EE 230
Lecture 9

Amplifiers and Feedback

Amplifiers are Really Useful Devices

It is a challenge to build amplifiers that have good linearity and precise gains with any basic electronic devices

- Vacuum tube (1878)
- Bipolar Transistor (~ 1948)
- MOSFET (~ 1920 , ~ 1970)

The History of Vacuum Tubes

Electron Tubes - History of the Electron Tube Highlights

By Mary Bellis

- In 1875, American, G.R. Carey invented the phototube.
- In 1878, Englishman Sir William Crookes invented the 'Crookes tube', an early prototype of cathode-ray tube.
- In 1895, German, Wilhelm Roengten invented an early prototype Xray tube.
- In 1897, German, Karl Ferdinand Braun invents the cathode ray tube oscilloscope.
- In 1904, John Ambrose Fleming invented the first practical electron tube called the 'Fleming Valve'. Leming invents the vacuum tube diode.
- In 1906, Lee de Forest invented the audion later called the triode, an improvement on the 'Fleming Valve' tube.
- In 1913, William D. Coolidge invented the 'Coolidge Tube', the first practical Xray tube.
- In 1920, RCA began the first commercial electron tube manufacturing.
- In 1921, American Albert Hull invented the magnetron electronic vacuum tube .
- In 1922, Philo T. Farnsworth develops the first tube scanning system for television.
- In 1923, Vladimir K Zworykin invented the iconoscope or the cathode-ray tube and the kinescope
- In 1926, Hull and Williams co-invented the tetrode electronic vacuum tube.
- In 1938, Americans Russell and Sigurd Varian co-invented the klystron tube.
- source - The Tube Guy

About Vacuum Discharge Tubes

PV Scientific Instruments sells reproductions of antique vacuum tubes and is worth a visit for the images of old vacuum tubes (click on the small images in the bottom row) and the historical information that is included:

> "The earliest forms of such tubes appeared in the late 17th century but, although experimenters like Jean Picard, Francis Hauksbee, William Morgan, and even Michael Faraday experimented with vacuum discharge tubes, it was not until the 1850s that sufficient technology existed to produce sophisticated versions of such tubes. This technology included efficient vacuum pumps, advanced glassblowing techniques, and the Ruhmkorff induction coil."

From A Thumbnail History of Electronics: Vacuum Tubes

Six major figures in the field of vacuum tubes are discussed in synopsis on this website.

General Understanding of Electron Tubes

Electron Tube: General Description

An electron tube typically consists of two or more electrodes enclosed in a glass or metal ceramic envelope that is wholly or partially evacuated.

How Tubes Work

How a typical triode vacuum tube works.

Electron Tube

An electron tube device consisting of a sealed enclosure in which electrons flow between electrodes separated either by a vacuum (in a vacuum tube) or by an ionized gas at low pressure (in a gas tube).

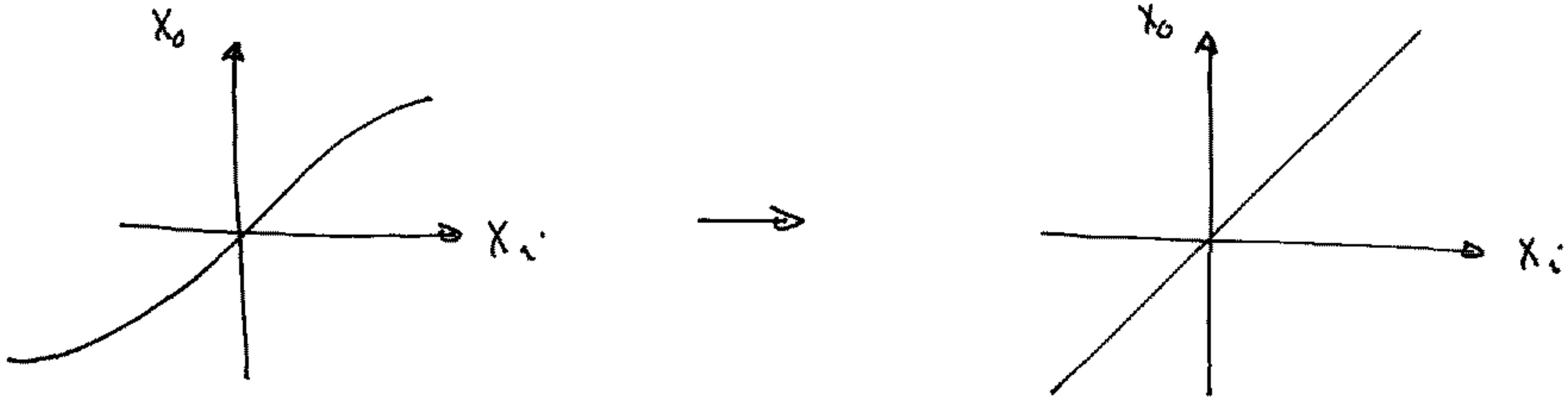
Electrical Engineers Struggled For Many Years (4 decades) with obtaining amplifiers with

1) Accurate Gains

2) Good Linearity

3) Good frequency response

The Amplifier Design Challenge



1) Linearity
2) Accuracy
3) Amplifier Insertion into Signal Path Changes Gain
4) Gain is Frequency Dependent

Why not just use either dependent sources or op amps as amplifiers?

Dependent Sources

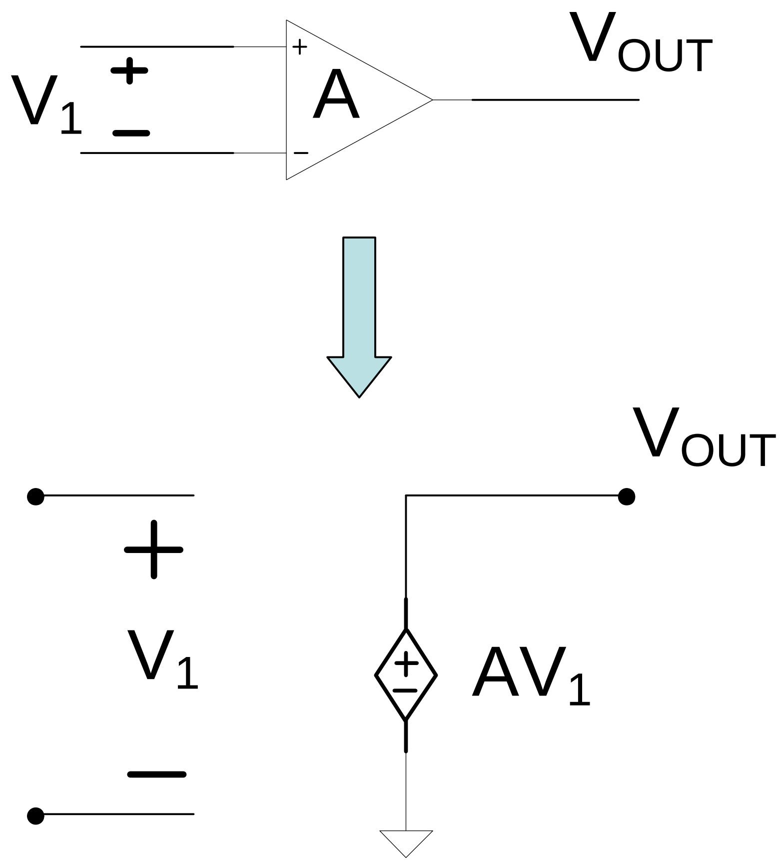
- Not a Basic Device
- How are they made?
  - Vacuum Tubes (in the past)
  - Transistors
    - MOSFET or BJT
  - Highly nonlinear, temperature dependent, process variable

Op Amps

- Gain not accurately controllable
- Gain often too large
- Highly nonlinear
- Difficult to keep operating point constant
  - (discuss this later)
- How are they made?
  - Vacuum Tubes (in the past)
  - Transistors
    - MOSFET or BJT
- Highly nonlinear, temperature dependent, process variable

Op Amp as an Amplifier

$$V_{OUT} = AV_1$$



Equivalent Circuit

Harold Black (1927) introduced feedback as an alternative way to build amplifiers that have

1) Accurate Gains
2) Excellent Linearity
3) Excellent Frequency Response

Harold Stephen Black

From Wikipedia, the free encyclopedia.

Harold Stephen Black (1898-1983) is an electrical engineer who revolutionized the field of applied electronics by inventing the negative feedback amplifier in 1927. He graduated from Worcester Polytechnic Institute in 1921. After his graduation, he went on to work in Bell Labs. To some, his invention is considered the most important breakthrough of the century in the field of electronics, since it has a wide area of application.

External link

- HS Black (http://www.invent.org/hall_of_fame/16.html)

This article about an engineer, inventor or industrial designer is a stub. You can help Wikipedia by expanding it (http://en.wikipedia.org/w/index.php?title=Harold_Stephen_Black&action=edit) .
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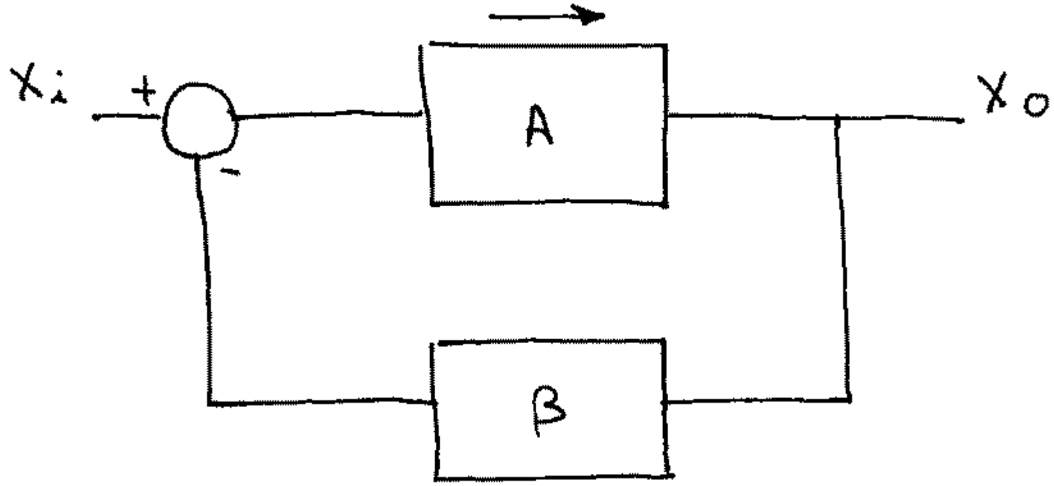
Category: Engineer stubs

Feedback Concept (1927)



$$X_o = (X_i - \beta X_o) A$$

$$X_i A = X_o (1 + A\beta)$$

$$\frac{X_o}{X_i} = \frac{A}{1 + A\beta}$$

if A very large so that $A\beta >> 1$,

$$\frac{X_o}{X_i} = A_{FB} \simeq \frac{1}{\beta} \quad !!!$$

Improvement of most paramaters of interest in feedback amplifiers is obtained simultaneously!

Performance improvement is often by a factor of $1 + A\beta$.

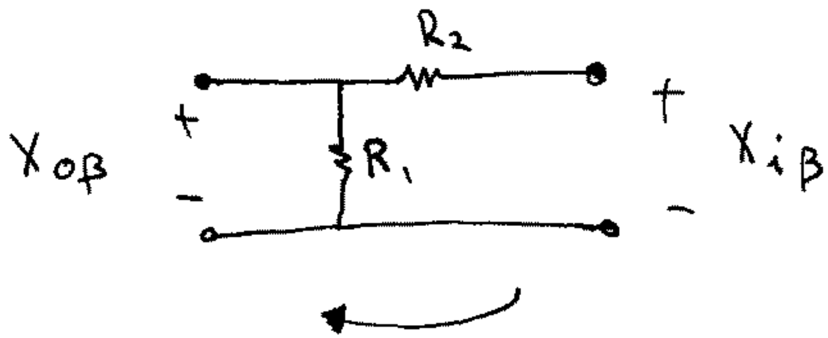
Will verify this fact later.

Example: If $A = 10^5$, $\beta = 1/2$, then

$$1 + A\beta \simeq 1 + 50{,}000 \simeq 50{,}000$$

Feedback has shifted performance requirements from A amplifier to the β amplifier

Example β "amplifier"



$$\frac{X_{o\beta}}{X_{i\beta}} = \frac{R_1}{R_1 + R_2}$$

Properties of this β Amplifier (attenuator)

1) very precise control of β
2) Very linear
3) Nearly independent of f
4) Very low cost (discrete)

Example: Determine A_{FB} if $\beta = \frac{R_1}{R_1 + R_2}$ and A is large

$$A_{FB} = \frac{A}{1 + A\beta} \overset{A \text{ Large}}{\simeq} \frac{1}{\beta}$$

but $\frac{1}{\beta} = 1 + \frac{R_2}{R_1}$

$\therefore$ $A_{FB} \simeq 1 + \frac{R_2}{R_1}$

If $A_{FB} \simeq \frac{1}{\beta}$, "where is waldo?"

$$A_{FB} = \frac{A}{1 + A\beta} \simeq \frac{1}{\beta}$$

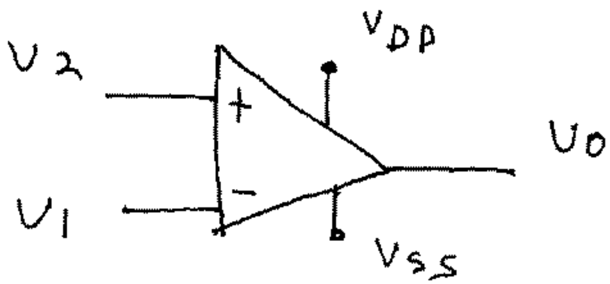
If the performance of the amplifier is essentially not observable at the output, then one has a good feedback amplifier.

After 1927, emphasis shifted to building amplifiers with very large gain

These amplifiers are called "operational amplifiers".

Op Amp

Voltage Amplifier

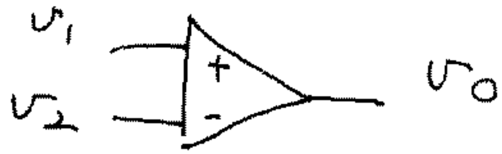


$$V_o = A(V_2 - V_1)$$

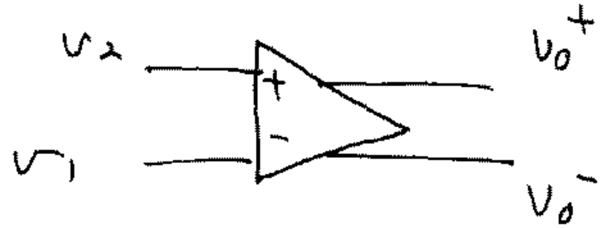
$R_{in} \simeq \infty$

$R_o \approx 0$

Simplified Notation



Fully Differential Op Amp



$$v_o^+ = A_1 (v_2 - v_1)$$

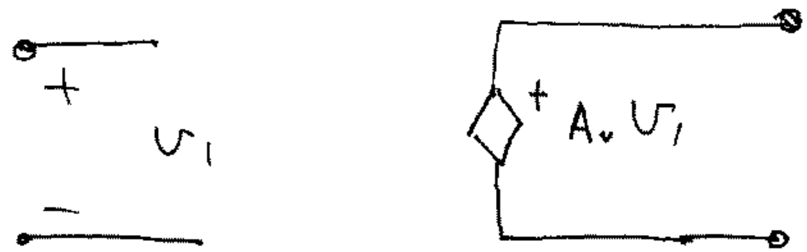
$$v_o^- = -A_1 (v_2 - v_1)$$

$$\therefore \quad v_o^+ - v_o^- = \boxed{2A_1} (v_2 - v_1)$$

$\boxed{2A_1}$ → A_d

$$v_o^+ - v_o^- = A_d (v_2 - v_1)$$

Model of Op Amp



$R_{in} \sim$ { 1 M — Bipolar op AMPs

100's MΩ or Larger — FET Input op amps

$R_o \sim 50\Omega$

$A_v \sim 10^5$ to 10^6