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

Submission Title: Evolution of Extreme Personal Bandwidth and Local Area Triple-Stack Terahertz Wireless Networks

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Re:

Abstract: Current device and network challenges will stimulate the evolution of highly intelligent avatar software within handheld devices. These intelligent agents are designed to engage with human hosts and efficiently harvest data and media from the internet via a proposed multi-gigabit high frequency (mm Wave and THz) wireless transport layer that overlays the existing wireless infrastructure, but utilizes available higher frequency spectrum outside the traditional cellular and Wi-Fi bands. This proposed third layer infrastructure is supplemental to existing wireless (cellular and Wi-Fi) infrastructure, and utilizes burst traffic techniques, software radio and a suite of front end transceivers designed to route high bandwidth traffic to and from the mobile customers device when the high frequency wireless link is available.

Purpose: Information on development of future THz communication systems

Evolution of Extreme Personal Bandwidth and Local Area Triple-Stack Terahertz Wireless Networks

David Britz

AT&T Labs Research – Shannon Laboratories

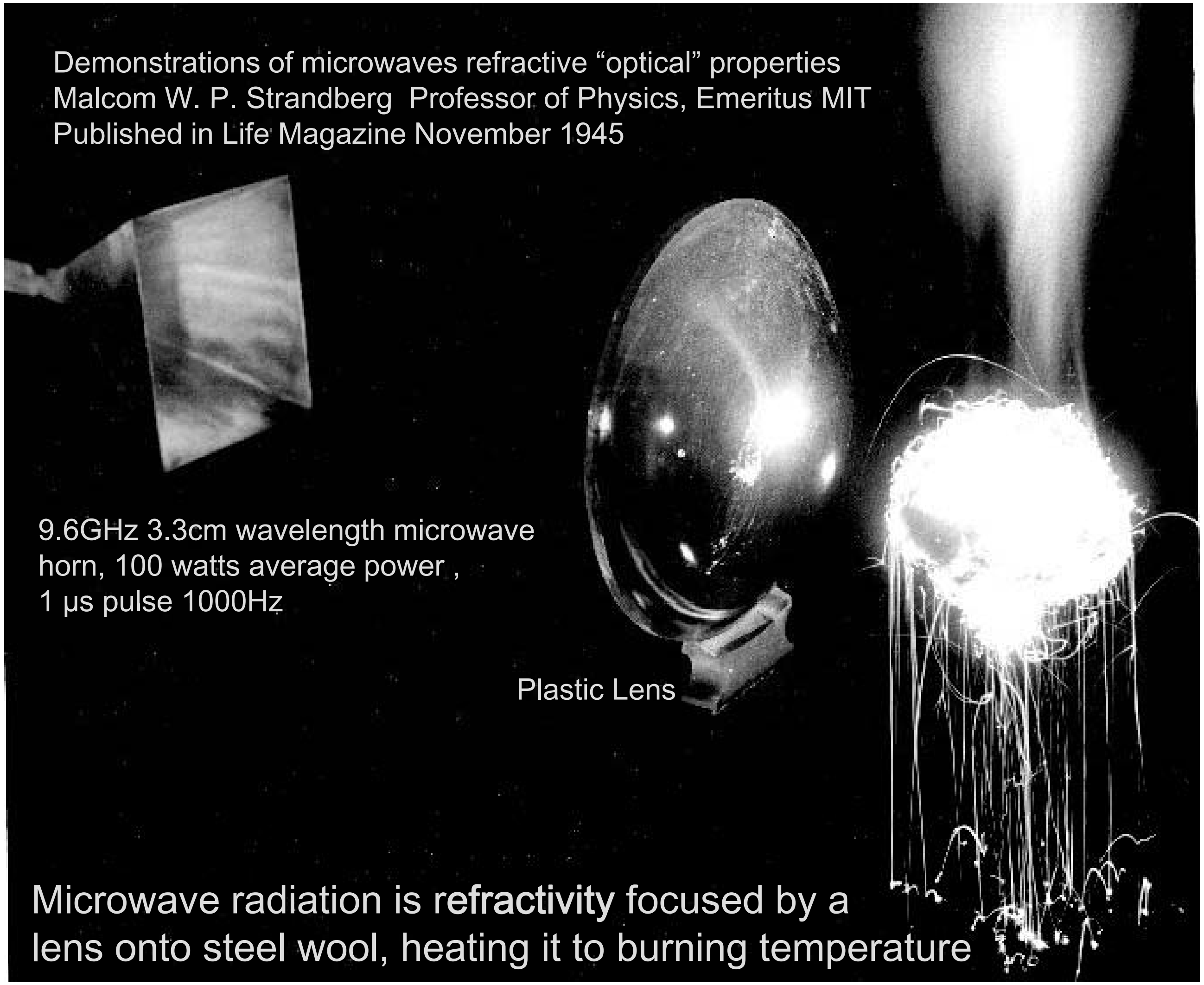
My Special Thanks to;

Robert R Miller, AT&T Labs Research

Lusheng Ji, AT&T Labs Research

Leonid Razoumov, AT&T Labs Research

Thomas Kürner, THz Communications Lab
Institut für Nachrichtentechnik



Terahertz
is it
light or radio?

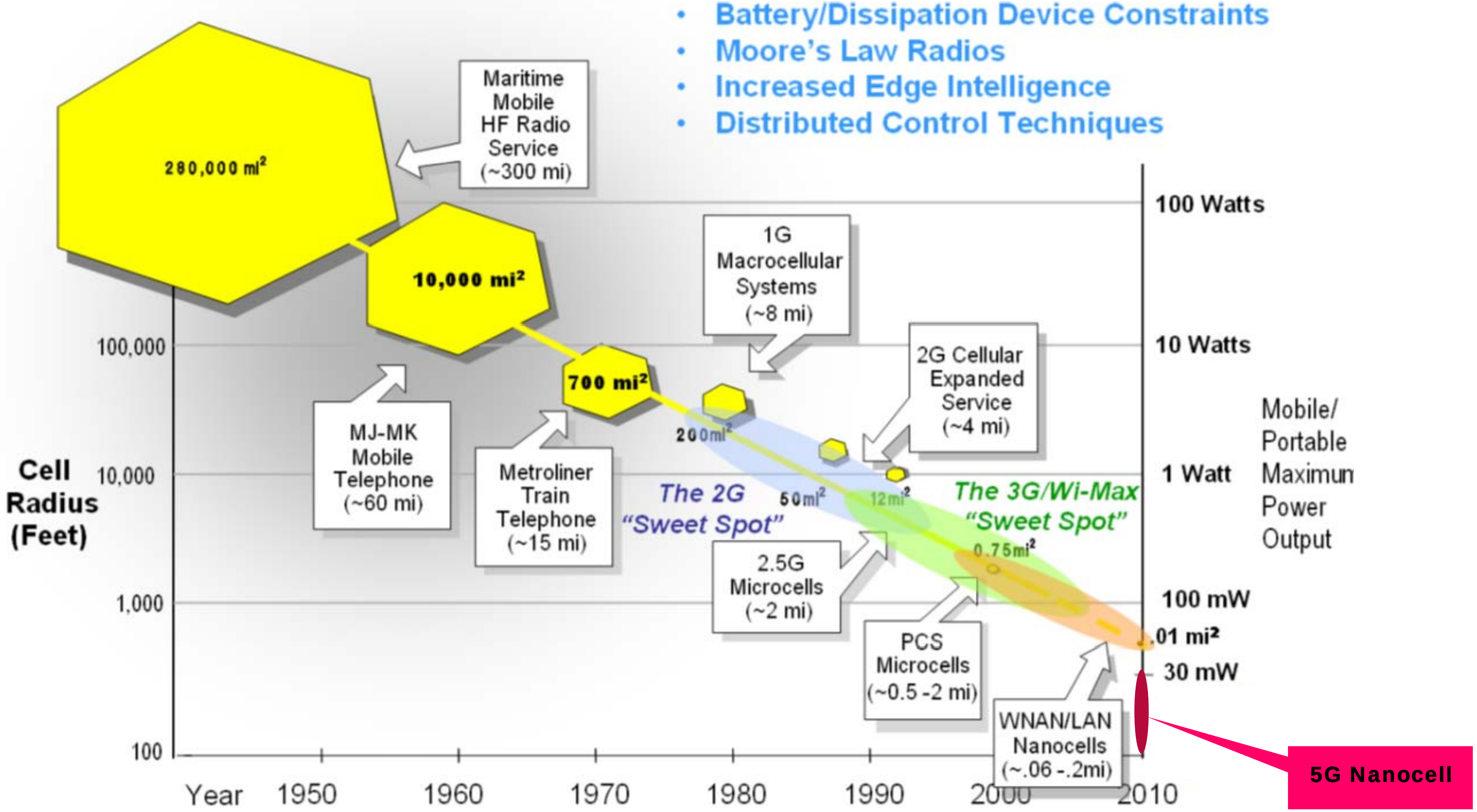
Through casual experience and observation one could easily conclude the natures and wave physics of light, terahertz and radio are very different, but they are not! But the optimized coupling of THz frequencies to matter, through the discovery or the making of new structured materials will be critical to a terahertz future

All things being equal, power scales with channel bandwidth

$$P_T = L_{90} - G_m - G_b - I_{sd} + SNR_0 + [\,-174\ \mathrm{dBm/Hz} + N_F + 10\log B\,]$$

For a given distance, frequency and environment

- Increased Bandwidth Demand/User
- Battery/Dissipation Device Constraints
- Moore's Law Radios
- Increased Edge Intelligence
- Distributed Control Techniques

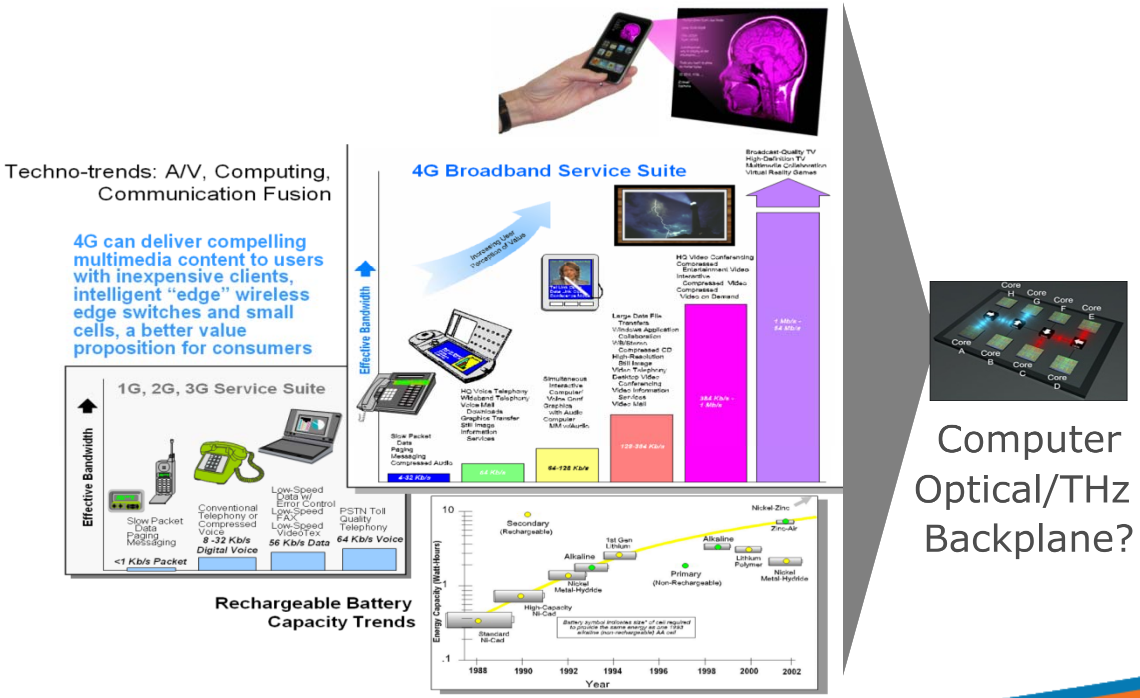


Slide Material Provided By Robert Miller, AT&T Labs Research

Re-think!

Human Interface / Device Bandwidth Evolution, Spectrum Allocation and Wireless Networks vs Portable power

Triple Stack; Future cellular networks and hand held devices, to support increasing data-dense media and services, will need to employ a broader range of frequencies, eventually including mm Wave and THz. These locally intelligent networks will choose spectrum bands and frequencies based on suitability for the application and local spectrum availability via COG and software defined radio and the use of multiple integrated front end radio antennas. On-board intelligent avatars will interface to networks, (in parallel to human conversations), using extreme frequency bandwidth to deliver, human-to-machine and machine-to-machine data and media rich services.



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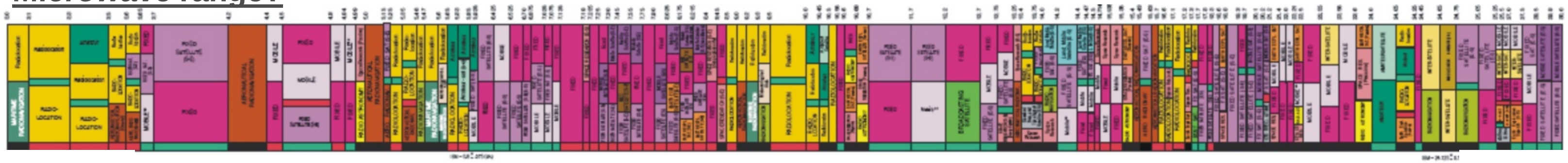
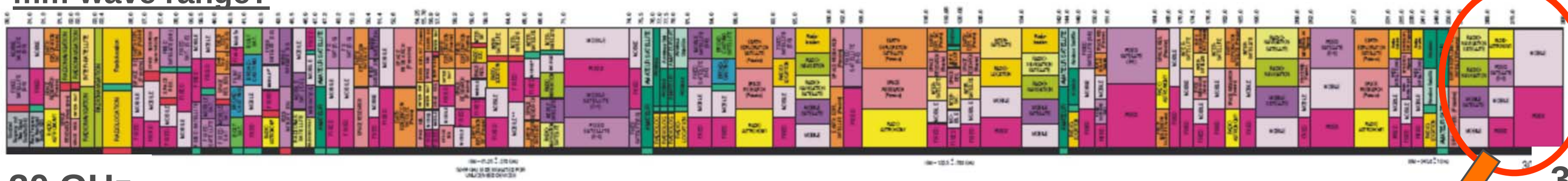
But we are running out of regulated radio spectrum!

Microwave range?



3 GHz 30 GHz

mm-wave range?



30 GHz US frequency allocations, Oct 2003

300 GHz

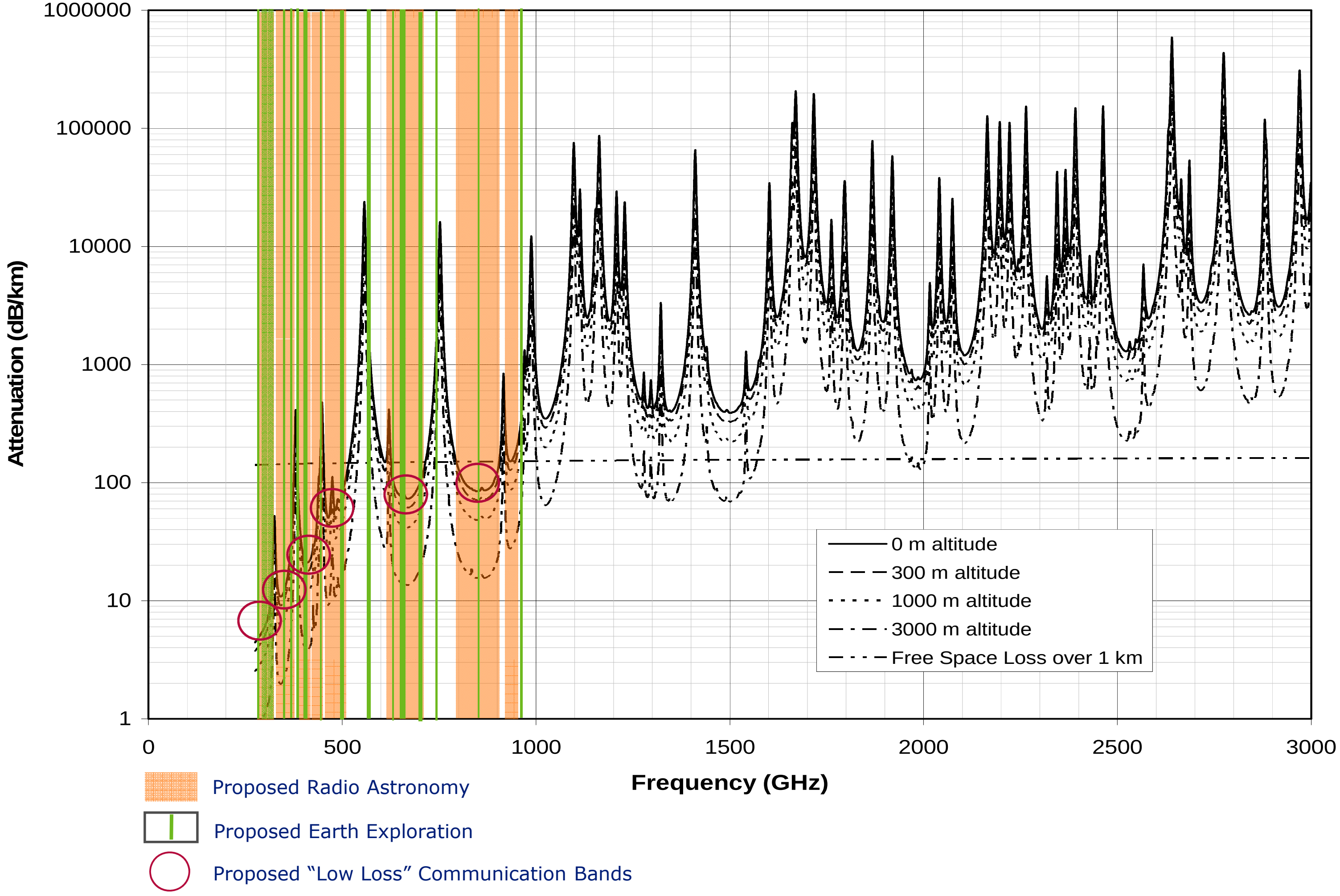
Potential at 300 GHz and above!

- Currently Unregulated Spectrum at THz frequencies (300 GHz-3 THz) available …
- 10 GHz bandwidth and 1 bit/s/Hz => 10 Gbps data rate (simple modulation scheme, no coding)
- 100GHz worth of unclaimed (low loss) spectrum between 300 - 1000GHz
- …but this spectrum is on the agenda for WRC 2011 (agenda item 1.6)!

0.01 – 0.3 µm 3500 THz | 0.3 - 0 .7µm 350 THz | 1.0µm 300THz | 3.0µm 100THz | 30.0µm 10 THz | 300.0µm 1THz | 1000.0µ 300 GHz | 100 GHz

My thanks to the Terahertz Communication Lab for the use of their slide material

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.

ITU Identified Bands

Radio astronomy service:
275-323 GHz, 327-371 GHz, 388-424 GHz, 426-442 GHz, 453-510 GHz, 623-711 GHz, 795-909 GHz and 926-945 GHz

Earth exploration-satellite service (passive) and space research service (passive):
275-277 GHz, 294-306 GHz, 316-334 GHz, 342-349 GHz, 363-365 GHz, 371-389 GHz, 416-434 GHz, 442-444 GHz, 496-506 GHz, 546-568 GHz, 624-629 GHz, 634-654 GHz, 659-661 GHz, 684-692 GHz, 730-732 GHz, 851-853 GHz and 951-956 GHz.

Interim Meeting Of The IARU Region 1 VHF/UHF Microwave Committee Vienna 2007

Bands of Interest		Bandwidth (GHz)
275 – 300 GHz		14
355 - 400		22
490 - 510		4
690 - 710		18
800 - 850		40
575 GHz		**98GHz**

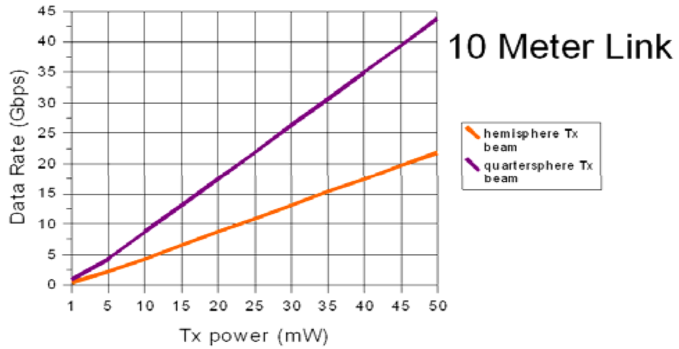
Reference material supplied by ITU-R USWPs 7D

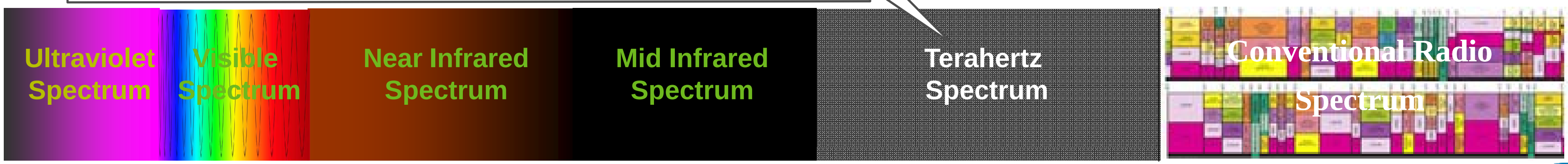
So Why Terahertz?

- 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

Bands of Interest	Attenuation (dB/Km)	Bandwidth (GHz)
275 – 300 GHz	6	14
355 - 400	10	22
490 - 510	10	4
690 - 710	50	18
800 - 850	50	40

Data Rate vs TX power vs Tx beam width

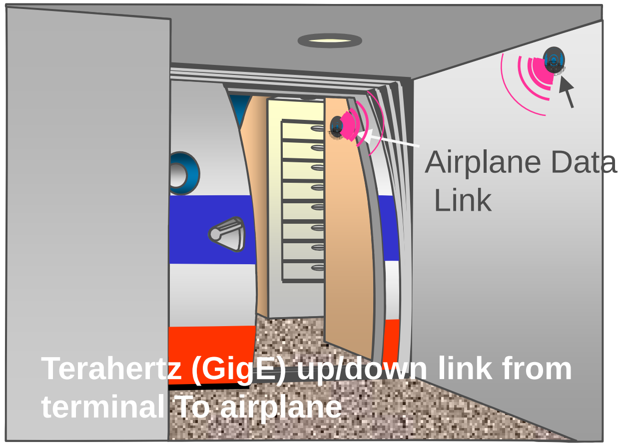




0.01 – 0.3 µm 3500 THz | 0.3 - 0 .7µm 350 THz | 1.0µm 300THz | 3.0µm 100THz | 30.0µm 10 THz | 300.0µm 1THz | 1000.0µ 300 GHz | 100 GHz

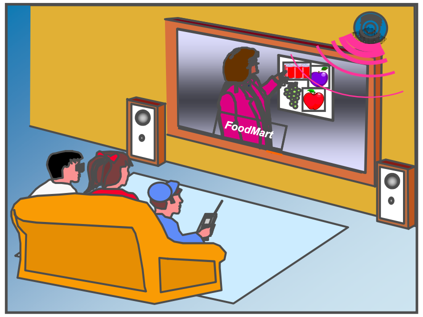
Initial THz Communication Applications

Short-distance high-data rate transfer for communications, entertainment, manifest and inventory control

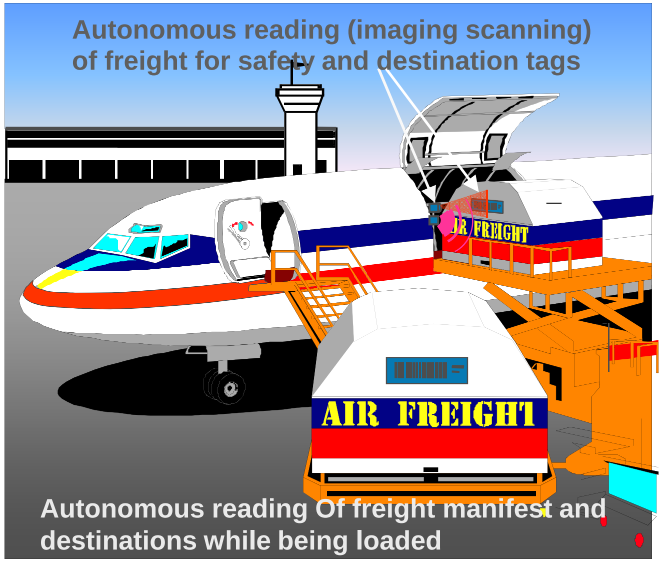


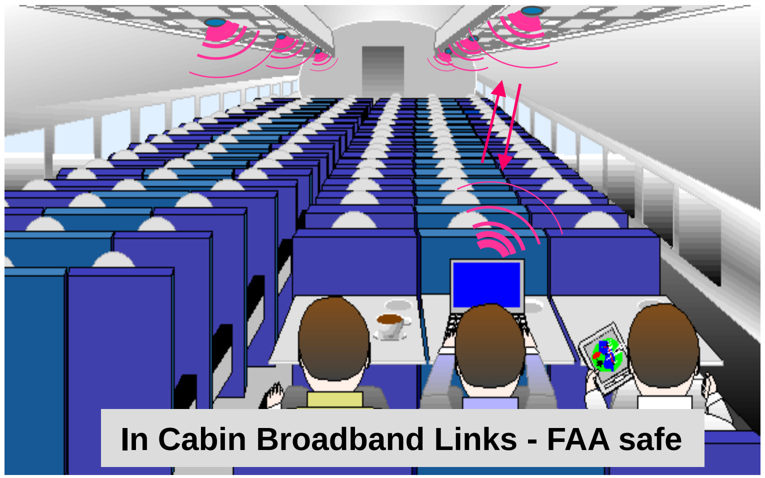
Education, Business Information And Telepresence Services

Electronic Entertainment, Gaming, Shopping, Smart Home And Medical Monitoring PAN's Next Gen IRDA's

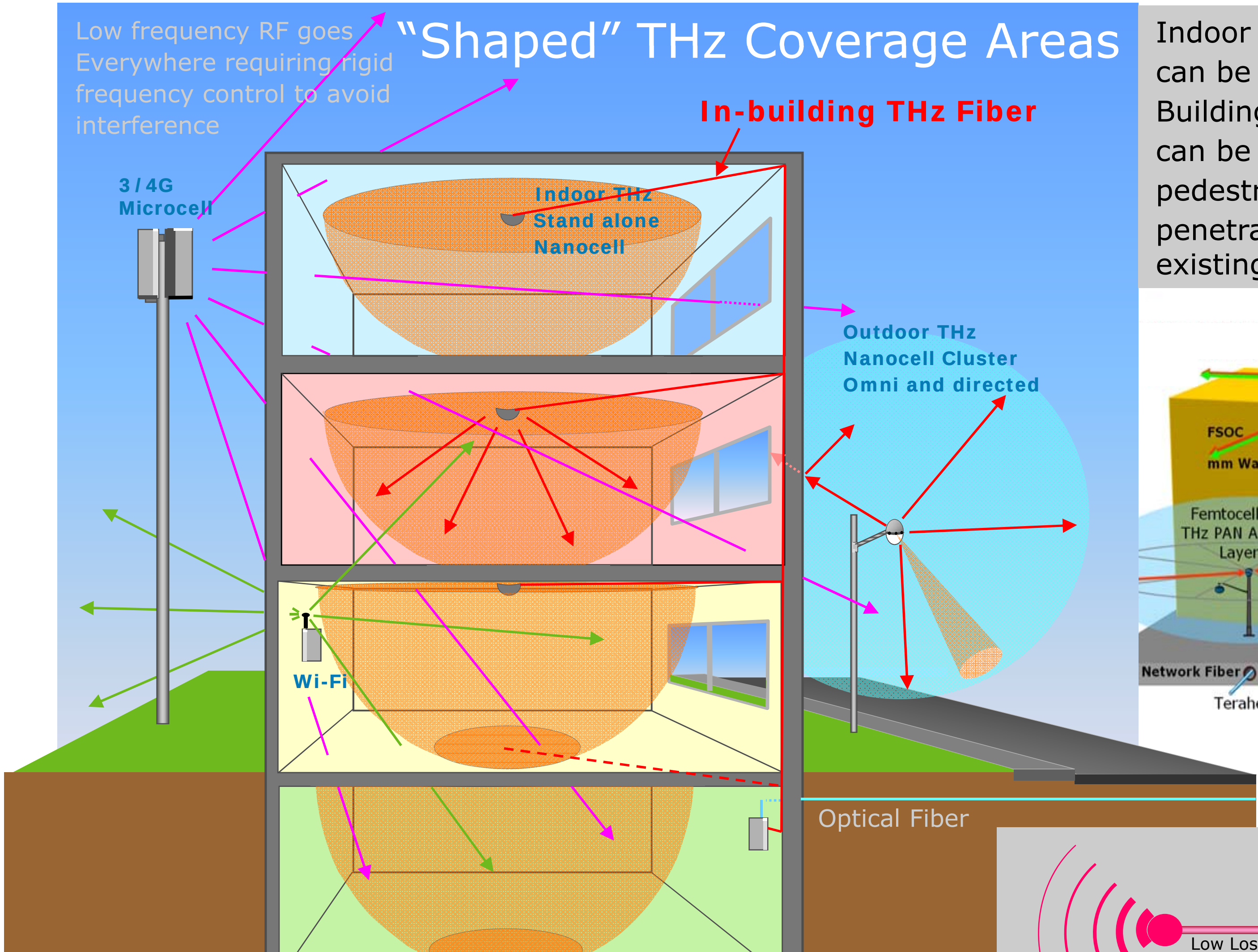


Digital Download Kiosk's for high speed video and data downloads, omni-directional Transmission 10+Gbps

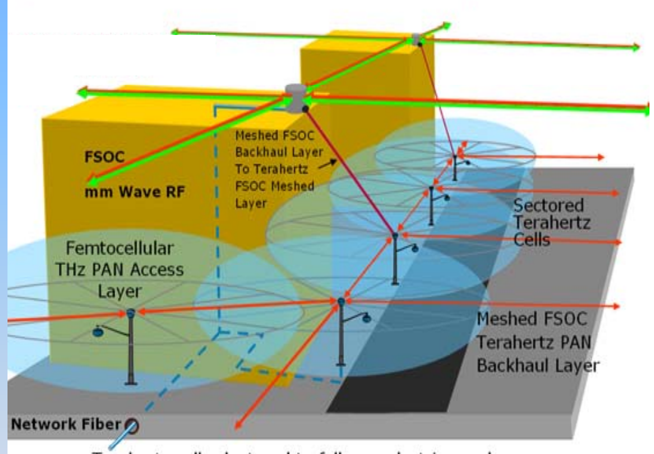




And later…. Longer distance "directed beam" applications for shaped coverage

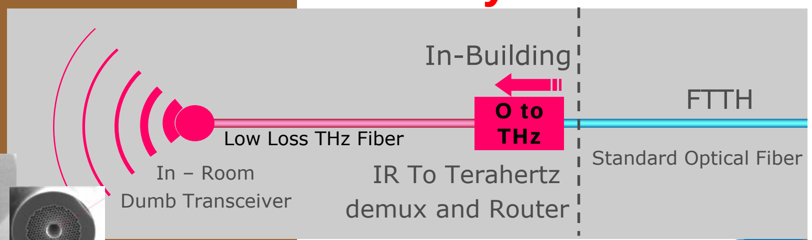


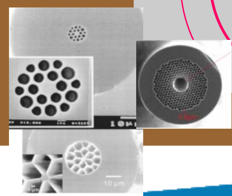
Indoor THz Nanocells transmissions can be **contained** within rooms and Buildings. Outdoor nanocell clusters can be **shaped** around vehicle and pedestrian traffic and will not easily penetrate indoors to interfere with existing THz systems.



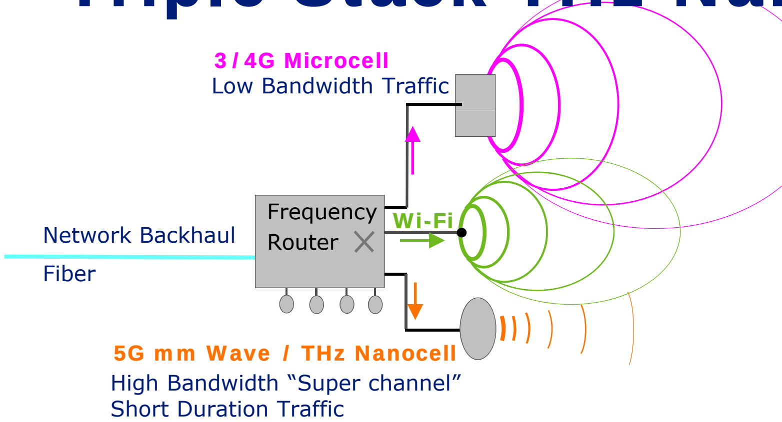
Terahertz cells clustered to follow pedestrian and vehicular neighborhood layout

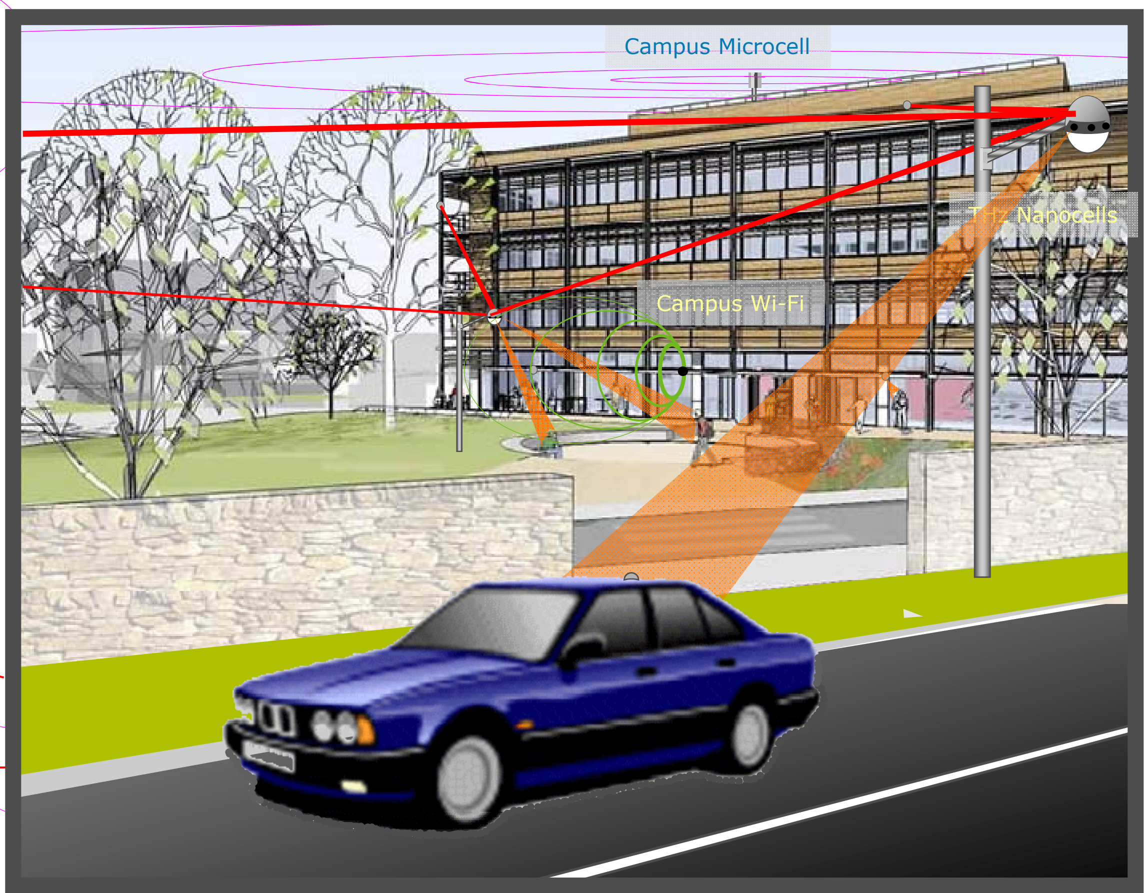
Holey THz Fiber

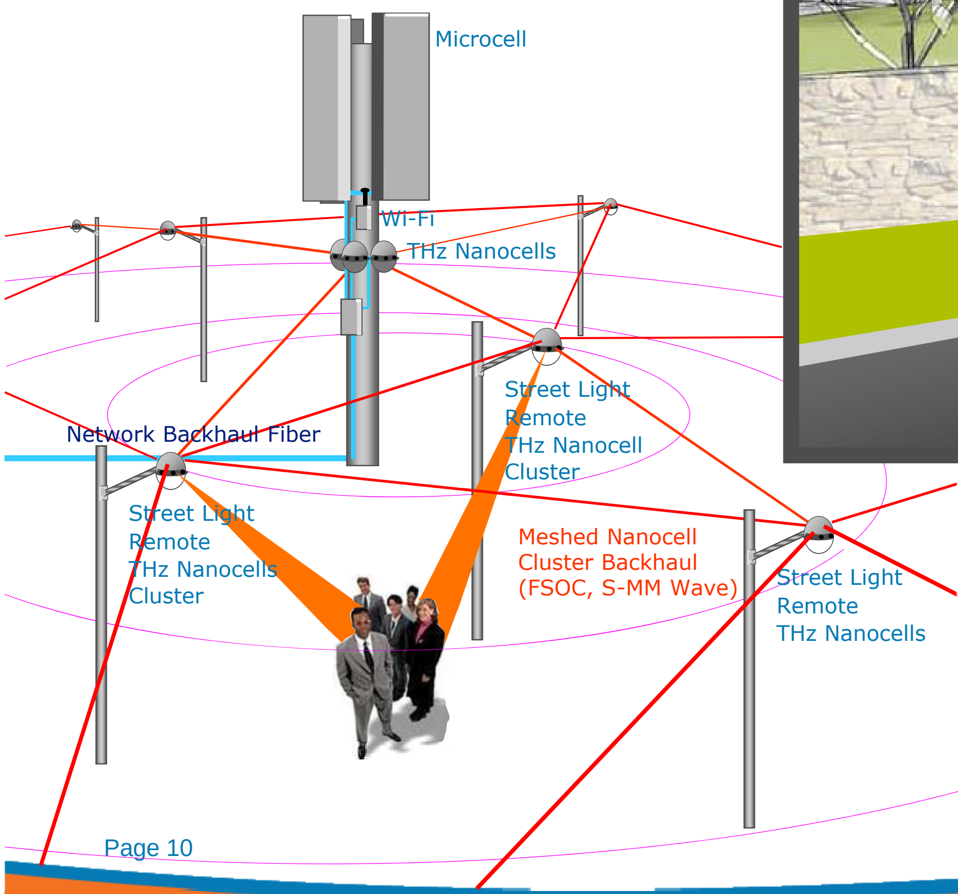




Triple Stack THz Nano Cell Cluster







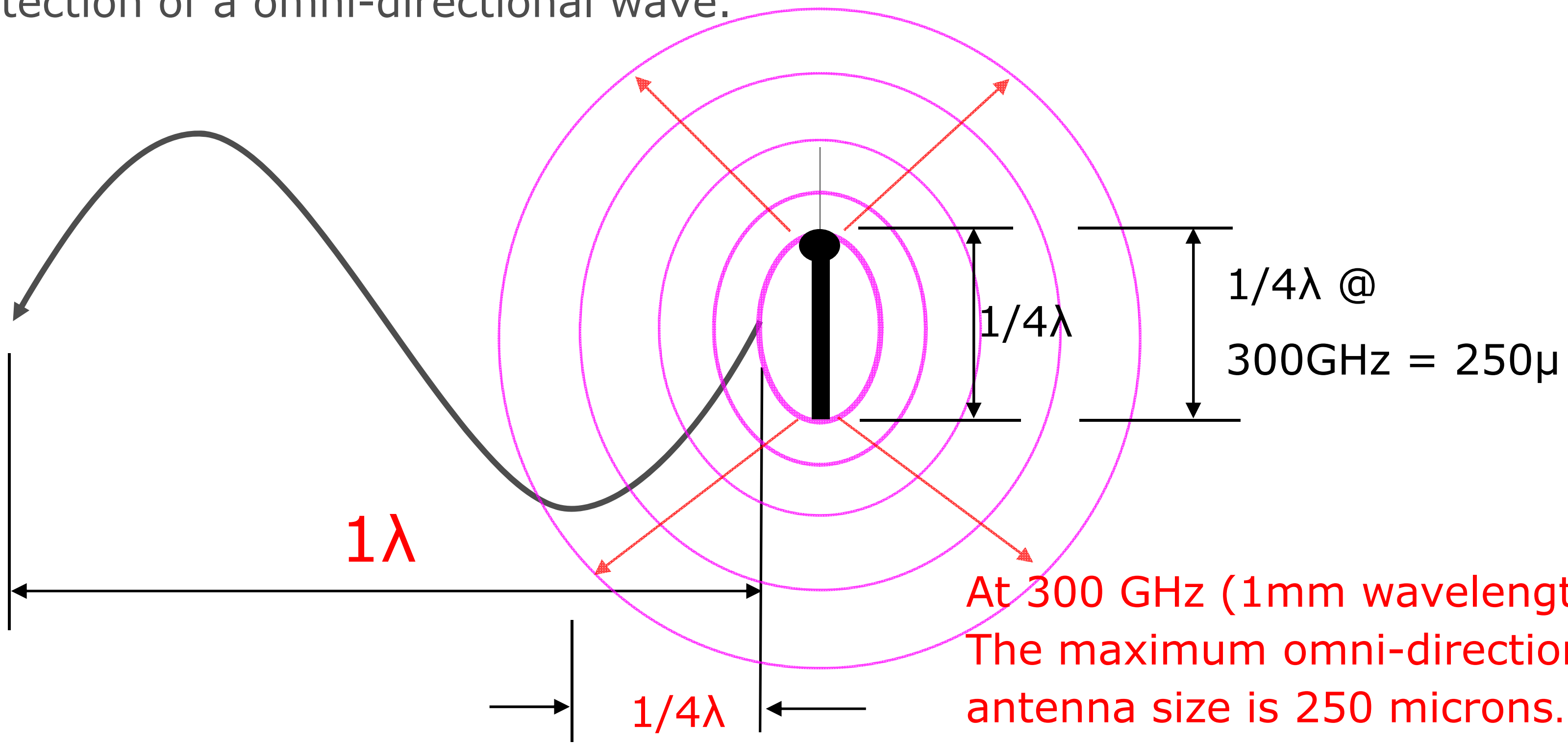
Triple Stack Concept

- Use existing Cellular and Wi-Fi infrastructure for low bandwidth services such voice, low bandwidth media services
- Utilize proposed 5G nano-cellular layer (mm Wave/THz) for high speed large bandwidth short burst data and media downloads
- Utilize frequency router for layer transport decisions
- Utilize software radio and multiple antenna head end for flexible spectrum selection
- Non-Interfering layers

Quarter Wave Antenna Problem

at mm Wave and THz Frequencies

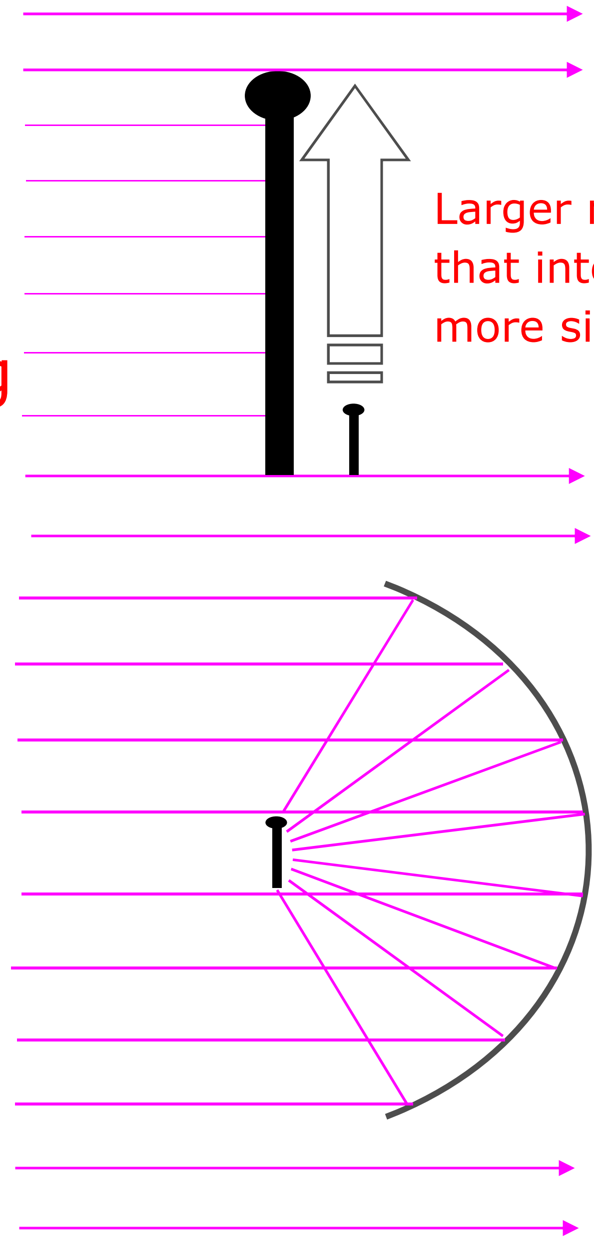
Cellular Antenna Wave Theory requires that the transceiver antenna be a quarter wave length (or less) for the maximum excitation, propagation and detection of a omni-directional wave.



At 300 GHz (1mm wavelength) The maximum omni-directional antenna size is 250 microns….. For a receiver this is a very small signal collecting area!

Best option to increase signal-to-noise ratio is via geometric scaling of the antenna

Increasing the antennas collecting aperture provides antenna gain



Larger multiple lambda antenna that intercepts and collects more signal

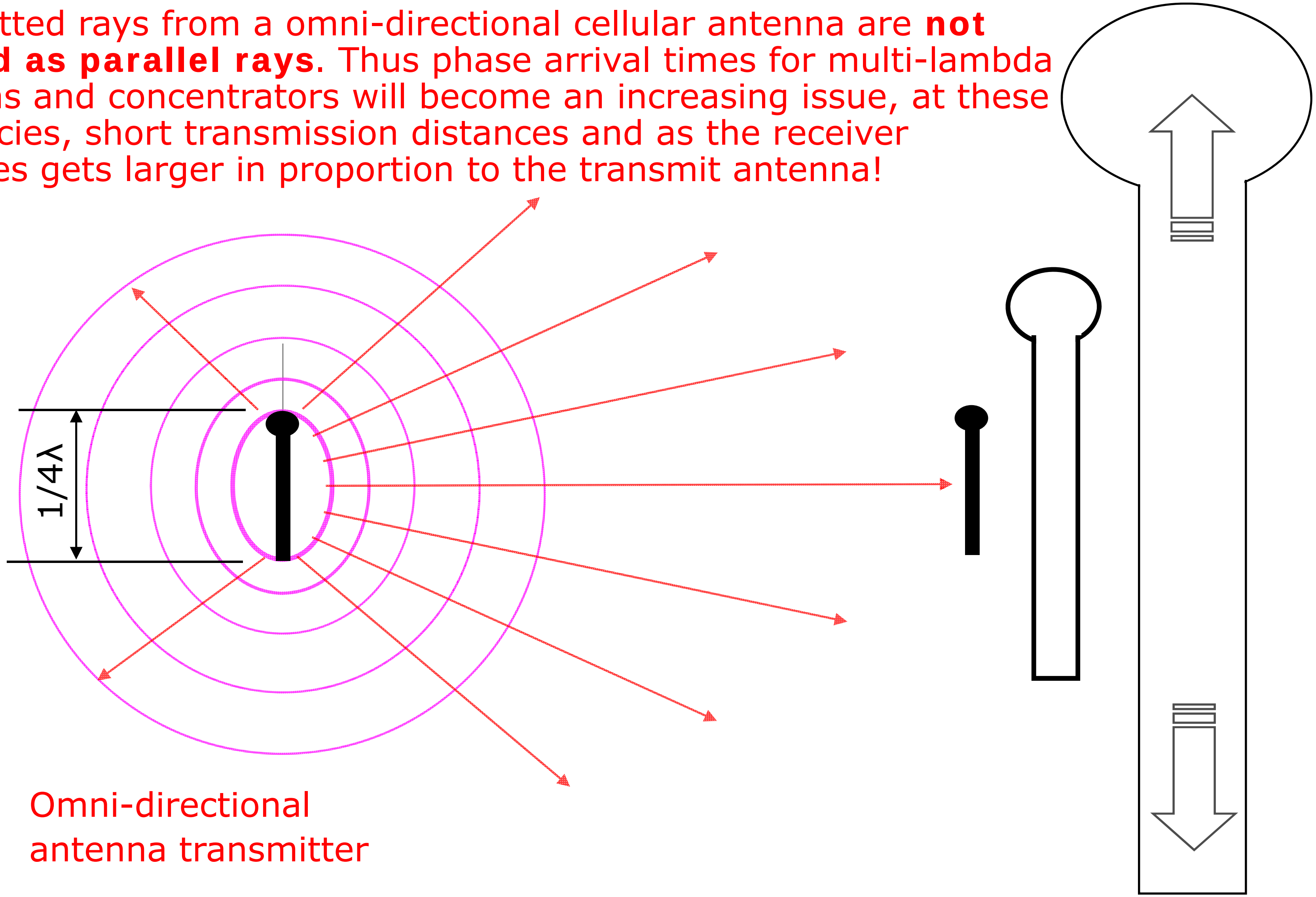
Or

¼ Wave antenna with larger collecting area concentrator to collect and concentrate more signal onto the detector

But!

From a Ray Modeling Perspective

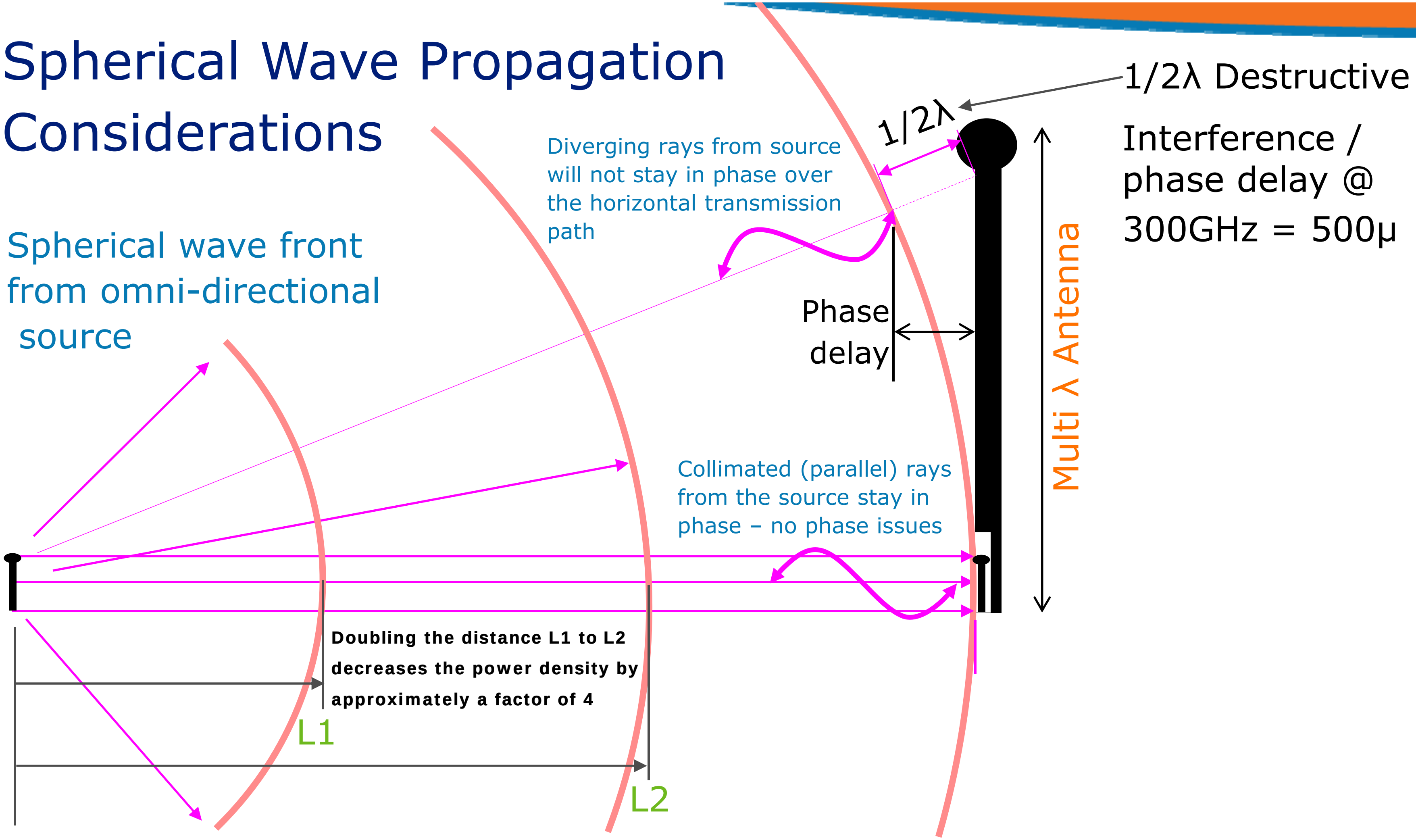
Transmitted rays from a omni-directional cellular antenna are **not emitted as parallel rays**. Thus phase arrival times for multi-lambda antennas and concentrators will become an increasing issue, at these frequencies, short transmission distances and as the receiver apertures gets larger in proportion to the transmit antenna!



Omni-directional antenna transmitter

at&t

Spherical Wave Propagation Considerations



- **In reality the ray paths (wave front) from an omni- directional source are divergent (as the spherical wave front shell expands away from the source).**
- **Signal power reduces per unit area due to the inverse square law.**
- **With use of multi-lambda antennas signal fades, and signal timing issues are possible due to phase arrival delay based destructive interference.**

So here’s the problem!

The inherent small size of high frequency mm Wave and THz antennas,

means for any application beyond 1 meter

Significant antenna gain will be required!

Antenna gain means beam directivity – no longer omni-directional coverage

More antenna gain equals more directivity!

More beam directivity means maintaining link alignment (LOS) is more difficult

For longer distance mm Wave and THz applications, other than fixed

point-to-point,

some level of dynamic beam shaping/steering technology will be required

What emerging technologies offer the possibility of
THz beam steering?

Micro-mirror arrays for THz beam shaping and steering

Tip, Tilt and Phase (Piston) Control

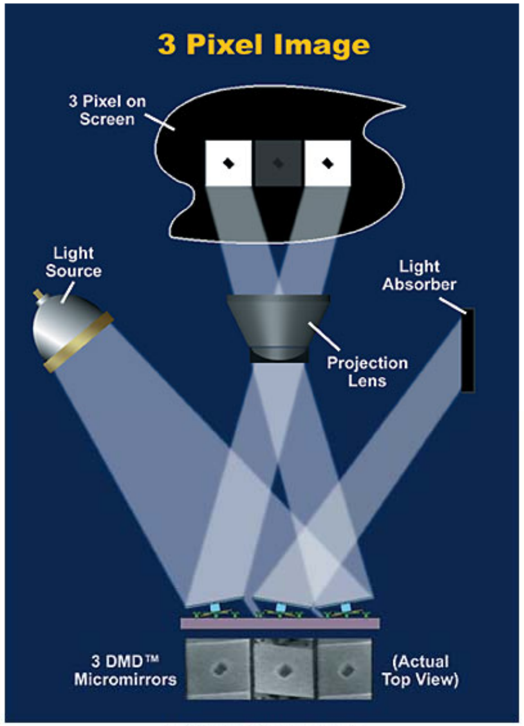
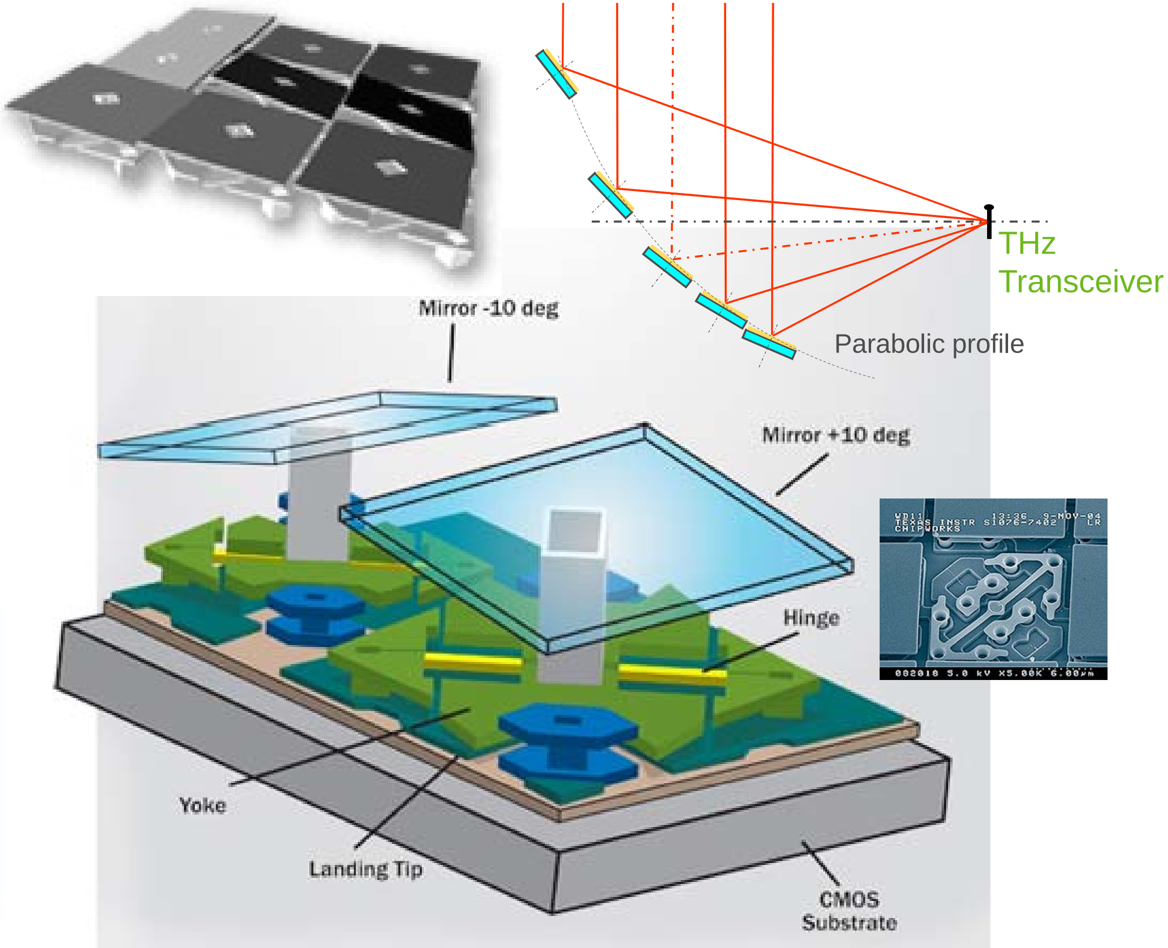
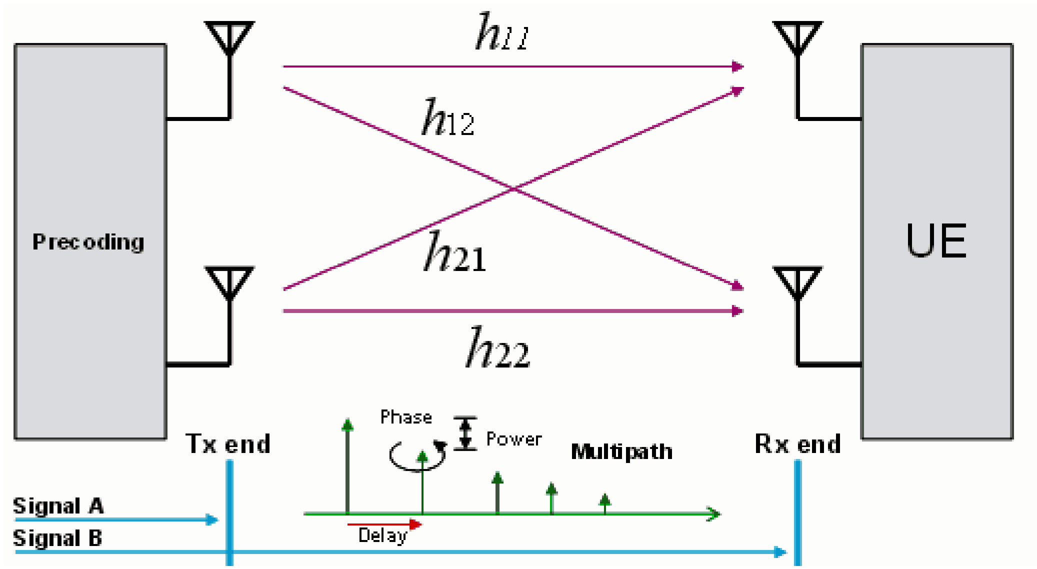


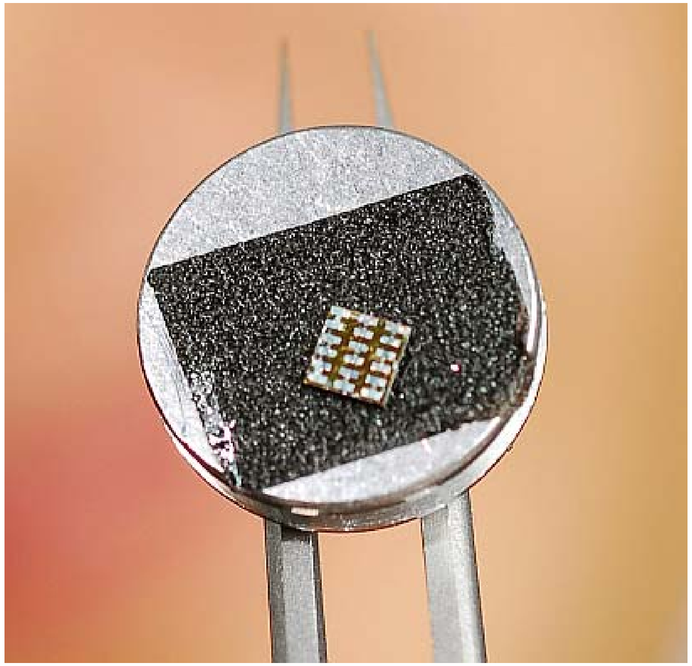
Photo courtesy Texas Instruments

Large-scale projectors use one chip for each primary color

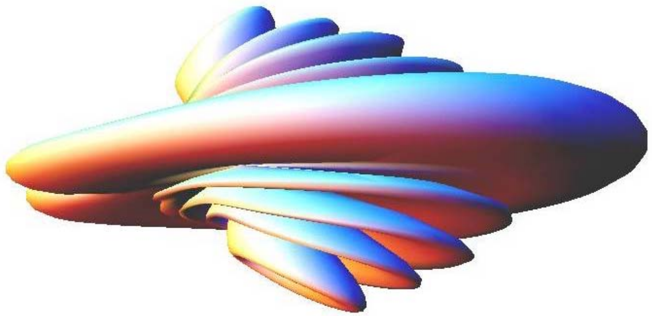


Beam Directional MIMO @ THz Frequencies?

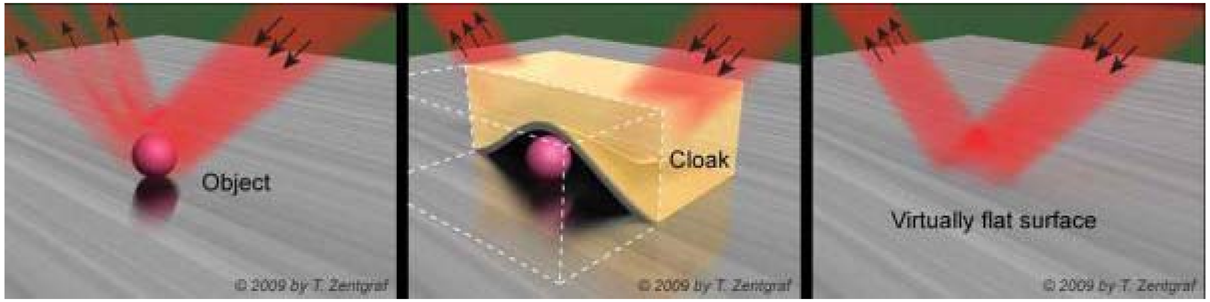




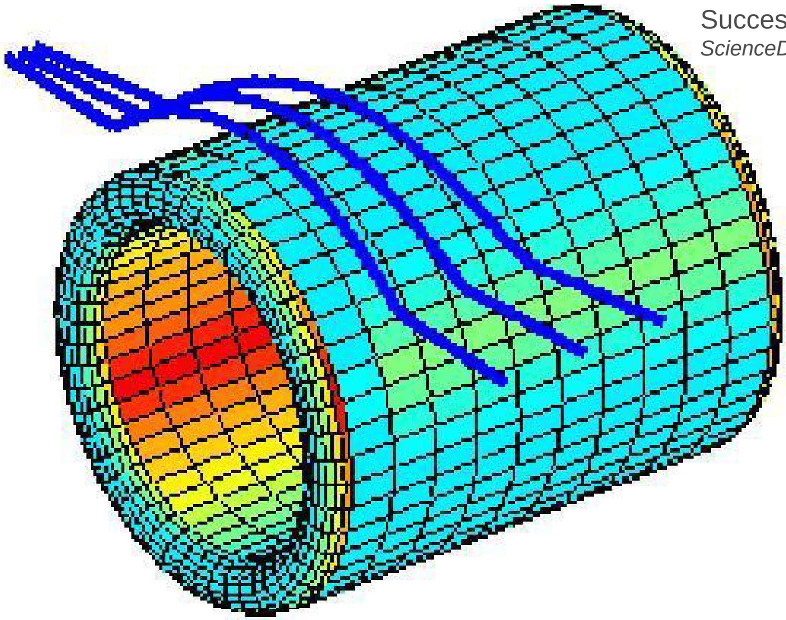
Monolithic Micro antenna arrays



Directional Smart antenna
Beam-forming pattern



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)

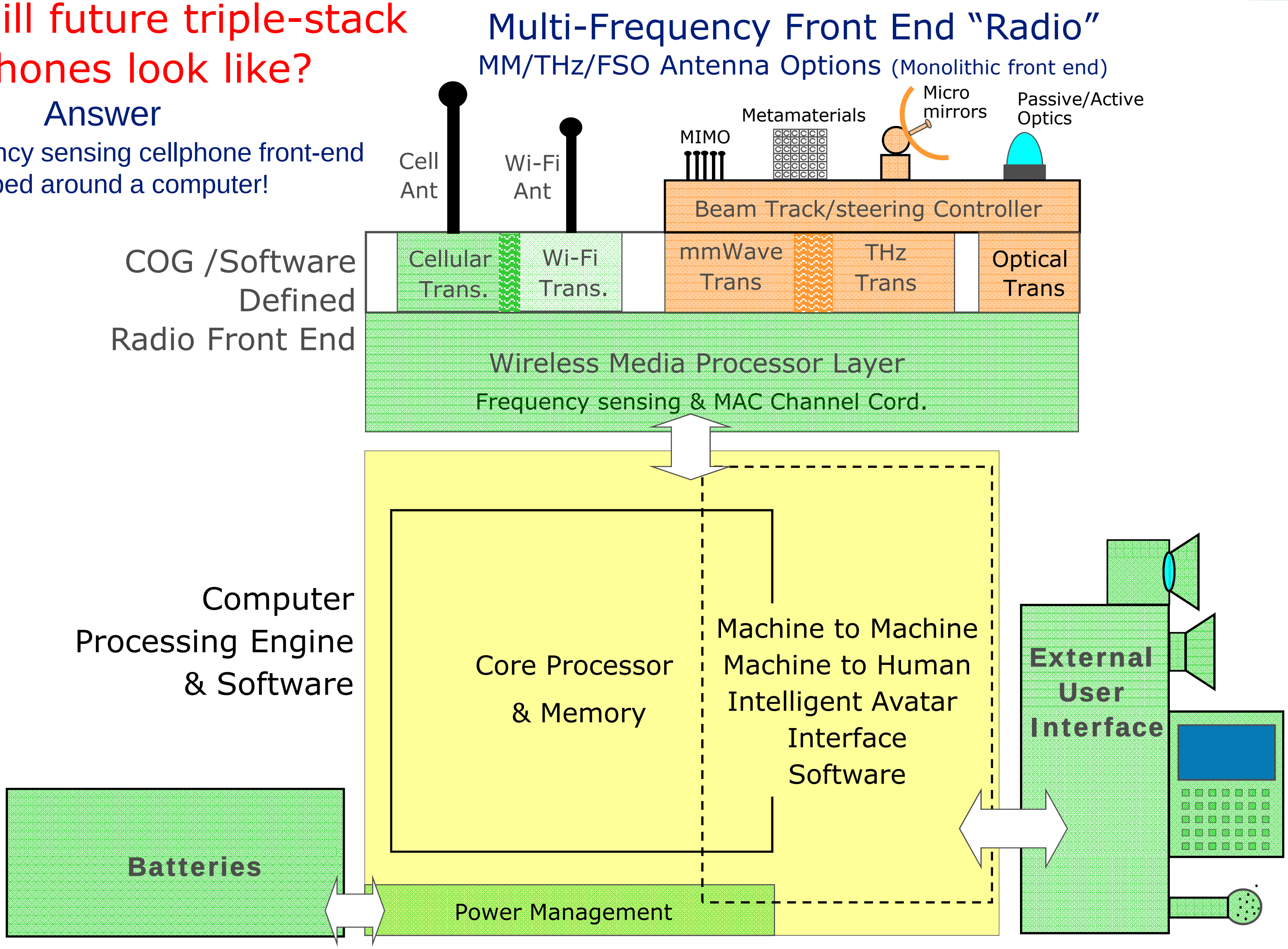
Wave shaping/steering capabilities of

Metamaterials

So what will future triple-stack cellphones look like?

Answer

A multi-frequency sensing cellphone front-end wrapped around a computer!



Multi-Frequency / Multi-Antenna Software Defined Radio "Cellular" Device Block Diagram

A Very Short List of Near Term THz Considerations

- **ITU spectrum settlement** – resolve the issued between science and active service spectrum concerns
- **RF to THz, Optical to THz or native THz devices** - What choices what challenges?
- **Room Temp THz Sources and detectors** - High output, low power, small size?
- **Battery Powered Requirement** – Especially for user side and handheld devices
- **Native THz modulators** - Direct THz modulation or Optical to THz?
- **Spectrum Efficiency Approach** - Bit Per Hertz/Simple Modulation? What's possible?
- **Photonic Crystals** - For precise THz Frequency channeling, what other choices (metamaterials)?
- **THz Holey / Solid fibers** – To avoid molecular attenuation losses for in-building device distribution
- **Beam steering and tracking technologies** – MIMO, metamaterials, active liquid lens & mirror arrays
- **Integrated multi-frequency (cellular, mmWave and THz) transceiver**
- **"Radio" front end with frequency router and sensing**

Conclusion

Market and customer demands, and a new generation of advanced media rich mobile devices are placing unprecedented pressure on network wireless capacity. Expansion of bandwidth capacity by 4G and LTE technologies utilizing traditional cellular frequencies will have limited long term benefit and will not likely keep up with exploding consumer bandwidth demand. What part software defined radio, intelligent Avatar software and expansion into high millimeter and sub-millimeter frequencies and devices will play in the evolution future broadband networks remains to be seen.

Thank you - Questions?

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