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Feedback Fundamentals: Basic Concepts and Circuit Topologies

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Feedback is used to control gain and reduce distortion, as well as provide other important functions in modern electronic designs

Feedback is an important concept in circuit design, where a signal or voltage derived from the output is superimposed on the input. This output-to-input path can be used for several purposes—control output voltage, control gain, reduce distortion, improve stability, or create instability, as in an oscillator.

This short tutorial reviews feedback, with emphasis on the classic negative feedback amplifier. Notes are also included on the methods for sampling the output and injecting the control signal at the input.

Feedback Principles

For a classic concept like feedback, classic reference texts are a good source of instruction. This section was written with the aid of three of those references [1, 2, 3].

A feedback control system consists of the building blocks shown in Figure 1. Although this is not the traditional control theory textbook diagram, it includes the necessary elements: the signal path, a means of sampling the output, processing of the feedback signal, and a means of reintroducing the error signal at the input. In the simplest feedback systems, the feedback signal processing may be one or two passive components, with direct connections to the through circuit at the output and input. The diagram can also become much more complex, with extensive signal processing and the addition of reference signals, comparators, delay lines and even multiple feedback loops.

Intuitively, feedback control loops are used to achieve a specific performance objective. In a simple solid state voltage regulator, the output sample is compared to a known reference, and error signal is used to adjust the conduction of the pass transistor until equilibrium is achieved—a constant output voltage.

A radio automatic gain control (AGC) system works similarly. In this case, a portion of the output signal is amplified, then rectified to create the DC voltage that can be compared to a reference. The error signal controls the gain

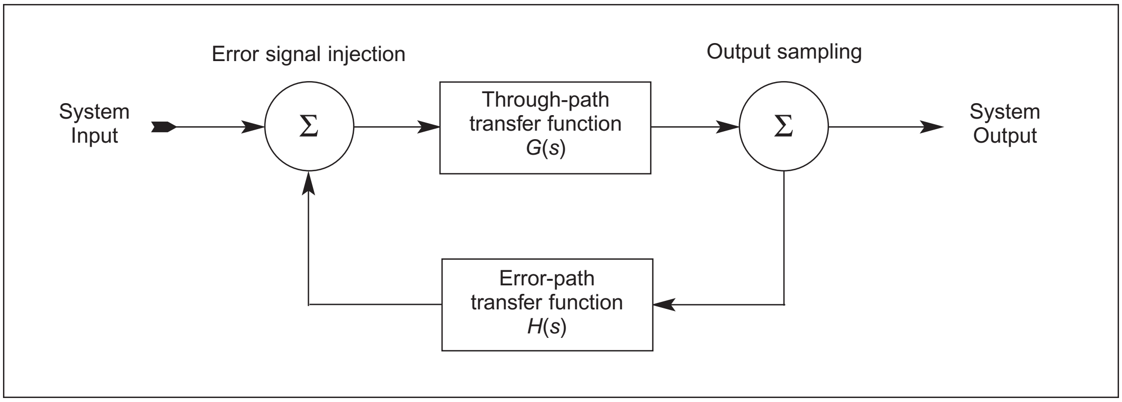

Figure 1 · The basic functions required to achieve feedback in an electronic system.

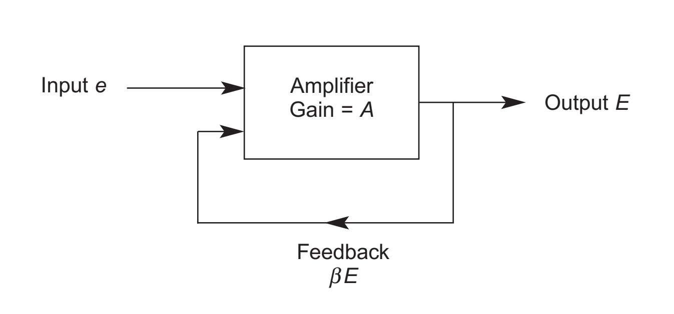

Figure 2 · Negative feedback amplifier block diagram.

of an amplifier or an attenuator until equilibrium is achieved—a constant RF signal level.

Readers unfamiliar with control theory (or who studied it too long ago!) should review a reference such as [3] to gain familiarity with the language and structure of feedback control systems. I won't review it here, but rather, we'll move on to a more specific application of feedback.

The Negative Feedback Amplifier

Negative feedback in amplifiers is one of the most common uses of feedback. The purposes of using negative feedback are to control the gain and reduce distortion (or, increase linearity). The earliest use of negative feedback was to reduce distortion in high power audio amplifiers. One common application was in the modulator of an amplitude modulated (AM) broadcast transmitter; another was in telephone system audio amplifiers.

Negative feedback is also used to improve the linearity of radio frequency amplifiers, especially since the introduction of the transistor. Today, transistor RF amplifiers use one or more techniques to obtain greater linearity through negative feedback. Feedback allows the designer to obtain amplifier characteristics (e.g., gain) that are not critically dependent on the parameters of a specific active device.

Conceptually, feedback amplifiers are very simple. Figure 2 shows that simplicity—a portion of the output is sampled and reintroduced at the input. The feedback signal must be inverted in phase (hence the term "negative" feedback), which is often automatically accomplished since most single-stage amplifiers invert the phase of the signal. Thus, all that is required to control the feedback is a voltage divider to provide the desired amount of feedback.

In the absence of feedback, the output is simply the gain times the input voltage;

$$E = eA$$

With feedback in the amount of βE, the actual input is $(e + \beta E)$, so the output becomes $(e + \beta E)A$.

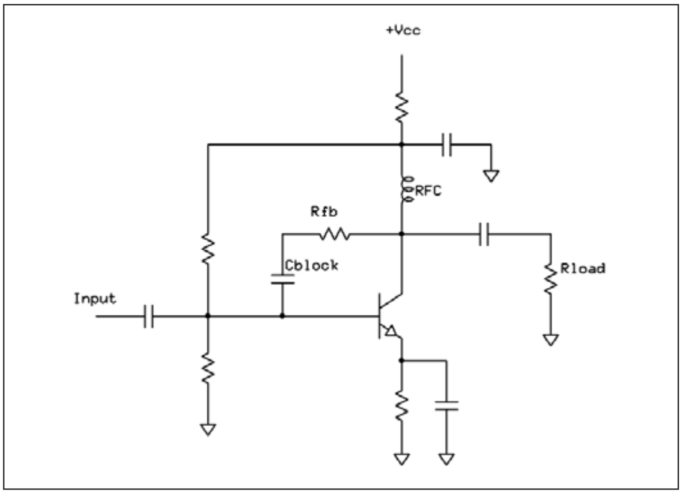

Figure 3 · Amplifier with shunt voltage feedback.

Since gain is defined as the ratio of output to input, the system gain with feedback is the ratio of the above actual output and input expressions, which reduces to

$$\text{Gain} = A/(1 - A\beta)$$

If we have a circuit that has its voltage gain reduced by 20 dB due to the application of feedback, then Gain is 1/10, giving $A\beta$, the feedback factor, a value of –9.

Distortion Reduction

In a feedback amplifier, distortion is reduced because the portion of the distorted output that is fed back to the input is re-amplified and, since it is out-of-phase, cancels out a larger part of the distortion. The amount of distortion reduction is the same as the reduction in gain noted above, or

$$D = d/(1 - A\beta)$$

where D is the distortion level at the output and d is the distortion level that would be present if no feedback was present.

We can see that a large amount of feedback would result in a large reduction in distortion, but we must remember that gain is also reduced. The amplifier must have sufficient excess gain to allow the desired amount of feedback. Most practical feedback circuit designs, particularly RF amplifiers, require tradeoffs between gain and the amount of feedback that can be applied to obtain the desired improvement in distortion.

Circuit Topology for Feedback

Negative feedback requires a sampling point for the output signal, a path from output to input (including amplitude and phase control circuitry, if needed), and an injection point at the input.

Bipolar transistor amplifiers are inverting, so it is possible to simply connect the collector to the base with appropriate components to control the feedback level and block DC voltage [4]. Figure 3 shows an amplifier with such a feedback scheme. R_{fb} sets the feedback level, sampling the output *voltage,* and forming a voltage divider with the base bias resistors and the base-emitter junction. The feedback voltage is applied in *shunt,* that is, in parallel with the input voltage. Capacitor C_{block} passes the RF feedback signal while blocking the DC path between collector and base.

Another common feedback topology—often used together with the voltage shunt method of Figure 3—is emitter degeneration, shown in Figure 4. A feedback *voltage* is derived from the collector *current* through an unbypassed emitter resistor R_{fb}. This voltage is re-introduced at the input because it is *in series* with the base-emitter path of the input signal.

Cautions and Limitations

There are many practical aspects of feedback in RF circuits. First, as frequency increases, physical dimensions will introduce greater phase shift in the feedback path. If too large, this can cause the amplifier to become unstable. Unwanted feedback paths are also possible, both via the circuit and internal to the device.

Also, device gain tends to decrease with increasing frequency, which may be insufficient to obtain the desired feedback amount.

Noise is a significant consideration in a feedback amplifier, as well. Each resistive feedback path represents a noise source that is summed with the input noise. Thus, feedback necessarily increases noise.

There have been numerous circuits developed that minimize noise by replacing resistive coupling with transformer coupling, but these often decrease output-to-input isolation, increasing the risk of instability. These “noiseless” techniques are also less broadbanded than resistive feedback, but this may not be an issue for narrow to moderate bandwidth requirements. Transformer coupling is also much harder to accomplish as frequency increases, so resistive feedback is usually the preferred technique for microwave frequencies and extremely wide bandwidths.

Although not mentioned earlier, the increase in noise with increasing feedback often becomes a performance tradeoff factor, along with gain and distortion objectives.

Summary

This brief tutorial is a reminder that feedback is an important part of high frequency design techniques. Hopefully, it will encourage those who need additional study to spend time reviewing pertinent reference material on the subject.

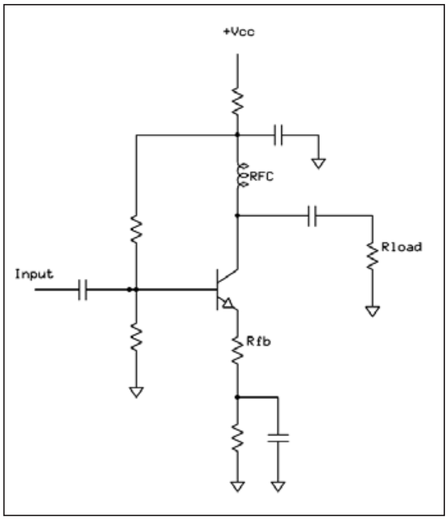

Figure 4 · Feedback may be obtained by emitter degeneration; an unbypassed emitter resistor.

References

1. F. E. Terman, *Electronic and Radio Engineering*, McGraw-Hill, Fourth Edition, 1955, Ch. 11.

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