Florinel Balteanu
Skyworks Solutions Inc.

MIPI RFFE® for 5G Front End Modules
Agenda

• 5G Deployment
• Solutions for 5G RFFE Control
• 4G/5G MIPI RFFE Control in version 3.0
  – Timed Triggers
  – Mappable Triggers
• 5G mmWave Challenges
• References
MIPI RFFE

• MIPI RFFE has been the de facto standard for RF control in mobile devices
• Multiple versions of the specification have been adapted to ever-evolving 3GPP wireless standards
• MIPI RFFE v3.1 is on track to be released later this year (2022)
• With 5G arrival the smartphone interfaces are becoming more complicated
• First 5G smartphones deployed in 2020
## MIPI RFFE Development

<table>
<thead>
<tr>
<th>Version</th>
<th>Adopted Date</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1.0</td>
<td>July-2010</td>
<td>1st release, 26-MHz, 3-Triggers</td>
</tr>
<tr>
<td>V1.1</td>
<td>Nov-2011</td>
<td>Bug Fixes, No major enhancements</td>
</tr>
<tr>
<td>V2.0</td>
<td>Dec-2014</td>
<td>Synchronous Read, Extended-Speed (52 MHz), Multi-Master Support</td>
</tr>
<tr>
<td>V2.1</td>
<td>April-2018</td>
<td>Masked-Write, Master Context Transfer, Longer Reach, Extended Trigger, Master Context Transfer, Reserved Reg-Space Expansion</td>
</tr>
<tr>
<td>V3.0</td>
<td>April-2020</td>
<td>Additional Extended-Triggers, Timed-Triggers, Mapped-Triggers</td>
</tr>
</tbody>
</table>

- MIPI RFFE development has followed the mobile devices evolution
- With the adoption of v3.0, MIPI RFFE has adapted to 5G sub-6GHz (FR1) requirements
  - Need to address the challenges for mmWave (FR2)
- Each RFFE bus instance can support up to 4 Main and 15 Subordinate devices
- At any given point of time, only one Main device has the bus ownership and is responsible for bus management
- Operation of the MIPI RFFE bus, while other RF activities are on, should be guided by required EMI limit bounds
• **SA** – standalone
• **NSA** – non-standalone

NSA 5G actual deployment comes with dual connectivity (DC):
• Keep 4G legacy
• Use 4G as backbone for signaling

• At 2022 MWC Barcelona -> demo show speeds up to 2.5Gbs for SA in FR1
5G RF Front End (RFFE) Structure

- 5G Front End Structure
- 6-8 antennas for several radios
- Each antenna reachable by any Tx/Rx
- Several (6-7) MIPI RFFE in parallel
• Under 6GHz is still the main 5G data pipe
• 5G comes with more radios working on the same time
  • Several FEMs active and therefore several active MIPI RFFE bus instances
• 5G smartphones structure with more than 15 MIPI RFFEs
• Size of MIPI RFFE increased due to extra timed & mappable triggers
Recently 3GPP release 17 introduces higher frequencies and carrier aggregation. MIPI RFFE bus would continue to play a big role for RF-Front-End control over these bands.

### mmWave (FR2) Frequencies

<table>
<thead>
<tr>
<th>5G mmWave Bands</th>
<th>Band Duplex Type</th>
<th>UL/DL Low [MHz]</th>
<th>UL/DL High [MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>n257</td>
<td>TDD</td>
<td>26500</td>
<td>29500</td>
</tr>
<tr>
<td>n258</td>
<td>TDD</td>
<td>24250</td>
<td>27500</td>
</tr>
<tr>
<td>n259</td>
<td>TDD</td>
<td>39500</td>
<td>43500</td>
</tr>
<tr>
<td>n260</td>
<td>TDD</td>
<td>37000</td>
<td>40000</td>
</tr>
<tr>
<td>n261</td>
<td>TDD</td>
<td>27500</td>
<td>28350</td>
</tr>
<tr>
<td>n262</td>
<td>TDD</td>
<td>47200</td>
<td>48200</td>
</tr>
<tr>
<td>n263</td>
<td>TDD</td>
<td>57000</td>
<td>71000</td>
</tr>
</tbody>
</table>
### 5G Data Rate

- **Downlink data-rate is governed by several factors DL requires at least 6% for CQI/ACK/NACK**

<table>
<thead>
<tr>
<th>Number of MIMO Streams/Antennas</th>
<th>Number of Bits Per Symbol</th>
<th>Number of 30kHz Resource Elements Per 100MHz Channel</th>
<th>Duty Cycle</th>
<th>Number of Symbols Per Slot Per Resource Element</th>
<th>Number of Slots Per Second</th>
<th>Number of Useful Data Bits Per Total Bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8</td>
<td>60%</td>
<td>3276</td>
<td>14</td>
<td>2000</td>
<td>70%</td>
</tr>
</tbody>
</table>

- **Sub-7GHz DL Total Data Rate**

\[
\text{Total Data Rate} = 1.23 \text{ Gbps}
\]

- **Sub-7GHz UL Total Data Rate**

\[
\text{UL DR} \sim 6\% \text{ DL DR}
\]

\[
\text{Total Data Rate} = 77 \text{ Mbps}
\]
5G RF Stringent Time Requirements

- Shannon theorem assumes isotropic systems
- In practice we deal with anisotropic systems; ET and PA is one example
  - Need time alignment ---→ The need for the MIPI RFFE time triggers

\[ C = B_w \sum_{k=1}^{k} \log_2 \left( 1 + \frac{en*S_k}{N_x + I_k} \right) \]
Example of MIPI RFFE Use for Smartphone Calibration

- Envelope Tracking calibration requires several MIPI RFFE bus instances to be active
- Ideal response based on equal peaks, delay calibration = 0.5ns-1ns
- Use low frequency baseband signals to manage duplexer delays

\[ ACLR = \min(IMD_{l,r}) + k \]

\[ IMD_{l,r} = 2\pi B_{RF} \Delta^2 \tau \]
Example of MIPI RFFE Use for Smartphone Calibration
5G Requires MIMO

- RFFE has several CMOS & SOI dies
  - Typical technology nodes 0.11um-0.13um
- 2 MIPI RFFE plus other digital circuits such as calibration, ADC for sensors
- Technology not scaled down as in modem (3nm) or RF transceivers (7nm-14nm)
MIPI RFFE Triggers

- MIPI RFFE v3.0 extends the triggering capabilities
- An additional 7 triggers to a total of 18 pre-defined triggers
  - Standard triggers (0, 1 and 2)
  - Block A triggers (extended Trigger 3 to 10)
  - Block B triggers (extended trigger 11 to 17)
- Timed triggers
- Mappable triggers
MIPI RFFE Time Triggers

- Load shadow registers and count-down register
- After the timed trigger register is written the firing is defined by $D$
  - $D$ resolution is one clock SCLK
### MIPI RFFE Time Triggers - example

#### MIPI RFFE v3.0 for ET3 … ET10

<table>
<thead>
<tr>
<th>USID/G Sid</th>
<th>EReg</th>
<th>Wr</th>
<th>BCnt</th>
<th>Ext-Trig Addr</th>
<th>Extended-Trigger bit pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA</td>
<td>0000</td>
<td>0000</td>
<td>0x2E</td>
<td>0 0 0 0 1 0 0 0</td>
<td></td>
</tr>
</tbody>
</table>

#### Timed-Trigger Counter

<table>
<thead>
<tr>
<th>USID/G Sid</th>
<th>EReg</th>
<th>Wr</th>
<th>BCnt</th>
<th>Timed-Trig Addr</th>
<th>Timed-Trigger Counter</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA</td>
<td>0000</td>
<td>0000</td>
<td>0x3A</td>
<td>count-down-val</td>
<td></td>
</tr>
</tbody>
</table>

#### EXT_TRIG_A_REG / 0x2E

<table>
<thead>
<tr>
<th>Time</th>
<th>Bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>0000</td>
</tr>
</tbody>
</table>

#### EXT_TRIG_A_MASK / 0x2D

<table>
<thead>
<tr>
<th>Time</th>
<th>Bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 1 0 1 1</td>
<td></td>
</tr>
</tbody>
</table>

#### EXT_TRIG_A_CNT_3 / 0x38

#### EXT_TRIG_A_CNT_4 / 0x39

#### EXT_TRIG_A_CNT_5 / 0x3A

#### EXT_TRIG_A_CNT_10 / 0x3F

- **shadow reg x**
- **active reg x** ET5-sensitive

MIPI RFFE Time Triggers - example
Extended Triggers Block A
Timed Triggers

- Mappable triggers have the ability to remap the triggers counters output for trigger firing purposes
- Useful for several 5G Tx/Rx configurations, due to its dynamic mapping capability
Phase shifting (PS - red arrow) can be done at VCO or RF

PS done by measuring SNIR at base-station

MIPI RFFE not able to handle the speed for phase shifting
mmWave Front End Structure

- 8/16 T/R paths (beam forming channels)
- On Tx side: up-conversion, splitting, phase shifting (PS), VGA, PA T/R switch
- On Rx side: T/R SW, VGA, PS, combining, down-conversion to zero, low or GHz IF output
- Tx/Rx gain (up to 6-8 bits with calibration), may be combined with PS (6-8 bits)
- More than one MIPI RFFE to be used
5G mmWave Beamforming

- Beamforming done by through Phase Shifting
- SNIR measured at base-station, both mmWave Tx & Rx involved
- The MIPI RFFE is slow to control this function
• Phase Shift done at RF – RF VCO
• MIPI RFFE controls the VGAs
5G mmWave Beamforming

- Phase Shift done at RF VCO & IF
- MIPI RFFE controls the VGAs
Summary

- MIPI RFFE plays a key role in 4G/5G RF Front End Control
- MIPI RFFE needs functionality upgrades for 5G FR2 Front Ends and next smartphone sensor applications
  - Speed
  - Front Ends have calibration and other sensors
ADDITIONAL RESOURCES

Jim Ross and John Oakley, February 2015

Jim Ross, Vic Wilkerson and Lalan Mishra, June 2020
https://www.youtube.com/watch?v=7EIVGQ04eqA

Lalan Mishra, September 2020
https://www.youtube.com/watch?v=SpAlkPlDtak

Andrew Scott-Mackie, October 2019

Florinel Balteanu, November 2019
"RF Front End Module Architectures for 5G," 2019 IEEE BCTM
THANK YOU!