« Silicon Power Amplifiers for 5G+ and IoT wireless communication applications”

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Connectivity is everywhere; PA is in each Connectivity

RF & WIRELESS 5G+ APPLICATIONS
Outline

- Introduction
- Silicon Processes for Power Amplifiers
- 5G+ Applications & Design examples
- Conclusions
Silicon Technology Evolution

Wireless Trends
PA is a mixt Application between More Moore and More than Moore.
Wireless Trends

- **Reconfigurability:**
  - Data-Rate, size, power consumption...
  - Data/Range Efficiency

- **Low Cost and Modularity:**
  - Light Infrastructure

- **Safety and Security:**
  - Smart Interactive Network
  - Sense and React concept
  - Secure links
CMOS Processes

SiGe HBT BiCMOS Processes

Summary
CMOS: Transistors on Bulk and SOI substrates

- Medium resistivity (~10 Ω.cm) in bulk technologies → substrate losses
- High resistivity (~1 KΩ.cm) *not used with bulk due to latch-up issues*
  - Solution: very good isolation and reduced losses thanks to High Resistivity substrates possible only on SOI

SOI technology (*STMicroelectronics*)

- Buried Oxide
- > 1kOhm-cm Si

65nm RF Bulk technology (*STMicroelectronics*)

- Bulk ~ 10 Ohm-cm

STI

0.2 μm
CMOS: Bulk and SOI devices RF performances

- Bulk **AND** SOI devices show similar HF performances:
  - SOI FB CMOS suffers from Kink effect, but in HF has same characteristics as a identical layout bulk device
  - SOI BC CMOS is penalized in HF by their specific layout (Rg and Cgs)

LP (RF) and GP (VLSI) devices

\[ f_T \propto \frac{1}{L_g \alpha} \quad (\alpha \sim 1) \]
CMOS: 28nm Planar UTBB FD-SOI Structure

Ultra Thin Body & BOX Fully Depleted SOI transistor

Thin BOX (25nm)
Thin Body (7nm)
Handle wafer
High-K Metal Gate
CMOS: 28nm Planar UTBB FD-SOI Specificities

- Ultra thin body
  - Better SCE immunity
- Ultra thin BOX
  - Extended body biasing
- Total dielectric isolation
  - Latch up immunity
- No channel doping
  - Improved variability

UTBB FD-SOI enables shorter channel length

Body-Bias

Hybrid zone

24nm
Interesting to temporarily trade-off leakage and speed
Interesting to compensate process fluctuations
Body Bias not degraded with scaling in FDSOI
Body biasing fully inefficient in Finfet
## CMOS Technologies Specificities

<table>
<thead>
<tr>
<th>CMOS Techno</th>
<th>GO1</th>
<th>GO2</th>
<th>Stack</th>
<th>LDMOS or DRIFT MOS</th>
<th>Passives</th>
<th>NVM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vdd</td>
<td>FT</td>
<td>Vdd</td>
<td>Fmax</td>
<td>Num of Trans</td>
<td>BV</td>
</tr>
<tr>
<td>HR PD SOI 130</td>
<td>1.2V</td>
<td>70GHz</td>
<td>2.5V</td>
<td>40GHz</td>
<td>10 - 15</td>
<td>14V</td>
</tr>
<tr>
<td>CMOS 65 (RF)</td>
<td>1.2V</td>
<td>140GHz</td>
<td>1.8V</td>
<td>60GHz</td>
<td>&lt; 4</td>
<td>8V (Free)</td>
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<tr>
<td>CMOS 40 (VLSI)</td>
<td>1.2V</td>
<td>220GHz</td>
<td>1.8V</td>
<td>60GHz</td>
<td>&lt; 4</td>
<td>NA</td>
</tr>
<tr>
<td>FDSOI 28</td>
<td>1.0V</td>
<td>320GHz</td>
<td>1.8V</td>
<td>70GHz</td>
<td>&lt; 6</td>
<td>6V (Free)</td>
</tr>
</tbody>
</table>

*ST-Microelectronics sources*
SiGe BiCMOS: SiGe HBT for Power Amplifier

- $f_t (L_c)$ vs. $V_{CE}$ (model vs. experiment) and extracted temperature rise
- $f_t (V_{BE})$ vs. temperature (-40 → +125°C) (model vs. experiment)
- $f_{max} (L_c)$ vs. emitter length (1 → 15μm) (model vs. experiment)
- NF$_{min}$ (frequency) vs. $V_{BE}$ (model vs. experiment)
- Base current noise power spectral density vs. frequency

- Self-heating is important!
- Still ~ 200GHz $f_t$ at 125°C!
- Little dependence of $f_t$ and $f_{max}$ on emitter length!
## SiGe BiCMOS Technologies Specificities

<table>
<thead>
<tr>
<th>SiGe BiCMOS Techno</th>
<th>GO1 Vdd</th>
<th>FT</th>
<th>GO2 Vdd</th>
<th>Fmax</th>
<th>LV HBT BV</th>
<th>Fmax</th>
<th>HV HBT BV</th>
<th>Fmax</th>
<th>Passives Q RF</th>
<th>Q mmW</th>
</tr>
</thead>
<tbody>
<tr>
<td>BiCMOS 130</td>
<td>1.2V</td>
<td>70GHz</td>
<td>2.5V</td>
<td>40GHz</td>
<td>5.5V</td>
<td>280GHz</td>
<td>14V</td>
<td>260GHz</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>BiCMOS 55</td>
<td>1.2V</td>
<td>140GHz</td>
<td>1.8V</td>
<td>60GHz</td>
<td>5.4V</td>
<td>350GHz</td>
<td>14V</td>
<td>260GHz</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

*ST-Microelectronics sources*
Summary: CMOS Technology for Power Amplifiers

HR PD SOI 130

FD SOI 28

CMOS 40 VLSI

CMOS 65 RF
Summary: SiGe BiCMOS Technologies Specificities
5G+ Applications & Design examples

- IoT – IoE Applications
- WLAN – WPAN Applications
- 5G Backhaul for Mini Cell Applications
- 5G Cellular Mini Cell – Devices Link Applications
- V2V, V2I and I2V Applications
- mmW Radar Applications
Wireless Sensors Networks  
Internet of Things / Internet of Everything  

WSN (Static)  
N2N – STAR – Cellular  

WBAN (static or dynamic)  
STAR  

Nodes  
Low End Node  
High End Node (LAN Master)  
High End Node (Cellular Master)  
High End Node (Cellular Node)  

Range:  
Short < 10m  
Medium < 100m  
Long < 1Km  
Cellular > 1Km  

IoT – IoE Frequencies & Standards  

ISO Bands  
UWB (Body transmission)  
Band 6  
7.6 to 8.7 GHz  

Nodes Connections  
Ad Hoc Com  
ZigBee™  
LoRa  
Bluetooth  

Cloud Connections  
LAN  
Cellular  

New 700 MHz Cellular opportunity  

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### IoT – IoE PAs Key Specifications

<table>
<thead>
<tr>
<th>Network</th>
<th>Nodes</th>
<th>Standards</th>
<th>Modulation</th>
<th>Frequency</th>
<th>RF Power</th>
<th>Form Factor</th>
<th>Si PA?</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSN</td>
<td>Low End SR</td>
<td>Zig. BTLE Ad hoc</td>
<td>Up to BPSK</td>
<td>ISM up to 2.5GHz</td>
<td>Up to 0dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Low End MR</td>
<td>Zig. BTLE BT Ad hoc</td>
<td>Up to BPSK</td>
<td>ISM up to 2.5GHz</td>
<td>Up to 10dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Low End LR</td>
<td>Zig. BTLE BT Ad hoc</td>
<td>Up to BPSK</td>
<td>ISM up to 2.5GHz And 700MHz BW</td>
<td>Up to 10dBm 16 dBm (To be Defined)</td>
<td>SIP</td>
<td>YES FEASIBLE</td>
</tr>
<tr>
<td></td>
<td>LAN Master</td>
<td>Zig. BTLE BT Ad hoc – WiFi ah (b g?)</td>
<td>Up to BPSK</td>
<td>ISM up to 2.5GHz WiFi 0.9GHz WiFi 2.5GHz</td>
<td>Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm</td>
<td>SOC</td>
<td>YES YES YES</td>
</tr>
<tr>
<td></td>
<td>Cellular Master</td>
<td>Zig. BTLE BT Ad hoc - Edge</td>
<td>GMSK to QPQK</td>
<td>ISM up to 2.5GHz LTE</td>
<td>Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm</td>
<td>SIP</td>
<td>YES FEASIBLE</td>
</tr>
<tr>
<td></td>
<td>Cellular Node</td>
<td>SigFox, ad hoc</td>
<td>GMSK to BPSK</td>
<td>868MHz ... 700, 915, 950MHz BW?</td>
<td>Up to 14dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td>WBAN</td>
<td>Node</td>
<td>Zig. BTLE Ad hoc UWB</td>
<td>Up to BPSK</td>
<td>ISM up to 2.5GHz UWB 7.6-8.7GHz</td>
<td>Up to 10dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>LAN Master</td>
<td>Zig. BTLE Ad hoc UWB – WiFi ah (b g?)</td>
<td>Up to BPSK Impulse Up to QPSK</td>
<td>ISM up to 2.5GHz UWB 7.6-8.7GHz WiFi 0.9GHz WiFi 2.5GHz?</td>
<td>Up to 10dBm Up to -14dBm Up to 0dBm Up to 0dBm Up to 0dBm Up to 0dBm Up to 0dBm Up to 0dBm Up to 0dBm Up to 0dBm</td>
<td>SOC</td>
<td>YES YES YES</td>
</tr>
<tr>
<td></td>
<td>Cellular Master</td>
<td>Zig. BTLE Ad hoc UWB – Edge</td>
<td>GMSK to QPSK &amp; Impulse</td>
<td>ISM up to 2.5GHz UWB 7.6-8.7GHz LTE WCDMA 2.2GHz</td>
<td>Up to 10dBm Up to -14dBm Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm Up to 10dBm</td>
<td>SIP</td>
<td>YES FEASIBLE YES</td>
</tr>
</tbody>
</table>
2GHz CMOS Bulk SFFD PA

- Size with pads: 2 mm²
- Size without pads: 0.672 mm²
- Low noise biasing and temperature independent

<table>
<thead>
<tr>
<th>Largeur de grille</th>
<th>Fréq GHZ</th>
<th>Valim</th>
<th>Pout</th>
<th>G(dB)</th>
<th>PAE (%)</th>
<th>Push-pull</th>
<th>Archi.</th>
<th>puce</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13μm</td>
<td>1.95</td>
<td>2.5V</td>
<td>Max: 33</td>
<td>16.76</td>
<td>Max: 65</td>
<td>W-CDMA</td>
<td>SFFDS</td>
<td>1.6 mm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OCP1: 28,25</td>
<td></td>
<td>À OCP1: 30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65 nm</td>
<td>1.95</td>
<td>2.1V</td>
<td>Max: 31</td>
<td>20</td>
<td>Max: 25</td>
<td>W-CDMA</td>
<td>SFFDS</td>
<td>0.672 mm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OCP1: 25.6</td>
<td></td>
<td>À OCP1: 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pout max = 31dBm / PAE max = 26%
Pout (1dB) = 25.6dBm / PAE (OCP1) = 10%
WLAN – WPAN – Device to Device - Applications

Future SOCs?

What About RF Power Interface?

57 – 66 GHz

D2D & LAN (Up to 7Gbs)

WLAN Master

Cloud

External

5-6GHz

10dBm to 18dBm

D2D PAN

Wi-Fi®

10dBm to 27dBm

LAN (Up to 500Mbs)

2.4GHz

10dBm to 18dBm

Present SOCs + FEM

0dBm to 10dBm (Up to 1Mbs)

2.4GHz

6GHz up to 33dBm

802.11 p?

0dBm to 10dBm (Up to 1Mbs)

Future SOCs?

What About RF Power Interface?

57 – 66 GHz

D2D & LAN (Up to 7Gbs)

WLAN Master

Cloud

External

5-6GHz

10dBm to 18dBm

D2D PAN

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LAN (Up to 500Mbs)

2.4GHz

10dBm to 18dBm

Present SOCs + FEM

0dBm to 10dBm (Up to 1Mbs)

2.4GHz

6GHz up to 33dBm

802.11 p?
# WLAN – WPAN – D2D: PAs Key Specifications

<table>
<thead>
<tr>
<th>Network</th>
<th>Objects</th>
<th>Standards</th>
<th>Modulation</th>
<th>Frequency</th>
<th>RF Power</th>
<th>Form Factor</th>
<th>Si PA?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LAN</strong></td>
<td>Low End Low Power short range</td>
<td>WiFi ah b</td>
<td>Up to QPSK</td>
<td>0.9GHz</td>
<td>Up to 0dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Up to QPSK</td>
<td>2.5GHz</td>
<td>Up to 20dBm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low End Long Range</td>
<td>WiFi b, g</td>
<td>Up to 16 QAM</td>
<td>2.5GHz</td>
<td>Up to 27dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>High End (phone, Tablet, Laptop ...)</td>
<td>WiFi ah a, b, g, n, ac, ad</td>
<td>Up to QPSK Up to 16 QAM Up to 64 QAM Up to 16 QAM</td>
<td>0.9GHz 2.5GHz &amp; 5GHz 2.5GHz &amp; 5GHz 60GHz</td>
<td>Up to 0dBm Up to 27dBm Up to 27dBm Up to 18dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Box</td>
<td>WiFi ah a, b, g, p n, ac ad BT, BTLE, Zigbee</td>
<td>Up to QPSK Up to 16 QAM Up to 64 QAM Up to 16 QAM Up to BPSK</td>
<td>0.9GHz 2.5GHz, 5-6GHz 2.5GHz &amp; 5GHz 60GHz 2.5GHz</td>
<td>Up to 0dBm Up to 33dBm Up to 33dBm Up to 18dBm Up to 10dBm</td>
<td>SIP</td>
<td>YES</td>
</tr>
<tr>
<td><strong>D2D PAN</strong></td>
<td>Low End (headphones ...)</td>
<td>BT</td>
<td>Up to BPSK</td>
<td>2.5GHz</td>
<td>Up to 10dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>High End (camera, screen ...)</td>
<td>UWB 7-10GHz, 60GHz D2D, ... Impulse</td>
<td>Up to 16 QAM</td>
<td>7-10GHz 60GHz, 120GHz</td>
<td>Up to -15dBm Up to 0dBm</td>
<td>SOC</td>
<td>YES</td>
</tr>
</tbody>
</table>

LETI WiFi Box PA Demonstration in 130nm CMOS PD-SOI targeting « FEASIBLE » specs is under test
A 60GHz PA for WiGig Application

- A 1.2V 20 dBm 60 GHz Power Amplifier with 32.4 dB Gain and 20 % Peak PAE in 65nm
  - 4 stages Power Amplifier
  - 8 to 1 output power combining
  - 7M BEOL CMOS 65 technology

![Graph showing S-parameters](image)

![Diagram of 60GHz PA](image)
4 channel 802.11.ad compliant

- Gain [dB]
- Output power [dBm]
- Pin [dBm] @ 60GHz

- PAE [%]
- Output power [dBm]
- Freq [GHz]

**Table:**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Channel 2</th>
<th>Channel 3</th>
<th>Channel 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psst [dBm]</td>
<td>19.8 ± 0.4</td>
<td>19.7 ± 0.1</td>
<td>19.3 ± 0.3</td>
</tr>
<tr>
<td>P_1dB [dBm]</td>
<td>17 ± 0.4</td>
<td>17.1 ± 0.2</td>
<td>16.3 ± 0.6</td>
</tr>
<tr>
<td>PAE_{max} [%]</td>
<td>20.8 ± 1.1</td>
<td>19.1 ± 1.1</td>
<td>16.75 ± 1.25</td>
</tr>
</tbody>
</table>
5G Backhaul for Mini-Cell: Cellular Network

Urban Networks: 4 Frequency Bands for Backhaul links;
Mini-Cell Distance: 150m – 300m

Suburban Networks: Multiple channels in 15 – 23GHz BW (source E//)
Up to 1Km

Rural Networks: Multiple channels in 6 – 13GHz BW (source E//)
Over 1Km

E// White Paper source
<table>
<thead>
<tr>
<th>Network</th>
<th>BW</th>
<th>Frequency</th>
<th>Modulations</th>
<th>RF Pout</th>
<th>Antenna(s) Gain</th>
<th>EIRP</th>
<th>Si PA?</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Band 6-13GHz</td>
<td>N x 30MHz</td>
<td>6–13GHz</td>
<td>&gt; 100 Mbs x N</td>
<td>Up to 32 dBm</td>
<td>Up to 48 dBi</td>
<td>Up to 80 dBm</td>
<td>FEASIBLE</td>
</tr>
<tr>
<td>Ku-K Band 15-23GHz</td>
<td>15–23 GHz</td>
<td>15–23GHz</td>
<td>&gt; 100 Mbs x N</td>
<td>Up to 27 dBm</td>
<td>Up to 50 dBi</td>
<td>Up to 77 dBm</td>
<td>YES</td>
</tr>
<tr>
<td>Ka Band 28GHz</td>
<td>1 GHz</td>
<td>28GHz</td>
<td>64 QAM Next 128 QAM</td>
<td>Up to 25 dBm</td>
<td>Up to 42.5 dBi</td>
<td>Up to 67.5 dBm</td>
<td>YES</td>
</tr>
<tr>
<td>Q Band 38GHz</td>
<td>2GHz</td>
<td>39 GHz</td>
<td>64 QAM Next 128 QAM</td>
<td>Up to 23 dBm</td>
<td>Up to 45 dBi</td>
<td>Up to 68 dBm</td>
<td>YES</td>
</tr>
<tr>
<td>V Band 60GHz</td>
<td>9 GHz</td>
<td>60GHz</td>
<td>16 QAM Next 64 QAM</td>
<td>Up to 10 dBm</td>
<td>Over 30 dBi</td>
<td>Up to 55 dBm</td>
<td>YES</td>
</tr>
<tr>
<td>E Band 71-86GHz</td>
<td>5 + 5 GHz</td>
<td>71-76 GHz</td>
<td>16 QAM Next 64 QAM</td>
<td>Up to 30 dBm</td>
<td>Over 38 dBi</td>
<td>Up to 85 dBm</td>
<td>CHALLENGING</td>
</tr>
</tbody>
</table>

ETSI Recommendations (ETSI TR 102 243-1 V1.2.1 (2013-07))
A 60GHz 28nm UTBB FD-SOI CMOS Reconfigurable Power Amplifier with 21% PAE, 18.2dBm $P_{1\text{dB}}$ and 74mW $P_{\text{DC}}$

- 3 stages Power Amplifier
- 8 to 1 output power combining
- 10M BEOL CMOS 28 FD-SOI technology

Area $A_{\text{CORE}} = 0.16\text{mm}^2$
Class-A and AB+B operating mode

- Splitting a power stage within a power amplifier into N units, having common input, ground and

- **Class-A operating mode** (Pdc=325mW):
  - Very high gain (up to 34dB@60GHz)
  - More than 11dB gain for one stage (+4dB w.r.t. to CMOS 65nm)

- **Class-AB + B operating mode** (Pdc=110mW):
  - Unique operating mode allowed by FDSOI technology
  - Still high gain (up to 20dB@60GHz)
  - 70% power reduction
4 channel 802.11.ad compliant

<table>
<thead>
<tr>
<th>Channel 1</th>
<th>Channel 2</th>
<th>Channel 3</th>
<th>Channel 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSAT [dBm]</td>
<td>19.1 ± 0.1</td>
<td>18.9 ± 0.1</td>
<td>18.35 ± 0.45</td>
</tr>
<tr>
<td>P-1dB [dBm]</td>
<td>18.5 ± 0.05</td>
<td>18.2 ± 0.25</td>
<td>17.7 ± 0.3</td>
</tr>
<tr>
<td>PAE-1dB [%]</td>
<td>20.9 ± 0.6</td>
<td>21.1 ± 0.4</td>
<td>19.3 ± 1.4</td>
</tr>
</tbody>
</table>
60-65GHz SiGe BiCMOS 130 PA

@ 60GHz
Gain = 18.3dB
OCP1 = 13.5dBm
ICP1 = -3.8dBm
PAE (@ CP1) = 3.9%
PAEmax = 9.8%
Compressed gain= 10.3dB
Psat = 18.8dBm.

@ 65GHz
Gain = 20.5dB
OCP1 = 14.5dBm
ICP1 = -5dBm
PAE (@ CP1) = 5%
PAEmax = 7.8%
Compressed gain= 15dB
Psat = 18dBm.
Mini-cell:
Circle: 100m – 200m; 360°

0.7 – 6GHz: Peak Pout 35dBm / Max EIRP 43 dBm (ETSI TR 143 030 V9.0.0 (2010-02) To be confirmed)

60GHz: Max Pout 10dBm / Max EIRP 55dBm / Min Antenna Gain: 30dBi / Dynamic Beam orientation

Cellular Device:
Up to 5 GHz – (Excluding WiFi) - 180°
0.7 – 5GHz: Max Pout up to 36 dBm.
(60GHz :treated with WiFi)
## 5G Mini-Cell Links: PAs Key Specifications

<table>
<thead>
<tr>
<th>Bands</th>
<th>BW</th>
<th>Standards</th>
<th>Modulations</th>
<th>RF Pout</th>
<th>EIRP</th>
<th>BEAM FORM</th>
<th>Si PA?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 – 3.7 GHz</td>
<td>3 GHz</td>
<td>2G 3G LTE WiFi-2.5</td>
<td>Up to 128 QAM</td>
<td>Up to 36 dBm</td>
<td>Up to 43 dBm</td>
<td>No</td>
<td>FEASIBLE</td>
</tr>
<tr>
<td>3 – 6 GHz</td>
<td>3 GHz</td>
<td>LTE WiFi-5 11.p</td>
<td>Up to 128 QAM</td>
<td>Up to 36 dBm</td>
<td>Up to 43 dBm</td>
<td>No</td>
<td>CHALLENGING</td>
</tr>
<tr>
<td>60GHz</td>
<td>9 GHz</td>
<td>60GHz</td>
<td>16 QAM Next 64 QAM</td>
<td>Up to 10 dBm</td>
<td>Up to 55 dBm</td>
<td>Dynamic</td>
<td>YES</td>
</tr>
</tbody>
</table>

**ETSI Recommendations**

*To be Confirmed for 0.7 – 6GHz*
## 5G Devices (cell standards): PAs Key Specifications

<table>
<thead>
<tr>
<th>Bands</th>
<th>BW</th>
<th>Standards</th>
<th>Modulations</th>
<th>RF Pout</th>
<th>BEAM FORM</th>
<th>Si PA?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 – 3.7 GHz</td>
<td>3 GHz</td>
<td>2G 3G LTE</td>
<td>Up to HPSK</td>
<td>Up to 36 dBm</td>
<td>No</td>
<td>YES</td>
</tr>
<tr>
<td>3 – 6 GHz</td>
<td>3 GHz</td>
<td>LTE</td>
<td>Up to HPSK</td>
<td>Up to 36 dBm</td>
<td>No</td>
<td>YES</td>
</tr>
</tbody>
</table>

**ETSI Recommendations**

*To be Confirmed*
KEY FEATURES

- Cellular applications
- Multimode Multiband
  - 2G/3G/4G
  - >10 cellular bands
- Reconfigurable
- Highly integrated solution
  (power devices, matching networks, switch, control)

**Performance Comparison of the Reported Reconfigurable MMPA**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Mode</th>
<th>Freq. [MHz]</th>
<th>2G</th>
<th>3G*</th>
<th>4G*</th>
<th>Supply [V]</th>
<th>Technology</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>P_{out} [dBm]</td>
<td>PAE [%]</td>
<td>ACLR [dBc]</td>
<td>P_{out} [dBm]</td>
<td>PAE [%]</td>
<td>ACLR [dBc]</td>
</tr>
<tr>
<td>This work</td>
<td>2G/3G/4G</td>
<td>700-900</td>
<td>34.6-35.5</td>
<td>53-61</td>
<td>≤-36</td>
<td>28-30</td>
<td>34-39</td>
<td>≤-33</td>
</tr>
<tr>
<td>[4]</td>
<td>2G/3G/4G</td>
<td>824.915</td>
<td>33.4-35.1</td>
<td>50.2-52.1</td>
<td>≤-39</td>
<td>28</td>
<td>40.41</td>
<td>≤-33</td>
</tr>
<tr>
<td>[9]</td>
<td>3G/4G</td>
<td>650-950</td>
<td>-</td>
<td>-</td>
<td>≤-38</td>
<td>27-28</td>
<td>47.53</td>
<td>≤-33</td>
</tr>
<tr>
<td>[6]</td>
<td>3G/4G</td>
<td>824.1920</td>
<td>-</td>
<td>-</td>
<td>≤-39</td>
<td>28.5</td>
<td>41.47</td>
<td>≤-33</td>
</tr>
<tr>
<td>[8]</td>
<td>4G</td>
<td>824.915</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>≤-33</td>
</tr>
</tbody>
</table>

Reconfigurable, High Power, High-Efficiency & Linearity

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Variable transconductance gain mixer
Self Adaptive PA

Single-ended On-wafer Load pull measures vs. class A PA
Low power consumption at cost of low linearity degradation

\[ OIP_3 @ V_{DD} = 3.5V, \ I_{DDQ} = 150mA, \ F_1 = 1750MHz, \ F_2 = 1750.2MHz \]
V2V & V2I – I2V: Transport Network

DSRC based on 802.11 p:
V2V – V2I: Circle, up to 1Km, 360°;
I2V: up to 1Km, Road angle.

5.85 _ 5.92 GHz:
V2V – V2I Max Pout up to 33dBm;
I2V Max Radiated Power 43 dBm (Road angle)

Modulation: Up to 64QAM
## V2V & V2I – I2V – I2I: Key Specifications

<table>
<thead>
<tr>
<th>Link</th>
<th>BW</th>
<th>Frequency</th>
<th>Modulations</th>
<th>EIRP</th>
<th>Antenna(s) Angle</th>
<th>BEAM FORM</th>
<th>Si PA?</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2V – V2I</td>
<td>10MHz</td>
<td>6 GHz</td>
<td>Up to 64 QAM</td>
<td>Up to 33 dBm</td>
<td>360°</td>
<td>NO</td>
<td><strong>FEASIBLE</strong></td>
</tr>
<tr>
<td>I2V</td>
<td>10MHz</td>
<td>6 GHz</td>
<td>Up to 64 QAM</td>
<td>Up to 43 dBm</td>
<td>10° to 30°: Road «angle» 360° : cross road</td>
<td>NO</td>
<td><strong>CHALLENGING</strong></td>
</tr>
<tr>
<td>I2I</td>
<td>No specific definition: Distance 200m to 5Km: Should use Telecom Infrastructure communications (E Band, Copper, Fiber ...)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Starting from work done for WiFi PA Demonstration in 130nm CMOS PD SOI Technology LETI plans to develop a 802.11p PA for V2X applications at “**FEASIBLE**” specs.
mmW Radar Sensors

Health Radar
- Heartbeats monitoring
- Respiration monitoring
- Distance < 2m
- Angle < 45°
- Frequency > 60GHz

Automotive Radar
## mmW Radar: Key Specifications

<table>
<thead>
<tr>
<th>Radar</th>
<th>BW</th>
<th>Frequency</th>
<th>Modulations</th>
<th>RF Pout</th>
<th>EIRP</th>
<th>Antenna(s) Angle</th>
<th>Si PA?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health 60GHz</td>
<td>9 GHz</td>
<td>60 GHz</td>
<td>FMCW or Pulse</td>
<td>Up to 10 dBm</td>
<td>Up to 10 dBm</td>
<td>45°</td>
<td>YES</td>
</tr>
<tr>
<td>Automotive SRR</td>
<td>4 GHz</td>
<td>79 GHz</td>
<td>FMCW or Pulse</td>
<td>Up to 30 dBm</td>
<td>Up to 55 dBm</td>
<td>80° H / 20° V</td>
<td>CHALLENGING</td>
</tr>
<tr>
<td>Automotive LRR</td>
<td>1 GHz</td>
<td>77 GHz</td>
<td>Pulse</td>
<td>Up to 23.5 dBm</td>
<td>Up to 55 dBm</td>
<td>20° H / 20° V</td>
<td>FEASIBLE</td>
</tr>
</tbody>
</table>

- **8 SRR Radar / Vehicle**
- **1 LRR Radar / Vehicle**
SiGe 130nm BiCMOS 79 GHz PA with integrated baluns

Chip size:
0.8mm*0.875mm=0.7mm²

Courtesy to IMS Bordeaux (E.Kerhervé, N.Demirel)
Results from ANRT VELO

Leti & List

DACLE Division | January 2014
SiGe 130nm BiCMOS 79 GHz PA

- Good agreement between measurement and simulation

- Maximum output power of 17dBm at 79GHz, making the PA suitable for automotive SRR application.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MEAS</th>
<th>SIMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>REASULTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP (dB)</td>
<td>18.1</td>
<td>18.3</td>
</tr>
<tr>
<td>OCP1 (dBm)</td>
<td>12.5</td>
<td>14.5</td>
</tr>
<tr>
<td>PSAT (dBm)</td>
<td>16.9</td>
<td>17.4</td>
</tr>
<tr>
<td>PAEmax (%)</td>
<td>6.4</td>
<td>6.5</td>
</tr>
</tbody>
</table>

- Peak gain @ 79GHz of 18.1dB (12GHz of bandwidth).

Courtesy to IMS Bordeaux (E.Kerhervé, N.Demirel)
Results from ANRT VELO
DACLE Division | January 2014 | 45
SiGe 130nm BiCMOS 79 GHz 4-PA & 4-ANTENNAS Co-integration

<table>
<thead>
<tr>
<th>Structure: Si Technology</th>
<th>$Pt$ (dBm)</th>
<th>$Gt$ (dBi)</th>
<th>$n$</th>
<th>$EIRP$ (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-integration</td>
<td>17</td>
<td>-10</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Co-design</td>
<td>19</td>
<td>-10</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Co-design (2PAs-2 antennas)</td>
<td>19</td>
<td>-10</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Co-design (4PAs-4 antennas)</td>
<td>19</td>
<td>-10</td>
<td>4</td>
<td>21</td>
</tr>
</tbody>
</table>

EIRP < 25dBm
SRR Specifications

Courtesy to IMS Bordeaux (E.Kerhervé, N.Demirel) and LABSTICC Brest (C.Person)
Results from ANRT VELO
### SiGe 130nm BiCMOS 79 GHz 4-PA & 4-ANTENNAS AND LENS Co-integration

**Antenna + Lens**

<table>
<thead>
<tr>
<th>Structure</th>
<th>$P_t$ (dBm)</th>
<th>$G_t$ (dBi)</th>
<th>$n$</th>
<th>$EIRP$ (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-design: 4 PAs-4 antenna on Silicon</td>
<td>19</td>
<td>-10</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>Co-design: 4PAs-4 antenna on BCB</td>
<td>19</td>
<td>-5</td>
<td>4</td>
<td>26</td>
</tr>
<tr>
<td>Co-design with 4PAs-4 antenna on silicon + lens</td>
<td>19</td>
<td>3</td>
<td>4</td>
<td>34</td>
</tr>
</tbody>
</table>

*Courtesy to IMS Bordeaux (E.Kerhervé, N.Demirel) and LABSTICC Brest (C.Person)*

*Results from ANRT VELO*

**FEASIBLE**

Satisfy the SRR Specifications

**CHALLENGING**
Summary: HR PD SOI 130 PA

- Very High Q Passives Available
- Frequency over 6GHz: Increase Fmax
- Architecture & Fmax
- High Perf RF switches Available
- Technology (BV)
- HR PD SOI 130

**RECONFIGURABILITY**

Source: ISSCC 2016 Trends

Figure 3: PAE (%) vs. output power for recent submicron CMOS PAs
Summary: CMOS RF 65 PA

- Architecture
- Technology (BV)
- Frequency over 60 GHz: Increase Fmax
- Architecture & Fmax
- Technology Fmax

Source: ISSCC 2016 Trends
RECONFIGURABILITY

Source ISSCC 2016 Trends

Frequency over 150 GHz: Increase Fmax

Architecture

Architecture (Stack) & Technology (BV)

Architecture & Fmax

Architecture (Stack) & Technology (BV & Fmax)

FD SOI CMOS 28

Source ISSCC 2016 Trends

Summary: FD SOI CMOS 28 PA
Summary: SiGe HBT BiCMOS PA

- VERY High Q PASSIVES
- Frequency over 140 GHz: Increase Fmax
- Frequency over 180 GHz: Increase Fmax
- INTEGRATION
- Architecture
- Architecture & Fmax
- Technology (BV)
- SiGe BiCMOS 130
- SiGe BiCMOS 55

Source ISSCC 2016 Trends

Figure 3: PAE (%) vs. output power for recent submicron CMOS PAs

Source ISSCC 2016 Trends

Figure 3: PAE (%) vs. output power for recent submicron CMOS PAs
CMOS and SiGe BiCMOS technologies allow designing PA for Connectivity Applications.

- **RF CMOS 65** processes are well adapted for **SOC** low power output, (up to 10 dBm) connectivity applications with operating frequencies up to 60GHz.

- **FD SOI CMOS 28** processes are well adapted for **SOC** low to medium power output, (up to 20 dBm) **RECONFIGURABLE** connectivity applications with operating frequencies up to 150GHz.

- **PD SOI CMOS 130** processes are well adapted for medium to « high » power output, (up to 36dBm) connectivity applications with operating frequencies up to 10GHz. The technology offers the possibility to implement **HIGH PERF RF SWITCHES** and the use of **HIGH Q PASSIVES**.

- **SiGe HBT BiCMOS 130** processes are well adapted for medium to « high » power output, (up to 33 dBm) connectivity applications with operating frequencies up to 140GHz. The technology offers **HIGH Q PASSIVE** availability.

- **SiGe HBT BiCMOS 55** processes are well adapted for medium to « high » power output, (up to 33 dBm) connectivity applications with operating frequency up to 180 GHz. With a **SOC** integration possibility.