Digital Cancellation Technique to Mitigate Receiver Desensitization in Cellular Handsets Operating in Carrier Aggregation Mode With Multiple Uplinks and Multiple Downlinks

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Abstract — Recent explosive growth in uplink and downlink carrier aggregation in cellular networks is leading to severe desense in receivers for deployment of certain band combinations. In this paper, we studied receiver desense caused by 2nd order nonlinearity of components in the signal chain. A practical case of two (bands 3 and 8) uplink aggregation and three (bands 3, 8 and 26) downlink carrier aggregation was considered to demonstrate greater than 20dB desense in band 26 receiver despite using state of the art frontend components including linear diplexer with IIP2 greater than +90dBm. We developed a digital cancellation technique that is capable of achieving greater than 20dB improvement in signal-to-interference-plus-noise ratio for 10MHz LTE signals.

Index Terms — Carrier aggregation, Digital Cancellation, Inter-modulation distortion, Least Squares Method.

I. INTRODUCTION

To meet increasing demands for high data rates, commercial wireless communication systems are beginning to use carrier aggregation techniques, so that a single user can access greater signal bandwidths than offered by a single channel \cite{1}. Numerous cell phones are now equipped to support downlink carrier aggregation, simultaneously receiving signals in different bands. It is expected in the near future that high end handsets will be able to support both downlink and uplink carrier aggregation i.e. simultaneously receive and transmit in multiple bands. This scenario presents a variety of challenges. A significant problem is the generation of spurious signals by the nonlinearity of components within the handset, which may interfere with the operation of the receivers.

Digital cancellation techniques have been employed to mitigate receiver desense due to 2\textsuperscript{nd} order and higher order non-linearity caused by self-jamming (paired transmit signal) \cite{2, 3}. More recently, this work has been extended to cancel 3\textsuperscript{rd} order intermodulation distortion caused by two transmit signals in band 5 (824-849 MHz) and band 13 (777-787 MHz), desensing one of the paired receivers in band 5 (869-894 MHz) in two uplink and two downlink carrier aggregation scenario \cite{4}.

In this paper, we consider the two uplink and three downlink carrier aggregation scenario illustrated in Fig. 1. Despite using separate antennas for band 3 and band 8, there is a significant coupling of power between the antennas. In addition, to provide frequency-selective signal routing in handsets, a diplexer is used to separate band 3 and band 26. The transmit signals from the uplinks (bands 3 and 8) go through 2\textsuperscript{nd} order intermodulation in the signal path and desense the unpaired receiver in the downlink (band 26).

![Fig. 1. Block diagram of 2 uplink and 3 downlink carrier aggregation illustrating the desense of unpaired receiver due to 2\textsuperscript{nd} order intermodulation.](image)

Experimentally, we demonstrated that the diplexer is the largest source of non-linearity, desensing the unpaired receiver by more than 20dB, despite having IIP2 of greater than +90dBm, due to large signals incident on the diplexer ports. We developed a digital cancellation technique that can be used to estimate and cancel the 2\textsuperscript{nd} order intermodulation signal leaking into the unpaired receive band.

It is also shown that in order to achieve the best cancellation performance, we need to consider terms beyond the 2\textsuperscript{nd} order in the Volterra series to generate a more accurate estimate of the distortion. The proper estimated interference is subtracted from the received
signal resulting in a cleaner signal consists of the desired received signal and the residual of estimation which eventually is translated to less EVM.

II. EXPERIMENTAL SETUP

Fig. 2 shows the experimental setup used to measure the desense in unpaired receive band. Transmitted RF signals in band 8 and band 3 (aggressors) are generated by Vector Signal Generators (VSGs) which accept the baseband signal in complex format from a PC. The desired received signal (victim) is generated by a third VSG and injected to the diplexer. The band 8 transmit signal, TX2 is injected through a directional coupler to emulate antenna coupling. All the signals used in this experiment are LTE with 10 MHz bandwidth. A Vector Signal Analyzer (VSA) is used to capture band 26 receive band signals and send them to the PC. All the processing is done in MATLAB.

To investigate the nonlinear interference experimentally, at first, no desired RX signal was applied to the setup. With only TX1 and TX2, with power of +14dBm and +24dBm at the antenna port of diplexer, the interference product IM2 with a level of -80dBm is observed. This 2nd order intermodulation product passes through band 26 duplexer without much attenuation except the passband loss and desensitizes the receiver by more than 20dB. Using (1), IIP2 of the diplexer can be determined to be +94dBm.

\[ P_{IM2} \approx P_{TX1} + P_{TX2} - IIP \quad (1) \]

The FIR filter coefficients can be found adaptively by minimizing the power of the error signal which calculated from subtracting the estimated im2 from the received signal or by using the least squares method. To achieve the best cancellation performance, the estimated distortion was manipulated by including additional terms according to (3),

\[ \hat{im2}(n) = tx1(n-K) \cdot tx2'(n) \quad (2) \]

In which the coefficient vector \( \tilde{a} = [A \ B \ C \ D]^T \) is found from solving the matrix equation in the form of \( U_K \tilde{a} = \bar{y}_{im2} \), where, \( U_K \) is the input matrix generated from the basis functions exist in (3) and \( \bar{y}_{im2} \) is the output vector.

The second term in (3) represents the 4th order nonlinearity effect and the third and fourth terms represent the cross-memory effects which allow for subsample alignment between TX1 and TX2.
Fig. 4. The IM2 signal captured without desired RX

Fig. 4 shows IM2 distortion (thick red curve), the modeled or estimated distortion (dotted blue curve), the noise floor of the system (dashed green curve) and the residual signal after cancellation (black curve). With the method presented in this paper and by using the estimated $\text{IM}_2$ according to (3), we were able to cancel the distortion almost all the way down to the system noise floor. After confirming the algorithm performance in presence of only distortion product, we studied the system performance in presence of the desired received signal. Fig. 5 and Fig. 6 show the cancellation performance for the cases that the desired received Signal-to-Interference-plus-Noise Ratio (SINR) is -10 dB and +10 dB respectively.

Fig. 5. Low power received signal with distortion before/after cancellation (SINR before/after cancellation ≈ -10dB/+9.4dB).

EVM of the received signal improves from more than 100% to 34%. For the cases that signal power is higher than the distortion power, the desired signal acts as a strong noise for the algorithm. However, the algorithm still cancels the distortion partially and improves the final SINR and EVM of the received signal. When the received signal is 10 dB stronger than the distortion, the EVM improves from 30.9% to 6.3%.

![Power Spectral Density](image1)

![Power Spectral Density](image2)

TABLE I

<table>
<thead>
<tr>
<th>RX power (dBm)</th>
<th>No IM2 SINR (dB)</th>
<th>EVM (%)</th>
<th>Before Cancellation SINR (dB)</th>
<th>EVM (%)</th>
<th>After Cancellation SINR (dB)</th>
<th>EVM (%)</th>
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<td>3.5</td>
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<td>30.9</td>
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<td>6.3</td>
</tr>
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</table>

VII. CONCLUSION

In advanced mobile communication systems, multiple uplinks and downlinks are used to increase data rate. In such systems, the linearity requirements for the front-end components are extremely stringent to keep receiver desense low. This would necessitate huge efforts to design more linear front-end components such as diplexers, antenna switches and duplexers. As cheaper alternative, we demonstrated a digital cancellation technique that can cancel up to 20dB, and improve the EVM significantly to be acceptable for deployment in the field.
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REFERENCES


