

Tu2C-6

Phased-Array Transceiver Chipsets and Modules for 5G FR2 and 60-GHz Fixed Wireless Access – A Commercial Perspective

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PERASO

- Introduction/Motivation
- 5G FR2 Single-Chip Beamformer
 - FWA CPE Requirements
 - Technical Considerations/Implications
 - Dual-Band TX/RX Front-End Slice
 - Measurement Results
- 802.11ad/WiGig Phased-Array IC and Module
 - Link Deployment and Performance
- Conclusion

Peraso Background

Technology

- mm-Wave chipsets and modules (24 GHz to 71 GHz)
- mm-Wave antennas, systems, and algorithms
- 802.11ad baseband MAC/PHY ICs and solutions

Products

- 802.11ad/WiGig RF + baseband chipset solutions
- 5G mm-wave phased-array chipsets and modules

Locations

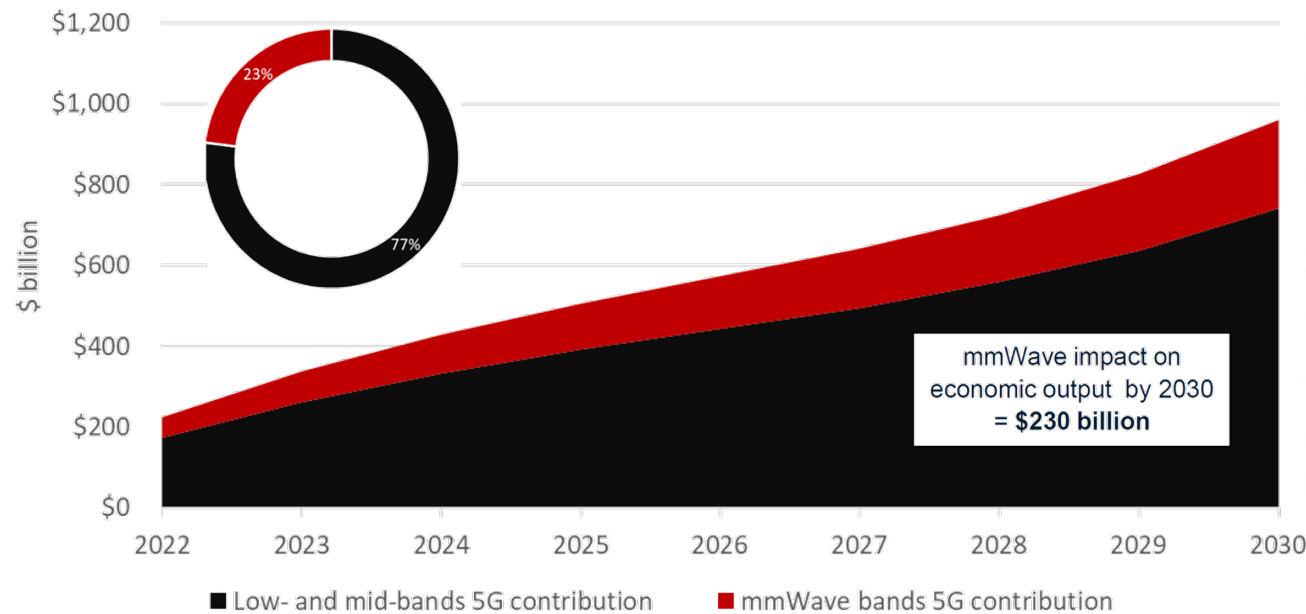
- Canada: Toronto and Markham
- USA: San Jose
- Taiwan: Taipei



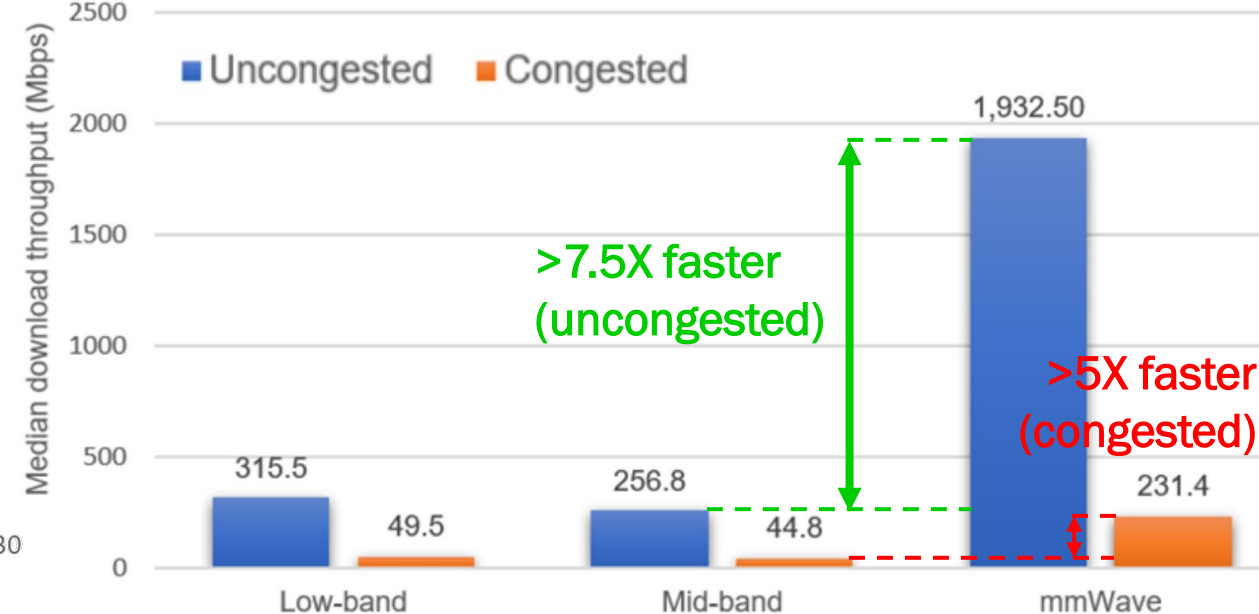
Corporate Snapshot

Peraso Technologies specializes in the development of mm-wave phased-array chipsets and modules. It is a subsidiary of Peraso, Inc. (NASDAQ: PRSO)

Millimeter-Wave FWA on the Rise



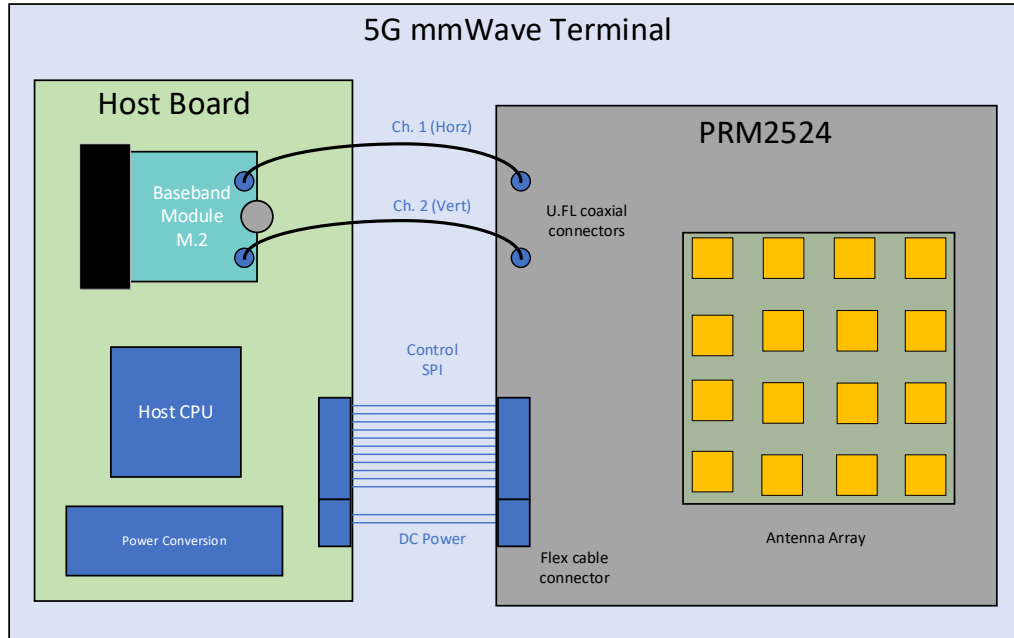
Source: 5G mmWave Summit (GSMA MWC2022)



Source: www.rootmetrics.com

- The already congested sub-7 GHz spectrum is expected to be augmented by the effective utilization of mm-Wave bands that provide larger available BW and increased network capacity.
- Fixed wireless access (FWA) has emerged as a key technology for replacing fiber and bridging the “digital gap” by offering seamless Gigabit+ services to underserved areas.
- With low-cost phased-array solutions, mm-Wave FWA (licensed 5G FR2 and unlicensed 60 GHz) is particularly attractive for high-data-rate and directional communications (e.g. PtP and PtMP).

5G FR2 CPE Implementation



- EIRP and EVM requirements (n257/n258/n261):
 - QPSK: >40 dBm @ -15.1 dB / 17.5%
 - 64-QAM: >35 dBm @ -21.9 dB / 8.0%
- Maximum: <35 dBm TRP, <55 dBm EIRP

Band	Frequency (GHz)	Bandwidth (MHz)	Country
n257	26.5 – 29.5	50/100/200/400	USA/Canada/India
n258	24.25 – 27.5	50/100/200/400	USA/EU/China/India
n259	39.5 – 43.5	50/100/200/400	USA/China/India
n260	37 – 40	50/100/200/400	USA/Canada/India
n261	27.5 – 28.35	50/100/200/400	USA/Canada/India

*LB = 24.25 – 29.5 GHz, HB = 37 – 43.5 GHz

- Customer premises equipment (CPE) is needed to complete the FWA deployment to the home
- Terminals must be cost-effective and easy to install while meeting requirements and limitations of a domestic deployment (versus an infrastructure deployment)
 - Suitable frequency/band coverage for a variety of regions and scenarios
 - Meets minimum necessary power for appropriate user-experience and performance (minimum EIRP targets, good sensitivity, high throughput)
 - Meets spectrum emission mask and regulatory requirements (safety and interference mitigation)

- **Full Band/Frequency Coverage**

- Support all 5G FR2 (Rel. 16) bands with a single device, providing wideband coverage of both frequency “groups”, here called:
 - Low band (n257/n258/n261): 24.25 – 29.5 GHz
 - High band (n259/n260): 37.00 – 43.5 GHz

- **Ease of Installation**

- High steerability through use of high-gain patch-arrays with good coverage across all frequencies

- **Low Cost**

- Dual-band coverage ensures reduced module and antenna area
- Reducing/minimizing component count through dual-band/dual-polarization design with high level of integration
- Higher chip-level integration enables lower overhead (bias, digital, calibration)

- **Performance and User Experience**

- Meet the required performance targets for both transmitter EIRP (power) and receiver EIS (sensitivity) through design optimization (both chip- and module-level) and array sizing

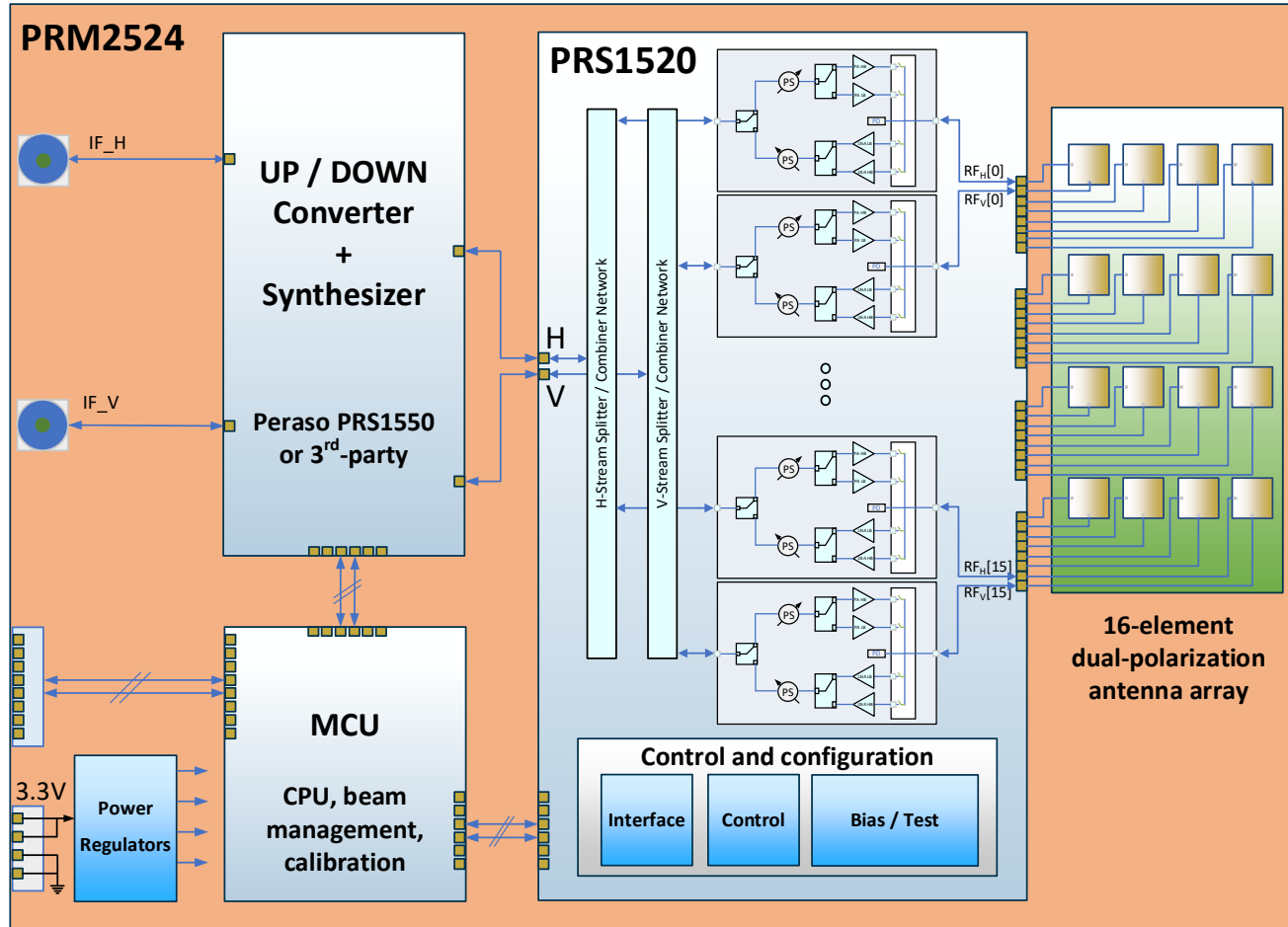
- **Phased-Array Architecture and Chip-Level Integration**

- Target EIRPs for CPE (i.e. QPSK @ 45-47 dBm) can be achieved using a range of channel counts, depending on the achievable PA output power for a given technology and the area/size limits.
 - Low channel/slice count (i.e. 8) requires excessive PA power while high channel/slice count (i.e. >32) imposes high area and integration challenges.
- Dual-band support requires 2 TX's and 2 RX's for each channel/slice, therefore a 16-channel dual-pol phased array corresponds to an equivalent of 128 signal chains (64 TX's and 64 RX's).

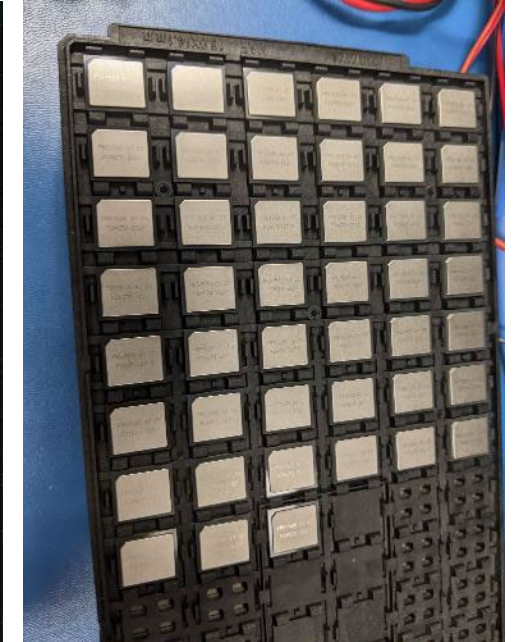
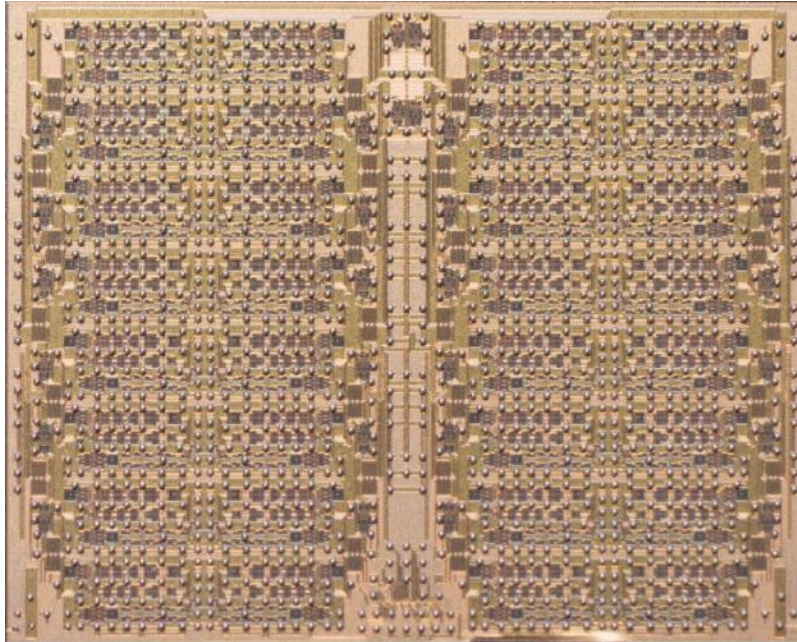
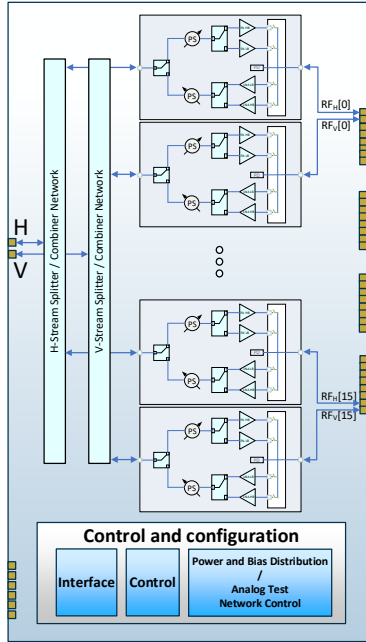
- **Antenna, Package, and Module Assembly**

- Single-chip integration helps reduce aggregate silicon area for a given total channel/slice count and target system $P_{OUT}/EIRP$.
- High chip-level integration ensures lowest channel-to-channel variation and reduces the need for external calibration or compensation.
- Minimizing chip count ensures fewer transitions and board-level interconnects (reducing verification/validation requirements), and less assembly steps for simpler module integration.
- Higher EIRP and/or multibeam MIMO solutions can still be achieved through tiling.

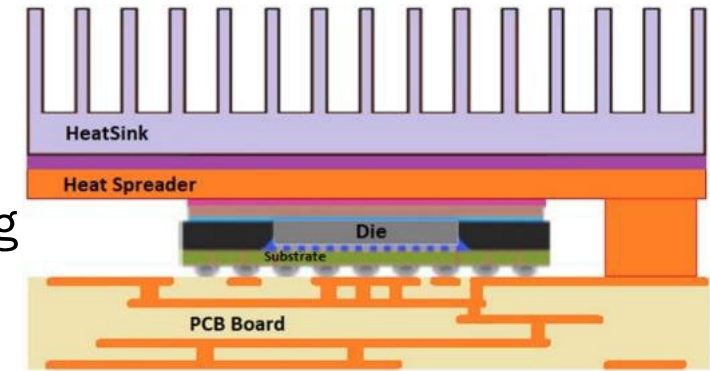
5G FR2 Module for CPE

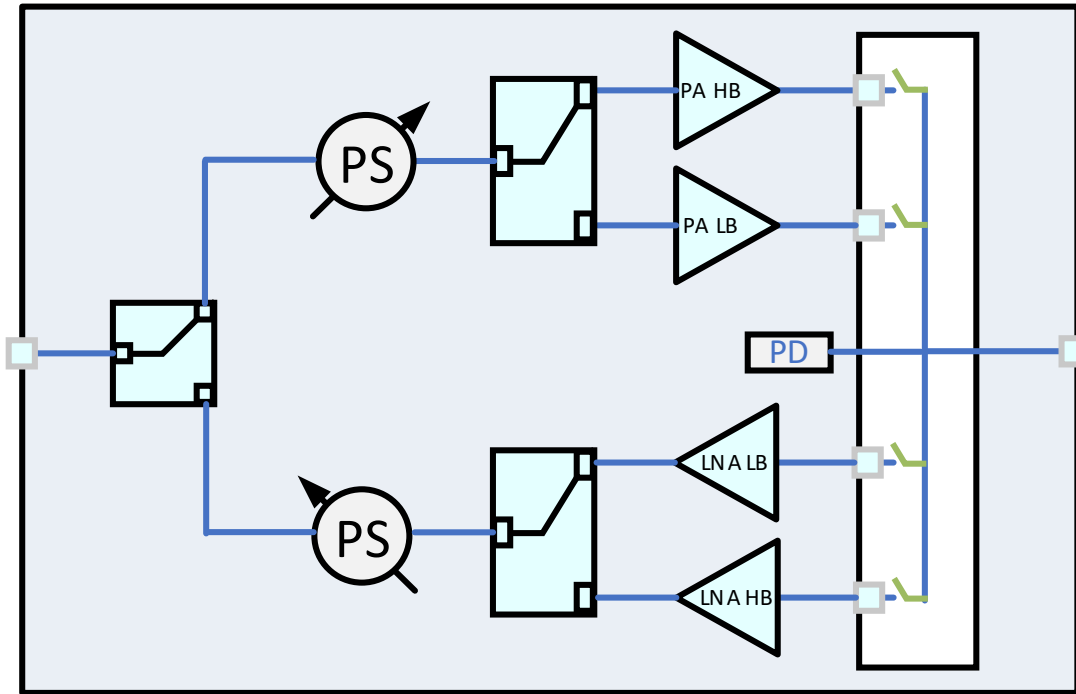


- PRM2524 module covering all CPE/FWA requirements for 5G FR2
- Heterogenous approach for optimal performance and cost efficiency
- Integrates:
 - Single-chip beamformer (PRS1520) supporting dual-band and dual-stream operation
 - 16-element, dual-resonant, dual-polarization patch-array
 - Up/down frequency converter and frequency synthesizer (PRS1550 or 3rd-party)
 - MCU to perform beam management and calibration (3rd-party)
- Supports IF from 3 to 7 GHz
 - Zero-IF is also supported



- Fully integrated single-chip CPE beamformer in RF-SOI (PRS1520)
 - 2 x 16 transmit/receive dual-band front-end slices (MIMO/dual-stream)
 - Adjustable gain, bi-directional power combiner/splitter network
 - Integrated biasing, thermal monitoring, switch control, and analog testing
 - Rapid beam switching and configuration
- Packaging: organic laminate interposer with integrated heat spreader
 - Low θ_{JC} (<1 °C/W)





Power Amplifier

- Differential stacked topology for reliability, P_{OUT} , and linearity
- 4-stage (low band) and 5-stage (high band) designs for wide bandwidth and high gain
- $P_{SAT} > 22$ dBm across all frequencies

Antenna Switch

- SP4T switch with low insertion loss and high linearity
- Insertion loss between 1–1.5 dB
- $P_{1dB} > 30$ dBm across all bands

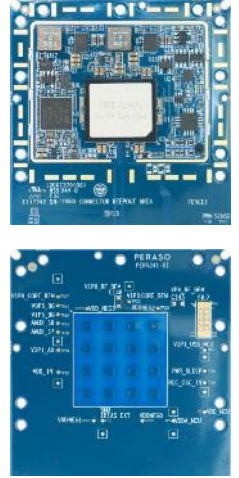
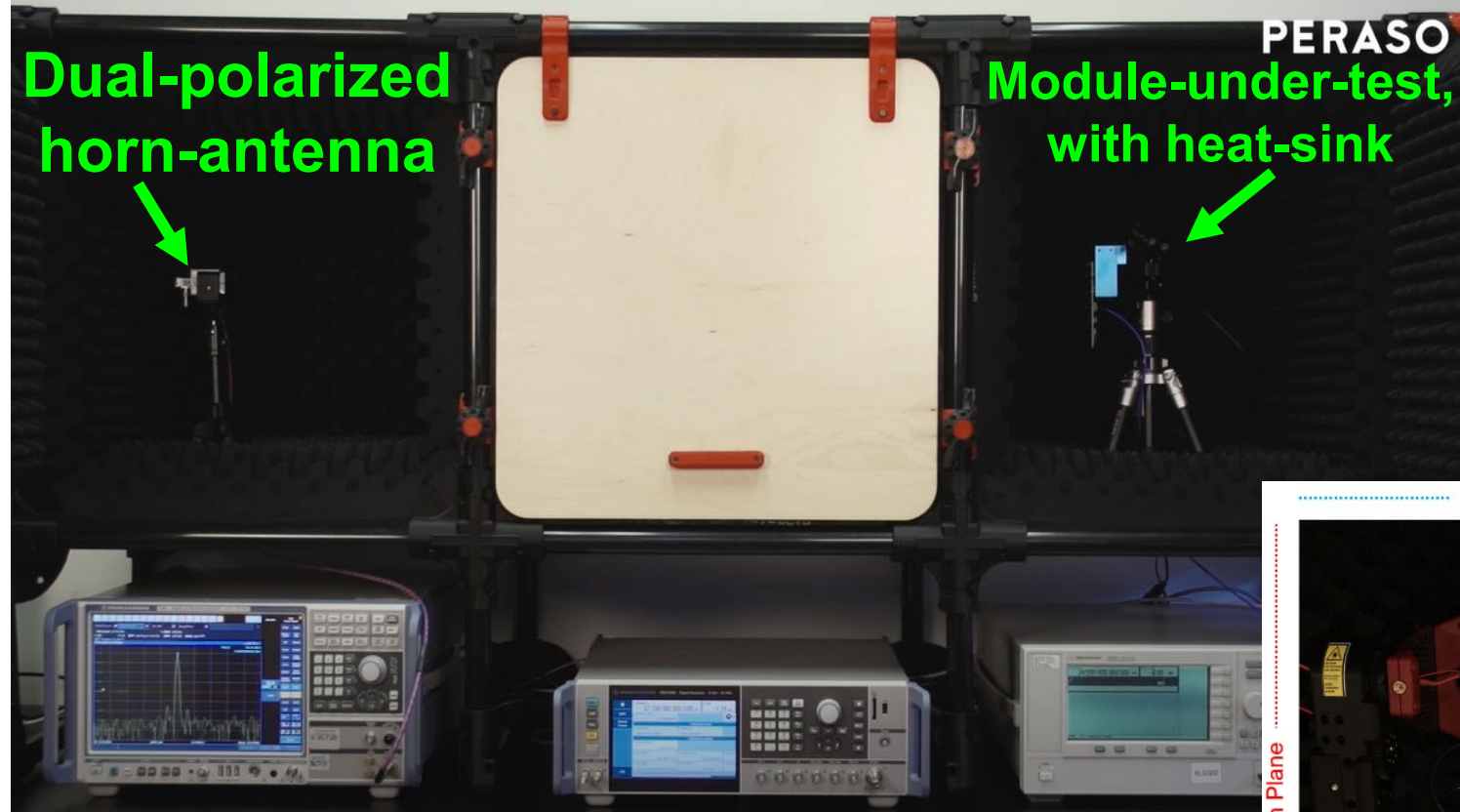
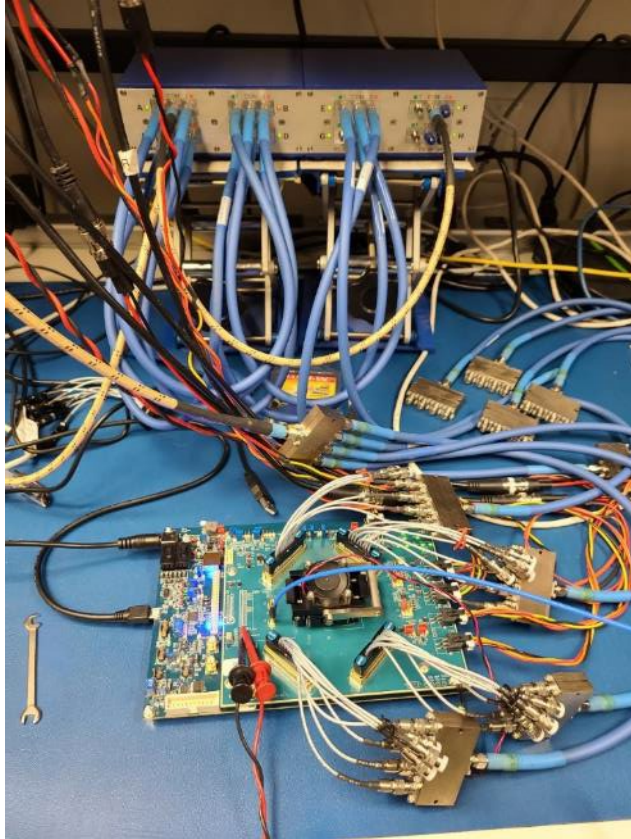
Low-Noise Amplifier

- 3-stage cascode providing > 30 dB gain and < 4 dB NF
- Integrated bypass/selector switches for coarse gain control and band selection
 - 12 dB steps, 8 - 32 dB gain range

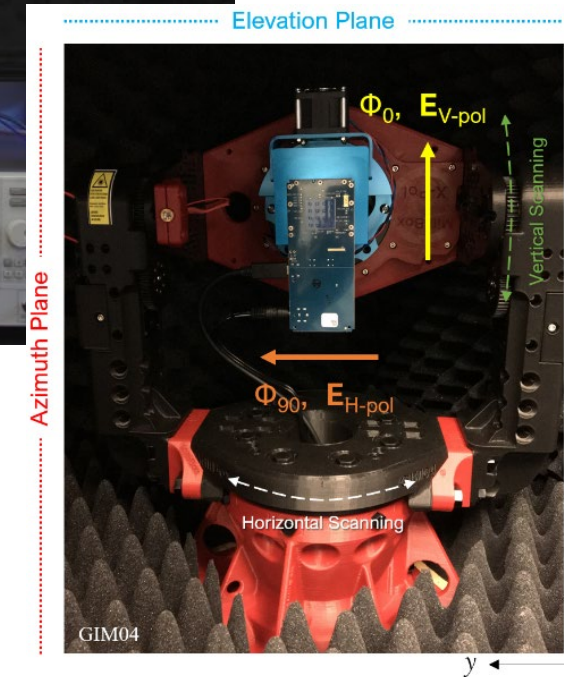
Phase Shifter

- Wideband phase shifter based on I/Q phase interpolation and transformer-based quadrature hybrid
- 6-bit phase resolution with < 0.6 dB RMS amplitude and 4° – 5° RMS phase error for both bands

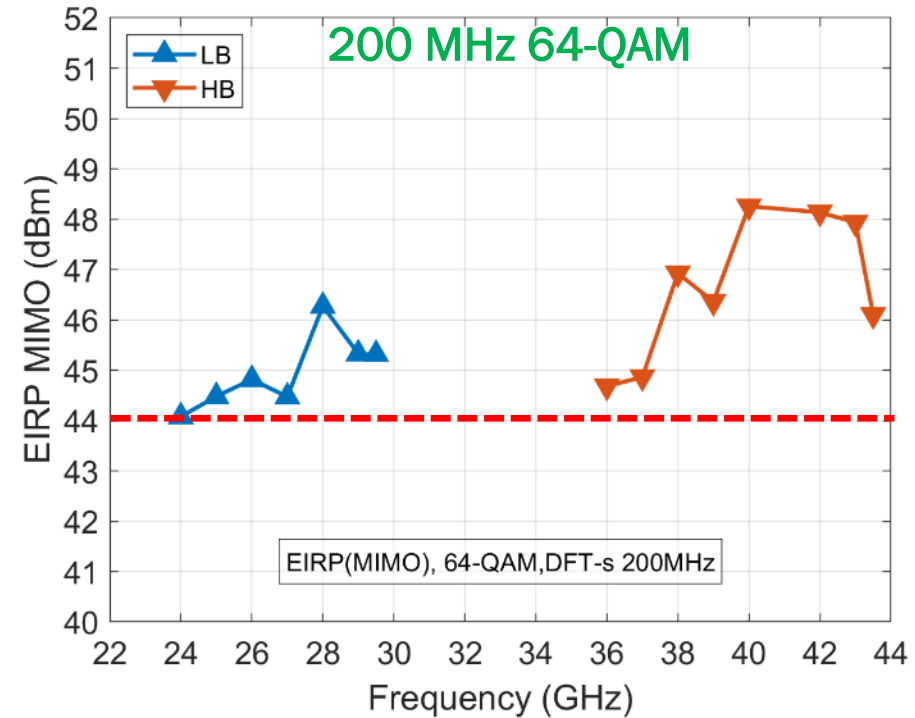
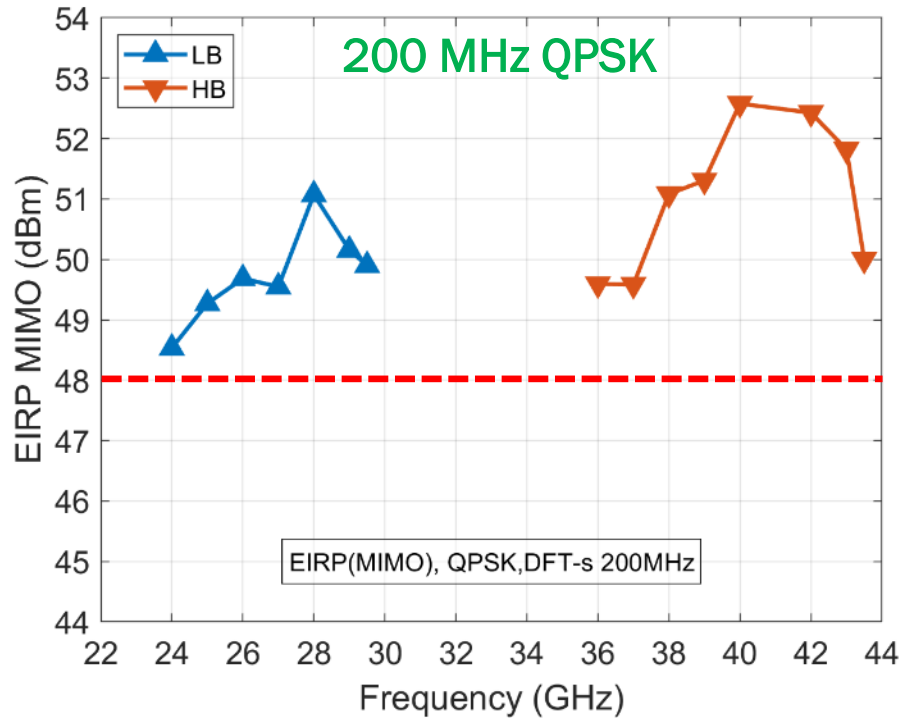
Measurement Setup



- Conducted signal measurements using 32-way switch/combiner matrix (left)
 - Small signal (S_{21} , NF, etc.) and large signal (P_{1dB} /IP3 and modulated signal)
 - Can perform individual elements/slices or combined full-array measurements
- Over-the-air (OTA) measurement setup for transmit EIRP of the phased array (right)
 - CW or modulated (i.e. 5G FR2 waveforms)



Measured TX EIRP (MIMO) vs. Frequency



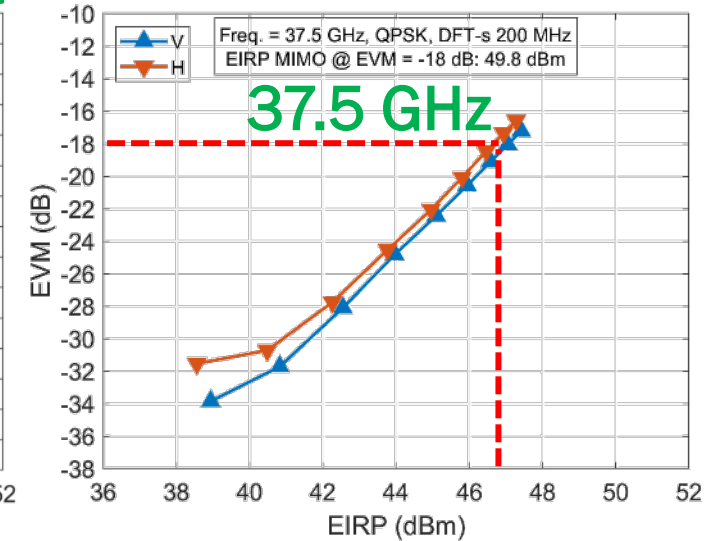
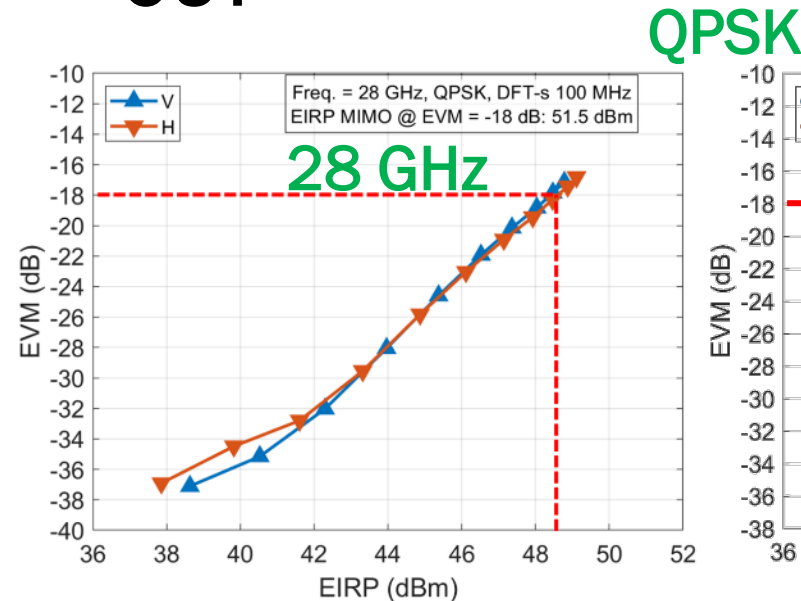
- EIRP QPSK >48 dBm across bands (EVM = -18 dB, MIMO/dual-pol, at 55°C junction)
 - P_{DC} ~19 to 22 W @ 100% duty cycle
- EIRP 64-QAM >44 dBm across bands (EVM = -25 dB, MIMO/dual-pol, at 55°C junction)
 - P_{DC} ~13 to 15 W @ 100% duty cycle
- EVM targets include a 3-dB margin over 3GPP specification (i.e. -15/-22 dB for QPSK/64-QAM)

* An additional 3 dB is included for dual-pol operation (EIRP MIMO)

Measured TX P_{OUT} – QPSK/64-QAM

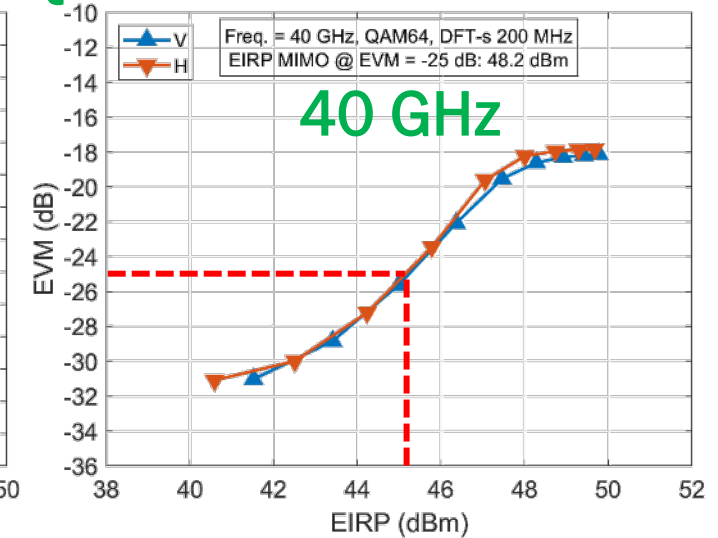
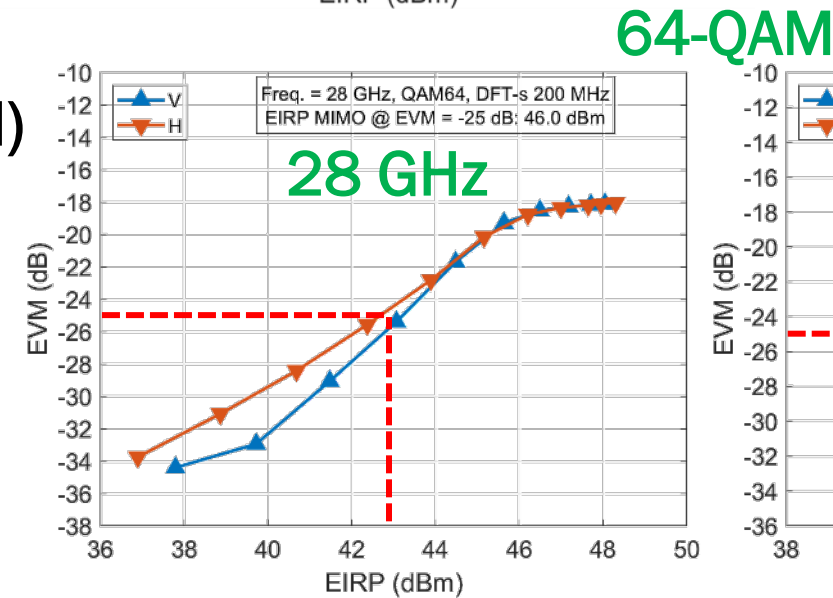
QPSK (@ -18 dB EVM DFT-s-OFDM)

- EIRP (SISO) = 48.5/46.5 dBm
- EIRP (MIMO) = 51.5/49.8 dBm
 - Freq = 28/37.5 GHz



64-QAM (@ -25 dB EVM DFT-s-OFDM)

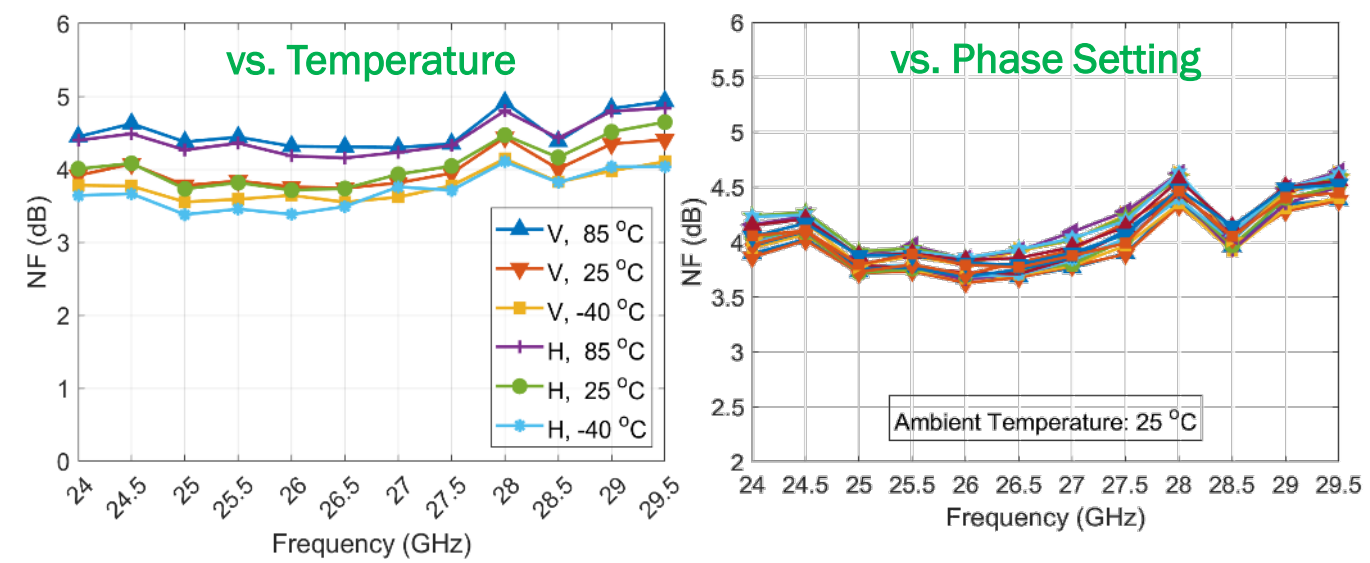
- EIRP (SISO) = 43/45 dBm
- EIRP (MIMO) = 46/48 dBm
 - Freq = 28/40 GHz



- Junction temperature of 55 °C

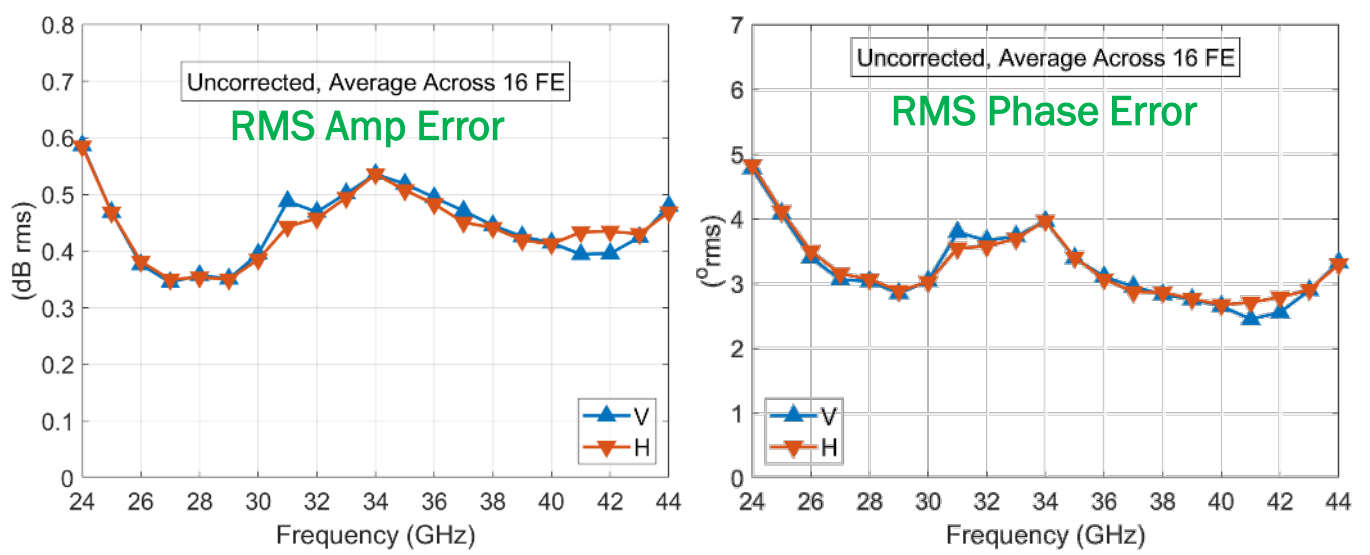
RX NF

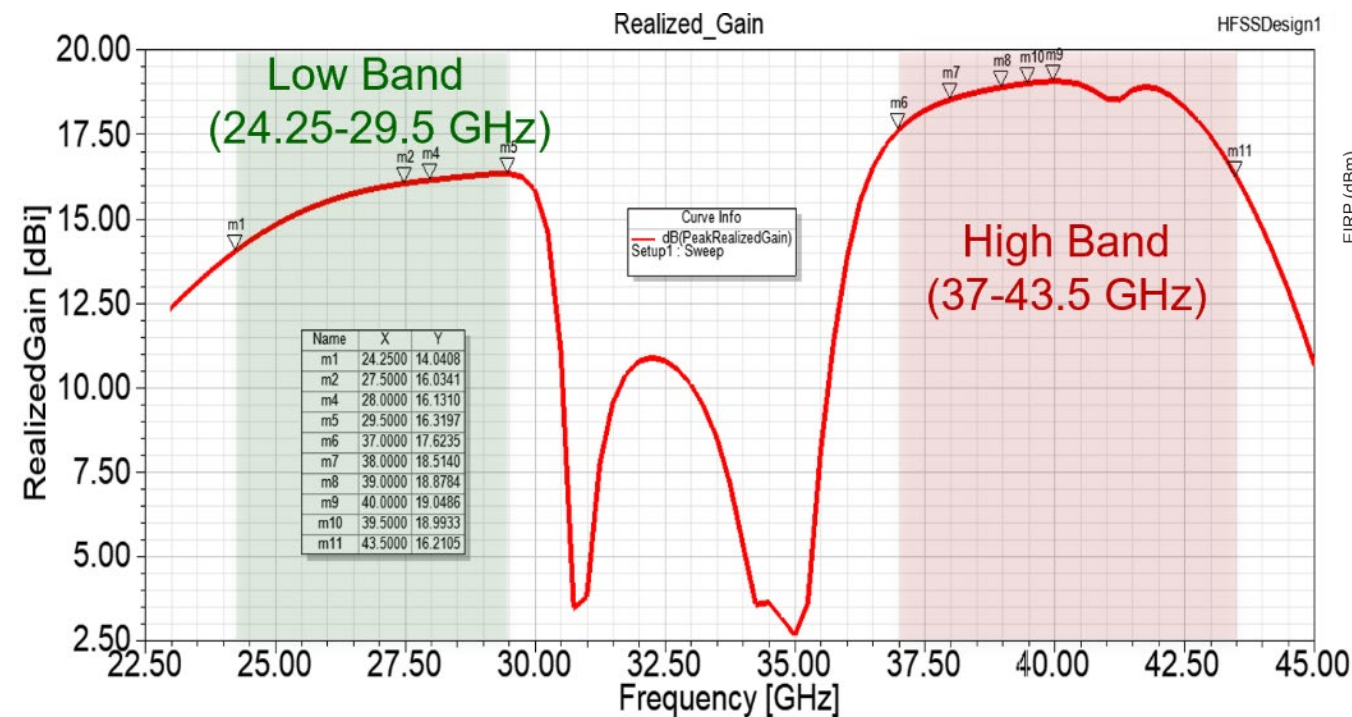
- Low-band NF <5 dB at ambient temp of 85 °C (left) and across different PS settings (0 to 360°) at ambient temp of 25 °C (right)
 - Package loss included



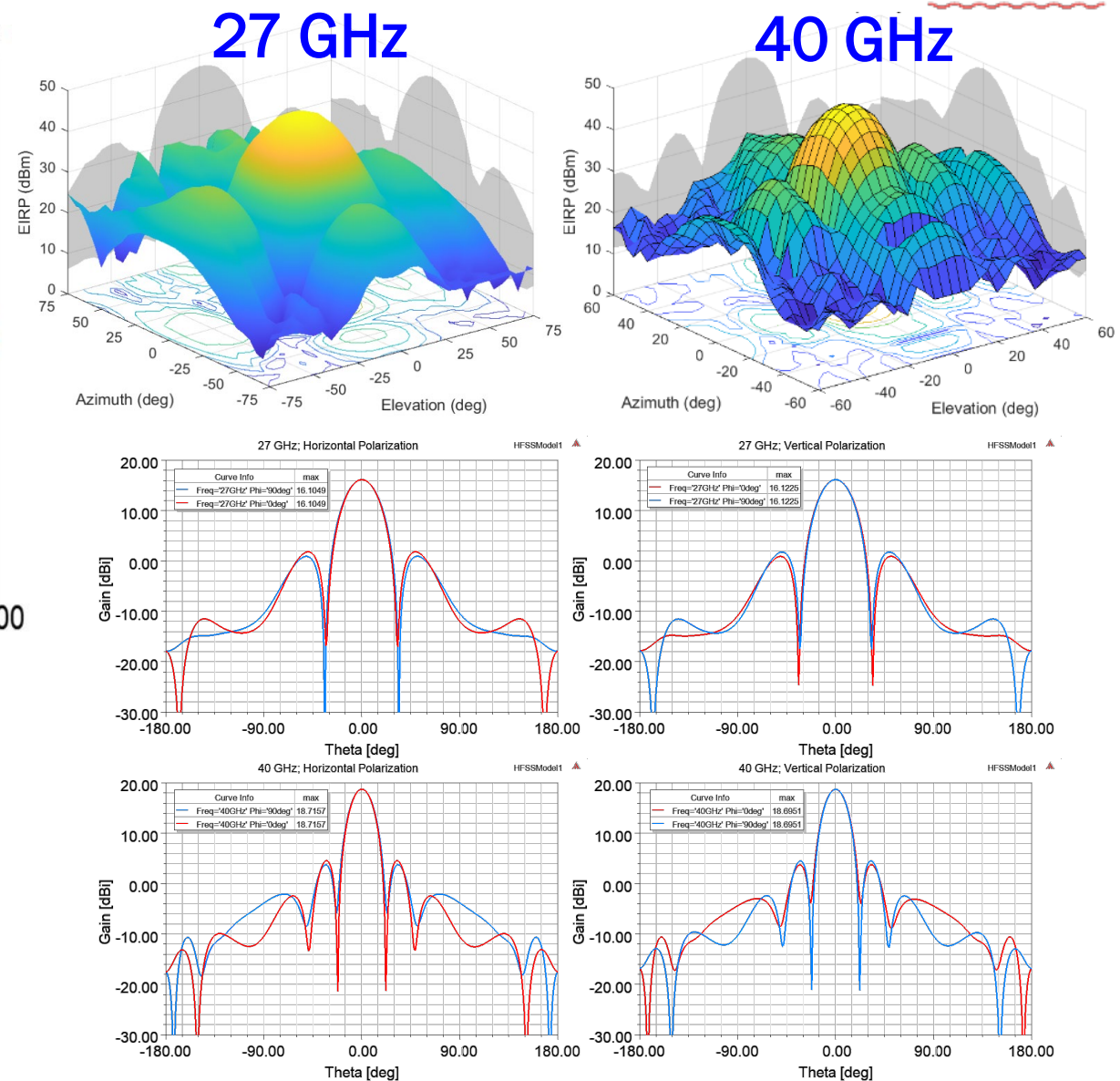
TX Phase Shifter

- TX phase shifter average RMS amp and phase error <0.6 dB and 5° across all frequencies
 - For junction temp of 55°C
 - Similar performance for RX





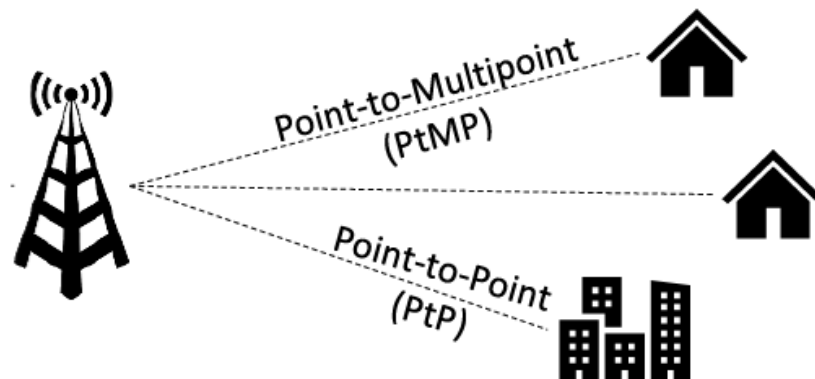
- 4 x 4 dual-band dual-pol antenna array with lattice spacing $\lambda/2$ @ 30 GHz.
- Antenna array gain between 14 to 16.5 dB for LB and 16.5 to 19 dB for HB (including array factor).
- HPBW between 25° to 30° (H and V pol).



Parameter		Value
RF bands	n257, n258, n261	24.25 - 29.5 GHz
	n259, n260	37.00 - 43.5 GHz
MIMO streams		Dual polarization (H + V)
# of channels		16 (H) + 16 (V)
TX EIRP (MIMO, H+V, DFT-s-OFDM, QPSK)		
n261		49 dBm
n260		51 dBm
n257, n258, n259		48 dBm
RX NF (LB: n257, n258, n261)		4.5 dB
Antenna gain (including feed loss)		n260: 18 dBi n261: 16 dBi
Azimuth/elevation scan (-6 dB)		120° (± 60°) / 120° (± 60°)
Phase shifter step size		5.625° (6-bit resolution)
Power consumption (@100% duty cycle, V+H MIMO)		TX: ~21 W (EIRP QPSK >48 dBm) TX: ~14 W (EIRP 64-QAM >44 dBm) RX: ~2.5 W

- Single RFIC solution for CPE/FWA applications
 - Single silicon covering all worldwide FR2 bands between 24.25 and 43.5 GHz
 - Supports scalability (i.e. tiling) for other applications (hotspots, small cells, etc.)
 - Full module designed to reliably operate across a full temperature range and output power (>10 years @25% duty cycle)
- Dual-resonant, dual-polarized antenna array provides high-gain and extremely wideband performance
- Integrated module meets or exceeds CPE user-terminal requirements:
 - Delivers peak EIRP beyond 51 dBm (QPSK, MIMO, 200 MHz BW)
 - Excellent RX NF ensures low sensitivity

802.11ad/WiGig-Based FWA Production Modules

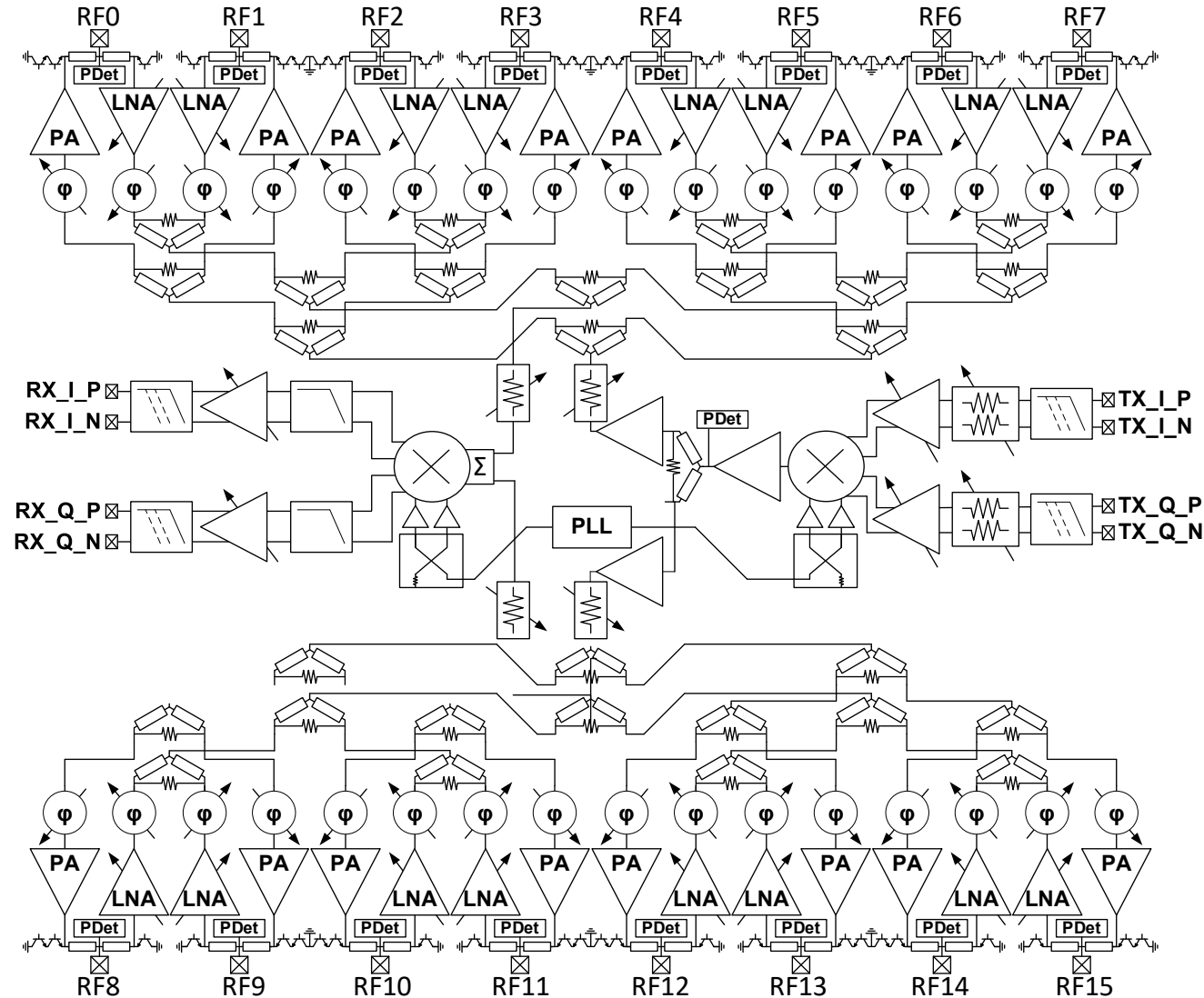


Channel	Center (GHz)
1	58.32
2	60.48
3	62.64
4	64.80
5	66.96
6	69.12

- Clear role for low-cost/unlicensed spectrum-based FWA in broadband deployment
 - Avoid costly licensing requirements, and allows small carriers or corporations to set-up and manage networks dynamically
 - Appropriate for non-critical traffic, especially when available with fall-over or backup links
- Especially relevant with inclusion of 60-GHz bands in proposal for 5G NR-U in 3GPP release 17
- The introduction of two upper channels in the 60-GHz band (channel 5/6) challenged the perception that the 60-GHz band is not suitable for large outdoor networks
- These channels experience between **11 and 12 dB less atmospheric attenuation**, making them attractive for longer distance, fixed-wireless applications
- Ultimately, diverse point-to-point (PtP) and point-to-multipoint (PtMP) links are needed to address the needs of a deployment, and a family of modules for each of these links

- PRS1165 “Rockfinch” RFIC
- 16-element transceiver for good compromise between performance, die-area, and beam steerability
- Cover full extended range, 57-71 GHz (adding CH 5 and 6)
- Support for high EIRP beyond 40-43 dBm FCC limit to ensure full coverage of scenarios with high operating temp and complex signals with high PAPR
- Support for half and quarter channel BWs (not standard compliant) to provide enhanced range options
- Integrated using cost-effective packaging and antenna materials to ensure low overall system cost

*Reference: A 16-Element Phased-Array Transceiver in 130-nm SiGe BiCMOS for Fixed Wireless Access Covering the Full 57-71 GHz Band, RWW 2020



60-GHz Module Family (PRM2140X)

	PRM2141X	PRM2142X	PRM2143X	PRM2144X
Status	In production (launch Q3 '21)	In production (launch Q2 '22)	In production (launch Q3 '22)	Samples (launch Q2 '23)
Baseband/RFIC	PRS4601 (Falcon) / PRS1165 (Rockfinch)			
Antenna Array	16-element patch array	32-element patch array	64-element patch array	128-element patch array
Max EIRP/G _{ANT}	~37 dBm / 15 dBi	~42 dBm* / 18 dBi	~45 dBm* / 22 dBi	~47 dBm* / 25 dBi
Scan range	±45° az / ±45° el	±45° az / ±20° el	±20° az / ±20° el	±10° az / ±20° el
Power consumption	TX: 7-11.5 W / RX: 4.5 W	TX: 11.5 W / RX: 4.5 W	TX: 11.5 W / RX: 4.5 W	TX: 11.5 W / RX: 4.5 W
Size	35 mm × 50 mm	50 mm × 50 mm	50 mm × 50 mm	55 mm × 55 mm
Description	Dish (reflector) antenna supported with EIRP >63 dBm	Higher gain antenna than PRM2141 in standalone operation.	Higher gain antenna, standalone operation.	Highest gain standalone antenna.

*FCC limited to +40 dBm



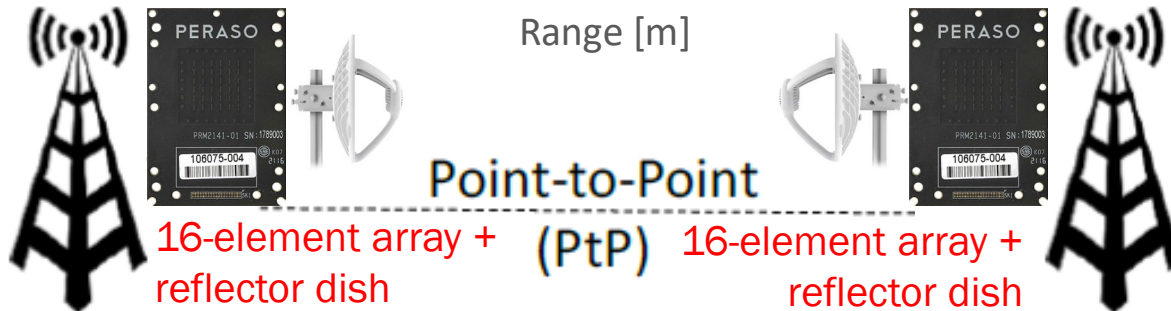
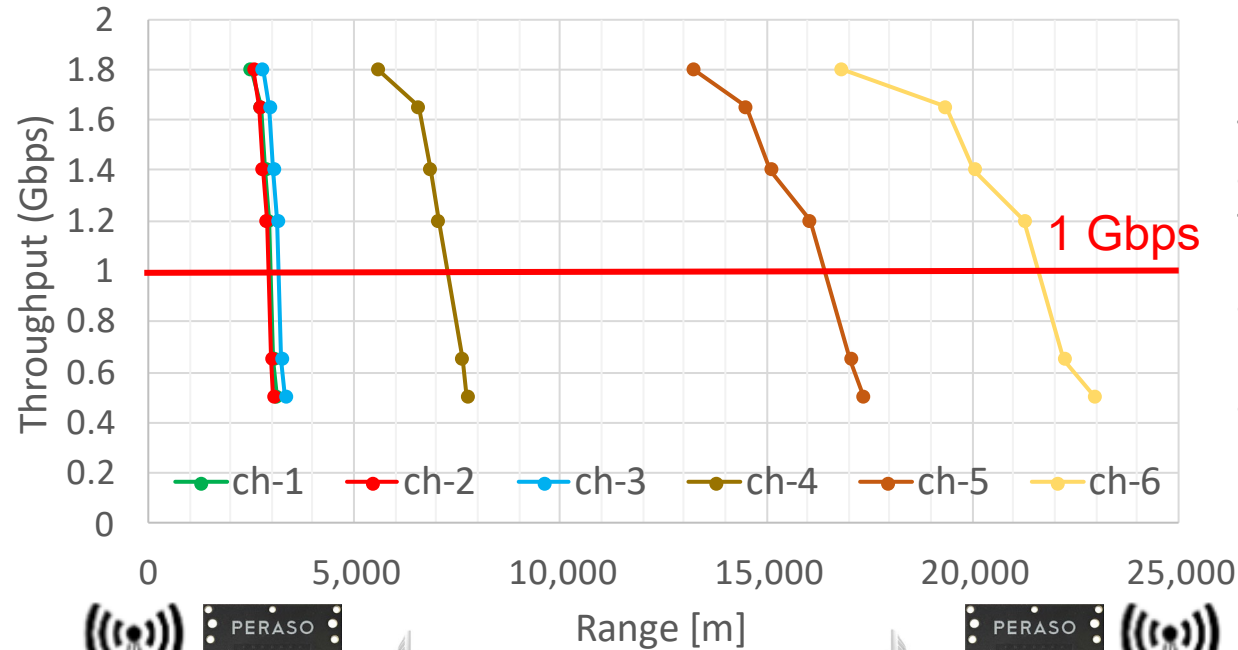
- Single board w/ RF, baseband, and integrated antenna
- 802.11ad/ay Channels 1-6 (57-71 GHz)
- 2 Gbps (MCS 9) peak throughput at peak power
- 3 Gbps (MCS 10-12) peak throughput
 - 16-QAM back-off power level

- Access Point or client applications (support >16 STA/clients)
- Supports full, half, and quarter channel operation
- USB data/control interface
- Power Consumption (QPSK, 16 elements active)
 - TX: 11.5W / RX: 4.5 W

Can accommodate the full range of implementations from wireless infrastructure (backhaul) to last-mile (point-to-point and point-to-multipoint)

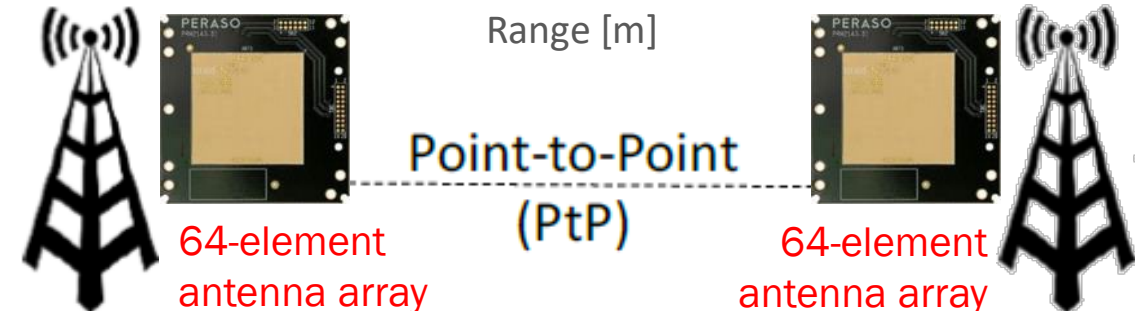
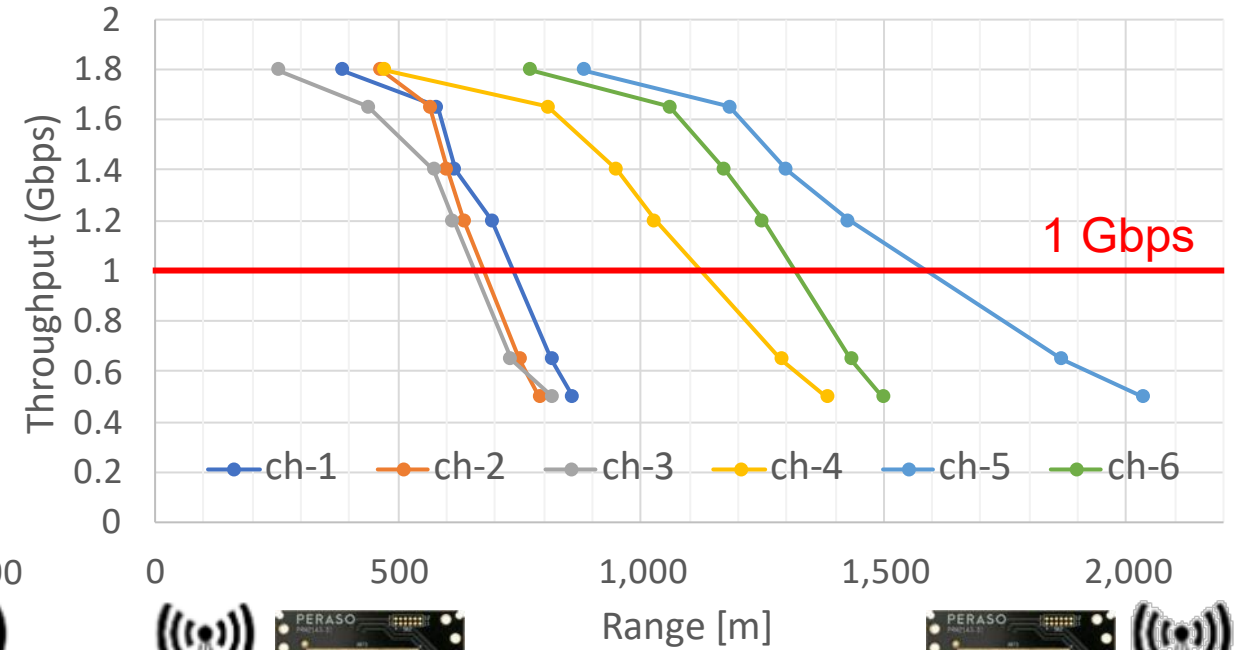
Link Analysis (Point-to-Point)

PRM2141X-dish Point-to-Point



- Maximum performance link with reflectors on both sides
- Capable of achieving ranges >20 km on CH 6

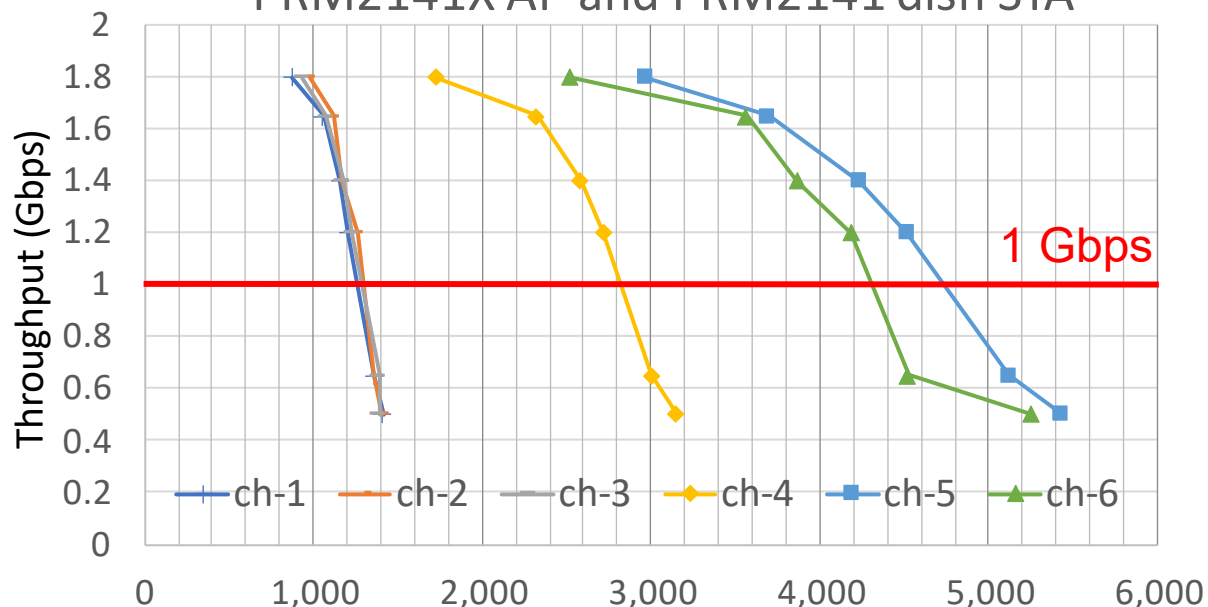
PRM2143X Point-to-Point



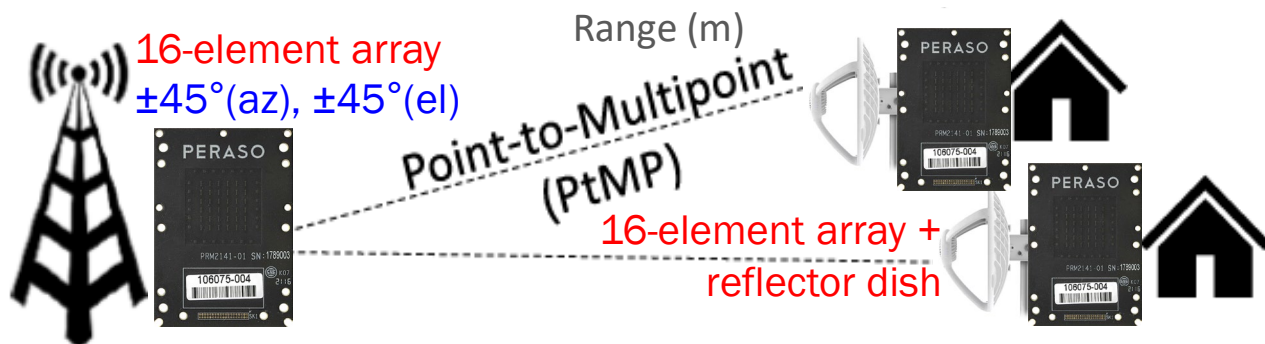
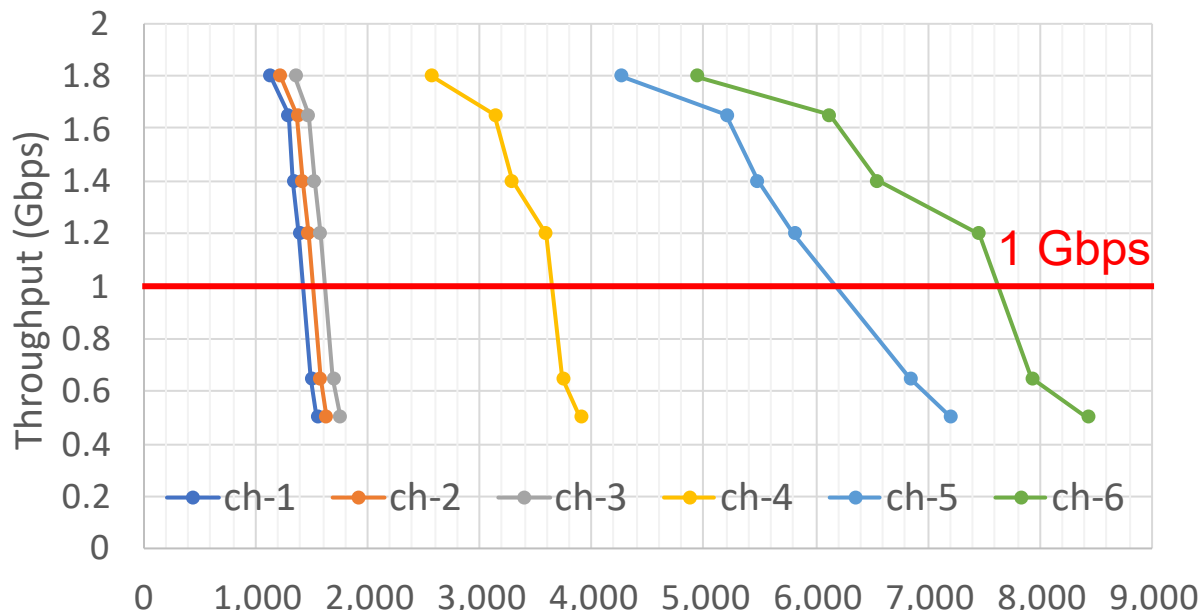
- Most cost- and area-efficient point-to-point link
- >1 km on CH 4-6 and >1.5 km on CH 5
- Also enables multi-point to multi-point

Link Analysis (Point-to-Multipoint)

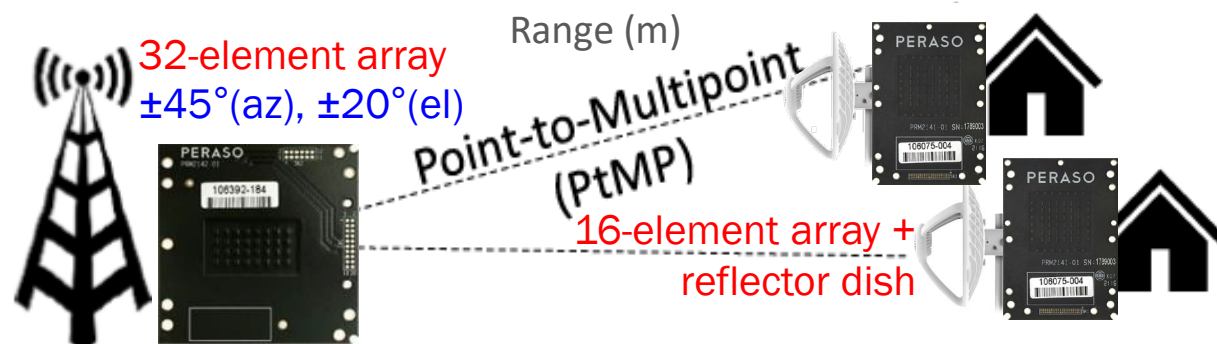
PRM2141X-AP and PRM2141-dish STA



PRM2142X AP and PRM2141Xdish STA



- Most flexible and steerable PtMP configuration
- Capable of covering 3-5 km (CH 4-6)



- Reduced steerability, but increased coverage from 5-8 km (CH 5-6)

Link Performance (Field Results)

Production and Customer Deployments

60GHz Link Deployment Contest

Contestants were asked to share their link deployments. You can check out the global results below!

PRM2141X: Operation with reflector dish for maximum range

Leaderboard

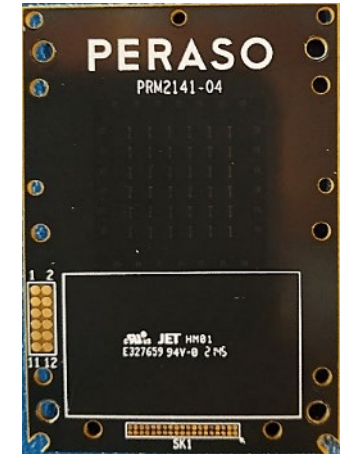
All Time

All Countries

Search...



#	LINK DISTANCE	LOCATION	LINK POTENTIAL	SIGNAL STRENGTH	CAPACITY
1	27.13 km	Grantsville, UT, US	98%	-73.0 dBm	900 Mbps
2	24.69 km	Marlena AH, South Africa	100%	-74.0 dBm	134 Mbps
3	24.59 km	Luis Moya, Mexico	93%	-73.0 dBm	600 Mbps
4	23.86 km	Vitkovice, Czechia	88%	-74.0 dBm	673 Mbps
5	22.82 km	Cedar Fort, UT, US	90%	-72.0 dBm	900 Mbps



- Customers regularly achieving >20 km links with parabolic reflectors.
 - Current record is >27 km in Utah
- Upper channels (CH 5 and 6) enable a wide range of long-distance links.

Conclusion

- mm-Wave FWA networks must fully utilize the range of licensed (5G) and unlicensed (802.11ad/60 GHz) bands in order to address deployments across a full gamut of service providers and applications.
- High adoption rates and penetration of the 5G FWA market requires low-cost CPE solutions that can only be achieved with simplified and highly-integrated solutions.
- This is achieved using a powerful single-chip beamformer that supports dual-band and dual-polarization operation while providing >50 dBm EIRP with low system complexity and minimal area/cost.
- A range of fully integrated wireless modules for the unlicensed 802.11ad FWA market can be used in diverse PtP and PtMP deployments that provide multi-gigabit solutions with ranges >20 km.

Please visit us at the Richardson RFPD exhibition booth and view the [YouTube video](#) for more information.



Thank You!

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