Nanoelectronics for Communication

- A wider perspective

-Use of Impulse based systems

Based on input from

Lars Ohlsson och Mats Ärlelid

Motivation

HDMI

Up to 10.2 Gbps

Wired vs. Wireless

Wifi 802.11n

Up to 600 Mbps

Bluetooth

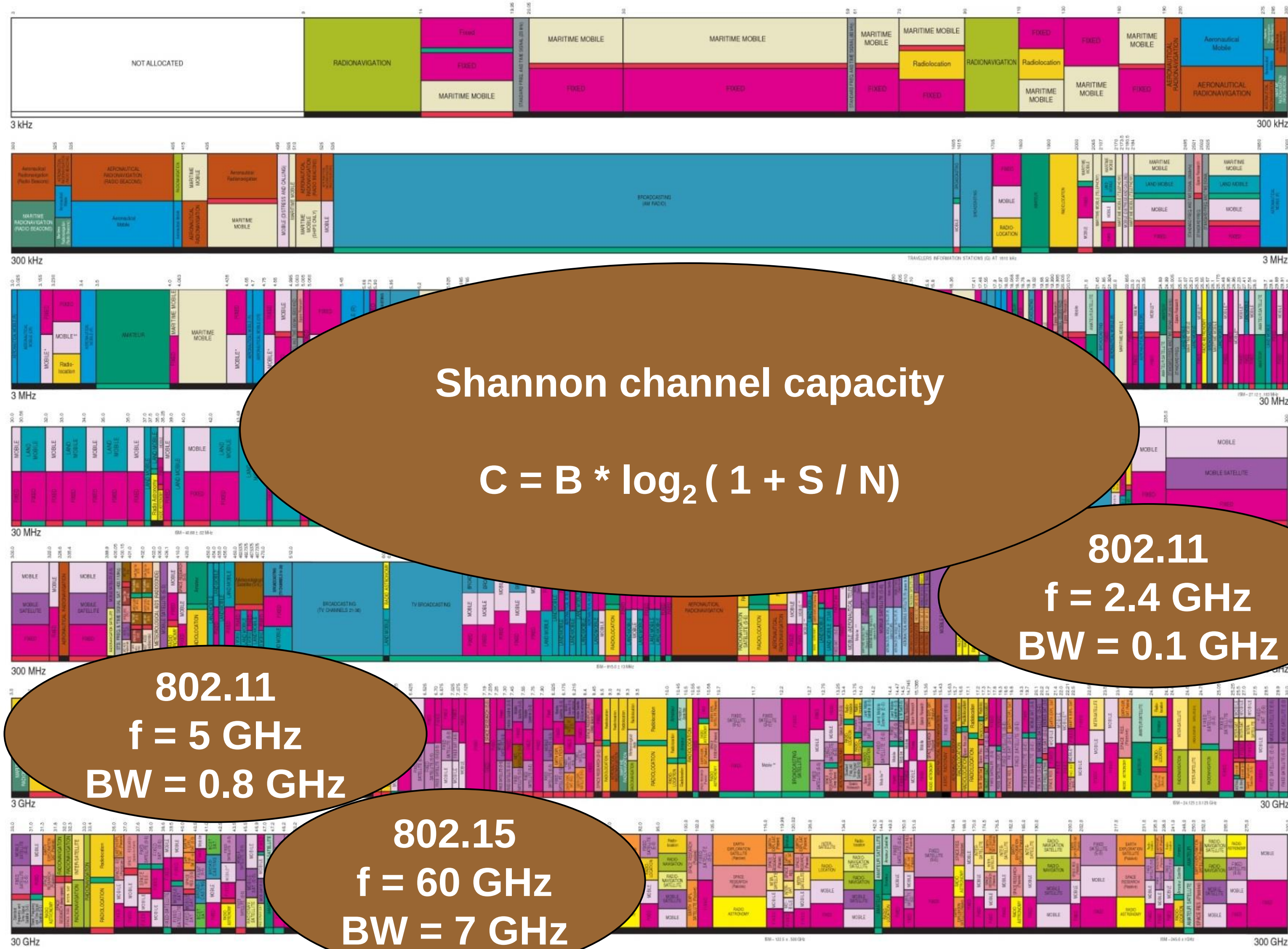
3 Mbps

USB 3.0

5 Gbps

Motivation

Federal Communications Commission (FCC) spectrum allocations for the US



Shannon channel capacity

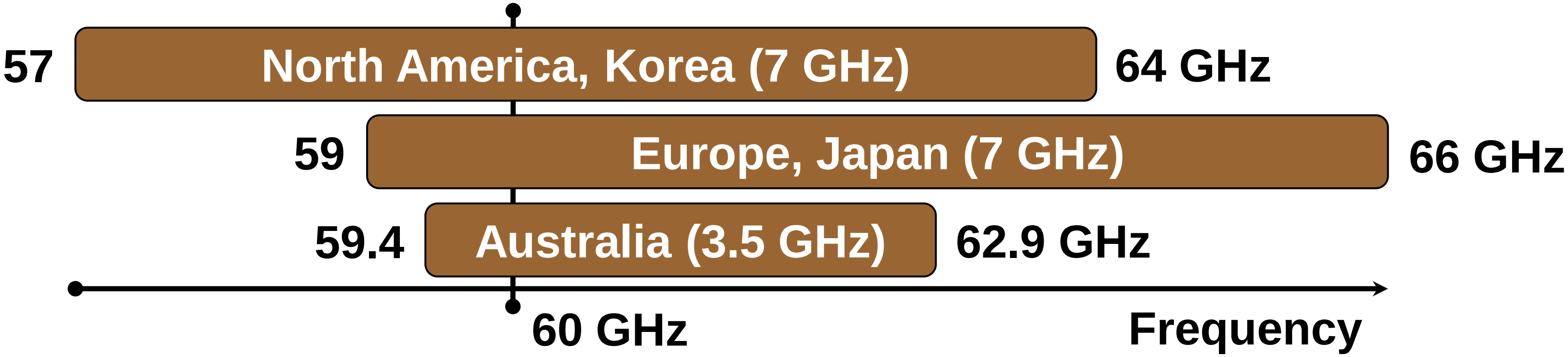
$$C = B * \log_2 (1 + S / N)$$

802.11
f = 2.4 GHz
BW = 0.1 GHz

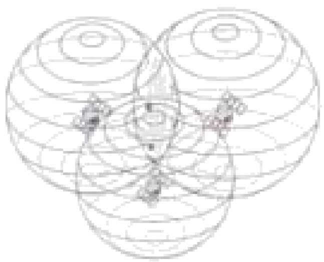
802.11
f = 5 GHz
BW = 0.8 GHz

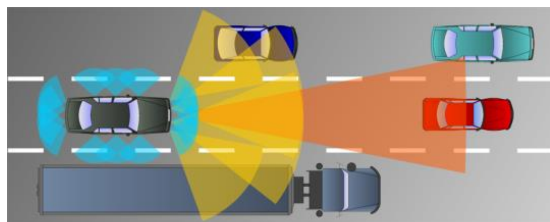
802.15
f = 60 GHz
BW = 7 GHz

Applications at 60 GHz and above



- Applications
  - Wireless HDMI
  - Simple docking
  - Radar
  - Imaging
  - Localisation





Benefits of Nanotechnology

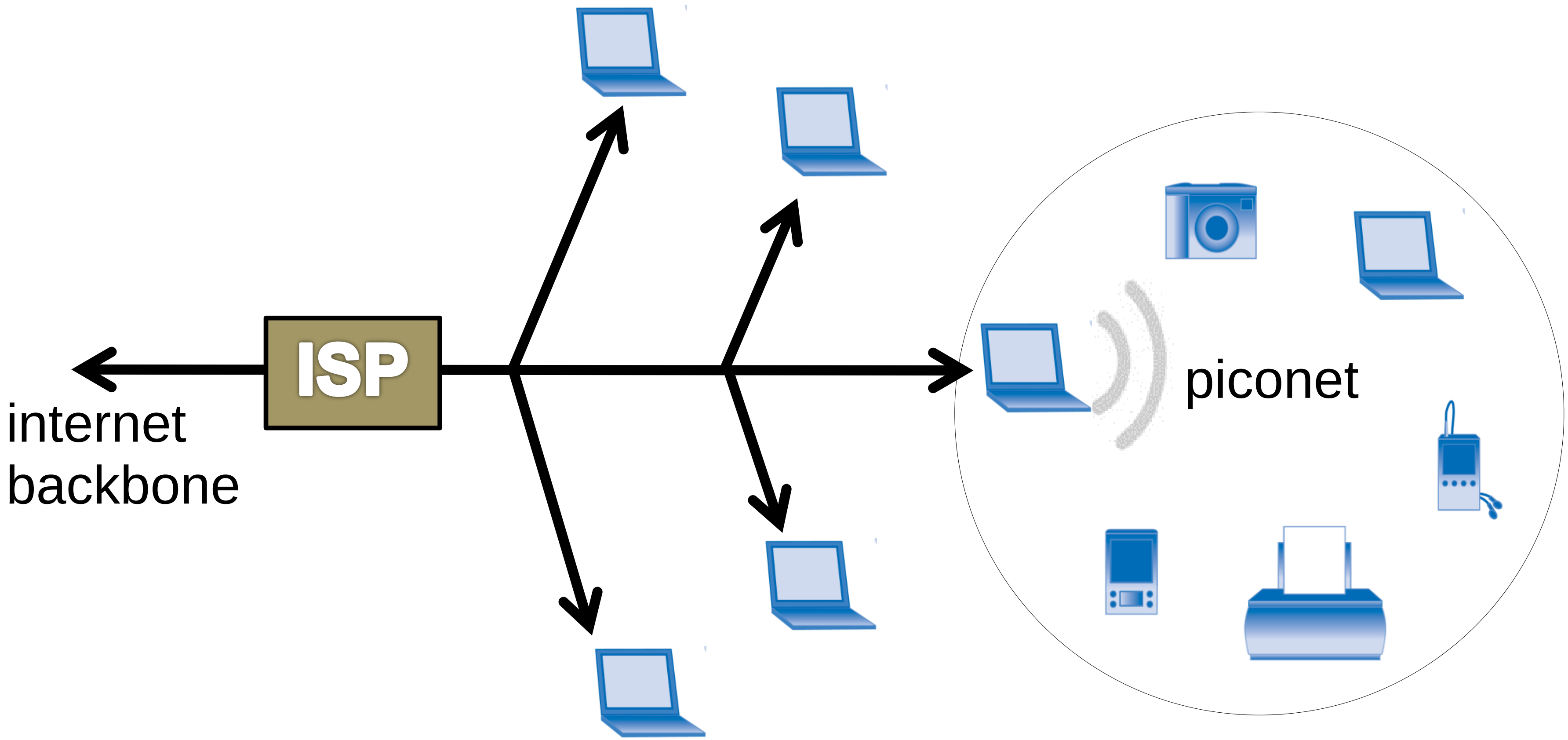
- Improved performance using III-V technology

- New approaches for signal generation and detection

Impulse Radio at 60 GHz

- Robust – Simple modulation
  - OOK, on-off keying
  - PPM, pulse position modulation
- High bit rate – Utilises alot of bandwidth
  - 7 GHz bandwidth available
- Limited range – Allows reusage of spectrum
  - Pathloss, proportional to prapagated wavelengths
  - 80 dB pathloss @ 60 GHz compared with 52 dB @ 2.4 GHz (4 meters)
- Small form factor - Wavelength is 5 mm @ 60 GHz
  - Antennas, typically ~½ wavelength
  - Inductors, typically << wavelength

High-Speed Wireless Communication



<u>Application trade-off:</u> Size of data **packets** – **range** – – allowed **latency** – number of **users**

Multiplexing – Coexisting Networks

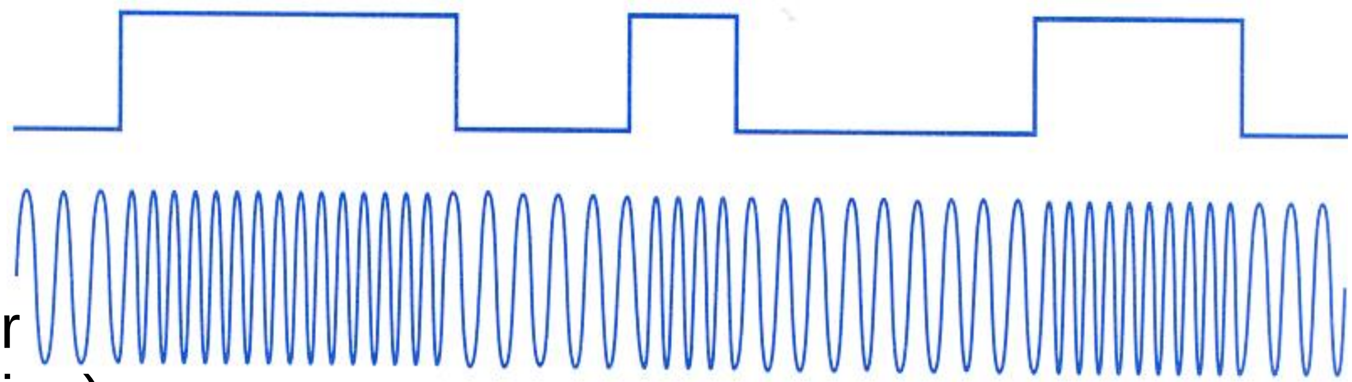
- Multiple Access Coding - Multiplexing
  - Coexisting networks on a spectral bandwidth.
  - Hopping provides better security and fidelity.
- Frequency Division Multiple Access (FDMA)
  - The band is divided into sub-bands
- Time Division Multiple Access (TDMA)
  - The band is used in different time-slots
- Code Division Multiple Access (CDMA)
  - A code-sequence with both time and frequency multiplexing is used for each channel

Example: Bluetooth

Binary data

0 1 1 1 0 0 1 0 0 0 1 1 0

Baseband signal



Modulated carrier (CDMA multiplexing)

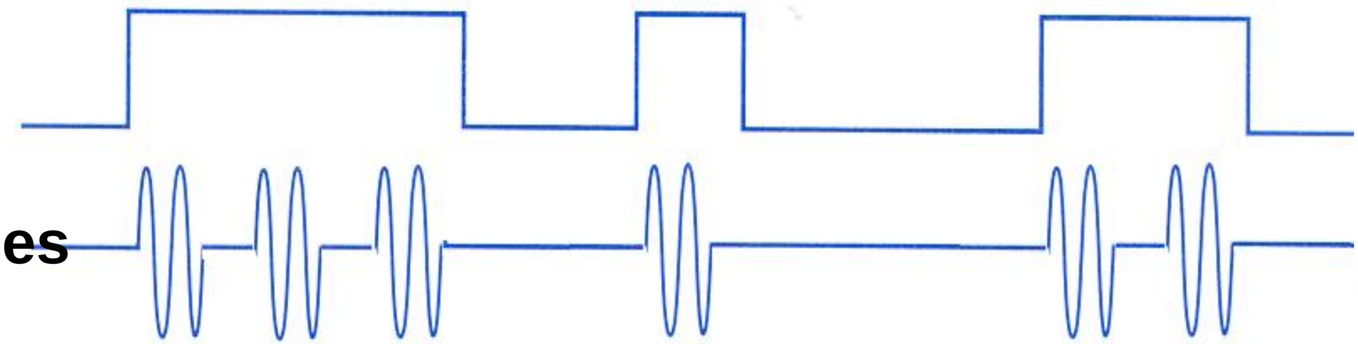
Bit rate: 3 Mbps
Carrier frequency: 2.4 Ghz
Range: 10 **m**
Maximum number of piconets ~10

Impulse radio

Binary data 0 1 1 1 0 0 1 0 0 0 1 1 0

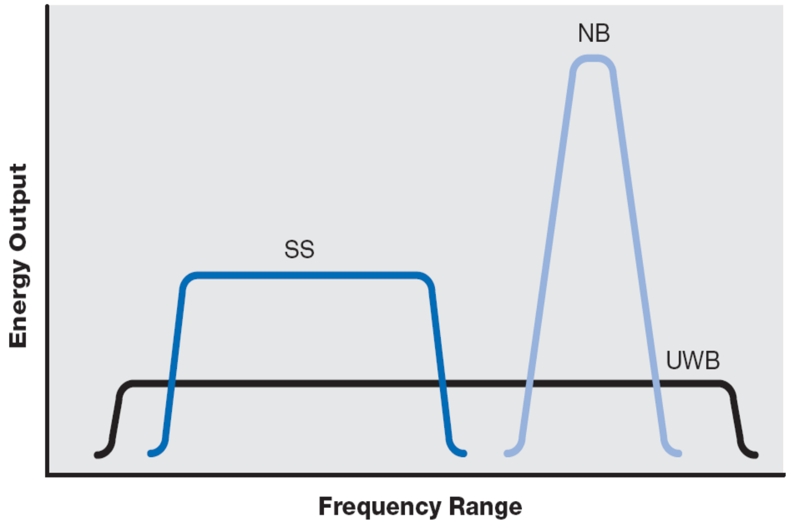
Baseband signal

Modulated **pulses**



Signal lacks continuous carrier –
Information is transmitted **“digitally”.**

Ultra wideband



Example: UWB system
Bit rate: 480 Mbps
Range: 3 m
Maximum number of piconets: 3

The power **is smeared out over a wide band**

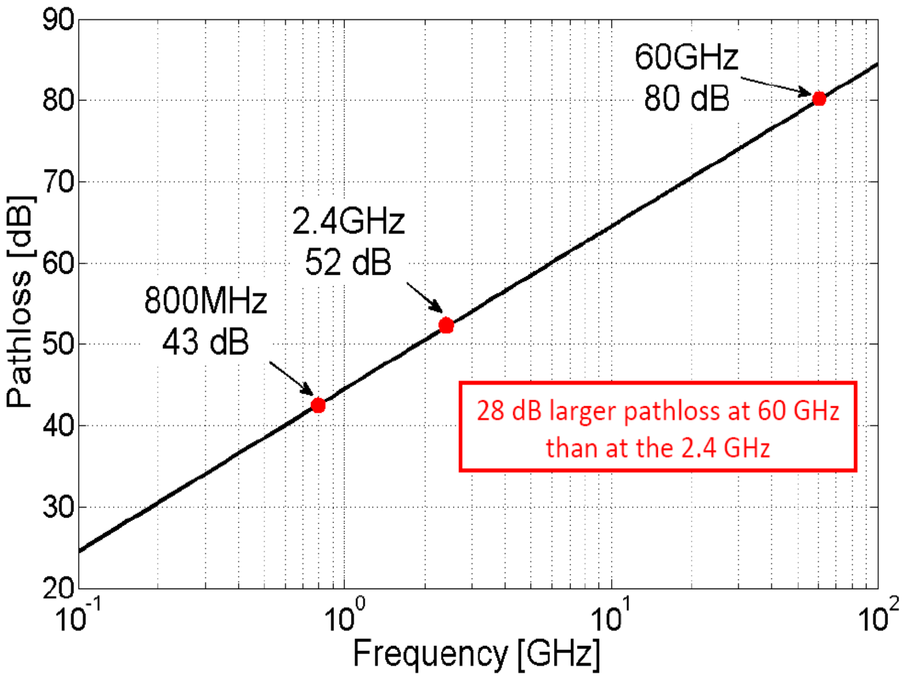
Coexists with other systems without degrading their performance (ideally)

Multipath Fading can never occur over the whole band

New window – new opportunities

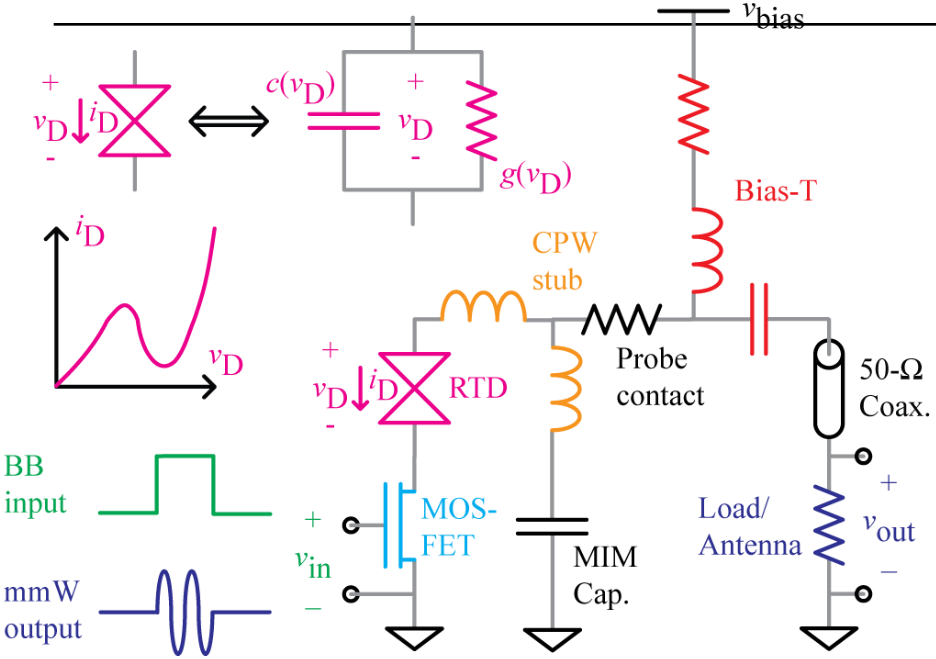
- 60 GHz band is unlicensed

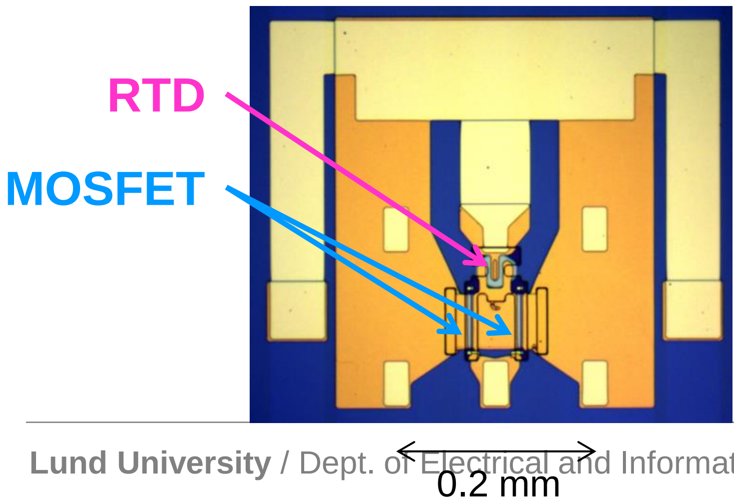
	Unlicensed spectrum [GHz]
North America	57-64
Europe	59-66
Australia	59.4-62.9
Korea	57-64
Japan	59-66

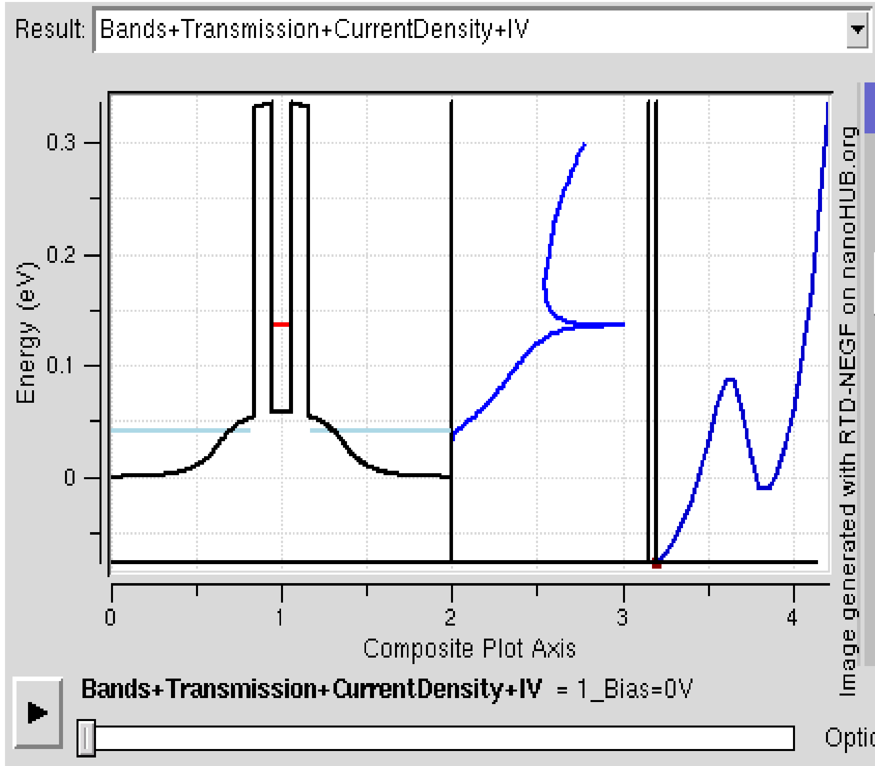


Free space path loss at 4 m

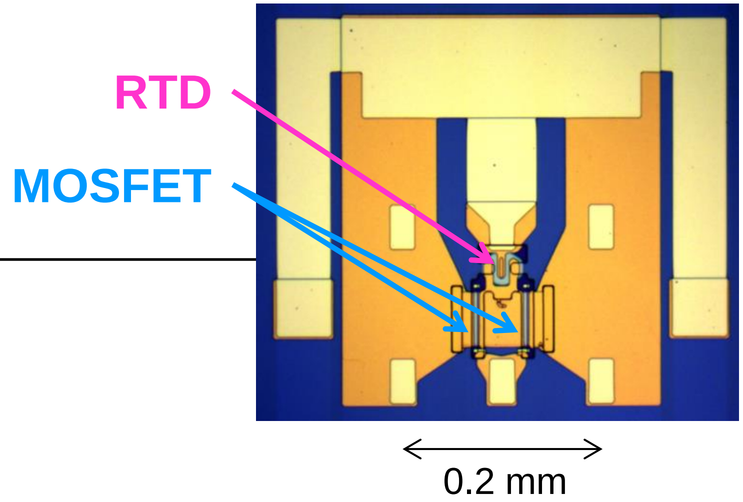
Resonant tunneling diode

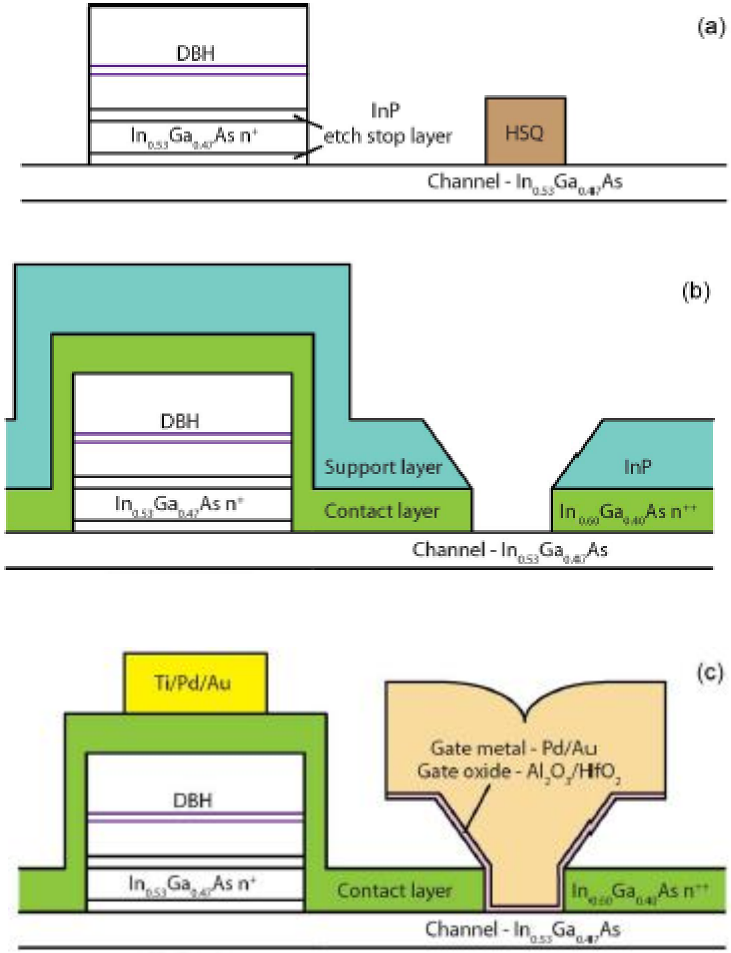


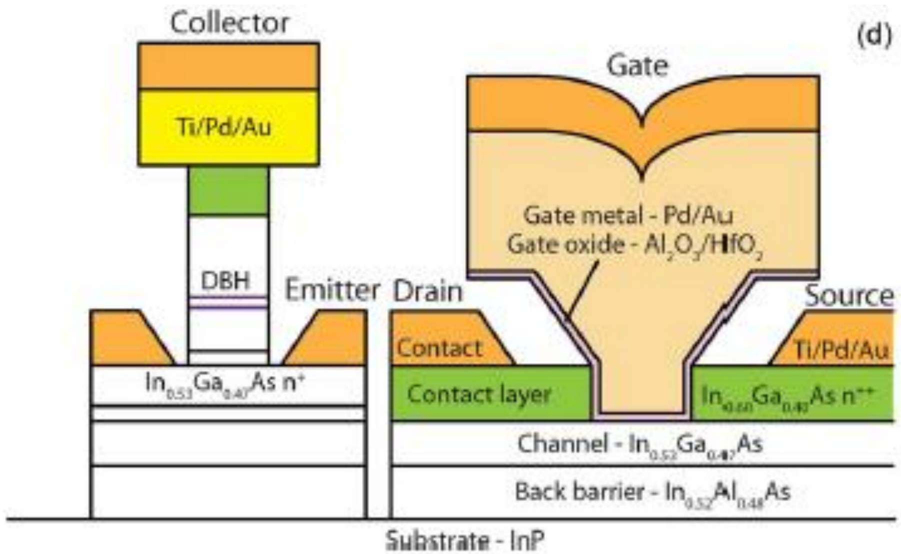




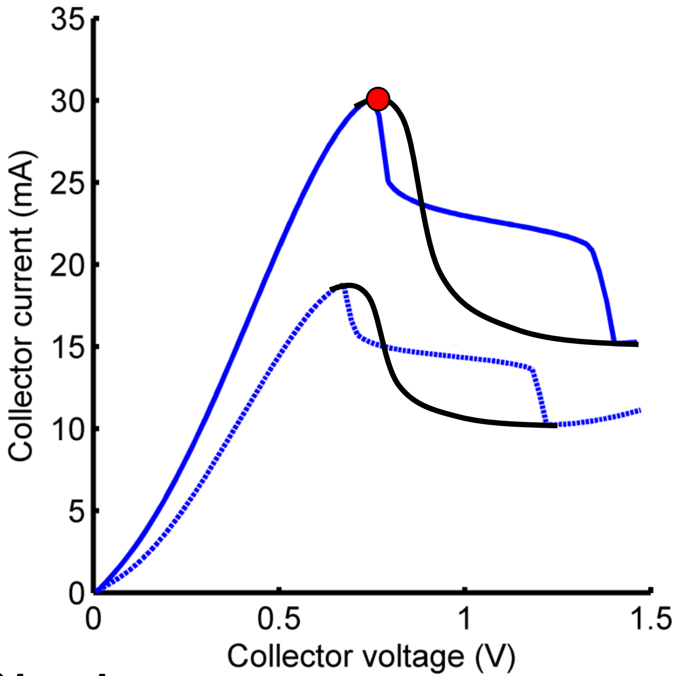
60 GHz Pulse Generator

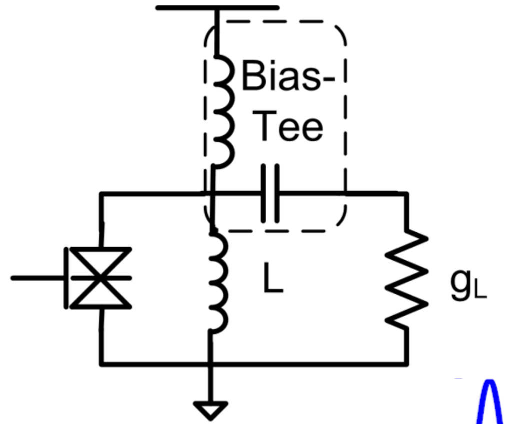


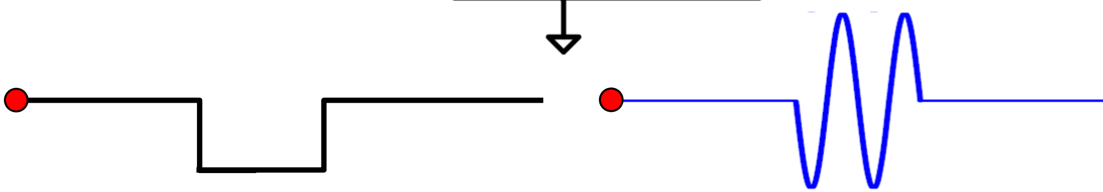




Nanotechnology from Lund







Startup

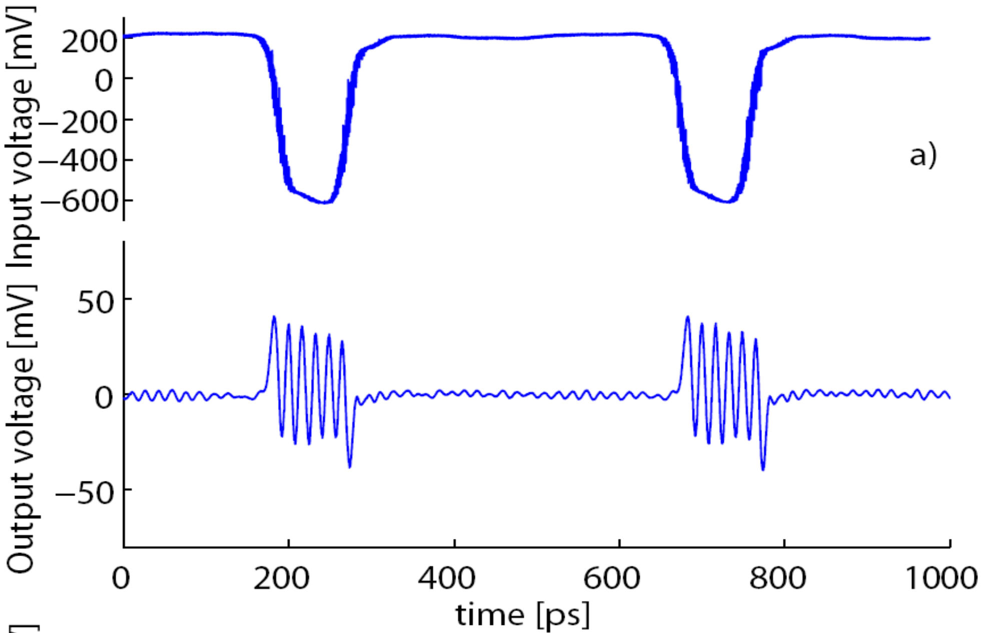
$$v(t) = \frac{2v_o}{\sqrt{1 + \left(\left(\frac{2v_0}{v(0)}\right)^2 - 1\right) e^{-\epsilon\omega_0 t}}} \cos(\omega_0 t + \varphi(0))$$

$$\epsilon = -\left(g_{oeq}(0)\sqrt{\frac{L_{eq}}{C_{eq}}} + \frac{1}{Q_{tank}}\right)$$

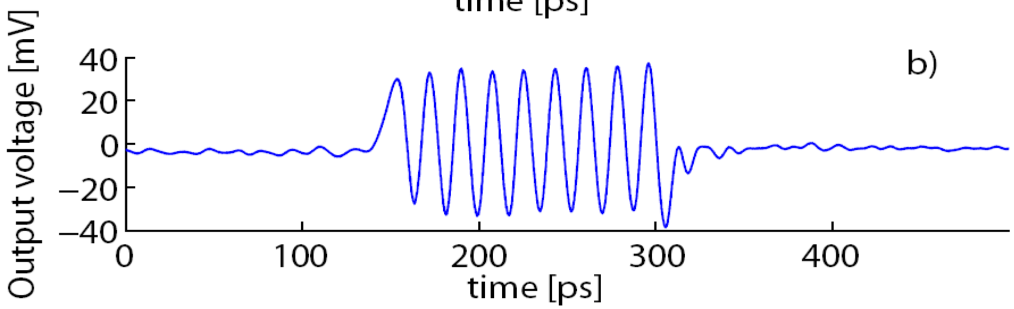
Decay

$$v(t) = V_{max} e^{\frac{-\omega_0}{2Q_{tankPDC}} t} \cos(\omega_0 t + \varphi(0))$$

The GTD Pulse Generator



62 GHz, 100 ps long



56 GHz, 160 ps long

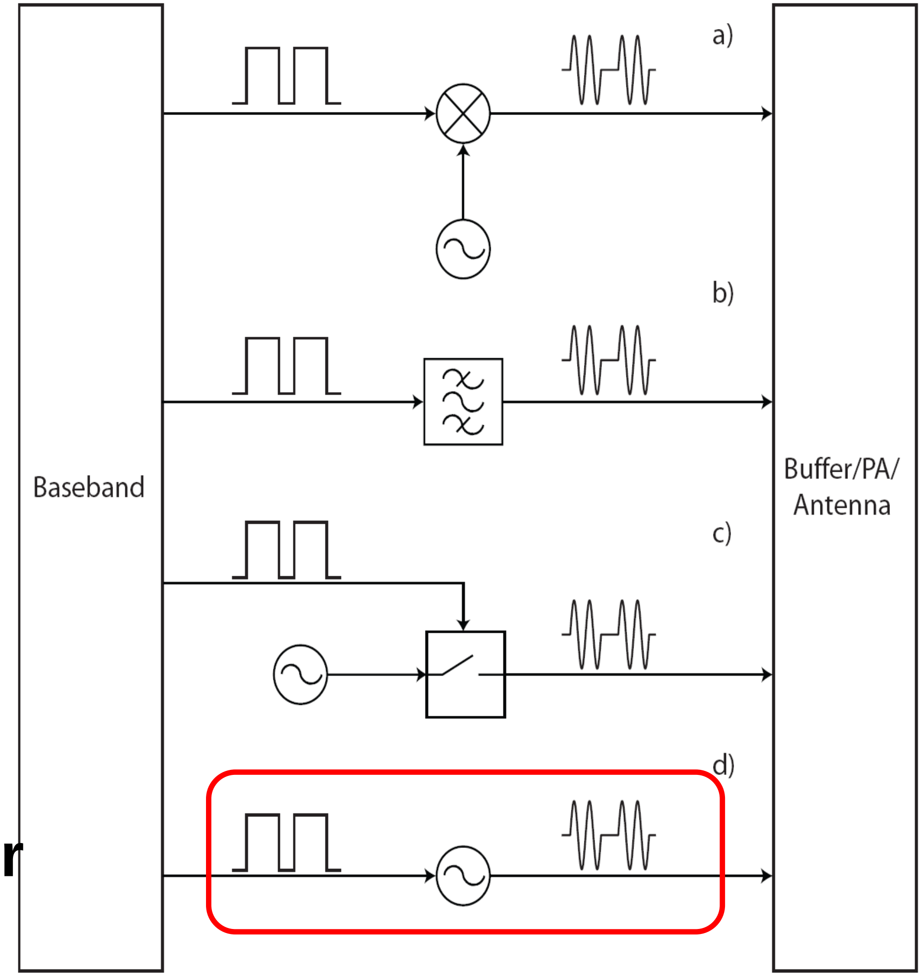
Comparing with other techniques

Mixer

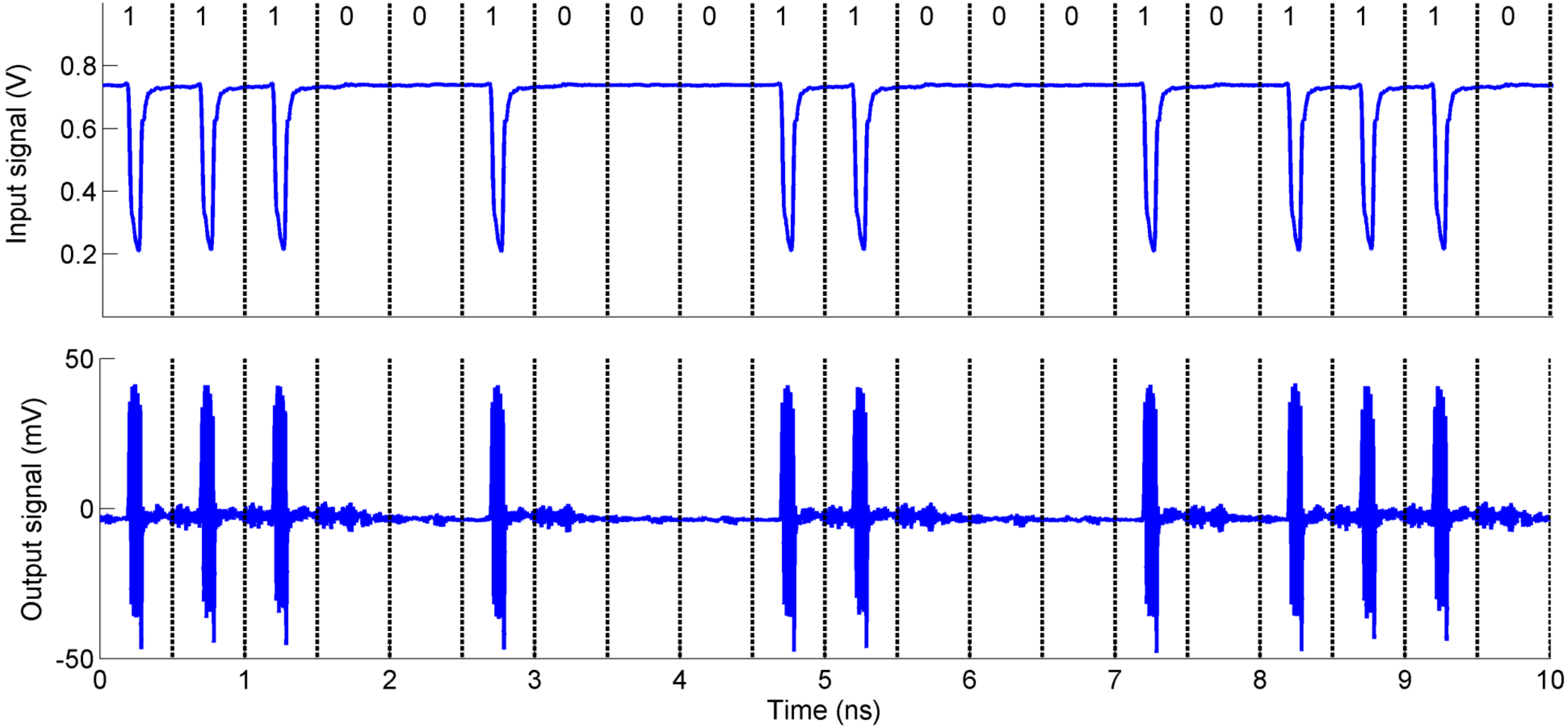
Filter

RF switch

Switched oscillator

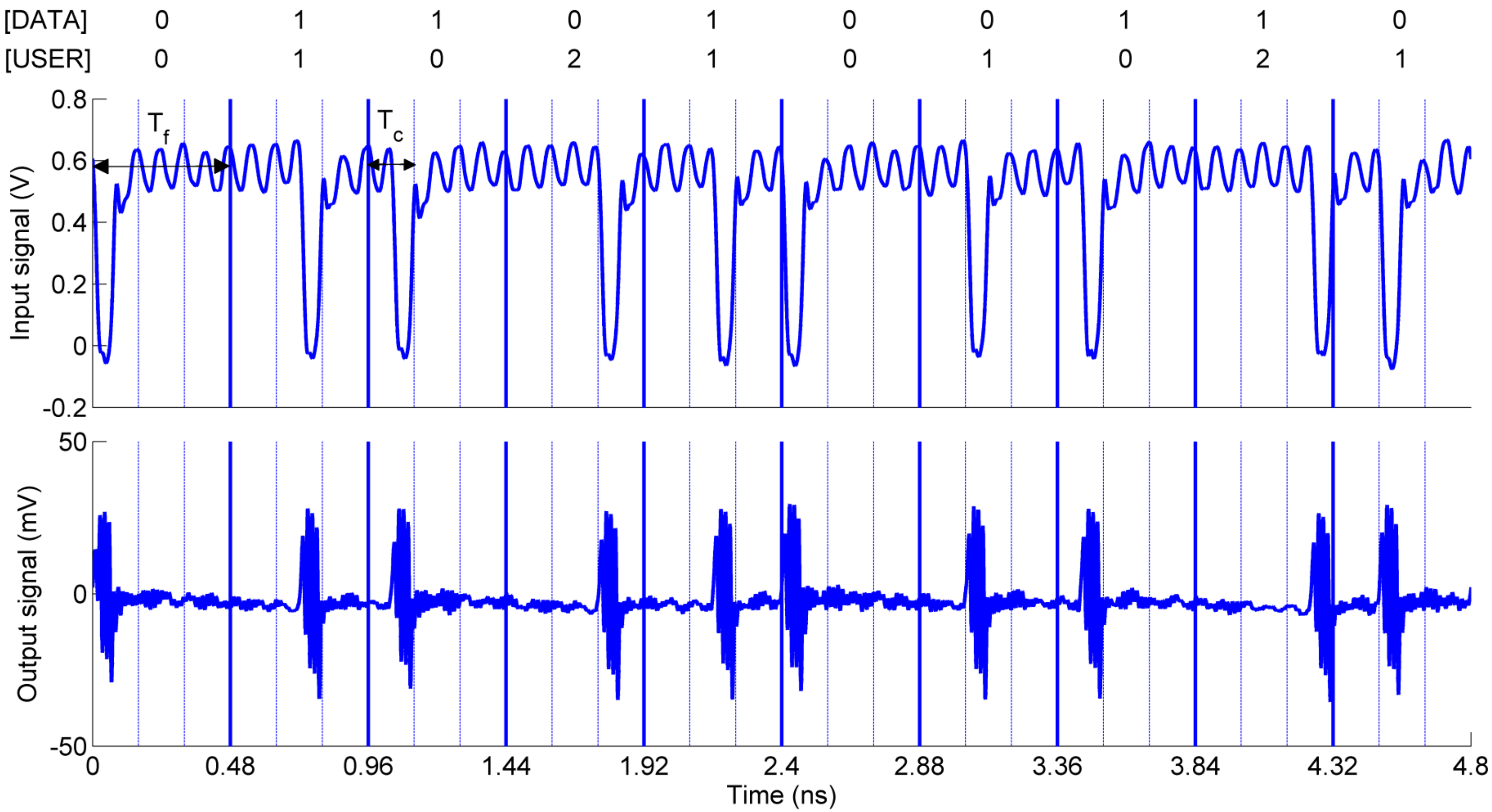


2 Gpulses/s OOK @ 60 GHz



- 100 ps långa pulser
- 162 mV_{pp}
- 59 GHz centerfrekvens

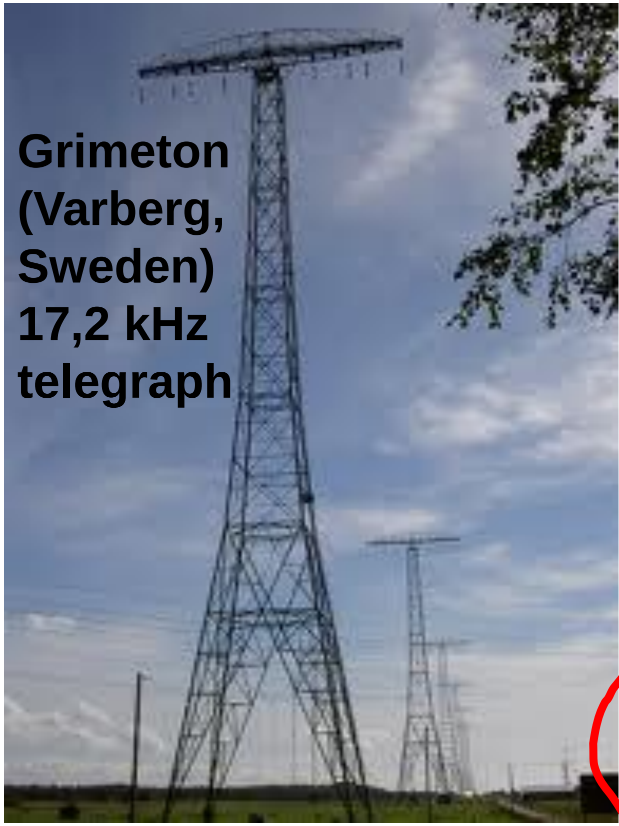
2.08 Gpulses/s TH-PPM @ 60 GHz

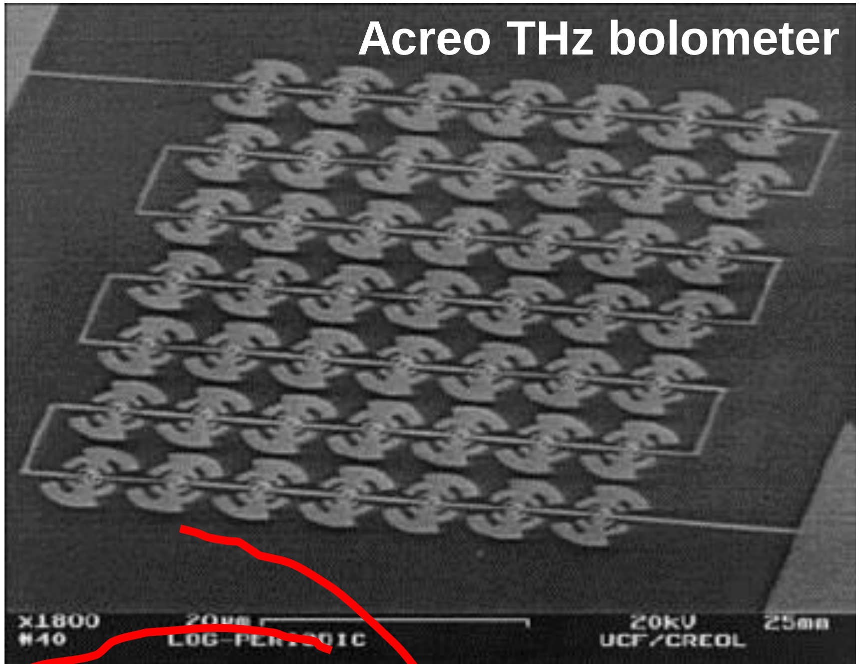


- **46 ps långa pulser**
- **148 mV_{pp}**
- **62 GHz centerfrekvens**

But we also need antennas!

- Longwave to THz



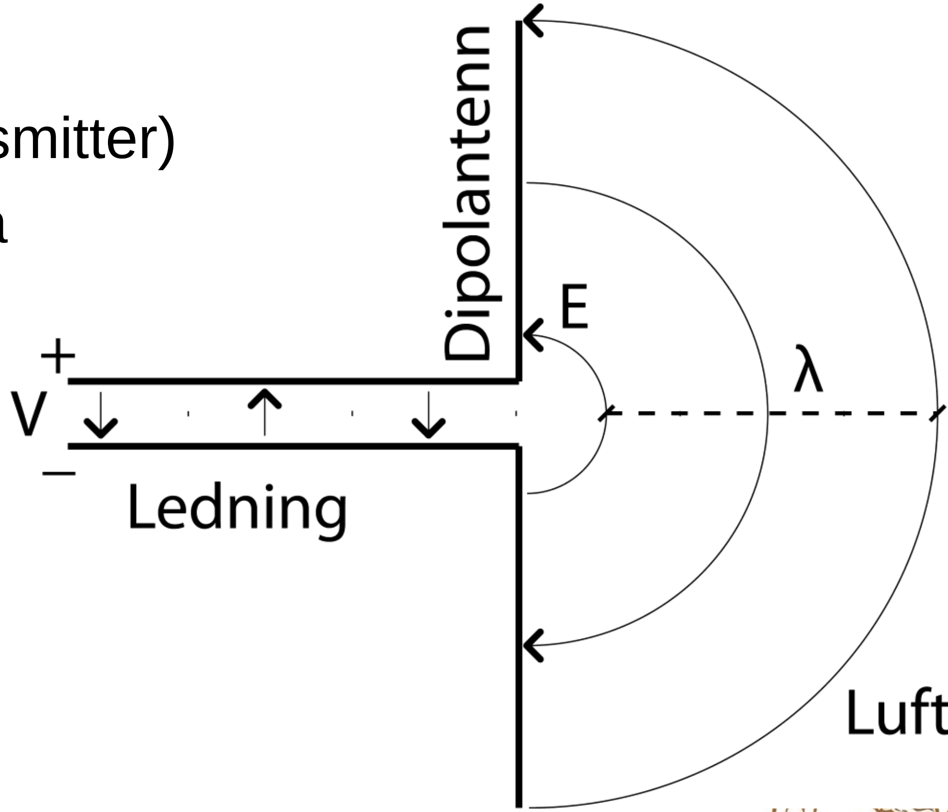


In between:

mm-Wave (30-300 GHz)

What Radiates, and Why?

- The Antenna Function
  - Convert Energy
  - IV to EM-wave (Transmitter)
- Example: Dipole Antenna
  - V projected to E-field
  - Electrically large
  - Charge imbalance
- ”Half-wave” is enough
  - L=1,3,5... x λ/2



Antenna (d)Evolution

- Where did the antenna go?

80's

f~1 GHz
λ~30 cm

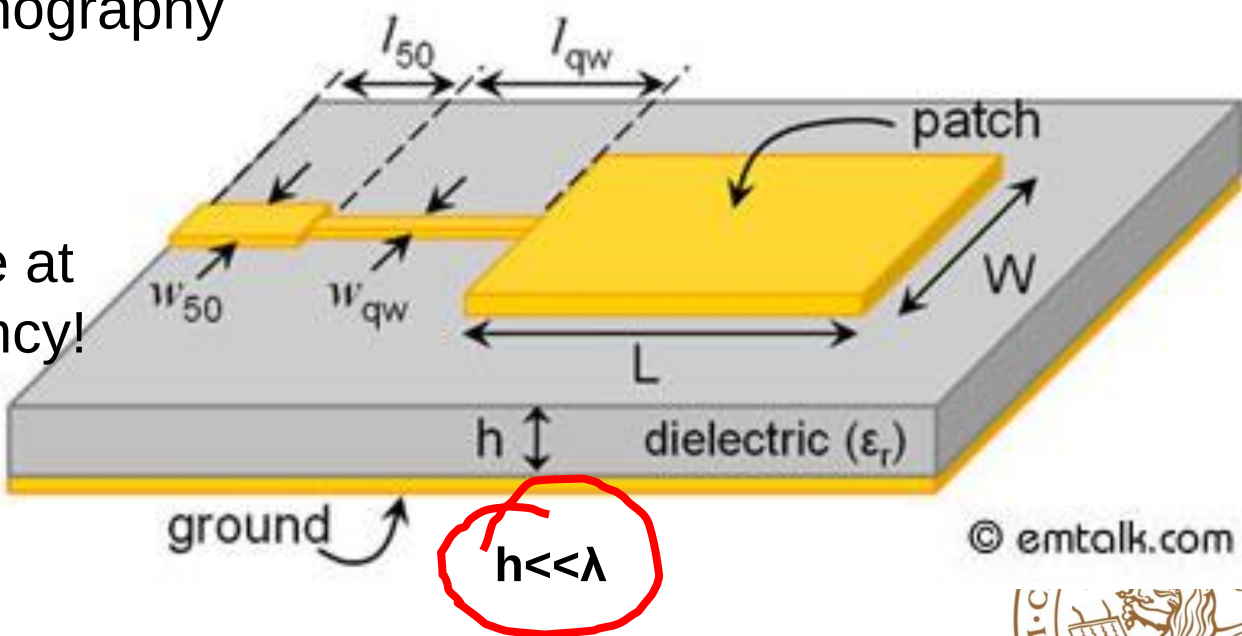
00's

WWII
"Walkie-talkie"

Smaller, Inefficient Antennas
(+ screen, processing, etc.)
= Power Drained Quickly

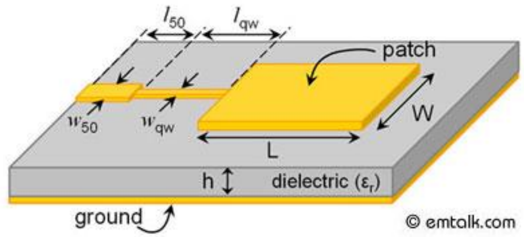
Patch Antenna

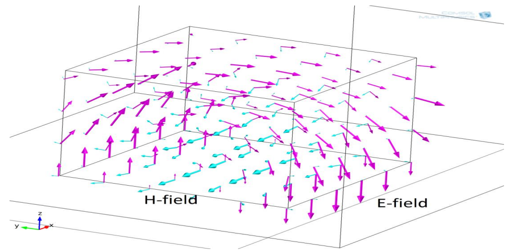
- Compact
  - Easy to integrate
- Easy to Fabricate
  - Milling or lithography
- Thin Substrate
  - h<<λ
  - Not possible at high frequency!



Efficient Millimeter-Wave Antenna?

- Conventional Antenns are Inefficient and Hard to Fabricate
  - Substrate is significantly thick
  - Scaling don't allow milled antenna
  - On-chip antenna ”radiates” into substrate
- Solution
  - Design a resonant mode for radiation



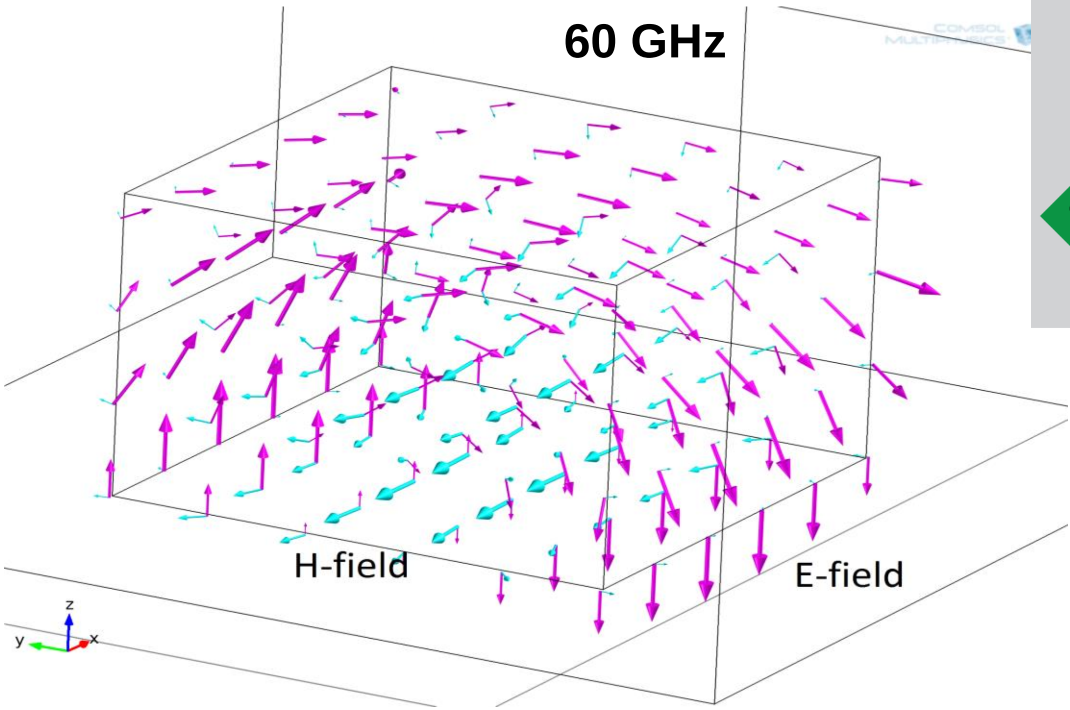


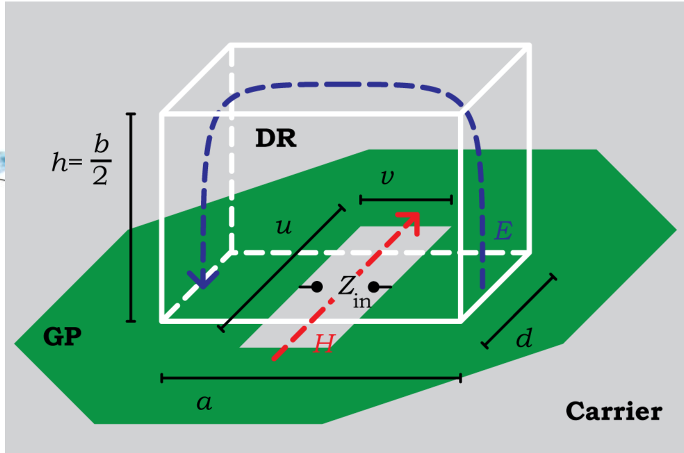
Don't struggle against the physics, let it do the job for you instead!

Dielectric Resonator Antenna (DRA)

- Utilise a Mode for Radiation
- Chip-Antenna on Carrier

60 GHz

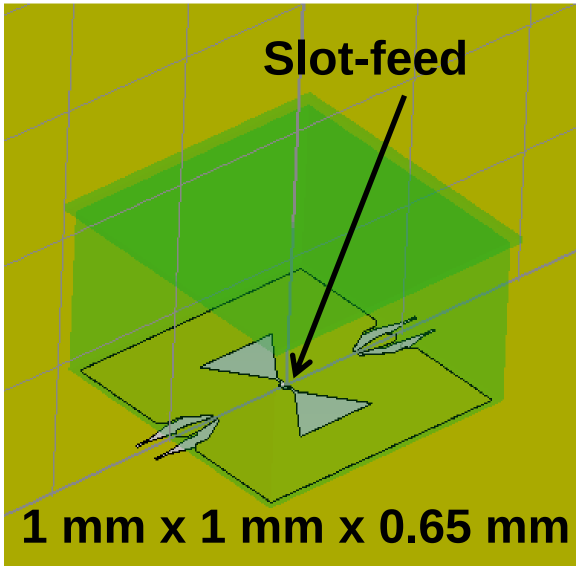


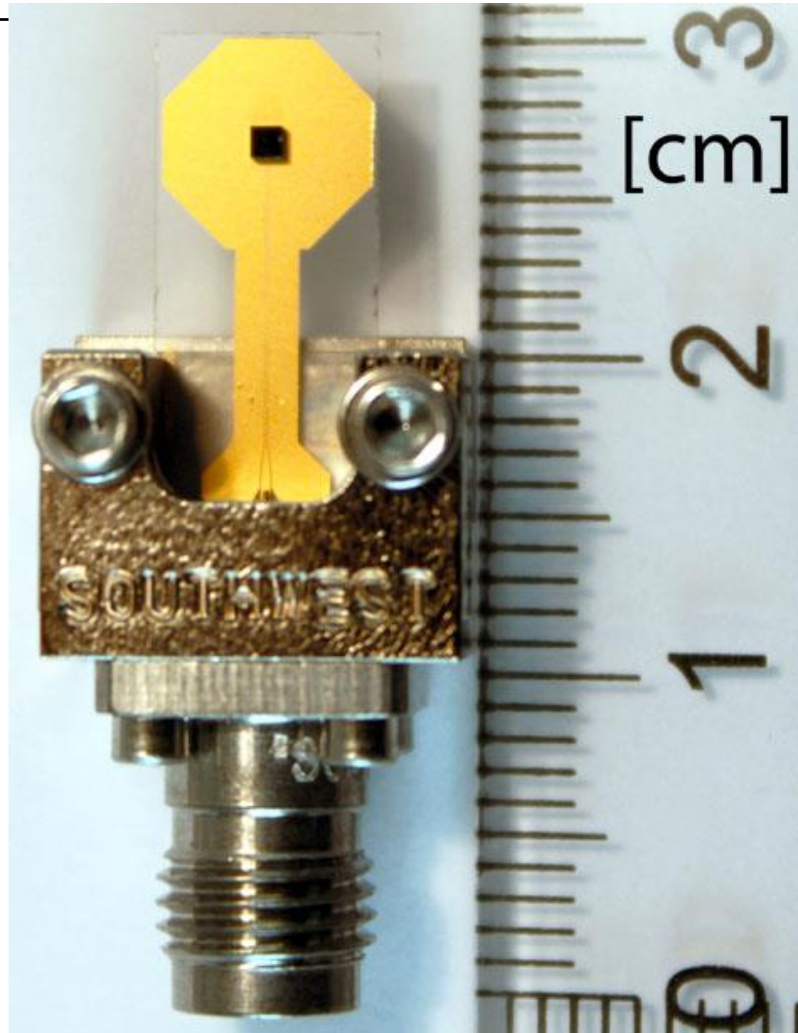


Slot-fed DRA

III-V Semiconductor DRA on Carrier

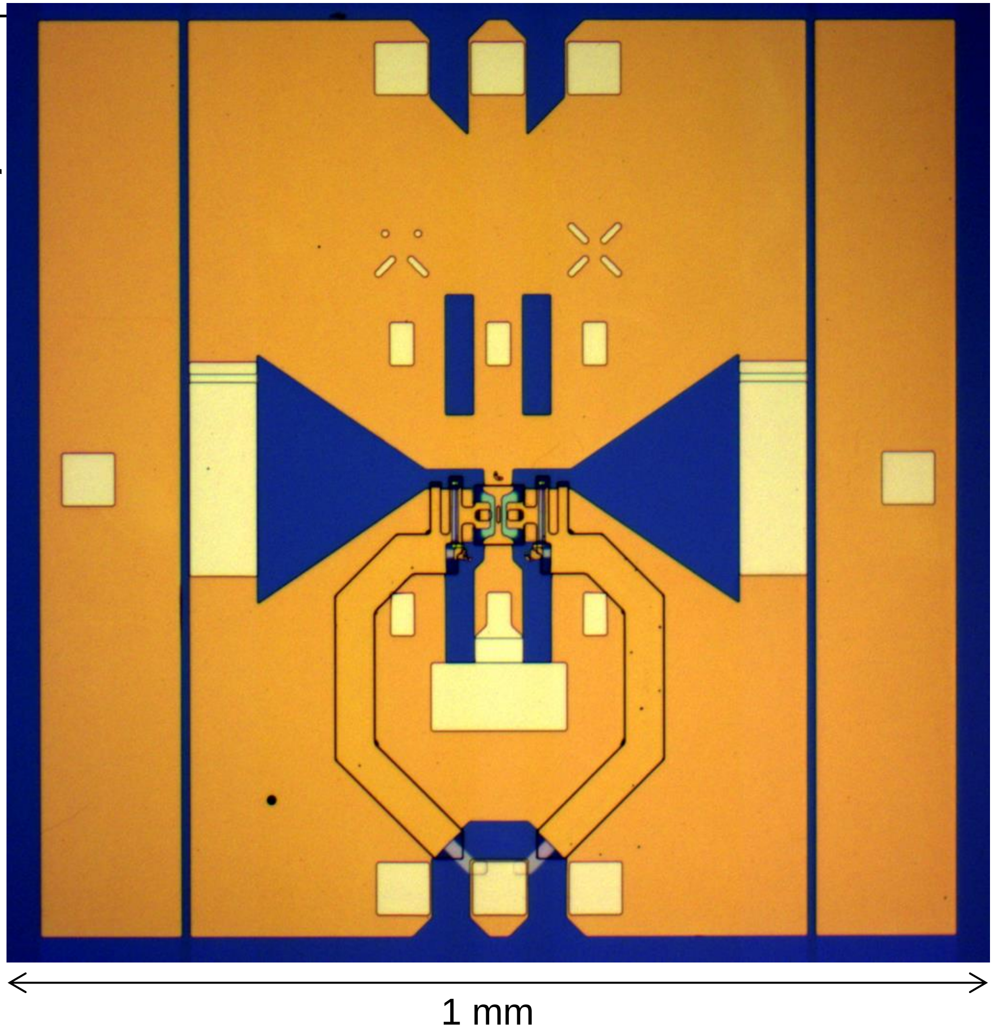
- Circuits on the Antenna
  - Frequency-Conversion
  - Amplification
  - Energy Sampling





Antenna Integrated with Pulse Generator

- Pulse Generator on DRA
- Transmitter
  - 60 GHz
  - 100 ps
  - 4 mW



From Research to Enterprise

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- Lund University
  - High-Speed Communication
  - Spectroscopy, Scattering, etc.
- Acconeer AB (founded winter 2011/12)
  - Non-destructive Material Qualification
  - Security Screening
  - Industrial Process Control