Evaluation of Electromagnetic Field Generated by LTE and NR Cellular Networks

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Abstract — **The article presents measurement options, changes, and results for electromagnetic exposure for New Radio (NR) mobile base stations. It is important because Internet of Digital Reality devices will also use New Radio (NR) cellular networks. In the article, the frequency-selective and code-selective measurement procedures are presented. In the case of New Radio cellular technology, the continuously broadcasted channels have changed, and the effects of it are examined. We summarized these, to present the New Radio extrapolation formula that is used to evaluate the measurements and its differences compared to the extrapolation formula used to measure the Electric and Magnetic Field (EMF) of 4G technology. We also mention the measurement procedure currently used to measure the electromagnetic exposure of 4G base stations. The 4G EMF measurement is detailed through a measurement we made. The aim of our work is to present the measurement procedures that are currently only recommended. Also, we illustrate the extent to which the exposure levels of New Radio systems differ from those measured for Long Term Evolution (LTE) systems. A new measurement method is explained for EMF testing, which was created by us. This simpler measurement method can make EMF testing faster and more economical.**

Index Terms— **EMF Test methods, Extrapolation, 4G and 5G measurement, NR system, Extrapolation formula**

I. INTRODUCTION

The article presents the electromagnetic exposure of the base stations of modern cellular networks, mainly the possible test methods of the fifth-generation mobile technology, based on the electromagnetic exposure tests used in case of the fourth-generation mobile technology, mainly the frequency-selective, code-selective measurement methods. The focus of the work was to present the main differences in the Electric and Magnetic Field (EMF) measurement of 5G technology. Compared to previous mobile technologies, the differences are beamforming, beamsweeping, and higher frequency bands, and the results of the study show that the power radiated by the base station due to beamforming is highly dependent on network traffic. In the case of the new technology, the continuously broadcast channels have changed, and their effects have been examined. We also examined the changes due to Time Division Duplex (TDD) technology and the short-term radiation due to high speeds. [1] The article summarizes these and presents the NR extrapolation formula for evaluating the measurements and the differences compared to the extrapolation formula used to measure the EMF of 4G technology. We present this through a measurement we performed, for which we developed a new measurement procedure. This measurement method can make the EMF test faster and more economical. This is important because the NR mobile network will also be used for Internet of Digital Reality purposes. The aim of the work is to present and compare the measurement procedures and extrapolation currently available only as a recommendation with the already standard LTE test and extrapolation procedure.

II. 5G BASE STATION EMF TEST METHODS

To investigate the exposure of 5G base stations, two basic recommendations are found. These are the frequency-selective and the code-selective measurement methods. [2] These two methods and the use of extrapolation give an accurate estimate of the maximum electromagnetic exposure of humans caused by the base station. However, there are some differences between the two procedures. In the case of frequency-selective testing, the extrapolated value exceeds the actual maximum exposure level, and in this case the extrapolation requires several system parameters from the operator to obtain the actual field strength levels. In the case of code-selective method, we get a more reliable, accurate value and need less information from the system operator. Frequency-selective emission measurement has additional disadvantages. In each case, the total field strength is determined in all channels of all E-UTRANs around the given measurement location. The measurement gives a result that is strongly dependent on the actual traffic on the system due to the traffic-dependent power radiation characteristic of NR. In the code-selective case, we can determine the value of the emission caused by each channel separately, so that we can intervene more effectively in the system parameters of the base station if necessary to improve them. The instantaneous power of signals from NR base stations changes rapidly over time and is highly dependent on the type of modulation used, which is also affected by the Frequency Division Duplexing (FDD) or Time Division Duplex (TDD) separation of the up / down direction. [3]

A. Extrapolation technique for NR signals

The maximum level of EMF at a given location is determined by the product of three factors:

$$E_{5G}^{max} = \sqrt{N_{SC}(B,\mu) F_{TDC} E_{RE}^{max}} \tag{1}$$

where:

- $N_{SC}\ (B,\mu)$ is the ratio of all subcarriers in the NR channel to the subcarriers in the Synchronization Signal (SS) / Physical Broadcast Channe (PBCH) block. This parameter depends on both the signal bandwidth (B) and the distance between the subcarriers (μ). To evaluate this parameter, it is necessary to determine the bandwidth of the SS / PBCH block by spectrum analysis, and then use a smaller RBW

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(resolution bandwidth) to determine the distance of the subcarriers in the block and the number of subcarriers from the two data. [4]

- F_{TDC} is the deterministic scaling factor that shows the downlink time range relative to the total signal transmission time. For stations operating in FDD mode, the value is 1, for stations operating in TDD mode it is determined by the Uplink / Downlink ratio.
- E_{RE}^{max} is the maximum EMF level measured at a single resource element (RE), which is the smallest unit of the resourceblock consisting of one carrier in a frequency domain and an OFDM symbol in the time domain.

The definition of E_{RE}^{max} plays a crucial role in the equation. As discussed in the previous sections, the main issues dealing with the choice of the pilot channel can be used as a reference for the extrapolation technique. In addition, some specific 5G characteristic effects that affect the reception performance of the pilot channel, such as beamforming, beamsweeping, TDD mode, and the number of beams produced using MU-MIMO antennas must also be considered. To harmonize the 4G and 5G extrapolation techniques, the proposed experimental channel is the PBCH demodulation reference signal (PBCH-DMRS). PBCH-DMRS is a component of SSBs, and its physical location is determined by the physical cell identifier. [5]

B. *Code-selective exposure testing of cellu-lar systems*

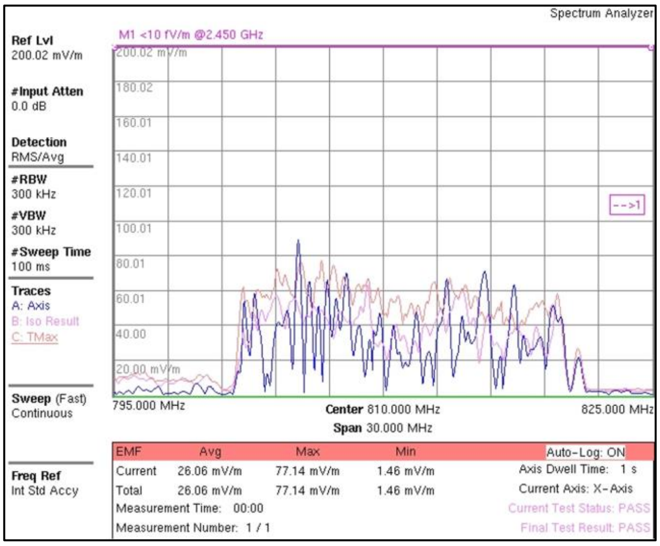
Code-selective tests require a code-selective receiver that can demodulate cell-specifically encoded RS signals to determine the field strength value generated by each RS. In addition to this cell-specific coding, it is also possible to measure the RS signal of each MIMO channel separately and display the results separately. It is true that the synchronization signals (P-SS and S-SS) are also cell-encoded, but it is not possible to separate them by MIMO paths with these signals, which is a clear disadvantage compared to analysis using RS signals. It is important to set the correct center frequency of the channel correctly, otherwise the instrument will not be able to demodulate the signal correctly, which may cause false result. The RS_{max} value will be used as the basis for the extrapolation. It is also a good idea to display the unique RS value of each MIMO channel in the radio cell, which makes it easier to determine if there is, for example, an exceptionally low- or high-level MIMO channel. If one of the MIMO channels radiates exceptionally low power during the test, this may result in underestimation of the emission in some cases. Conversely, we may overestimate the value of the emission, but with this method we are able to ignore these channels. During the test, the instrument uses the general extrapolation formula of the given mobile technology for the extrapolation, in which it substitutes the field strength value of the currently measured reference signal, however, for the LTE test the instrument uses a general value as the n_{CRS} weighting parameter, which is 11.65. This is one of the reasons why only a few instruments are currently able to code-selectively examine NR channels, because in this situation it is much more difficult to generalize extrapolation parameters. [6]

III. Test with an Anritsu MS2720T Measuring Equipment

The measurements were made outdoors with an Anritsu MS2720T near a base station. During the tests, the value of the electromagnetic exposure of the base station was measured in the frequency-selective and code-selective mode as well. The measurements were performed in two different environments, observing the ratio of the obtained exposure values between LTE and NR technologies. Therefore, a 4G / 5G-capable device (Nemo Handy) was placed relatively close to the measuring instrument, which communicated with the base station under study and in the meantime generated the largest possible data traffic. In the case of LTE, it was also performed both frequency-selective and code-selective testing. [7] Subsequently, the frequency-selective measurement on the 4G system was repeated on the 5G system. It is important to set the appropriate instrument parameters, including the individual polarization measurement times, their averaging, and the selection of the total measurement time, which plays a major role in the result. [8]

A. *Frequency-selective testing for LTE*

The Anritsu analyzer was configured by setting the appropriate RBW and VBW (300 kHz) measurement parameters.



Ref Lvl 200.02 mV/m
#Input Atten 0.0 dB
Detection RMS/Avg
#RBW 300 kHz
#VBW 300 kHz
#Sweep Time 100 ms
Sweep (Fast) Continuous
Freq Ref Int Std Accy
Center 810.000 MHz
Span 30.000 MHz

EMF	Avg	Max	Min
Current	26.06 mV/m	77.14 mV/m	1.46 mV/m
Total	26.06 mV/m	77.14 mV/m	1.46 mV/m

Measurement Time: 00:00
Measurement Number: 1 / 1
Auto-Log: ON
Axis Dwell Time: 1 s
Current Axis: X-Axis
Current Test Status: PASS
Final Test Result: PASS

Fig. 1: LTE frequency-Selective EMF Measurement Results

To obtain the maximum exposure value of the base station, the measured result must be extrapolated. For this, the power level of the PBCH block of the measured channel was used, which is always transmitted in LTE with a fixed periodicity around the center frequency of the carrier, so it was wrote it out in the trace t-max hold function examined during the measurement. This is marked with a marker in the Figure 2 and is 27,664 mV/m.

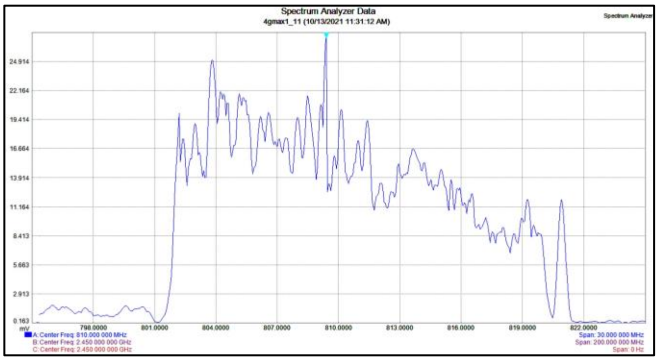


Fig. 2: Frequency-selective EMF measurement 1 Marker PBCH block

The value has been replaced by the extrapolation formula recommended by the IEEE (2).

$$E_{LTE}^{max} = \sqrt{k_{CSC} E_{CRS}} \tag{2}$$

The k_{cRS} value for the 20 MHz bandwidth is an average of 1200 divided by the subcarrier number of the reference PBCH block and corrected by the number of subcarriers in the SSS block. Thus, the extrapolated value was 0.567 V/m. This value is well below the limit specified by International Comission on Non-ionizing Radiation Protection (ICNIRP), which is 41 V/m for this frequency range, so the exposure value of the base station under study is adequate. [9] For the accurate exposure measurement the actual system parameters are required. In addition, we cannot disregard the measurement uncertainty and the possible overestimation of the frequency-selective measurement method, because in this case the systems operating at this frequency increase the power density and thus the value of the measured field strength.

B. *Code-selective testing for LTE*

In the case of code-selective testing, the measurement instrument was used in LTE demodulation mode. During the measurement the CRS signals are decoded by the instrument. All RS, P-SS and S-SS cell reference signals were decoded by the device in the examined band, so the value of the field strength P-SS and S-SS measured in the code-selective case can be compared with the field strength of the PBCH block used as a reference in the frequency-selective case. The extrapolation was activated so that the instrument automatically extrapolated the measured results. For this, the instrument uses a general k_{cRS} value and an RS (reference signal) value. In the case of code-selective measurement, the maximum exposure level estimated by base station extrapolation is 414.82 mV/m. The value is well below the limit.

Among the measurement results there is an extremely high value, 9.22 kV/m, it can be seen in Table 1. This value may be caused by a possible error in the demodulation procedure, which can be ignored. During the evaluation in the case of the frequency-selective measurement the test result is derived from the PBCH block (P-SS, S-SS) signals, in the case of code-selective measurement from the RS reference signal of the base station. In addition, we cannot ignore the measurement uncertainty. However, the frequency-selective and code-selective measurements yielded different results, the former -0.691 dBm/m^2 the latter -3.423 dBm/m^2. This deviation of about 3 dB is acceptable, given that the two methods use a different reference value as a basis. [10]

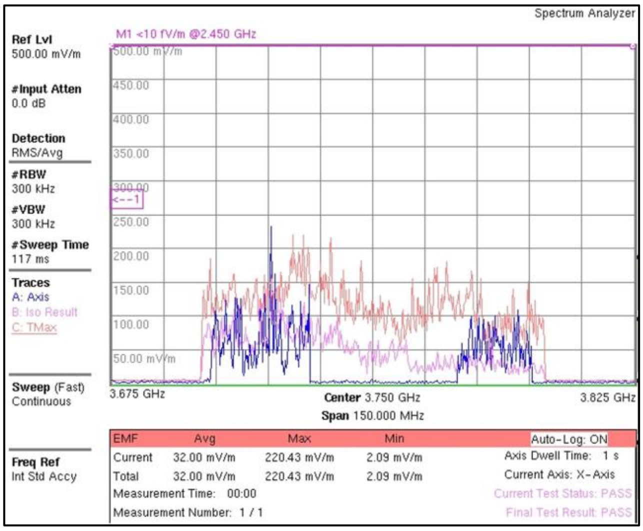
TABLE I
CODE-SELECTIVE EMF MEASUREMENT WITH DIRECT DATA TRAFFIC

Index	Cell Id (Grp, Sec)	RS (Avg/Meas)	P-SS (Avg/ Meas)	S-SS (Avg/Meas)
1	15 (5, 0)	10.04 mV/m	1.64 mV/m	11.80 mV/m
2	16 (5, 1)	1.33 mV/m	469.70 mV/m	1.41 mV/m
3	175 (58, 1)	2.93 mV/m	>9.22 kV/m	1.18 mV/m
4	181 (60, 1)	49.26 uV/m	8.22 uV/m	10.34 uV/m
5	260 (86, 2)	58.43 uV/m	516.14 uV/m	529.13 uV/m
Total		14.95 mV/m	>9.22 kV/m	14.93 mV/m
Field Strength (Ex Avg)		414.82 mV/m		
Field Strength (Total Ex Avg)		414.82 mV/m		

LTE Band 20 DL(791-821 MHz) (6350)
Center Freq: 811.000 MHz
BW 20 MHz

C. *Frequency-selective testing for NR*

It was used the same instrument parameters for the measurement as for the frequency-selective measurements for LTE.


Ref Lvl
500.00 mV/m
#Input Atten
0.0 dB
Detection
RMS/Avg
#RBW
300 kHz
#VBW
300 kHz
#Sweep Time
117 ms
Sweep (Fast)
Continuous
Freq Ref
Int Std Accy

EMF	Avg	Max	Min
Current	32.00 mV/m	220.43 mV/m	2.09 mV/m
Total	32.00 mV/m	220.43 mV/m	2.09 mV/m

Measurement Time: 00:00
Measurement Number: 1 / 1
Auto-Log: ON
Axis Dwell Time: 1 s
Current Axis: X-Axis
Current Test Status: PASS
Final Test Result: PASS

Fig. 3: NR frequency-selective EMF measurement determination of maximum field strength

To obtain the maximum exposure value of the base station, the measured result must be extrapolated. For this, it was used the power level of the SS / PBCH block located in the lower half of the measured channel, the average value of which was entered in the previously proposed extrapolation formula Equation (1). [11]

$$E_{5G}^{max} = \sqrt{N_{SC}(B,\mu) F_{TDC} E_{RE}^{max}} \tag{1}$$

The NSCs, the number of all subcarriers, required the bandwidth and the distance between the subcarriers. This is 100 MHz, which was determined by measurement. In this

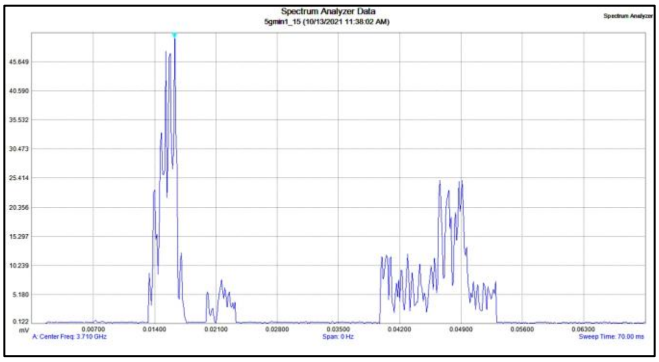


Fig. 4: Determination of the field strength of a frequency selective SSB block

case, we were examined the center of the band with 80 kHz span and a low-resolution bandwidth. Markers were used for evaluation and the distance between the subcarriers was determined from the difference between the two. The distance is 30 kHz, hence the NSC value is 3300. This is corrected by the number of the SS / PBCH block subcarrier. The station operates in TDD mode, therefore it is necessary to determine the F_{TDC}. This parameter was determined using the Nemo Handy to generate traffic during the measurement. This parameter was 0.5 value in this case. So, uplink and downlink communication are symmetric. The next was to determine the value of E_{RE}^{max}. The highest field strength levels of the SSBs was used, which is 48,247 mV/m (Figure 4), with this we compared the field strength levels for the maximum data traffic, which is 220.43 mV/m (Figure 3). The two values show a significant difference, so the signaling and traffic processes take place through a different gain beam. Therefore, the value of E_{RE}^{max} must be corrected by the average of the SSB blocks with the highest power level and the ratio of Traffic channel power levels according to Equation (3), so this value is 1.14.

$$E_{5G}^{max} = (E_{RE}^{PBCH-DMRS})\sqrt{\frac{F_{beam}}{R}} \tag{4}$$

The extrapolation was performed with the obtained parameters, so the estimated maximum exposure of the base station is 0.611 V/m. This is also well below the limit. [12] It can be seen that the highest field strength levels of the SSBs are nearly the same value as the Total Average Field strength, which is currently 32,00 mV/m. It can be also used to extrapolation, and it give nearly the same result, but in this situation also change the value of E_{RE}^{max}. Taking these into account the estimated maximum exposure of the base station is 0.543 V/m. The deviation is within measurement uncertainty 3.404 dB. With this simpler measurement method, EMF testing can be performed faster and more economically. The effects of the new technology, such as beamforming, beamsweeping, and burst-like ultra-high-speed data transmission, are strongly influenced by current field strength levels. [13] This is well reflected in the fact that the field strength level of the SS/PBCH block measured with zero span differs by four and a half times the performance of the current transmission channel. However, this effect was corrected in the previously evaluated parameter E_{RE}^{max}. [14]

IV. CONCLUSION

Based on the measurements the determination of the maximum base station exposure value estimated by extrapolation is uncertain even in the case of the previous technology (4G). However, with the appropriate reference signal and the use of extrapolation, the frequency-selective method can be used for base station exposure measurement with some measurement uncertainty. The average field strength value of the frequency-selective EMF measurements is close to the field strength value of the PBCH and SS / PBCH reference signals used. However, an inappropriate reference value, such as the use of the maximum field strength level for frequency- selective measurements for extrapolation, results in a very overestimated exposure value. This effect makes a bigger difference for 5G NR (NR) base stations because the radiated power level is extremely variable due to technological innovations. In addition, the difference between the two measurement methods was noticeable, because in the case of code-selective examination only the values of the field strength that belong to the examined base station are evaluated. However, the frequency-selective measurement better reflects the total electromagnetic exposure of humans at a given location. The new simplified measurement procedure what made by us gives a good value within the measurement uncertainty, but a simpler, faster and more economical test procedure. Based on the test results, the value of the electromagnetic exposure caused by the base stations is adequate. For all three measurement methods, the measured power density is well below the limit recommended by ICNIRP.

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