



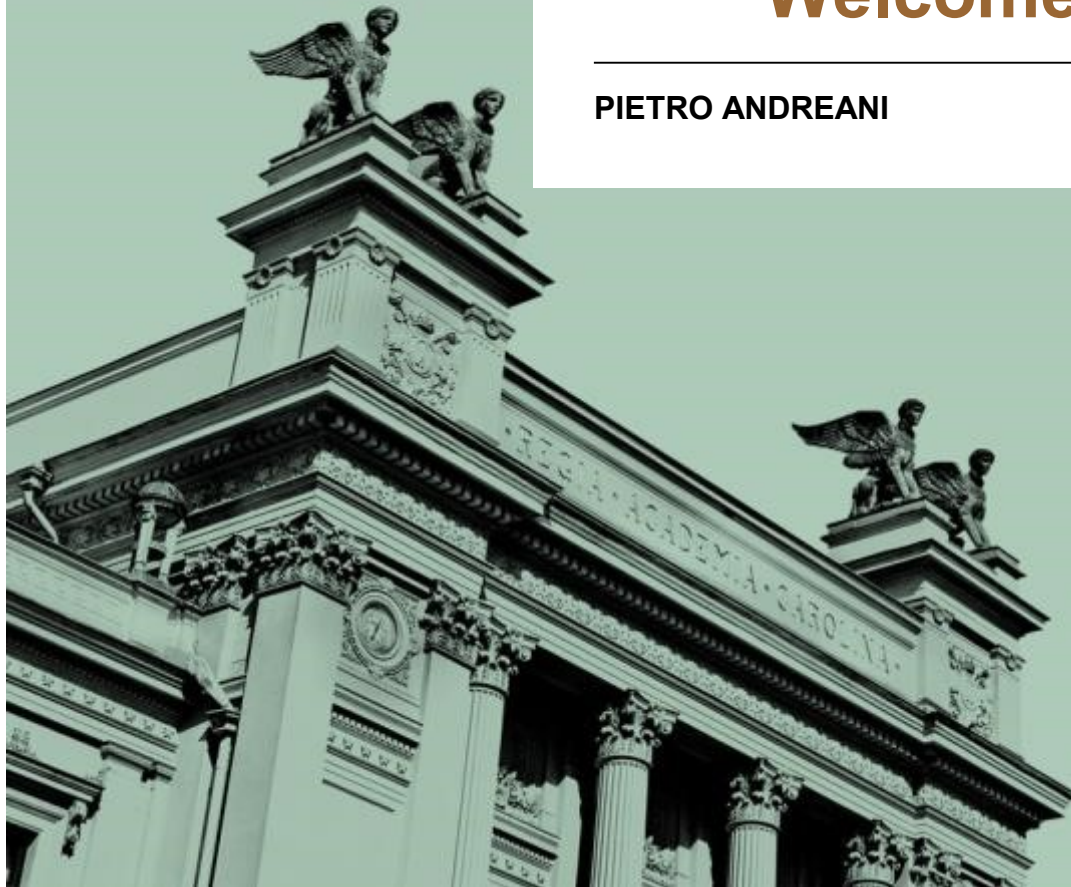


# 2016 Lund Circuit Design Workshop

## Welcome and Introduction

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PIETRO ANDREANI

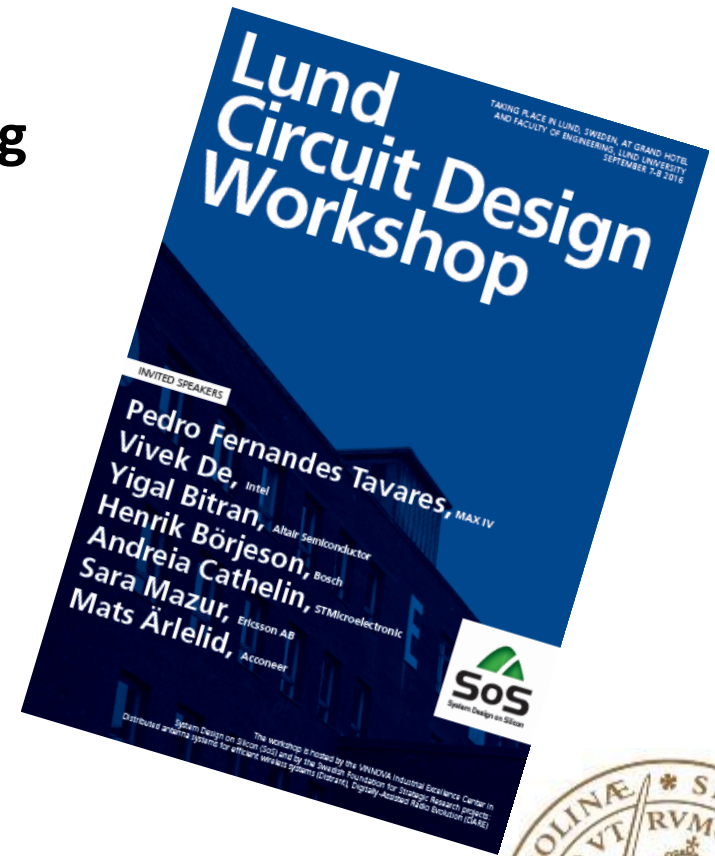


# Welcome to two exciting days with SoS!

## Together with 150 colleagues!

You have received a folder containing

- Workshop program
- Invited speakers
- Senior researchers
- PhD students
- International Advisory Board
- SoS Board



# Thematic Sessions

## Day 1

- **Session 1: Energy-Aware ICs**
- **Session 2: Cellular Communication**
- **Session 3: New Directions – Technologies and ICs**

## Day 2

- **Session 4: Future Technologies**
- **Session 5: 5G**
- **Conclusion**





# Invited Speakers, day I (a)

- **Vivek De**, Intel, Portland, OR  
*Energy Efficient Computing in Nanoscale CMOS*
- **Yigal Bitran**, Altair Semiconductor, Israel  
*Taking LTE to the extremes*

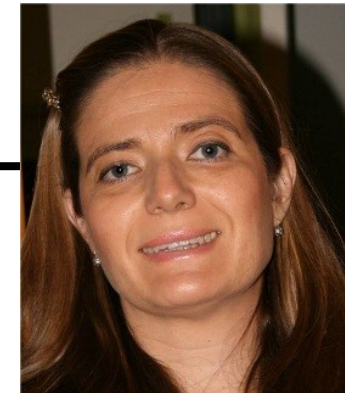


# Invited Speakers, day I (b)

- **Henrik Börjeson**, Bosch, Lund  
*From consumer to commercial: connectivity solutions for the automotive industry*



- **Andreia Cathelin**, STMicroelectronics, Crolles, France  
*FD-SOI Technology – Advantages for Analog/RF and Mixed-Signal Designs*





# Invited Speakers, day I (c)

- **Pedro Fernandes Tavares, MAX IV, Lund**  
***Status and Future Development Plans for the MAX IV Light Sources***



# Invited Speakers, day II

- **Mats Ärlelid**, Acconeer, Lund  
*60GHz radar for consumer products*
- **Sara Mazur**, Ericsson AB, Stockholm  
**5G for the Networked Society**





# Important people in

## The SOS Board



Sven Mattisson, Chairman  
Ericsson

Andreia Cathelin  
STM



Franz Dielacher  
Infineon



Peter Karlsson  
Sony



Anton Klotz  
Cadence



Klas Malmqvist  
LTH



Peter Olanders  
Ericsson



Per Runeson  
Computer Science, LTH

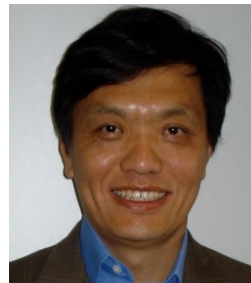


## The International Advisory Board

Mike Faulkner  
Victoria University,  
Melbourne



Qiuting Huang  
ETH, Zurich



Jan Rabaey  
UC Berkeley, CA





# Some Logistics

- **Today we are at Grand Hotel, including lunch**
- **Dinner is in Lilla Salen, AF Borgen, at 7pm**
- **Tomorrow we are at the Faculty of Engineering, LU**

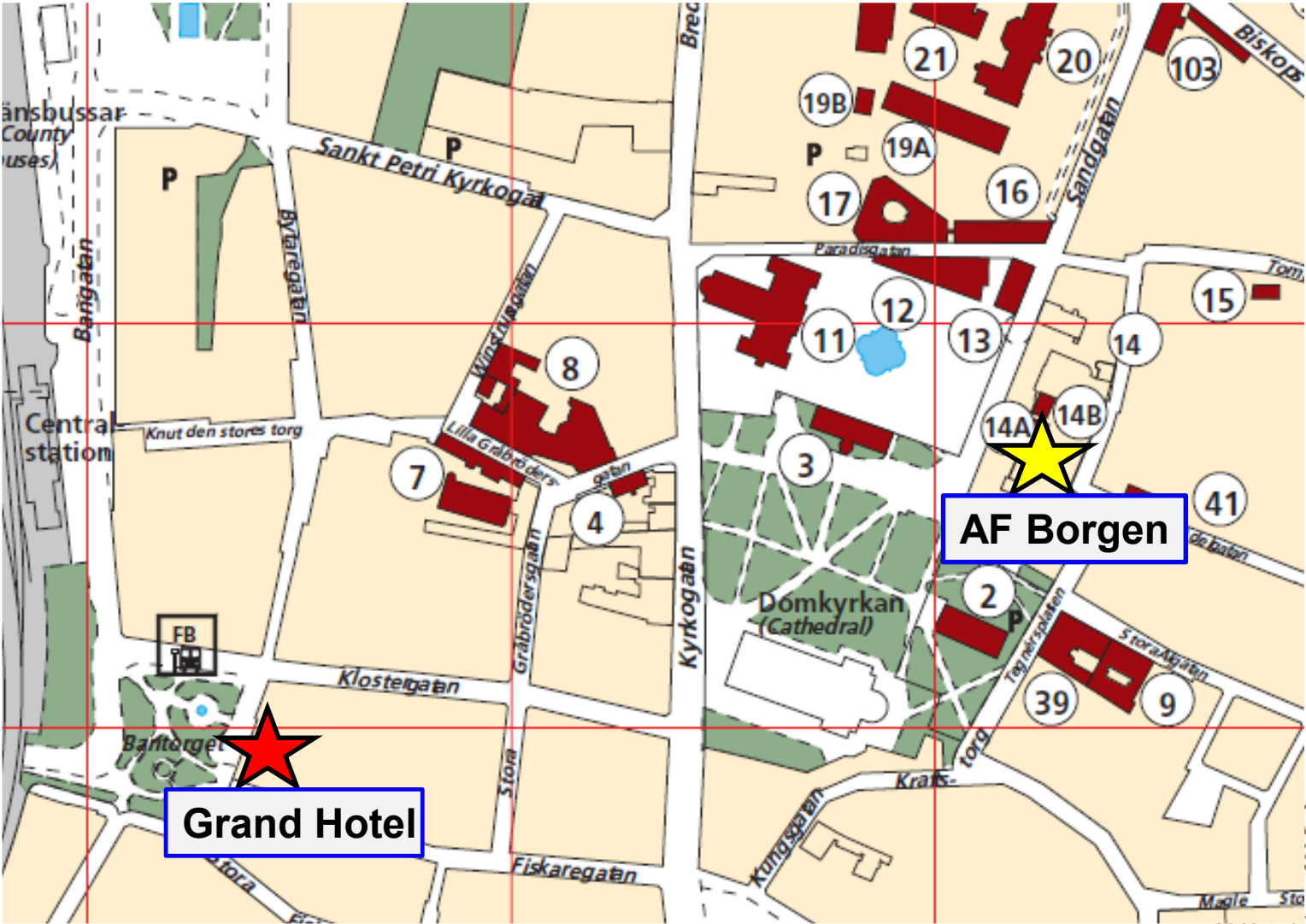


# Dinner: AF Borgen





# Dinner: AF Borgen



# Some Logistics



- Today we are at the Faculty of Engineering, LU
- Dinner is in Liljevalchska Villa, 7pm
- Tomorrow we are at the Faculty of Engineering, LU
  - E-building
  - A 25-minute walk from Grand Hotel

## Room E:1406





# INSTITUTIONSKARTA LUNDS UNIVERSITET

(Kartan omfattar institutionerna i Lund.)

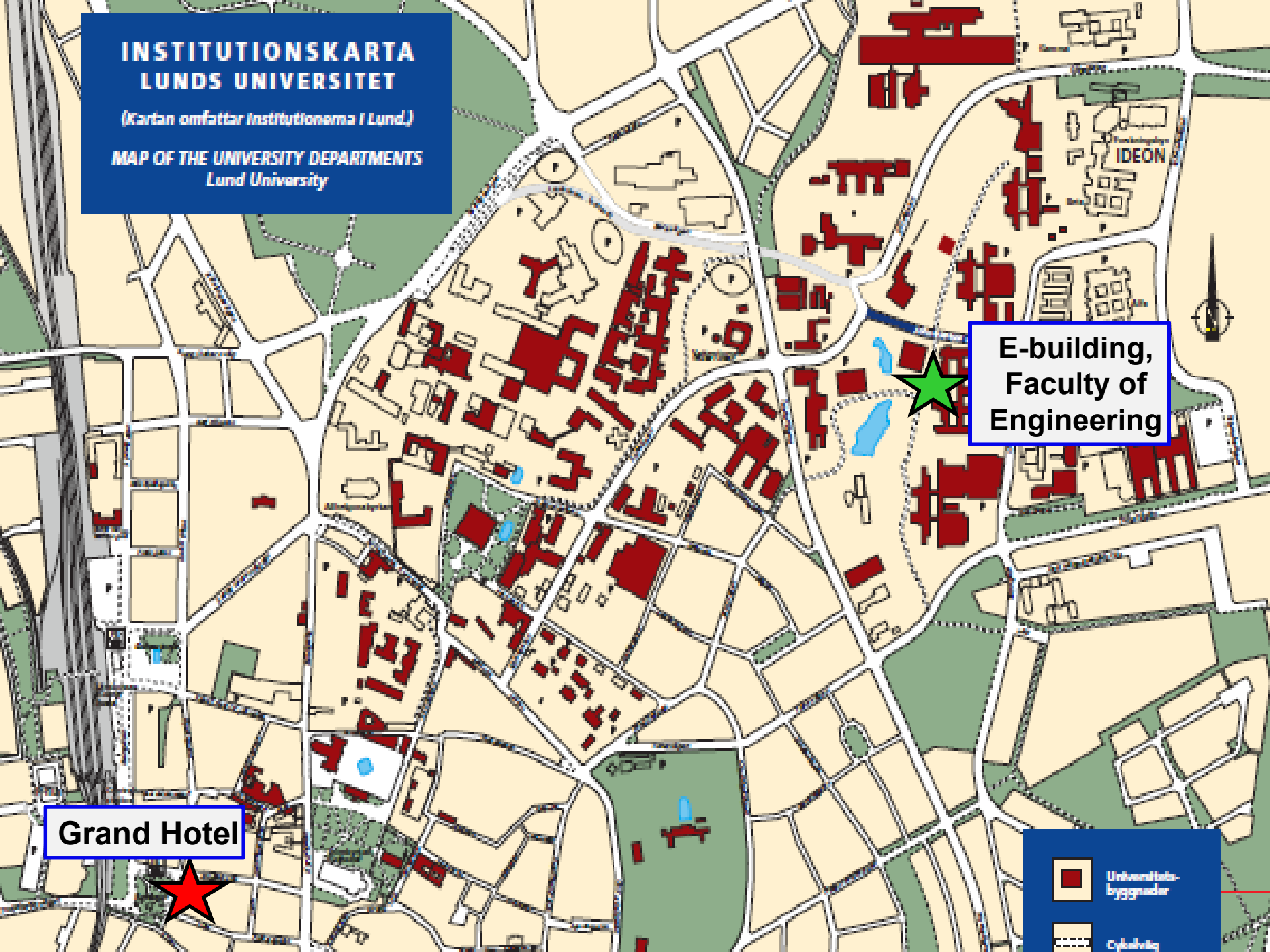
MAP OF THE UNIVERSITY DEPARTMENTS  
Lund University

E-building,  
Faculty of  
Engineering

Grand Hotel

Universitets-  
byggnader

Cykelsväg



# The Hosts



**Industrial Excellence  
Center in**



# The Hosts: the SSF programs

**DARE**  
Digitally-Assisted  
Radio Evolution  
Pietro Andreani

2011-2015/16



**Distraint**  
Advanced Systems  
Fredrik Tufvesson



# More programs



SWEDISH FOUNDATION for STRATEGIC RESEARCH

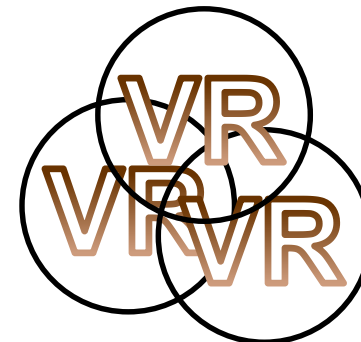


## Horizon 2020



• MAMMOET  
• BASTION

DARF  
DISTRANT  
HiPEC



### Strategic Research Area (SFO)





# New Projects – Smartare Elektroniksystem

## Prototype system for massive MIMO in new 5G frequency band

2.1 MSEK over two years: August 2016 to July 2018

EIT: Liang Liu, Fredrik Tufvesson, Ove Edfors

Project Partner: Sony Mobile

Med stöd från:



STRATEGISKA  
INNOVATIONS-  
PROGRAM

# SONY



# New Projects – 5G lab

## Funding for 5G lab equipment

1.2 MSEK over 5 years (LTH)  
200 kSEK (Crafoord)

Fredrik Tufvesson



*LTHs Infrastrukturmedel*

**The Crafoord Foundation**

ESTABLISHED BY HOLGER CRAFOORD IN 1900



# Ongoing Projects - Multi-antenna mm-wave systems

## 28GHz real-time MIMO Channel Sounder

Fredrik Tufvesson, Carl Gustafson



# New Projects – Intel SRC Project

## Coordination in Distributed Multi-User High-Performance Dense Networks

375 KUSD over three years: May 2016 to Apr 2019

EIT: Liang Liu, Ove Edfors

Project Partner: Intel





# Ongoing Projects – MAMMOET, FP7

Mission of MAMMOET:  
 Advancement of  
 Massive MIMO for  
 radio access



Project Partners:



Technikon Forschungs- und Planungsgesellschaft mbH (Austria)



Interuniversitair Micro-Electronica Centrum VZW (Belgium)



Ericsson AB (Sweden)



Infineon Technologies Austria AG (Austria)



Katholieke Universiteit Leuven (Belgium)



Lunds Universitet (Sweden)



Linköpings Universitet (Sweden)



Telefónica Investigación y Desarrollo SA (Spain)



# Ongoing Projects – Vetenskapsrådet (VR)

**Future communications, Massive MIMO, efficient signaling**

1 PhD position funded by VR

Project Manager: Viktor Öwall



# Ongoing Projects – Vetenskapsrådet (VR)

## High Efficiency Millimeter Wave Transmitters using CMOS technology

1 PhD position funded by VR

Project Manager: Markus Törmänen



# Ongoing Projects – Smartare Elektroniksystem

## TX front-end building practices for 5G Massive MIMO systems

3 MSEK over two years: August 2015 to July 2017

Project Manager: Markus Törmänen

Project Partner: Ericsson Research

Med stöd från:



STRATEGISKA  
INNOVATIONS-  
PROGRAM





# Ongoing Projects – H2020

## Flex5Gware

Two years: July 2015 to July 2017

Project Manager at LTH: Henrik Sjöland (60GHz LO generation)

Project Partner: Ericsson Research

**Horizon2020**

**ERICSSON**   
**TAKING YOU FORWARD**



# SoS: 2008 – 2017

- SoS will close its very successful 10-year mission at the end of next year (2017)
- VINNOVA opened a call for existing Centers in 2015
- 5 Centers out of the existing 30 will be funded for 5 more years
- SoS applied for a continuation/evolution → SoS++



# The SoS++ application

## Three-pronged research proposal

- Wireless and massive MIMO
- Low-power transceivers in Si CMOS
- III-V CMOS for near antenna-array electronics

**Reviewed by VINNOVA experts (anonymous)  
in spring 2016**



# The future of SoS/SoS++

- We will continue in the spirit of the SoS++ application
  - Protect SoS brand and competence, although at a lower activity level
  - Lund Circuit Design Workshop
  - Next VINNOVA center call in three years → our target
- We will form an independent center
  - OK from LTH, but no LTH/VINNOVA money
  - Partner cooperation as stated in the SoS++ application



# Faces in SoS

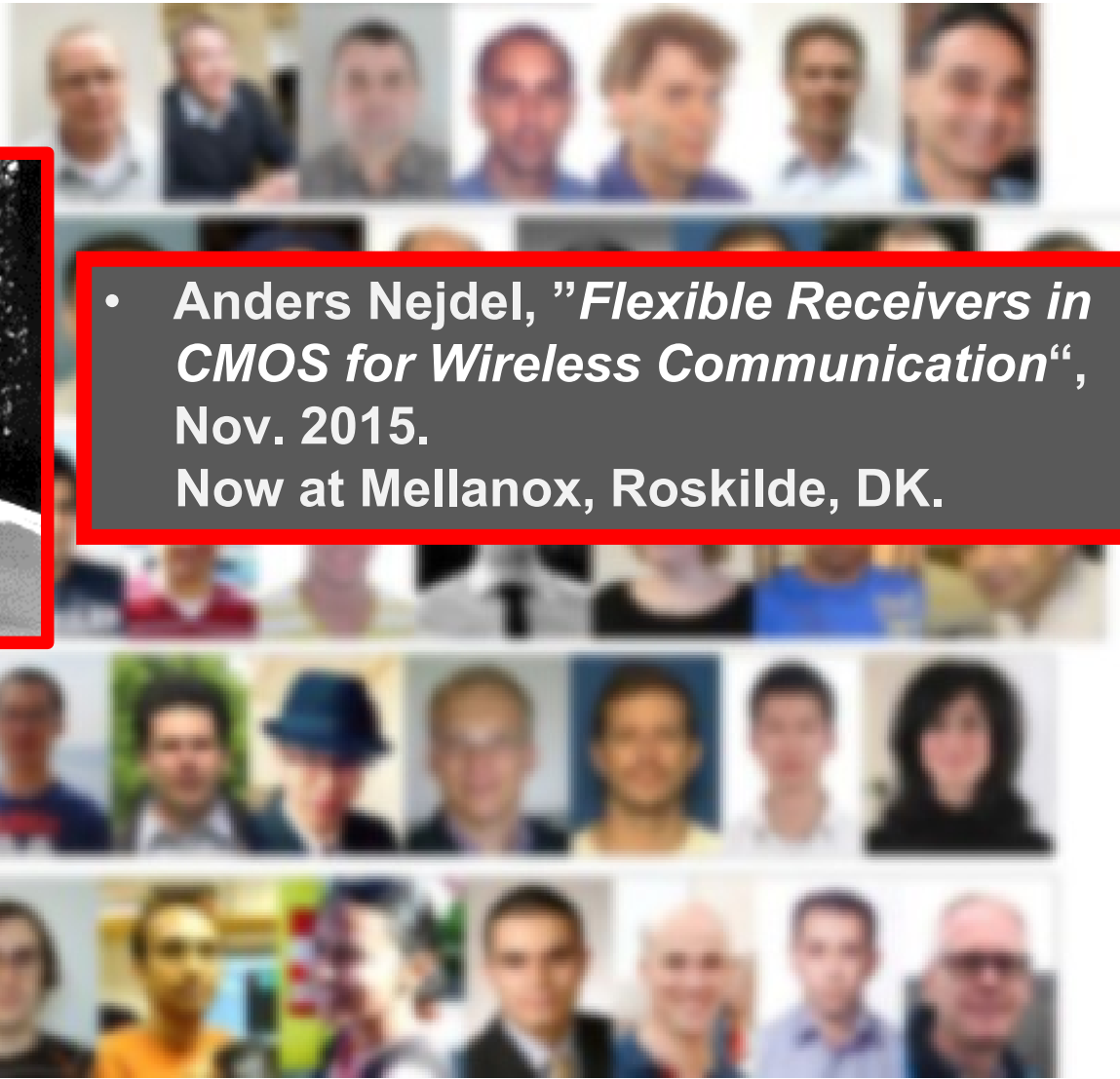




# Peter Nilsson



# Recent graduates



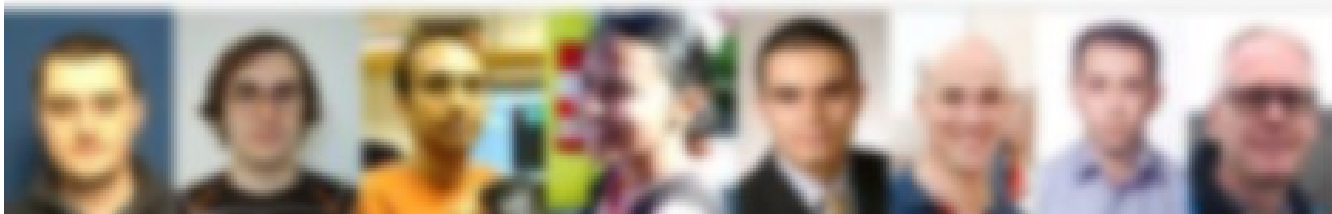
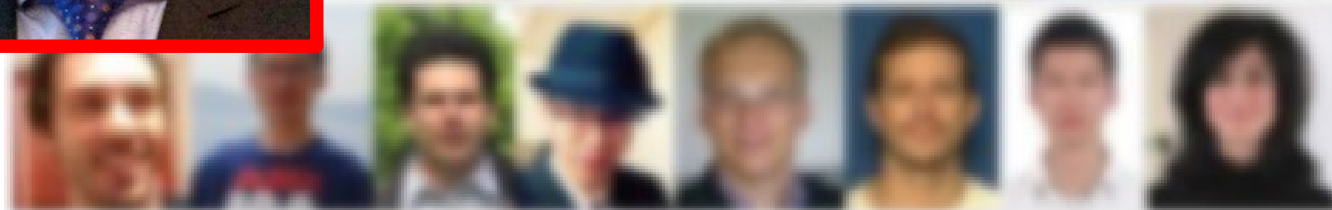
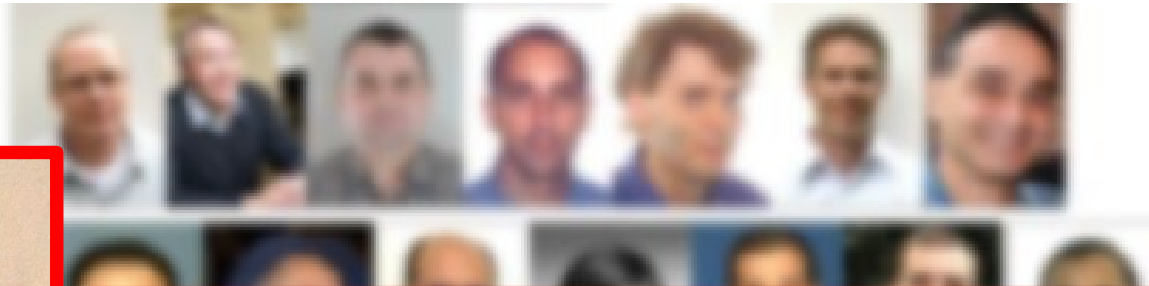
- Anders Nejdell, "*Flexible Receivers in CMOS for Wireless Communication*", Nov. 2015.  
Now at Mellanox, Roskilde, DK.



# Recent graduates



- Iman Vakili, "*Time-Domain Antenna and Scattering Analysis for Micro- and Millimeter-Wave Applications*", Nov. 2015.  
Now at Volvo Car.





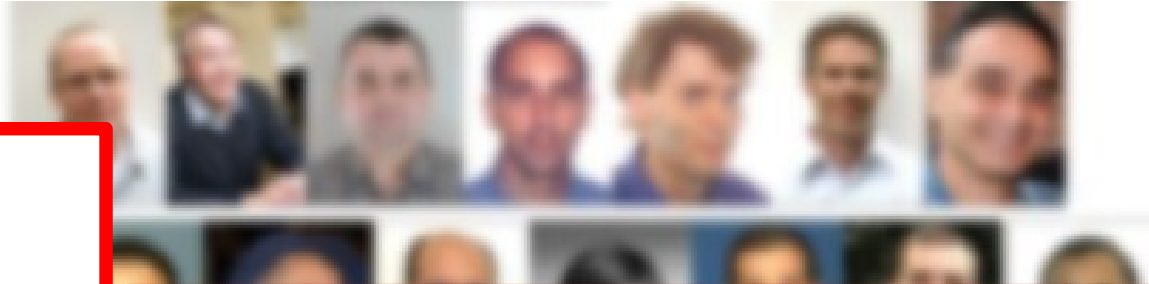
# Recent graduates



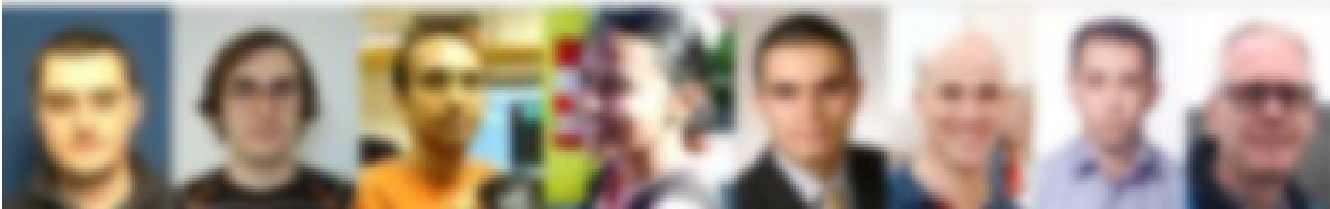
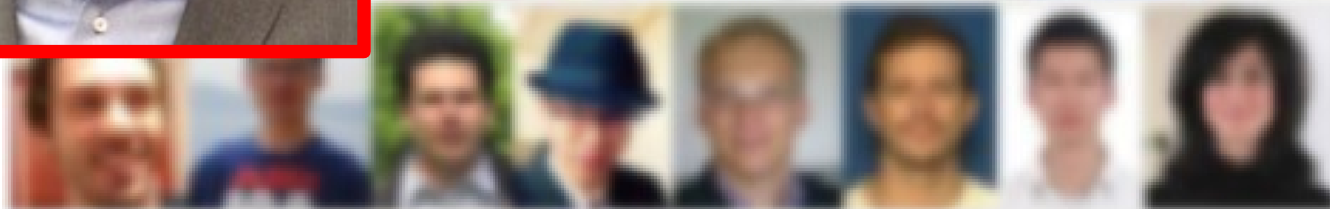
- Xiang Gao, "Massive MIMO in real propagation environments", Feb. 2016.  
Where is she?



# Recent graduates

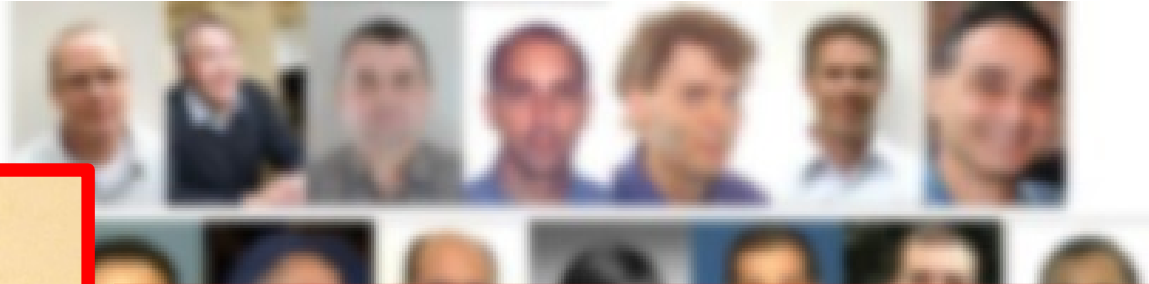


- Mohammed Abdulaziz, “Linearity Enhancements of Receiver Front-End Circuits for Wireless Communication“, June 2016.  
Now postdoc with us.

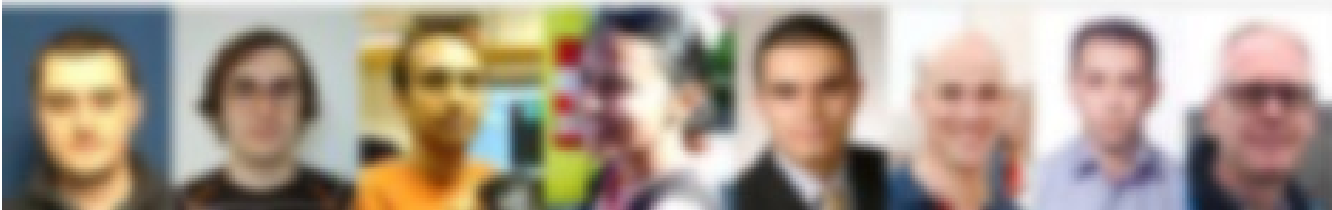
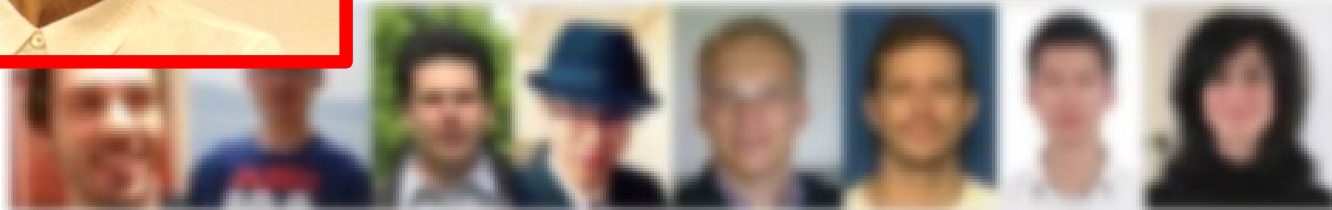




# Recent graduates

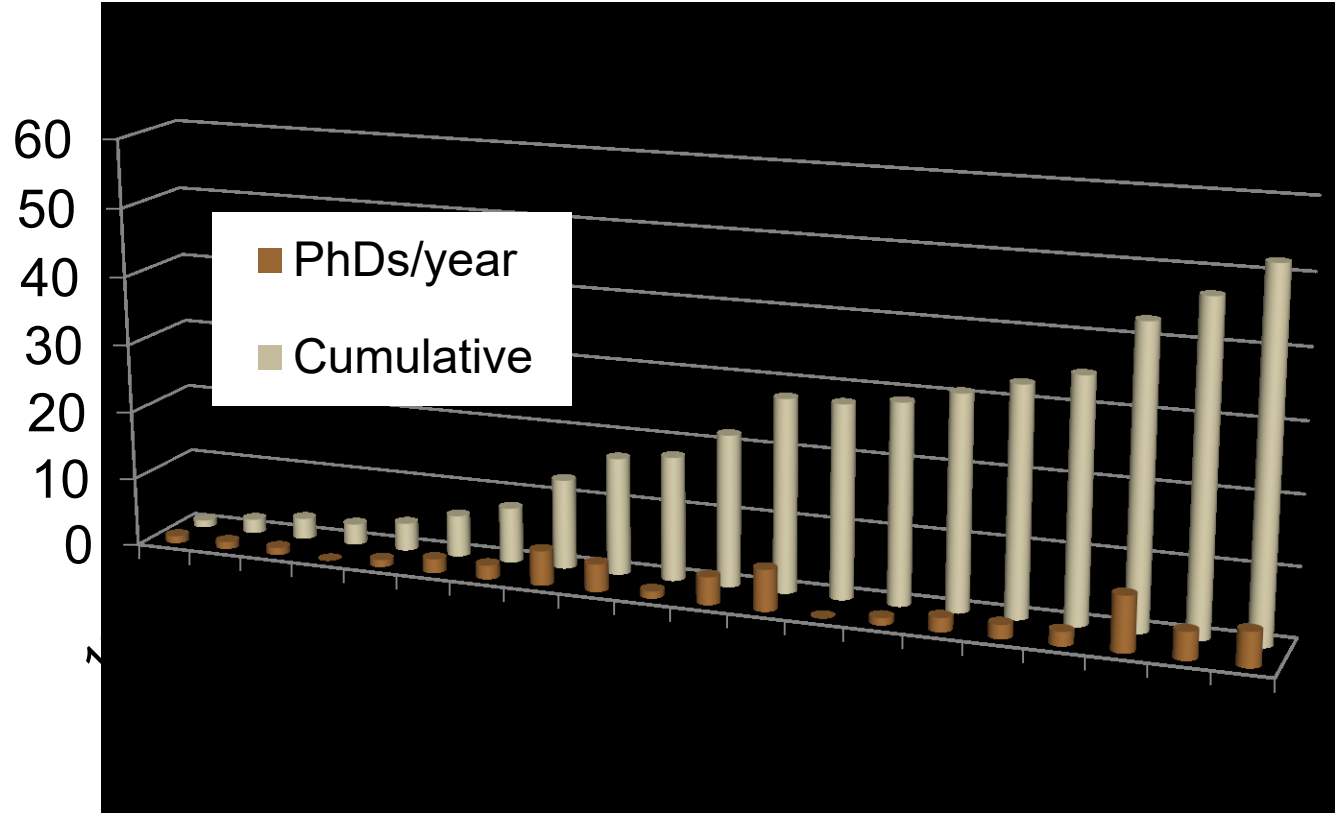


- Nafiseh Mazloum , “Duty-Cycled Wake-Up Schemes for Ultra-Low Power Wireless Communications“, June 2016.  
Now on vacation.



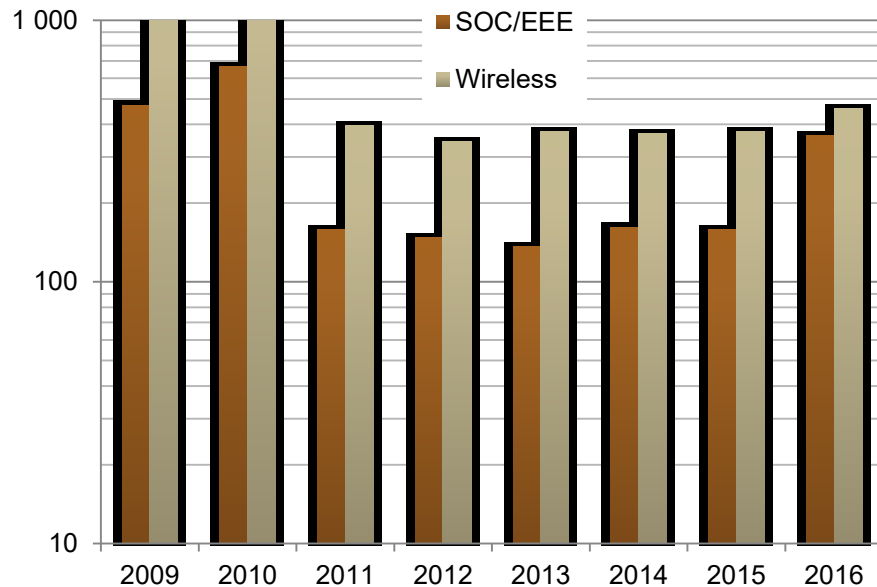
# PhDs graduated since the start of CCCD

52 PhDs since 1997

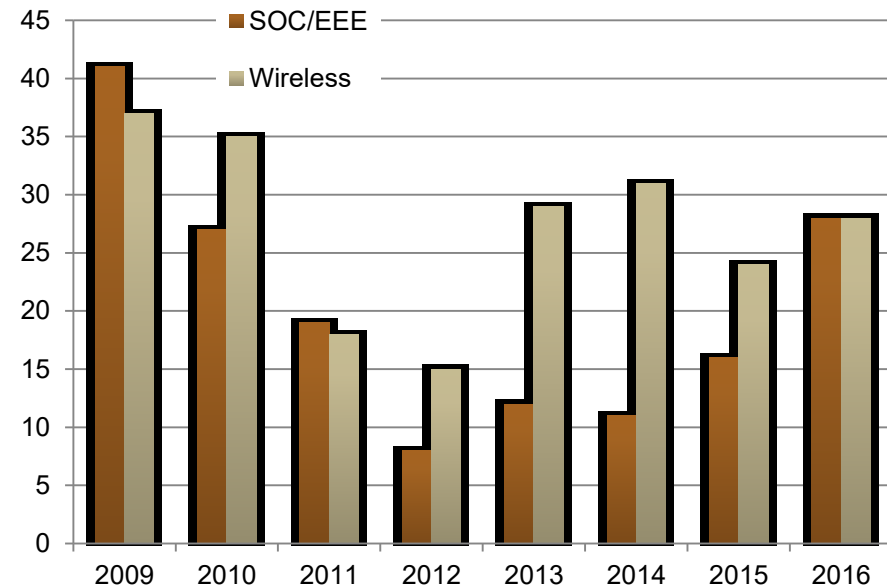


# Master Programs

- Wireless and Embedded Electronics Engineering (EEE, replacing the SOC program)
- 28 students admitted (22♂, 6♀ for EEE) – twice as many as in 2015!



Applicants



Admitted



# Some Research Highlights



# IoT network and OpenDoor at EIT

EIT operates an open LoRa IoT network

Inaugurated at the IoT conference in Lund tomorrow

Moreover, EIT opens the electronics lab (“OpenDoor”) to regional start-ups

Short briefing later by J. Rodrigues





# Internships



- Hemanth Prabhu at Xilinx, Cork, Ireland



- Steffen Malkowski at National Instruments, Austin, Texas



- Waqas Ahmad at Qualcomm, San Diego, California



# Massive MIMO out-door mobility test



Collaboration with  
University of Bristol  
—  
Outdoors  
measurements with  
mobile UEs





# World Record in 5G!!

**145.6 bits/s/Hz on  
a 20MHz channel**

evertiq Nyheter TEC Events Om Skicka Nyhetstips

Välkomna!

COGRA PRO AB  
Familjeföretag sedan 1996

Cogra

## Lund slog världsrekord i 5G

LTH-doktoranden Steffen Malkowsky har tillsammans med forskarkollegor från Lunds och Bristols universitet slagit ett världsrekord i 5G-teknik.

Steffen Malkowsky var dock redan i våras med och satte det tidigare världsrekordet. Det lyckade experimentet beskrivs som ett viktigt steg mot en ny typ av trådlös kommunikation – ett system där extremt svaga radiosignaler lyckas ge radikalt förbättrad uppkoppling.

Systemet bygger på en teknik som kallas Massiv MIMO (efter multiple input, multiple output) och har satt inte bara ett utan två världsrekord i så kallad spektrumeffektivitet för trådlös kommunikation. Den teknik som forskarna tagit fram är en extremt effektiv 5G-teknik – den mest effektiva någonsin när det gäller att hantera många samtidiga användare. I sitt senaste världsrekord lyckades forskarlagen från Lund och Bristol uppnå mer än tjugo gånger så hög total datahastighet som dagens 4G-teknik. Därmed dubblerade de nästan sitt tidigare rekord, där de med samma teknik uppnådde en tolvfaldig förbättring.

– Att vi satte världsrekordet var en viktig händelse, eftersom vi visade att det är möjligt att överföra 22 gånger mer data än i nuvarande trådlösa system. Även om målet för 5G är att öka den sammanlagda överföringskapaciteten 1 000 gånger är detta ett stort steg, säger Steffen Malkowsky, doktorand i Elektro- och informationsteknik vid Lunds Tekniska Högskola.

Bristol and Lund set a new world record in 5G wireless spectrum efficiency

New research by engineers from the Universities of Bristol and Lund, working alongside National Instruments (NI), has demonstrated how a massive antenna system can offer a

12-fold increase in spectrum efficiency compared with current 4G cellular technology.



## Nytt 5G-rekord

LTH-doktoranden Steffen Malkowsky har tillsammans med forskarkollegor från Lunds och Bristols universitet slagit ett världsrekord i 5G-teknik och därmed överträffat det tidigare världsrekordet. Det lyckade experimentet är ett viktigt steg mot en ny typ av trådlös kommunikation – ett system där extremt svaga radiosignaler lyckas ge radikalt förbättrad uppkoppling.

## Nytt 5G-rekord och prisregn över doktorander

ON AUG 10, 2016 14:02 CET

Paul Harder,  
Läs mer..

- Ladda ner instr.
- Läs temaartiklarna
- Läs temaartiklarna on
- Klicka här för att prenun.
- Elektronik i Nordens Nyhe
- Läs nyhetsbrevet på webber.

LTH-doktoranden Steffen Malkowsky har tillsammans med forskarkollegor från Lunds och Bristols universitet slagit ett världsrekord i 5G-teknik och därmed överträffat det tidigare världsrekordet. Det lyckade experimentet är ett viktigt steg mot en ny typ av trådlös kommunikation – ett system där extremt svaga radiosignaler lyckas ge radikalt förbättrad uppkoppling.

Forskare vid Lunds och Bristols universitet har i en rad experiment använt en 5G-teknik som kallas Massiv MIMO (efter multiple input, multiple output) och satt inte bara ett utan två världsrekord i så kallad spektrumeffektivitet för trådlös kommunikation. Något förenklat kan man säga att spektrumeffektivitet mäter hur mycket data man lyckas packa in i den radiosignal som skickas ut från antennen.

Den teknik som forskarna tagit fram är en extremt effektiv 5G-teknik – den mest effektiva någonsin när det gäller att hantera många samtidiga användare. I sitt senaste världsrekord lyckades forskarlagen från Lund och Bristol uppnå mer än tjugo gånger så hög total datahastighet som dagens 4G-teknik. Därmed dubblerade de nästan sitt tidigare rekord, där de med samma teknik





# 1 paper + 1 workshop presentation at RFIC 2016

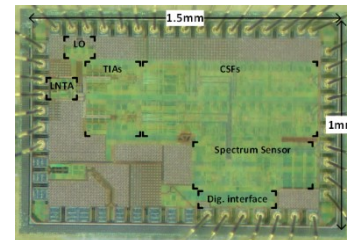
S. Francisco, CA, May 22-26



# 1 paper + 1 workshop presentation at RFIC 2016



- M. Abdulaziz, W. Ahmad, A. Nejedel, M. Törmänen, and H. Sjöland, "*A Cellular Receiver Front-End with Blocker Sensing*"



- P. Andreani, "*Harmonic Integrated Oscillators*", workshop presentation





# 1 paper at APMC 2015



- T. Forsberg, H. Sjöland, and M. Törmänen, "A Two-Stage mm-wave PA with 18.5% PAE in 65nm CMOS"

**Best Student Award  
Asia-Pacific Microwave  
Conference 2015**



# 1 paper at ESSCIRC 2016



B. Mohammad, O. Andersson, J. Nguyen,  
L. Ciampolini, A. Cathelin, J. Rodrigues,  
*“A 128 Kb Single-Bitline 8.4 fJ/Bit 90MHz at 0.3V  
7T Sense-Amplifierless SRAM in 28 nm FD-SOI”*



Lausanne,  
September 12-15



# 1 paper at ASSCC 2016



B. Mohammadi, O. Andersson, X. Luo,  
M. Nouripayam, J. Rodrigues, “*An Area  
Efficient Single-Cycle  $xVDD$  Sub- $V_{th}$  on-  
Chip Boost Scheme in 28 nm FD-SOI*”

富山 IEEE Asian Solid-State Circuits Conference 2016

November 7 (Mon.) - 9 (Wed.), 2016  
Toyama International Conference Center, Toyama, Japan

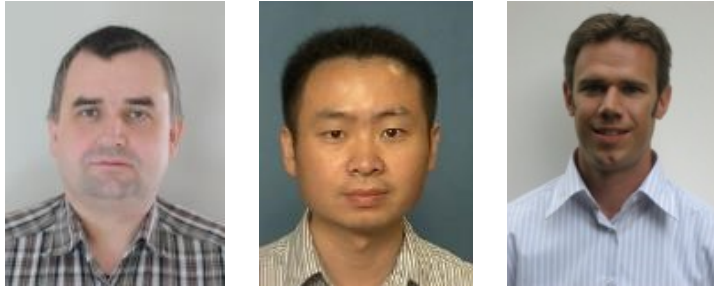
Organized by  

The banner features the Japanese characters '富山' (Toyama) in large black font. Below the title, there are five small images: a traditional Japanese castle, a colorful autumn landscape, a close-up of food, a traditional Japanese building, and a display of sake bottles. The IEEE and SSCS logos are at the bottom.

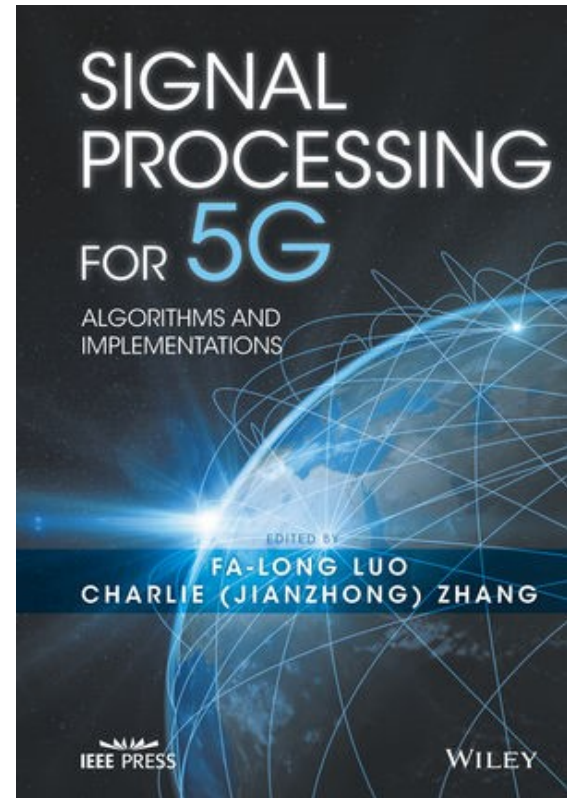
# Noteworthy publications



# Wiley 5G book chapter

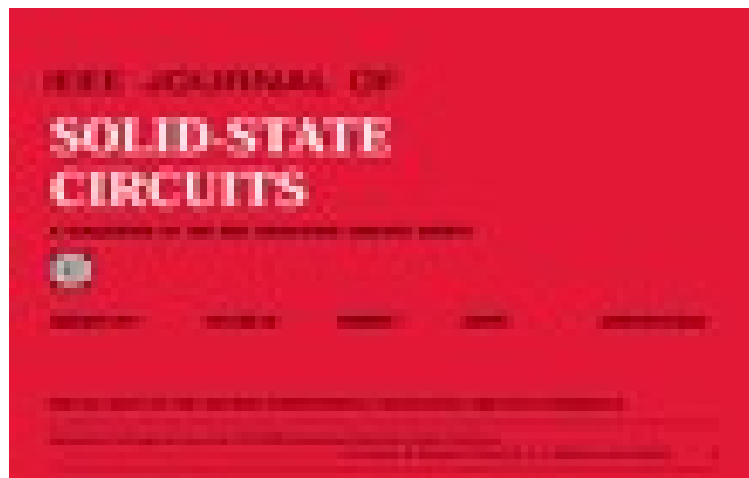


O. Edfors, L. Liu, F. Tufvesson,  
N. Kundargi and K. Nieman:  
“Massive MIMO for 5G: Theory,  
Implementation and Prototyping”





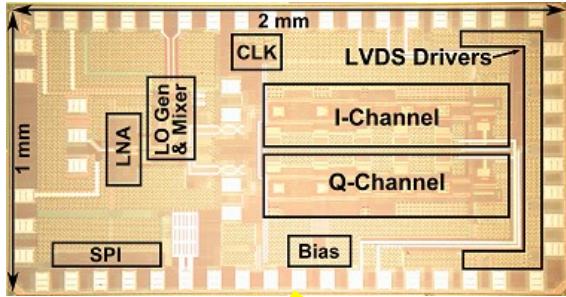
# IEEE JSSC special issue on ESSCIRC 2015



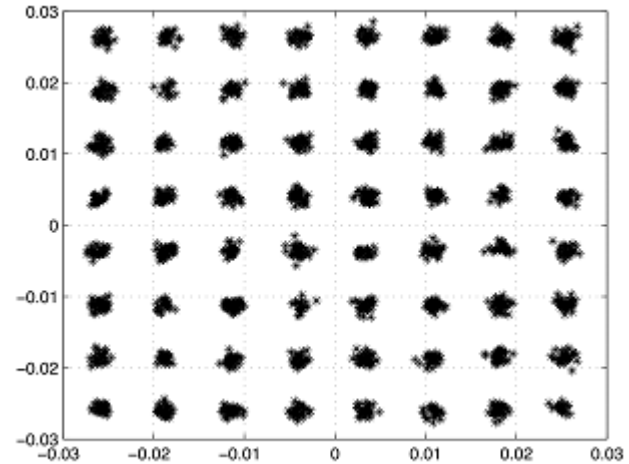
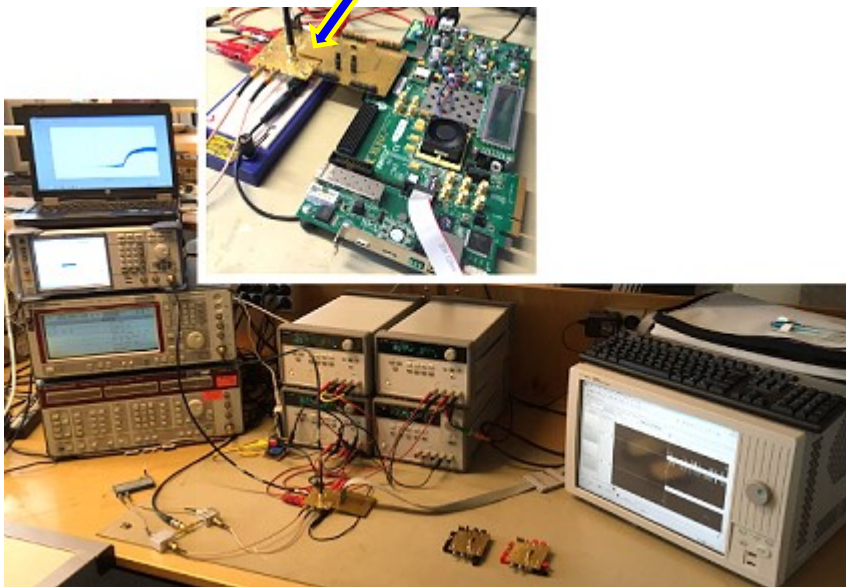
X.Liu, A. Nejdell, M. Palm, L. Sundström, M. Törmänen, H. Sjöland and P. Andreani, “A 65 nm CMOS Wideband Radio Receiver with  $\Delta\Sigma$ -Based A/D-Converting Channel-Select Filters”, IEEE J. of Solid-State Circuits, Vol. 51, No. 7, pp. 1566-1578, July 2016.



# Demonstrator of complete radio RX



From antenna to constellation!



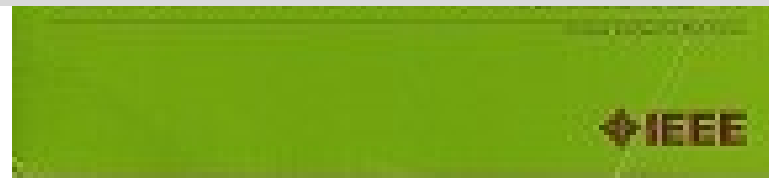
SSF DARE project



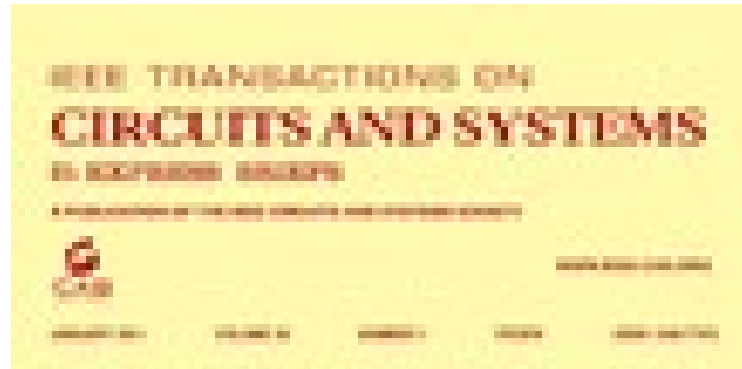
# IEEE T-MTT paper



I. Vasilev, J. Lindstrand, V. Plicanic, H. Sjöland, and B. K. Lau: “*Experimental investigation of adaptive impedance matching for a MIMO terminal with CMOS SOI tuners*”, IEEE Transactions on Microwave Theory and Techniques, Vol. 64, No. 5, pp. 1622-1633, 2016.



# IEEE TCAS-I paper



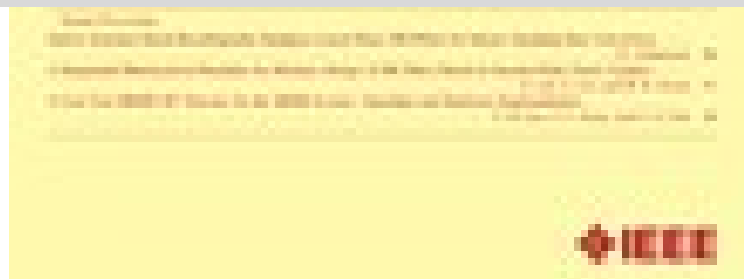
O. Andersson, B. Mohammadi, P. Meinerzhagen, A. Burg, and J. N. Rodrigues, “Ultra Low Voltage Synthesizable Memories: A Trade-off Discussion in 65 nm CMOS,” *IEEE Transactions on Circuits and Systems – I*, vol. 63, no. 6, pp. 806–817, June, 2016.



# IEEE TCAS-II paper



R. Gangarajaiah, M. Abdulaziz, H. Sjöland, P. Nilsson, and L. Liu, : “*A Digitally Assisted Nonlinearity Mitigation System for Tunable Channel Select Filters*”, IEEE Trans. Circuits Syst. – II, Vol. 63, No. 1, pp. 69-74, Jan. 2016.

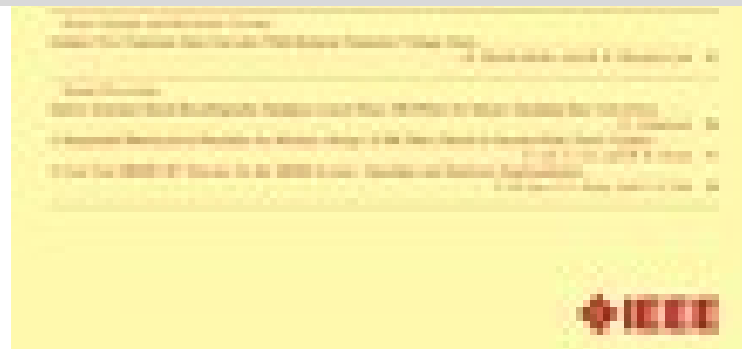




# IEEE TCAS-II paper



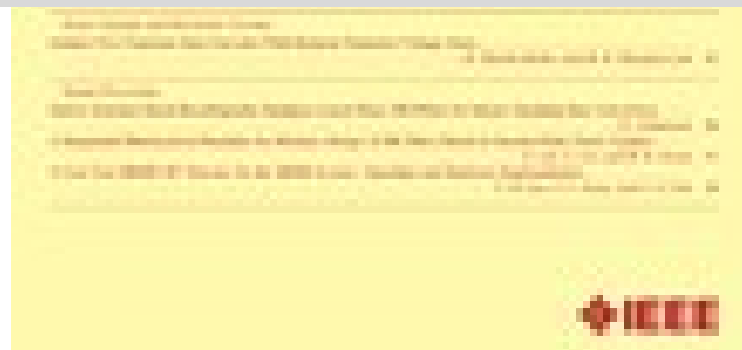
F. Pepe and P. Andreani: “*Still More on the  $1/f^2$  Phase Noise Performance of Harmonic Oscillators*”, IEEE Trans. Circuits Syst. – II, Vol. 63, No. 6, pp. 538-542, June 2016.



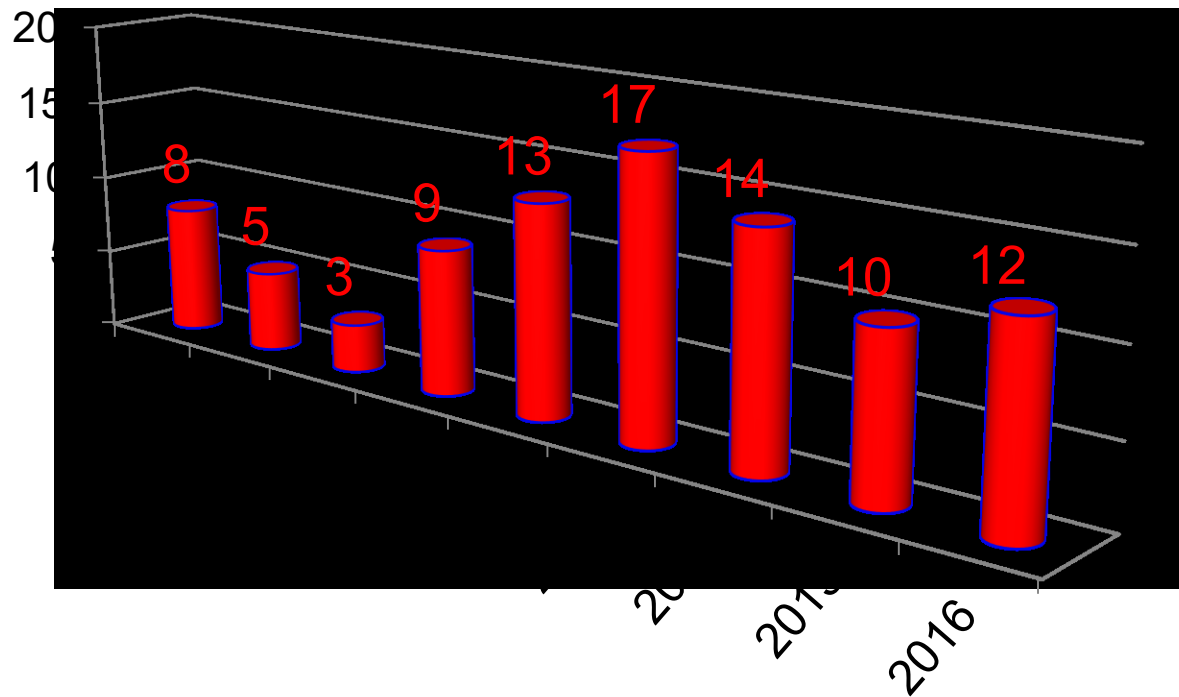
# IEEE TCAS-I paper



F. Pepe and P. Andreani: “*A General Theory of Phase Noise in Transconductor-Based Harmonic Oscillators*”, to appear in IEEE Trans. Circuits Syst. – I, pp. 1-16.



# Journal publications in circuit design



# ... and some unpublished results

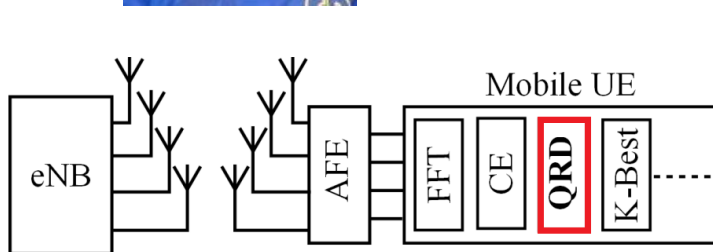




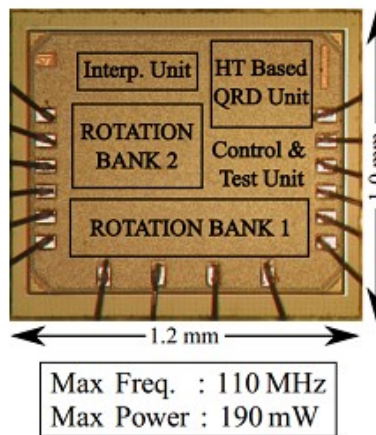
# Adaptive QR Matrix Decomposition for LTE-A MIMO



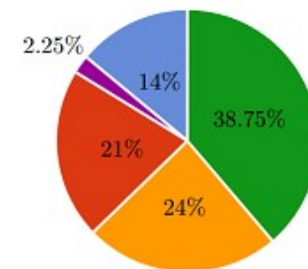
SSF DARE project



A typical LTE-A MIMO system with a QRD unit



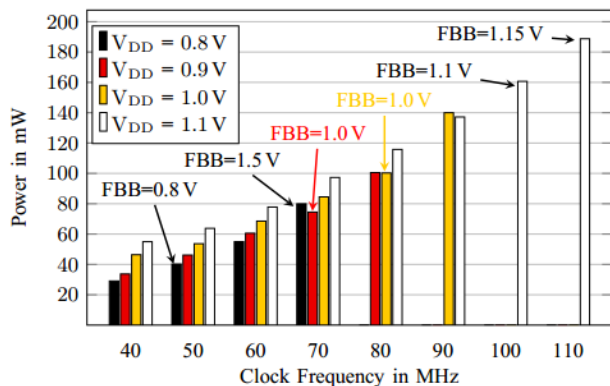
Chip microphotograph



- HT Based QRD Unit
- Interp. Unit
- ROTATION BANK 1
- ROTATION BANK 2
- Control & Test Unit

Area Breakdown

Power Consumption with different FBB in IP4 mode

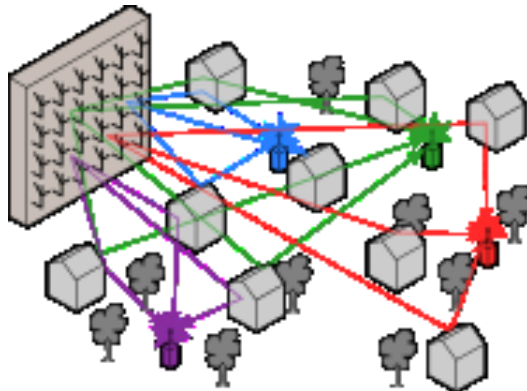


STM 28nm UTBB FD-SOI CMOS

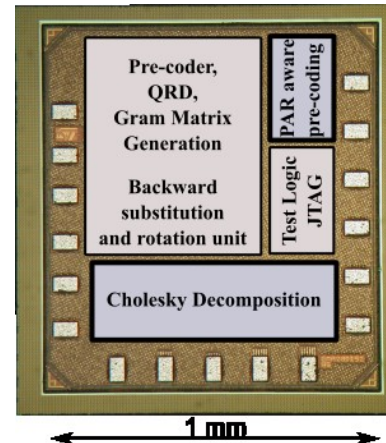
FBB = forward body bias



# Massive MIMO Baseband Processing



MAMMOET FP7 project



8x128 Massive MIMO Pre-coder

Gate Count (QRD)	138 K
Max. Freq	300 MHz
Clock Cycles	64 or 128
Power	33 mW

8x8 Cholesky Decomposition

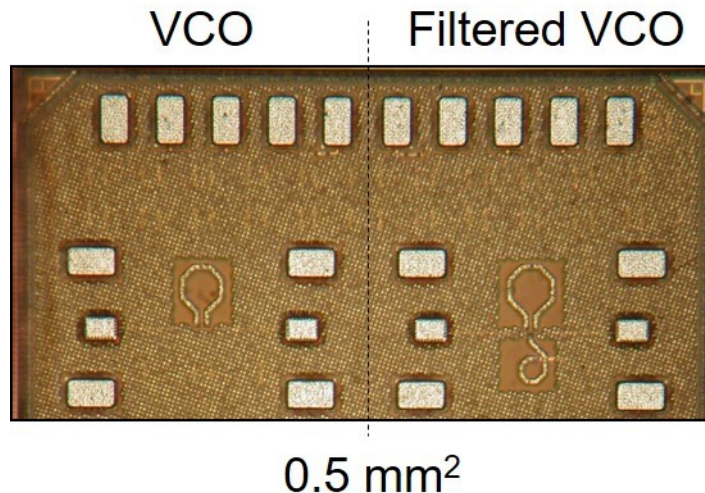
Gate Count	79.7 K
Max. Freq	300 MHz
Clock Cycles	325
Power	20 mW @ 0.9V

STM 28nm UTBB FD-SOI CMOS

- Adaptive downlink pre-coding based on approximate QR decomposition
- Linear/non-linear uplink detection based on LU decomposition



# Two mm-wave VCOs



VR project

- Tuning range of 11% (60 – 67 GHz)
- Lowest power consumption at 3.15 mW
- State-of-the-art FOM of -187 dBc/Hz for filtered VCO

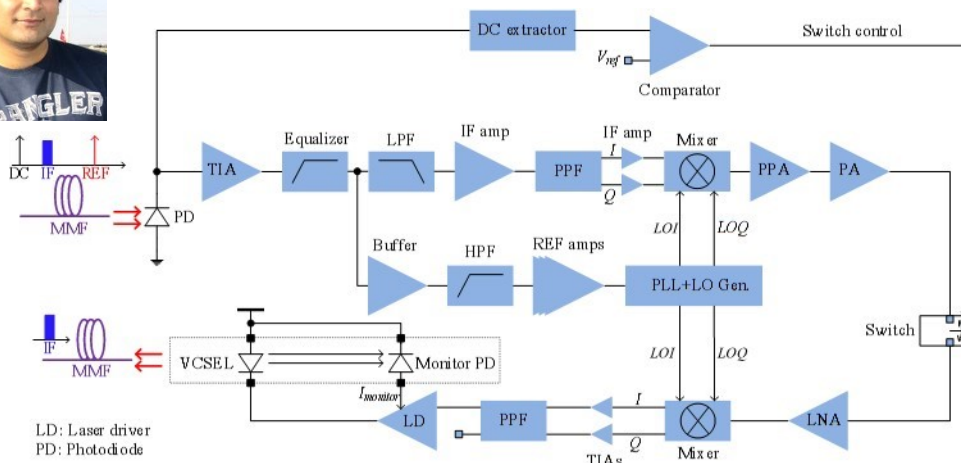
STM 28nm UTBB FD-SOI CMOS



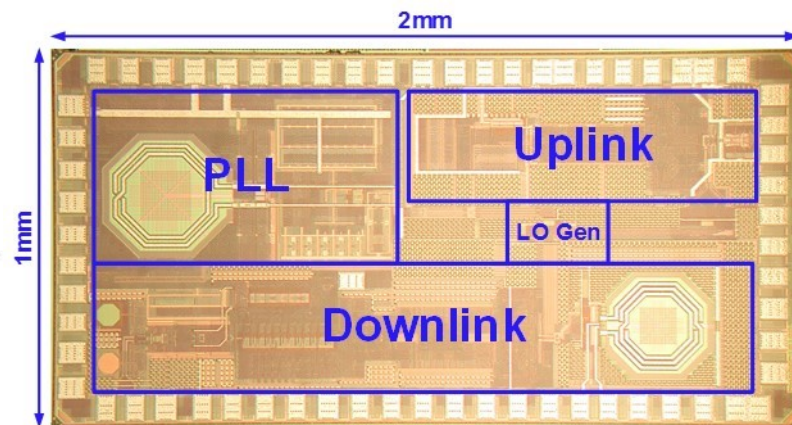




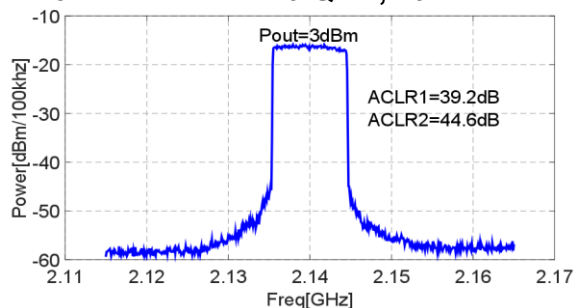
# CMOS RAU for Fiber-Fed Distributed MIMO



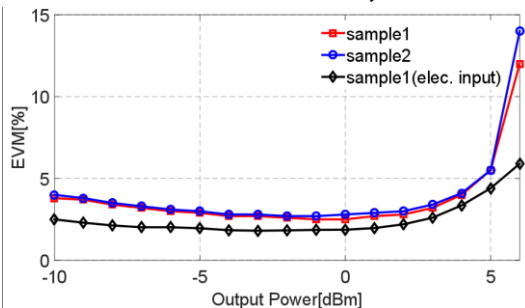
## SSF DISTRANT project



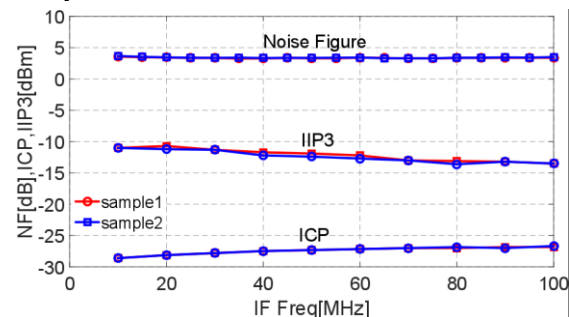
Downlink ACLR: 16-QAM, 10 MHz LTE



Downlink EVM: 16-QAM, 10 MHz LTE



Uplink continuous wave measurements



STM 65nm CMOS

Submitted to T-MTT

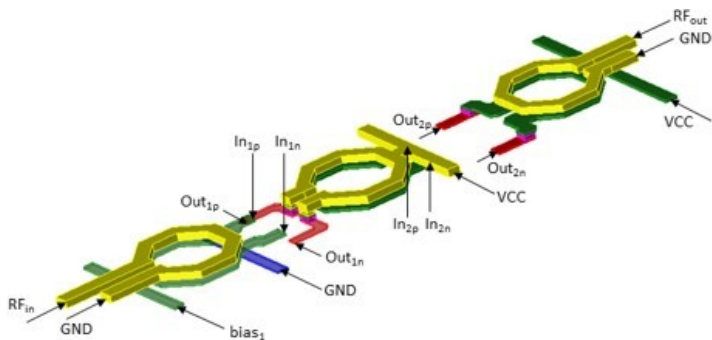




# mm-wave Power Amplifiers



SoS project

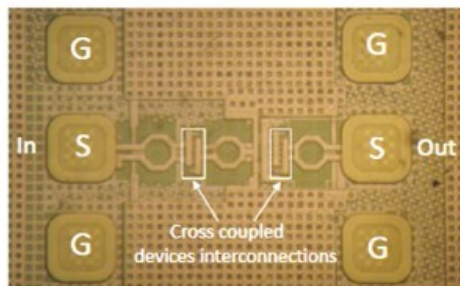


Infineon b7hf200 SiGe process

2-stage, cross-coupled

$G = 10\text{dB @ } 93\text{GHz}$

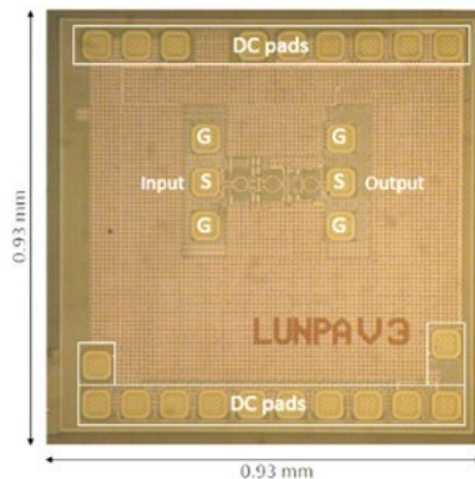
$P_{\text{sat}} = 15\text{dBm}$



2-stage, cascode

$G = 16\text{dB @ } 92\text{GHz}$

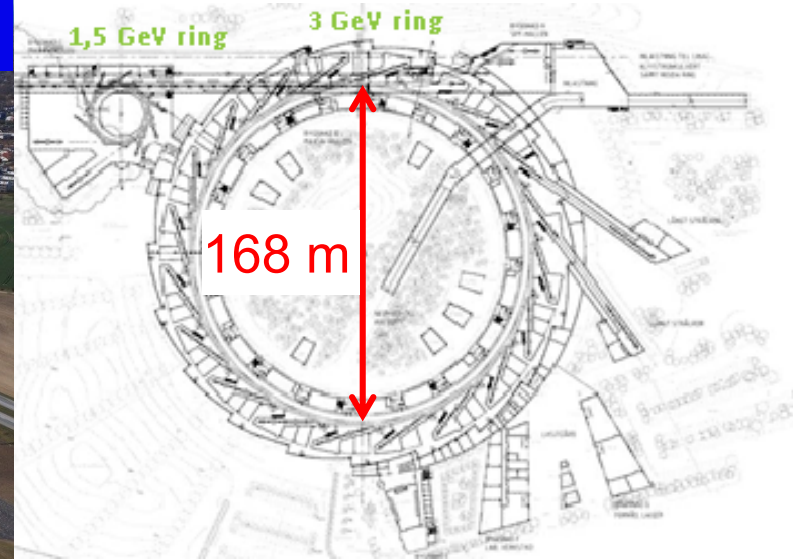
$P_{\text{sat}} = 17\text{dBm}$



# Our Neighbors



## The most modern synchrotron light facility in the world



Later today a presentation by  
Pedro Fernandes Tavares from MAX IV





# European Spallation Source (ESS)





# ESS – aerial photo from Feb. 2016





# ESS – progress of constructions

Test hall for modulators and klystrons



Accelerator tunnel



Accelerator gallery



Bulding hosting the target





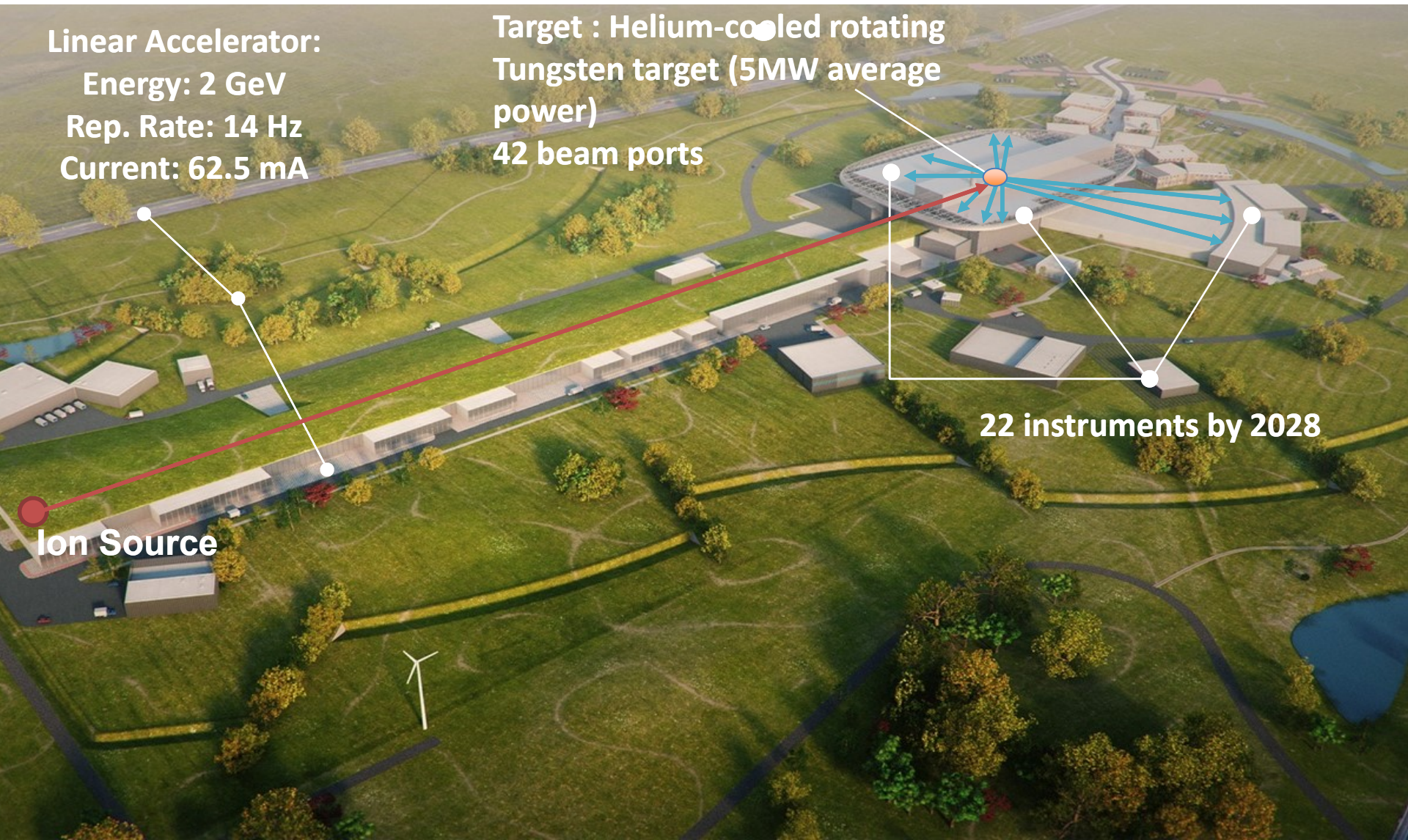
# ESS – the way it will be

Linear Accelerator:  
Energy: 2 GeV  
Rep. Rate: 14 Hz  
Current: 62.5 mA

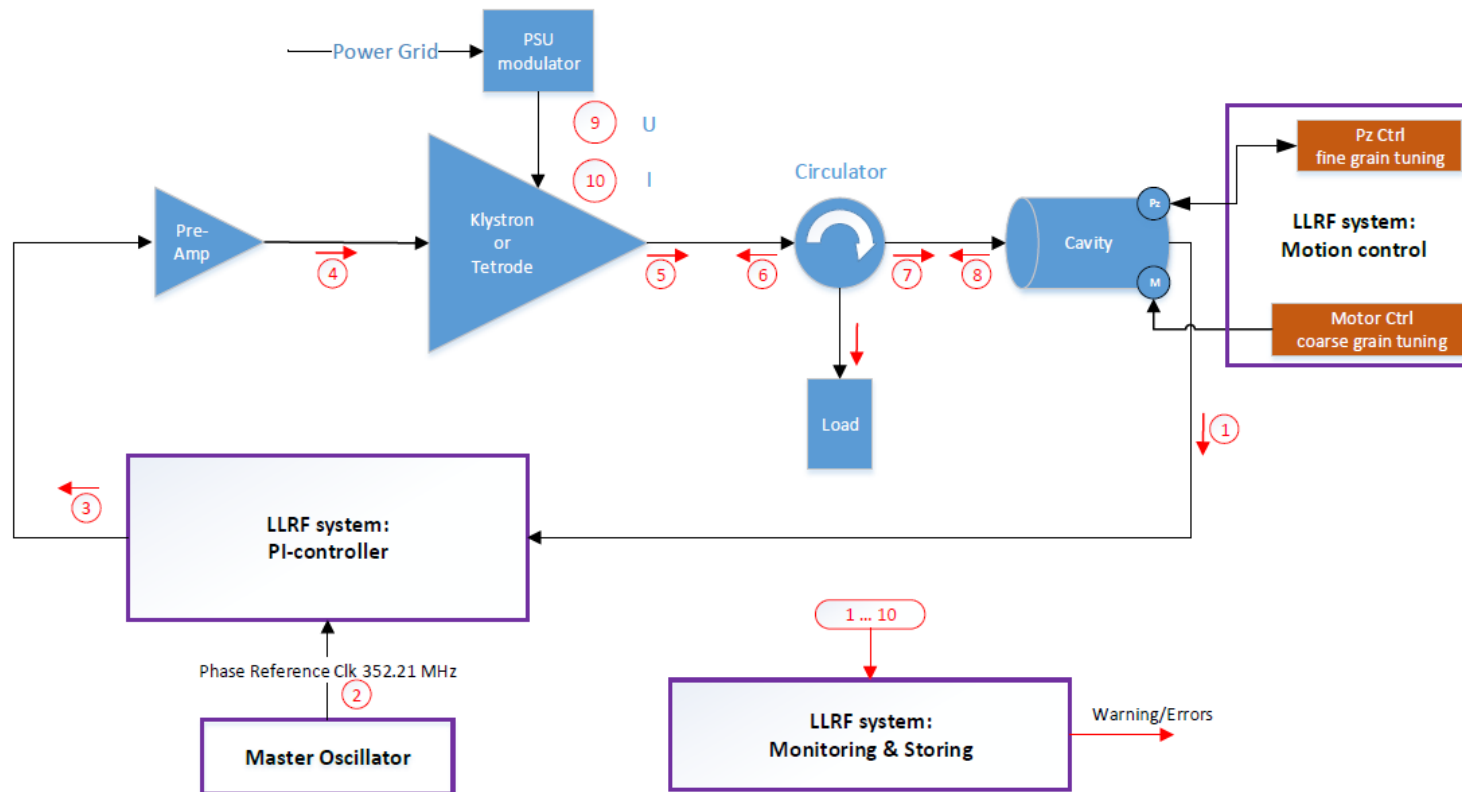
Target : Helium-cooled rotating  
Tungsten target (5MW average  
power)  
42 beam ports

Ion Source

22 instruments by 2028



# LTH activities for the ESS accelerator



## Lund University will design part of the low-level RF (LLRF) system for the linear accelerator

The LLRF system controls phase and amplitude of the electric field at the accelerating cavities to within  $0.1^\circ$  and  $0.1\%$  (the klystron PA delivers 1 MW to one cavity)

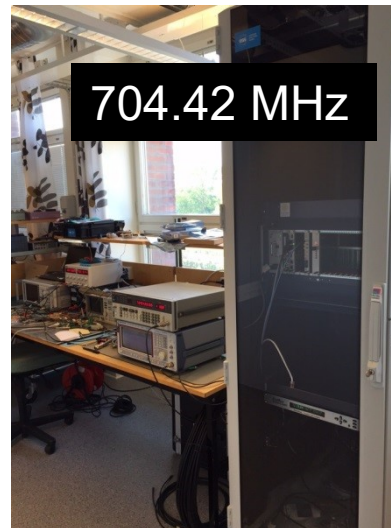
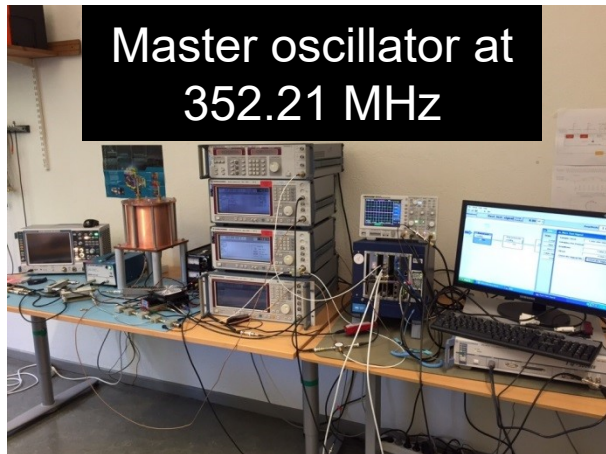




# LTH activities for the ESS accelerator – II

120kV power-supply modulator

- pulsed @ 14Hz
- 5% duty cycle



# What's next?

**We are one of the few groups  
that actually design and test ICs...**

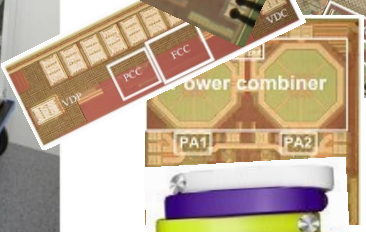
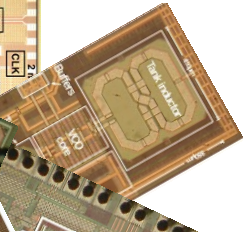
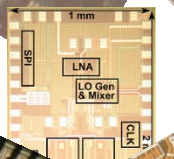
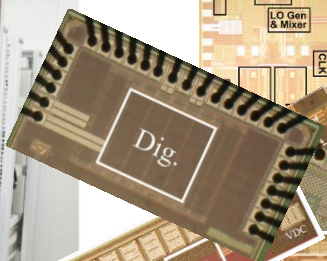
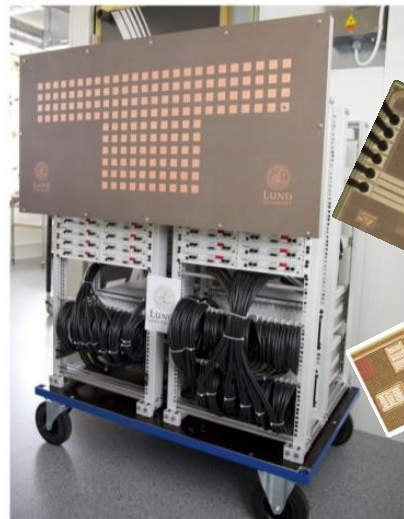
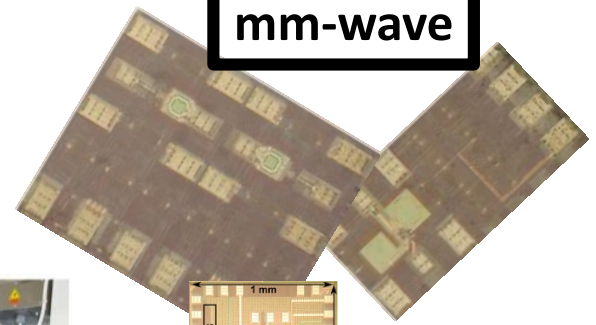
**... and we want to continue!**





# The IC!

mm-wave



Low Power Connectivity

MAX IV and ESS

