<u>Feedback</u>

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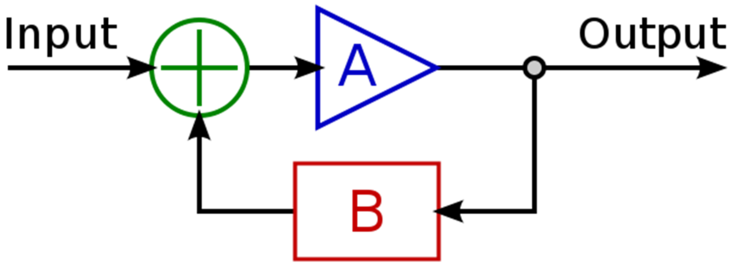
Feedback is where a portion (B) of the output of a process (A) is fed back and summed with the input - a **feedback loop** is formed.



If the feedback is of the same polarity (in-phase) as the input signal it will reinforce (add to) the input signal and cause the output to increase. This is called **positive feedback.**

If the feedback is in the opposite polarity (out of phase) as the input signal it will subtract from the input signal and cause the output to reduce. This is called **negative feedback**.

Feedback is evident everywhere in nature, medicine, mechanics, economics, and electronics - anywhere the output of a process changes one or more of its input variables. One example of negative feedback is how a cruise-control system maintains an accurate vehicle speed by feeding back information from a speed sensor to the engine management computer. In biology, negative feedback mechanisms are used to regulate the control of movement, blood chemistry, sugar levels, and many other essential functions.

The General Feedback Equation

The easiest way to understand feedback is by understanding the **general feedback equation**, which defines how the gain of an amplifier will be changed by the application of feedback:

$A = \frac{Ao}{1+\beta Ao}$ Where:

A is the total amplification

Ao is the gain of the amplifier without feedback, also called the **Open Loop Gain**.

β is the fraction of the output that is looped back to the input.

If βAo is very large and positive (and causing negative feedback with an inverting amplifier), then the formula can be simplified to:

$A = \frac{Ao}{\beta Ao}$ and, by cancelling out the term Ao it can be simplified to: $A = \frac{1}{\beta}$

This means that for large amounts of feedback the gain of an amplifier is independent of the open-loop gain (the gain of the amplifier devices themselves). ***The gain is then solely determined by the ratio of the feedback signal***.

Positive Feedback

In electronics, positive feedback is used to reinforce an input signal and to cause an amplifier to oscillate at some resonant frequency, perhaps that of a tuned circuit, or crystal or ceramic resonators. You can hear the effect of positive feedback when a microphone is placed close to a loudspeaker – the squeal produced is the natural resonant frequency which is the combination of all the equipment and the room acoustics.

Digital circuits use feedback in bistable clock circuits, called flip-flops, to continuously toggle between two stable voltage states or logic states.

Negative Feedback

We will now concentrate on negative feedback which is used extensively in process-control and amplifier circuits, but first a couple of definitions:

Open-loop gain is the gain of an amplifier with no feedback (an open or disconnected feedback loop).

Closed-loop gain is the gain of an amplifier with feedback, (a closed or connected feedback loop).

Distortion is a variation in the response of an amplifier at different input signal voltages, so, if the closed-loop gain is solely determined by the ratio of the feedback loop, (which is determined by passive resistors - not by the open-loop gain of an active non-linear amplifier) there should be no distortion.

In a similar manner, as the general feedback formula does not have a frequency component, if the feedback loop works equally well at all frequencies an amplifier with a large amount of negative feedback should have infinite frequency response.

Also, as the gain is set by the feedback ratio, it should be independent of changes in input and output impedances.

Clearly, in the real world, we can't make such an amplifier with infinite frequency response, zero distortion, or total independence from input and output impedance variation, no matter how much feedback we apply. This is because there is always a limit to how much open-loop gain we can achieve in an amplifier, and there will always be a frequency where the amplifier's open-loop gain starts to fall off.

Also, as frequency is increased, the feedback signal will start to depart from a perfect inverted signal with a 180-degree phase shift compared to the input signal. Perfect subtraction at the input summing point will no longer occur.

So, in the real world, the general feedback equation is never perfectly applicable and performance depends on the complex interaction of gain, bandwidth, phase characteristics of the amplifier and feedback circuitry, and the amount of feedback applied i.e., the AC performance of the total feedback loop.

Negative Feedback in Audio Amplifiers

Negative feedback is commonly used in amplifiers to achieve various benefits, such as improving frequency response, decreasing output impedance, reducing distortion, and precisely setting the circuit gain.

For example, if an amplifier has 20 decibels (dB) of negative feedback, its voltage gain, distortion, and output impedance would be reduced by a factor of 10, (the output impedance would also depend on the series impedance of any output coupling capacitor outside the feedback loop, at any particular frequency).

The power output of the amplifier for the same input signal voltage would be reduced by a factor of 100. This is because 20 dB in voltage is a factor of 10, while 20 dB in power is a factor of 100. See the tutorial on decibels.

Global Feedback

Amplifiers typically consist of multiple stages, and **global feedback** refers to the feedback loop that is connected around the entire circuit, from output to input. Amplifiers with a significant amount of global negative feedback can have impressive specifications, but as we will see it's possible that the feedback may be masking some serious underlying issues.

Nested/Local Feedback

In amplifiers without global feedback, there can still be local feedback loops that are less obvious. These occur within individual amplifier stages and are referred to as **nested feedback** loops or **local feedback**. Examples of local negative feedback include the use of emitter or cathode resistors that are not bypassed with a capacitor for AC signals.

Phase Shifts and Feedback

It's crucial to carefully design the entire amplifier to avoid the introduction of phase shifts or resonances that could cause the feedback to become positive at certain frequencies, leading to oscillation. Oscillation can have detrimental effects, including damage to loudspeakers or other components. A poorly designed audio amplifier may oscillate at frequencies outside the human hearing range, making it difficult to detect the issue through listening, but it can cause damage over time.

Tube amplifiers are particularly susceptible to oscillation caused by high-frequency signal phase shifts occurring in output transformers (especially low-cost transformers). For this reason, additional components are often used to attenuate high frequencies before they reach the output transformer, and large amounts of negative feedback should be used very carefully.

Transient Distortion

One potential problem with using large amounts of global negative feedback is **transient distortion** - a type of distortion that occurs during sudden, high-speed transients in music or human voice waveforms. Tube amplifiers with large amounts of negative feedback are particularly susceptible to this type of distortion.

Say you have an amplifier with 20dB of negative feedback (not an uncommon amount). That amplifier will have a voltage gain reduction of 10 due to the action of the feedback, and probably have very good specifications on paper. However, if a fast rise time voltage transient is applied to the input, the amplifier operates at its full open-loop gain until the transient works its way through the amplifier circuit and the feedback loop. It’s only after a portion of the signal is fed back to the input amplifier that the open-loop gain will be reduced.

During that instant of time, the amplifier open-loop gain will be 10 times greater than normal, so even a small input signal could easily drive the amplifiers into hard overload.

The easiest way to fix this is to ensure that the rise time of the input signal can never approach the maximum speed of the amplifier feedback loop. Amplifiers commonly have components to intentionally limit the rise time (and therefore frequency response) in order to reduce the possibility of transient distortion.

The slowest component in a tube amplifier is almost always the output transformer which is located at the very end of the amplifier chain, just before the negative feedback is sourced from the loudspeaker terminals. Without some sort of frequency limiting in the early stages of a tube amplifier with large amounts of negative feedback, transients that are faster than the output transformer can easily overload the amplifier and cause severe transient distortion.

Solid-state amplifiers are less prone to transient distortion because they do not have an output transformer, and the entire feedback loop is usually extremely fast, usually far faster than the rise time of an audio signal. However, output stage MOSFETs or transistors are still usually the slowest part of the amplifier circuit, and some frequency limiting in the early amplifier stages is common.

In terms of sound quality, some audio amplifiers with substantial amounts of negative feedback have been described as sounding harsh or fatiguing. This could be attributed to transient distortion.

The Red Roo SE5 Amplifier

The Red Roo SE5 amplifier incorporates a small amount of global negative feedback; approximately 6dB for 12AT7 tubes. The amplifier features a switch on the rear panel that allows the global negative feedback to be switched off. When the feedback is switched off, the amplifier's performance changes.

Firstly, the gain of the amplifier increases. With the negative feedback removed, the overall circuit gain is no longer reduced, leading to a higher amplification of the input signal.

Secondly, the distortion of the amplifier increases. Negative feedback reduces distortion, so when it is switched off distortion levels rise. In the single-ended Red Roo design this distortion is predominantly 2nd harmonic distortion (that people usually find pleasing).

Thirdly, the frequency response of the amplifier narrows slightly. Negative feedback aids in flattening the frequency response, so without it, the amplifier's frequency response slightly decreases.

Lastly, the output impedance of the amplifier rises when negative feedback is switched off. This means that the amplifier's ability to control the movement of the loudspeaker's cone, known as the **damping factor**, is reduced. This can have a noticeable effect on the interaction between the amplifier and the loudspeaker, and the sound, particularly the bass.

The most audible difference when switching off the negative feedback will likely be the impact on the loudspeaker's natural resonance. Larger loudspeakers with high cone mass, and open box or ported enclosures that have less mechanical loudspeaker damping, may exhibit more pronounced effects. The cone of the loudspeaker will be seen to move more freely on bass notes. Small lower-mass speaker cones, and headphones, will show lesser effects.

The overall sound of the amplifier without negative feedback is described as becoming fuller, forward, or more resonant. However, it's important to note that the subjective experience of the sound will depend on many factors, including the listening environment and the size and characteristics of the loudspeakers being used.

The output impedance of the Red Roo SE5 can be decreased without using NFB. The output transformer transforms the high impedance at the output tubes to a low impedance at the speaker terminals. Impedance is transformed by the square of the transformer turns ratio, so by switching to the 4-ohm speaker switch position the output impedance is further reduced by the greater turns ratio. The maximum power output of the amplifier is only slightly reduced.

Negative Feedback in Radio Frequency (RF) Amplifiers

Radio receivers usually incorporate an **Automatic Gain Control (AGC)** which adjusts the gain of the receiver depending on the strength of a received signal. This is done by sampling the output from the receiver and rectifying it to produce a varying DC voltage which is then used to adjust the gain of the input RF amplifier.

AGC achieves two things: firstly, it keeps the audio volume, or a data signal voltage, constant over a very wide range of received signal strengths; secondly, and importantly, by reducing the gain of the first RF amplifier after the antenna it improves the dynamic range of the receiver, and prevents it from being overloaded by very strong signals. AGC is a form of negative feedback.

Negative feedback is also used in radio transmitters, where a high-power RF amplifier needs to have a linear (low distortion) response to a varying RF input signal, to avoid harmonics and other problems causing interference to stations on other frequencies.

One such application is the transmission of single sideband voice (SSB), where a negative feedback loop may be used around the power amplifier stages to improve the linearity of the transmitted signal.

Summary

Overall, negative feedback plays a significant role and provides several benefits in terms of performance, control, and an amplifier’s on-paper specifications. However, the implementation and amount of feedback should be carefully managed to avoid potential issues which are not so obvious and will affect an amplifier's overall performance.

Quality amplifiers are designed to perform well even without negative feedback, and negative feedback is then applied in prudent amounts to further improve their performance.