Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of

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| Petition for Declaratory Ruling Regarding | ) | |
| Treatment of Rulemakings and Waivers | ) | |
| Related to New Equipment and Services | ) | ET Docket 13-259 |
| at Frequencies Greater Than 95 GHz | ) | |
| | ) | |
| Use of Spectrum Bands Above 24 GHz | ) | |
| For Mobile Radio Services | ) | GN Docket No. 14-177 |

**Comments On Terahertz Technology**

**submitted by Daniel Mittleman**

**on behalf of a group of academic researchers**

I am a Professor at Brown University in Providence RI. I am submitting this comment on behalf of myself and my faculty colleagues at Brown University and several other US universities.

For over 20 years, my area of specialization has been the science and technology of sub-millimeter and terahertz waves, and their uses in spectroscopy, imaging, and sensing. My colleagues and I feel very strongly that this region of the spectrum is poised to have an enormous economic impact. This feeling is based on the rapid pace of technological progress in the field, as well as the astounding acceleration in recent interest on the part of many companies, both in the US and abroad. We feel that this impact will be felt in many different areas. One obvious example in which submillimeter waves will play a crucial role is the area of wireless communications; however, many other examples are in the works, with some already in commercial deployment. We are submitting this comment to provide our perspectives about the technological areas in which submillimeter or terahertz waves will play a critical role in the near future. It is our hope that these considerations will inform the FCC's future decisions regarding this fruitful region of the electromagnetic spectrum.

One key concern is in the area of future wireless technologies. It is clear that there is an upper limit to the data transfer rates on existing networks, and that we are rapidly reaching that limit. It is also clear that demands for so-called 'big data' will continue to grow exponentially for at least the next several years (if not longer). This confluence of events will, without any doubt, overwhelm the capacity of existing network infrastructure. One solution that is gaining favor among researchers, as well as groups such as the IEEE 802.15 WPAN Terahertz Interest Group (IGTHz), is the idea of developing new network capabilities, not to replace but to supplement the existing cellular architecture. These new capabilities would rely on a higher carrier frequency, with a shorter range but massive (by current standards) bandwidth for high-data-rate transmission. Modeling indicates that various bands within the 100 GHz – 1 THz range can be used in such applications, for backhaul between small cells, as well as for bursty download links. This range of frequencies is simply better suited to transporting large data than the already over-utilized frequencies in the 1-5 GHz range. Routing big data to a terahertz layer would provide the opportunity to return much of the existing cellular spectrum currently tied up with data delivery back to enhance the capacity of voice services. These frequencies would coexist and not interfere with the existing cellular and Wi-Fi infrastructure. Crucially, because of the short propagation distances, narrowly focused beams that are readily achieved at these frequencies due to their small wavelength, and the opacity of most materials, these services would also not interfere with passive applications such as earth observing or astronomy. Indeed, most uses of these frequencies involve indoor applications that would be blocked by building materials from interfering with passive users, or involve outdoor applications where beam patterns could be tightly restricted to the near horizontal plane to avoid impacting passive users.

Evidently, fiber optics technology is cross-elastic for some of the envisioned communications applications, and has low hardware cost today. However, there are many obvious situations in which a wireless link is preferred or required. Moreover, fiber optic technology has highly variable installation costs that can dominate in certain applications such as unexpected needs in highly urbanized areas. In such cases radio system can be installed much faster and at much lower costs even though optical systems are less expensive generally. In the special case of restoring communications networks after a major catastrophe these radio systems fill a niche with no other viable alternative. Finally, radio systems have an intrinsic time latency advantage of about 30% due to the lower index of refraction of air versus the glass material in fiber optics.

In addition to this vision for future wireless data services, a host of other applications using the same spectral range are already in development, or in deployed use. Low-power short range terahertz systems are already being used for sensing, imaging, package inspection, security, and quality control, in a variety of manufacturing and process environments, both in the US and overseas, as well as in many basic scientific studies involving spectroscopy and imaging. This technology space already includes a number of companies in the US, both large and small, who sell systems that use terahertz radiation, and their number is growing rapidly. The ongoing advances in terahertz technologies, including rapid developments in silicon CMOS-based solutions, quantum cascade lasers, and terahertz and sub-millimeter-wave components, will continue to accelerate these trends. All of this effort is driven by compelling needs. There are many sensing and imaging tasks for which radiation in this spectral range is simply the only solution; in other cases, terahertz imaging systems may provide a more cost-effective or less hazardous alternative to other more conventional technologies such as x-ray imaging or beta gauges. Terahertz imaging systems are projected to constitute a $0.5 billion market by 2021. Clearly, issues of regulation and spectrum allocation will have a significant impact on US competitiveness in this burgeoning technology space.

In 2017, my colleagues and I are planning to create a university-based center devoted to terahertz science and technology. The goal of this Center will be to create collaborative research and development projects between our academic partners and a group of industrial affiliates from the US and around the world, all working towards the development of terahertz imaging and communications systems. For example, we envision a ten-year goal of creating a commercially viable multi-node mobile wireless network operating in the sub-millimeter range. We will produce a diverse and highly skilled group of students with a strong background in this technology area, to provide US companies with the trained workforce necessary to sustain these efforts. Critically, this Center could also serve as a nexus for conversations about spectrum allocation, regulation, health and safety considerations, and the development of standards. We will invite all of the various stakeholders with concerns about future uses of millimeter and sub-millimeter waves to engage in the Center. This will provide a central point from which informed policy recommendations can be developed.

The goals for this technology are not merely "pie in the sky" visions of a few academics. For example, the graph below shows a summary of recent research results (as of late 2016) from terahertz wireless communications test beds around the world. This plot, adapted from reference [1] with the

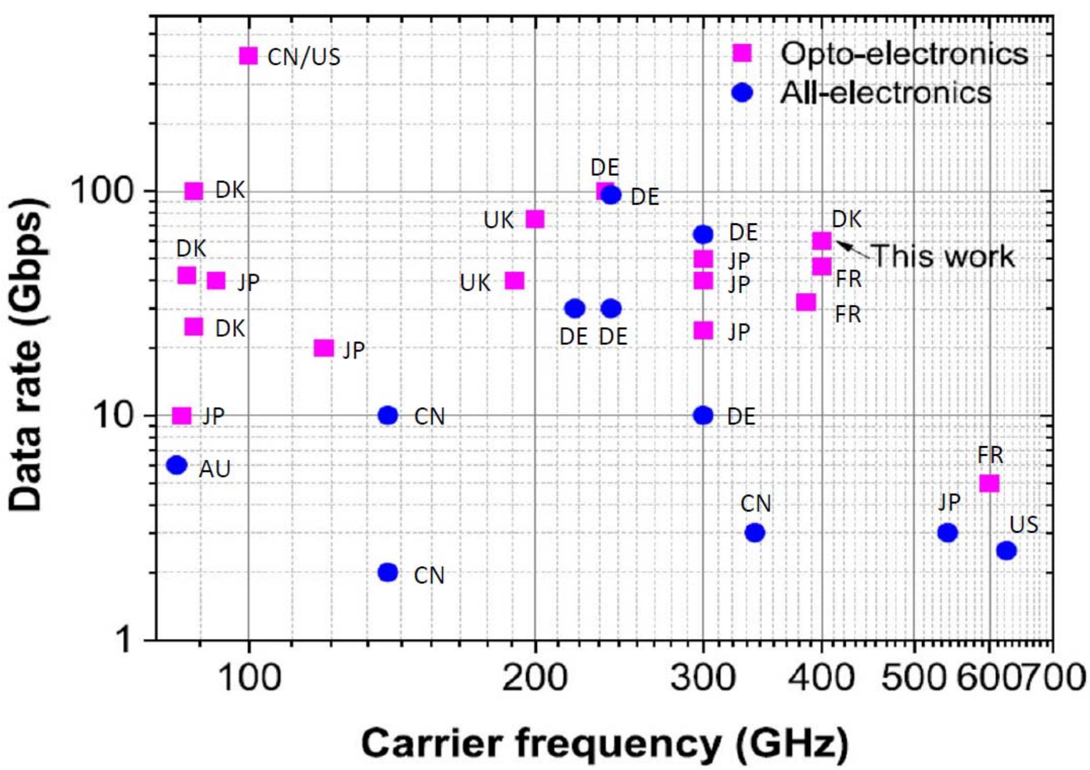


**Figure 1** – A summary of all of the recent experimental demonstrations of terahertz wireless links, plotted to indicate the achieved data rate and carrier frequency used in each experiment. Each data point is labeled according to the nationality of the authors. The point labeled "this work" refers to reference [1], from which this plot was adapted with the assistance of its authors. Note that only two of these include co-authors from the US.

[1] X. Yu, et al., *IEEE Transactions on THz Science and Technology*, vol. 6, p. 765 (2016).

assistance of its authors, convincingly demonstrates two facts: (1) the field of terahertz wireless communication research is active and growing, with rapid progress in the development of tools and systems that can solve real-world problems; and (2) essentially all of this research is happening outside of the US. This second fact is alarming, because US leadership in wireless technology is at risk, as is the enormous economic benefit that has resulted from that leadership. Our competitors around the world are running ahead in this technology arena. If we remain passive, then by the time these networks are ready for commercial deployment, the US will no longer be the world's leader, and the majority of the economic impact will flow elsewhere.

Figure 1 represents merely one example illustrating the explosive growth in the terahertz field in recent years, and the tremendous potential perceived by research communities around the world.

We must emphasize the important role played by agencies such as FCC in the future growth of this technology in the US. A lack of clarity in the processes for spectrum allocation and the rules regarding sale and use of terahertz equipment will undoubtedly inhibit innovation and commercial growth. Even in the academic world, we are substantially impacted by this uncertainty. For example, the Center effort mentioned above will only be successful with the active participation of companies who stand to benefit from research collaborations, technology transfer, and access to a pool of trained students. Yet, many companies may be reluctant to put resources into such collaborations when they perceive regulatory roadblocks which would inhibit their future ability to exploit the fruits of those labors.

As the representative of this group of the nation's foremost experts in terahertz and sub-millimeter-wave science and applications, I urge you to carefully consider all of the envisioned uses of these technologies in your deliberations. Our strong opinion is that technologies which exploit terahertz and submillimeter waves are poised to have a significant economic impact in the near future, creating jobs and stoking innovation in the US and abroad. Federal agencies such as FCC are in a position to foster this emerging area, to help restore and maintain our nation's competitive position. With many exciting new technologies on the near horizon, the time to begin this discussion is now.

I and my colleagues are at your disposal as a resource for further information or discussions.

Respectfully,

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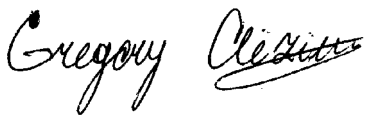

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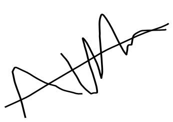

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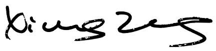

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