

KIVI afdeling Telecommunicatie

Towards the limits of miniaturized RFID - and beyond

Peter Baltus

Monday, March 2nd 2015



CWTe

Centre for Wireless Technology Eindhoven

TU/e

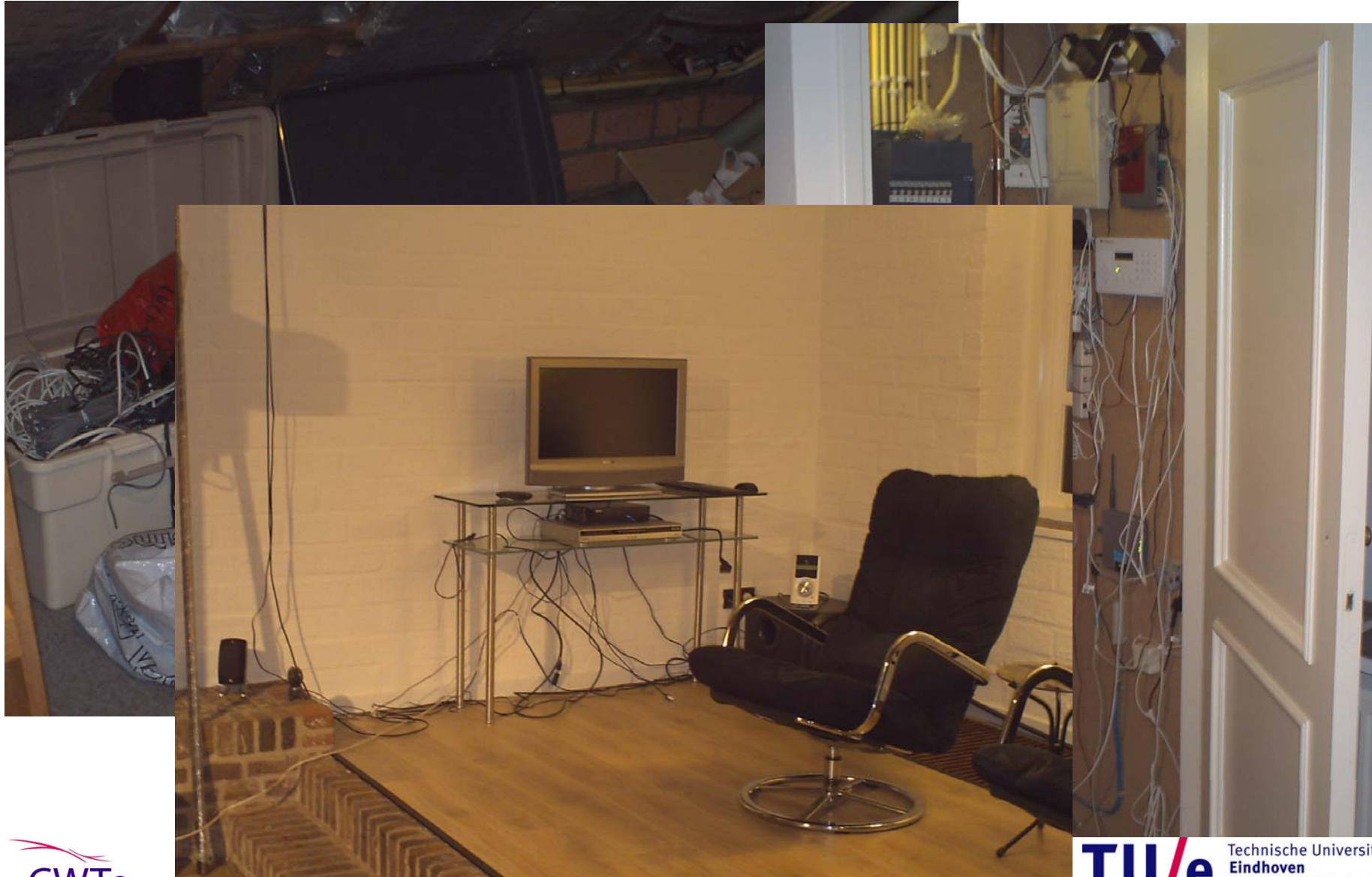
Technische Universiteit
Eindhoven
University of Technology

Where innovation starts

- **Introduction: CWTe**
- **The ULP program: Trends & vision**
- **The Limits of battery-less systems**
- **And Beyond**
- **Conclusions**
- **Questions (& possibly answers)**

Introduction: CWTe

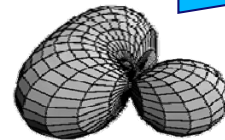
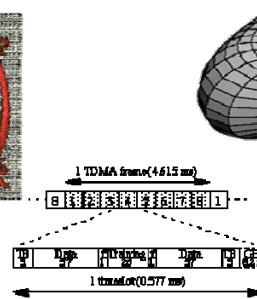
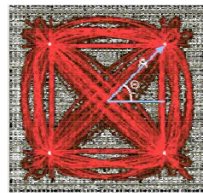
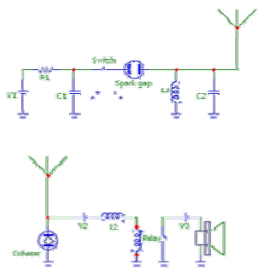
Wireless...



Wireless Technology Trends



“Ubiquitous”: Invisible & cheap



$$\xi = 135^\circ$$



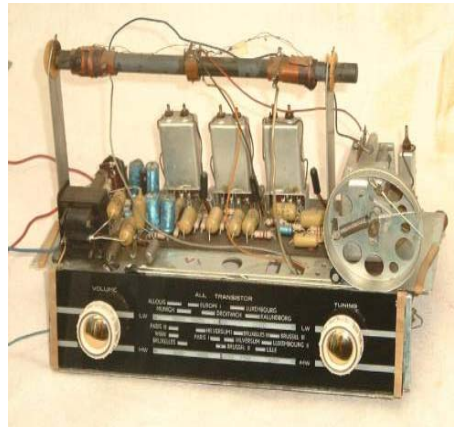
“Shared Channel”: Robust & Efficient

Complexity

Specialisation

- Complexity → Specialisation

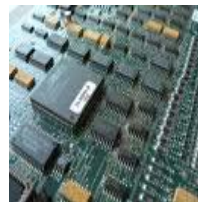
- From:



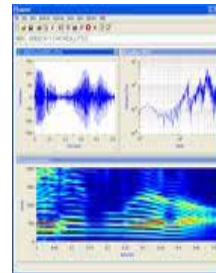
- To:



Antennas + Propagation



Circuit Design (analog, mixed & digital)



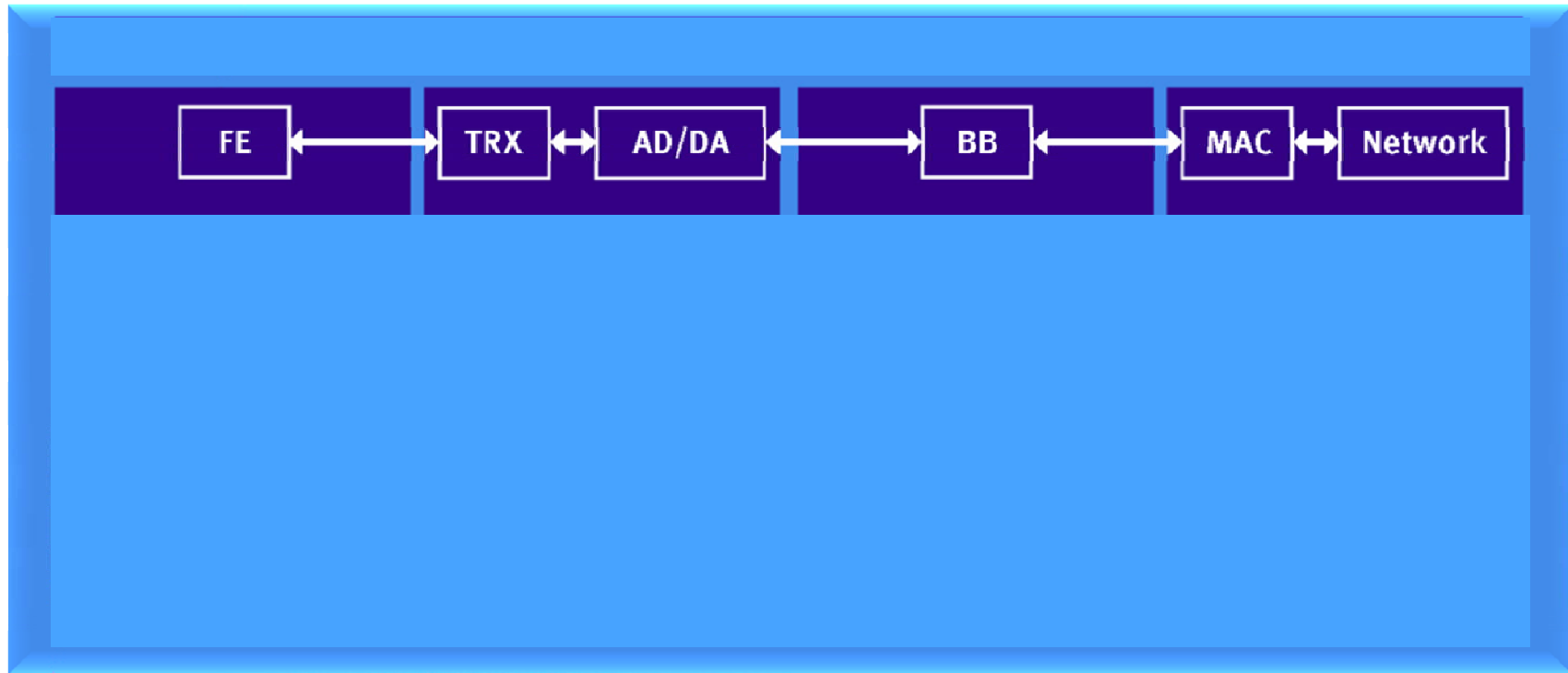
Digital Signal Processing



Network protocols

Filling the Gap: CWTe

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ULP Program: Trends & Vision

Exciting Trends: WWRF 2020 vision

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- **Wireless World Research Forum**
 - **Global organization**
 - **Since 2001**
 - **140 members (industry & research)**
- **Shared vision on the future of wireless**
 - **To drive standardization**
- **Prediction:**
 - **In 2020:**
“On average 1000 wireless devices / person worldwide”

Low Power consequences

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- **WWRF prediction 2020:**
→ **Growth area...**
- **Replace batteries**
 - **If battery Life ~ 1 jaar**
 - **Then replace 3 batteries/day pp...**
- **Consequences for:**
 - **Environment**
 - **Cost**
 - **Reliability**
 - **Customer satisfaction & mental health**



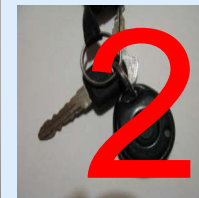
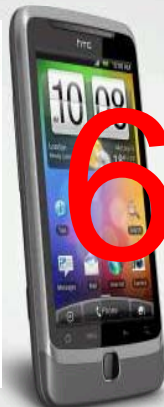
Reality check: is this really happening?

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1950: ~1 per family:



2011: > 25 on person:



- + TV, radio, WLAN, alarm, rc,... @ home
- + Remote, radio, GPS, handsfree, ... @ car
- + ...

2020 ???

Reality check: is this really a problem?

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- **Replace battery 3x per day**
- **Use rechargeables**
- **Increase battery lifetime somewhat more**

- **It brings you so much functionality!**

- **Isn't that worth it?**

- **Who's complaining?**

Is this really going to happen? A short story

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**A short story to better understand the urgency
of battery-less wireless sensors**

Warning & Disclaimers:

**Contains nocturnal bedroom scenes
With consenting adults**

Contains violent language

02:45 AM



02:45 AM

Snore

02:45 AM



02:45 AM

Snore

02:46 AM



02:46 AM



BEEP!!!

02:46 AM

Dear Peter, please Wake-up!

That @#&% smoke alarm

Is beeping again!



Huh? What?
Yes Dear!

02:46 AM

Where's
that stupid
Flashlight?

Ouch....

Stumble...
...Bump

02:46 AM

Found
it!



02:47 AM

Not the one
in my office

BEEP!!!



02:48 AM

Not the one in
the utility
closet either...

BEEP!!!



02:49 AM

Must be
upstairs?

BEEP!!!



02:50 AM

Not this one
either...

BEEP!!!



02:51 AM

Yes! It's the
one in the
Attic!!!

BEEP!!!

But I can't reach it!
I need to get the
@#&* Ladder
downstairs...

02:52 AM

BEEP!!!



02:53 AM

BEEP!!!



02:54 AM

BEEP!!!



02:55 AM

Yes! Did it!
Now back
to sleep....



2:57 AM

Need to
dream up
Battery-less
sensors!



Snore

The (happy?) End

The Limits of Battery-less Systems

High data rate: the basics

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Shannon:

$$C = BW \log_2(1 + SNR)$$

Transmission:

$$P_{RX} = P_{TX} G_{RX} G_{TX} \left(\frac{\lambda}{4 \pi r} \right)^\alpha$$

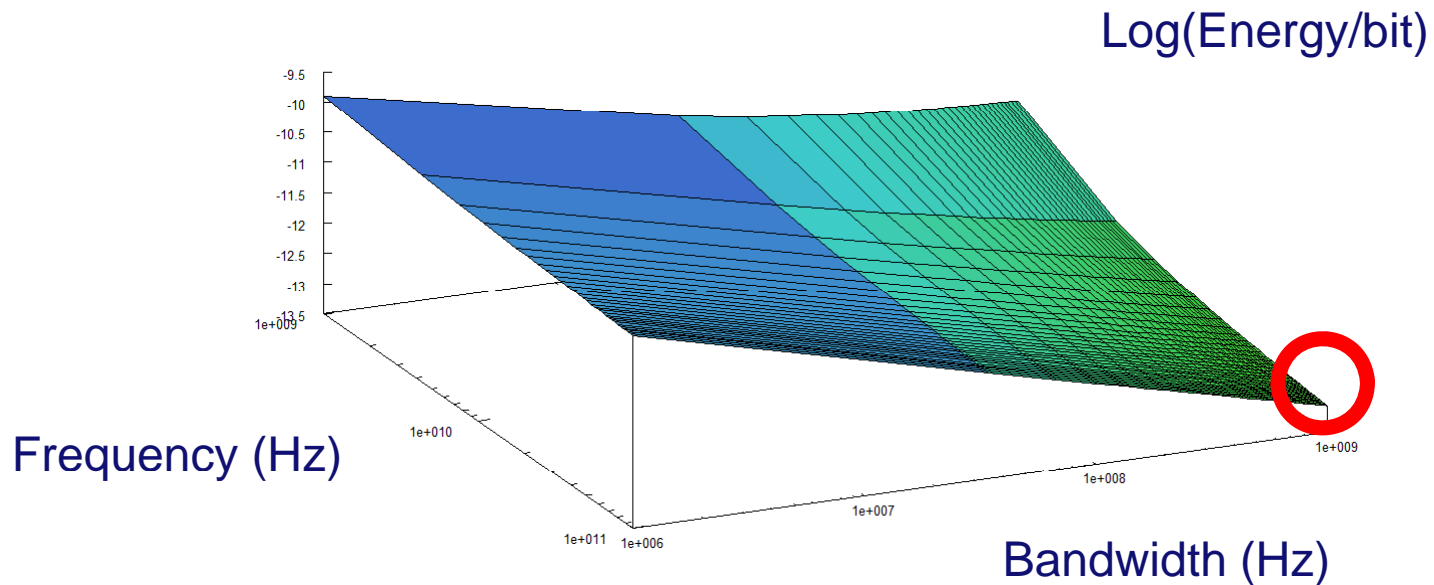
Data rate

Frequency

Bandwidth

$$R \leq BW \log_2 \left(1 + \frac{P_{TX} G_{RX} G_{TX} \left(\frac{\lambda}{4 \pi r} \right)^\alpha}{k T BW} \right)$$

Spatial Confinement: “Wireless Wire”

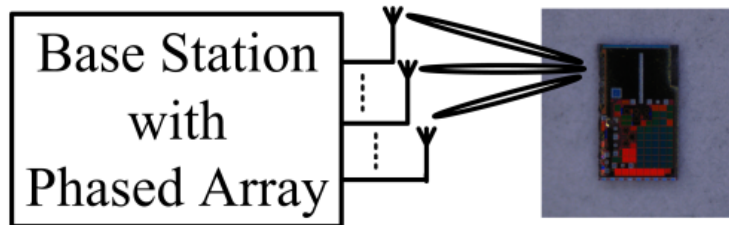


Original Plan

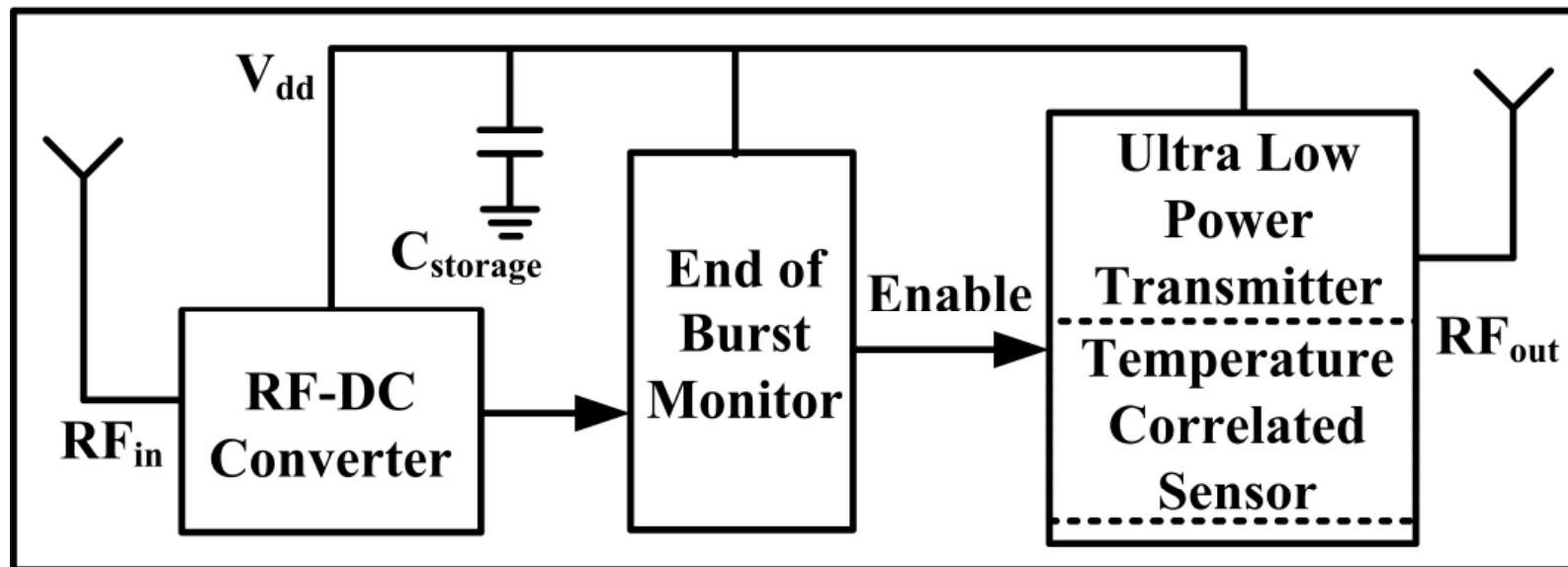
Item	Value	Unit
Transmit power of the central node	20	dBm
TX antenna gain of the central node	20	dB (100 elements)
LOS attenuation at 5 m distance, 60 GHz	82	dB
RX antenna gain of the sensor node	0	dB (includes losses)
Receive power efficiency	-6	dB (25%)
=> RX power of the sensor node	-48	dBm
=> Received energy the sensor node (10 ms)	0.16	nJ
Time asymmetry (charge vs. transmit time)	60	dB (10ms RX, 10ns TX)
Transmit efficiency	-6	dB (25%)
=> Transmit power of the sensor node (10 ns)	6	dBm
TX antenna gain of the sensor node	0	dB (includes losses)
LOS attenuation at 5 m distance, 60GHz	82	dB
RX antenna gain of the central node	20	dB (100 elements)
=> RX power of the central node	-56	dBm
=> RX SNR (BW = 2 GHz)	25	dB

The System

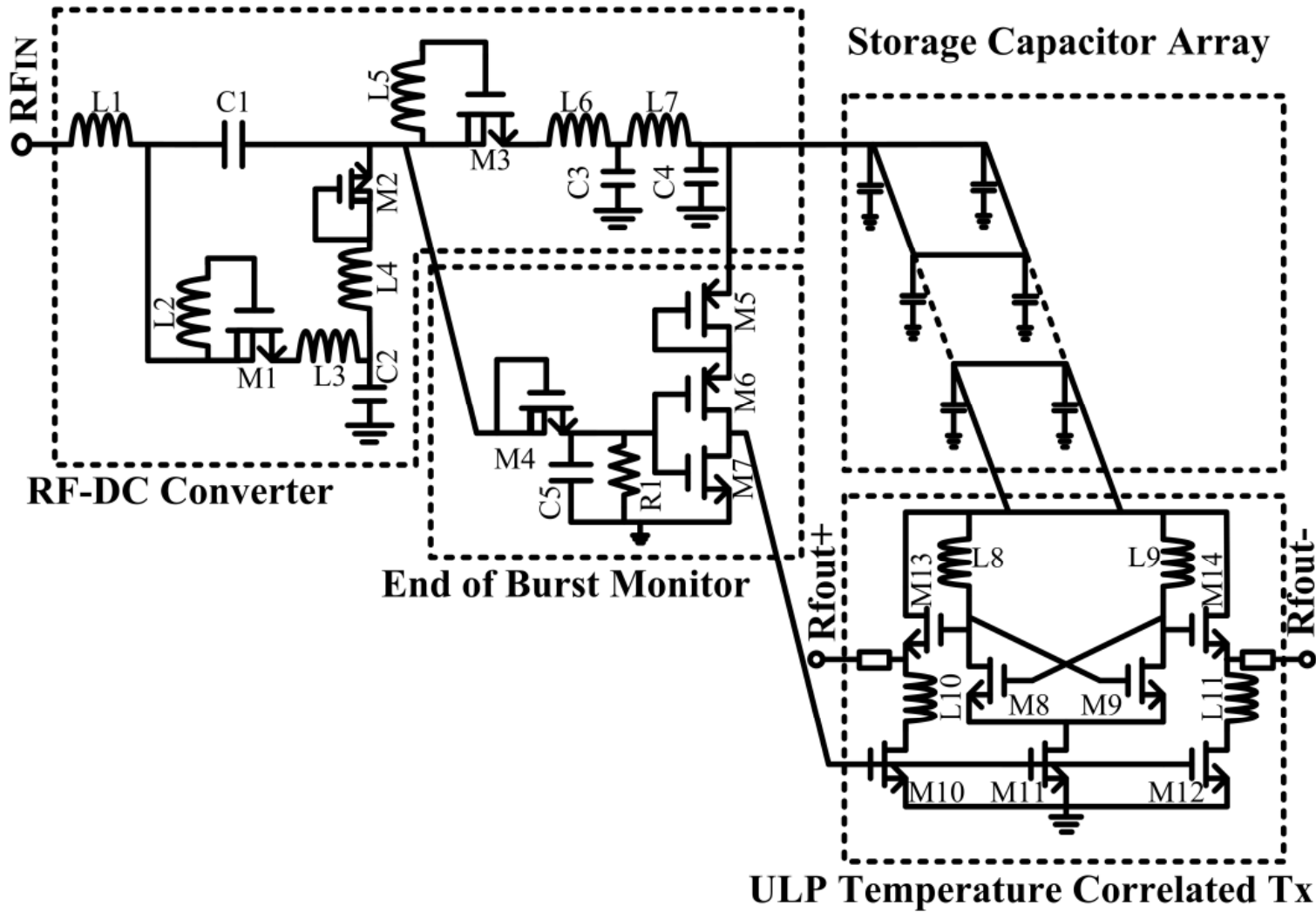
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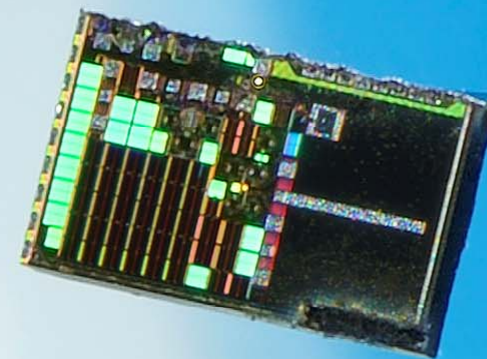
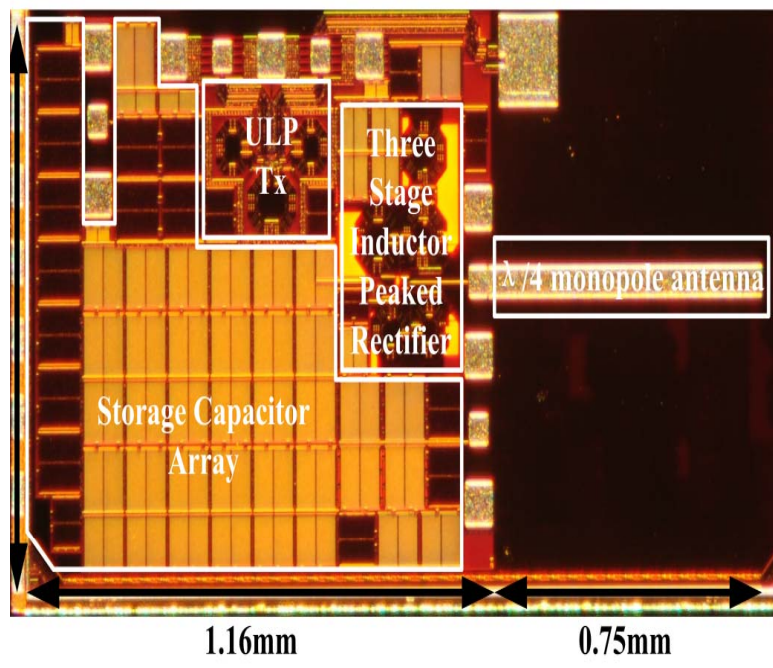


Wireless Temperature Sensor Nodes



The Circuit





And Beyond...

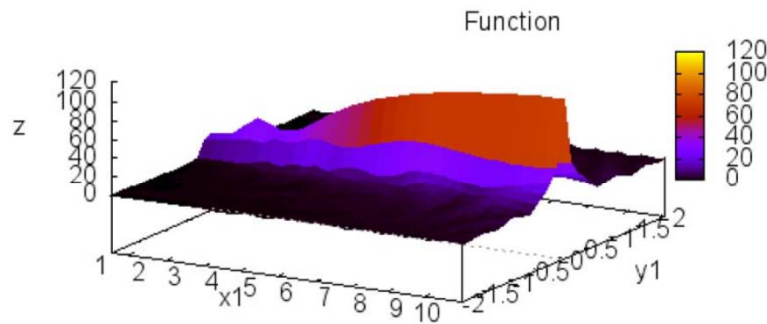
- **Rectifier**
 - **Optimized for low power: maximum non-linearity**
 - **Optimized for charging a capacitor**
 - **Optimized for high frequencies**
 - **Co-designed with antennas**

- **Wireless antenna**

Spatial Confinement: The Next Step

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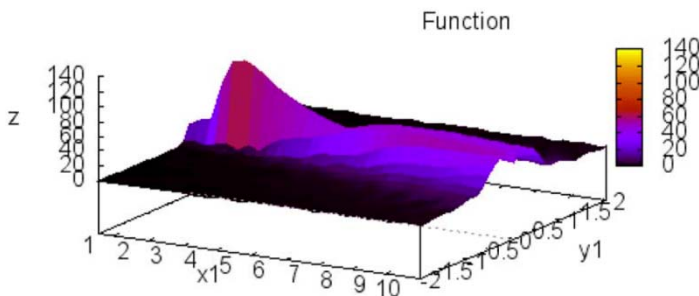
- **Phased arrays:**
 - **Better performance @ high frequencies**
 - **Miniaturization**



Near field boundary:

$$R_{nf} = \frac{2 D^2}{\lambda}$$

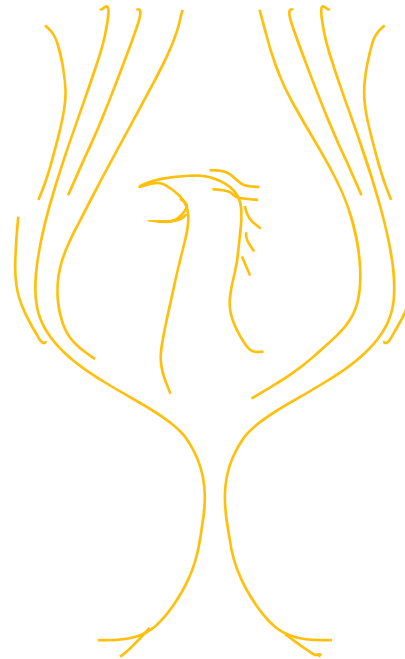
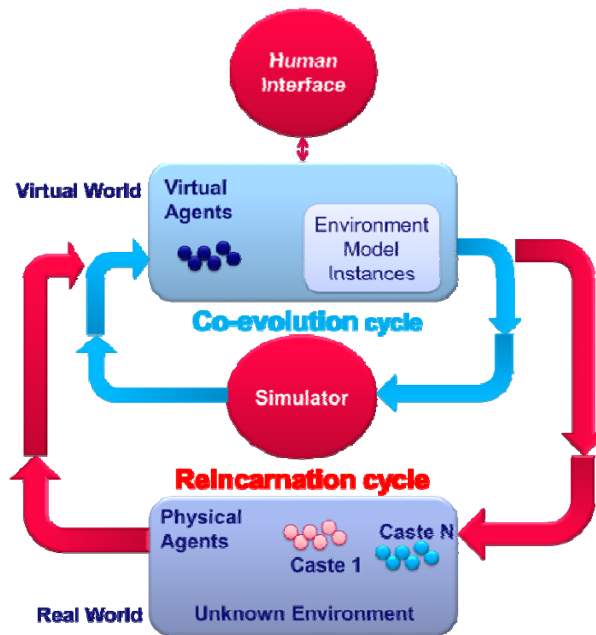
- **Next step:**
 - **Convergent beams**



Ultimate Functionality & Size

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- Sensor Arrays & Accurate Positioning
- Evolving Devices:



- THz Spectroscopical Imaging

Thanks for your attention!

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Do you have questions or comments?



