Digital Interference Cancellation in a Full Duplex System

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Abstract—This paper describes a method to suppress interference in a WCDMA transceiver in the digital domain and thus improve the sensitivity of the receiver. The interference is caused by the leakage signal from the transmitter and by feedback information from the transmitter received signal.

An adaptive least mean square algorithm is used to estimate the correct amount of the interference and to provide tracking ability for temperature variations.

I. INTRODUCTION

In a full duplex system as WCDMA a mobile phone transmits and receives at the same time. The transmitted signal will cause interference in the receiver which must be suppressed to not get degraded sensitivity. To be able to connect the transmitter and receiver to the same antenna a duplex filter is normally used. Such a filter will not provide infinite isolation and a strong leakage signal can occur at the LNA input. This puts high demands on linearity of receiver components [1].

The leakage signal from the LO is another signal that also is generated by the transceiver itself and this signal will together with the TX leakage signal also produce interference products in the desired RX band. The problem with a full duplex transceiver is depicted in figure 1. Because the interference contains modulated information from the TX signal it should be possible to create a replica of the interference and subtract it from the desired RX signal in the digital domain of the transceiver.

This paper investigates this idea and is organized in the following subsections. First the interference problem is theoretically analyzed and a closed-form equation, summarizing the four different nonlinearity effects, is presented. Section III describes the design of the cancellation block which is used to suppress the arised interference and in section IV results from Matlab simulations are presented. Finally the cancellation method is summarized and conclusions presented.

II. MATHEMATICAL DESCRIPTION OF THE PROBLEM

Four different cases of nonlinearity effects have been studied and will briefly be described. All effects are activated by the nonlinearities in the receiver and the leakage signal from the transmitter. A nonlinear block that is assumed to be weakly nonlinear and memoryless can be expressed using the Taylor expansion in equation 1 [2].

\[ y(t) = a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) + \ldots \]  

Fig. 1. A direct conversion receiver and the two dominating leakage signals generated by the transceiver itself. Far away from the base station the transmitter transmits with a high output power. An interference, proportional to the amplitude of the squared TX signal, will then occur in the baseband and decrease the sensitivity of the receiver. It will be shown that this interference can be suppressed with an LMS algorithm.

A. Crossmodulation distortion

Crossmodulation occurs in the LNA and in RF-parts of the mixer and is dependent of the IP3 performance. Because of the nonlinearities in the LNA modulated TX leakage information is transferred to another carrier [3], e.g. the leakage signal from the LO. Interference products will therefore end up in the desired RX band.

B. Second order distortion in base band

The LNA is generally in high gain to be able to detect the weak receiver signal. The TX leakage signal can therefore be as high as -10 dBm at the mixer input [1]. Consequently there will also be a strong leakage signal in the base band and because of second order distortion in base band blocks interference will occur in the desired RX band.

C. Second order distortion in RF-parts

The same phenomena as described above can arise in RF-parts of the ASIC. Interference containing modulated TX information will end up at DC and if the isolation in the mixer is not large enough this interference signal can leak through the mixer and interfere with the desired signal.

D. Self-mixing of TX leakage signal

If a clean-up filter is not used after the LNA the leakage signal from the transmitter is still strong at the mixer input. If the isolation between the mixer ports is bad some
of the TX泄漏信号将泄露到另一个端口，并且由于自混频干扰将产生在基带波束带内，且频率与信号相同。

The four effects described above are all generated by the internal signals within the transceiver and the interference is always present in the desired RX band during simultaneous communication. The interference contains modulated information from the TX leakage signal and can therefore not be filtered away. The four effects have all the same interference profile and can be written in a general expression with an unknown coefficient.

\[ y_{BB,undesired}(t) = C \cdot A^2_{TX}(t) = C \cdot (I^2_{TX}(t) + Q^2_{TX}(t)) \] (2)

The coefficient C is dependent of dominating effect and is above all unique for each transceiver ASIC. Furthermore is the coefficient different in the I- and Q-channel of the receiver and the coefficients are also subject for slowly variations with temperature and voltage supply.

III. THE CANCELLATION BLOCK

The cancellation block can be divided into three different sub blocks, shown in figure 2. The task of the cancellation block is to create a resembled replica of the interference and subtract it from the desired signal in the digital base band.

The topmost block in figure 2 contains two adaptive LMS filters, which perform estimations of the interference coefficients in the I- and Q-channel of the receiver respectively. To be able to perform this estimation a reference signal of the interference is needed and a replica of the interference profile, according to equation 2, is therefore created in the leftmost sub block in figure 2. The block in the middle is a compensation block used to compensate for delays occurring in transmitter- as well as receiver-blocks. The functionality of each subblock will be described in details below.

A. Creation of Interference Replica

The signal from the transmitter is measured as late as possible in the transmitter uplink, normally just before the DAC, to avoid as many imperfections as possible. A reference signal with the same profile as in equation 2, except for the unknown coefficient value, is then created.

B. Compensation Block

The compensation block compensates for all delays caused by digital blocks in both the transmitter and receiver. The block performs also a nominal compensation for delays occurring in analog block. However, no compensation is done for the spreading in delay between different transceiver ASICs.

C. Adaptive Filter Block

The adaptive filter block is designed around two LMS filters, which separately tries to estimate correct coefficient values of the interference in the I- and Q-channel of the receiver and subtract correct amount of the interference in the digital base band.

IV. SIMULATION RESULTS

All simulations were performed in Matlab using a WCDMA modulator to generate the TX leakage signal. Because the interference problem is largest at high TX output power levels, i.e. when the mobile phone is far away from the base station, the received signal is assumed to be weak and placed below the thermal noise floor. The downlink signal was therefore, in these simulations, modeled as thermal noise only.

Two aspects that have been examined are how dependent the improvement by using the cancellation block is of the two major imperfections; the distortion in the uplink and the spreading in TX/RX path delay. These two imperfections are neither estimated nor measured by the cancellation block and will therefore decrease the improvement. The distortion in the uplink (EVM) is modeled as additive white gaussian noise (AWGN) at symbol rate.

To be able to evaluate the cancellation block the noise-to-distortion ratio (NDR) was defined and this is a measure related to remaining interference in the base band. The reason to define the noise-to-distortion ratio is because the downlink signal is modeled as thermal noise only.

Two different simulations have been performed and are shown in figure 3 and 4. In the first simulation the uplink distortion was held fixed at 5% error vector magnitude (EVM) and a number of simulations with different spreading in TX/RX path delay were added. A simulation was also performed with the cancellation block off to get a reference curve (dashed-dotted).

In figure 4, the spreading in TX/RX path delay was instead kept fixed at 10 ns and simulations were performed for different uplink distortions. Also here was a simulation, with the cancellation block off, performed to obtain a reference.

Both plots show the improvement of the NDR level for the entire interference test interval. The test interval goes from -10 dB to 20 dB and is the power of the interference (including the DC component) versus the thermal noise power. For higher and higher uplink distortions as well as
for longer and longer spreading in TX/RX path delay the curves appear closer and closer to the reference, indicating decreased improvement. Increasing distortions in the transmitter chain affect the interference suppression much more in comparison to the spreading in delay.

At a constant NDR level, for an uplink distortion equal 5% and an assumed 10 ns spreading in TX/RX path delay, a 12 dB larger interference power is tolerated in the baseband with the cancellation block enabled. A 12 dB larger interference power corresponds to a 6 dB larger TX leakage signal at the LNA input.

V. Conclusion

In this paper we have presented a method to digitally suppress the interference caused by the leakage signal from the transmitter in a direct conversion WCDMA receiver. The cancellation block, placed in the digital domain between the transmitter and the receiver, has been designed around the well known adaptive least mean square (LMS) algorithm.

Simulations have shown that it is possible to suppress the interference and the suppression is not limited by the choice of the LMS algorithm. Instead the algorithm provides both sufficient rate of convergence and a low misadjustment. The LMS algorithm is also, because of its low computational cost, a good choice to implement in hardware.

The main limitation in improvement by using the cancellation block is determined by the distortion in the transmitter uplink. This is an imperfection that is neither estimated nor measured by the cancellation block.

The compensation block compensates for all delays caused by digital blocks in the receiver and the transmitter and it provides also a nominal compensation for delays caused by analog blocks. The spreading in delay, between different transceiver ASICs, will affect the improvement, but not at all as much as increasing uplink distortions.

Simulations have also shown that there is no gain to create the replica of the interference at a higher sample rate than two times the chip rate.

References

[1] M. S. Khan and N. Yanduru
