Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

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Re: n/a]
Abstract: This tutorial gives an overview of current issues in the emerging field of THz communications targeting to deliver wireless 100 Gbps over short distances. It starts by providing the motivation for the development of multi-gigabit wireless systems and gives an overview of current technological challenges. A concept for radio channel modeling is presented together with the latest channel investigation results and demonstrations in the corresponding frequency ranges. In the last part of the tutorial an overview about the status quo of the activities of the IEEE 802.15 IGTHz is given and highlights also the hot spectrum issues in conjunction with the preparation of the next ITU World Radio Conference (WRC) in 2012.

Purpose: Tutorial on THz Communications presented to the IEEE 802 Plenary

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Towards Wireless 100 Gb/s beyond 300 GHz

Tutorial @ IEEE 802 Plenary

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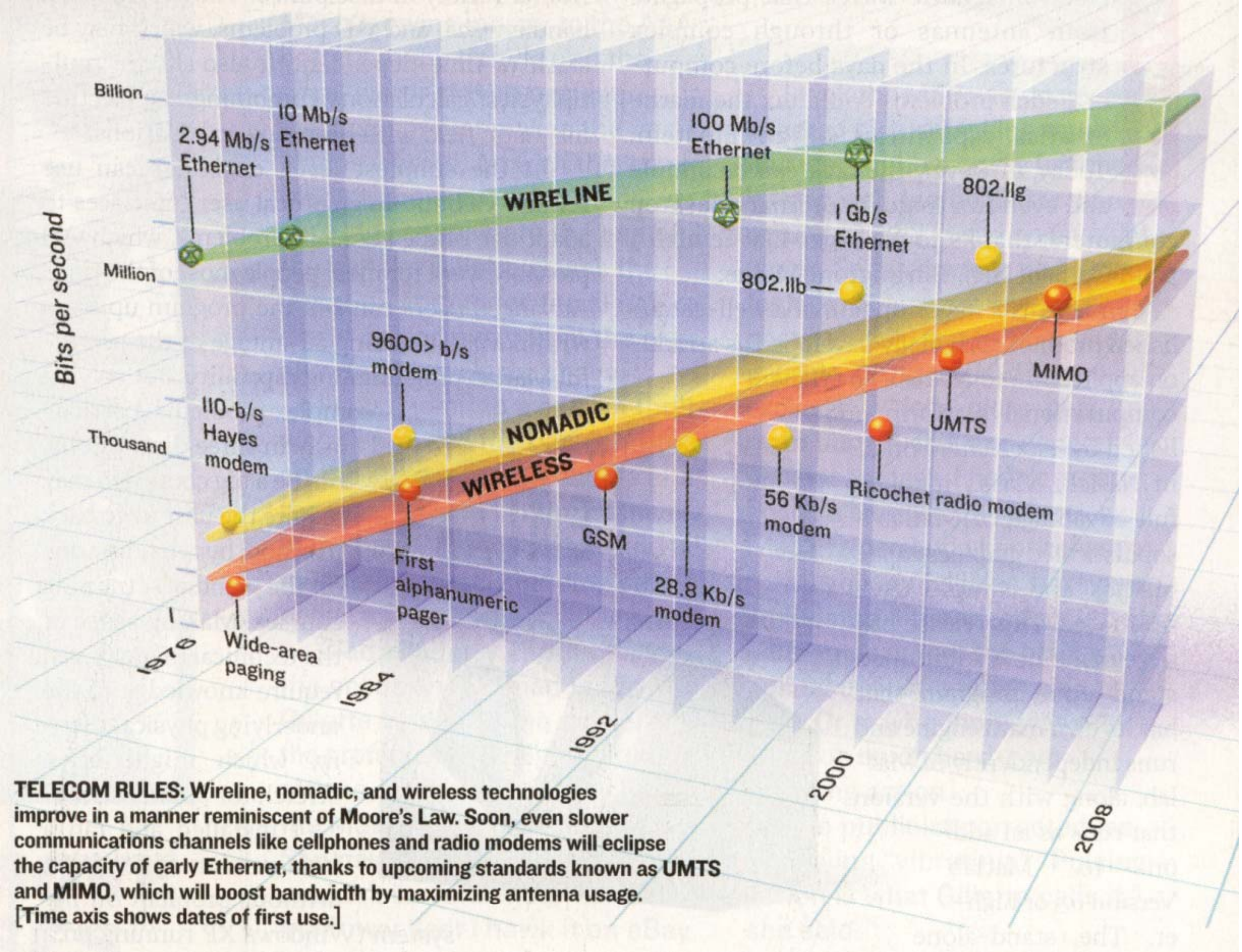
Chair IEEE 802.15 IG THz

Outline

- Motivation and Applications
- Propagation Conditions and Channel Modeling beyond 300 GHz
  - Measuring Basic Propagation Phenomena
  - Measuring the Impact of Antenna Misalignments
  - Measurements in more Realistic Scenarios
  - Research Tasks on Channel Modeling
- Results from Demonstrations
  - Transmitting DVB-T/S2-Signals @300 GHz
  - Transmitting DVB-C-Signals@220 GHz
  - Towards 20 Gbit/s – recent achievements in Japan
- Activities in Developing the Technology
- Status in Regulation and in IEEE 802
- Future Tasks and Challenges

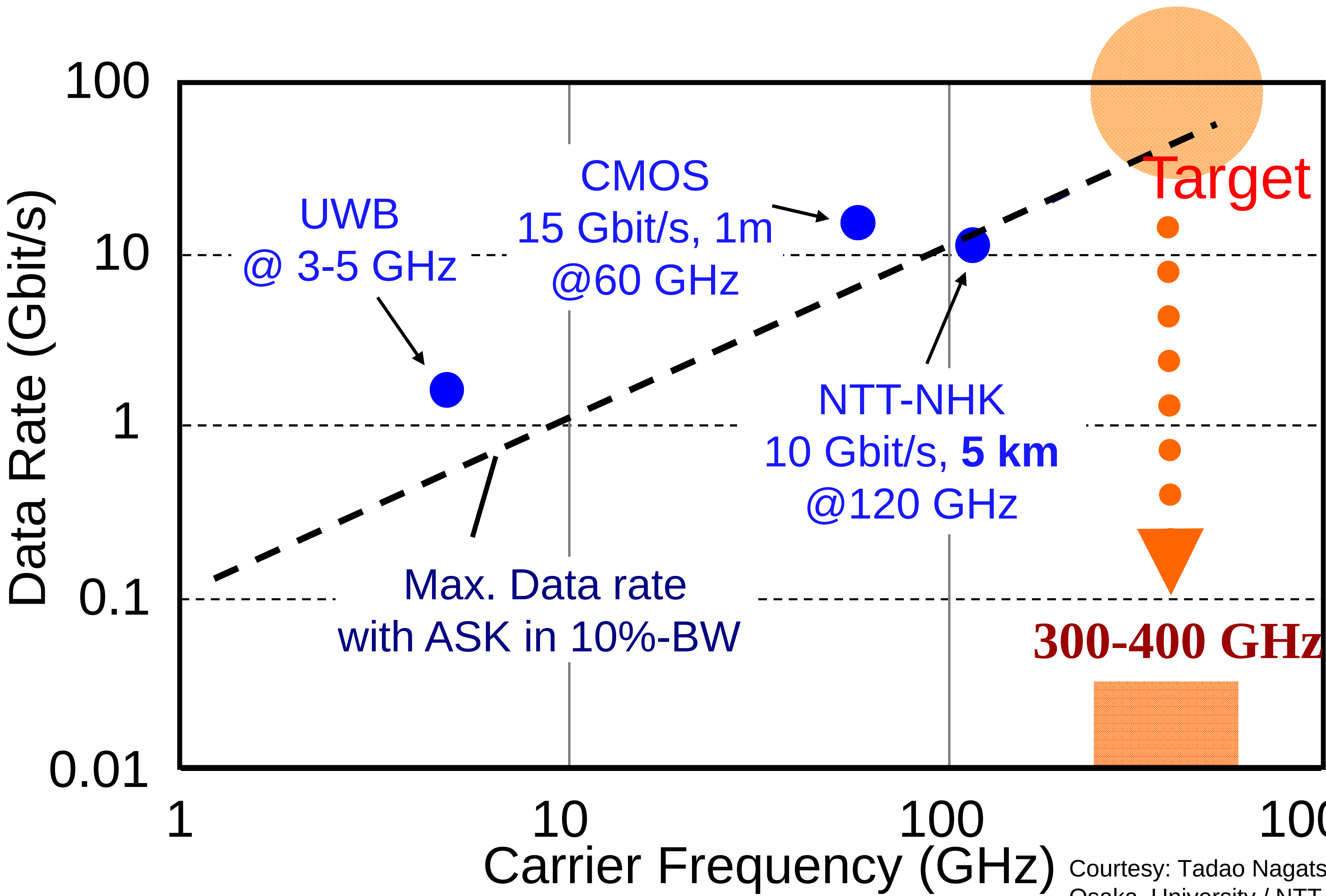
Motivation and Applications

Edholm‘s Law of data rates



Source: IEEE Spectrum, Juli 2004

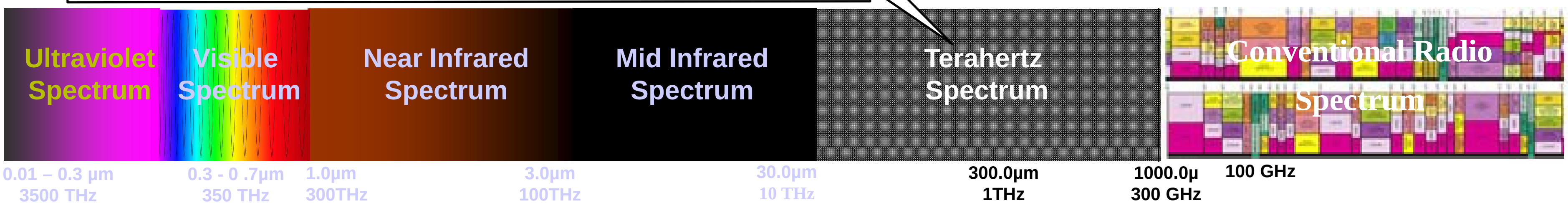
Carrier Frequency vs. Data Rate



Courtesy: Tadao Nagatsuma, Osaka University / NTT

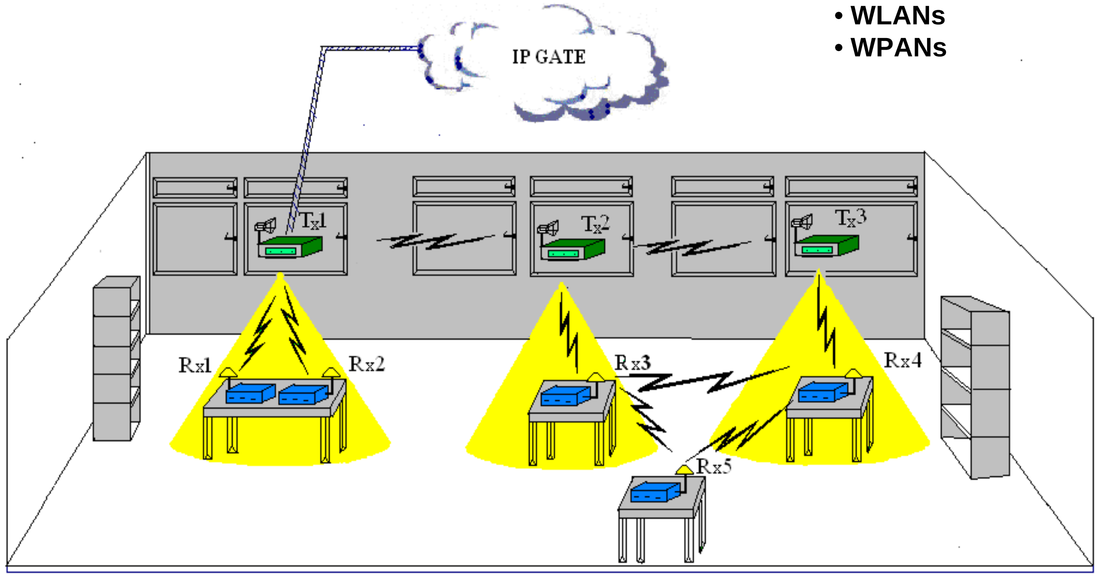
So why Terahertz?

- Vast unregulated spectral resource, Gigahertz channel bandwidths possible
- Device technologies maturing rapidly (for security scanning solutions)
- Target application: In-Building, In-Room, Outdoor “Hotspot” WLAN systems
- Communications standards initiatives begun (802.15 IG THz)
- Potential throughput: Multi-Gig-E and above



Courtesy: David Britz, AT&T Shannon Labs

What are potential Applications for Multi-Gigabit Radio Systems?



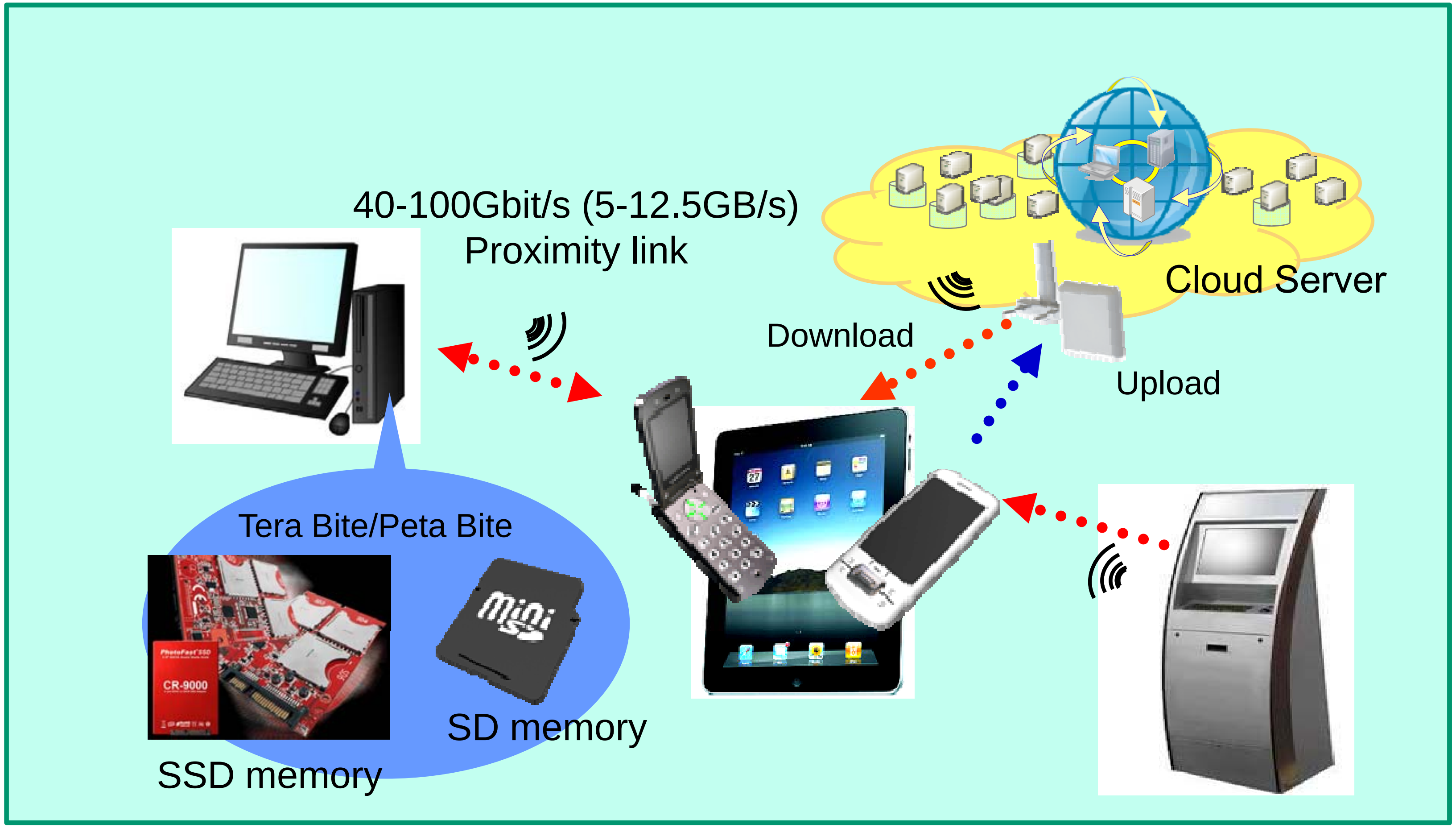
- WLANs
- WPANs

- Wireless extension of Ethernet and GigabitEthernet LANs

…some more Examples for Wireless Systems beyond 1 Gbps

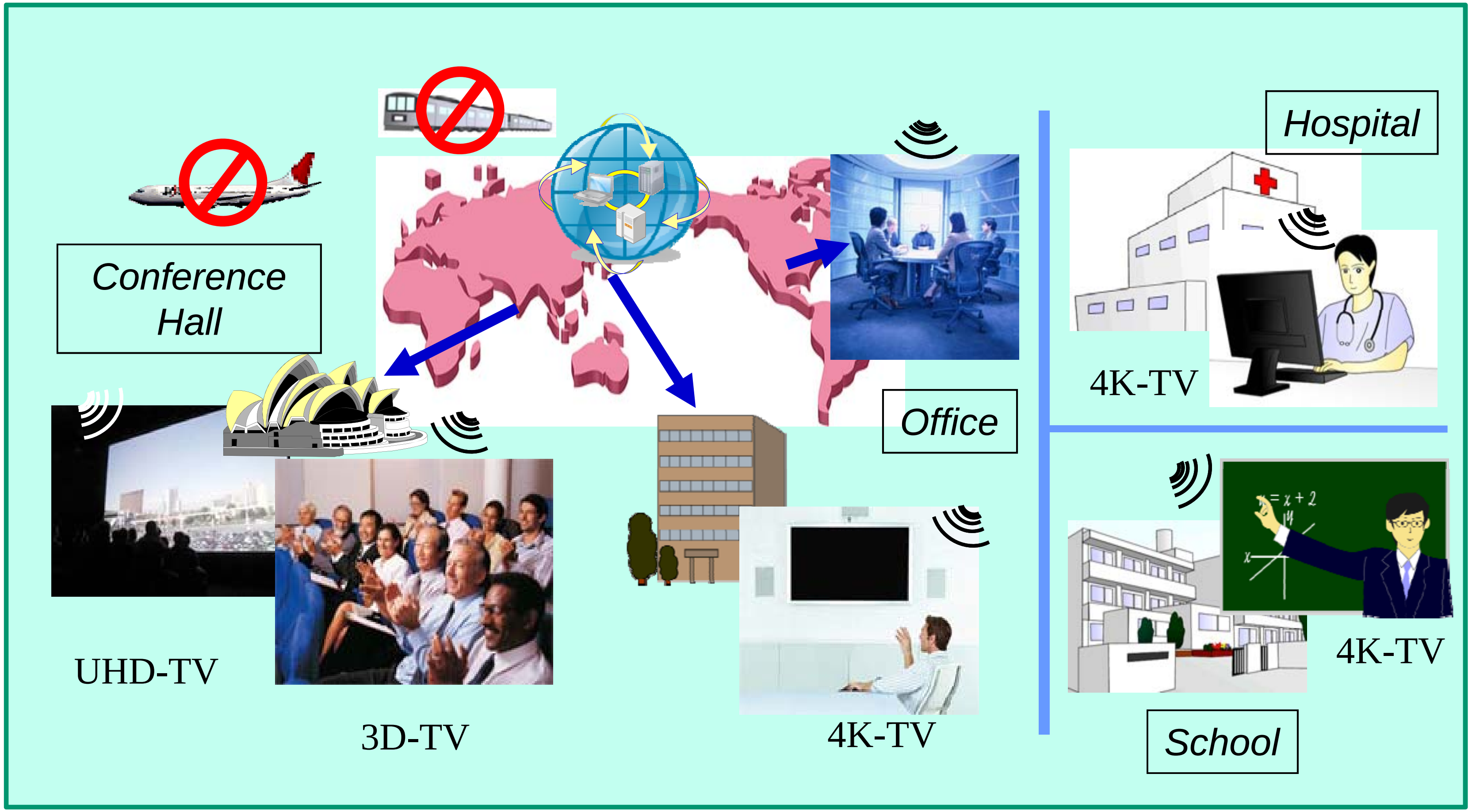
Wireless HDMI

Instantaneous transfer of high-volume storage data between consumer devices



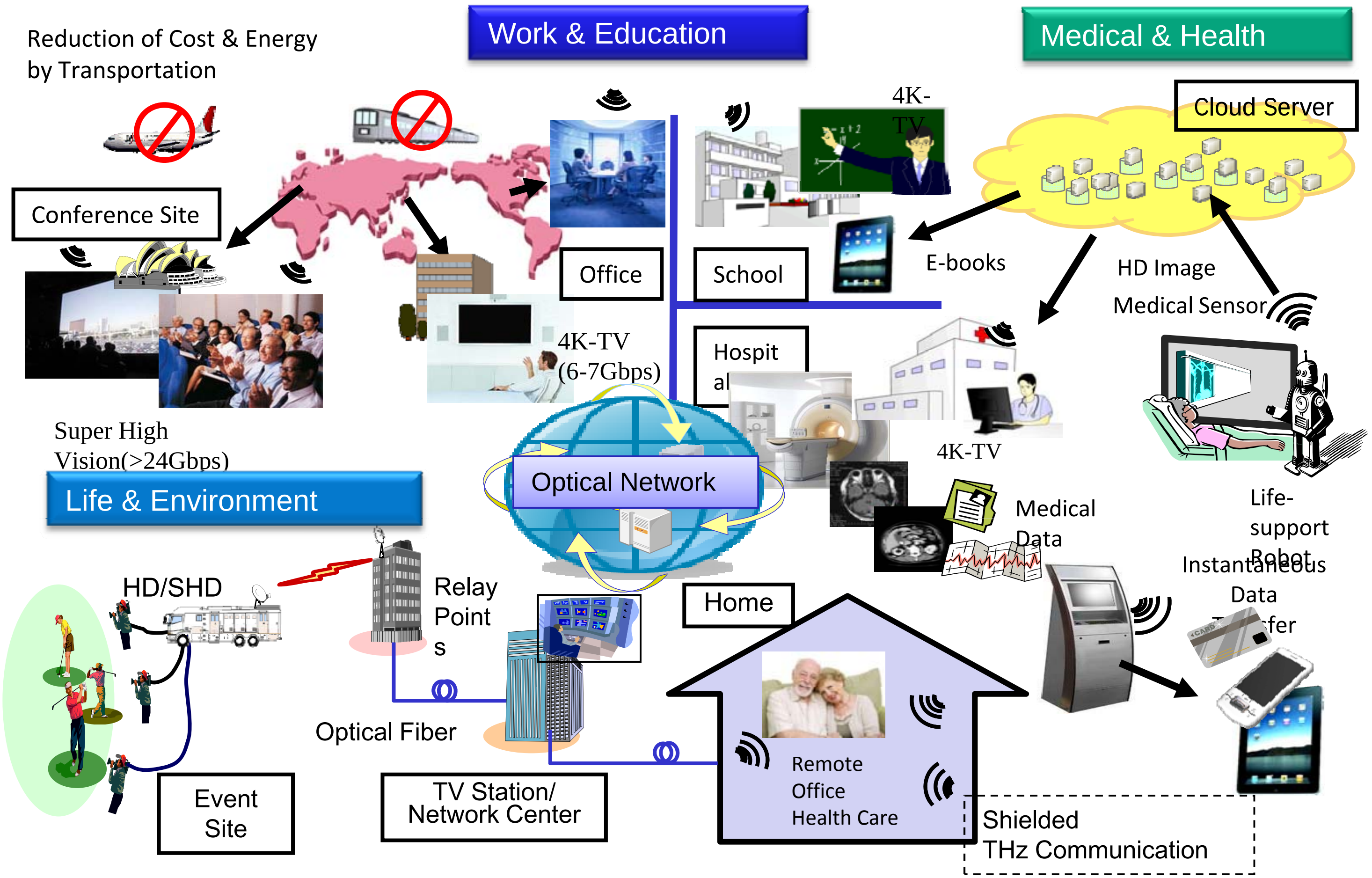
Courtesy: Tadao Nagatsuma, Osaka University / NTT

Highly-realistic sensation teleconference, telemedicine, remote-education



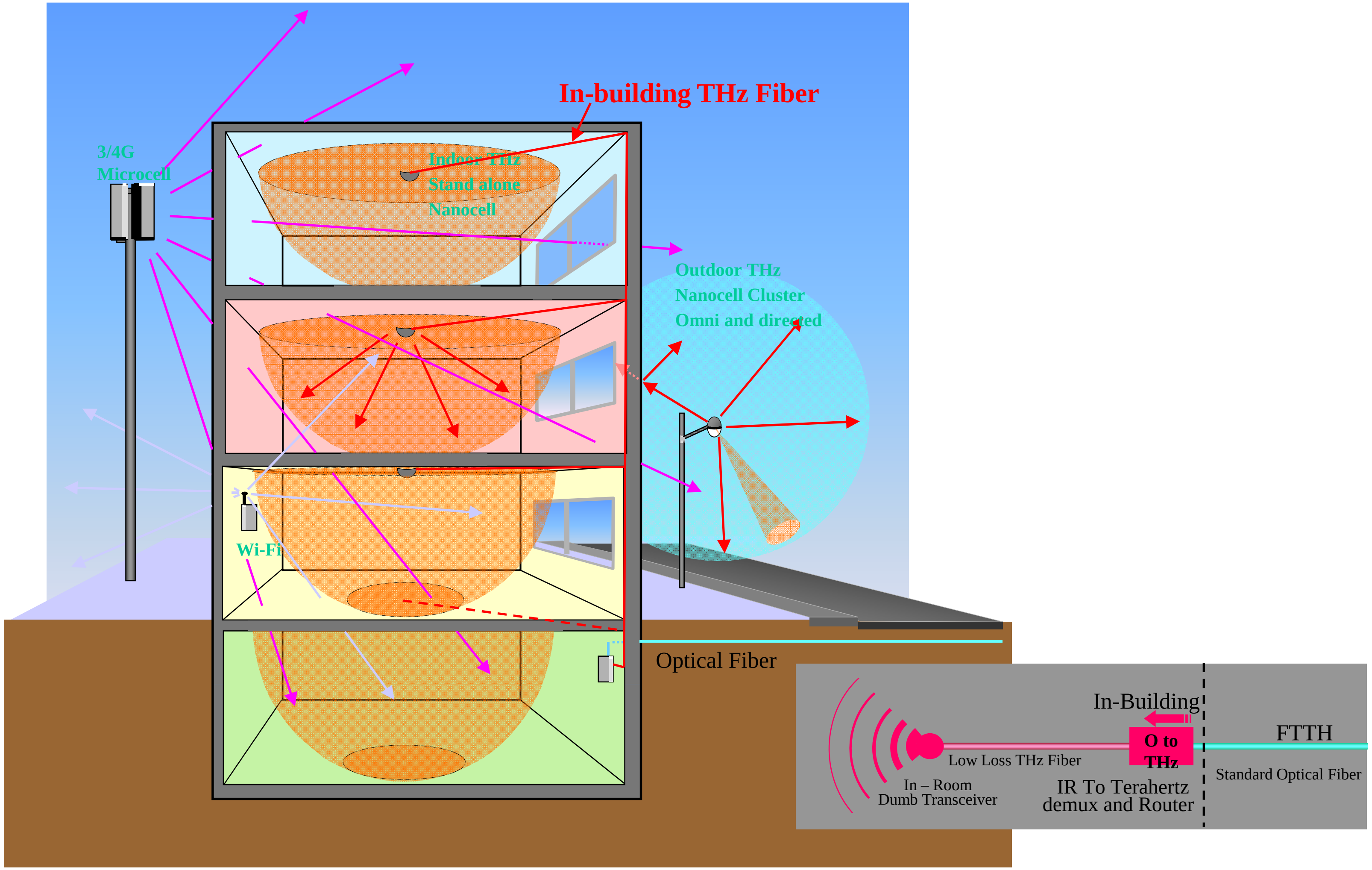
Courtesy: Tadao Nagatsuma, Osaka University / NTT

Last Access of Network → All wireless, Seamless Between Fiber and Wireless
Wireless Interface/Connection → Instantaneous Data Transfer, Low Power



Courtesy: Tadao Nagatsuma, Osaka University / NTT

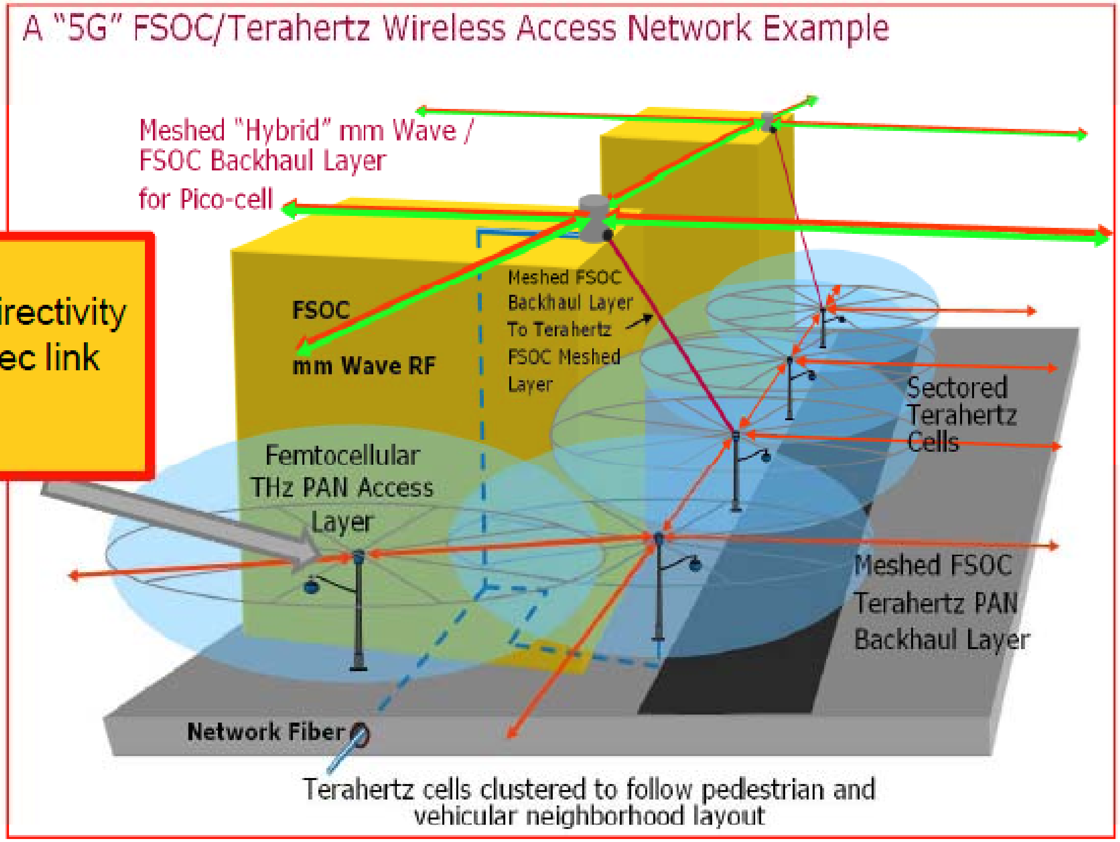
„Shaped“ THz Coverage Areas



Courtesy: David Britz, AT&T Shannon Labs

THz Wireless Access Network Example

Femtocell Needs:
1- High Antenna Gain/Directivity for Point to Point Gbpsec link
2- Low Cost
3- Power efficient

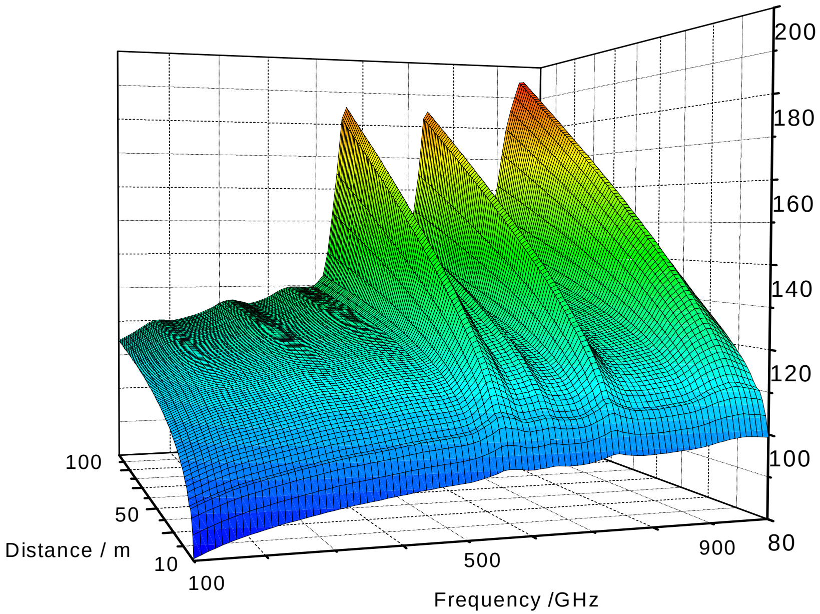


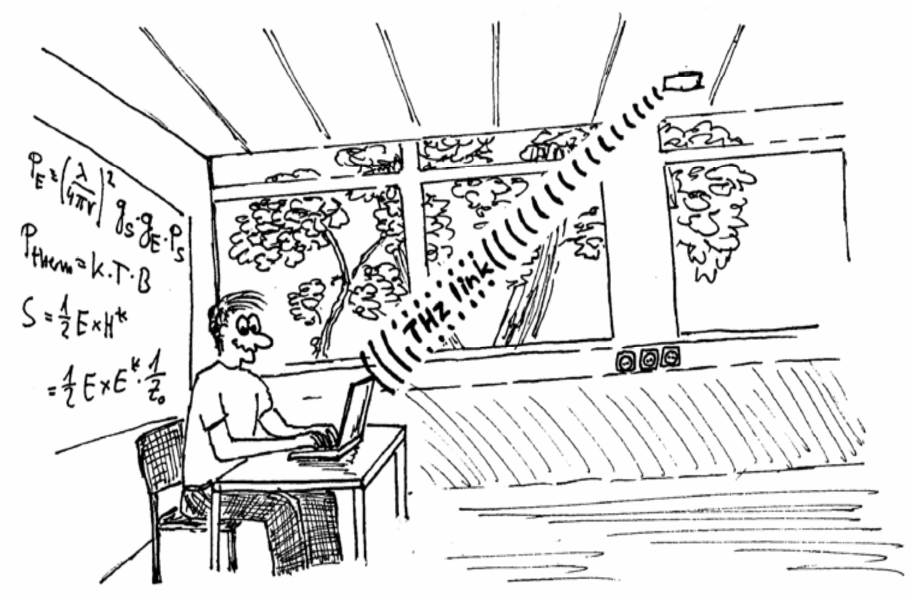
Courtesy: David Britz: dbritz@research.att.com
AT&T Labs Research – Shannon Laboratories

Propagation Conditions and Channel Modeling beyond 300 GHz

Measuring Basic Propagation Phenomena

Free Space Loss and Atmospheric Attenuation





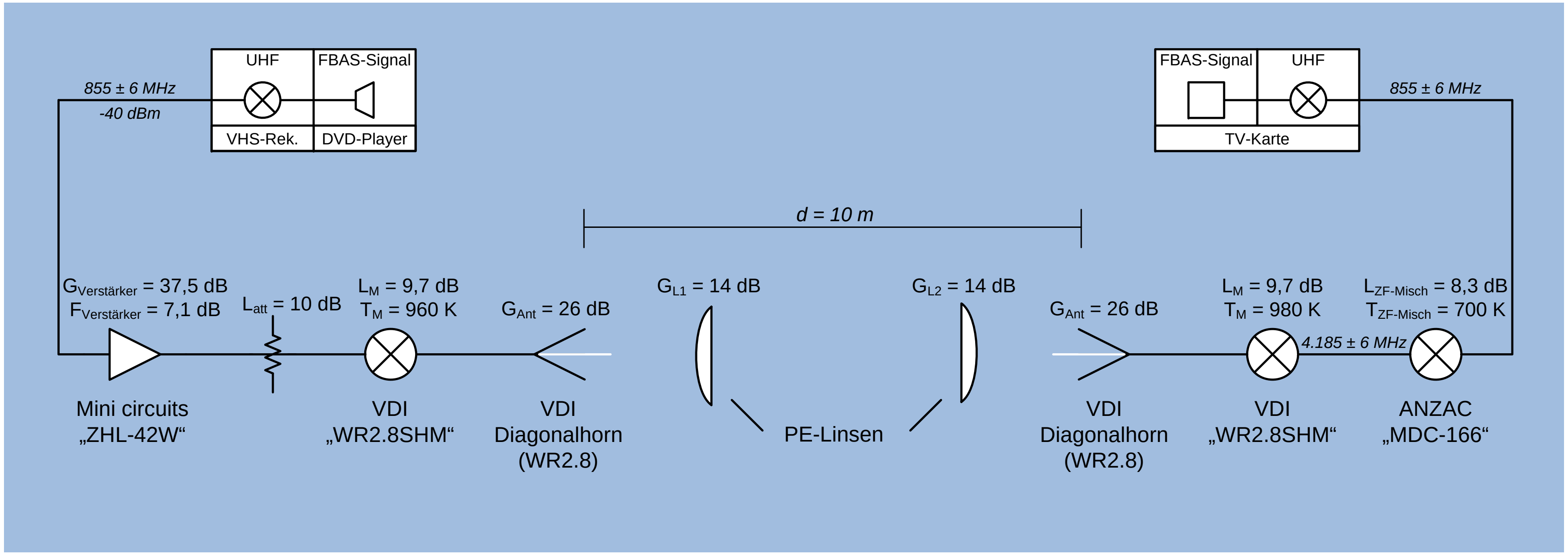
Source: Martin Koch, Uni Marburg

- High gain antennas are required
- Atmospheric attenuation can be neglected in indoor environments

300 GHz Transmission System

Source: Terahertz Communications Lab

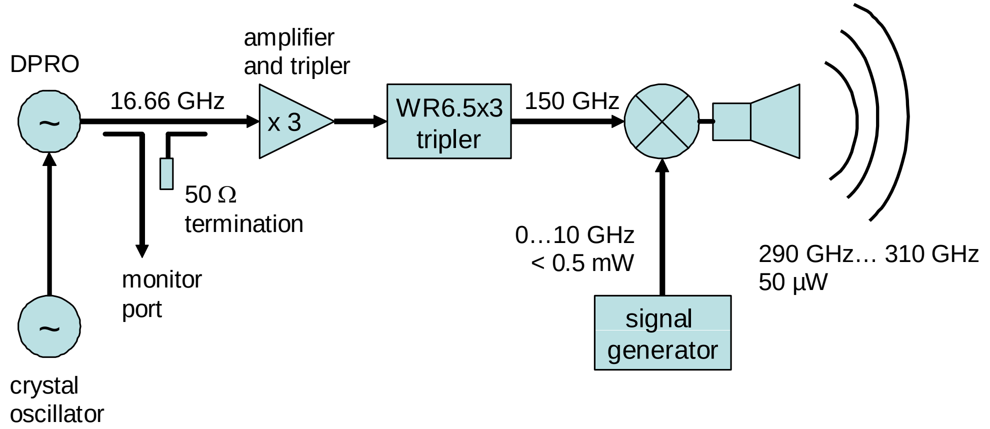
300 GHz Transmission System



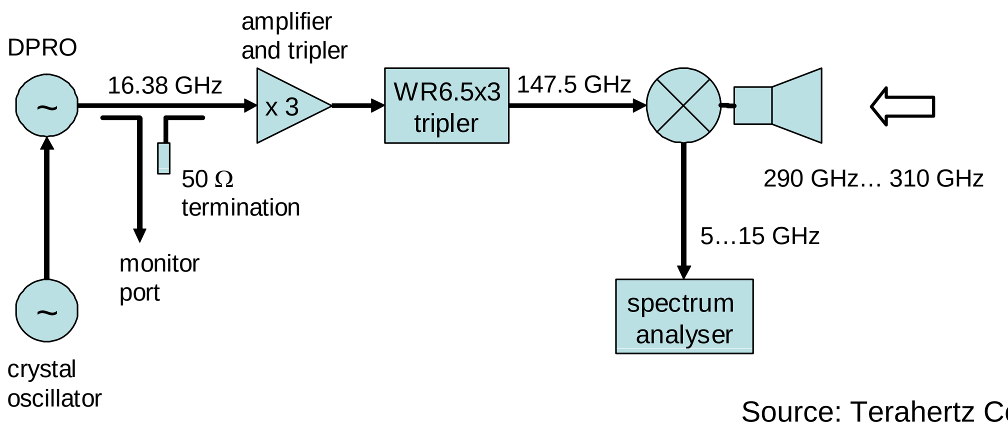
Jastrow, C., Münter, K., Piesiewicz, R., Kürner, T., Koch, M., Kleine-Ostmann, T., '300 GHz transmission system', IEE Electronics Letters, Vol. 44, No. 3, January 2008, pp. 213-214.

…more details on the mixer

a)

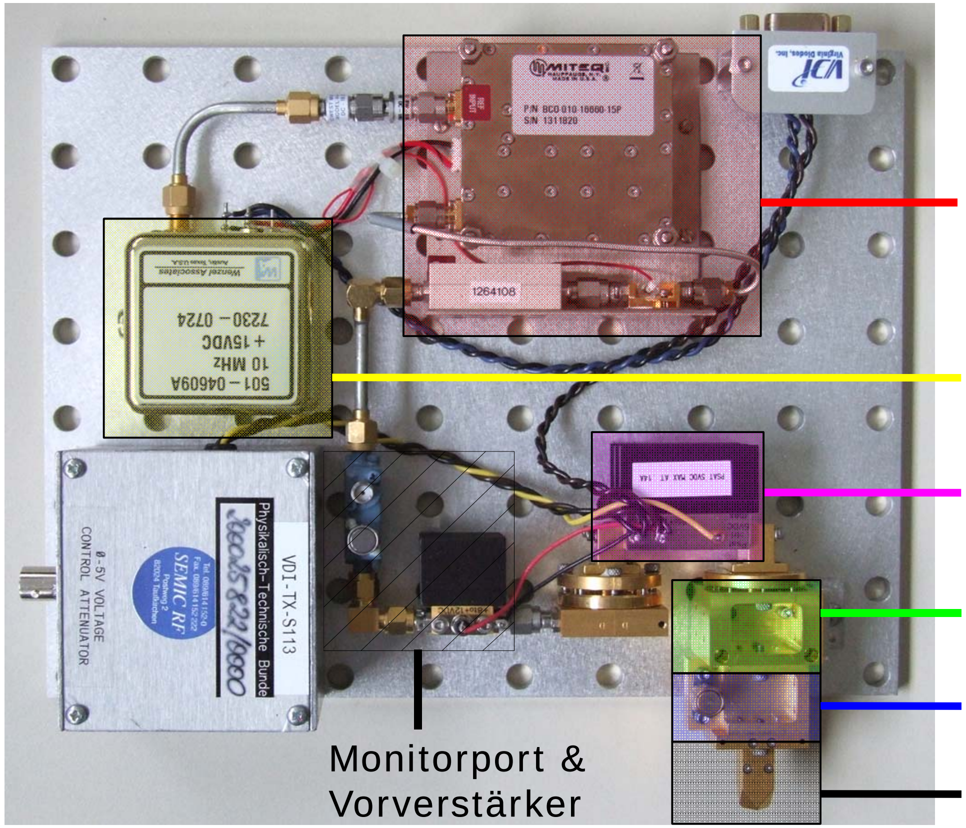


b)



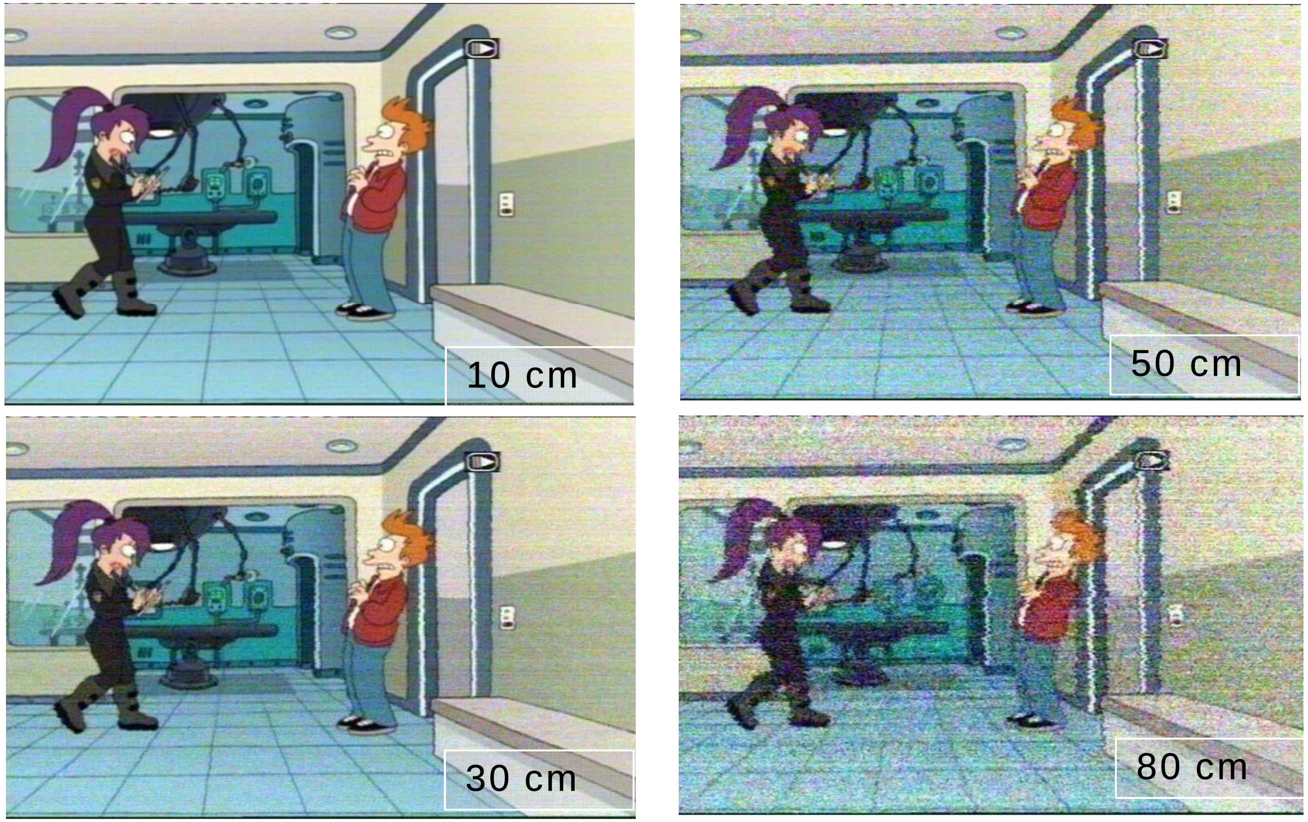
Source: Terahertz Communications Lab

Transmitter



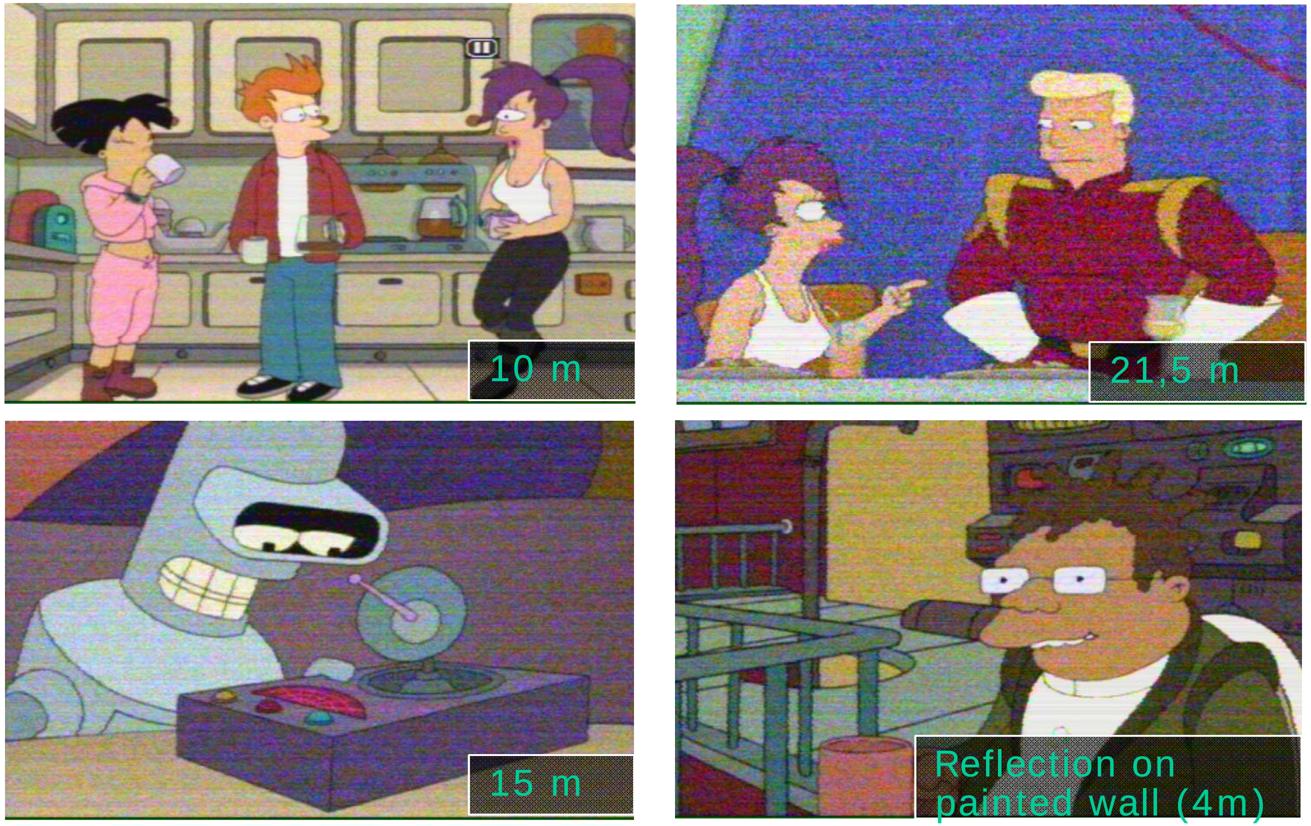
Source: Terahertz Communications Lab

Received signal without lense antennas



Source: Terahertz Communications Lab

Received signal with lense antennas



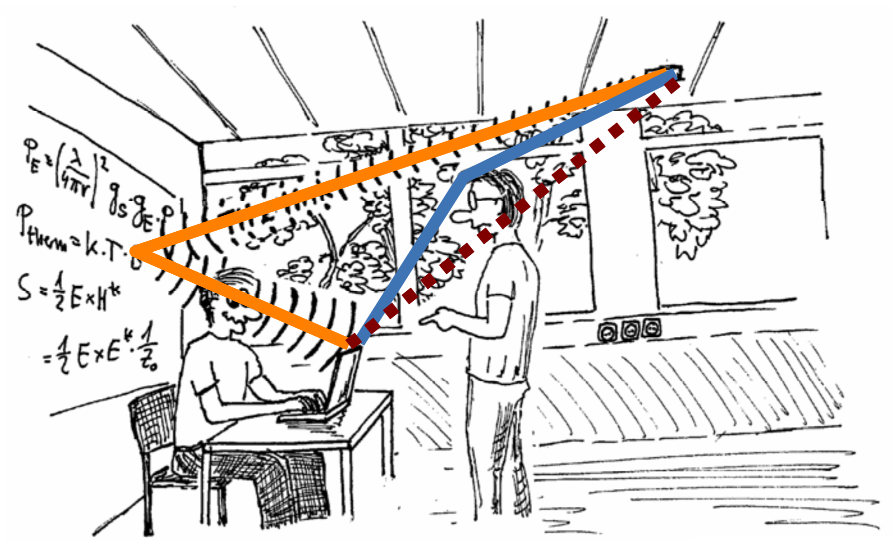
Source: Terahertz Communications Lab

Transmission, Diffraction and Reflection/Scattering

- attenuation is high enough to neglect transmission as a relevant propagation mechanism in indoor environments at THz frequencies

- diffraction does not contribute significantly to the received power already at mm-waves

- Reflection and scattering are the most relevant mechanisms



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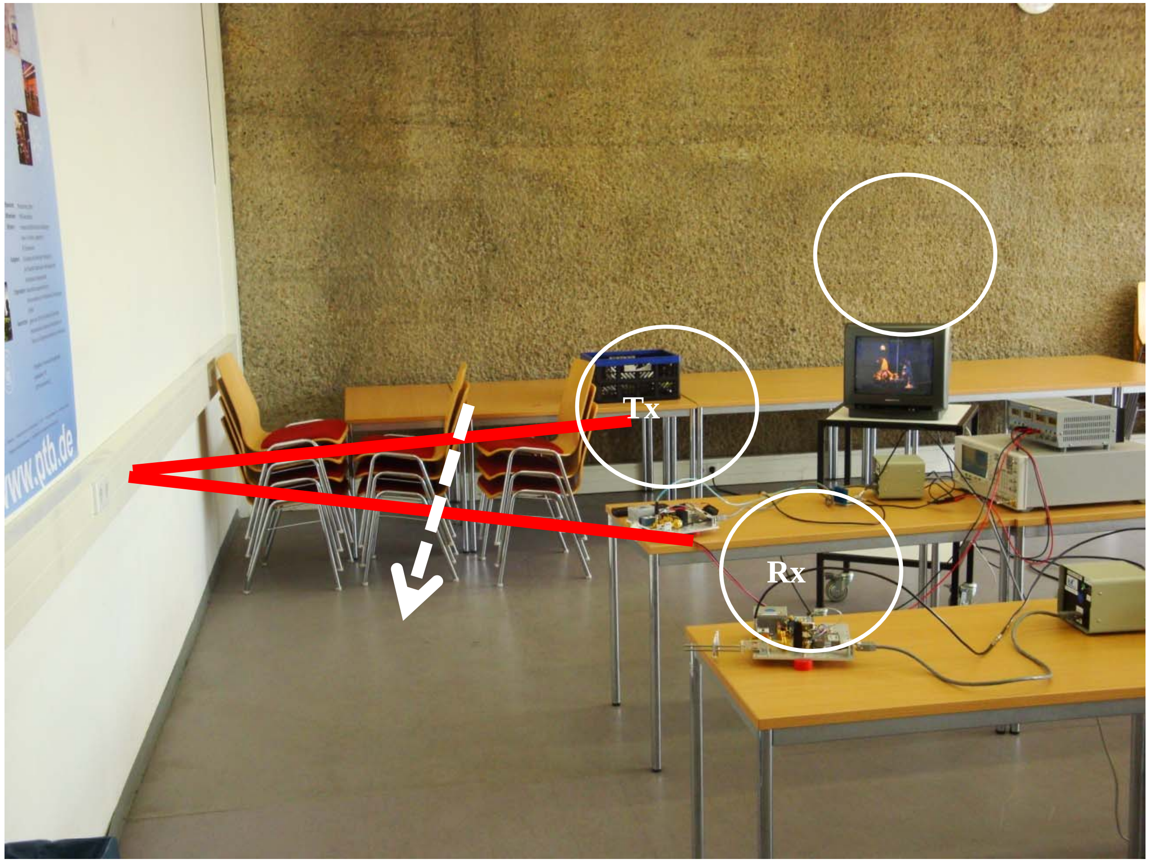
Source: Terahertz Communications Lab

An experiment using the 300 GHz system



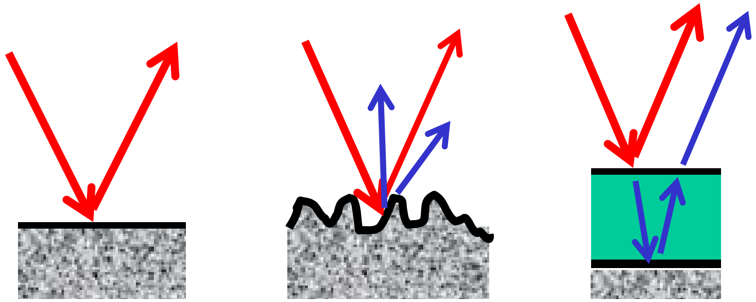
Source: Terahertz Communications Lab

An experiment using the 300 GHz system

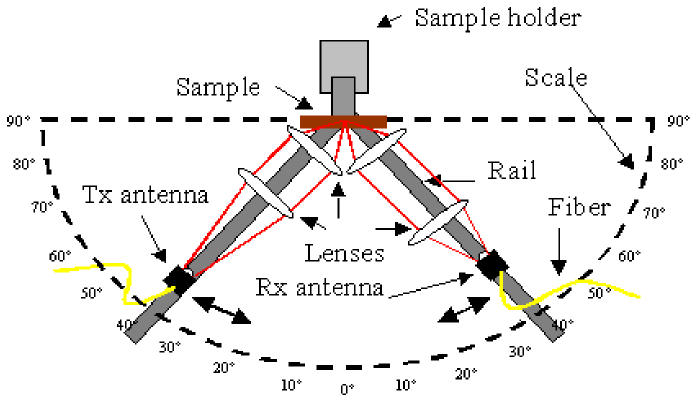
Modelling the Indoor Propagation Channel

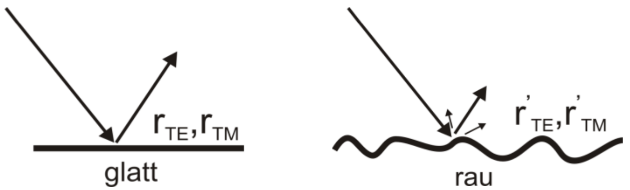
– As at 60 GHz Ray-tracing is well-suited to model the propagation channel beyond 100 GHz in indoor environments

– Proper modelling of reflection and scattering processes for typical building materials required:
  - Reflection on smooth surface
  - Scattering on rough surface
  - Reflection on multi-layer objects

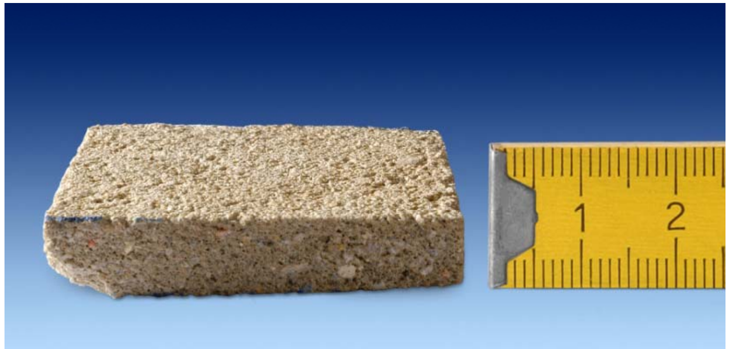


Rough Surface Scattering in Specular Direction





Scattering on Rough Surfaces



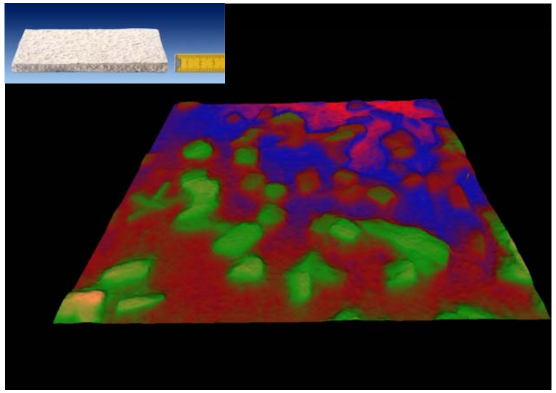
plaster

Raufaser wallpaper

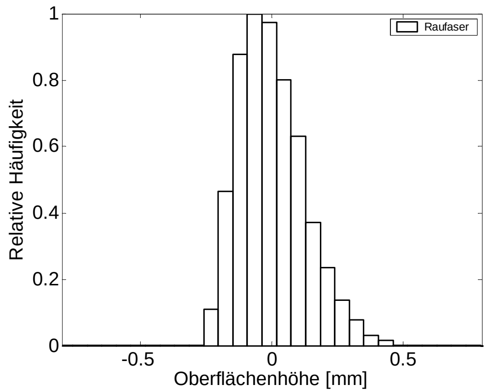
Source: Terahertz Communications Lab

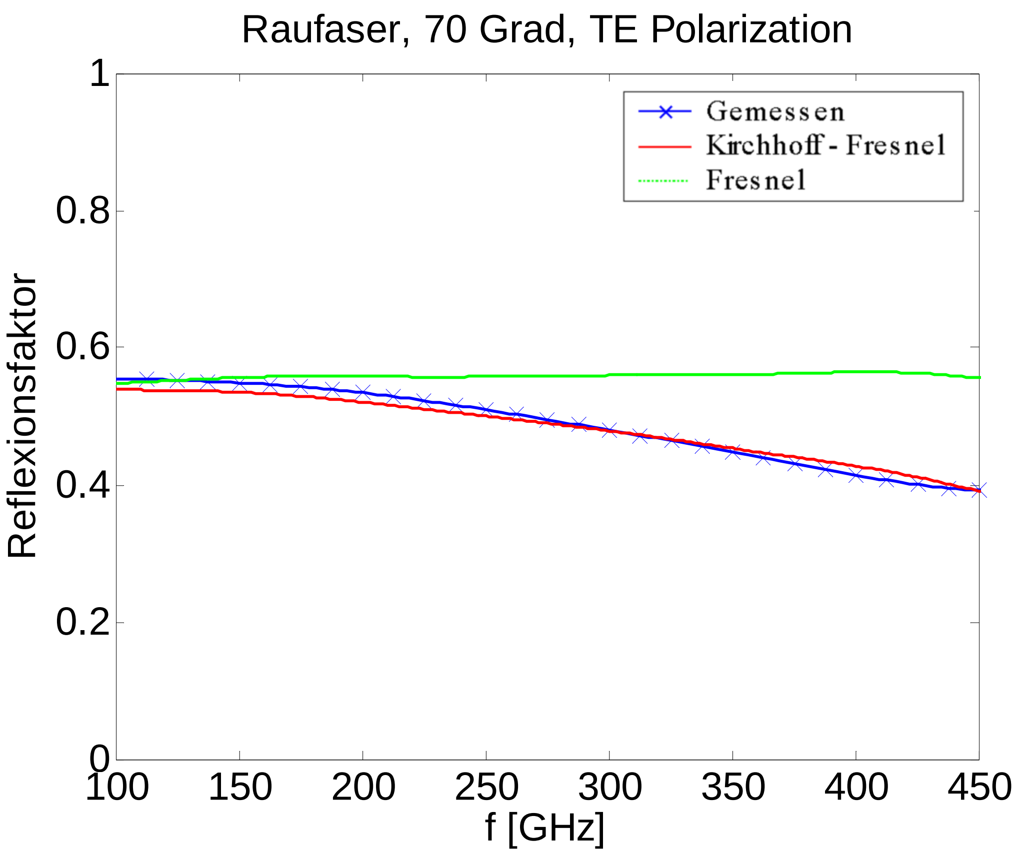
Rough Surface Scattering in Specular Direction

Source: Terahertz Communications Lab



Measured Surface Properties of Raufaser

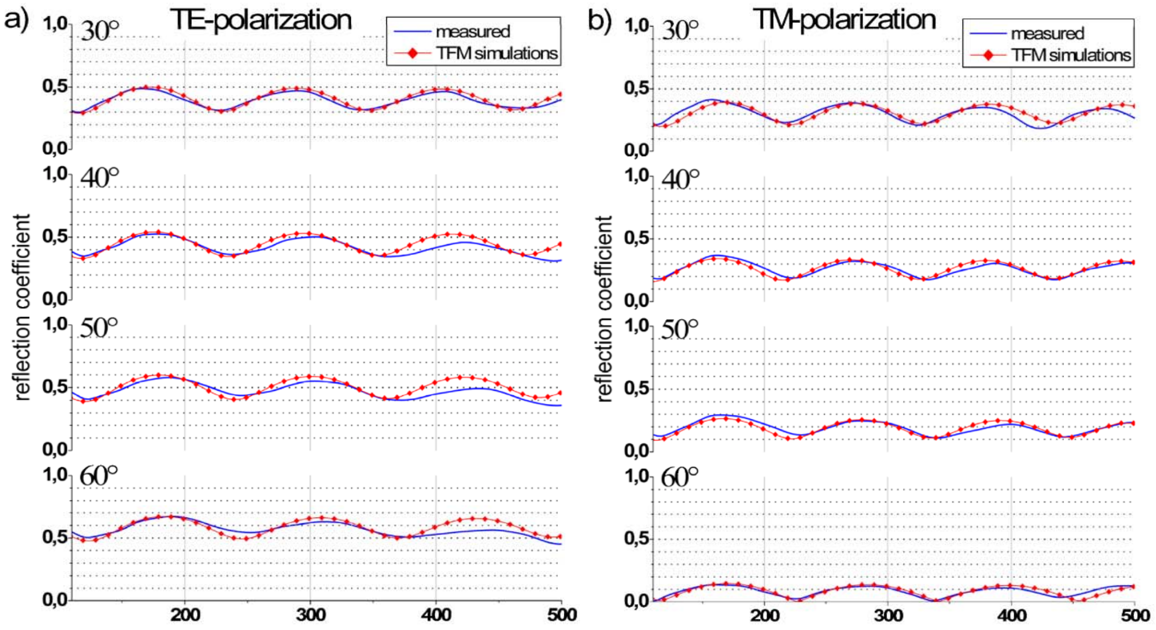




Multiple Layer Modelling

– Calculation of reflection and transmission coefficients by transfer matrix method

paint: 0.695 mm
plaster: thick

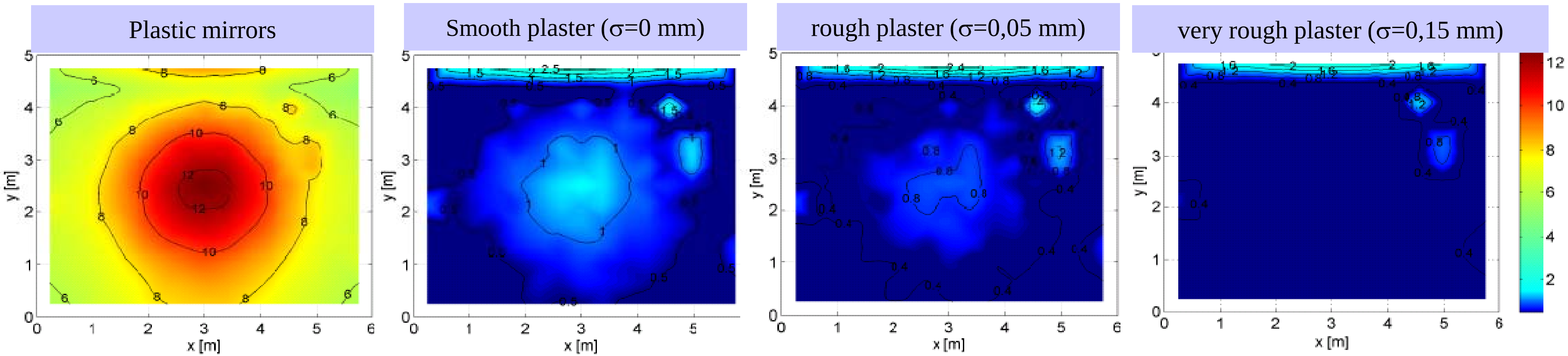


Magnitude of reflection coefficient: white paint on plaster

Source: Terahertz Communications Lab

Influence of wall materials

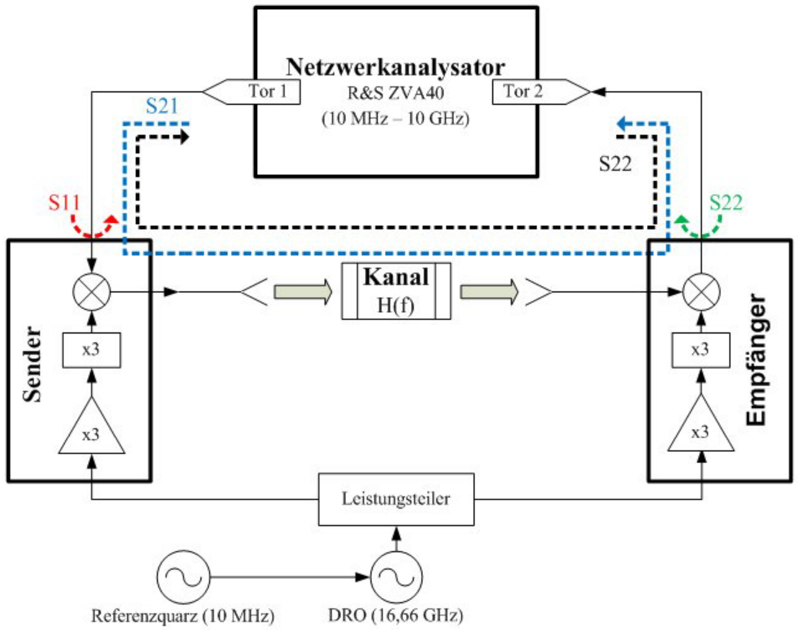
- Maximum achievable data rates for different for wall materials form link level simulation
  - empty room scenario
  - assuming all walls are covered by the same material
  - BPSK modulation
  - once-reflected paths



Source: Terahertz Communications Lab

300 GHz Radio Channel Measurement System

- R & S ZVA40 Vector Network Analyzer
- External 300 GHz transmitter (Tx) and receiver(Rx) front ends
- Core component: subharmonic schottky diode mixer
- Same external local oscillator (DRO) (16.66 GHz x3 x3) for Tx and Rx for phase synchrony
- Three different types of antennes used
- Frequency range: 290 – 310 GHz
- Frequency Domain → Time Domain

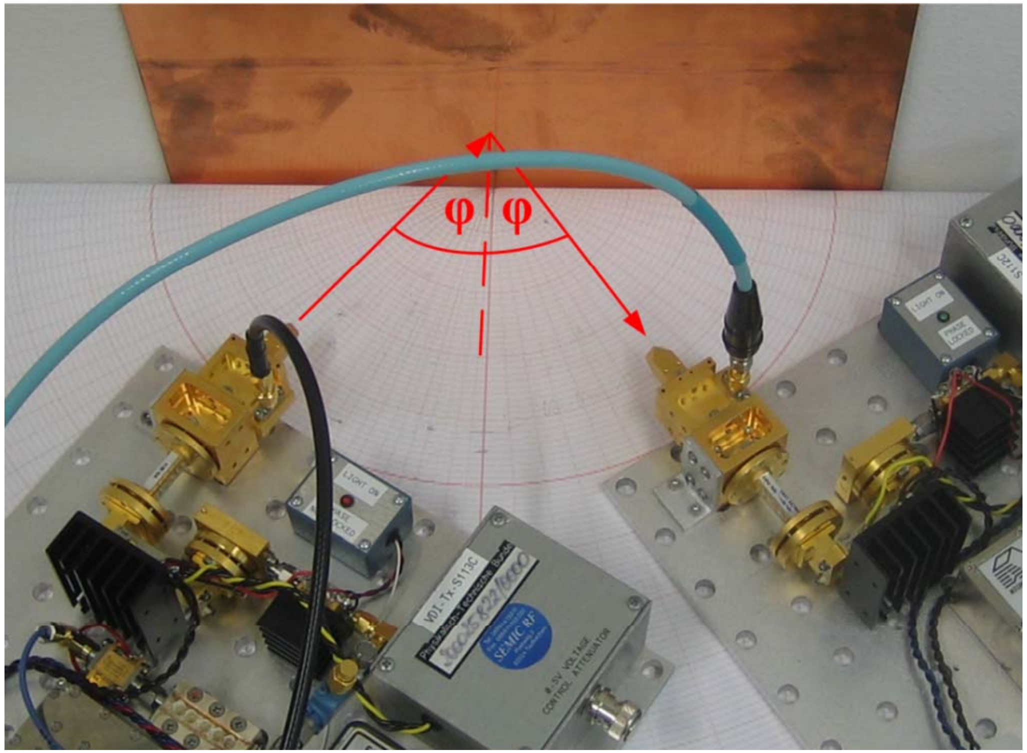


Source: Terahertz Communications Lab

Reflection and Scattering Measurements

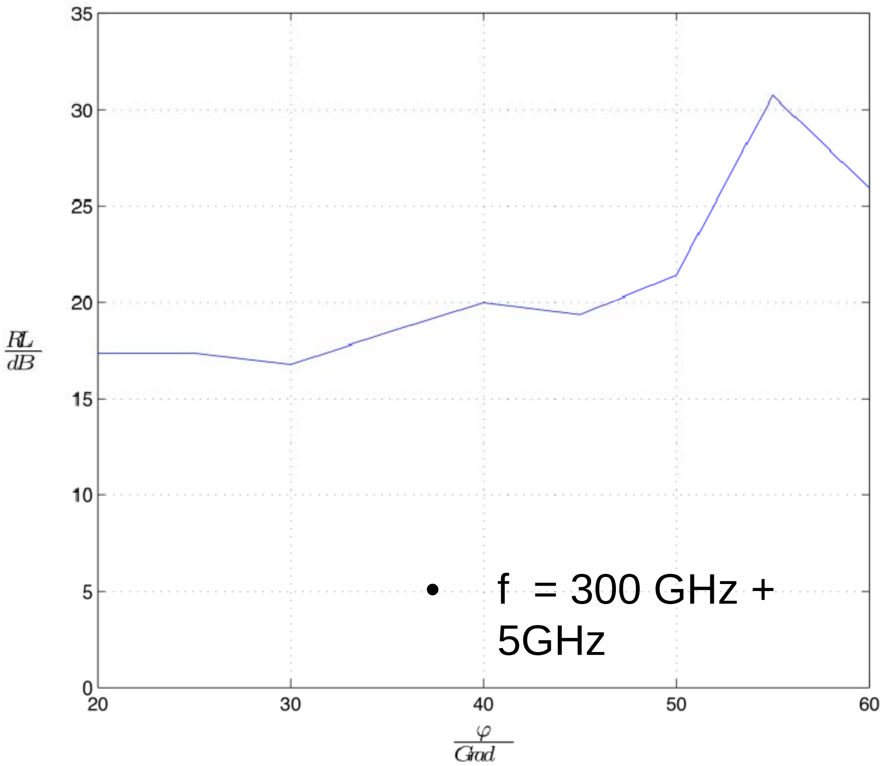
- Measurement Set-up
  - Reference measurement using a copper plate
  - Reflection Loss

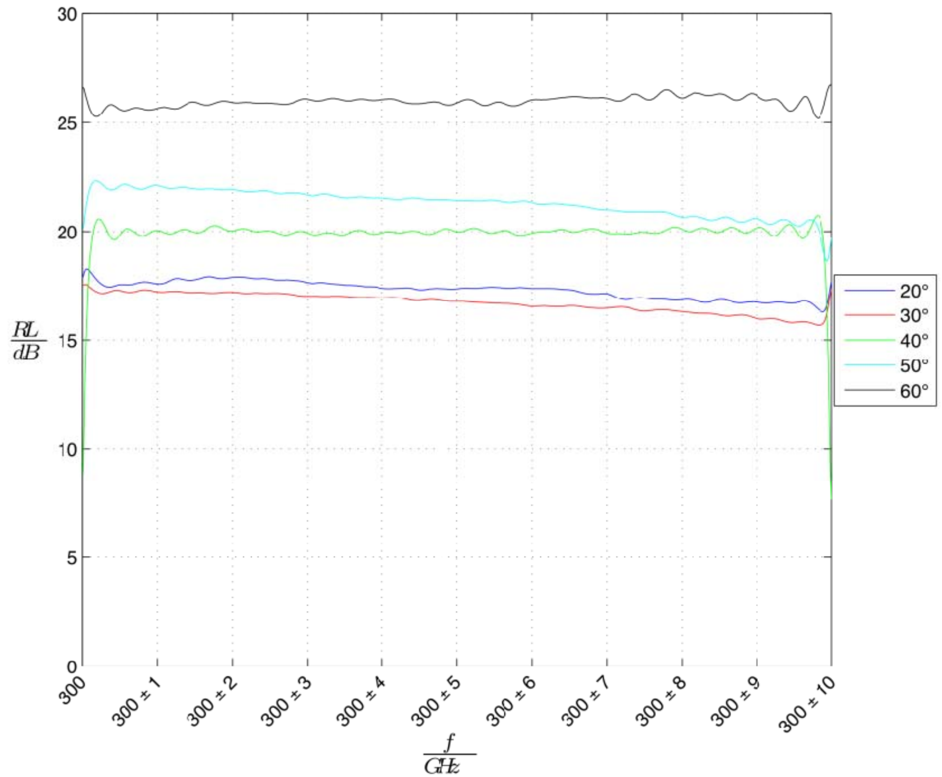
$$RL\big|_{dB} = S_{21,MUT}\big|_{dB} - S_{21,Copper}\big|_{dB}$$



Source: Terahertz Communications Lab

Reflection Loss (TM Polarization): Wood

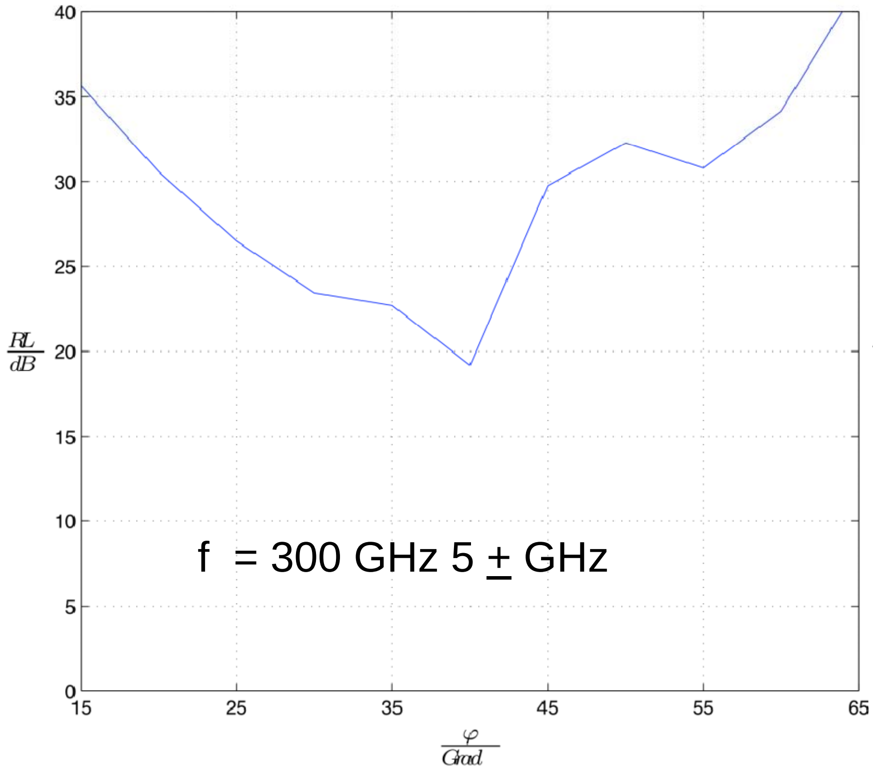




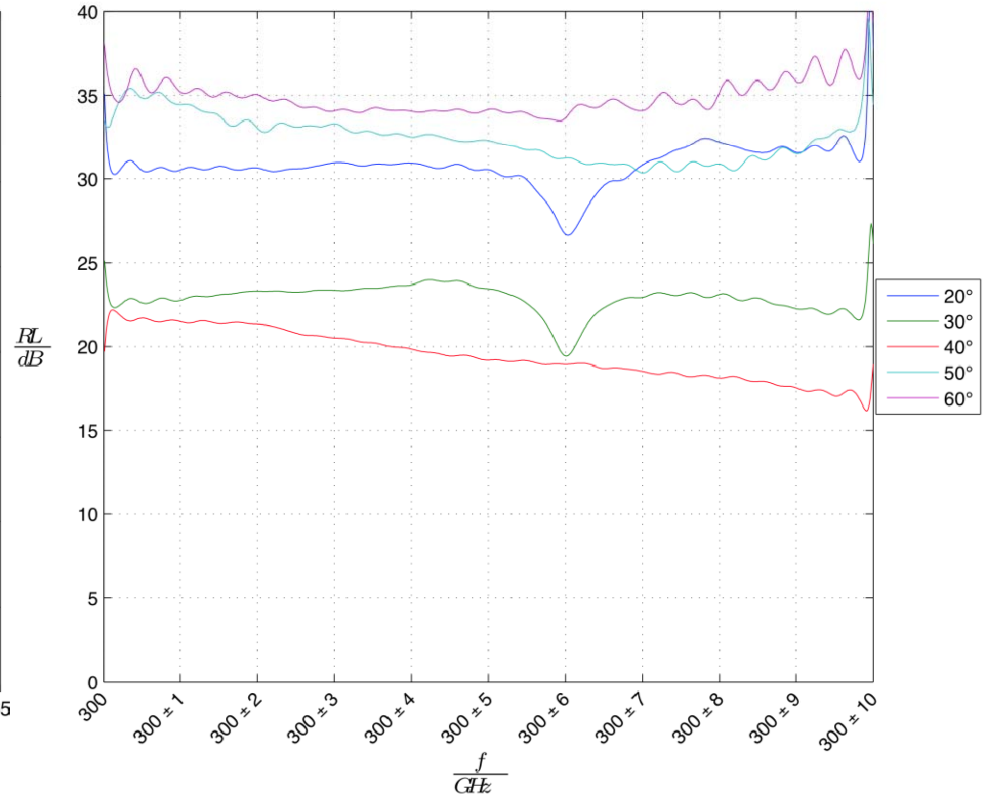
- f = 300 GHz + 5GHz

Source: Terahertz Communications Lab

Scattering Loss (TM Polarisation): Wood

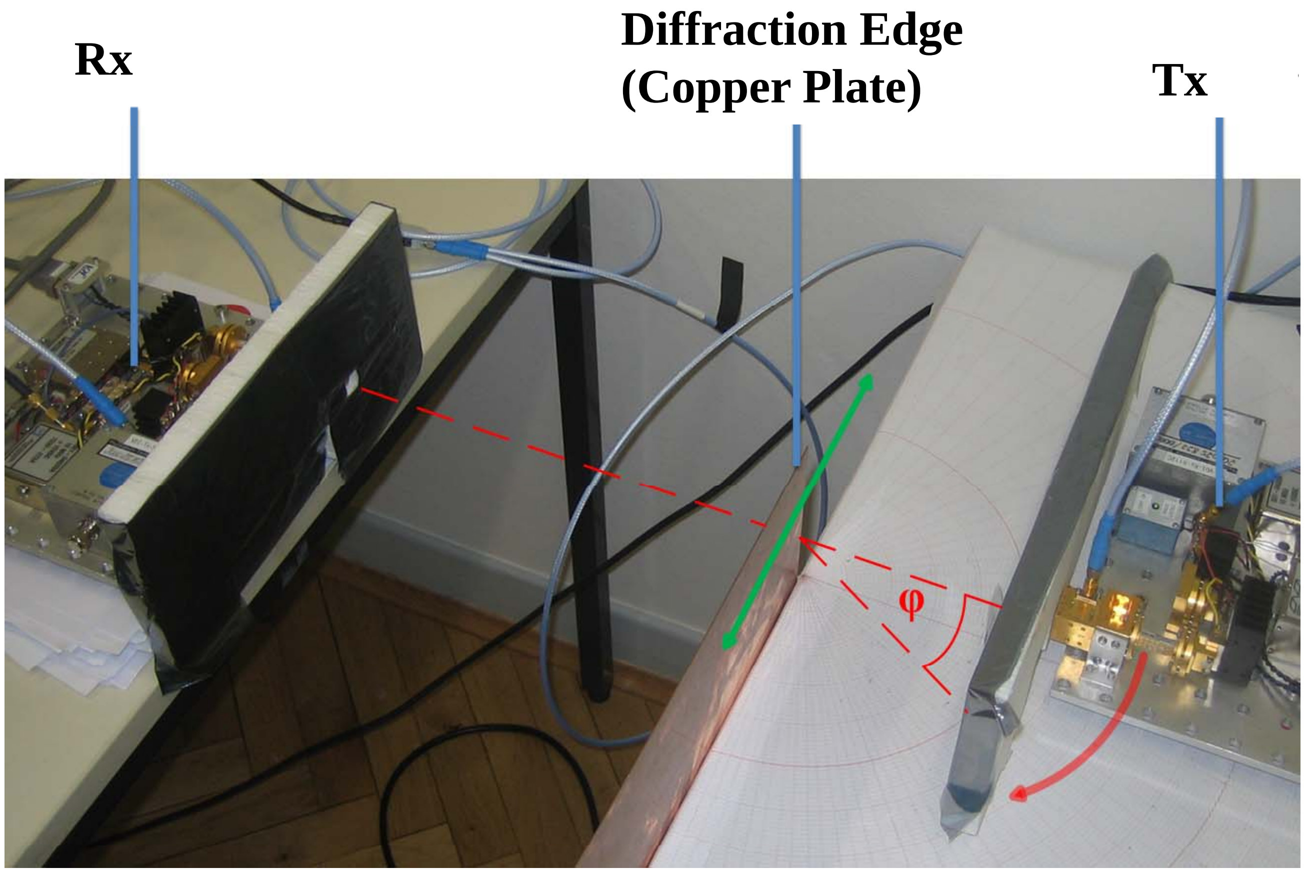


incidence angle φi= 40°



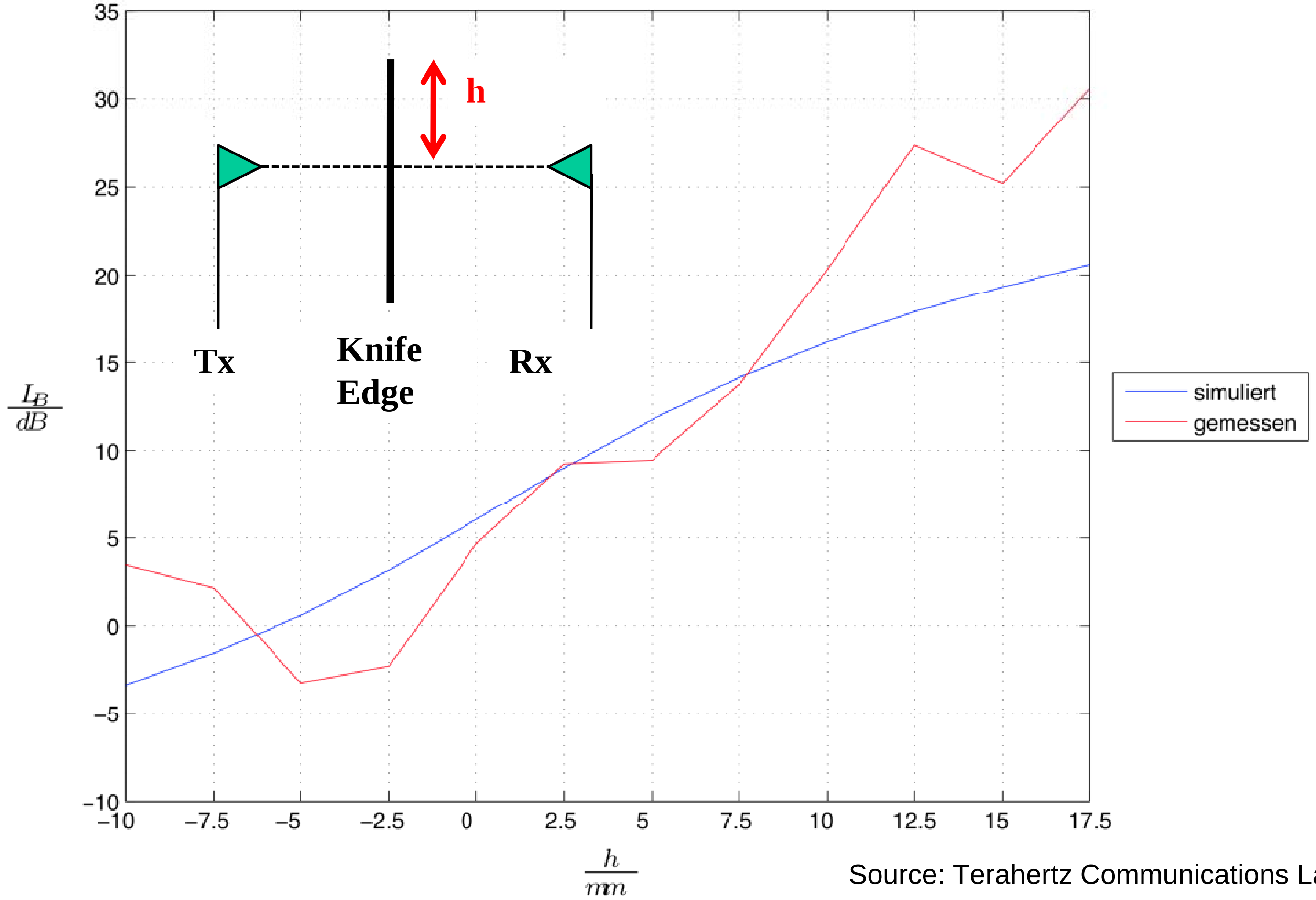
Source: Terahertz Communications Lab

Measurement of Diffraction Loss



Source: Terahertz Communications Lab

Comparison of Measured Diffraction Loss with Simulations based on a Knife Edge

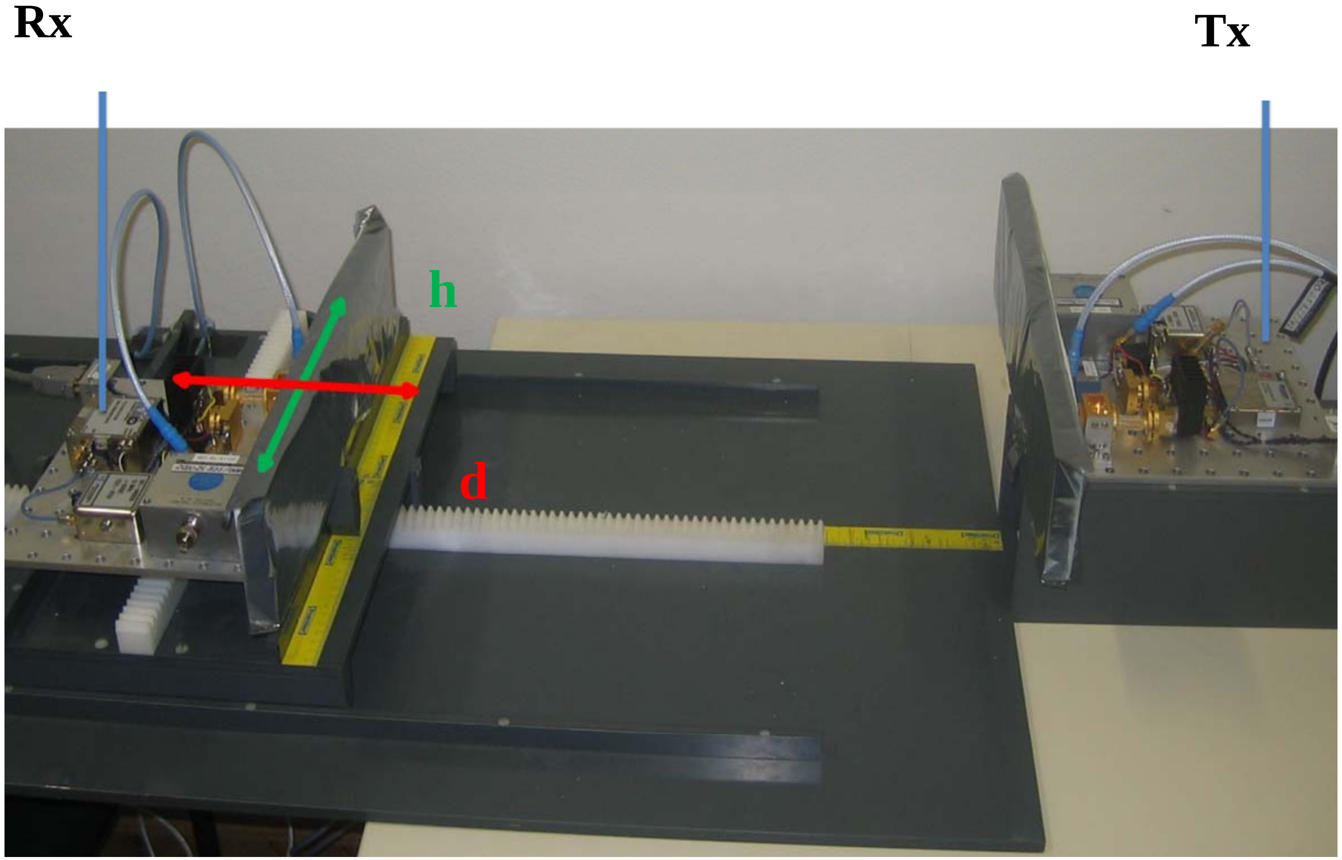


Source: Terahertz Communications Lab

Propagation Conditions and Channel Modeling beyond 300 GHz

Measuring the Impact of Antenna Misalignments

Measuring the Influence of Antenna Misalignment Measurement Set-Up

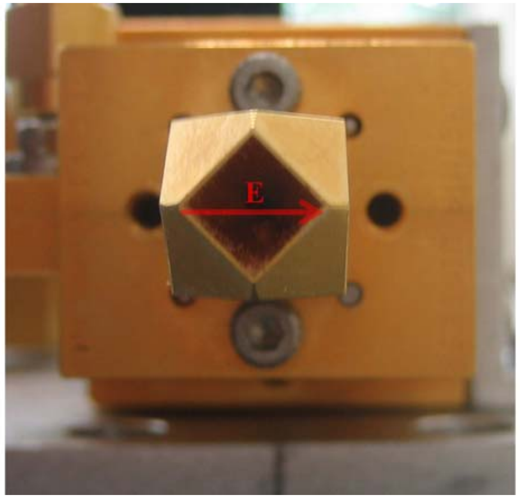


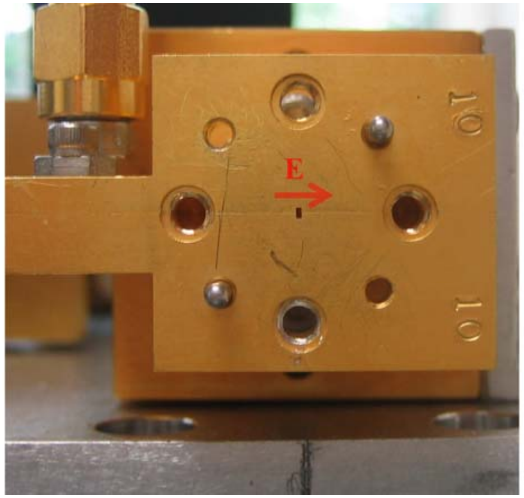
Measurements for Horn Antenna at Tx and different Antennas at Rx

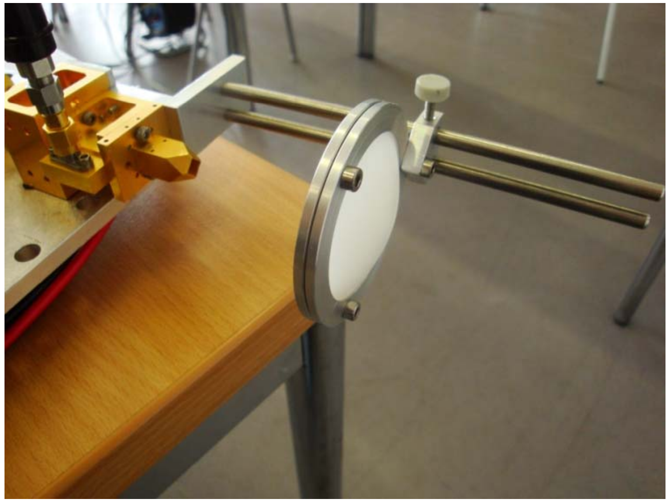
Source: Terahertz Communications Lab

Measuring the Influence of Antenna Misalignment - Antennas under Test

	Horn Antenna	Wave Guide	Horn Antenna with Polyethylen Lens
Gain	26 dBi	10 dBi	40 dBi
3 dB- width	11°	100°	1°

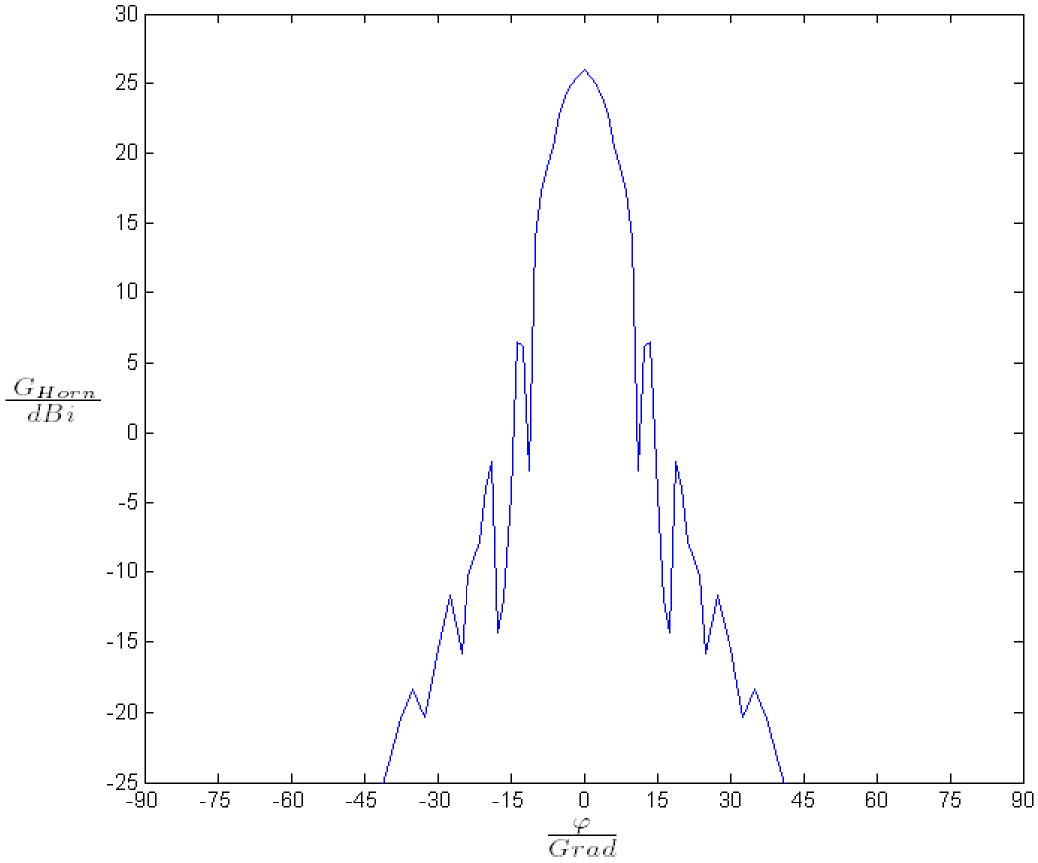






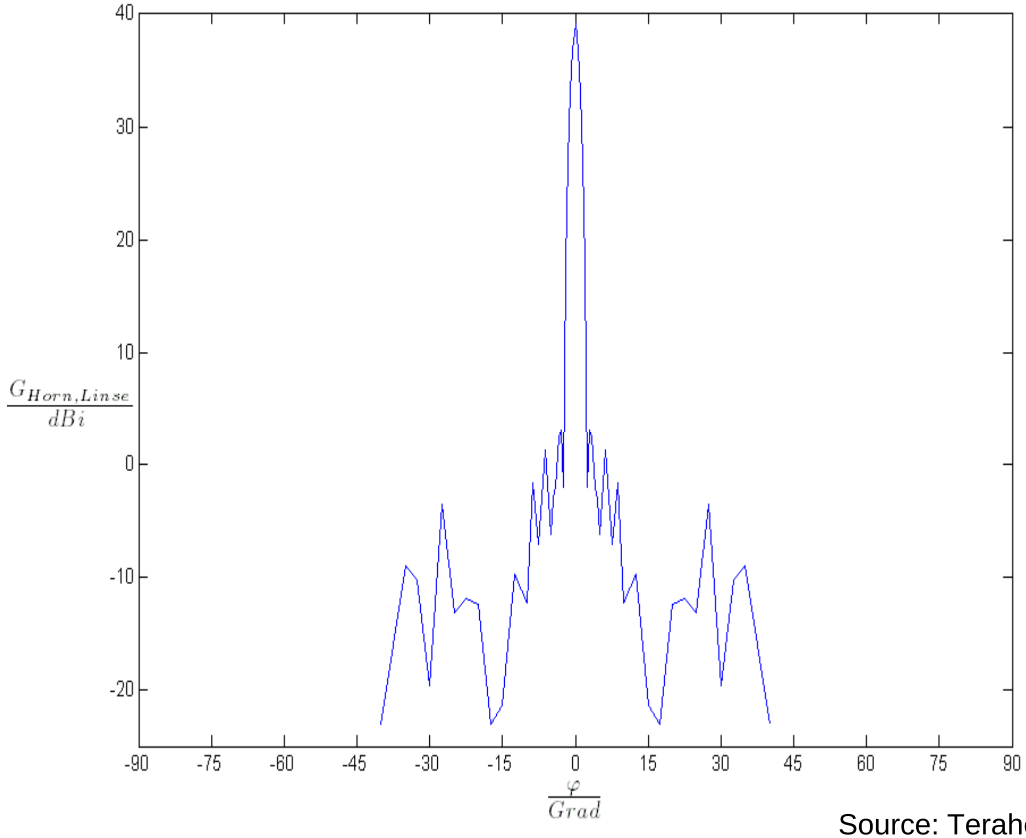
Source: Terahertz Communications Lab

Antenna Diagram: Horn Antenna



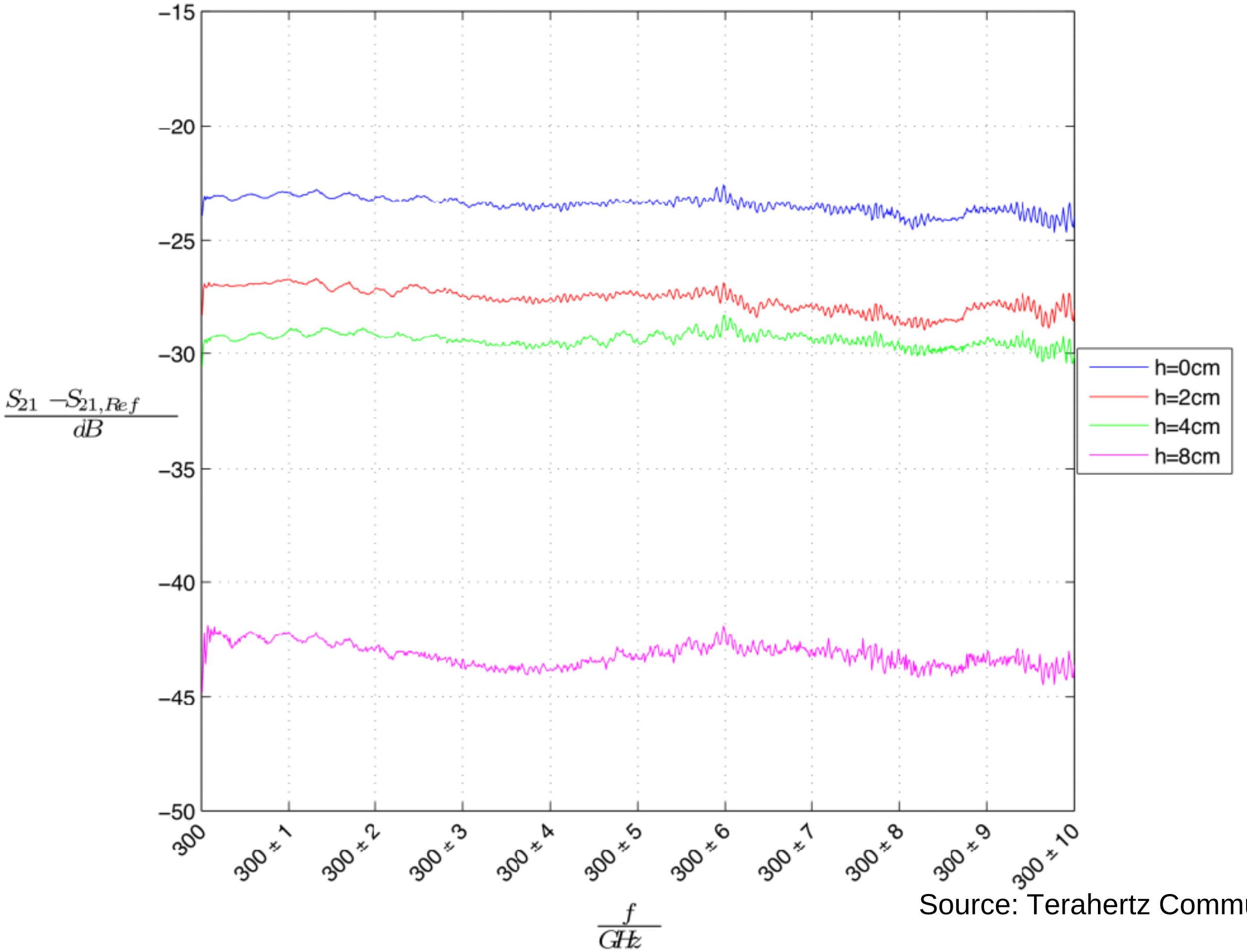
Source: Terahertz Communications Lab

Antenna Diagram: Horn Antenna with Polyethylen Lens



Source: Terahertz Communications Lab

Exemplary Result: Horn Antennas used at Tx and Rx



Source: Terahertz Communications Lab

Summary on Antenna Misalignment Measurements

Displacement	Antenna at Rx		
	Horn Antenna	Wave Guide	Horn Antenna with Polyethylen Lens
d = 40 cm, h = 0 cm	-23,3 dB	-44,3 dB	-12,3 dB
d = 40 cm, h = 2 cm	-27,4 dB	-45,2 dB	-19,7 dB
d = 40 cm, h = 4 cm	-29,3 dB	-47 dB	-41,4 dB

Source: Terahertz Communications Lab

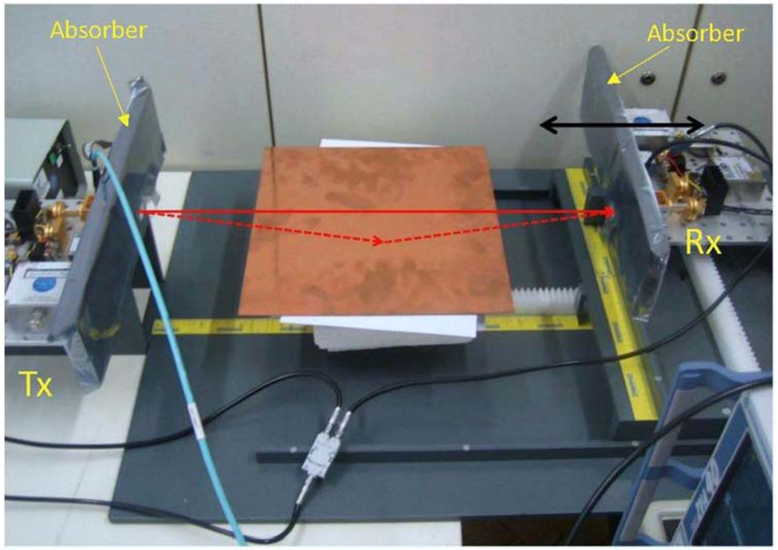
Propagation Conditions and Channel Modeling beyond 300 GHz

Measurements in more Realistic Scenarios

Measuring complete Scenarios

- In the following three measurement set-ups are applied
  - Set-Up 1: Two-ray propagation scenario
    - Variation of distance between Tx and Rx
    - Metal plate at ground used
    - Absorbers at Tx and Rx
  - Set-Up 2: Influence of metallic parts of RF front end
    - Tx and Rx at a distance of 55 cm
    - Measurements with/without absorber at Tx and Rx
  - Set-Up 3: Mutipath propagation in a complete room
    - AoD and AoA in an small room
  - Set-Up 4: Propagation measurements on a desktop
    - Channel Impulse Response

Set-up 1: Example Application – Fast Data Transfer

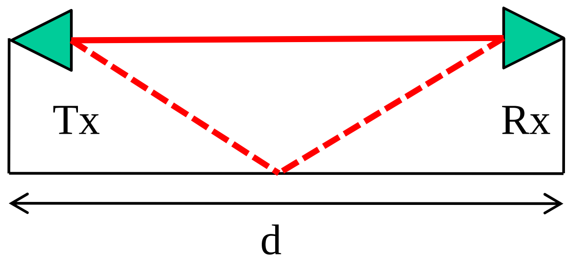


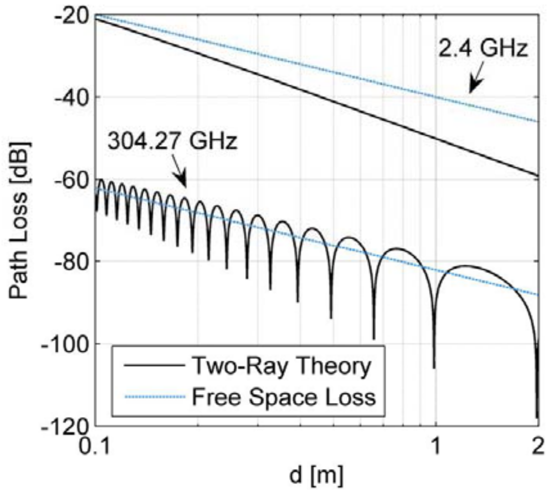
– Realistic application Gbps-Link between two electronic devices
– Propagation scenario
– Superposition of reflection from the desktop and direct path
– Investigated experimentally and by simulations

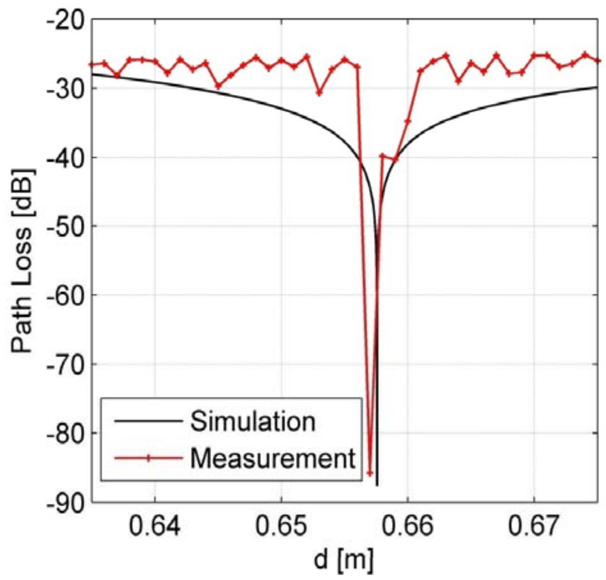
Source: Terahertz Communications Lab

Results from Set-up 2: Two-Ray Propagation Scenario

- Superposition of direct signal and signal reflected from desktop taking into account proper phase of both signals
- Metal plate → reference for maximum expected signal fluctuations
- Different behaviour than for lower frequencies

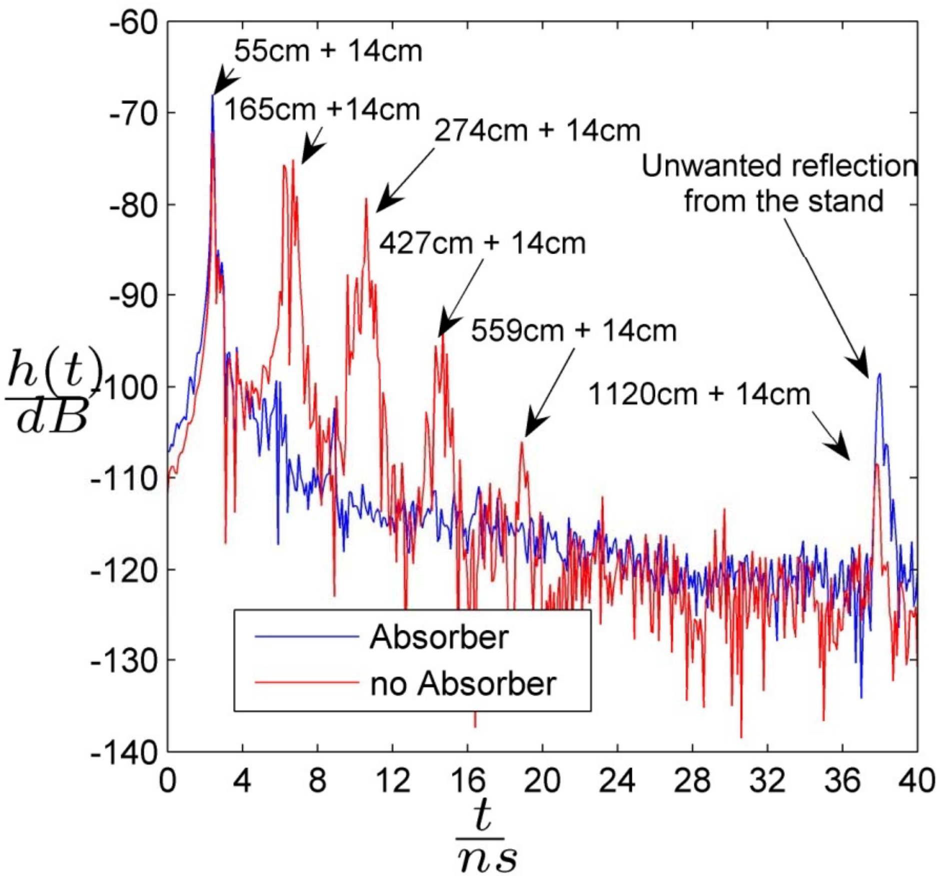




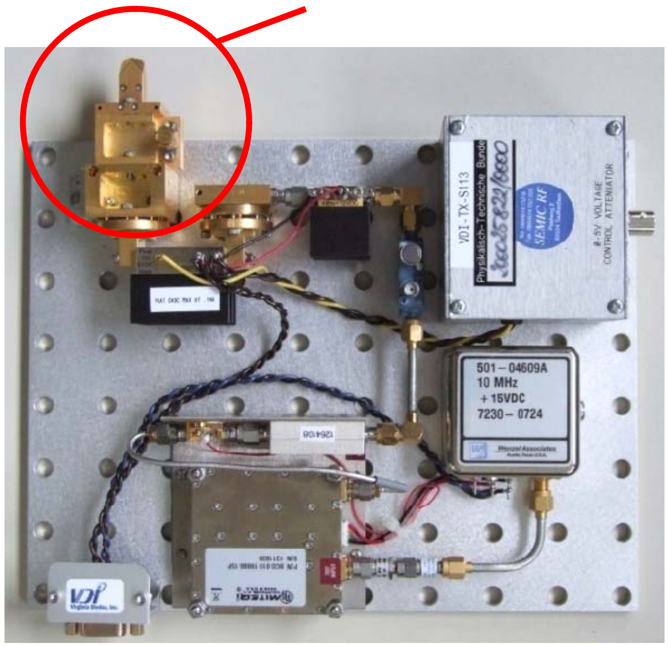


Source: Terahertz Communications Lab

Results from Set-up 2: Measured Impulse Responses



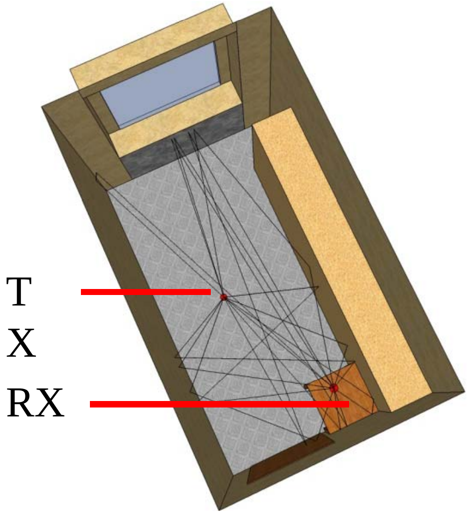
Antenna

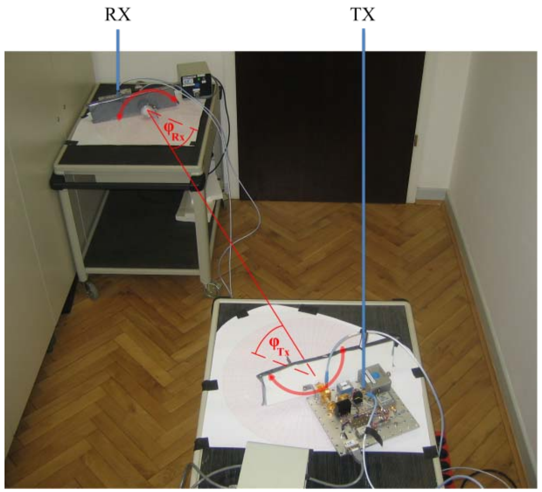


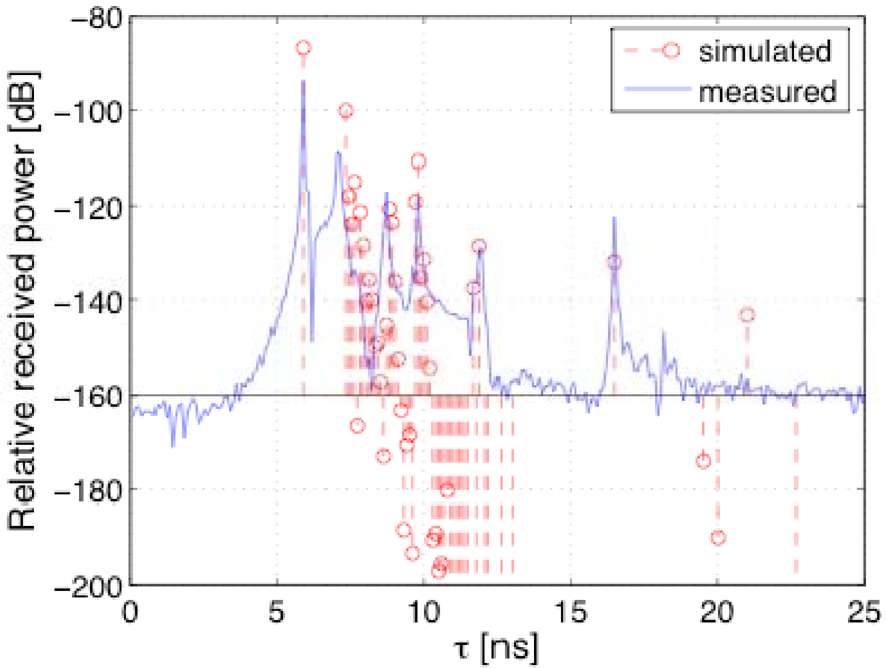
RF Front End

Source: Terahertz Communications Lab

Set-up 3: Measuring in a complete Room

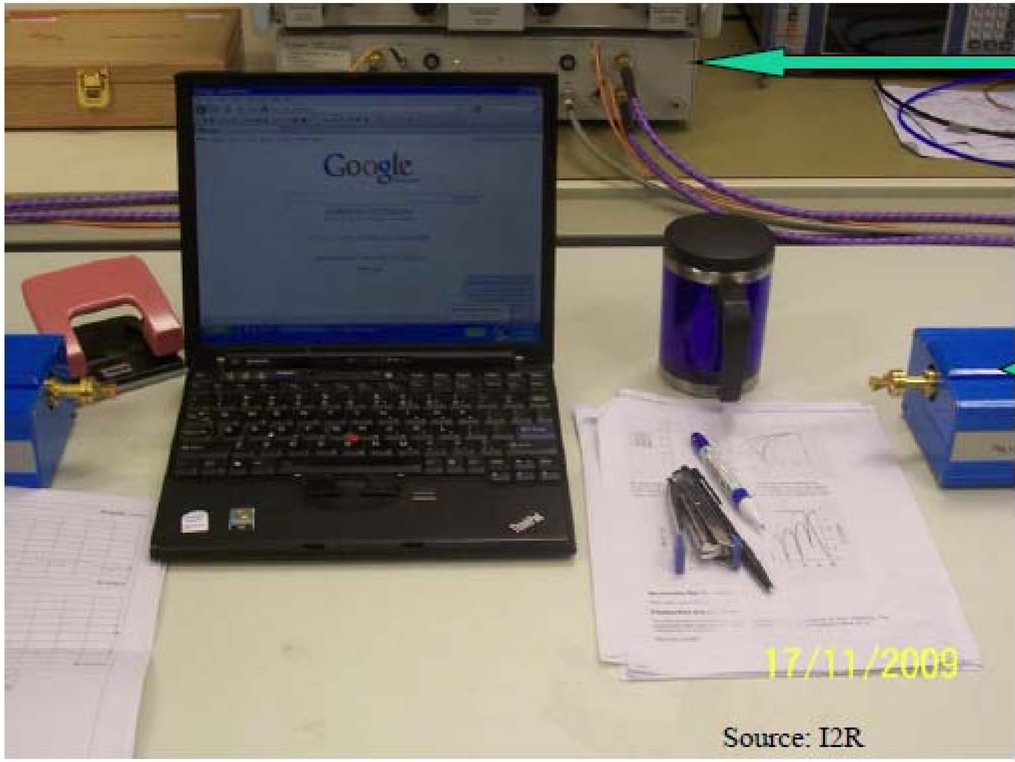






Source: Terahertz Communications Lab

Set-up 4: Propagation channel measurements for typical office or lab environment (table top)

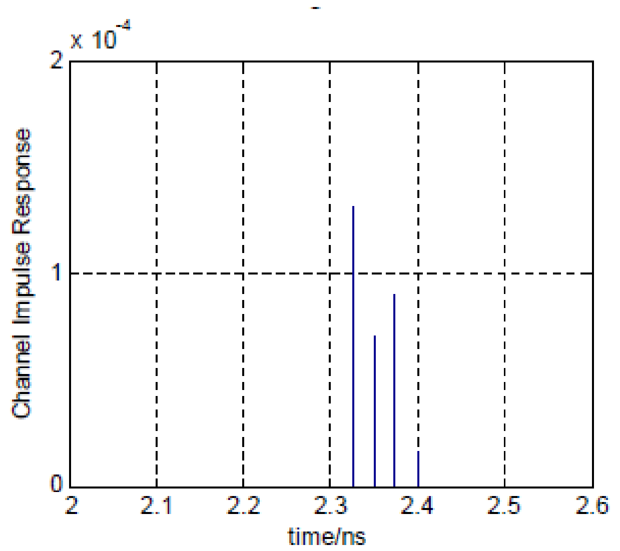


Agilent Vector Network Analyser

OML head Up to 325 GHz

Source: Michael Y.W. Chia, Institute for Infocomm Research
doc. IEEE 802.15-15-09-0-0777-00-0thz

Preliminray Results



Source:I²R

- Measured Channel Impulse Response at about 300GHz over tens of GHz bandwidth with resolutions in the order of picoseconds....
- Multiple delays of the THz signal i.e. multi-paths effects can be observed due to scatterings by the neighboring objects.

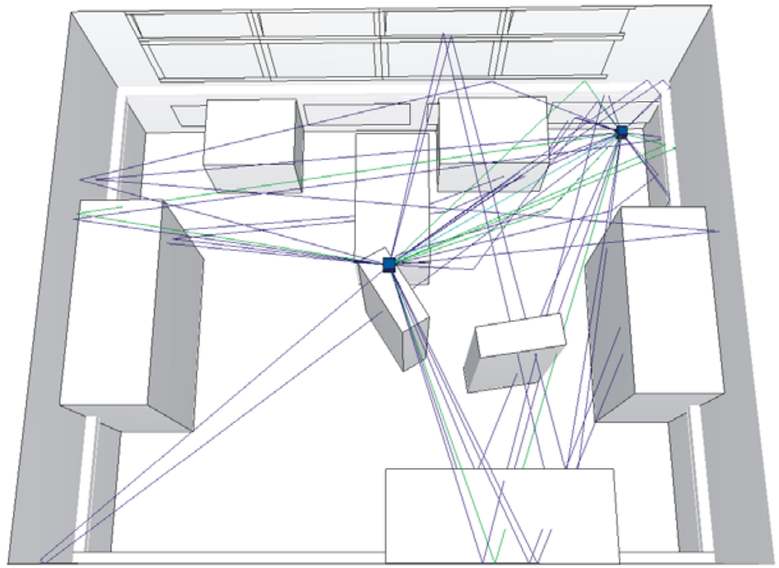
Source: Michael Y.W. Chia, Institute for Infocomm Research
doc. IEEE 802.15-15-09-0-0777-00-0thz

Propagation Conditions and Channel Modeling beyond 300 GHz

Research Tasks on Channel Modeling

Research: Propagation, Channel Characterisation and System Simulation

- Verification of complete ray-tracing model
- Measurements and modelling of rough surface scattering in non-specular directions
- Modelling of rough surfaces on multiple layers
- In-depth channel characterisation both by measurements and simulaton
  - Enabling system simulations
  - Development of system architectures (antenna concepts, transmission systems – low complexity !?)



Source: Terahertz Communications Lab

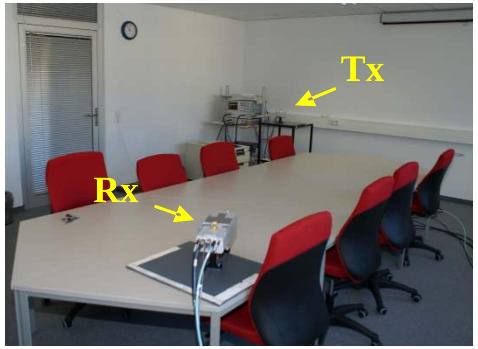
…and what can be learned from Channel Modeling at 60 GHz?

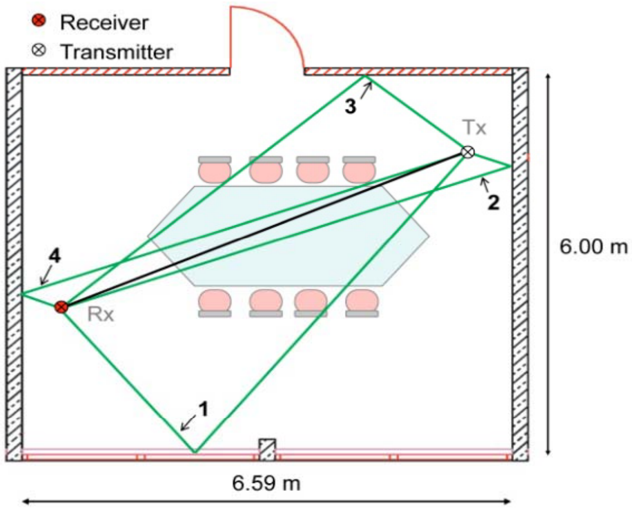
- Two IEEE 802 standards on 60 GHz have been or are currently being developed:
  - IEEE 802.15.3c
  - IEEE 802.11ad
- Influence of blocking humans and demand for beamforming/beam shaping already required at 60 GHz

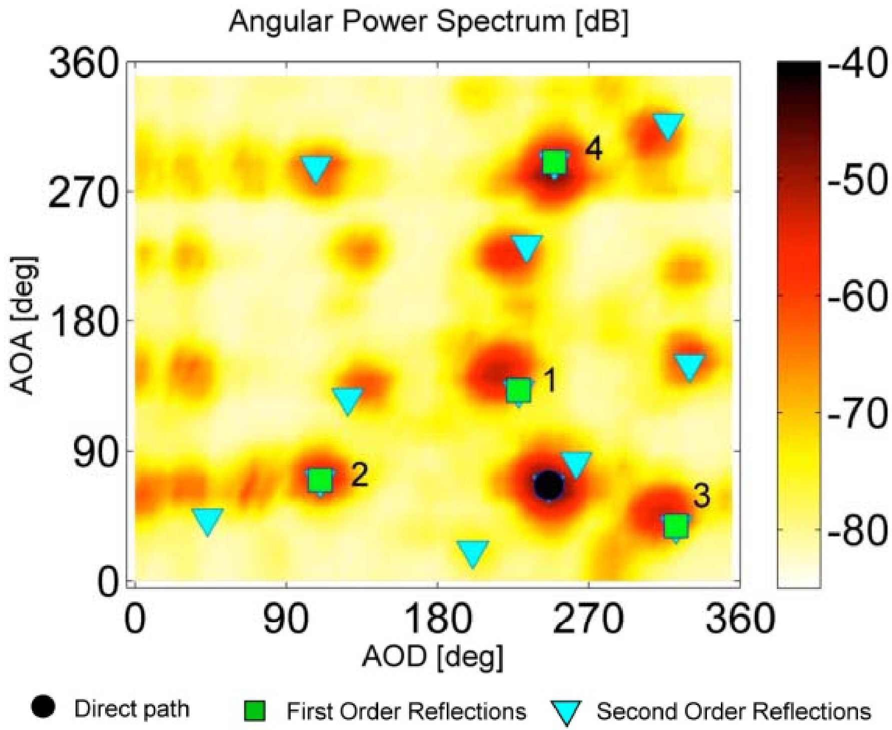
Source: Terahertz Communications Lab

- Channel models from these two standards can be used as a starting point
- TU Braunschweig (TCL) has been involved in defining the channel model in used in TGad (especially in those parts dealing with dynamics caused by human blocking)

Accuray of Ray Tracing at 60 GHz - Comparison with Measurements of AoA vs. AoD





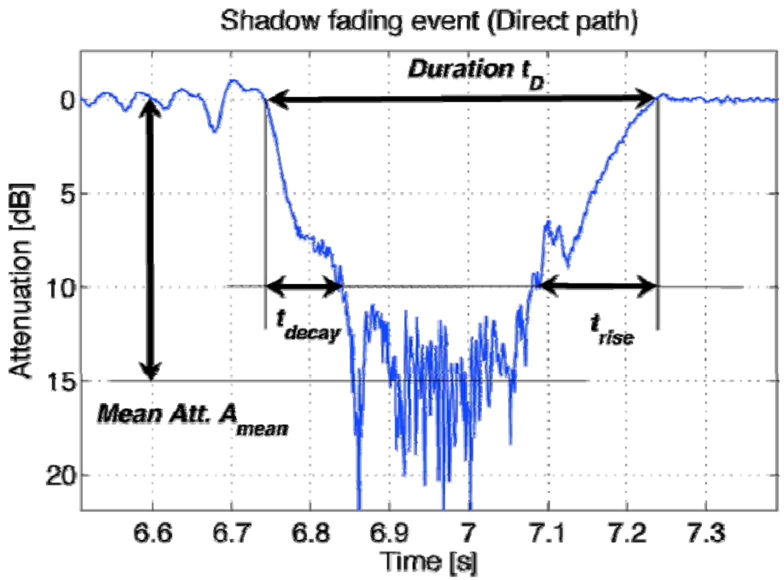


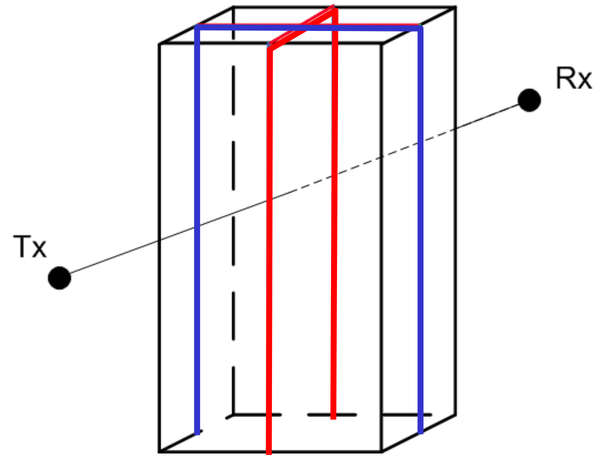
Source: Terahertz Communications Lab

Measurements of Attenuation by human Blockage

Source: Terahertz Communications Lab

Characterizing of Shadowing Events



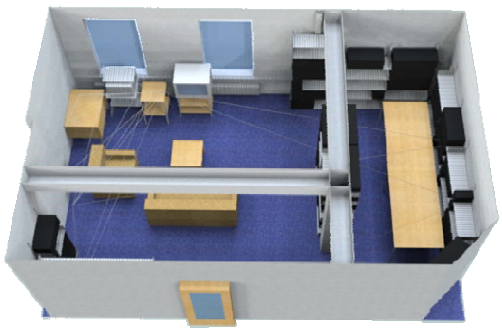


- Mean attenuation $\boldsymbol{A_{mean}}$ for the window (t_d/3<t<2/3 t_d)
- Maximum attenuation $\boldsymbol{A_{max}}$
- Decay time $\boldsymbol{t_{decay}}$
- Rise time $\boldsymbol{t_{rise}}$
- Duration $\boldsymbol{t_D}$

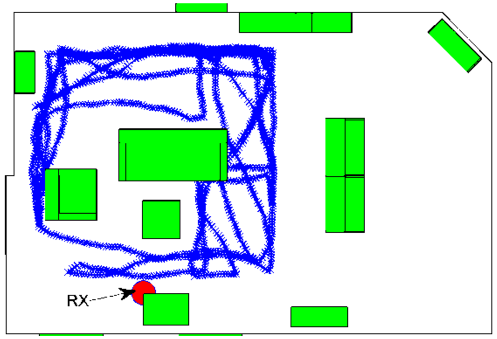
- Modeling humans as cuboids
- Appliying multiple edges to model diffraction

Source: Terahertz Communications Lab

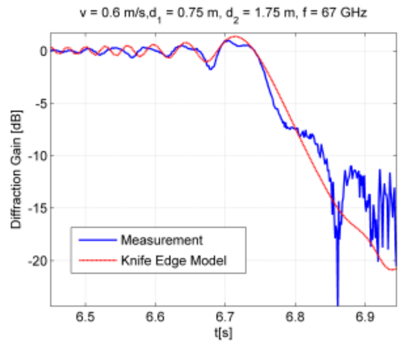
Procedure applied to derive Statistical Channel Models in IEEE 802.11 TGad



Ray Tracing

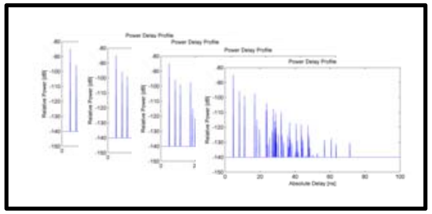


Random Walk Model



Diffraction Model

Set of **time variant channel realizations**

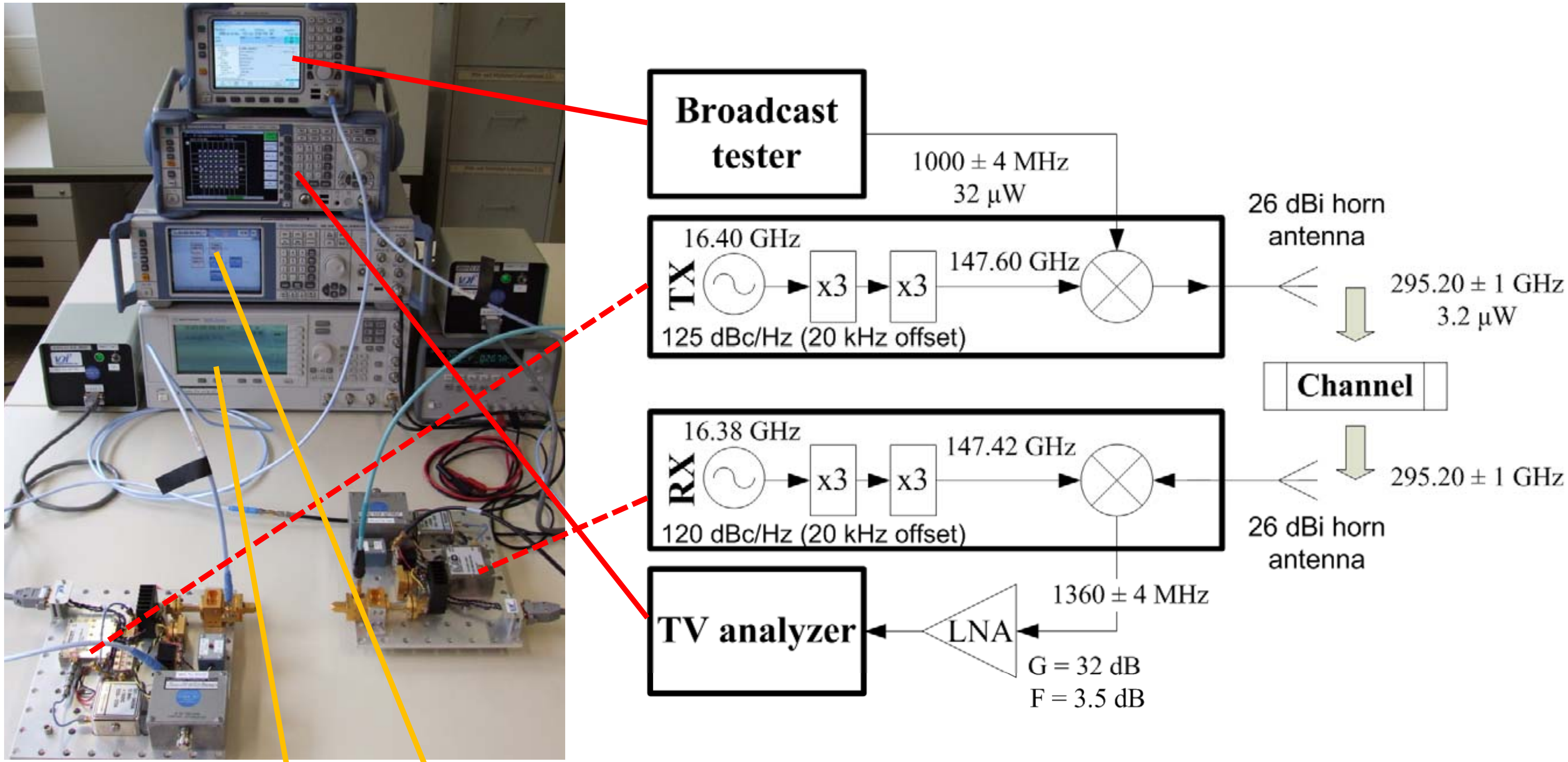


Blockage statistics	**Amplitude Statistics**	**Occurence Rate**

Results from Demonstrations

Transmitting DVB-T/S2-Signals
@300 GHz (TCL, Germany)

DVB-T Test Signal Transmission

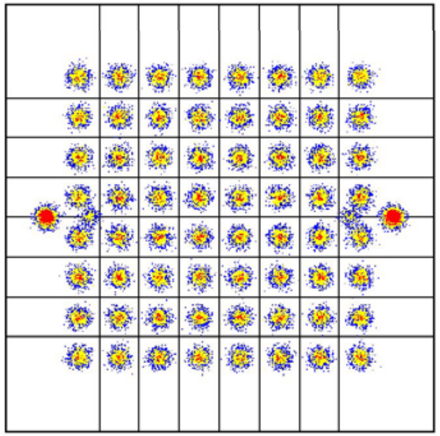


Signal generators as local oscillators

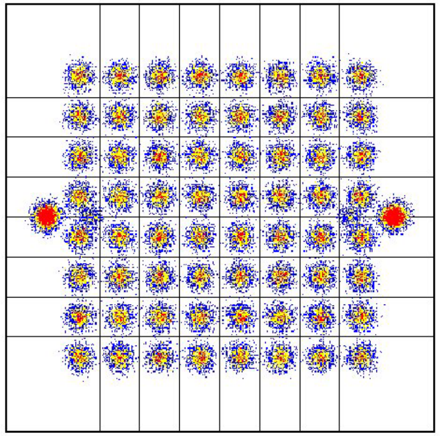
Source: Terahertz Communications Lab

Constellation diagrams for a DVB-T test signal

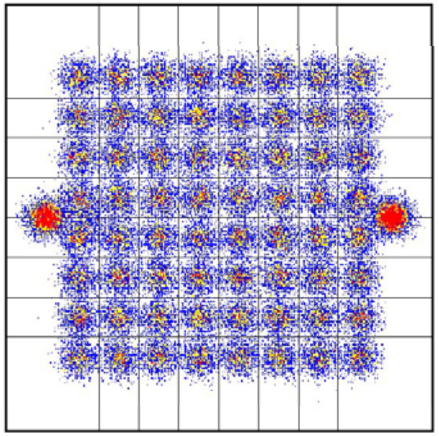
- 2k subcarriers
- code rate rc = 7/8
- channel bandwidth B = 8 MHz
- Psignal = -15 dBm
- guard interval 1/32×TS
- modulation scheme: 64 QAM
- Data rate 31.668 Mbit/s



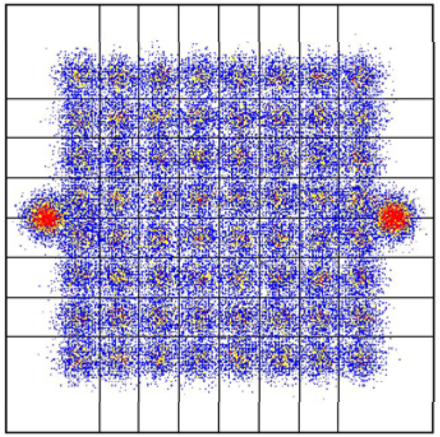
d = 10 cm, $BER_{before\ RS} < 10^{-9}$



d = 30 cm, $BER_{before\ RS} = 2.6 \times 10^{-8}$



d = 50 cm, $BER_{before\ RS} = 1.2 \times 10^{-4}$

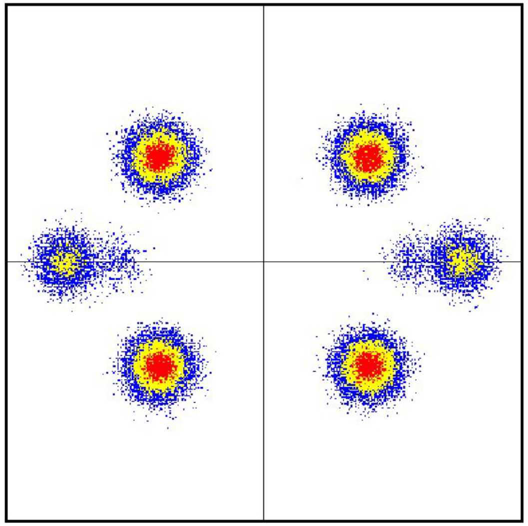


d = 70 cm, $BER_{before\ RS} = 3.4 \times 10^{-3}$

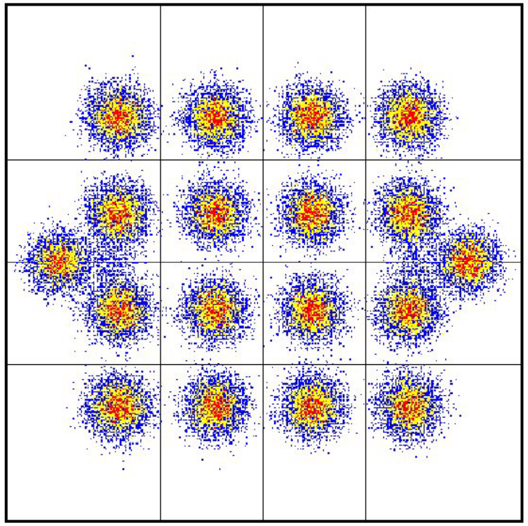
Source: Terahertz Communications Lab

Transmission with lense antennas

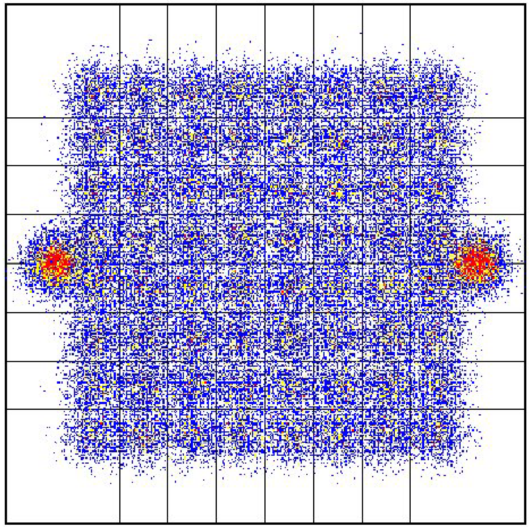
- Transmission distance of 52 m with lenses
  - PRX = -52.9 dBm



QPSK: BER < 10^{-9}



16 QAM: BER < 10^{-8}



64 QAM: BER = 2.8×10^{-4}

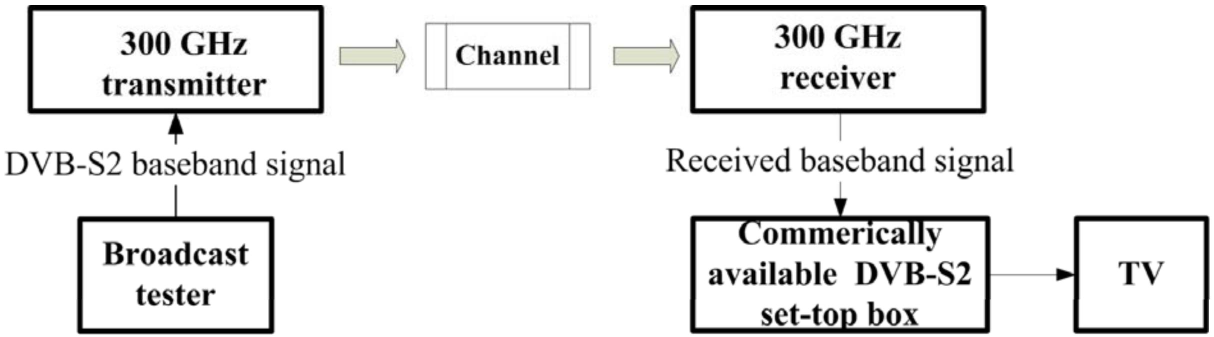
- Usage of simple modulation schemes allows better performance
- Tradeoff: Robustness vs. Spectral efficieny

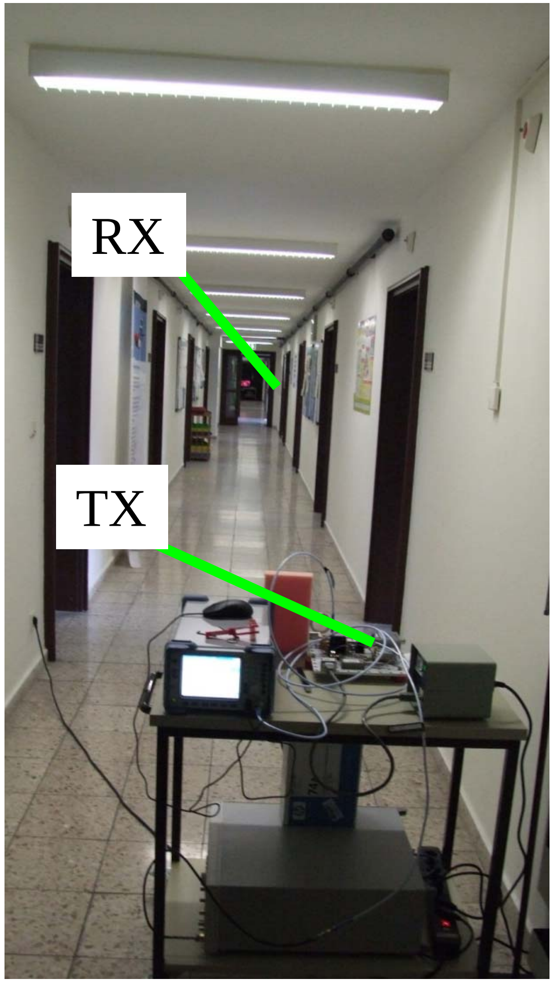
Source: Terahertz Communications Lab

DVB-S2 Feasibility Demonstration

- Feasibility demonstration with commerically available DVB-S2 receiver
  - No high-end components like in measurement equipment used before
- 1080p video signal: B = 36.8 MHz, r_c = 9/10, 8 PSK

  → net bit rate 85.78 Mbit/s





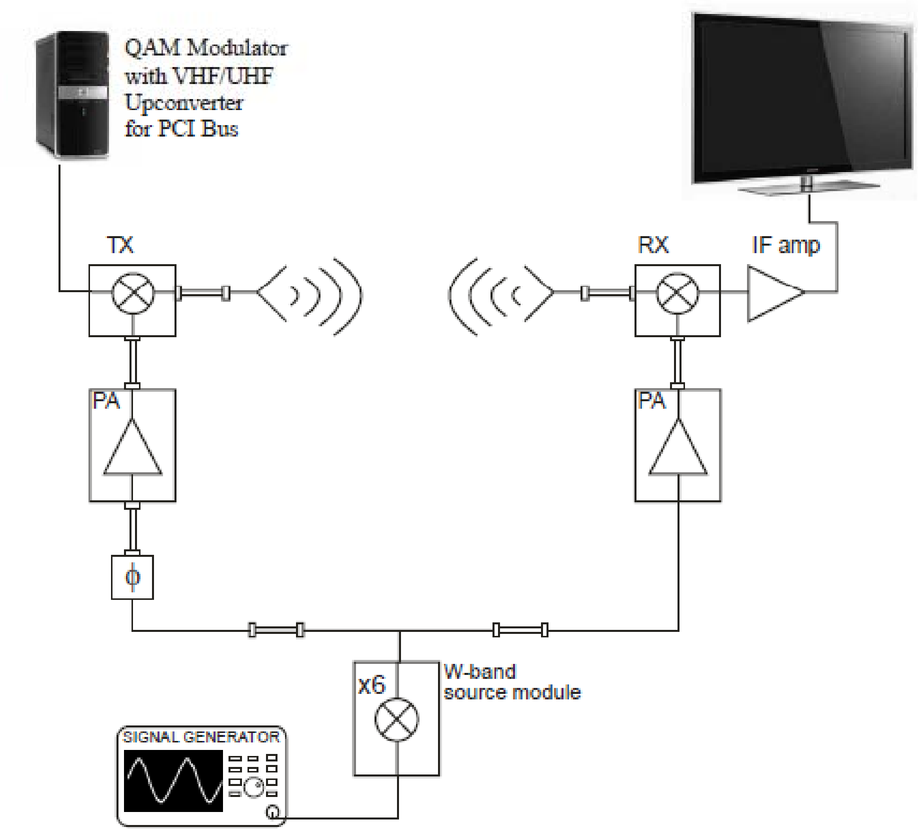
Source: Terahertz Communications Lab

Results from Demonstrations

Transmitting DVB-C-Transmission
@220 GHz (Millilink Project Germany)

DVB-C-Transmission@ 220 GHz (1)

- Carrier @ 220 GHz (LO @ 110 GHz)
- DVB-C media stream @ 64 QAM
- IF amplification 33 dB



Source: Ingmar Kallfass, Fraunhofer IAF / KIT
doc. IEEE 802.15-15-10-0-0824-00-0thz

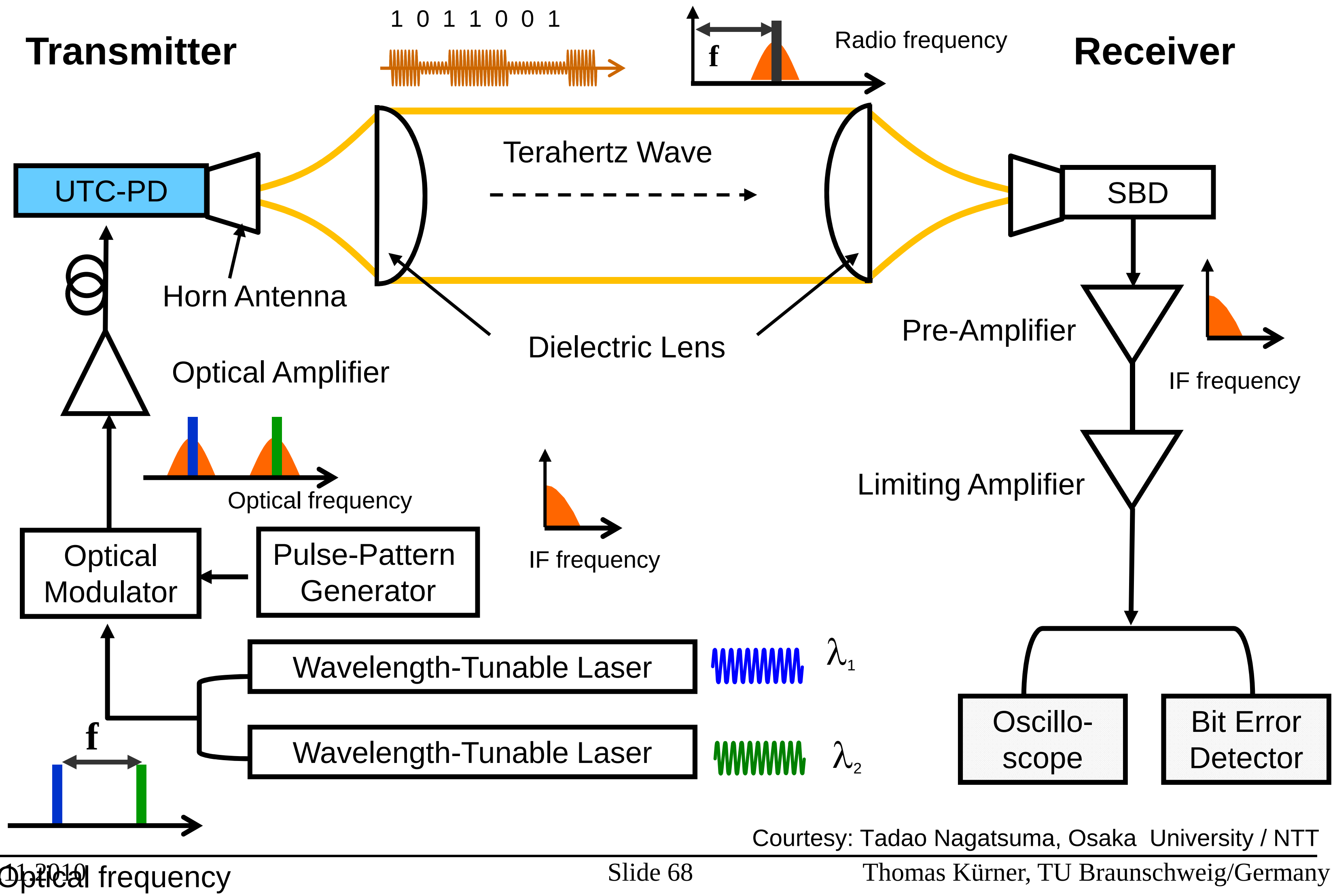
DVB-C-Transmission@ 220 GHz (2)

Source: Ingmar Kallfass, Fraunhofer IAF / KIT
doc. IEEE 802.15-15-10-0-0824-00-0thz

Results from Demonstrations

Towards 20 Gbit/s – recent achievements in Japan

Experimental Wireless Link

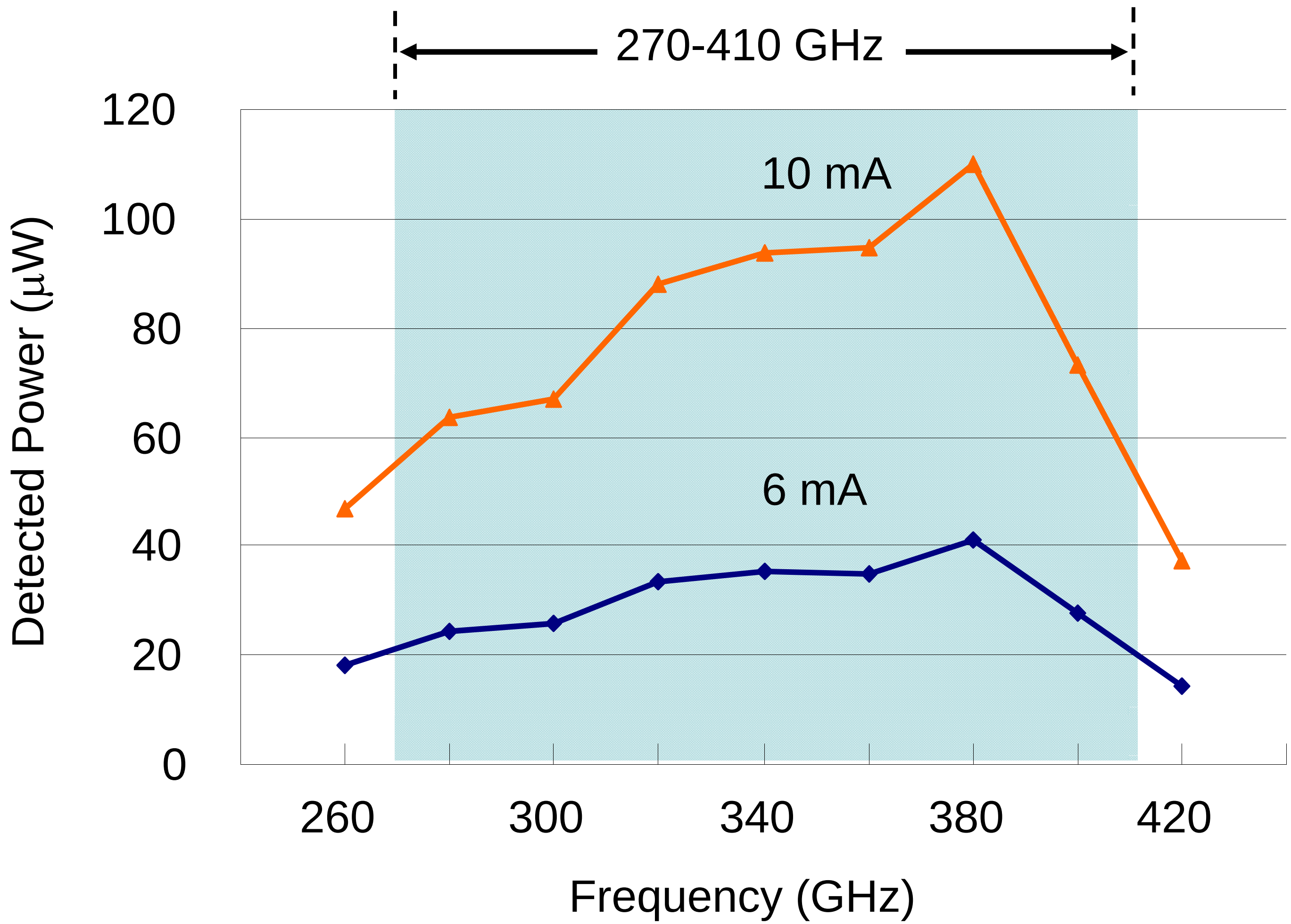


Courtesy: Tadao Nagatsuma, Osaka University / NTT

Photo of Transmitter

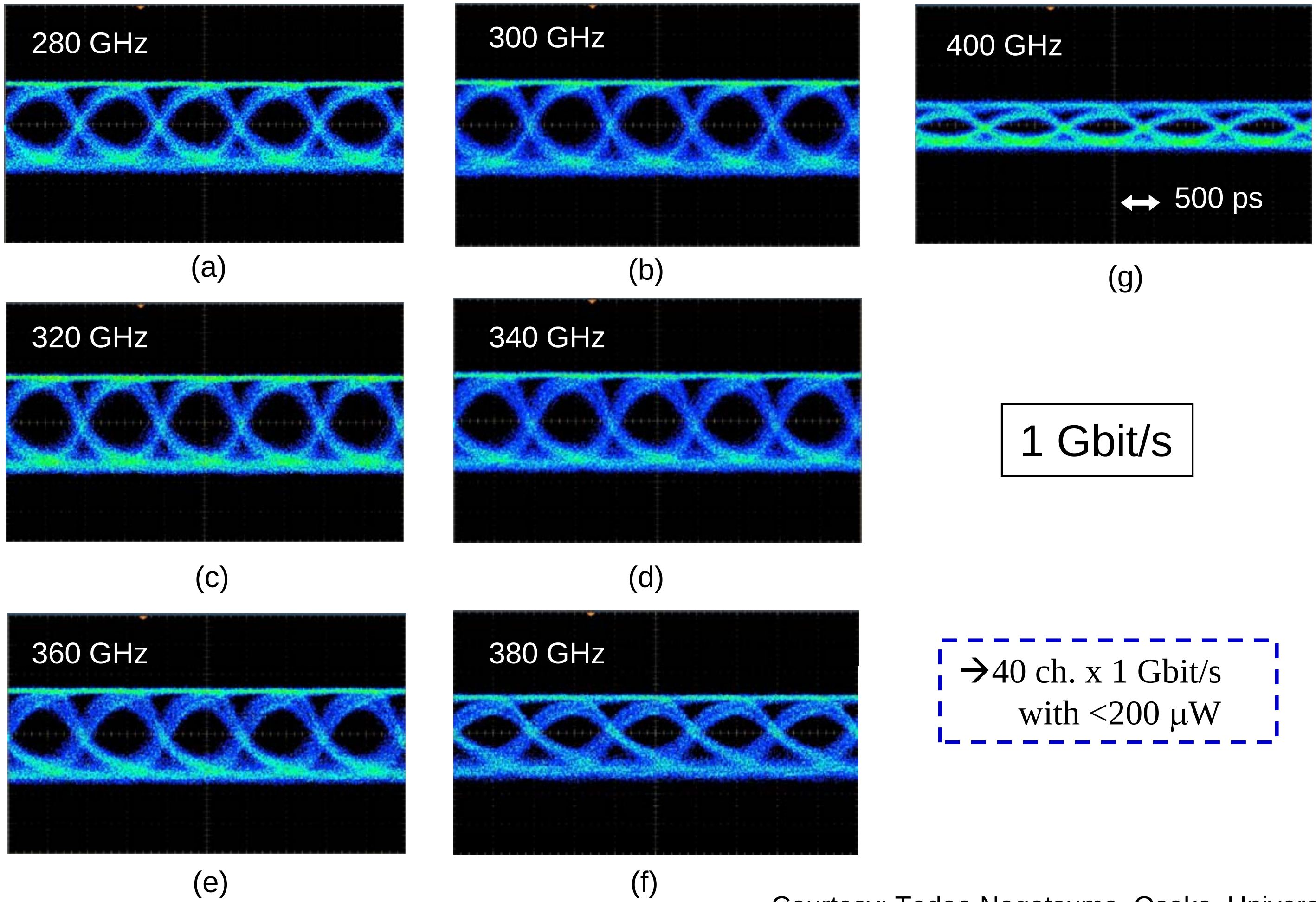
Courtesy: Tadao Nagatsuma, Osaka University / NTT

Output Power at 300-400 GHz



Courtesy: Tadao Nagatsuma, Osaka University / NTT

Transmission Characteristics (1)



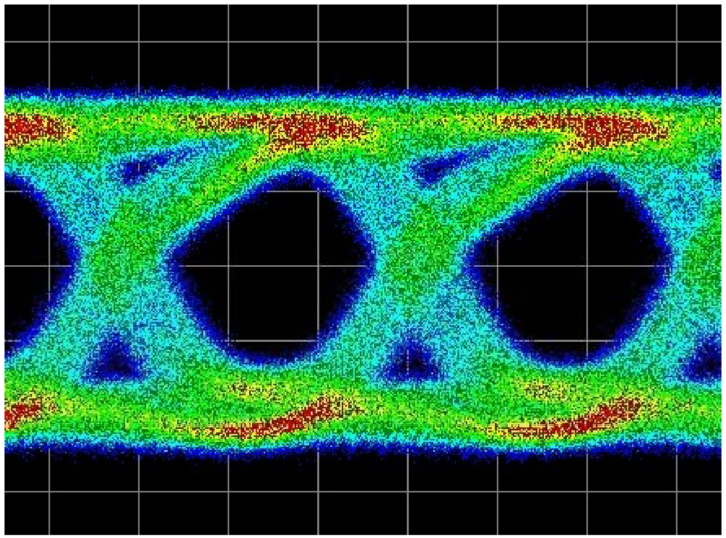
1 Gbit/s

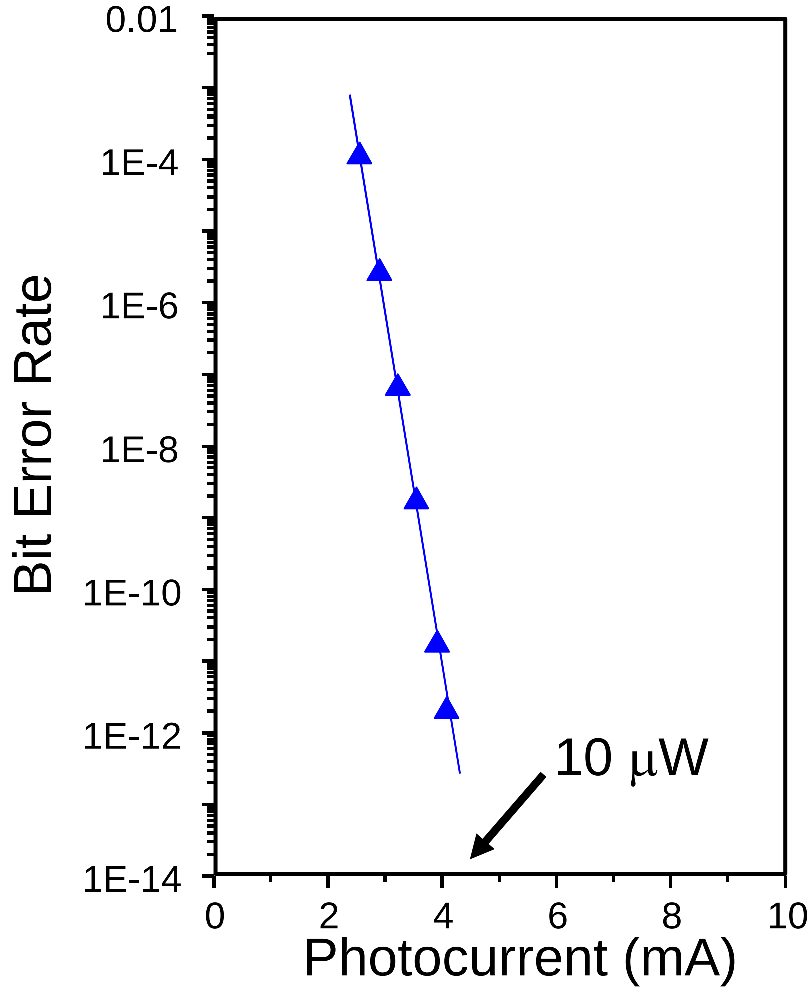
→40 ch. x 1 Gbit/s
with <200 µW

Courtesy: Tadao Nagatsuma, Osaka University / NTT

Transmission Characteristics (2)

12.5 Gbit/s





Courtesy: Tadao Nagatsuma, Osaka University / NTT

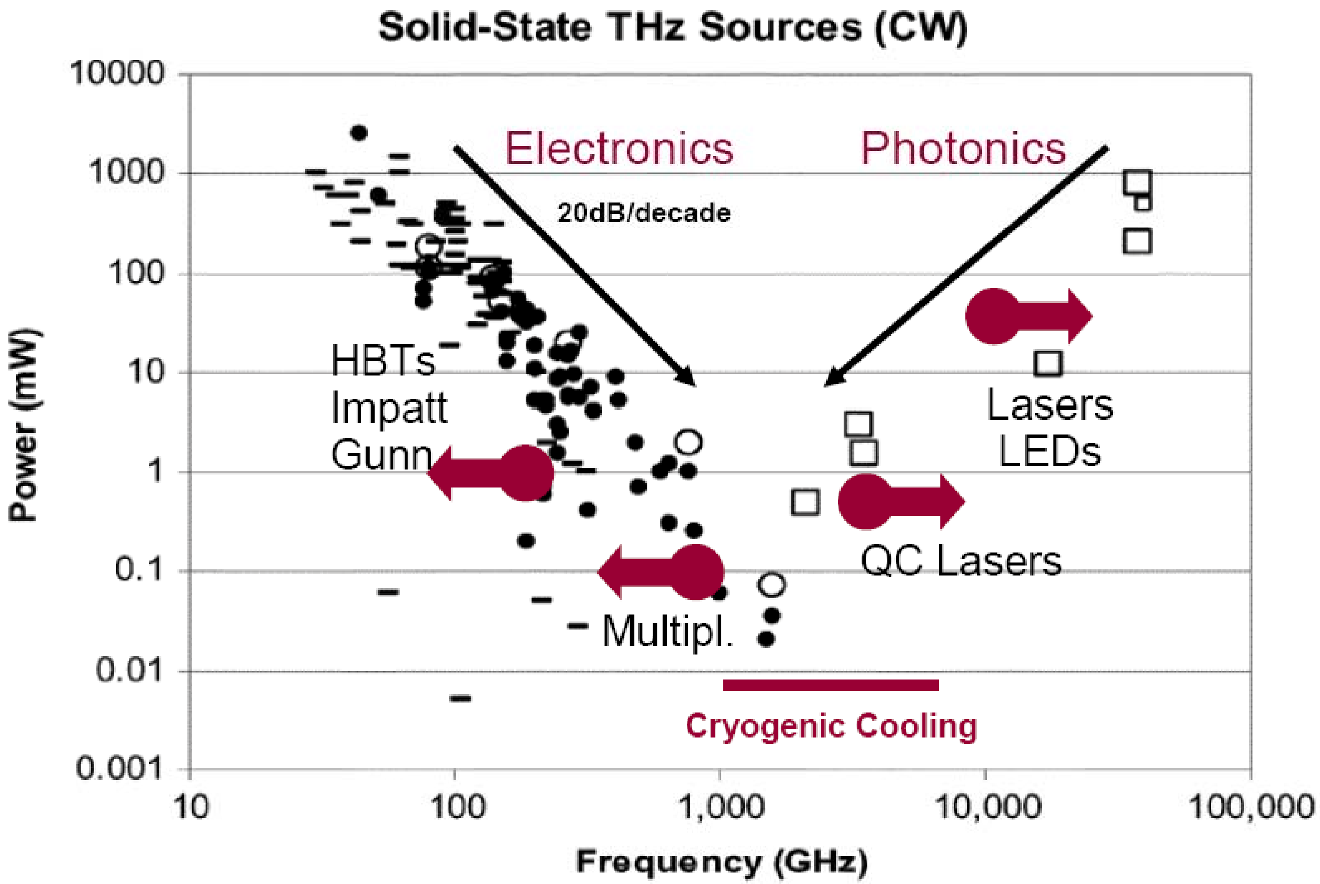
Activities in Developing the Technology

Some General Considerations

Technological Challenges

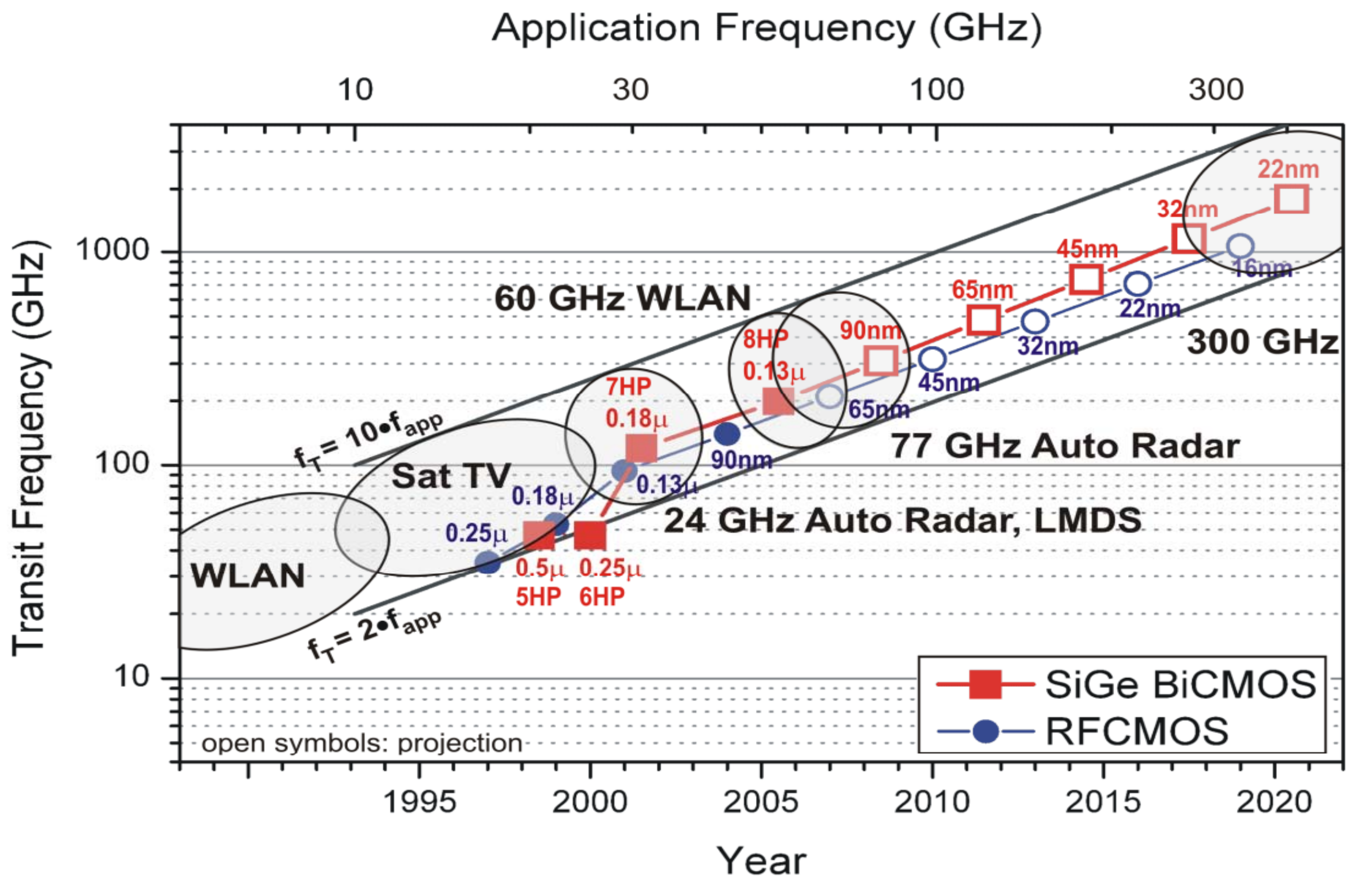
- Development and characterisation of components
  - Emitter
  - Receiver
  - Amplifier
  - Antennas
  - Feeding of the antennas
  - Mixer

The THz „Gap“



[1] T. Crow et.al., “Opening the Terahertz Window With Integrated Diode Circuits”, JSSCC 2005

Trends in increasing Transit Frequency



R. Piesiewicz et al., IEEE Ant. and Prop. Magazine, 2007

Activities in Developing the Technology

Selection of Some Ongoing Research Projects and Activities

(Incomplete) Listing of Research Groups and ongoing Research Projects

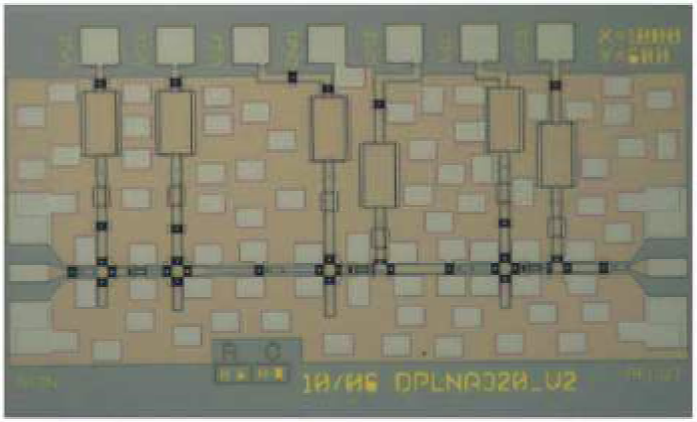
- Labs in the US
  - AT&T Shannon Labs
  - UCLA
  - Georgia Tech
  - TI Kilby Labs
- Labs in Europe
  - TCL @ Braunschweig / Marburg
  - Fraunhofer IAF / KIT
  - IHP
- Labs in Asia
  - NTT
  - Osaka University
  - Korea University
  - Institute for Infocomm Research, Singapore
- Running Projects in Europe
  - Millilink
  - FP7-RooTHz
  - FP7-dotFive
  - FP7-IPHOBAC

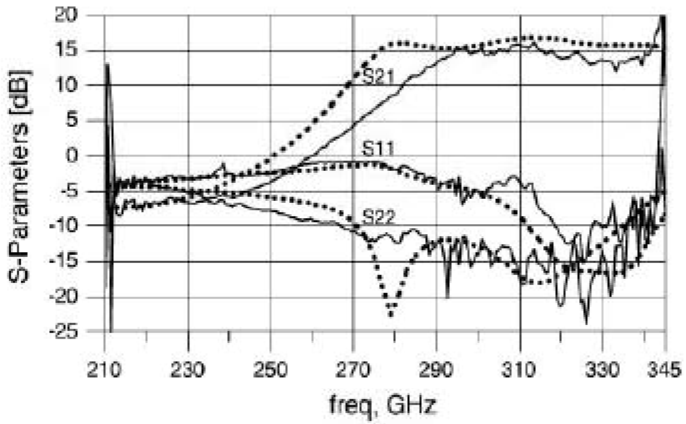
Advances in Research for Technology for THz Communciations

- The following slides provide some exemplary results on technology research
- All of them have been presented in meetings of IEEE802.15 IG THz

InP MMIC Amplifier @300-345 GHz (Korea University Seoul)

2008 "Submillimeter-Wave InP MMIC Amplifiers From 300–345 GHz"





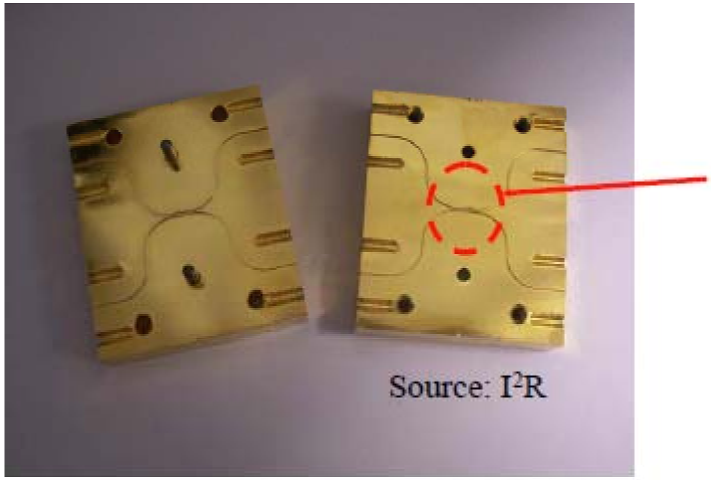
- Northrop 35nm InP HEMT* process is used
- Three-stage common-source type: 15dB at 310GHz
- Circuit size: 1.0x0.6 mm^2

* High Electron Mobility Transistor

Source: Korea University Seoul
doc. IEEE 802.15-15-10-0-0587-01-0thz

300 GHz Transceiver Design (Institute for Infocomm Research, Singapore)

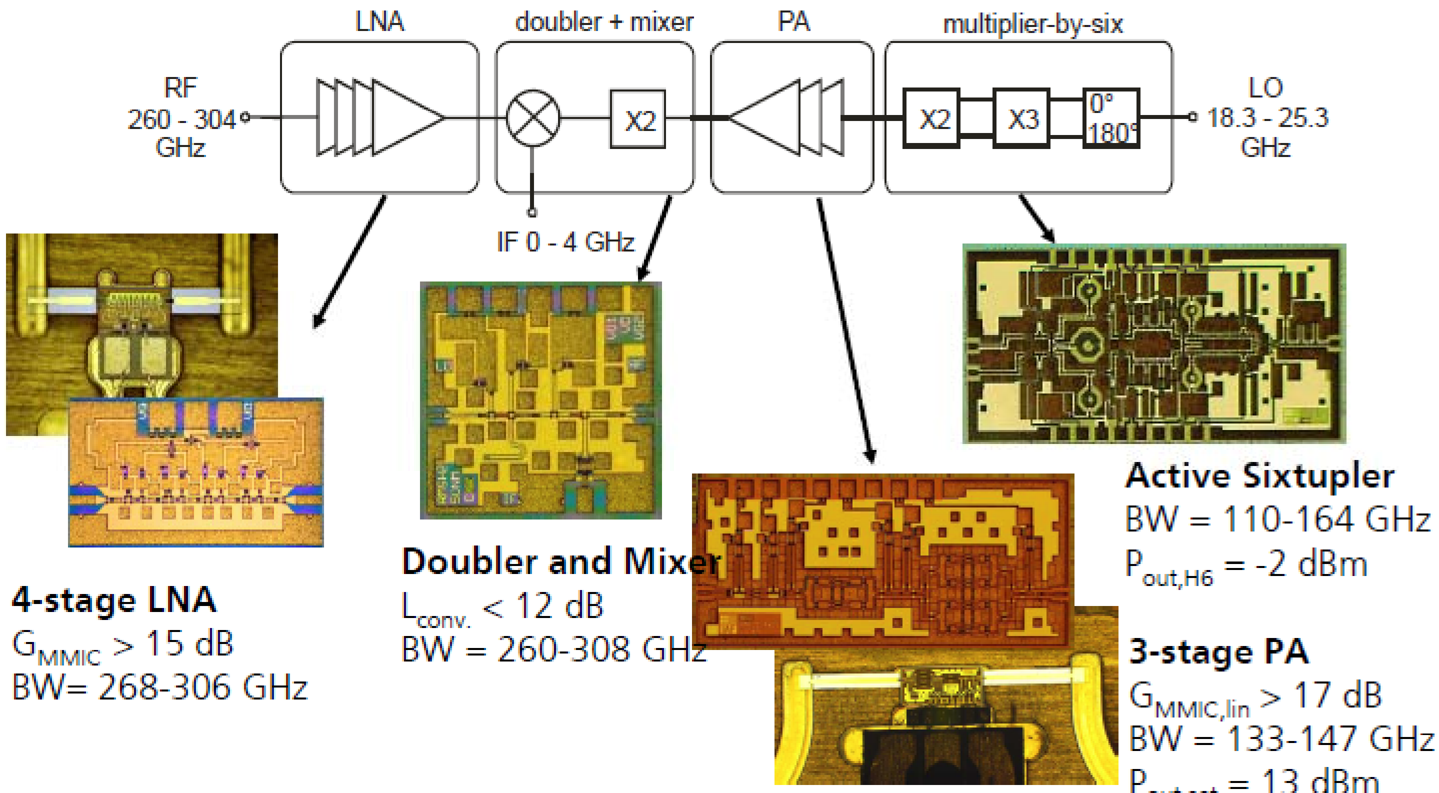
- A hybrid silicon circuits and III-V based circuits.
- Circuits integrated within WG modules at 300 GHz band



Submillimeter dimensions of micomachined passive circuits..

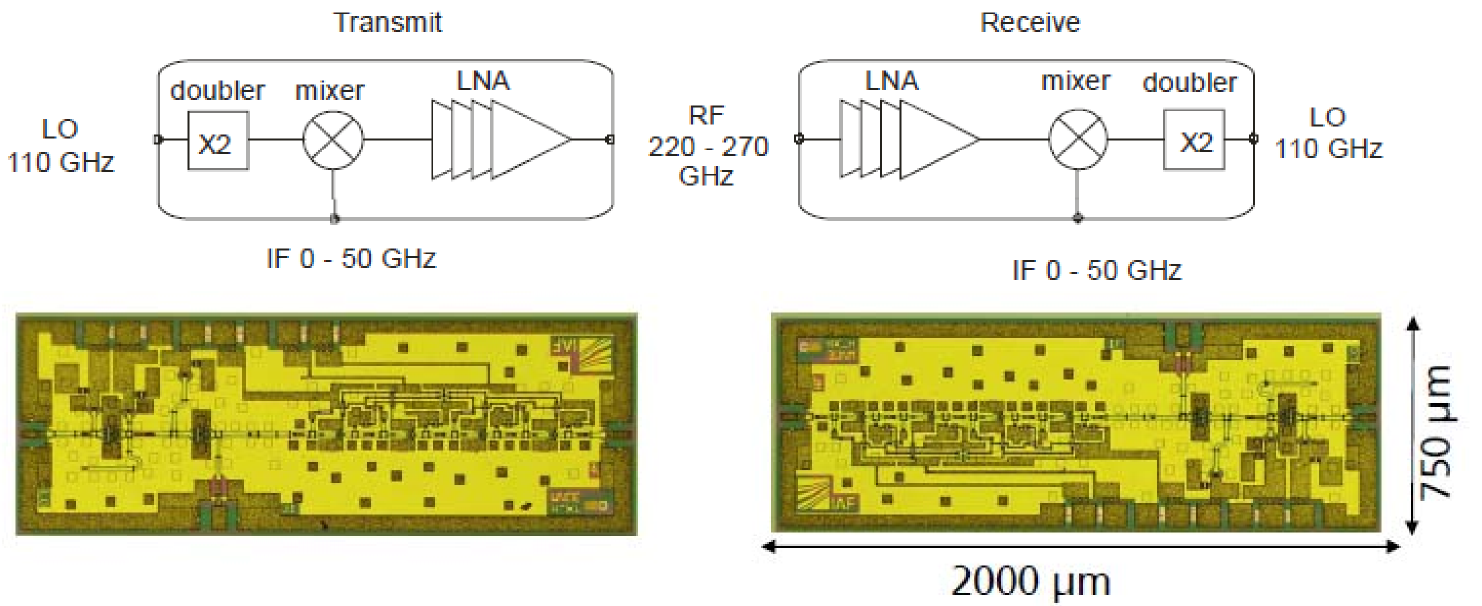
Source: Michael Y.W. Chia, Institute for Infocomm Research
doc. IEEE 802.15-15-09-0-0777-00-0thz

Towards an all-MMIC-based 300 GHz Receiver (Fraunhofer IAF, Germany)



Source: Ingmar Kallfass, Fraunhofer IAF / KIT
doc. IEEE 802.15-15-10-0-0824-00-0thz

Multifunctional Integration (Fraunhofer IAF, Germany)

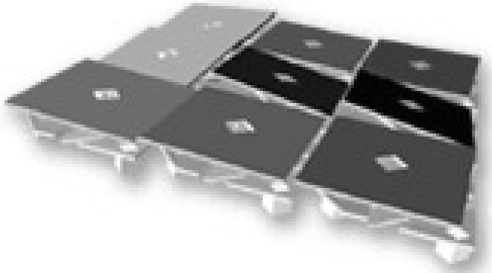


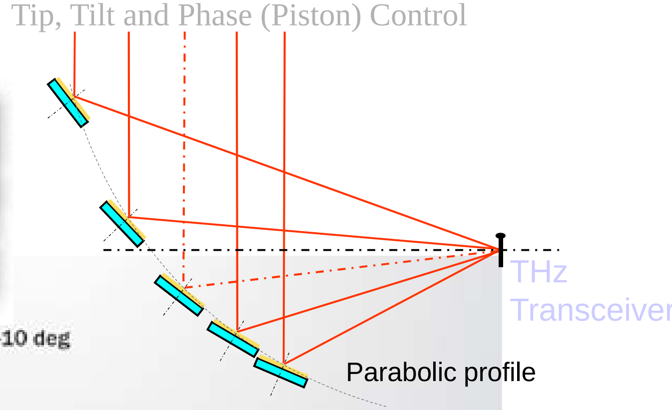
- Wideband IF
- Mirrored LNA in Transmitter
- Identical chip interface for packaging
- Receive conversion gain: 3.5 dB
- RF transmit power: up to -1.5 dBm (LNA saturation)

Source: Ingmar Kallfass, Fraunhofer IAF / KIT
doc. IEEE 802.15-15-10-0-0824-00-0thz

- …some ideas on beam steering and beam shaping

Micro-mirror arrays for THz beam shaping and steering





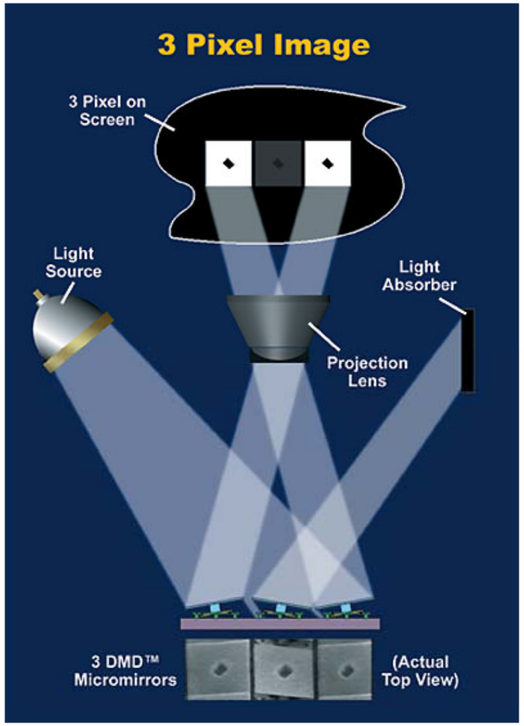
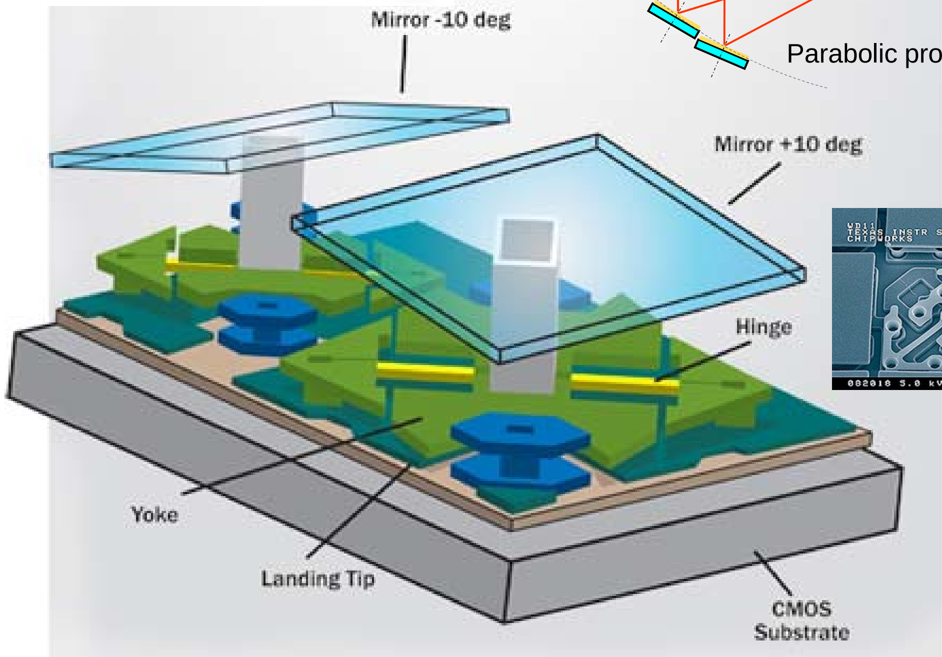
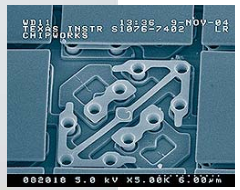


Photo courtesy Texas Instruments

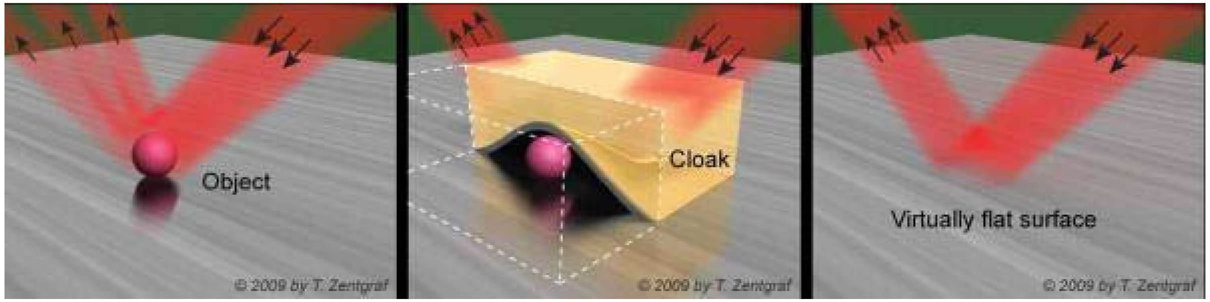
Large-scale projectors use one chip for each primary color



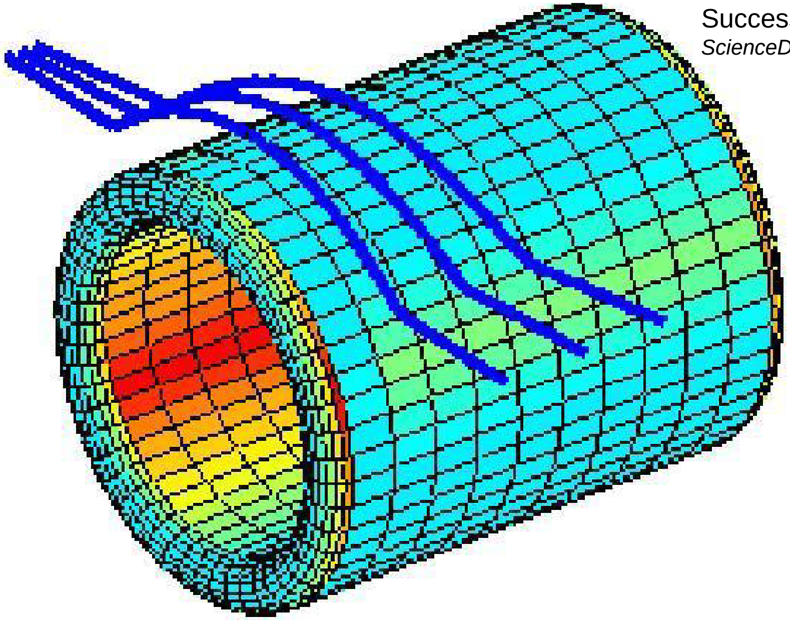


Source: David Britz, AT&T Shannon Labs doc. IEEE 802.15-10-0-0150-00-0thz

Wave Shaping/Steering Capapbilities of Metamaterials



DOE/Lawrence Berkeley National Laboratory (2009, May 2). 'Invisibility Cloak' Successfully Hides Objects Placed Under It.
ScienceDaily. Retrieved November 9, 2009, from http://www.sciencedaily.com- /releases/2009/05/090501154143.htm



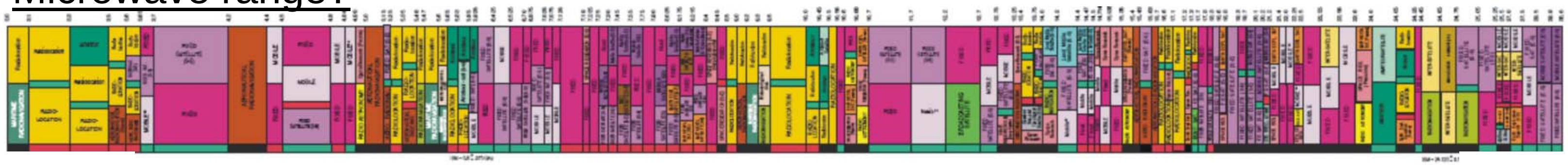
Light flowing around the metamaterial "tunnel"
(Credit: Image courtesy of University of Rochester)

Source: David Britz, AT&T Shannon Labs doc. IEEE 802.15-10-0-0150-00-0thz

Status in Regulation and IEEE 802
Future Tasks and Challenges

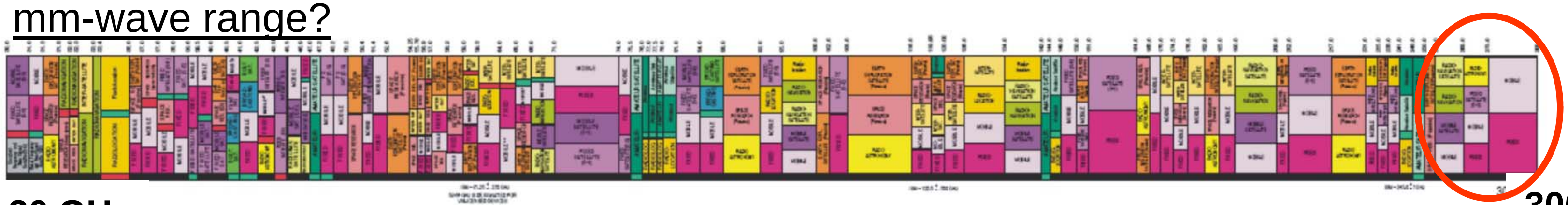
Availability of additional frequency bands

Microwave range?



3 GHz 30 GHz

mm-wave range?



30 GHz US frequency allocations, Oct 2003 300 GHz

Potential at 300 GHz and beyond!

- Currently unregulated spectrum at THz frequencies (300 GHz- 3 THz) available …
- …but this spectrum is on the agenda for WRC 2011 (agenda item 1.6)!

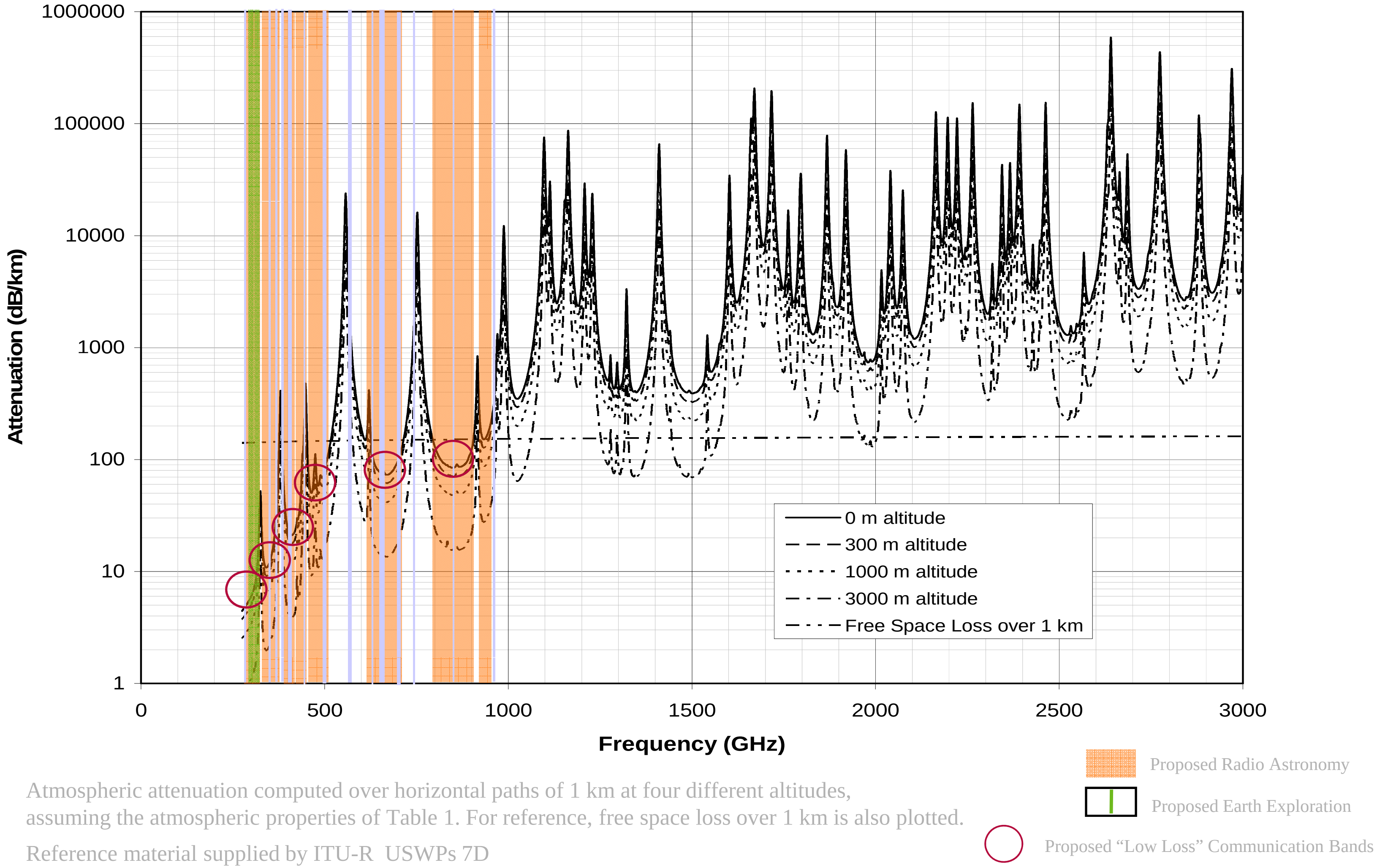
Spectrum issues

– Agenda item 1.6. covers passive services (Radio astronomy, Passive Remote Sensing, Aeronomy)

– Agenda item 1.6 will most probably modify Footnote Footnote 5.565: which currently reads „… The frequency band 275-1 000 GHz may be used by administrations for experimentation with, and development of, various active and passive services...” yielding a more detailed specification of the operational conditions of the passive services.

– Stakeholders of active services have to take care that the active service is not removed in the footnote

THz Spectrum „Land Grab“



Atmospheric attenuation computed over horizontal paths of 1 km at four different altitudes, assuming the atmospheric properties of Table 1. For reference, free space loss over 1 km is also plotted.

Reference material supplied by ITU-R USWPs 7D

Source: David Britz, AT&T Shannon Labs doc. IEEE 802.15-10-0-0150-00-0thz

Spectrum available for active services without sharing with passive services (based on current staus of discussion towrads WRC 2012)

Frequency Bands	Total available Bandwidth	Maximum Attenuation within the Band at 10 m
286-294 GHz*	**8 GHz**	101,8 dB
307-313 GHz	**6 GHz**	102,4 dB
356-361 GHz	**5 GHz**	103,7 dB
366-369 GHz	**3 GHz**	103,9 dB
392-397 GHz	**5 GHz**	104,5 dB
399-409 GHz	**10 GHz**	104,8 dB
411-416 GHz	**5 GHz**	104,9 dB
434-439 GHz	**5 GHz**	105,8 dB
467-477 GHz	**10 GHz**	106,5 dB
502-523 GHz	21 GHz	107,7 dB
527-538 GHz	11 GHz	109,9 dB
581-611 GHz	30 GHz	110,0 dB
629-634 GHz	**5 GHz**	108,9 dB

Frequency Bands	Total available Bandwidth	Maximum Attenuation within the Band at 10 m
692-713 GHz	21 GHz/**19 GHz**	110,1 dB
718-729 GHz	11 GHz	111,1 dB
733-750 GHz	17 GHz	> 145 dB
755-771 GHz	16 GHz	> 145 dB
776-823 GHz	47 GHz/**28 GHz**	111,9 dB
846-850 GHz	**4 GHz**	111,4 dB
854-857 GHz	**3 GHz**	111,5 dB
862-866 GHz	**4 GHz**	111,6 dB
882-905 GHz	**13 GHz**	112,2 dB
928-951 GHz	**23 GHz**	112,9 dB
956-968 GHz	12 GHz	115,6 dB
973-985 GHz	12 GHz	123,3 dB
990-1000 GHz	10 GHz	141,8 dB

Activities of IG THz and/or its Members towards WRC 2012

- Regular contact with IEEE 802.18
- Members of IG THz are involved in their national WRC preparatory activities (e. g. in the US, Germany, Japan)
  - Activities generated awareness for THz communications in these countries and their corresponding regional organisations (e. g. CEPT) including some input documents
  - Discussion on having an agenda item at WRC 2016 on frequency allocation beyond 275 GHz including active service has been triggered (input to AI8.2 of WRC 2012)

THz Interest group @ IEEE 802.15

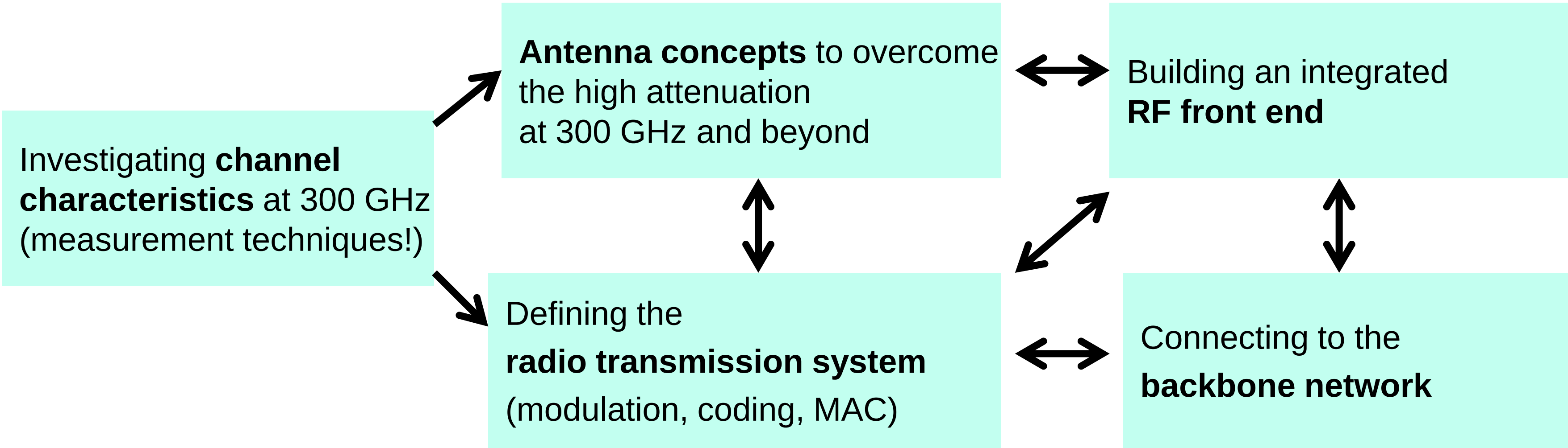
- IEEE 802.15 has established a THz Interest Group for Wireless Systems operating at 300 GHz and beyond

- Tasks of IEEE 802.15 THz Interest Group
  - Survey of technological developments
  - Channel modeling
  - Spectrum Issues (WRC 2012, agenda item 1.6)

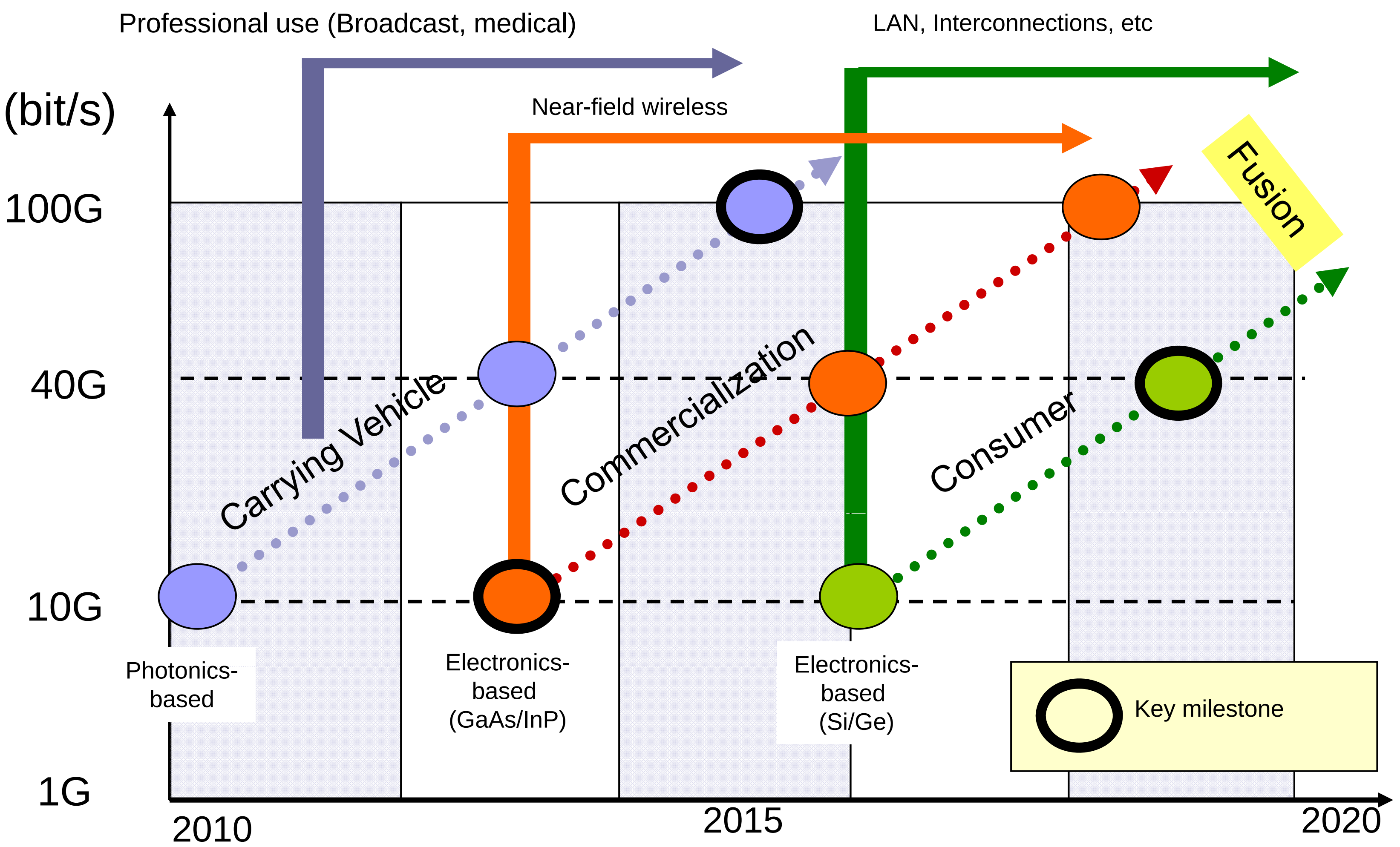
- Chair: Thomas Kürner (TU Braunschweig, Germany)
- Vice-Chair: David Britz (AT&T Shannon Labs, USA)
- Secretary: tbd

Future Tasks and Challenges

An Interdisciplinary approach is required to make THz Communication happen



Roadmap of THz Communications Technology



Courtesy: Tadao Nagatsuma, Osaka University / NTT

Next Steps for the THz Interest group

- Most important task is currently to follow and accompany the WRC 2012 process
- Following and evaluating THz activities in terms of
  - R&D in technology
  - Market trends
  - Channel Modeling
- Depending on the outcome of WRC 2012 mid 2012 may be a good time to think about establishing a study group

Thank you for your attention!