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ATLANTA, GA
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2021 Fall Technical Forum
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Wireless Access Network

Terahertz (THz) Spectrum CHALLENGES, POTENTIAL AND APPLICATIONS

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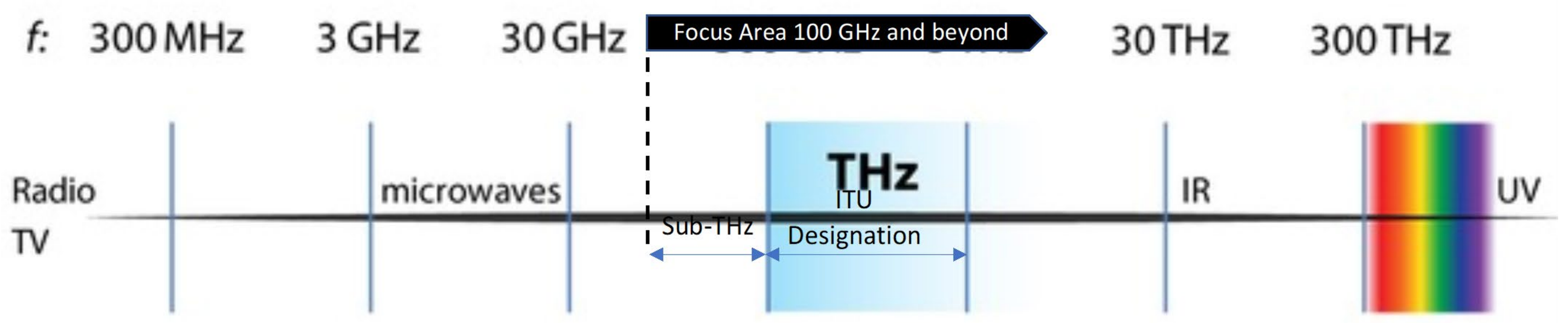
Agenda

- Terahertz (THz) Spectrum
  - Wireless data communications trends
  - THz wave characteristics – THz wall
  - THz development challenges – THz gap
  - Use cases/applications
  - Development status
  - Review and Q&A

Terahertz (THz) Spectrum - Definition



- Terahertz (THz) waves is a part of the electromagnetic spectrum between microwave and infrared radiation
- International Telecommunications Union (ITU) has designated 300 GHz to 3 THz as THz band
  - Region between 100 and 1 THz is called sub-THz region
  - Wavelength of THz waves from from 1 mm to 30 µm (sub-mm)
  - THz waves are also known as µmWave to distinguish them from mmWave

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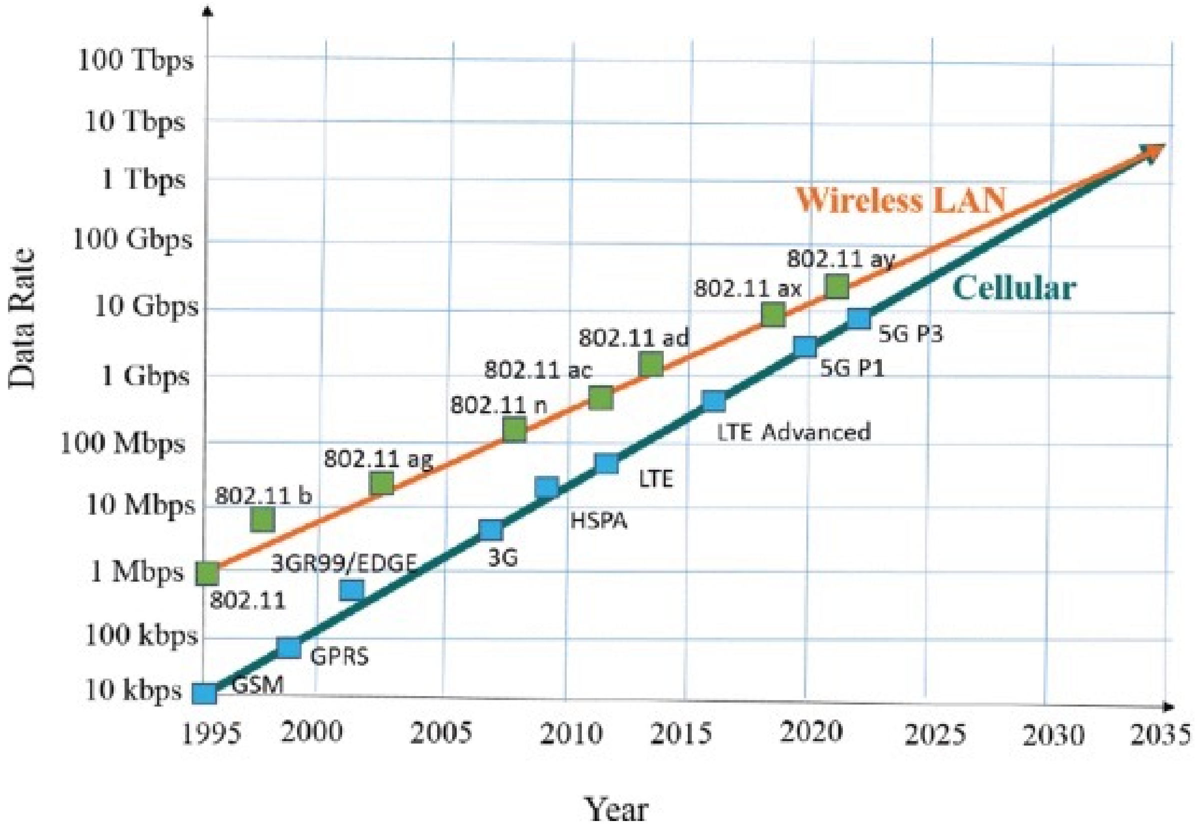
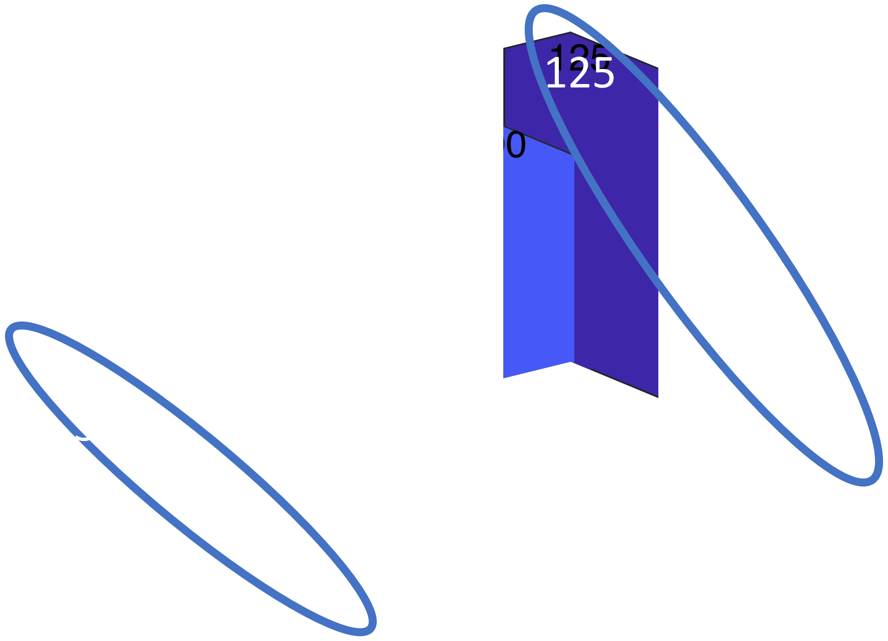
Wireless Data Demand

- Information creation and sharing growing exponentially
- Societies becoming – intelligent, data-centric, data-dependent and automated
- Need for speed is growing
- Data rates are doubling every 18 months in line with Edholm's law
  - 1 Tbps (Tera bit per second) is possible by 2030
  - Under consideration as a 6G goal (KPI)



Path to 1 Tbps

- Bandwidth requirement depends on
  - Modulation scheme
  - Number of MIMO channels
- Existing technologies have limitations e.g. spectral efficiency
- High bandwidths (e.g. 20 GHz) only available beyond 100 GHz
- Terahertz emerging as a key enabler



Assumptions:
- OFDM
- No error control coding

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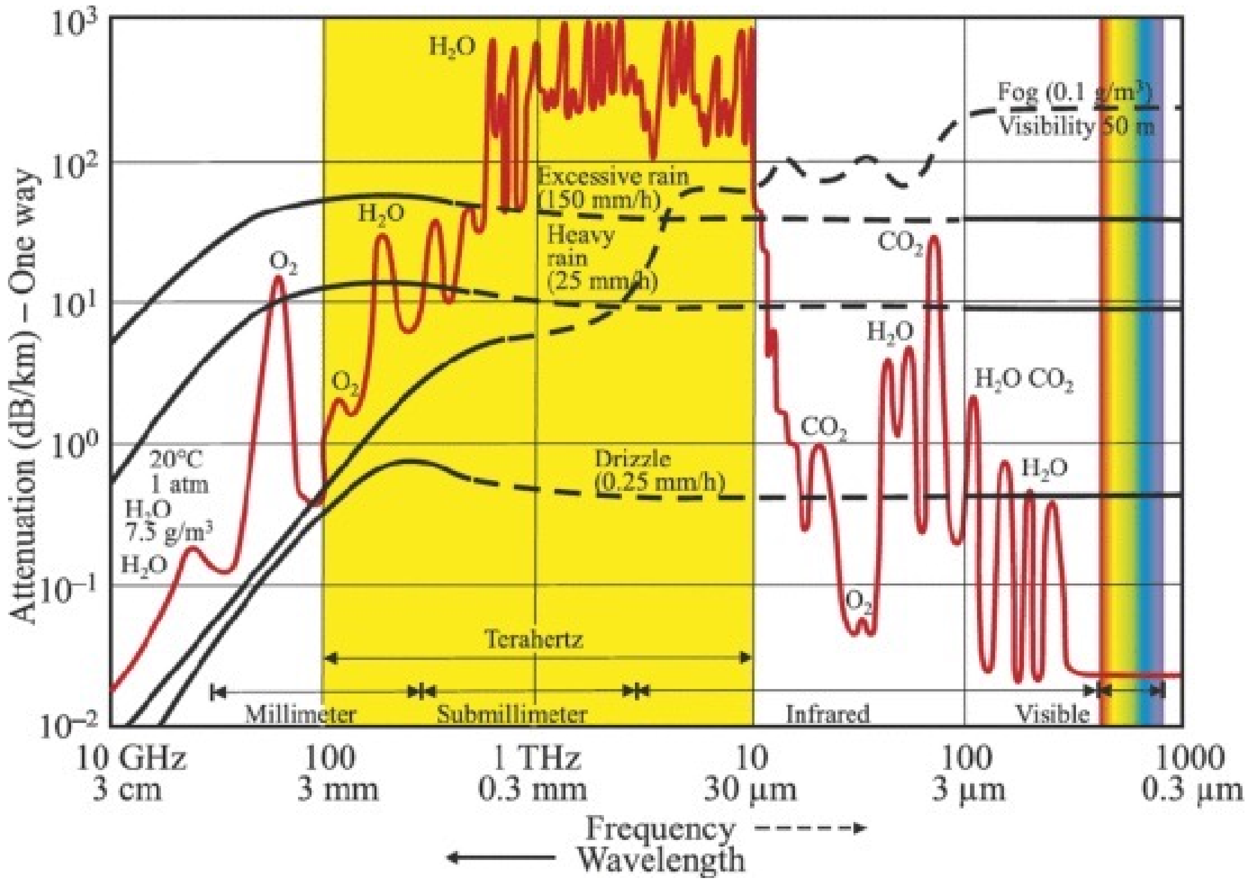
Very high atmospheric attenuation

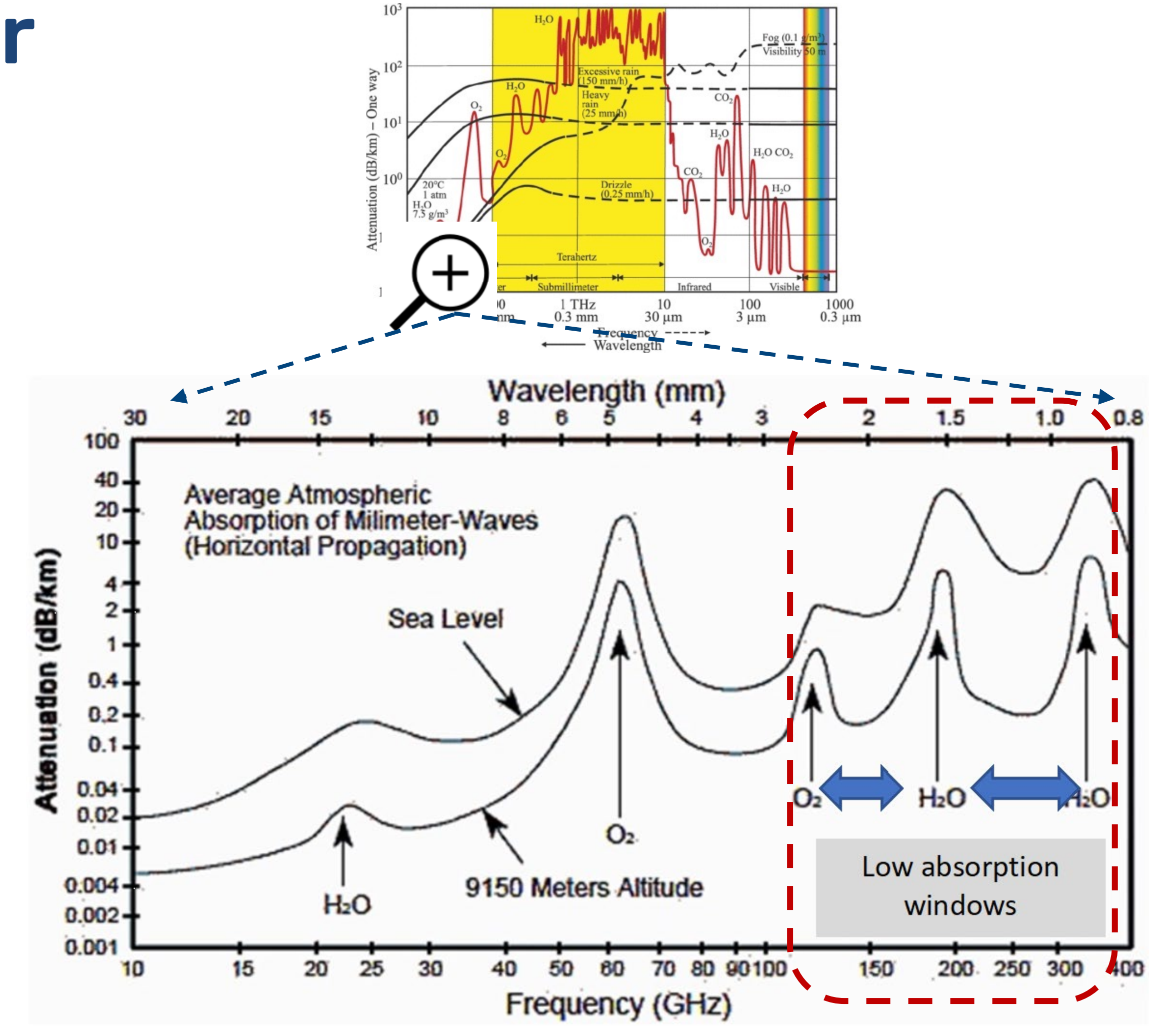
- High molecular absorption – oxygen and water, significant weather impact
- High dispersion loss due to small effective antenna aperture
- Attenuation increases with frequency - signals die down fast
- THz wall - increasing power becomes impractical after certain is achieved
- THz waves are beams not brodcasts



Non-linear path loss and other properties

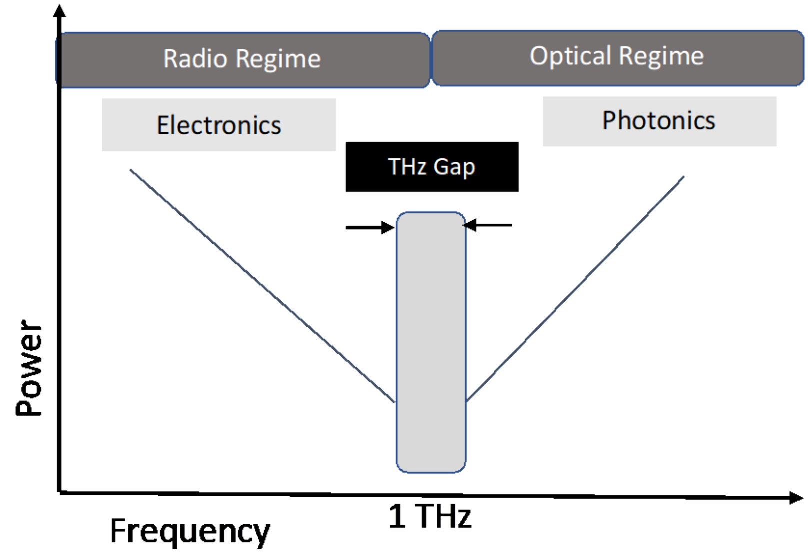
- Lower attenuation at certain frequencies
- Candidates for viable communication links – distances of 2 to 8 Kms possible

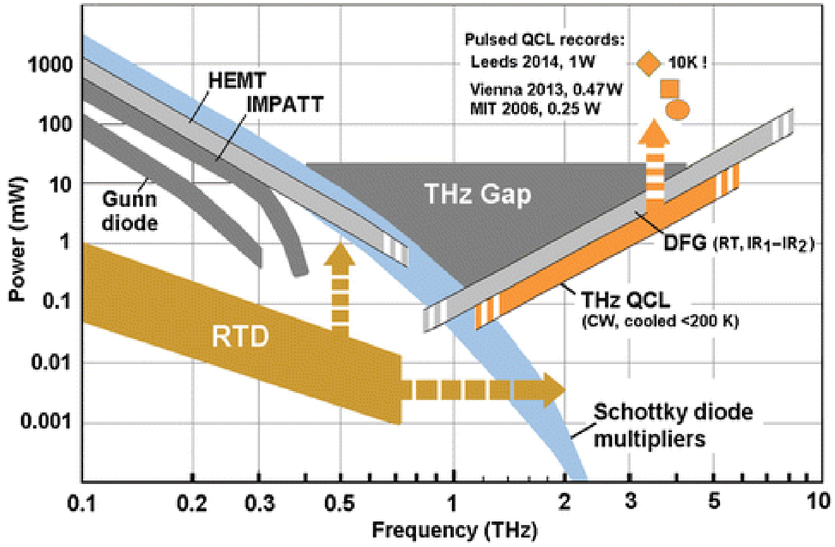
- Other important characteristics
  - Non-ionizing hence harmless to tissue
  - Can pass through certain opaque e.g. paper, fabric, cardboard etc
  - Unique spectral fingerprints for molecules



Lack of devices in THz region

- THz gap – lack of compact energy efficient devices
- Poor power-frequency scaling exhibited by both electronic and photonic devices
- High frequency requires smaller sizes
- Higher power density at smaller sizes requires adequate cooling





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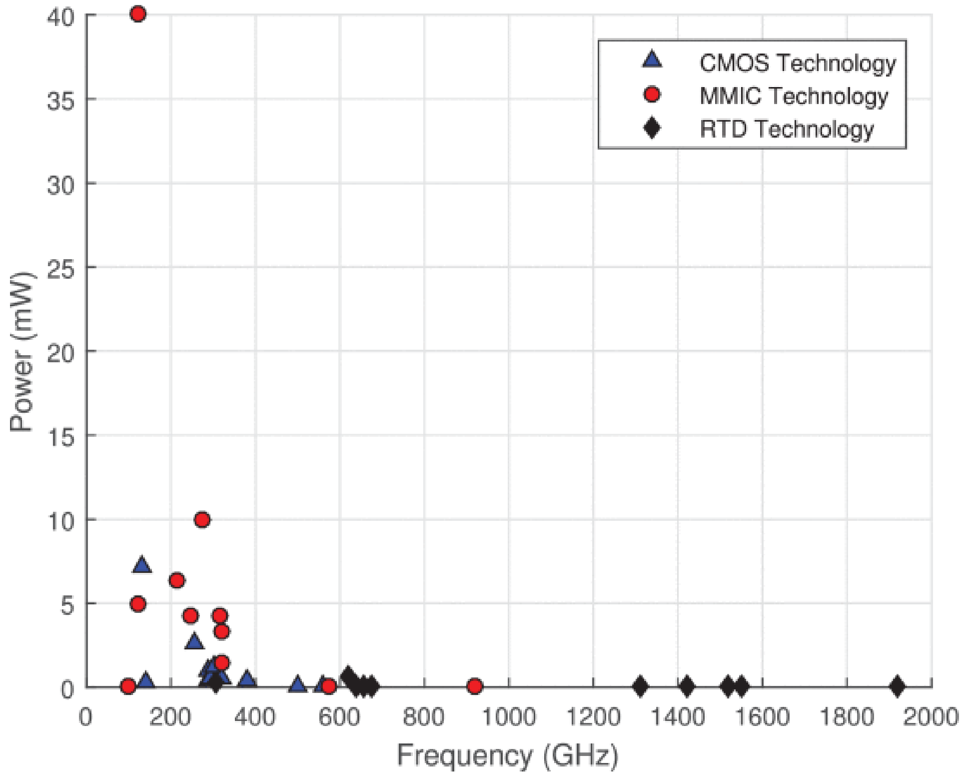
Bridging the THz gap

- CMOS, MMIC and RTD technologies are helping out in bridging the gap
- Nano technology and graphene plasmonic devices look promising
- THz gap is getting narrower



CMOS: Complimentary Metal Oxide Semiconductor
MMIC: Monolithic Microwave Integrated Circuits
RTD: Resonant Tunnel Diode

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Main Application Areas

- Wireless data communications
  - THz can support high bandwidth for ultra broadband links

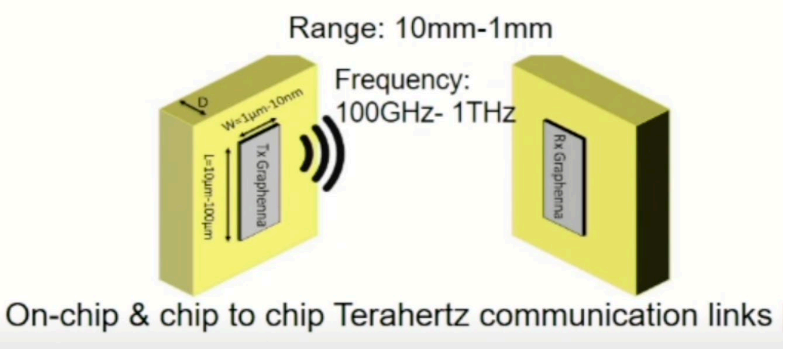
- Wireless Data Application categories
  - Nanoscale - nano to centimeter
  - Microscale - centimeter to meter
  - Macroscale – over one meter (>>10m)

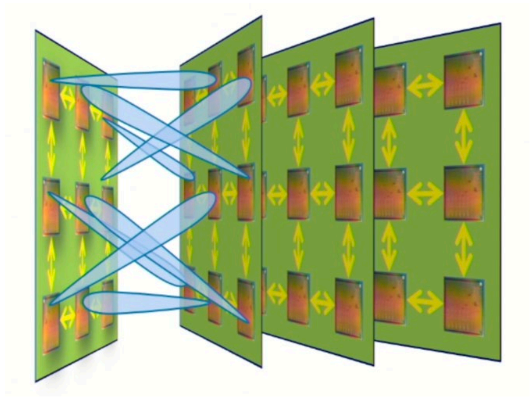
- Imaging
  - THz waves are harmless to tissue
  - Can pass through opaque materials (e.g. paper, fabrics)

- Spectroscopy
  - THz waves generate a unique spectral fingerprints for different molecules
  - Can be used to identify chemicals

Small device and antenna sizes

- THz links ranging from nano to centimeter
- On chip and inter chip communications
- Intra device communications e.g. in mobile devices and computers
- Body area network (BAN)
    - Inter-sensor
    - Sensor to gateway device

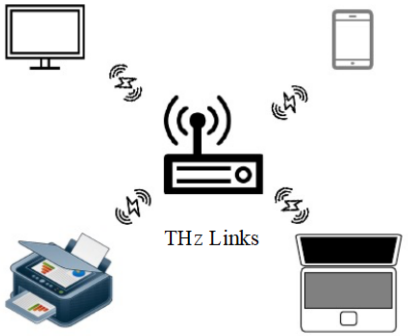


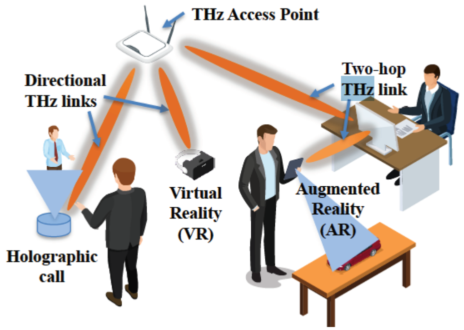


Wireless interconnect on PCB

Point to point links (up to one meter)

- Personal area networks (PAN)
- Data center networks (DCN)
- Tera-fi – THz based wireless local area networks (WLAN)
- Information showers
- Information kiosk





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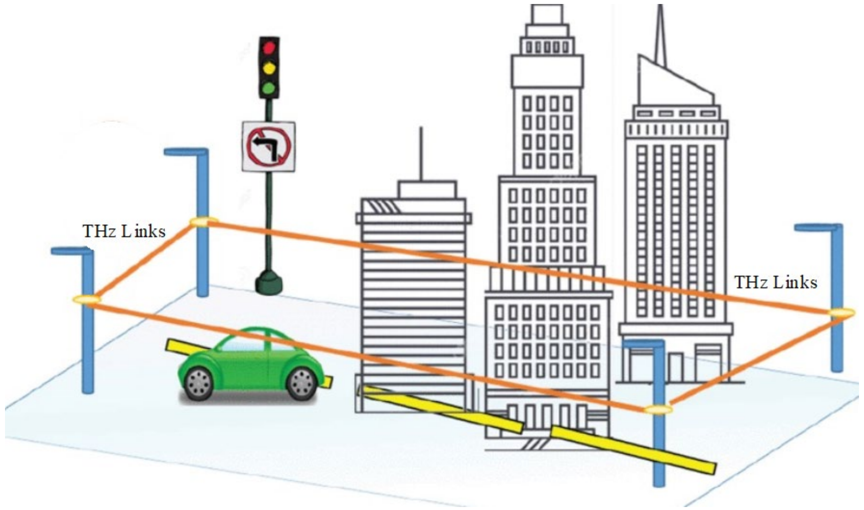
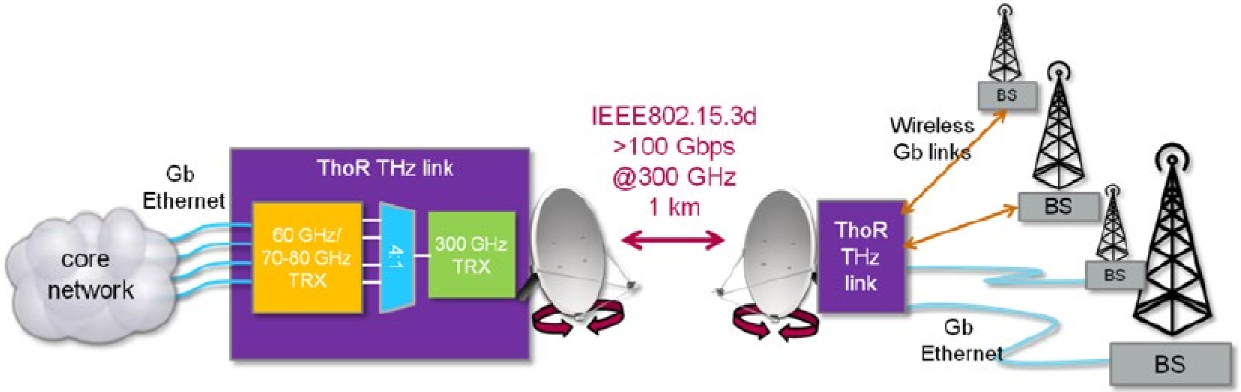
Wireless backhaul

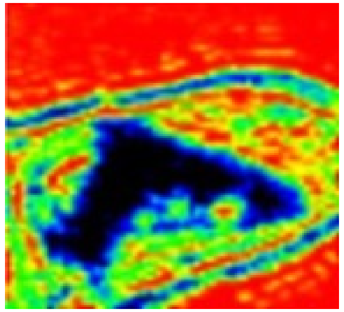
- Backhaul link between core and radio networks
- Backhaul aggregation for small cells
- vRAN/cRAN – fronthaul connectivity between DU (distributed unit) and RU (radio unit)

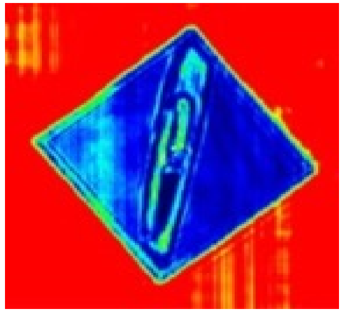


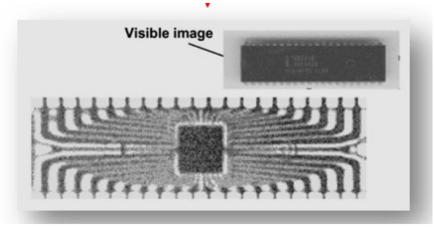


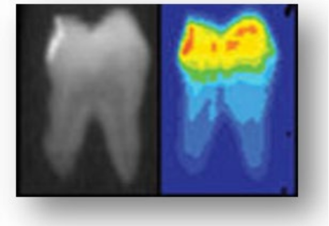
Security, Industrial, medicine

- Package/mail inspection without opening
- Quality control – Non-destructive testing in food packaging, water content monitoring for freshness, ceramics, wood
- Semiconductor chip inspection
- Non invasive medical diagnosis
  - Skin cancer detection
  - Blood testing
  - Dental care
  - Under bandage wound inspection



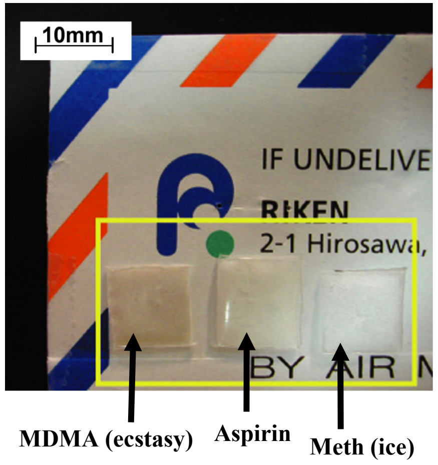


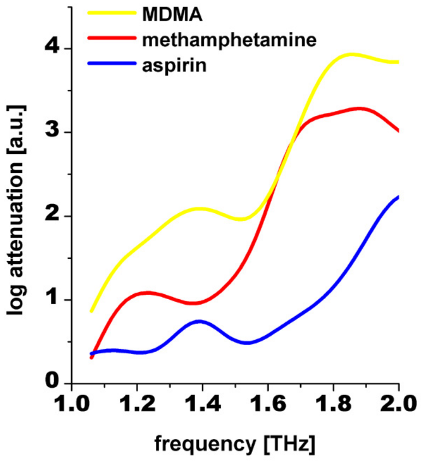


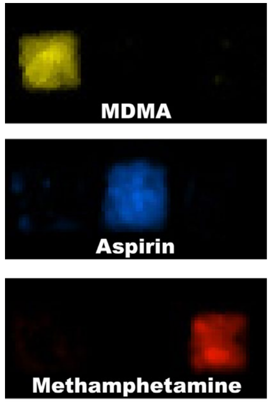


Chemical recognition

- Air quality detection
- Personal health monitoring systems
- Explosive detection and gas sensing
- Narcotic drugs, toxic industrial chemicals (TICs), precursors, etc







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Focused research Groups

- Global uptake in THz research activity
- Significant growth in technical publications
- New products are becoming commercially available

Research Group/Lab	Location	R&D Activities
Mittleman Lab at Brown University	USA	THz PHY layer, spectroscopy, THz probes
Broadband Wireless Networking Lab at Georgia Tech	USA	THz PHY and MAC layer, THz Nano-communications, THz devices
NaNoNetworking Center in Catalunya	Spain	THz Nano-communications
Ultra-broadband Nano-Communications Lab at Univ. of Buffalo	USA	THz PHY and MAC layer, THz Nano-communications, THz devices
THz Electronics Lab at UCLA	USA	THz devices, reconfigurable meta-films, spectroscopy
MIT Terahertz Integrated Electronics Group	USA	Sensing, Metrology, security and communication.
Fraunhofer Institute for Applied Solid State Physics	Germany	THz PHY and MAC layer, THz electronics
Terahertz Communication Lab	Germany	Channel investigation and THz reflectors
Core Technology Lab Group NTT Corp	Japan	Terahertz IC and modularization technology
Texas Instrument Kilby Lab	USA	Ultra-Low Power sub-THz CMOS systems
Tonouchi Lab at Osaka Univ.	Japan	THz Nanoscience, THz bio-science, THz bio-sensing and industrial applications
THz Electronics Systems Lab at Korea Univ.	Korea	THz PHY and MAC layer, THz electronics
Nano-communications Center at Tampere Univ. of Technology	Finland	THz PHY layer, THz Nano-communications

European Union Horizon 2020

- Multiple projects funded to promote innovation on Terahertz
  - Use case focused research
  - New channel coding techniques
  - Channel modeling

Project Name	Band	Target Speed	Focus
iBrow	60 GHz-1 THz	10 Gbps	Innovative ultra-broadband ubiquitous wireless communications through THz. Low cost and simple wireless transceiver architecture. Integrated semiconductors emitters and detectors with seamless fiber-wireless links
TERRANOVA	300 GHz	100 Gbps	Tbps wireless connectivity by THz innovative technologies to deliver optical network quality of experience in systems beyond 5G
TERAPOD	300 GHz	100 Gbps	Terahertz based ultra-high bandwidth wireless access networks for data centers
ULTRAWAVE	300 GHz	100 Gbps	High capacity backhaul links to enable 5G cell densification by exploiting bands beyond 100 GHz.
EPIC	-	1 Tbps	Enabling practical wireless Tbps communication with next generation of coding. Develop new FEC (forward error correction) codes for Tbps rates.
DREAM	D-band	100 Gbps	D-band reconfigurable meshed radio solution at 100 Gbps by exploiting radio spectrum bands like 130-174.8 GHz with beam steering functionality to reach optical systems speed.
WORTECS	90 GHz	10 Gbps	Wireless optical radio terabit communication system. Use 90 GHz for proof of concept with Gbps rates.
ThoR	300 GHz	100 Gbps	Front and backhaul solutions at 300 GHz for data rates beyond 5G.
TERAPAN	300 GHz	100 Gbps	Adaptive wireless point-to-point terahertz communication systems for indoor environments for distances of up to 10 m at data rates of up to 100 Gbps
ROOTHz	THz	-	Development of solid state nanodevices at room temperature of THz communications

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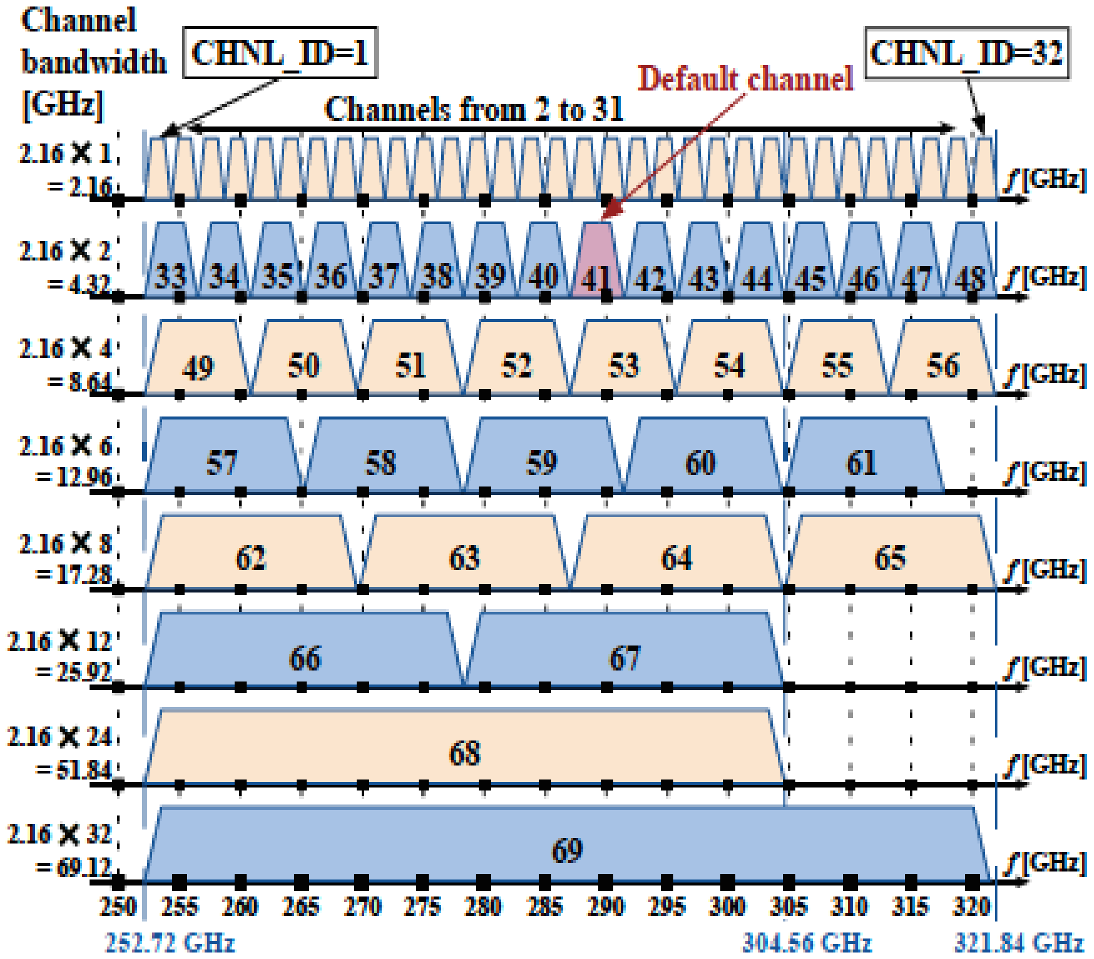
IEEE 802.15.3d

- Approved channelization (252.72 to 321.84 GHz)
- 8 different channel bandwidths (multiple of 2.16 GHz)
- 2 PHY modes: THZ-SC PHY and THz-OOK-PHY
- 7 modulation schemes: BPSK, QPSK, 8-PSK, 8-APSK, 16-QAM, 64 QAM, OOK
- 3 channel coding schemes: 14/15-rate LDPC (1440,1344), 11/15-rate LDPC (1440,1056), 11/15-rate RS(240,224)-code.



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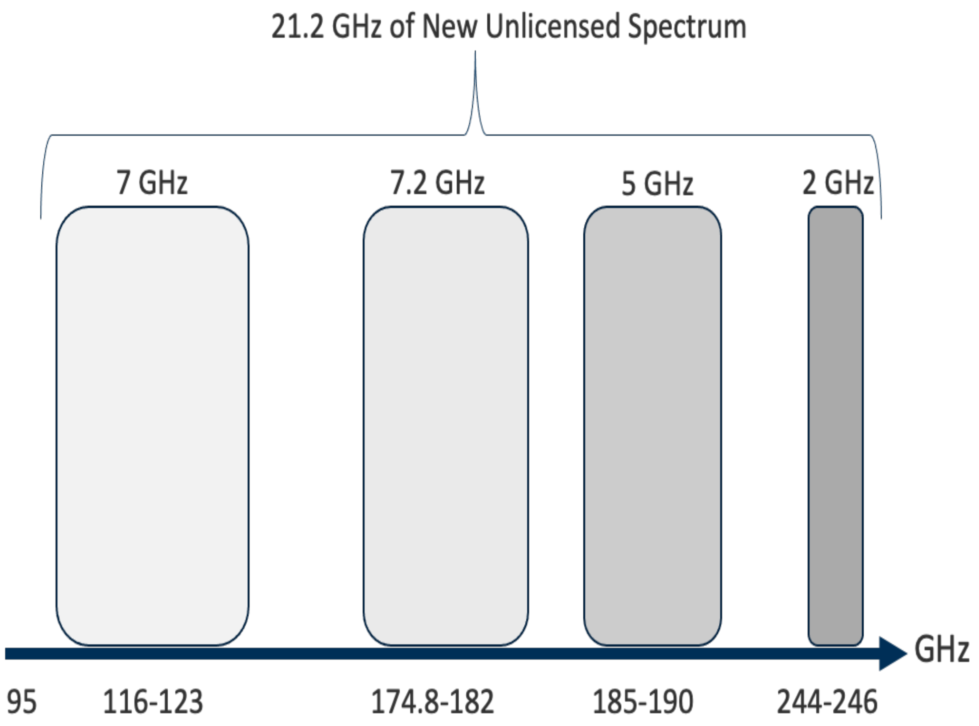
Global regulatory support

- World Radio Communication-2019
  - Made 190 GHz (252 to 356 GHz) of spectrum available for THz research
  - No specific EESS (Earth Exploration Satellite Services) protection requirements
- Federal Communications Commission
  - Unlicensed 21.2 GHz spectrum between 95 GHz and 3 THz
  - Should not interfere with existing systems
  - Maximum threshold of average EIRP (Effective Isotropic Radiated Power) of 40 dBm



Review of key discussion points

THz Characteristics
- Offer large bandwidth in 10s of GHz
- Can support Tbps data rates
- Hight atmospheric absorption limits propagation distances (in meters)
- Safe - non-ionizing to tissue
- Spectral fingerprints for many molecules

THz Applications
- Data communications
- WPAN
- Backhaul/fronthaul
- Data center
- Information showers/kiosk
- Imaging/sensing/IoT
- Spectroscopy

THz Challenges
- THz gap – lack of low cost, efficient and small devices
- THz wall – high atmospheric absorption
- Significant advances in materials, computing and chip designs are required to overcome the challenges

- THz Band is an enabler for "fiber-equivalent" wireless connections
- Significant global interest for technology commercialization
  - However, today's commercial systems are limited to imaging and spectroscopy, and not for communication

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Thank You!

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