Error Signal Reuse in a Feedforward Amplifier

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Abstract: **In this paper, the concept of frequency selective feedback will be examined in the context of feedforward (FFWD) amplifier architecture. In a typical FFWD system, a time-delayed signal that represents the distortion products is injected in anti-phase at the main amplifier output, thus improving the overall intermodulation distortion (IMD) of the system. This signal may also be reused as a feedback signal for improving the uncorrected main amplifier performance. Main amplifier linearity improvement is important in terms of efficiency, size and cost, and can be achieved at a small price in terms of added complexity. This paper presents simulation and measured results that were obtained from a realized system. The practical limitations of this technique are also outlined.**

I. Introduction

Feedforward amplification is a technique that is widely used for the reduction of intermodulation distortion in power amplifiers [1], [2]. The basic structure is shown in Fig. 1. The cancellation of IMD products is limited by the phase and amplitude imbalance of the two main loops, i.e. the carrier and error cancellation loops [3] and [4]. The amount of cancellation of the carrier cancellation loop should be enough so that the residual carrier does not saturate the error amplifier. The following equations set the conditions for the required level of cancellation.
For the phase response, it is given as [5]:

$$Cancellation = 20\log(2\sin\phi_e/2) \qquad (1)$$

The cancellation limit as a function of the amplitude error is defined by:

$$Cancellation = 20\log\left|10^{E/20}-1\right| \qquad (2)$$

The above two equations are valid for both the carrier and error cancellation loops, with the exception that the phase and amplitude match in the 2nd loop (error cancellation) has to be satisfied over at least three times the bandwidth required of the first loop. This in practice is a formidable task in terms of broadband matching design, particularly so when dealing with power devices with very small impedance. Therefore, the cancellation achievable is in practice limited to the range of 25 – 30 dB. This translates to an equal level of system linearization over a large bandwidth that is still unmatched even by the most sophisticated digital predistortion techniques. The uncorrected main amplifier used in the FFWD system must still be relatively linear, and it must operate at the appropriate back-off point. Any technique that allows this amplifier to be more linear without adding more Silicon (or GaAs as the case may be), only enhances manufacturing margins and reduces product cost. This paper describes a technique that is relatively simple and effective in achieving this goal. Simulation results and measured performance will be presented for this modified amplifier system.

II. Overview of the Basic Structure and Theory of Operation

The basic network is shown in shown in Fig. 1, where the error signal (IMD products) are pre-amplified to the required level in the error amplifier chain before extracted (tapped) for feed back. The amplitude and phase of the feedback signal (error) is conditioned prior to the injection at the input of the main amplifier. It is clear that by recombining the feedback components in the main amplifier output, the IMD products can be reduced provided that the correct magnitude and (anti) phase is realized over the desired frequency range.

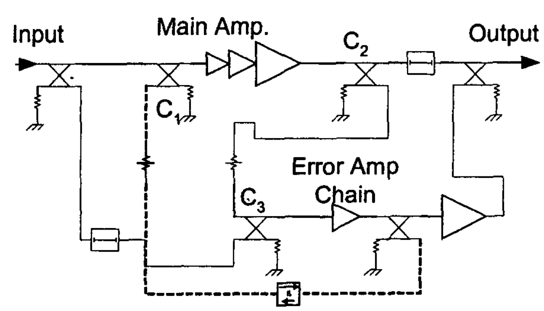

Fig. 1. The basic structure of feedforward amplifier. The dotted line depicts the feedback path.

III. Feed Back Network

The feedback network comprises of a coupler C_2, the connection cables, and a fixed attenuator followed by the combiner coupler C_3, the output of which is the error

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signal. The error signal is attenuated by the coupling ratio of C_2 and C_3 and any other passive resistive components in between, $L_{1(dB)}$. The total attenuation is given as:

$$L_{1(dB)} = C_{1(dB)} + C_{3(dB)} + L_{P(dB)} \qquad (3)$$

The carrier signal is also suppressed to the extent dictated by equation (1) and (2). One of the differences between feedback and the conventional feedforward is the required level of amplification gain in the feedback path is given as:

$$Gain_{efb} = L_1 - Gain_{Mainamp} \qquad (4)$$

The small gain required justifies the idea of tapping into the error amplifier chain. In order to close the loop, an adjustable attenuator and a phase shifter will suffice. It is worth noting that the feedback network is very similar to the feedforward 2nd loop and in that both techniques will require an injection coupler. However, the injection coupler in feedforward has to be relatively large to minimize the power loss, where as the feedback network does not have this limitation and a coupling ratio of 3dB is appropriate.

Other considerations that must be taken into account are:

A. Stability

Like any feedback system, the loop (amplifier) stability is of major concern. At first glance, it appears that if the 1st loop cancellation is greater than the amplification in the feedback loop, the circuit should remain stable. In essence, this is the necessary but not sufficient condition for stability. This is due to the fact that the couplers have a limited bandwidth and the nominal cancellation discussed above, is only achievable in their effective bandwidth. Therefore, attention to the loop gain over and beyond the operating bandwidth is essential, and the loop gain minus cancellation has to be less than one at all times. This is a condition that is relatively easy to achieve when the main amplifier gain has a band-pass response.

B. Bandwidth

It is imperative that the bandwidth of the feedback linearisation is limited. As a matter of fact, the bandwidth is inversely related to the linearisation goal desired from the feedback (not the overall FFWD system), and is limited by the delay in the feedback loop. This can be demonstrated by the following example. If the desired cancellation of 3rd order IM product of the main amplifier is 10dB, a vector misalignment of 18.5 degrees between the amplifier IMD voltage and the feedback signal is permissible (perfect cancellation requires 180 degrees). Assuming the group delay around the feedback loop is 5 ns, the useful bandwidth can be calculated as:

$$2\pi\Delta f\tau = \Delta\phi \qquad (4)$$

This in turn will result in a useful bandwidth of 10.28 MHz.

III. SIMULATED RESULTS

Fig. 2-a, b shows the simulated results before and after applying feedback. In order to investigate the sensitivity of the circuit to the phase (delay variation is inevitable in a practical circuit), the phase shift has been swept over a wide range and plotted against IMD cancellation. It was observed that the circuit performance is not very sensitive to the phase alignment. It is worth noting that amplifier models used are polynomial representations with OIP3 and OIP2 of 45 and 55 dBm respectively and do not posses a group delay response.

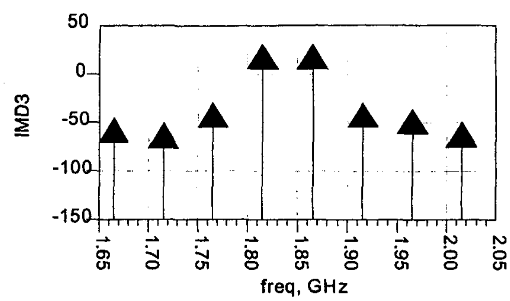

Fig. 2-a Simulated IMD3 without feedback.

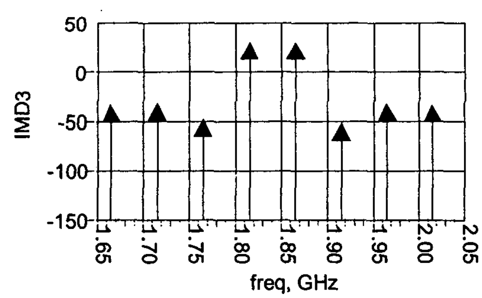

Fig. 2-b Simulated IMD3 with feedback applied.

IV. PRACTICAL RESULTS

Fig. 3-a and b show the response achieved by applying the above technique in a breadboard amplifier.

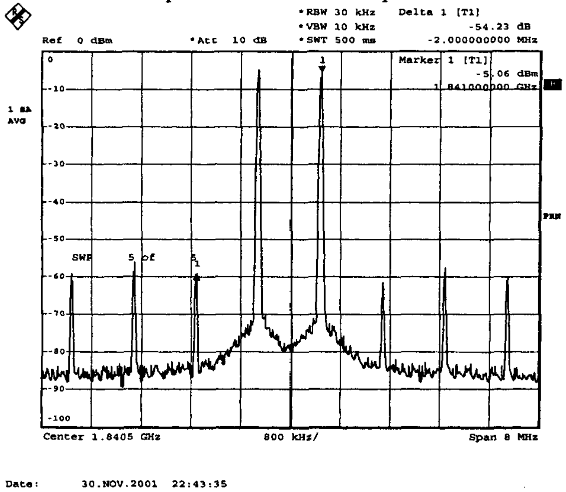

Fig. 3-a. Measured IMD without feedback.

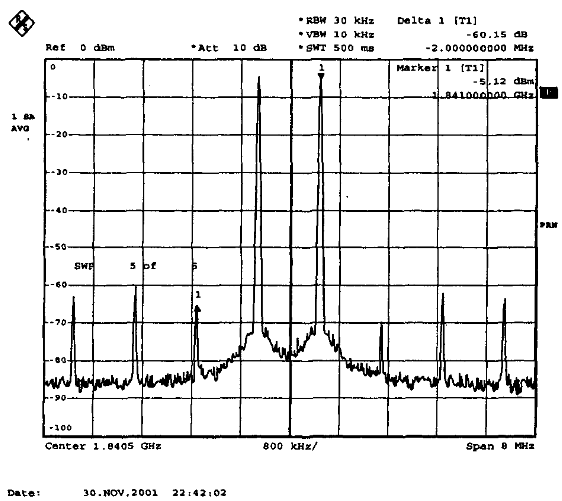

Fig. 3-b. Measured IMD with feedback.

The delta marker reading of the Fig. 3-a and b shows just under 7dB of improvement in IMD3 when the feedback loop is closed. This is in a good agreement with the simulation, however, the bandwidth was limited by the group delay of the particular test bench used in this exercise.

V. CONCLUSION

In this paper, a novel combination of linearisation techniques has been demonstrated. The application of feedback is facilitated by the availability of the error signal. The limiting factor is the delay in the feedback loop, and the useful bandwidth can be improved by minimizing the group delay.

ACKNOWLEDGEMENT

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