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Finger Ring Phased Antenna Array for 5G IoT and Sensor Networks at 28 GHz

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***Abstract*—In this paper, a circular phased antenna array has been constructed on the finger ring for the 28 GHz 5G communication systems. The antenna array has been verified in free space and with user's hand phantom on three fingers by the simulations. It has been found that such antenna structure is resilient towards the user effects and has a stable coverage efficiency characteristics. The coverage efficiency of 80 % with the realized gain of 5 dBi has been observed when the ring simulated with the user's hand. The correlation between high power loss density with antenna de-tuning has also been observed.**

***Index Terms*—Antennas, Finger Ring Antenna, Phased Array, 28 GHz, 5G, IoT, Sensor Networks, Wearable Antennas, User effects.**

I. Introduction

Recently 5G communication systems and internet of things (IoT) have become a hot research topic. IoT applications would include a number of different applications in the different domains, such as healthcare, transportation, industry, agriculture, smart home, vehicles, school, market, and industry [1]. A wearable finger ring antenna could be used as a high data rate health monitoring, tracking, and even maybe even as a future smart communication device in the scope of wearable applications [2].

To achieve the high data rate in 5G mobile networks a frequency band at 28 GHz has been proposed. Furthermore, as frequency increases the path loss increases as well. However, the high path loss can be overcome by utilizing high gain directional antennas with beam steering capabilities [3]. Such antenna arrays have already been in research for the 5G mobile terminal applications in [4] and [5]. The performance of the 28 GHz mobile antenna array is usually done by considering the coverage efficiency as a metric of choice, proposed in [6]. However investigation of the performance of wearable 5G phased antenna arrays are limited. Furthermore, the user effects on the mobile terminal antennas at 28 GHz has been investigated in [7] and [8]. It has been found that the shadowing from the user plays the major role in the performance of the mobile terminal antenna. However, there are no user effect studies done on the performance of 28 GHz wearable phased antenna array. The finger ring antennas have already been investigated for the frequencies below 28 GHz, however because of the absorption losses the efficiency of those designs is very low. In [9] the finger ring antenna, designed on the Rogers RT 6006 substrate for 5 GHz in the scope of the wireless sensor networks. In [10] a wearable finger ring antenna performance has been evaluated in relation to the position and rotation of ring on the finger phantom at 2.5 GHz. Similar studies have been done in [11]–[14] at 900 MHz, 1.8 GHz, 2.4 GHz, and UWB high band (7.25 – 10.25 GHz). However, no such studies have been done on the phased antenna arrays at 28 GHz. The electromagnetic field (EMF) exposure study at 28 GHz has also been carried out in [15] only of the mobile terminal antenna array.

In this paper, the finger ring phased antenna array for 28 GHz is proposed. On the contrary to the low frequency designs, the efficiency of the proposed antenna is higher, because of the high frequency. Furthermore, the phased antenna array performance has been studied with the user's hand. The full body simulations have not been done because no standard positions of the user with the finger ring can be defined and the hand location can be arbitrary. Finally, the EMF exposure of human hand to finger ring phased antenna array also has also been conducted.

II. Phased Antenna Array Geometry

The proposed finger ring circular phased antenna array is composed of inverted-L antenna elements, as shown in Fig 1. Antennas are distributed around the ring circle with 18° angles, as shown in Fig. 1(b). Thus, the distance between antenna elements in the proposed circular antenna array is 4 mm, as shown in Fig. 1(c). The antenna is build up of four layers of material (see Fig. 1(a)) counting from the middle of the ring:

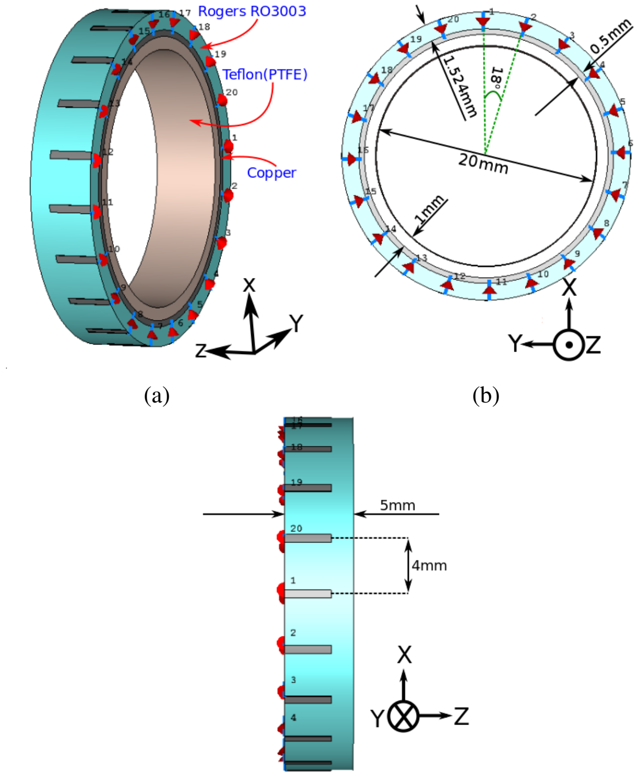
- Teflon ring spacer - diameter of 10 mm, a thickness of 1 mm.
- Copper ring ground plane - diameter of 11 mm, a thickness of 0.5 mm.
- Rogers RO3003 substrate - diameter of 11.5 mm, a thickness of 1.524 mm.
- Copper antennas printed on top of Rogers substrate - a thickness of 0.034 mm.

The width of the ring is 5 mm as shown in Fig. 1(c). The antenna elements have dimensions of 3.4 mm $\times$ 0.6 mm and fed with the discrete ports in at the corner of the element. The teflon ring spacer has been used in order to reduce the impact of the finger on the antenna.

III. Free Space Performance

In this section the operation principle and free space performance of the proposed phased antenna array will be described.

The reflection coefficients of the proposed antenna array elements are shown in Fig. 2. The impedance bandwidth of 1 GHz at −10 dB reference level has been achieved. The



(a) (b)

(c)

Fig. 1. Geometry of the phased antenna array in (a) 3D, (b) xy-plane, and (c) xz-plane.

isolation between antennas has not been shown, however, isolation does not exceed -15 dB level.

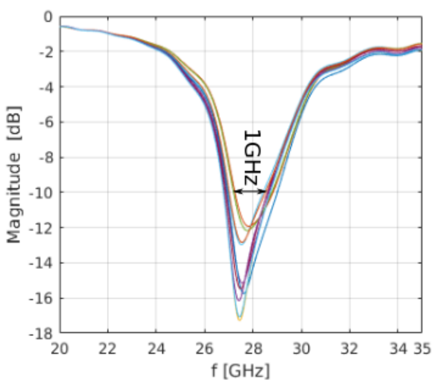


Fig. 2. Reflection coefficients of the proposed finger ring antenna array elements.

Each element in array have a broadside radiation pattern away from the ground plane ring with the HPBW of 119.2°. However, because the antenna elements are distributed around the ring in 18° steps only radiation patterns of four antenna elements overlap efficiently. Thus, it has been chosen that at any time only four co-located elements can be combined into an array. In Fig. 3 it has been chosen to choose element 1 to 4 and then combine them into a sub-array. The resulting gain is 9.4 dBi.

In order to achieve the full coverage, the four active elements are scanned with the progressive phase shift up to 100°. Then, the next element in the sub-array become active and last element in the array become inactive. In this way, the sliding around the circle sub-array of four elements is created. For example:

1) Sub-array 1 - elements 1-4.
2) Sub-array 2 - elements 2-5.
3) Sub-array 4 - elements 3-6.
4) And so on until the last sub-array 20 - elements 20, 1, 2, 3.

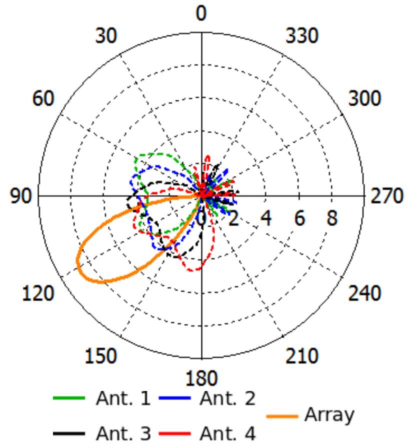
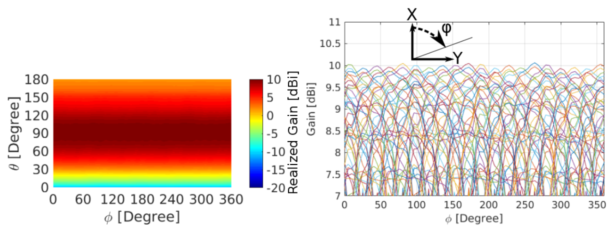


Fig. 3. ϕ / Degree vs dB at $\theta = 90°$

The total scan pattern of the proposed array is calculated for the all 20 sub-arrays for phase shifts of 10 to 100° with 10° steps. The total scan pattern is shown in Fig. 4(a). It can clearly be seen that antenna array have very low coverage in the region from $\theta = 0°$ to $\theta = 30°$. Nevertheless, unidirectional coverage with the gain over 5 dBi can be seen in the region from $\theta = 60°$ to $\theta = 150°$. This can be illustrated more clearly by inspecting the beam-switching pattern of the phased antenna array at $\theta = 90°$ cut as illustrated in Fig. 4(b).



(a) (b)

Fig. 4. (Total scan pattern (a) and the beam-switching pattern (b) of the proposed phased antenna array.

To further investigate the spatial coverage performance of the proposed finger ring phased antenna array the cover efficiency has been calculated from the total scan pattern as:

$$\eta_c = \frac{\text{Coverage solid angle}}{\text{Total solid angle}} \tag{1}$$

where the total solid angle is defined as 4π steradians.

The coverage efficiency for the free space phased finger ring antenna array is shown in Fig. 5 [6]. The proposed phased antenna array can cover 60 % of space with the gain of 7.5 dBi.

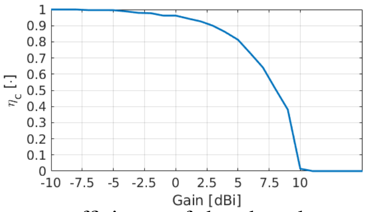


Fig. 5. Coverage efficiency of the phased array in free space.

IV. User Effects

However, the finger ring antennas can not be studied only in free space. It is important to verify the performance with the presence of the user. In this paper two cases has been studied:

1) User affects the antenna - miss-match loss, absorption loss, and shadowing loss.
2) Antenna effects the user - power loss density in the tissue.

It has been chosen to simulate the ring with the CTIA hand, using a different finger for the ring placement. The chosen setups are: the index finger 6(a), middle finger 6(b), and ring finger 6(a).

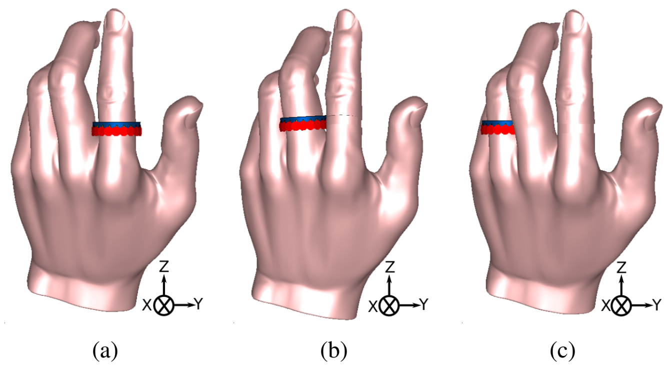


Fig. 6. Finger ring phased antenna array a) setup 1, b) setup 2, c) setup 3.

A. Reflection Coefficient

It has been chosen to only look on reflection coefficients of the array elements, as the coupling between antennas is very low. Isolation is lower than -15 dB in free space and with the user. The reflection coefficients of the antenna array simulated with the user can be seen in Fig. 7. It can be noticed that antennas which are touching the human skin are not so efficient. In Fig. 7(a) antennas 5, 10 and 9 are affected the most by the user's finger proximity. Next, in Fig. 7(b) antennas 9 and 8 are affected considerably by the user in setup 2, and antenna 20 is de-tuned towards the higher frequency. Finally, in Fig. 7(c) antennas 18 and 19 are affected considerably by the user effects, and the resonance of the antenna 17 is shifted towards the higher frequencies. Furthermore, it can be noticed that in the case of the antenna 5 in setup 1 and the antenna 19 in setup 3 very low broadband reflection coefficient has been achieved. However, that phenomenon occurred because of the user interference. Thus, the antennas 5 and 19 in setups 1 and 3 have very low radiation efficiency (≤ -20 dB) because of the absorption losses.

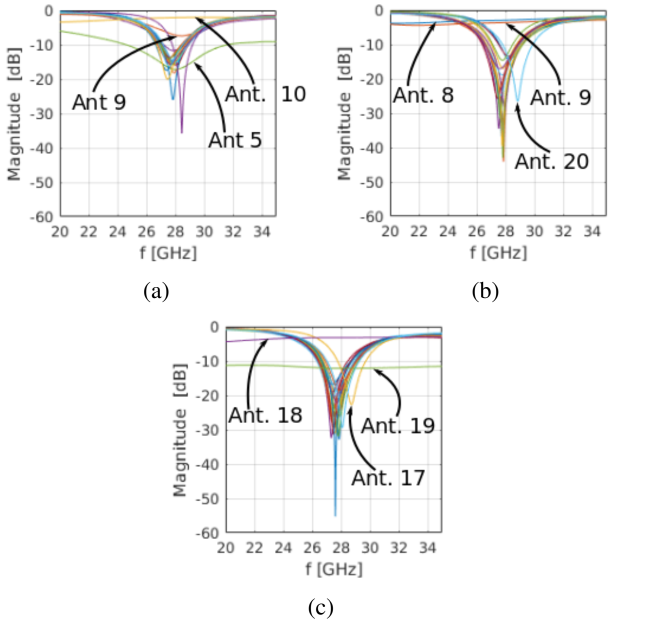


Fig. 7. Reflection coefficients of all antenna elements in (a) setup 1, (b) setup 2, and (c) setup 3.

B. Total Scan Pattern and Coverage Efficiency

Total scan pattern of the proposed finger ring circular antenna array in the three setups with the user's hand are shown in Fig. 8. The total scan patterns have a different shape than the scan pattern of the simulated in free space antenna array in Fig. 4(a). The scan pattern is not continuous in ϕ direction, because of the blockage induced by the user's fingers. The lobe at $\phi = 140°$ is present in all of the total scan patterns. Furthermore, two other big lobes are located on both sides of the lobe at $\phi = 140°$. The gain at the areas around $\theta = 180°$ and $\theta = 0°$ is still lower than 2 dBi.

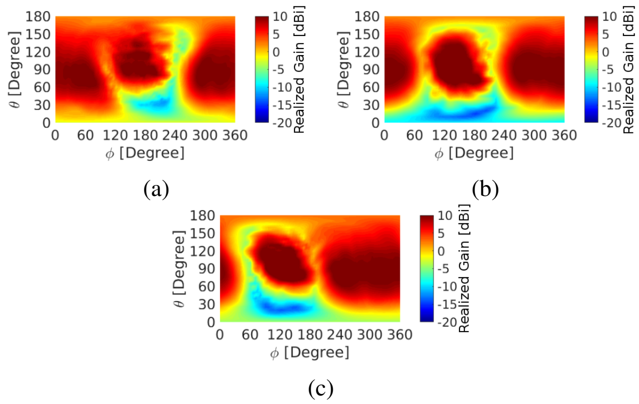


Fig. 8. Total scan pattern of the proposed phased antenna array for (a) setup 1 (b) setup 2, and (c) setup 3.

To investigate the coverage performance of the proposed phased antenna array, the coverage efficiency is calculated from the total scan patterns in Fig. 8. The coverage efficiency of the phased antenna array is shown for three setups in Fig. 9(a). The coverage efficiency of the phased antenna array with the user's hand is 20 % lower than the free space coverage efficiency in Fig. 5 for the gain of 7 dBi. Most importantly, all of the curves in Fig. 9(a) have a similar shape, which means that the proposed antenna is resilient to the effects of the user's hand. However, the simulations with a full body have not been done. Thus, a random shadowing from the body is expected because the position of the ring and hand can change arbitrarily. The similar effects as described in [7] can be expected.

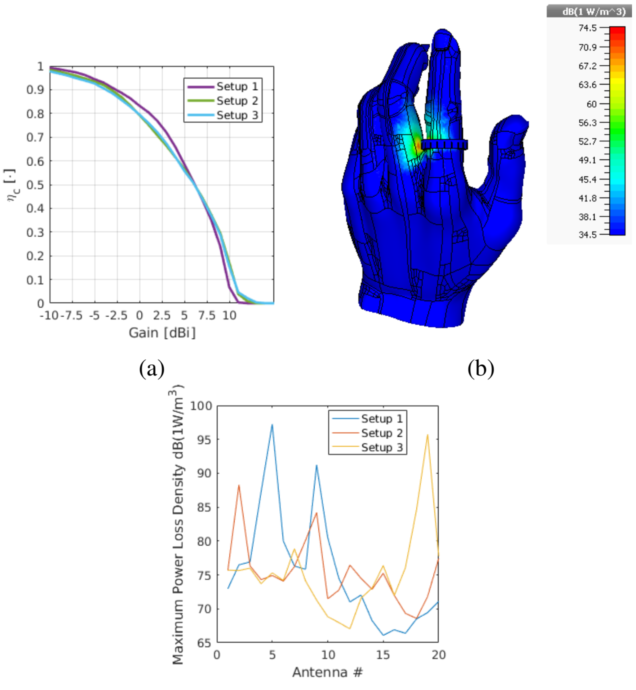


Fig. 9. Plots of (a) coverage efficiency of the antenna, (b) power loss density simulated results shown on 3D hand model, and (c) maximum power loss density of the phased antenna array in three setups with the user's hand.

C. Power Loss Density

Because of the lack of SAR standards for the mobile devices operating in the cm-wave frequency range, it has been chosen to investigate the antenna effect on the user by means of power loss density. The power loss density has been simulated for all of the array elements in three setups with the hand. The example of the power loss density simulated for the antenna 11 in setup 1 is shown in Fig. 9(b). The maximum value of the power loss density has been extracted from each of the 3D simulation and plotted for each antenna and three setups in Fig. 9(c). Not surprisingly, the power loss density peaks correspond to the antennas with changes in reflection coefficient in Fig. 7. Furthermore, the mean maximum of power loss density of array elements is 75.45 dB(W/m^3) for setup 1, 75.32 dB(W/m^3) for setup 2, and 75.3 dB(W/m^3) for setup 3. The standard deviation between antennas of 8.4 dB(W/m^3) for setup 1, 4.6 dB(W/m^3) for setup 2, and 6.24 dB(W/m^3) for setup 3 can be observed.

V. Conclusion

In this paper, a circular phased antenna array has been constructed on the finger ring for the 28 GHz 5G communication systems. The antenna array has been verified in free space and with user's hand phantom on three fingers. The coverage efficiency of 70 % for 7 dBi gain has been observed in free space. However, when user effects are introduced to the simulation setup a drop of 20 % has been recorded, but none the less, coverage efficiency curves for all of the three setups with the user have a similar shape. Finally, the maximum power loss density has also been simulated. The mean of around 75 dB(W/m^3) and standard deviation of 4.6 to 8.4 dB(W/m^3) has been observed for all of the setups. The correlation between high power loss density with antenna detuning has also been observed. In the future work, the full body user model should be used in order to simulate the shadowing.

References

[1] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," 2015.

[2] O. Boric-Lubecke, V. M. Lubecke, B. Jokanovic, A. Singh, E. Shahhaidar, and B. Padasdao, "Microwave and wearable technologies for 5g," in *2015 12th International Conference on Telecommunication in Modern Satellite, Cable and Broadcasting Services (TELSIKS)*, pp. 183–188, Oct 2015.

[3] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. N. Wong, J. K. Schulz, M. Samimi, and F. Gutierrez, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," *IEEE Access*, vol. 1, pp. 335–349, 2013.

[4] S. Zhang, X. Chen, I. Syrytsin, and G. F. Pedersen, "A Planar Switchable 3D-Coverage Phased Array Antenna and Its User Effects for 28 GHz Mobile Terminal Applications," 2017.

[5] N. Ojaroudiparchin, M. Shen, S. Zhang, and G. F. Pedersen, "A Switchable 3-D-Coverage-Phased Array Antenna Package for 5G Mobile Terminals," 2016.

[6] J. Helander, K. Zhao, Z. Ying, and D. Sjöberg, "Performance analysis of millimeter-wave phased array antennas in cellular handsets," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 504–507, 2016.

[7] I. Syrytsin, S. Zhang, G. Pedersen, K. Zhao, T. Bolin, and Z. Ying, "Statistical investigation of the user effects on mobile terminal antennas for 5g applications," *IEEE Transactions on Antennas and Propagation*, vol. PP, no. 99, pp. 1–1, 2017.

[8] K. Zhao, J. Helander, D. Sjoberg, S. He, T. Bolin, and Z. Ying, "User Body Effect on Phased Array in User Equipment for 5G mm Wave Communication System," *IEEE Antennas and Wireless Propagation Letters*, vol. PP, no. 99, p. 1, 2016.

[9] W. Farooq, M. Ur-Rehman, Q. H. Abbassi, X. Yang, and K. Qaraqe, "Design of a finger ring antenna for wireless sensor networks," 2016.

[10] N. Noda and H. Iwasaki, "Evaluation related to finger position and rotation of wearable dual band inverted-F finger ring antenna," 2015.

[11] H. Sugiyama and H. Iwasaki, "Wearable finger ring dual band antenna made of fabric cloth for BAN use," 2013.

[12] H. Horie and H. Iwasaki, "Wearable finger ring type antenna made of fabric cloth for BAN use at UHF and ISM bands," 2013.

[13] H. Goto and H. Iwasaki, "A low profile wideband monopole antenna with double finger ring for BAN," 2011.

[14] N. A. Samsuri and J. A. Flint, "A study on the effect of loop-like jewellery items worn on human hand on specific absorption rate (SAR) at 1900 MHz," 2008.

[15] K. Zhao, Z. Ying, and S. He, "Emf exposure study concerning mmwave phased array in mobile devices for 5g communication," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1132–1135, 2016.