Analysis on the Effect of Averaging Duration on Radio Frequency Dosimetry in Residential Environments

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***Abstract*— The potential hazards of electromagnetic waves have raised concerns in related authorities to propose standards and limit lines on the electromagnetic field levels. Most of the radio frequency (RF) dosimetry measurement procedures referred to in safety compliance standards, suggest 6-minute averaging, in addition to spatial averaging, which can be time-consuming for primilary measurements. Measurement analysis in residential environment in this paper demonstrates that lowering the time interval of measurements to about 30 seconds, which suggests the possibility of reducing the measurement time with minimal reduction to measurement accuracy. For all measurement results shown in this paper, having a 30-second averaging time, the relative error, compared to 6-minute averaging and spatial averaging, is less than 5% for radio frequency (RF) level in the environment. This paper provides a potential solution to pre-compliance RF dosimetry process with less required time and cost.**

Keywords—ICNIRP, RF dosimetry, residential environments, the general public, specific absorption rate, electromagnetic waves

I. Introduction

There are many misconceptions and controversial claims about the effect of electromagnetic waves on human health, but it is also inaccurate to say that there is no effect of electromagnetic waves on human health. Several papers published in recent years attempt to correlate electromagnetic waves on human health. For instance, in [1], radio frequency (RF) induced body heating is analyzed. The paper verified that RF waves can result in a harmful effect on the reproductive system and central nervous systems of humans. The concern about the effect of electromagnetic waves is not limited to human health. Electromagnetic waves can also affect electronic devices and needs to meet Electromagnetic Compatibility (EMC) standards. The main motivation behind this work is to study the applicability of a faster and thus lower-cost RF-dosimetry procedure enabling ordinary people to perform the pre-compliance measurement in huge residential environments.

The study of the electromagnetic waves on human health depends on trusted measurements. Therefore, a good technique for measuring electromagnetic waves is valuable. Many studies have been done in recent years to achieve the best technique for measuring electromagnetic waves in different environments.

As mentioned in [2] there are different measurement strategies for monitoring radiation in different locations such as using fixed measurement stations, using portable dosimeter devices like spectrum analyzers and antennas, and applying personal dosimeters.

The effect of increasing wireless devices is examined in[3]. The measurements in [3] are done in different urban environments, especially in public places, and the results are compared with three years before that. The level of GSM signals (900 and 1800MHz) are measured with the help of a portable spectrum analyzer and antenna at 60 points in [4]. Based on the measurements in [4], the outdoor exposure factor is twice as high as the indoor level on average. The peak value of electromagnetic radiation from mobile phones is examined in [5] .The results show that the peak of electrical field strength in the 2G network is more than 3G and LTE. Nowadays, 4G and 5G are added to the previous cellular and it is expected that RF power density is even higher than last decade.

In [6] the authors have reviewed the measurement methods in accordance with international standards. The method introduced in [6] not only reduced the cost of measurement but also decrease the averaging time length (ATL) to 30 seconds. However, regardless of the environment, ATL is considered as 6 minutes based on the most international standards such as IEEE C95 [7], ICNIRP[8], and some national standards such as Australian standards[9], and Iranian standards INSO 8567[10]. The criterion of 6 minutes is selected by Foster [11] who chose this time one-tenth of an hour (0.1 h) which is not too long or too short and is appropriate for measuring.

This paper is a further investigation to verify the method introduced in [6]. Here, three public residential environments

2023 IEEE Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMC+SIPI) | 979-8-3503-0976-8/23/$31.00 ©2023 IEEE | DOI: 10.1109/EMCSIPI50001.2023.10241710

are selected. These areas are uncontrolled environments which means a different type of electromagnetic pollution is available. The "public environment standards" are used for measurements. The test setup and measurement techniques are introduced in section II. Section III describes the measurement scenario in detail come along with the effect of averaging time length on measurement performance. Also, a theoretical discussion and comparison between two different time lengths are provided and the results of the measurements are numerically analyzed. Finally, the paper is concluded in section IV.

II. MEASUREMENT

A. *Purpose of Measurement*

Depending on the propagation channel model and the source of electromagnetic waves, the public environments are divided into several subcategories such as residential, industrial, business environment, etc.
Here, a crowded place is identified which is located in the west of Tehran, Iran. In this area, thousands of people live where there are various types of electromagnetic pollution exist. Cellular signals such as LTE, 2G,3G, and 4G in the different frequency bands (900 MHz, 1800 MHz, 2100 MHz), UHF TV, and Wi-Fi (2.4 GHz) are the most available signals in environments. Fig. 1 is a snapshot of this place.

Fig. 1. View of one of the assessed residential environments in Tehran with some types of electromagnetic fields sourses such as LTE, 2G,3G, and 4G in the different frequency bands (900 MHz, 1800 MHz, 2100 MHz), UHF TV, and Wi-Fi (2.4 GHz)

B. *Measurement Setup*

All the measurements in this paper are done with the help of the NBM 550 NARDA probe. EF1891 is used as a directional probe (Fig.2). This probe is wideband (30 MHz up to 18 GHz) with high accuracy in measurement (1uv/m) in three different polarizations . NBM 550 is suitable for long time study and measurement. Its uptime is over 12 hours and allows the user to perform dosimetry in several days with a frequency sampling of 1 Hz. This measurement setup includes a wooden movable stand and its height is set to about 170 cm.

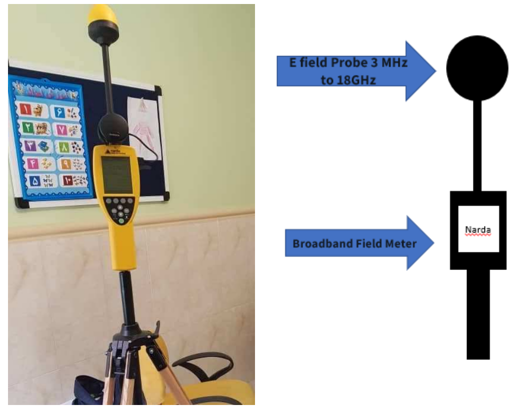


Fig. 2. NBM 550 NARDA probe Measurement instruments setup placed in a residential place first floor

C. *Measurement procedure*

The measurement method used here is adopted from [6] with the help of the NARDA probe in two different time duration. The first sampling measurement time is between 2 to 3 hours and the second last about 12 hours, and the power density is measured every second in both.

III. RESULTS AND DISCUSSIONS

A. *Measurement Scenario*

The probe is set up in different locations in one place for more than 2 hours. The measurements are done in different places such as bedrooms where there are many concerns about it. Because people spend a long time there and the E.M. can affect human health. .

Based on [6], the important parameters are defined as follows. The Start Moment of Averaging (SMoA) which shows the exact moment when each averaging function starts. The averaging time length (ATL) which is the average time length duration, and the average power density (APD) which is the average power density for each sample over ATL. APD is an important parameter due to the fact that used for comparison in different locations. APD is calculated with the help of (1) where T_0 is SMoA, T is the averaging time length, and W_{ij} is the measurement power per sample. Index i refer to samples during time and j is the location of the sample around an object this index used for location base averaging.

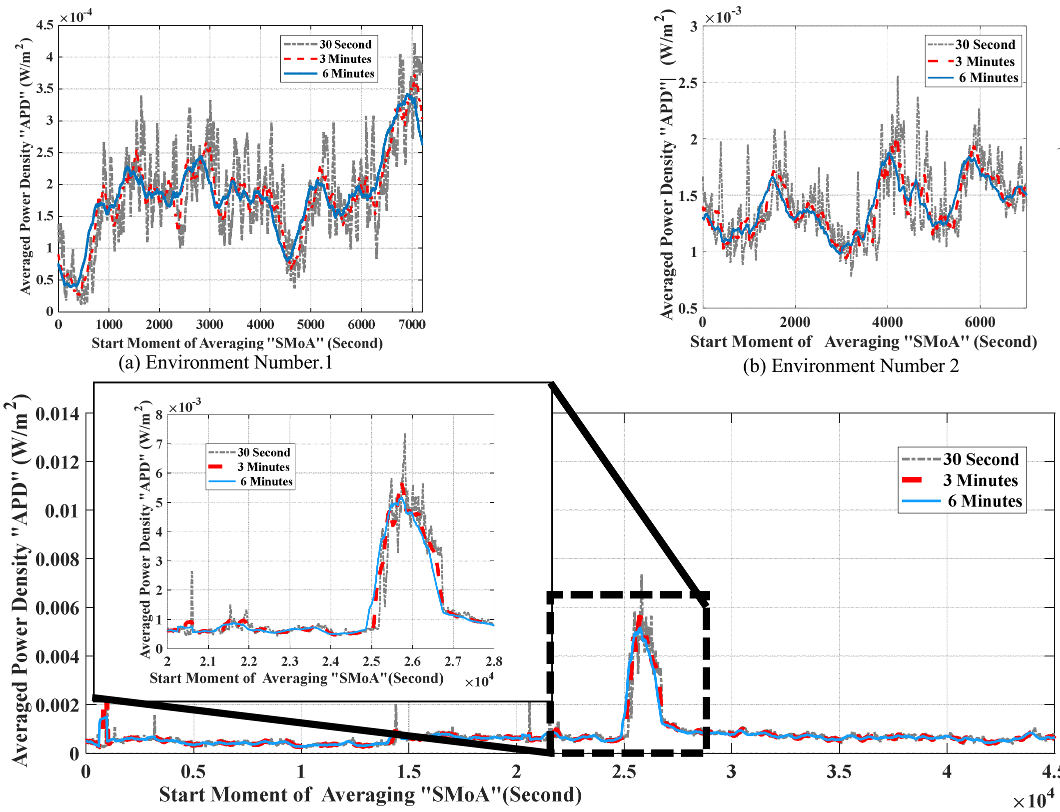
$$W_j = \frac{1}{T} \sum_{i=T_o}^{T+To} W_{ij} \tag{1}$$

B. *Effect of ATL*

The effect of ATL is investigated in three different T, T=30 seconds, T= 1 minute, and T=6 minutes in the public environment. Fig 3 (a) shows a comparison among three different T. SMoA is sweeping throughout a single capture. APD is calculated by equation (1) and used as a factor for comparison. The measurements are repeated in other locations and the results are reported as well in Fig 3 (b). The horizontal axis in Fig. 3 is dedicated to SMoA in second.

Referring to the Figs. 3, APD shows different values for three different ATLs (0.5, 1, 6 minutes). This variation occurred due to the time-varying specification of the signals. However, the difference between the result of 0.5 minutes ATL and 6 minutes is less than 3 dB which is not a significant value for long time measurement (about 2 hours here).

There is an unexpected signal around SMoA=2000 s which is shown in Fig.3 (c). To find the source of this signal the environment is examined and a temporary transmitter is identified as the noise source The UHF TV broadcast signals, mobiles base stations in the different frequency bands (900 MHz, 1800 MHz, 2100 MHz), and Wi-Fi stations can be examples of this temporary transmitter Figure 3 demonstrates that such slow variations in the time domain do not cause any difference between the APD of 30 seconds, 3 minutes . and 6 utemins.



(a) Environment Number.1

(b) Environment Number 2

(c) Environment Number 2-12h in Day

Fig. 3. APD comparison among three ATLs plotted versus SMoA (up to 7000 seconds) and for two residential environments. Each value in the plot shows the APD (Averaged power density)value which is averaged from that moment (SMoA) and ends 30 seconds, 3 minutes, and 6 minutes later

C. *Theoretical Discussion*

To calculate the variance of the difference between the estimated value and the actual value of measured power density, the following equations are used. In Equation 2a, *x[n]* is the measured power density in the environment. Measured power density is the actual value of the average and the error value, respectively. The actual value, x_0, is unknown. *W[n]* error the of measured power density in the environment. The normal distribution so *W[n]* is white Gaussian noise. However, Equation 2b is statistically used to estimate it from *N* captured *x[n]* samples. [12]

$$X[n] = x_0 + W[n] \tag{2a}$$

$$\hat{x}_{0_s}^{\ N} = \frac{1}{N}\sum_{i=s}^{s+N} X[n] \tag{2b}$$

$\hat{x}_{0_s}^{\ N}$ is the estimated value from *N* number of samples starting from the s^{th} samples. To calculate the variance between the estimate and actual value it is necessary to have the actual value, x_0, which is not available in practical measurements. However, a good estimation could be practical. For instance, averaging with a high number of sample size could be a suitable estimation. The variance of difference between the estimated value and the best possible estimation can be defined and calculated by (3)

$$\sigma^2_{\hat{x}_0^N} = \frac{1}{M-N-1}\sum_{s=1}^{M-N}\sigma_s^2 \quad (3a)$$

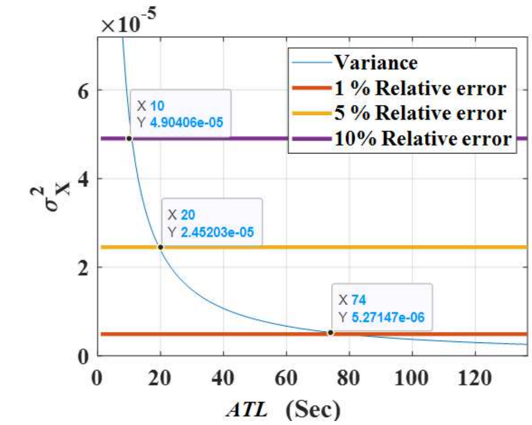
$$\sigma_s = \left|\hat{x}_{0_s}^{\ N} - \hat{x}_0^M\right| \quad (3b)$$

where $\hat{x}_0^M$ is estimated by averaging from the largest number of available samples. Here M=45000 for 12 hours. N can be selected as a smaller number of samples, 30, 60, or 360 seconds M is the total number of available measured samples. $\hat{x}_0^M$ does not depend on start moment of averaging (s), it is supposed the best estimation of x_0. [13]

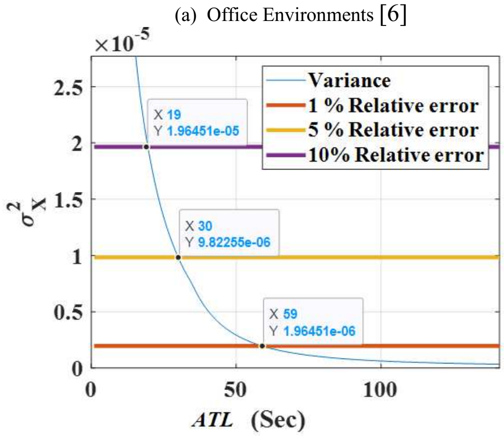
In Fig. 4, three different plots showing the variance of the different $\sigma^2_{\hat{x}_0^N}$ versus N- the length of the samples, are depicted. The measurements are done in three different residential environments.

Based on the diagrams when N tends to M, $\sigma^2_{\hat{x}_0^N}$ converges to 0 and $\hat{x}_{0_s}^{\ N}$ approach to $\hat{x}_0^M$. Fig.4 (a) depicted the measurement result of an office in 12 hours. Based on this figure, only 10 seconds need for $\sigma^2_{\hat{x}_0^N}$ to reach below the 10% error threshold. In 20 seconds and 74 seconds, the error was reduced to 5% and 1% respectively.

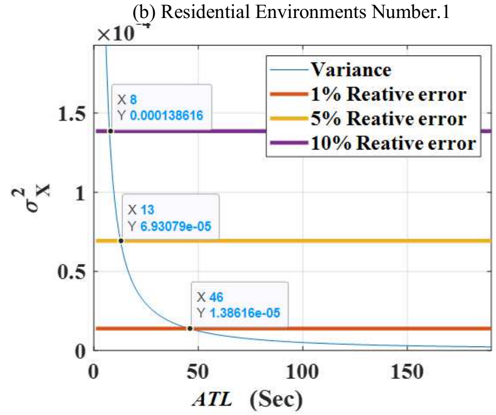
Fig.4 (b) and Fig.4 (c) show 2 hours measurements for two different residential places. To reach 10%, 5%, and 1% errors ATL of about 19, 30, and 59 seconds are required at first residential place, respectively. These numbers changed to 8, 13, and 46 seconds for the same error percentages in the second residential place.



(a) Office Environments [6]



(b) Residential Environments Number.1



(c) Residential Environments Number.2

Fig. 4. The variance of the difference for N seconds measurement from the long term - average, $\sigma^2_{\hat{x}_0^N}$.

Fig. 5 demonstrates an overlay comparison between The variance of the estimated values in the previous measurement that are shown in Fig 4.

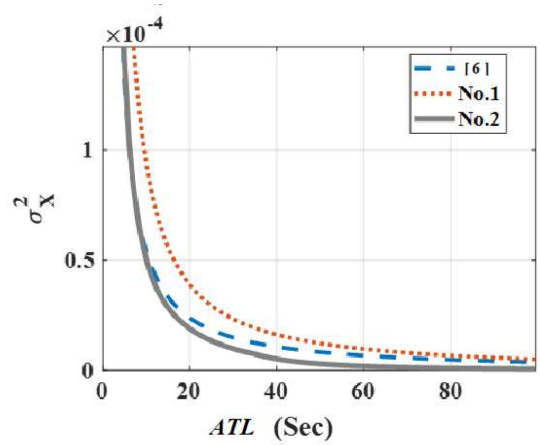


Fig. 5. Comparison between two environments and [6]

D. *Comparing 30-second and 6-minute ATL*

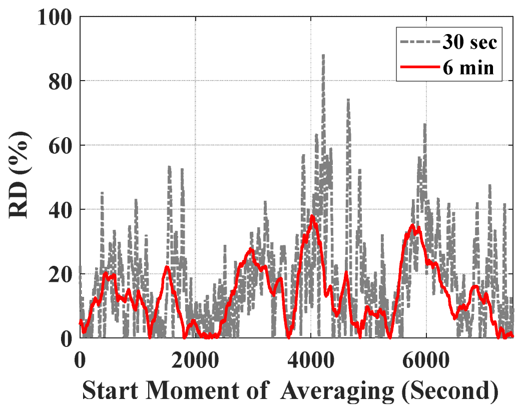
To compare two ATLs, for instance, 0.5 minutes and 6 minutes for up $t_0$2 hours, a new variable "Relative Diversion from M-sample Average Power Density" RD is defined as (3)

$$RD = \left[\frac{|APD_{ATL}(To) - APD_M(To)|}{APD_M(To)}\right] \times 100 \quad (3)$$

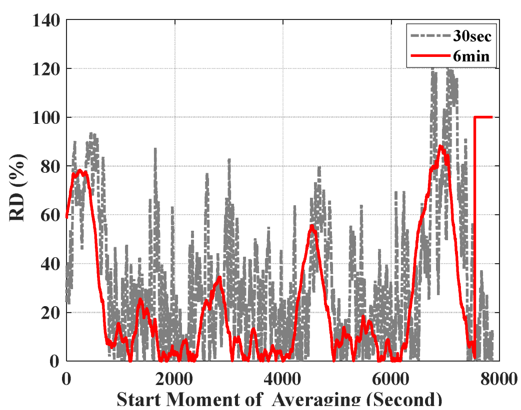
$$ATL \in \{30\ s\ , 6\ min\}$$

M is the number of total measured samples, for instance, 8000, and t is SMOA which is needed for calculating APD. "Relative Diversion from 2 hours APD" for two ATL values in 0.5 and 6 minutes which is measured in an indoor residential place is depicted in Fig. 6. The difference between Relative Diversion from the reference value for 0.5 and 6 minutes is not much different. It can be observed that in some second like SMoA=4200 the value of "RD from 2 hours APD" increase up to 80% in Fig. 6(a); however, the maximum value for 6 minutes is about 40%. In Fig.6 (b), the second residential place is examined and the same pattern is observed . Based on the figure Fig.6 (b) maximum value of "RD from 2 hours APD” for 0.5 minutes is about 140% while for 6 minutes measurement is about 90%.

based on these measurement results we can conclude that measurement time averaging can be reduced up to 30 seconds at least for residential environments, where telecommunication and broadcast signals are dominant.



(a) Residential Environments Number.1



(b) Residential Environments Number.2

Fig. 6. Measurement of Relative Diversion from the reference APD value for two ATL values, namely 30 seconds and 6 minutes compared for residential environments.

IV. Conclusion

In this paper, the process of simplifying the RF dosimetry of the public residential environment was examined. According to statistical analysis, the measurement time of 6 minutes can reduce to 30 seconds. These results confirm that there is no significant difference between the defined Relative Diversion of 30-second averaging and 6-minute averaging. The difference is 26% to 33% on average.To confirm the claim, the measurements are done in several environments. The environments selected carefully where the electromagnetic pollution level is as high as the population to prepare for future standards processing.

V. References

[1] R. Acharya, D. Kumar, and G. Mathur, "Study of electromagnetic radiation effects on human body and reduction techniques," in *Optical and Wireless Technologies*: Springer, 2018, pp. 497-505.

[2] J. Miyakoshi, H. Tonomura, S. Koyama, E. Narita, and N. Shinohara, "Effects of exposure to 5.8 GHz electromagnetic field on micronucleus formation, DNA strand breaks, and heat shock protein expressions in cells derived from human eye," *IEEE transactions on nanobioscience,* vol. 18, no. 2, pp. 257-260, 2019.

[3] H. Jalilian, M. Eeftens, M. Ziaei, and M. Röösli, "Public exposure to radiofrequency electromagnetic fields in everyday microenvironments: An updated systematic review for Europe," *Environmental research,* vol. 176, p. 108517, 2019.

[4] R. N. Iyare, V. Volskiy, and G. A. Vandenbosch, "Study of the correlation between outdoor and indoor electromagnetic exposure near cellular base stations in Leuven, Belgium," *Environmental research,* vol. 168, pp. 428-438, 2019.

[5] M. Ibrani, E. Hamiti, L. Ahma, and B. Shala, "Assessment of personal radio frequency electromagnetic field exposure in specific indoor workplaces and possible worst-case scenarios," *AEU-International Journal of Electronics and Communications,* vol. 70, no. 6, pp. 808-813, 2016.

[6] R. Asadi, H. Aliakbarian, G. Khayambashi, and P. Majdolashrafi, "A case-study on the effect of averaging duration on RF dosimetry of general public environments," *IEEE Electromagnetic Compatibility Magazine,* vol. 9, no. 3, pp. 45-54, 2020.

[7] IEEE Standards Coordinating Committee, "IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3kHz to 300GHz," *IEEE C95. 1-1991,* 1992.

[8] I. C. o. N.-I. R. Protection, "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)," *Health physics,* vol. 118, no. 5, pp. 483-524, 2020.

[9] H. Jammet *et al.*, "Guidelines on limits of exposure to radiofrequency electromagnetic fields in the frequency range from 100 kHz to 300 GHz," *Health Physics,* vol. 54, no. 1, pp. 115-123, 1988.

[10] *Non-ionozing radiation*, I. N. Standardization and Organization, Tehran,Iran, 2026.

[11] K. R. Foster, A. Lozano - Nieto, P. J. Riu, and T. S. Ely, "Heating of tissues by microwaves: A model analysis," *Bioelectromagnetics: Journal of the Bioelectromagnetics Society, The Society for Physical Regulation in Biology and Medicine, The European Bioelectromagnetics Association,* vol. 19, no. 7, pp. 420-428, 1998.

[12] A. Papoulis and S. Unnikrishna Pillai, *Probability, random variables and stochastic processes*. 2002.

[13] A. Papoulis and S. U. Pillai, *Probability, random variables, and stochastic processes*. Tata McGraw-Hill Education, 2002

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