AMPLEON

CWTe 6G Symposium

Sept 15, 2023

Next generation of efficient 6G power amplifiers

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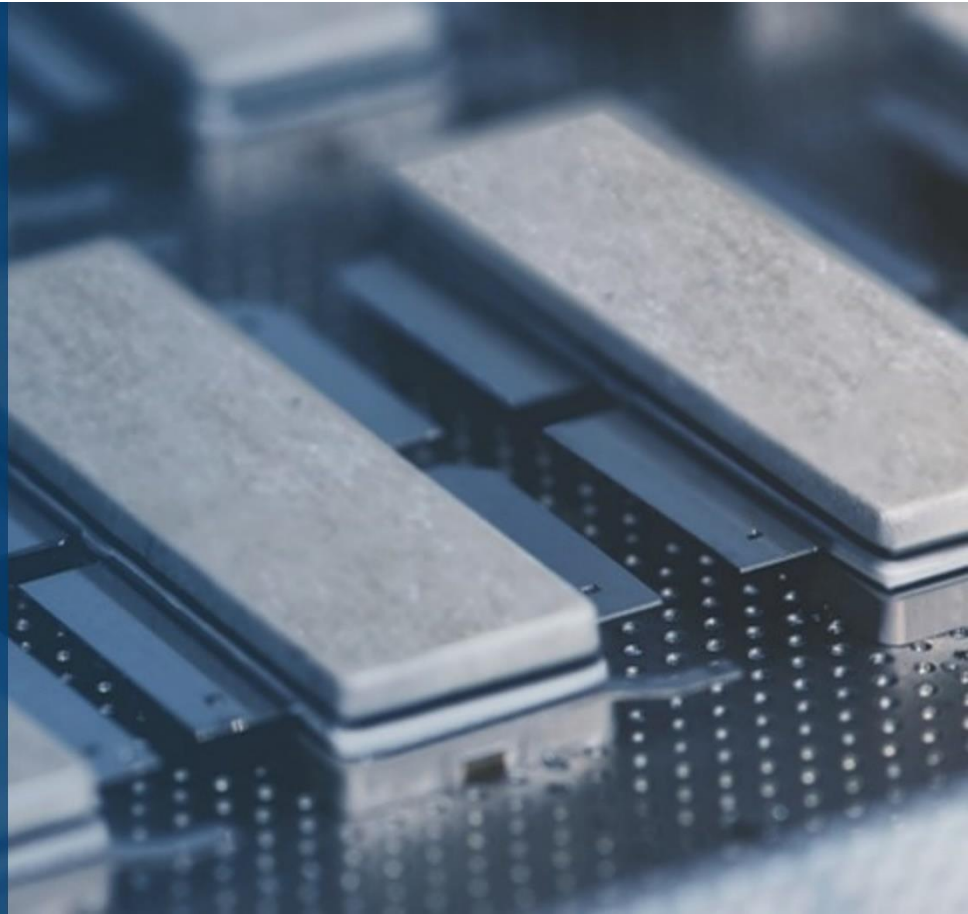

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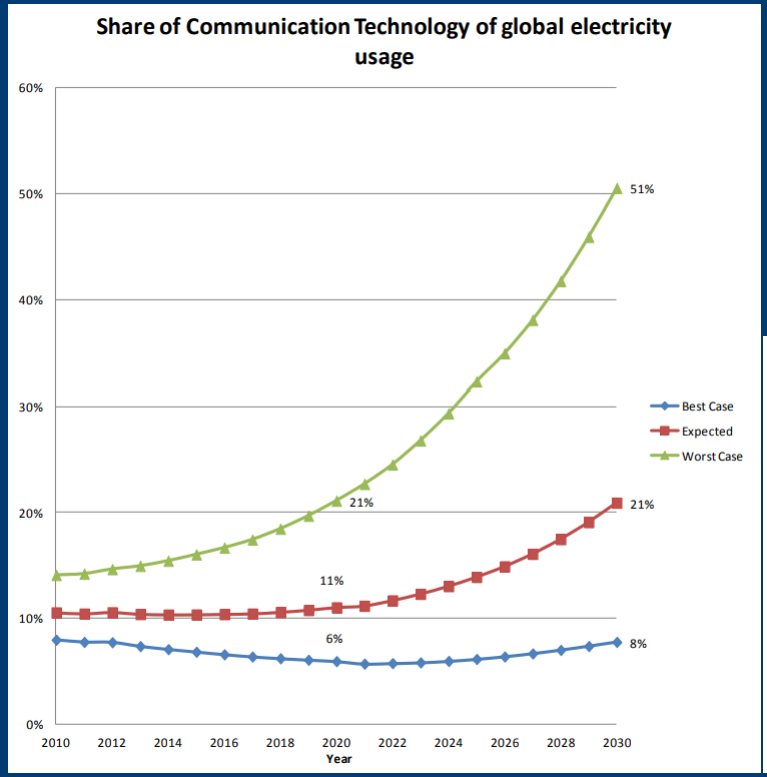
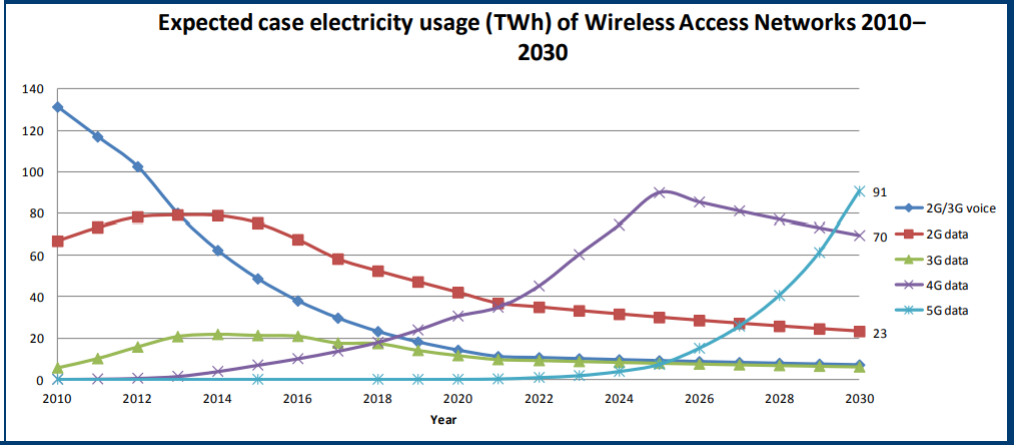
- Overview current BST systems
  - Technology trends
  - PA concepts
- State of the art PA efficiencies
- Summary

The need for energy/power efficiency

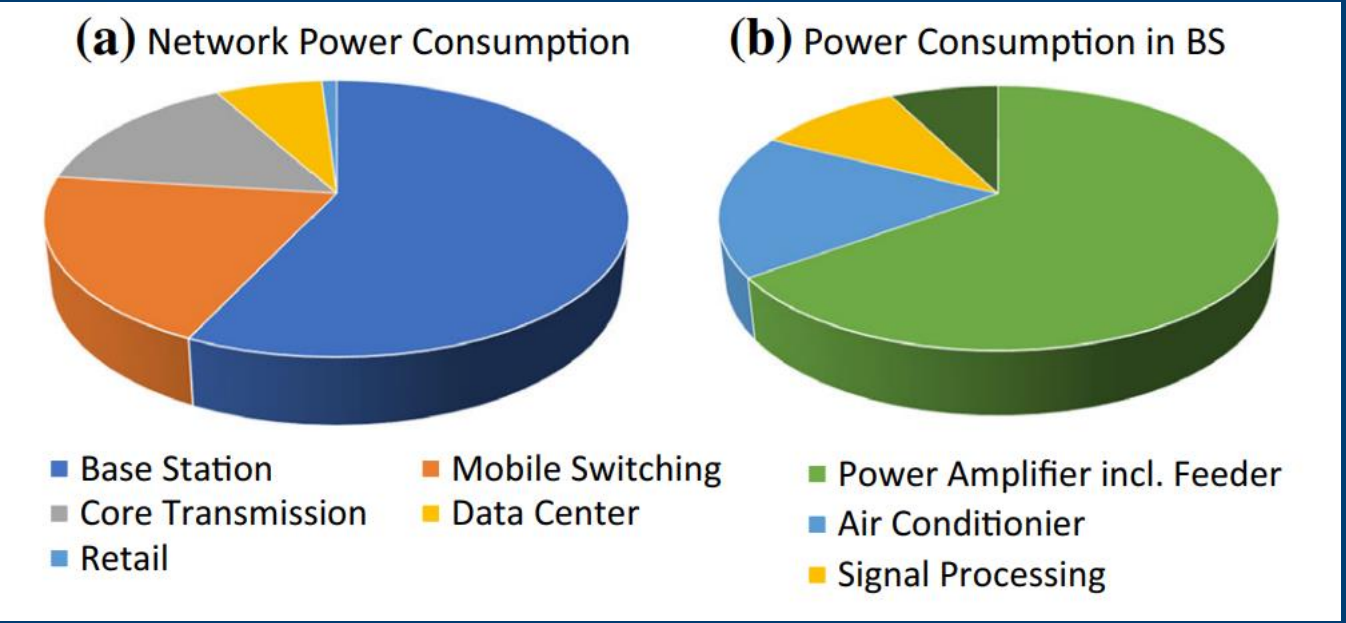


- Telecommunication infrastructure accounts now for 2-3% of total global energy consumption.
- Data efficiency is increasing (bits/Joule) but with increasing data capacity targets of 5/6G the number of basestation increases more rapidly.
- This could lead to 20% of global energy consumption of CT in 2030.

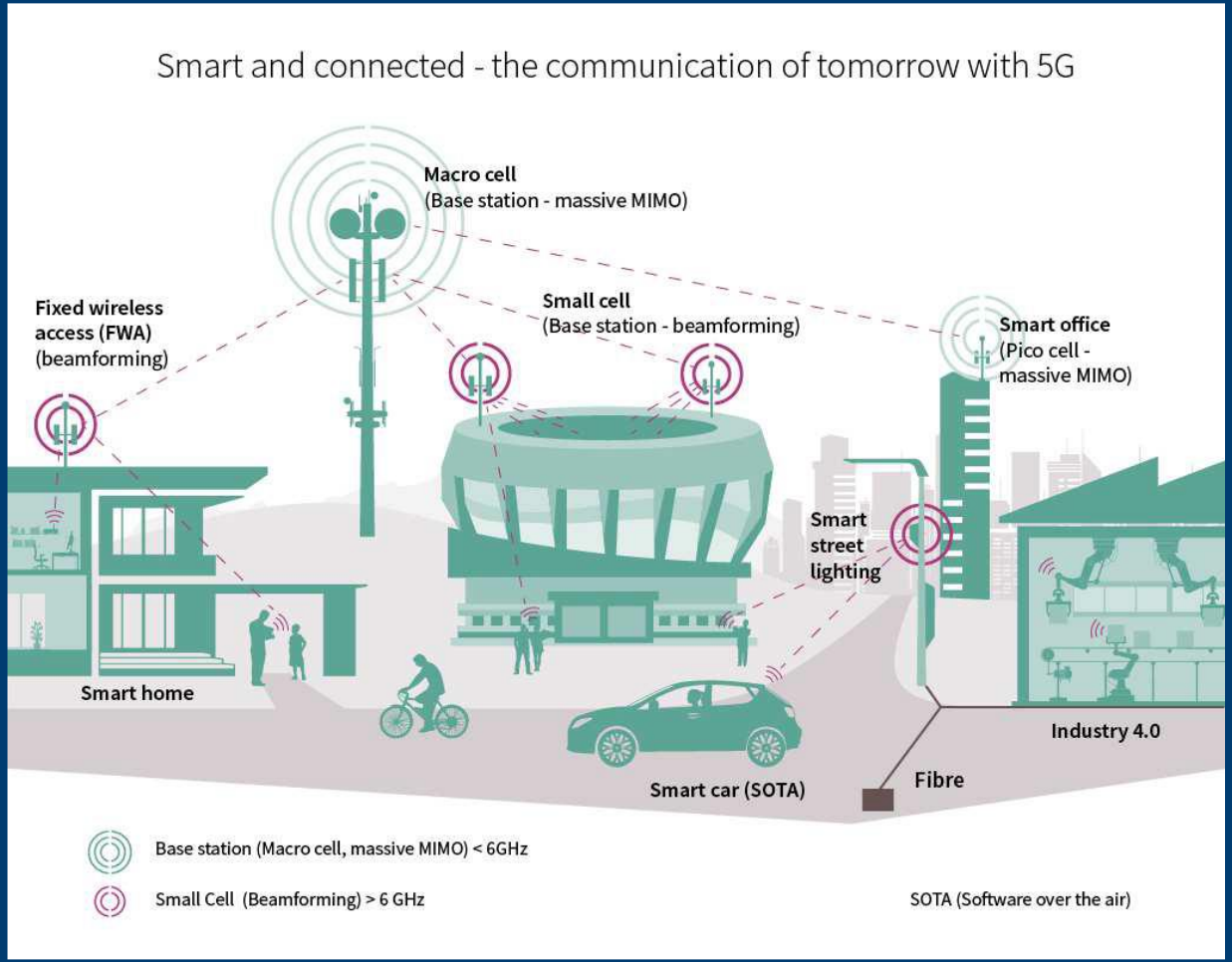


The need for energy/power efficiency

- Power amplifier is one of the main contributors to total BST power consumption.



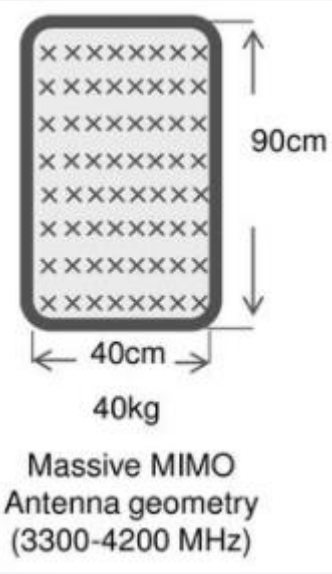
From white paper Ericsson



Current systems from PA perspective.

Sub 6GHz systems:

- Macro BST:
  - Psat 300-1000 W
- mMIMO:
  - Psat: 30-100 W
- Small cells:
  - Psat: < 10 W


90cm
40cm
40kg
Massive MIMO
Antenna geometry
(3300-4200 MHz)

Currently

Typical modern 4/5G macro base station amplifier:

600 W LDMOS packaged asymmetric Doherty power transistor for base station applications at frequencies from 1930 MHz to 1995 MHz.

Table 1. Typical performance

Typical RF performance at T_{case} = 25 °C in an asymmetrical Doherty production test circuit. V_{DS} = 30 V; I_{Dq} = 1060 mA (main); $V_{GS(amp)peak}$ = 1.0 V, unless otherwise specified.

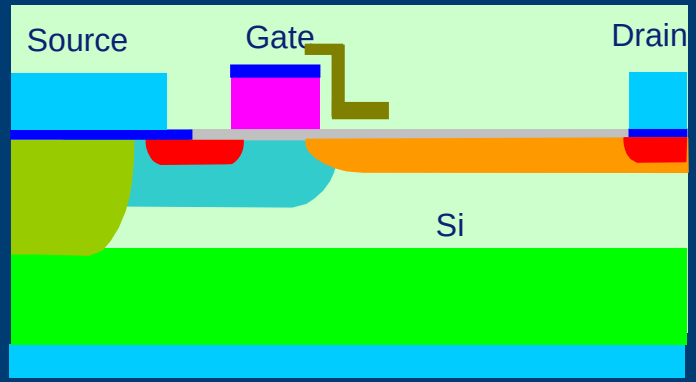
Test signal	f	V_{DS}	$P_{L(AV)}$	G_p	η_D	ACPR
	(MHz)	(V)	(W)	(dB)	(%)	(dBc)
1-carrier W-CDMA	1930 to 1995	30	112	15.5	48.5	–34 [1]

Main-stream technologies:

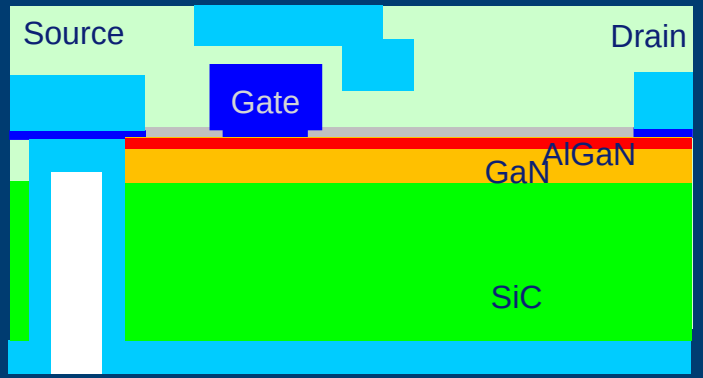
1. LDMOS and GaN semiconductor technology
2. Doherty PA concept

Device technologies

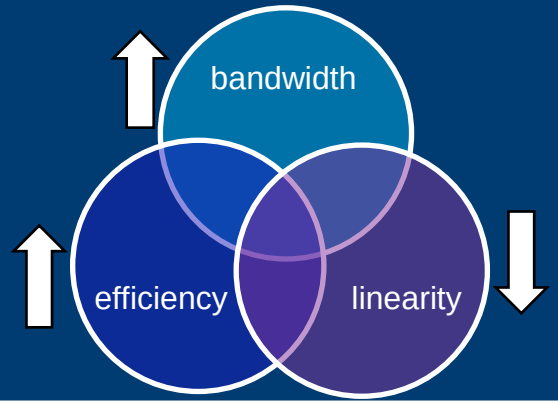
LDMOS



GaN-HEMT



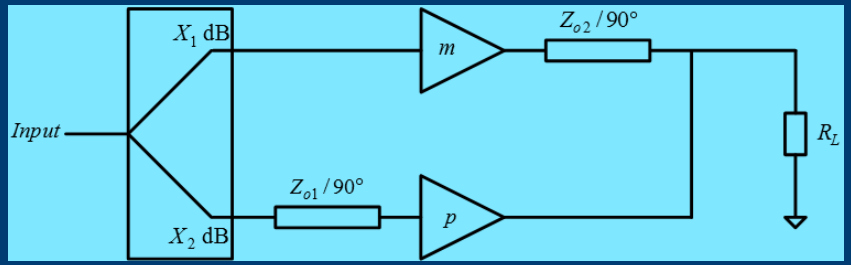
	Si-LDMOS	GaN HEMT
Supply voltage (V_{dd})	30 V	50 V
Power-density (P_{dens})	1.5 W/mm	9 W/mm
Peak Efficiency	70%	80%
Output capacitance (C_{ds})	0.18 pF/W	0.04 pF/W
RF Bandwidth FOM ($\propto \frac{1}{V_{dd}^2 C_{ds}}$)	1	1.6

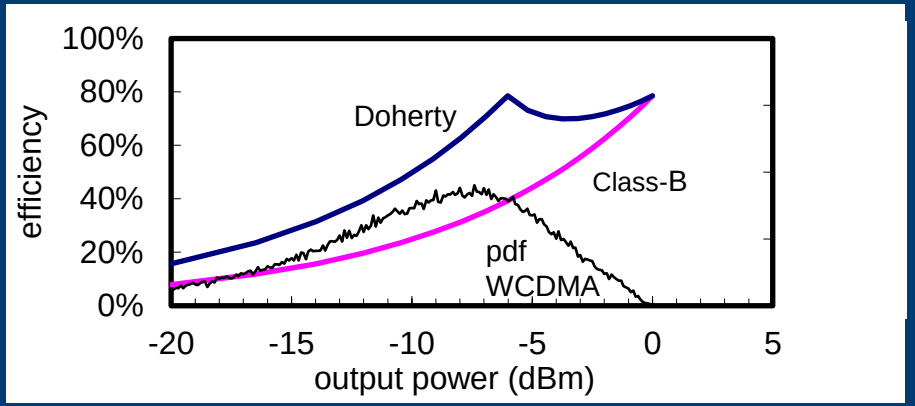


Doherty PA concept.

Doherty PA to increase efficiency in back-off. Essential for modulated signals.

W. H. Doherty, "A new high efficiency power amplifier for modulated waves", *Proc. IRE*, vol. 24, no. 9, pp. 1163-1182, 1936.





Theoretically, with peak efficiency of 78% and 8dB PAR:

- The average efficiency in class-B: 35%
- With Doherty concept (asym) : 60%

In practice, with new requirements, the limits of Doherty becomes visible.

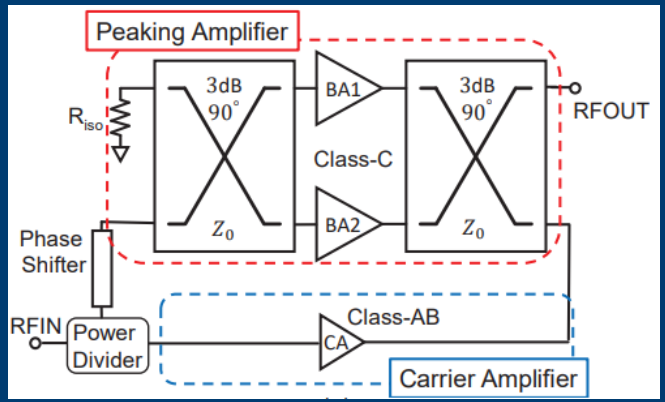
Interesting new PA concepts

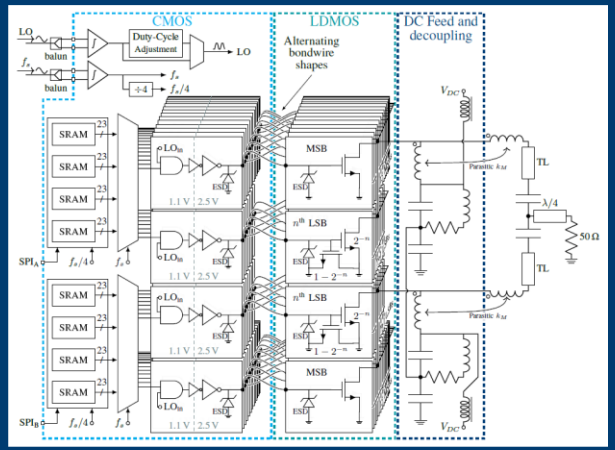
Two approaches:

(1) Combinations of existing concepts e.g.
- Doherty-Chireix concept
- Doherty-voltage modulation concept
- Load modulated balanced PA
- …

(2) Digital intensive PA's (RF-DAC)

Tudelft,
IMS2020, R.J. Bootsman, et al.
"An 18.5 W fully-Digital Transmitter with 60.4% Peak System Efficiency."





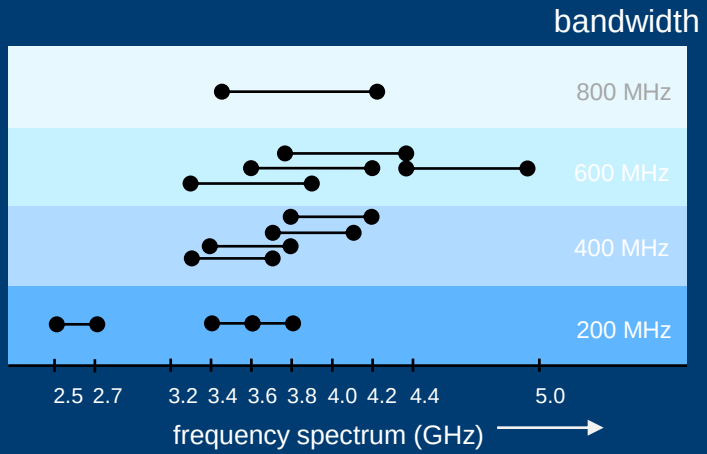
Efficiency trade-offs

$$\eta_{LU} = \eta_{peak}\,\eta_{mod}\,\eta_{driver}\,\eta_{iso}$$

η_{peak}	: peak efficiency	LDMOS: 0.7 GaN: 0.8
η_{mod}	: average efficiency	Class-AB: 0.4 Doherty: 0.7
η_{driver}	: including drivers	Typical: 0.95
η_{iso}	: isolator losses	Typical: 0.93
η_{LU}	: total LU efficiency	Typical: 0.5

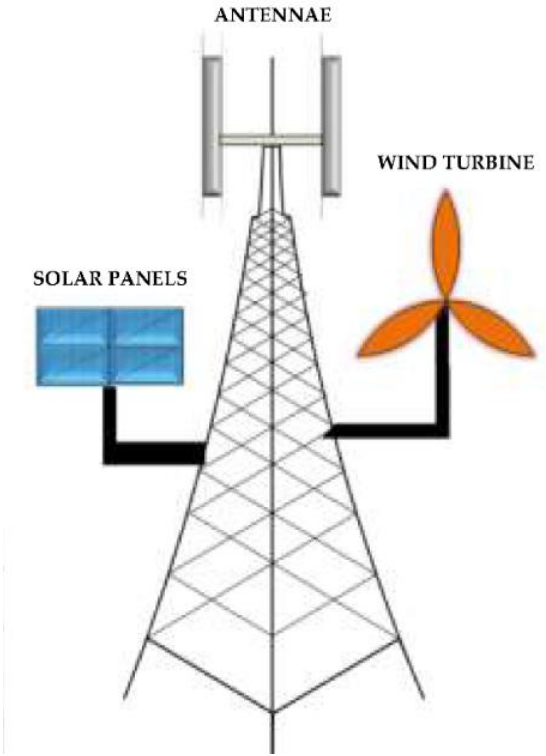
Massive MIMO system trends on PA-level

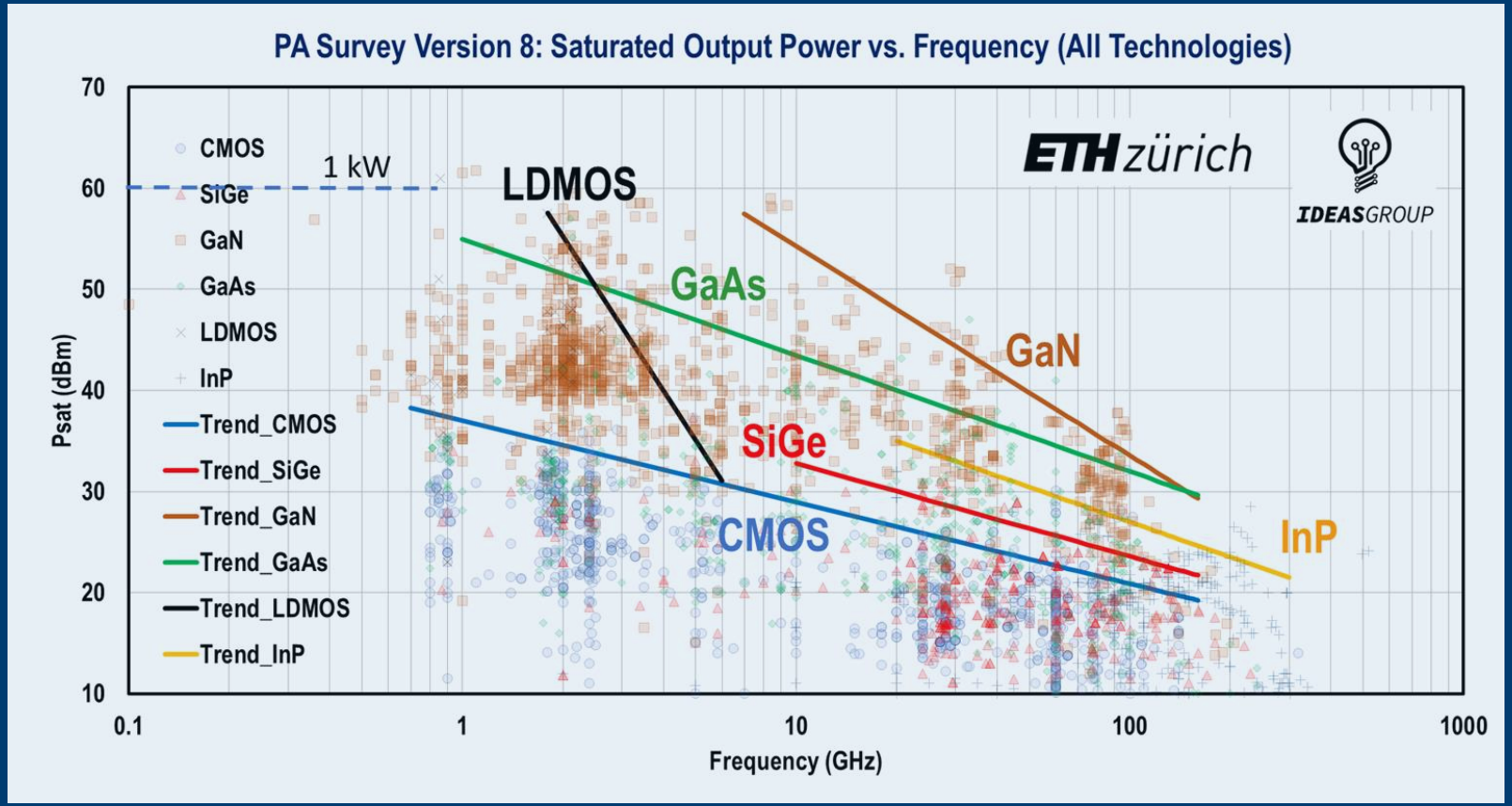
- Per PA less output power is required.
- Move to higher frequencies
- Much larger bandwidth required
- More digital pre-distortion friendly: linearity



iBW	100 MHz	200 MHz	400 MHz	400 MHz	600 MHz	800 MHz
#T/total Pout	**120 W**	**240 W**	**320 W**	**400 W**	**600 W**	**640 W**
32T		7.5/75	10/100	12.5/125	18.7/187	20/200
64T	1.9/19	3.8/38	5/50	6.3/63	9.4/94	10/100
128T					4.7/47	5/50
256T						2.5/25

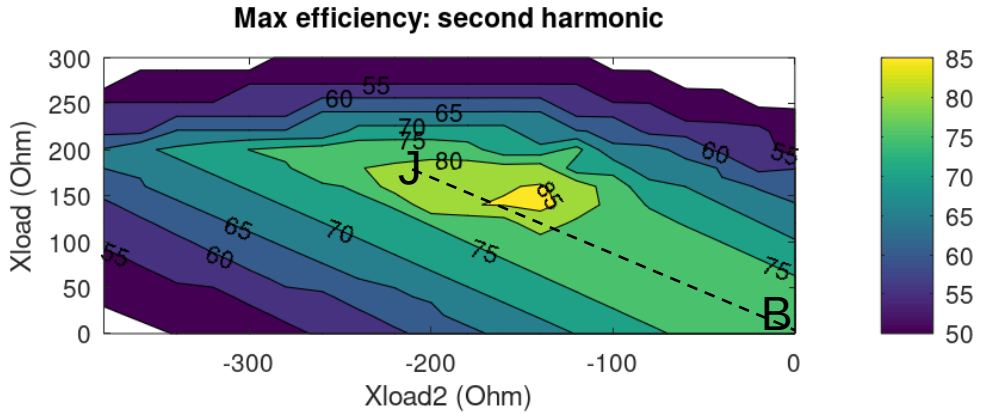
State of art PA efficiencies

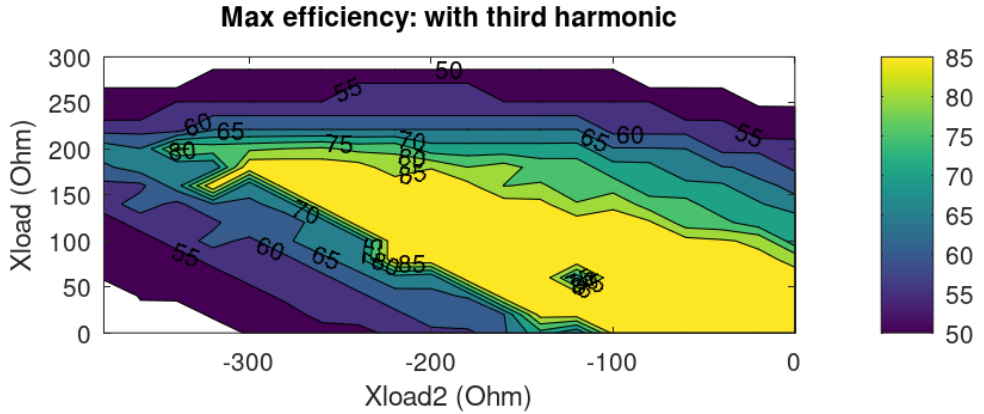




- Technologies needed depends very much on required power levels (from ETH PA Survey).

Theoretical efficiency limit





Max obtainable efficiency for ideal transistor with real IV-curves.

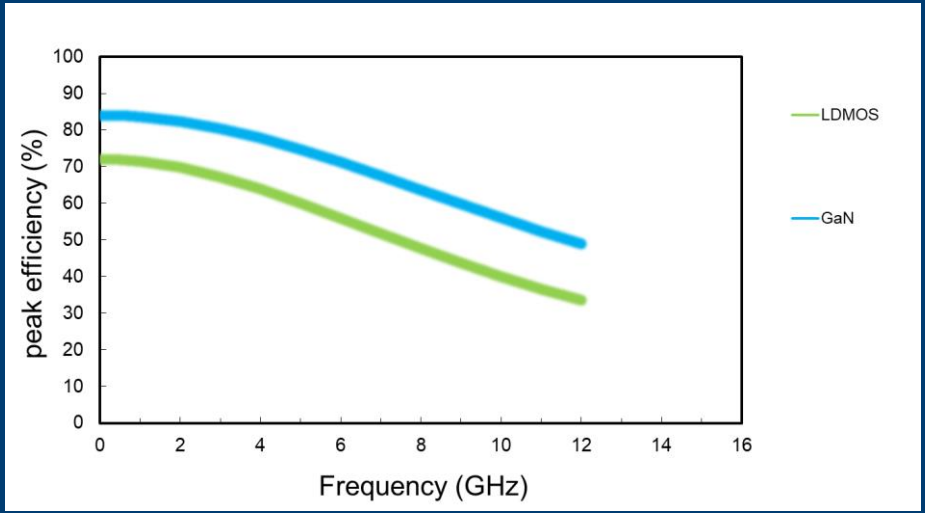
n	Efficiency	class
1	78%	B
2	85%	J
3	90%	

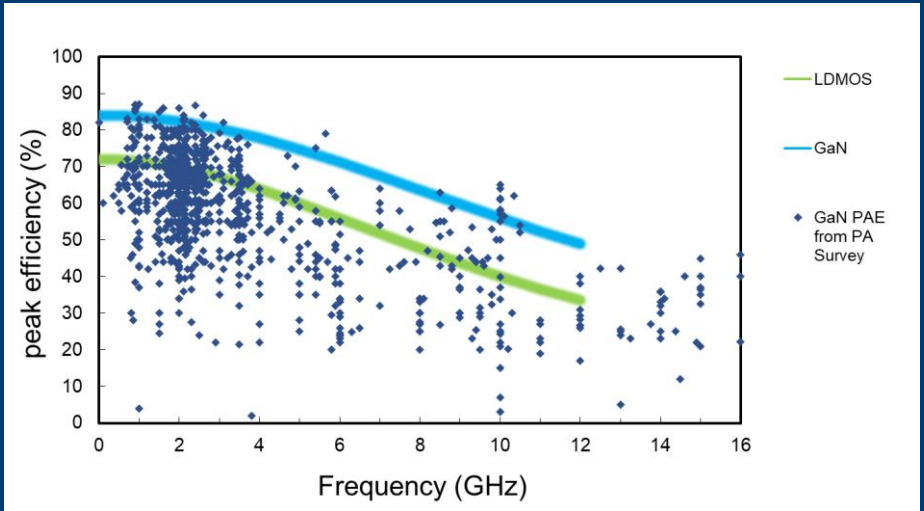
Table from F. Raab.

MAXIMUM EFFICIENCY AND POWER-OUTPUT CAPABILITY OF CLASS-F PAS

m	η n = 1	n = 3	n = 5	n = ∞
1	1/2 = 0.500	$1/3^{1/2}$ = 0.5774	0.6033	2/π = 0.637
2	0.7071	0.8165	0.8532	0.9003
4	0.7497	0.8656	0.9045	0.9545
∞	π/4 = 0.785	0.9069	0.9477	1 = 1.000

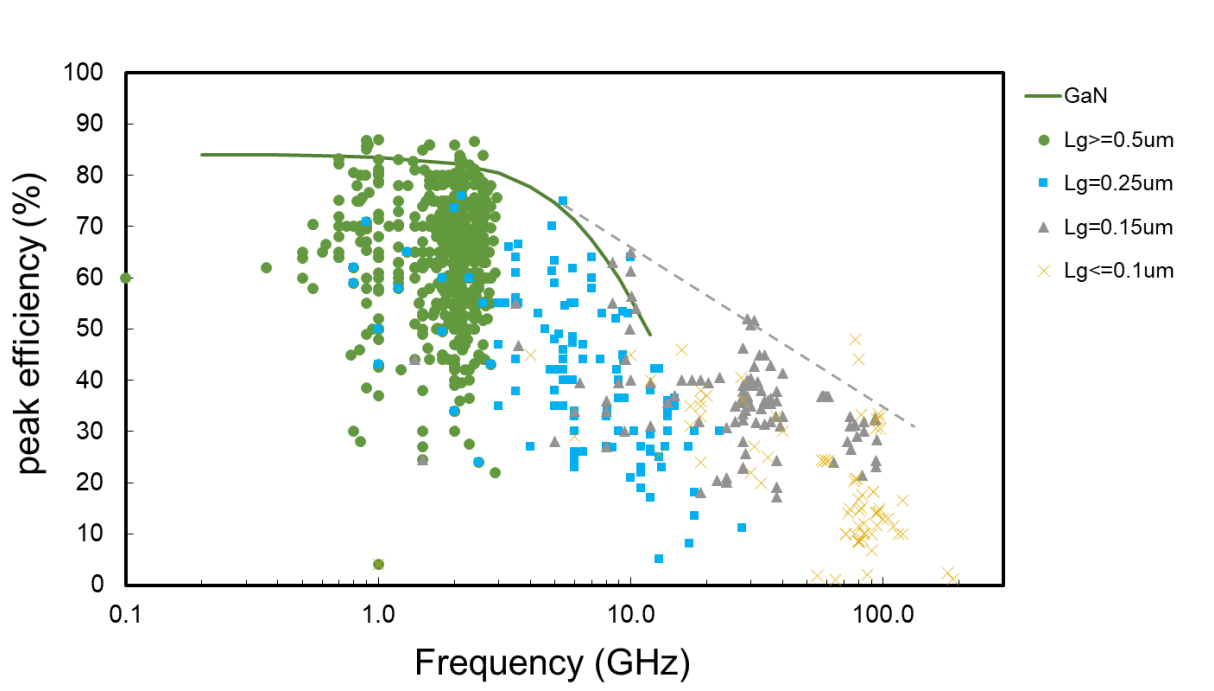
Efficiency performance vs frequency





- Slow decline of efficiency vs frequency (left).
- Results confirmed by data from literature (right).

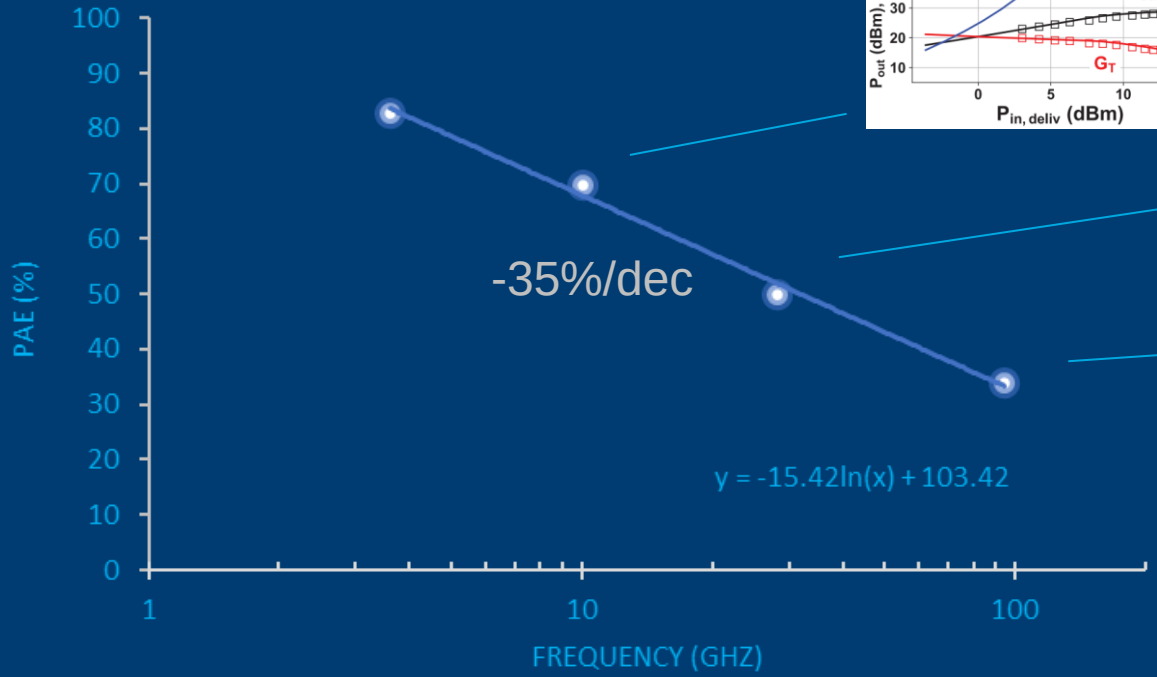
Efficiency performance extended to THz frequencies for GaN

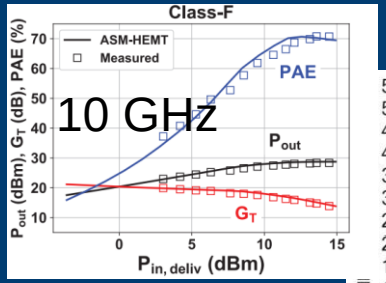


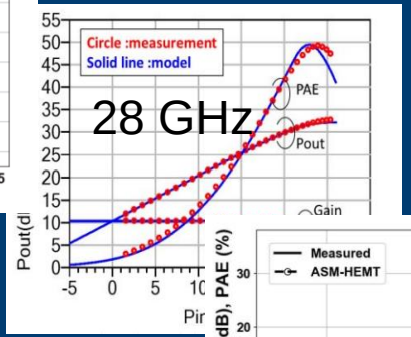
- There seems to be a universal curve

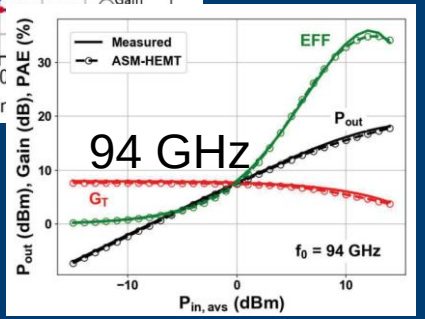
Best efficiency performance vs frequency

$$\eta_{LU} = \eta_{peak}\,\eta_{mod}\,\eta_{driver}\,\eta_{iso}$$









Summary: The need for energy/power efficiency

$$\eta_{LU} = \eta_{peak}\,\eta_{mod}\,\eta_{driver}\,\eta_{iso}$$

		Sub 6 GHz		94 GHz	
η_{peak}	: peak efficiency	GaN:	0.8	0.3	(other technologies?)
η_{mod}	: average efficiency	Doherty:	0.7	?	(class AB)
η_{driver}	: including drivers	Typical:	0.95	↓	(need more gain/stage)
η_{iso}	: isolator losses	Typical:	0.93	↓	(balun)
η_{LU}	: total efficiency	Typical:	0.5	Typical:	0.10 (peak eff)

- Surely, the PA efficiency can never reach efficiencies of sub 6GHz. But much can also be done at system level.

It is clear that advances need to be made at all levels.

Thanks for your attention.