A 27.5dBm EIRP D-Band Transmitter Module on a Ceramic Interposer

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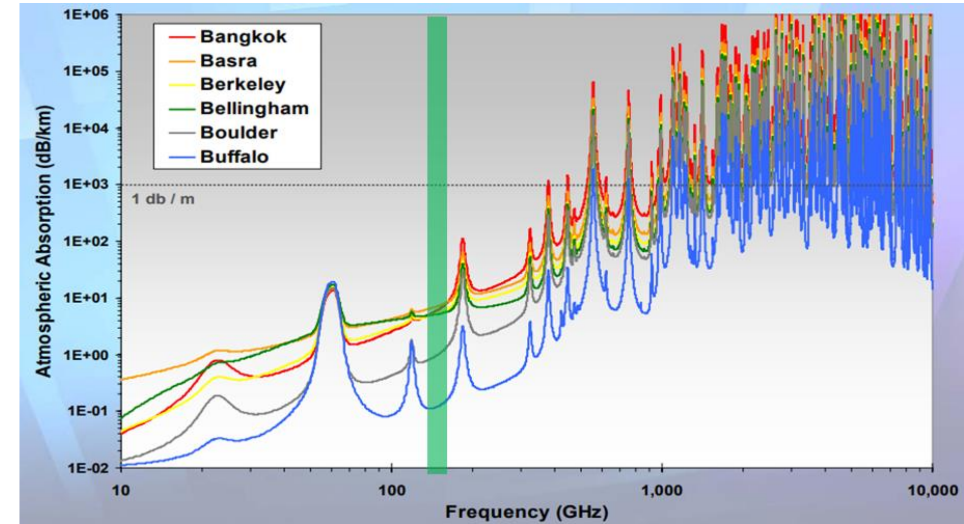
Outline

- Motivation
- Module design and stack build up
- CMOS/PA transition design
- PA/Antenna Co-design
- Integrated Transmitter module
- Module Link measurement
- Conclusion

Opportunities and challenges at mmwave

- Large available spectrum (√)
- High-capacity wireless communication systems (√)

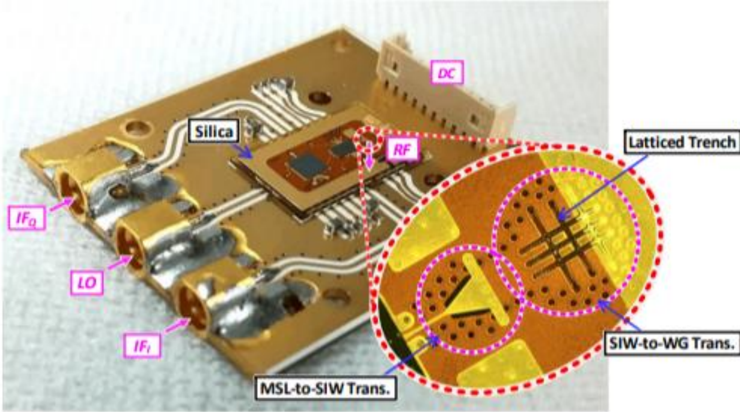


[M.Rosker, IMS2007]

Challenges:

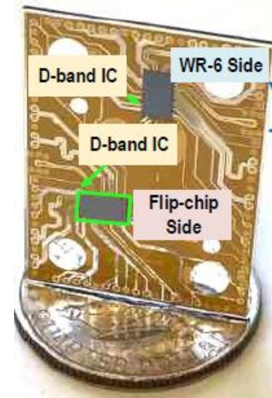
- High atmospheric attenuation and $\frac{\lambda^2}{R^2}$ losses (!)
- Moderate to high transmitter's EIRP
- Low-cost high-performance packaging technologies

Packaged D-band transmitter modules



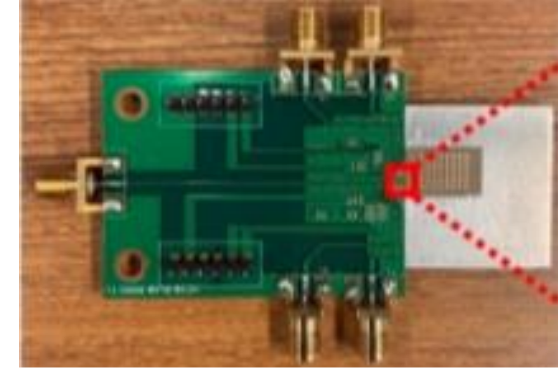
[Ito et. al]

- 70nm GaAs HEMT
- Silica based package
- $P_{sat} = 8dBm$
- Transition loss=3.5dB



[Singh et. al]

- 0.13µm SiGe BiCMOS
- Radio on Glass
- $P_{sat} = 13dBm$
- Transition loss=1dB

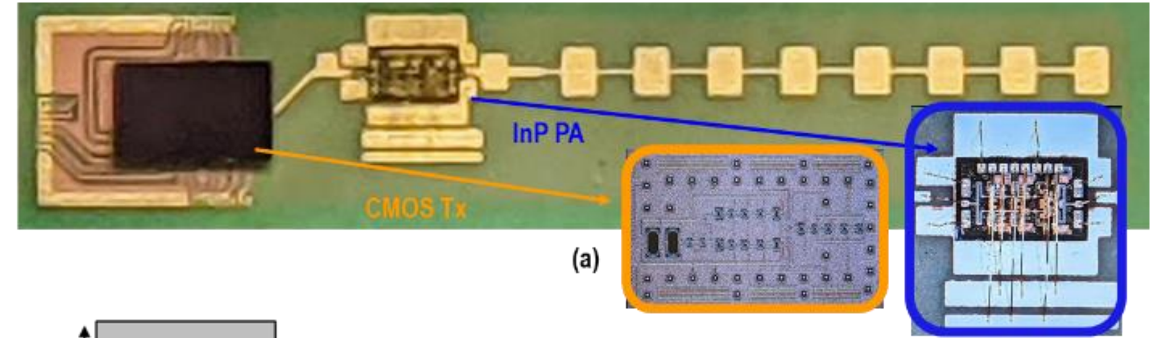


[Simsek et. al.]

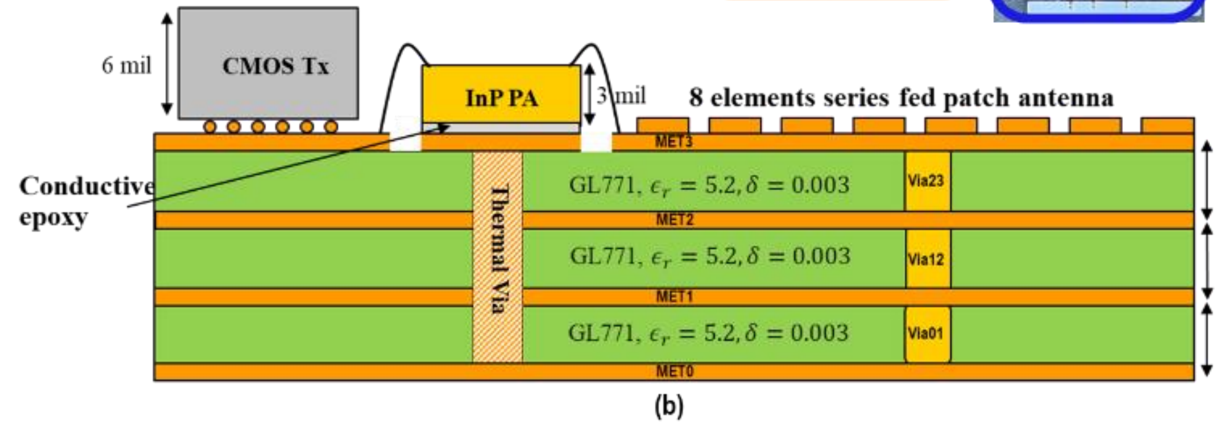
- 45nm CMOS SOI
- Radio on Isola Astra Laminate
- $P_{sat} = 2dBm$
- Transition loss=1dB

Transmitter module on LTCC carrier

- Direct conversion Tx design using GF 22FDSOI
- High power PA designed in Teledyne 250nm InP HBT
- 3 Layer Low temperature co-fired ceramic carrier (Kyocera GL771)



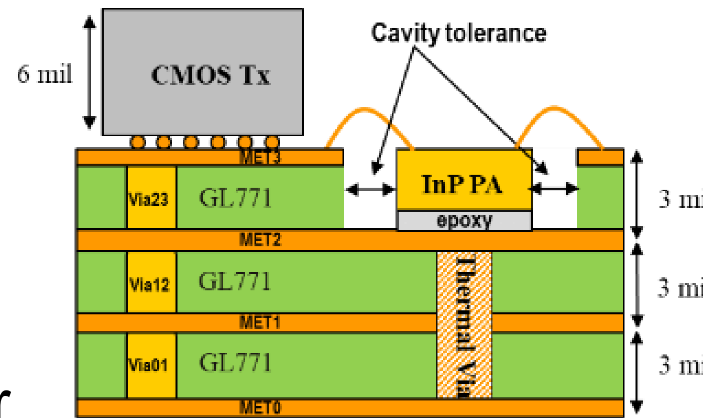
(a)



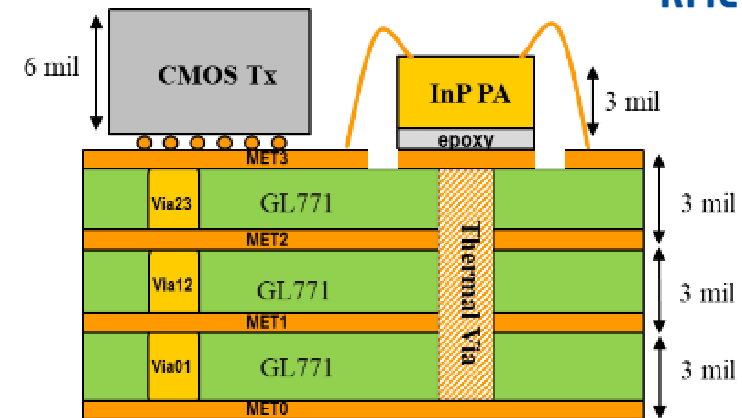
(b)

Transmitter module assembly challenge

- CMOS TX is flipchip bonded to carrier using 50µm diameter copper pillars



(A)



(B)

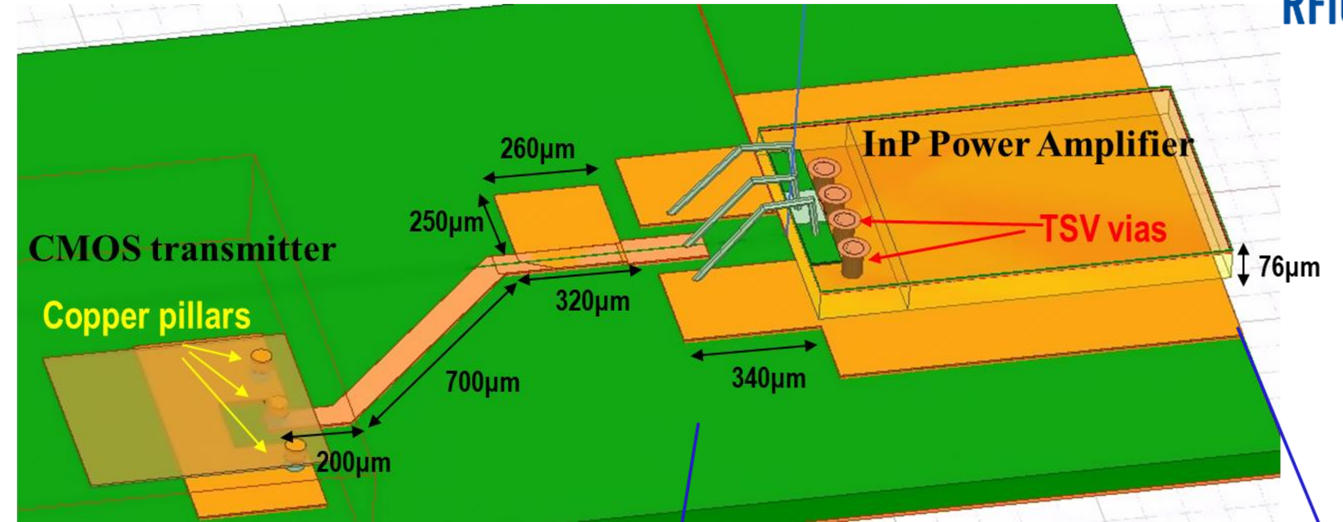
- InP PA is attached to interposer using conductive epoxy

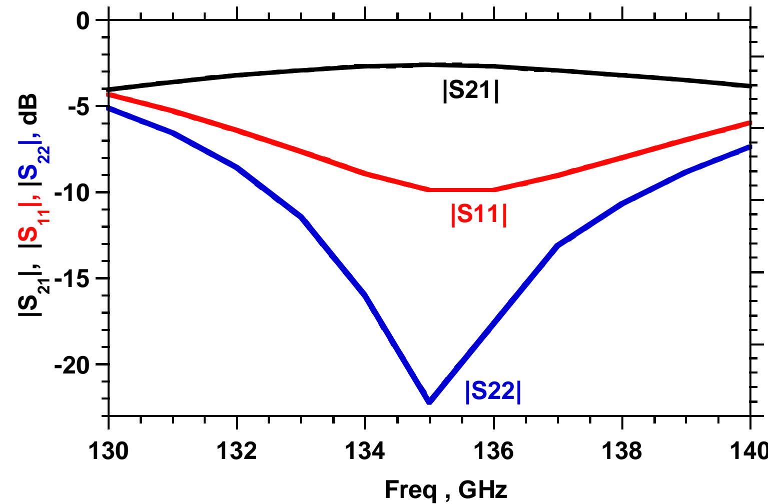
- Copper filled vias below InP PA to get the heat out of the chip (thermal vias)

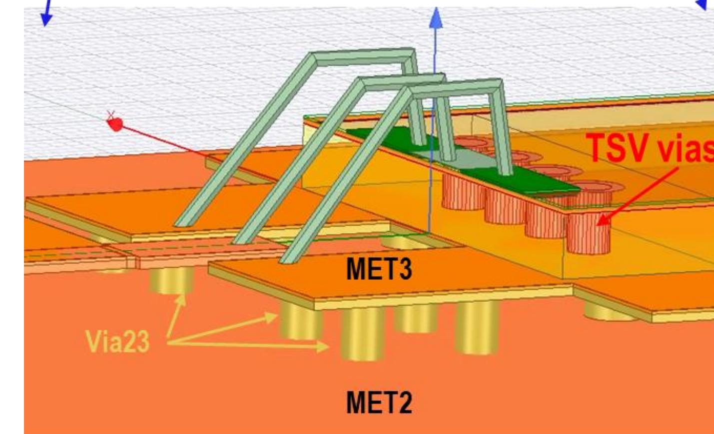
- To minimize wirebond length
  - A. PA in cavity (lateral tolerance =+/-6mil)
  - B. Surface mounting (√)

CMOS/InP PA transition design

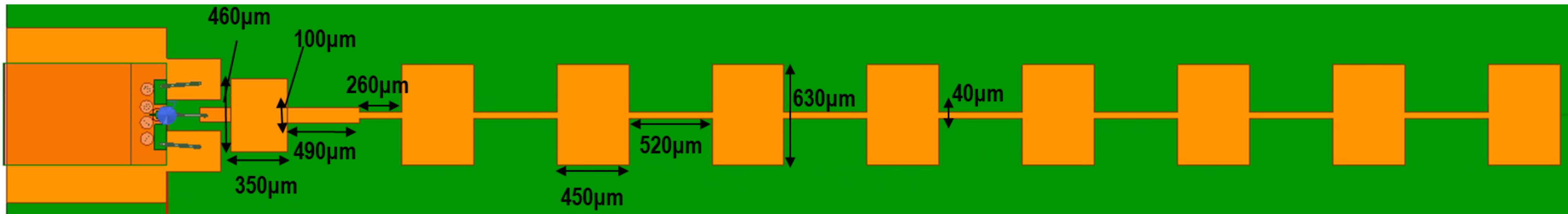
- Au wirebonds with 150μm length and 1-mil diameter at the I/O of the InP PA
- InP PA ground return current through TSV
- PA matching network has 2.6dB simulated insertion loss



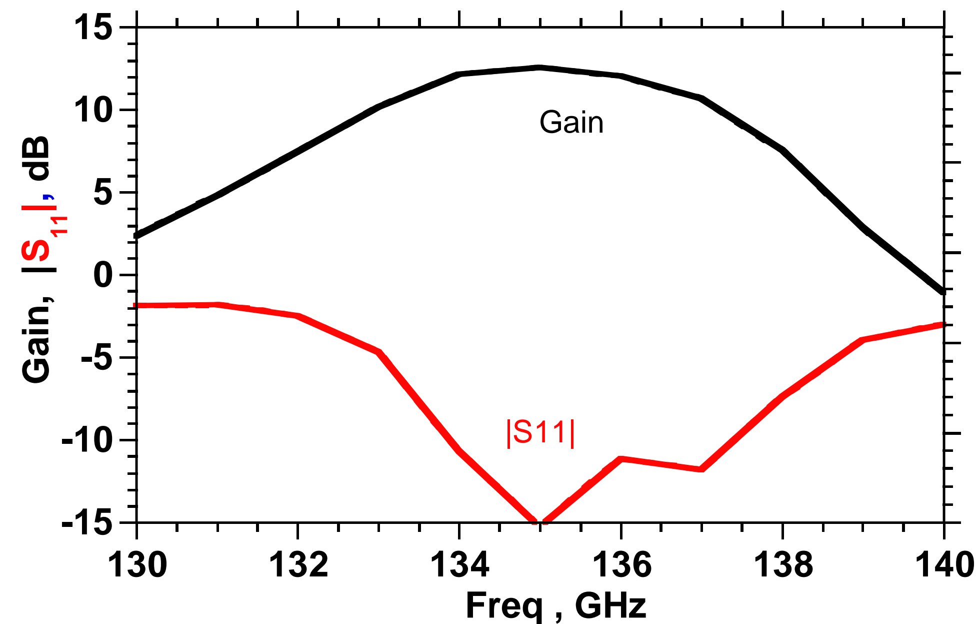




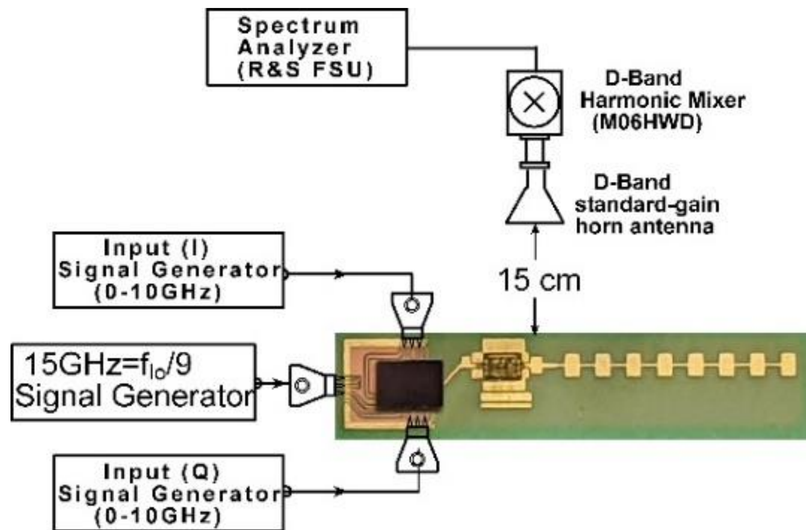
InP PA/antenna transition design

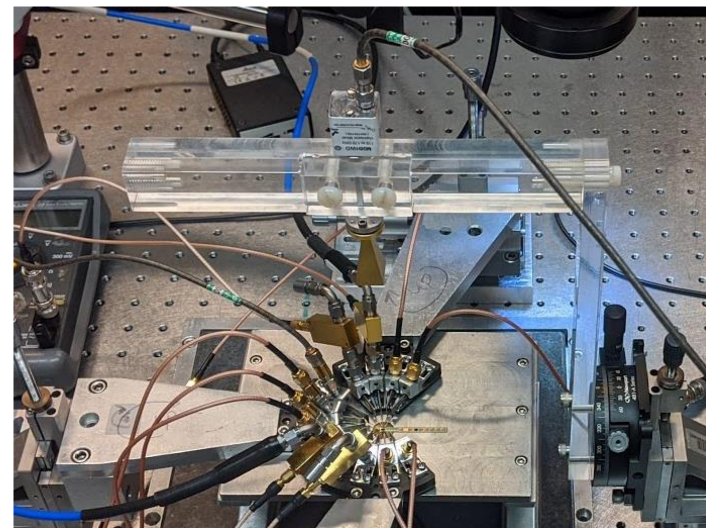


- 8-elements series fed-patch antenna
- Antenna input impedance matched to PA output 50Ω impedance using stepped impedance transmission line
- 12dB simulated antenna gin, 6GHz 3-dB bandwidth

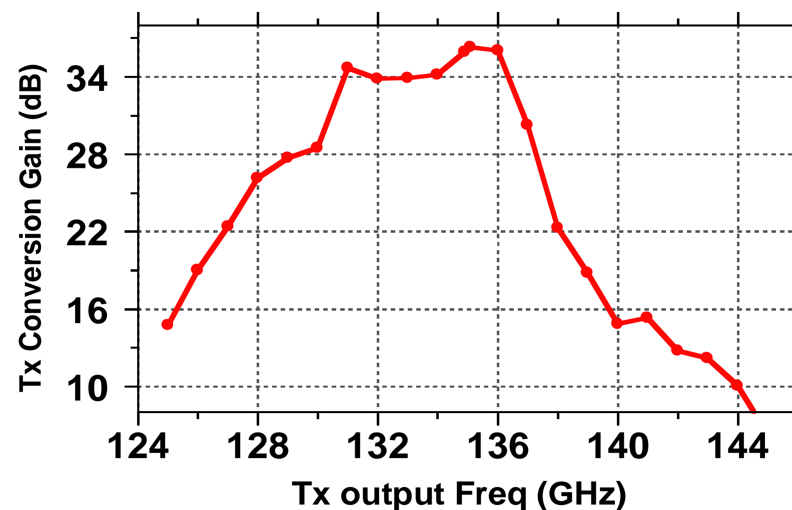


Integrated transmitter module

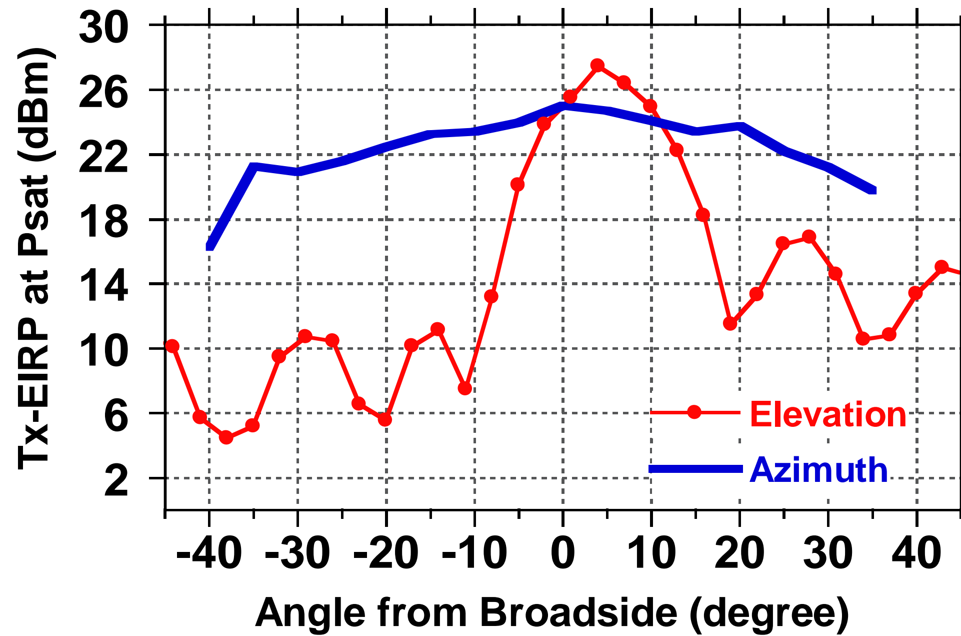


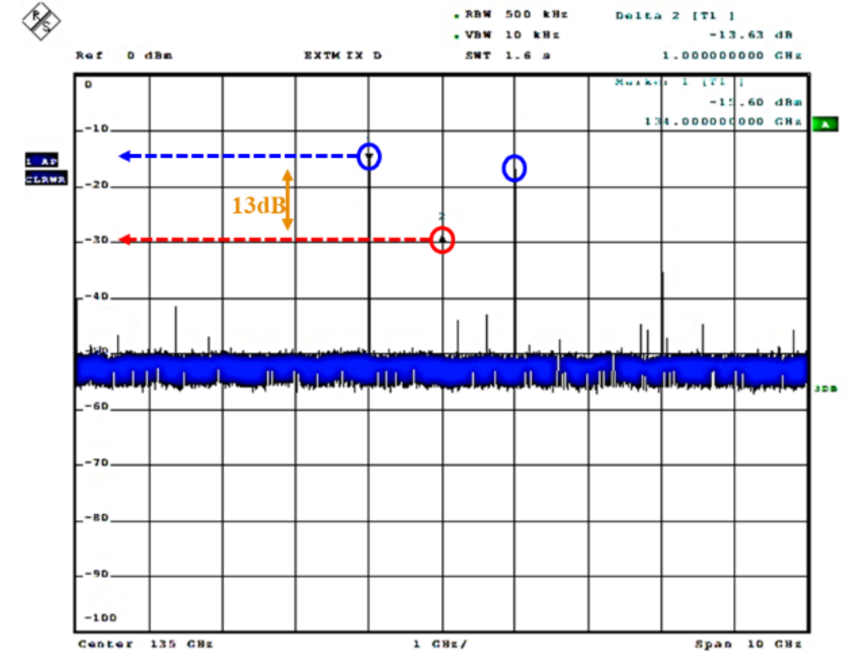


- 6-GHz 3-dB modulation BW (antenna)
- 35~36dB measured conversion gain (USB)
  17dB power gain from CMOS TX
  InP PA measured gain=19dB
  Measured antenna gain=11dB
  Wirebond transition loss=5dB (I/O transitions)



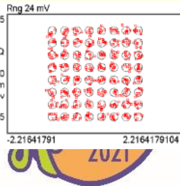
Integrated transmitter module



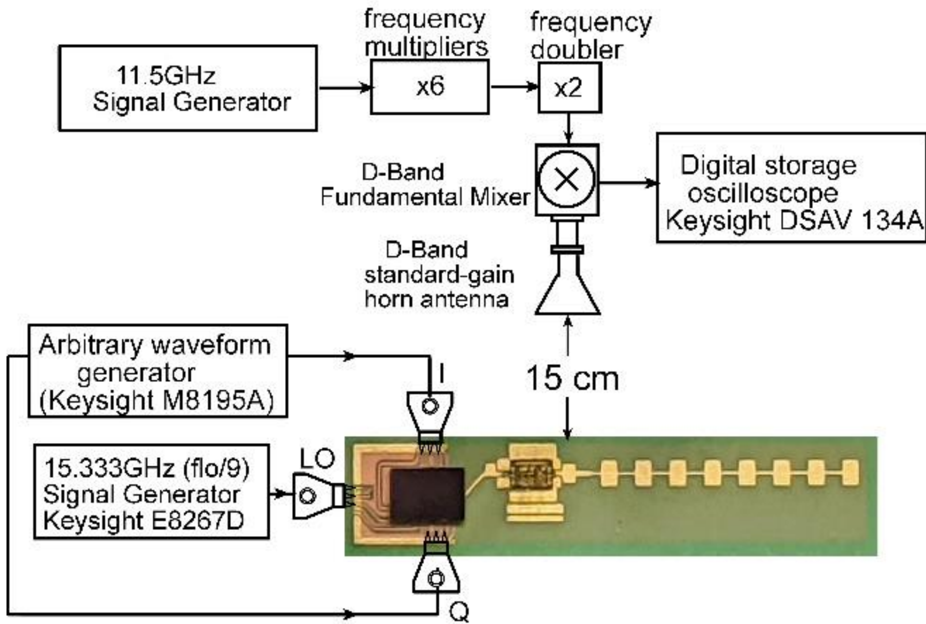


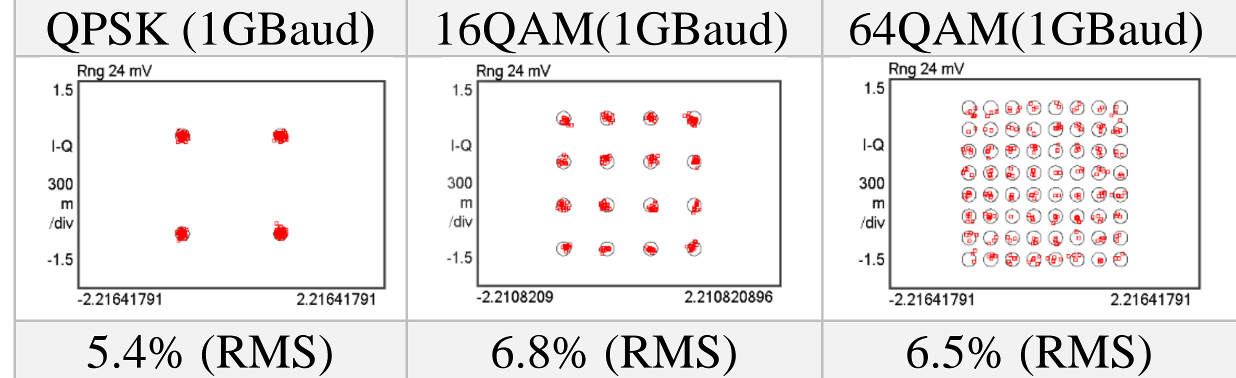
- Measured transmitter $EIRP_{psat}$=27.5dBm
- 3-dB beamwidth=14^0 in elevation

- LO suppressed by 13dB relative to USB and LSB

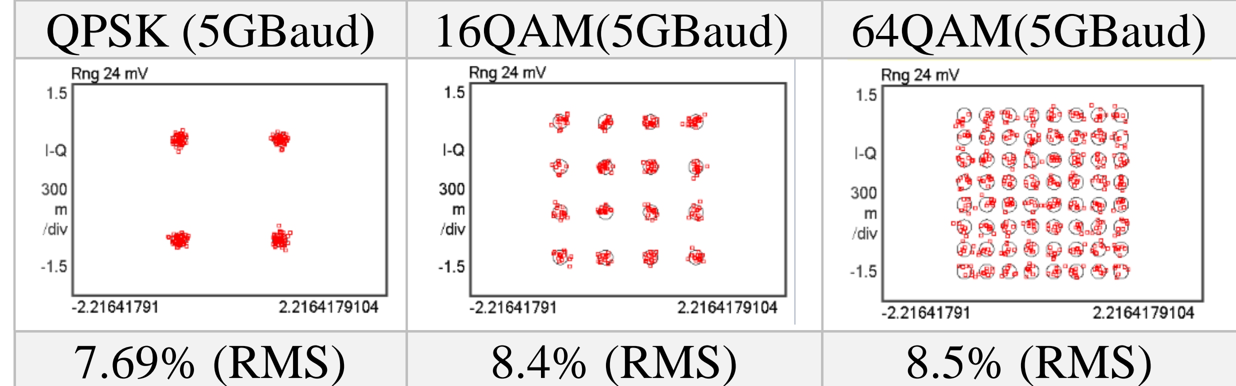


Transmitter module modulation performance





EIRP=24dBm/ 3dB Back off from P_{sat}		
QPSK (1GBaud)	16QAM(1GBaud)	64QAM(1GBaud)
5.4% (RMS)	6.8% (RMS)	6.5% (RMS)

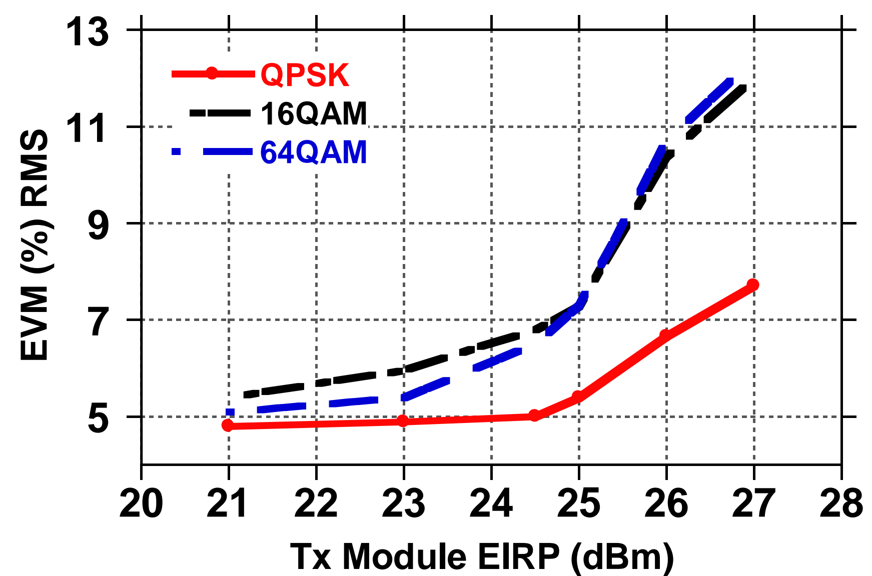


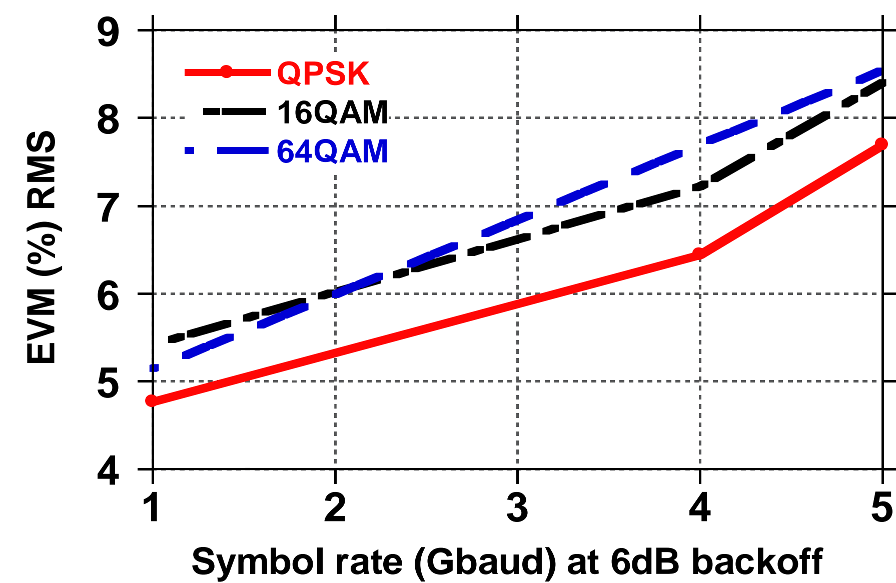
EIRP=21dBm/ 6dB Back off from P_{sat}		
QPSK (5GBaud)	16QAM(5GBaud)	64QAM(5GBaud)
7.69% (RMS)	8.4% (RMS)	8.5% (RMS)

- Transmitter (I,Q) data driven by AWG at 4GHz IF
- EVM measurements with equalization at DSO.

- EVM reference is the constellation RMS (not constellation maximum)

Transmitter module modulation performance





- Fixed data rate of 1GBaud
- Measured EVM vs transmitter Pout

- Measured EVM vs data rate at 21dB EIRP

Comparison with state of the art

	Ito [BCICST'19]	Singh [RFIC'20]	Simsek [RWS'20]	Carpenter [MTT'16]	**This Work**
Package Technology	Silica based with WR-6 transition	Radio on Glass with WR-6 transition	Radio on PCB (Astra MT77)	No	LTCC Interposer
IC Technology	70nm GaAs mHEMT	0.13µm SiGe-BICMOS	45nm CMOS SOI	0.25µm InP DHBT	22nm FDSOI + 0.25µm InP HBT
Antenna Integration	No	No	Antenna on PCB	No	Antenna on Ceramic carrier
Frequency (GHz)	142-157	115-155 (LB) 135-170 (HB)	142-147	110-160	131-137
Tx Gain	12dB	17dB (LB) 18dB (HB)	NA	24dB	36dB
EIRP (dBm) at Psat	-	-	14dBm	-	27.5dBm
Tx-Psat	8dBm	13dBm	2dBm	9dBm	17dBm*
Tx Pdc (mW)	1100	1350 (LB) 2100 (HB)	-	170	760
Tx Peak data rate/ Modulation	10Gb/s (128QAM) EVM (N/A)	42-Gb/s (128-QAM) EVM (4.4%)	10Gb/s (QPSK) EVM (NA)	20-Gb/s++ 32QAM EVM (10.6%)	30Gb/s (64QAM) EVM-RMS (8.5%)
P_{out} at Peak data rate	NA	0.5dBm	2dBm	NA	11dBm*

Conclusion

- Packaged heterogeneously integrated D-band transmitter with record EIRP of 27.5dBm
- Module has 6GHz 3-dB BW (limited by series fed-patch antenna BW)
- 5GBaud data rate at 64QAM (30Gbps)

Acknowledgment

- Authors would like to thanks
  - Kyocera Japan for ceramic interposer fabrication
  - Kyocera San Diego for module assembly
  - GlobalFoundries for CMOS chip fabrication and free access to advanced copper pillars
  - Teledyne scientific for InP PA fabrication

Questions?