SENSITIVITY OF DISTORTION CANCELLATION IN FEEDFORWARD AMPLIFIERS TO LOOPS IMBALANCES

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Abstract

The sensitivity of distortion cancellation in feedforward amplifiers to amplitude and phase imbalances is investigated. Some workers [1,2] have suggested that the amplifier is more sensitive to imbalance in signal cancellation loop. It is shown here that this is not true in general. It can become more sensitive to imbalance in either cancellation loop depending on their level of cancellation. Results of a feedforward amplifier simulation are presented to confirm this finding.

Introduction

Feedforward linearisation [3,4] is a promising technique for improving linearity of amplifiers for use in cellular and personal communications where low distortion amplification of multicarrier signals is of primary concern. Its ability to achieve broadband distortion cancellation makes it the most attractive of the available linearisation techniques [5].

Intermodulation cancellation in feedforward amplifier is based on precise amplitude and phase balances within the signal and distortion cancellation loops. As a result, the cancellation is sensitive to any drift in balances from initial settings. A complete analysis on the sensitivity of distortion cancellation in feedforward amplifier is reported in this paper. The results show that the sensitivity of the overall cancellation can be more sensitive to imbalances in either loop depending on their cancellation level. K. Konstantinou *et al* [1] reported that the overall cancellation is more sensitive to imbalances in the signal cancellation loop than in the distortion cancellation loop. This is shown to hold only for certain values of cancellation and cannot be deduced as a general observation. The importance of understanding the sensitivity of the feedforward amplifier is that it provides essential information for the implementation of digital control of feedforward amplifiers [6] in which the more sensitive loop can be subjected to adaptive control to reduce the sensitivity of the feedforward linearisers to amplitude or phase drift.

An analysis on a feedforward amplifier model was carried out to verify the above finding. The feedforward amplifier is based on a newly proposed topology [7] which employs phase equalisers to compensate for the phase nonlinearity of the amplifiers, thereby improving the broadband distortion cancellation. The results show that overall distortion cancellation in this case is more sensitive to imbalances in the distortion cancellation loop than in the signal cancellation loop.

Sensitivity of Distortion Cancellation in Feedforward Amplifier

Figure 1 shows a block diagram of feedforward amplifier. It consists of two cancellation loops, the first being for signal cancellation and the second for distortion cancellation. The input signal is sampled by the input coupler and the sampled signal is phase nonlinearised and delayed by a phase equaliser and linear delay line respectively. The main signal is cancelled at the output of the second coupler which leaves only the distortion signal to be amplified by the error amplifier. The distortion signal is amplified and recombined with the main signal at the third coupler. The phase equalisers are employed to compensate the nonlinear phase delay of the amplifiers in order to improve the wideband performance [7]. Perfect distortion cancellation can be achieved if the amplitude and phase differences between the two distortion signals are zero and 180° respectively at the output where a distortion free signal is obtained.

The cancellation in each loop of the feedforward amplifier, using vector analysis, can be defined as [8]:

$$can_1 = 10log(1+ \quad_1^2 - 2 \quad_1 cos \quad_1) \quad \text{dB} \qquad (1)$$

$$can_2 = 10log(1+ \quad_2^2 - 2 \quad_2 cos \quad_2) \quad \text{dB} \qquad (2)$$

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where $can_{1,2}$, $_{1,2}$ and $_{1,2}$ are the cancellation, amplitude imbalance and phase imbalance in the signal (1st loop) and distortion (2nd loop) cancellation loops respectively.

The overall intermodulation cancellation, $can_{overall}$, of the feedforward amplifier is given by [1]:

$$can_{overall} = 20\log\left[\sqrt{can_2} + \sqrt{can_1^3\left(\frac{IP_{main}}{IP_{error}}\right)^2 \frac{1}{C_3^2}\frac{T_2^2 L_2^2 T_3^2}{{}_2^2}}\right] \text{dB} \qquad (3)$$

where IP_{main} and IP_{error} are the third order intercept point of the main and error amplifier respectively and T_2, T_3 and C_3 are the transmission loss of the 2nd and 3rd coupler and the coupling coefficient of the 3rd coupler respectively and L_2 is the loss of the phase shifter and delay line in 2nd loop.

The sensitivity of the overall cancellation of feedforward amplifier to amplitude or phase imbalances in either loops is defined as :

$$S_a^{can_{overall}} = \frac{can_{overall}}{a} \Big/ \frac{can_{overall}}{a} \qquad (4)$$

where $a = \ _1,\ \ _2,\ \ _1,\ \ _2$

To determine in which loop imbalances are more important the following sensitivity parameters are defined:

$$sensitivity_{amplitude} = S_{1}^{can_{overall}} - S_{2}^{can_{overall}} \qquad (5)$$

$$sensitivity_{phase} = S_{1}^{can_{overall}} - S_{2}^{can_{overall}} \qquad (6)$$

A positive result of equation (5) or (6) implies the feedforward amplifier is more sensitive to first loop imbalance whereas a negative result implies the feedforward amplifier is more sensitive to 2nd loop imbalance.

The term $\frac{T_2^2 L_2^2 T_3^2}{C_3^2}$ of equation (3) is set equal to $\frac{1}{0.1^2}$ and the third order intercept points of the main and error amplifiers are 33dBm and 30dBm respectively, which are obtained from the simulated feedforward amplifier. Figures 2 and 3 show the sensitivity of feedforward amplifier for different imbalances based on equations (5) and (6). Referring to Figure 2, the overall cancellation is more sensitive to 2nd loop imbalance (negative sensitive value) when 1st loop amplitude imbalance is low and becomes more sensitive to 1st loop imbalance when 1st loop amplitude imbalance increases for various phase imbalances. The amplifier is particularly sensitive to the 2nd loop imbalance when all imbalances are maintained at low levels, referring to Figure 2a, and reduces gradually with the increase in imbalances. Similar results for phase imbalance are observed in Figure 3. The overall cancellation is more sensitive to 2nd loop imbalance when 1st loop phase imbalance is low and becomes more sensitive to 1st loop imbalance when 1st loop phase imbalance increases. The results indicate that cancellation sensitivity is highly dependent on the loops' cancellation. The original setting will determine the sensitivity of intermodulation cancellation to any particular loop. Figures 2 and 3 indicate the sensitivity of feedforward cancellation for a given amplitude and phase imbalances in the cancellation loops. The results reported in [1] are not generally applicable, particularly for feedforward amplifiers which attain high cancellations in the cancellation loops.

Simulation of Feedforward Amplifier to Loops Imbalances

Simulation was carried out, using the microwave software package HP-EESof Series IV, on a feedforward amplifier in order to verify the effect of loop imbalances on intermodulation cancellation. The feedforward amplifier with phase equalisers is shown in Figure 1 and has been reported in [7]. Figure 4 shows the change in third order intermodulation level, with two-tone input at 1.79GHz and 1.81GHz, for a 1dB amplitude imbalance in 1st loop and 2nd loop and is compared with the cases of original setting and no feedforward linearisation. The intermodulation cancellation reduces by 20dB for 2nd loop imbalance and is less sensitive to 1st loop imbalance.

Figure 5 shows a similar analysis with a 5° phase imbalance in either loop. The feedforward amplifier is, again, more sensitive to the imbalance in the 2nd loop with a 19dB reduction in cancellation. The imbalance in the 1st loop has a minimal effect on overall distortion cancellation.

Conclusions

A complete analysis of the sensitivity of feedforward amplifiers on loop imbalances is presented. It is shown that the sensitivity of distortion cancellation in feedforward amplifiers to amplitude and phase imbalances is dependent on the cancellations in both loops. The feedforward amplifier is more sensitive to the distortion cancellation loop imbalances provided that the signal cancellation loop's cancellation is maintained at a high level, otherwise it is more sensitive to 1st loop imbalances.

CAD analysis of a feedforward amplifier based on a newly proposed topology which employs phase equalisers to compensate for phase nonlinearity was carried out. This feedforward amplifier maintains a high degree of cancellation in both loops and it has been shown that it is more sensitive to distortion cancellation loop imbalances than signal cancellation loop imbalances. This demonstrates that feedforward amplifiers can be more sensitive to distortion cancellation loop imbalance when high cancellations are achieved in both cancellation loops.

Acknowledgement

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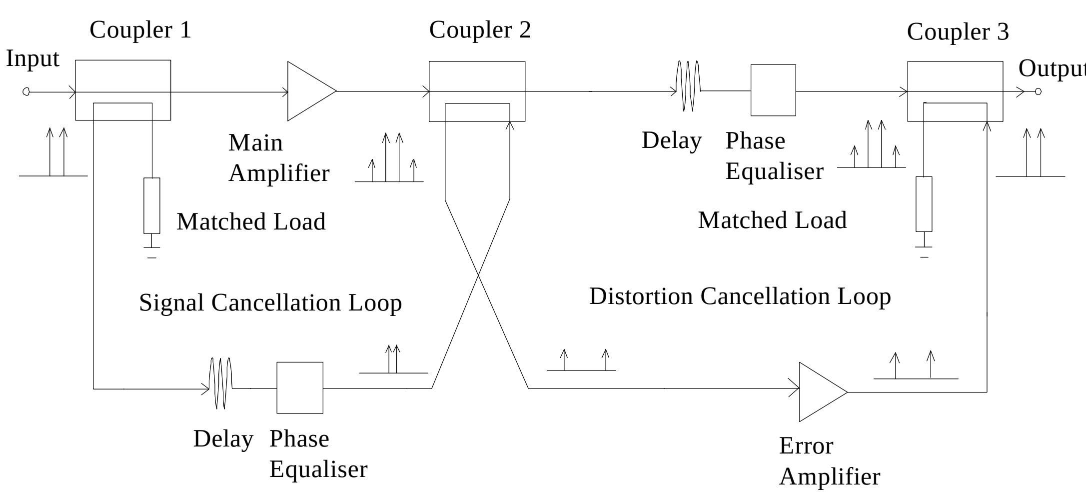

Figure 1 Feedforward amplifier with phase equalisers

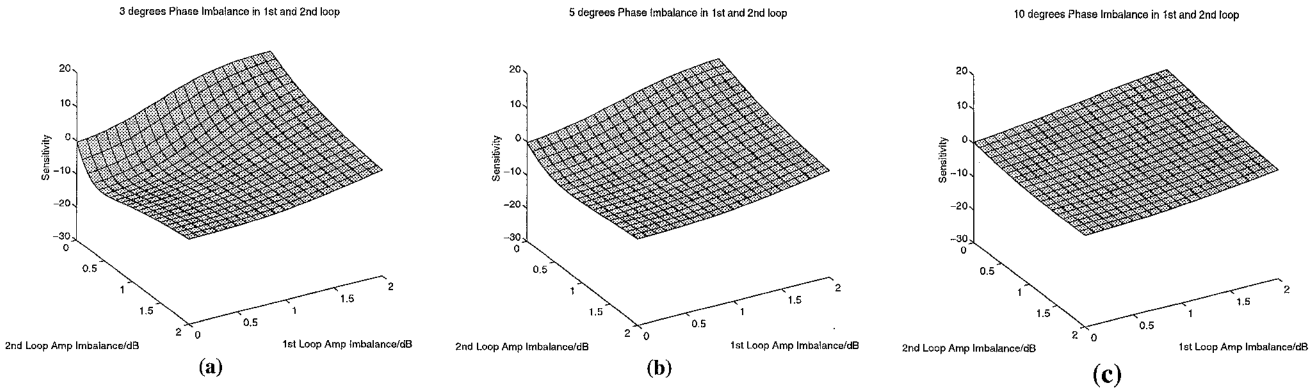

Figure 2 Sensitivity of overall distortion cancellation to amplitude imbalances in 1st and 2nd loops

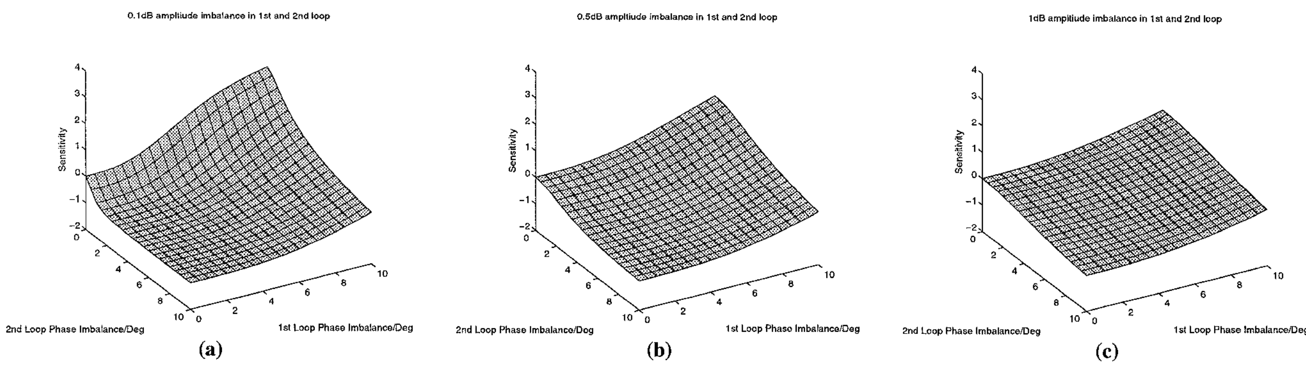

Figure 3 Sensitivity of overall distortion cancellation to phase imbalances in 1st and 2nd Loops

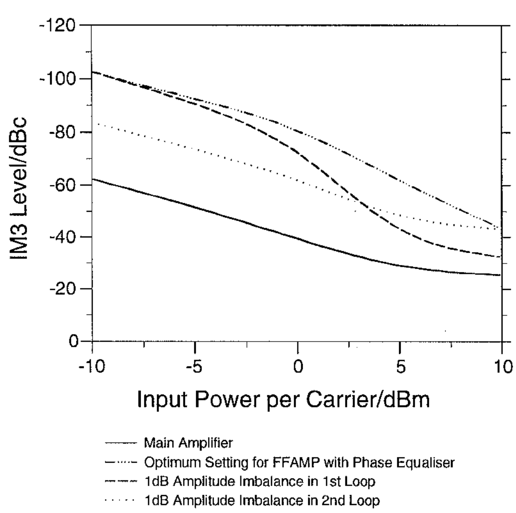

Figure 4 Output IM3 level with 1dB amplitude imbalance in 1st or 2nd loop

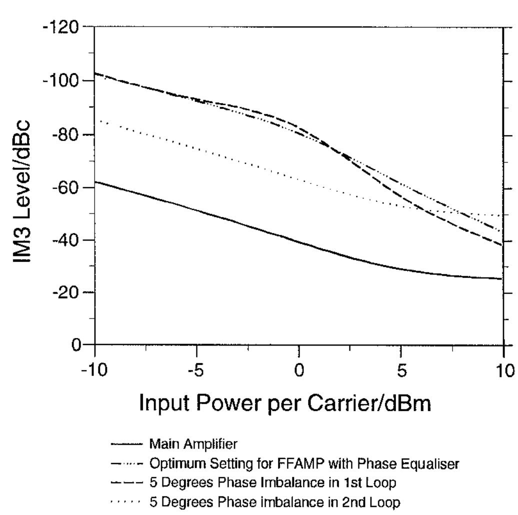

Figure 5 Output IM3 level with 5 degrees phase imbalance in 1st or 2nd loop