Current Feedback Amplifiers - 1

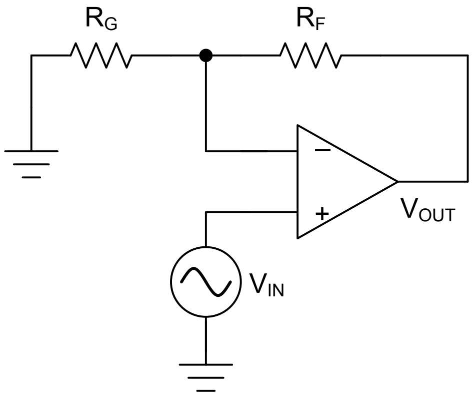
TIPL 2011

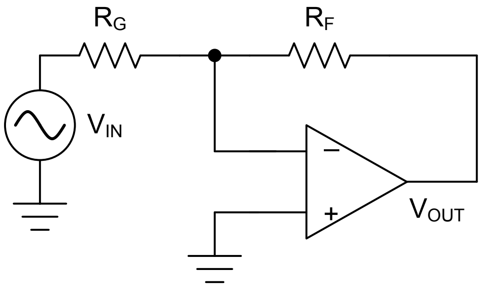
TI Precision Labs: High-Speed Operational Amplifiers

Prepared and Presented by Samir Cherian

No Change in Basic Op-amp Concepts!

Non-inverting and Inverting Configurations





$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_G}$$

$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_F}{R_G}$$

- CFB is still in a negative-feedback loop
- Virtual-ground concept still holds and $V_{IN+} = V_{IN-}$

VFB: Voltage-Feedback Amplifier

CFB: Current-Feedback Amplifier

Benefits of Current Feedback Amplifiers

- No constant gain bandwidth product relationship like in VFBs.

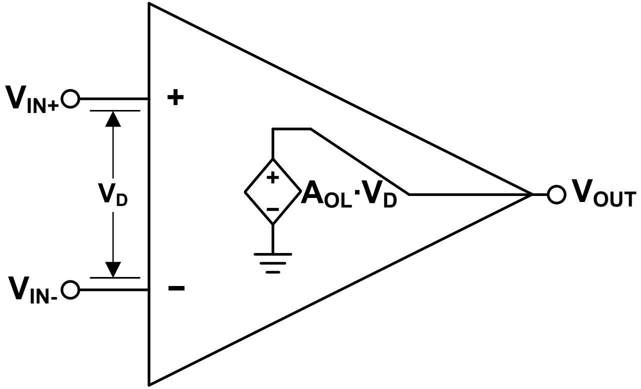
	Ideal VFB	Ideal CFB
Gain = 1 V/V	100 MHz	100 MHz
Gain = 10 V/V	10 MHz	100 MHz

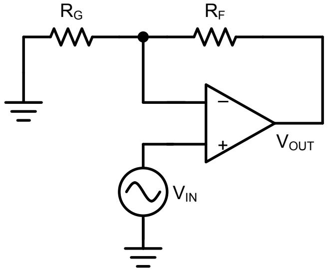
- The CFB architecture can achieve much higher slew rates relative to VFBs.

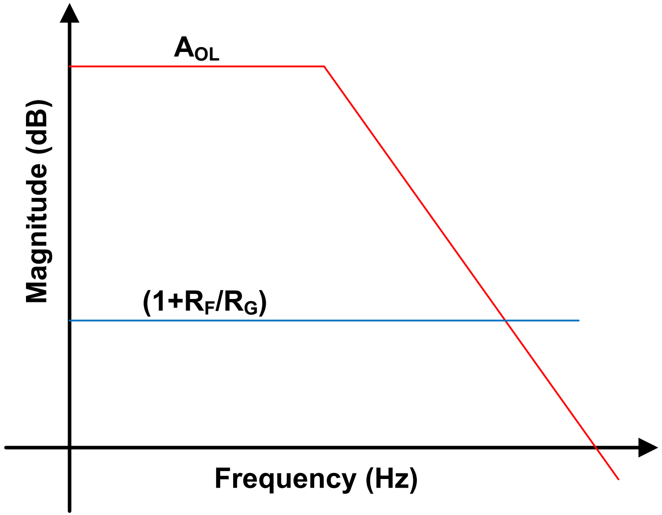
$$\text{Slew Rate} = V_{PEAK} \cdot 2\pi \cdot f_{MAX}$$

where f_{MAX} is the amplifiers full-power bandwidth

VFB: Bandwidth Depends on Gain

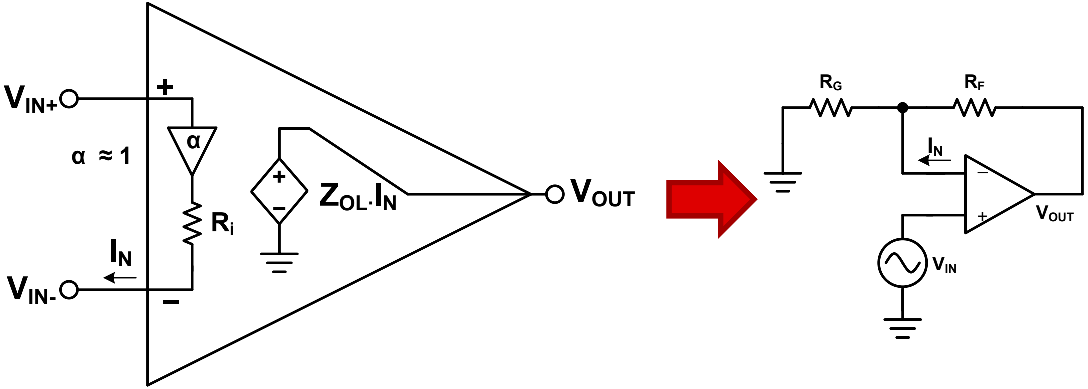






$$A_{CL} = \frac{V_{OUT}}{V_{IN}} = \left(1+\frac{R_F}{R_G}\right) \cdot \frac{1}{\left(1+\frac{\left(1+\frac{R_F}{R_G}\right)}{A_{OL}}\right)}$$

CFB: Bandwidth Independent of Gain



Loop gain is a function of the open-loop transimpedance, Z_{OL}, and the **feedback transimpedance**, (R_F + R_i·Noise Gain), of the amplifier.

If R_F = 1 kΩ and Ri = 50Ω, and the amplifier is configured in a gain of 5V/V, then the feedback transimpedance is (1000Ω + 5V/V·50Ω) = 1250 Ω

The noise gain scaling term (5V/V·50Ω = 250 Ω) has a relatively insignificant effect on the magnitude of the numerator in the loop gain equation.

$$I_N + \frac{V_{OUT} - V_{IN-}}{R_F} = \frac{V_{IN-}}{R_G}$$

Also,

$$V_{IN-} = \alpha \cdot V_{IN+} - I_N \cdot R_i$$

and, $V_{OUT} = I_N \cdot Z_{OL}$

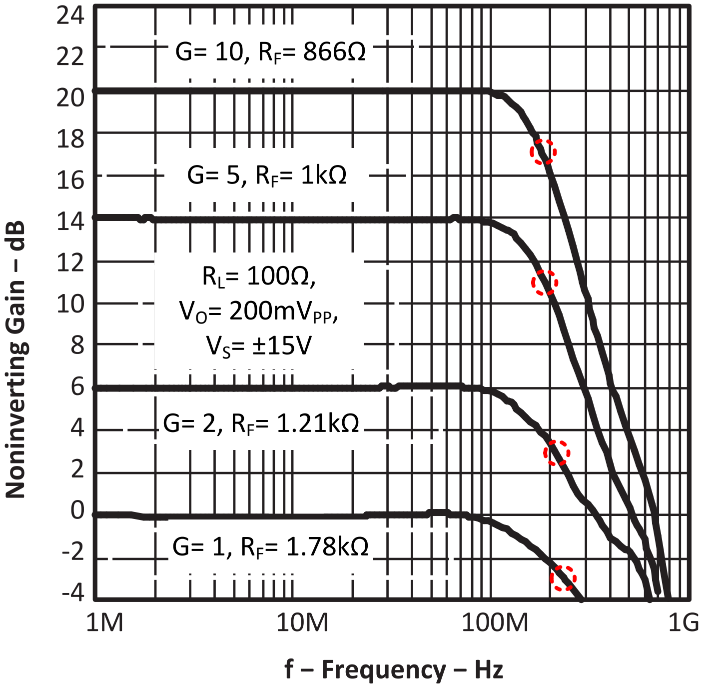
After further simplification,

$$\text{Closed Loop Gain, } A_{CL} = \frac{V_{OUT}}{V_{IN+}} = \frac{\alpha \cdot (1+\frac{R_F}{R_G})}{1+\frac{R_F + R_i \cdot (1+\frac{R_F}{R_G})}{Z_{OL}}}$$

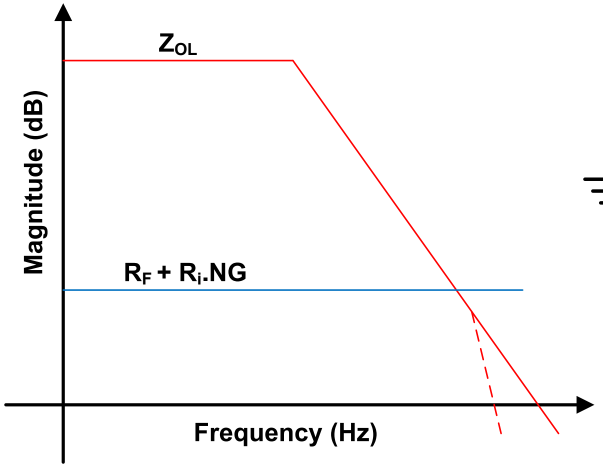
$\alpha \approx 1$ and $(1+\frac{R_F}{R_G}) =$ Noise Gain, NG

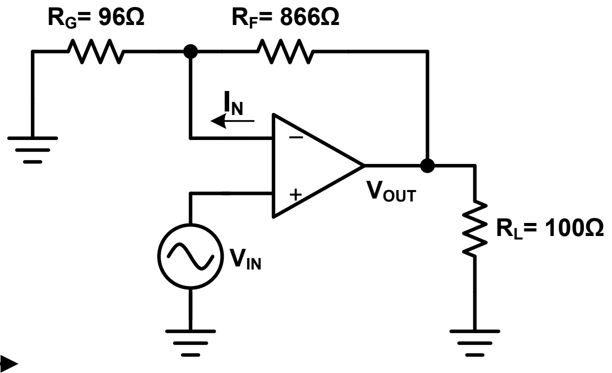
$$A_{CL} = (1+\frac{R_F}{R_G}) \cdot \frac{1}{1+\frac{(R_F + R_i \cdot NG)}{Z_{OL}}}$$

CFB: Bandwidth versus Gain and R_F



THS3091 Small-Signal Frequency Response versus Gain and R_F



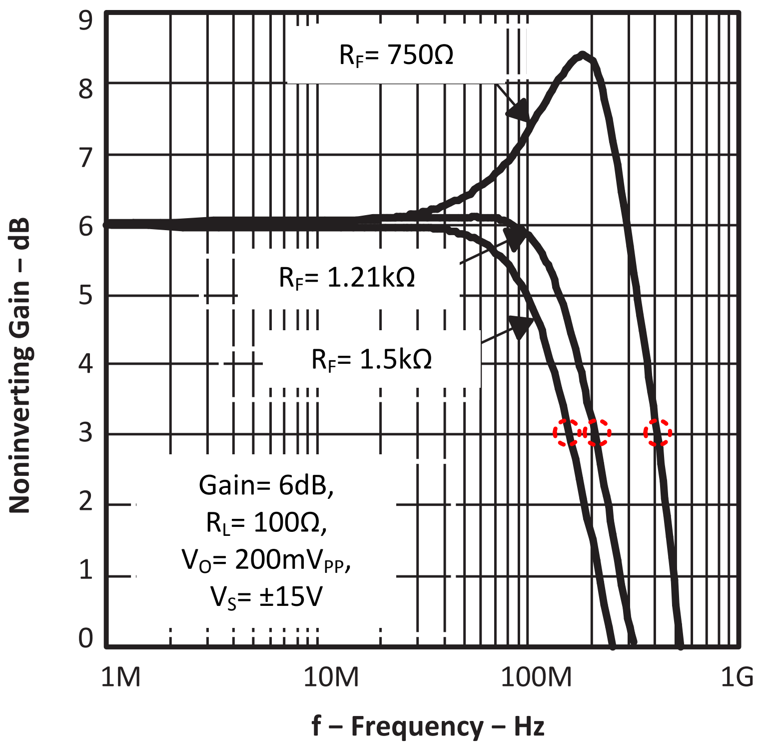


$$R_{LOAD} \,||\, (R_F + (R_G \,||\, R_i)) = 89.6\Omega$$

, assuming $R_i << R_G$

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
AC PERFORMANCE						
Small-signal bandwidth, –3 dB	G = 1, R_F = 1.78 kΩ, V_O = 200 mV_{PP}	T_A = 25°C		235		MHz
	G = 2, R_F = 1.21 kΩ, V_O = 200 mV_{PP}	T_A = 25°C		210		
	G = 5, R_F = 1 kΩ, V_O = 200 mV_{PP}	T_A = 25°C		190		
	G = 10, R_F = 866 Ω, V_O = 200 mV_{PP}	T_A = 25°C		180		
0.1-dB Bandwidth flatness	G = 2, R_F = 1.21 kΩ, V_O = 200 mV_{PP}	T_A = 25°C		95		
Large-signal bandwidth	G = 5, R_F = 1 kΩ , V_O = 4 V_{PP}	T_A = 25°C		135		

CFB: Bandwidth versus Gain and R_F (Cont.)



THS3091 Small-Signal Frequency Response versus R_F

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
AC PERFORMANCE						
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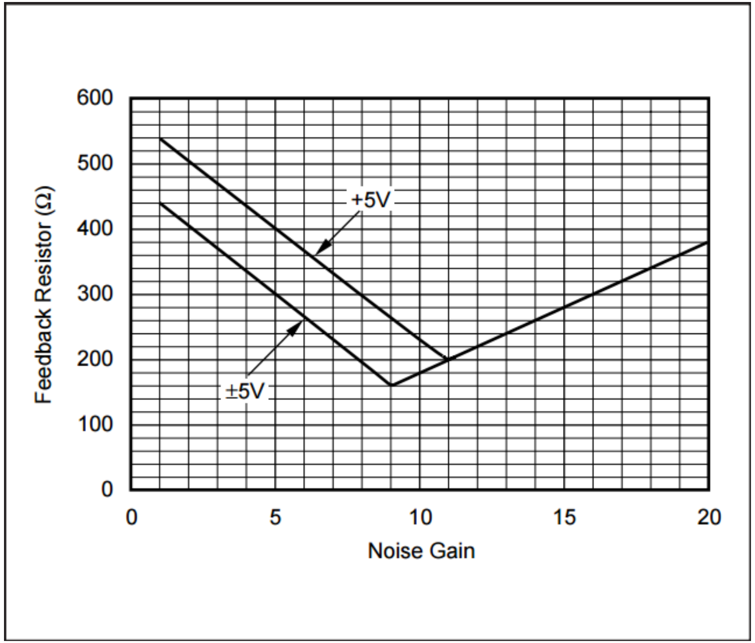
Feedback Transimpedance =(R_F + R_i × NoiseGain)

OPA691 Recommended Gain vs. R_F



Feedback Transimpedance =(R_F + R_i × NoiseGain)

Using the Feedback transimpedance equation for gains of 2V/V and 5V/V:

400Ω + (2·R_i) = 300Ω + (5·R_i)

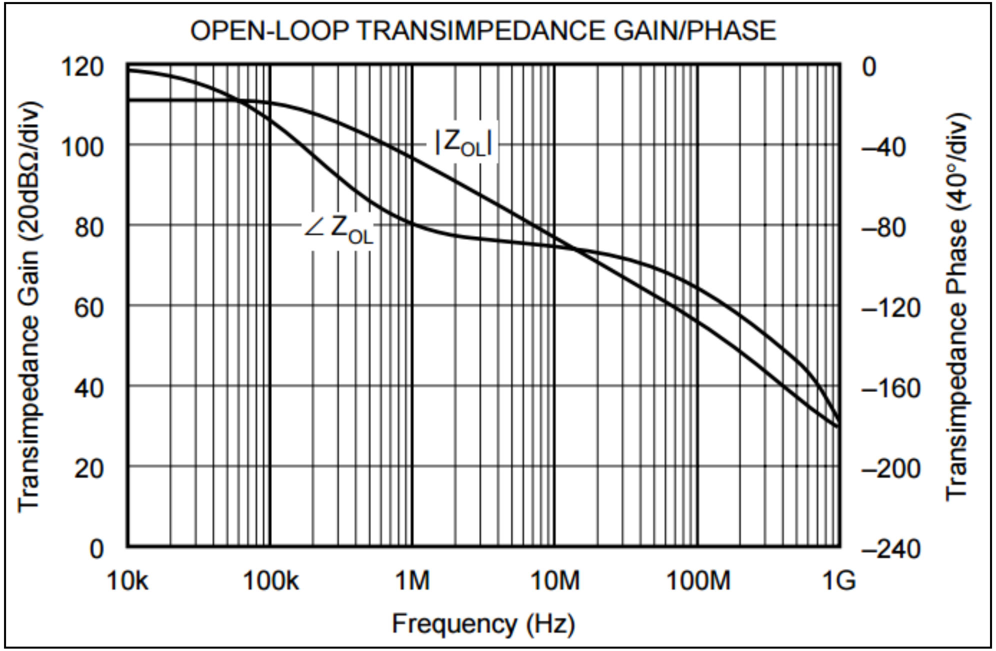
⇒ R_i = 33.33 Ω

Target Feedback transimpedance for OPA691:

400Ω + (2·35 Ω) = 470Ω

INPUT								
Common-Mode Input Range[5]		±3.5	**±3.4**	±3.3	±3.2	V	min	A
Common-Mode Rejection	V_{CM} = 0V	56	**52**	51	50	dB	min	A
Noninverting Input Impedance		100 || 2				kΩ || pF	typ	C
Inverting Input Resistance (R_I)	Open-Loop	35				Ω	typ	C

Estimating f_{-3dB} from Z_{OL} curve

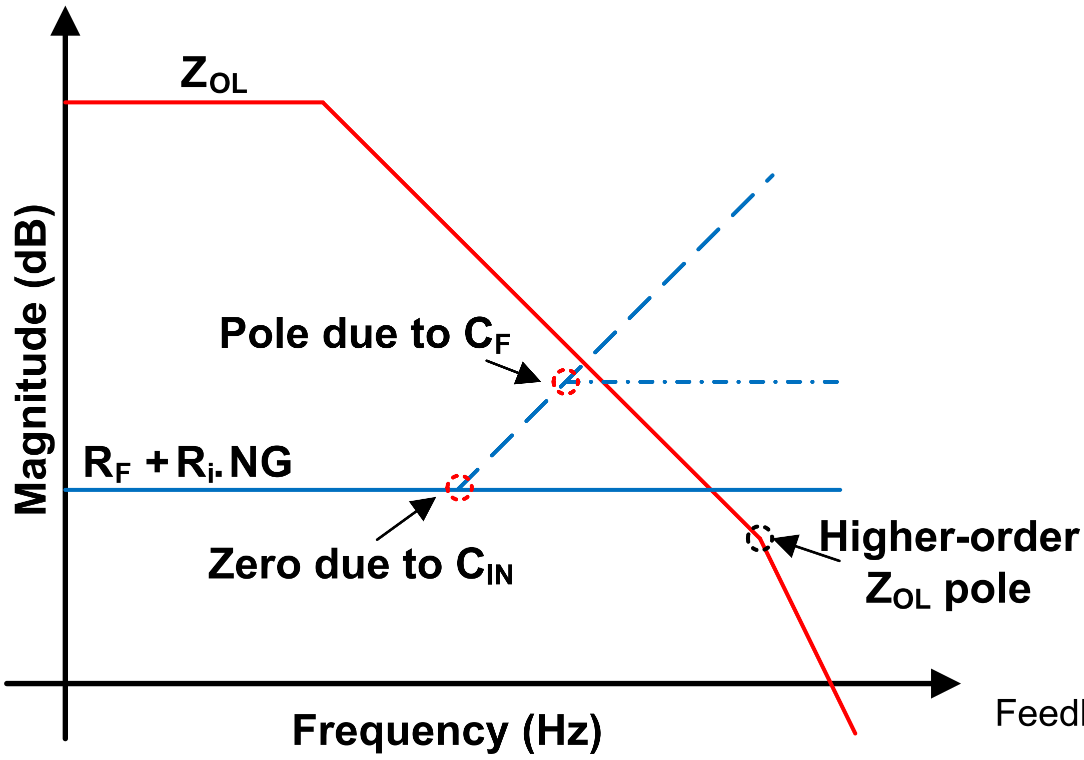


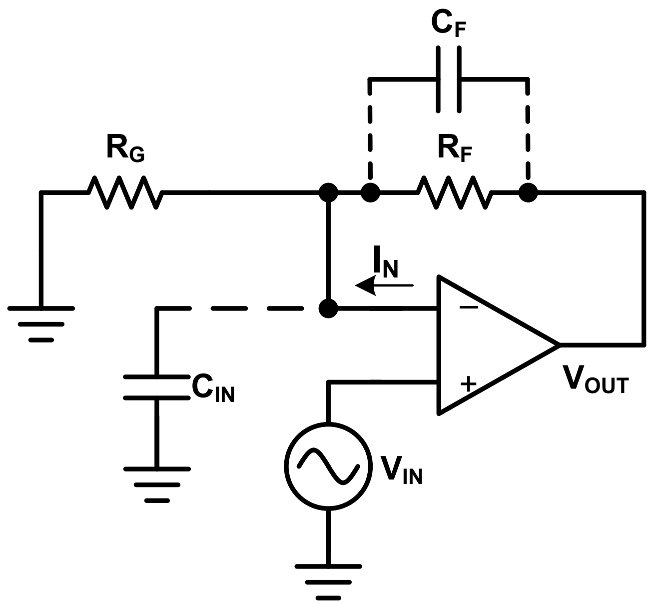
Target Feedback transimpedance for OPA691:

400Ω + (2·35 Ω) = 470Ω = 53.4 dBΩ

AC PERFORMANCE (see Figure 2) Small-Signal Bandwidth (V_O = 0.5V_{PP})	G = +1, R_F = 499Ω G = +2, R_F = 453Ω G = +5, R_F = 340Ω G = +10, R_F = 180Ω	210 190 180 155	168	160	140	MHz MHz MHz MHz	typ min typ typ	C B C C

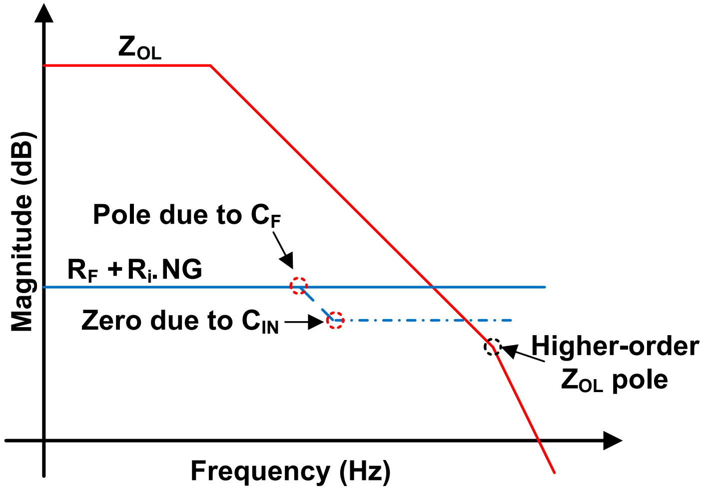
Effect of Input and Feedback Capacitance



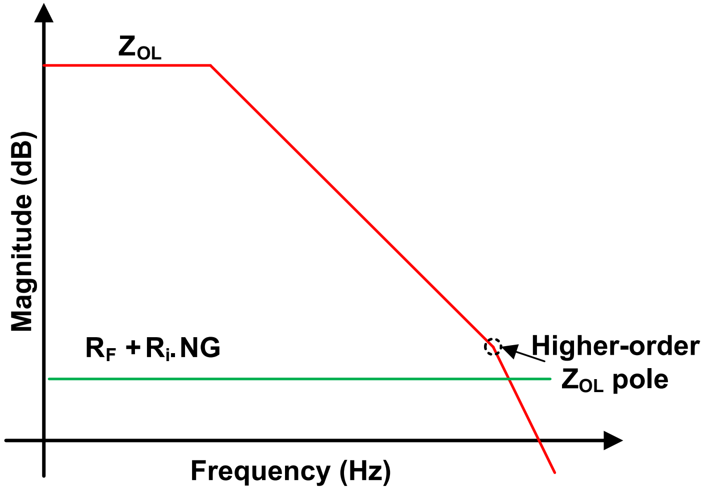


Feedback Transimpedance =(R_F + R_i × NoiseGain)

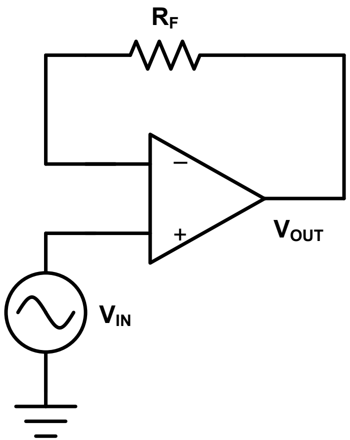
Effect of Non-Ideal R_F and C_F



Effect of C_F >> C_{IN}



Effect of R_F << Recommended datasheet value



Unity Gain Config.

Thanks for your time and please take the quiz!

Current Feedback Amplifiers - 1

Exercises

TI Precision Labs: High-Speed Operational Amplifiers

Prepared and Presented by Samir Cherian

Current Feedback Amplifier – Quiz 1

(1) A CFB datasheet recommends a feedback resistance, R_F = 800Ω, when configured in a gain of 2 and R_F = 700Ω, when configured in a gain of 4. What is the inverting input impedance, R_i of the amplifier?

a) 25Ω

b) 50Ω

c) No sufficient information provided

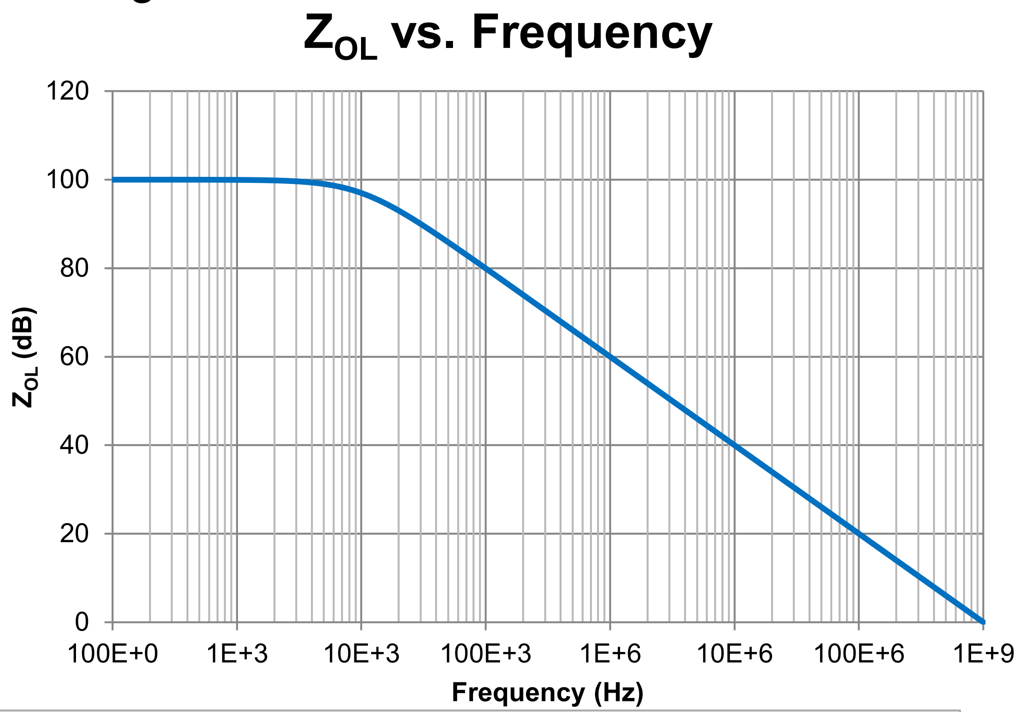
d) None of the above

(2) A CFB datasheet recommends a feedback resistance, R_F = 800Ω, when configured in a gain of 2. What is the recommended R_F when configured in a gain of -1?

a) Value of R_i is needed in order to answer this
b) 700Ω
c) 800Ω
d) None of the above

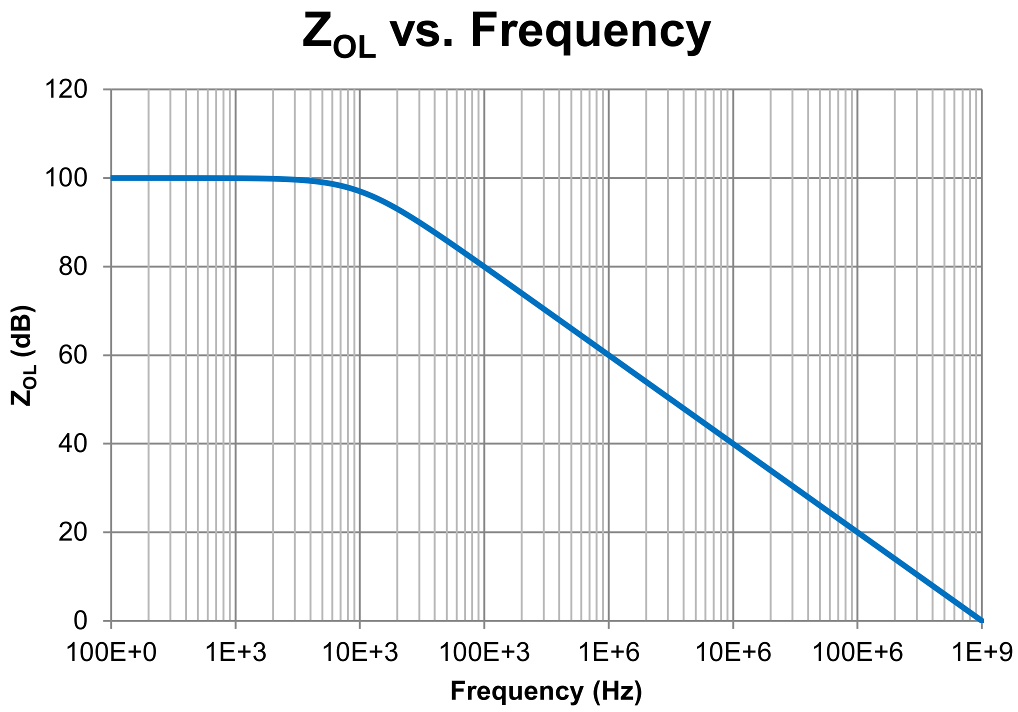
(3) The Z_{OL} curve of a CFB is shown below. If the recommended R_F= 900Ω when configured in a gain of 4 and the inverting input impedance, R_i = 25Ω, what is the closed loop bandwidth of the amplifier in a gain of 4?

a) 1 MHz
b) 3.16 MHz
c) 2 MHz
d) 10 MHz



(4) In the previous example, what is the phase-margin of the amplifier when configured in a gain of 4? (R_F= 900Ω , R_i= 25Ω)

a) 45°
b) 90°
c) 135°
d) 180°



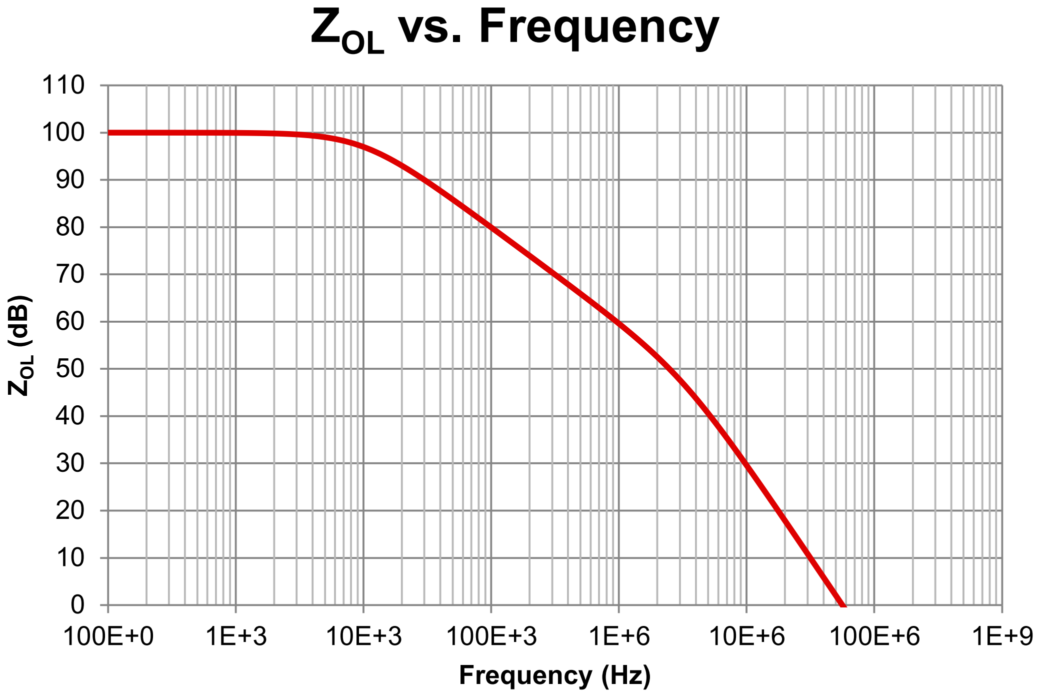
(5) The previous example was modified to have a 2nd Z_{OL} pole at 3.16MHz as shown below. What is the new phase margin?

a) 45°

b) 67.5°

c) 0°

d) 90°



Answers

(1) A CFB datasheet recommends a feedback resistance, R_F = 800Ω, when configured in a gain of 2 and R_F = 700Ω, when configured in a gain of 4. What is the inverting input impedance, R_i of the amplifier?

b) 50Ω

Answer: In order to maintain a constant feedback transimpedance, (R_F+ R_i×Noise Gain),

$800\Omega + R_i \times 2 = 700\Omega + R_i \times 4$

$\Rightarrow 2 \times R_i = 100\Omega$

$\Rightarrow R_i = 50\Omega$

(2) A CFB datasheet recommends a feedback resistance, R_F = 800Ω, when configured in a gain of 2. What is the recommended R_F when configured in a gain of -1?

c) 800Ω

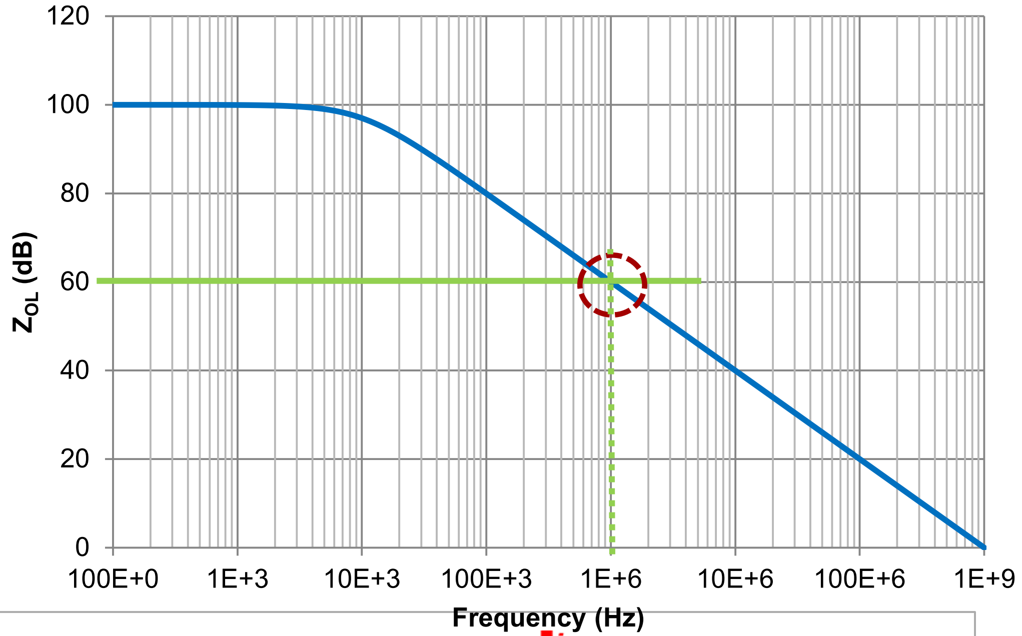
Answer: An inverting gain of -1 corresponds to noninverting gain of 2. Hence the feedback resistance RF will stay the same.

(3) The Z_{OL} curve of a CFB is shown below. If the recommended $R_F = 900\Omega$ when configured in a gain of 4 and the inverting input impedance, $R_i = 25\Omega$, what is the closed loop bandwidth of the amplifier in a gain of 4?

a) 1 MHz

__Answer:__ The feedback transimpedance is 900Ω+25Ω×4 = 1000Ω, which corresponds to a gain of 60dB. A straight line curve at 60dB intersect the Z_{OL} curve at 1 MHz as shown here.

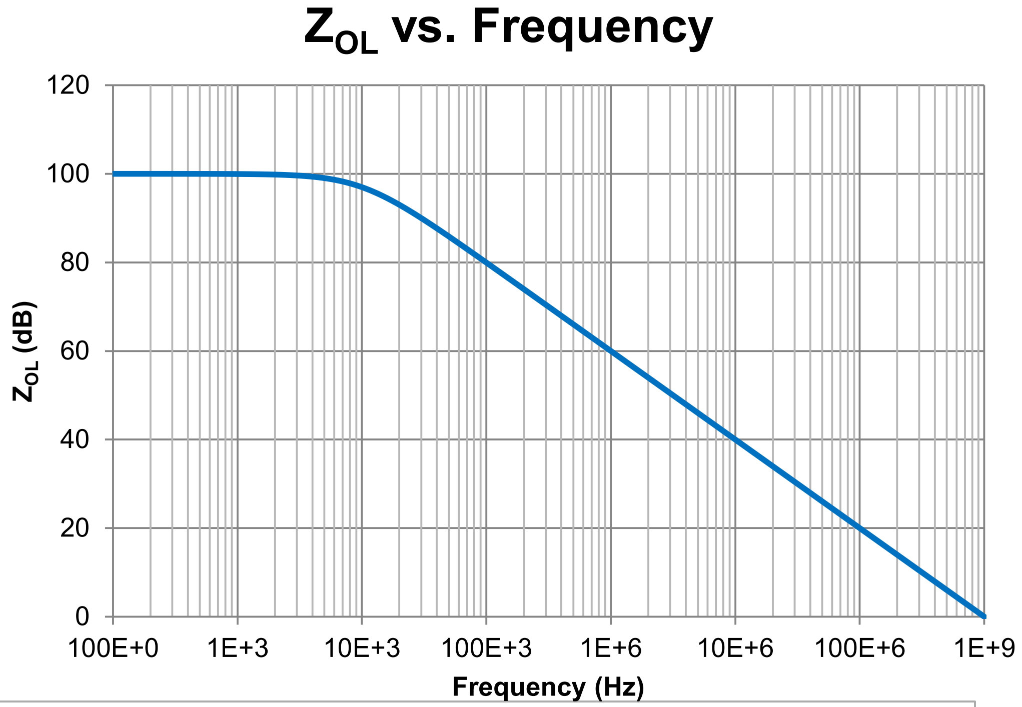
Z_{OL} vs. Frequency



(4) In the previous example, what is the phase-margin of the amplifier when configured in a gain of 4? (R_F= 900Ω , R_i= 25Ω)

b) 90°

Answer: The dominant pole of the amplifier at 10kHz contributes a total phase shift of 90° by 100KHz assuming straight line ideal Bode theory. The crossover occurs at 1MHz and since this is a 1-pole system the phase margin is 180°-90° = 90°



(5) The previous example was modified to have a 2nd Z_{OL} pole at 3.16MHz as shown below. What is the new phase margin?

b) **67.5°**

Answer: From the graph 3.16MHz corresponds to a Z_{OL} of 50dB while crossover occurs at 60dB. We know the phase changes at 45°/decade starting one decade before the pole frequency or 316kHz. The phase margin is thus 180° - 90°(dom. Pole) – 22.5°(½ decade from 2nd pole) = 67.5°