Implementation Challenges and Opportunities

In Beyond-5G and 6G Communication

CWTe 6G Vision Workshop, TU Eindhoven

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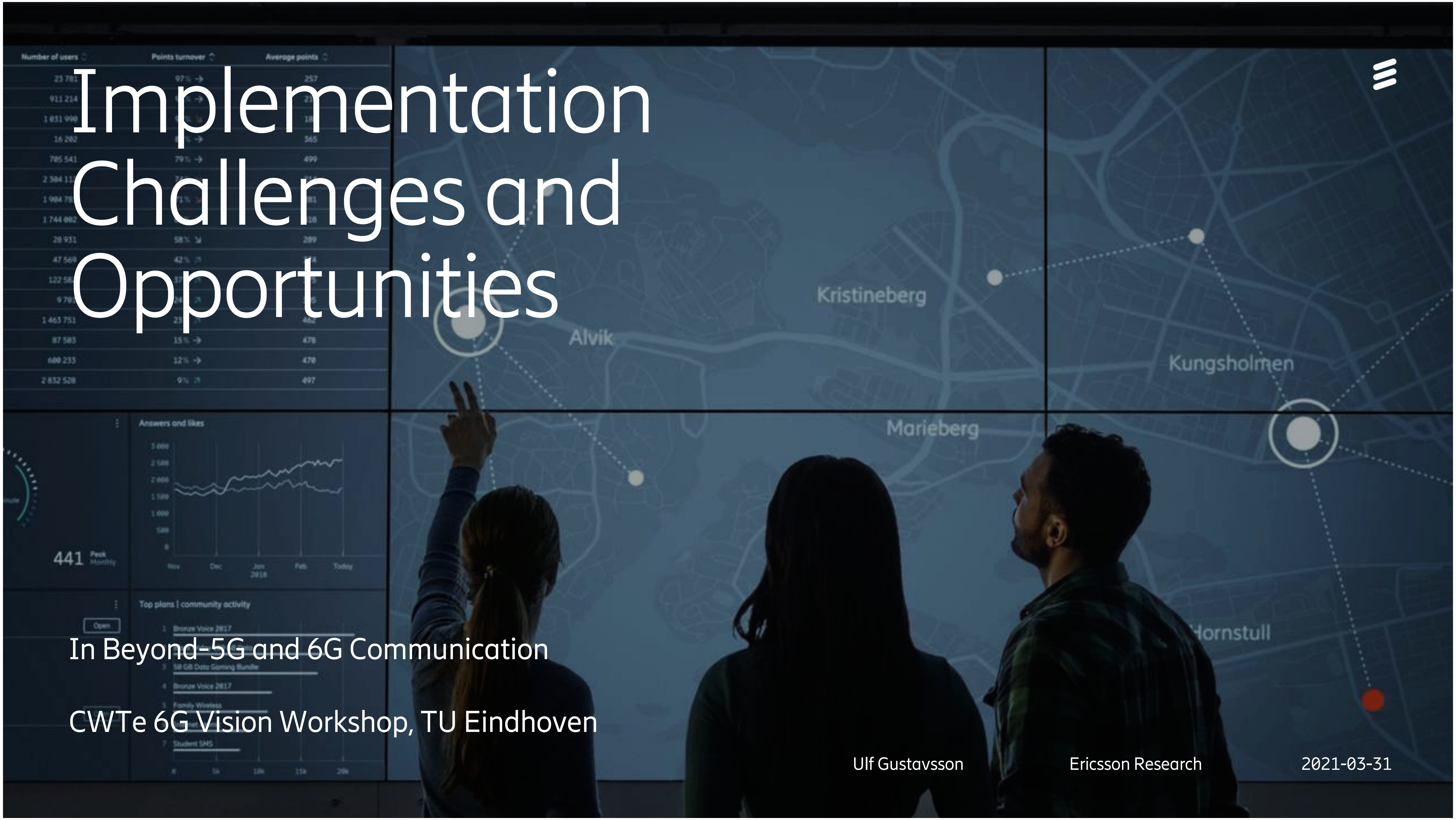


What is 6G wireless access ?

1990		2000		2010		2020		2030	
	2G era GSM, IS-136, PDC, IS-95		3G era WCDMA → HSPA cdma2000 → EvDO		4G era LTE		5G era NR		6G era ?
	Digital **Voice**		**Wideband** **Data**		**OFDM + MIMO** **Mobile broadband**		**mmw + BF** **Mobile broadband and IoT**		**?**

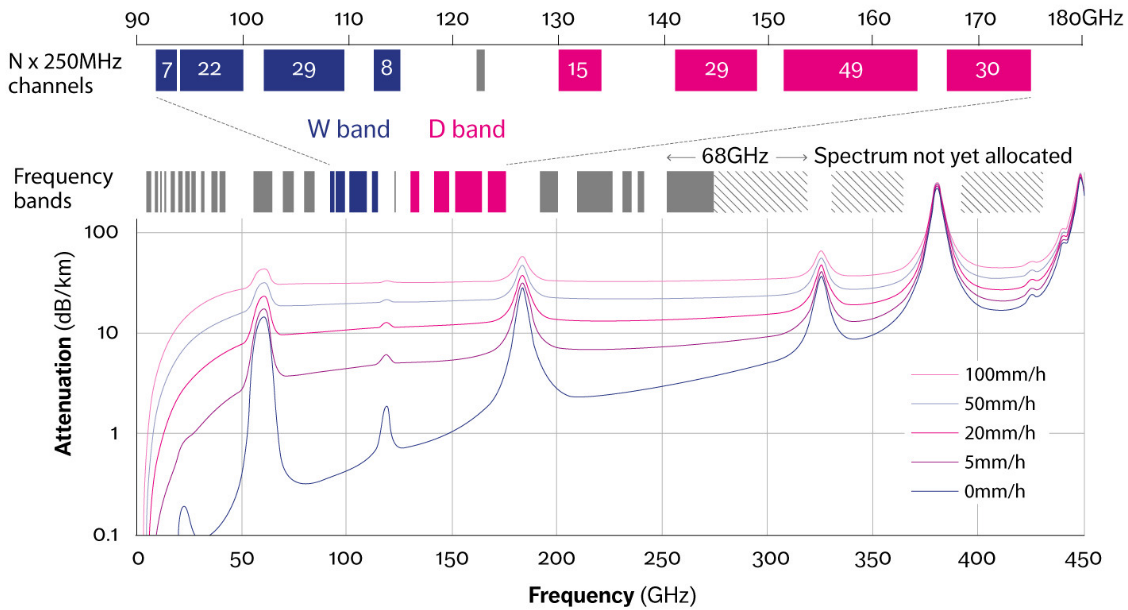
Each generation typically associated with specific new radio-access technology but
- cdma2000 was an evolution of IS-95, NR at least to some extent based on LTE
- sometimes the important technology step has taken place within a generation (e.g. WCDMA → HSPA)

"6G" is the overall wireless access solution available around 2030
- May be associated with a completely new radio-access technology or an evolution of current technology
- The important thing is the new capabilities and the enabling technology components

Sub-millimeter wave communication

- The trend toward higher frequencies continues
  - 5G NR uses FR2 @ 24.2-52.6 GHz
  - 5G evo. investigates FR3 @ 52.6-71 GHz
  - 6G to look at 90-100, 120+ GHz
  - Channel bandwidths increases

- Technical challenges
  - Power amplifier power, linearity and efficiency
  - RF oscillator phase-noise
  - Receiver noise-figure
  - Data converter dynamic range



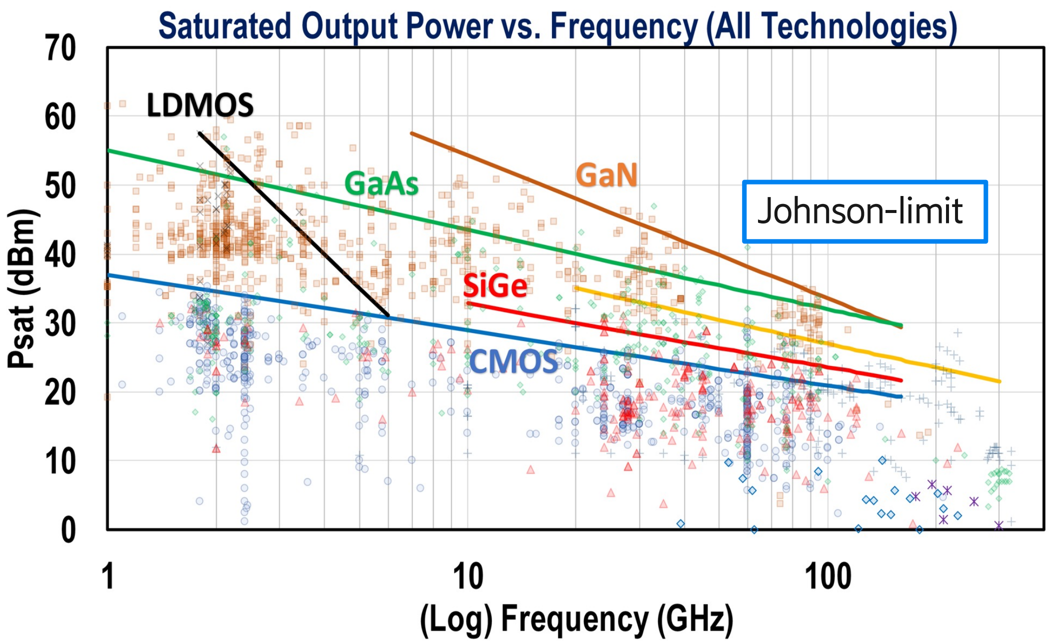
Power amplifiers – output power

$$P \propto V_m^2 = \frac{1}{f_T^2}\left(\frac{E v_s}{2\pi}\right)^2$$

- Achievable output power decreases
  - Scales with $1/f^2$ according to Johnson-limit

- Spectrally efficient waveforms an issue
  - High PAPR reduces average power
  - Increased bandwidth requires more power

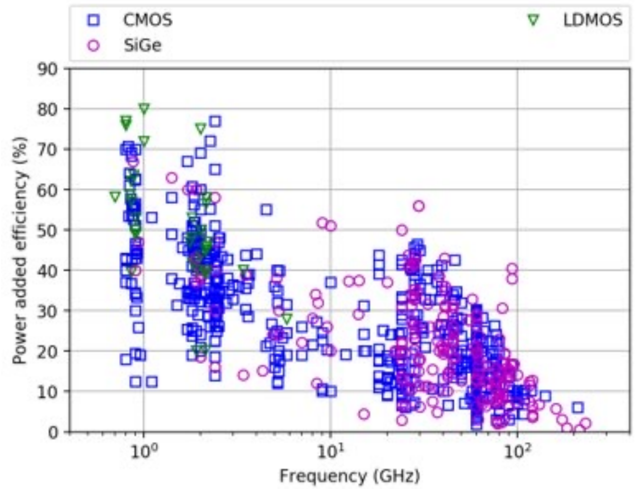
- Increase output power by choosing semiconductor process
  - Increases cost
  - Possible issues in building practice
  - More limiting for UE rather than BS

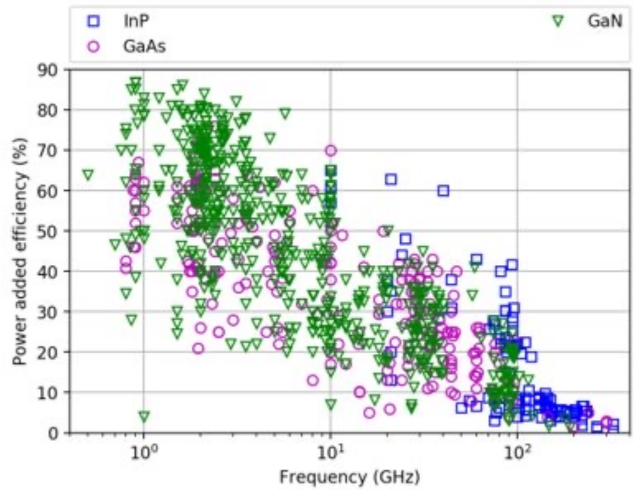


Source: https://gems.ece.gatech.edu/PA_survey.html

Power amplifiers – power efficiency

- Power efficiency trending downward vs. freq.
  - Intrinsic losses and parasitics
  - Passives with low-Q, skin-effect and losses
  - Low gain operating close to f_t/f_{max}
- Low output power, but densely integrated
  - Heat dissipation a challenge

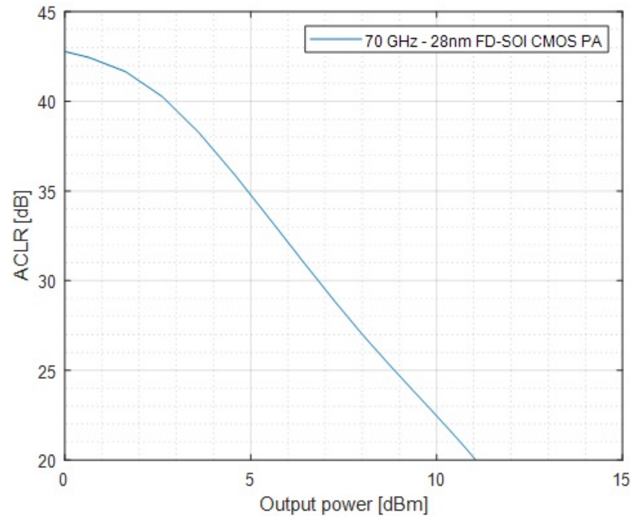


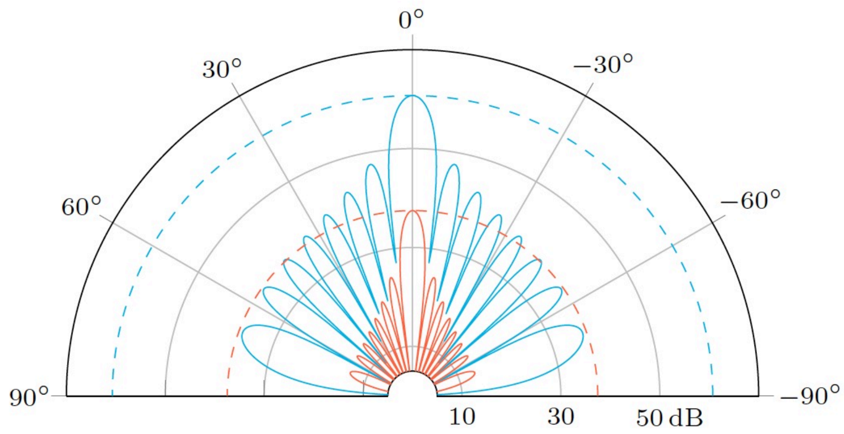


Power amplifiers - linearity

- PA linearity crucial for throughput
  - Large part of EVM-budget if uncorrected
- Digital Pre-Distortion commonly used, but
  - Requires oversampling
  - Impractial for very large channel BW
- Back-off possible, but output power is quite low
  - Exploit spatial-filtering?

Ex. Simulated 70 GHz FD-SOI CMOS PA





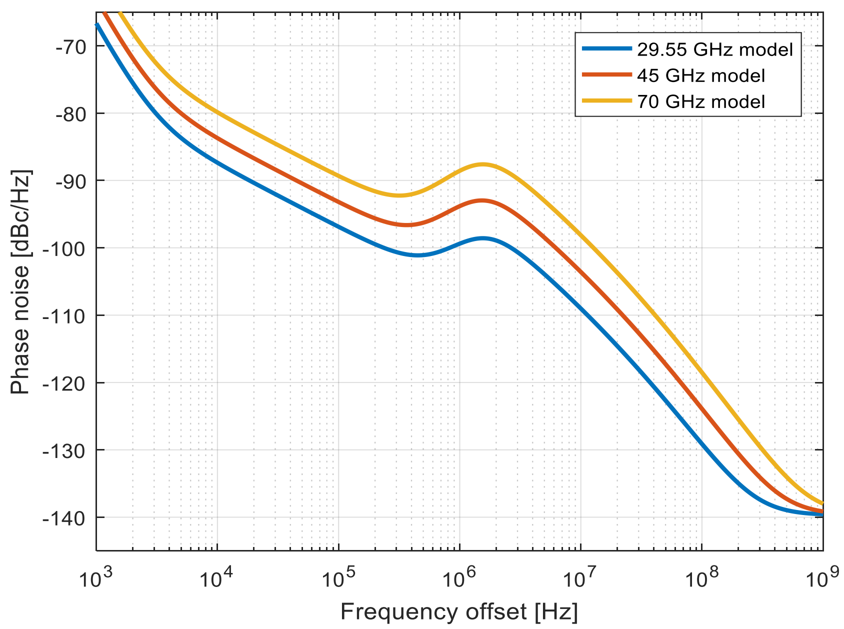
RF local oscillators

- Phase-noise increase with RF carrier frequency
  - Leeson's equation, ignoring the $1/f$ noise:

$$L(df) \propto \frac{P_{DC}}{df^2}$$

- Per doubling of frequency
  - For fixed P_{DC}, phase-noise increases ~6 dB
  - For fixed $L(df)$, $4\times P_{DC}$ is needed

Measurement-based phase-noise model.

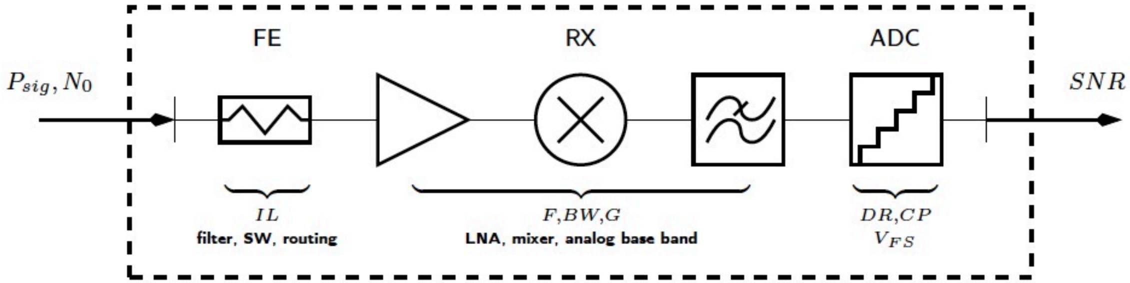


Source: S. Andersson et al. "Design considerations for 5G mm-wave receivers",

Receiver Noise-Figure

- SNR degeneration mainly stems from
  - LNA thermal noise
  - Insertion loss – filter, mixer, TL
  - TR-switch
  - ADC dynammic range

- Similar to PA, it can be improved
  - Semiconductor process improvement over time
  - Higher integration
  - Averaging over many antennas



$$F = \frac{N_{out}}{N_{in} \cdot G} = \frac{N_{out} \cdot S_{in}}{N_{in} \cdot S_{out}} = \frac{SNR_{in}}{SNR_{out}} \qquad NF = 10 \cdot \log_{10}(F)$$

expected total NF

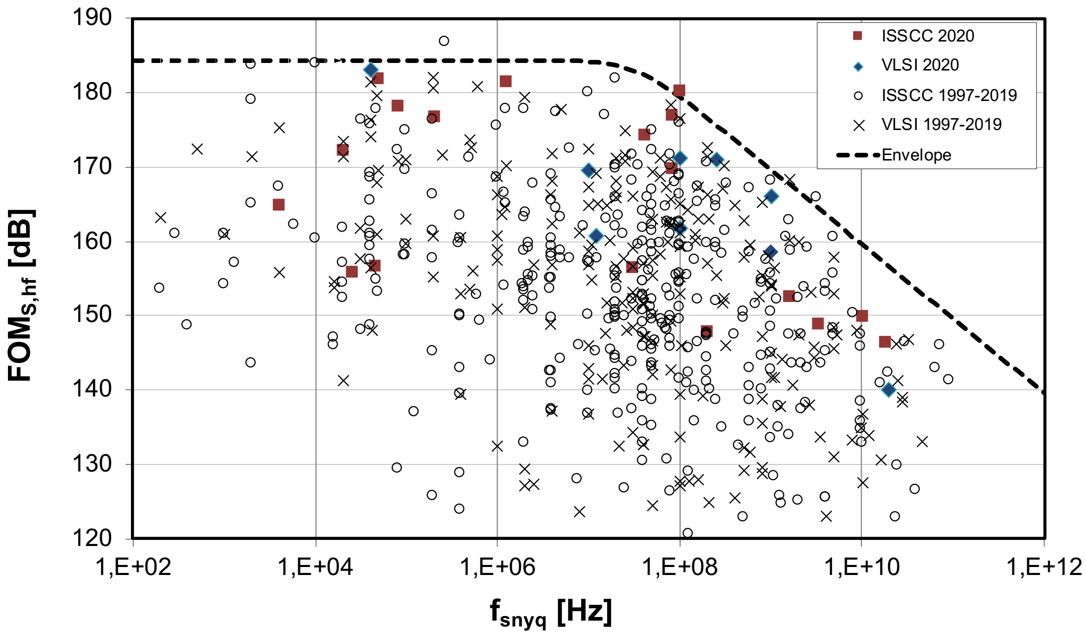
	2	30	45	70	GHz
2016	5.1	9.1	10.7	12.8	dB
2021	5.0	7.8	8.7	10.1	
2026	5.0	7.7	8.6	9.9	

Source: S. Andersson et al. "Design considerations for 5G mm-wave receivers",

Data-converters

$$\mathrm{FOM} = (DR)_{dB} + 10\log_{10}\left(\frac{BW}{\mathrm{Power}}\right)$$

- Schreier FOM for ADC's
  - SNDR for the high sample-rate-region
- Dynamic range is expensive!
  - 3dB DR cost the same as 2xBW
  - Roughly: +1 ENOB ∝ 4xPower
  - DAC follows roughly the same trend
- Cost of interface can't be ignored
  - DAC/ADC needs to be integrated
  - Interface-cost non-neglectable



Source: Prof. Boris Murmann, Stanford Uni.

Closing remarks

- With sub-mm wave spectrum, opportunities comes with free spectrum, but building efficient and cost-effective antenna systems is challenging

- PA technology can be a bottleneck, in particular in the up-link
  - Achievable output power drops with $1/f^2$
  - Increased losses lowers the efficiency and linearity is expensive

- Receiver NF and phase-noise increases with frequency

- Converter technology a challenge
  - Power consumption in the converter and the interface increases with sample-rate

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Implementation Challenges and Opportunities in Beyond-5G and 6G Communication

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Thanks for your attention!!

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