Efficient Linear Power Amplifiers for use in 4G systems

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Overview

- Main Drivers for Power Amplifier Design
- Envelope Tracking and Non Linear Envelope Tracking
- Class J Amplifiers
- Class J Linearization using Generic Techniques
- Inverse Doherty Amplifier Design
- Conclusions
• **Main drivers**

• **GREEN**
  - Environmental concerns
  - Operational expenses

• **SIMPLE**
  - Deployment costs
  - Maintenance

• **FAST**
  - User experience

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In PA words:

• **Efficiency**
• **Linearity**
• **Bandwidth**

Which one is more important?
Long Term Evolution (LTE)

- 3GPP LTE → Downlink Data rate \( \leq 100 \text{Mbps} \):
  - OFDM (QPSK, 16 QAM, and 64 QAM)
  - Various RF bandwidths: 1.4-20 MHz
  - Various Peak-to-Average-Power-Ratios (PAPR)
LTE RF signals

<table>
<thead>
<tr>
<th>Channel bandwidth $\text{BW}_{\text{Channel}}$ [MHz]</th>
<th>1.4</th>
<th>3</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{PAPR}$ [dB]</td>
<td>23</td>
<td>16.5</td>
<td>13.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10 MHz: 50 RB
10 MHz: 20 RB
1.4 MHz: 6 RB

Envelope Tracking System

ENVELOPE TRACKING

DSP

Envelope

Envelope amplifier

Amplitude and phase

PA

Output power
Envelope Tracking (ET) Power Consumption Comparison

- Fixed PS
- ET system
- Higher efficiency
- Less need for cooling
Non-Linear Envelope Tracking Amplifier

Schematic of the NET System

NET characterization measurement results
## Performance Measurements

<table>
<thead>
<tr>
<th>SETUP</th>
<th>ACLR (dBc)</th>
<th>ACLR Alternate (dBc)</th>
<th>EVM (%)</th>
<th>$\eta_D$ (%)</th>
<th>PAE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>16-QAM</td>
</tr>
<tr>
<td>Classic ET</td>
<td>30</td>
<td>30</td>
<td>47.5</td>
<td>46.6</td>
<td>10</td>
</tr>
<tr>
<td>Classic ET with Pre-distortion</td>
<td>50.6</td>
<td>50.6</td>
<td>57.8</td>
<td>58</td>
<td>1</td>
</tr>
<tr>
<td>NONLINEAR ET with Pre-distortion</td>
<td>49</td>
<td>49</td>
<td>51</td>
<td>51</td>
<td>1</td>
</tr>
</tbody>
</table>
• **The Class J Amplifier**

• Recently introduced Broadband Efficient Technique
• Under harmonically tuned category (up to second harmonic)
• Better control of trade-offs
• Highly efficient
• Quasi-linear
• Super-set of Class-B operation

GREEN

SIMPLE

WIDEBAND
• **Class J theory**

- Biased as Class-B, deep AB
- Second harmonic not shorted (purely reactive)
- Complex fundamental impedance
- No "knee" voltage crossing occurs
- Same efficiency/output power as Class-B
- Large drain voltage swing almost 3x supply voltage

\[
Z_{fo} = 1.4142 \angle 45^\circ \\
Z_{2fo} = 1.1781 \angle -90^\circ
\]
• **PA realisation**

- Input stabilization network
- Harmonic control
  - Two at the input
  - Three at the output
- RT-Duroid 8550 substrate
  - $E_r = 2.2$
  - $T = 0.787\ mm$
- Fully distributed architecture
- Size: 13.5 x 6.5 cm
• Frequency Response
Class-J PA

Generic Pre-distortion

Generic Pre-distortion in the presence of LTE 1.4 MHz signal

\[ V_{GSQ\ OPT} = -2.38V, \text{ RF path Delay} = 4 \ Te; (Te=1/100e6); \]
\[ \text{Pgmax} = -14.2\text{dBm} \]

<table>
<thead>
<tr>
<th>Item</th>
<th>Min</th>
<th>Mean</th>
<th>Mean Limit</th>
<th>Max</th>
<th>Max Limit</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVM PDSCH QPSK</td>
<td></td>
<td>1.15</td>
<td>17.50</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>EVM PDSCH 16QAM</td>
<td></td>
<td>1.28</td>
<td>12.50</td>
<td></td>
<td></td>
<td>%</td>
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<td>EVM PDSCH 64QAM</td>
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<td>1.15</td>
<td>8.00</td>
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<td></td>
<td>%</td>
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</table>
Inverse Doherty Amplifier

- Output current of the carrier and peaking amplifier combine out of phase at point $\alpha$
- Load modulation occurs at output power back-off
- Load impedance must equal $Z_{C1}$
RF Power Amplifier Test bed

Data Capture

Test Amplifier

Linearisation and Efficiency Performance Evaluation
Implementation

- Dedicated design:
  - Identical devices used for the carrier and peaking amplifier (CGH40010 – 10W GaN) at 2.1GHz
  - Identical input and output matching networks
  - Smaller peaking amplifier is emulated by reducing the drain supply voltage (29V and $I_{DSQ}$ of 5mA for the carrier amplifier, 13V and $I_{DSQ}$ of 5mA for the peaking amplifier)
Measurement Results

- Dual-Drive approach:
  - Allows for generic characterization
  - All possible input combinations tested
  - PAE is calculated by subtracting the input power of the carrier and peaking amplifier from the total output power

75% (59%) drain efficiency (PAE) at 8dB OPBO

60% (50%) drain efficiency (PAE) at 10dB OPBO
Linearity Performance

1.4MHz LTE

<table>
<thead>
<tr>
<th>Channel</th>
<th>Bandwidth</th>
<th>Adjacent Channel</th>
<th>Power</th>
<th>Lower</th>
<th>Upper</th>
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</thead>
<tbody>
<tr>
<td>Tx Channel</td>
<td>1.095 MHz</td>
<td></td>
<td>7.10 dBm</td>
<td>-50.60 dB</td>
<td>-49.26 dB</td>
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<tr>
<td>Adjacent</td>
<td>1.095 MHz</td>
<td>1.4 MHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate</td>
<td>1.095 MHz</td>
<td>2.8 MHz</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

10MHz LTE

<table>
<thead>
<tr>
<th>Channel</th>
<th>Bandwidth</th>
<th>Adjacent Channel</th>
<th>Power</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx Channel</td>
<td>9.015 MHz</td>
<td></td>
<td>6.65 dBm</td>
<td>-46.11 dB</td>
<td>-48.01 dB</td>
</tr>
<tr>
<td>Adjacent</td>
<td>9.015 MHz</td>
<td>10 MHz</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Alternate</td>
<td>9.015 MHz</td>
<td>20 MHz</td>
<td></td>
<td></td>
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</tbody>
</table>
Conclusions

• Peak to Average Power Ratios cause significant problems with amplifier efficiency
• Variable signal bandwidths cause problems with linearisation
• The major challenge for future efficient linear amplification is the amplification of signals across a large number of non-contiguous bands.