mipi DEVCON

MIPI ALLIANCE DEVELOPERS CONFERENCE

20-21 SEPTEMBER 2022

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Skyworks Solutions Inc.

MIPI RFFE® for 5G Front End Modules

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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

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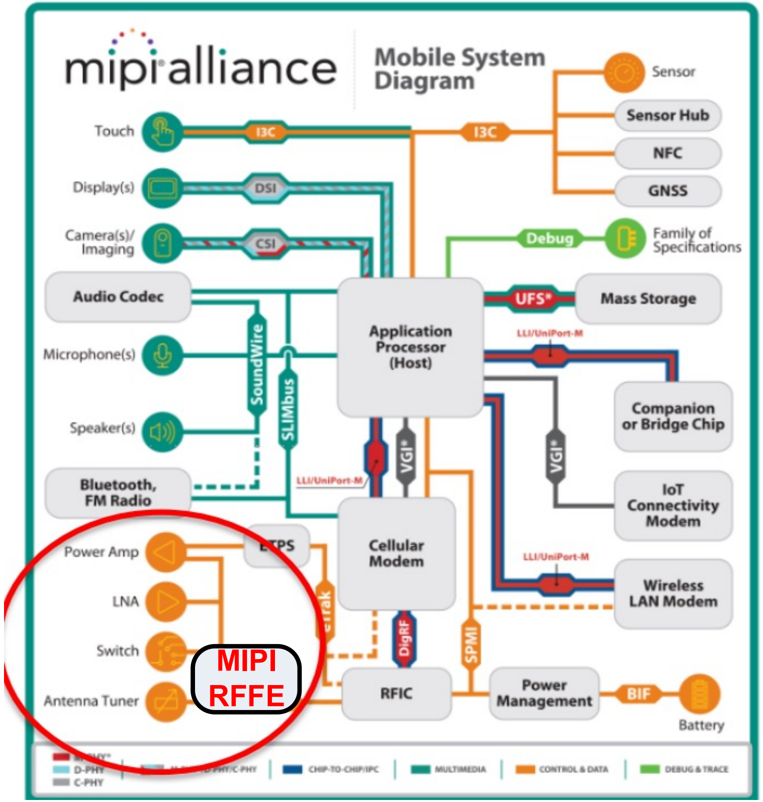
MIPI RFFE

- 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)



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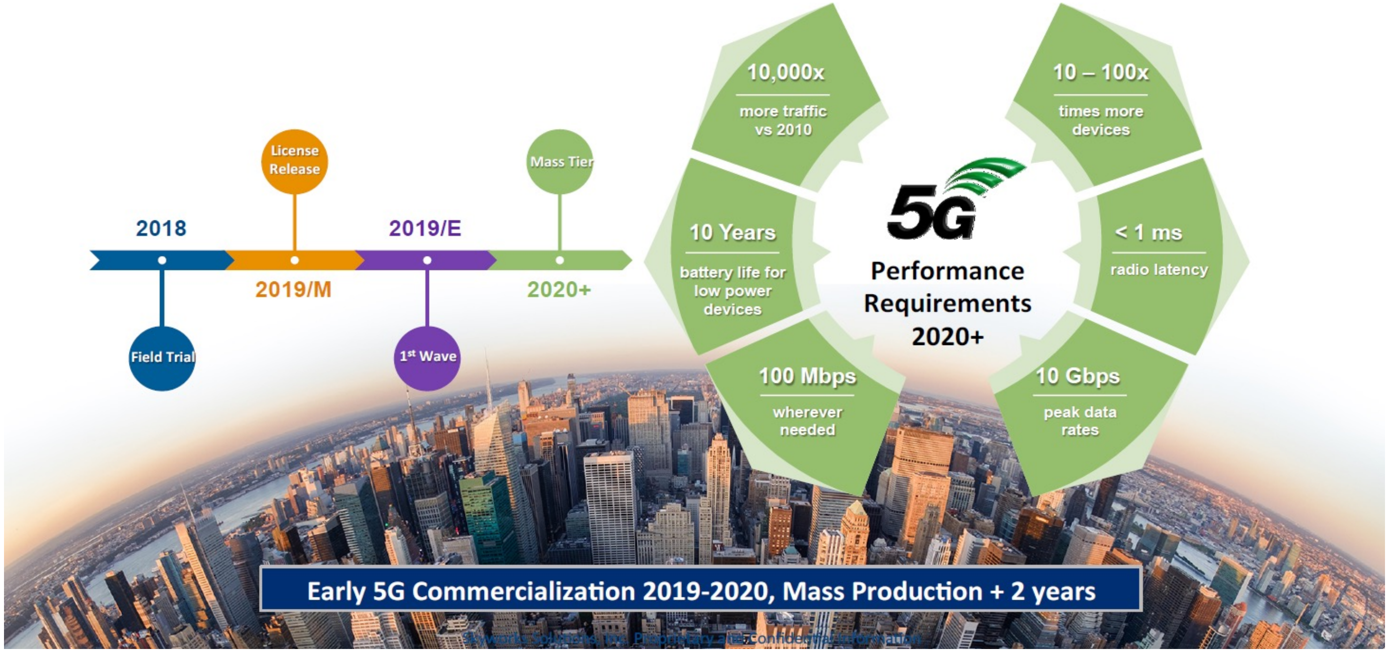
5G Deployment



- With 5G arrival the smartphone interfaces are becoming more complicated
- First 5G smartphones deployed in 2020

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MIPI RFFE Development

V1.0 Adopted July-2010	V1.1 Adopted Nov-2011	V2.0 Adopted Dec-2014	V2.1 Adopted April-2018	V3.0 Adopted April-2020
• 1st release • 26-MHz • 3-Triggers	• Bug Fixes • No major enhancements	• Synchronous Read • Extended-Speed (52 MHz) • Multi-Master Support	• Masked-Write • Master Context Transfer • Longer Reach • Extended Trigger • Master Context Transfer • Reserved Reg-Space Expansion	• Additional Extended-Triggers • Timed-Triggers • Mapped-Triggers

- 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)

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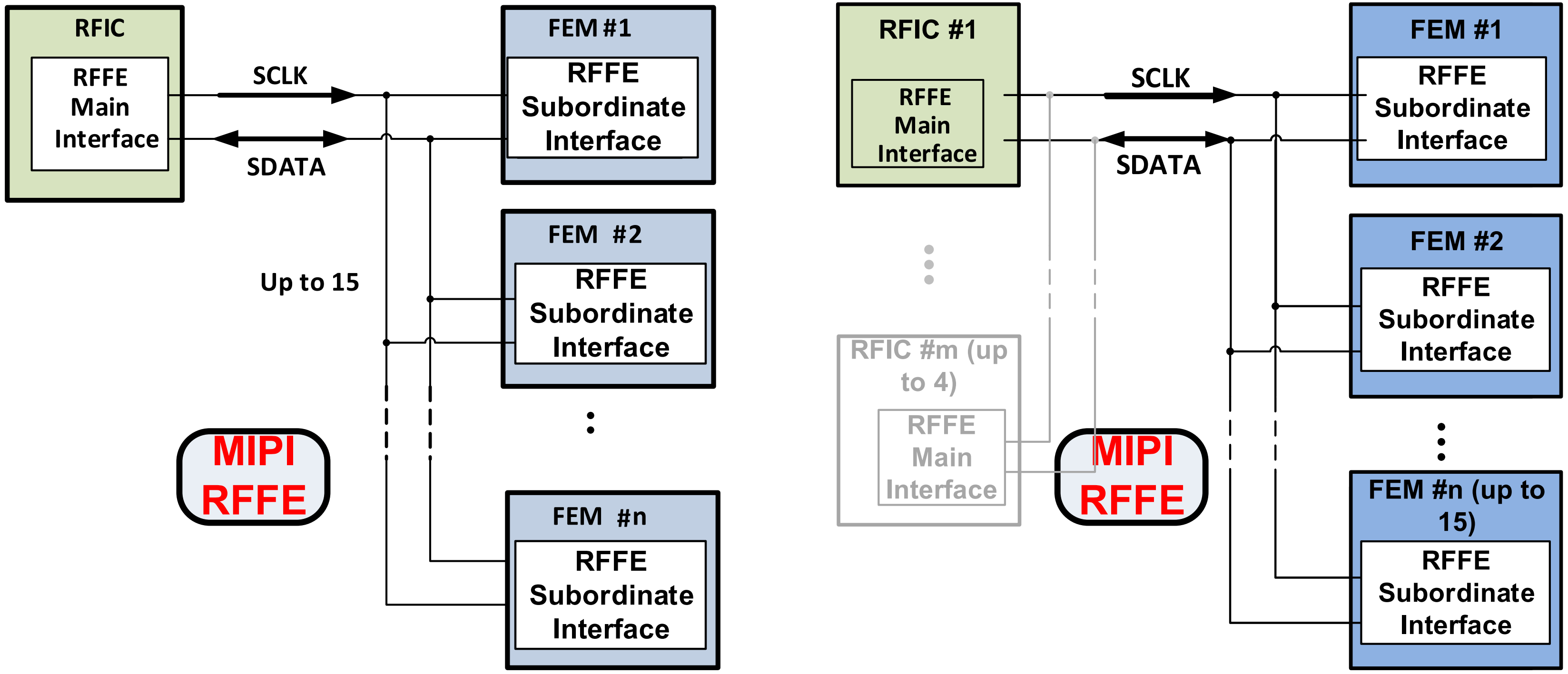

- Each RFFE bus instance can support up to 4 Main and 15 Subordinate devices
- At any given point of time, only one Main device has the bus ownership and is responsible for bus management
- Operation of the MIPI RFFE bus, while other RF activities are on, should be guided by required EMI limit bounds

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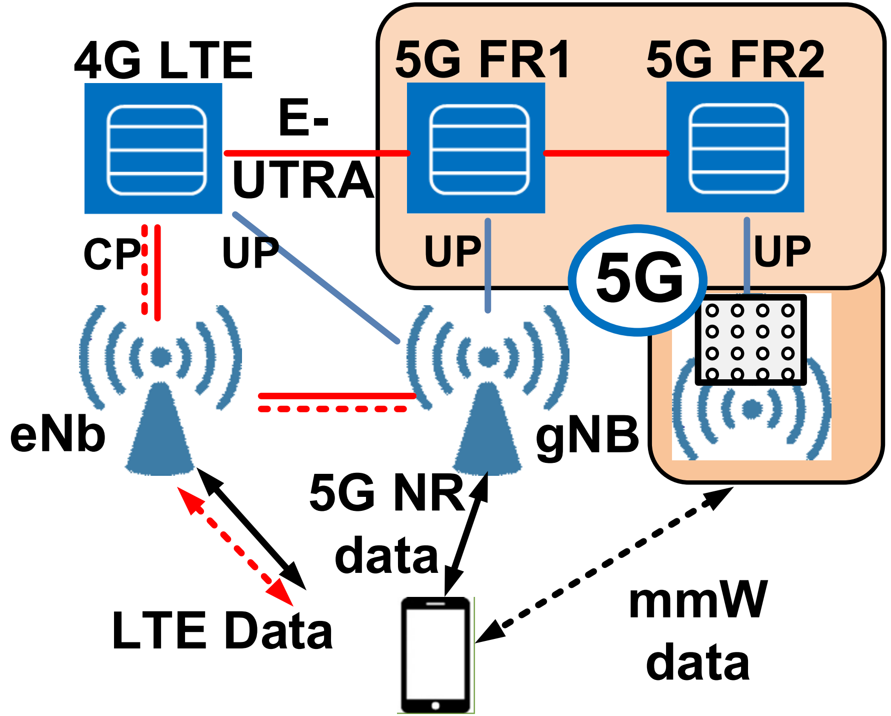
4G/5G Coexistence



- **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

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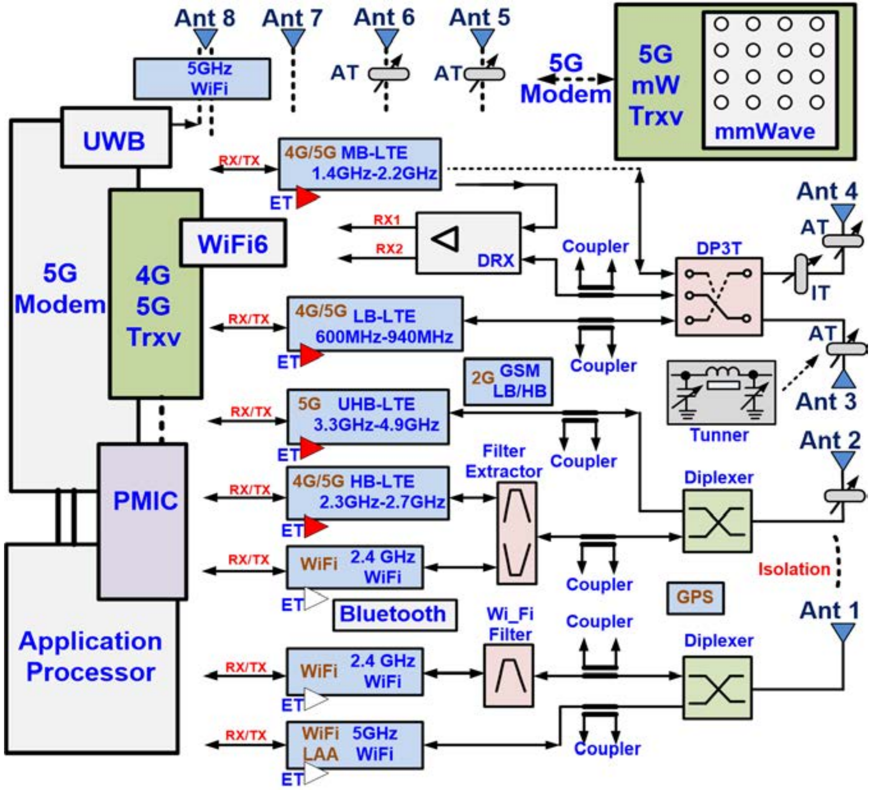
5G RF Front End (RFFE) Structure



- 5G Front End Structure
- 6-8 antennas for several radios
- Each antenna reachable by any Tx/Rx
- Several (6-7) MIPI RFFE in parallel

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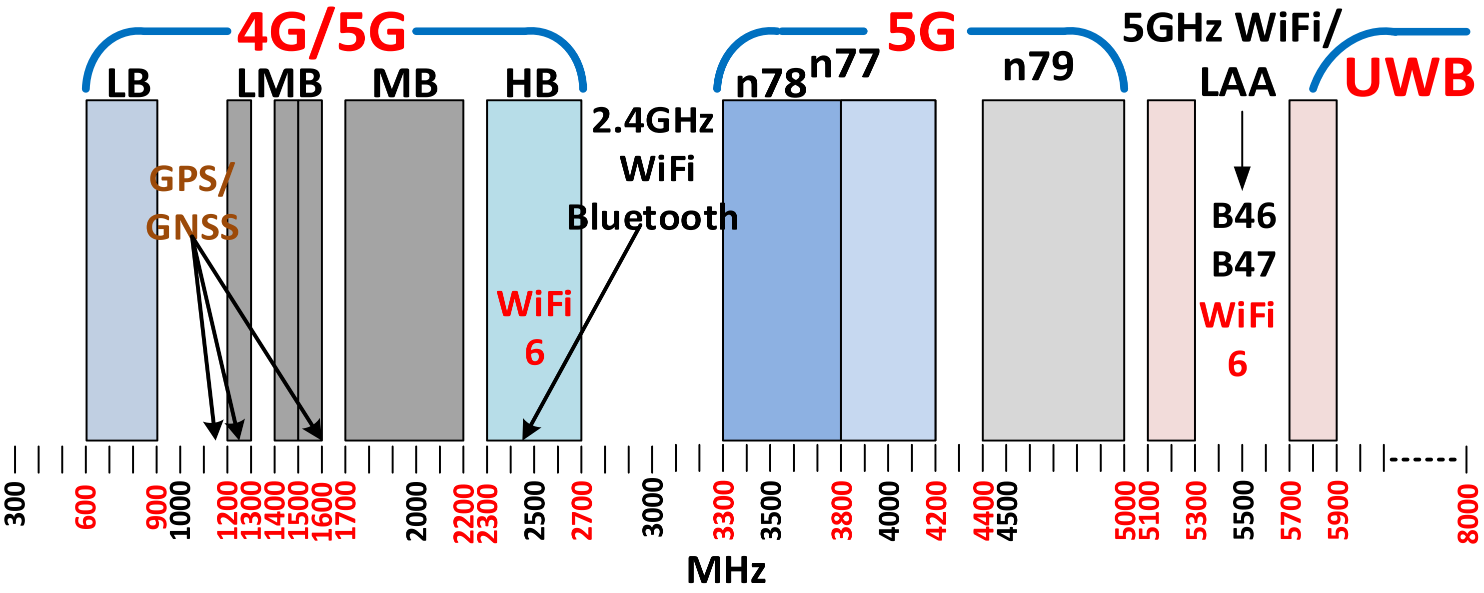
4G/5G RF Frequency Bands - MHz



- 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

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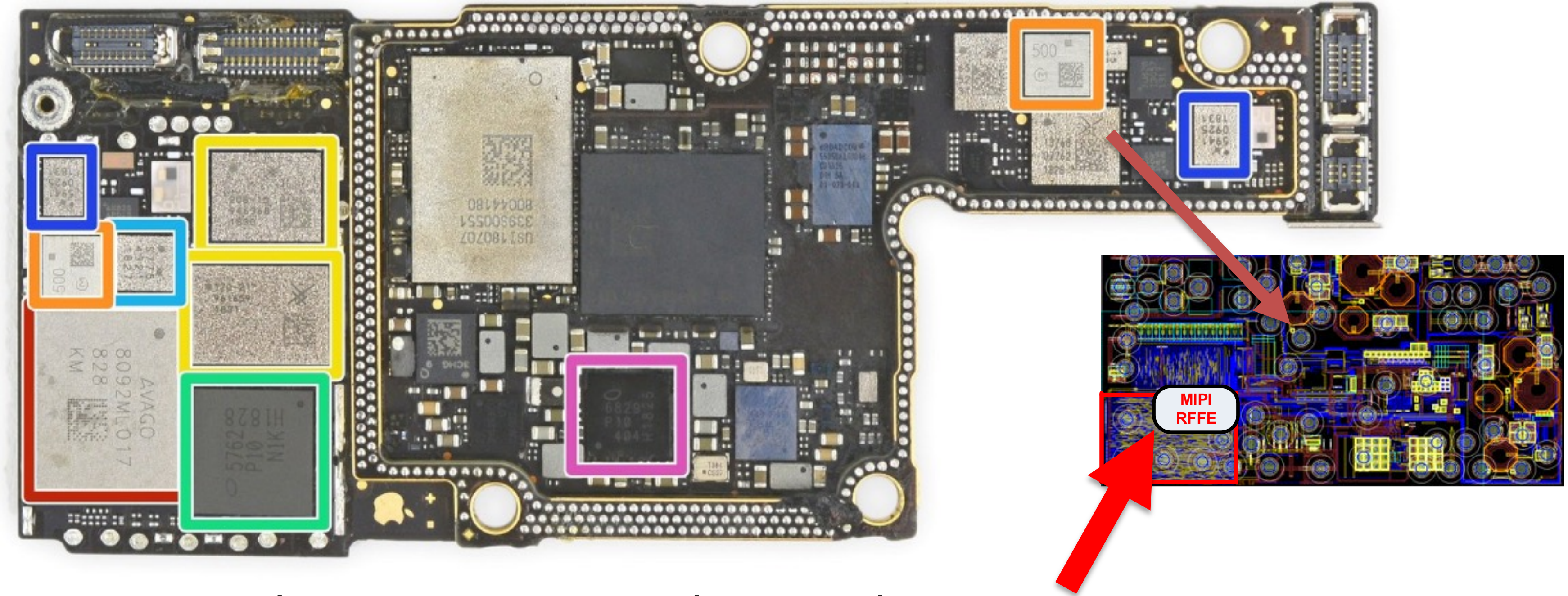
IFIXIT Smartphone Teardown – 2021



- 5G smartphones structure with more than 15 MIPI RFFEs
- Size of MIPI RFFE increased due to extra timed & mappable triggers

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mmWave (FR2) Frequencies

5G mmWave Bands	Band Duplex Type	UL/DL Low [MHz]	UL/DL High [MHz]
n257	TDD	26500	29500
n258	TDD	24250	27500
n259	TDD	39500	43500
n260	TDD	37000	40000
n261	TDD	27500	28350
n262	TDD	47200	48200
n263	TDD	57000	71000

- 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

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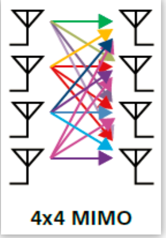
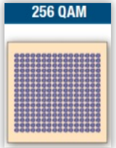
5G Data Rate

MIMO | Modulation | Carrier Aggregation





Carrier Aggregation 100MHz Total Bandwidth

1CC x100 MHz

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

Number of MIMO Streams/ Antennas		Number of Bits Per Symbol		Number of 100MHz Channels		Duty Cycle		Number of 30kHz Resource Elements Per 100MHz Channel		Number of Symbols Per Slot Per Resource Element		Number of Slots Per Second		Number of Useful Data Bits Per Total Bits		Sub-7GHz DL Total Data Rate
4	*	8	*	1	*	60%	*	3276	*	14	*	2000	*	70%	=	1.23 Gbps

UL DR ~ 6% DL DR

1CC x100 MHz

Number of MIMO Streams/ Antennas		Number of Bits Per Symbol		Number of 100MHz Channels		Duty Cycle		Number of 30kHz Resource Elements Per 100MHz Channel		Number of Symbols Per Slot Per Resource Element		Number of Slots Per Second		Number of Useful Data Bits Per Total Bits		Sub-7GHz UL Total Data Rate
1	*	6	*	1	*	20%	*	3276	*	14	*	2000	*	70%	=	77 Mbps

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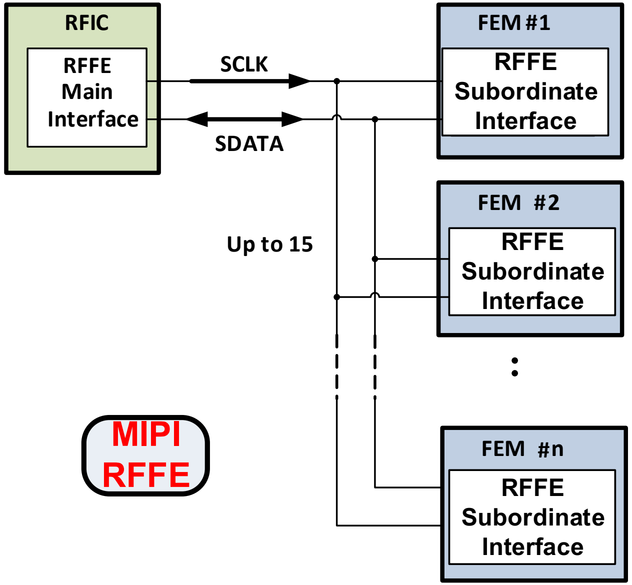
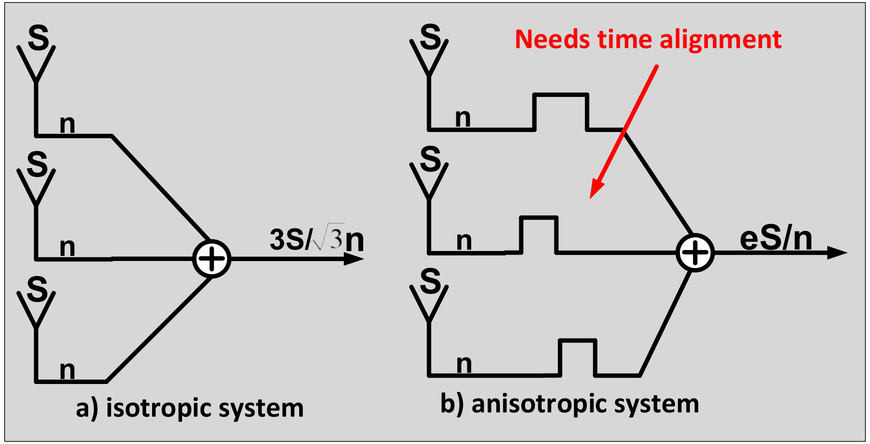
5G RF Stringent Time Requirements





$$C = B_w \sum_{k=1}^{k} \log_2\left(1 + \frac{en * S_k}{N_x + I_k}\right)$$

- 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

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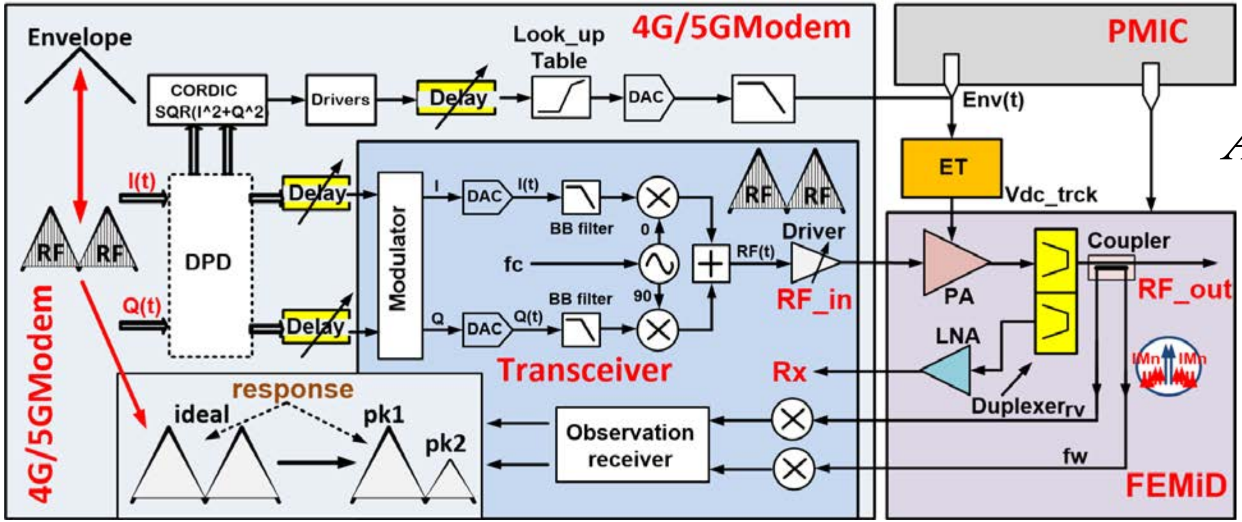
Example of MIPI RFFE Use for Smartphone Calibration



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

$$IMD_{l,r} = 2\pi B_{RF}^{2} \Delta_{\tau}^{2}$$

- 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

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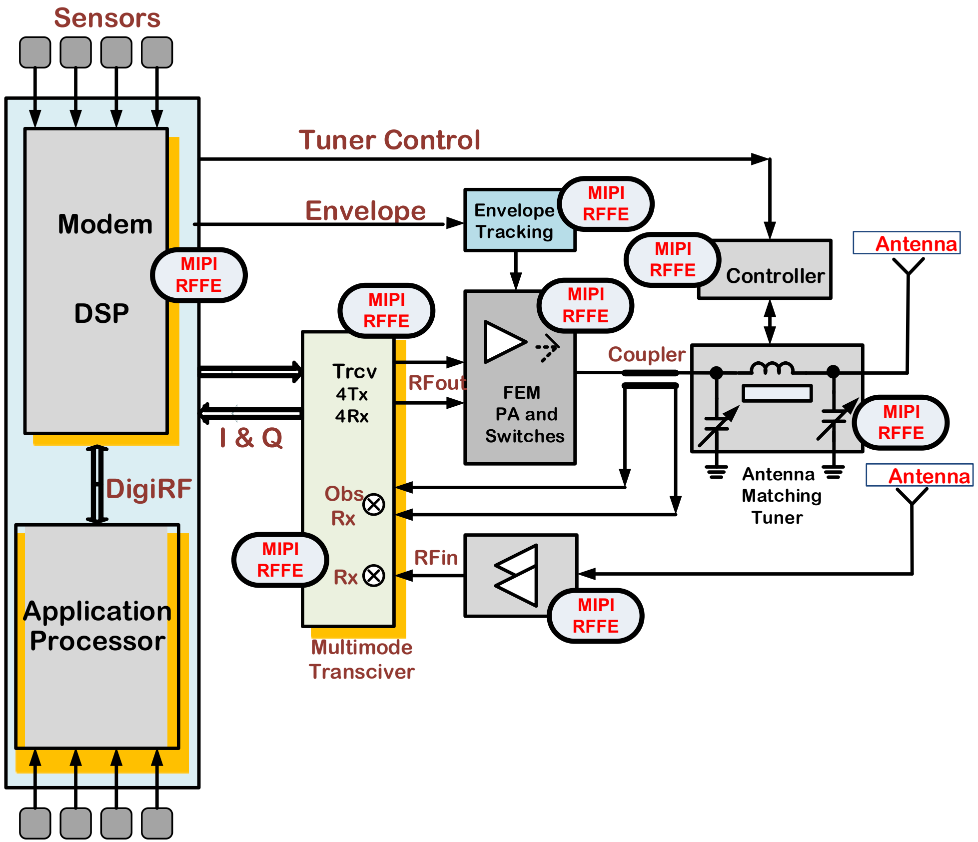
Example of MIPI RFFE Use for Smartphone Calibration



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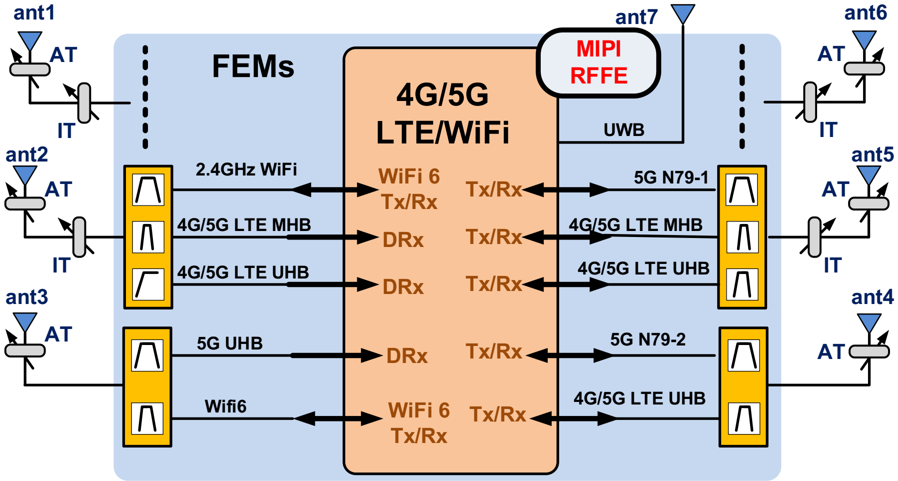
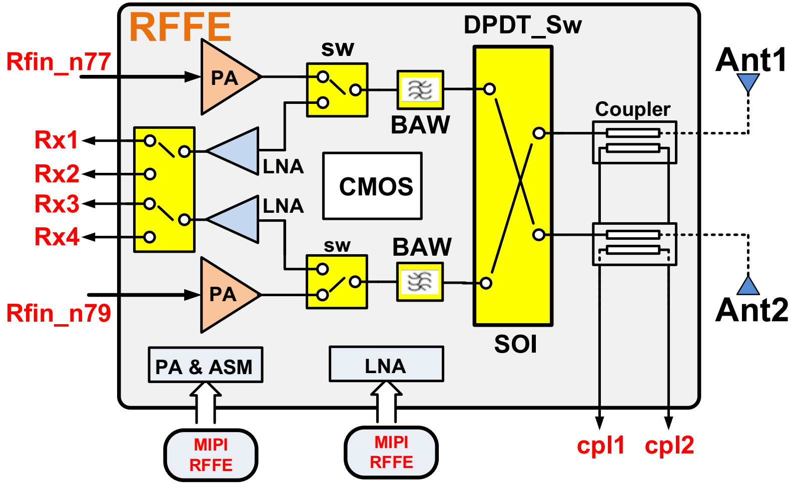
5G Requires MIMO





- 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)

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MIPI RFFE Triggers

v1.0
3 Triggers

v2.1
11 Triggers

v3.0
18 Triggers
Timed Triggers
Mappable 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

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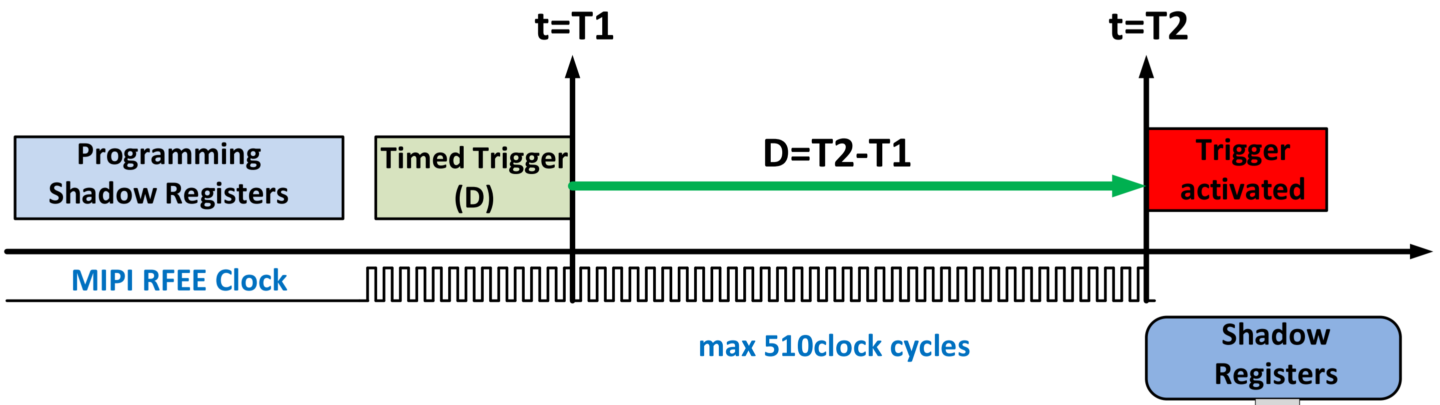
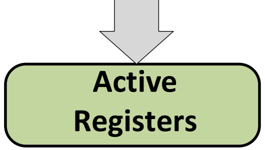
MIPI RFFE Time Triggers





- 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

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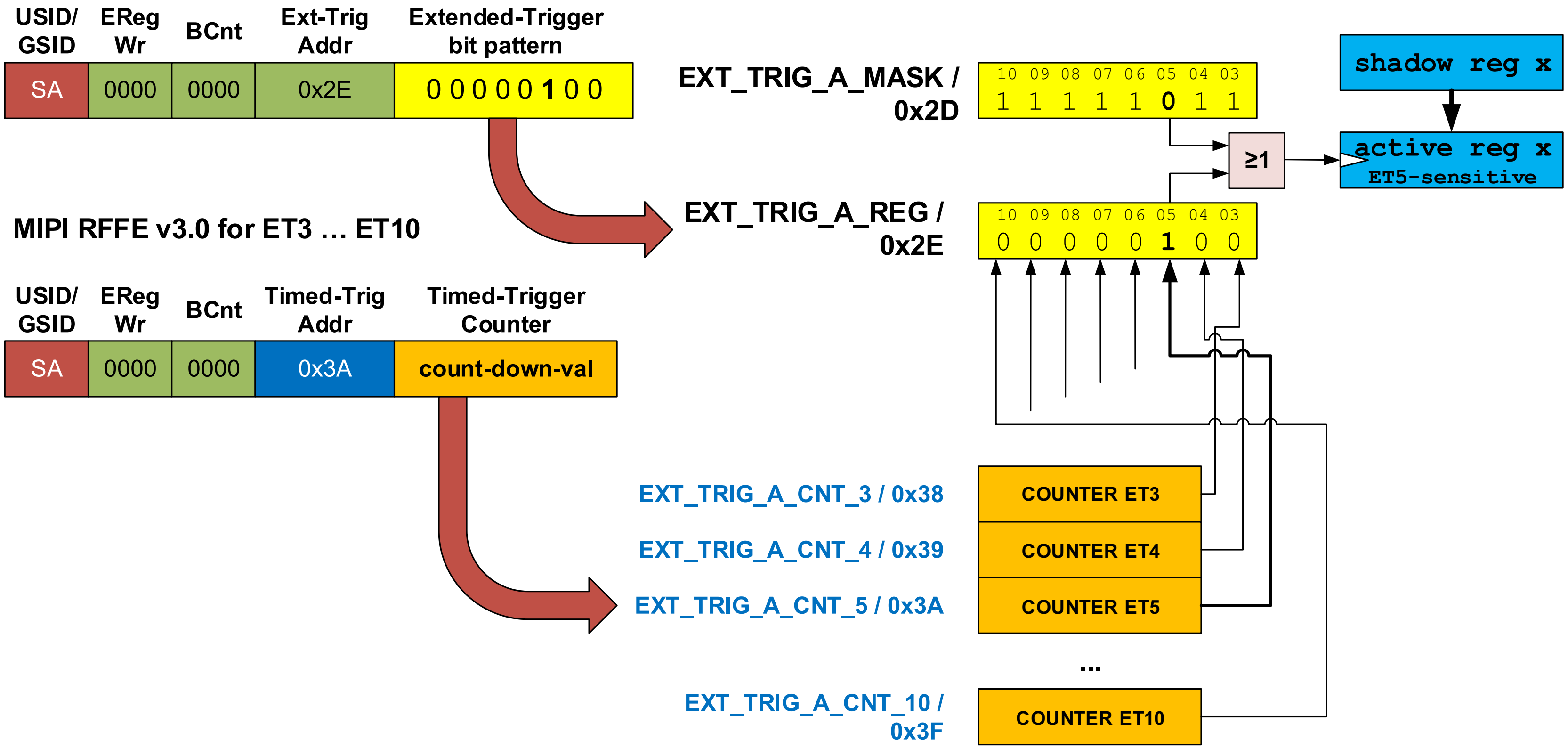
MIPI RFFE Time Triggers - example



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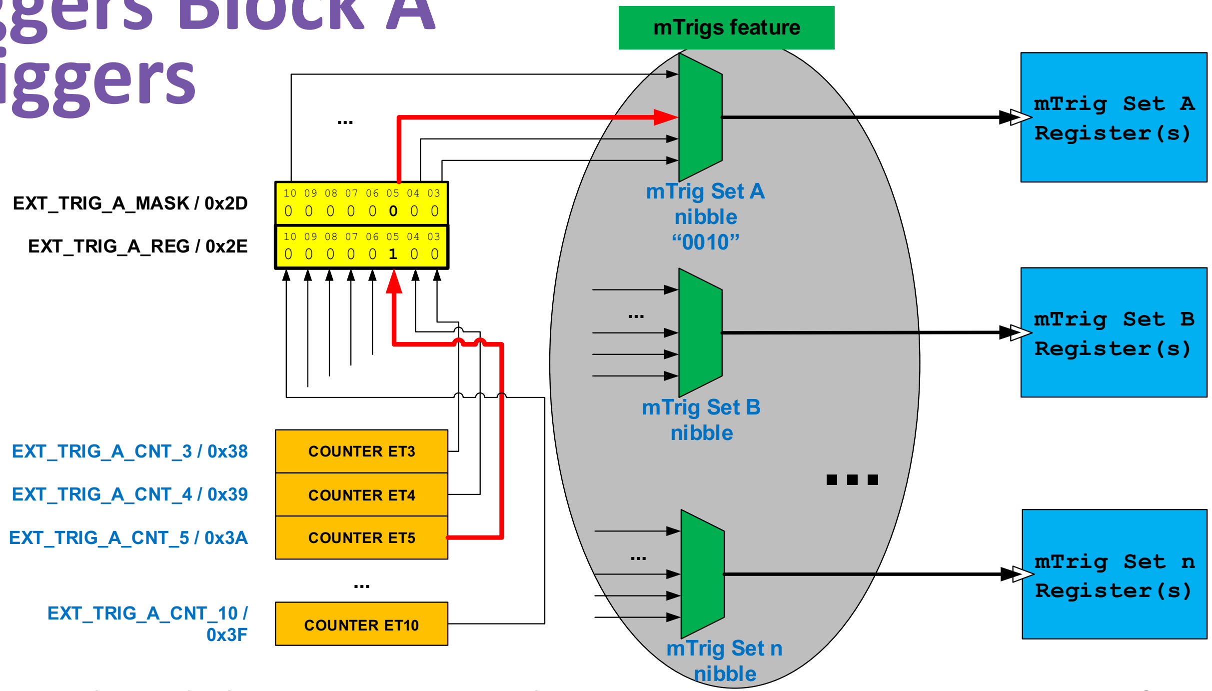
Extended Triggers Block A
Timed Triggers



- 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

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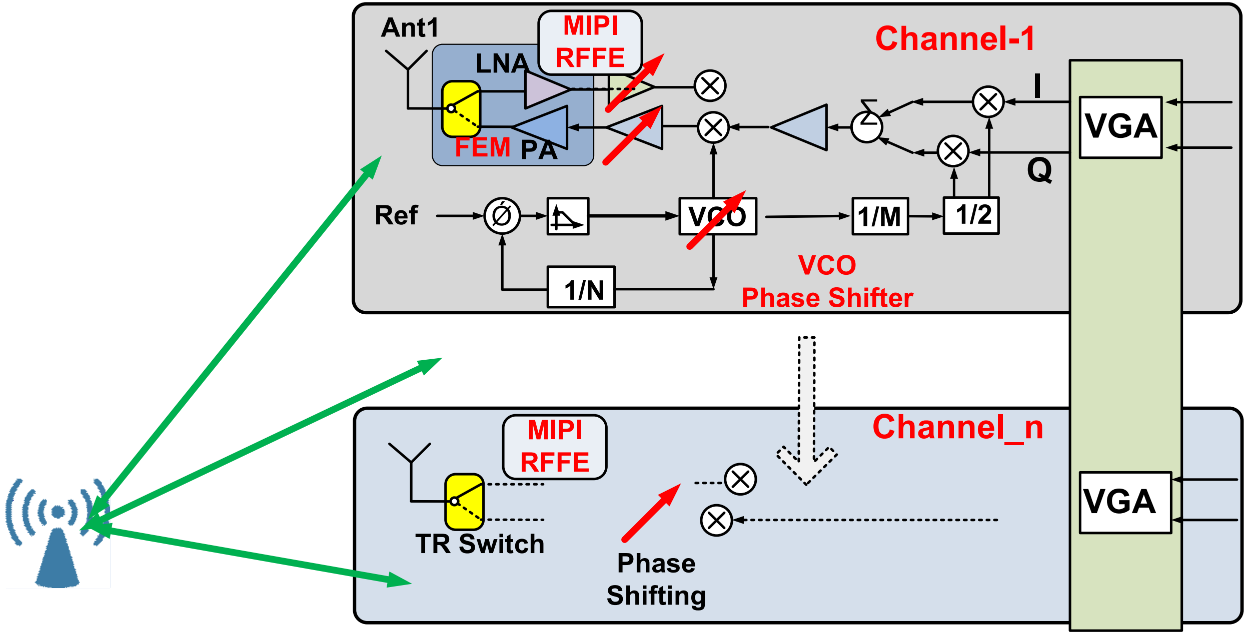
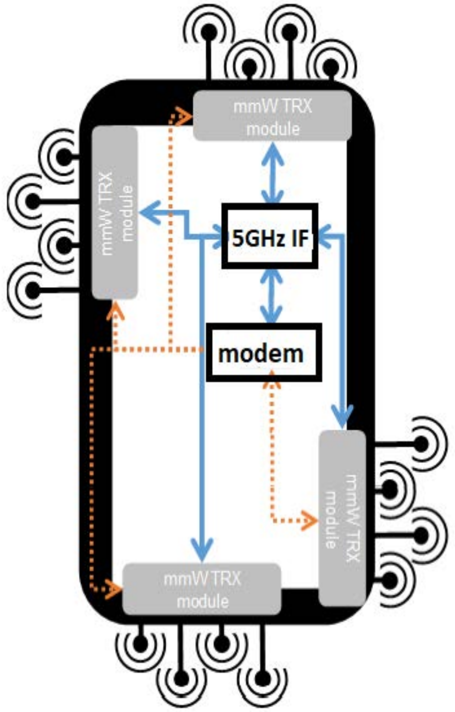
5G mmWave





- 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

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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

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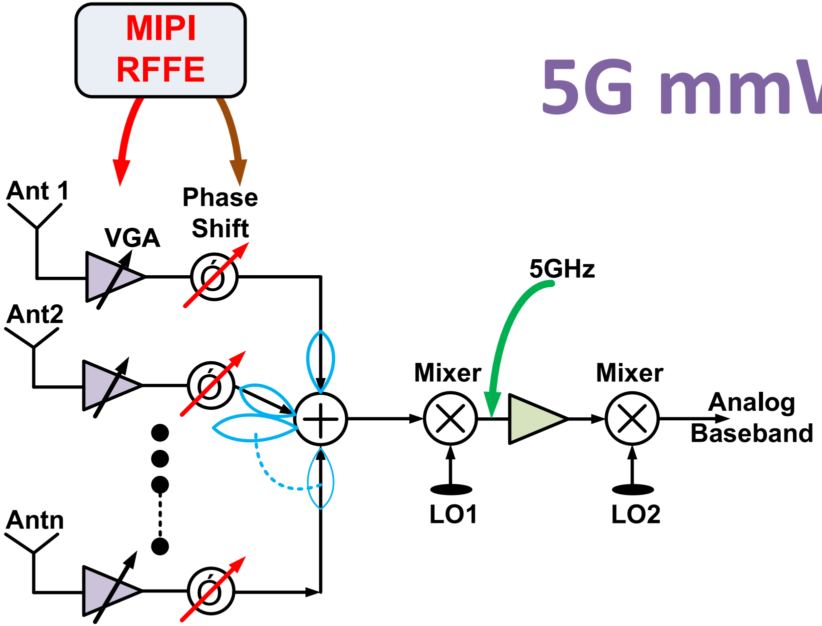
5G mmWave Beamforming



- 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

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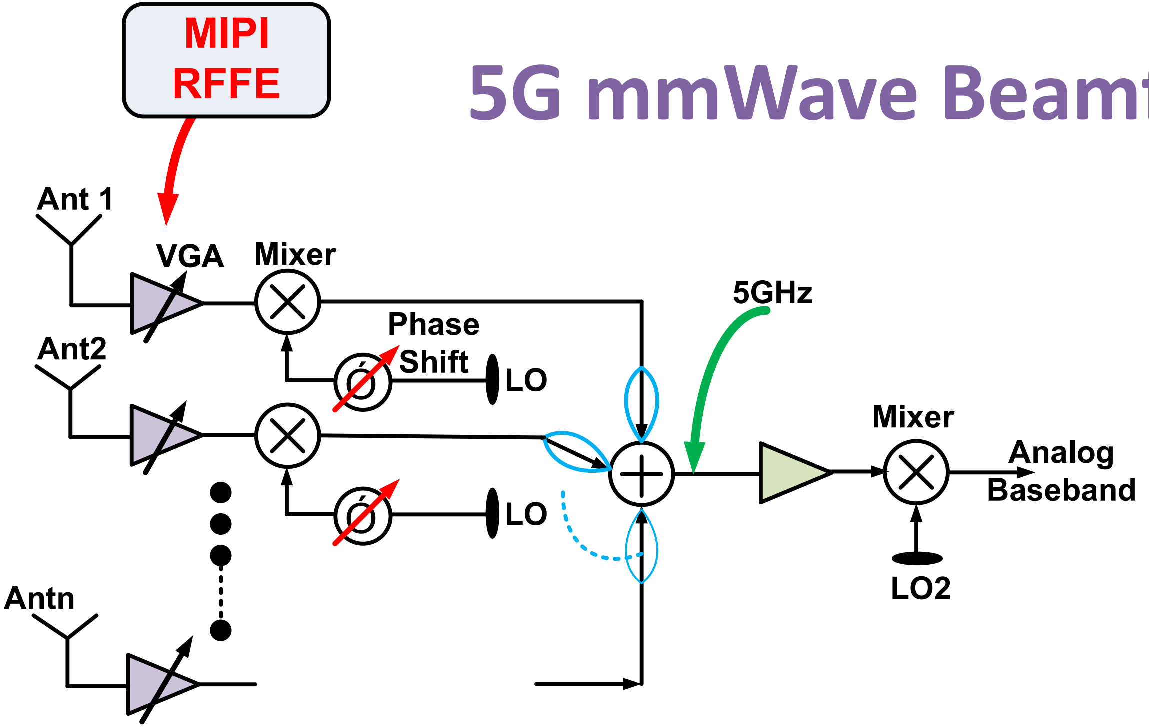
5G mmWave Beamforming



- Phase Shift done at RF – RF VCO
- MIPI RFFE controls the VGAs

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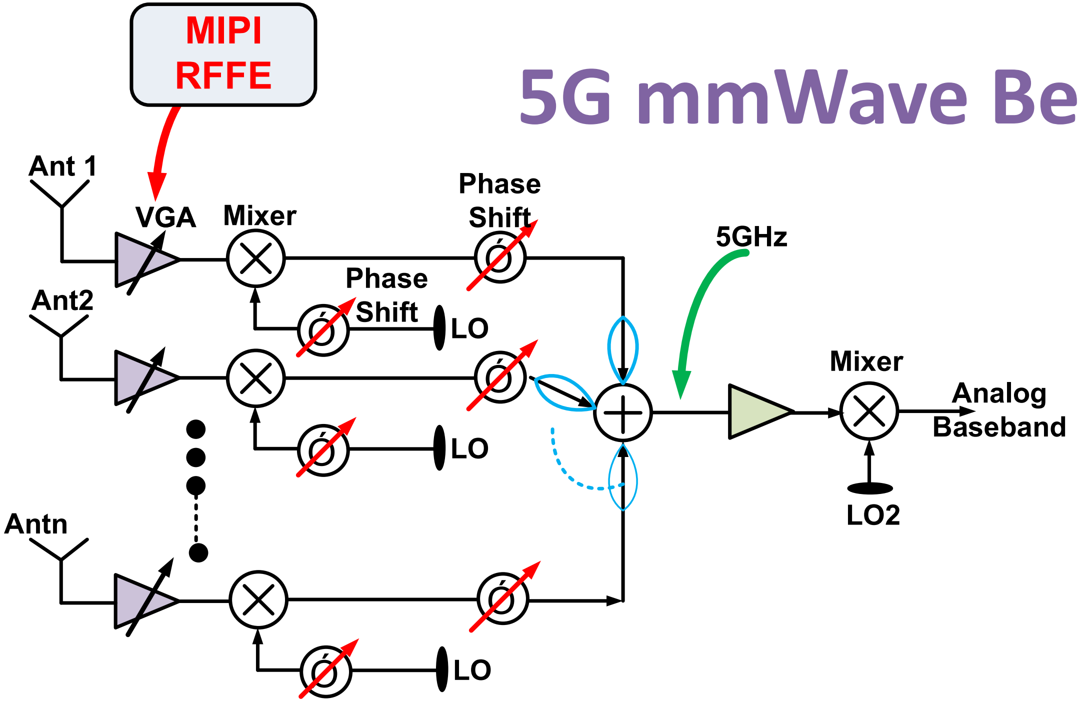
5G mmWave Beamforming



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

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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

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ADDITIONAL RESOURCES

Jim Ross and John Oakley, February 2015

https://www.mipi.org/sites/default/files/MIPI-RFFEv2.0-150216-Webinar-Final.pdf

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

MIPI DevCon 2019 – Taipei (https://www.mipi.org/devcon/taipei/agenda/addressing-5g-rffe-control-challenges-mipi-rffe-v30)

Florinel Balteanu, November 2019

"RF Front End Module Architectures for 5G," 2019 IEEE BCTM

https://www.skyworksinc.com/-/media/SkyWorks/Documents/Articles/IEEE_BCICTS_201911.pdf

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THANK YOU!

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Q&A

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