FEED IT FORWARD

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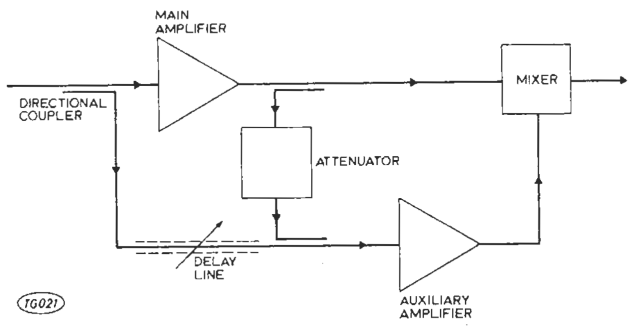

INVENTED BEFORE FEEDBACK, THE PRINCIPLE OF FEEDFORWARD CORRECTION HAS MUCH TO OFFER MODERN DESIGNERS.

IN 1924, Black, working at Bell Telephone Laboratories, discovered the principle of *feedforward.* In 1929, he discovered feedback, which was destined to become one of the many developments of that most remarkable research institute to sweep the electronics world. The 'sweeping' took some time; probably no more than a handful of professionals had heard of the principles of feedback in the thirties, and it was the intensive development of electronics during the war which spread the news around a bit. It did, however, become the hottest property in amplifier design in the early 1950s, and appears in all but the humblest of books on electronics.

Feedforward was rather less fortunate, and but for the work of Seidal, also at Bell Telephone, in the late sixties, would have become as obscure as the "talking flame" method of modulating a spark transmitter. As so often happens, however, old ideas take on a new significance when new requirements appear, and feedforward may very well be due for a rather belated appearance in everyday electronics.

A LOOK BACK AT FEEDBACK

Let's refresh our memories about feedback. In a feedback circuit, a fraction of the output of an amplifier is fed back to the input and compared with the input signal at the input. The difference between input signal and the feedback signal is then passed through the amplifier again in such a phase as to act as a correcting signal, if the feedback is negative. Since positive feedback is seldom used in amplifiers deliberately, we shall stay with negative feedback. For example, if a positive going spike appears in the output, and is not present in the input, negative feedback will ensure that this is fed to the input in a polarity which will cause a negative going spike at the output, thus cancelling out the distortion of the signal. The amount of cancellation would be complete only if the amplifier had infinitely large gain, but can be made great enough for very satisfactory results.

Negative feedback of this kind has some advantages but also some disadvantages. On the plus side there is a very considerable reduction in distortion caused inside the amplifier, coupled with a reduction in gain and an increase in bandwidth. Any changes in the characteristics of the transistors or other devices used cause very small changes in the characteristics of the amplifier. The amplifier, however, may suffer from stability problems, caused by the phase of the feedback varying with frequency. The problem region may be outside the normal bandwidth of the amplifier, so that an amplifier has to be designed for a much greater bandwidth than is used. In addition, the amplifier, which is stable with a resistive or inductive load may be unstable with a capacitive load.

A SEPARATE AMPLIFIER

Feedforward, by contrast, samples a fraction of the signal at the output and compares it with a sample of the signal fed forward from the input. The difference is then amplified in a *separate* amplifier, and added to the output in such a phase as to correct for errors. The separate amplifier is the clue to the long time this technique has been ignored; in the days of valve or transistor amplifiers this made the technique uneconomic. The use of ICs puts rather a different complexion on it, since two amplifiers can be put on one chip almost as cheaply as one.

Oddly enough, the technique was not revived because of the easy availability of ICs, but because of distortion and noise in microwave amplifiers using travelling-wave tubes.

In any microwave tube amplifying a signal which may be in the region of 10GHz (10000MHz), the delay time of the signal — the time which it takes to pass from the input of the amplifier to the output — is several cycles, perhaps about 50. In such amplifiers, feedback cannot be used because it is not possible to make the feedback appear 50Hz *earlier* than the signal which causes it! Feedforward can, however, be used by taking the input signal and splitting it so that one part goes into an amplifier and another part is delayed and compared to the output. The difference is then amplified in another microwave amplifier and added in antiphase to the output. Figure 1 shows the type of circuit used. The coupling methods used must permit signal flow in one direction only, and some allowance must be made for the time delay caused by each coupling, amplifying, or mixing stage.

For such an amplifier, this is the only possible method of distortion reduction, and it has several other advantages over negative feedback.

There is, for example, no reduction in gain apart from that caused by the couplings and mixers, yet an increase in bandwidth is possible if the auxiliary amplifier has a greater bandwidth than the main amplifier. This is because the reduction of gain at the edge of the band acts as a distortion of signal and is compensated by the auxiliary amplifier just as any other distortion is compensated, assuming the auxiliary amplifier is able to cope. The delay in the amplifier is easily compensated for by time delays in the coupling to the auxiliary amplifier, and the distortion of the main amplifier may be reduced to as low a factor as desired by making the auxiliary amplifier better. The whole arrangement is stable under all conditions, and at all frequencies, and there is no need to worry about what the amplifiers are doing outside the band of interest.

DRAWBACKS

All of these advantages make this a circuit technique well worth looking at for other applications . . . . there has to be a snag somewhere! It lies in the auxiliary amplifier, which decides how good the main amplifier will be. Unlike the case of negative feedback, this is not a closed loop circuit, and changes in the auxiliary amplifier are not compensated for in the circuit, unless the auxiliary amplifier is itself a *feedback* amplifier. If the gain of the main amplifier is to be controlled to within 3db or so over a given bandwidth, then the gain of the auxiliary amplifier has to be controlled to a small fraction of this, the fraction being roughly the stepdown ratio at the output which enables us to compare it with the input. It is this requirement for the auxiliary amplifier which has kept feedforward from becoming better known.

AREAS OF APPLICATION

Having established these principles, however, we are left with a fascinating field for experiments, a challenge for those who say that there is nothing left for the amateur to discover. Lets toss around some ideas.

For one, we can easily make voltage amplifiers of high gain, good linearity, stability, and low noise. We can, if we like use feedback in their construction. We can also make rather cheap and nasty power amplifiers churning out many watts at high gain. Combine the two in a feedforward circuit, and we could have a good high power, high gain amplifier, stable under all conditions in which the auxiliary amplifier was stable. The output of the auxiliary amplifier need not be very high, since it exists only to correct the distortion of the main amplifier. Might this technique enable us to say goodbye to crossover distortion at low power levels?

Taking another field altogether, consider timebases. It is easy to generate a linear sawtooth of a few volts, more difficult to generate one of amplitude close to the amplitude of the power supply available, or to preserve the linearity in an inductive load. Why not generate a small amplitude linear timebase and use it as the reference in a feedforward amplifier to correct another timebase?

On another trail now, the distortion of an amplifier to which feedforward is applied is easily measured, it is simply the correction signal at the output of the feed-forward stage. All in all, there seem to be possibilities for this old idea now in the field of wideband amplifiers, transmitter modulation, crosstalk reduction, control of signal strength and goodness knows what else. We may be seeing some feedforward circuits in ETI before long! ●