Adaptive power amplifier concepts preserving linearity under severe mismatch conditions

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Motivation

- PA
- Output match
- $Z_{ant}$

Body effects

$|Z_{ant}|$

fo
Outline

• Motivation
• Distortion due to antenna mismatch
• Adaptive concepts preserving PA linearity
• Experimental verification
• Conclusions
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Collector voltage saturation

- Voltage clipping of lower–side envelope
- Severe distortion

\[ v_{col\_min} > V_{sat} \]

\[ I_c \]

\[ V_{sat} \]

\[ V_{bat} \]

\[ V_{ce} \]

\[ f(\Gamma) \]

\[ P_{out} \text{ [dBm]} \]

- EVM, ACPR and Eff. optimized at 50 Ohm

Operating area of concern
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Control criterion

\[ V_{col\_min} > V_{sat\_NPN} \]

\[ V_{col\_min} = V_{supply\_min} - \sqrt{P_{out\_max}} \cdot Z_{col\_max} \]

\[ Z_{col\_max} = R_{col\_nom} \cdot \frac{1 + \Gamma_{col}}{1 - \Gamma_{col}}; \quad \angle \Gamma_{col} = 0 \]
Detection and correction

- Detection:
  - Minimum collector peak voltage

- Correction:
  - Output power
  - Supply voltage
  - Collector load impedance
Output power adaptation

- Adaptation via existing power control blocks
- Very low cost implementation
Load line adaptation

- Compensation of the mismatch is best
- Needs linear high-Q variable Ls or Cs (RF-MEMS)
Supply voltage adaptation

- Needs (slow) up-conversion of the supply voltage
- Can be combined with efficiency enhancement by down-conversion of the supply voltage
Simulated acquisition of power adapting loop

- Closing the loop avoids collector voltage clipping
- Pre-amplifier gain reduction with ripple due to re-activation of T&H circuit
Simulated spectral re-growth

- VSWR = 4, worst case phase; Pout = 28.5dBm at 50 Ω
- Closing the loop reduces spectral re-growth
Simulated Vcontrol vs. mismatch phase

- Limited range of mismatch phases
- Largest correction when $Z_{col}$ is largest

![Graph showing Vcontrol vs. mismatch phase](image-url)
Comparison based on simulations

- Load line adaptation gives best compromise

<table>
<thead>
<tr>
<th>Method to preserve linearity</th>
<th>Pout [dBm]</th>
<th>Vsupply [V]</th>
<th>Zcol [Ω]</th>
<th>ACPR [dBc]</th>
<th>EVM [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (50 Ω ref.)</td>
<td>28.6</td>
<td>3.5</td>
<td>2.5</td>
<td>-59</td>
<td>2.5</td>
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<tr>
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<td>Isolator</td>
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<tr>
<td>Output power</td>
<td>24.1</td>
<td>3.5</td>
<td>7.7</td>
<td>-59</td>
<td>3.1</td>
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<tr>
<td>Load line</td>
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<td>3.5</td>
<td>2.8</td>
<td>-58</td>
<td>2.5</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>28.6</td>
<td>6.1</td>
<td>7.7</td>
<td>-59</td>
<td>2.5</td>
</tr>
</tbody>
</table>

VSWR = 4; worst case phase
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Adaptive PA used for measurements

Semiconductors

A.van Bezooijen

BGA2031

Pin

Vbat

Match

PAM

P_ref_ant

P_inc_ant

P_diss

Z_load

VSWR = 4:1

0 ... 360°

Biasing

Peak detector

Comparator

T&H

PCB

Pinc_ant

Vdetector

Vdetector

Chold

π/2

Vdetector

Pref_ant

Vref

Col

Vdetector

Pin

p2

p1

Vdetector

V detector

Biasing
Prototypes

GSM/Edge PAM with discrete detection diode

Integrated detection diode
Measured EVM and peak voltage

- Strong correlation between EVM and minimum detected collector peak voltage; $P_{out} = 28.5 \text{dBm}$
Measured ACPR and peak voltage

- Strong correlation between ACPR and minimum detected voltage; $P_{out} = 28.5\text{dBm}$
Measured EVM vs. mismatch phase

- VSWR = 4; Pout = 28.5dBm at 50 Ω
- 5% EVM improvement at worst case phase
Measured ACPR vs. mismatch phase

- VSWR = 4, worst case phase; Pout = 28.5dBm at 50 Ω
- 10% ACPR improvement at worst case phase
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Conclusions

• Minimum collector voltage can be used as control criterion to preserve linearity adaptively
• Output power adaptation can be implemented at very low cost
• Load line adaptation is very promising and needs linear high-Q Ls or C’s (RF-MEMS)
• Supply voltage adaptation needs (slow) up-conversion and can well be combined with efficiency enhancement methods
• Adaptation makes isolators redundant
Thanks for your attention