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# Wireless 5G Radiofrequency Technology – An Overview of Small Cell Exposures, Standards and Science

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**ABSTRACT** 5G small cell antenna systems are among the latest technologies that support wireless communications by the transmission of radiofrequency (RF) signals. Coded RF signals in the range of 0.6 to 47 GHz from fixed small cell antennas supplement wireless communications from 3G and 4G wireless systems. This paper describes the propagation of RF signals from a pole-mounted 5G antenna and how the signal strength declines with distance for a representative installation operating at 39 GHz. The far field exposure from the antenna is compared to those from multiple natural and man-made RF sources. In the United States, RF exposure standards are issued by the Federal Communications Commission. We review the history and derivation of these standards in relation to other national and international standard-setting bodies. Some have raised concern as to whether sufficient health and safety studies have been performed on RF from 5G systems, but the commonality of RF frequencies up to 300 GHz enables health agencies and standard-setting bodies to assess the potential for effects across this frequency spectrum. A 5G RF signal does not have a different mode of action than a lower frequency communication signal; both involve tissue heating at sufficient field strengths. The key difference for 5G frequencies above 6 GHz is that the body's electrical properties better limit energy deposition to a shallow depth, largely confined to superficial layers of the skin. Research to date has not provided a reliable scientific basis to conclude that RF communication signals at 5G or other frequencies will cause or contribute to adverse health effects.

**INDEX TERMS** Radio frequency, RF, 5G mobile communication, millimeter wave communication, standards, health and safety.

## I. INTRODUCTION TO RADIOFREQUENCY WIRELESS COMMUNICATIONS

Radiofrequency (RF) signals, first used for broadcast radio transmission about 100 years ago, are a form of invisible energy described as electromagnetic waves or fields. These signals are the basis for all wireless technologies, including traditional broadcast radio, television, cellphones, cordless phones, garage door openers, baby monitors, wireless computer networks, security systems, radar, and global positioning systems.

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These wireless technologies communicate using radio transmitters and receivers that exchange coded signals with frequencies from 3,000 Hertz (Hz) ($3 \times 10^3$ Hz) to 300 billion Hz ($3 \times 10^{11}$ Hz),i.e., 300 Gigahertz [GHz]). The strength of these signals is typically measured in units of milliwatts per square centimeter (mW/cm$^2$).

Cell phones and the cell sites that transmit information to our cell phones commonly operate with frequencies between 0.5 GHz (0.8 billion Hz) and 40 GHz (40 billion Hz). Whereas the specific frequencies depend on the wireless provider, 2G networks typically use the 0.9 GHz to 1.8 GHz spectrum, 3G networks rely on the 0.7 GHz to 3.5 GHz spectrum, and 4G networks are built on the 0.5 GHz to 5.8 GHz spectrum. The new 5G networks will be built using these latter


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frequencies, as well as those up to 47 GHz. For example, telecommunication companies are installing system additions at 2.5 GHz (Sprint); 0.6 GHz, 28 GHz, and 39 GHz (T-Mobile); and 28 GHz (Verizon, AT&T) [1].

The newest aspect of 5G technologies involves the addition of small cell antennas. These antennas provide high speeds and greater bandwidth to 5G networks to support more wireless devices. Such capabilities enhance broadband support for video communications, machine communication from environmental sensors, communication with autonomous vehicles, and ultra-reliable, low-latency industrial process controls, including medical technologies [1]. These capabilities are achieved by locating small cell antennas closer to users, by transmitting signals at these higher frequencies, and by steering signals to users in a small area in a single direction rather than in all directions, as do radio station antennas.

Along with these benefits, there are associated challenges to the use of 5G technology including the cost of installing many more additional antenna nodes because of the shorter distances and building interference, and the adoption of new networking standards to attain full performance [1]. Power consumption from both the antenna nodes and connected devices is an additional challenge. Some estimates indicate the current information and communications technology industry accounts for as much as 5% of the world's carbon footprint [2]. Thus, energy efficiency is a key metric in the design of 5G networks [3]. Another challenge is the potential concern about health and safety effects of RF energy. While 5G systems can use higher frequencies than used by earlier wireless generations, general population exposure to RF may decrease since small cell, directionally-limited transmissions require less power, and less RF energy is absorbed within the body at higher frequencies. That reduction may be offset to some extent by the greater density of small cells in the future compared to existing 3G and 4G systems [1].

This paper provides an overview of the RF signals from fixed 5G antennas, comparisons of 5G exposures to other common RF sources, Federal Communication Commission (FCC) standards for RF exposure in the United States, and a discussion of how scientific and health assessments that inform the FCC and international standards relate to questions about the safety of 5G exposures.

## II. RADIOFREQUENCY SIGNALS FROM 5G SMALL CELLS

To function, a cell site's transmitter signal must be strong enough to reach a cell phone and not be interfered with by other signals. The power of the signal from the cell site's transmitter is limited by the capability of the transmitter and peak power. For example, a small cell transmitter is typically expected to transmit less than 120 watts effective radiated power (ERP). For perspective, consider that 1 watt is 1/60th the power of a typical incandescent light bulb. A light bulb transmits light, not RF fields, but both light and RF are electromagnetic energy and are measured in watts. In addition, whether light or RF, the strength of this signal decreases rapidly with distance from the source.

To provide context for understanding how the strength of wireless signals from a 5G small cell transmitter diminishes with distance, we calculated typical exposures from a 60-watt ERP 5G source at 39 GHz mounted on a pole 25 feet above ground.[1] The example described here is one application of a 5G wireless technology; other applications may differ in the details. The exposures in Fig. 1 are expressed as a percent of the FCC's maximum permissible exposure limit on power density of exposures of the general public (1 mW/cm$^2$) that is applied to the range of frequencies between 1.5 and 100 GHz [5]. This is a convenient way to compare exposures from RF sources operating at different frequencies and exposure limits.

Fig. 1 illustrates the signal strength from an example 5G small cell antenna mounted on a telephone pole (transmitting at 39 GHz). The signal strengths in Fig. 1 show that exposures to RF from the small cell antenna are very low and diminish quickly with distance. RF signals from the small cell antenna measured inside buildings would be even lower. The calculated exposure in Fig. 1 at 50 feet is 0.7% of the FCC's standard directly in the main beam of the antenna, assuming all transmitted power is focused in a single direction; exposures outside the main beam of the antenna are lower. Small cell antennas are mounted far above the ground, therefore exposure is in what is termed the far field. At farther distances, the exposure is progressively lower, becoming less than 0.1% at 150 feet and vanishingly small at 500 feet.

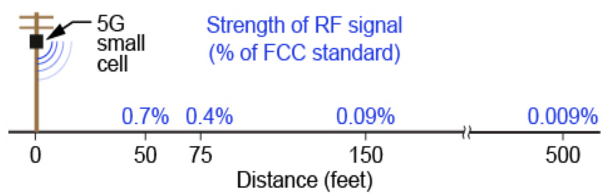


**FIGURE 1.** **5G signals from a pole-mounted small cell antenna as a function of distance.**[2]

Another way to compare the RF exposure of common devices or sources is to rank them by relative intensity. Fig. 2 shows the contribution of eight common sources of RF exposure expressed as a percent of the FCC limit. Fig. 2 illustrates that the RF signal at a middle distance from a 5G small cell antenna is roughly 5 times lower than a cordless phone and 20 times lower than a cell phone, both of which are typically used close to the body, but is higher than some other common sources of RF. These values represent typical exposure levels. If a person were to use a cell phone near a

[1]The FCC has determined that certain wireless facilities with total power up to several thousand watts or mounted more than 32.8 feet (10 meters) above ground are categorically excluded from further RF evaluation because "they are unlikely to cause exposures in excess of the FCC's guidelines" [6].

[2]The maximum calculated exposure in this figure is at 50 feet directly in the main beam of the antenna, assuming all transmitted power is focused in a single direction; exposures outside the main beam of the antenna are lower.

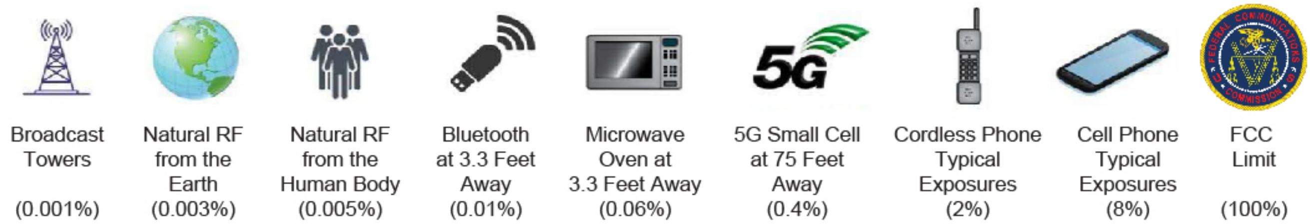


**FIGURE 2.** Ranking of common examples of RF sources by percent of FCC limit from lowest (left) to highest (right).

5G small cell antenna, then the cell phone may only need to transmit at a low power level to communicate over the shorter distance, and RF exposure from the cellphone could be lower. It may be surprising to some that the human body and the earth itself are sources of exposure throughout the RF frequency range, including at 5G frequencies.

## III. STANDARDS FOR RADIOFREQUENCY EXPOSURE

IEEE first developed RF exposure standards in 1960. Its active standards now include those that cover the use of RF by the general public and in industrial and military environments [7]–[11]. Another expert organization, the National Council on Radiation Protection and Measurements (NCRP), also developed standards for RF exposure [12].

After cell phones came onto the market in 1983 and use became widespread, the FCC revised its guidelines for RF exposure in 1996 to ensure that devices that transmit RF, such as communication devices, operate safely and do not interfere with other services [4], [13]. To ensure its guidelines were based on established science, the FCC looked for guidance to other organizations that had conducted health risk assessments and made recommendations for the safe use of RF energy, including the NCRP and IEEE [12], [14]. The IEEE committee that updated their RF standard in 1992 was dominated by members from academic and government organizations, with small representations from industry and other groups, and included physicians, scientists, and engineers [15]. The FCC provided its own input and distributed its proposed limits to federal health and safety agencies, including the Environmental Protection Agency, the Occupational Safety and Health Administration, the National Institute of Occupational Safety and Health, and the Food and Drug Administration (FDA), and received comments back from these agencies. The FCC's rules reflect the input from these health and safety agencies.

The earliest studies of RF identified the effects of exposure arising from the heating of water molecules as the result of friction by the movement of atoms or molecules. It was then determined that RF heating did not change the structure of molecules by ionization. Research over many decades confirms these observations and informs the basis for health and safety standards. The FCC standard, like many other national and international RF standards, was set to ensure that exposure does not reach a level that would raise

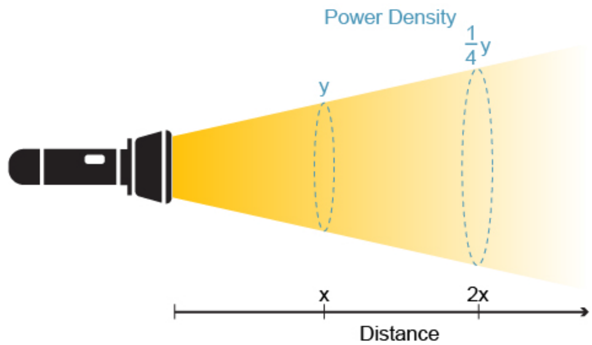


**FIGURE 3.** Power density is analogous to the brightness of a light focused on an object. The light on a piece of paper held 1 foot away from a flashlight is brighter than when the paper is held 2 feet away.

whole body temperature. An increase in body temperature by a small amount—much like what we experience when we exercise, or through any number of daily occurrences—is not an adverse outcome. While the human body is used to routinely adapting to this type of temperature increase, the FCC exposure limit is set to avoid any such increase, and is set below the level at which minor behavioral changes in animals occur with body heating [11], [13], [14].

This means that for a member of the general public, the whole-body exposure limit to RF at frequencies above 2 GHz is 50 times lower than this threshold. The FCC standard is designed to protect everyone, including sensitive populations such as children and the elderly, from the effects known to occur with sufficiently high exposure to RF energy (i.e., raising the temperature of exposed body tissues).

The FCC and federal health agencies, including the FDA, recently reviewed the FCC RF exposure limits; the FCC found a "lack of data" and "no appropriate basis" to amend them [16] and the FDA concluded that "there are no quantifiable adverse health effects in humans caused by exposures at or under the current cell phone exposure limits" [17].

The variation in RF exposure with distance is analogous to the brightness of a light focused on an object (Fig. 3). The light on a piece of paper held 1 foot away from a flashlight is 4-times brighter than when the paper is held 2 feet away.

## IV. HEALTH QUESTIONS ABOUT RF

Over the years, research studies have investigated other effects of RF exposure, but where these effects were confirmed, they occur at higher levels of exposure than those which cause behavioral disruption from overheating, and are far above exposure levels established in standards and FCC guidance. Claims for still other effects at levels below RF exposure limits also were reviewed by scientific and regulatory agencies, but these data are not accepted as reliable because they are not consistent or reproducible, and are not supported by any plausible biological explanation as to how they could occur [11], [18]–[25].

The World Health Organization (WHO) established the International EMF Project in 1996 to coordinate research funding and assess the scientific evidence of possible health effects of electromagnetic frequencies in the range that includes radio waves [26]. In 2013, a review conducted by an agency of the WHO concluded that ''[t]here is limited evidence in humans for the carcinogenicity of radiofrequency radiation. Positive [statistical] associations have been observed between exposure to radiofrequency radiation from wireless phones and glioma, and acoustic neuroma'' [27]. This conclusion was based largely on the statistical associations reported in several studies of RF exposure from mobile phone communications, including ''a very large international, multicentre case-control study and a separate large case-control study from Sweden on gliomas and meningiomas of the brain and acoustic neuromas.[3] While these studies showed an association between glioma and acoustic neuroma and mobile-phone use, specifically in people with the highest cumulative use of mobile phones, they all were affected by selection bias and information bias to varying degrees. The comparative weakness of the associations in the INTERPHONE study and inconsistencies between its results and those of the Swedish study led to the evaluation of ''limited evidence for glioma and acoustic neuroma'' [27]. The WHO's classification of the evidence as limited, however, does not imply that a cause-and-effect relationship has been established between RF exposure and cancer development. To the contrary, it means that the study results provided no clear indication of a causal association and that limitations of the studies preclude ruling out other explanations, including chance, confounding, and bias, for the limited statistical associations reported.

A 2015 comprehensive review of the literature commissioned by the European Commission concluded ''[o]verall, the epidemiological studies on mobile phone RF EMF [electromagnetic field] exposure do not show an increased risk of brain tumours. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region'' [31]. The current view of the research by the WHO is that ''[b]ased on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields. However, some gaps in knowledge about biological effects exist and need further research'' [26]. The WHO recommends that countries adopt international exposure guidelines [11], [25], which are the same as the limits set by the FCC for RF frequencies from 2 to 300 GHz [13].

The Center for Devices & Radiological Health of the FDA just released a review, conducted by their doctors, scientists, and engineers, of human epidemiologic and *in vivo* (animal) studies on RF exposure published from 2008 to 2018. They concluded that the epidemiologic studies indicated ''that there is no quantifiable causal link between RFR [radiofrequency radiation] exposure and tumor formation'' and that of the *in vivo* studies reviewed, ''none have adequately demonstrated that localized exposure of RFR at levels that would be encountered by cell phone users can lead to adverse effects'' [17]. The FDA's review of the *in vivo* research included the 2018 technical reports released by the U.S. National Toxicology Program (NTP) on whole-body exposure of rats and mice to two specific modulations of RF signals from cell phones. The NTP study reported ''clear evidence of carcinogenic activity'' related to malignant schwannomas and ''some evidence of carcinogenic activity'' related to malignant gliomas, both based on associations observed in male rats only [32], [33]. In their review, the FDA disagreed with the NTP's final conclusions regarding the level of evidence of carcinogenic activity, stating that the effects of whole-body RF exposure to rats and mice cannot be directly related to the localized exposures humans receive when using a cell phone. Limitations of the NTP study also were discussed in 2018 by the International Commission on Non-ionizing Radiation Protection (ICNIRP) in a note explaining why the study ''does not provide a reliable basis for revising the existing radiofrequency exposure guidelines'' [34].

As new 5G communication systems are proposed and deployed, some have raised questions as to whether sufficient health and safety research has been performed on the new frequency bands above those used by existing 2G, 3G, and 4G systems. Much of this concern stems from research on potential effects of the existing wireless systems and other RF sources, not 5G [35]. For animal studies of RF exposure, the authors [35] also point to the predominance of studies of pure carrier frequencies without modulation and the absence of real-life interactions with chemical and biological toxins. A recent review of biological studies of a variety of species that focused specifically on the range of frequencies that are used, or may be used, by 5G wireless systems did not identify any adverse effects or ''a consistent relationship between intensity (power density), exposure time, or frequency, and the effects of exposure,'' but did call for more research of better quality, including the ability to distinguish between thermal and potential athermal responses [36]. Although additional research is always useful in making evaluations, the commonality of RF exposure characteristics up to 300 GHz has enabled health agencies and standard-setting committees to assess the potential effects across this spectrum based on all the evidence, not just at a single frequency.

The simple reason for considering research on all RF frequencies in assessments is that although RF signals are

[3]Referring to the Interphone Study [28], [29] and Hardell *et al.*, 2011 [30].

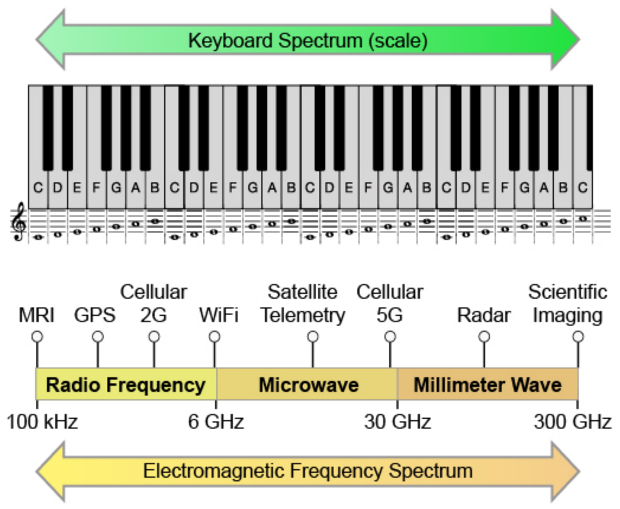


**FIGURE 4. The range of frequencies in the electromagnetic spectrum (bottom) is analogous to the range of frequencies played on a keyboard (top).**

distinguished by different frequencies, it does not mean their fundamental properties are vastly different. In this regard, it is useful to compare frequencies of RF (e.g., between 100 kHz and 300 GHz) to the tones created by striking different keys on a piano (Fig. 4). At one end of the keyboard, the keys create sound waves with lower frequencies (left side) than at the upper end of the keyboard (right side).

But a melody played on the keys at the lower end is no different than a melody played on keys at the upper end and the sound intensity is similar. Neither does a higher frequency 5G RF signal have a different mode of action than at a lower frequency RF communication signal; both involve tissue heating at sufficient field strengths. In addition, a higher frequency RF signal does not necessarily have a greater intensity than a lower frequency RF signal, especially since extensive signal processing and RF signal reception techniques allow receivers to recover signals that are thousands of times below background exposure. This is analogous to a human's ability to recognize a very quiet voice in a loud crowded room. To date, the only confirmed biological difference between exposures to RF frequencies less than 6 GHz and RF frequencies above 6 GHz is that at the higher frequencies the body's electrical properties better limit energy deposition to a shallow depth, largely confined to the skin. Thus, at frequencies above 6 GHz the hazard to be avoided is painful heating of the skin.

## V. 5G HEALTH AND SAFETY SUMMARY

Fixed small cell wireless communication installations—such as small cell antennas—that operate in compliance with the regulations of the FCC will produce RF exposures well within the recommended exposure limits of the FCC, ICNIRP, and IEEE. Research to date does not provide a reliable scientific basis to conclude that the operation of these facilities will cause or contribute to adverse health effects in the population. Research on RF will continue, as often occurs with new technologies, but not because public health authorities have established that the use of RF communication technologies today causes adverse health effects or is unsafe [37].

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