Chapter 10

Feedback
1. Ch 7: Current Mirrors and Biasing
2. Ch 9: Frequency Response
3. Ch 8: Active-Loaded Differential Pair
4. Ch 10: Feedback
5. Ch 11: Output Stages
Learning Objectives

1) The general structure of the negative-feedback amplifier and the basic principle that underlies its operation.

2) The advantages of negative feedback, how these come about, and at what cost.

3) The appropriate feedback topology to employ with each of the four amplifier types: voltage, current, trans-conductance, and trans-resistance.

4) Why and how negative-feedback amplifiers may be unstable (i.e. oscillate) and how to design the circuit to ensure stable performance.
Feedback

Two Stage Op Amp (MOSFET)
“The good news is we’re getting a lot of feedback. The bad news is we’re getting a lot of feedback.”
Introduction

- Most physical systems incorporate some sort of feedback: examples include insulin change in blood after eating, carbon cycle, animal populations, digestive system.

- There are two types of feedback in amplifiers: positive (regenerative: increases the process rate), negative (degenerative: decreases the process rate).

- Positive: feedback signal is in phase with the input signal.
- Negative: feedback signal is out of phase with the input signal.
Introduction

Positive (Regenerative) Feedback

- Feedback signal is in phase with the input signal
- Creates oscillations in the output and makes the amplifier unstable: amplifier will saturate and output will be distorted
- Good for oscillators as it will create stable oscillations
- Chapter 17: Oscillators

Op amp with positive feedback (bistable oscillator)

Colpitts Oscillator
Introduction

Negative (Degenerative) Feedback

- Feedback signal is out of phase with the input signal
- Negative feedback is used to improve fidelity (reduce noise and distortion) of an amplifier by limiting the input signal
- It can stabilize an amplifier with inadvertent positive feedback

Op amp with negative feedback

Precision full-wave rectifier negative feedback
Advantages and Disadvantages of Neg. Feedback

- **Negative feedback** may be used to:
  - **desensitize the gain** (less sensitive to variation in the values of the circuit components due to changes in temperature etc)
  - **reduce nonlinear distortion** (constant gain independent of signal level)
  - **reduce the effect of noise** (minimize interference and unwanted signals)
  - **control the input and output resistances** (raise or lower depending on the feedback topology)
  - **extend bandwidth**

- **Negative feedback** results in **loss of overall gain**
  - Trade-off gain for the above properties
Feedback

- **Not always as expected:**
  - Under certain conditions, negative feedback can become positive: causes oscillation
  - Positive feedback does not always lead to instability: can be used in active filtering

**Why study feedback?**

- important tool for analysis and design of circuits
- valuable insight by thinking in terms of feedback
10.1 The General Feedback Structure

Open-loop amplifier has gain $A$ ($x_o = Ax_i$)

- **Output** ($x_o$) is fed to load as well as feedback network
- **Feedback factor** ($\beta$) defines feedback signal ($x_f$)
- **Feedback signal** ($x_f$) is subtracted from input ($x_i$): **negative feedback**.
- Gain of feedback amplifier is almost entirely determined by feedback network.
- Amount of feedback = $1 + A\beta$

**Figure 10.1**: General structure of the feedback amplifier. This is a signal-flow diagram, and the quantities $x$ represent either voltage or current signals.

$eq10.4: A_f = \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$

$A\beta >> 1 \rightarrow A_f = \frac{x_o}{x_s} = \frac{1}{\beta}$
10.1 The General Feedback Structure

(eq10.6) feedback signal: \( x_f = \frac{A\beta}{1 + A\beta} x_s \)

(eq10.7) input signal: \( x_i = x_s - x_f = x_s - \frac{A\beta}{1 + A\beta} x_s \)

(eq10.6) input signal: \( x_i = \left(1 - \frac{A\beta}{1 + A\beta}\right) x_s \)

(eq10.6) input signal: \( x_i = \left(\frac{1}{1 + A\beta}\right) x_s \)
Example 10.1 (read-only): Gain Desensitivity

(f) Closed-loop gain $A_f$ (the over-all gain of the amp with feedback) is nearly independent of variations in open-loop gain $A$

e.g. 20% reduction in $A$ results in only 0.12% reduction in $A_f$

desensitivity factor $= 1 + A\beta$ = amount of feedback
10.2 Some Properties of Negative Feedback

10.2.1. Gain De-sensitivity

- Equations (10.8) and (10.9) define \textit{de-sensitivity factor of} \((1+\alpha A \beta)\)

10.2.2. Bandwidth Extension

- Equations (10.10) through (10.13) demonstrate how \(3\text{-}dB\) frequencies may be shifted via negative feedback
- The bandwidth is increased by \(1+\alpha A \beta\)
- The gain is reduced by \(1+\alpha A \beta\)

\[ eq 10.12 : \omega_{Hf} = \omega_H (1 + A_M \beta) \]

\[ eq 10.13 : \omega_{Lf} = \frac{\omega_L}{(1 + A_M \beta)} \]
10.2 Some Properties of Negative Feedback

Figure 10.3 Application of negative feedback reduces the midband gain, increases $f_H$, and reduces $f_L$, all by the same factor, $(1+A_M \beta)$, which is equal to the amount of feedback.
10.2 Some Properties of Negative Feedback

10.2.3 Interference Reduction

- Signal-to-interference ratio w/o preamp = $S/I = V_s/V_n$

- Reject Power Supply Hum in the output stage by factor of $A_2$, which provides Pre-amplification

- Signal-to-interference ratio with FB and preamp
  $= S/I = A_2*V_s/V_n$

![Diagram of negative feedback system with preamplifier and power supply noise](attachment:image.png)
10.2 Some Properties of Negative Feedback

- **10.2.4 Reduction in Nonlinear Distortion**
  - Negative feedback may facilitate linearization.

![Graph showing reduction in nonlinear distortion with negative feedback](image-url)
List of Problems

Advantages of Negative Feedback
p10.1: Feedback gain
p10.11: Gain desensitivity
p10.16: Bandwidth extension