EE124 Lab Experiment 5 Design of a Feedback Circuit

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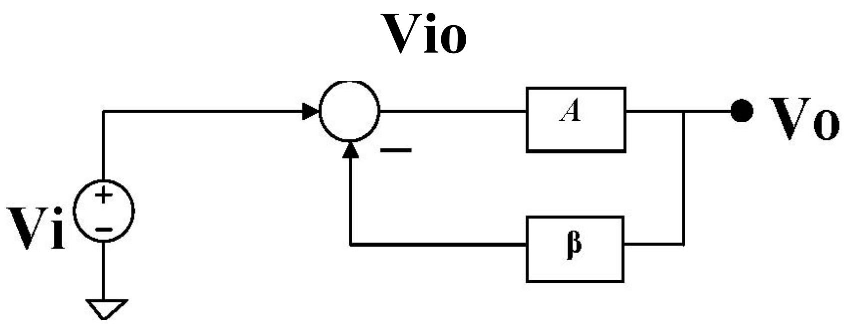
Feedback Theory



Definitions:

Open loop gain: $A = \frac{Vo}{Vio}$

Loop gain : Make Vi = 0

Open the loop at a convenient place, for example at Vio. Apply a test signal Vt there. Then $LG = (\beta A V_t) / V_t = -A\beta$

Closed Loop gain: $Af = \frac{Vo}{Vi} = A / (1+A\beta)$ **; If** $A\beta >> 1$**, then** $Af \approx 1/\beta$

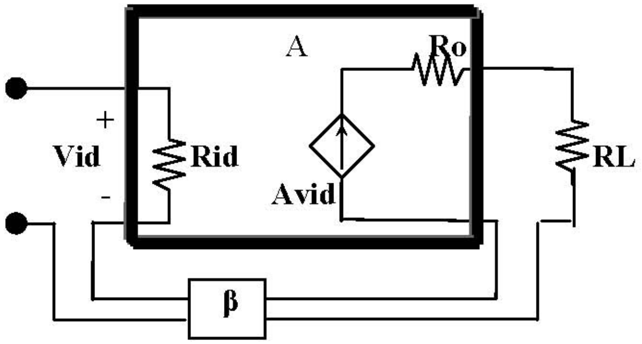
Advantage: Af depends mostly on the β network, thus is less-sensitive to variations of the open loop amplifier characteristics. Other advantage : Dependent on the feedback configuration the input and the output resistance may be increased and/or decreased, respectively.

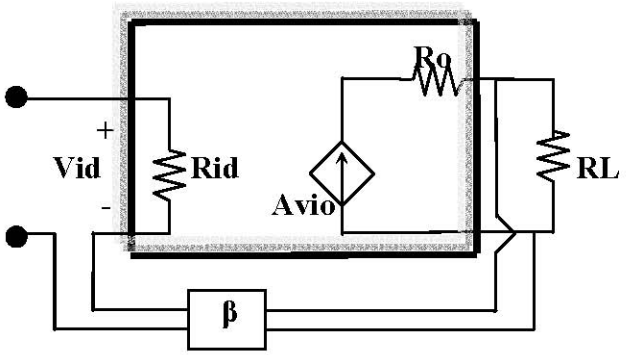
To obtain a deeper understanding of feedback theory you should study the feedback portion of Sedra/Smith, Microelectronic

Circuits. a) Fifth Edition: pp. 799 – 831 (The most important part pertaining to Lab 5 would be on pp. 799 – 810 and on page 830).
b) Fourth Edition: pp. 675 – 709 (The most important part pertaining to Lab 5 would be on pp. 675 – 688 and on page 709).

Only two feedback configurations are shown below. The designer should know that in feedback circuits the relative high open loop gain is traded into a lower closed loop gain. The "payback" is that the input impedance and/or output impedance of the open loop amplifier may be altered depending on the feedback configuration used. If you wish to increase the existing open loop amplifier input resistance then you must choose a series-input (voltage combining) configuration. If you wish to decrease the existing open loop amplifier output resistance then you must choose a shunt-output (voltage sampling) configuration.

Examples of Feedback configurations: Effect on

<table>
<tr><th>Feedback configuration</th><th>Name</th><th>Rif</th><th>Rof</th></tr>
<tr><td>


</td><td>Series-
Series</td><td>Rid(1 + Aβ)</td><td>Ro(1 + Aβ)</td></tr>
<tr><td>


</td><td>Series-
Shunt</td><td>Rid(1 + Aβ)</td><td>Ro / (1 + Aβ)</td></tr>
</table>

The Lab 5 Experiment

In the Lab 5 experiment the transconductance amplifier characterized in Lab 4 is used as an open loop amplifier. A circuit has to be designed such as to meet one of a set of three specifications given in the Appendix of the EE124 Lab Manual. The specifications of the feedback amplifier call for a reduced gain Af, an increased

input resistance Rif, and a decreased output resistance Rof. Thus it is obvious that only a series-shunt feedback configuration will do this job. This decision has been done for you already in the lab manual by suggesting the circuit where the feedback output (left side of the beta-network) is in series with the input to the open loop amplifier, and where the feedback circuit input (right side of the beta-network) is in shunt with the load resistor RL. Let us consider an example, where the spec's to be achieved are in the left column of the following table, and where the measured properties of the open loop amplifier are in the right column.

Note: your values will be different dependent on your specification and on the values measured in Experiment 4.

Closed Loop Amplifier Specification Example	**Open Loop Amplifier: Measured properties**
RL = 10 k	**A = 190 V/V**
Af = 5 ± 10 %	**Rid = 18 kOhm**
Rof ≤ 750 Ω	**Ro = 50 kOhm**
Rif ≥ 330 k	

Note: Before you trust your measured data of Expt 4, you should verify the validity of your measurements by using your understanding of the model of the transconductance amplifier. A = GMRL=gmRL=(Ic/Vt)RL=(Ibias/2Vt)RL. Assuming Ibias = 1mA and RL=10kOhm, we get A=(1m/(2*25m))*10k=200V/V. It looks like our predicted gain is fairly close to the measured gain in above table.

Rid ≈ $* 2 r_\pi = * 2(\beta+1) * r_e = * 2(\beta+1) * V_t / I_e = * 2(\beta+1) 2 * V_t / I_{bias}$

Assuming β= 100 **, we get Rid=2*101*50m/1m=10.1 kOhm. It looks like the measured Rid is almost a factor of two higher than our predicted Rid. The reason for this discrepancy is that our** β **-assumption is too low. More likely the actual device beta is almost a factor of two higher. In Lab 4 we "measured" the beta indirectly by measuring the base current Ibase, and then using the formula**

I_C

β= **, where Ic=Ibias/2. Thus we don't have to guess the beta in order to**

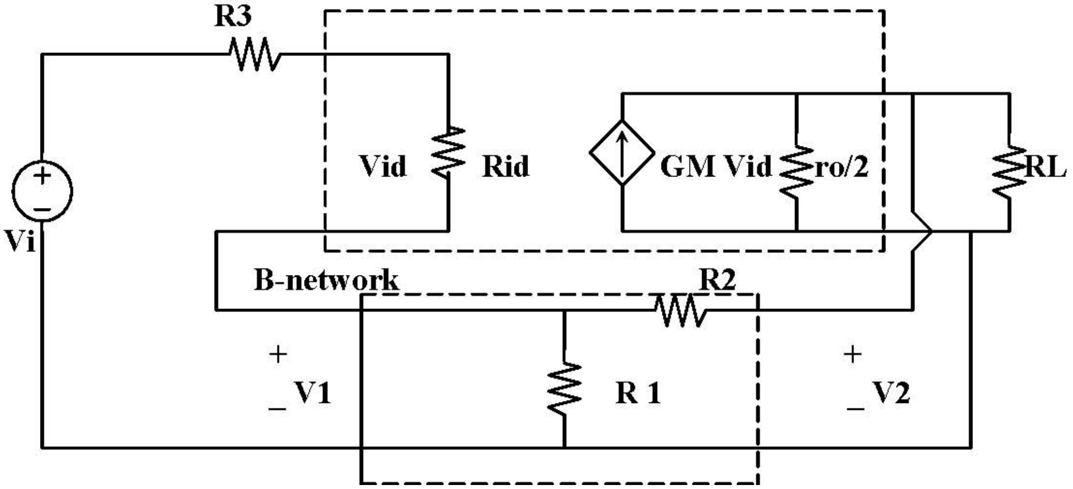
I_{Base}

calculate the expected Rin.

Ro ≈ $\frac{ro}{2}$, since we are looking into the collector of two parallel transistors from the output node in the transconductance amplifier of Expt. 4. Though we didn't make any measurement of the Early resistance of the transistors within the transconductance amplifier, we may assume that ro is similar as that of the current mirror of Experiment 1. Thus let us use ro=100 kOhm, resulting in Ro=50kOhm.

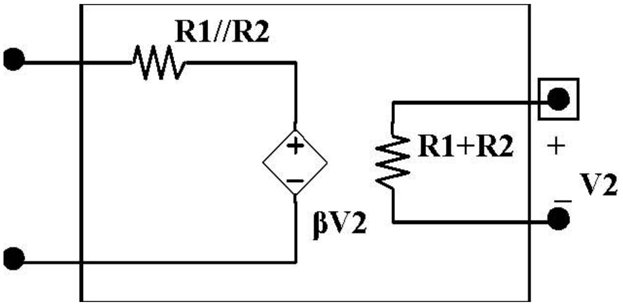
Analysis of the Feedback Circuit of Expt. 5

Initial Circuit Model: To use the Rof formula (Rof = Ro / (1 + Aβ)) you need to idealize the β network. This is done in two steps:

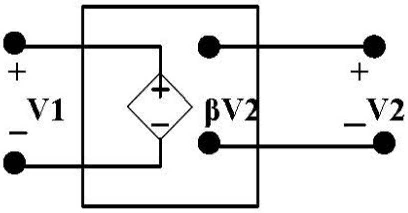


1. **1. Convert above β- network into a network where you have a series resistor on the left and a shunt resistor on the right. This may be achieved by using the h-parameter representation of the β-network.**
2. **2. Idealize the β network by moving the resistors into the amplifier above. R1//R2 is moved by sliding the resistor combination along the input wire. R1 + R2 is moved by sliding the resistors between the two output wires.**

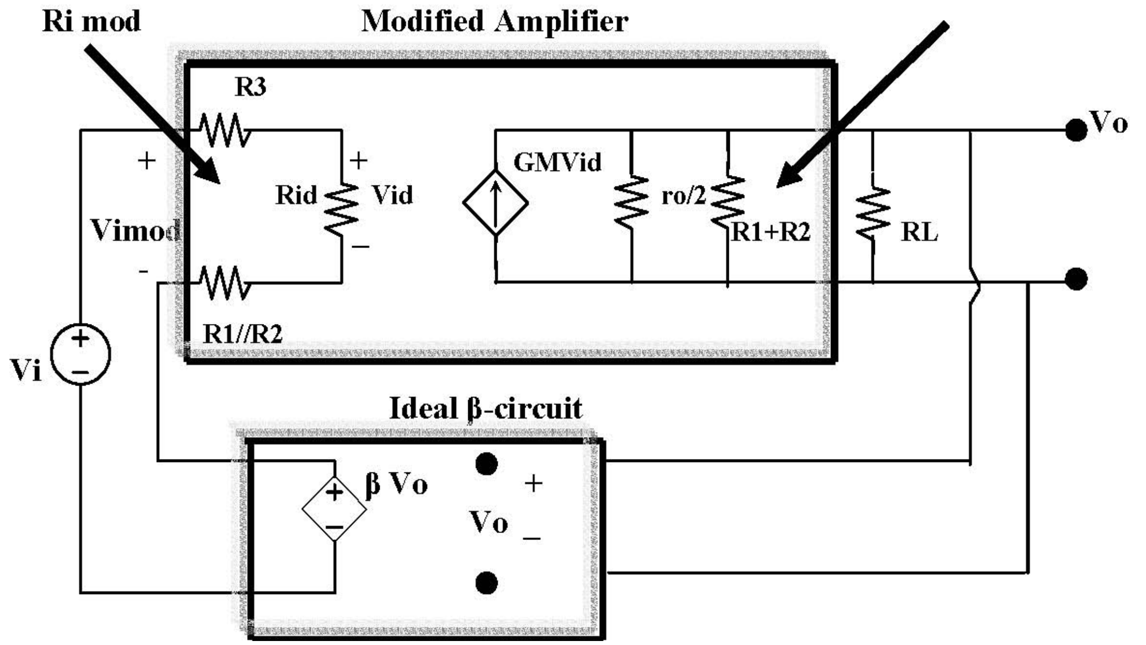
Modified β net work



Idealized β net work



Redraw the total circuit with the idealized β network. Since we modified the original open amplifier, we rename it the "Modified Amplifier".



Ro mod To apply the simplified feedback formulas, you need to re-calculate the parameters of the modified amplifier

Amod = $\frac{Vo}{V_i\text{mod}}$**, where** $V_i\text{mod}$ **is the input voltage to the modified amplifier.**

Vo = GMVid ($\frac{ro}{2}$ **// (R1+R2)// RL)**

Assume $\frac{ro}{2}$ **>> (R1+R2)// RL**

Substitute R22 = R1 + R2

Then Vo = GM Vid $\frac{RLR22}{RL + R22}$

Rid

But Vid = Vimod

Rid + R3 + R// 1 R2 **Purpose of R3 : To balance the offset voltage caused by R1//R2. Therefore, make R3 = R1 // R2 Thus**

Rid RLR22

Amod = GM ; where R22 = R1 + R2 and R3 = R1// R2

Rid + 2R3 RL + R22

Ro mod = R1 + R2 = R22 Ri mod = Rid + R3 +R1 // R2 = Rid + 2R3

*R*1

β =

R1 + R2

Now finally you can apply the feedback equations:

Af = Amod / (1 + Amod β)= 5

Rof = Ro mod / (1+Amod β) ≤ 750 Ω

Rif = Rimod (1 + Amod β) ≥ 330 kΩ

Finding R1 and R2

To meet the design goal, above equations and inequalities have to be satisfied. The only real unknowns are R1 and R2. In the initial stage you may reduce your problem to one unknown, either R1 or R2, by taking advantage of the approximation: $Af \approx 1/\beta$ **. Assume you choose R1 to be the unknown. Make an educated guess of the value for that unknown and run through all the equations, to see which equation and/or inequality is met. Looking at the result you will find that you most likely have to tweak the R1 resistance. Obviously, many iterations may be necessary to eventually converge to a solution. Thus it makes sense to set up all the equations and inequalities in Excel or Matlab. Refer the variables of the equations to actual numbers, consisting of measured data, specified data and/or assumed data. Then try different R1 values.**

For some design problems a solution may not exist within the given design constraints. In that case you may have to renegotiate the specifications with your customer or change your circuit approach. For this lab, due to time constraints, the specifications or altering the circuit constraints are non-negotiable. However, you have to put an honest effort into this design problem, and attempt to satisfy as many spec's as possible and as close as possible. Priorities are given to satisfy

first the gain spec, then the input impedance spec, then the output impedance spec and at last the signal swing spec.

When you finish your hand-design you must simulate your circuit using PSPICE and verify whether your design spec's are met or how close you come in meeting your design spec's. In the beginning of the official last lab-meeting for Experiment 5 you must bring all your hand-calculations, the results of your PSPICE simulation, a tabulation comparing spec's, hand-calculations and PSPICE simulation. As part of the Prelab 5 Quiz these data will be collected. The last Experiment 5 meeting is devoted only to measurements. At that time you have to complete the 4th column of your results: the measurements column.

Design Contest

Let us have a design contest, where the success of your design may be evaluated by using the following score-board. The number in the score board represents the maximum # of points if the spec is completely met in a particular category. Partial credit may be given by reducing the number of points in a cell dependent on how close you came to meeting the spec's. You can see that meeting the gain spec has a higher priority than meeting the output resistance spec. Also, you can see that in the measurement column you earn double the # of points compared to the hand-calculation or PSPICE column. This is realistic, since in the end, it is the measurements which determine whether your product is successful. Hand-calculations and PSPICE are simply tools which help you in achieving a design goal. Whether your end-product is compatible on the market depends on what it "does" and not what it is supposed to do. Whether you design an audio system, a space probe, a bridge (for example the Bay Bridge), it is the end-product which will determine the success or failure of your mission!

	Hand Calculation	**PSPICE evaluation**	**Measurement**
Af	**10**	**10**	**29**
Rif	**8**	**8**	**16**
Rof	**6**	**6**	**12**
Max Signal Swing	**4**	**4**	**8**
Max possible points	**28**	**28**	**56**

The total points possible, including each column, are 112 points. Unfortunately no

grants are available to reward the highest scoring contestants. However, satisfaction of doing a decent job, and also a better quiz-grade for the Quiz on Lab5B and the Quiz 6 should be enough incentive.