$$\begin{split} I_{\rm source,sink} &> 5~{\rm mA}\\ {\rm SR} &> 1.5~{\rm V}/\mu{\rm s}\\ V_{\rm sat} &< 0.25~{\rm V} \end{split}$$

Modeling OpAmp

Small-signal dynamic behavior OPA211



.model 0PA211_A0 0V + cd = 8p ; differential-mode input capacitance + gd = 50u ; differential-mode input conductance + cc = 2p ; common-mode input capacitance + av = {A_0*(1+s/2/PI/40M)/(1+s/2/PI/120)/(1+s/2/PI/20M)} ; voltage gain + zo = {3.6k/(1+s*3.6k*8u) + 0.7 + s*900n*60/(60+s*900n)} ; output impedance TEXAS INSTRUMENTS

OPA211, OPA2211

SBOS377K-OCTOBER 2006-REVISED SEPTEMBER 2018

Typical Characteristics (continued)



Modeling OpAmp

OPA211, OPA2211

SBOS377K-OCTOBER 2006-REVISED SEPTEMBER 2018

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6.6 Electrical Characteristics: $V_s = \pm 2.25$ to ± 18 V (OPAx211)

at $T_A = 25^{\circ}$ C, $R_I = 10 \text{ k}\Omega$ connected to midsupply, $V_{CM} = V_{OUT}$ = midsupply, (unless otherwise noted) **TEST CONDITIONS** PARAMETER MIN TYP MAX UNIT OFFSET VOLTAGE OPA211: ±30 ±125 μV $V_{S} = \pm 15 V$ V_{OS} Input offset voltage OPA2211: ±50 ±150 μV $V_{S} = \pm 15 V$ $V_{S} = \pm 15 V$ ±0.35 ±1.5 dV_{OS}/dT Input offset drift μV/°C $T_{A} = -40^{\circ}C \text{ to } +125^{\circ}C$ Input offset voltage vs $| T_A = 25^{\circ}C$ 0.1 1 μV/V PSRR power supply $T_{\Delta} = -40^{\circ}C$ to $+125^{\circ}C$ 3 μV/V INPUT BIAS CURRENT $V_{CM} = 0 V$ ±60 ±175 nA OPA211: ±200 $V_{CM} = 0 V$ nA $T_{A} = -40^{\circ}C \text{ to } +125^{\circ}C$ Input bias current OPA2211: $V_{CM} = 0 V$ ±250 nA $T_{\Delta} = -40^{\circ}C$ to $+125^{\circ}C$ $V_{CM} = 0 V$ ±25 ±100 nA Input offset current los $V_{CM} = 0 V$ nΑ ±150 $T_{A} = -40^{\circ}C \text{ to } +125^{\circ}C$ NOISE f = 0.1 to 10 Hz 80 Input voltage noise nV_{PP} er nV/√Hz $f = 10 \, \text{Hz}$ 2 Input voltage noise nV/√Hz *f* = 100 Hz 1.4 density nV/√Hz f = 1 kHz1.1 3.2 pA/√Hz $f = 10 \, \text{Hz}$ Input current noise density pA/√Hz 1.7 f = 1 kHz**INPUT VOLTAGE RANGE** V $V_{\rm S} \ge \pm 5 \rm V$ (V-) + 1.8(V+) – 1.4 Common-mode V_{CM} voltage range $V_S < \pm 5 V$ (V-) + 2(V+) – 1.4 V $V_{S} \ge \pm 5 V$ dB $(V-) + 2 V \le V_{CM} \le (V+) - 2 V$ 114 120 $T_A = -40^{\circ}C$ to $+125^{\circ}C$ Common-mode CMRR rejection ratio $V_S < \pm 5 V$ 120 dB $(V-) + 2 V \le V_{CM} \le (V+) - 2 V$ 110 $T_{A} = -40^{\circ}C \text{ to } +125^{\circ}C$ INPUT IMPEDANCE Differentia 20 || 8 kΩ || pF Common-mode 10 || 2 GΩ || pF **OPEN-LOOP GAIN**

SLiCAP O dcvar

Mean value bias current

SLiCAP O noise

Spectral density noise current



SLiCAP noise and bias models

nullor with offset and bias

- Standard deviation offset voltage Standard deviation offset current
- Standard deviation bias current
- $svo = 40 \times 10^{-6}$ $sio = 30 \times 10^{-9}$ iib = 0 $sib = 60 \times 10^{-9}$

nullor with equivalent input noise sources

- Spectral density noise voltage
- $sv = 1.2 \times 10^{-18}$ $si = 2.9 \times 10^{-24}$

SLiCAP noise verification



Noise figure 2.4dB over 1.57x500kHz bandwidth.

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SLiCAP biasing verification



All component tolerances 1% (3-sigma) Standard deviation of the output voltage: 10mV

Frequency response





Uncompensated amplifier

Frequency compensation





Compensated amplifier

Construction





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Small-signal step response Source: 2mV_{pp}, 100kHz, 50% Uncompensated amplifier Total load capacitance 3.4nF





Small-signal step response Source: $2mV_{pp}$, 100kHz, 50%Partly compensated amplifier Total load capacitance 3.4nF





Small-signal step response Source: $2mV_{pp}$, 100kHz, 50%Partly compensated amplifier Total load capacitance 3.4nF





Small-signal step response Source: 2mV_{pp}, 100kHz, 50% Compensated amplifier

Total load capacitance 3.4nF





Large-signal step response Source: $50mV_{pp}$, 100kHz, 50%Compensated amplifier Total load capacitance 3.4nF





Large-signal sine response Source: $50mV_{pp}$, 100kHzCompensated amplifier Total load capacitance 3.4nF





Large-signal overdrive

- Source: 100mV_{pp}, 1kHz, triangle
- Compensated amplifier
- Total load capacitance 3.4nF
- Source/sink voltage drop < 10mV





Small-signal transfer HP4195A, source -40dBm Compensated amplifier Total load capacitance 3.4nF



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Oscilloscope noise 83uV RMS Shorted input

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						μ±2σ 9 μ±3σ 9)5.6%)9.7%	Bin Widt	h 16.1 μV		Peak 3.59	3090 Mhits	

Output noise

- 385uV RMS
- Compensated amplifier
- Total load capacitance 3.4nF
- Corrected for scope noise: 376uV
- N=2.3dB @ 1MHz NBW
- N=2.7dB @ 900kHz NBW



Conclusions and remarks

- 1. Amplifier performance complies with requirements
- 2. Spice simulation with TI macro model did not show small-signal instability
- 3. Modeling of individual performance aspects seems successful approach