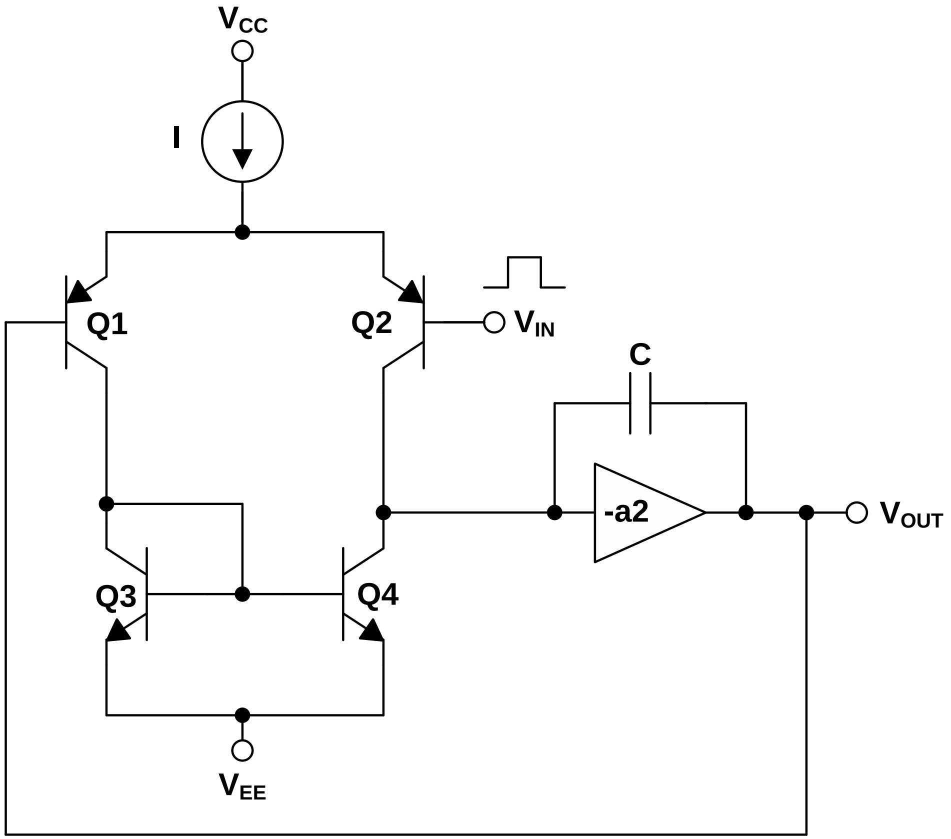
Current-Feedback Amplifiers – Part 2

TIPL 2012

TI Precision Labs: High-Speed Operational Amplifiers

Prepared and Presented by Samir Cherian

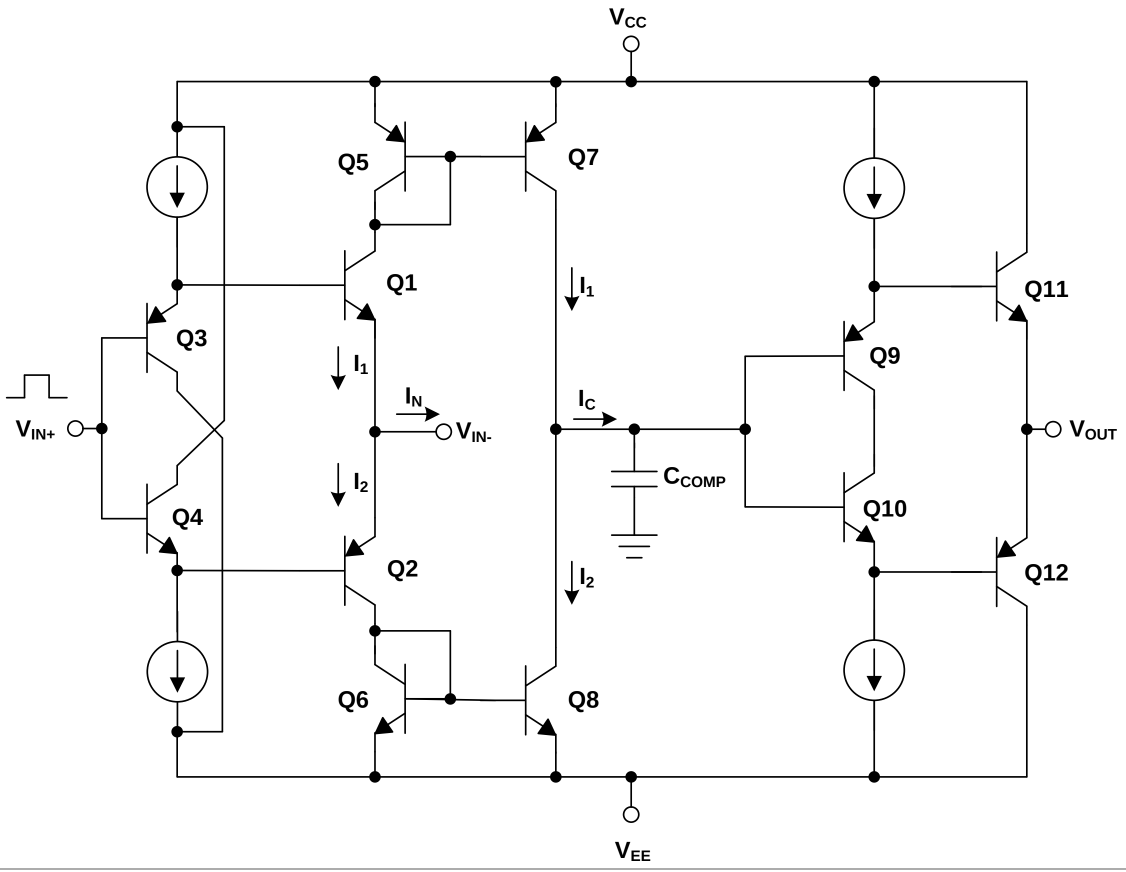
Slew-rate Limitation of VFB



- If I = 100µA and C = 10pF, then,

  $\text{Slew Rate} = 100\mu A / 10pF = 10V / \mu s$

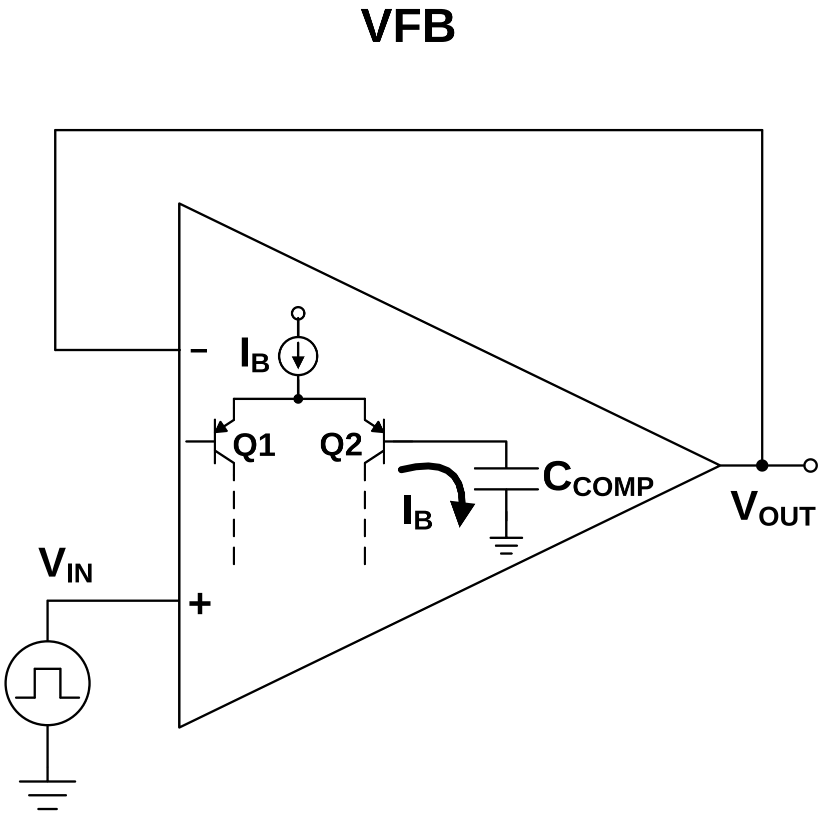
Slew Rate Enhancement with CFB

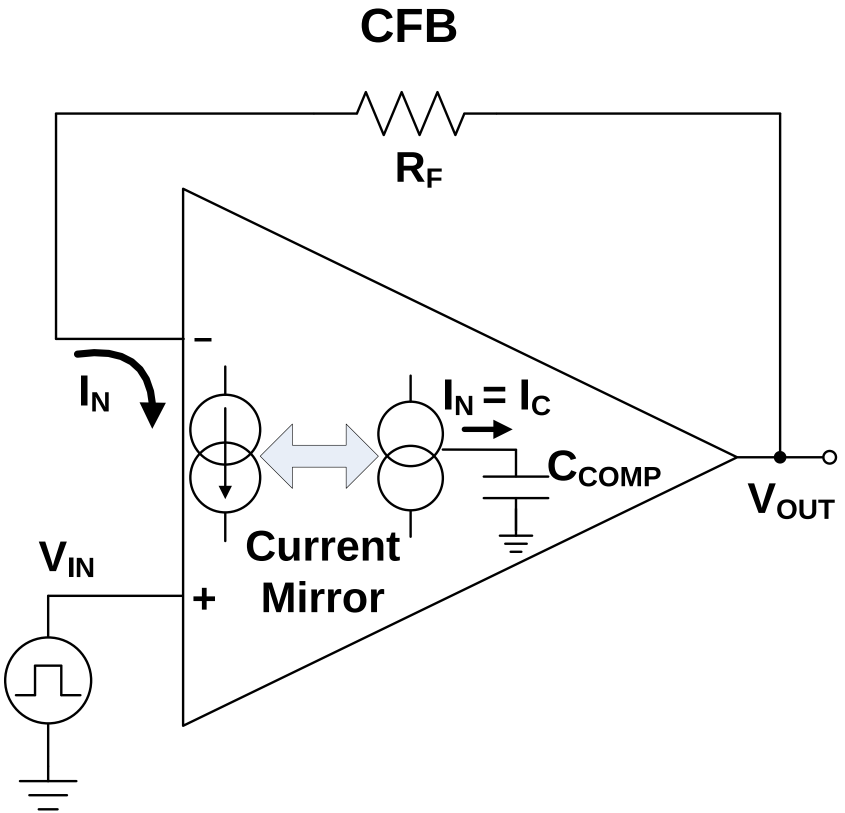


$$I_N = I_1 - I_2$$

$$I_N = I_C$$

Slew Rate VFB vs CFB





Slew Rate: VFB vs CFB

Current Feedback

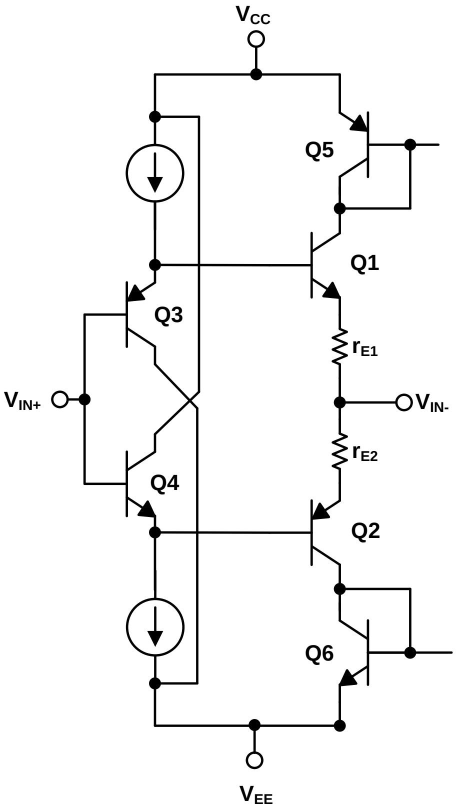
Device	Slew Rate (V/µs)	I_Q (mA)
OPA683	210	0.79
OPA684	820	1.7
OPA691	2100	5.1
OPA695	4300	12.9
THS3001	**6300**	**6.6**
THS3061	**7000**	**8.3**
THS3091	**7300**	**9.5**

Voltage Feedback

Device	Slew Rate (V/µs)	I_Q (mA)
THS4281	35	0.8
LMH6619	57	1.45
OPA820	240	5.6
OPA846	625	12.6
OPA637	**100**	**7**
THS4051	**240**	**8.5**
THS4631	**1000**	**11.5**

Products in bold text are high-voltage op-amps with max. supply >24V

Low-Power CFB Amplifier Designs

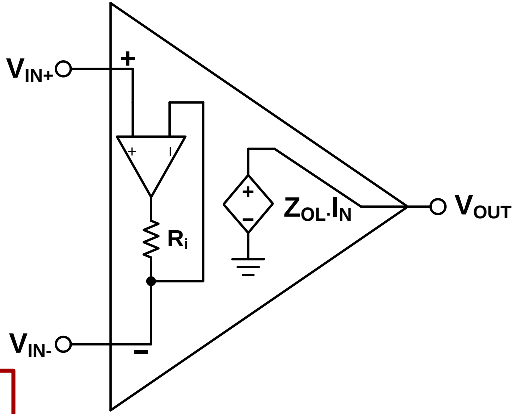


$$r_E = \frac{V_T}{I_E}$$,

r_E = Emitter Resistance

V_T = Thermal Voltage

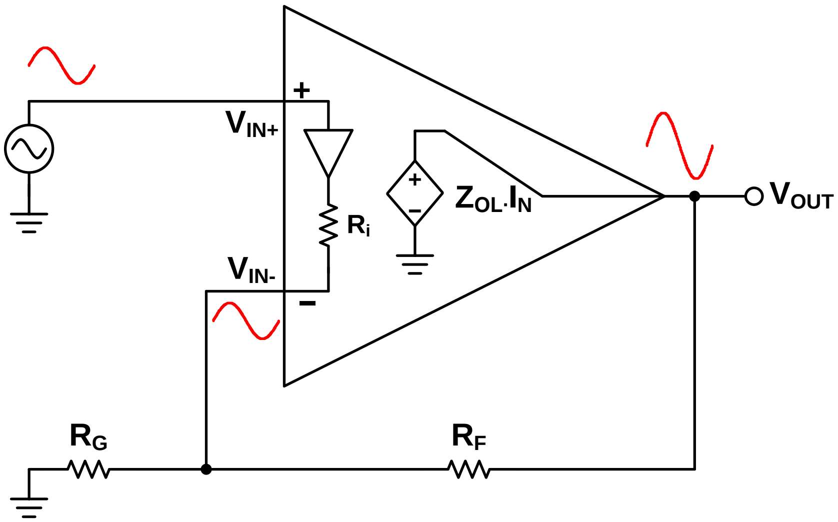
I_E = Emitter Current

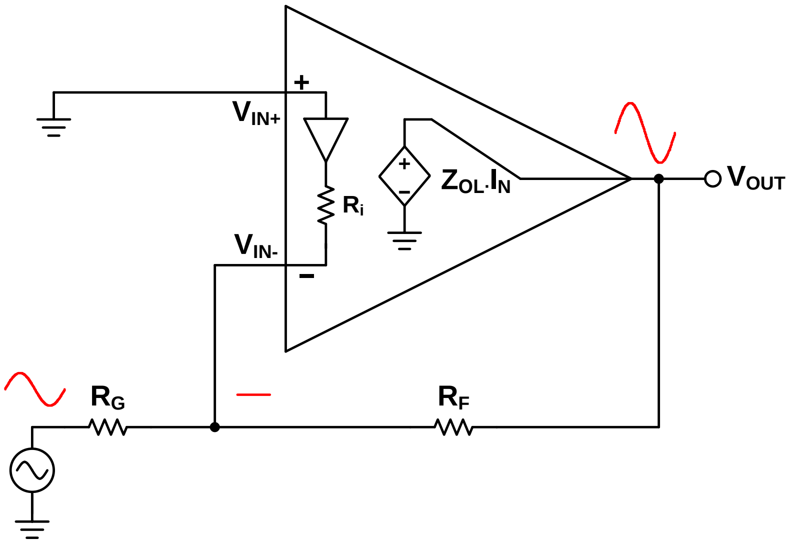


Feedback Transimpedance =(R_F + R_i × NoiseGain)

Specification	OPA691 (Open Loop Buffer)	OPA683 (Closed Loop Buffer)
Quiescent Current, I_Q	5.1 mA	0.82 mA
Inverting Input Resistance, R_i	35 Ω	4.5 Ω

Noninverting versus Inverting Configuration

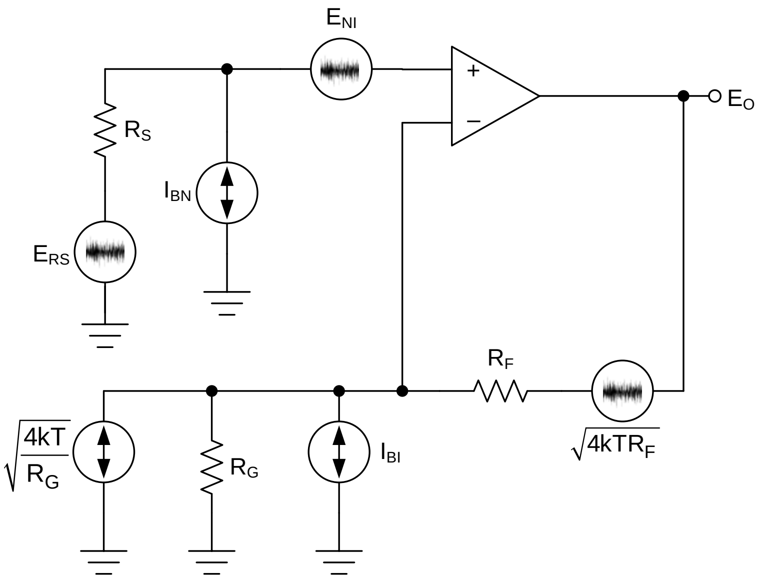


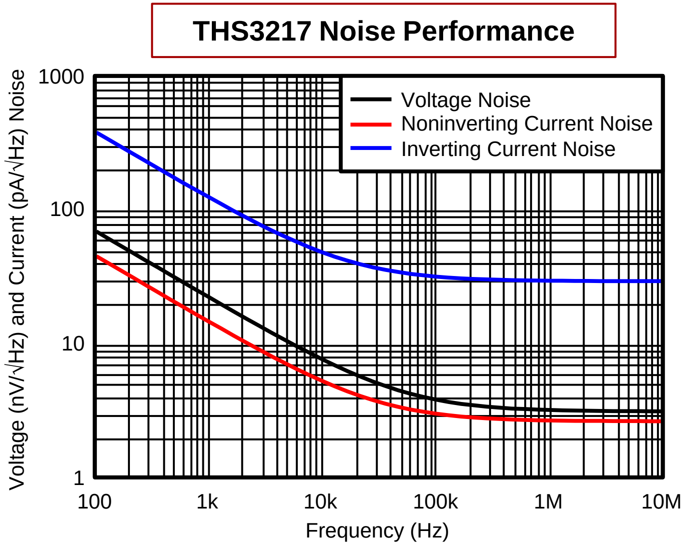


Slew rate (25% to 75% level)	G = 2, V_O = 10-V step, R_F = 1.21 kΩ	T_A = 25°C	5000	V/µs
	G = 5, V_O = 20-V step, R_F = 1 kΩ	T_A = 25°C	7300	

$$\text{Slew Rate} = 8V_{PEAK} \cdot 2\pi \cdot 100\text{MHz} = 5025\text{V} / \mu\text{sec}$$

CFB Noise Analysis





$$E_0 = \sqrt{\left(E_{NI}^2 + (i_{BN}R_S)^2 + 4kTR_S\right)G_N^2 + (i_{BI}R_F)^2 + 4kTR_FG_N} ,$$

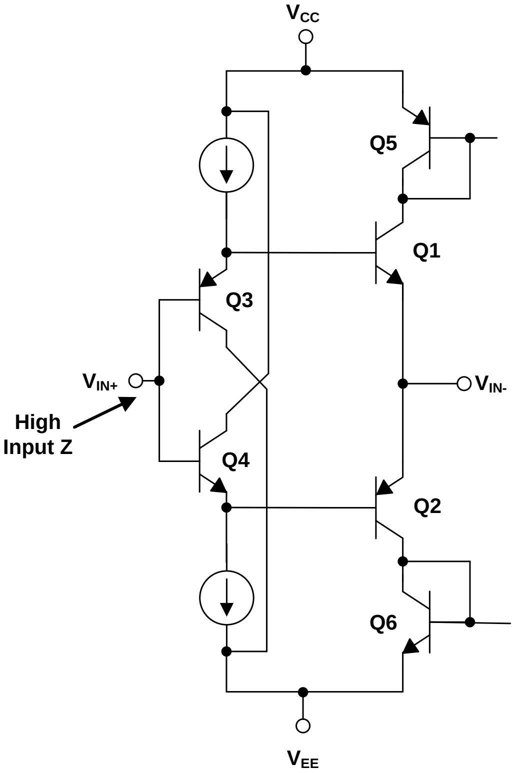
E_{NI}= Amplifier Voltage Noise

i_{BN}= Noninverting Current Noise

i_{BI}= Inverting Current Noise

G_N= Noise Gain = $(1+R_F/R_G)$

Input Bias Current and Current Noise



Specification	THS4271 (VFA)	OPA695 (CFA)	Units
I_B, Non-inverting Bias Current	6	±13	µA
I_B, Inverting Bias Current		±20	µA
I_{BOS}, Bias Current Offset	±1	20	µA
Non-inverting Bias Current Noise	3	18	pA/√Hz
Inverting Bias Current Noise		22	pA/√Hz

Summary Comparison

Parameters	VFA	CFA
DC Accuracy	**Good**	Poor
Output Swing	**Many rail-to-rail output options**	Larger headroom needed for output
Distortion	Better low-frequency distortion	Better high-frequency distortion
Slew Rate	Limited slew rate	**Very high slew rate facilitating high full-power bandwidth**
Bandwidth	Bandwidth varies with gain	**Almost constant bandwidth over gain**
Gain Stability	Restriction on the minimum stable gain for decompensated amplifiers	**Stable across gains if feedback transimpedance is kept constant**
Noise	**Low input-referred voltage and current noise**	Higher input-referred current noise (unequal for inverting and non-inverting inputs)
Typical Applications	- Applications requiring DC precision - Pulse-oriented application - High-speed and precise ADC interface - Transimpedance	- DAC interface - Output drivers - High-speed ADC interface - Sallen-Key filters.

Thanks for your time and please take the quiz!

Current Feedback Amplifiers - 2

Exercises

TI Precision Labs: High-Speed Operational Amplifiers

Prepared and Presented by Samir Cherian

Current Feedback Amplifier – Quiz 2

(1) A CFB amplifier has a small-signal bandwidth of 1 GHz in G=1 configuration and a slew-rate of 1000 V/µs. What is its slew rate in G=2?

a) 500 V/µs

b) 2000 V/µs

c) Insufficient information provided

d) 1000 V/µs

(2) An application requires faithful reproduction of a $5V_{PP}$, 100 MHz signal. What is the minimum slew rate of the amplifier that will meet this specifications?

a) 785 V/µs

b) 1570 V/µs

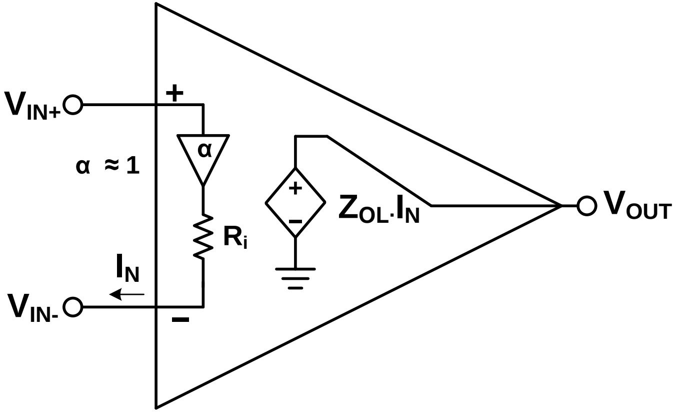
c) 3140 V/µs

d) None of the above

(3) How would you find a current feedback amplifier in the Texas Instruments product portfolio with slew-rate between 7000V/µs and 8000V/µs. Search on www.ti.com.

(4) This next problem is a little advanced and requires the use of TINA-TI. Use TINA simulations on the THS3091 at ±15V supplies and determine its

a) Z_{OL} (Open loop transimpedance) vs frequency
b) Inverting input resistance R_i.
c) Input Buffer Gain, α. (We assumed so far that the buffer gain α = 1, however in a real world amplifier α < 1)



Answers

(1) A CFB amplifier has a small-signal bandwidth (SSBW) of 1 GHz in G=1 configuration and a slew-rate of 1000 V/µs. What is its slew rate in G=2?

d) 1000 V/µs

Answer: To the 1st order Slew rate (SR) does not depend on the gain configuration irrespective of the amplifier configuration (CFB or VFB) as long as SSBW >> SR. However when the SSBW approaches SR then the overall large-signal response of the amplifier will depend on both SSBW and Slew Rate.

(2) An application requires faithful reproduction of a $5V_{PP}$, 100 MHz signal. What is the minimum slew rate of the amplifier that will meet this specifications?

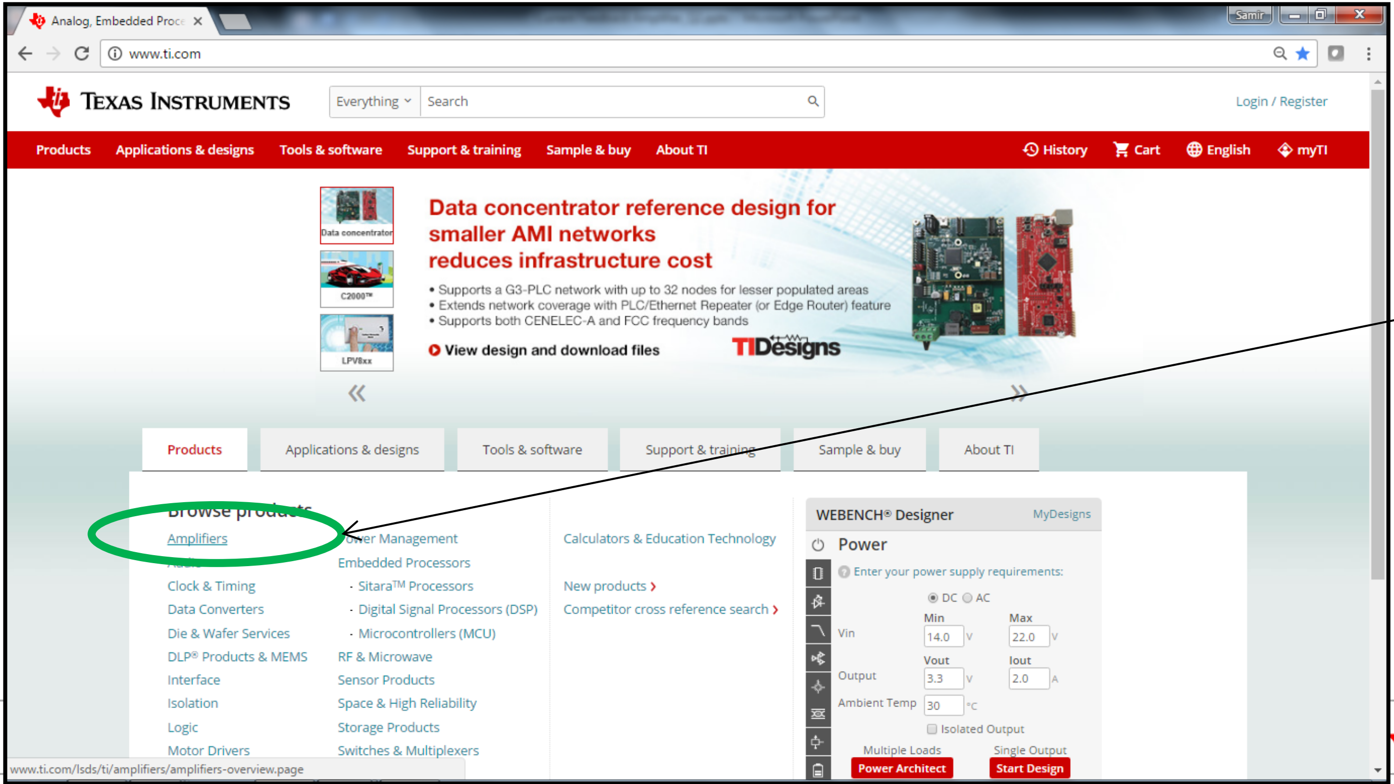
b) 1570 V/µs

Answer: Use the formula, $SR = f_{MAX} \cdot 2\pi \cdot V_{PEAK}$

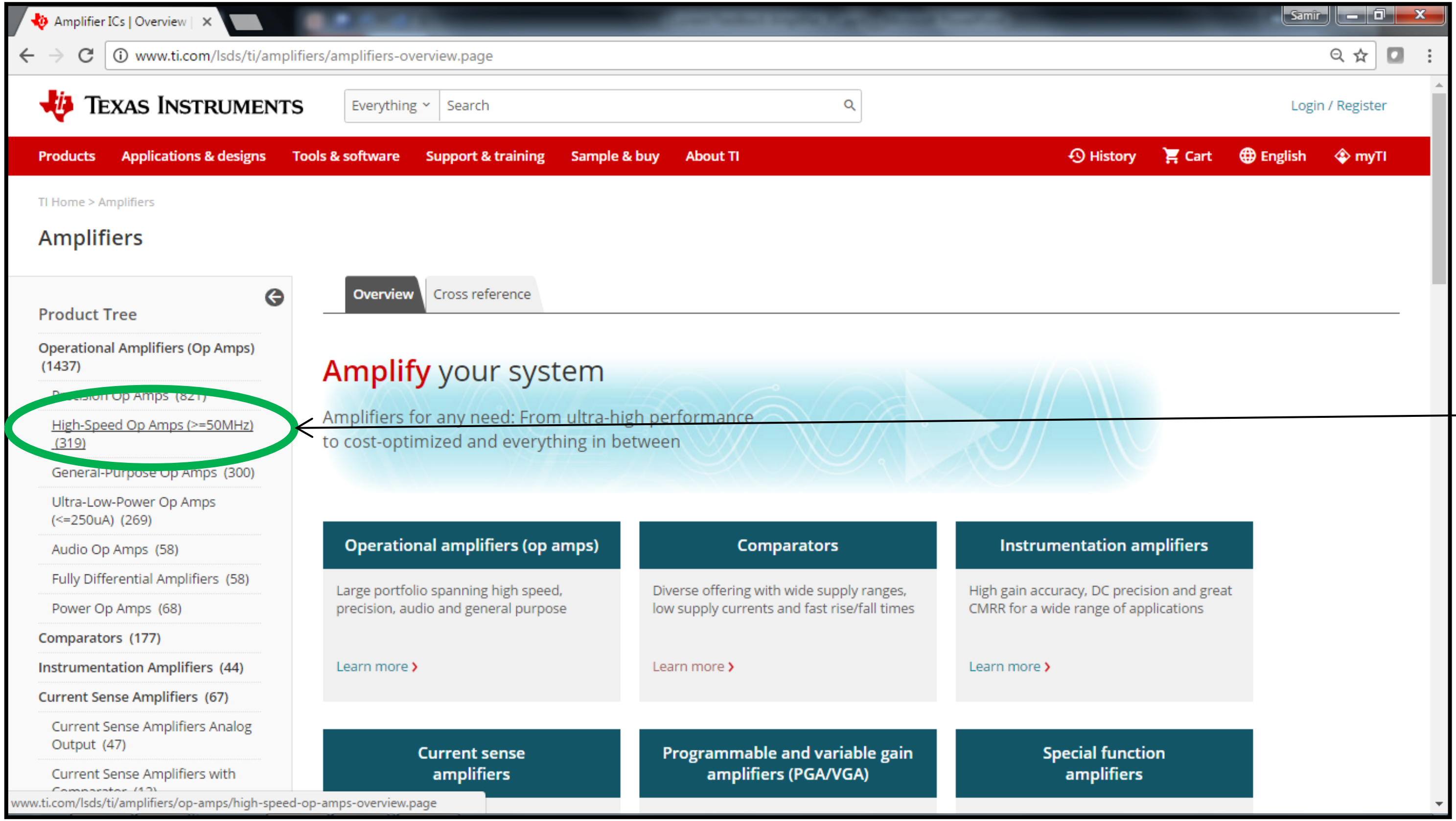
Where, f_{MAX} = 100 MHz and $V_{PEAK} = 1/2 \cdot V_{PP}$ = 2.5V, which results in a minimum slew rate of 1570 V/µs.

Note that there will be significant distortion at the f_{MAX} frequency. For improved linearity performance select an amplifier with slew rate 2x-3x greater than the calculated slew rate.

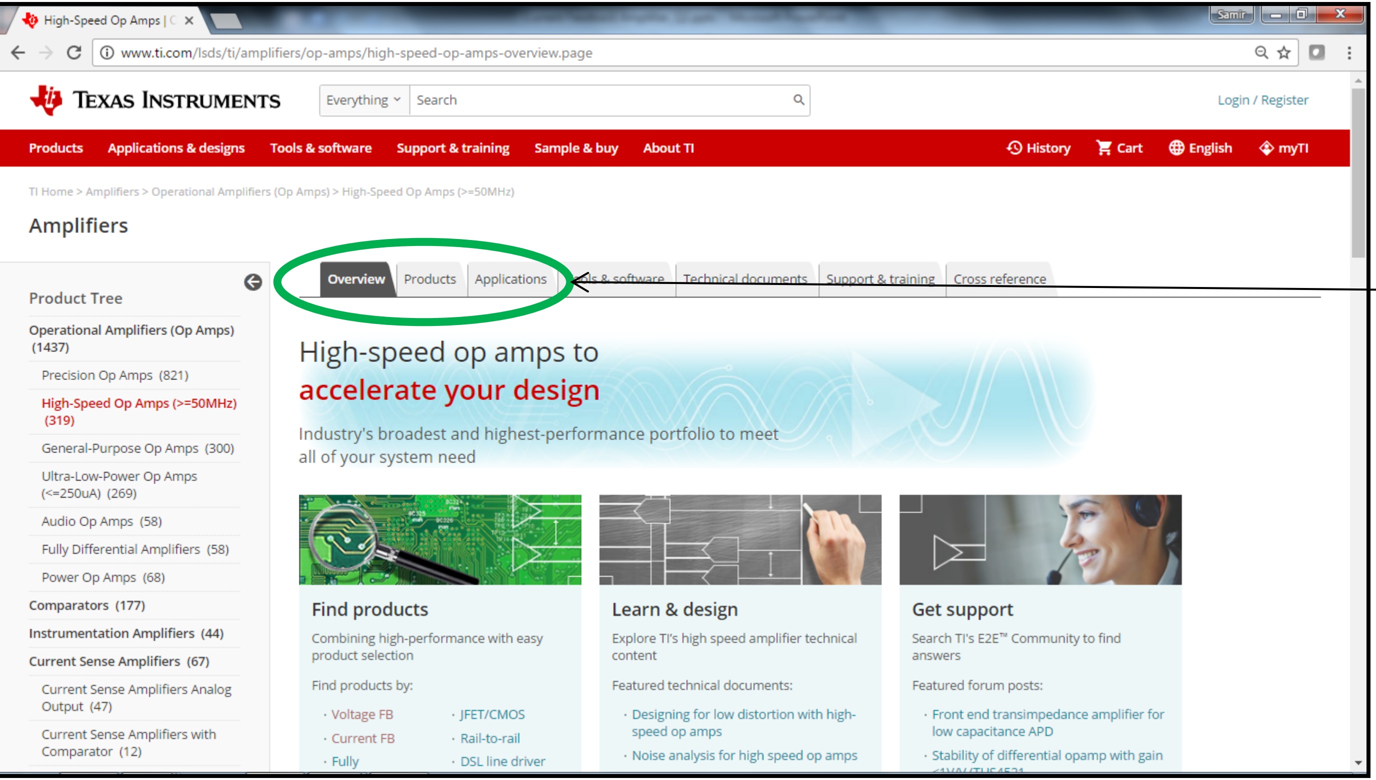
(3) How would you find a current feedback amplifier in the Texas Instruments product portfolio with slew-rate between 7000V/µs and 8000V/µs. Search on www.ti.com.



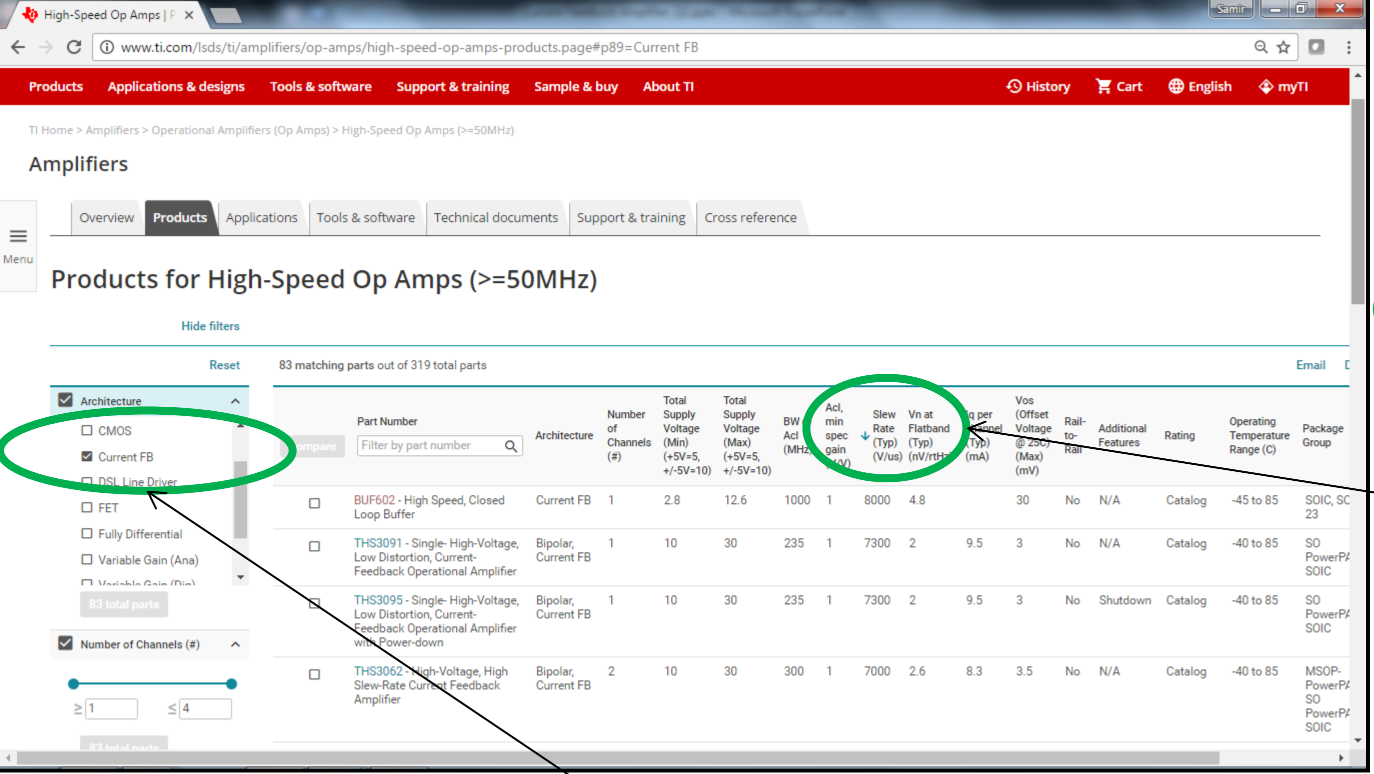
Select “Amplifiers”



Select "High-Speed Op Amps (>=50 MHz)"



Select “Products” tab



2

Double click on "Slew Rate" to sort the amplifiers in ascending or descending order of slew rate

1

Select "Current FB" under Architecture to limit product search to only Current Feedback Amplifiers

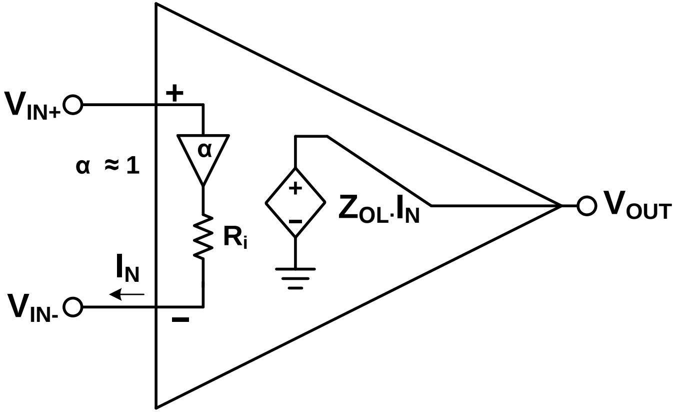
(4) This next problem is a little advanced and requires the use of TINA-TI. Use TINA simulations on the THS3091 at ±15V supplies and determine its

a) Z_{OL} (Open loop transimpedance) vs frequency..

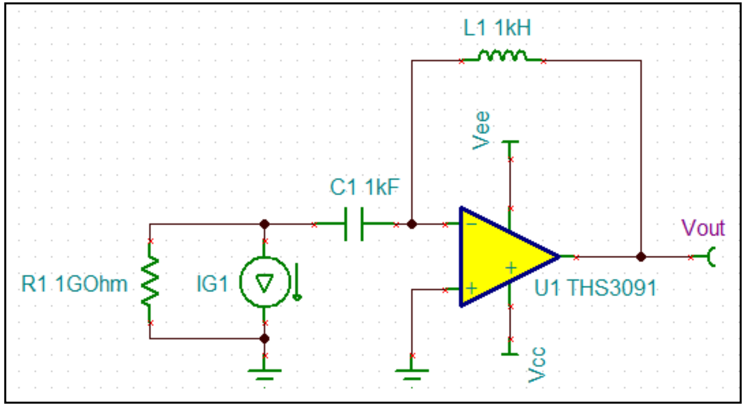
b) Inverting input resistance R_i.

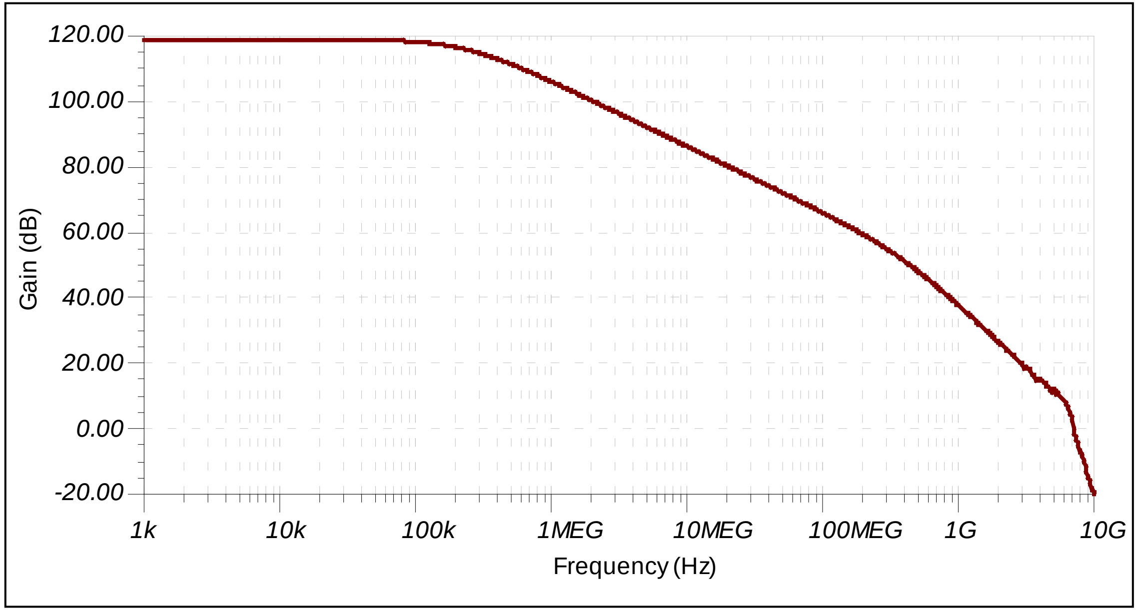
c) Input Buffer Gain, α. (We assumed so far that the buffer gain α = 1, however in a real world amplifier α < 1)

The TINA circuits and results are shown in the subsequent slides.

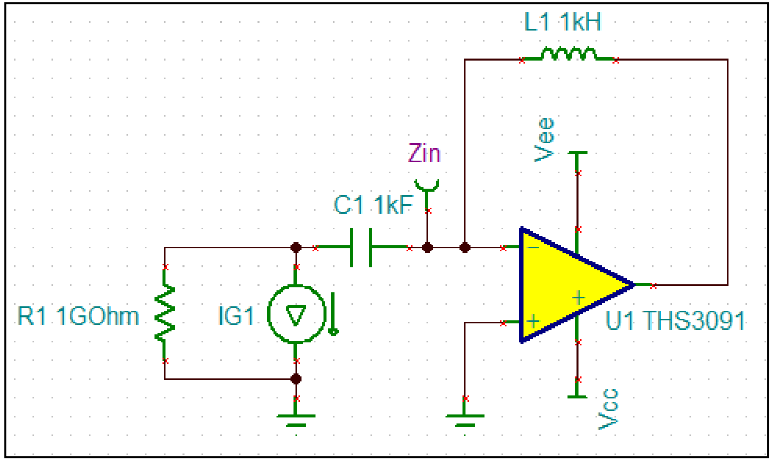


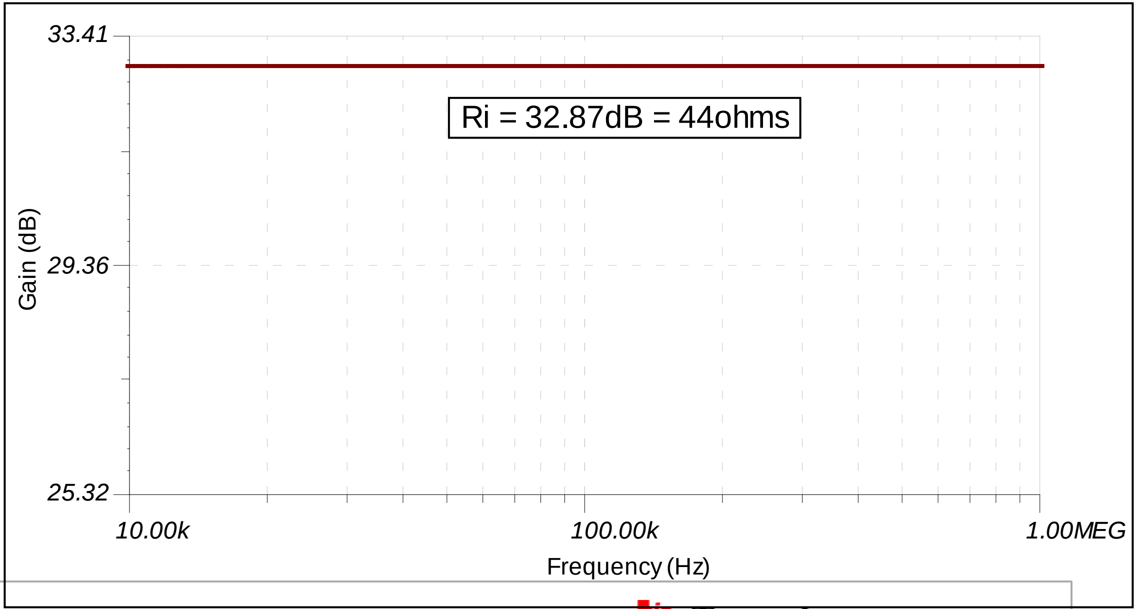
Z_{OL}- Since we are measuring open-loop transimpedance (Z_{OL}), we use a current source stimulus (IG1) and measure the output voltage (Vout), Z_{OL}= Vout/IG1. The 1kF input capacitor and 1kH feedback inductor represent the traditional circuit used to break the amplifier loop. The 1GΩ resistor is needed to provide a current path for the source @ Dc. An AC response simulation directly results in the amplifier Z_{OL}.





R_i - When measuring R_i we will continue to use the open loop configuration as before, however the output signal is now measured at the inverting input (Z_{IN}). Since the noninverting input is grounded the signal at the inverting input is $I_{IN} \cdot R_i$. The output does not depend on the buffer gain since the noninverting pin is at GND. An AC response simulation directly gives R_i. The output of 32.87dB corresponds to $R_i = 44\Omega$



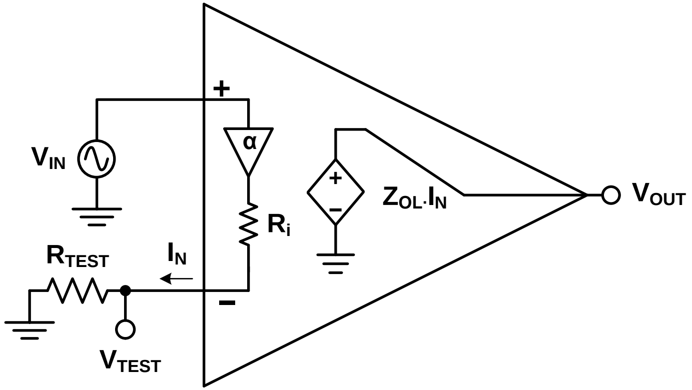


α - So far we have assumed α=1, however practically α is slightly less than 1 and is usually an error source in a CFB op amp. In the previous tests the noninverting input was grounded in order to eliminate the effects of α.Here the input signal (VG1) is applied directly to the noninverting input.

The test circuit and the math is shown below. The value of Ri is known from the previous test. The SPICE circuit and results are shown on the next slide

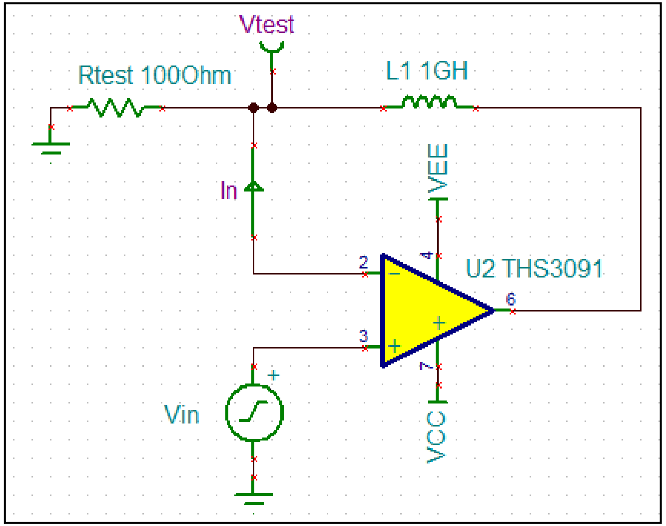
$$\frac{\alpha \cdot V_{IN} - V_{TEST}}{R_i} = I_N$$

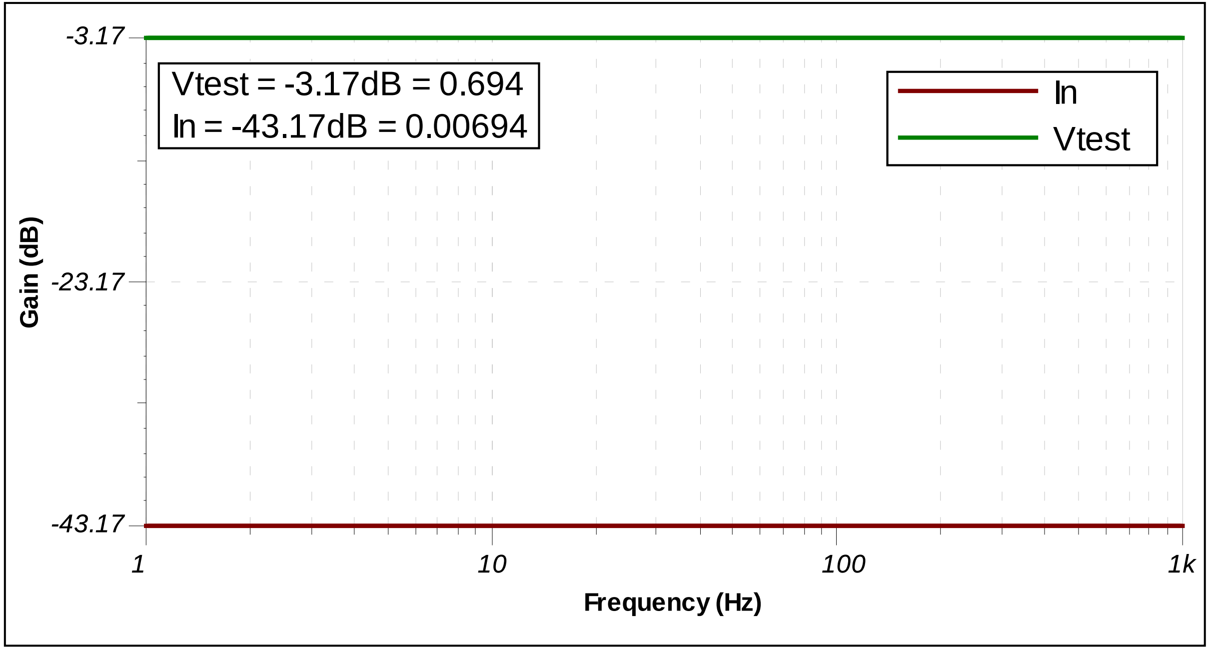
$$\Rightarrow \alpha = \frac{I_N}{V_{IN}} \cdot R_i + \frac{V_{TEST}}{V_{IN}}$$



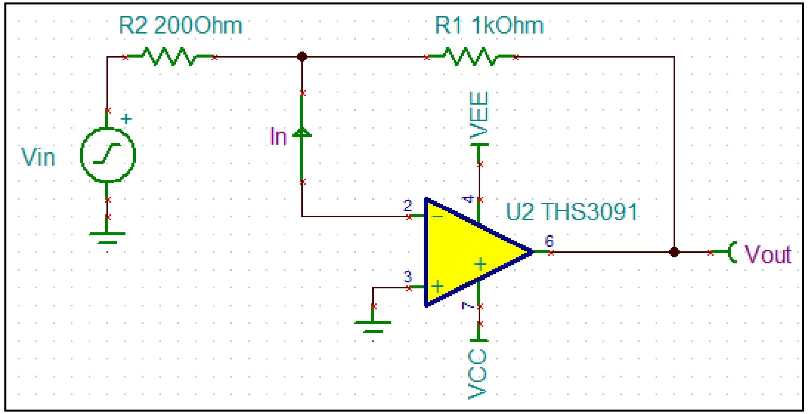
An AC simulation on the circuit shown below will directly give I_N/V_{IN} and V_{TEST}/VI_N which can help α using the equations on the previous slide. R_i = 44 Ω from the earlier test. R_{TEST} can be chosen to be any value. It provides a signal path to GND for the error current I_N. The 1GH inductor puts the THS3091 in open-loop configuration.

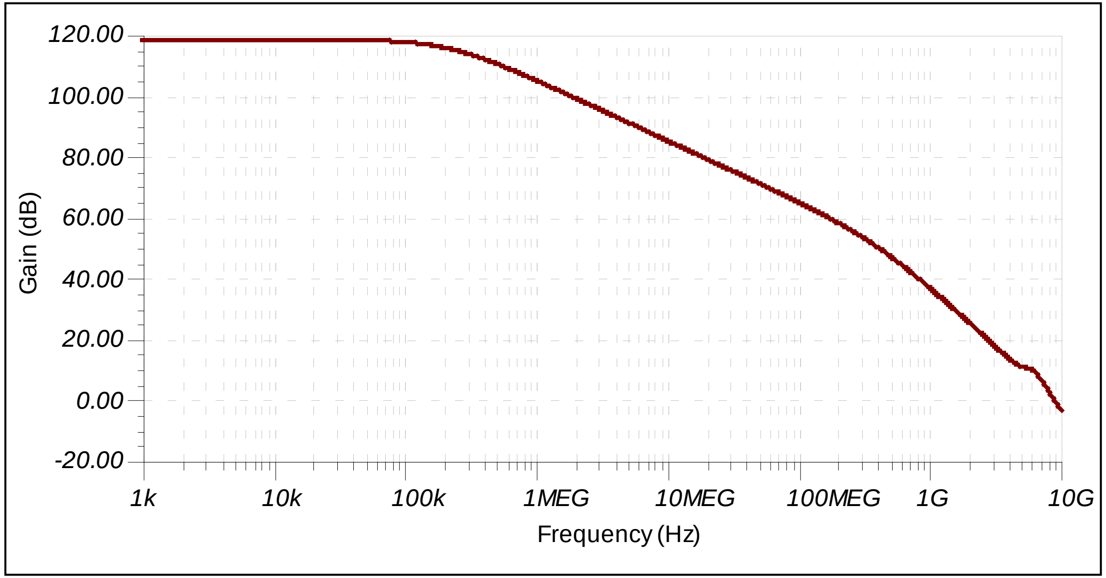
$$\alpha = 0.00694 \cdot 44 + 0.694 = 0.999$$





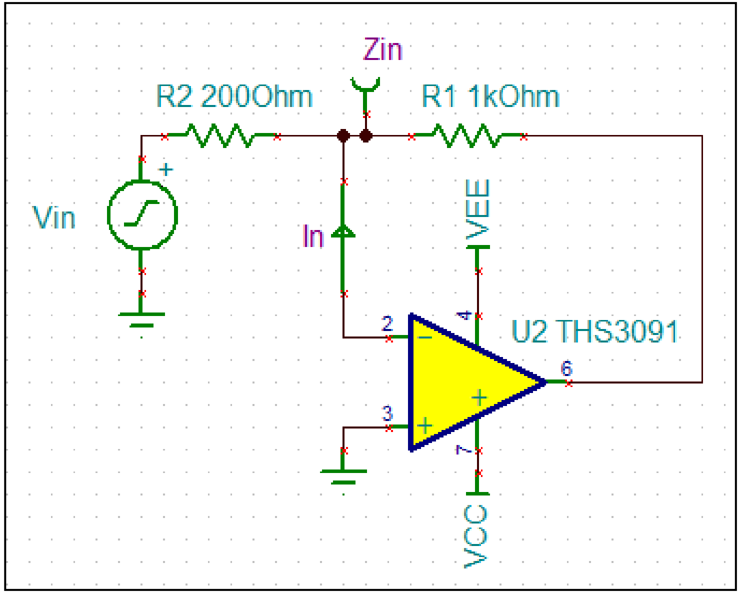
So far we used the open-loop configuration to measure the parameters, however a closed-loop config. may also be used. The Z_{OL} closed loop test is shown below. Use the test circuit shown below and use the post-processor feature where $Z_{OL} = V_{OUT}/I_N$. Note that in a closed-loop system the amplifiers closed-loop output impedance will affect the results at the higher frequencies.

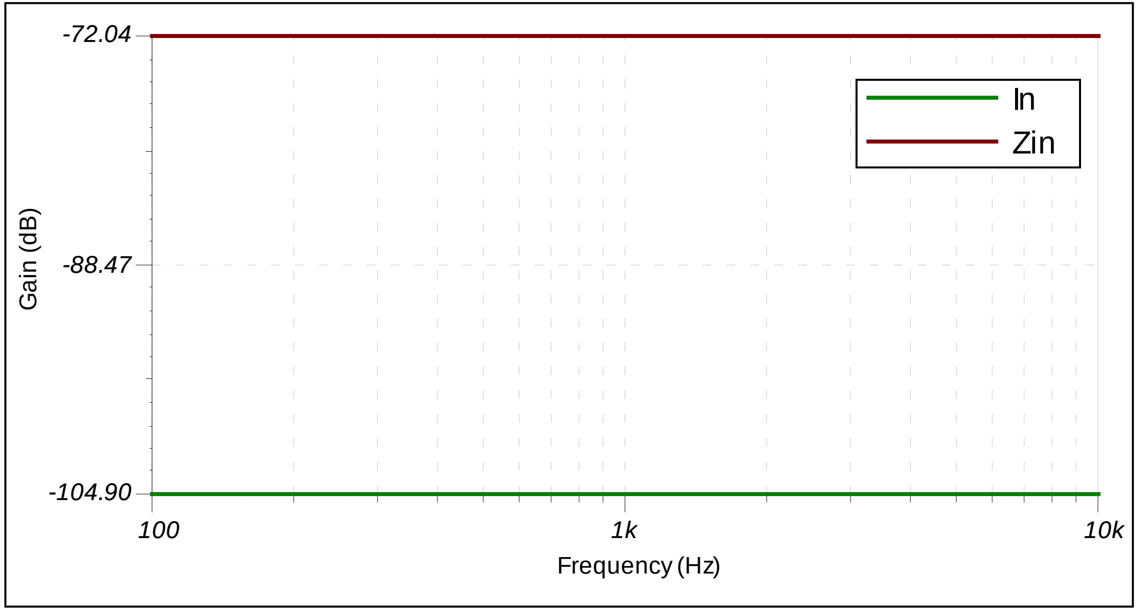




The circuit to measure Ri and the simulated results are shown below. I have focused on the low frequency region. Again the post processor feature in TINA is used where $R_i = Z_{IN}/I_N$.

$$R_i = \frac{Z_{IN}}{I_N} = -72.04 - (-104.9) = 32.86\text{dB}\Omega = 43.95\Omega$$





I will leave the calculation of α in a closed-loop configuration as a reader exercise. For more support on current feedback amplifiers contact us on the E2E support forums:

http://e2e.ti.com/support/amplifiers/high_speed_amplifiers/