A Modified Feed-Forward Technique for Mixer Linearization

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Abstract: **The technique of feed-forward correction for increased linearity is commonly used in amplifier design, especially in commercial cellular systems where there are strict requirements on intermodulation performance for multi-carrier signals. This paper introduces a modified version of the original feed-forward concept that can be applied to mixer design. A 2 GHz mixer designed and fabricated using this new technique showed a 33dB reduction in the intermodulation products when the feed-forward system was activated. With the same levels of feed-forward performance common to today's amplifiers, this technique can be used to significantly lower the intermodulation products of a mixer.**

Introduction

The Feed-Forward technique for the reduction of distortion was reported for microwave frequencies by Seidel at Bell Labs [1]. The process involves the combination of signals both in and out of phase in order to isolate the distortion products of an amplifier and then to combine those products destructively with the output signal. The resulting output signal is an undistorted, amplified version of the original signal. A block diagram of a feed-forward amplifier is shown in Figure 1. In the first loop the signal to be amplified is sampled before it is distorted by the amplifier (usually a power amplifier). The signal is sampled again after the amplification, where significant distortion from the amplifier may be present. The two signals are adjusted to be of equal amplitude and opposite phase so their combination yields a signal of only the distortion products. This "error" signal is then amplified with a linear amplifier and adjusted to combine destructively with the distortion products introduced by the power amplifier. The resulting output

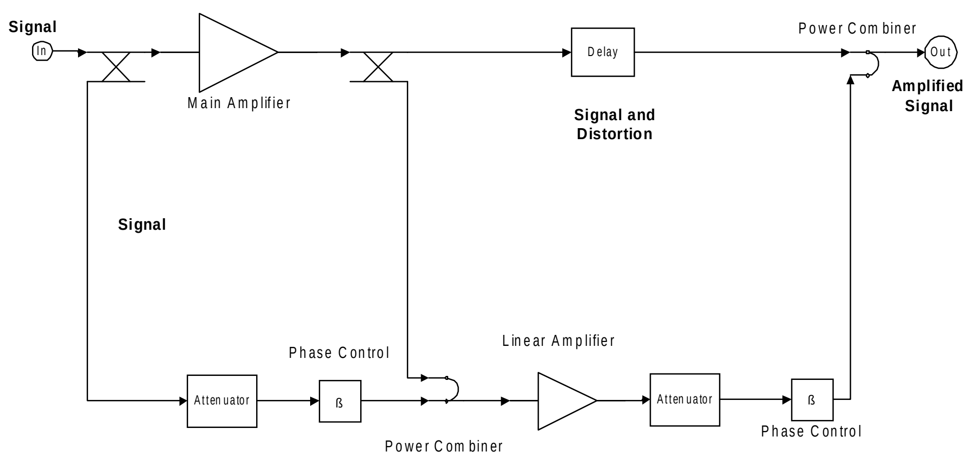


Figure 1. The block diagram of a feed-forward amplifier.

signal is an amplified, but undistorted version of the original. In commercial power amplifiers for cellular systems, the requirements for the intermodulation distortion levels can be as high as 60 to 70 dB below the level of the wanted carrier levels. This degree of cancellation can be achieved with a microprocessor actively controlling the amplitude and phases of the signals. A sensitivity study showing the requirements on the amplitude and phase controls for a given level of distortion reduction was done by Cho [2]. A graphical representation of the sensitivity is displayed in Figure 2, which shows the degree of signal cancellation as a function of the amplitude and phase deviation from the optimum of 0 amplitude, 180° phase imbalance.

Application to Mixer Design

The technique described works on the ability to isolate the unwanted signal components from the desired ones. In the case of the amplifier, the "clean" signal was simply the original signal,

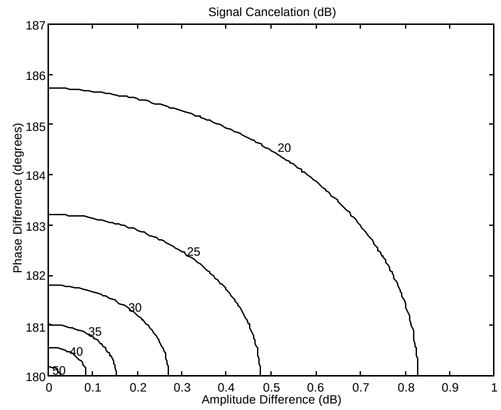


Figure 2. The sensitivity of a feed-forward system on amplitude and phase controls.

coupled away from the input's main amplification path. It is important to recognize that it is not the original signal that is required but merely one that will isolate the distortion products. The only real requirement of the "reference" signal is that it can be combined with the distorted signal to isolate the distortion products. What this work proposes is to use two mixers in a configuration similar to the amplifiers described in the introduction. A diagram of the proposed system is shown in Figure 3. The first mixer is operated at high power levels with relatively large distortion products. A second mixer translates the same input

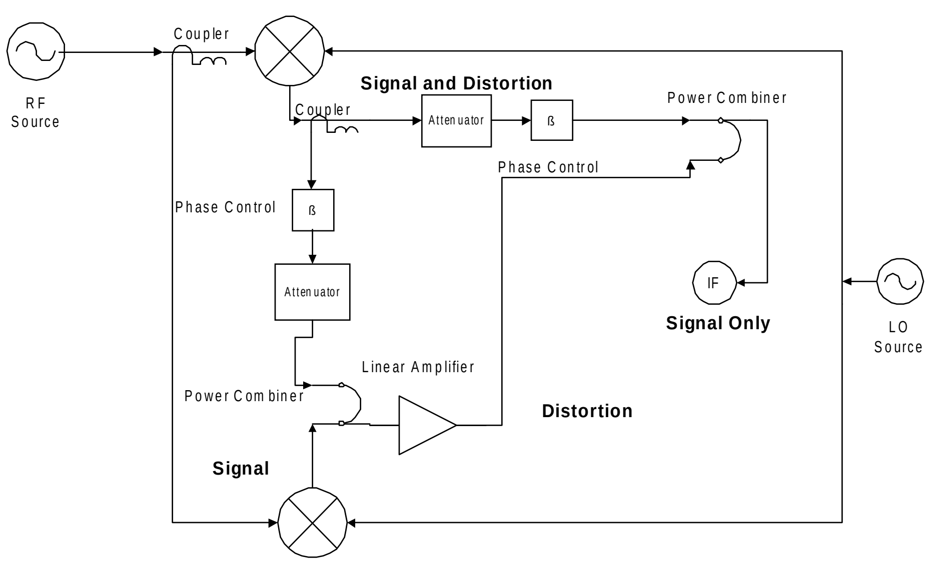


Figure 3. The system diagram of a Feed-Forward mixer.

RF signal but with much lower distortion levels relative to the wanted signals. In this particular case the mixer was operated at a much lower RF power level. The second signal can be used to isolate the distortion products of the main mixer as long as the levels of the intermodulation products are lower than that of the main signal, relative to their respective carrier levels. The resulting "error" signal is then fed back into the main signal path with an amplitude equal to and a phase opposite of the original intermodulation products, resulting in an output from the primary mixer with the distortion products greatly reduced.

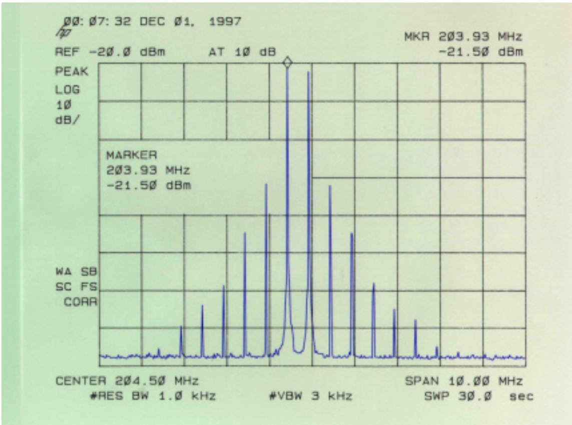
In the particular design used for this paper, the secondary mixer was operated with the same LO power as the primary mixer (+6 dBm) but the RF signal was reduced by approximately 20 dB. This resulted in intermodulation products that were significantly lower (as compared to the desired signal levels) than the ones from the primary mixer. This allowed for the cancellation of the "carrier" signal without significantly effecting the levels of the intermodulation products of the primary mixer. There are a number of factors that influence the linearity of a mixer [3], any of which can be exploited by the secondary mixer in order to isolate the distortion products.

Feed-Forward Mixer Design

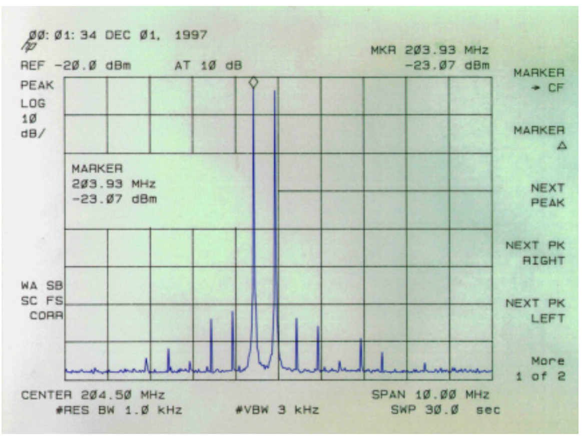
A simple balanced mixer design was used for the demonstration of the new feed-forward technique. However, since this paper is reporting a technique and not a specific design, it is important to note that the procedure can be used to improve the linearity of almost any mixer. The particular aspects of the individual mixer designs are not relevant (as long as the previously explained requirements on distortion levels are met) and will not be given here. A harmonic balance simulation using Libra [5] showed the resulting intermodulation products would be reduced by 45 dB when the feed-forward process was active. The RF signal was a two-tone sine wave at 2.1 and 2.1005 GHz. These frequencies were chosen because of their proximity to a commercial cellular band and for the ease of circuit fabrication, but are also not important to the demonstration of this concept.

Results

The measured results for the feed-forward mixer design are displayed in Table 1. The IM# refers to the index number of the two-tone intermodulation products above and below the two desired signals. The measured reduction of intermodulation products agrees well with the simulated performance. A larger degree of cancellation was not achieved due to a limited range of phase control in the output loop. The initial isolation of the distortion products from the mixer was also not optimum. There was a residual component of the carrier that recombined destructively with the wanted output signals, which is shown by the 2dB drop in signal level when the feed-forward process was applied. The power levels were increased to create higher intermod products and the mixer was again tested. The measured power spectrum for the mixer is shown in Figure 4. Had the first loop been fully optimized, no reduction in carrier power would have been observed.



(a)



(b)

Figure 4. The measured power spectrum for the mixer (a) before and (b) after feed forward correction was applied.

Conclusion

A modified feed forward technique for linear mixer performance has been presented. The measured results show that the distortion products resulting from multi-carrier mixer operation can be reduced through this technique. The improvements and innovations applied to feed forward amplification since its inception should also apply to feed forward mixing. If fully exploited this technique should offer significant improvements in the performance of multi-carrier communication systems.

Bibliography

[1] Seidel, "A Microwave Feed Forward Experiment", Bell Syst Tech J V 50 n 9, November 1971

[2] Cho, "Sensitivity Analysis of Feed Forward Amplifier", *IEEE* Int Conf on Commun, Conf Rec, June 1974

[3] Mass, "Microwave Mixers : 2nd Edition", Artech House Publishers.

[4] HP-EESof Series IV Libra – Microwave Circuit Simulation

Measured	IM1 (dBm)	IM2 (dBm)	S1 (dBm)	S2 (dBm)	IM3 (dBm)	IM4 (dBm)
Initial	-88	-61	-27	-27	-62	-87
Final	-89	-94	-29	-29	-94	-88
Reduction	**1** dB	**33** dB	**2** dB	**2** dB	**32** dB	**1** dB

Table 1. The measured power levels of the feed-forward mixer before and after the intermodulation cancellation was applied.