Effect of Dielectric Properties of Human Hand Tissue on Mobile Terminal Antenna Performance

Zhekov, Stanislav Stefanov; Pedersen, Gert Frølund

Published in:
2020 14h European Conference on Antennas and Propagation (EuCAP)

DOI (link to publication from Publisher):
10.23919/EuCAP48036.2020.9135910

Publication date:
2020

Document Version
Accepted author manuscript, peer reviewed version

Effect of Dielectric Properties of Human Hand Tissue on Mobile Terminal Antenna Performance

Stanislav Stefanov Zhekov and Gert Frølund Pedersen
Department of Electronic Systems, Technical Faculty of IT and Design, Aalborg University, Aalborg, Denmark
e-mail: stz@es.aau.dk; gfp@es.aau.dk

***Abstract*—A good approach when designing antennas for mobile terminals is to optimize them for operation in the vicinity of the user body. The presence of a lossy human tissue in the antenna's near field has an adverse effect on the radiator's performance. The focus of this paper is on studying the change in the antenna performance due to the change in the dielectric properties of the human hand holding the mobile terminal. The investigation is conducted by using an antenna array consisting of two identical and symmetrical PIFA antennas covering the frequency band from 5.8 GHz to 7.7 GHz. Several different values of the complex permittivity are assigned to a human hand phantom in the numerical simulations and it is found that the variation of the complex relative permittivity within a large range of values does not change largely the S-parameters and radiation efficiency of the antenna.**

***Index Terms*—Mobile terminal antenna, user hand effect, complex permittivity variation, antenna performance.**

I. Introduction

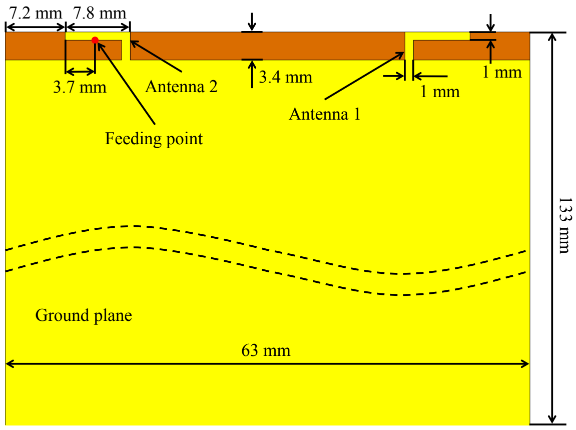
The inherent operation of the mobile terminals close to the lossy tissue of the user brings to an inevitable problem with their antennas. The proximity of the human body to the handset deteriorates the performance of its antennas. Due to that one of the challenges when designing handset antennas is to make them as robust as possible against the closely located human tissue, i.e. to lower the user effect on the antenna performance. In general, the presence of the human body next to the mobile terminal antenna alters its input impedance and therefore its matching. Part of the radiated by the antenna power is absorbed by the human tissue which in turn lowers the antenna radiation efficiency. The absorption and reflection by the human body change the electromagnetic field generated by the antenna and thus changes the antenna radiation pattern. That is, the degradation of the antenna total efficiency as well as the mean effective gain due to the presence of the user might have a critical impact on the performance of the mobile communication system.

Multiple investigations of the user effect have been conducted over the years and some of them can be found in [1]–[21]. Focusing on the effect of the human hand since it is of main interest in this paper, it is well known that different antennas are affected in a different way by the human hand [3], [6], [12], [13], [15]. Also, the hand position and grip can have a significant impact on the antenna performance [3], [9], [10], [12]–[14], [17]. In other words, the level of degradation of the performance can be very different from one antenna design to another and from one user to another. In this paper however, we are not looking into this aspect but rather we are interested in the impact of a hand with different dielectric properties on the antenna operation. In other words, it is checked whether having a hand with different complex permittivity in the vicinity of the antenna will change dramatically the radiator's performance.

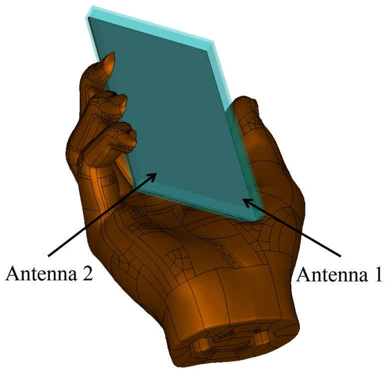
There has already been conducted similar research on this topic in [12], where it has been presented numerical study for the effect of the dielectric properties of the human hand phantom on the performance [in terms of total radiated power (TRP)] of antennas operating at 900 MHz and 1750 MHz. It has been shown that changing the dielectric constant and the conductivity of the human hand (while keeping the grip and position of the hand the same) with up to 15% does not have large impact on the antenna performance. Also, it should be mentioned that in [21] we have checked the effect of a human hand phantom having the dielectric properties of dry and wet palm on the performance of an antenna array. However, now we are extending the work regarding the variation in the antenna performance (in the study is used an antenna array with two radiators, the impedance of which is matched for operation in free space in the frequency range 5.8-7.7 GHz) in the presence of a human hand tissue with several different values of the complex permittivity. The knowledge obtained from this investigation will tell the antenna designers whether it is needed to further test and optimize their radiators for different values of the dielectric properties of the human hand or it is not necessary.

II. Antenna Array Design

The geometry of the antenna array used for the study is presented in Fig. 1(a). The array consists of two identical PIFA antennas having mirror symmetry. The antennas are printed on FR4 substrate with dimensions of 133 x 63 x 0.8 mm^3. The employed FR4 material has dielectric constant of 4.3 and loss tangent of 0.025. The antennas are placed along the short edge of the substrate at its left and right corner. The ground plane is printed on the same side of the substrate as the antennas. Part of the ground plane at the edge of the substrate, where the antennas are located, with a width of 3.4 mm is cut out. The entire structure (antennas, ground plane, and substrate) is encompassed with plastic cover mimicking the mobile phone casing. The dimensions of this box are 135 x 65 x 8 mm^3, it has a thickness of 1 mm and is made of a material with



(a)



(b)

Fig. 1: (a) Geometry of the antenna array without the mobile phone casing; and (b) antenna array with the mobile phone casing (semi-transparent) located in a hand phantom (the antennas are pointing toward the phantom).

dielectric constant of 2.1 and loss tangent of 0.002. The mobile phone housing is in contact with the surface of the antennas.

III. Dielectric Properties of Human Hand

In our previous work [21], we measured the dielectric properties of human hands (in total 22 individuals participated in the study) over the frequency band 5-67 GHz. More precisely, by using an open-ended coaxial probe the complex relative permittivity was tested at 6 points on each right and left palm of all 22 volunteers. Also, the dielectric properties were measured at 2 points on the tip of each right and left thumb of 16 of the volunteers. Both palms and thumbs were tested in two stages - dry (or having natural hydration level) and wet (deionized water was used for moistening the hand and the surface water was wiped out before the measurement). Also, the data for all test cases (dry and wet palm and fingertip of thumb) were modeled by using both single-pole Cole-Cole model and multi-pole Debye model.

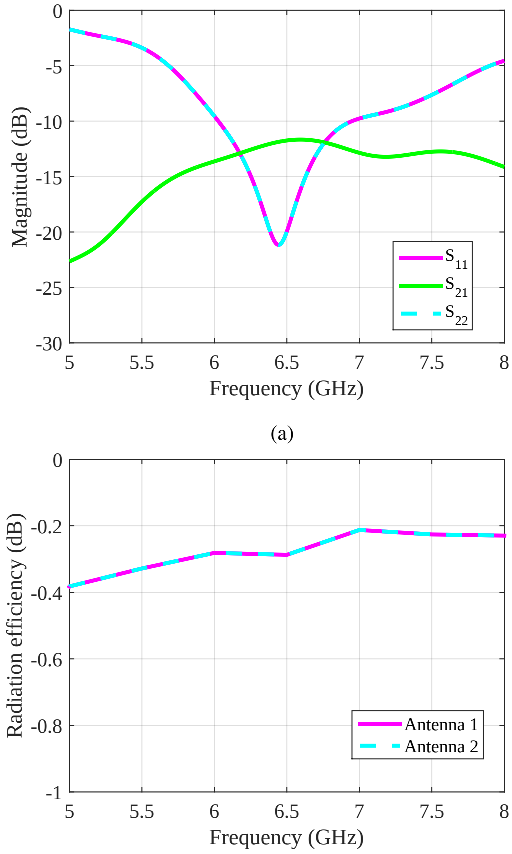
In [21], we checked the change in the antenna performance in the presence of a hand phantom, when the mean dielectric properties, found in the study, for dry and for wet palm were assigned to the phantom. Different users load the mobile phone antenna with hand tissue having different values of the complex permittivity (the persons have different dielectric properties of the hand). Hereof in this paper, we are studying the degree of change in the performance of the mobile terminal antenna due to the change in the human hand dielectric properties.

TABLE I: Dielectric properties assigned to the human hand phantom in the study.

No.	$\varepsilon_r^{'}$	$\varepsilon_r^{''}$
1	6.2	1.6
2	7.3	1.9
3	15.8	7.3
4	20.7	10.3
5	34.3	18.1
6	39.5	20.8

The human hand phantom holding the mock-up (placed in data mode) is presented in Fig 1(b). This configuration array - hand was chosen since the antennas (placed at the bottom of the substrate) are in the vicinity of the palm (this is the tissue, the dielectric properties of which are used for the study). More specifically, with this arrangement antenna 1 is right next to the palm while antenna 2 is located a short distance from the palm. This placement of the handset gives the opportunity to see how the change in the complex relative permittivity of the palm will influence the performance of antennas with different distance to that part of the hand.

In total six pairs of values for the dielectric constant $\varepsilon_r^{'}$ and loss factor $\varepsilon_r^{''}$ were employed for the study. These combinations are given in Table I and most of them are taken at 6.5 GHz from the already discussed investigation presented in [21]. In the following text, the numeration from the table is used. Combinations No. 2 and No. 5 correspond to the minimum value found for $\varepsilon_r^{'}$ and for $\varepsilon_r^{''}$ in case of dry palm and maximum value found for $\varepsilon_r^{'}$ and for $\varepsilon_r^{''}$ in case of wet palm, respectively (it should be mentioned that these are the maximum and minimum values found among all test points on both left and right palm of all volunteers; it should not be mistaken with the results in Fig. 4 in [21], where the extreme mean values are presented, i.e. the ones obtained after averaging over all test points for both palms for each volunteer). It should be mentioned that both $\varepsilon_r^{'}$ and $\varepsilon_r^{''}$ are higher for wet palm tissue than for dry one. The latter is because of the higher dielectric constant and loss factor of water than these for dry palm tissue, i.e. the moistening increases both $\varepsilon_r^{'}$ and $\varepsilon_r^{''}$ of the palm tissue. The combinations No. 3 and No. 4 correspond to the mean value found for $\varepsilon_r^{'}$ and for $\varepsilon_r^{''}$ in case of dry palm and mean value found for $\varepsilon_r^{'}$ and for $\varepsilon_r^{''}$ in case of wet palm, respectively. Combinations No. 1 and 6 do not correspond to any measured values but they are rather made up. Combination No. 1 has both $\varepsilon_r^{'}$ and $\varepsilon_r^{''}$ 15% lower compared to those for No. 2, while combination No. 6 has both $\varepsilon_r^{'}$ and $\varepsilon_r^{''}$ 15% higher compared to those for No. 5. In this way, it is checked the effect of even smaller/higher values of $\varepsilon_r^{'}$ and $\varepsilon_r^{''}$ on the antenna performance. No dispersion of the dielectric properties of the palm tissue is considered, i.e. in the simulations to the phantom is assigned complex



(a)

(b)

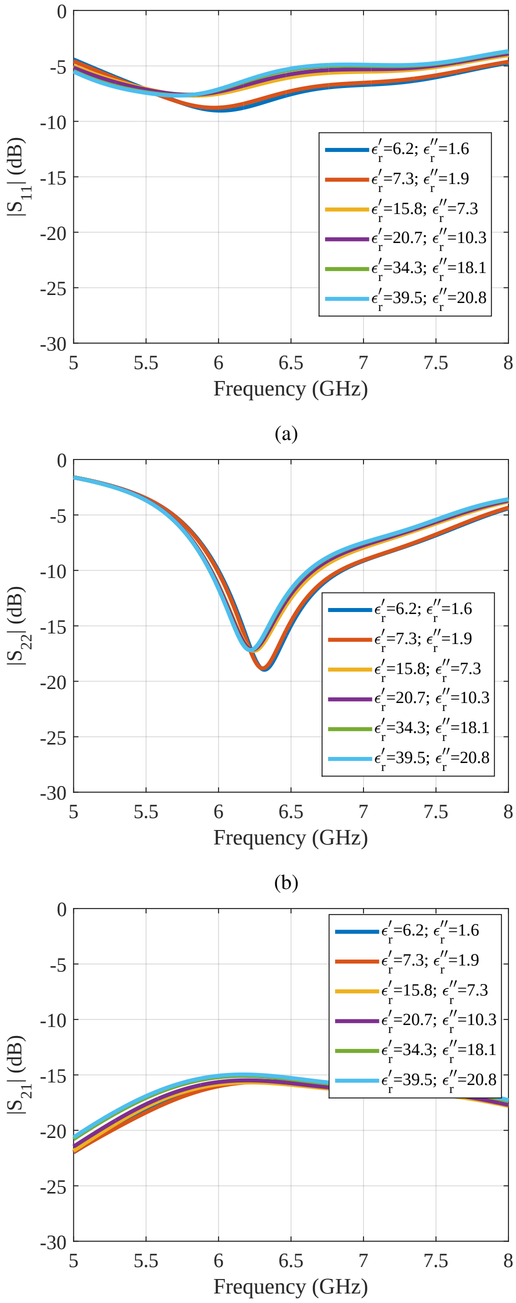
Fig. 2: Free space performance of the antennas: (a) magnitude of S-parameters; and (b) radiation efficiency.

permittivity with a constant value over the entire frequency band of interest. The reason for this is that the dispersion is expected to bring only insignificant changes in the results. All studies were performed by using CST Microwave Studio 2019.

IV. Results and Discussion

The magnitude of the simulated S-parameters of the antennas in free space is presented in Fig. 2(a). Since the antennas are identical and have mirror symmetry, S_{11} and S_{22} are exactly the same. In free space, the antennas cover the frequency range 5.8 - 7.7 GHz with return loss higher than 6 dB (the band from 6 GHz to 7 GHz is covered with S_{ii} below -10 dB). Over the covered frequency band, S_{21} is lower than -11.5 dB. The radiation efficiency is shown in Fig. 2(b). As one can see this parameter is between -0.3 dB and -0.2 dB over the impedance bandwidth. It should be mentioned that it was decided to perform the investigation over this part of the spectrum because future 5G communication systems might be deployed at frequencies between 5.9 GHz and 7.1 GHz [22].

As already discussed, the values (constant over the studied frequency band) for ε_r' and for ε_r'' from Table I were assigned to the human hand phantom. Fig. 3 shows the simulated results for S-parameters of the antennas when the mock-up is placed in the hand phantom. As one can see the matching of antenna 1 (right next to the palm) is significantly more influenced than that for antenna 2 (further away from the palm) when compared to the free space case. The presence of more tissue around antenna 1 is the reason for the larger change in S_{11} compared to the change in S_{22}. That is, the degree of impact depends on the position of the antennas with respect to the phantom. The tendency of shifting of the dip in the matching towards lower frequencies with increasing the complex permittivity ε_r^* of the phantom is observed. The

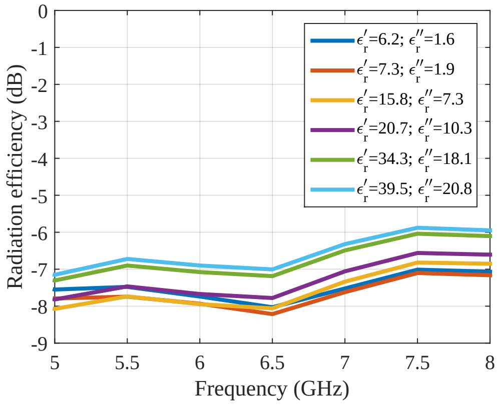


(a)

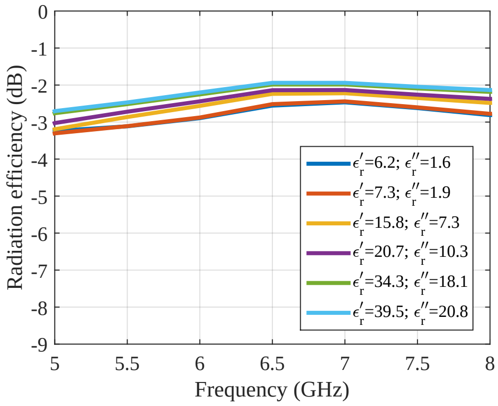
(b)

(c)

Fig. 3: Magnitude of S-parameters of the antennas in data mode: (a) S_{11}; (b) S_{22}; and (c) S_{21}.



(a)



(b)

Fig. 4: Radiation efficiency of the antennas in data mode: (a) antenna 1; and (b) antenna 2.

coupling S_{21} in the presence of a phantom is lower than that in free space.

As one can see from the results, both S_{11} and S_{22} change slightly among the cases mean measured ε_r^* for dry and for wet palm ($\varepsilon_r^* = 15.8 - j7.3$ and $\varepsilon_r^* = 20.7 - j10.3$), and maximum measured ε_r^* for wet palm ($\varepsilon_r^* = 34.3 - j18.1$). These results are also similar to the ones for the made up case with the highest employed dielectric constant and loss factor ($\varepsilon_r^* = 39.5 - j20.8$). The matching for each antenna, when the lowest measured ε_r^* for dry palm ($\varepsilon_r^* = 7.3 - j1.91$) is used and the matching when the lowest employed (made up) ε_r^* ($\varepsilon_r^* = 6.2 - j1.6$) is used, is similar. Comparing all studied scenarios one can see that: 1) for S_{11} the difference between the highest and lowest dip is of 1.4 dB and the largest difference in the resonant frequency is of 300 MHz; and 2) for S_{22} the difference between the highest and lowest dip is of 1.8 dB and the largest difference in the resonant frequency is of 100 MHz. The difference between the curves for S_{21} for the different combinations of dielectric constant and loss factor is up to some 1.3 dB over the covered frequency band in the presence of a hand.

The numerically obtained data for the radiation efficiency of the antennas is shown in Fig. 4. Comparing with the free space case (Fig. 2(b)), one can see that in the vicinity of the human hand the radiation efficiency of the antennas is lower. The higher radiation efficiency of antenna 2 than that of antenna 1 is because of the presence of less human tissue around antenna 2 resulting in less absorbed power.

The difference in the radiation efficiency of the same antenna for different combinations of the dielectric constant and the loss factor of the human palm is not high. More specifically, comparing all combination one can see that the difference between the minimum and maximum radiation efficiency is some 1 dB for antenna 1 and some 0.6 dB for antenna 2 over the covered frequency band in the presence of a human hand.

V. Conclusion

Numerical investigation of the effect of the change in the dielectric properties of human hand palm on the mobile terminal antenna performance has been presented in this paper. The purpose of the study has been to see how sensitive is the antenna performance to the difference in the complex permittivity of the users' palm tissue. For the sake of the investigation, an array consisting of two PIFA antennas covering the frequency band from 5.8 GHz to 7.7 GHz in free space has been employed. The complex relative permittivity of the hand phantom has been varied from $\varepsilon_r^* = 6.2 - j1.6$ to $\varepsilon_r^* = 39.5 - j20.8$ in 6 steps. It should be mentioned that both the lowest and highest employed dielectric properties in the study have been made up, i.e. they have not been observed in our previous measurements of the complex permittivity of a human hand. It has been shown that the difference in the S-parameters of the corresponding antennas when loading the radiators with palm tissue with different material properties, while keeping the same grip, is not large. The variation of the complex permittivity of the palm tissue has a little impact on the radiation efficiency of the antennas when they are in the vicinity of the palm. Based on the presented results, even though the dielectric constant has been varied with 33.3 units and the loss factor with 19.2 units, the performance of the antennas has not changed crucially. Therefore, the antenna designers might not need to consider testing and optimizing their radiators for different values of the complex permittivity of the human hand.

References

[1] J. Toftgard, S. N. Hornsleth and J. B. Andersen, "Effects on portable antennas of the presence of a person," *IEEE Trans. Antennas Propag.*, vol. 41, no. 6, pp. 739-746, June 1993.

[2] M. Okoniewski and M. A. Stuchly, "A study of the handset antenna and human body interaction," *IEEE Trans. Microw. Theory Techn.*, vol. 44, no. 10, pp. 1855-1864, Oct. 1996.

[3] M. A. Jensen and Y. Rahmat-Samii, "The electromagnetic interaction between biological tissue and antennas on a transceiver handset," in. *Proc. IEEE Antennas Propag. Soc. Intern. Symp.*, vol. 1, pp. 367-370, June 1994.

[4] G. F. Pedersen, J. O. Nielsen, K. Olesen, and I. Z. Kovacs, "Measured variation in performance of handheld antennas for a large number of test persons," in. *Proc. 48th IEEE Veh. Tech. Conf.*, vol. 1, pp. 505-509, May 1998.

[5] G. F. Pedersen, K. Olesen, and S. L. Larsen, “Bodyloss for handheld phones,” in. *Proc. 49th IEEE Veh. Tech. Conf.*, vol. 2, pp. 1580-1584, May 1999.

[6] K. R. Boyle, “The performance of GSM 900 antennas in the presence of people and phantoms,” in. *Proc. 12th Intern. Conf. Antennas Propag.*, vol. 1, pp. 35-38, March 2003.

[7] O. Kivekas, J. Ollikainen, T. Lehtiniemi, and P. Vainikainen, “Bandwidth, SAR, and efficiency of internal mobile phone antennas,” *IEEE Trans. Electromagn. Compat.*, vol. 46, no. 1, pp. 71-86, Feb. 2004.

[8] J. Krogerus, J. Toivanen, C. Icheln and P. Vainikainen, “Effect of the human body on total radiated power and the 3-D radiation pattern of mobile handsets,” *IEEE Trans. Instrum. Meas.*, vol. 56, no. 6, pp. 2375-2385, Dec. 2007.

[9] S. S. Zhekov, A. Tatomirescu, E. Foroozanfard, and G. F. Pedersen, “Experimental investigation on the effect of user’s hand proximity on a compact ultrawideband MIMO antenna array,” *IET Microw. Antennas Propag.*, vol. 10, no. 13, pp. 1402-1410, Oct. 2016.

[10] M. Pelosi, O. Franek, M. B. Knudsen, and G. F. Pedersen, “Influence of dielectric loading on PIFA antennas in close proximity to user’s body,” *Electron. Lett.*, vol. 45, no. 5, pp. 246-247, Feb. 2009.

[11] V. Plicanic, B. K. Lau, A. Derneryd, and Z. Ying, “Actual diversity performance of a multiband diversity antenna with hand and head effects,” *IEEE Trans. Antennas Propag.*, vol. 57, no. 5, pp. 1547-1556, May 2009.

[12] C. Li, E. Ofli, N. Chavannes, and N. Kuster, “Effects of hand phantom on mobile phone antenna performance,” *IEEE Trans. Antennas Propag.*, vol. 57, no. 9, pp. 2763-2770, Sept. 2009.

[13] M. Pelosi, O. Franek, M. B. Knudsen, G. F. Pedersen, and J. B. Andersen, “Antenna proximity effects for talk and data modes in mobile phones,” *IEEE Antennas Propag. Mag.*, vol. 52, no. 3, pp. 15-27, June 2010.

[14] J. Holopainen, O. Kivekäs, J. Ilvonen, R. Valkonen, C. Icheln, and P. Vainikainen, “Effect of the user’s hands on the operation of lower UHF-band mobile terminal antennas: focus on digital television receiver,” *IEEE Trans. Electromagn. Compat.*, vol. 53, no. 3, pp. 831-841,, Aug. 2011.

[15] B. Yanakiev, J. Ø. Nielsen, M. Christensen, and G. F. Pedersen, “Antennas in real environments,” in. *Proc. 5th Eur. Conf. Antennas Propag. (EuCAP)*, pp. 2766-2770, Apr. 2011.

[16] S. S. Zhekov, A. Tatomirescu, O. Franek, and G. F. Pedersen, “Study of the interaction user head-ultrawideband MIMO antenna array for mobile terminals,” in. *Proc. Int. Conf. Electromagn. Advan. App. (ICEAA)*, pp. 930-933, 2016.

[17] J. Ilvonen, O. Kivekas, J. Holopainen, R. Valkonen, K. Rasilainen, and P. Vainikainen, “Mobile terminal antenna performance with the user’s hand: effect of antenna dimensioning and location,” *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 772-775, 2011.

[18] C. Di Paola, I. Syrytsin, S. Zhang, and G. F. Pedersen, “Investigation of user effects on mobile phased antenna array from 5 to 6 GHz,” in. *Proc. 12th Eur. Conf. Antennas Propag. (EuCAP)*, pp. 1-5, Apr. 2018.

[19] K. Zhao, J. Helander, Z. Ying, D. Sjoberg, M. Gustafsson, and S. He, “mmWave phased array in mobile terminal for 5G mobile system with consideration of hand effect,” in. *Proc. 81st IEEE Veh. Tech. Conf.*, pp. 1-4, May 2015.

[20] B. Yu, K. Yang, C. Sim, and G. Yang, “A novel 28 GHz beam steering array for 5G mobile device with metallic casing application,” *IEEE Trans. Antennas Propag.*, vol. 66, no. 1, pp. 462-466, Jan. 2018.

[21] S. S. Zhekov, O. Franek, and G. F. Pedersen, “Dielectric properties of human hand tissue for handheld devices testing,” *IEEE Access*, vol. 7, pp. 61949-61959, 2019.

[22] Spectrum for 4G and 5G. [Online]. Available: Available: https://www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf