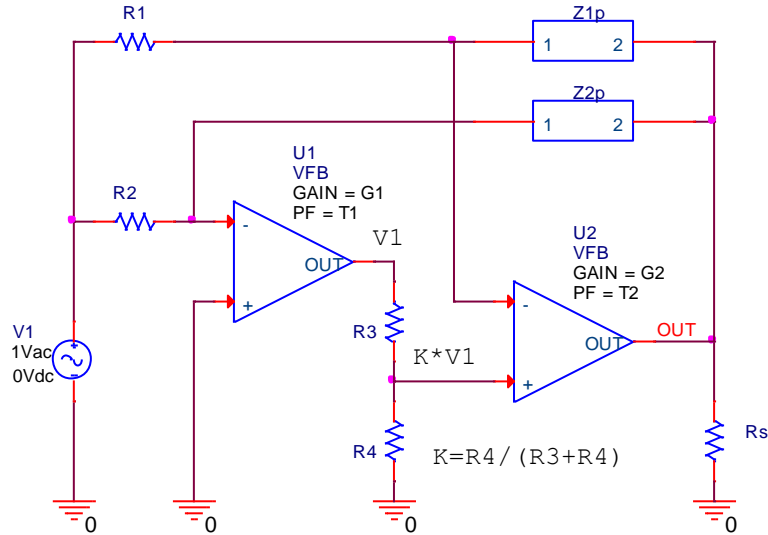


Consider the following composite inverting opamp configuration.



In the above schematic, U1 and U2 are ideal opamps, characterized by G_i the open loop LF gain and T_i the time constant associated to a single pole 3dB frequency response.

$$F_{pi} = \frac{1}{2\pi\tau_i}$$

Let's find out its transfer function and a condition to get the pole zero cancellation. After some ugly but elementary algebra we get:

$$A_u = \frac{V_{OUT}}{V_1} = - \frac{\frac{Z_{1p}}{R_1 + Z_{1p}} + K \frac{G_1}{1 + j\omega T_1} \frac{Z_{2p}}{R_2 + Z_{2p}}}{\frac{R_1}{R_1 + Z_{1p}} + K \frac{G_1}{1 + j\omega T_1} \frac{R_2}{R_2 + Z_{2p}} + \frac{1 + j\omega T_2}{G_2}}$$

Assume for the moment the last term in the denominator as very small (its real part is $1/G_2$ (really small)), while the imaginary part is inverse proportional to the U2 gain-bandwidth product, hence the need for an (as much as possible) high speed opamp. U2 usually contains the output power stage, with its usual bandwidth limitations, so we'll eventually see how to deal with this constraint.

Now, introduce two notations:

$$\frac{R_1}{R_1 + Z_{1p}} \div p \text{ and } \frac{R_2}{R_2 + Z_{2p}} \div q$$

Therefore:

$$\frac{Z_{1p}}{R_1 + Z_{1p}} \div 1 - p \text{ and } \frac{Z_{2p}}{R_2 + Z_{2p}} \div 1 - q$$

The transfer function becomes:

$$A_u = \frac{V_{OUT}}{V_1} \approx - \frac{(1-p) + K \frac{G_1}{1+j\omega T_1} (1-q)}{p + K \frac{G_1}{1+j\omega T_1} q}$$

Now put $p=q=m$ and the transfer function is:

$$A_u = \frac{V_{OUT}}{V_1} \approx - \frac{1-m}{m}$$

Assume the two impedances Z_{1p} and Z_{2p} as RC parallel cells, $R_{1p} || C_{1p}$ and $R_{2p} || C_{2p}$ respectively. Therefore, $p=q$ above becomes:

$$\frac{R_1}{R_2} = \frac{R_1 + Z_{1p}}{R_2 + Z_{2p}}$$

Now make the Z_{1p} and Z_{2p} associated time constants equal:

$$R_{1p}C_{1p} = R_{2p}C_{2p} \therefore \tau$$

We can now expand the previous complex expression:

$$\frac{R_1}{R_2} = \frac{R_1(1+j\omega\tau) + R_{1p}}{R_2(1+j\omega\tau) + R_{2p}} = \frac{R_1 + R_{1p}}{R_2 + R_{2p}} \frac{1+j\omega \frac{\tau R_1}{R_1 + R_{1p}}}{1+j\omega \frac{\tau R_2}{R_2 + R_{2p}}}$$

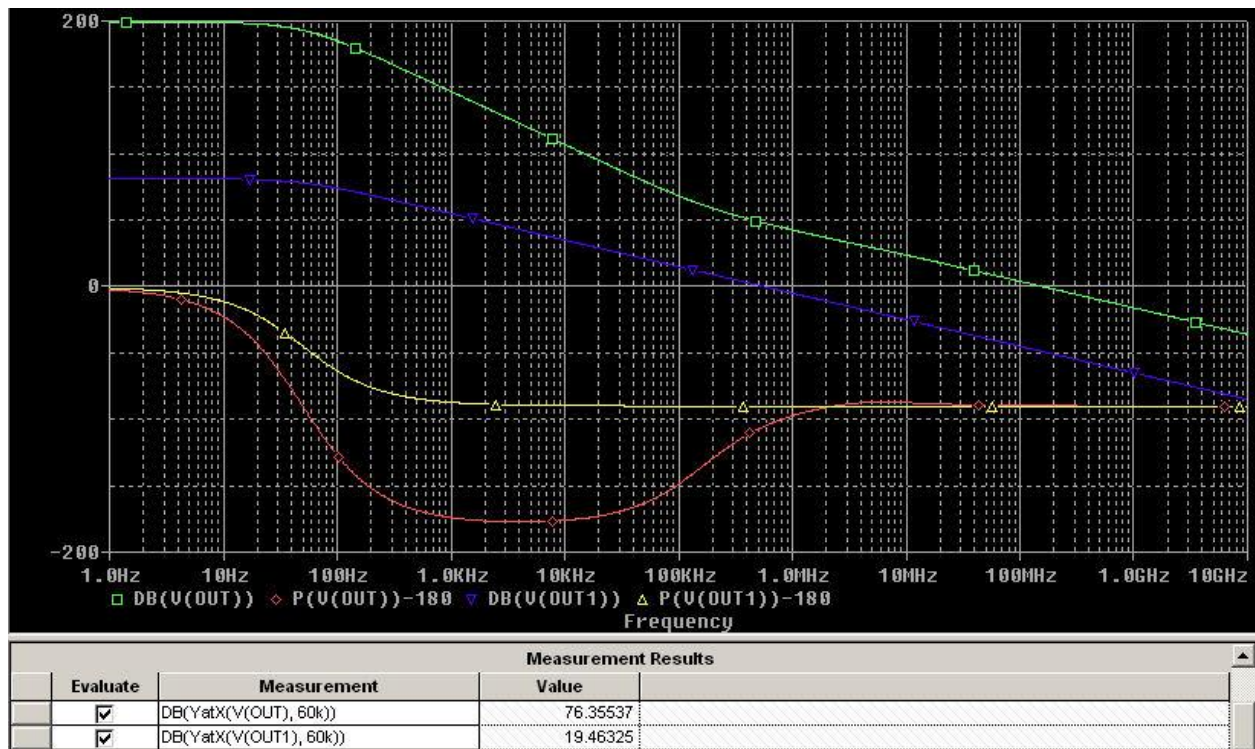
We would like to have this frequency independent, so the imaginary parts at the numerator and denominator have to be equal which leads to:

$$\frac{R_1}{R_2} = \frac{R_{1p}}{R_{2p}}$$

This is the first pole/zero cancellation condition. Now substituting in $p=q$ we get the second condition:

$$\frac{R_1}{R_2} = \frac{C_{2p}}{C_{1p}}$$

The conclusion: If the second stage has a pole placed at a high enough frequency, and the two conditions above are fulfilled, then the first stage pole is exactly cancelled by a zero, and the closed loop frequency response is controlled by the (closed loop) second stage pole only. Here's a loop gain simulation of this ideal configuration, for $G_1=G_2=100\text{dB}$ and $F_{p1}=F_{p2}=50\text{Hz}$. These are pretty typical values for a modern opamp and they are chosen from the Texas Instruments TLE2072 datasheet. This opamp will be used throughout this work. Note that it is critical the gain stages to have single (dominant) pole characteristics. There are no provisions in this technique to deal with any residual poles, these can really mess up the phase to the point of making the composite amp sing even at several hundred of MHz!



On the same graph above, the loop gain (blue is gain, yellow is phase) of a single opamp with these parameters, set for the same closed loop gain of 27, is represented. Both configuration are stable with a phase margin of 90 degrees(which is typical for a single dominant pole response). But look at the unity loop gain frequency – the single gain stage has an ULGF of some 600KHz, while the composite opamp has an ULGF of 150MHz! As a result, the loop gain available to linearize the amp increases at 60KHz from 19dB to no less than 76dB! Such a loop gain will certainly bring a regular audio amp with an open loop distortions THD20 of 0.1%, mostly third harmonic, to 0.000016%, or 0.16ppm.

Interesting enough, if the cancellation condition is maintained, the loop gain does not depend on K (the resistive divider ratio). From a theoretical perspective, that divider is not really required. It though has some advantages in a more practical approach as we're going to eventually discuss.

To be continued...