



CWTe

Centre for Wireless Technology Eindhoven

Wireless Wire—the mmW Ultra-Low-Power and High- Data-Rate Wireless System

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TU / **e**

Technische Universiteit
Eindhoven
University of Technology

Where innovation starts

Outline

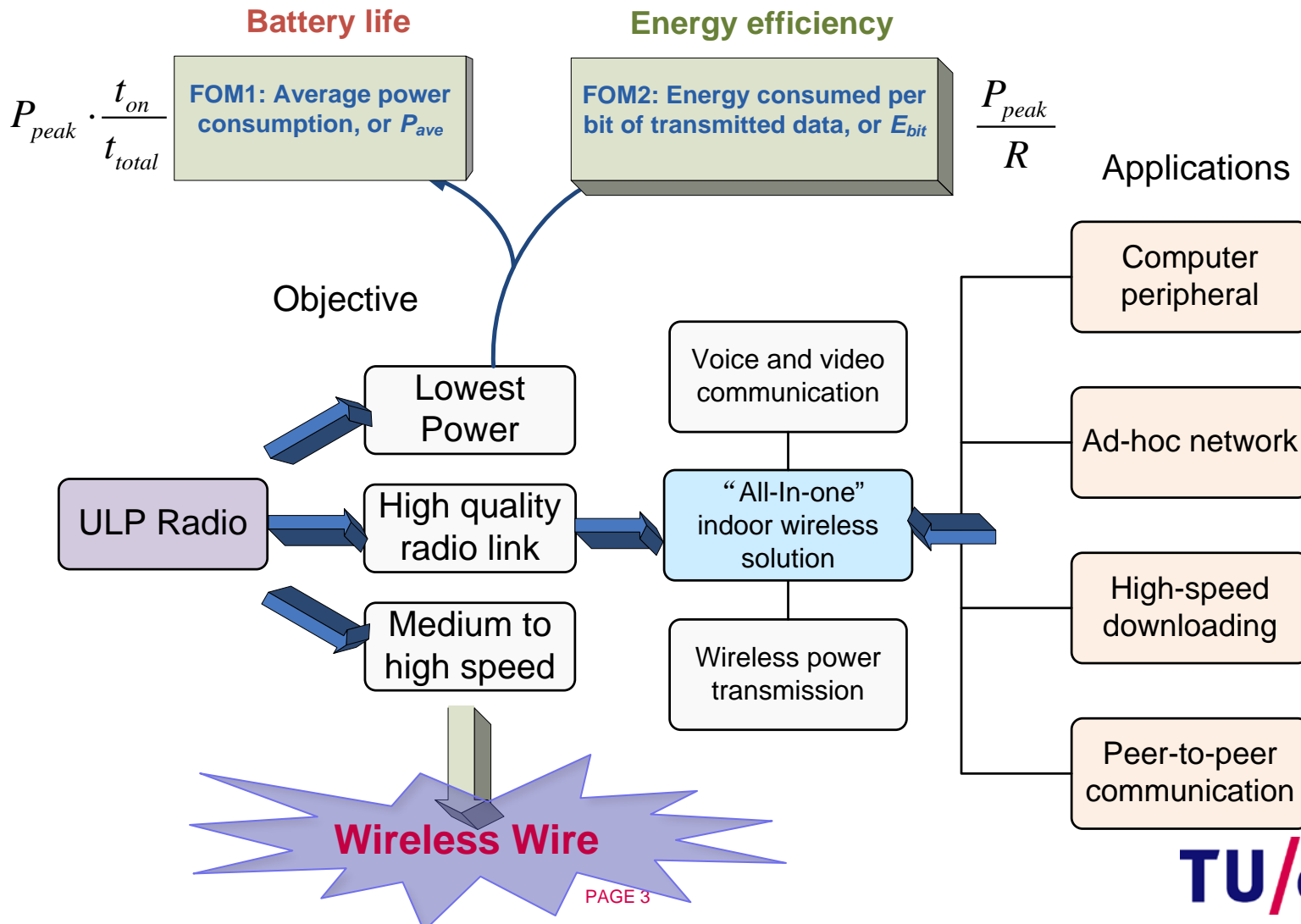
- **Applications and Objectives**
- **System-Level Research**
- **Circuits and Measurement Results**
- **Conclusions**

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- **Applications and Objectives**
- **System-Level Research**
- **Circuits and Measurement Results**
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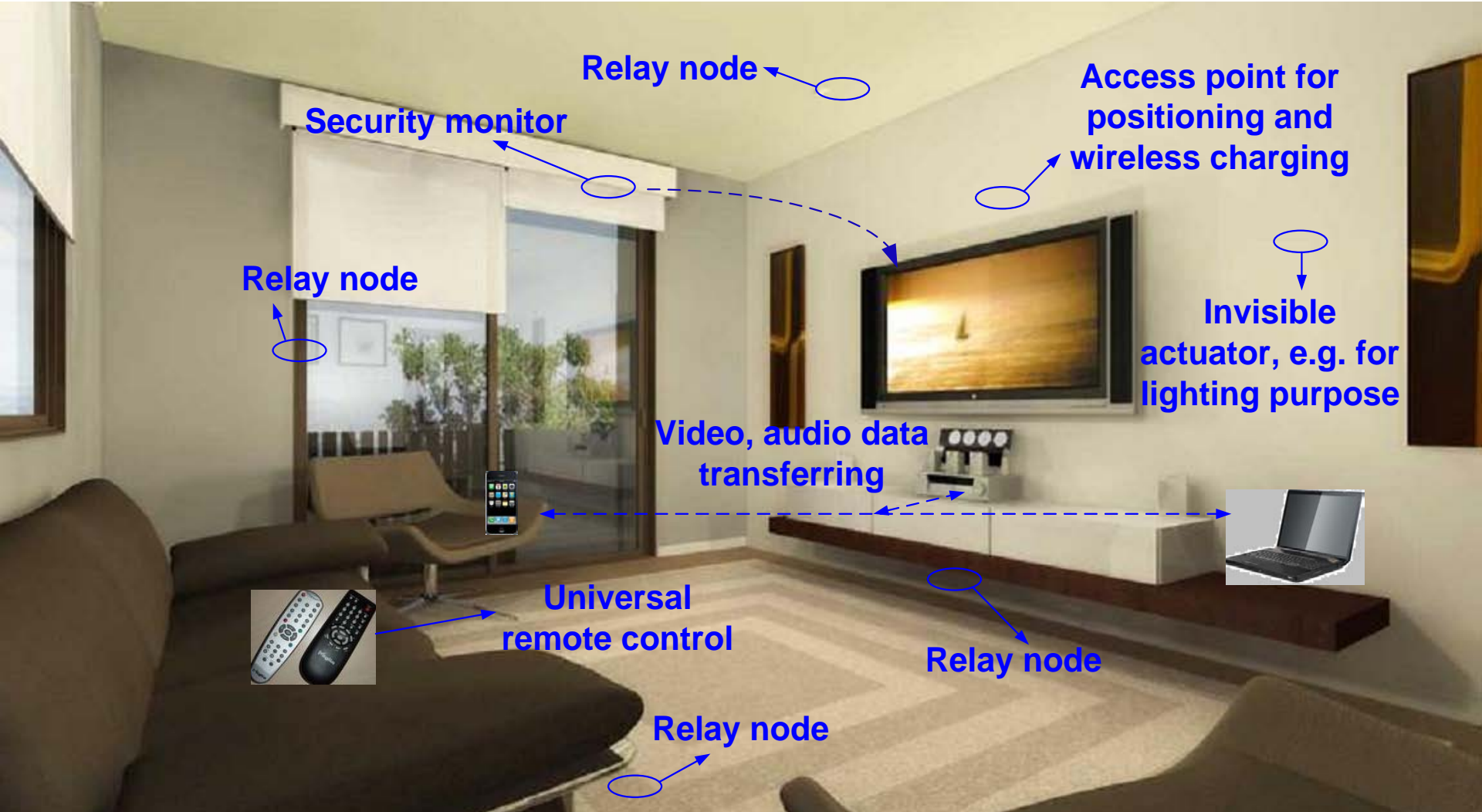
Applications and Objectives

- Applications and Objectives



Applications and Objectives

- Application Example



Applications and Objectives

- **Required Features**

- **Low average power consumption (P_{ave})**

- ➔ **Battery, energy scavenging or wireless charging**

- **Low energy per bit (E_{bit})**

- ➔ **Highly efficient communication**

- **Medium to high data rate (Gbps)**

- ➔ **Versatile applications**

- **Robust link**

- ➔ **No blockage problem under LoS assumption**

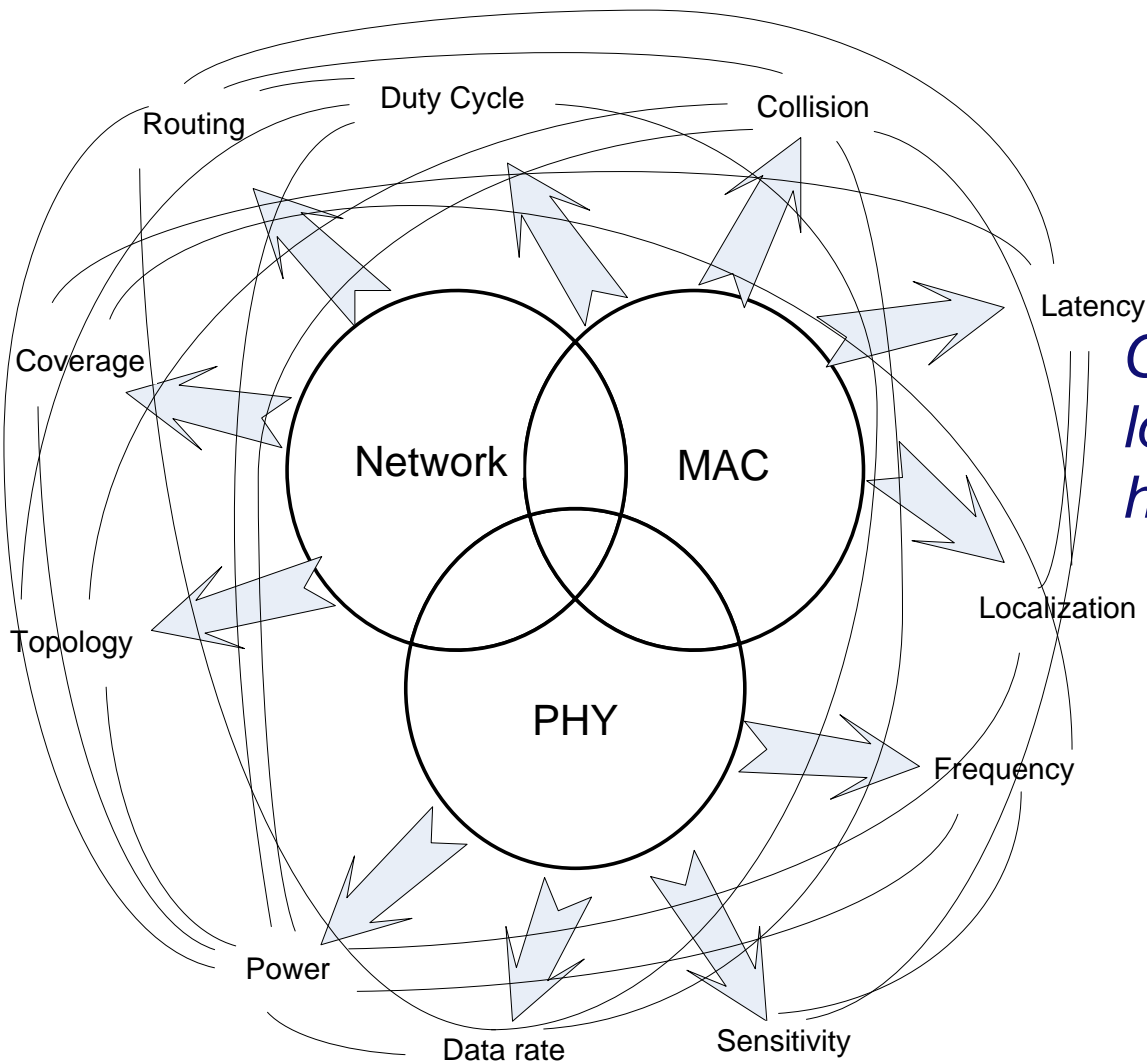
- **Smart link**

- ➔ **Adaptive neighborhood recognition**

- **....**

Applications and Objectives

- Research Question



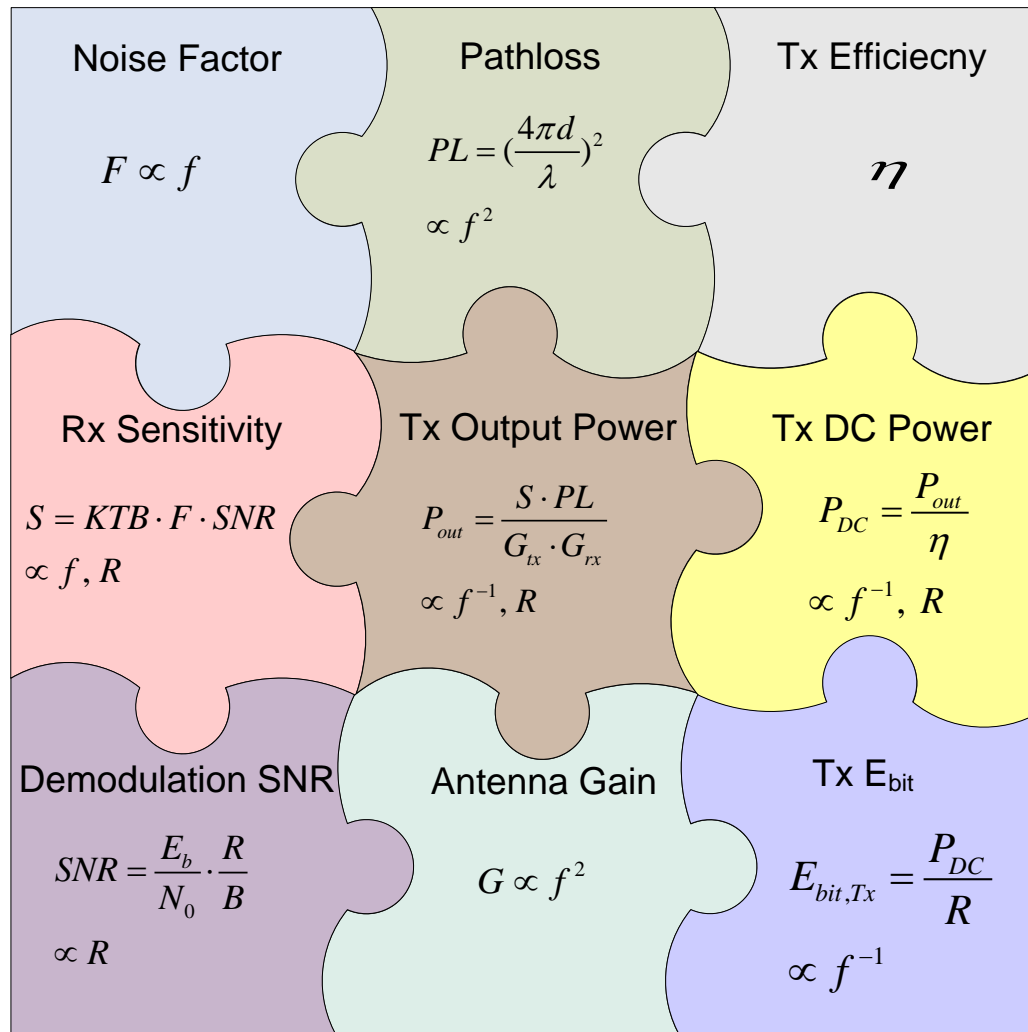
Can we achieve low P_{ave} and low E_{bit} simultaneously with high data rate, e.g. 1 Gbps?

Outline

- **Applications and Objectives**
- **System-Level Research**
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System-Level Research—Optimum E_{bit}

- E_{bit} optimization—(peak power/peak data rate)



With certain technology

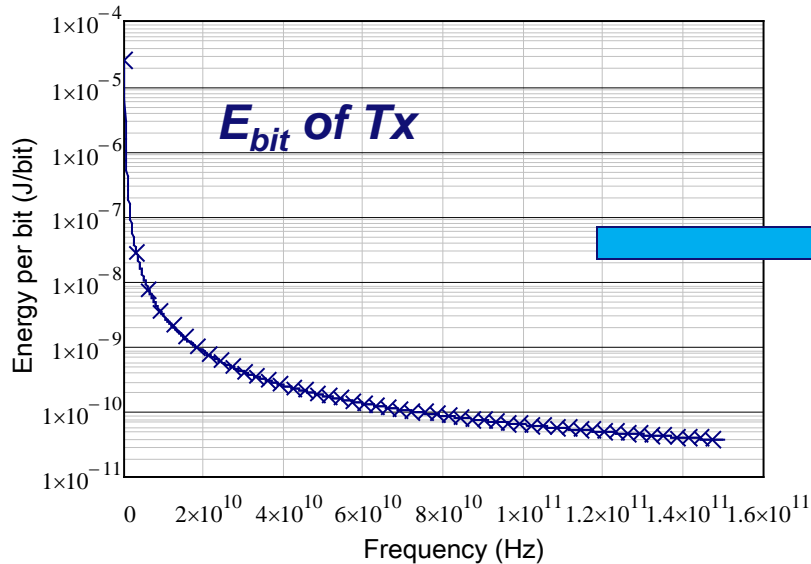
With certain distance

With certain BER requirement

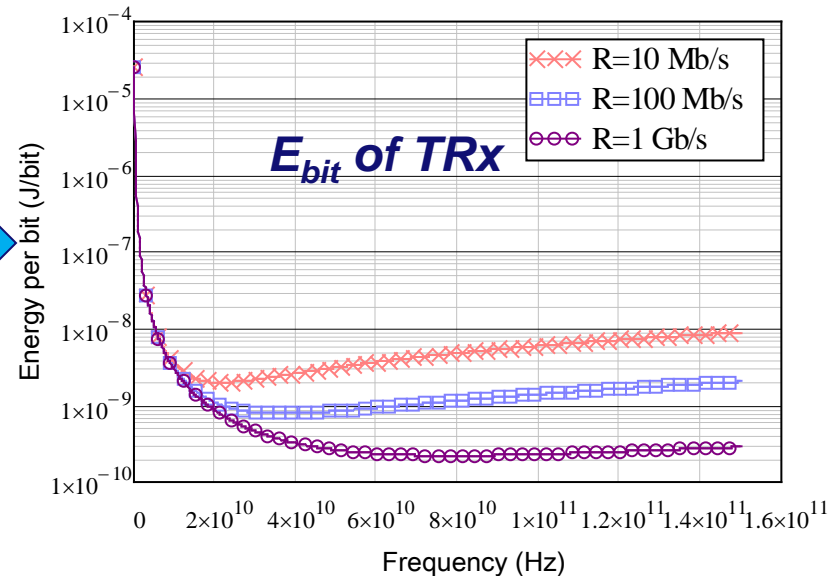
With certain Antenna area

System-Level Research—Optimum E_{bit}

• E_{bit} optimization



- $E_{bit,Tx}$
- Decreasing with frequency
 - Independent with data rate



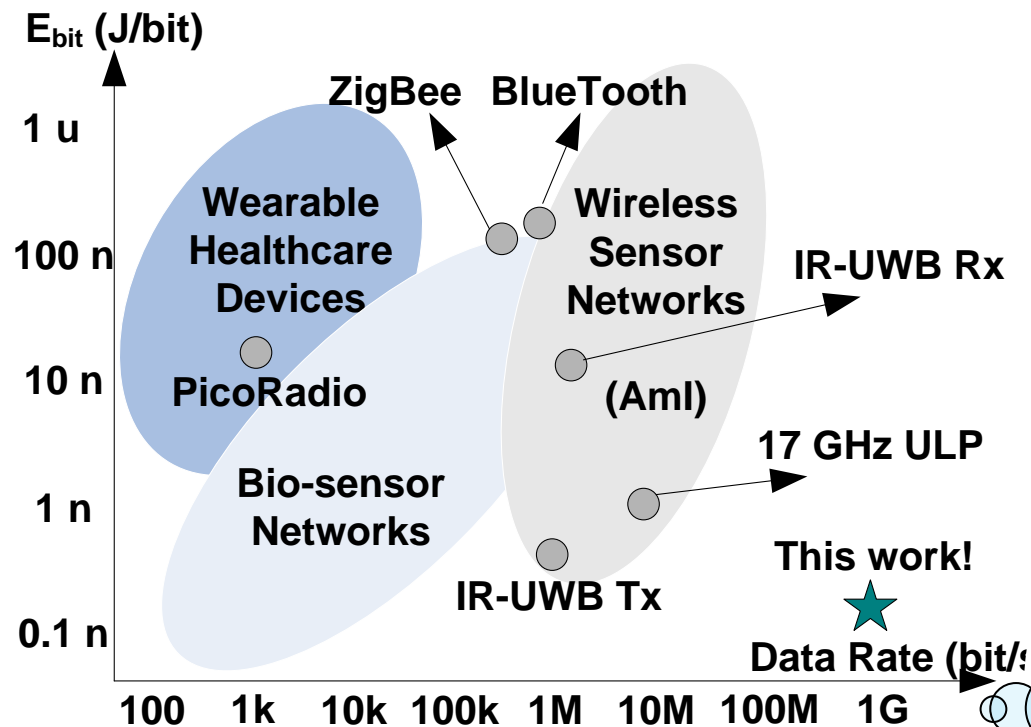
- $E_{bit,TRx}$
- Decreasing with data rate
 - Optimum frequency exists (with certain BER and technology)

Choose high frequency, directional antenna and high data rate for optimum energy per bit!

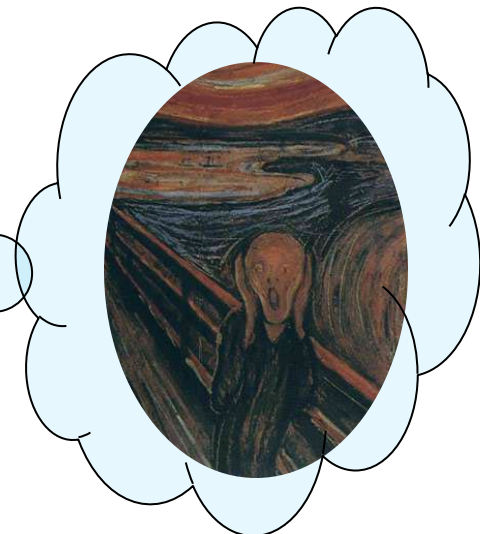
System-Level Research—Minimum E_{bit}

- In a 60 GHz FE, E_{bit} is 200 pJ/bit for the TRx at 1 Gbps data rate!

(BER= 10^{-3} , distance is 5 meters)

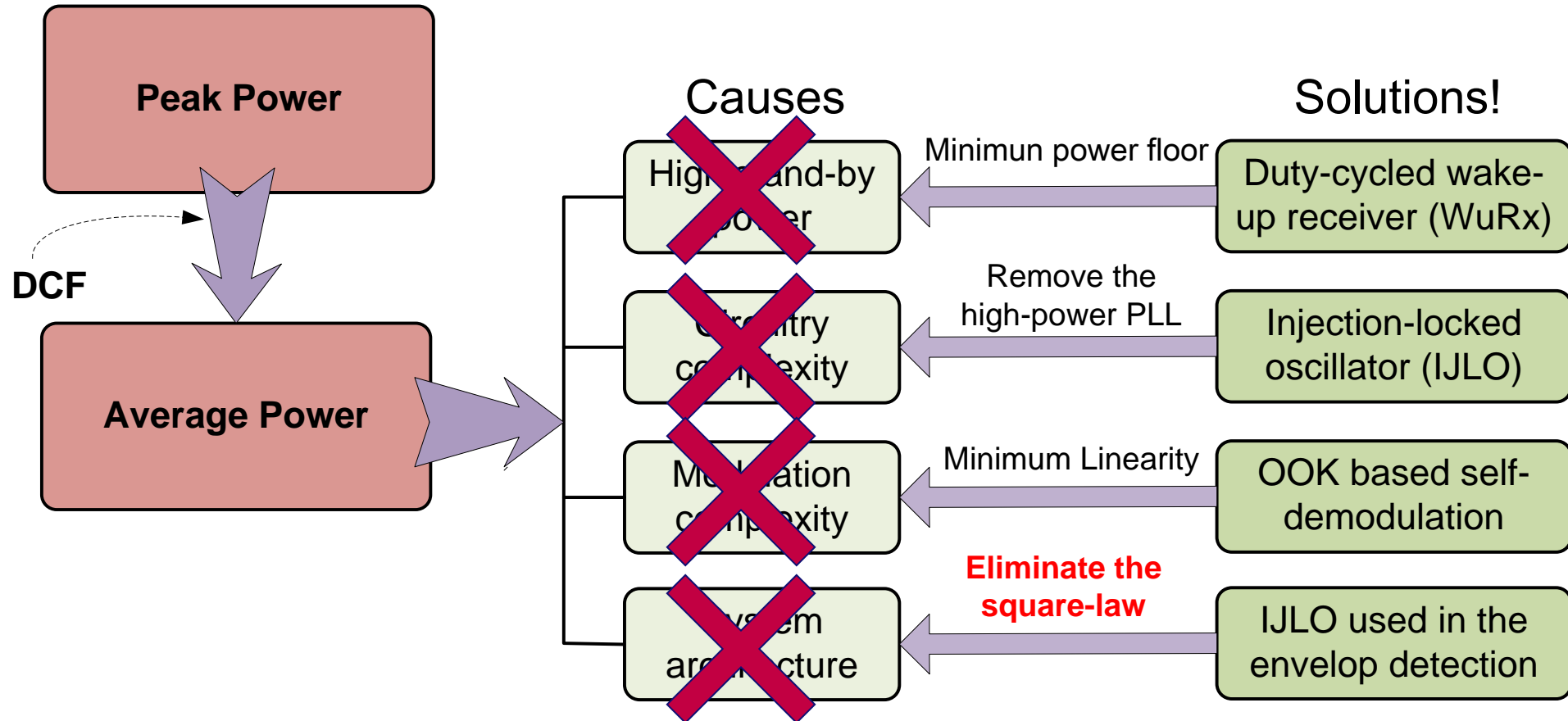


- ...however, the peak power is 200 mW...
- What about the average power?



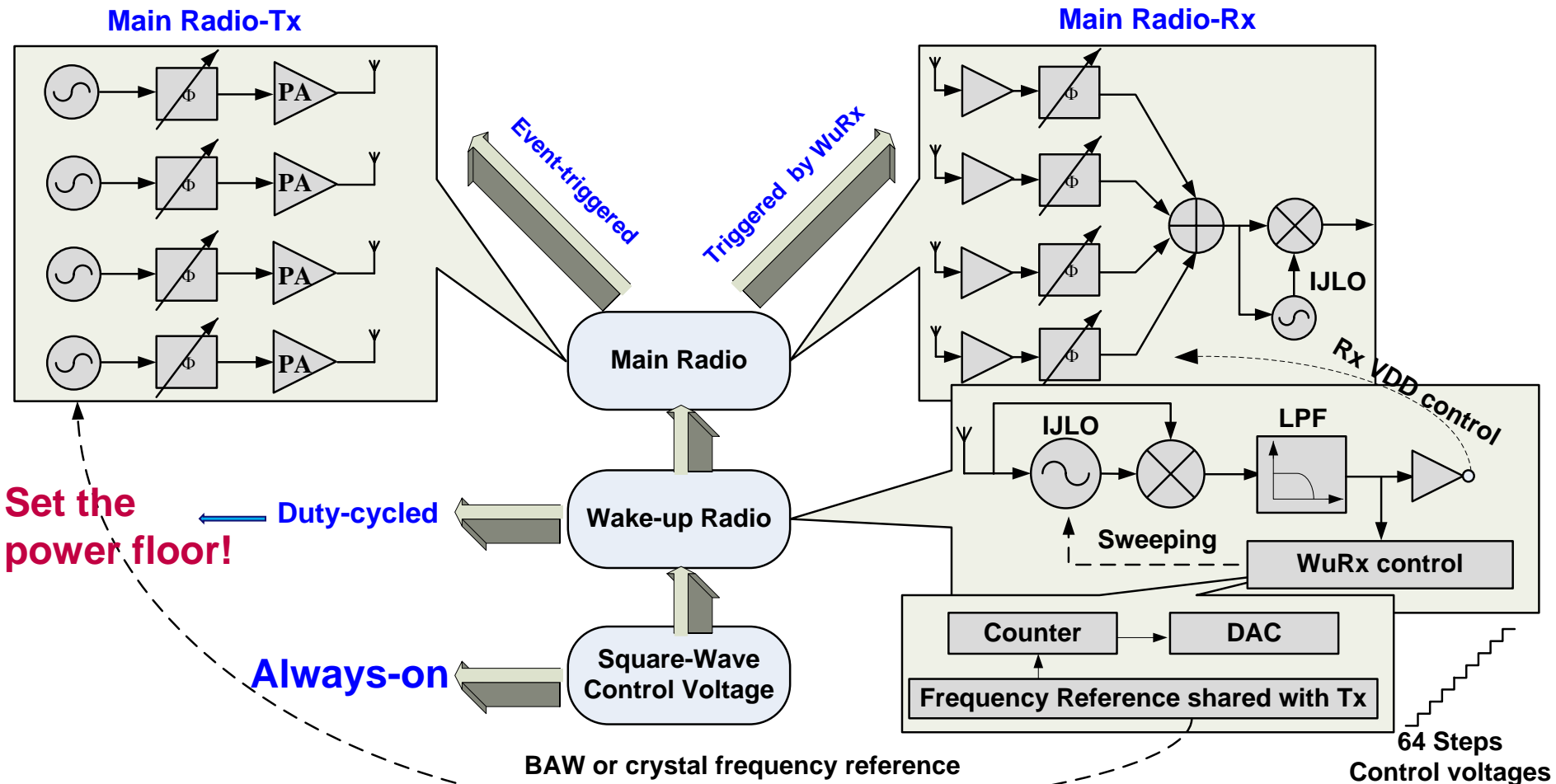
System-Level Research— P_{ave}

- Average power consumption optimization



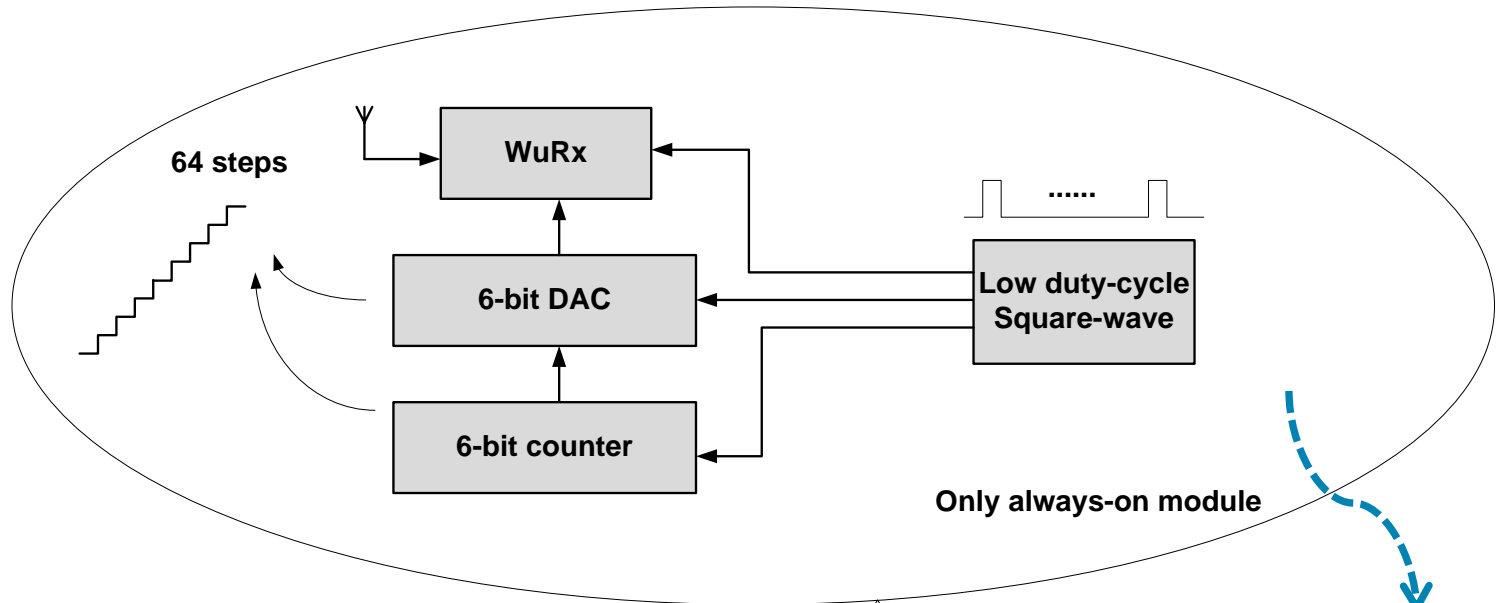
System-Level Research—Architecture

- Asynchronous duty-cycled wake-up scheme



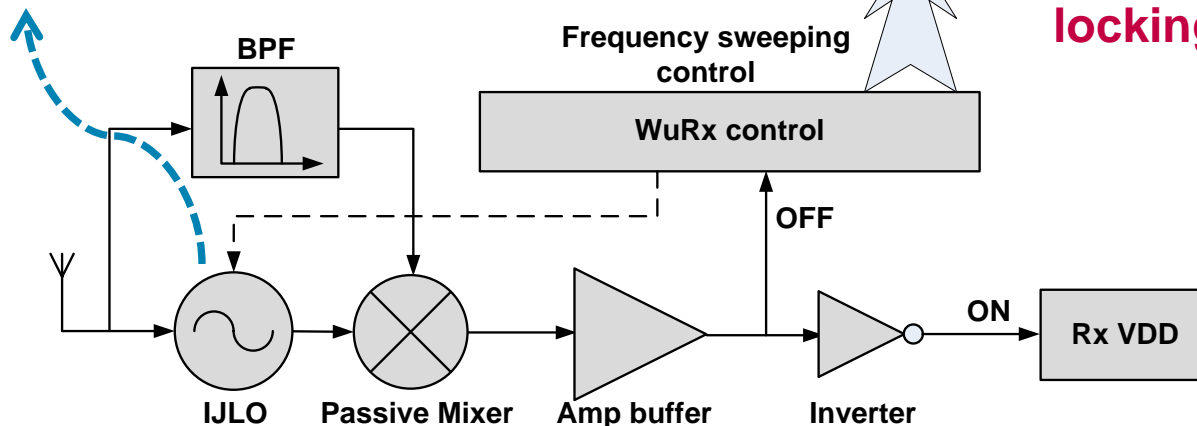
System-Level Research—WuRx

- WuRx Architecture



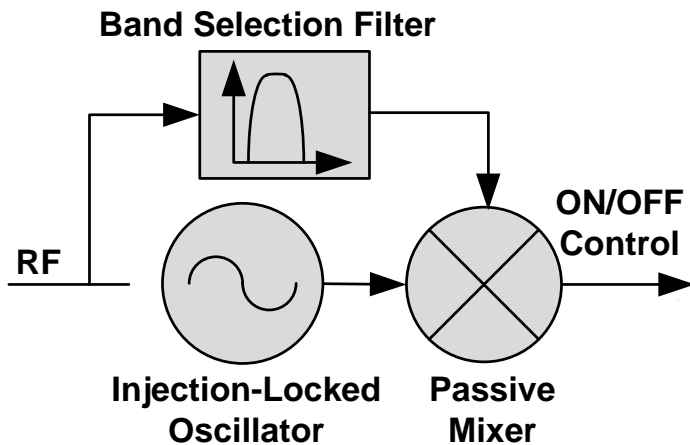
No square-law!

High sensitivity and wide locking range!

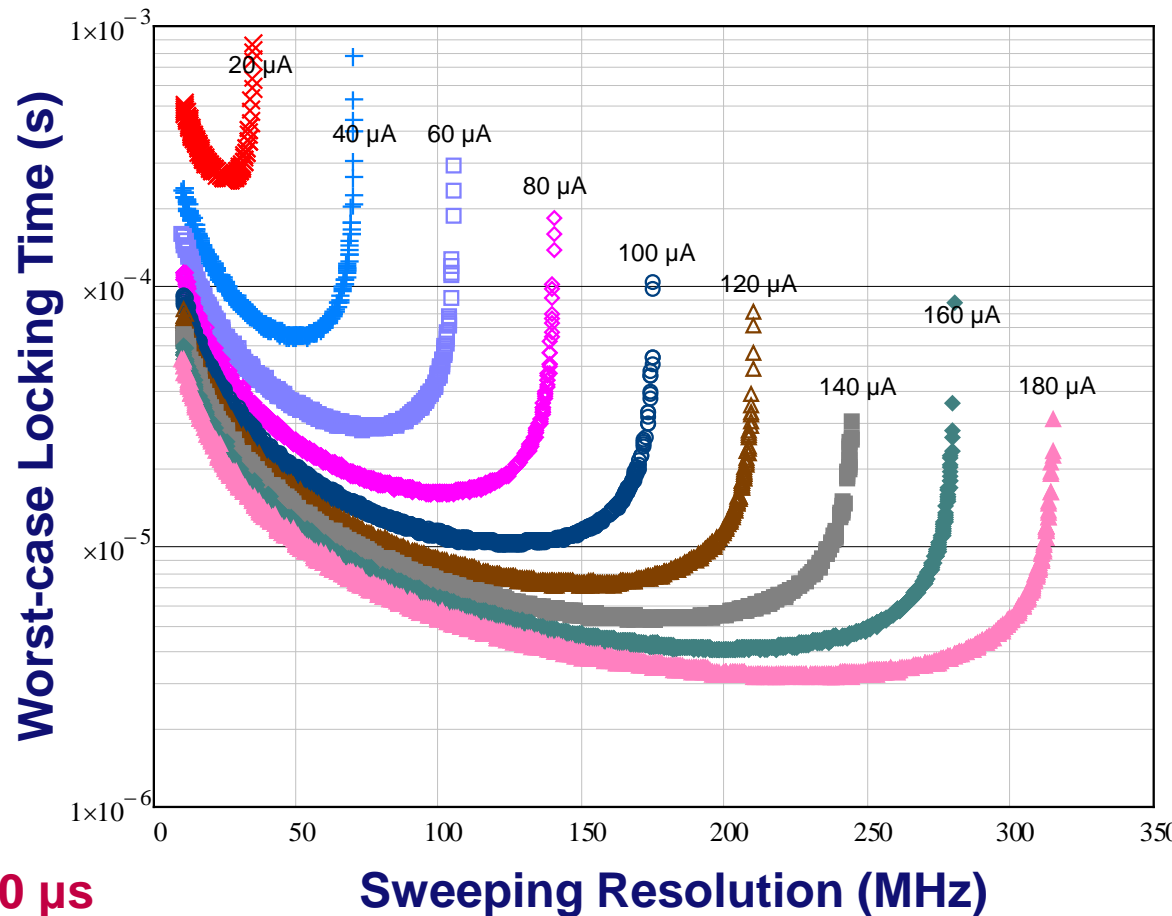


System-Level Research—WuRx

- Locking time and sensitivity of the WuRx

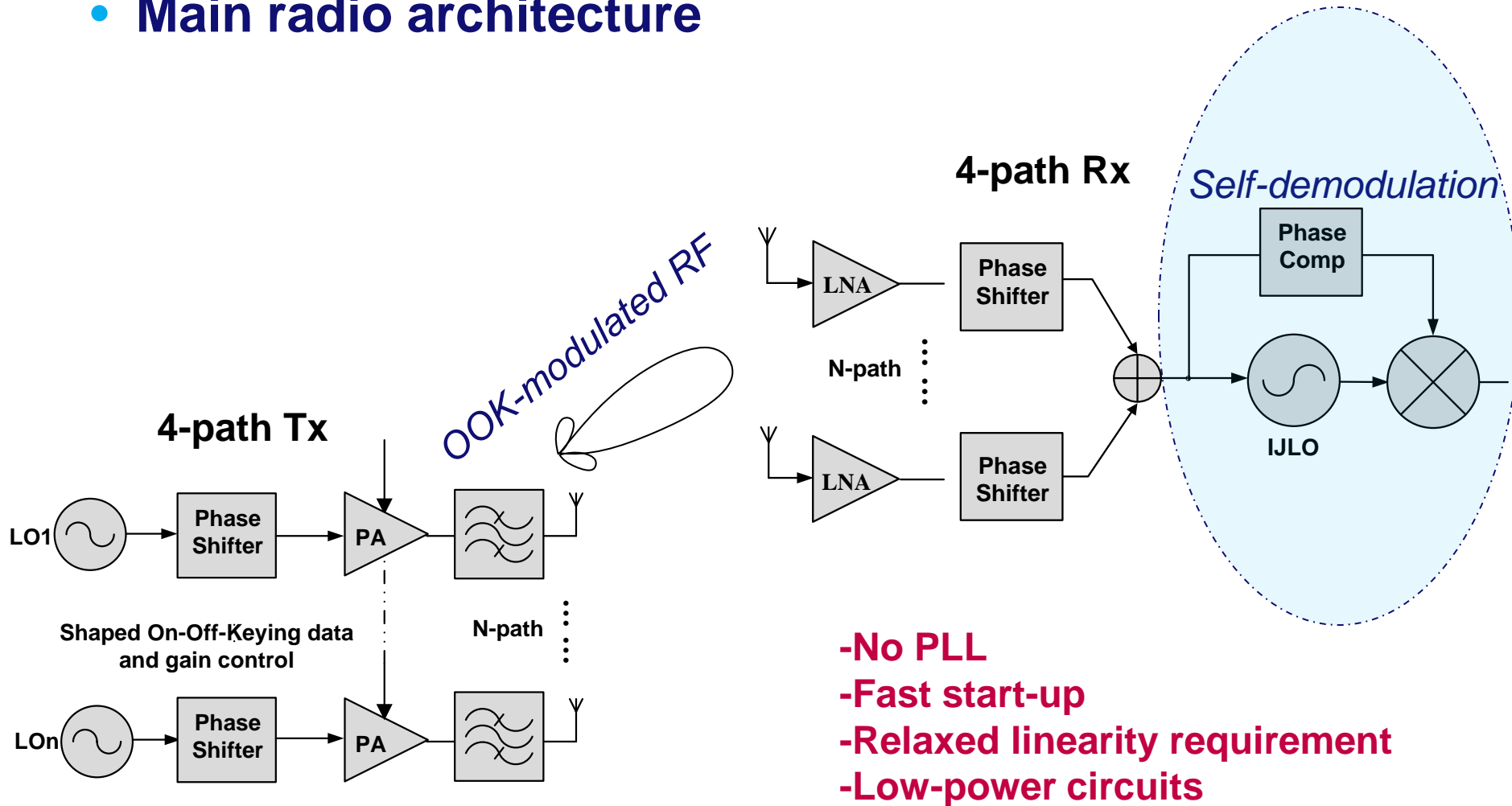


- No PLL
- Fast with high sensitivity
- Worst-case sweeping time is 20 μs with 80 μA injection current!



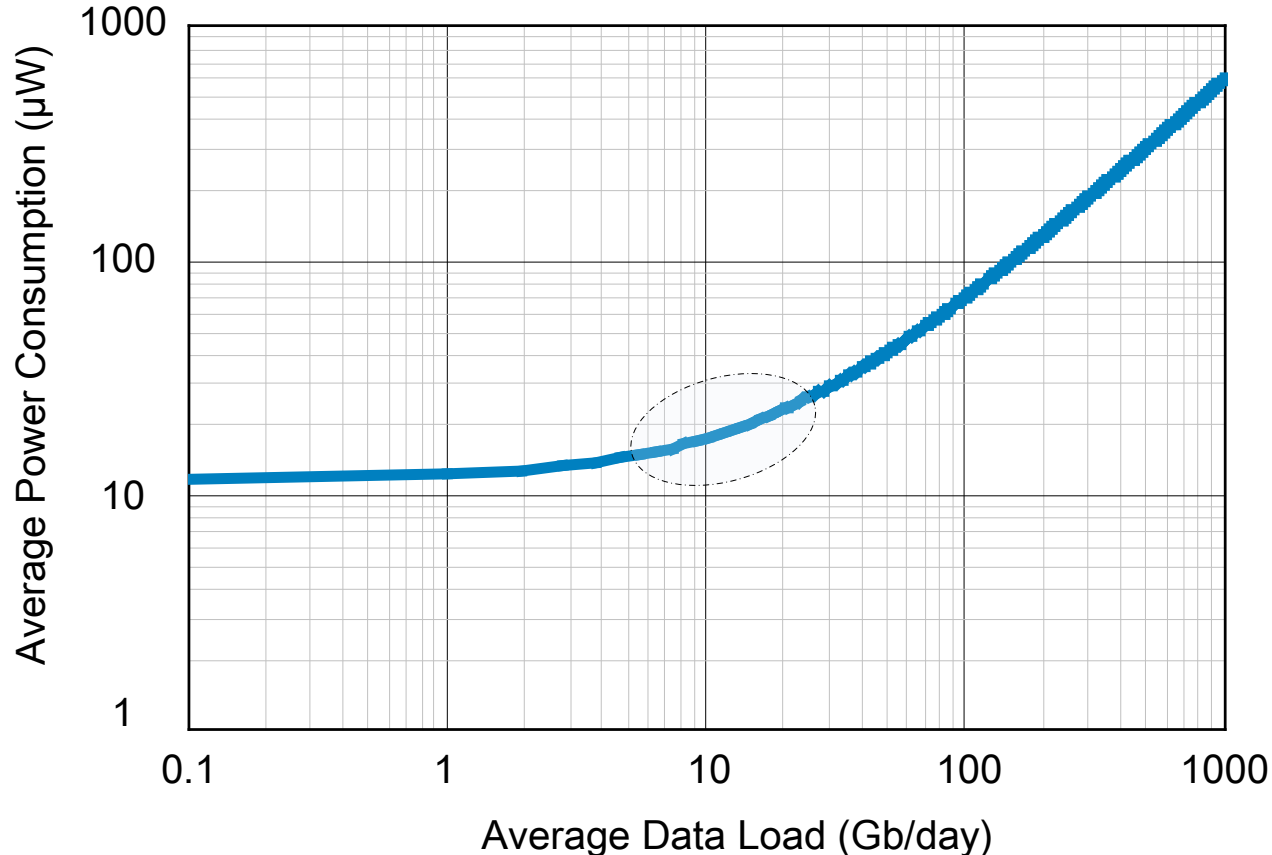
System-Level Research—Main Radio

- Main radio architecture



System-Level Research—Power Budget

- **Average power**



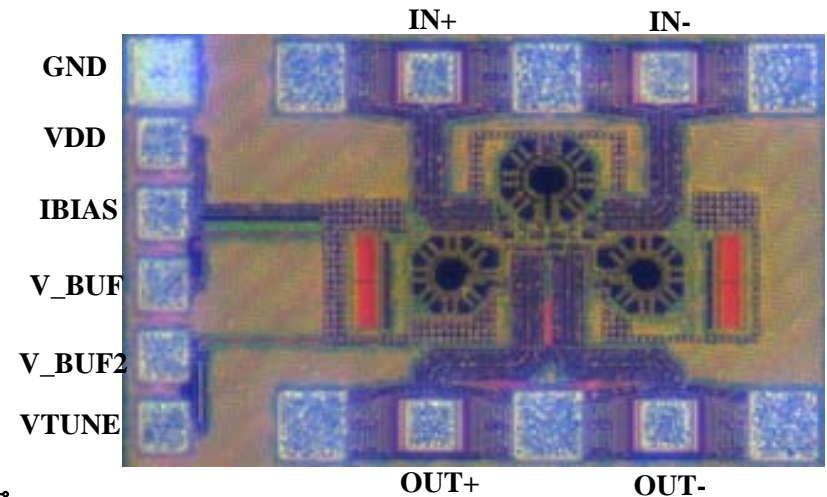
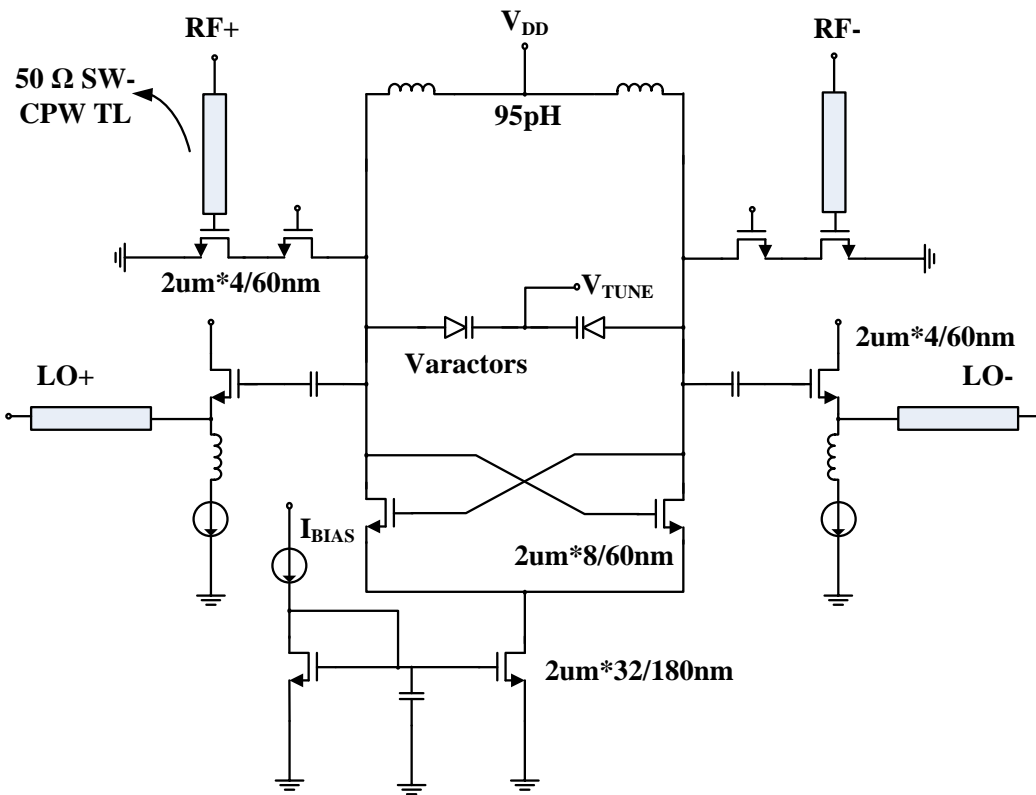
Average power consumption of the entire wireless wire FE is about 20 µW with 10 Gb/day overall data amount!

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- **Circuits and Measurement Results**
- Conclusions

Circuits and Measurement Results

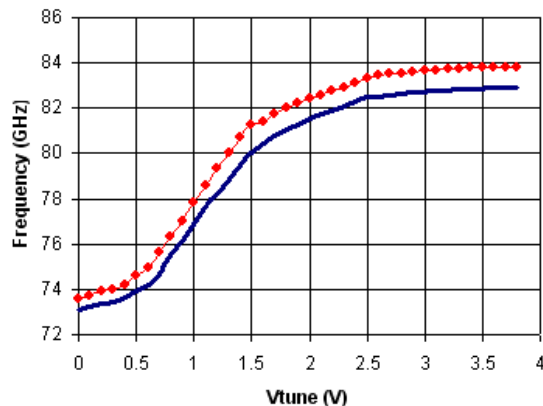
• IJLO Measurement



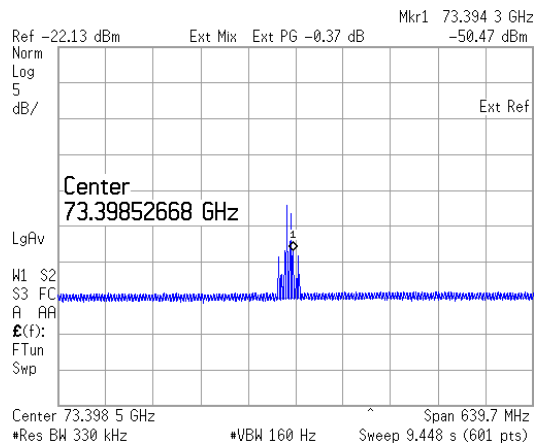
73 to 83 GHz
Locking range: 10 GHz
 P_{out} : -10 dBm
 P_{DC} : 9 mW

Circuits and Measurement Results

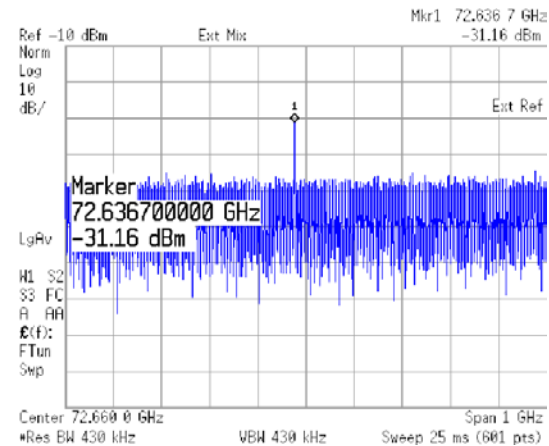
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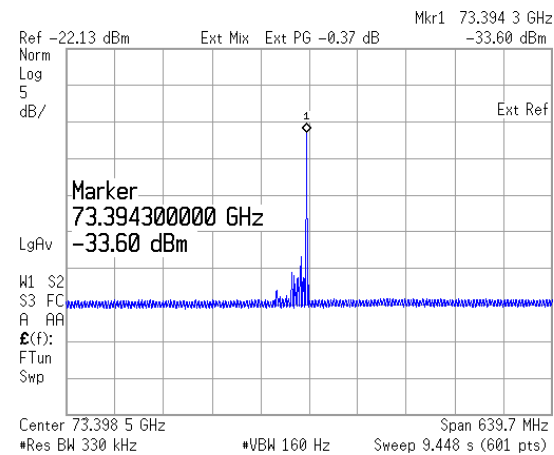
Tuning Range



Free-running spectrum



Output Spectrum

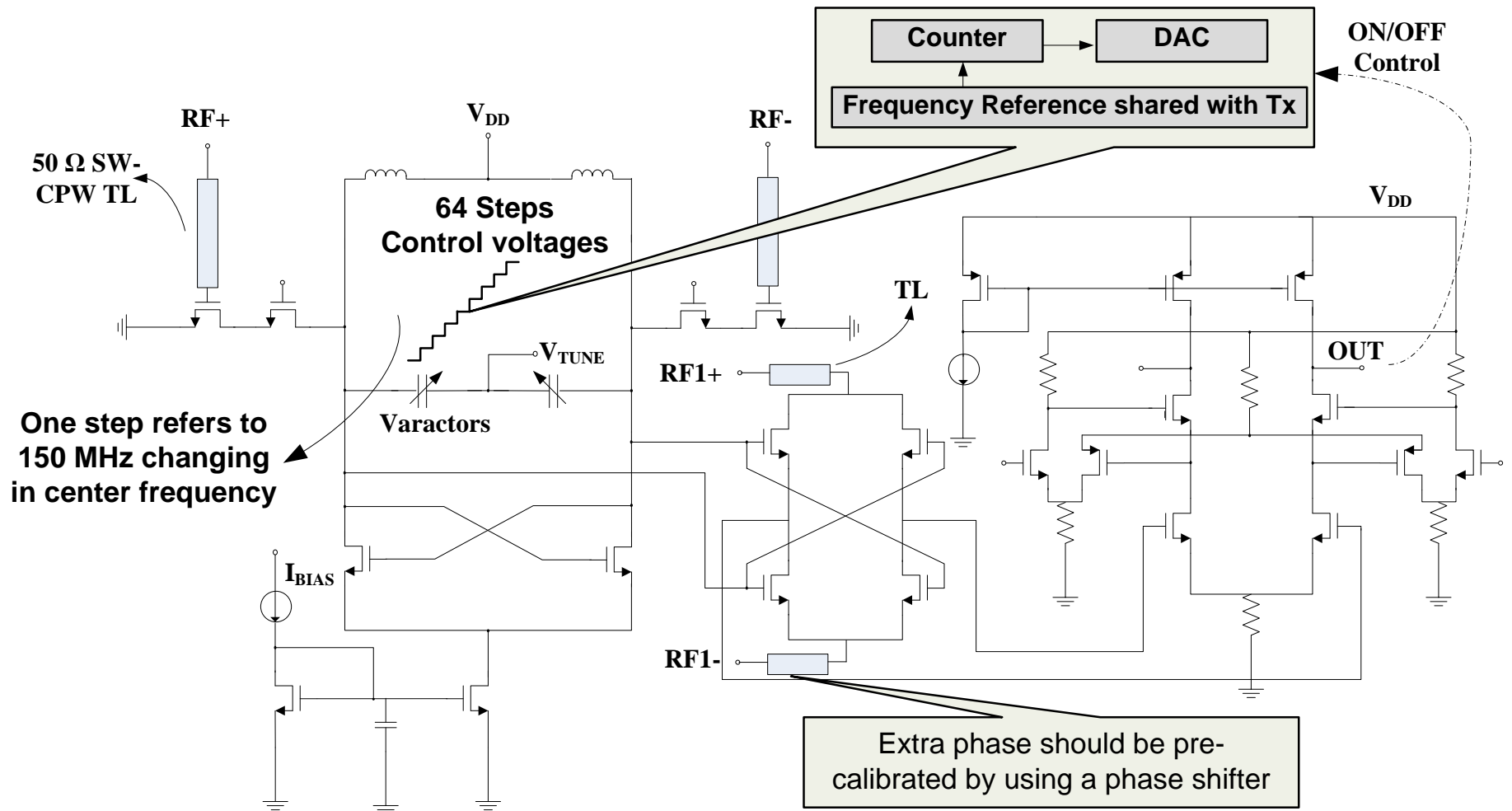


Locked spectrum (under -60 dBm injection)

-Power is concentrated in a narrower spectrum range.

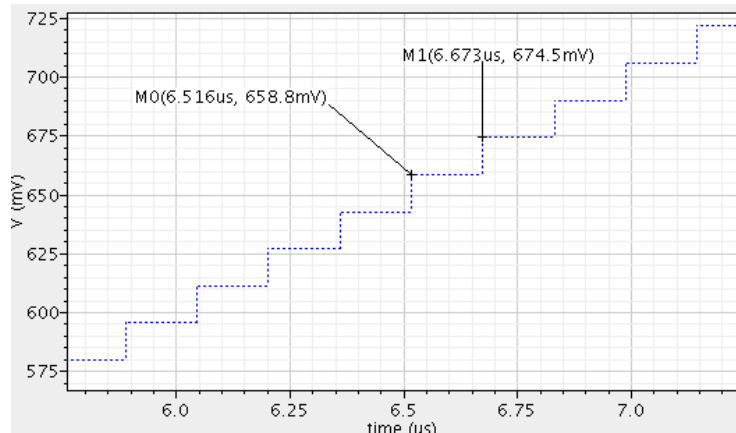
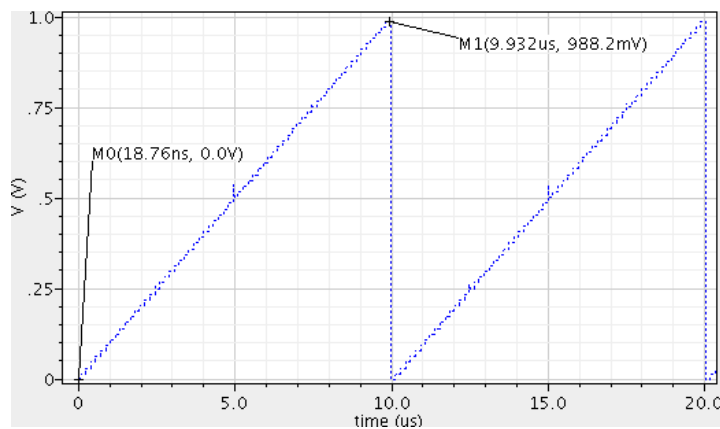
Circuits and Measurement Results

- WuRx Measurement

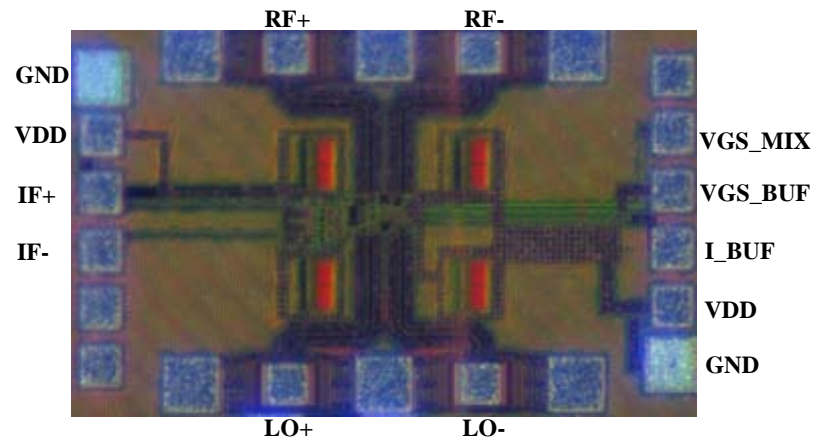


Circuits and Measurement Results

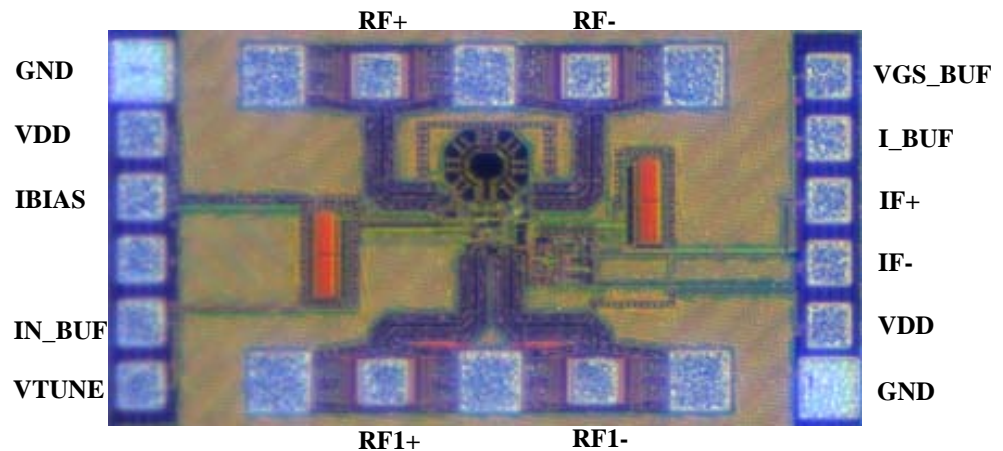
- WuRx Measurement



Digital control voltage



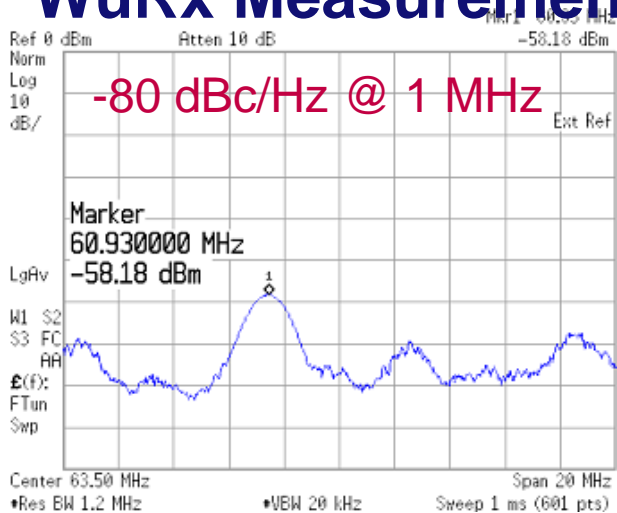
Passive mixer



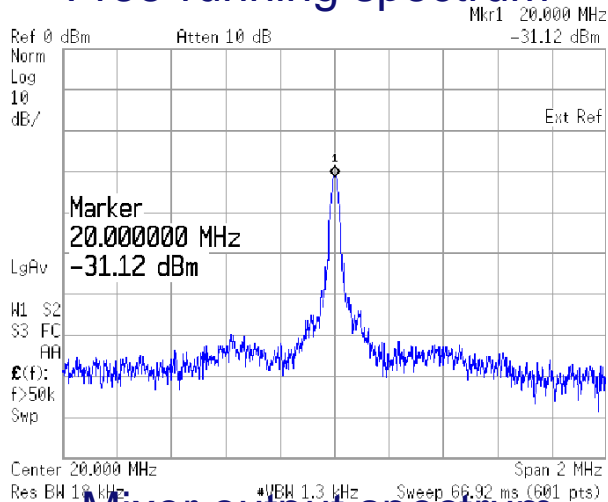
WuRx

Circuits and Measurement Results

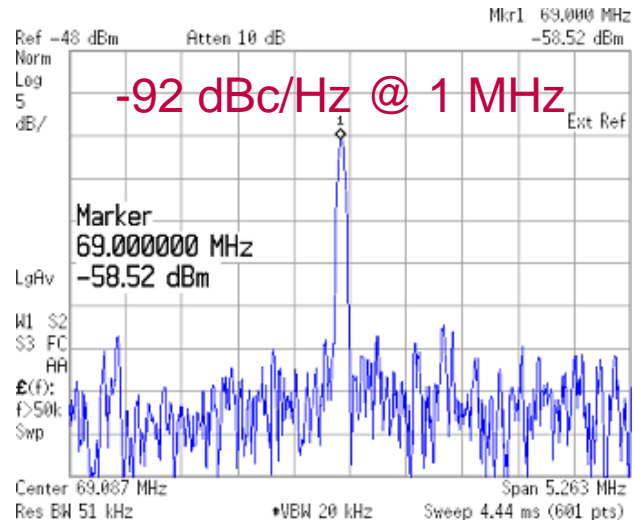
- WuRx Measurement



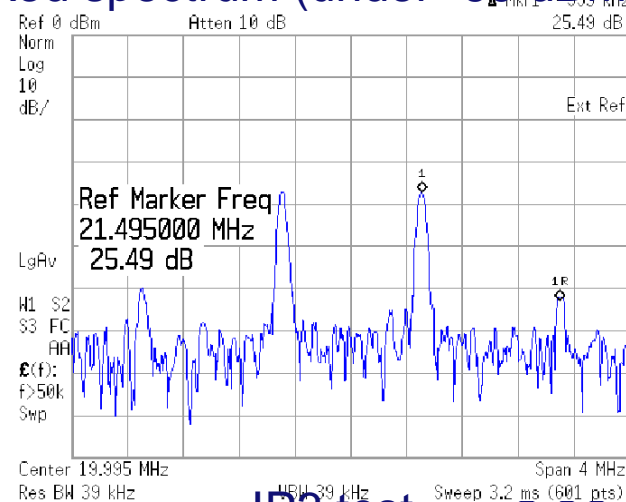
Free-running spectrum



Mixer output spectrum



Locked spectrum (under -60 dBm injection)



IP3 test

Circuits and Measurement Results

- **WuRx Measurement**

	Measurement Results
Technology	TSMC 65-nm CMOS
Frequency (GHz)	70.86 to 79.29
Bandwidth (GHz)	8.43
Power consumption (mW)	10.2
Conversion gain (dB)	10
IIP3 (dBm)	-14.75
Sensitivity (dBm)	-60
LO-RF isolation (dB)	20
Effective die size (mm²)	0.072
Energy per bit (pJ/bit)	10.2

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Circuits and Measurement Results

- Achievements so far

	Design	Tape-out
System-level	Y	
IJLO	Y (10 mW)	Y
Mixer	Y	Y
WuRx	Y (10 mW)	Y
LNA	Y (10 mW)	N
Phase shifter	Y (10 mW)	N
4-path Rx	Y (90 mW peak power)	N

Circuits and Measurement Results

- **Next steps**

	Design	Tape-out
LNA	Y	N
Phase Shifter	Y	N
Rx	Y	N
TL	Y	N
Tx (PA)	N	
Wireless charging	N (another project)	
Prototype	N	

Conclusions

- A wireless wire communication system is designed and optimized.
- 200 pJ/bit E_{bit} and 20 μW average power are obtained at 1 Gbps through the cross-layer optimizations.
- Low-power IJLO and WuRx are designed, implemented and tested, which match the theories quite well.
- Other key RF modules of the Rx are designed and optimized in the circuit-level.

Thank you!