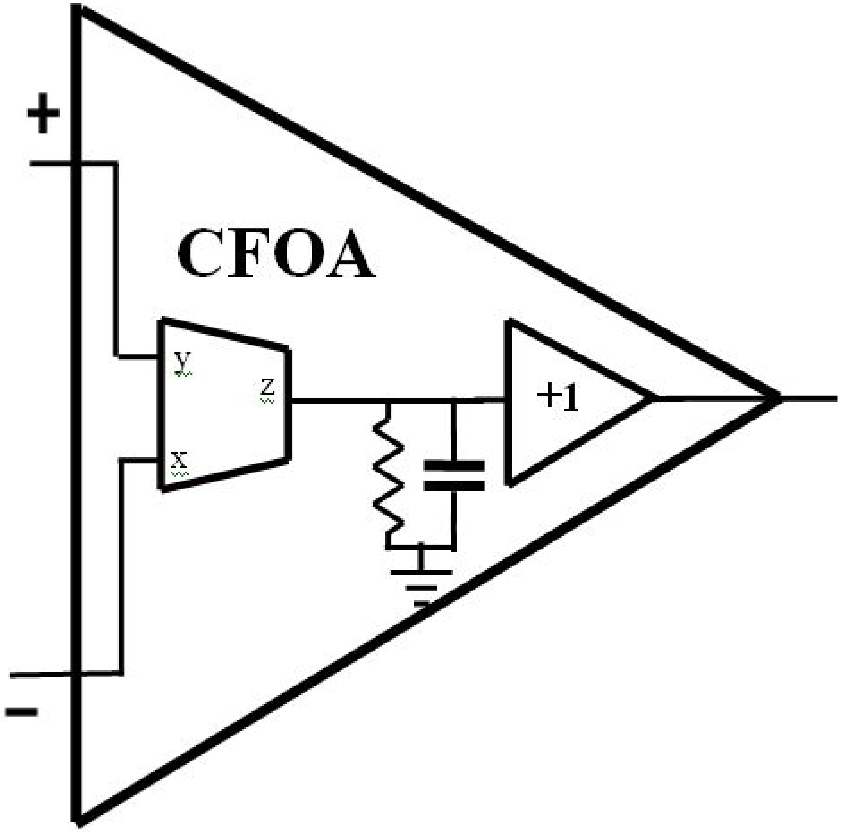
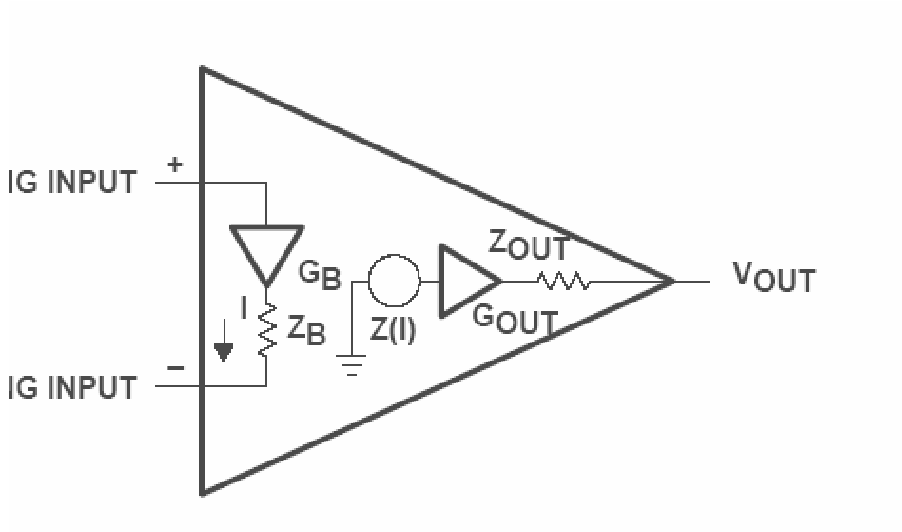
Current feedback op-amps

References:
National Semiconductor application notes: OA15, AN-597
Texas Instruments: OpAmps for Everyone, Chapter 8: CFOA
Intersil Elantec EL-5166 datasheet

What is a CFOA?

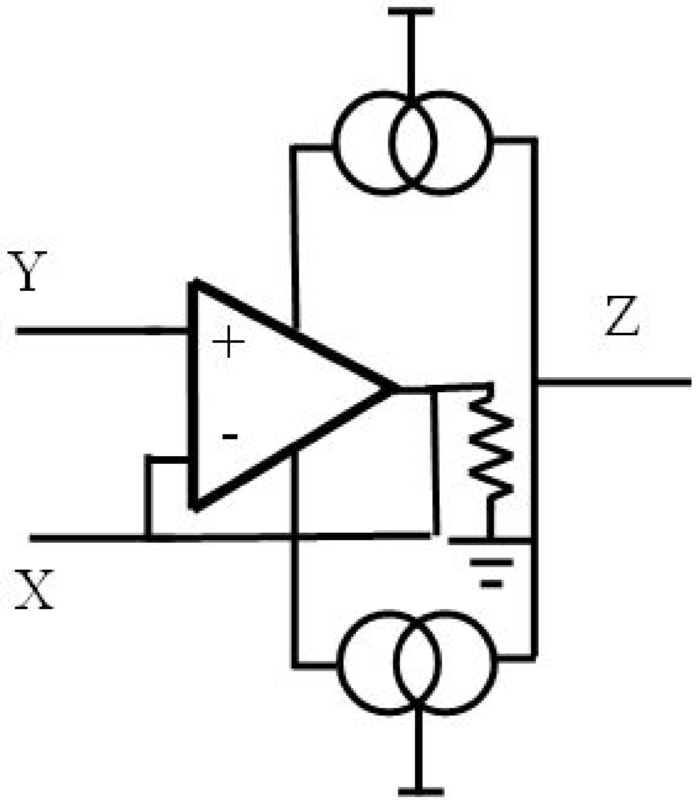




A CCII- , a voltage follower, and a node impedance

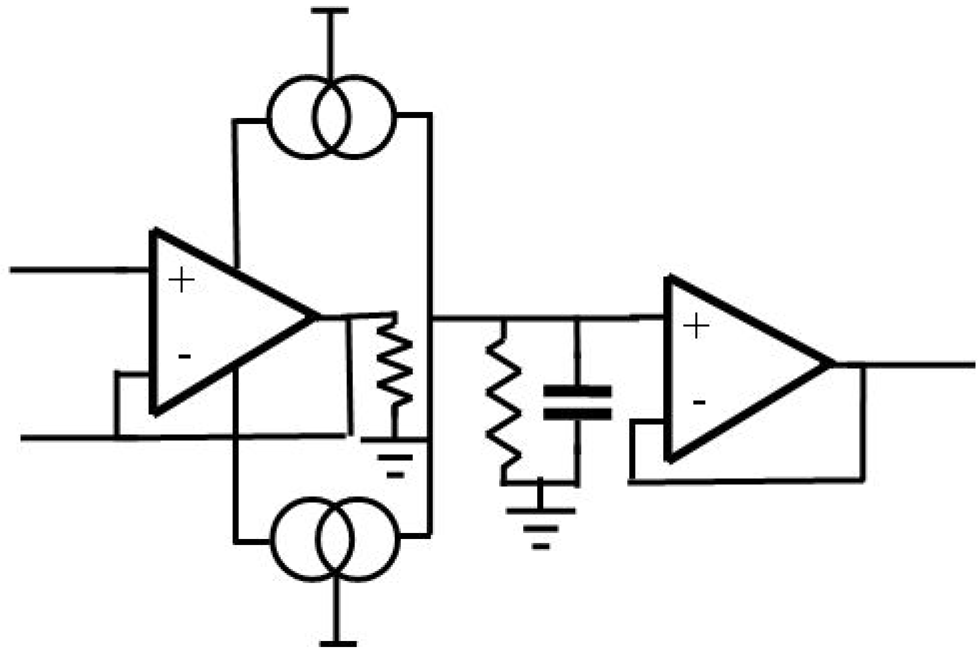
How did the idea come about?

Supply mirroring: CC



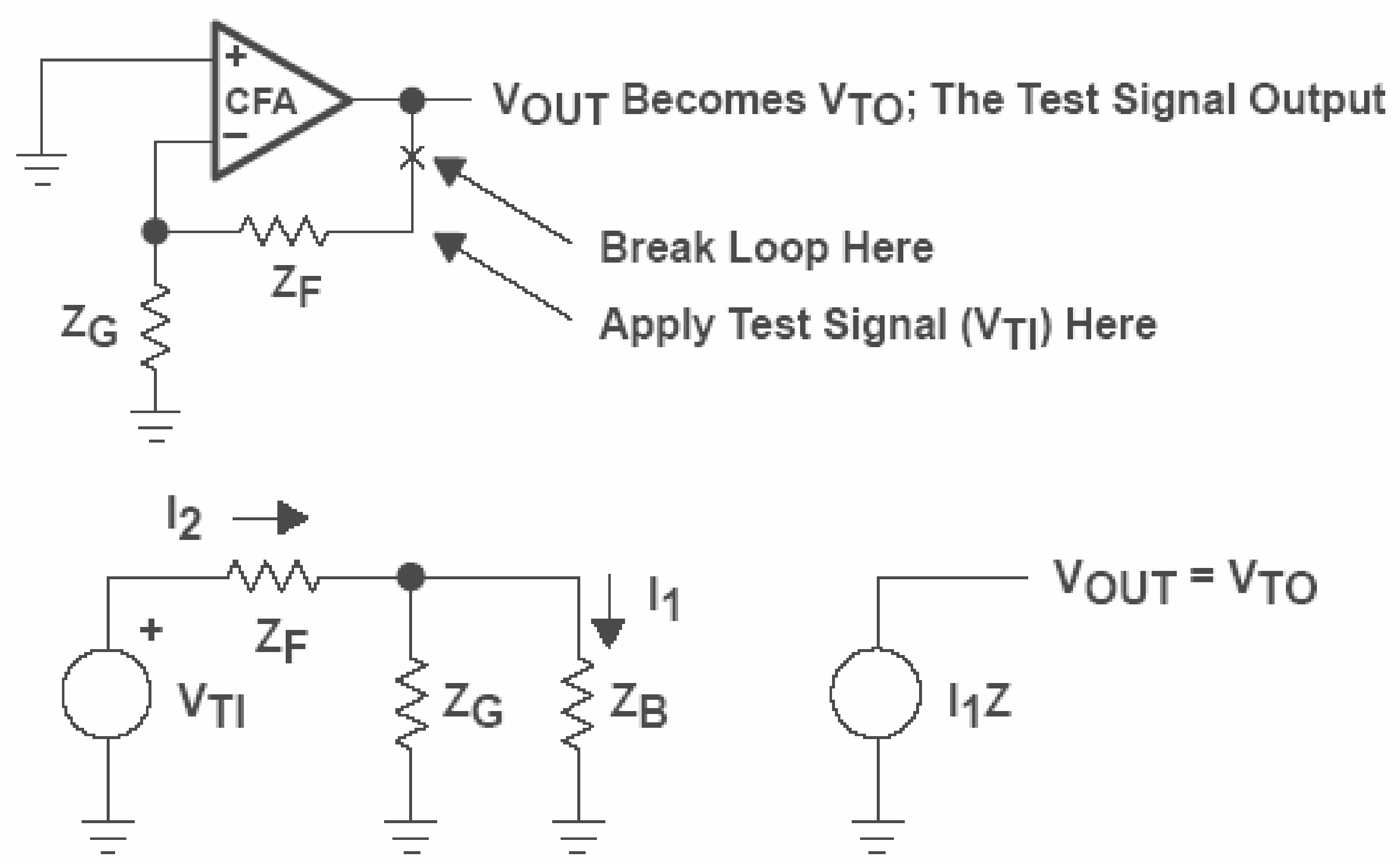
Current conveyor

Supply mirroring + Buffer

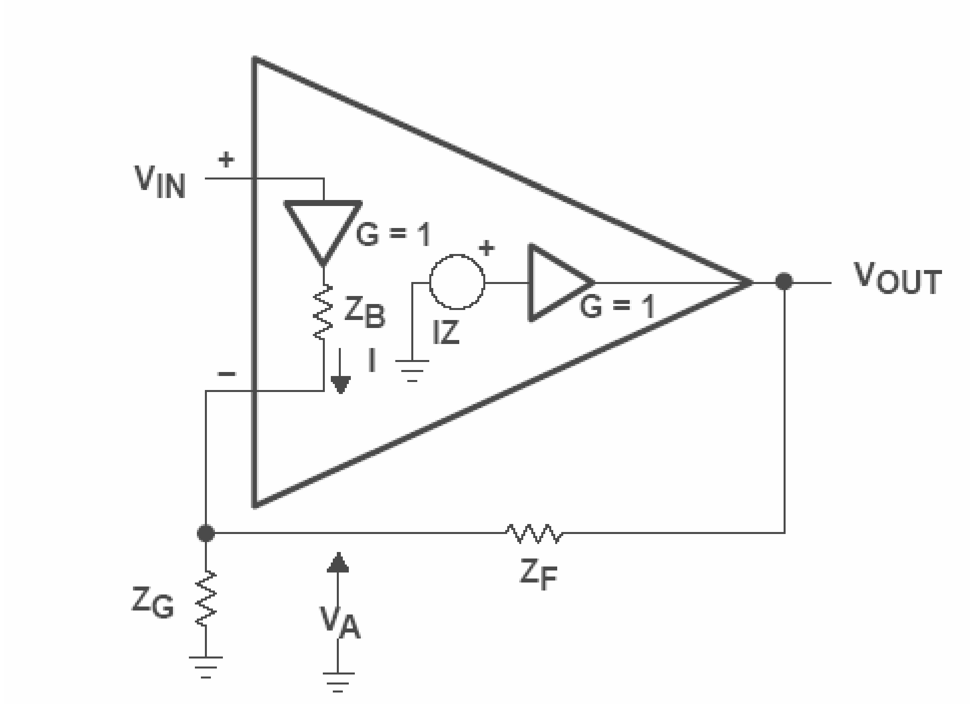


Current feedback op-amp

Loop gain calculation



Basic usage: Non inverting amplifier

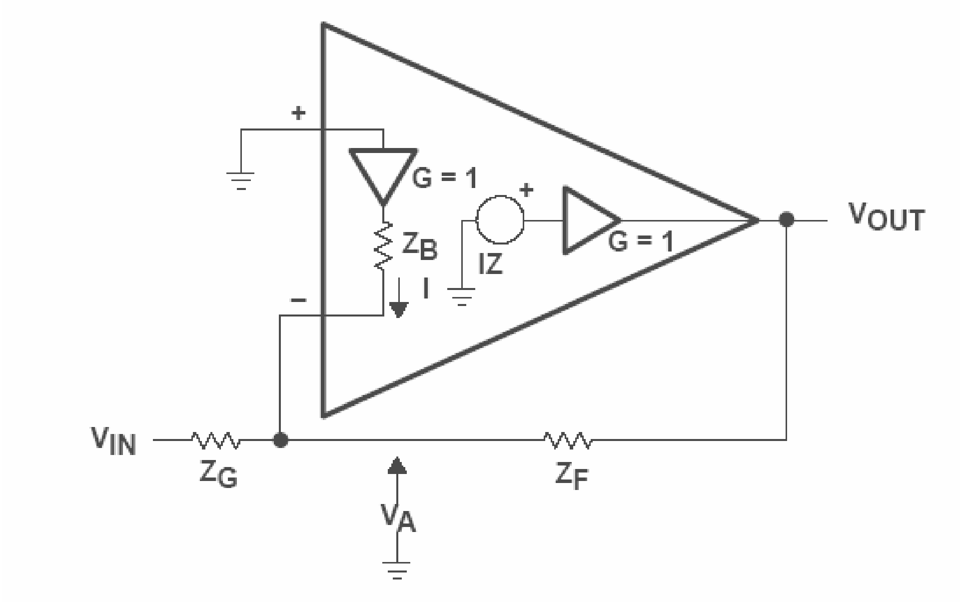


$$G_{NINV} = \frac{dV_{OUT}}{dV_{IN}} = \frac{Z\left(Z_F + Z_G\right)}{ZZ_G + Z_F Z_B + Z_G Z_B + Z_F Z_G}$$

$$\lim_{Z \to \infty} G_{NINV} = 1 + \frac{Z_F}{Z_G}$$

Note that we have not introduced explicit frequency dependence!

Not common usage: Inverting



$$G_{INV} = \frac{-ZZ_F}{ZZ_G + Z_B Z_F + Z_B Z_G + Z_F Z_G}$$

$$\lim_{Z \to \infty} G_{INV} = -\frac{Z_F}{Z_G}$$

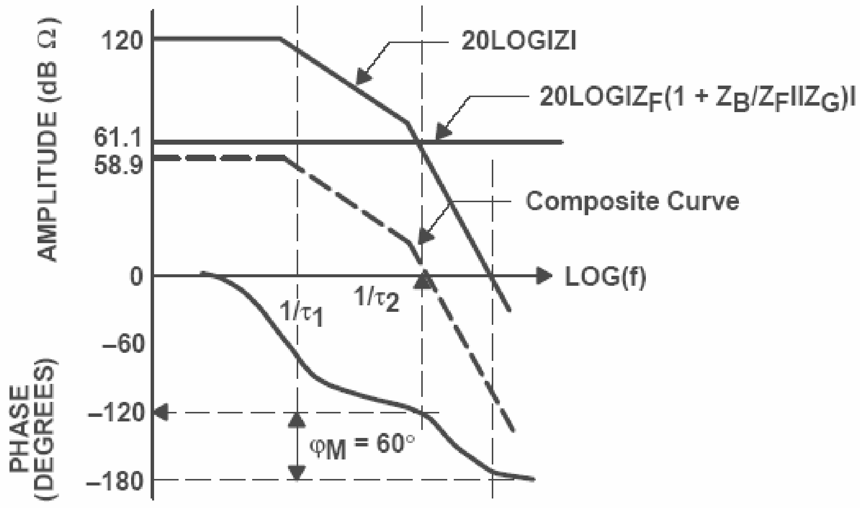
Gain calculation – frequency response

$$G_{NINV} = \frac{ZZ_F + ZZ_G}{ZZ_G + Z_B Z_F + Z_B Z_G + Z_F Z_G} \quad Z_B = h_{ib} + \frac{R_B}{\beta_0 + 1}\left(\frac{1 + s\beta_0 \tau_T}{1 + s\tau_T/(1 + 1/\beta_0)}\right)$$

$$Z_T = \frac{Z_0}{(1 + s\tau_1)(1 + s\tau_2)}$$

Transimpedance Z_T has two poles: due to the impedance of the high Z node and also due to the current mirror delay

Z_B is the output impedance of the input buffer, small but not necessarily much smaller than Z_G



Gain calculation – frequency response (2)

$$G_{NINV} = \frac{ZZ_F + ZZ_G}{ZZ_G + Z_B Z_F + Z_B Z_G + Z_F Z_G} \quad Z_T = \frac{Z_0}{(1+s\tau_1)(1+s\tau_2)}$$

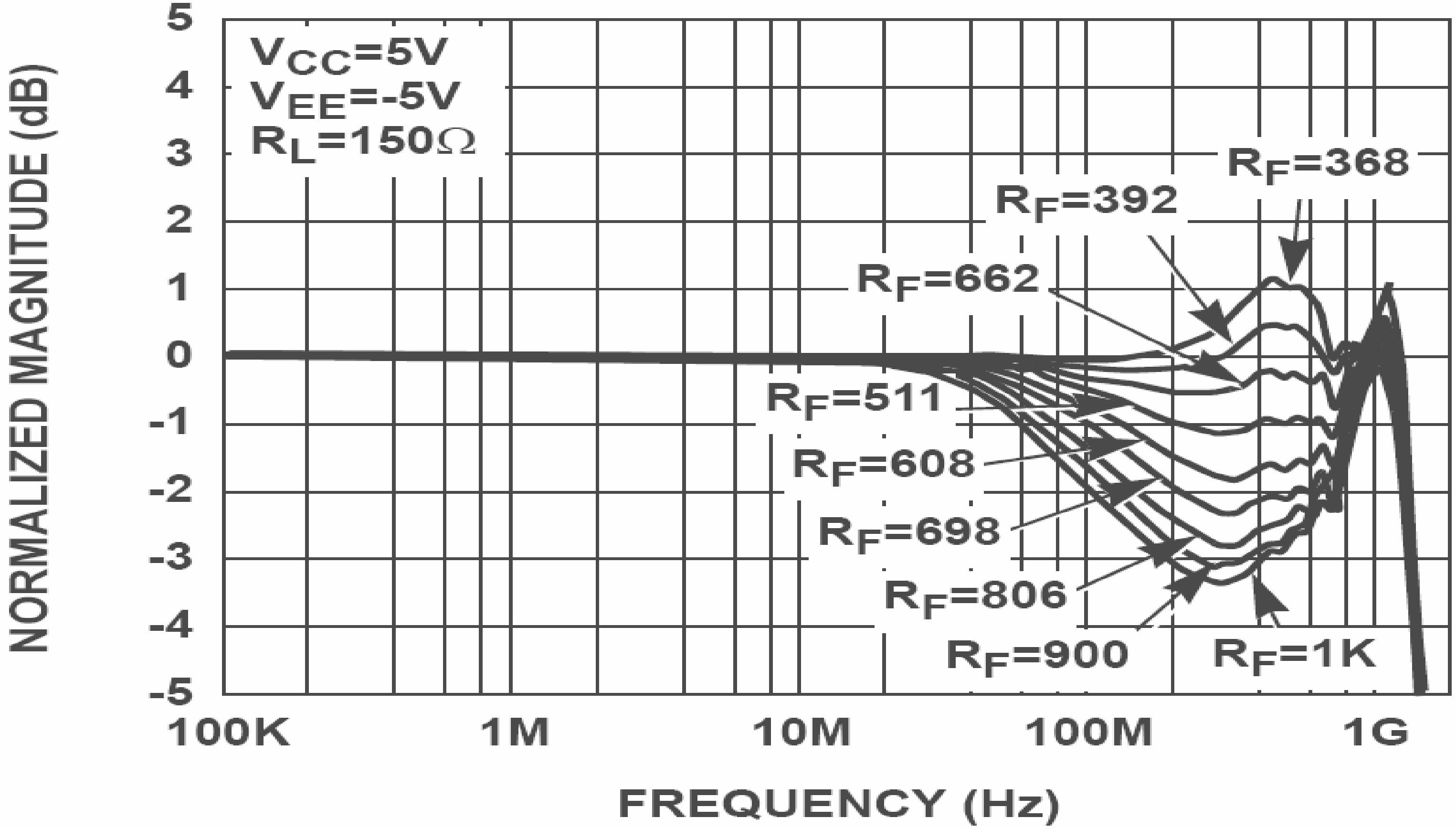
Neglect Z_B since it is much smaller than anything else. Then,

$$Z_{NINV} \simeq \frac{Z\left(Z_F + Z_G\right)}{ZZ_G + Z_F Z_G} = \underbrace{\left(1 + \frac{Z_F}{Z_G}\right)}_{Gain} \underbrace{\frac{1}{1 + Z_F / Z}}_{Bandwidth}$$

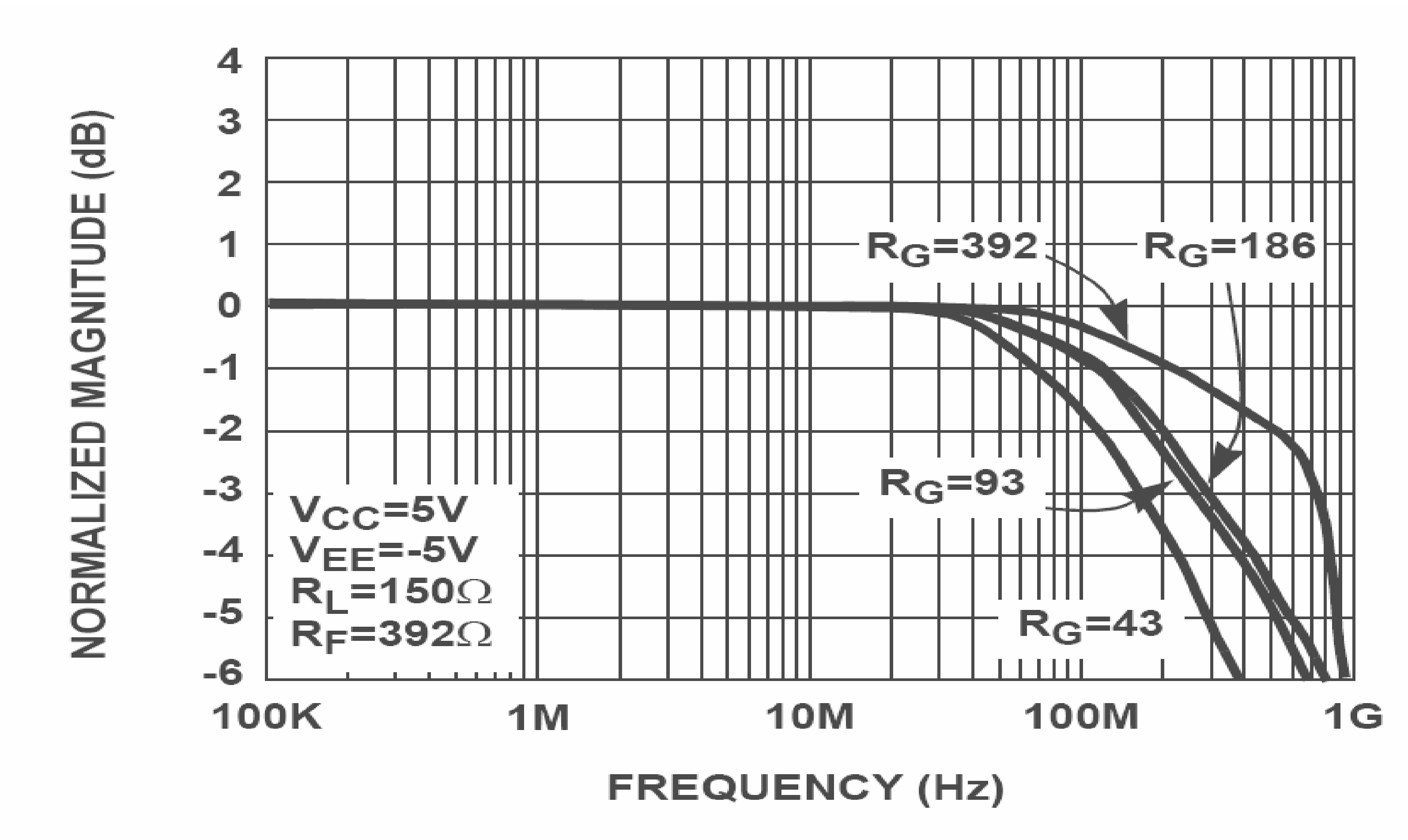
Observe that the gain and bandwidth have been decoupled. The bandwidth depends only on Z_F (and Z_B, really), while the gain depends on both Z_F and Z_G

There is no magic involved. The CFOA is a dominant pole transimpedance amplifier, while the voltage and current buffers have poles at much higher frequencies.

Gain vs. frequency with R_F (EL5166)

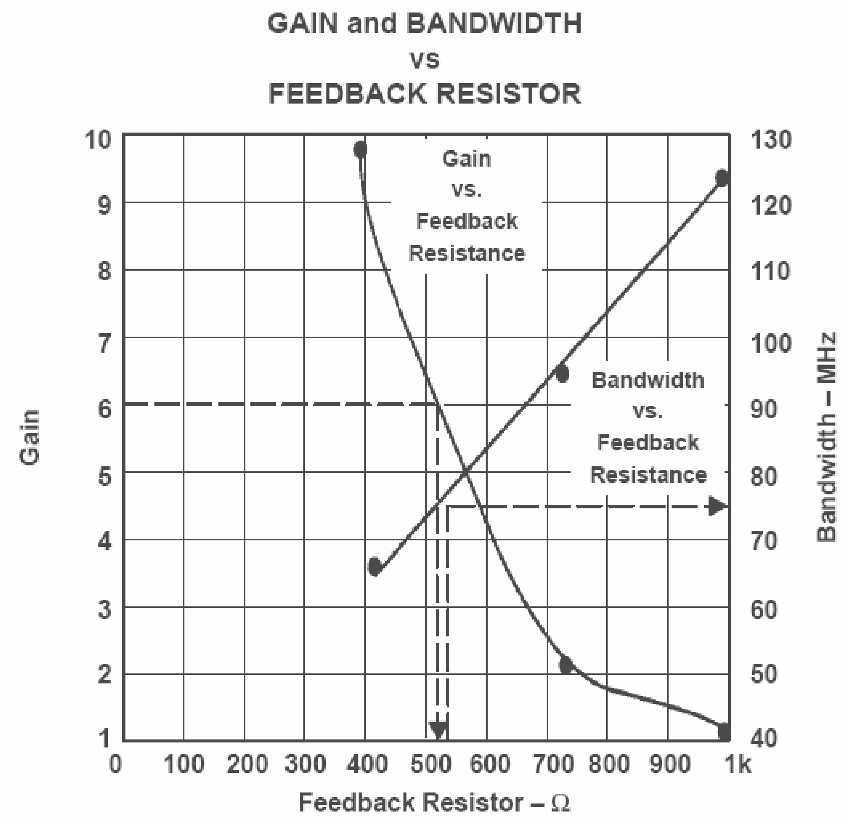


Gain vs frequency with R_G (EL5166)



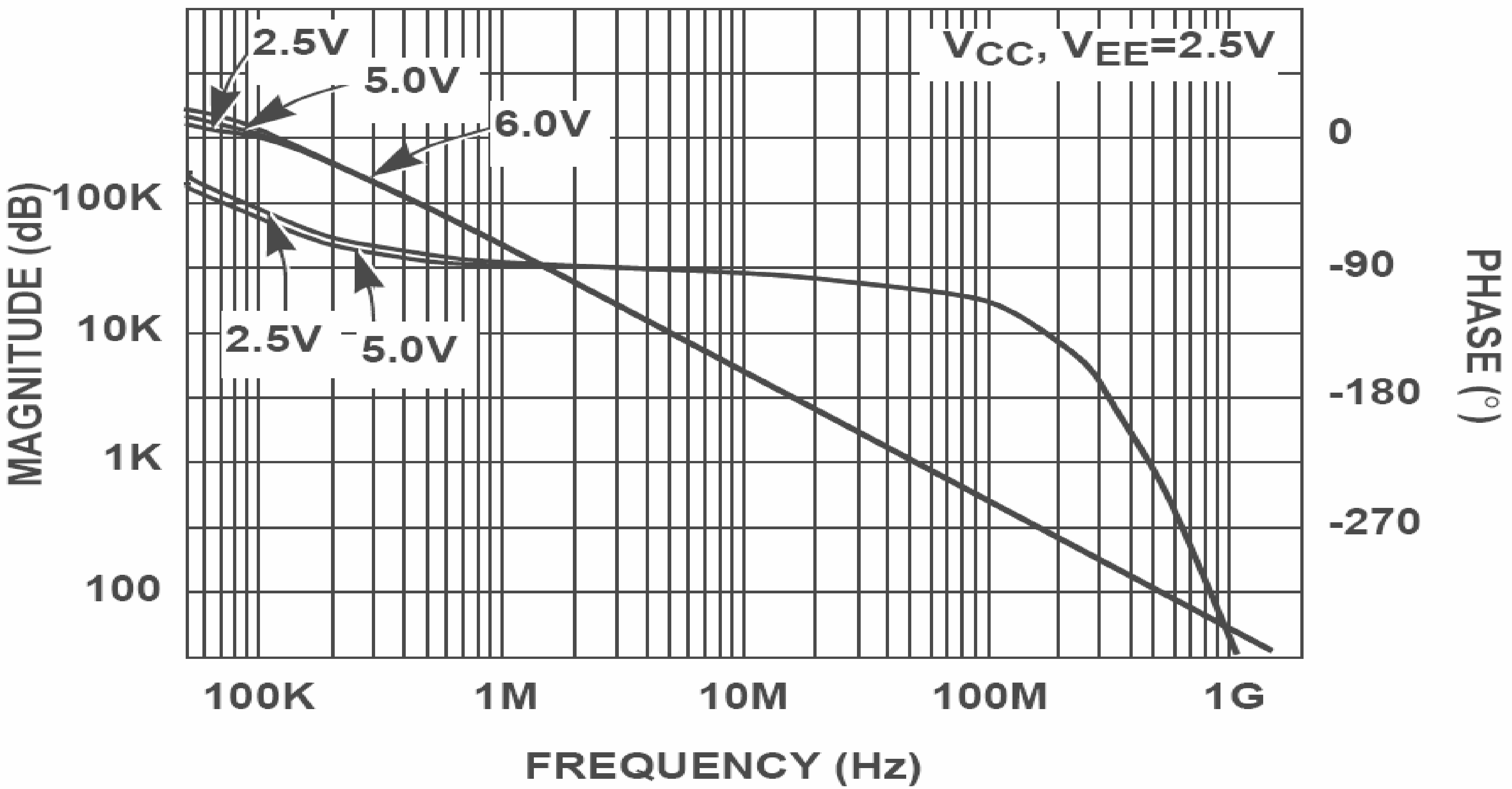
Notice that despite what our approximations say the BW still depends on gain!

Gain bandwidth product – example



GAIN (A_{CL})	R_F (Ω)	BANDWIDTH (MHz)
+ 1	1000	125
+ 2	681	95
+ 10	383	65

Frequency response of transimpedance



The transimpedance has a dominant pole at 100kHz

Slew rate: VFOA vs CFOA

- VFOA: $I_{outVFOA} \propto \tanh\left(V_+ - V_-\right)$

- CFOA: $I_{outCFOA} \propto \exp\left(V_y\right)$

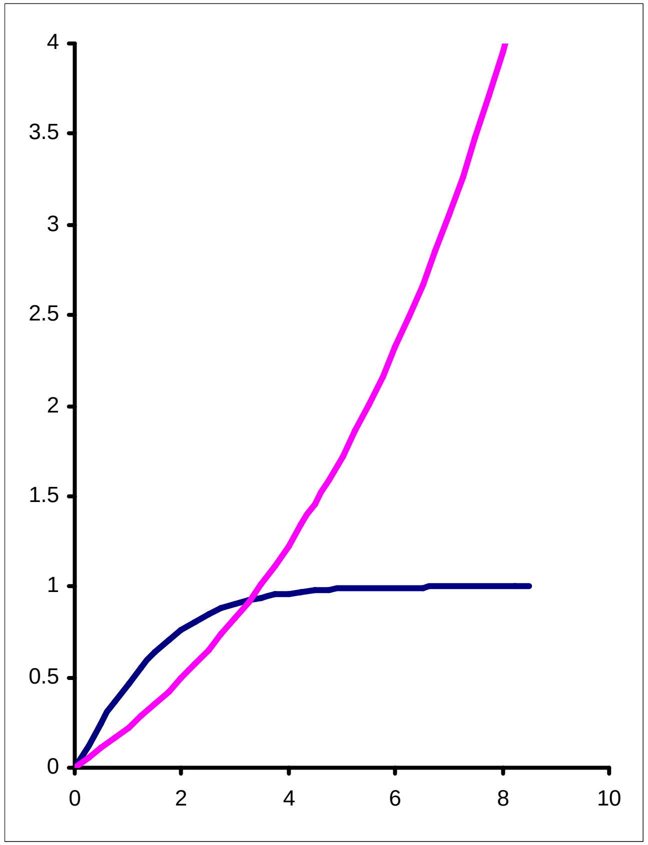
In the limit of large input voltages,
in the VFOA:

$$\frac{dI_{out}}{dV_{in}} \rightarrow 0$$

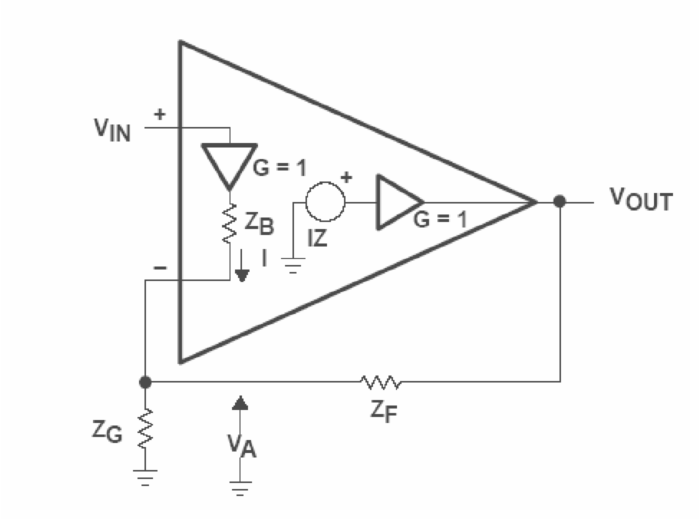
While in the CFOA we get:

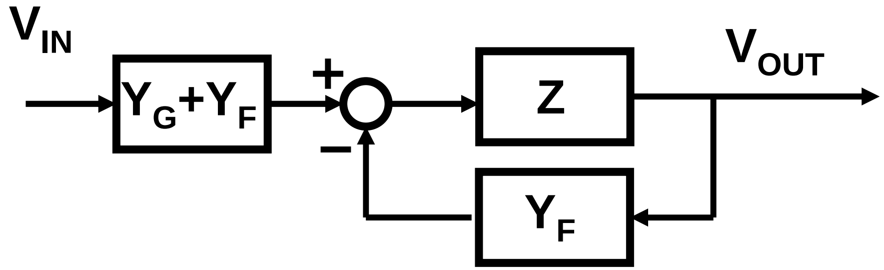
$$\frac{dI_{out}}{dV_{in}} \rightarrow \propto I_{out}$$

The slew rate in the CFOA is power limited



Re-visit the non inverting amplifier



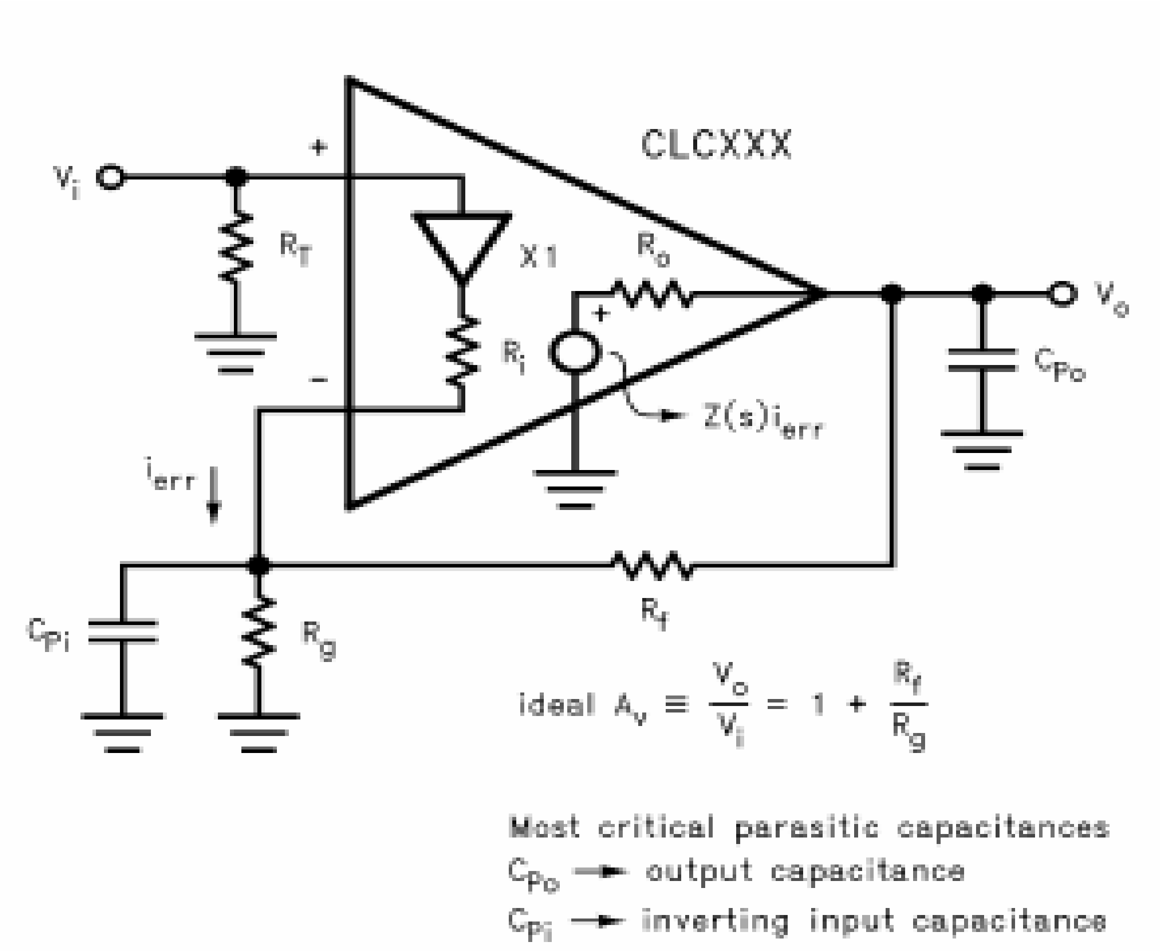


The CFOA is a transimpedance amplifier, i.e. equivalent to the block diagram
The response is, in terms of the transimpedance Z is the usual FB expression:

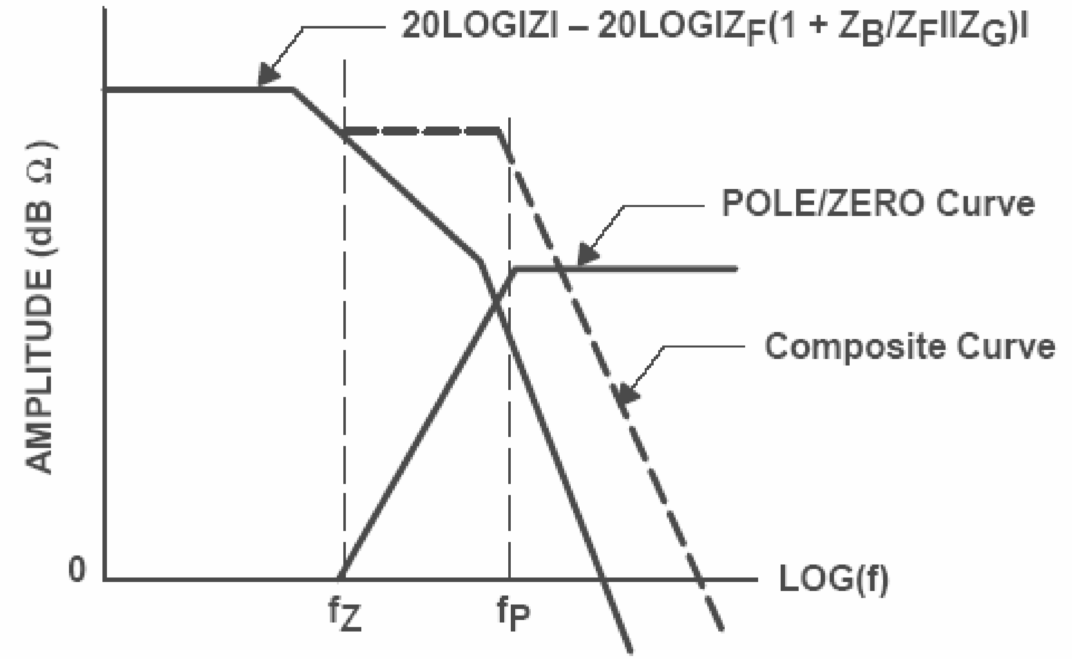
$$G_{NINV} = \frac{Z\left(Y_G + Y_F\right)}{1 + ZY_F} \Rightarrow \lim_{Z\to\infty} G_{NINV} = 1 + \frac{Y_G}{Y_F} = 1 + \frac{Z_F}{Z_G}$$

Notice that the loop gain is ZZ_F and that Z is typically second order beyond the first pole, so that, for a parallel RC in the feedback path we get a second order underdamped system.

Avoid capacitances!



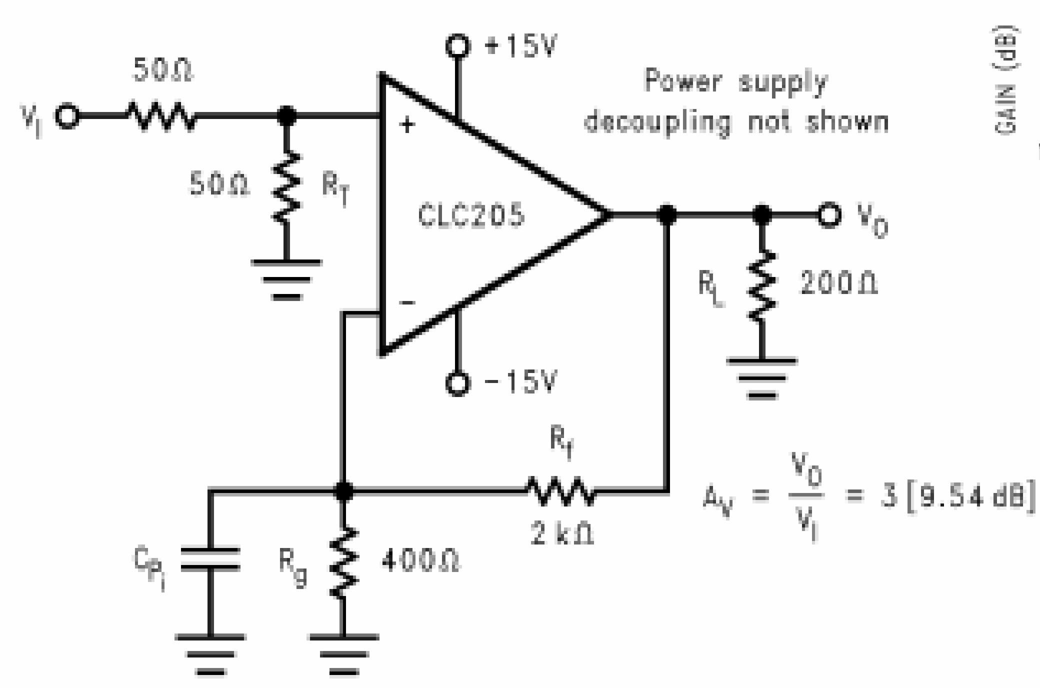
Effect of Feedback capacitance

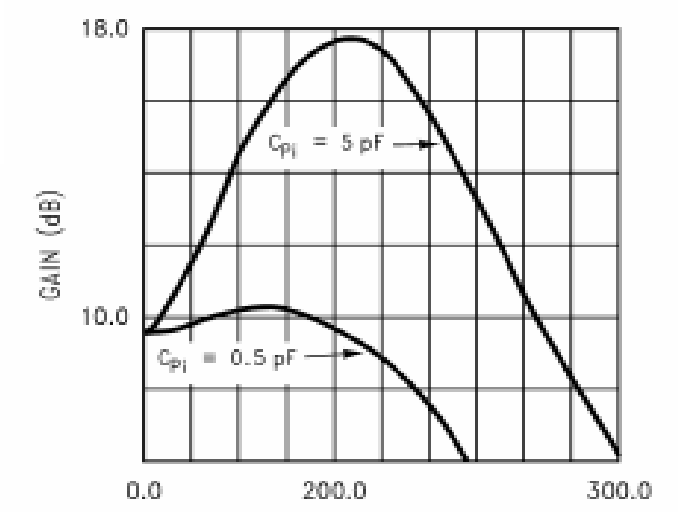


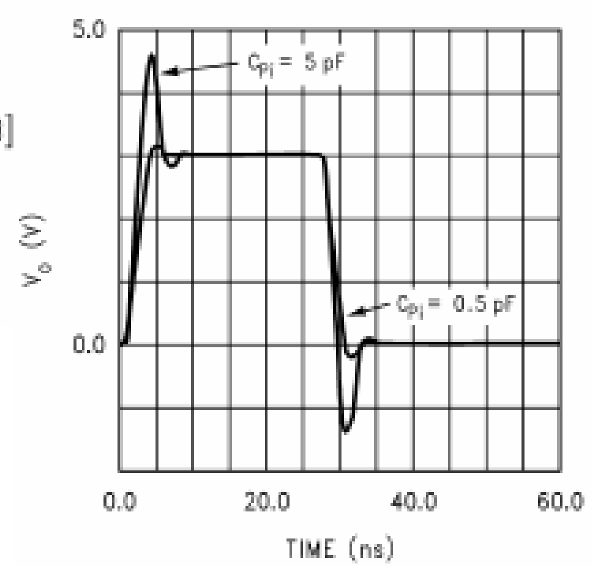
$$A\beta = \frac{Z\left(1 + R_F C_F s\right)}{R_F\left(1 + \frac{R_B}{R_F \| R_G}\right)\left(R_B \parallel R_F \parallel R_G \left(C_F + C_G\right) s + 1\right)}$$

➔ INSTABILITY unless we introduce extra pole!

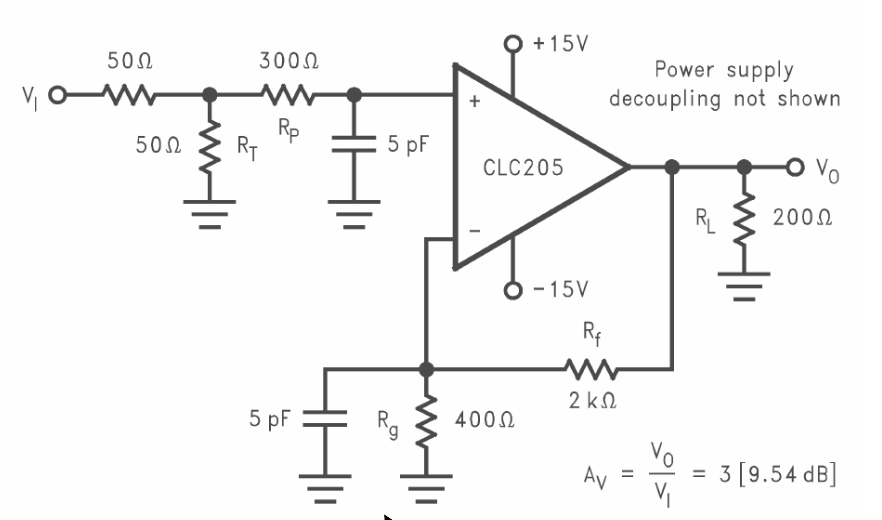
Input capacitance

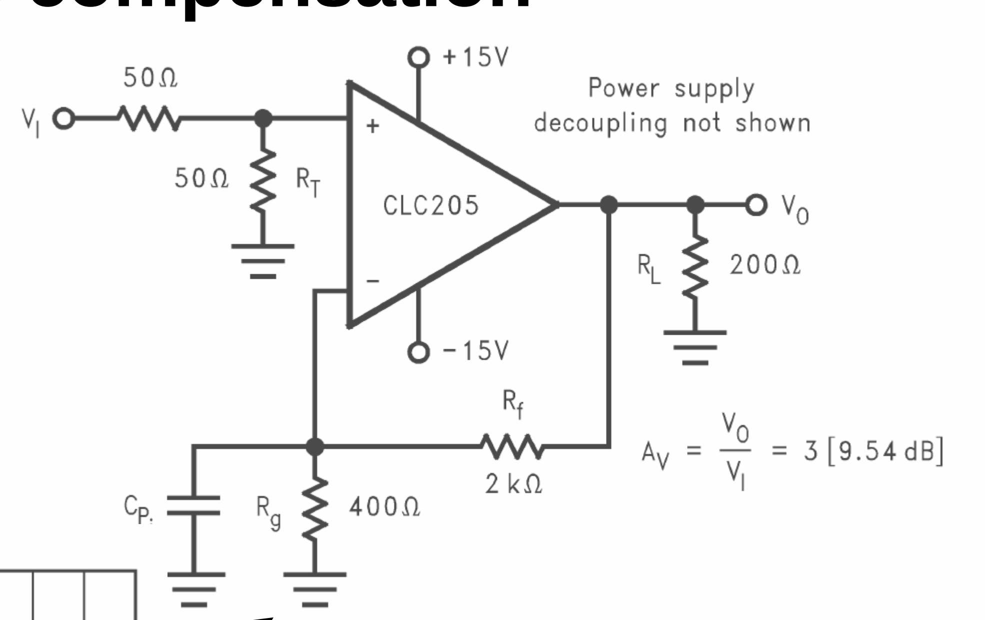


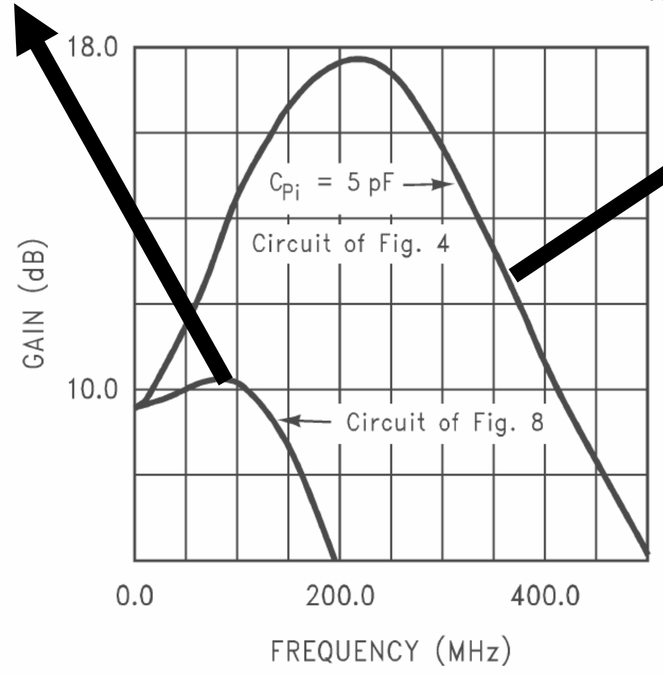




Brute force compensation

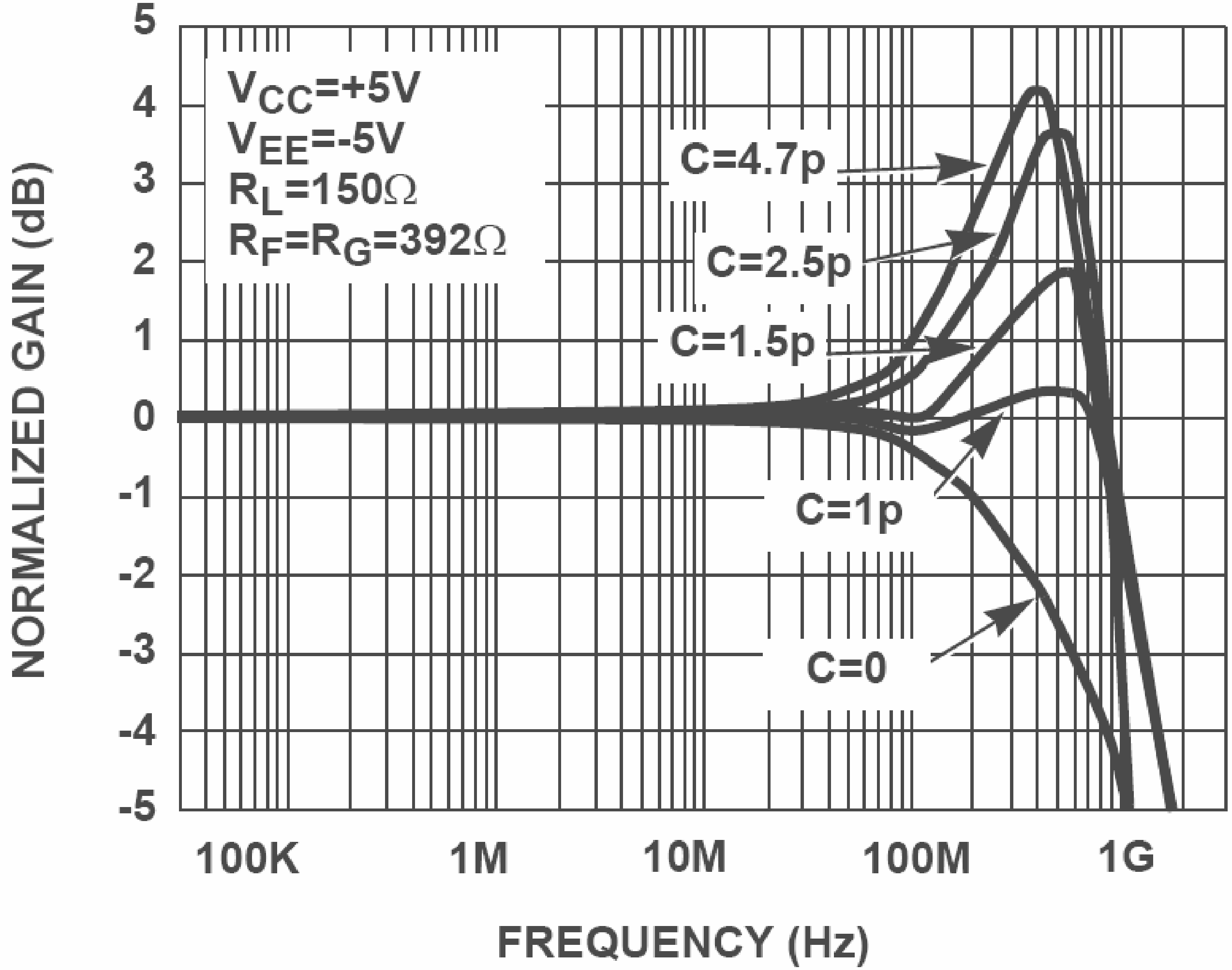




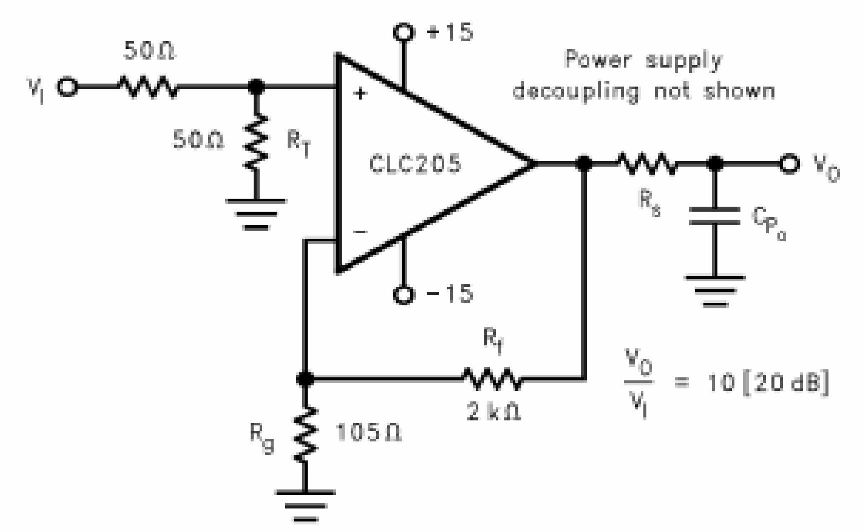


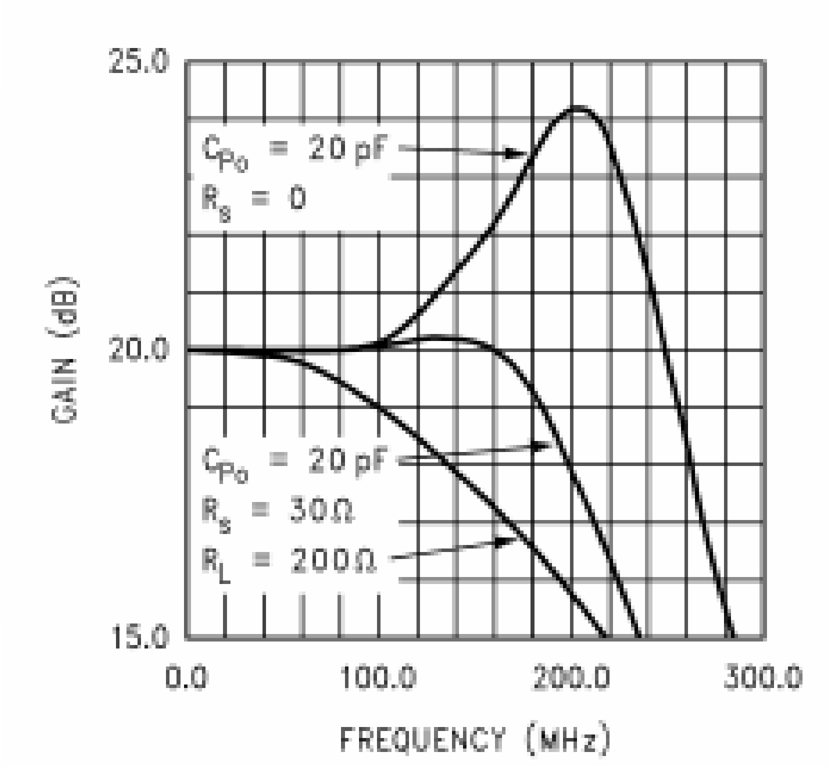
Low pass the non-inverting input to compensate for stray capacitance, i.e. brute force compensation

Effect of input (stray) capacitance

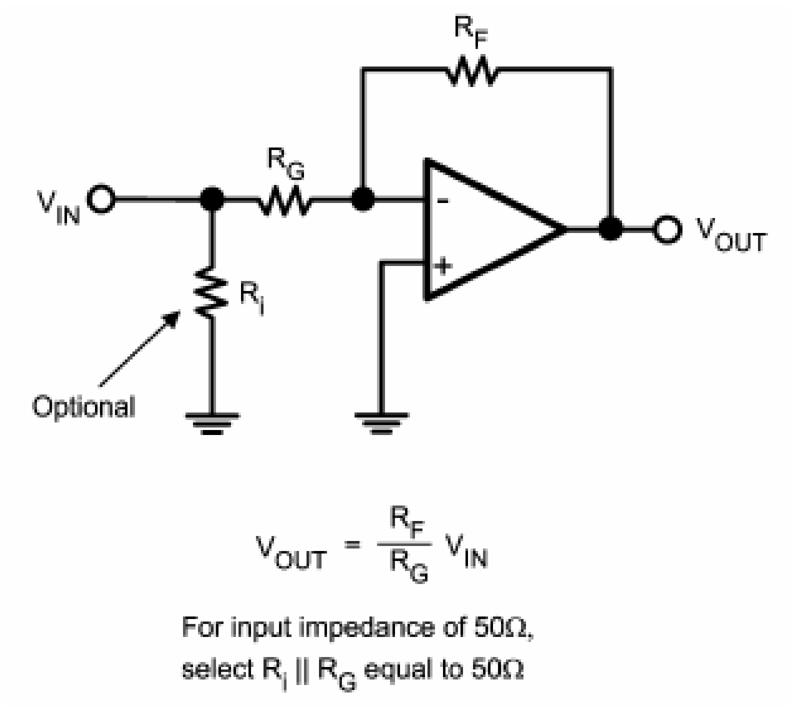


Output (load) capacitance

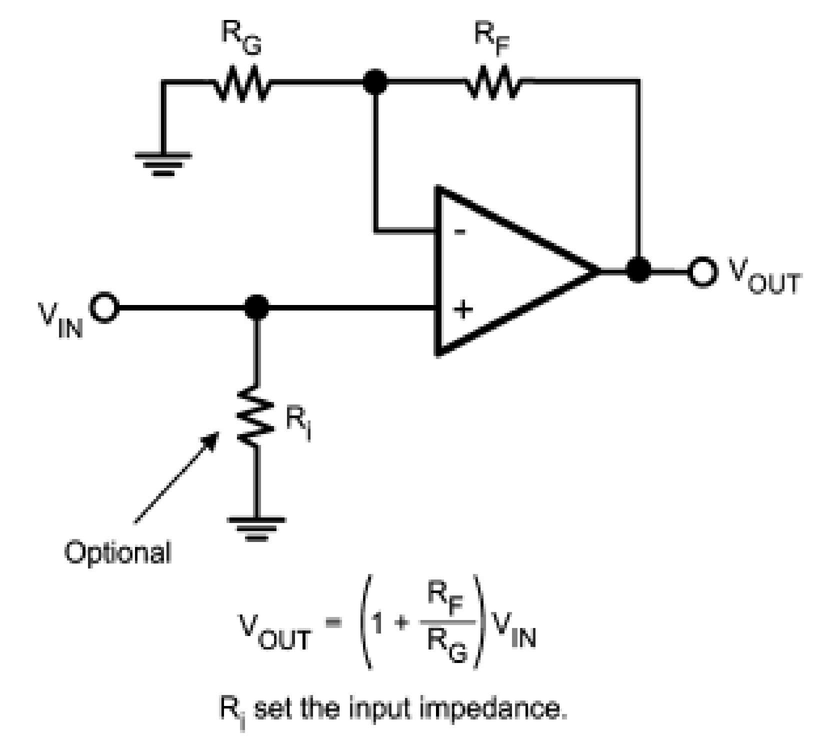




Applications I

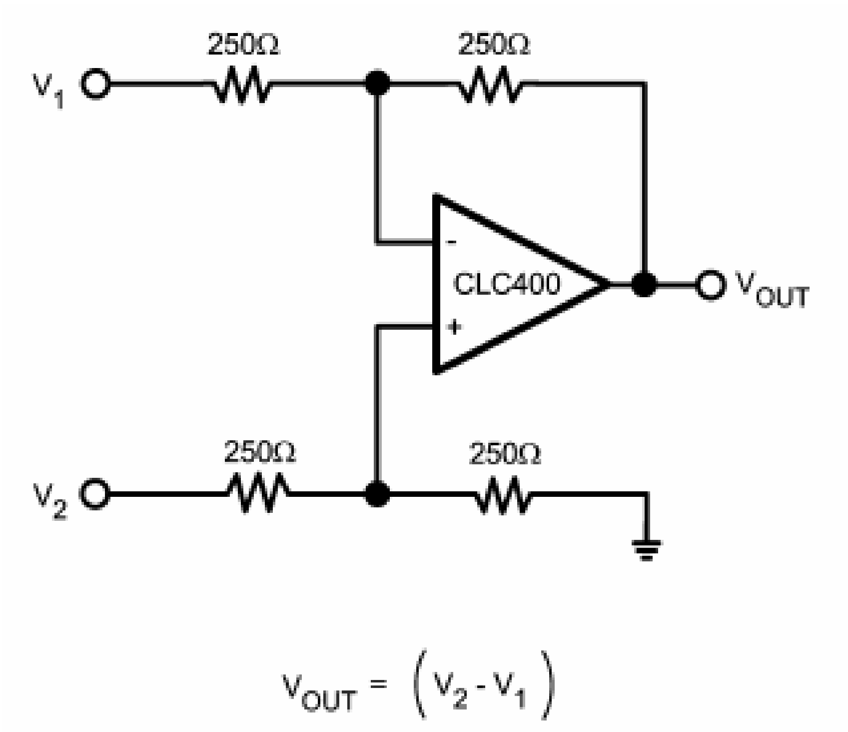


Inverting receiver

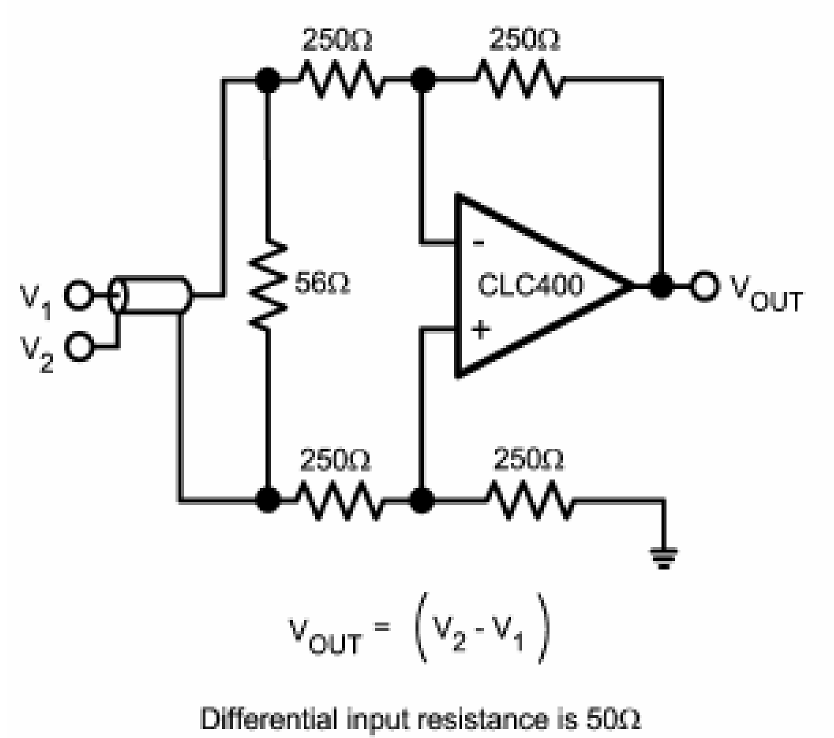


Non-inverting receiver

Applications II

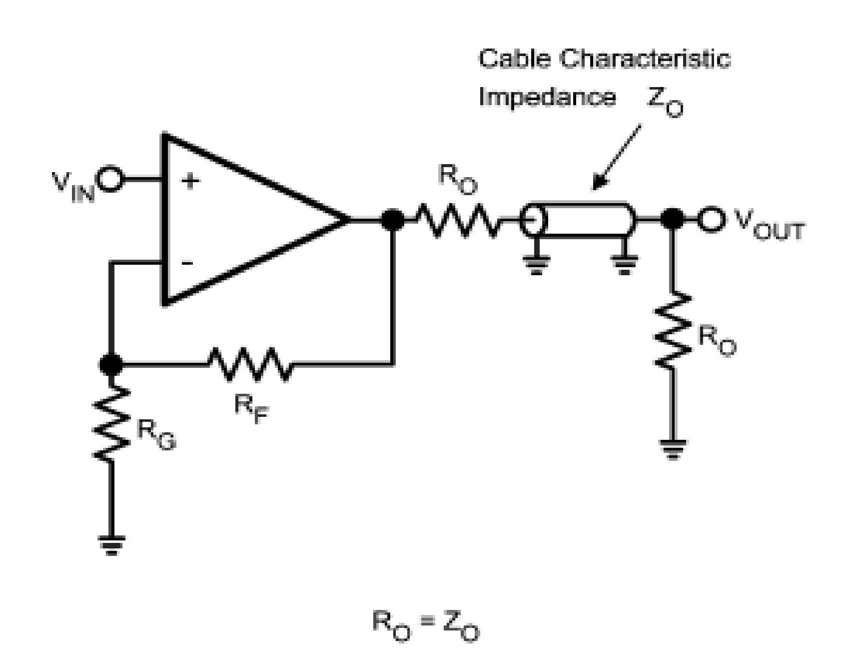


Differential amplifier

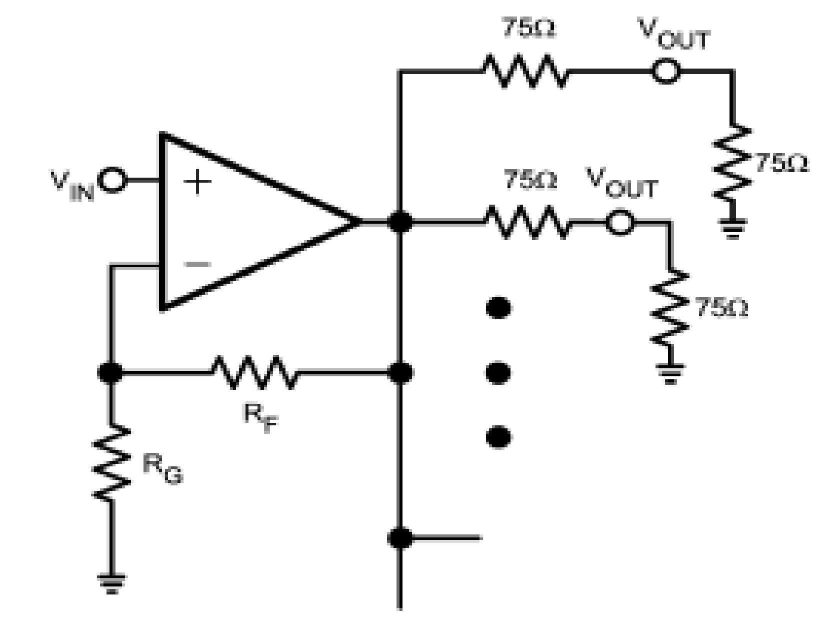


Differential line driver

Antenna circuits

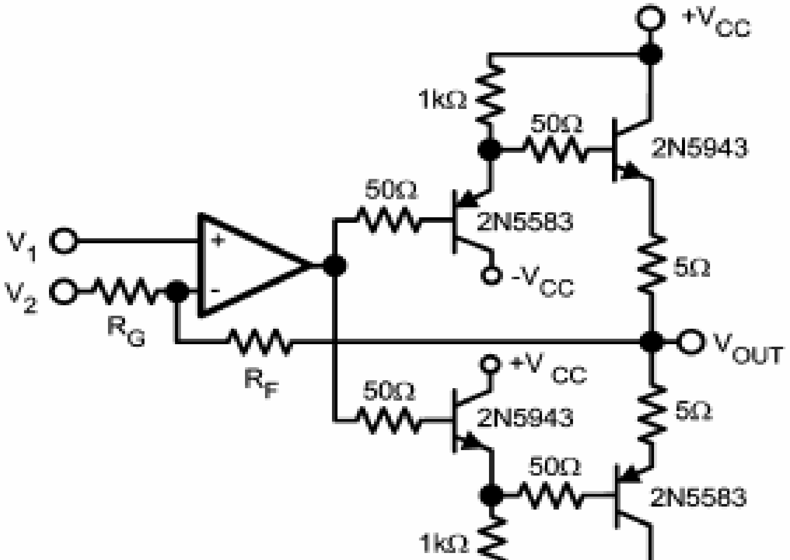


Coax cable driver



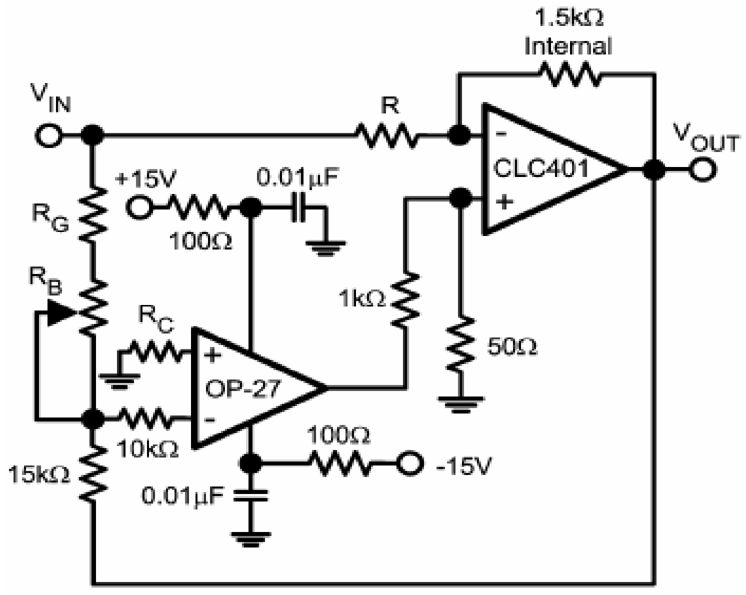
Distribution amplifier

CFOA can be combined with other stages…



$$V_{OUT} = V_1\left(1+\frac{R_F}{R_G}\right) - V_2\left(\frac{R_F}{R_G}\right)$$

With emitter follower



$$V_{OUT} = -\left(\frac{1500}{R}\right) V_{IN}$$

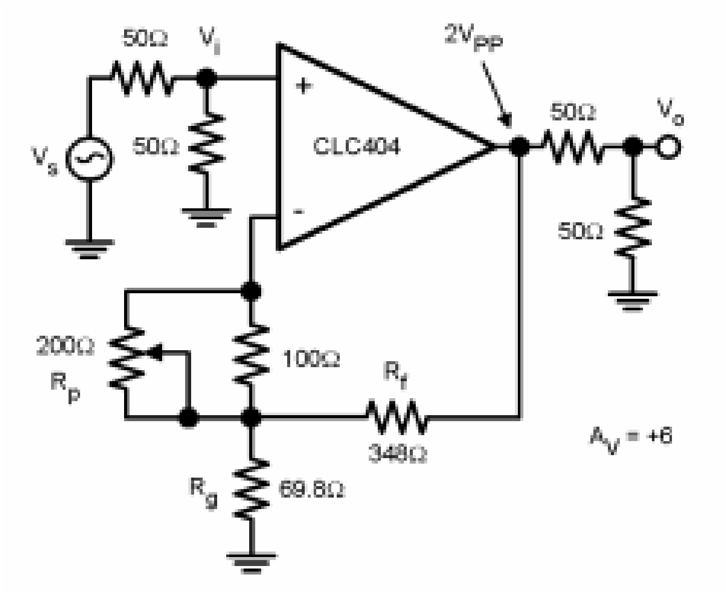
$R_A \cong 9.5R$

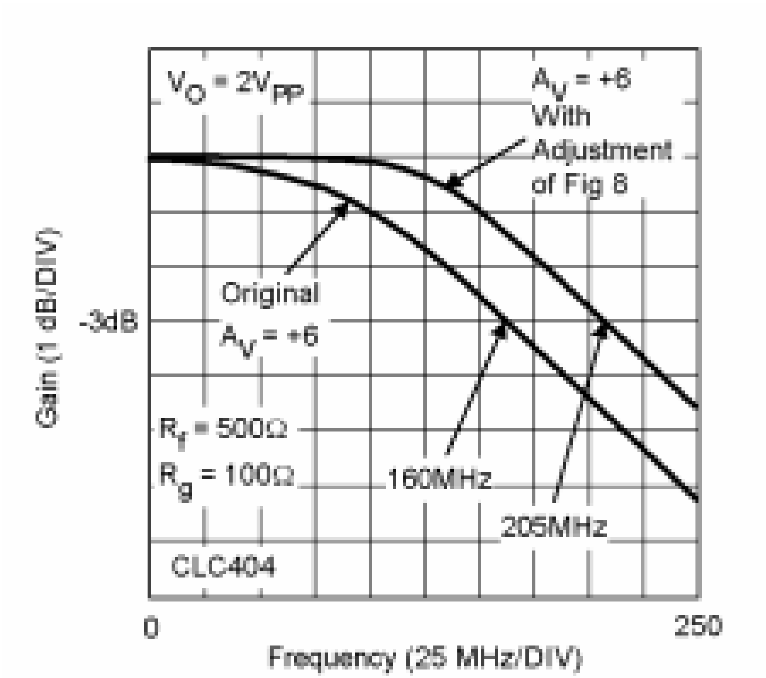
$R_B \cong 0.5R$

$R_C \cong 10K - 15K \parallel (R_A + R_B)$

With op-amps

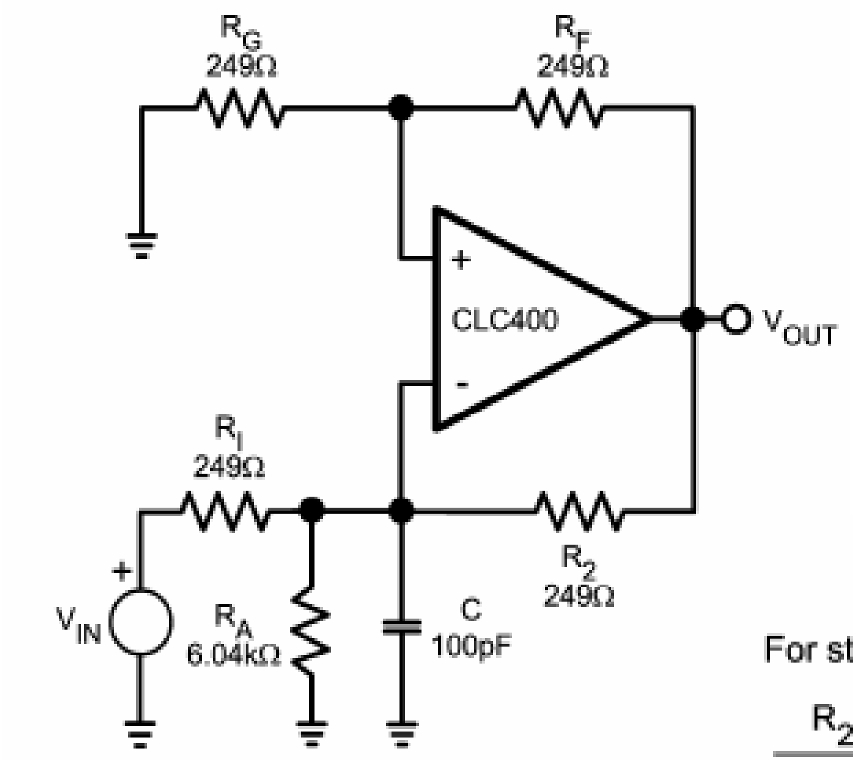
Bandwidth and stability





Adjust BW by increasing inverting input impedance!

Integrator



Integrating capacitance NOT in feedback path.
Capacitance must be lossy enough!

For stable operation,

$$\frac{R_2}{R_1 \| R_A} \geq \frac{R_F}{R_G}$$

All resistors are 1%

$$V_{OUT} = V_{IN}\left[\frac{1 + \frac{R_F}{R_G}}{sR_1C}\right]$$

$$V_{OUT} \backsim V_{IN}\,\frac{2\pi\,(12.8\text{MHz})}{s}$$

Implementation note:
Supply bypassing is NOT optional!