Brief Overview of Transceiver Architectures

J.L. Julian Tham
Desired Features of Commercial Radios

- Low Cost
- Small Form Factor
- Long Range
- Robustness
- Interoperability
- Long operating life
- Higher data rates
Outline

• Systems requirements
• Receiver architectures
• Transmitter architectures
• Examples of transceiver implementations
• Trends
• Conclusions
Outline

- **Systems requirements**
- Receiver architectures
- Transmitter architectures
- Examples of transceiver implementations
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- Conclusions
Implications of Desired Features

Low Cost / Small Form Factor => Small die size, minimizing external components

Long Range => High sensitivity -> low RX NF; High TX power

Interoperability => Low spurious emissions

Robustness / jamming immunity => High linearity and selectivity

Long operating life => Low power consumption

Higher data rates => Higher order modulation -> higher quadrature accuracy
### Example of Receiver Requirements

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1—Adjacent channel power, equal bandwidth to the main channel.
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5—Transmitter signal mask at 11-MHz offset.

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Example of Receiver Requirements

- Range of the Mobile => Sensitivity < -102dBm
- Near-Far Problem => Large Dynamic Range
- Presence of Nearby Users => IIP3 > -17dBm
Outline

• Systems requirements
• **Receiver architectures**
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• Conclusions
RX Direct Conversion

Properties of Direct Conversion

+ Low frequency signal facilitating programmable filters
+ Integration potential
+ Signal is its own image – required IR set by baseband SNR
- Self-mixing effects
- Problematic 1/f, DC offset and IP2 interference
RX Direct Conversion

• DC Offsets -> Offset cancellation in BB with or without DSP aid.

• LO Self mixing -> Differential signals, Offset LO or sub-harmonic mixers.

• Even-Order Distortion -> Differential signals or IP2 beat rejection.

• Phase & Gain Mismatch -> Calibration.

• Flicker Noise -> Passive mixers.

• Most of the above issues apply to any RX architecture that uses a last zero IF.
Low IF Receiver

Properties of Low-IF Receivers

- Less susceptible to low frequency interference
- Image rejection must be addressed
Low IF Receiver

- Allows high-pass filtering in baseband to remove DC offsets and part of flicker noise spectrum.

- Image rejection is an issue - requires more stringent I/Q matching than in zero-IF RX.

- LO leakage and even-order distortion are still problematic.

- Higher IF increases power consumption of filters.

- Baseband A/D converters are run faster than zero-IF RX.
Weaver Image–Reject Receiver

- Allows relatively broadband and process–insensitive image rejection. (But still limited by mismatches.)
- First IF image cancelled through quadrature mixing, poly-phase filters are not needed
- Last IF is usually set to zero to avoid secondary image.

Rudell et al, ISSCC 1997
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Direct Conversion Transmitters

Properties of Direct Up-Conversion Transmitters

+ Single conversion eliminates IF filter
+ High linearity
  - Requires Pre-PA filter for harmonic rejection
  - Wideband modulator noise demands filtering
Zero- or Low-IF TX with Offset LO

• LO pulling and leakage are resolved.

• Unwanted LO sideband $\rightarrow$ image issue in RX.

• DC offsets, flicker noise, and even-order distortion still critical.
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Example of Transmitter Specifications

TX Noise in RX Band

- Receive Band Noise at 20MHz offset, PN < -162dBc/Hz
- Modulation Mask at 400kHz offset requires high linearity and low phase noise
- Modulation Accuracy of: $\varphi_{\text{RMS}} < 5^\circ$
TX Offset Phase-Locked Loop

- PLL frequency translates phase modulated signal
- High output spectral purity / higher transmitter efficiency
- For constant envelope modulations only
- Leverage narrowband signal to enable integration
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Polar Transmitter

- Possible for non-constant envelope modulations
- PLL frequency translates phase modulated signal
- Power amplifier output is amplitude modulated
- Alignment of amplitude and phase modulations is critical.
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Direct-conversion WCDMA Transmitter

[Brenna et al, ISSCC’03]
Problem of Carrier Leakage

- Affects:  - Error vector magnitude (EVM)
            - Output power accuracy

- Limits useful gain control range

[Brenna et al, ISSCC’03]
Calibration to Suppress Carrier Leakage

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<td>13–50%</td>
<td>−60 (3)</td>
</tr>
<tr>
<td>EDGE</td>
<td>0.2</td>
<td>3π/8-8PSK</td>
<td>3.2</td>
<td>17</td>
<td>27</td>
<td>half</td>
<td>30</td>
<td>13–50%</td>
<td>−54 (3)</td>
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<td>UMTS</td>
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<td>HPSK</td>
<td>3.5–7</td>
<td>infinite</td>
<td>24</td>
<td>full</td>
<td>80</td>
<td>100%</td>
<td>−33 (1)</td>
</tr>
<tr>
<td>IS-95B</td>
<td>1.23</td>
<td>OQPSK</td>
<td>5.5–12</td>
<td>26–infinite</td>
<td>24</td>
<td>full</td>
<td>73</td>
<td>100%</td>
<td>−42 (2)</td>
</tr>
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<td>cdma2000</td>
<td>1.23</td>
<td>HPSK</td>
<td>4–9</td>
<td>infinite</td>
<td>24</td>
<td>full</td>
<td>80</td>
<td>100%</td>
<td>−42 (2)</td>
</tr>
<tr>
<td>TETRA</td>
<td>0.25</td>
<td>π/4-DQPSK</td>
<td>3.5</td>
<td>19</td>
<td>36</td>
<td>half</td>
<td>45</td>
<td>25%</td>
<td>−60 (1)</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>1</td>
<td>GFSK</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>half</td>
<td>—</td>
<td>variable</td>
<td>−20 (4)</td>
</tr>
<tr>
<td>802.11b</td>
<td>11</td>
<td>QPSK</td>
<td></td>
<td>infinite</td>
<td>20</td>
<td>half</td>
<td>—</td>
<td>variable</td>
<td>−30 (5)</td>
</tr>
<tr>
<td>802.11a/g</td>
<td>18</td>
<td>OFDM</td>
<td></td>
<td>infinite</td>
<td>20</td>
<td>half</td>
<td>—</td>
<td>variable</td>
<td>−20 (5)</td>
</tr>
</tbody>
</table>

Spectral Quality Notes:
1—Adjacent channel power, equal bandwidth to the main channel.
2—Nearby (985-kHz offset) channel power, measured in 30-kHz bandwidth.
3—Transmitter signal mask at 400-kHz offset.
4—Transmitter signal mask at 500-kHz offset.
5—Transmitter signal mask at 11-MHz offset.

I/Q Calibration

- Compute TX I/Q Mismatch and LO Leakage.

- Use corrected TX path.
- Compute RX mismatch.

[Vassilou et al, JSSC December 2003]
Measured TX Sidebands

Pre-calibration

<table>
<thead>
<tr>
<th>Marker</th>
<th>Trace</th>
<th>Type</th>
<th>X Axis</th>
<th>Amplitude</th>
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</thead>
<tbody>
<tr>
<td>1R</td>
<td>(1)</td>
<td>Freq</td>
<td>5.239 706 GHz</td>
<td>7.48 dBm</td>
</tr>
<tr>
<td>1a</td>
<td>(1)</td>
<td>Freq</td>
<td>627 kHz</td>
<td>-24.15 dB</td>
</tr>
<tr>
<td>2R</td>
<td>(1)</td>
<td>Freq</td>
<td>5.239 706 GHz</td>
<td>7.48 dBm</td>
</tr>
<tr>
<td>2a</td>
<td>(1)</td>
<td>Freq</td>
<td>313 kHz</td>
<td>-6.96 dB</td>
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</table>

Post-calibration

<table>
<thead>
<tr>
<th>Marker</th>
<th>Trace</th>
<th>Type</th>
<th>X Axis</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1R</td>
<td>(1)</td>
<td>Freq</td>
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<td>7.51 dBm</td>
</tr>
<tr>
<td>1a</td>
<td>(1)</td>
<td>Freq</td>
<td>627 kHz</td>
<td>-54.30 dB</td>
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<tr>
<td>2R</td>
<td>(1)</td>
<td>Freq</td>
<td>5.239 706 GHz</td>
<td>7.51 dBm</td>
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<tr>
<td>2a</td>
<td>(1)</td>
<td>Freq</td>
<td>313 kHz</td>
<td>-41.09 dB</td>
</tr>
</tbody>
</table>

[Vassilou et al, JSSC December 2003]
Outline

- Systems requirements
- Receiver architectures
- Transmitter architectures
- Examples of transceiver implementations
- Trends
- Conclusions
Some transceiver trends

- Multi-band
- Multi-mode
- Multi-antenna
MIMO example

Garrett et al., JSSC January 2005
Beam forming

[Paramesh et al, JSSC Dec. 2005]
SNR improvement with 2\textsuperscript{nd} antenna enabled

[Paramesh et al, JSSC Dec. 2005]
Interference rejection with 2nd antenna enabled

[Paramesh et al, JSSC Dec. 2005]
Digital Radio: Digital transmitter & discrete-time receiver

Staszewski et al, JSSC December 2004
Software Defined Radio

Classic SDR as defined by Mitola
Software Defined Radio

Realization of anti-aliasing sampler and subsequent decimation stages.

Bagheri et al, JSSC December 2006
Conclusions

• An overview of various transceiver architectures was presented.

• The impact of system requirements was illustrated with some examples of transceiver implementations.

• There is still room for more innovation!
What does it take to develop successful RF Transceiver products?
What does it take to develop successful RF Transceiver products?

Teamwork

• BRENNAR et al.: 2-GHz CARRIER LEAKAGE CALIBRATED DIRECT-CONVERSION WCDMA TRANSMITTER IN 0.13-μm CMOS, IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 39, NO. 8, AUGUST 2004

• VASSILION et al.: SINGLE-CHIP DIGITALLY CALIBRATED 5.15–5.825-GHz 0.18-μm CMOS TRANSCEIVER FOR 802.11A WIRELESS LAN, IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 38, NO. 12, DECEMBER 2003

• GARRETT et al.: A 28.8-Mb/s 4x4 MIMO 3G CDMA RECEIVER FOR FREQUENCY SELECTIVE CHANNELS, IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 40, NO. 1, JANUARY 2005

• PARAMESH et al.: FOUR-ANTENNA RECEIVER IN 90-nm CMOS FOR BEAMFORMING AND SPATIAL DIVERSITY, IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 40, NO. 12, DECEMBER 2005

• ABIDI: RF CMOS COMES OF AGE, IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 39, NO. 4, APRIL 2004

• BAGHERI et al.: AN 800-MHz–6-GHz SOFTWARE-DEFINED WIRELESS RECEIVER IN 90-nm CMOS, IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 41, NO. 12, DECEMBER 2006

• STASZEWSKI et al.: ALL-DIGITAL TX FREQUENCY SYNTHESIZER AND DISCRETE-TIME RECEIVER FOR BLUETOOTH RADIO IN 130-nm CMOS, IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 39, NO. 12, DECEMBER 2004