Wireless 5G Radiofrequency Technology

AN OVERVIEW OF SMALL CELL EXPOSURES, STANDARDS AND SCIENCE

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JANUARY 2020

An introduction to radiofrequency (RF) 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.

These wireless technologies communicate using radio transmitters and receivers that exchange coded signals with frequencies between 3,000 Hertz (Hz) ($3x10^3$ Hz) to 300 billion Hz (3×10^{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).

Cellphones and the cell sites that transmit information to our cellphones commonly operate with frequencies between 0.8 GHz (0.8 billion Hz) and 40 GHz (40 billion Hz). While the specific frequencies depend on the wireless provider, 2G networks typically have used 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 frequencies as well as those up to 47 GHz. For example, telecommunication companies are installing system additions at 2.5 GHz (Sprint); 600 MHz, 28 GHz, and 39 GHz (T-Mobile); 28 GHz (Verizon); and 28 GHz (AT&T) (Blackman and Forge, 2019).

The newest aspect of 5G technologies involves the addition of **small cell** antennas. These antennas help provide 5G's high network speeds and greater bandwidth to support more wireless devices.

These capabilities are achieved by locating small cell antennas closer to users, transmitting signals at these higher frequencies, and by steering signals to users in a small area rather than in all directions as do radio station antennas.

Radiofrequency signals from 5G small cells

To function, a cell site's transmitter signal must be strong enough to reach a cellphone 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 expected typically 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 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 the environment in which the 5G wireless system operates, our engineers have illustrated typical exposures from a 60-watt ERP 5G source at 39 GHz mounted on a pole 25 feet above ground and pointed in the direction of each location, along with exposures from other common RF sources within and outside buildings.[1] These exposures are expressed in Figure 1 as a percent of the Federal Communication Commission's (FCC) limit. This is a common way to compare exposures from a range of different RF frequencies since all RF systems sold in the United States are subject to limits imposed by the FCC on power and exposure to workers and the general public.

The exposure limit for the 39 GHz small site in the example below is 1 mW/cm^2. The example described here is one application of a 5G wireless technology; other applications may differ in the details.

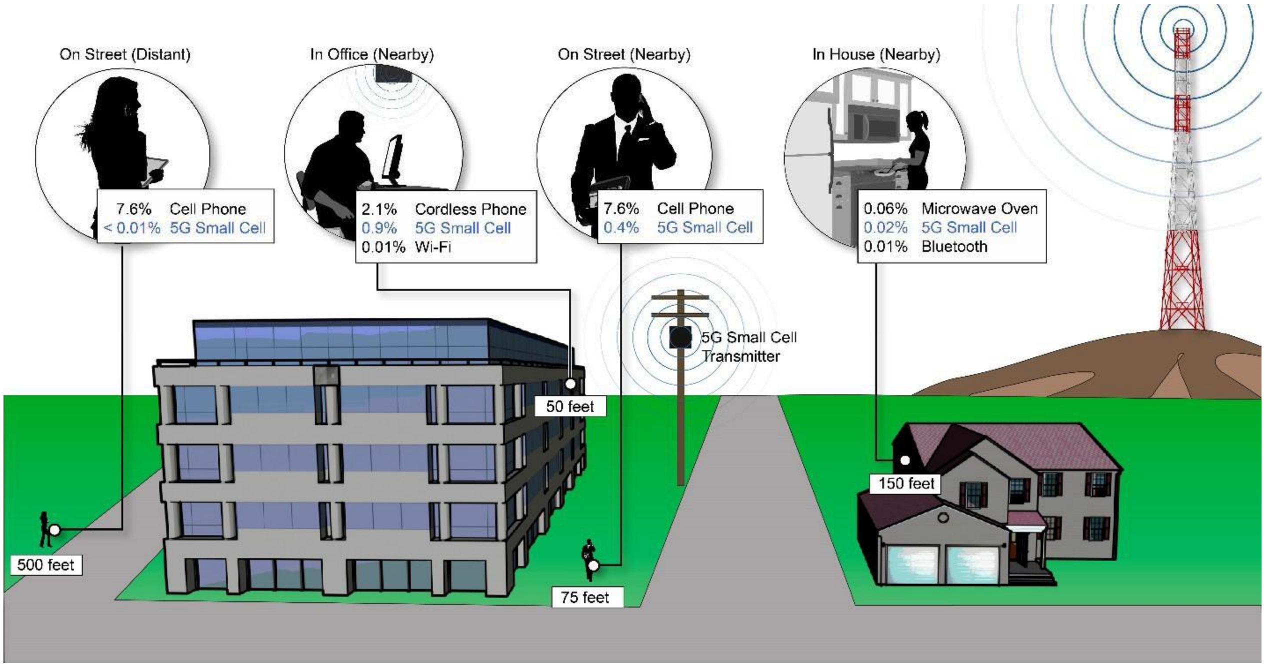

Figure 1. Pole-mounted 5G and RF exposures in a residence, on the street, and in an office building.

Figure 1 illustrates the maximum signal strength from an example 5G small cell antenna mounted on a typical telephone pole (transmitting at 39 GHz) expressed as the percent of the FCC limit, and typical signal strengths of other sources experienced by, from left to right: a) a person using a cellphone in a street 500 feet from the 5G small cell transmitter; b) a person at the window in an office building that also has cordless phone and Wi-Fi sources, and is slightly higher than the 5G small cell transmitter and 50 feet from the 5G pole; c) a person outdoors using a cellphone 75 feet from the 5G small cell transmitter; and d) a person in a nearby residence that also has Bluetooth and microwave oven sources and is 150 feet across the street from the 5G pole. As illustrated by the broadcast transmitter at the far right of the figure, all these locations are also receiving RF

[1] The maximum calculated exposure is at 75 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. Small cells are mounted far above the ground and therefore exposure is in what is termed the far field. The FCC has determined that 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” (FCC, 2000).

signals from either a broadcast radio or TV station.

The first thing to note in the hypothetical exposure scenario in Figure 1 is that exposure to RF from the outdoor tall broadcast radio or TV tower, as well as mobile phones, is everywhere. Exposures to 5G signals outdoors in the hypothetical illustration (0.01% and 0.4% of the FCC limit) are 800 to 20 times lower than exposure from other sources at these locations. Inside the residence and office nearby in these example scenarios, 5G signal levels are similar to or lower than 5G signal levels outdoors (0.02% and 0.9% of the FCC limit).

Another way to compare the RF exposure of common devices or sources is to rank them by relative intensity. Figure 2 shows the contribution of eight common sources of RF exposure expressed as a percent of the FCC limit.

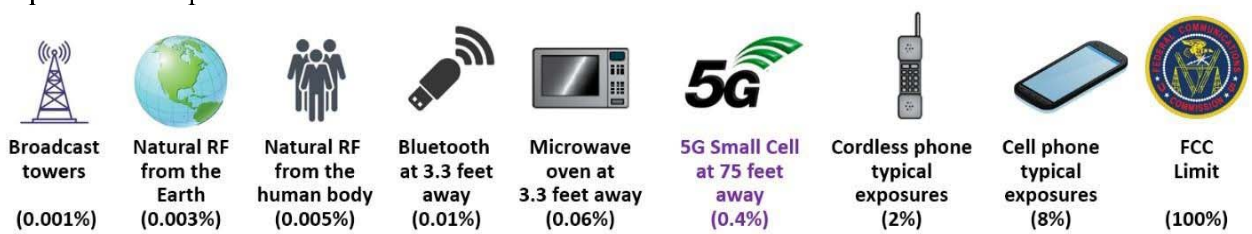

Figure 2. Ranking of common examples of RF sources by percent of FCC limit from left (lowest) to right (highest).

Figure 2 illustrates that the strongest RF signal from a 5G small cell antenna is roughly 5 times lower than a cordless phone and 20 times lower than cellphones, 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 cellphone near a 5G small cell antenna, then the cellphone 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 temperature of the human body and the earth itself is sufficient to produce exposure throughout the RF frequency range, including at 5G frequencies.

Standards for radiofrequency exposure

RF exposure standards were first developed in 1960 by the Institute of Electrical and Electronics Engineers (IEEE). Its active standards include those that cover the use of RF by the general public and in industrial and military environments (IEEE, 2002a, 2002b, 2014a, 2014b, 2018, 2019). Another expert organization, the National Council on Radiation Protection and Measurements (NCRP), also developed standards for RF exposure (NCRP, 1986).

As cellphones came onto the market in 1996, the FCC revised its guidelines for RF exposure as required by the Telecommunications Act to ensure that devices that transmit RF, such as communication devices, operate safely and do not interfere with other services (FCC, 1996; FCC/OET, 1997; FCC/OET, 1999). Since health and safety is not the FCC's primary focus, it looked to other organizations for guidance, including the NCRP and the IEEE that had conducted health risk assessments and made recommendations for the safe use of RF energy (NCRP, 1986; IEEE/ANSI, 1992). The IEEE committee that prepared the 1992 standard was dominated by academic and government scientists and engineers, with small representations from industry and other groups, and included physicians, scientists, and engineers (Ziskin, 2005). 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, and received comments back from these agencies. The FCC's rules reflect the comments from these health 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 confirmed 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 whole body temperature. An increase in body temperature by a small amount—much like what we experience when we exercise, or go through any number of daily occurrences—is actually not an adverse outcome, and to which the body is used to routinely adapting, but 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 (IEEE/ANSI, 1992; FCC/OET, 1999; IEEE, 2019).

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 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's RF exposure limits, called the maximum permissible exposure, are expressed as RF strength (i.e., power density, which is power in watts over a specified area, such as mW/cm^2).[2] Power density is analogous to the brightness of a light focused on an object (Figure 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.

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2 The limits developed by NCRP and IEEE were based on the RF dose, also known as the specific absorption rate of RF, in combination with thermal modeling and dosimetric studies. The specific absorption rate, however, is not easy to estimate directly, so the standard provides limits on the RF levels in the environment that can be measured or calculated as power density (power in watts per unit area). To assess compliance, power density is measured or predicted by engineering calculations for areas where people may encounter RF fields.

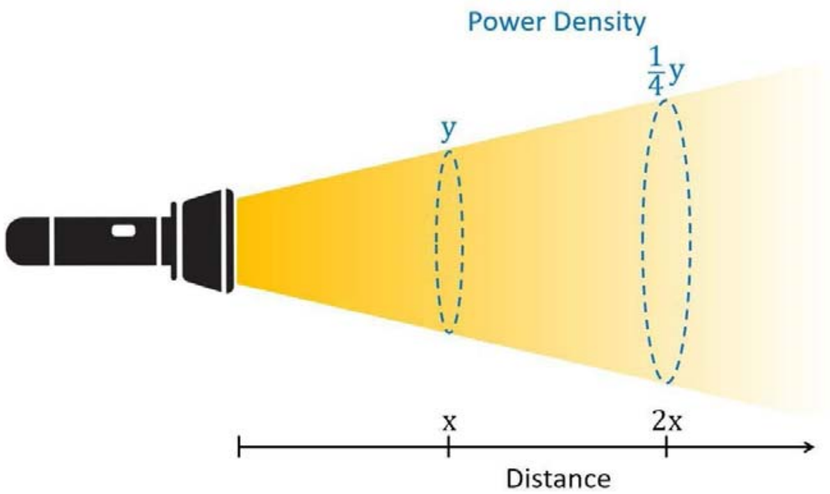

Figure 3. Power density is analogous to the brightness of a light focused on an object. The light on a piece of paper held 1 foot away from a flashlight is brighter than when the paper is held 2 feet away.

Health questions about RF

Over the years, research studies have suggested other effects of RF exposure, but where these effects were confirmed, they occur at higher levels of exposure than behavioral disruption from overheating and far above exposure levels in standards and FCC guidance. Claims for still other effects at levels below RF exposure limits were also 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 (NRPB, 2004; ICNIRP, 2009; HCN, 2009; SCENIHR, 2009; SSM, 2009; EHFRAN, 2012; IEEE, 2019).

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.[3] 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" (IARC, 2013). A 2015 comprehensive review of the literature commissioned by the European Commission concluded "[o]verall, the epidemiological studies on mobile phone RF EMF 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" (SCENIHR, 2015). The current view of the research 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" (WHO, 2019). The WHO recommends that countries adopt the International Commission on Non-ionizing Radiation Protection's (ICNIRP) exposure limits, which are the same as the limits set by the FCC, and IEEE for frequencies between 2 GHz and 100 GHz (ICNIRP, 1998; FCC, 1996; IEEE, 2019).

[3] http://www.who.int/peh-emf/en/

As new 5G communication systems are proposed and deployed, some have raised questions as to whether enough health and safety research has been performed on the new frequency bands above those used by existing 2G, 3G, and 4G systems. 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 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 (Figure 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 at 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.

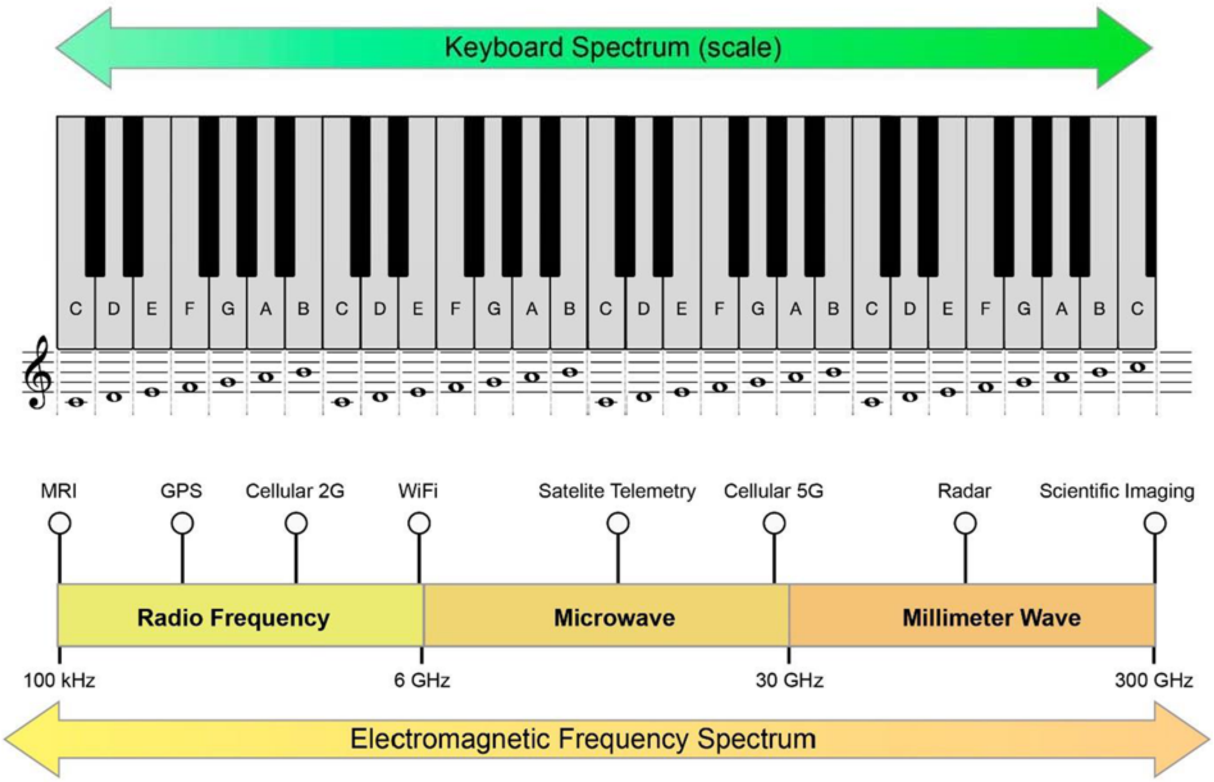

Figure 4. The range of frequencies in the electromagnetic spectrum (bottom) is analogous to the range of frequencies played on a keyboard (top).

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 is often done with new technologies, but not because public health authorities have established that the use of RF communications technologies today causes adverse health effects or is unsafe.

Author Biography

William H. Bailey, Ph.D., is a health scientist and researcher in the Center for Occupational and Environmental Health Risk Assessment at Exponent, Inc., an international scientific and engineering firm. His work over the past 35 years relates to the exposures and potential biological, environmental, and health effects associated with electromagnetic fields and RF signals produced by a wide variety of electrical facilities and devices, including wireless communication systems, electric utility facilities, electrified railroad lines, industrial equipment, appliances, and medical devices. Exposure assessment is a key element in the assessment of potential risks of chemicals and physical agents and in environmental epidemiology studies. The science of exposure assessment encompasses studies based on chemical, biological, and physical principles required to analyze human exposure from single and multiple routes; occupational exposure studies; and population- based studies. These studies are essential for the translation of toxicity data to assess the potential for risk to individuals and populations and to inform public health decisions.

Dr. Bailey is also an Associate Editor of the journal *Health Physics*, with primary responsibility for the peer review of manuscripts describing the results of research on electromagnetic fields including both RF and other frequencies, a role he also served in as a grant reviewer for the U.S. National Institutes of Health. He works on setting standards for RF and extremely-low-frequency fields for the IEEE's International Committee on Electromagnetic Safety, and he also served as an elected member of the Committee on Man and Radiation of the IEEE Engineering in Medicine and Biology Society from 1998–2001. In addition, he has served as an advisor on health risk assessments and public policy to various international scientific and health agencies, including the WHO, on topics relating to electromagnetic fields. Dr. Bailey has published or presented more than 90 scientific papers on this and related subjects.

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