Richard (Ric) A. Tell, K5UJU

Richard Tell Associates, Inc., 10037 Long Meadow Rd., Madison, AL 35756; **rtell@radhaz.com**

Amateur Portable Radios (Handheld Transceivers): Exposure Considerations Based on SAR

New FCC rules related to human exposure that went into effect on May 3, 2021 may now potentially require compliance with limits on specific absorption rate.

Introduction

In what might have been unnoticed by most hams, the FCC has instituted new rules related to human exposure that went into effect on May 3, 2021 that may now potentially require compliance with limits on specific absorption rate (SAR) **[1]**. This new rule, among others, is a part of what is called the FCC's *ET Docket No. 19-226* that changes the way that parties determine and achieve compliance with the Commission's limits on human exposure **[2]**. Of special interest to amateur radio licensees, the new rules no longer necessarily exempt handheld transceivers (handhelds) used by hams from certification that their use will comply with an SAR limit, something that historically has always been a requirement for commercial handhelds — those used outside the amateur radio service.

According to the FCC announcement, it appears that the commission intends to grandfather any equipment that was presumed to be compliant prior to the May 3 date. Since amateur radio equipment has never been required to be certified as to performance, except for certain power amplifiers, it seems reasonable to assume that all existing handhelds, the focus of this article, would remain designated as compliant devices. Nonetheless, new handhelds purchased after the effective date would presumably need to become certified, but any SAR testing, if mandatory by the FCC, might conceptually only become required after some to-be-determined review period. The most likely scenario is that, going forward, manufacturers will be required to evaluate SAR for amateur radio handhelds. In summary, amateurs are no longer relieved from compliance with FCC RF exposure rules by exception. Rather the amateur service will now be treated similar to all of the other services regulated by the FCC.

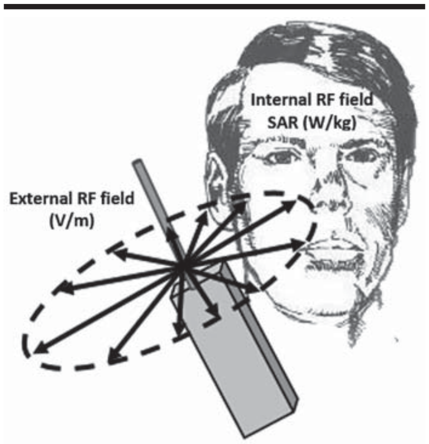

Figure 1 — RF electric and magnetic fields external to the body result in internal electric fields that can produce tissue heating based on the specific absorption rate (SAR).

Aside from the question of exactly when operation of a particular handheld is expected to comply with the new rules, the whole matter of SAR and how it relates to exposure of the user and others nearby is a complex subject and generally not familiar to most hams. Indeed, the assessment of SAR itself is beyond the capability of the vast majority of licensees. This article helps provide a basic understanding of what SAR is all about and how it relates to the safety of operating equipment, whether handheld of not, that produces radio frequency (RF) fields. The following presents 1) a simplified explanation of SAR to help in appreciating the complexity of the new FCC requirements as they may relate to controlling SAR and, 2) insight as to the likely SARs that might result from use of amateur handhelds.

Background

Fundamentally, RF fields interact with objects in an environment, often inducing RF currents to flow in those objects. If the exposed object is composed of a lossy (absorptive) material, such as human tissue, the induced currents largely lead to heating. If the heating effect is sufficiently robust, associated with very intense RF field strengths, there may be an increase in the temperature of the exposed tissues. Hence, tissue heating is directly related to the strength of the electric field strength within the tissue. The preferred way to quantify this internal heating effect is a quantity called the SAR expressed by the unit watt per kilogram (W/kg) of tissue. SAR expresses the rate at which an electromagnetic field delivers energy to the subject tissue. SAR is an expression of energy absorption rate because power is the time derivative of energy; 1 W is equivalent to 1 J/s. Thus, an SAR of 1 W/kg is equivalent to an energy absorption rate of 1 J/kg·s.

RF electric and magnetic fields external to the body result in internal electric fields that can produce tissue heating based on the SAR, see **Figure 1**.

SAR limits for safe exposure

The FCC RF exposure limits are based on limiting the SAR averaged over the whole body and as averaged over any one gram of tissue. These limits are designed to protect against increases in core temperature of the body and of localized regions of tissue that might result in an adverse health effect. For amateur radio licensees, members of the licensee's household and persons who are occupationally exposed to RF fields, the whole body SAR limit is set at 0.4 W/kg (averaged over the entire body mass) and a local (spatial maximum) SAR limit of 8 W/kg (averaged over any single gram of tissue in the body). For members of the general population (all persons who are not amateur licensees or occupationally exposed), the corresponding SAR values are 0.08 W/kg whole body and a local value of 1.6 W/kg. The FCC RF exposure limits specify maximum permissible exposure (MPE) values of RF fields that exist outside the body that are expressed as values of electric (*E*) field strength (V/m) and magnetic (*H*) field strength (A/m) as well as power density (W/m^2 or mW/cm^2). Compliance with the MPEs is intended to ensure that the whole body SAR and local SAR limits within the body are always respected and, clearly, electric and magnetic field strengths in air are much easier to measure (and calculate) than those values inside the body. Because cell phones are used by the general population with no particular expectation they may be exposed to RF fields, the applicable limit is the more stringent SAR value of 1.6 W/kg. Handhelds used in commercial activities must comply with the less restrictive limit of 8 W/kg.

It should be noted that the FCC in the US references the limit for local SAR to an average over a one gram cube of tissue. The recommended local SAR limit developed by the Institute of Electrical and Electronics Engineers (IEEE) in their *IEEE Std™ C95.1-2019* specifies a larger averaging tissue mass of 10 g in the shape of a cube **[3]**. This greater averaging mass has been found to better correlate local tissue temperature increase with local SAR. This same larger averaging mass is also specified in the International Commission on Non-ionizing Radiation Protection (ICNIRP) guidelines widely applied in Europe **[4]**. More about this later.

For RF sources that are sufficiently far from the body, MPE values accurately correlate with SAR. A complicating factor, however, is that a measurement of the *E* or *H* fields (or power density) outside the body does not necessarily accurately correlate with the local SAR in tissue *when the RF source is extremely close to the body surface*. This is why the FCC requires all commercially used handhelds including cell phones to be evaluated on the basis of local SAR, not MPE, before they are allowed to be sold in the US. As might be suspected, for cell phones as well as handhelds, the greatest SAR in the body is usually at the point where the transmitter is positioned. This might be the ear in the case of a cell phone or the front of the face in the case of a handheld. During SAR measurements, the transmitter is positioned either in direct contact with the head or other part of the body such as when cell phones or handhelds are mounted at the waist. When test laboratories evaluate SAR for common handheld use, the handheld is positioned at typically 2.5 cm in front of the face, similar to when the handheld is held in front of the mouth. A specially shaped phantom is often used for laboratory measurements of SAR, the phantom being similar to a manikin filled with a material that simulates the RF absorption characteristics of human tissue. Cell phone and commercial handheld manufacturers must commit to these detailed laboratory measurements for every model of their RF emitting product, revealing the maximum local SAR that can result when the device is operating normally at its maximum rated power. This has led to a gigantic database of equipment certifications resident in the FCC's equipment authorization database **[5]**. In each testing case, the product is placed in appropriate positions relative to the phantom while miniature probes are robotically moved throughout the interior of the phantom to measure the *E* field strength. Based on the measured *E* field in the phantom and the conductivity of the tissue equivalent material filling the phantom, the SAR is determined. See the **Sidebar: Determining SAR**.

Determining SAR

SAR can also be determined through theoretical analysis but, in practice, cell phones and commercial handhelds are always evaluated for SAR using the described laboratory procedures. The analysis approach makes use of the so-called finite difference time domain (FDTD) method, a complex computer based computation wherein the human body is modeled by breaking it into a very large number of small voxels — typically measuring one or two mm on a side — each with an assigned set of electrical properties to mimic the electrical characteristics of human tissues. The computations can take hours to run on super-fast machines with the output data ultimately processed to display local SAR values in a three dimensional fashion.

A challenge for amateur radio licensees

Fortunately, this SAR evaluation process has never before been required for equipment used in the amateur radio service, which can lead to increased costs of equipment. It remains to be seen how these new FCC rules will impact the certification of amateur radio handhelds for conformance with the local SAR limit. Just as important, though, is the matter of how amateur radio operators would be able to conclude that their use of a ham handheld complies with the relevant SAR limits for the equipment that they currently operate.

Confronted with this challenge, an alternative but practical approach to assessing compliance of amateur radio handhelds against the fundamental exposure criterion of SAR is required. This paper suggests that, at this point in time and supported by the extensive database of equipment certifications available from the FCC, most amateur radio handhelds already can be expected to comply with local SAR values that underlie the FCC RF exposure rules. For example, the FCC's equipment authorization database represents more than two decades worth of detailed, time consuming and expensive SAR test results for cell phones and commercially used handhelds as well as for all kinds of other RF emitting devices that may be used close to the body. It is proposed that this extensive set of SAR certification data can be used to amateur radio's advantage. Of particular interest are the many reports filed in the database on commercial handhelds that operate in frequency bands that are extremely close to — or, in some cases, actually within — those authorized for the amateur service. Fortunately, there are several bands allocated for commercial communications that are essentially similar to those used by hams in the VHF and UHF spectrum. For example, the US amateur bands at 2 m (144-148 MHz), 1.25 m (219-225 MHz), 70 cm (420-450 MHz) and 33 cm (902-928 MHz) are frequency allocations very close to those used for commercial communications activities and for which SAR evaluations have been conducted.

By examining SAR measurement results for commercial handhelds operated in these close-by frequency bands, significant insight can be gleaned on the likelihood of compliance of similar amateur radio handhelds despite the fact that the amateur versions of these radios have not necessarily been directly measured for SAR. For instance, say that 2 W commercial handhelds that operate just below and just above the two-meter band are found to comply with the SAR limit. It would seemingly be reasonable to conclude that a 2 W amateur handheld that operates in the two-meter band would also be found to be similarly compliant.

A practical example

To help illustrate this concept, an example search of the FCC equipment authorization database was conducted of a limited number of SAR certifications; the sheer size of the database begs the question of how much effort would be required to query every certification to determine its relevance to VHF/UHF handheld compliance. Ideally, some sort of automated process would be very helpful in sorting through the thousands of reports but that remains to be determined, if feasible, by the FCC. The manual approach to searching the database and extracting relevant SAR data, while extremely time consuming, can, nonetheless, result in helpful insights.

Of great utility, virtually all of the SAR certifications of commercial handhelds contained in the FCC database include the results of SAR measurements averaged over both the FCC's 1 g averaging mass as well as a 10 g averaging mass applicable to most markets outside the US. **Figure 2** for 1-gram averaging mass, and **Figure 3** for 10-gram averaging mass illustrate the results of an initial and limited inspection of the FCC's database for SAR certifications of commercially used handhelds across the VHF/UHF spectrum for compliance with the FCC limits. The indicated local SAR values retrieved from SAR reports have been normalized to 1 W and are relative to a duty cycle of 50% based on the push-to-talk (PTT) operation of the handheld. For compliance determination purposes, the FCC applies a presumed duty cycle of 50% for PTT operation of the handheld.

Figure 2 shows the local one-gram averaged SAR produced by commercial handhelds that operate near or within amateur radio bands (based on 50% PTT duty cycle and 1 watt). These data are potentially applicable to US amateurs regulated by the FCC should the FCC require compliance with SAR limits.

Of particular note is the lower normalized local SARs associated with VHF handhelds as opposed to those used in the UHF range; the higher frequencies result in a shorter depth of penetration resulting in higher surface region SARs. Also apparent from the data in **Figure 2** is the relatively wide margin by which the VHF local SARs

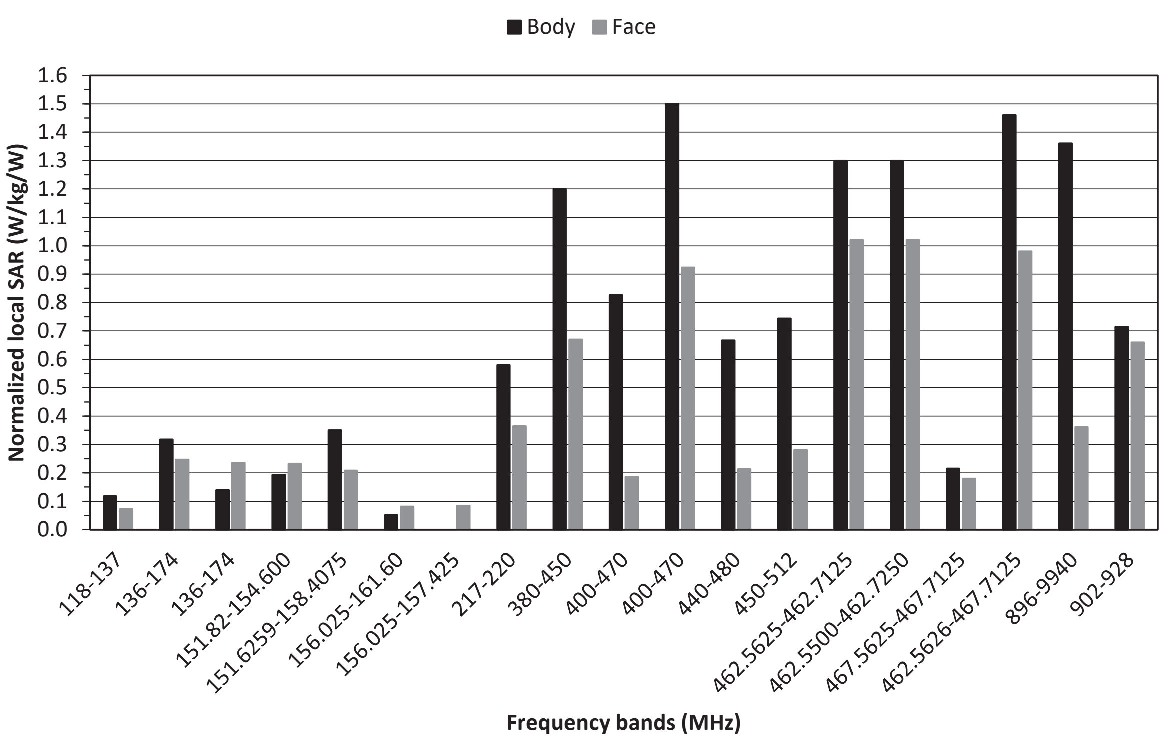

Figure 2 — Local one-gram averaged SAR produced by commercial handhelds that operate near or within amateur radio bands (based on 50% PTT duty cycle and 1 watt).

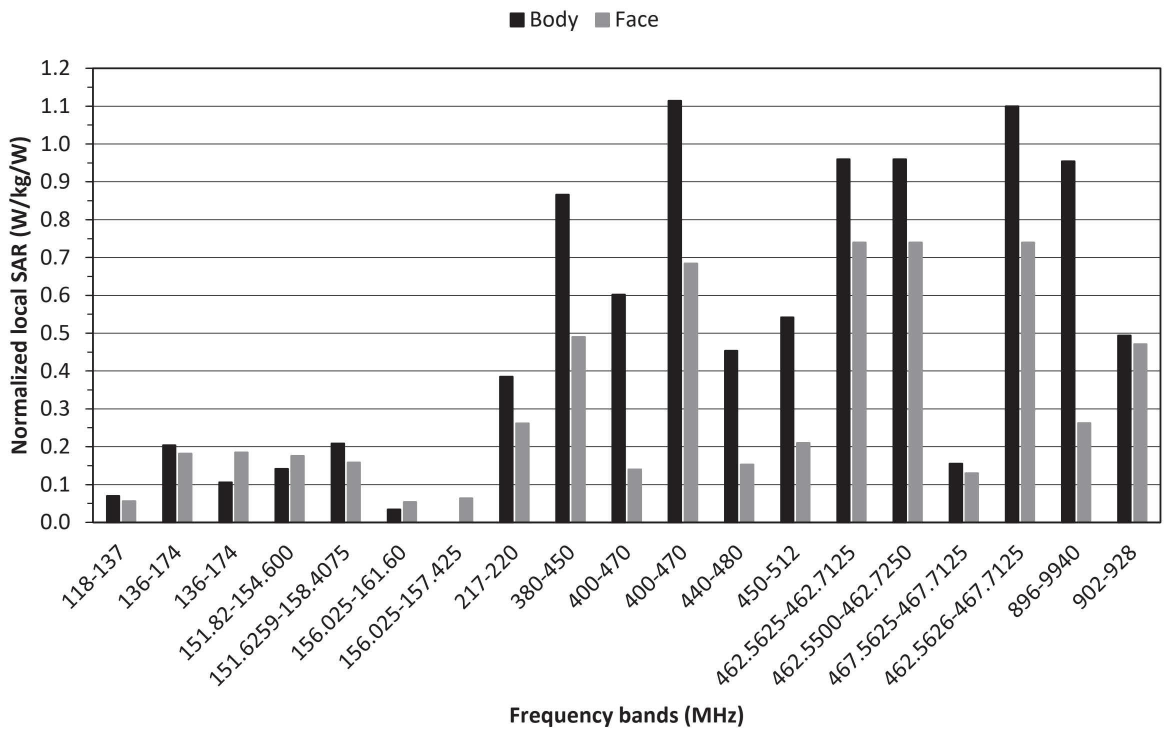

Figure 3 — Local ten-gram averaged SAR produced by commercial handhelds that operate near or within amateur radio bands (based on 50% PTT duty cycle and 1 watt).

comply with the more stringent local SAR required for devices used by the general population, i.e., 1.6 W/kg. The FCC applies the occupational MPEs (and by association, a higher local SAR limit, i.e., 8 W/kg) to amateur radio operators and members of their households. In the US, the application of occupational limits to hams is based on the presumption by the FCC that licensed radio operators have a basic awareness of their potential exposure and are knowledgeable of how to prevent excessive, unsafe exposures.

A practical application of **Figure 2** is the extrapolation of the normalized local SARs to a local SAR of 8 W/kg (the FCC limit for amateurs) to determine the power level that would result in 8 W/kg. For example, in the 2 m band, it might be presumed that an handheld operating with a power of up to 22.9 W (not realistic for an handheld) could be used before exceeding the amateur radio operator SAR limit (8 W/kg divided by 0.35 W/kg/W). For a 70 cm handheld, a power of 5.3 W could be used that would just comply with the local SAR limit (8 W/kg divided by 1.5 W/kg/W).

A similar display of normalized local SAR based on an averaging mass of 10 g, rather than just 1 g, is provided in **Figure 3**. It shows the local ten-gram averaged SAR produced by commercial handhelds that operate near or within amateur radio bands (based on 50% PTT duty cycle and 1 W). These data are potentially applicable to amateurs subject to regulations based on SAR limits as specified by ICNIRP. Whether regulatory agencies in countries other than the US presume a PTT duty cycle of 50% is not certain.

The same attribute of relatively lower local SAR for VHF handhelds is apparent, but the actual normalized values are less than those that would result from the smaller averaging mass of 1 g. This characteristic results from the greater volume of tissue over which highly localized points of SAR within tissue may be averaged. The practical upside of this is, obviously, that 10 g averaging allows for higher handheld operating powers.

It is also noteworthy that there is a variation in the normalized SAR values,

Work in progress

In the US, the American Radio Relay League (ARRL) is working diligently toward development of guidance to amateurs to help in their compliance efforts in view of the new FCC RF rules. In this context, the ARRL RF Safety Committee, chaired by Dr. Gregory Lapin, N9GL, (email: **n9gl@arrl.org**) is monitoring the new regulatory requirements that are applicable to the amateur radio service and working to develop appropriate methods to help hams in their compliance efforts.

Simultaneously, a small group of UK amateurs in the Radio Society of Great Britain (RSGB) and the ARRL in the US have been convening since mid-2020 to collaboratively attack the same issue, i.e., how amateurs can best assert and/or demonstrate compliance with the proposed new RF rules to be administered by Ofcom in the UK and the new changes in how the FCC rules are being applied to hams in the US. For more information on this activity, see articles in *RadCom* from the RSGB or contact John Rogers, MØJAV (email: **m0jav@rsgb.org.uk**).

sometimes among different handhelds that operate in an identical frequency band. This is likely to reflect differences in the antennas or other accessories that may be used with the specific radios.

For hams outside the US who must comply with ICNIRP guidelines, assessing compliance would be based on applying the 10 g averaging mass and on somewhat greater SAR values. For instance, the ICNIRP local SAR limit for occupational exposure is 10 W/kg as compared to the FCC's 8 W/kg while the local limit for the general public is 2 W/kg compared to the FCC's 1.6 W/kg. Hence, the normalized SARs shown in **Figure 3** should be extrapolated to a value of 10 W/kg for estimating the maximum handheld power that would comply with the ICNIRP occupational SAR limits. This results in greater permissible handheld powers than could be permitted with the smaller averaging mass specified by the FCC. Two competing factors are potentially relevant to the handheld compliance issue where exposure limits are based on ICNIRP. First is whether hams are considered as members of the general public or whether they are treated as occupationally exposed workers, the public exposure limits being a factor of five more stringent. Second, the greater local SAR averaging mass would help mitigate against noncompliance.

Irregular ham Handheld configurations and SAR

When reviewing the SAR certification reports in the FCC database, it is evident that the SAR testing procedures can become rather onerous. This is reflected in the multiple configurations of an handheld with different antennas, battery packs and other accessories such as microphones and headsets that are each individually evaluated for many commercial handhelds. From a ham's perspective, however, this extensive testing process for commercial handhelds would seem to help support an argument that common amateur use of third-party accessories such as higher gain antennas, etc., will not materially change the rather clear conclusion that ham handhelds would continue to comply with exposure rules requiring assessment of SAR. Of particular relevance, for the handhelds identified in this limited exercise, a variety of antenna lengths were found to have often been included in the tests. The results plotted in **Figures 2** and **3** encompass the absolute maximum reported local SARs for each handheld, regardless of a particular accessory, in the interest of conservatism. An important principal, relative to local SAR associated with handhelds, is the physical size of the antenna; for a given power, contrary to how gain is generally proportional to antenna size, smaller antennas result in a higher concentration of energy absorption. For hams, replacement of antennas on handhelds to improve potential coverage is most often accomplished with larger, longer antennas. This fundamental relationship between antenna size and local SAR likely means that using third-party antennas on handhelds results in lower SARs.

Conclusions

A careful but limited examination of SAR test results available in the FCC's equipment authorization database suggests that handhelds commonly used in the amateur radio service would not exceed exposure regulations based on the magnitude of local SARs. This tentative conclusion could be used to support an amateur radio operator's contention that their past use of existing handhelds as well as acquisition and use of new handhelds complies and will be expected to comply with possible SAR based exposure regulations. Extension of this initial data analysis is recommended to further clarify this conclusion. Operation of relatively higher power handhelds could result in exceeding local SAR limits for members of the general population and care should be exercised in permitting unlicensed persons to use such handhelds even under the supervision of a licensed control operator. See the **Sidebar: Work in progress**.

Outside the jurisdiction of the FCC, Ofcom in the UK has announced that it will impose new license requirements for UK hams that are based on the ICNIRP guidelines. The RSGB has developed useful information on this upcoming requirement **[6]**. At this time, however, it remains to be seen exactly how such new regulations might impact UK hams. Interestingly, Ofcom is only concerned with radio operations that cause exposure of the general public, not with the potential exposure of hams themselves. However, Public Health England and/or the UK Health and Safety Executive, separate government entities in the UK, could recommend RF exposure limits that might include exposure limits for hams. Whether any of the possible regulatory provisions in the UK would apply the more permissive exposure limits for occupational exposure to amateur radio operators, similar to the FCC, or the more restrictive limits applicable to the general public, is unknown.

Ric Tell, K5UJU, received his Novice ticket in 1959, first operating with a home brew 7.5 W transmitter during the greatest solar cycle of his life. Eventually achieving an Amateur Extra class license in 1970, his predominant activities have included his professional pursuits in the areas of RF safety, RF instrumentation, antenna analysis, hazard assessments and compliance evaluations. After spending 20 years with the Environmental Protection Agency, he has operated his own scientific consulting business since 1987. His ham radio interests are primarily QRP CW operation and experimenting with antennas. He holds a BS degree in physics and an MS degree in radiation sciences and is a member of the ARRL RF Safety Committee and is a Life Fellow of the IEEE. Ric chairs the IEEE Committee on Man and Radiation (COMAR) and Subcommittee 2 on RF safety programs in the IEEE International Committee on Electromagnetic Safety, Technical Committee 95.

References

[1] *FCC Public Notice*. Office of Engineering and Technology announces May 3, 2021 as the effective date for RF exposure rule changes and beginning of the two-year review period for existing parties. Available at: **https://docs.fcc.gov/public/attachments/DA-21-363A1.pdf**.

[2] *Human Exposure to Radiofrequency Electromagnetic Fields and Reassessment of FCC Radiofrequency Exposure Limits and Policies*. Final rule. Federal Register, Vol. 85, No. 63, Wed., April 1, 2020, pp. 18132-18151. Available at: **https://www.govinfo.gov/content/pkg/FR-2020-04-01/pdf/2020-02745.pdf**.

[3] *IEEE (2019). IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.* IEEE Std C95.1-2019. Available at: **https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82**.

[4] *ICNIRP (2020). Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). Health Physics*, Vol. 118, No. 5, pp. 483-524. Available at: **https://www.icnirp.org/en/publications/article/rf-guidelines-2020.html**.

[5] FCC equipment authorization database at: **https://apps.fcc.gov/oetcf/eas/reports/GenericSearch.cfm**.

[6] *EM Field Exposure. Radio Society of Great Britain (RSGB).* Available at: **https://rsgb.org/main/technical/emc/emf-exposure/**.