WME-3

Advances in high performance cost effective MMIC and SMD from V to D-band

Göran Granström, Marcus Gavell, Iltcho Angelov, Herbert Zirath

Gotmic AB

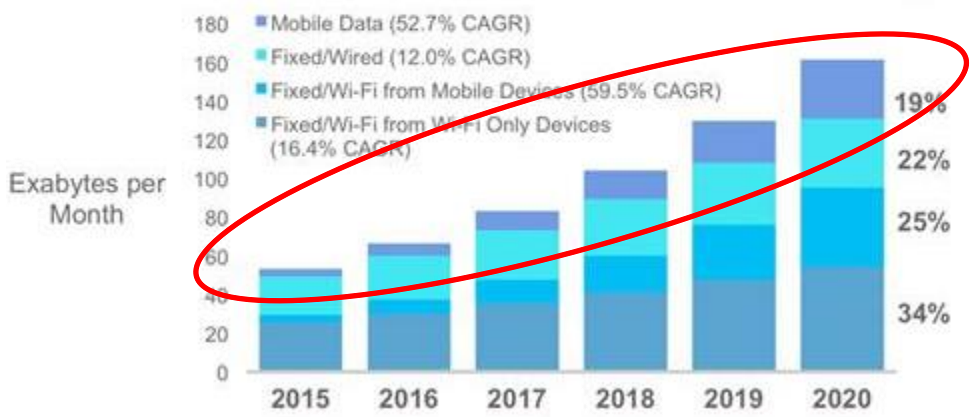
HAWAI'I 5G Catch the Wave!

Outline

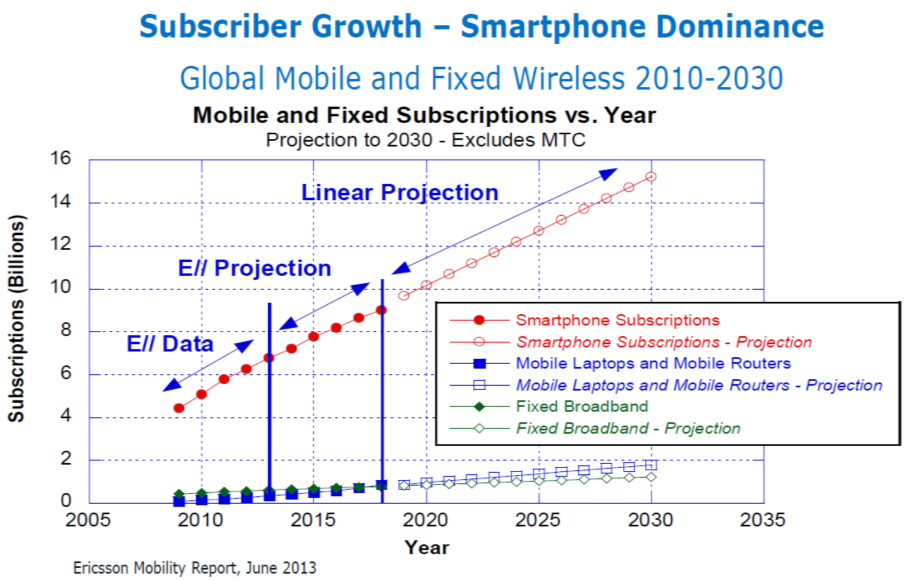
- Introduction to mmWave radios
- Gotmic product roadmap
- mmWave MMIC technologies
- D-band MMIC development
- Next generation front-end solutions
- mmWave packaging technologies
- Conclusions

Broadband telecom technologies

Mobile data increase



Source - CISCO



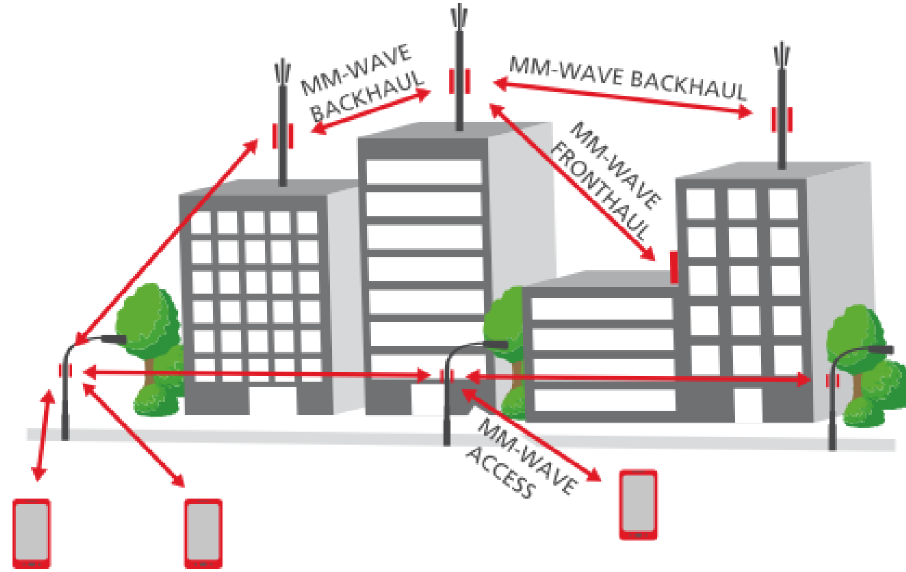
Source - Ericcson

The bandwidth requirements in the backbone is doubling every 12 – 18 months

mmWave in 5G

5G Backhaul

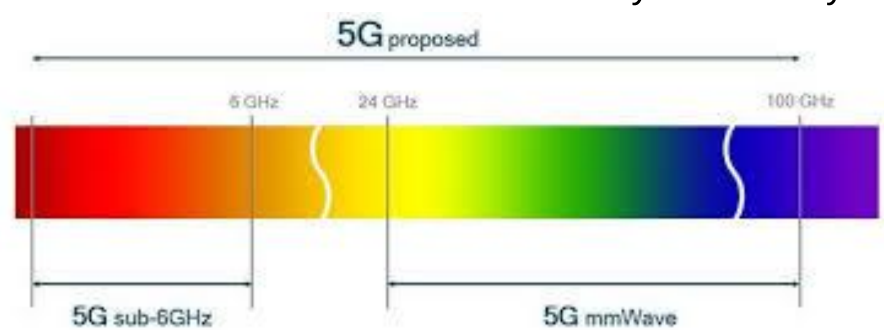
- Aggregated access points
- Multi-GHz bandwidths
- High spectral efficiency
- High frequencies 60+ GHz



Source – Heinrich Hertz Institute / Tokyo University

5G Access

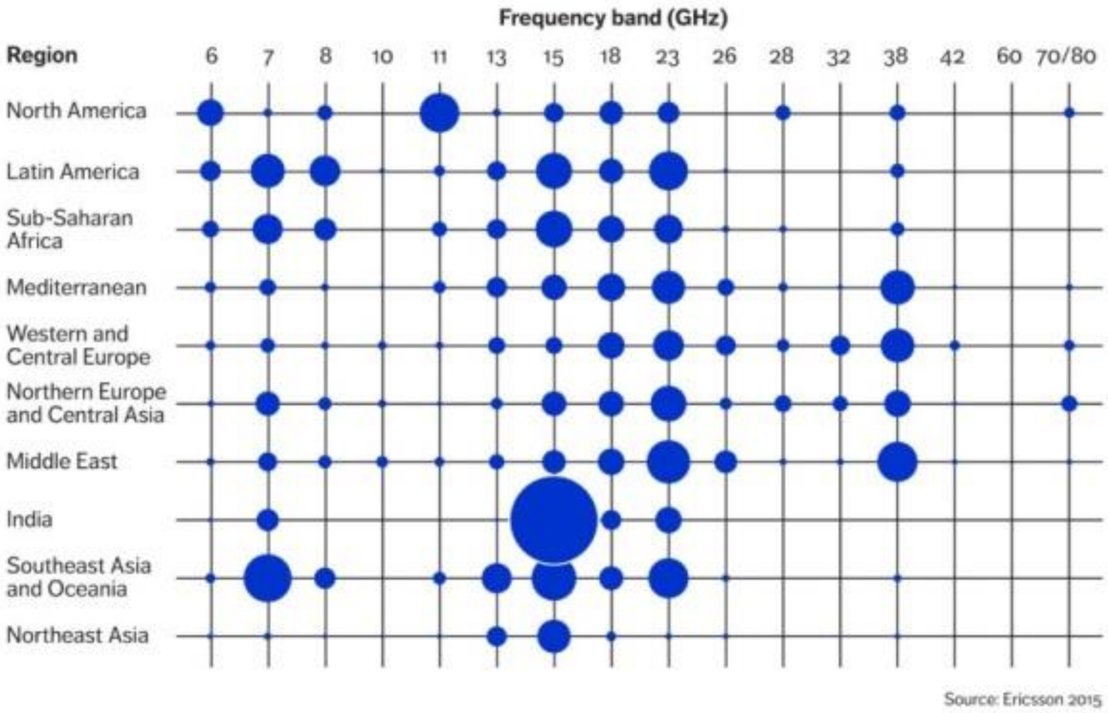
- Sub GHz bandwidths
- < ~30 GHz
- Entering traditionally microwave bands



Source – Qualcomm

P2P radio for wireless access

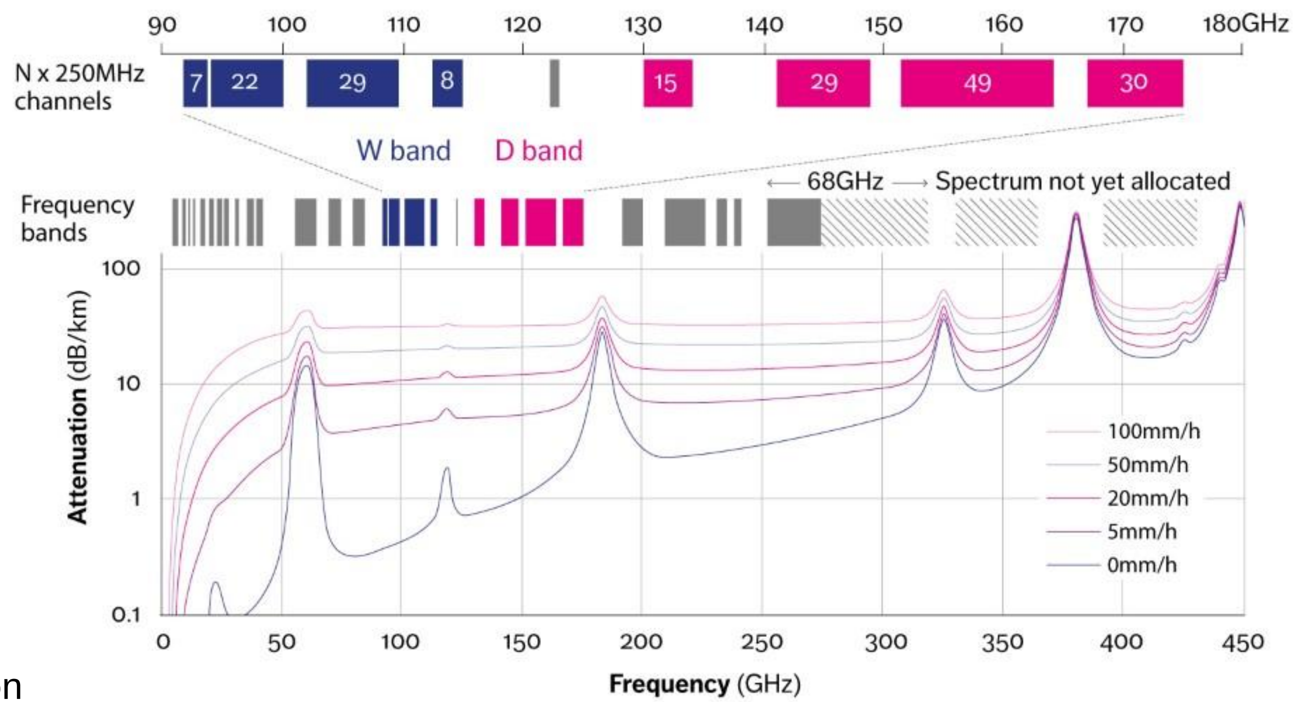
- The traditional microwave bands are very congested
- Limited available spectrum and channel bandwidth



Source – Ericsson

P2P radio for wireless access

- The demand for higher data rates requires more bandwidth
  - Existing 60 GHz, E-band
  - Planned spectrum available in W- and D-band



Source - Ericsson

Future of mmWave radios

Datarate
Hop-length

→

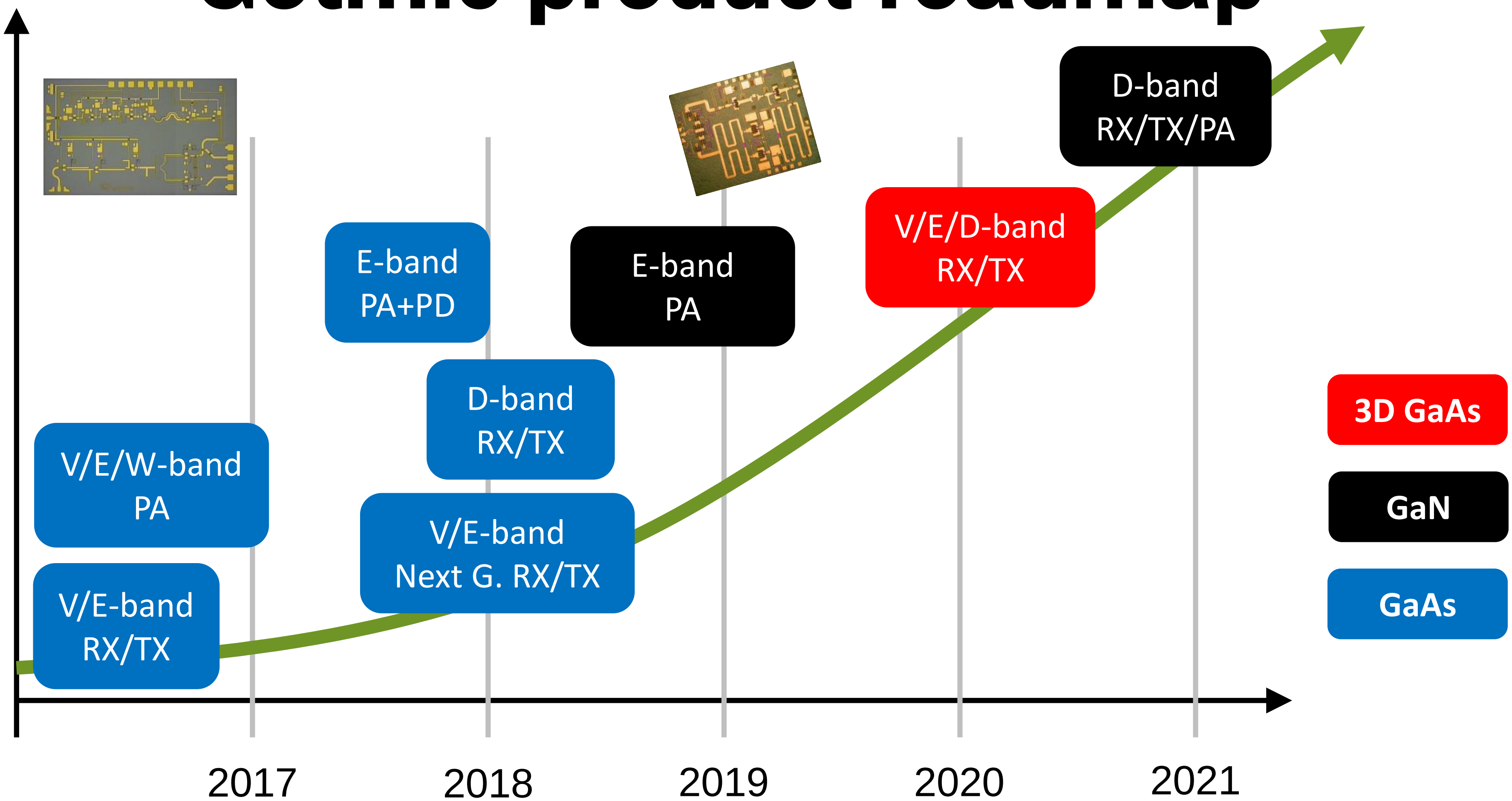
Output power
Bandwidth
Spectral efficiency

→

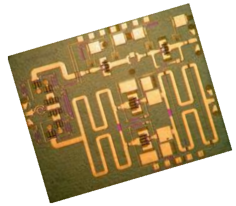
CI3, CI5
SNR

- ROI, bits per $
- Bandwidth, spectral efficiency and output power
- Front-end integration and linearization

Gotmic product roadmap

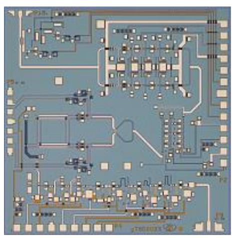


mmWave technologies

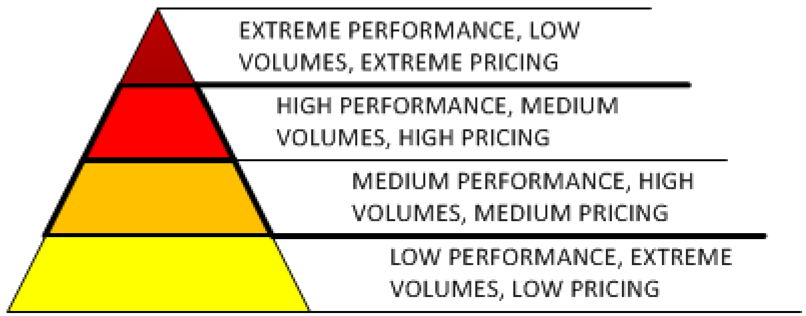


GaN, AlN

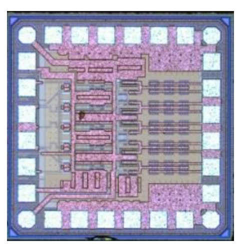
SOTA Military applications

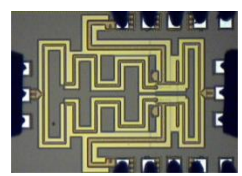


GaAs



Commercial medium-High Volume high Performance radios





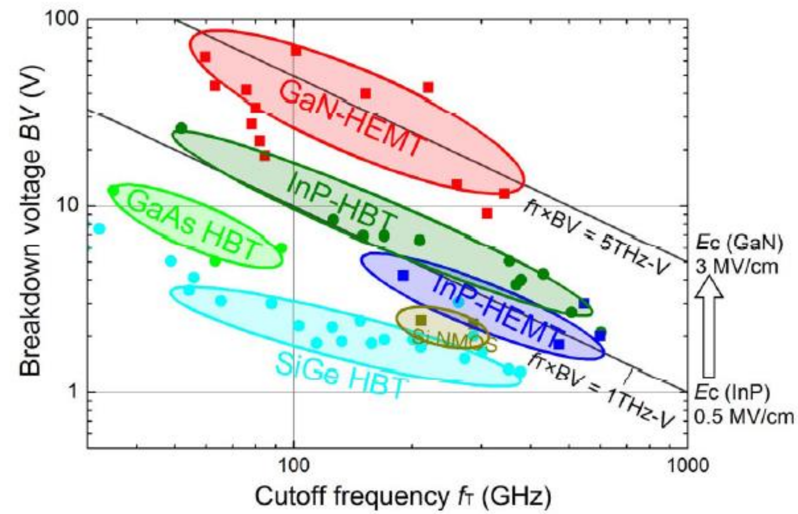
Commercial high Volume short range radios

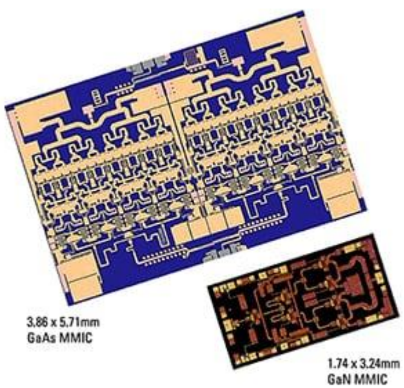
CMOS, SiGe

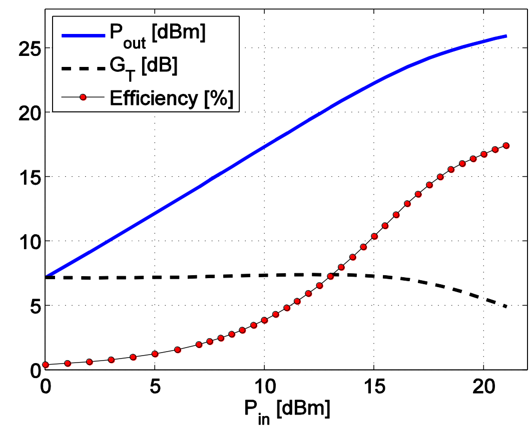
Source - Chalmers University of Technology

Wide bandgap technologies

- High power generation
- Linearity
- High frequency
- Reliability
- Low noise
- High temperature
- Size reduction





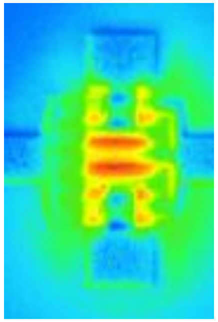


Source - Mouser, Chalmers

Emerging wide bandgap tech.

Property	GaAs	CMOS	SiGe HBT	GaN	AlN
Band gap (eV)	1.42	1.1	0.7-1.1	**3.39**	**6.28**
Electron mobility (cm^2/Vs)	8500	1400	1100	**900**	**1100**
Critical field (MV/cm)	0.4	0.3	0.05	**3.3**	**4**
Thermal cond (W/m·K)	55	130		**130**	**340**

High power density and Thermal conductivity



Available MMIC technologies

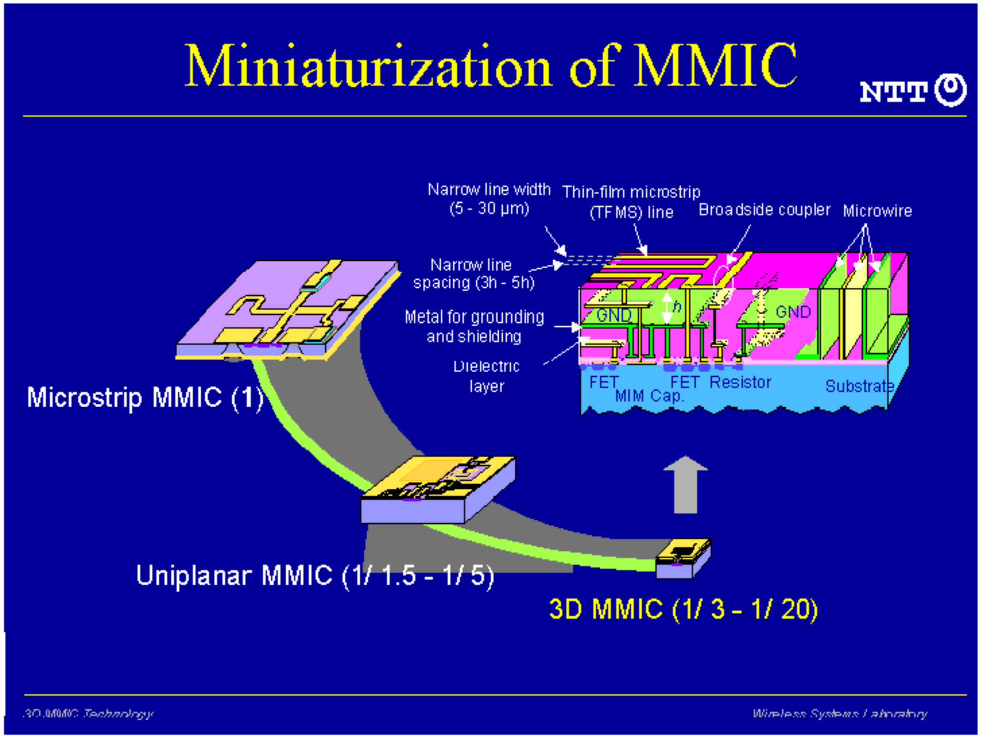
Technology	Feature size (nm)	fMAX (GHz)	Vbr (V)	NFmin (dB) at 50GHz**	Production or research?
GaAs pHEMT	100	185	7	0.5	P
GaAs mHEMT	70	450	3	0.5	R*
GaAs mHEMT	35	900	2	1	R
InP HEMT	130	380	1	<1	R
InP HEMT	30	1200	1	<1	R
GaN HEMT	60	250	20	1	R
GaN HEMT	40	400	42	1.2	R
SOI CMOS	45	280	1	2–3	P
SiGe-HBT	130	400	1.4	2	P
InP DHBT	250	650	4	3	R*
InP DHBT	130	1100	3		R

*Ready to be commercialized in 1–2 years
**NFmin is proportional to the frequency.

Courtesy: Ericsson Technology Review #2-2017
J. Edstam et. al.

MMIC miniturization

Size Reduction



Source -Tsueno Tokumitsu

Compact Integration

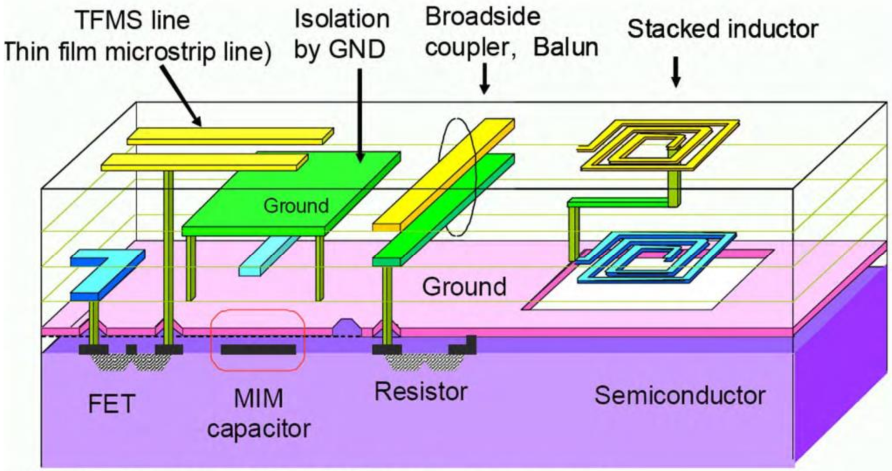
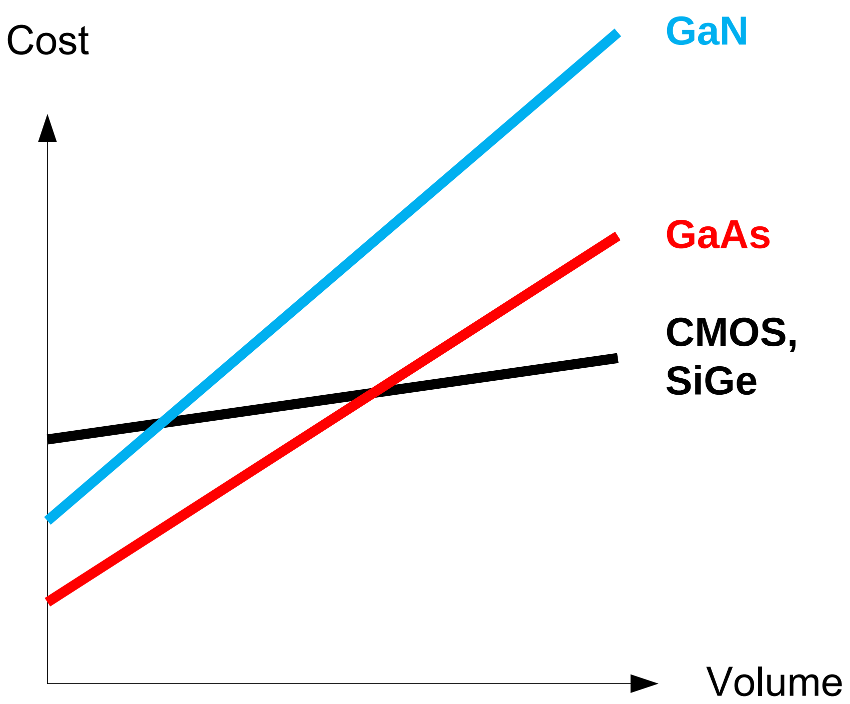


Fig. 1. Structure of 3D MMIC and passive circuits

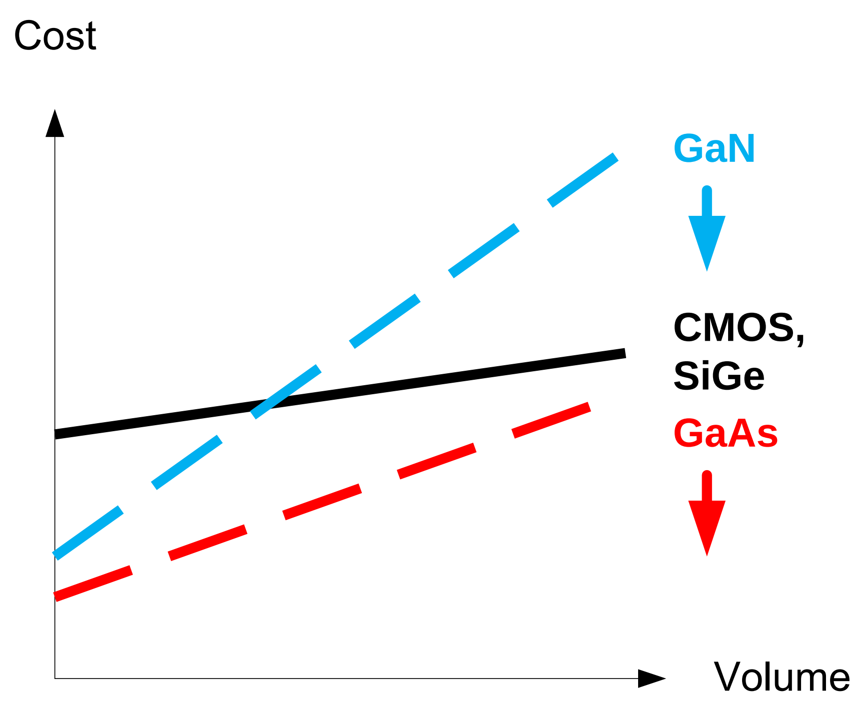
Common BEOL in CMOS
Showed in GaAs already in the 90's

Economies of scale

Present situation



Future situation



Future of high volume GaAs

Present GaAs

- GaAs is price attractive for medium volumes!
- Good high frequency performance NF/Power
- Reliability
- Product development time

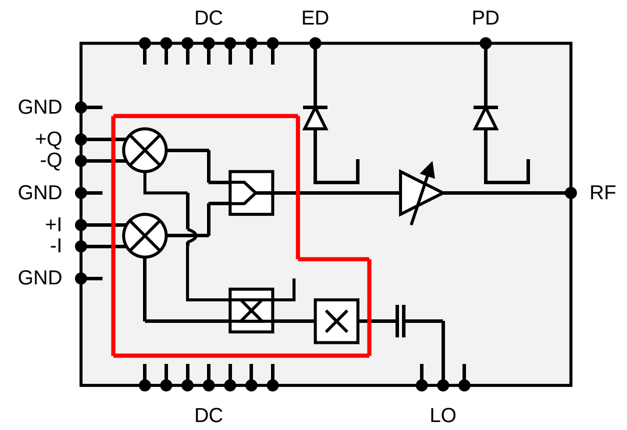
Emerging GaAs

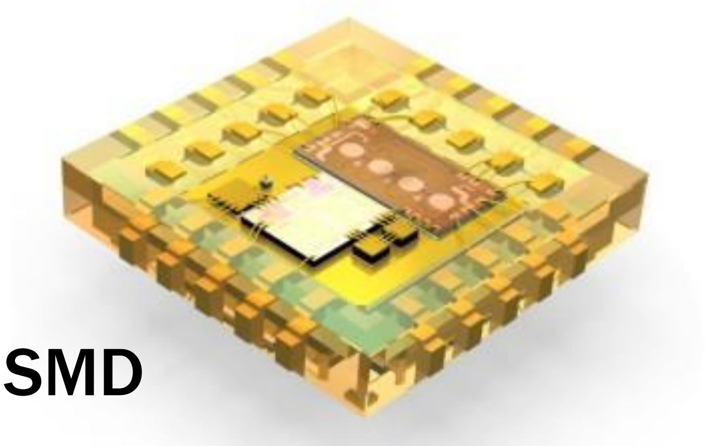
- Size reduction to 1/3
- Maintained performance
- Much reduced price in high volumes
- Competitive in high volumes

D-band development

- MMIC design
  - Frequency multiplier (GaAs)
    - X6, X12
  - IQ mixer (GaAs)
    - Fundamental, sub-harmonic
  - PA (Other technology)
  - LNA (Other technology)

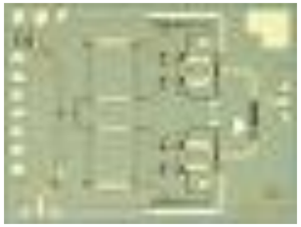
- Packaging
  - Multi chip module technology, SMD
  - Waveguide interface



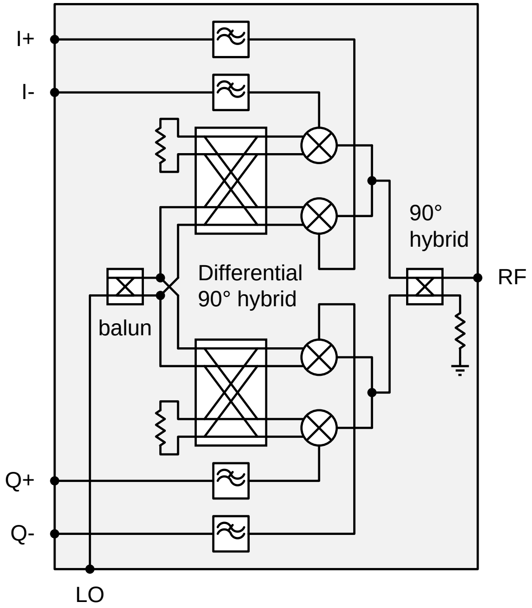


Source - Linewave

D-band subharmonic mixer

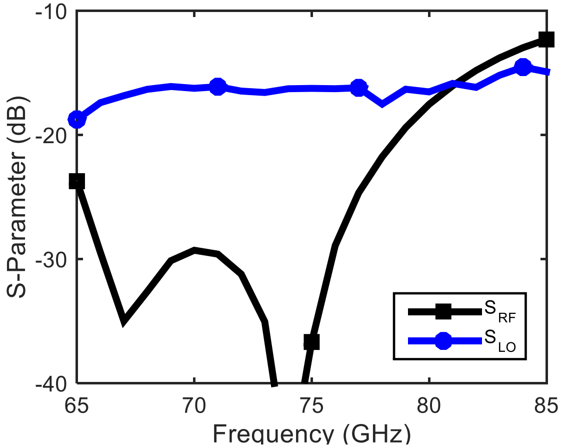


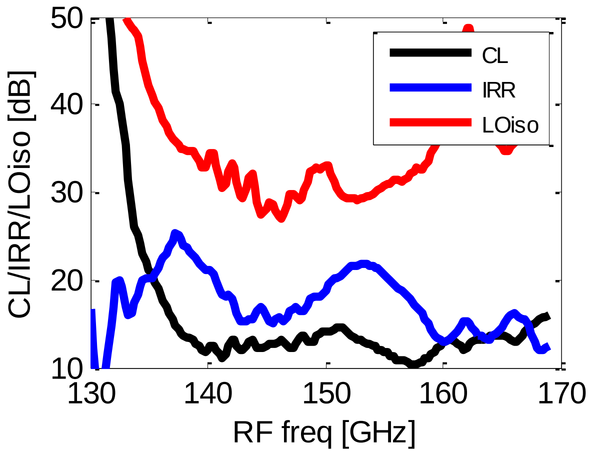
- Resistive mixer
- Compatible with existing E-band LO
- D-band coverage (140-170 GHz)
- Balanced topology
- Inherent LO isolation
- High linearity

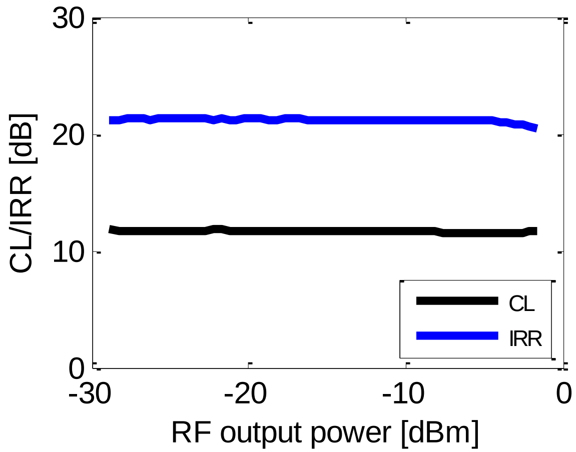


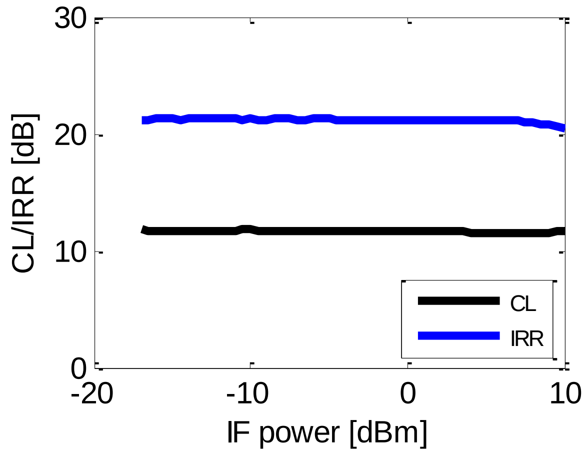
D-band sub-mixer measurements

- High linearity
- Flat frequency response
- High return loss
- High 2xLO isolation (DC offset applicable)







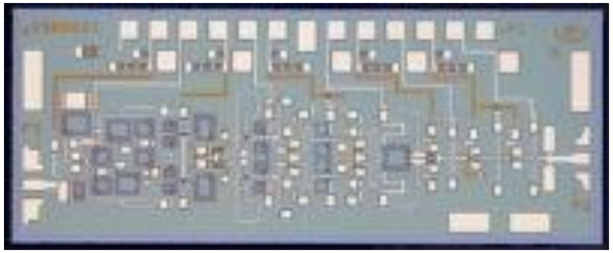


E-band X6 frequency multiplier

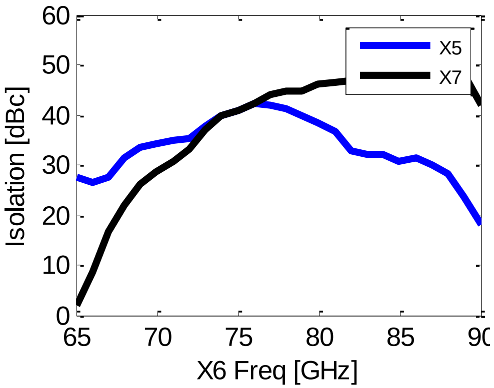
Circuit Summary

- Chip size 3 x 1.2 mm
- Superior harmonic isolation, >30 dBc
- 14 dBm output power
- High efficiency, 500 mW PDC typical
- Compact and efficient differential X3 and balanced X2 multiplier

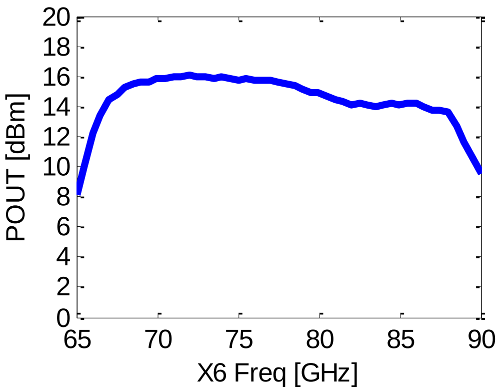
Layout



3x1.2 mm²

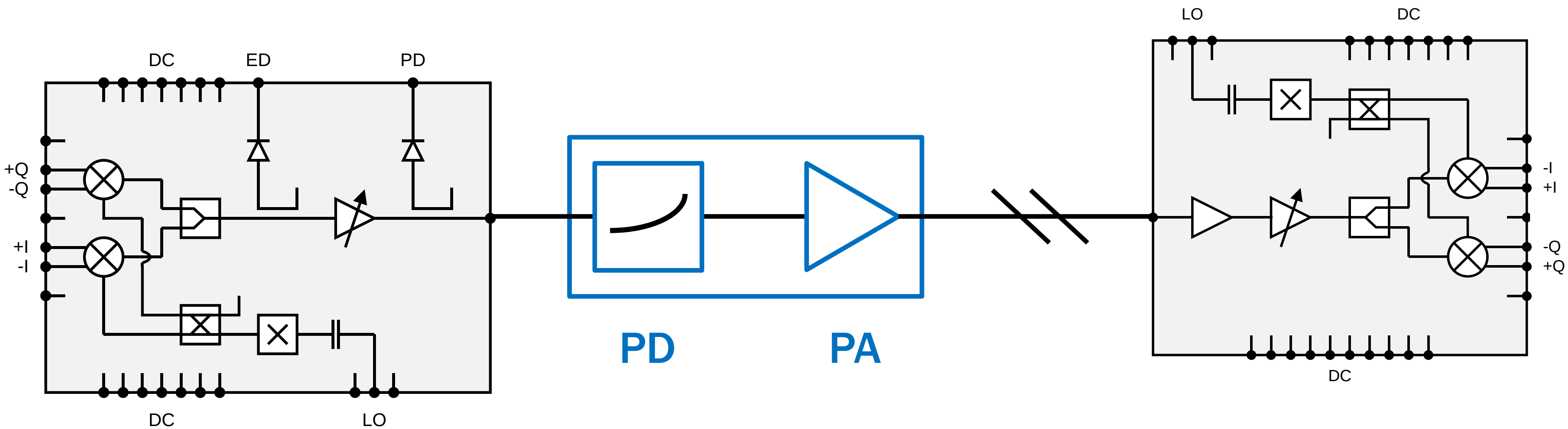


Harmonic isolation



Output power

Next generation front-end



Features

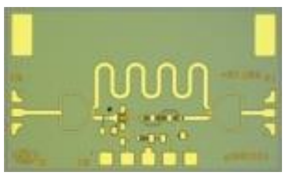
- High output power
- High spectral efficiency
- Gain control
- Cost effective

Design

- Highly integrated
- Analog predistortion
- Packaged solution

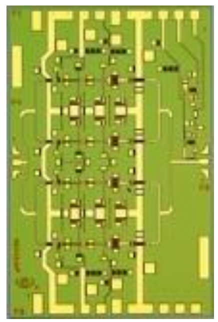
Linearization of PA

APD

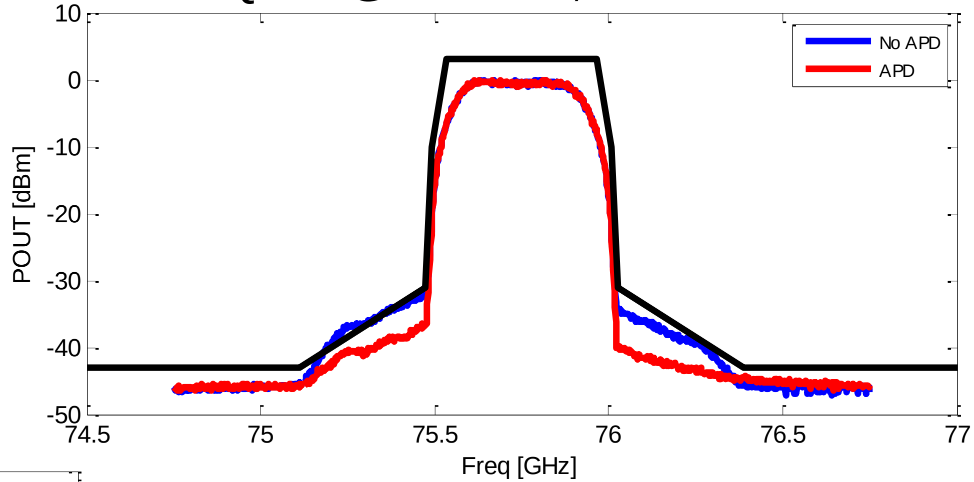


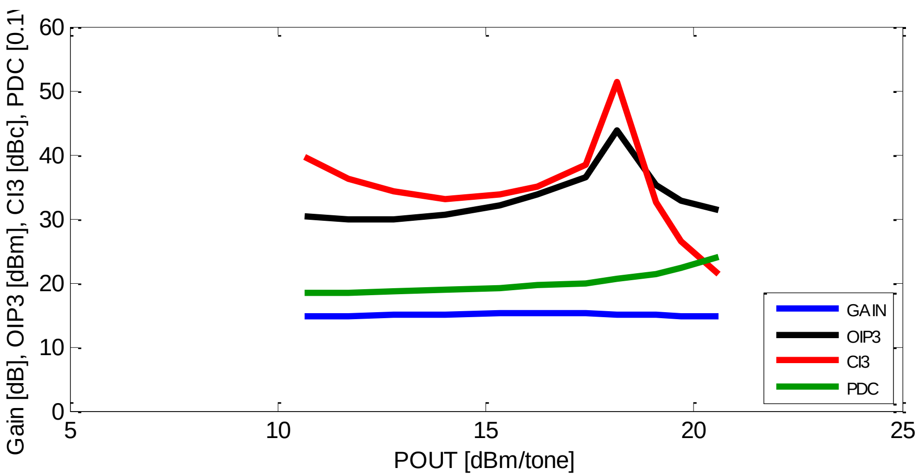
\+

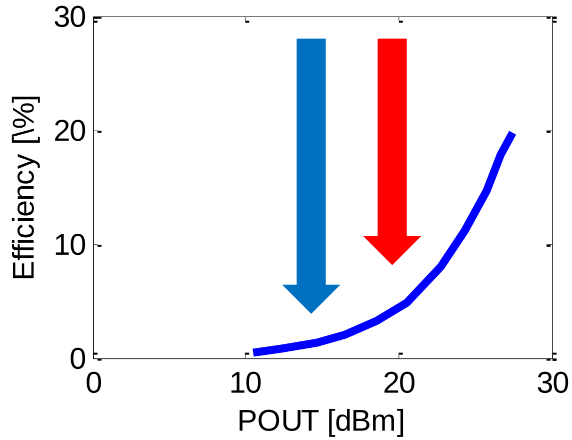
PA



64 QAM @ 76 GHz, 17 dBm RMS

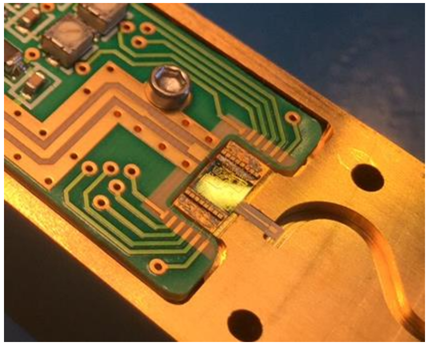






mmWave packaging

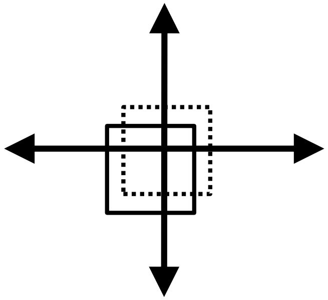
	Bare die	Packaged die
Yield		✓
Handling, assembly		✓
Production flow, RnD		✓
Standard footprint		✓
Performance	✓	✓
Cost	✓	✓


Example of bare die assembly


Package assembly

Technical challenges

- Low cost solution
  - Max 1.5X bare die cost
- Production friendly testing
  - Custom made test-jigs needed

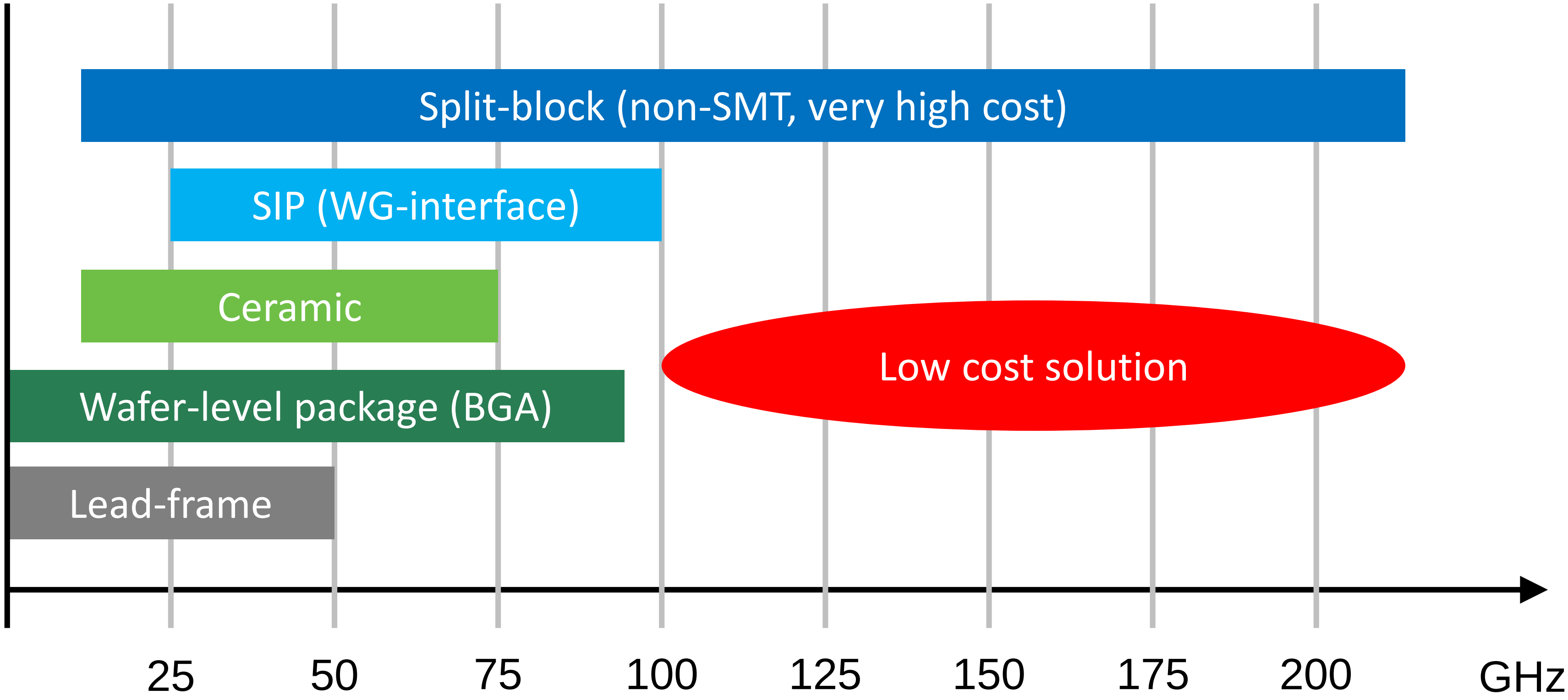


- SMT compatible
  - Pick & place and PCB technology tolerance
- Minimize sensitivity to assembly handling
  - Alignment and soldering tolerance

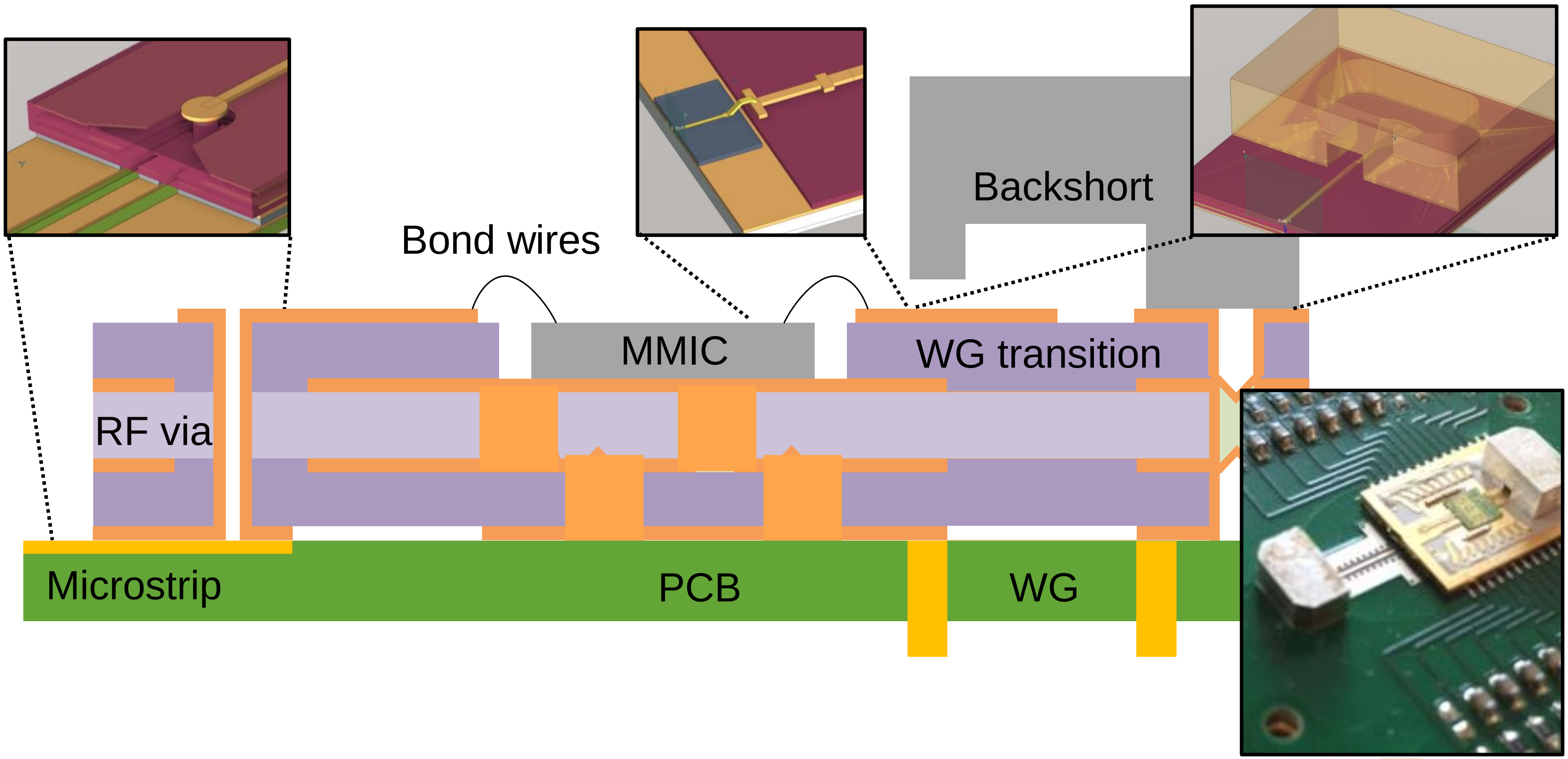
Technical challenges

- Degradation of bare die performance
- Input/output return loss
  - Interacts with external load, standing waves
  - Gain ripple and sub-optimal loading
- Low loss materials
  - Resistive (main loss) and dielectric loss
- Good heat sinking
  - Thermal conductivity

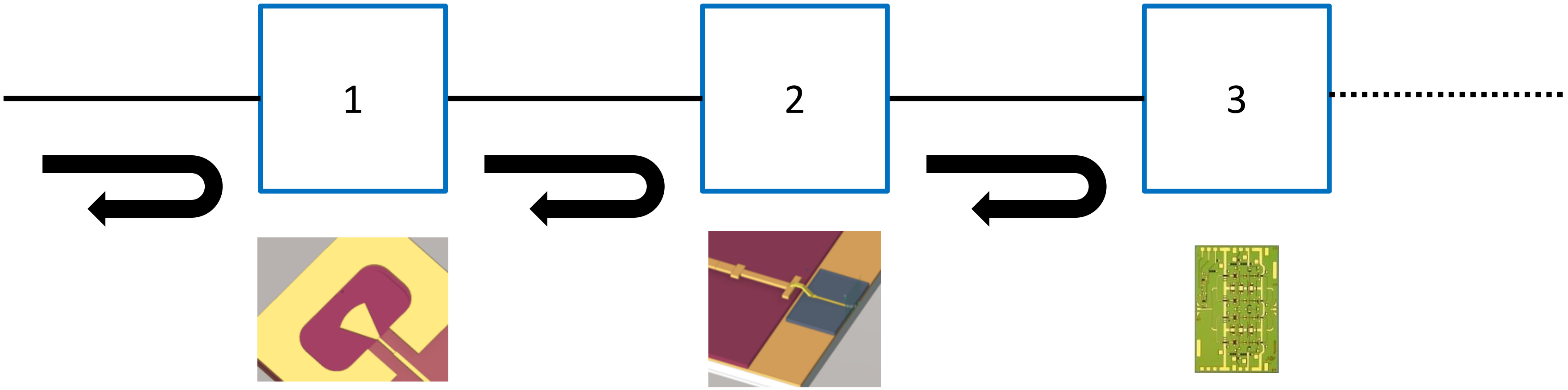
Packaging technologies



mmWave package example

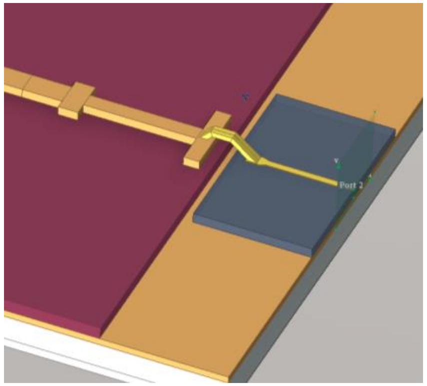


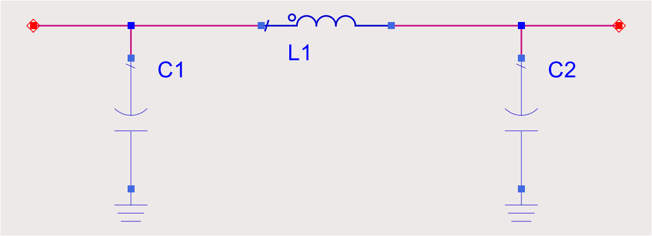
Interface return loss

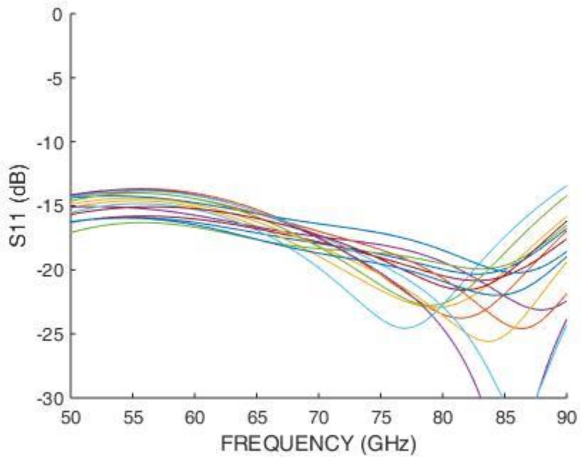


- Cascaded reflections adds up
- Maintain return loss at every sub-interface >15-20 dB
- Total return loss >10-15 dB

RF interface limitations

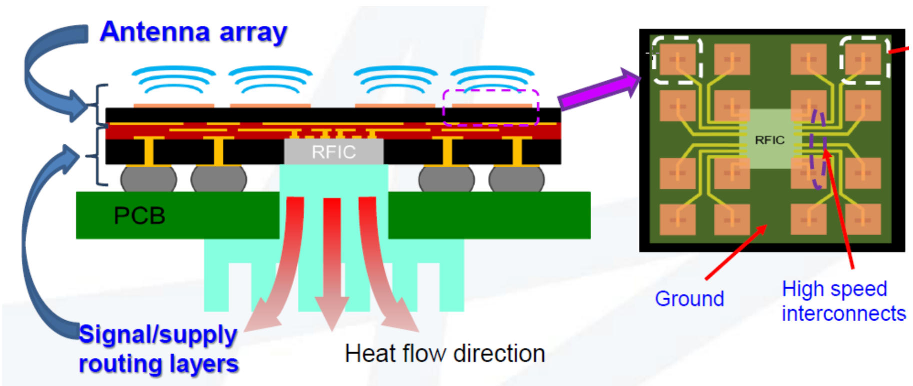




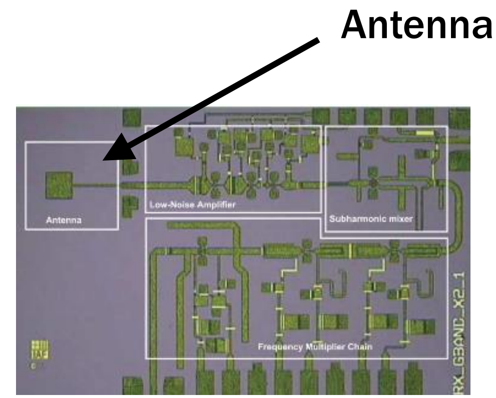


- Compensate for bondwire inductance
  - C-L-C low-pass network
  - Performs well up to ~100 GHz
- Sensitive to bondwire length and substrate tolerance

100+ GHz RF interface



Source – IME Industry Forum



Source – Chalmers Univ .Tech.

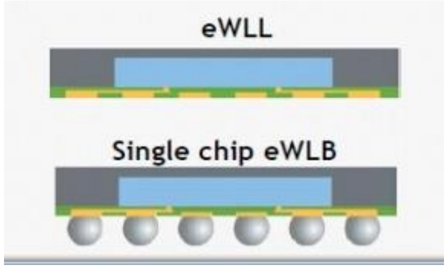
- Probe or antenna element on chip
- Couple to waveguide, lens or free-space
- Transition becomes part of an integrated MMIC
- Handling simplified with package solution

Package cost challenges

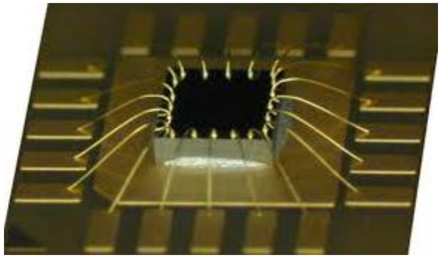
Typical chip and wire package cost distribution

Cost	Unit (%)	Comments
Materials	50	Substrate, lid, caps etc
Handling costs	10	Storage of materials, shipping
Assembly	30	Chip n wire, tape & reel
Test & Verification	10	Compliance test

- Reduce assembly cost (WLP)
- Increase integration on chip (avoid expensive RF substrates)



Source – Nanium



Source – T. Lizak

Conclusions

- 5G is a driving factor for high data throughput of mmWave backhaul and wireless access
- Future mmWave radios will require more bandwidth and high spectral efficiency
- High integration is necessary for reducing cost and increasing yield
- Analog predistortion is a suitable wideband technique to increase efficiency and output power
- A packaged solution at 100+ GHz is required due to chip and wire limitations and end-user complexity