CWTe
Centre for Wireless Technology Eindhoven

Wireless Energy for Battery-less Sensors

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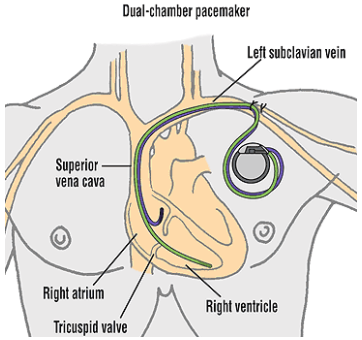
Where innovation starts

Outline

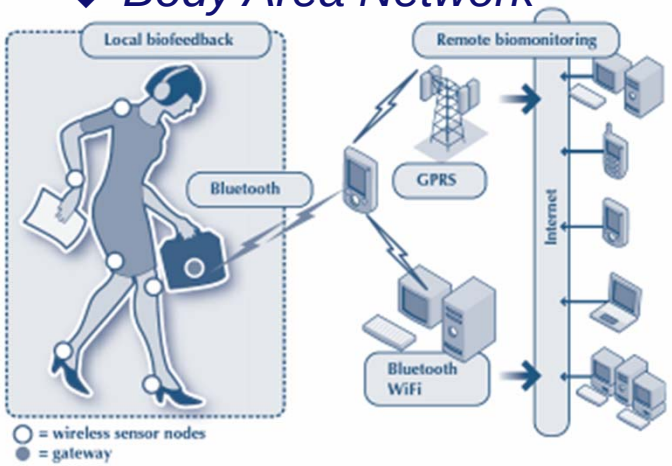
- System of Wireless Power Transfer (WPT)
- 2.4 GHz RF Wireless Power Transfer
- 60 GHz RF Wireless Power Transfer
- 60 GHz Ultra Low Power Radio
- Conclusions

Wireless Power Transfer (WPT) Application

- *Medical and Health monitoring*



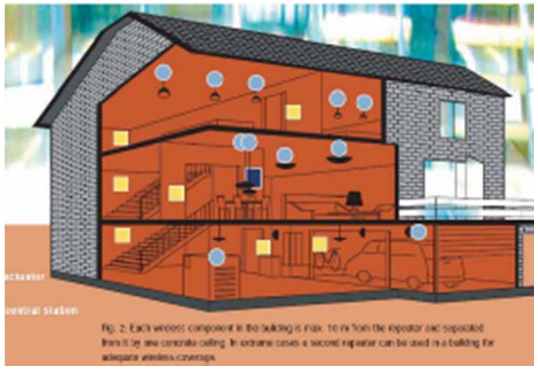
- *Body Area Network*



- *Structure Health monitoring*

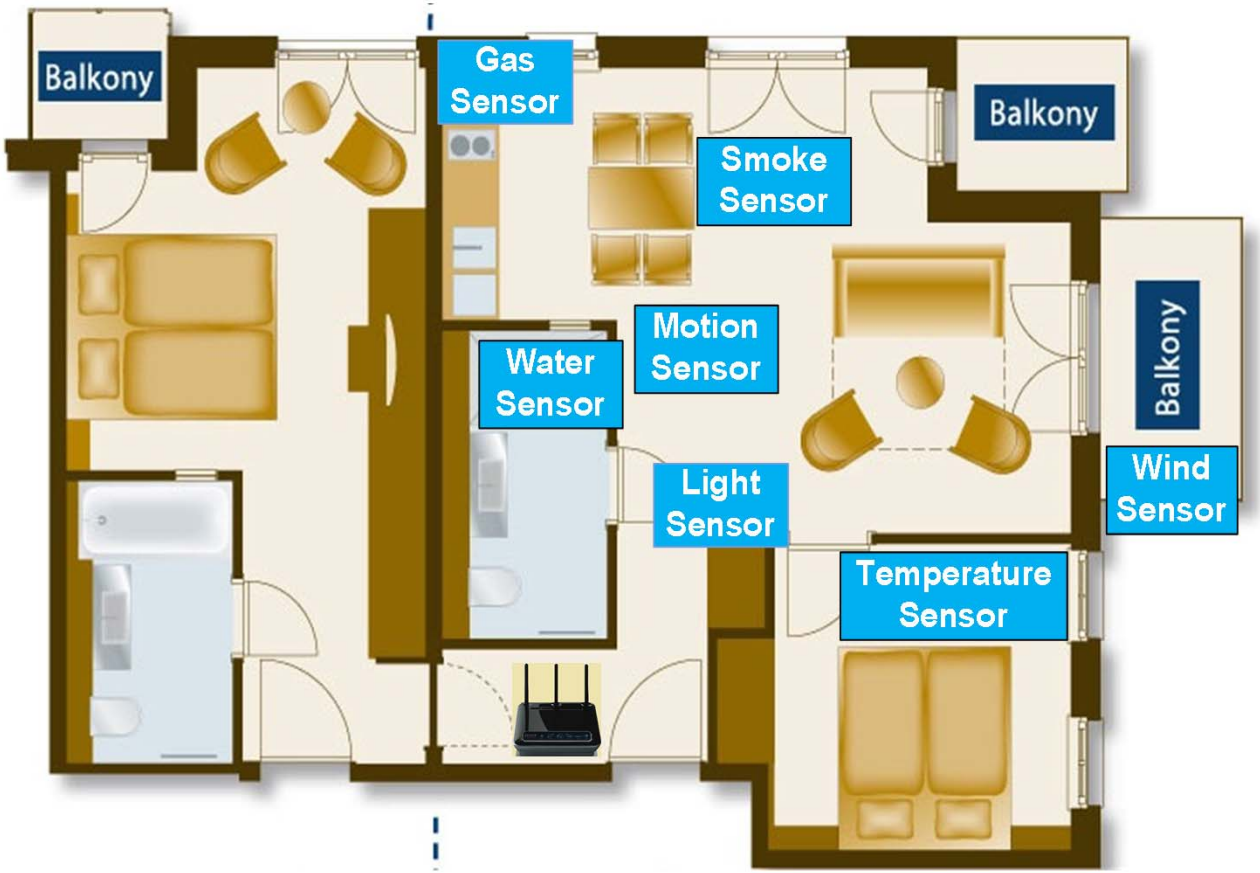
- *Wireless Sensor Networks*

- *Smart building*



Low data rate / low duty cycle / ultra-low power

Wireless Sensor Network



Battery Supply

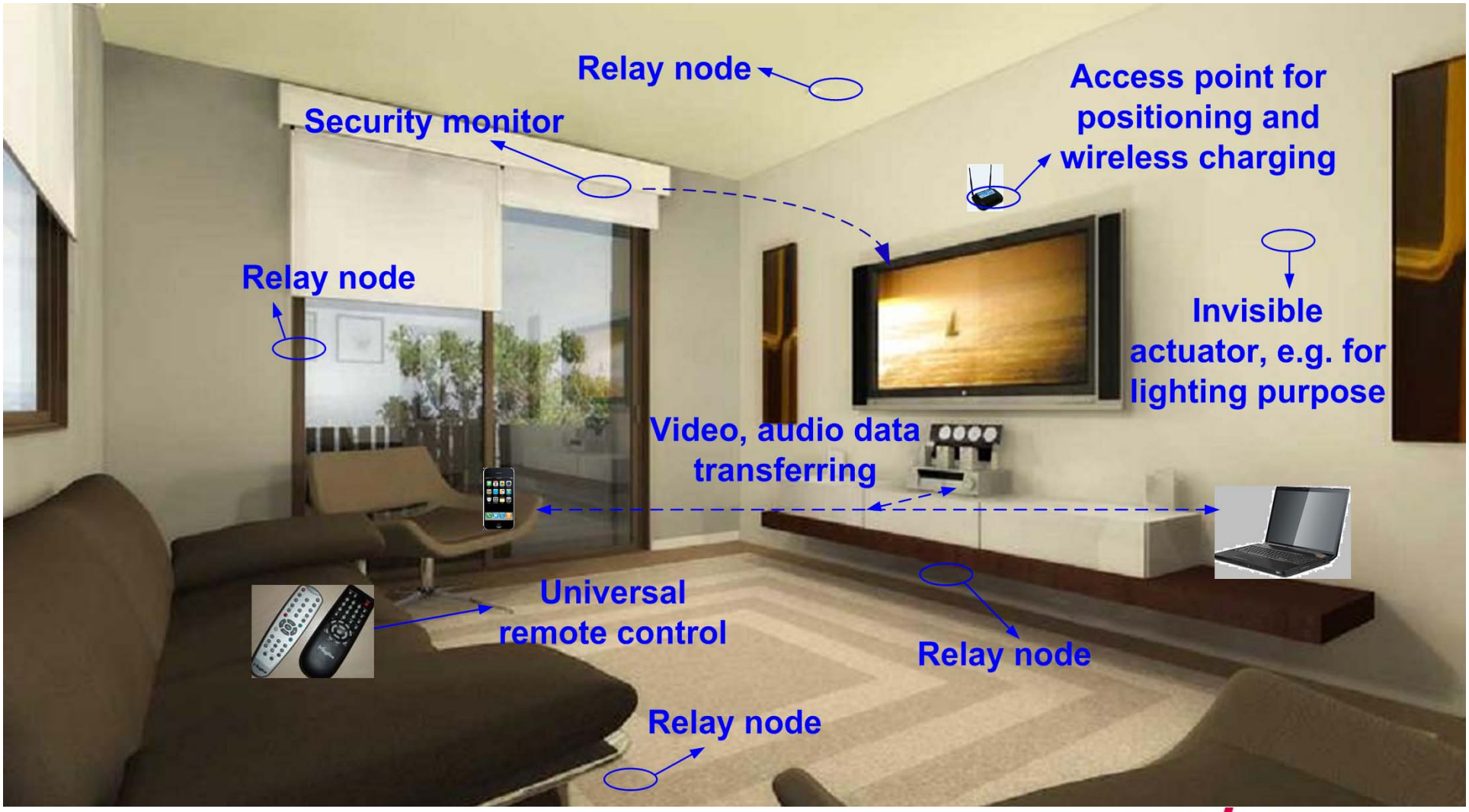
Advantage:

- *Easy to build*
- *Easy to assembly*
- *Long communication distance*

Disadvantage:

- *Limited life time*
- *Battery replacement*
- *Big Size*
- *High Cost*

Applications and Objectives



RF Power Transfer System

Energy Harvesting:

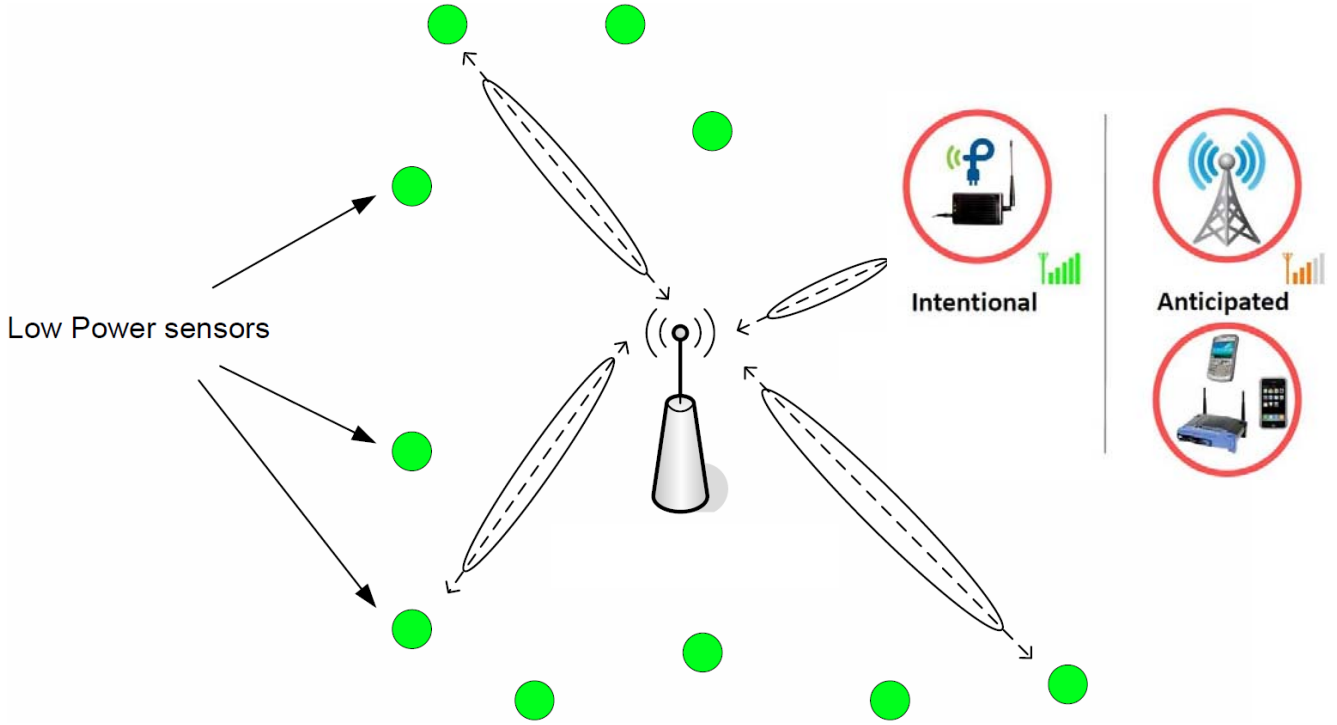
- *Chemical*
- *Mechanical*
- *Electrical*

Sensor Network Composed of:

- *Central controller as gateway*
- *Power wireless transfer to nodes*
- *ULP Wake Up radio*

RF Power Transfer

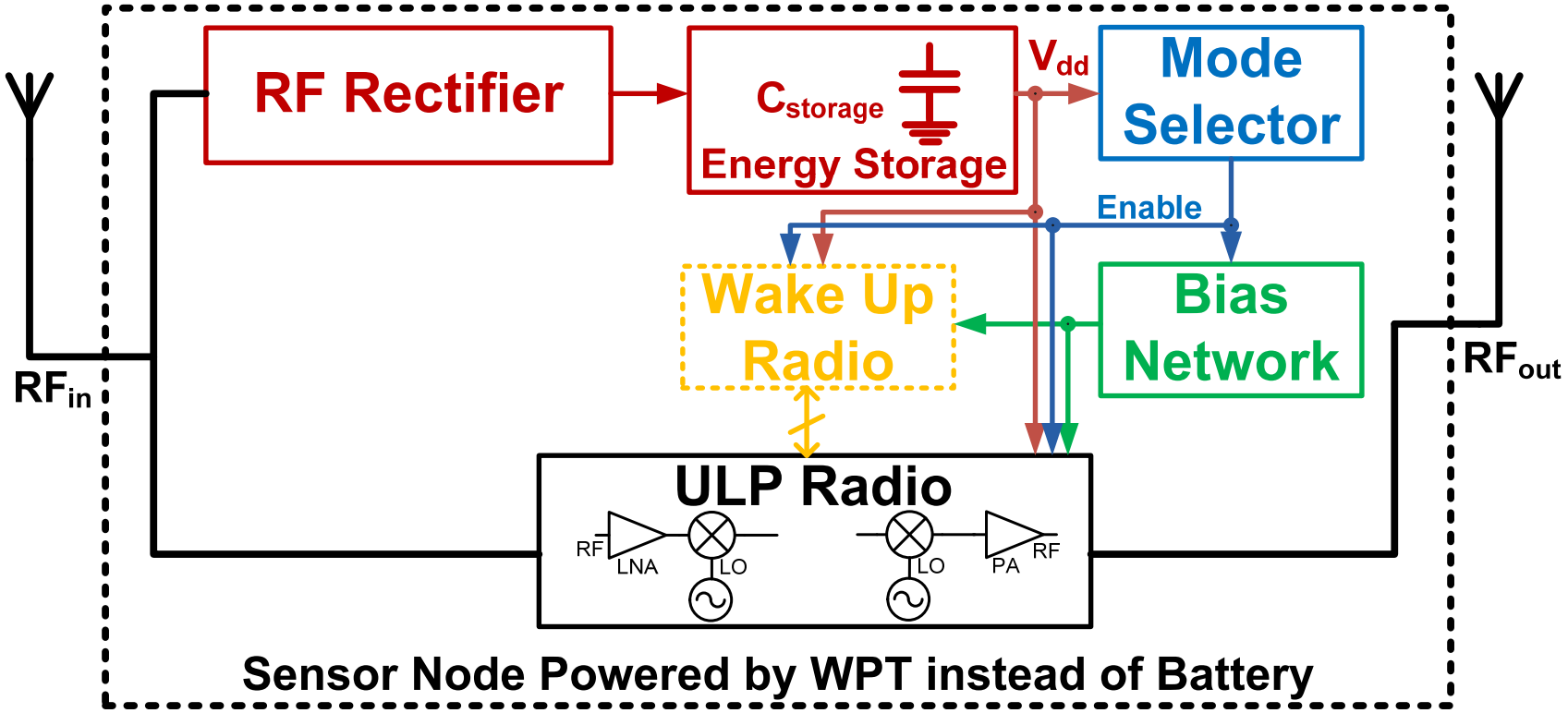
- *Wire-free*
- *Reliable*
- *Easy to integrated*



STW Project: "PREMISS" (Power Reduced Monolithic Sensor System)

Architecture of Sensor Node

Sensor Node: Wireless Power Receiver + Wake Up Radio



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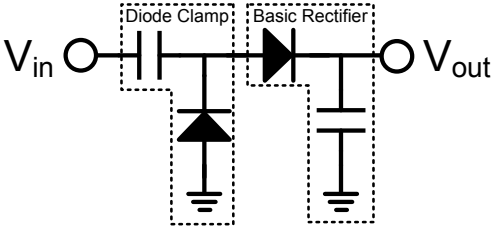
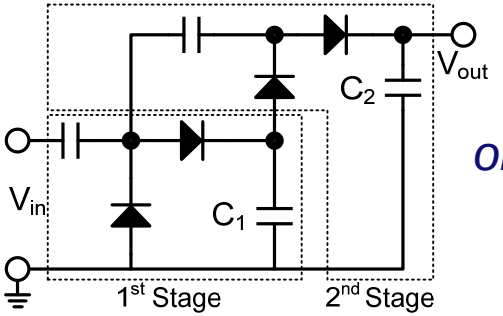
2.4 GHz Dickson Structure multi-stage Rectifier

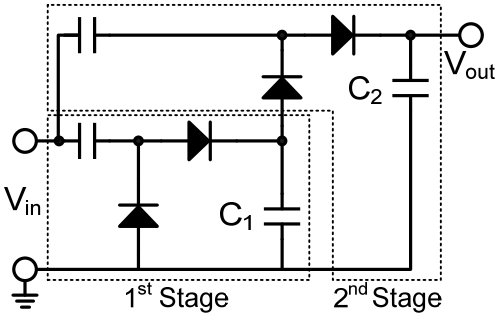


(Voltage Doubler)



(Villard Cascaded)

or



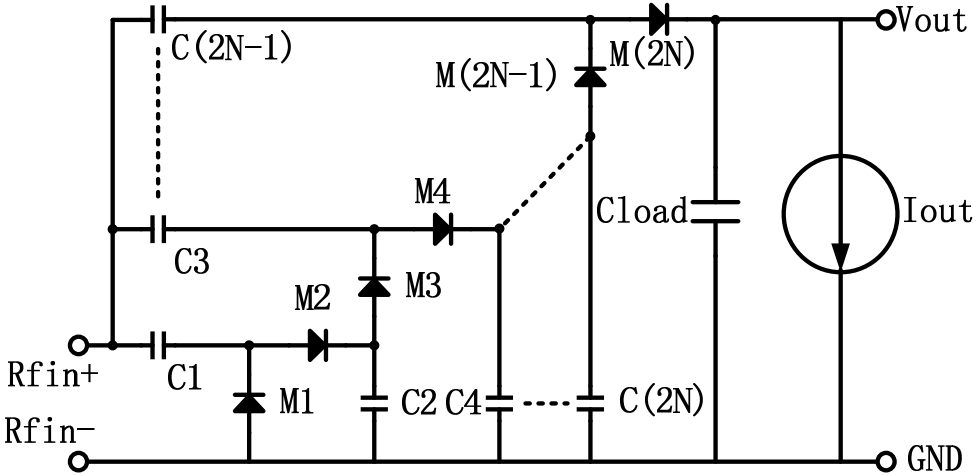
(Dickson Cascaded)

Basic Element: RF-DC Convertor

(Voltage Doubler)

Dickson vs. Villard Cascaded:

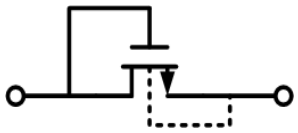
- *Symmetric in AC and DC path*
- *Stronger current drive ability*
- *Capacitor with full DC voltage*

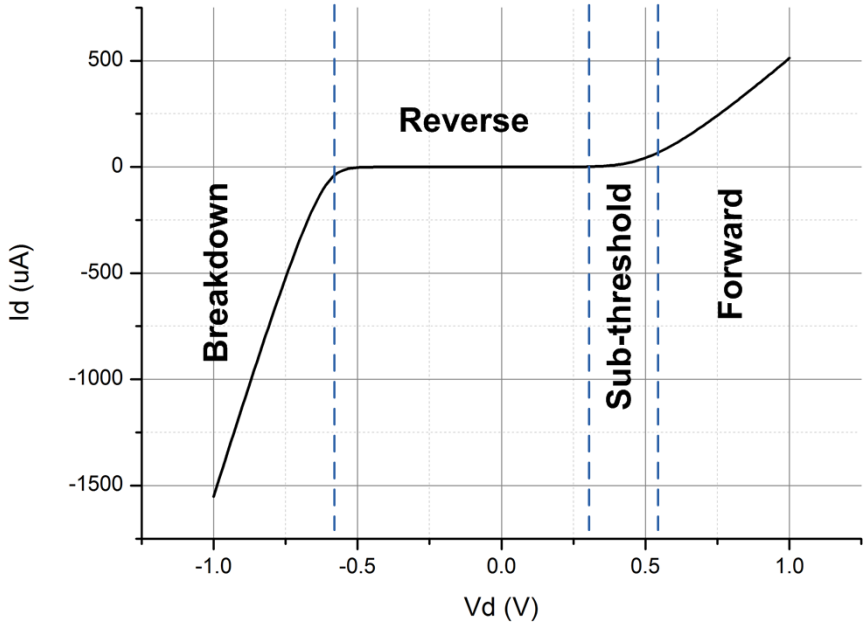


(Basic N-Stage Rectifier)

Diodes for CMOS Technology

- **Diode Connected Transistor**





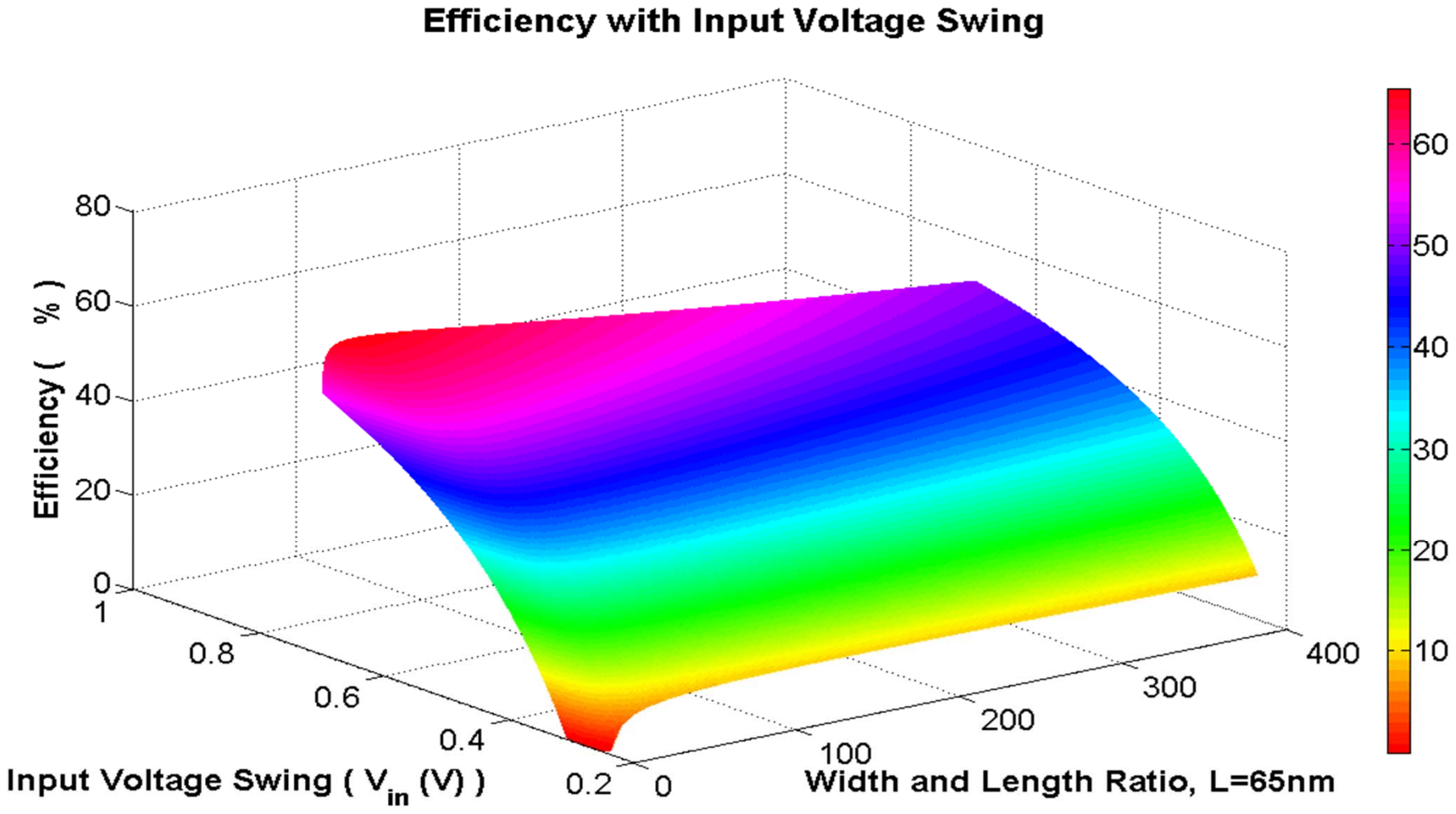
I-V Characteristics of Diode Connected Transistor in 65nm CMOS

Future: Schottky Diodes

Cut-off Frequency of Schottky Diodes in 65nm CMOS beyond 220 GHz

But: Non-standard in CMOS Technology

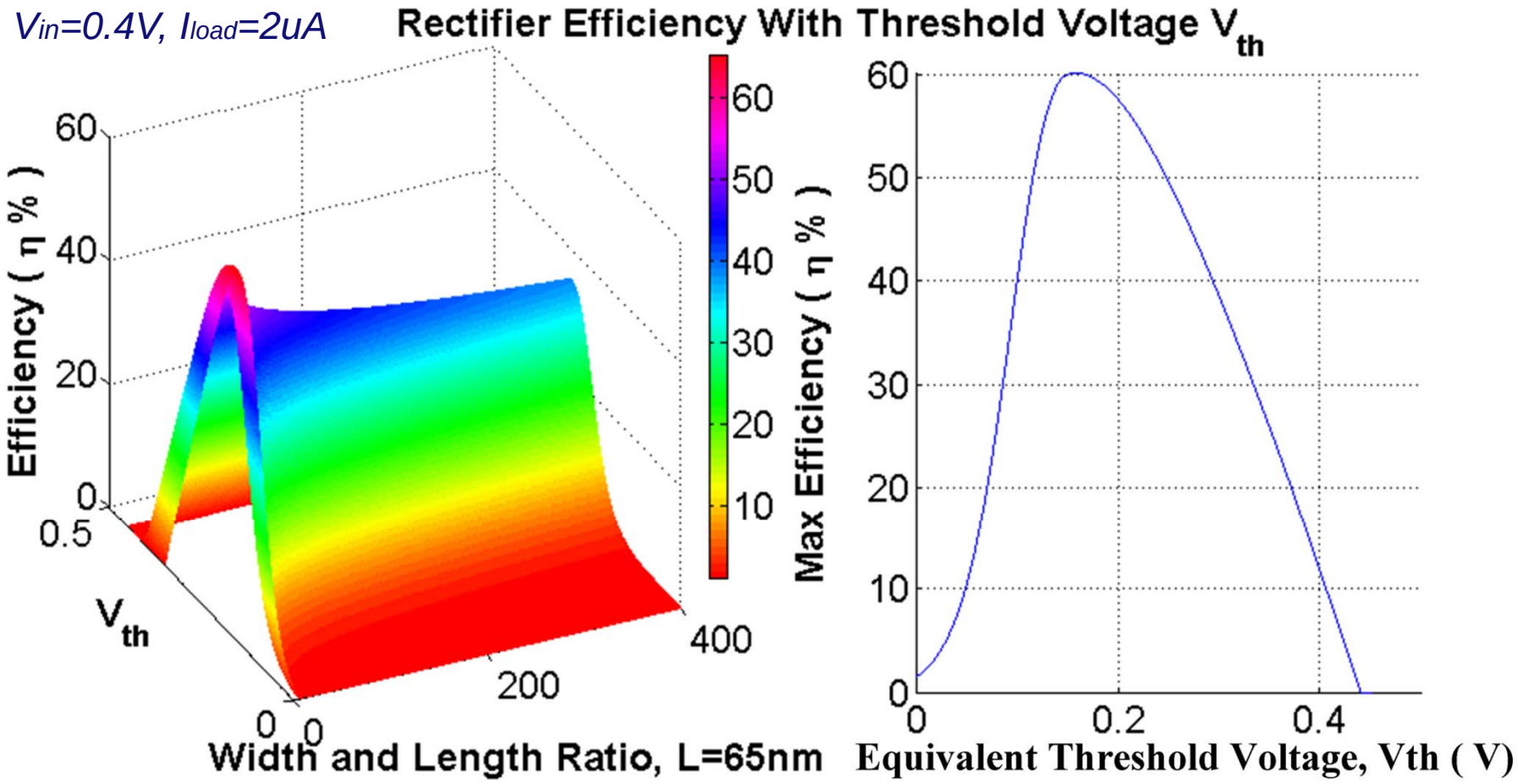
Efficiency with Input Voltage Swing



Bigger input voltage/power, the better efficiency, but limited by antenna and matching

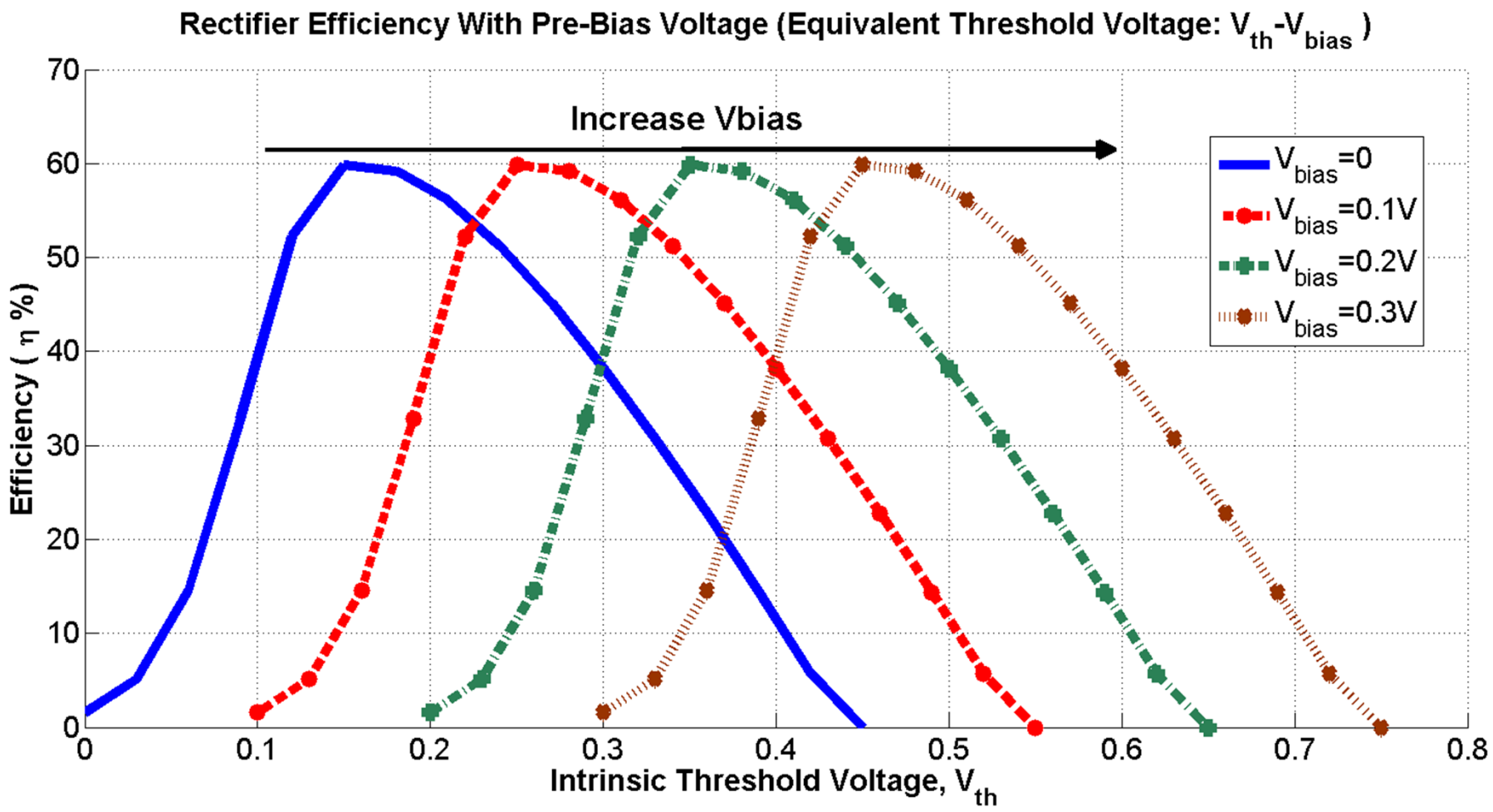
Efficiency with Threshold Voltage

V_{in}=0.4V, I_{load}=2uA



An optimized equivalent threshold voltage value for given technology

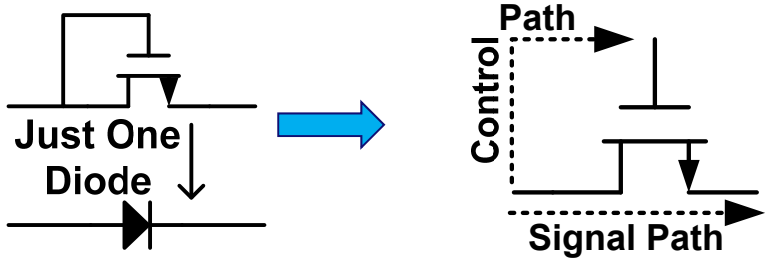
Efficiency with Pre-Bias Technology



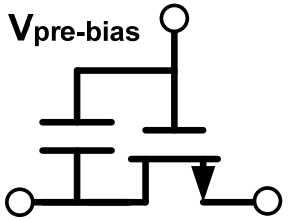
***Principle**: shift the original threshold to fit the given process*

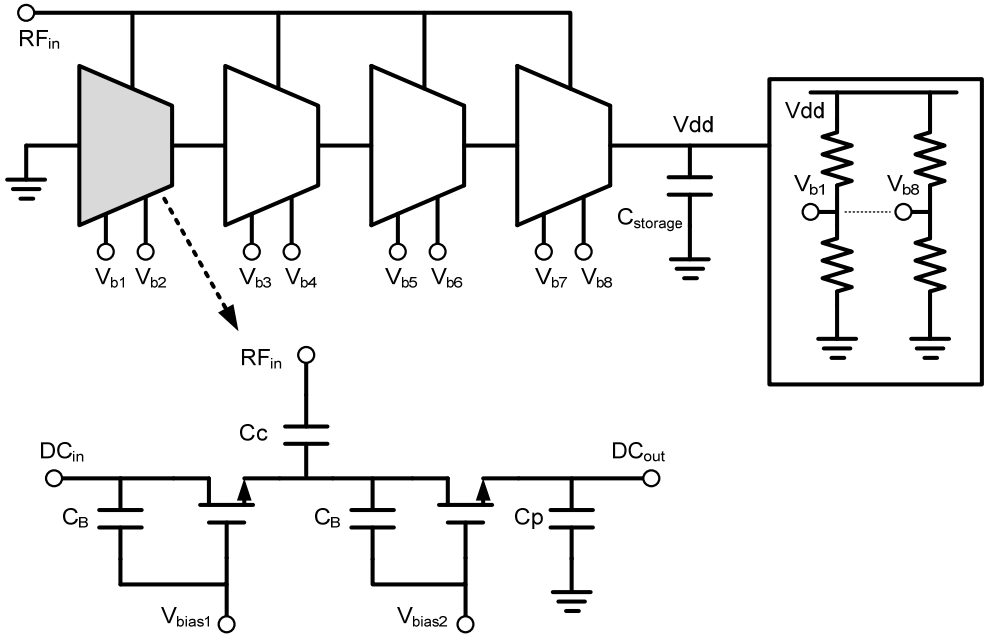
Circuit Implementation of Pre-Bias Technology

Another way to treat diode connected :



Pre-Bias Technology :





Pre-Biasing High Efficiency Rectifier: Original: 21.5%, Improved: 31%

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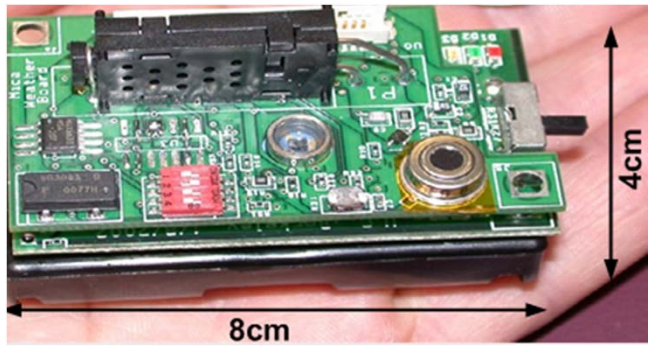
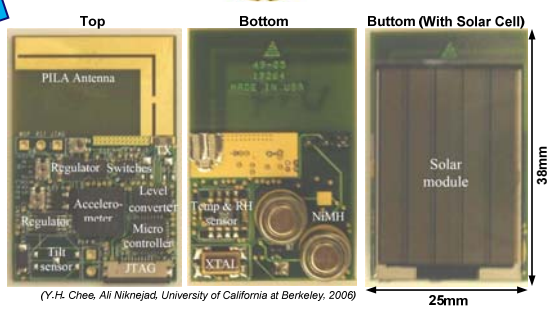
Motivation: 60 GHz



8cm × 4cm
32cm²

÷ 3.3



(Y.H. Chee, Ali Niknejad, University of California at Berkeley, 2006)

3.8cm × 2.5cm
9.5cm²

÷ 475

0.2cm × 0.1cm
0.02cm²

?

Problems:

- *Antenna Integration*
- *Assembly Components*
- *Battery Size*
- *Cost*

(2.4 GHz)

Problems:

- *PCB Based*
- *Harvesting Method*
- *not easy to integrate*

(1.8 GHz)

Solution:

- *mm-Wave*
- *On-chip antenna*

(60 GHz)

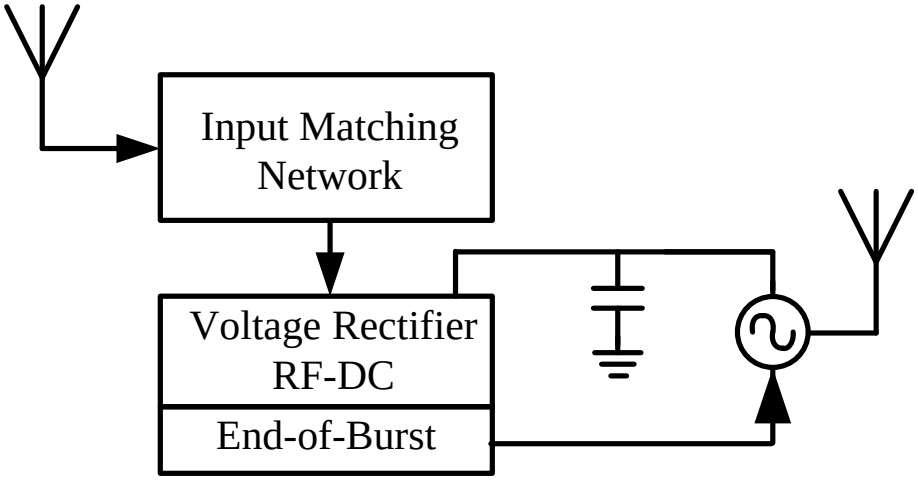
(Y.H. Chee, Ali Niknejad
University of California at Berkeley, 2006)

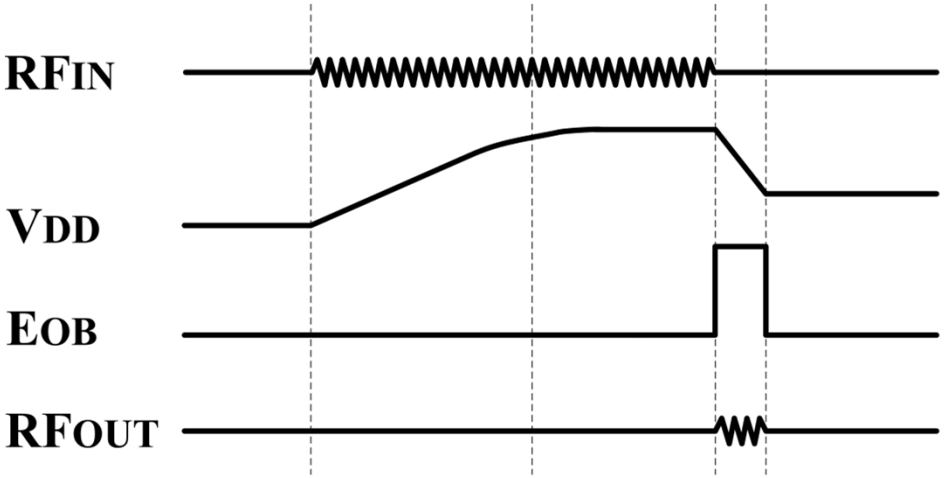
Motivation: 60 GHz

- Small wavelength enables:
  - Integrate antenna on-chip
  - Create antenna arrays to
    - Provide high antenna gain
    - Create highly directional pencil beams

- Wide bandwidth available at 60 GHz enables
  - High data rate in the order of Gbits/s
  - Short transmission burst

Proposed System of 60 GHz Monolithic Wireless Sensor Nodes





On-Chip Antenna:
Small size

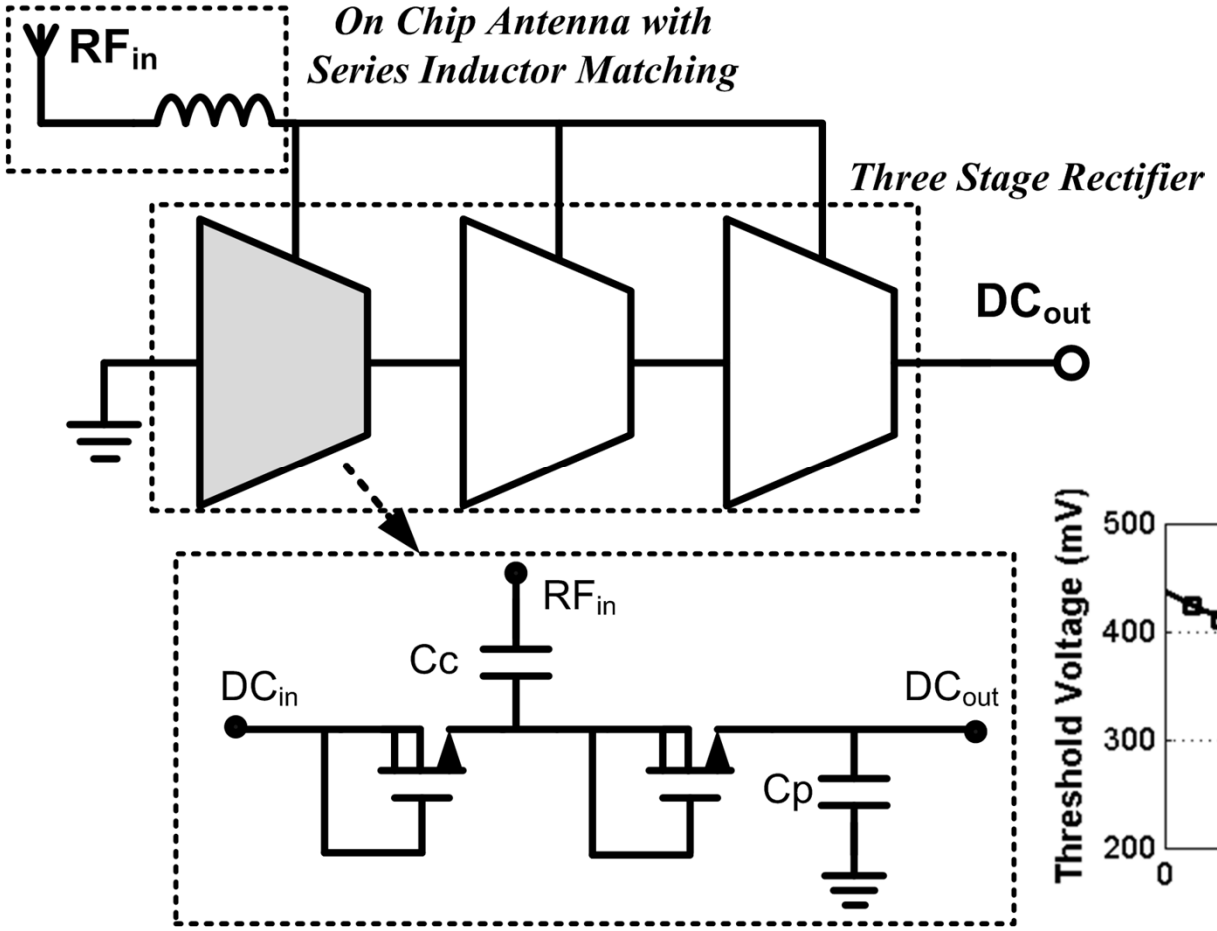
Rectifier:
Used as the supply voltage generator

End-of-Burst:
Used as the input power monitor

Advantage:

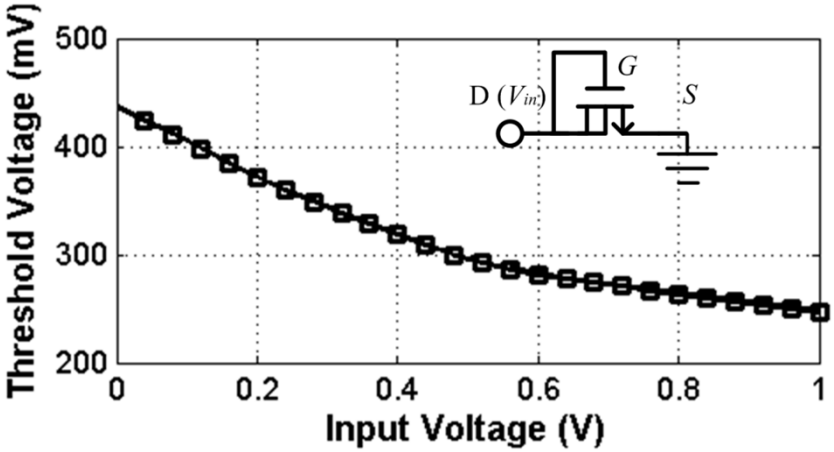
- ***Monolithic, fully integration***
- ***Small size, 2mm ×1mm***

60 GHz Rectenna

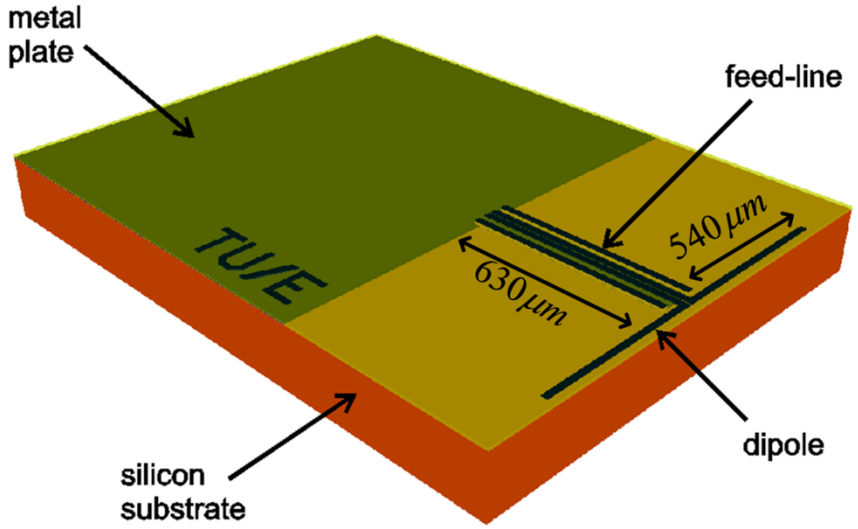


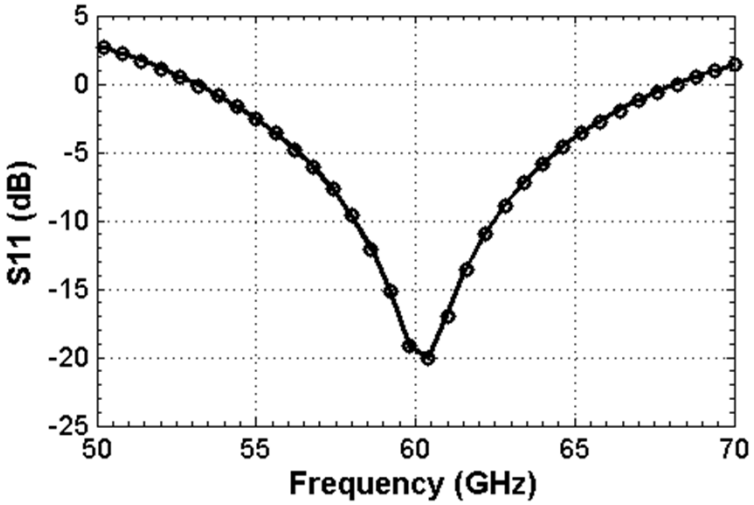
60 GHz Rectenna:

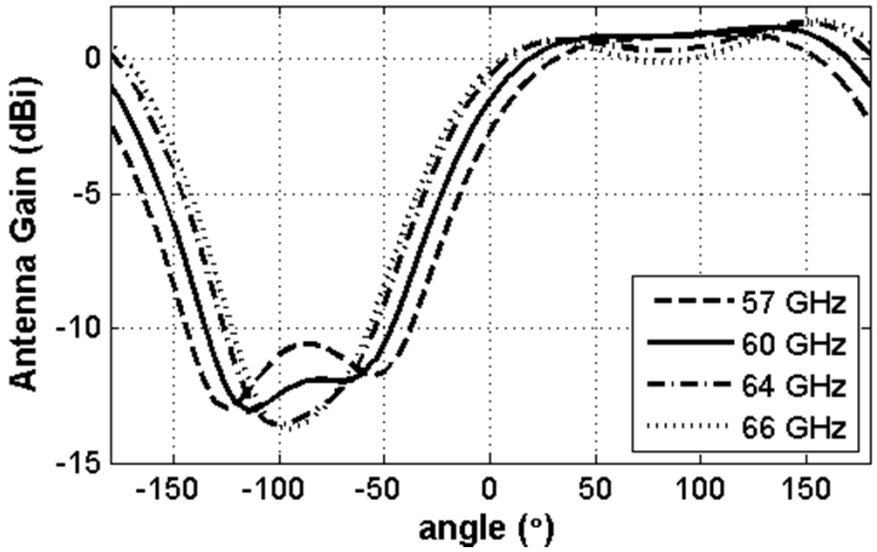
- Co-design of on-chip antenna + Rectifier
- Self-threshold voltage modulation

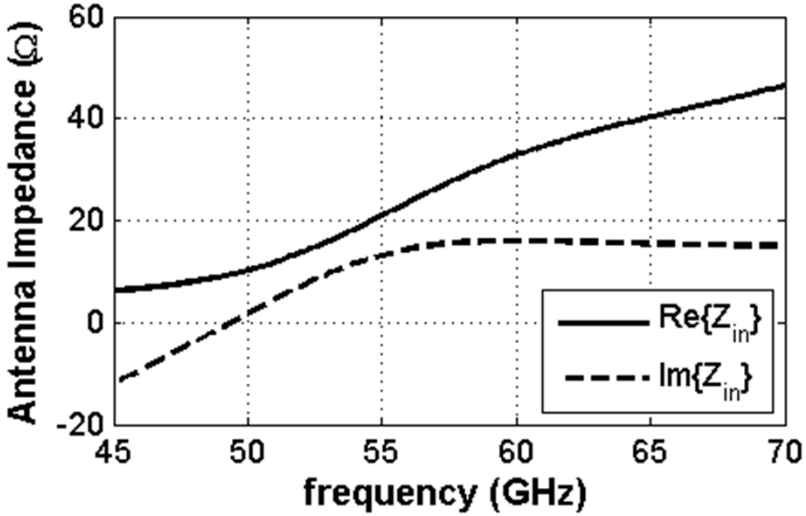


60 GHz Rectenna: On-Chip Antenna



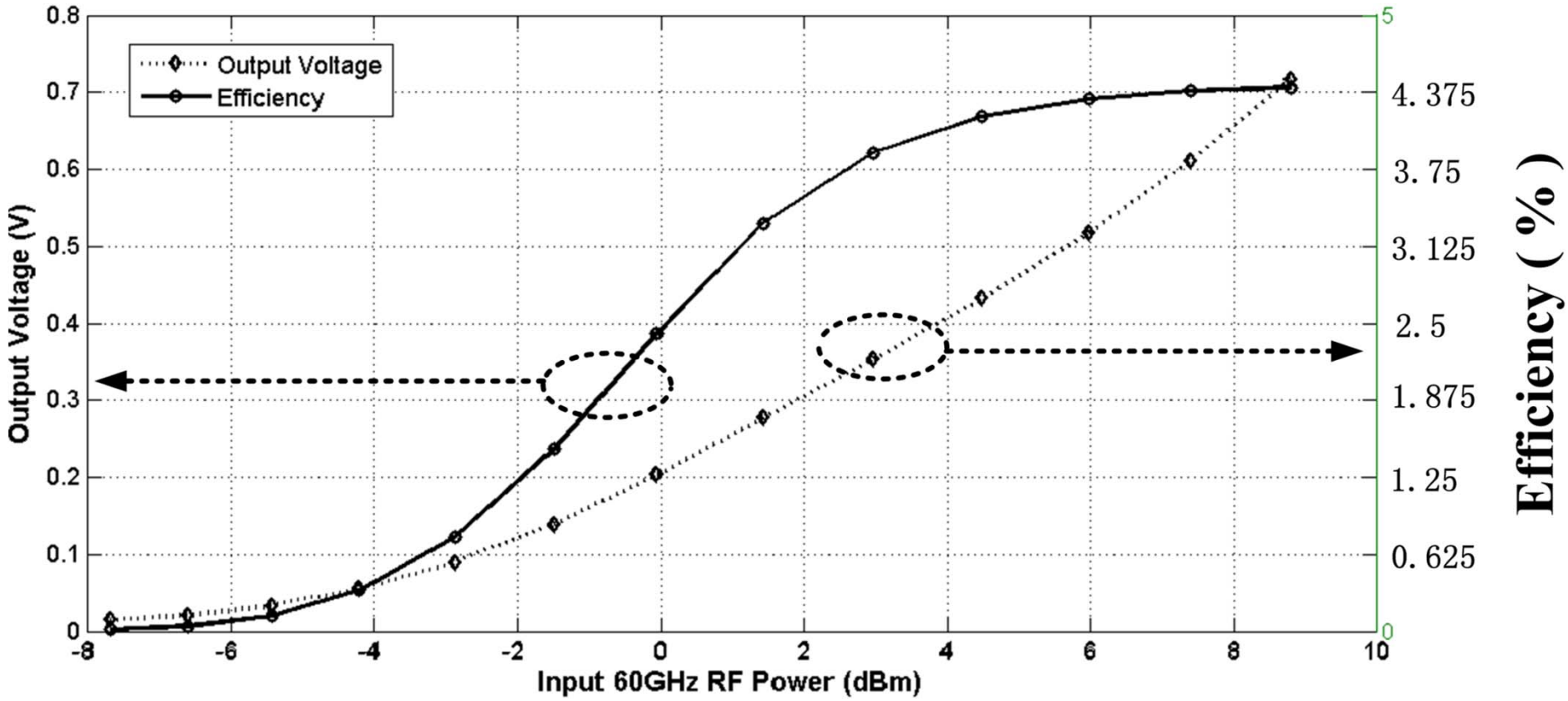






Ulf Johannsen (Electromagnetics Group)

60 GHz Rectenna: Rectifier Performance



With 1.5kΩ load, it reaches 4.4% efficiency in simulation with 7dBm input power, and output voltage 0.7V. Corresponding output current is 0.46mA.

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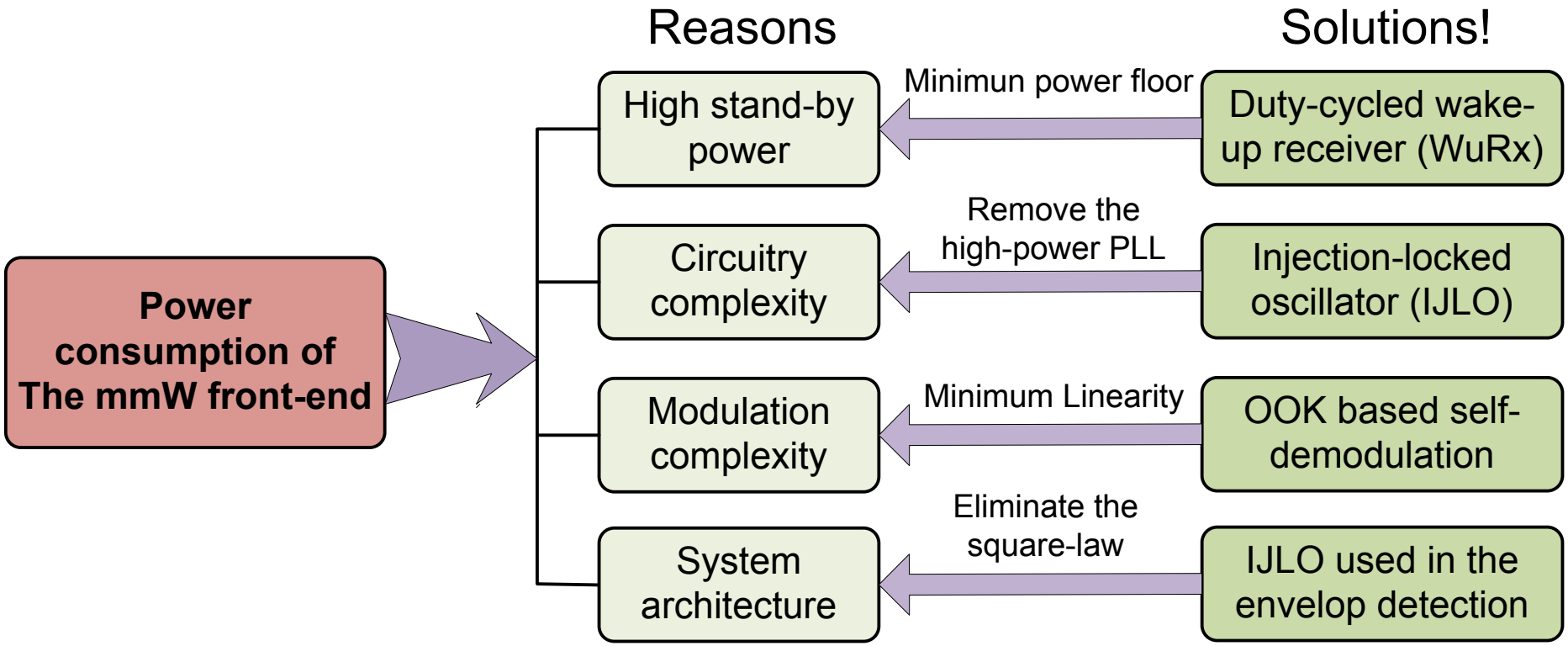
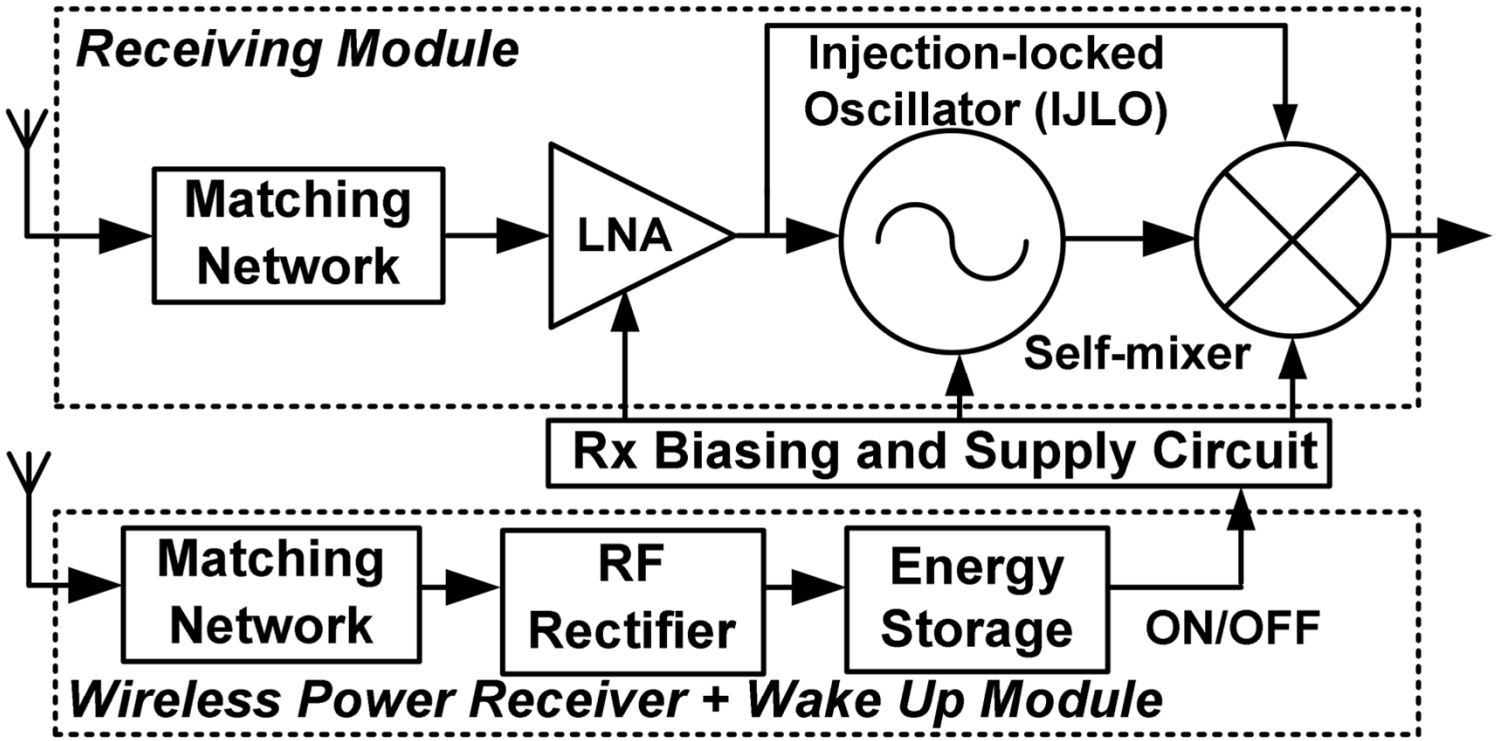
System-Level Research

- **Average power consumption optimization**

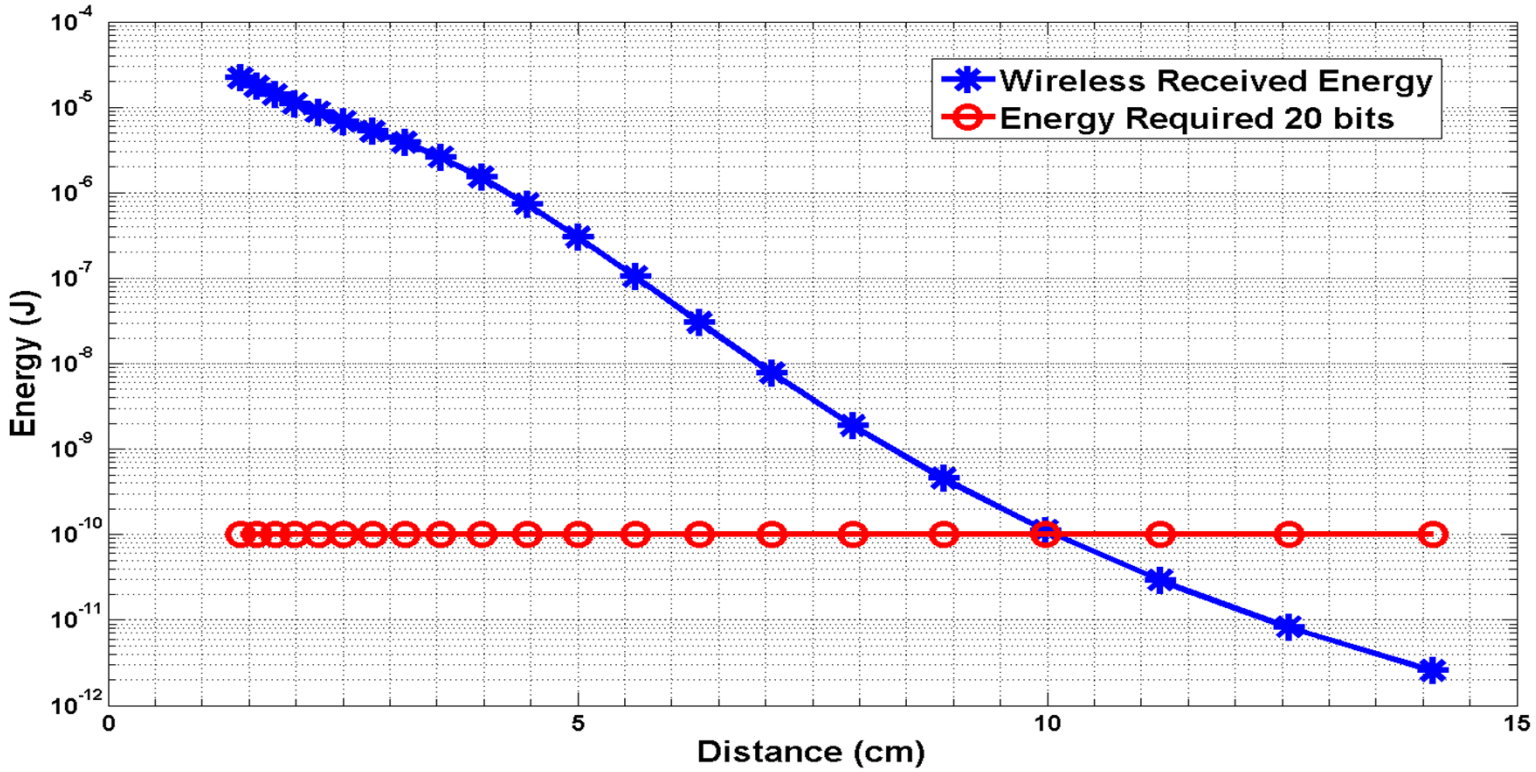


Radio-Triggered Monolithic Wireless Sensor Node



	Gain (dB)	NF (dB)	IIP3 (dBm)	P_{dc} (mW)
LNA	16.2	4.8	-18	5
Mixer	-15	15	-22.4	
	f_{rf} (GHz)	**P_{out} (dBm)**	**Sensitivity (dBm)**	**P_{dc} (mW)**
IJLO	61.6	-22.5	-60	3
60 GHz RF Front-End Parameters				

System Evaluation



TX Power	Ant Gain TX	Ant Gain Rx	Modulation
10 dBm	20 dBi	0 dBi	OOK
BW	**T_{scav}**	**Pac. Len**	**Rx %**
2 GHz	1ms	20 bits	50
System parameters			

Future: mm-wave Direction

Future work:

- ***Improve mm-wave rectifier efficiency***
- ***ULP radio***
- ***Directional on-chip antenna array***

Conclusion

Battery-less sensor nodes enable many applications

Mm-wave wireless power transfer with integrated on chip antenna is an elegant way for low cost solution

- ***Key Circuit Blocks: High efficiency rectifier***
- ***System Level : 60 GHz Ultra Low Power Radio***

Acknowledgement

- STW
- Philips
- Holst Centre