MACOM™
Partners from RF to Light

MACOM Technology Solutions Holdings (MTSI)

March 2019

Safe Harbor

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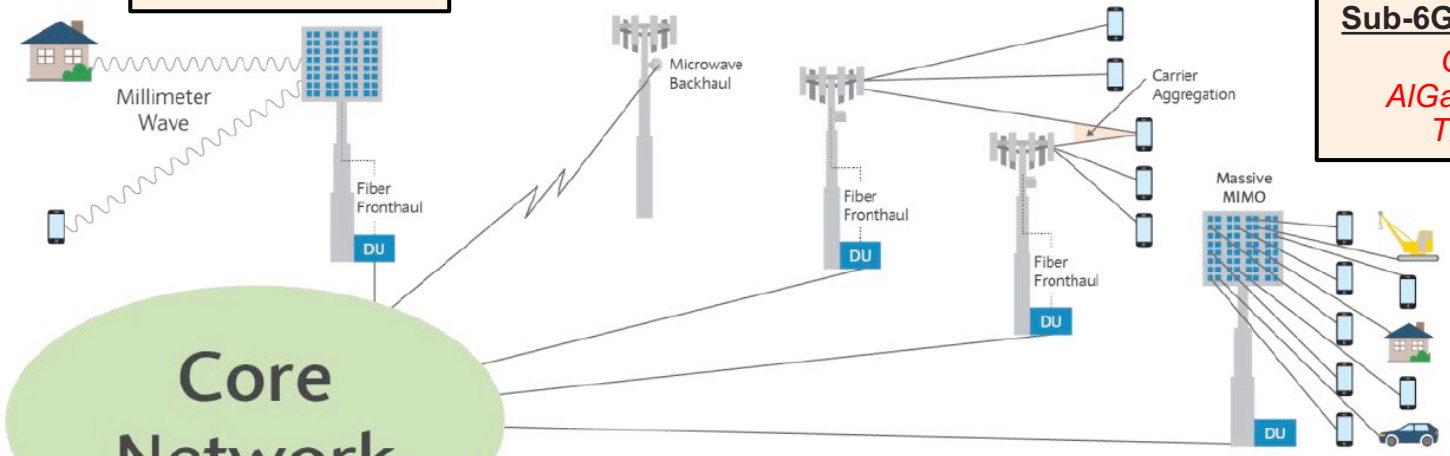
5G—New Network Architecture

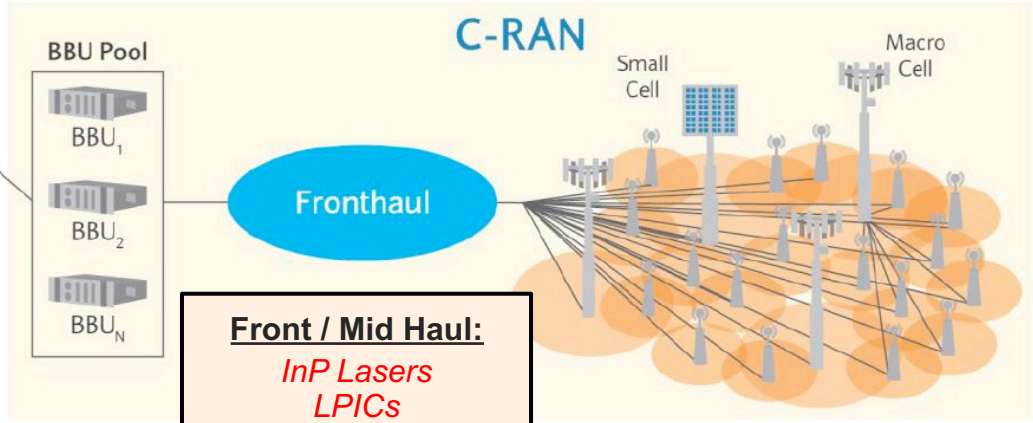
Massive MIMO Active Antenna Arrays, More Optical Links

24GHz - 39GHz
Repeaters & CPE:
AlGaAs Switches



Sub-6GHz Macro Cell:
GaN PA's
AlGaAs Switches
TxRx HMIC

Backhaul:
Coherent Drivers & TIAs



Front / Mid Haul:
InP Lasers
LPICs
Drivers, TIAs, CDRs

Key
DU: Digital Unit/Baseband
C-RAN: Cloud/Centralized Radio Access Network

Source: Barclays Research

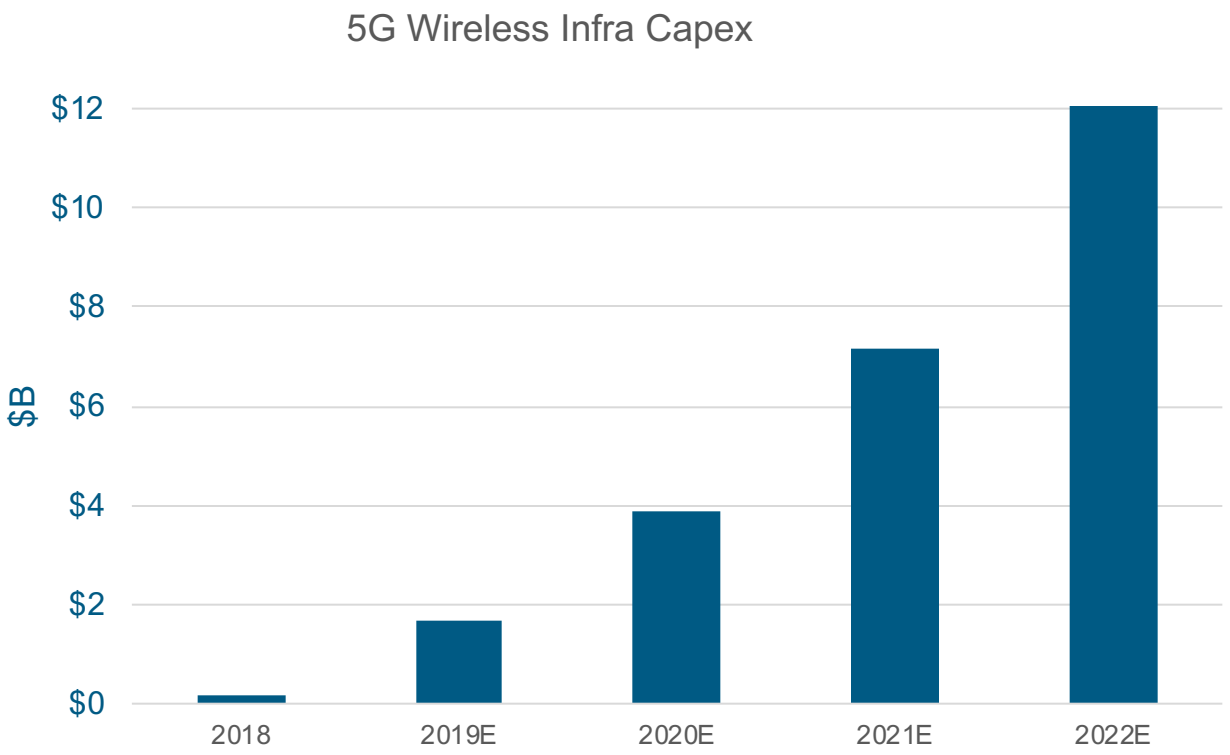
5G—New Technical Challenges

Deploying 5G antennas requires breakthroughs in energy efficiency, cost structures, quality of service and subscriber coverage

Critical challenges remain:

- Quality of service goals constrained by **performance** of traditional microwave and millimeterwave technologies
- **Form factor and thermal constraints** inhibit conventional beamforming architectures
- **Cost structures** not yet affordable for mainstream deployments
- **Energy consumption** does not meet operating expense targets and thermal constraints
- **Supply chains** for key technologies not robust across the industry

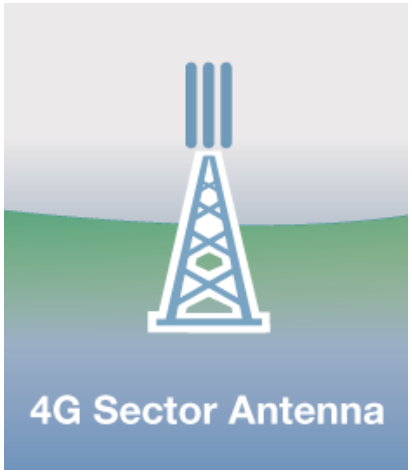
5G Wireless Infrastructure Capex



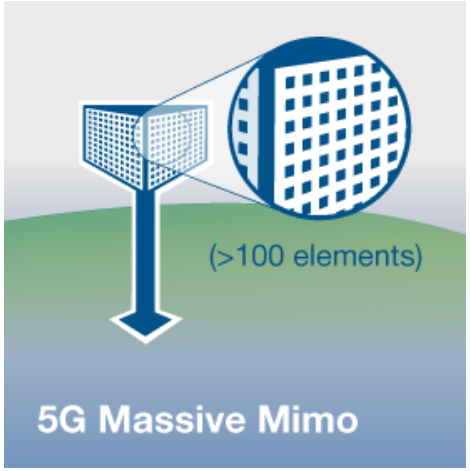
Source: Dell'Oro, Mobile RA Five Year Forecast, July 2018

Sub-6GHz Growth Engine

Sub-6GHz Massive MIMO

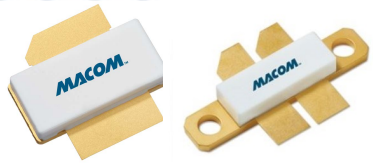


16-32x Increase in PA Count per Sector



4G Macro BTS:

- Up to 4x4 MIMO (4T4R)
- P_{peak} ~200W–750W
- Freq: 700MHz–2.6GHz



Ceramic Package

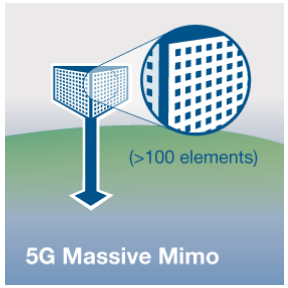
Air Cavity Package

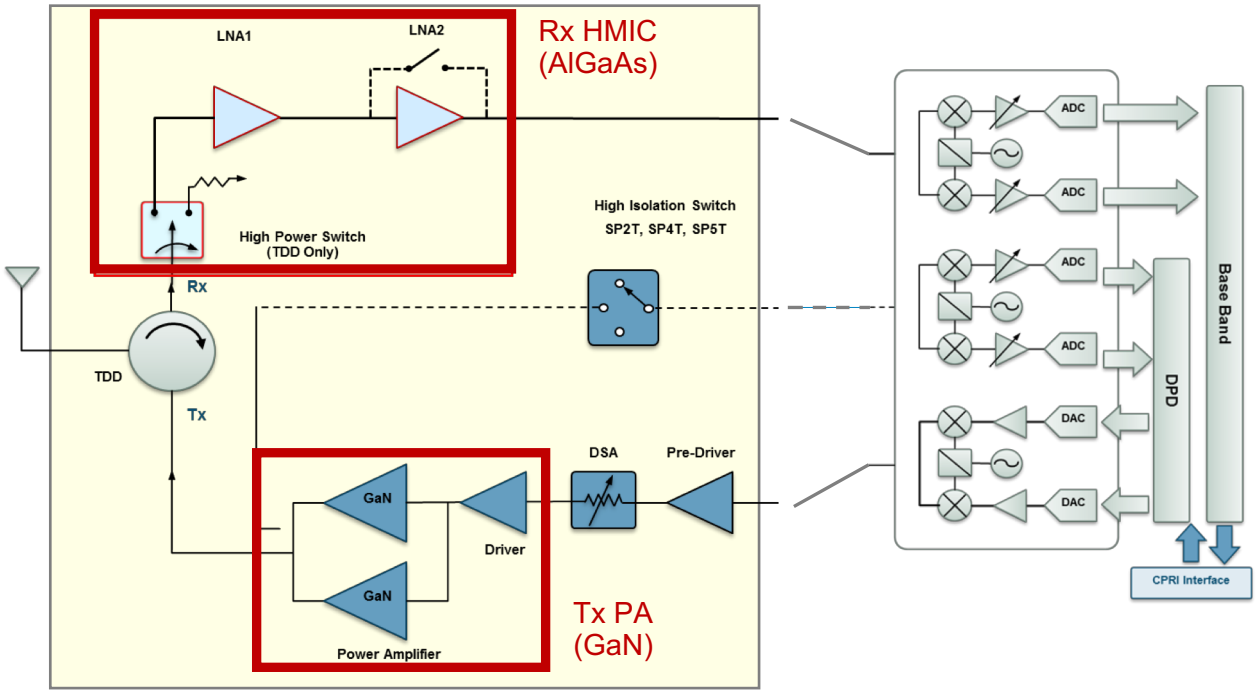
5G M-MIMO BTS:

- 64 Element Array (64T64R)
- P_{avg} ~6W–8W (~50W_{peak})
- Freq: Sub-6GHz

QFN Package

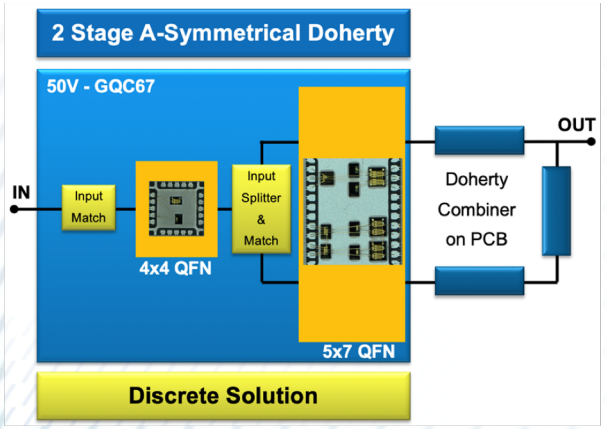
Sub-6GHz Massive MIMO

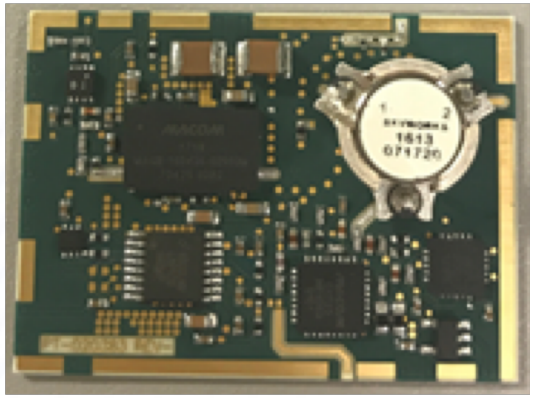




TxRx Element Detail

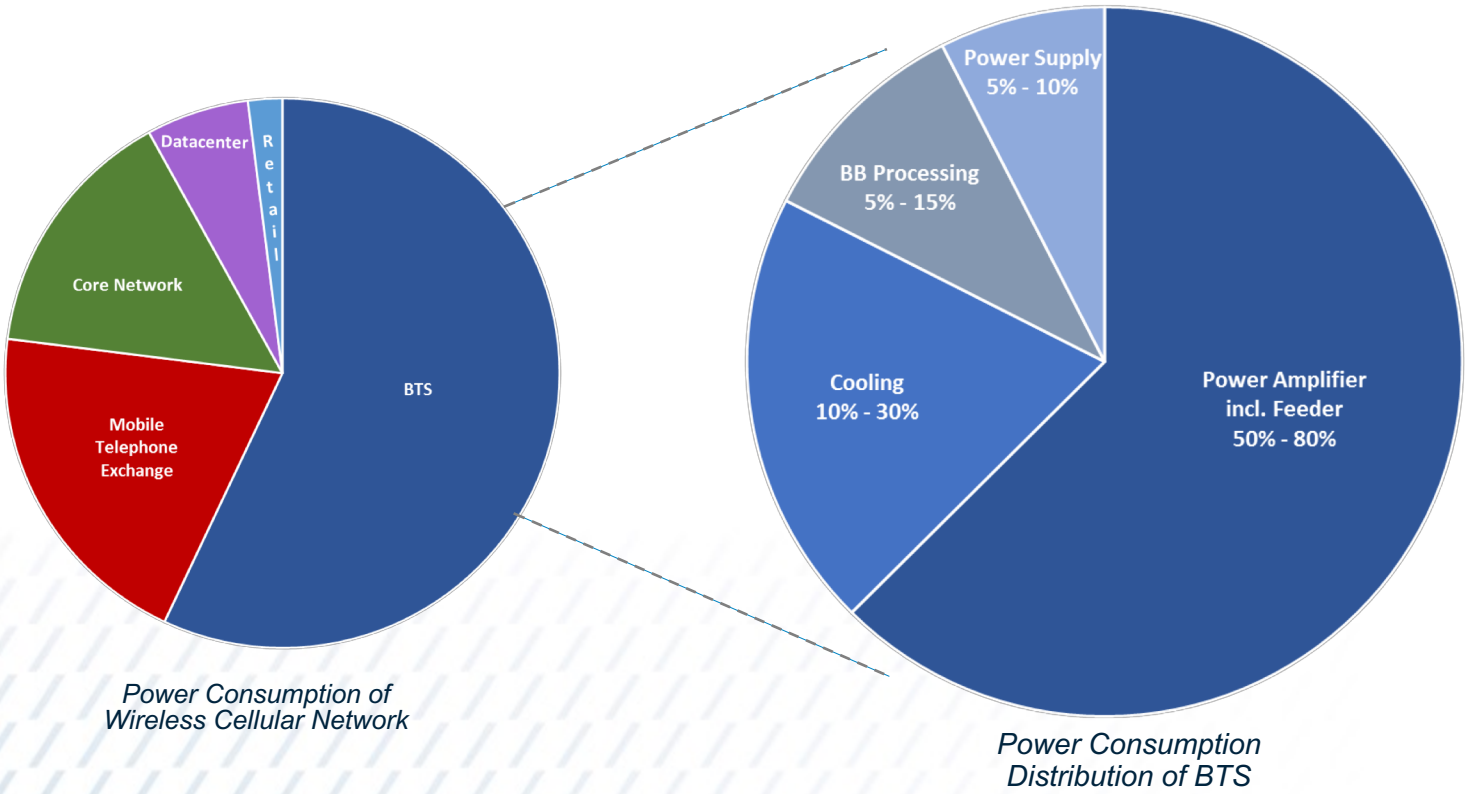
Single Element Complete TR Module





GaN is a Requisite for 5G M-MIMO

Power Amplifiers Comprise up to 75% - 90% of Total BTS Power Consumption, Either Directly or Indirectly



Power Consumption of Wireless Cellular Network

Power Consumption Distribution of BTS

Source: Alsharif, M.; Kim, J.; Kim, J. Green and Sustainable Base Stations: An Overview and Future Research Directions. *www.mpdi.com/journal/energies*

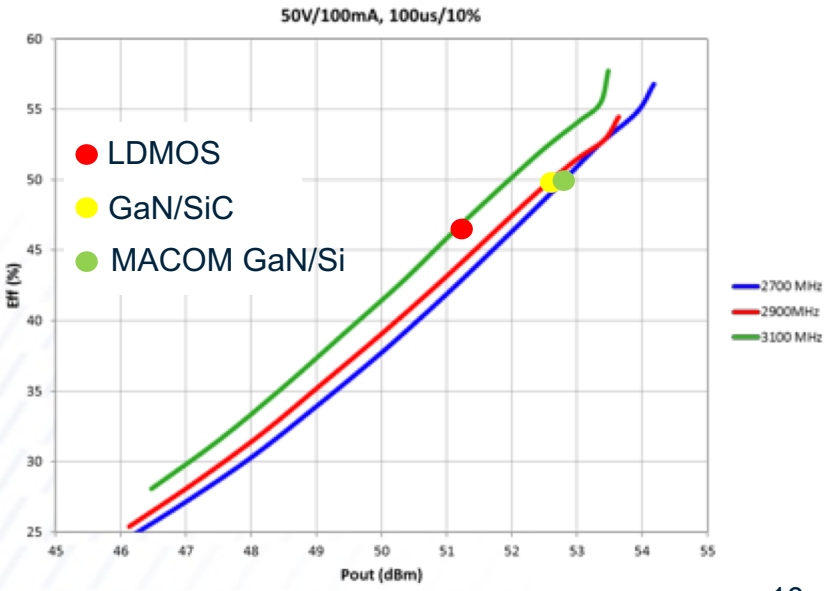
GaN-on-Si Basestation Power Amplifiers

MACOM GaN Technology Fully Qualified and Deployed in the Field

MAGX-102731-180

AC-360B

- V_{DS} = 50 V
- Freq. = 2700 – 3100 MHz
- P_{OUT} = 180 W
- Pulse Conditions: 100 µs / 10%
- Power Gain > 14.5 dB
- Drain Efficiency >50%



Over 1.5 Million GaN-on-Si Devices in the Field Today

Customers

HARRIS

NOKIA

Rockwell Collins

Products

5G MMIC Comparison

MACOM GaN vs. GaN on SiC vs. LDMOS

	LDMOS	MACOM GaN	GaN on SiC	Benefits
2-stage Doherty PA Efficiency @3.6 GHz	**43%**	**48%**	**48%**	*Lower Operating Expense*
Higher Frequency Bands	**2.7GHz & 3.8GHz**	**Up to and >6GHz**	**Up to and >6GHz**	*New Spectrum Deployments*
Wider Bandwidths	**100MHz**	**200MHz**	**200MHz**	*Higher Capacity per BTS*
Power Density	**1-1.5W/mm**	**4-8W/mm**	**4-8W/mm**	*Smaller Antenna, Lower CapEx*
Linearity	**DPD Friendly**	**DPD Friendly**	**Charge Trapping**	*Higher Modulation Schemes/Capacity*
Supply Chain	**8”**	**Up to 8”**	**4” → 6”**	*Operational Scale/ Surge Capability*
Cost	**Silicon Substrate**	**Silicon Substrate**	**SiC Substrate**	*LDMOS-like Cost Structure*

MACOM & ST
Investment in Industrialization

RF Power Amplifier TAM Expected to Exceed $3 Billion* by CY2022

Catania, Italy

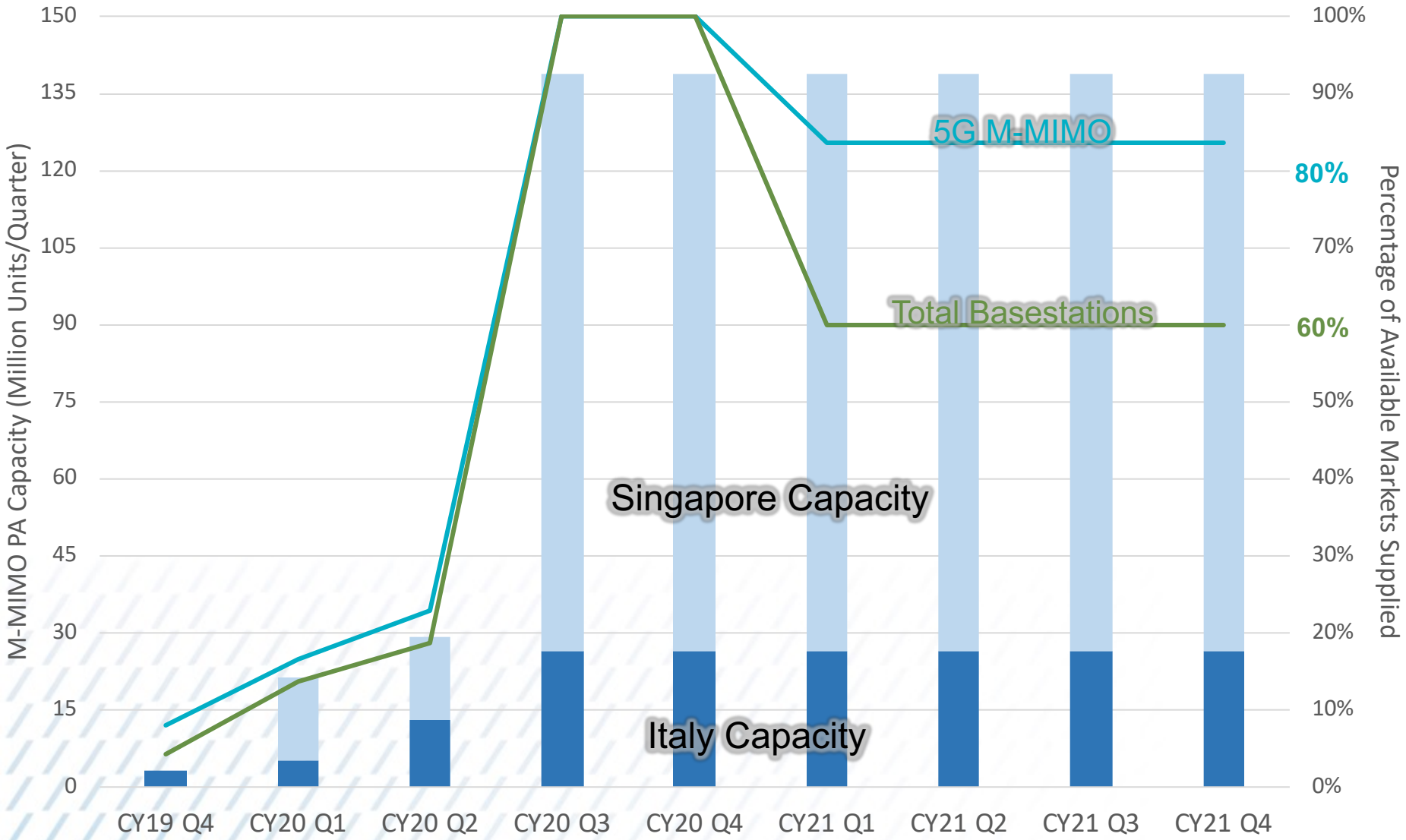
Singapore

- Dual, independent sources in Europe and Asia
- Copy exact, 6”/8” (150/200mm) capacity
- 0.5µm > 0.25µm > 0.15µm

**TAM based on Customers’ Forecasts and MACOM Internal Estimates*

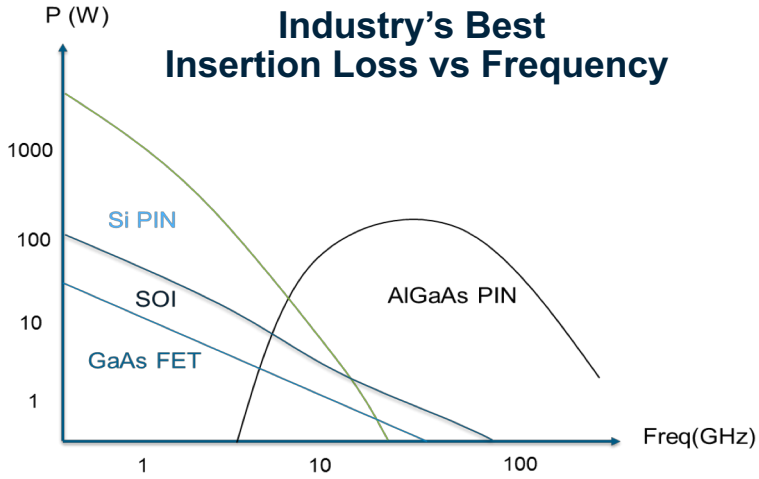
Basestation PAs

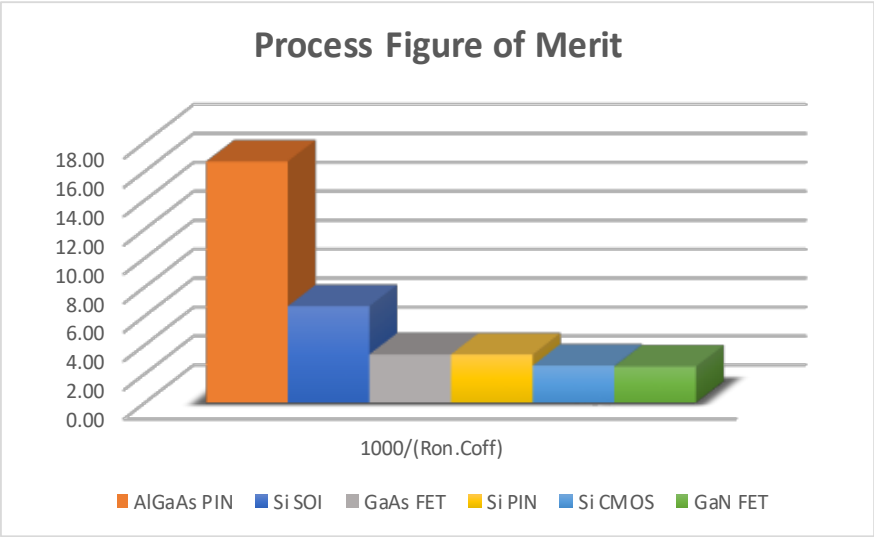
Estimated ST Enabled Capacity and Coverage of Available Market



The AlGaAs Advantage

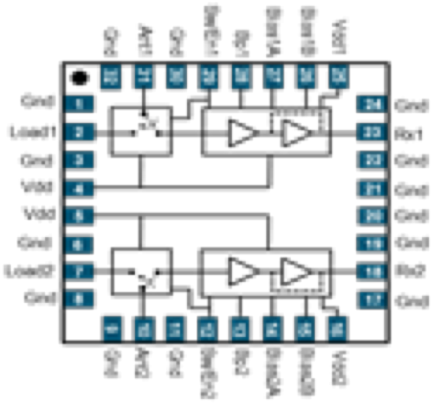
- Patented AlGaAs Discrete and MMIC Processes and Products
- Broad Portfolio of Millimeterwave PAs and LNA's to Offer Full System Solutions



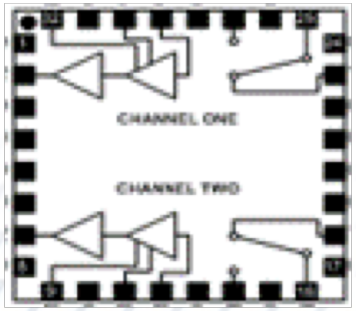


5G—HMIC

Heterolithic Microwave IC



Dual SW+LNA Module



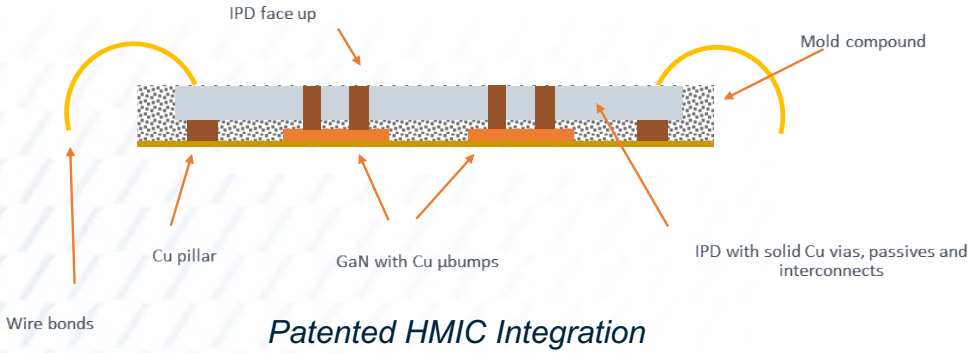
Dual SW+LNA with Bias and Matching

> Rx HMIC

- GaAs LNA
- AlGaAs T/R Switches
- SOI Switches and Control Components

> TRx HMIC

- GaN PA, GaAs LNA, Switch, PMIC, Coupler, Circulator

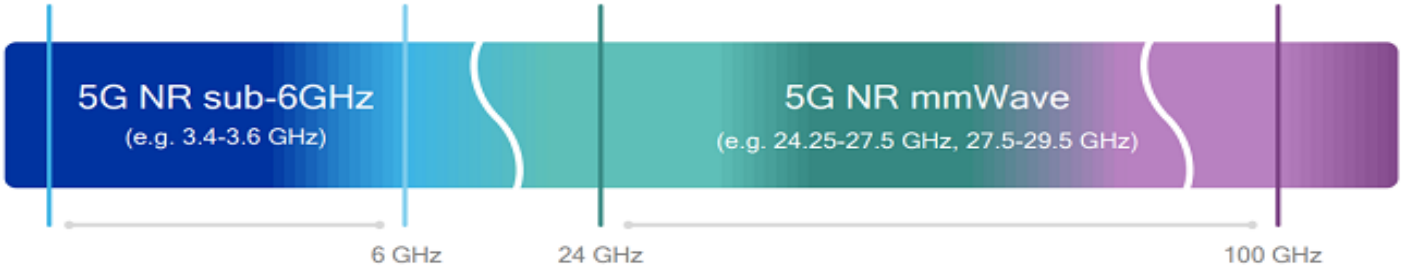


Patented HMIC Integration

5G Millimeterwave Growth Engine

5G Requirements for RF Components

To Support 5G Across All Frequencies and Power Levels and Geographies – Cost, Performance, Integration and Technology

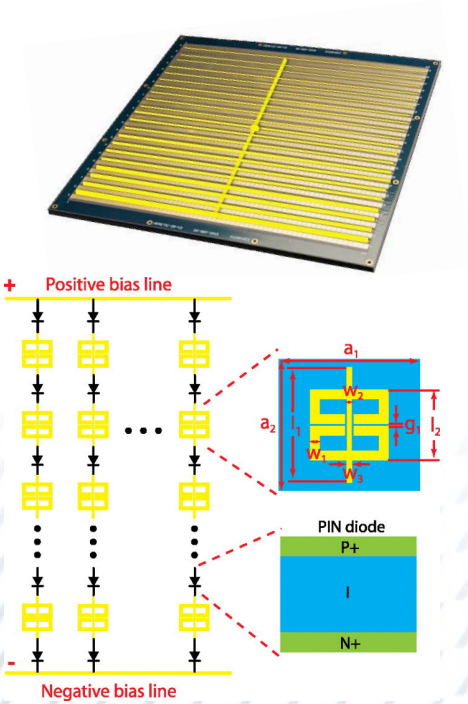


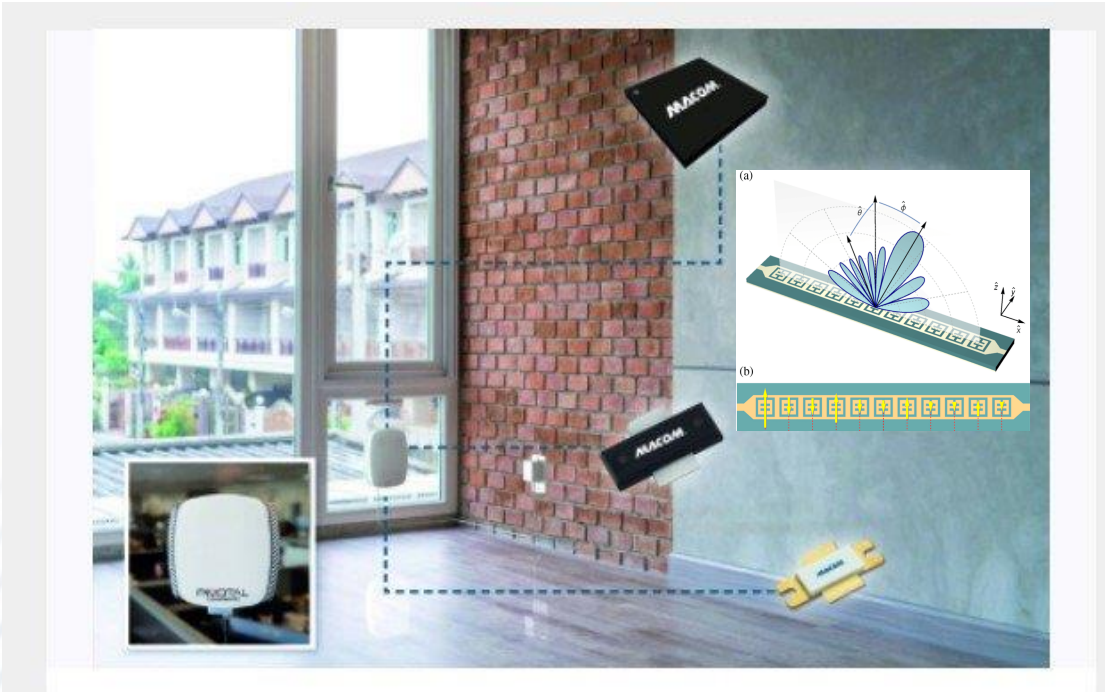
- **"Macro" Power Levels: 100's Watt**
  - Frequency 600 MHz → 5 GHz
  - Traditional "Basestation" model of discrete transistor based power
  - Additional Bands at 3.5 and 4.9 GHz → drives GaN solutions
- **Integrated Solutions – Power Levels <10 Watt**
  - Requires GaN MMIC products
  - Integration key for performance and cost

- **5G mmWave Challenges**
  - Multiple Approaches
  - Requires Beamforming
  - Common Issues: Cost, Component Size, Thermal Management, Architecture
  - Multiple Frequency Bands: 24 GHz → 39GHz → ??

Metamaterial Array Antennas

- Uses an Array of 600-1000 MACOM GaAs and AlGaAs Components
- *Holographic Beam Forming*® Antenna Topology
- Lowest C-SWaP Compared to Conventional Millimeterwave Beamforming





Echo 5G Network Infrastructure