The effects of negative feedback on an amplifier:

**Disadvantage**
- Lower gain

**Advantages**
- Higher input impedance
- More stable gain
- Improved frequency response
- Lower output impedance
- Reduced noise
- More linear operation
Feedback Connection Types

- Voltage-series feedback
- Voltage-shunt feedback
- Current-series feedback
- Current-shunt feedback
Voltage-Series Feedback

For voltage-series feedback, the output voltage is fed back in series to the input.

The feedback gain is given by:

$$A_f \approx \frac{1}{\beta} = \frac{R_1 + R_2}{R_2}$$
Voltage–Shunt Feedback

For a voltage-shunt feedback amplifier, the output voltage is fed back in parallel with the input.

\[ V_o = \frac{V_i}{R_1} \]

The feedback gain is given by

\[ A_f = -\frac{R_o}{R_i} \]
Current-Series Feedback

For a current-series feedback amplifier, a portion of the output current is fed back in series with the input.

To determine the feedback gain:

\[ A_f = \frac{I_o}{V_s} = \frac{A}{1 + \beta A} = \frac{-h_{fe}/h_{ie}}{1 + (-R_E)\left(\frac{-h_{fe}}{h_{ie} + R_E}\right)} \approx \frac{-h_{fe}}{h_{ie} + h_{fe}R_E} \]
Current-Shunt Feedback

For a current-shunt feedback amplifier, a portion of the output current is directed back in parallel with the input.

The feedback gain is given by:

\[ A_f = \frac{I_o}{I_s} \]
# Summary of Feedback Effects

## Summary of Gain, Feedback, and Gain with Feedback

<table>
<thead>
<tr>
<th>Shunt</th>
<th>Voltage-Series</th>
<th>Voltage-Shunt</th>
<th>Current-Series</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain without feedback</td>
<td>$A$</td>
<td>$\frac{V_o}{V_i}$</td>
<td>$\frac{I_o}{I_i}$</td>
<td>$\frac{I_o}{I_i}$</td>
</tr>
<tr>
<td>Feedback</td>
<td></td>
<td>$\frac{V_f}{V_o}$</td>
<td>$\frac{I_f}{I_o}$</td>
<td>$\frac{I_f}{I_o}$</td>
</tr>
<tr>
<td>$A_f$</td>
<td>$\frac{V_o}{V_i}$</td>
<td>$\frac{V_o}{I_i}$</td>
<td>$\frac{I_o}{V_i}$</td>
<td>$\frac{I_o}{I_i}$</td>
</tr>
</tbody>
</table>

## Effect of Feedback Connection on Input and Output Impedance

<table>
<thead>
<tr>
<th>Voltage-Series</th>
<th>Current-Series</th>
<th>Voltage-Shunt</th>
<th>Current-Shunt</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_{of}$</td>
<td>$Z_i (1 + \beta A)$</td>
<td>$\frac{Z_i}{1 + \beta A}$</td>
<td>$\frac{Z_i}{1 + \beta A}$</td>
</tr>
<tr>
<td>(increased)</td>
<td>(increased)</td>
<td>(decreased)</td>
<td>(decreased)</td>
</tr>
<tr>
<td>$Z_{of}$</td>
<td>$\frac{Z_o}{1 + \beta A}$</td>
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<td>(decreased)</td>
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</tbody>
</table>
Frequency Distortion with Feedback

• If the feedback network is purely resistive, then the gain with feedback will be less dependent on frequency variations. In some cases the resistive feedback removes all dependence on frequency variations.

• If the feedback includes frequency dependent components (capacitors and inductors), then the frequency response of the amplifier will be affected.
Noise and Nonlinear Distortion

- The feedback network reduces noise by cancellation. The phase of the feedback signal is often opposite the phase of the input signal.

- Nonlinear distortion is also reduced simply because the gain is reduced. The amplifier is operating in midrange and not at the extremes.
Bandwidth with Feedback

Feedback increases the bandwidth of an amplifier.
Gain Stability with Feedback

Gain calculations with feedback are often based on external resistive elements in the circuit. By removing gain calculations from internal variations of $\beta$ and $g_m$, the gain becomes more stable.
Phase and Frequency Considerations

At higher frequencies the feedback signal may no longer be out of phase with the input. The feedback is thus positive and the amplifier, itself, becomes unstable and begins to
The feedback signal must be positive.

If the feedback signal is not positive or the gain is less than one, the oscillations dampens out.

The overall gain must equal one (unity gain).

If the overall gain is greater than one, the oscillator eventually saturates.
Types of Oscillator Circuits

- Phase-shift oscillator
- Wien bridge oscillator
- Tuned oscillator circuits
- Crystal oscillators
- Unijunction oscillator
Phase-Shift Oscillator

The amplifier must supply enough gain to compensate for losses. The overall gain must be unity.

The RC networks provide the necessary phase shift for a positive feedback.

The values of the RC components also determine the frequency of oscillation:

\[
f = \frac{1}{2\pi RC\sqrt{6}}
\]
Phase-Shift Oscillator

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\[ f = \frac{1}{2\pi \sqrt{6RC}} \]
Wien Bridge Oscillator

The amplifier must supply enough gain to compensate for losses. The overall gain must be unity.

- The feedback resistors are $R_3$ and $R_4$.
- The phase-shift components are $R_1$, $C_1$ and $R_2$, $C_2$.

\[ f_0 = \frac{1}{2\pi \sqrt{R_1 C_1 R_2 C_2}} \]
Tuned Oscillator Circuits

Tuned oscillators use a parallel LC resonant circuit (LC tank) to provide the oscillations.

There are two common types:

**Colpitts**—The resonant circuit is an inductor and two capacitors.

**Hartley**—The resonant circuit is a tapped inductor or two inductors and one capacitor.
Colpitts Oscillator Circuit

The frequency of oscillation is determined by:

\[ f_0 = \frac{1}{2\pi\sqrt{LC_{eq}}} \]

where:

\[ C_{eq} = \frac{C_1C_2}{C_1 + C_2} \]
Hartley Oscillator Circuit

The frequency of oscillation is determined by:

\[ f_o = \frac{1}{2\pi \sqrt{L_{eq} C}} \]

where:

\[ L_{eq} = L_1 + L_2 + 2M \]
Crystal Oscillators

The crystal appears as a resonant circuit.

The crystal has two resonant frequencies:

**Series resonant condition**
- RLC determine the resonant frequency
- The crystal has a low impedance

**Parallel resonant condition**
- RL and $C_M$ determine the resonant frequency
- The crystal has a high impedance

The series and parallel resonant frequencies are very close, within 1% of each other.
Series Resonant Crystal Oscillator

- RLC determine the resonant frequency
- The crystal has a low impedance
Parallel Resonant Crystal Oscillator

- $R_L$ and $C_M$ determine the resonant frequency
- The crystal has a high impedance
Unijunction Oscillator

The output frequency is determined by:

\[ f_0 = \frac{1}{R_T C_T \ln[1/(1 - \eta)]} \]

Where \( \eta \) is a rating of the unijunction transistor with values between 0.4 and 0.6.
Unijunction Oscillator Waveforms

The unijunction oscillator (or relaxation oscillator) produces a sawtooth waveform.