Implementation Challenges in Full-duplex Radio Transceivers

Dani Korpi, Mikko Valkama, Taneli Riihonen, and Risto Wichman

25.4.2013
Wireless single channel full-duplex communications

- Transmitting and receiving data simultaneously, using only one channel
Implementational challenges

• Achieving a sufficient amount of self-interference cancellation
• Nonlinear distortion caused by the strong self-interference signal
• Dynamic range of the analog-to-digital converter
Analyzed transceiver model
Parameters

- Typical parameters for the components were chosen from previous literature

- Two cases for the RF cancellation reference signal path were considered

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR requirement</td>
<td>5 dB</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>3 MHz</td>
</tr>
<tr>
<td>Sensitivity level</td>
<td>-100.1 dBm</td>
</tr>
<tr>
<td>Received signal power</td>
<td>-95.1 dBm</td>
</tr>
<tr>
<td>Antenna separation</td>
<td>30 dB</td>
</tr>
<tr>
<td>RF cancellation</td>
<td>40 dB</td>
</tr>
<tr>
<td>Digital cancellation</td>
<td>35 dB</td>
</tr>
<tr>
<td>ADC bits</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Gain</th>
<th>IIP2</th>
<th>IIP3</th>
<th>NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA (Tx)</td>
<td>27 dB</td>
<td>-</td>
<td>15 dBm</td>
<td>5 dBm</td>
</tr>
<tr>
<td>LNA (Rx)</td>
<td>25 dB</td>
<td>43 dBm</td>
<td>-15 dBm</td>
<td>4.1 dBm</td>
</tr>
<tr>
<td>IQ Mixer (Rx)</td>
<td>6 dB</td>
<td>42 dBm</td>
<td>15 dBm</td>
<td>4 dBm</td>
</tr>
<tr>
<td>VGA (Rx)</td>
<td>0-69 dB</td>
<td>43 dBm</td>
<td>10 dBm</td>
<td>4 dBm</td>
</tr>
</tbody>
</table>
Analytical system calculations

- Based on determining the power levels of the different signal components at certain points in the receiver chain
  - Signal of interest
  - Thermal noise
  - Self-interference
  - Nonlinear distortion
  - Quantization noise
  - etc.
Analytical system calculations

• Nonlinear distortion:
  – Calculations are based on intercept points (IIP2 and IIP3)
    • ”The point at which the power of the \( n \)th order nonlinearity is as powerful as the fundamental signal”

• Dynamic range of the ADC
  – It is calculated based on the well-known equation for the SNR of an ADC
    • \( SNR_{ADC} = 6.02b + 4.76 - PAPR \)
Example result (Case A)

Power levels of the different signal components after digital cancellation

Amount of bits lost at the ADC due to self-interference
Example result (Case B)

Power levels of the different signal components after digital cancellation

Amount of bits lost at the ADC due to self-interference
Increasing digital cancellation

- It has been shown that more digital cancellation can be achieved with higher transmit powers.
- Thus, it is also analyzed how increasing the amount of digital cancellation to sustain a 3-dB loss of SINR affects the results.
Power levels of the different signal components after digital cancellation. The amount of digital cancellation is increased to sustain a 3-dB loss of SINR.

The required amount of digital cancellation for sustaining the specified SINR loss.
Waveform simulations

• To assess the reliability of the results, they were compared to results obtained from complete waveform simulations
• Same transceiver model was used in the simulations as in the analytical calculations
• OFDM signal with 16-QAM constellation was used
Waveform simulation results

The SINR value at the input of the detector.

- The analytically calculated SINR value is slightly lower than the simulated value.
- However, the difference is nevertheless quite small.

Antenna separation: 30 dB, RF cancellation: 40 dB, digital cancellation: 35 dB, ADC bits: 10, sensitivity level: -100.1 dBm (Case A)
Conclusions

• The strong SI signal produces nonlinear distortion, which must be considered
  – Especially if the amount of SI cancellation is increased

• With high SI levels, the dynamic range of the ADC might be insufficient
  – The amount of bits should be increased, or higher amounts of SI cancellation should be performed in the analog domain