332:364 Analog Electronics Laboratory

Laboratory Experiment IV

Feedback Amplifiers

IV.1 Introduction

Objectives

- To demonstrate how feedback can be added to a transconductance and a transresistance amplifier
- To study the effects of feedback on the gain and on the output resistance

Overview

This lab is one of two that are designed to familiarize the student with the effects of feedback. In particular, it is designed to explore the effects of feedback on a transconductance and a transresistance amplifier with respect to gain and output resistance. In particular, it is demonstrated that different types of sampling result in different effects of feedback in desensitizing the gain from changes in the circuit.

The two different configurations are chosen so that two types of feedback are used: series-series and shunt-shunt. The gain and output resistance of each amplifier is determined first without feedback and subsequently after local feedback is applied.

The laboratory experiment is divided into two activities:
   (A) The first activity involves the operation of a simple transconductance amplifier without and with feedback.
   (B) The second activity involves the operation of a simple transresistance amplifier without and with feedback.

The actual laboratory experiments are designed to verify the concepts by direct measurement of currents and voltages. Some of the necessary theory is presented below and the prelab exercises are designed to promote familiarity with the concepts.
V.2 Theory

The material that is relevant to this particular lab is too extensive to be reproduced or summarized here. It covers pages 791-830, of the textbook. Summaries for the cases of series-series and shunt-shunt are reproduced below.

### IV.2.1 The series-series case (voltage-mixing current-sampling)\(^1\)

![Diagram of series-series feedback amplifier](image)

The series-series feedback topology stabilizes \(I_o/V_i\) and is therefore best suited for transconductance amplifiers. The figure above shows the practical structure for the series-series feedback amplifier set up in order to derive the amplifier quantities with feedback from the A circuit. It consists of an assumed unilateral open-loop amplifier (the A circuit) and an assumed ideal feedback network\(^2\). Note that in this case A is a transconductance, and the gain with feedback is:

\[
A_f \equiv G_{of} = \frac{I_o}{V_i} = \frac{A}{1 + \beta A}
\]

while \(\beta\) is transresistance. Thus the loop gain \(A\beta\) remains a dimensionless quantity, as it should. The input resistance seen by the source with feedback is

\[
R_i = R_i (1 + \beta A)
\]

Notice that voltage (or series) mixing always increases the input resistance.

The output resistance \(R_{of}\) of the series-series feedback amplifier is given by:

\[
R_{of} = R_o (1 + \beta A)
\]

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\(^2\) The assumptions involved are that the amplifier only conducts in the forward direction and the feedback network in the reverse. In practice this is not true, but the signals involved are small as compared to their counterparts so that the assumption is usually reasonable.
That is, in this case the negative feedback increases the output resistance. This should have been expected, since the negative feedback tries to make $I_o$ constant in spite of chances in the output voltage, which means increased output resistance. Current (series) sampling always increases the output resistance.

The values for $A$, $\beta$, $R_i$, and $R_o$ are deduced from the fictitious amplifier-without feedback-but-taking-the-loading-of-feedback-into-account (the “A circuit” for short) as below.

Note that $R_{if}$ is the resistance seen by the source, and therefore includes $R_s$ (in series) so from the definition of $R_{in}$ in the first figure it follows that

$$R_{in} = R_{if} - R_s$$

and similarly

$$R_{out} = R_{of} - R_L$$
IV.2.2 The shunt-shunt case (current-mixing voltage-sampling)\textsuperscript{3}

The shunt-shunt feedback topology stabilizes $V_o/I_s$ and is therefore best suited for transresistance amplifiers. The figure above shows the practical structure for the shunt-shunt feedback amplifier set up in order to derive the amplifier quantities with feedback from the A circuit. It consists of an assumed unilateral open-loop amplifier (the A circuit) and an assumed ideal feedback network. Note that in this case A is a transresistance, and the gain with feedback is:

$$A_f = R_mf = \frac{V_o}{I_s} = \frac{A}{1 + \beta A}$$

while $\beta$ is transconductance. Thus the loop gain $A\beta$ remains a dimensionless quantity, as it should. The input resistance seen by the source with feedback is

$$R_{if} = \frac{R_i}{1 + \beta A}$$

Notice that current (or shunt) mixing always decreases the input resistance. Note that this is the resistance seen by the current source, thus it includes (in parallel) any source resistance. Therefore $R_{in}$ as defined in the circuit above will be

$$R_{in} = \frac{1}{\frac{1}{R_{if}} - \frac{1}{R_s}}$$

The output resistance $R_{of}$ of the series-series feedback amplifier is given by:

$$R_{of} = \frac{R_o}{1 + \beta A}$$

That is, in this case the negative feedback decreases the output resistance. Note that this resistance includes (in parallel) any load resistance. Therefore $R_{\text{out}}$, as defined in the circuit above will be

$$R_{\text{out}} = \frac{1}{R_{\text{of}}} - \frac{1}{R_L}$$

The values for $A$, $\beta$, $R_i$ and $R_o$ are deduced from the fictitious amplifier-without feedback-but-taking-the-loading-of-feedback-into-account (the “A circuit” for short) as below.
IV.3 Prelab Assignment: Calculations & PSPICE simulation

Study part V.2 above and review the theory of local shunt and local series feedback. (Sedra and Smith, pp. 791-830 and Table 8.1).

Read the experiment that follows and use the computer software tool OrCAD PSPICE to simulate all lab activities. Make sure to bring the PSPICE results to the laboratory. In addition to being an aid in immediately verifying measured results, they will be the basis of your Prelab grade for this lab.

Specifically, the following items must be addressed using OrCAD PSPICE as part of the prelab assignment:

- Circuit drawings with the nodes labeled and with DC node voltages;
- Magnitude and phase Bode plots of the voltage gains (i.e., generally $V_{\text{out}}/V_{\text{in}}$ in dB).

Also:
- Calculate the transconductance, $G_m (=I_i/V_o)$, of the circuit of figure IV.1 without the 100 $\Omega$ emitter resistor.
- Calculate the transresistance, $R_m (= V_o/I_i)$ of the circuit of figure IV.2, without the 10 k$\Omega$ resistor between the base and the collector.
- Calculate the DC node voltages at the emitter, base, and collector of the transistor in Fig. IV.2.

Fill in all entries in the tables provided below that are labeled “calculated”.

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
IV.4 Experiments

Suggested Equipment

- Protoboard
- Tektronix FG 501A 2MHz Function Generator
- HP (Agilent) 34401A Voltage meter
- Keithley 179A Ammeter
- Tektronix PS 503 Power Supply
- HP 54600A or Agilent 54622A Oscilloscope
- Resistors: 2 x 100 Ω, 2 x 470 Ω, 2 x 1kΩ, 1 x 10 kΩ, 1 x 4.7 kΩ, 1 x 2.2 kΩ
- Transistors: 1 x 2N3904
- Capacitors: 2 x 100 μF
- Variable Resistance Box

Laboratory Activities

Activity IV.4.A.: Local Series-Series Feedback

In this activity, the collector resistance is varied to determine the effect on the gain ($G_m$) of the circuit. Local series feedback is added, and the same changes are made. The effect on the change in the gain of the circuit is compared to the change without feedback.

- IV.4.A. Build the circuit given in Fig. IV.1

![Fig. IV.1: Transconductance amplifier](image)

(i) With no input applied, measure and record the DC node voltages at the base, emitter, and collector. In case the measured values deviate more than 20% from
the values obtained via the OrCAD PSPICE computer simulation in the prelab make sure to fix the circuit before proceeding.

<table>
<thead>
<tr>
<th>Activity A.i. DC voltages</th>
<th>$V_{\text{calc}}$ (V)</th>
<th>$V_{\text{meas}}$ (V)</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{E}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{B}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{C}$</td>
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<td></td>
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</tbody>
</table>

(ii) Perform the following procedure:

a. Apply a 1 V$_{p-p}$ input signal at 1 kHz and perform the following:

1. With an AC voltmeter, measure the AC base voltage.
   
   $V_b = \underline{\phantom{10000}}$ V

2. Adjust the output voltage of the function generator until 20 mV is applied to the base of the transistor.

3. Using the AC ammeter measure the current into the collector. Record all measurements.
   
   $I_c = \underline{\phantom{10000}}$ mA

4. What is the measured $G_m$ (i.e., $I_c/V_b$) of this circuit?
   
   $G_m = I_c/V_b = \underline{\phantom{10000}}$ mA/V

b. Replace the 2.2 kΩ collector resistor with a 1 kΩ resistor and repeat part a. Apply a 1 V$_{p-p}$ input signal at 1 kHz and perform the following:

1. With an AC voltmeter, measure the AC base voltage.
   
   $V_b = \underline{\phantom{10000}}$ V

2. Adjust the output voltage of the function generator until 20 mV is applied to the base of the transistor.

3. Using the AC ammeter measure the current into the collector. Record all measurements.
   
   $I_c = \underline{\phantom{10000}}$ mA

4. What is the measured $G_m$ (i.e., $I_c/V_b$) of this circuit?
   
   $G_m = I_c/V_b = \underline{\phantom{10000}}$ mA/V

5. By what fraction did the output current change?
   
   $\Delta I_c / I_c = \underline{\phantom{10000}}$ %
c. Return the original 2.2 kΩ collector resistor to the circuit and remove the 1 kΩ. Modify the circuit given in Fig. IV.1 by adding a 100 Ω resistor in series between the emitter of the transistor and the $R_{E\,C_E}$ parallel (resistor-capacitor) combination. This adds a local series feedback ($\beta_f = 100 \ \Omega$) to the circuit. Apply a 1 V_{p-p} input signal at 1 kHz and perform the following:

1. With an AC voltmeter, measure the AC base voltage.
$$V_b = \underline{\hspace{2cm}} \ \text{V}$$

2. Adjust the output voltage of the function generator until 100 mV is applied to the base of the transistor.

3. Using the AC ammeter measure the current into the collector. Record all measurements.
$$I_c = \underline{\hspace{2cm}} \ \text{mA}$$

4. What is the measured $G_m$ (i.e., $I_c/V_b$) of this circuit?
$$G_m = I_c/V_b = \underline{\hspace{2cm}} \text{mA/V}$$

d. Replace the 2.2 kΩ collector resistor with a 1 kΩ resistor and repeat part c. Apply a 1 V_{p-p} input signal at 1 kHz and perform the following:

1. With an AC voltmeter, measure the AC base voltage.
$$V_b = \underline{\hspace{2cm}} \ \text{V}$$

2. Adjust the output voltage of the function generator until 100 mV is applied to the base of the transistor.

3. Using the AC ammeter measure the current into the collector. Record all measurements.
$$I_c = \underline{\hspace{2cm}} \ \text{mA}$$

4. What is the measured $G_m$ (i.e., $I_c/V_b$) of this circuit?
$$G_m = I_c/V_b = \underline{\hspace{2cm}} \text{mA/V}$$

5. By what fraction did the output current change, and how does this fractional change compare to the change in part b?
$$\Delta I_c / I_c = \underline{\hspace{2cm}} \%$$

6. How does adding local series feedback change the output resistance of the amplifier?
Activity IV.4.B: Local Shunt-Shunt Feedback
In this activity, the collector resistance is varied to determine the effect on the gain ($R_m$) of the circuit. Local shunt feedback is added, and the same changes are made. The effect on the change in the gain of the circuit is compared to the change without feedback.

- **II.4.B.** Build the circuit given in Fig. IV.2

![Fig. IV.2: Transresistance amplifier](image)

(i) With no input applied, measure and record the DC node voltages at the base, emitter, and collector. In case the measured values deviate more than 20% from the values obtained via the OrCAD PSPICE computer simulation in the prelab make sure to fix the circuit before proceeding.

<table>
<thead>
<tr>
<th>Activity B.i. DC voltages</th>
<th>$V_{calc}$ (V)</th>
<th>$V_{meas}$ (V)</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_E$</td>
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<tr>
<td>$V_C$</td>
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</table>

(ii). Perform the following procedure:

a. Apply a 1 $V_{p-p}$ input signal at 1 kHz and perform the following:
1. With an AC ammeter, measure the AC base current.
   \( I_b = \underline{\ldots} \) µA

2. Adjust the output voltage of the function generator until 50 µA is fed to the base of the transistor.

3. Using an AC voltmeter measure the voltage at the collector. Record all measurements.
   \( V_{bc} = \underline{\ldots} \) V

4. What is the measured \( R_m \) (i.e., \( \frac{V_c}{I_b} \)) of this circuit?
   \( R_m = \frac{V_c}{I_b} = \underline{\ldots} \text{ M}\Omega \)

b. Add an additional load to the circuit by connecting a series combination of a 100 µF capacitor and a 470 Ω resistor from the collector to ground. Apply a 1 V\(_{p-p}\) input signal at 1 kHz and perform the following:

5. With an AC ammeter, measure the AC base current.
   \( I_b = \underline{\ldots} \) µA

6. Adjust the output voltage of the function generator until 50 µA is fed to the base of the transistor.

7. Using an AC voltmeter measure the voltage at the collector. Record all measurements.
   \( V_c = \underline{\ldots} \) V

8. What is the measured \( R_m \) (i.e., \( \frac{V_c}{I_b} \)) of this circuit?
   \( R_m = \frac{V_c}{I_b} = \underline{\ldots} \text{ M}\Omega \)

9. By what fraction did the output voltage change?
   \( \Delta V_c / V_c = \underline{\ldots} \% \)

c. Remove the components added in part b. Modify the circuit in Fig. IV.2 by adding a 10 kΩ resistor from the collector to the base of the transistor. This adds a local shunt feedback (\( \beta_f = 0.1 \text{ mS} \)) to the circuit. Apply a 1 V\(_{p-p}\) input signal at 1 kHz and perform the following procedure:

1. With an AC ammeter, measure the AC base current.
   \( I_b = \underline{\ldots} \) µA
2. Next, adjust the generator's output voltage until 200 µA is fed to the base of the transistor.

3. Using the AC voltmeter measure the voltage at the collector. Record all measurements.
   \[ V_c = \text{__________ V} \]

4. What is the measured \( R_m \) (i.e., \( V_c/I_b \)) of this circuit?
   \[ R_m = V_c/I_b = \text{__________ M\Omega} \]

d. Add an additional load to the circuit by connecting a series combination of a 100 µF capacitor and a 470 Ω resistor. Apply a 1 Vp-p input signal at 1 kHz and perform the following procedure:

1. With an AC ammeter, measure the AC base current.
   \[ I_b = \text{__________ µA} \]

2. Next, adjust the generator's output voltage until 200 µA is fed to the base of the transistor.

3. Using the AC voltmeter measure the voltage at the collector. Record all measurements.
   \[ V_c = \text{__________ V} \]

4. What is the measured \( R_m \) (i.e., \( V_c/I_b \)) of this circuit?
   \[ R_m = V_c/I_b = \text{__________ M\Omega} \]

5. By what fraction did the output voltage change and how does this fractional change compare to the change in part b?
   \[ \Delta V_c/V_c = \text{__________ \%} \]

6. How does adding local series feedback change the output resistance of the amplifier?
IV.5 Report

The laboratory report should follow the outline given in the handout titled “Laboratory Report Guidelines.”

The following items should be addressed in the appropriate sections of the report:

- IV.5.1-2. DC nodal voltage analysis for each Activity in this laboratory experiment;
- IV.5.3-11. AC analysis (including transconductance and transresistance gains) for each activity of this laboratory experiment;
- IV.5.12-13. Compare the results of part b with part d for both activities and discuss the effects feedback has on both the gain and output resistance.