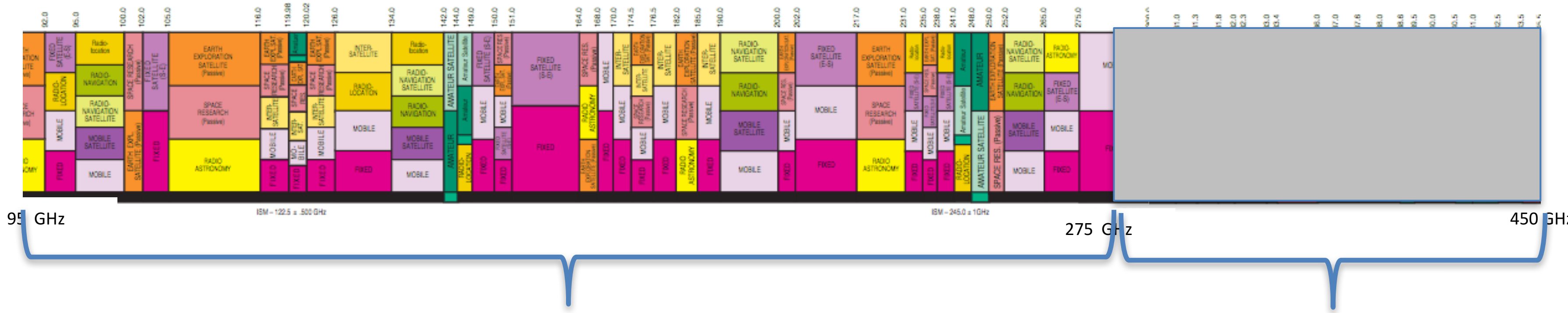


FCC Docket 14-177

WRC-19
Agenda Item 1.15

Opening Parts of 95-450 GHz to Civil Use: Opportunities and Sharing Challenges

Michael J. Marcus, Sc.D., F-IEEE

Adjunct Professor EECS, Virginia Tech
Director, Marcus Spectrum Solutions LLC
Technical Director, Millimeterwave Coalition
FCC/OET (Retired)

mjmarcus@marcus-spectrum.com

ISART
INTERNATIONAL SYMPOSIUM ON ADVANCED RADIO TECHNOLOGIES
CENTER FOR ADVANCED COMMUNICATIONS

- **Much of CSMAC & ISART discussions yesterday & today have focused on spectrum needs of today's cellular industry**

- **<u>This talk</u> will focus on putting currently unused 95+ GHz spectrum to work for various uses to increase economic growth & national tech competitiveness**

- **Pragmatic preconditions:**
  - **Protect from interference passive science spectrum uses that have allocations or other legal protection**
  - **Leaving 95+ GHz Mobile allocations intact pending new tech & demand**

Why the Focus on 95+ GHz Here?

- FCC and ITU have allocations up to 275 GHz
- There are **NO** FCC provisions for licensed or unlicensed use of spectrum above 95 GHz
  - Developers face huge regulatory uncertainty
- WRC-19 Agenda Item 1.15 addresses terrestrial use of 275-450 GHz subject to protection of passive uses in RR 5.565 which requires “all practicable steps” are taken to protect passive services.

Basic Issues

- 95+ GHz technology is here but FCC service rules have stopped at 95 GHz since 2003
  - **More proactive views of FCC foreign counterparts *and* their national support of R&D in band threatens US tech leadership**
  - Issues involve *both* service rules in 95-275 GHz and WRC-19 Agenda Item 1.15 for 275-450 GHz
  - Previous 95+ issues languishing in FCC limbo
    - Battelle petition – RM-11713 (2/6/14)
    - IEEE-USA petition – Docket 13-259 (7/1/13)
- FCC 95+ GHz experimental license applications have faced NTIA coordination hostility, major lack of transparency & unreasonable delays
- Potential investors can see this regulatory uncertainty!

Someone Else in Favor of 95+ GHz

"Here's one example of how the Section 7 process could work. As part of our so-called "Spectrum Frontiers" proceeding, we asked questions about allowing novel wireless uses and technologies in frequencies above **95 GHz**. Those frequencies haven't traditionally been used for mobile wireless technologies. But I believe that, instead of having regulators decide which frequencies are useful, we should put spectrum out there as a testbed and leave it to the innovators to figure out how to use it. Applications for experimentation above the **95 GHz** band could qualify for Section 7 treatment. And this determination, in turn, could accelerate the deployment of cutting-edge wireless services and other innovations."

3/15/17

https://apps.fcc.gov/edocs_public/attachmatch/DOC-343903A1.pdf

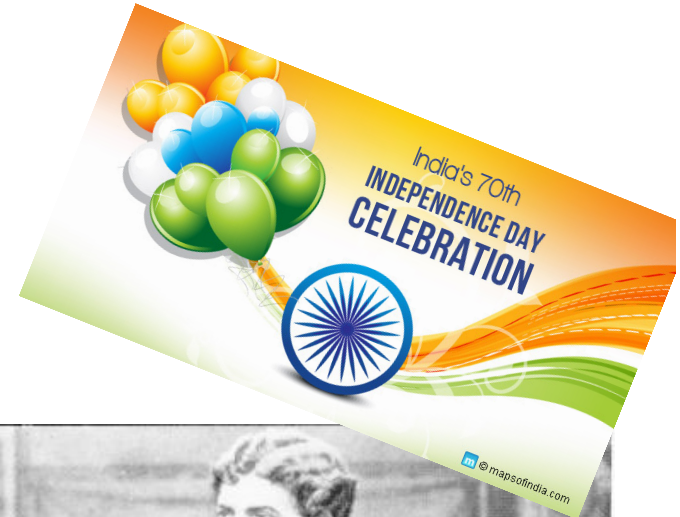
Visionary 1985 Statement of FCC Commissioner (Later Chairman) Dennis Patrick

"It's an excellent item for one reason which I think involves philosophy, our approach in general to authorizing technologies. I think that to the extent possible we should allow any technology that does not result in undue interference or waste of spectrum or involve any other related substantial downside, rather than authoring only those technologies which have been from time to time specifically requested and prohibiting by omission the rest. This item, I think, represents a change in philosophy in the sense that we're moving more towards the former and any from the latter approach and I think that's good precisely because it with the flexibility and the options to innovate, develop new technologies and new applications of old technologies which we may not have had occasion to consider. So to I think it is the extent that this item is moving us in that direction it is very helpful."

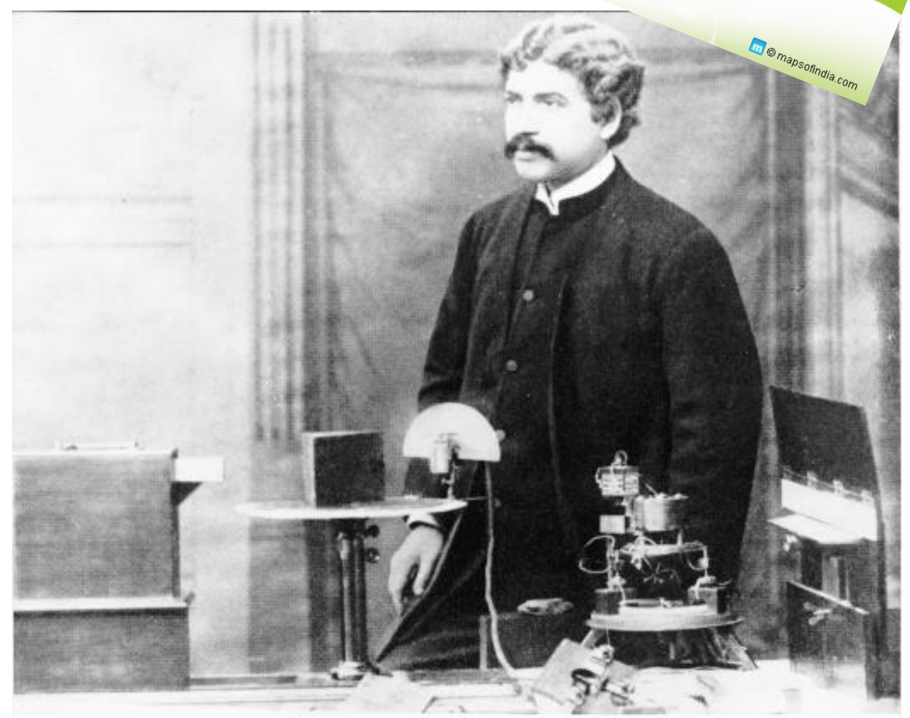
FCC Commissioner (later Chairman) Dennis Patrick 5/9/85
Commenting on approvals of rules that became bsis of Wi-Fi

"Requirements" & "requests" should not be the *only* focus of spectrum policy!

Early History of mmW



- First demonstrated in India by Sir J. C. Bose,FRS using spark gap technology in 1895
- Limited power and crude detectors limited range to <1 m
  - Diffraction grating measurement showed f ~ 60 GHz



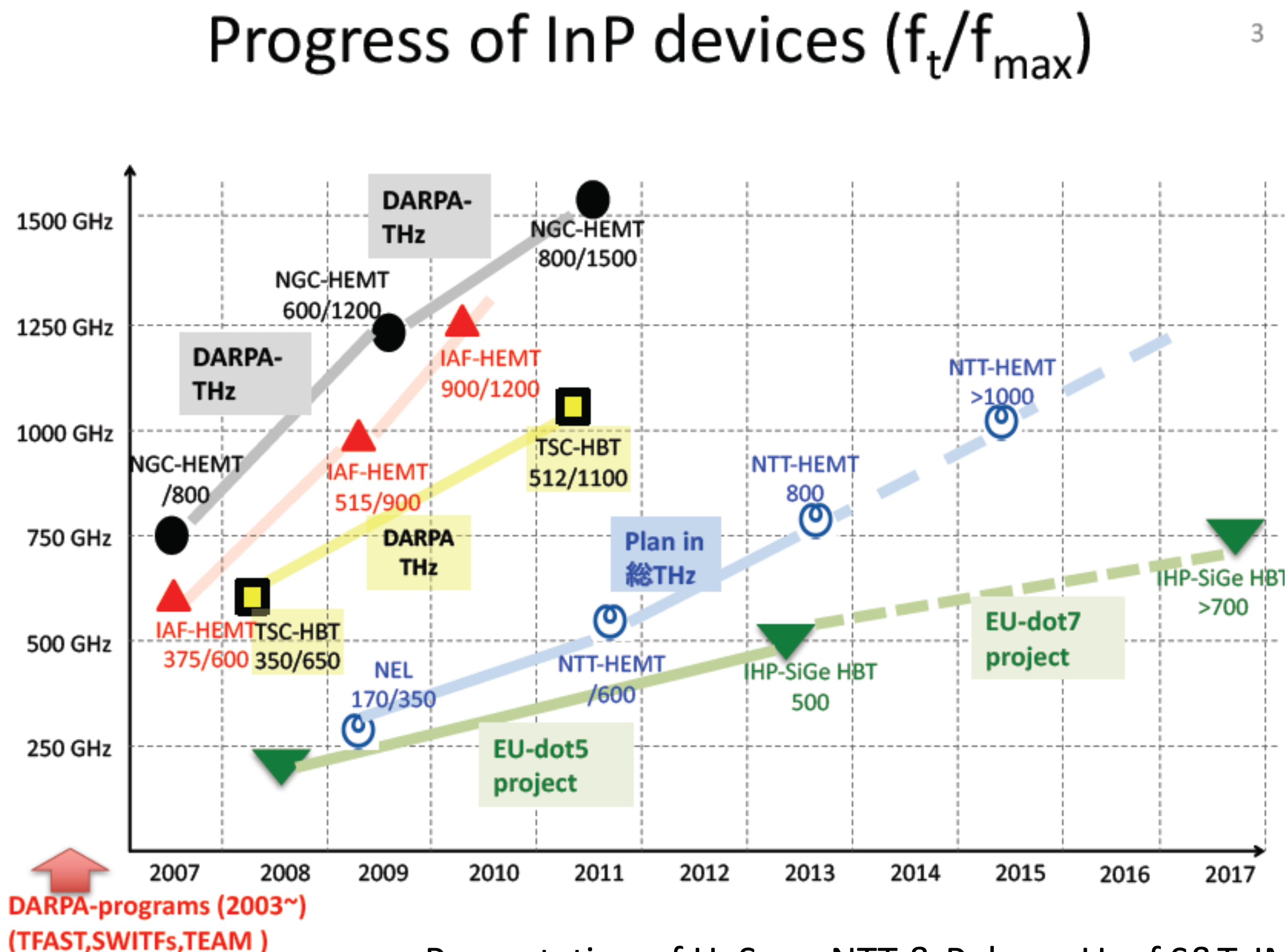
This Technology Has Been Used Outside of Laboratory Already

- NTT 125 GHz system used at 2008 Beijing Olympics for video
  - Included hybrid fiber optic/RF technology licensed from US’ Battelle Memorial Laboratories

https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200903sf3.html

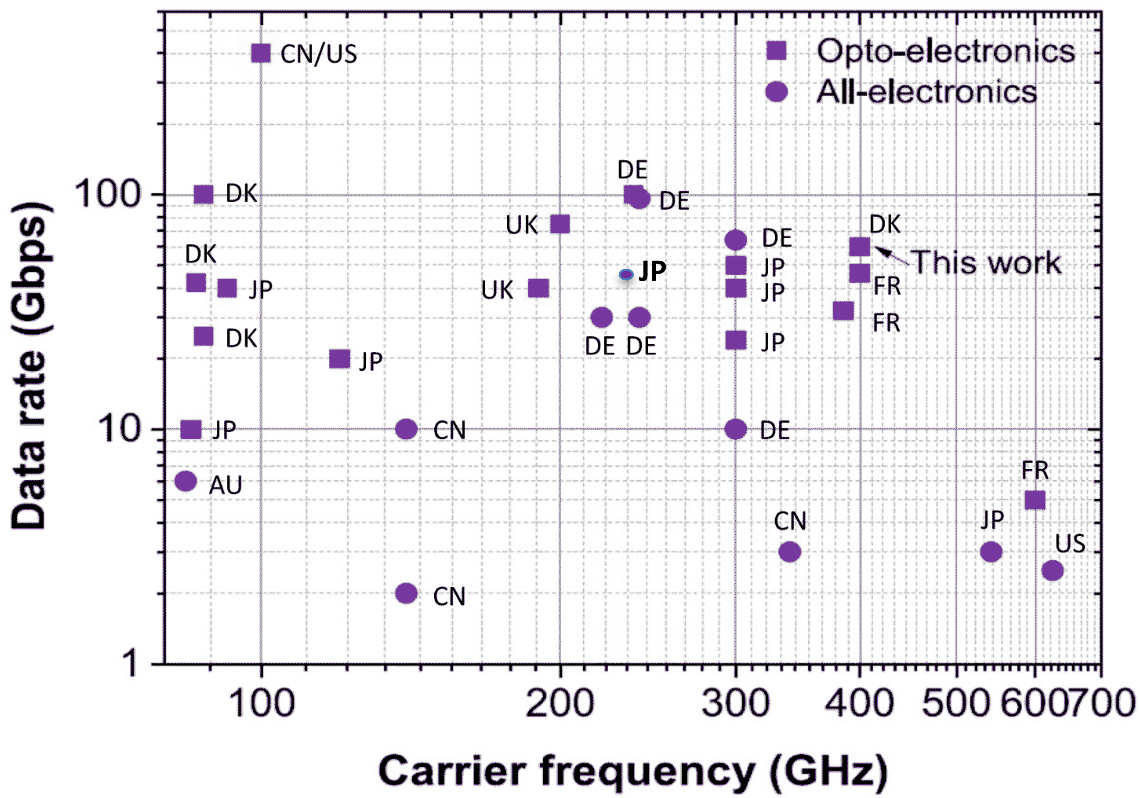
US Leads in *Basic* mmW/THz Technology

But Lacks *Any* Clear Vision in Spectrum Policy



Presentation of H. Song NTT & Pohang U. of S&T, IMS 2017

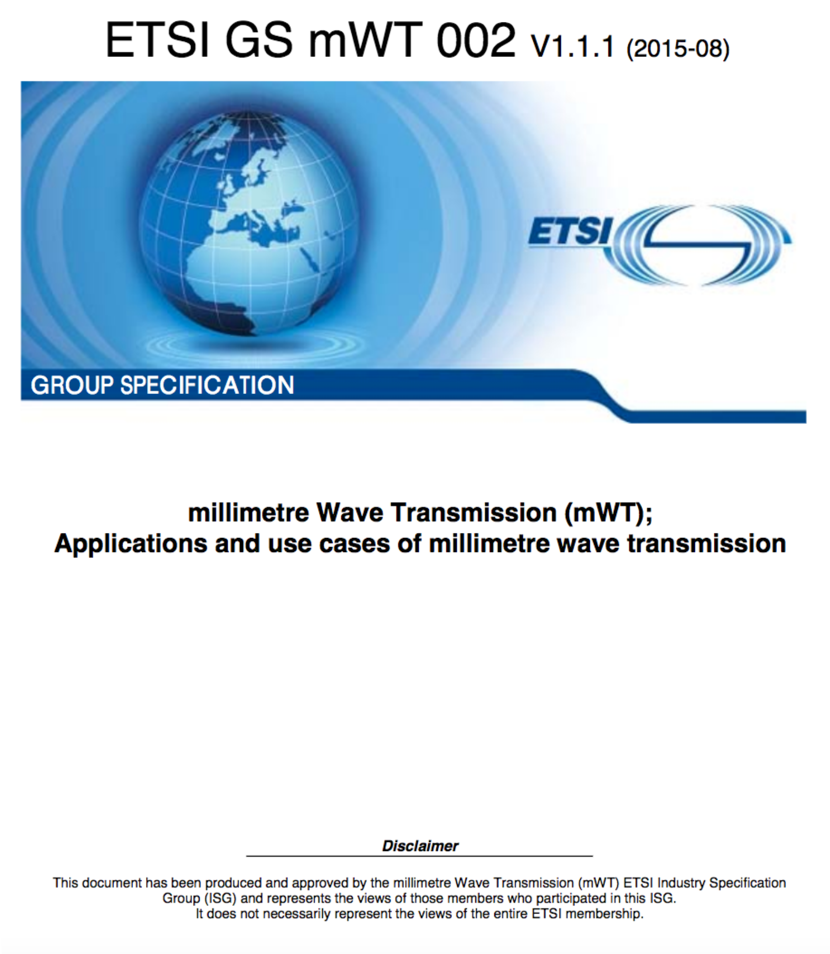
Published Articles Worldwide on mmW/THz System Experiments



- R&D, <u>often with national government support</u>, is underway around the world as high as 600 GHz!
- **But little from US!**

Yu, Asif, *et al.*, "400-GHz Wireless Transmission of 60-Gb/s Nyquist-QPSK Signals Using UTC-PD and Heterodyne Mixer," *IEEE Transactions on Terahertz Science and Technology*, Issue No. 99, p. 1-6 (August 2016) (http://ieeexplore.ieee.org/document/7556985/)
Update - https://www.sciencedaily.com/releases/2017/02/170205190911.htm

Europe Inc. is Actively Pursuing Commercialization of 95+ GHz


ETSI GS mWT 002 V1.1.1 (2015-08)

millimetre Wave Transmission (mWT);
Applications and use cases of millimetre wave transmission

Disclaimer

This document has been produced and approved by the millimetre Wave Transmission (mWT) ETSI Industry Specification Group (ISG) and represents the views of those members who participated in this ISG.
It does not necessarily represent the views of the entire ETSI membership.

In the light of the expected emerging broadband communication demands and the increased challenges for the next generation transmission networks, ETSI Industry Specification Group (ISG) on millimetre Wave Transmission (mWT) aims to be a worldwide initiative with global reach that will facilitate the use of

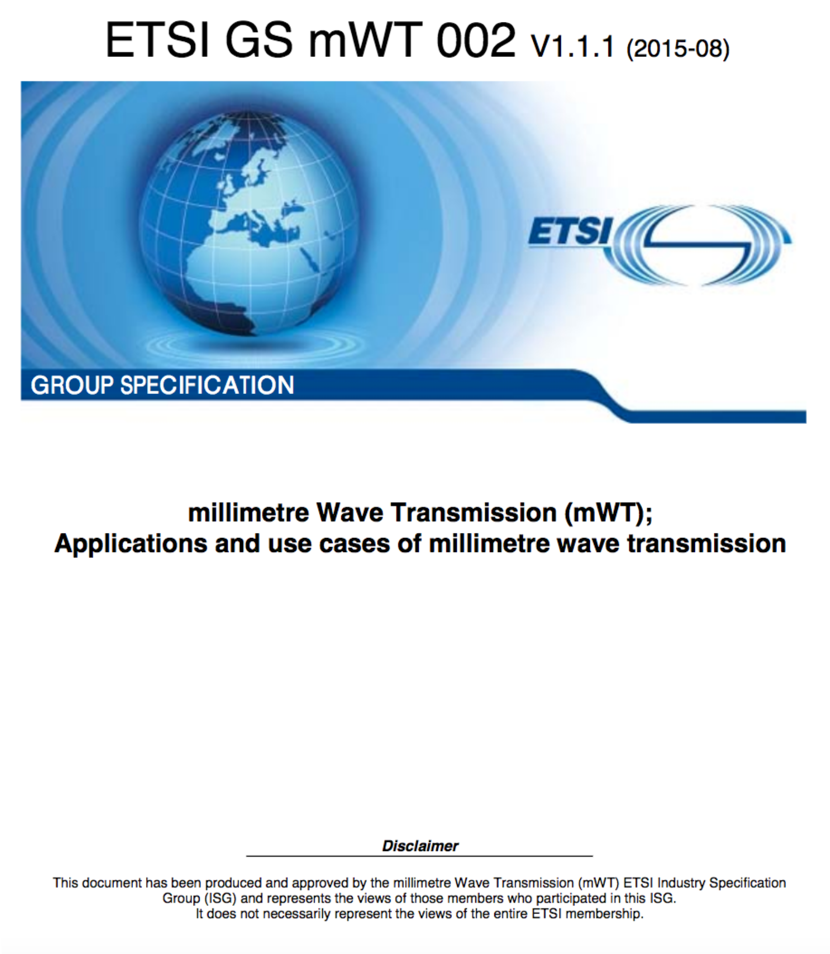
- the V-band (57 - 66 GHz);
- the E-band (71 - 76 & 81 - 86 GHz);
- in the future - higher frequency bands from 50 GHz up to 300 GHz

----

"Similarly, at frequency bands above 100 GHz, there are blocks of plentiful spectrum, which could be allowed for extra bandwidth for future broadband wireless transmission services."

http://www.etsi.org/deliver/etsi_gs/mWT/001_099/002/01.01.01_60/gs_mWT002v010101p.pdf

Europe Inc. is Actively Pursuing Commercialization of 95+ GHz



ETSI GS mWT 002 V1.1.1 (2015-08)

GROUP SPECIFICATION

millimetre Wave Transmission (mWT);
Applications and use cases of millimetre wave transmission

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"With reference to their radio propagation properties, millimetre wave bands are defined by short-to-medium ranges (from a few hundred metres up to several kilometres), making technology at this spectrum suitable for applications in urban and suburban areas."

"Furthermore, millimetre wave spectrum technology provides very high-frequency re-use capabilities. Due to the high operating frequency and resulting short wavelength even physically small antennas would provide relatively high directivity and low side lobe level."

http://www.etsi.org/deliver/etsi_gs/mWT/001_099/002/01.01.01_60/gs_mWT002v010101p.pdf

Views from Europe Inc.

ERICSSON

"The aim is to open up spectrum beyond 100 GHz frequencies for up toward 100 Gbps capacity to support different applications and use cases with hop distances of up to a few kilometers. In the longer term, it is expected to serve as a high-capacity complement to the use of other frequency bands, especially in urban and suburban areas"

"THE AIM IS TO OPEN UP SPECTRUM BEYOND 100GHZ FREQUENCIES FOR UP TOWARD 100GBPS CAPACITY"

"IT IS IMPORTANT FOR SPECTRUM REGULATIONS BEYOND 100GHZ TO ENABLE EMERGING AND FUTURE INNOVATIONS"

https://www.ericsson.com/assets/local/publications/ericsson-technology-review/docs/2017/etr-beyond-100ghz.pdf

Views from Europe Inc.

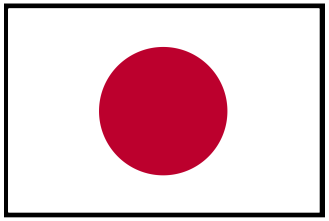
ERICSSON

"The ceaseless quest to provide higher data-carrying capacities has led to the use of ever higher frequencies where more spectrum is generally available. The tremendous growth in the use of the 70/80GHz band that we can see today was made possible by several years of research and development and a great deal of work on spectrum regulation, as well as the experience gained from several technology and product generations.

Similar efforts are now underway on the road to microwave backhaul beyond 100GHz, supported by the rapid evolution of high frequency semiconductor technologies and promising new devices. In light of this, we expect to see the large-scale deployment of beyond 100GHz solutions in 2025 to 2030. The W and D bands will undoubtedly be able to support capacities in the 5 to 100Gbps range, over distances up to a few kilometers."

W band: 92-114 GHz D band: 130-175 GHz

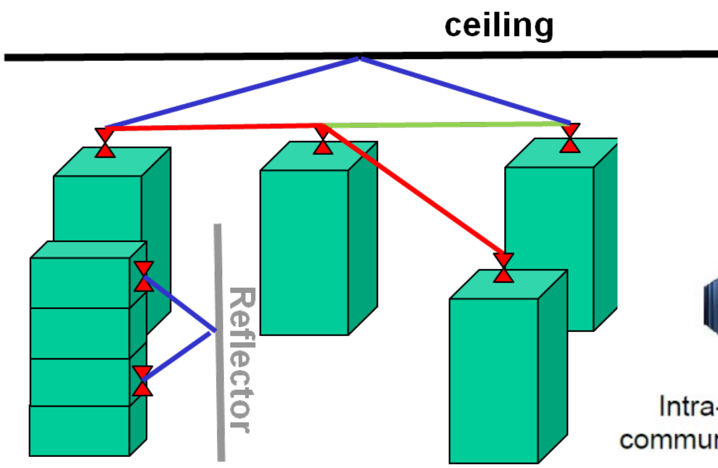
https://www.ericsson.com/assets/local/publications/ericsson-technology-review/docs/2017/etr-beyond-100ghz.pdf

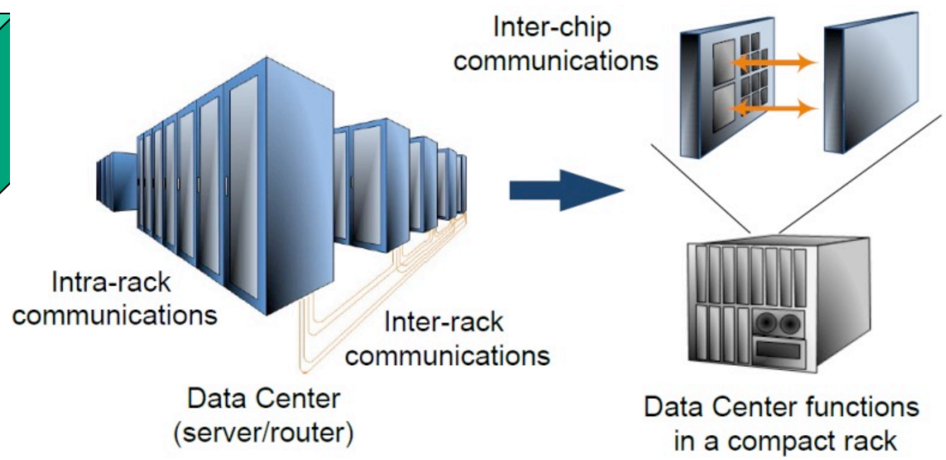


View of Japan Inc.

Proposed Frequency Bands to Identify

- Landmobile Applications
  - ✓ 275-320 GHz
  - ✓ 275-325 GHz
  - ✓ 275-450 GHz

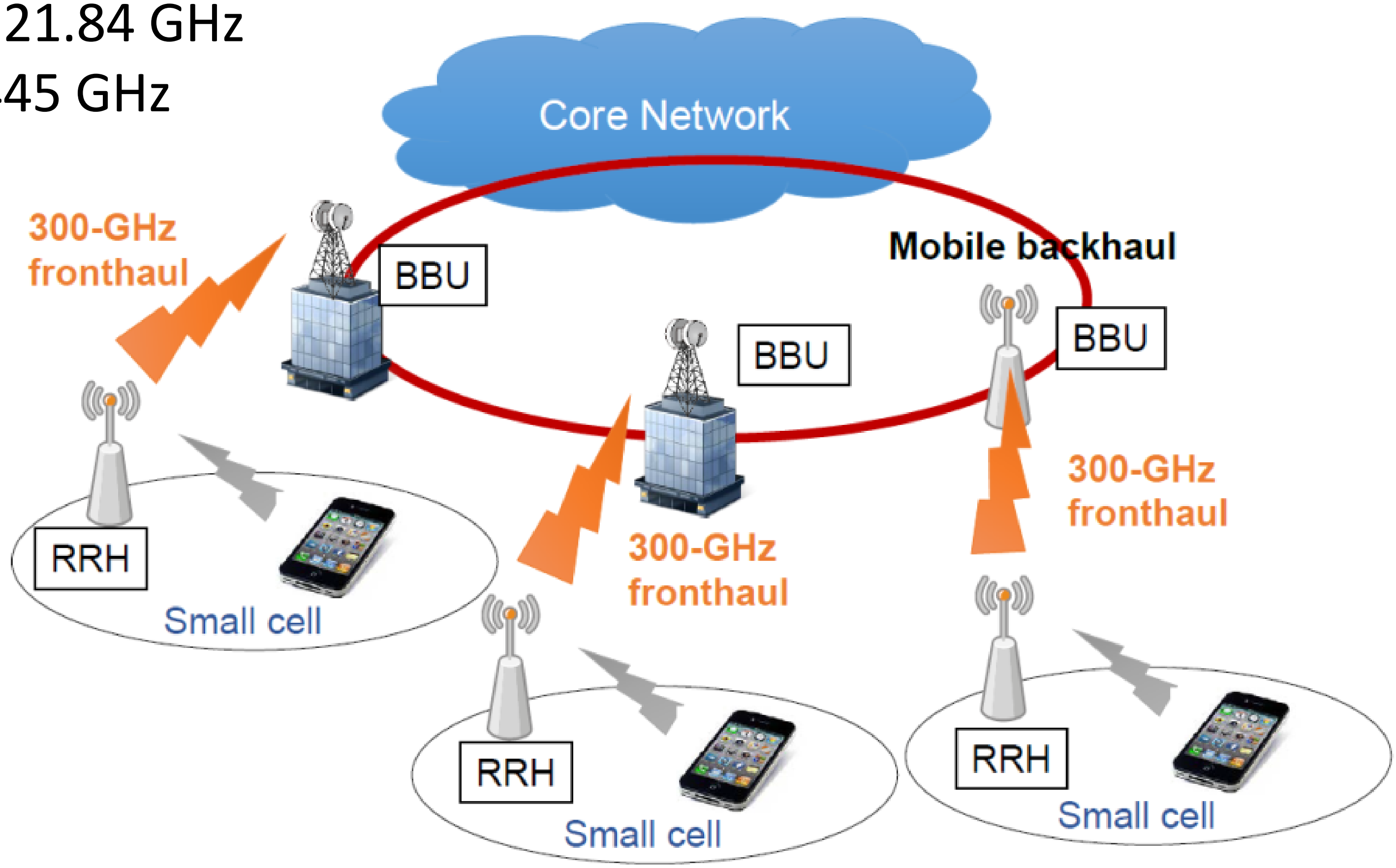




Presentation of A. Kasamatsu, H. Ogawa, I. Hosako NICT at IMS 2017

View of Japan Inc.

- Fixed Applications
  - ✓ 275-316 GHz
  - ✓ 275-321.84 GHz
  - ✓ 380-445 GHz



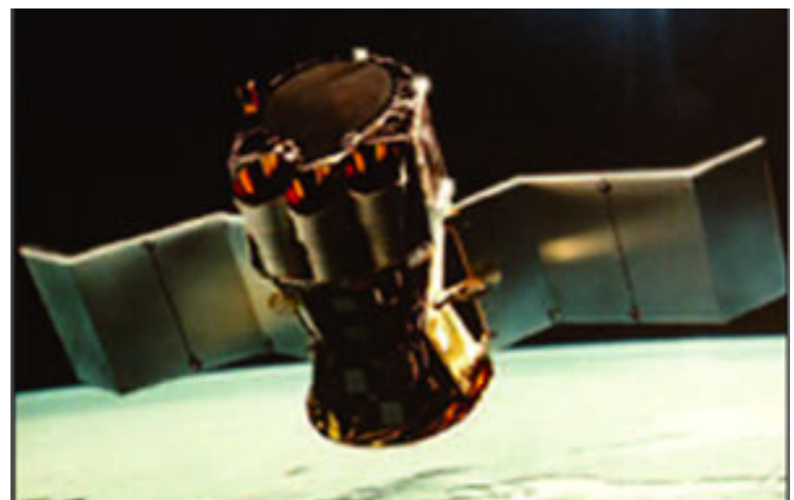
Presentation of A. Kasamatsu, H. Ogawa, I. Hosako NICT at IMS 2017

Possible Uses of 95-450 GHz Spectrum

- Passive uses with existing allocations/provisions
  - Radio astronomy
  - Satellite-based remote sensing
- Fixed communications
- Mobile communications
- Noncommunications

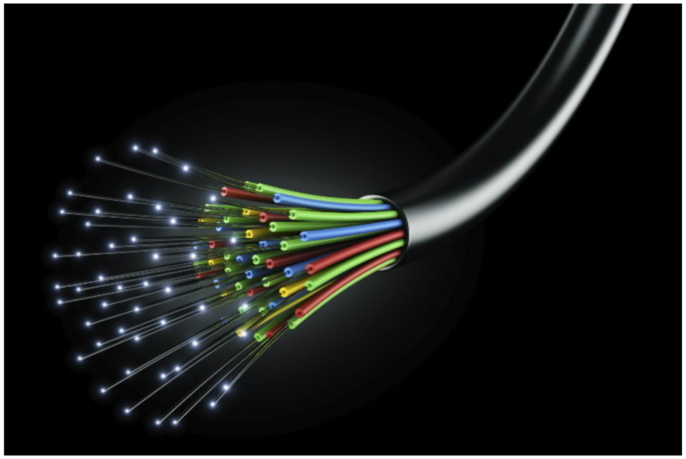
Passive Uses

- Existing uses pioneered technology & access to this spectrum
- Physics of mmW/THz spectrum permits active/passive sharing options *very different* than in lower bands



Fixed Communications/Part 101

- Point-to-point terrestrial communications
  - ***If*** large bandwidth channels are available could achieve rates comparable to optical fiber
  - While fiber hardware is always less expensive, in ***some*** cases installation costs dominate
  - Fiber installation usually slow - especially in populated areas



Fixed Communications/Part 101

- Point-to-point terrestrial communications
  - While fiber can be repaired quickly in case of cuts from construction accidents, quick repair may not be possible after *some* types of disasters
    - *e.g.* earthquake with ground rupture
    - Fiber over fault lines, *e.g.* California
  - Special events with short time lead
  - mmW has ~30% lower time latency than fiber

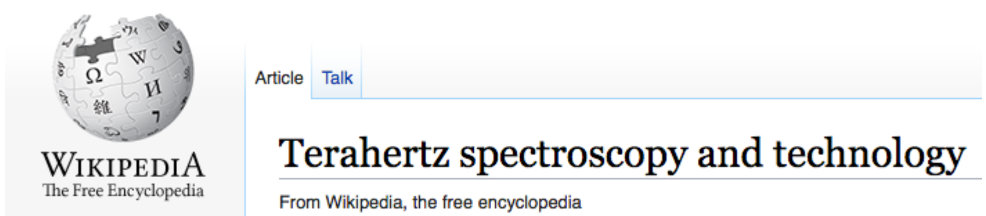
San Andreas fault

Mobile Communications

- In ITU-R study group discussions of "close proximity mobile systems (CPMS)" for large file sizes to be transferred in a few seconds.
  - Some examples could be systems such as kiosk systems or ticket gate systems, which could be used for the purchase of a movie downloaded to a mobile device.
  - Power ~ 10 dBm
  - Range <1m

Noncommunications Uses

- Most appear to be possible nonthermal Part 18 applications
- Pioneered by NASA R&D to enhance Space Shuttle safety
- Often referred to as "Terahertz spectroscopy"



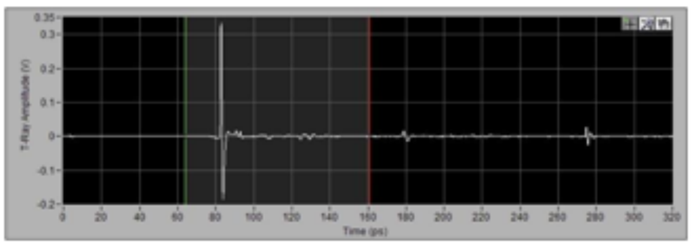
- Legal status in US now "ambiguous"

Quote from a Former Boss of Speaker

- "If you are looking for interesting ideas in spectrum policy, take things that people are doing illegally *without causing problems* and make them legal!"
  - Historic examples
    - Carterphone
    - C band home TVRO
  - Is THz spectroscopy a good new example?

THz Spectroscopy

– Useful for both scientific research and some industrial operations
– Two versions (analogous to UWB):
  • "time domain"



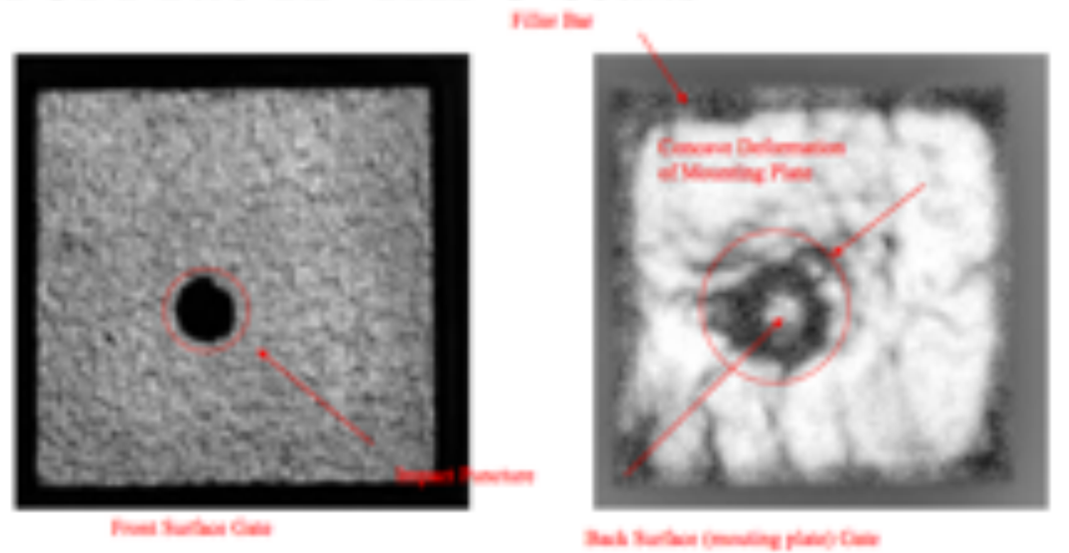
  • "frequency domain"
    – Stepped frequency

Frequency 50 GHz – 4 THz per NASA R&D website

– cm ranges
– generally indoor
– very low power

Use of THz Spectroscopy in NASA Space Shuttle Program

TUFI Tile TD-THz C-Scans



- Tile dimensions L6 in. x W6 in. x H1.72
- Mounted on L12 in. x W12 in. 1/32 in. thick aluminum sheet
- Aluminum mounting sheet metal was deformed into a bulge and punctured/torn.
- Front: Power integration between 0.3 and 2 THz
- Back: Centroid delay with 0.3 to 0.8 THz bandpass filter.

Applications of THz Spectroscopy

- Study of
  - Polymers
  - Semiconductors
  - Ceramics and glasses
  - Organic molecules
  - Gas spectroscopy
  - Conductive films
  - Liquid crystals
  - Composites
  - Oils
  - Nondestructive testing
- Aircraft Non-destructive Testing
- Examination of Packaged Goods
- Spacecraft Non-destructive Testing
- Radome Inspection
- Pipeline Repair Inspection
- Monitoring production lines of plywood

Current THz Spectroscopy Products

MAILSECUR™
SAFE ACCESSIBLE DETECTION

- Nonionizing imaging system for mail security & detection of powders and fluids
- ~400 GHz
- Received approval of Canadian (former IC) regulator 90 days after informal discussion

TeTechS
Measure, Identify, Inspect

Plastic Bottle and Container Thickness Measurement

- Time domain/impulsive waveform
- ~50-400 GHz
- Non-destructive, multi-layer thickness measurement system for plastic bottles, containers and thin wall packaging

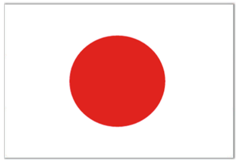
Approved by Canadian regulator 6 weeks after an informal request!

Innovation, Science and Economic Development Canada

http://raysecur.com/en/mailsecur

http://tetechs.com/plastic-bottle-container-thickness-measurement/

Current THz Spectroscopy Products



- **ADVANTEST TAS7500 Series Terahertz Spectroscopic / Imaging System**
  - “The TAS7500 series is a family of compact and multipurpose terahertz spectroscopic / imaging systems. Utilizing the unique properties of the terahertz region (0.1 – 10.0THz) of the electromagnetic spectrum, these systems perform non-destructive analysis of pharmaceuticals, chemicals, communications materials, etc., without requiring a specially constructed analysis environment. Speed and ease of operation are the hallmarks of Advantest’s terahertz analysis systems. In addition to industrial applications, the TAS7500 series is also an optimal choice for terahertz – related research, leveraging Advantest’s high-precision detection technology to provide best-in-class sampling performance”.

https://www.advantest.com/products/terahertz-spectroscopic-imaging-systems/tas7500-series-terahertz-spectroscopic-/-imaging-system

- **LUNA Luna Innovations/Advanced Photonix T-Gauge®**

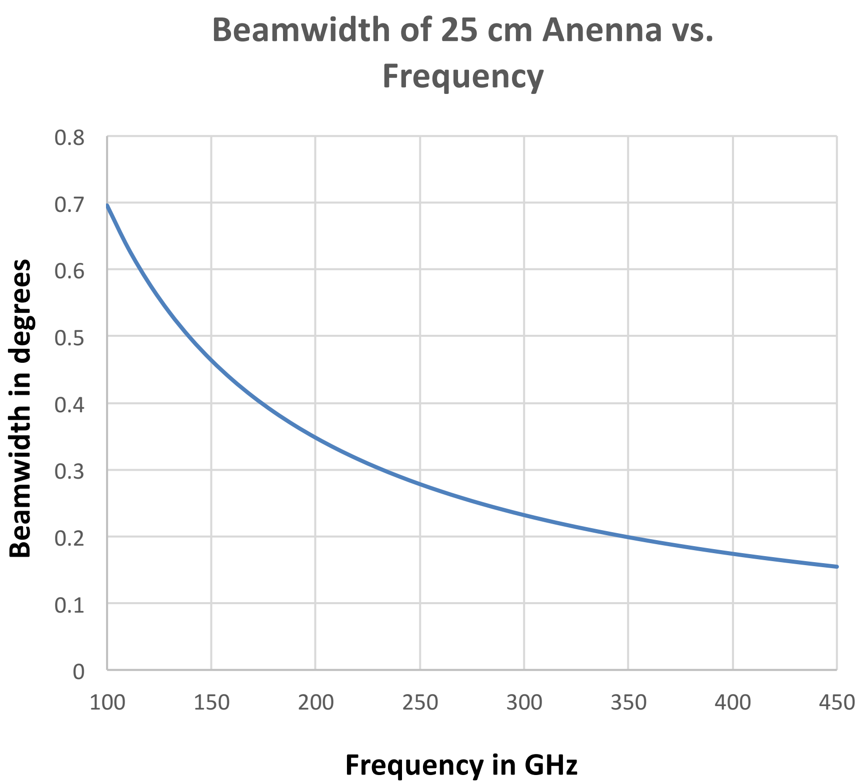
- “T-Gauge®Picometrix sensor is the first web scanning Time Domain Terahertz solution for plant floor deployment to measure basis weight, caliper, density, moisture on laminated and multi-layer composites. Terahertz technology previously limited to research facilities, military, aerospace and homeland security is now available to the industrial web processing market.”

- US Regulatory status – “complicated”

http://lunainc.com/thz/products/t-ray5000

Basic Physics of mmWave Spectrum Policy

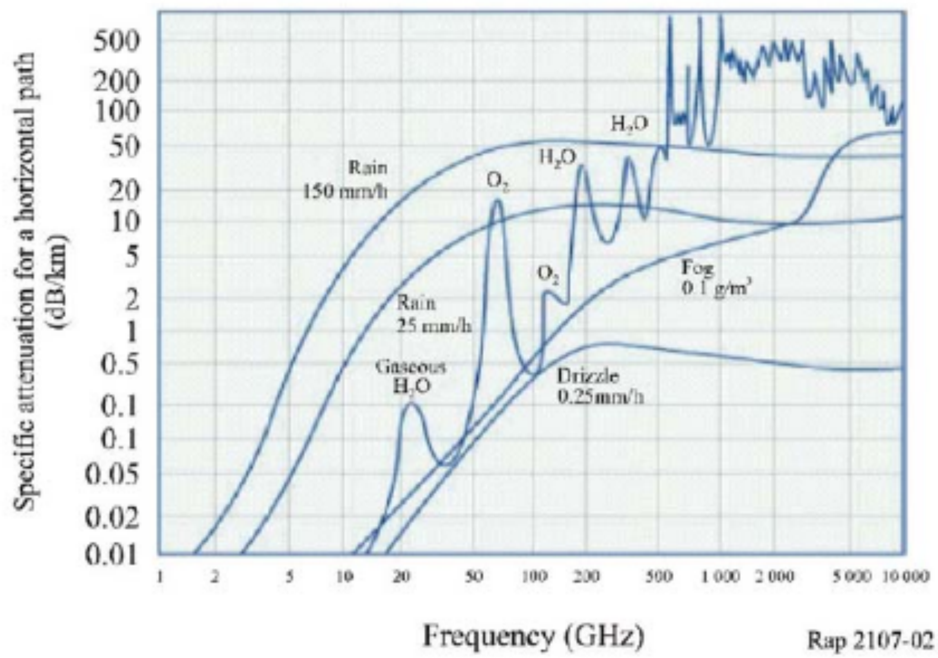
Narrow beamwidth

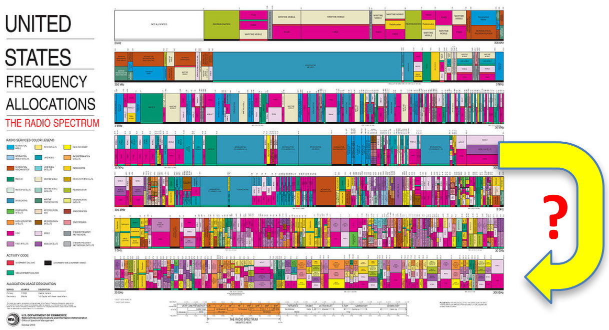


Note: Sidelobe levels do <u>not</u> scale with frequency

High path loss

<u>Extra</u> Path Loss Due to Absorption



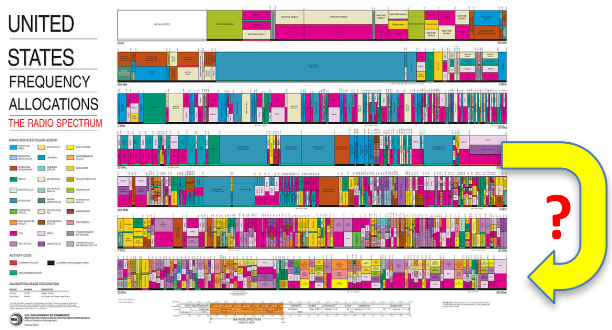


Basic Technical Issues

95+ GHz is **<u>not</u>** "UHF with a few extra zeroes"

– Interference issues are <u>fundamentally different</u>

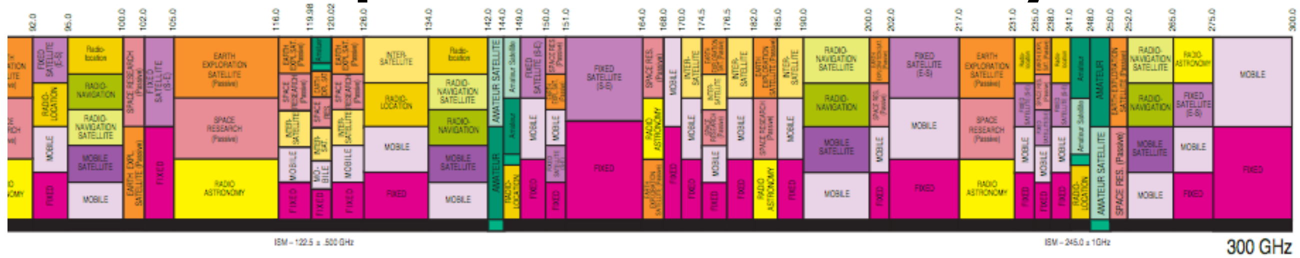
- **Absorption** of signals by atmosphere markedly decreases ranges – no parallel at lower bands
- Due to small λ, modest size antennas have very narrow beams to keep power on intended target and away from others
- **NO** Intermittent long range quirky "anomalous propagation" in these bands *e.g.* ducting, sporadic E



Basic Technical Issues

- Intraservice interuser interference, the basic reason for spectrum regulation, is very unlikely due to propagation and antenna issues
  - FCC SPTF 2002 recommendation #34:
    - "All future rulemaking for terrestrial use above 50 GHs should include *de novo* review of the merits of licensing"
  - Interservice sharing, even fixed/mobile sharing in same area, much easier than at lower bands
    - "Self backhaul" being discuss in 5G
    - Radio telescopes for these bands sited on remote arid mountaintops due to physics

mmW Spectrum Policy Issues



- ***All*** spectrum in 48-275 GHz is G/NG shared
- Basic problems of FCC/NTIA bifurcation of regulation, dating back to §§301,305, exacerbate policy problems
  - Complicated by IRAC ill will created by pressure for reallocation of G spectrum for cellular

Basic Policy Issues

- **No** national framework for 95+ GHz spectrum issues
  - NTIA/IRAC members reluctant to engage on issue
  - Indications other countries more open and doing R&D in nominal passive bands
    - Public records in FCC application files shows FCC/NTIA problems on experimental licenses in these bands

Basic Issues

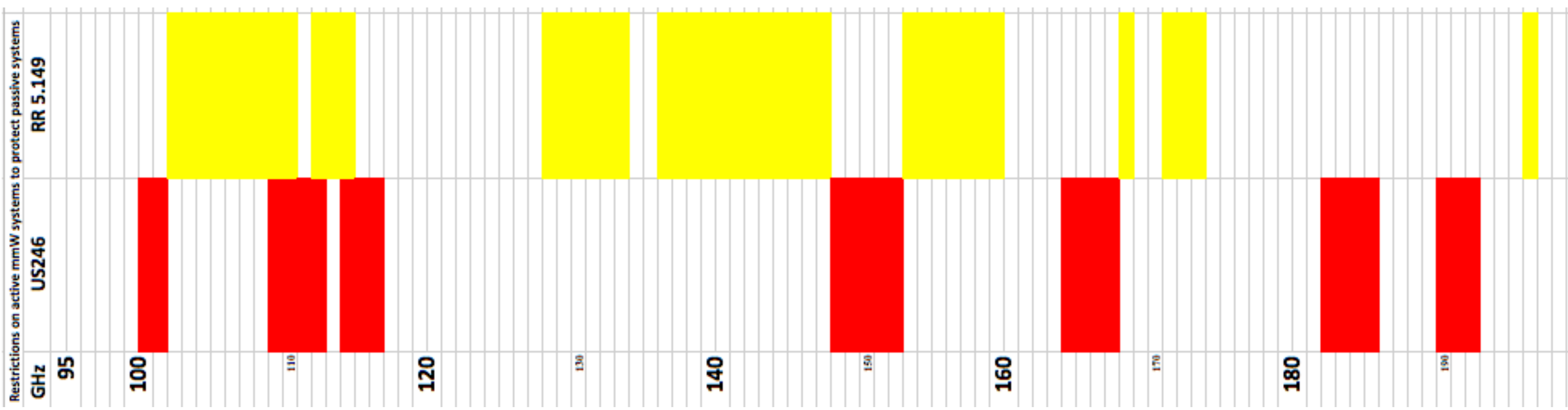
- Impact of passive allocations <u>much greater</u> than at lower bands
  - Much larger fraction of spectrum >15%
  - Locations of passive allocations, which are due to physics, balkanize available spectrum - limiting large bandwidth necessary for some applications
  - While <u>strictly exclusive</u> passive spectrum (US246) is easy to justify at lower bands, physics of these bands offer new options for *careful* sharing 95+ GHz deserve *de novo* review
    - Note US246 has been amended twice to permit sharing of lower bands – **not cast in stone**!

Harassment of mmW Experimental License Applications in IRAC

- File 1047-EX-ST-2014
  - Military contractor application rejected for brief experiment to prove feasibility of new modulation
- File 0231-EX-CN-2017
  - University researcher seeking to do campus propagation test excluded from 100-102 GHz band
- No even vaguely real interference concerns in either case
  - In both cases frequency selection driven by limited OTS equipment availability for concept demonstrations
- Updated FCC Rule § 5.85(a) explicitly allows experiments in passive bands w/conditions
  - Does IRAC/FAS not accept this policy?
  - Does NTIA management monitor these actions?

Spectrum Balkanization by Passive Bands

95-200 GHz

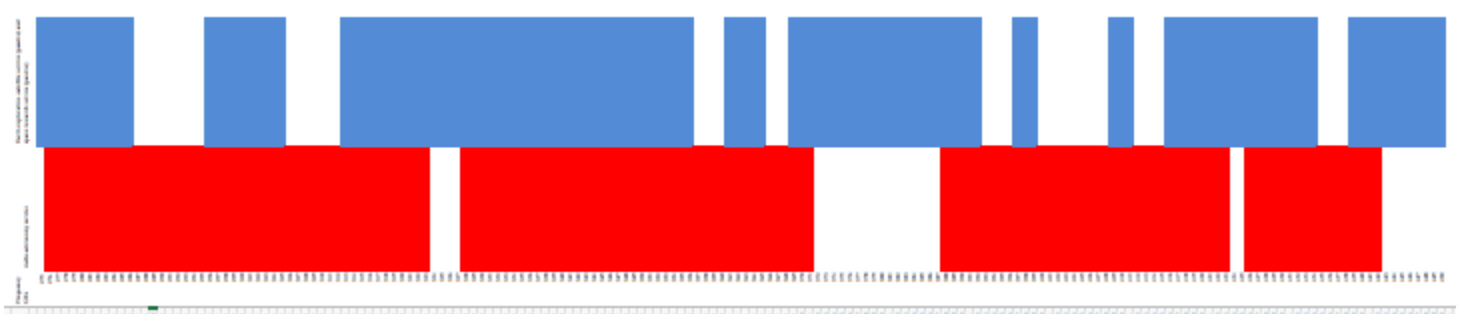


275-450 GHz

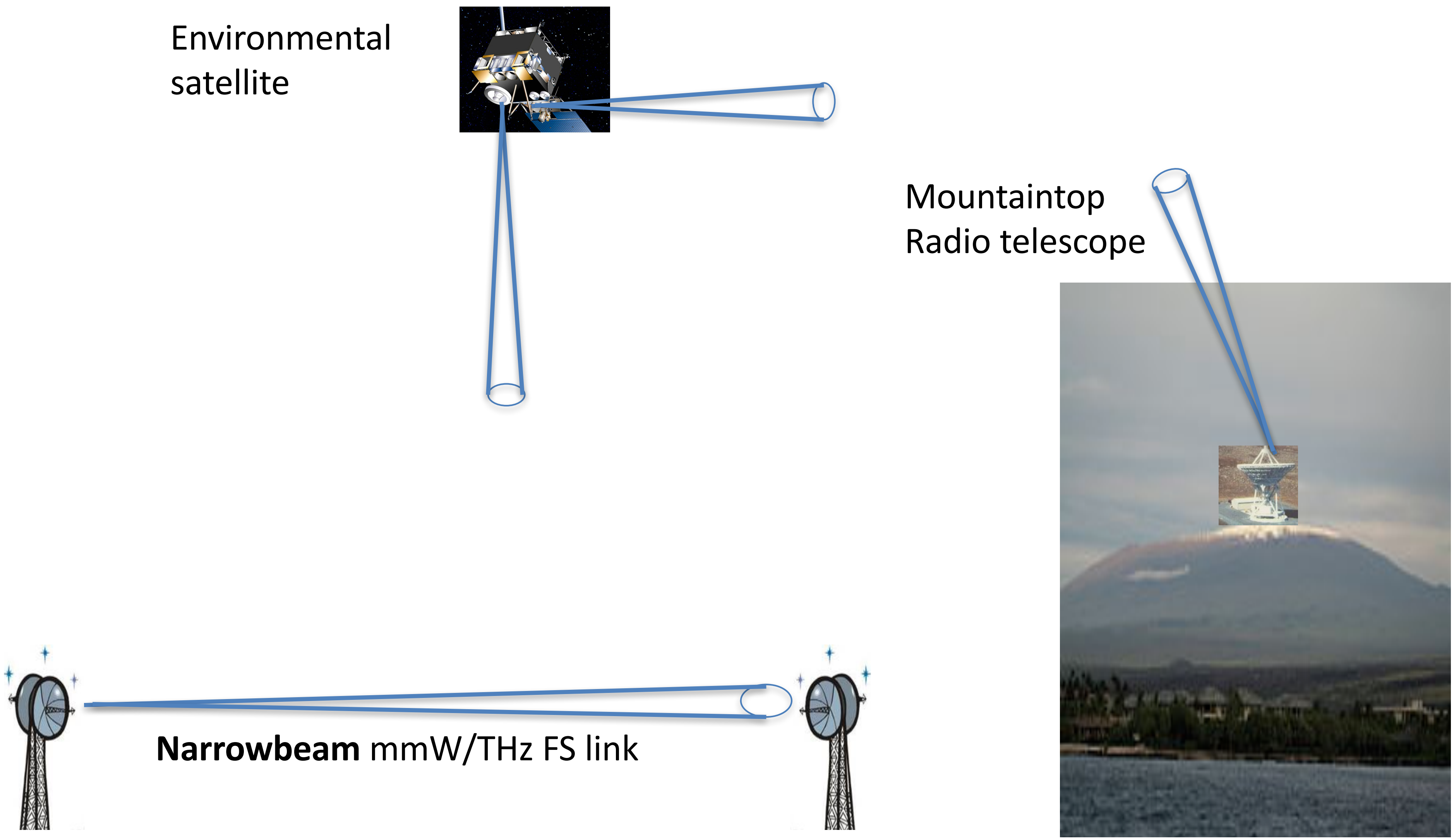
RR 5.565

ES

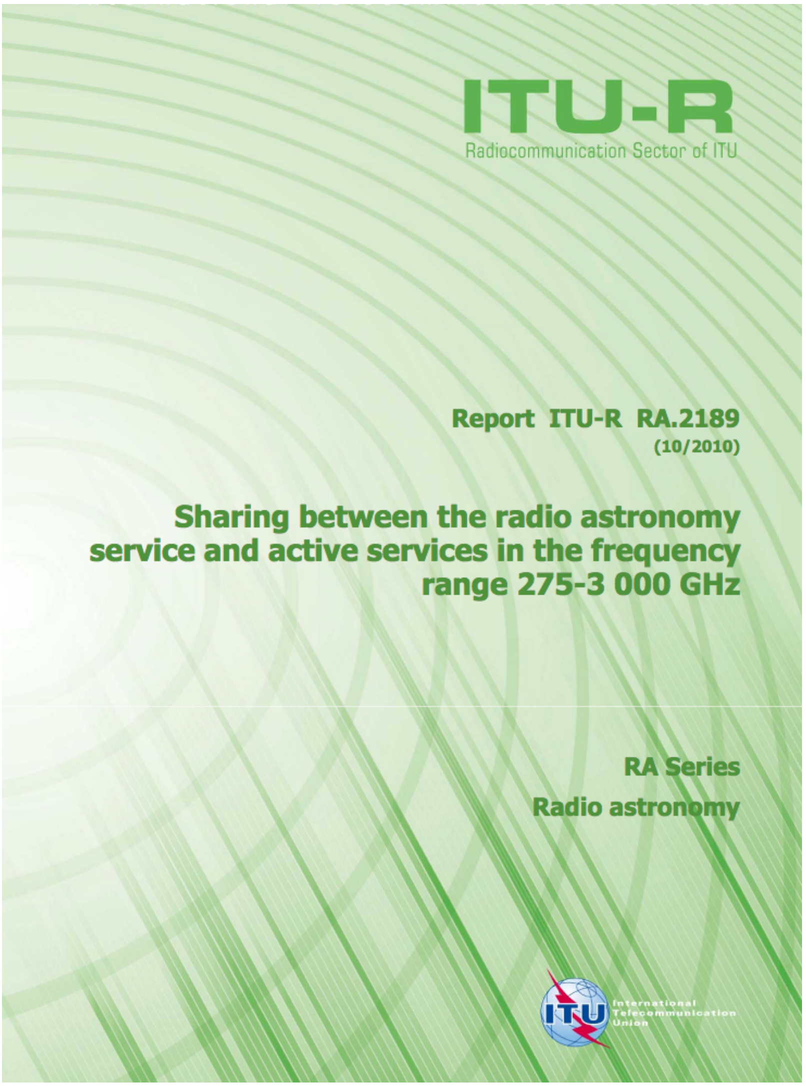
RA



Geometry of proposed sharing with passive users



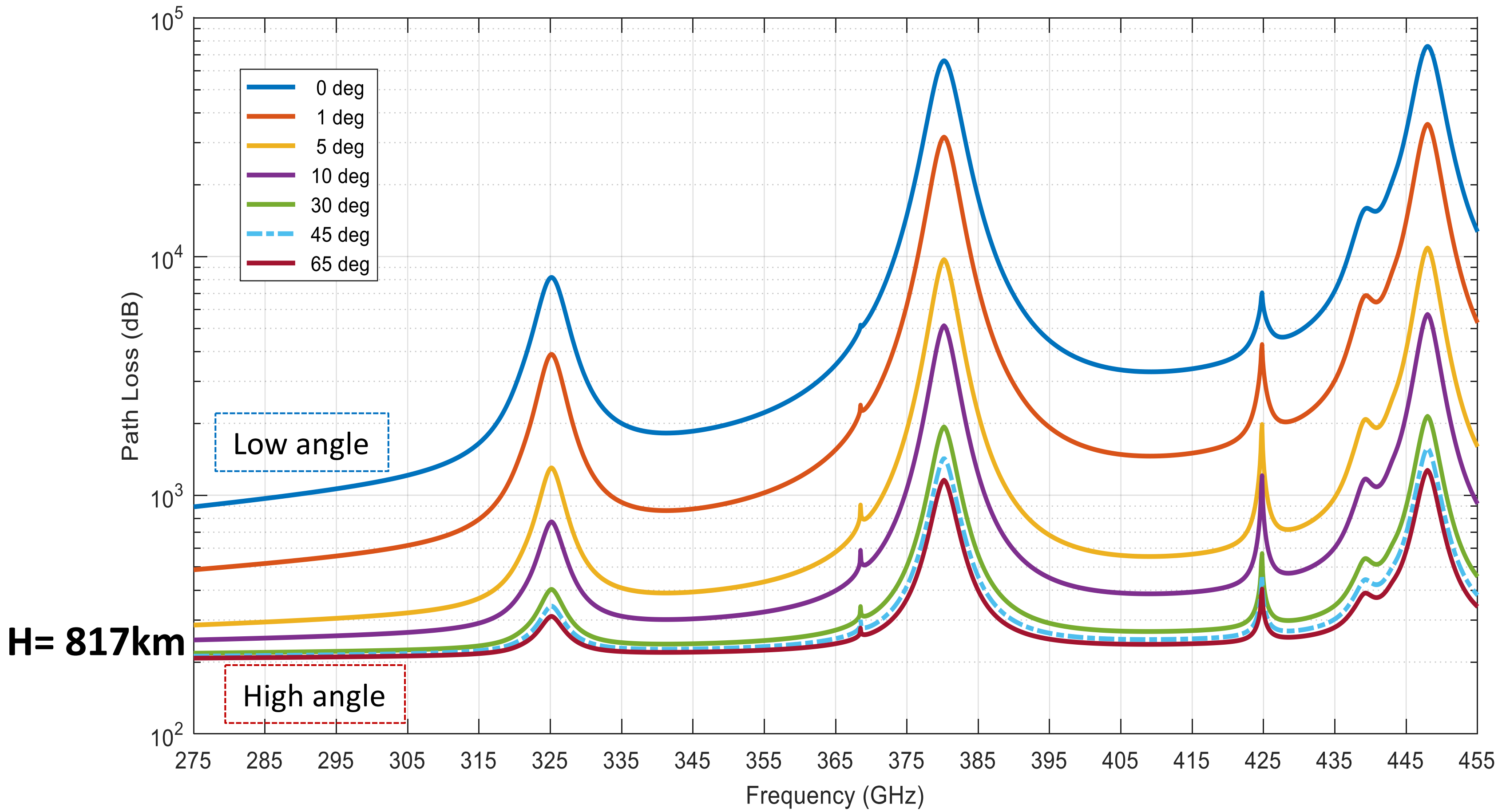
Is Sharing Possible?



http://www.itu.int/pub/R-REP-RA.2189-2010

- 2010 ITU-R report indicates that sharing above 275 GHz is possible for radio astronomy and terrestrial users.
  - Does not address other passive services
- Is 275 GHz lower limit of this report a physical lower limit or a bureaucratic one?

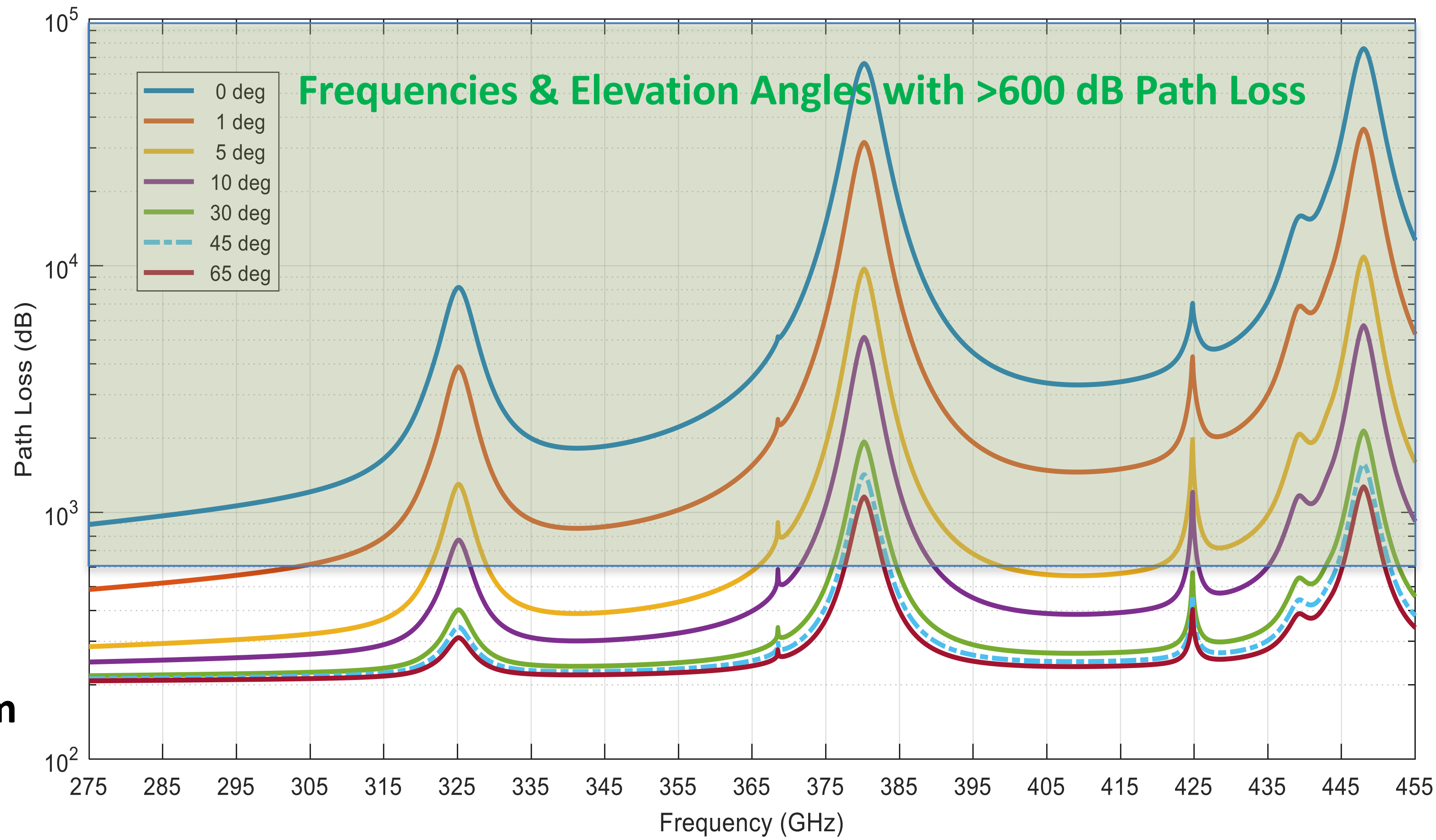
Path loss from terrestrial sources to LEO sensors varies greatly with elevation angle as well as frequency



NASA calculations in US ITU-R SG 1 contribution

Base on Rec. ITU-R P.676 (Software not publicly available)

When Path Loss is Greater than 600 dB (10^{-60}) Sharing Opportunities are Clear!



H= 817km

NASA calculations in US ITU-R SG 1 contribution

Suggested Action Plan

- **Open up spectrum above 95 GHz in present Fixed allocations for Part 101 use on a "licensed light" basis like 70/80 GHz bands**
  - **Keep Mobile allocations in place**
- **Update present US Allocation Table US246 to enable responsible & conservative sharing of passive upper spectrum with active users**
  - **Now strictly prohibited**

Suggested Action Plan

- **Clarify/update Part 15 or Part 18 unlicensed rules for indoor use of very low power terahertz spectroscopy equipment**
  - **Confirm §§18.301,303,305(b) as possible basis for use *or***
  - **Propose new Part 15 or 18 rules**
- **Extend quantitative RF safety limits above present 100 GHz – perhaps using the same IEEE standard which is the basis for lower frequencies and which now extends to 300 GHz**

Suggested Action Plan

- **Create usable large contiguous block of FS spectrum by proposing service rules for Fixed Service that span both *existing* FS bands and present US 246 bands, *e.g.* 102-130 GHz:**
  - **Shared use of passive bands subject to <u>“extreme vetting”</u> to explicit criteria**
  - **28 GHz of bandwidth for wide blocks that will enable fiber optic-like capacity for applications where fiber is not viable**
  - **Leave open possibility of future mobile use in bands w/mobile allocation**

102-105 FIXED MOBILE RADIO ASTRONOMY 5.341 US342	
105-109.5 FIXED MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.341 US342	
109.5-111.8 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY US74 SPACE RESEARCH (passive) 5.341 US246	
111.8-114.25 FIXED MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.341 US342	
114.25-116 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY US74 SPACE RESEARCH (passive) 5.341 US246	
116-122.25 EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562C SPACE RESEARCH (passive) 5.138 5.341 US211	
122.25-123 FIXED INTER-SATELLITE MOBILE 5.558 5.138	122.25-123 FIXED INTER-SATELLITE MOBILE 5.558 Amateur 5.138
123-130 FIXED-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) RADIONAVIGATION RADIONAVIGATION-SATELLITE Radio astronomy 5.554 US211 US342	

DOC and Its Mission

COMMERCE.GOV

Mission Statement

The mission of the Department is to create the conditions for economic growth and opportunity.

Vital to *balance* this with spectrum needs of federal users

https://en.wikipedia.org/wiki/Deep_state_in_the_United_States

Suggested Action Plan

- **FCC & NTIA should actively support reasonable action in the US preparation for WRC-19 on Agenda Item 1.15 (275-450 GHz) and engage IRAC members on reasonable protection of the passive bands identified in RR 5.565 for protection by "all practicable steps"**
- **Create joint FCC/NTIA effort to develop & support new uses of 95-450 GHz spectrum**

mmW/THz & CSMAC

- Should NTIA ask CSMAC to look at mmW/THz sharing issues with G spectrum users?
  - Would probably need an infusion of new people into working group since main CSMAC members have little interest

Suggestion

- In order to develop a 95+ GHz spectrum strategy that is truly in the national interest, IRAC deliberations on 95+ GHz need *both* more transparency and Silicon Valley-style "adult supervision" from NTIA for compliance with **national goals** not just goals of individual agencies

Thanks!

Questions?

FCC approval of 57-64 GHz Rules 12/15/95
https://youtu.be/wMC4wLFCLIc