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3G, 4G Antennas: What's Next?

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Abstract— Future wireless communication systems have ambitious objectives in terms of performance and quality of service under 5G' umbrella. Moreover, new network topologies are likely to be introduced. It will include high frequency bands in the centimetre-wave bands and possible also at millimetre-wave bands. Therefore, the antenna design has to evolve to meet the new requirements. To design the future antennas for mobile terminals, not only the bandwidth and antenna efficiency need to be acceptable, but also beam pointing and beam coverage is essential and knowledge of the mobile channel will be needed. It is an object of the present paper to provide and discuss the main challenges that will have to be addressed by antenna engineers. For instance, the integration of different applications and platforms, Full Duplex, MIMO, the migration towards mmWave frequencies and the interaction with the human operator in terms of low Specific Absorption Rate (SAR).

Keyword— 3G, 4G, 5G, SAR, Massive MIMO.

I. Introduction

Personal communication has become a part of daily-life and the business feature is now changing rapidly from voice to data communication modes with much higher data rate through wireless channel.Today's technological advancements in wireless communication and the diversity of needs in this area are leading to the creation of ever smaller, lighter, and more multifunctional mobile handsets. As a result, the design of a wireless transceiver in a smart phone or a portable device has gone from external to internal; they have also become subject to numerous constraints in size, function and must support multisystem operations.

The Forthcoming fifth-generation cellular systems (often referred to 5G) will feature several innovative strategies with respect to existing LTE systems, including, among others, extensive adoption of small cells, use of millimetre-wave (mmWave) communications for short-range links, large-scale antenna arrays installed on macro base stations, Massive MIMO, Full Duplex, cloud-based radio access network, and, possibly, opportunistic exploitation of spectrum holes through a cognitive approach. 5G cellular networks will have more stringent requirements than LTE in terms of latency, energy efficiency, and data rates, which again are impacted by the adopted modulation scheme [1]. We are at the start of working towards the next generation—5G, which is likely to be standardized and be rolled out from 2020 in Europe, with the first phase in Korea and Japan. In a nutshell, differences between 4G and 5G mobile communication include greater spectrum allocations at mmWave frequency bands, lower infrastructure costs, highly directional beamforming antennas at both the mobile device and base station, longer battery life, lower probability of disable state, much higher bit rates in larger coverage area, and higher collective capacity for many coinciding users in both licensed and unlicensed spectrum to allow rapid deployment and mesh-like connectivity with cooperation between base stations. [2,3].

Antennas play a dominant role in wireless communication system at both, transmitter as well as receiver end. It has been stated that any communication system is only as good as its antenna. Unfortunately, the performance requirements for the antenna are rarely relaxed with the demand for smaller size. In fact, the performance requirements generally become more complex and more difficult to achieve as the wireless communications infrastructure evolves. For antennas to satisfy the requirements of the current market, they must be compact while having multiband capability. Currently, multiband operation is almost a common standard. Therefore, the antenna embedded in the mobile phone or smart phone must be capable of operating at several frequency bands. Traditionally, each antenna operates at a single or dual frequency bands, where different antenna is needed for different applications. This causes a limited space and place problem. Due to the compatibility of 2G/3G WWAN and 4G LTE, the 5G phone antenna must realize the multiband/multi-antenna operation with a small size/volume, which is the main challenge. However, to integrate some of 5G's key technologies within a smartphone, like massive MIMO, Full Duplex, (etc) is another challenge. Accordingly, attention is being focused on high-performing antennas with simple structures, one of which is the planar inverted-F antenna (PIFA). A PIFA is composed of a ground plane, radiator, feed line, and short pin. Because it operates at a resonant length of $\lambda / 4$, it is highly conducive to a small and lightweight design, and thus well-suited for use as an internal antenna [4]. The PIFA has the advantage of a low profile, but its narrow bandwidth makes it difficult to realize multiband capability with a single resonator. While this problem can be resolved by using additional resonators [5], such additions tend to increase the size of the antenna. This means that with a PIFA, it is difficult to simultaneously achieve miniaturization and multiband capability. Some known variations include antennas with the radiator connected to the feed [4], those equipped with a parasitic patch [6], and those with a parasitic plane and stub [7].

On the other hand, tuneable or reconfigurable antennas offer diverse functions. They are used to change the radiation direction, the polarization, beam width, or even the operating frequency. Thus, a combination of all these factors have received significant attention in wireless communications [8].

To achieve an acceptable level of matching, like 10dB, for mobile phone antennas, is a big challenge. However, tunable/reconfigurable topologies have been already proposed to overcome the matching problem and decrease the reflection coefficient in a wider band [9,10,11,12].

Furthermore, the complexity of handheld (phone) antenna design is continuously increasing, not only by the pressure of the market needs but also by the duty of safety regulations which require efficient antennas capable of radiating as much power as possible in free-space conditions, while minimizing the power radiated towards the human head. When we think about environment, typically the first things that come to mind are energy efficiency, the elimination of toxins in manufacturing process, recyclability etc. Engineers also have to take in account radiation emissions, as recent studies find significantly higher risks for brain and salivary gland tumors among people using cell phones for 10 years or longer.

II. Component Effects to the Antenna Design

The demand for multisystem handset equipment has recently increased rapidly. The phone antenna as an independent branch of the antenna has gathered a lot of scholars and experts from academy and industry. These days, cell phones provide an incredible array of functions, and new ones are being added at a breakneck pace; depending on the cell phone model. All enhanced technology advances with simultaneous presence of 2G, 2.5G, 3G, 3.5G, 4G and the forthcoming 5G networks. The effect of many services on network efficiency has become more critical. In current mobile device, lots of wireless functions like LTE, GPS, Wi-Fi, Bluetooth even NFC (Near Field Communication) have been included, which means lots of antennas also need to be designed, Fig-1. However, since a smart phone is a highly integrated and compact device, so the components inside like touch panel, ferrite sheet even speaker and/or receiver will probably impact the antenna design resulting in performance degradation. The evolution of the mobile phone antennas was generally driven by two major forces. The first one is the user demand, which is mainly composed of aesthetical and ergonomic issues. It is required to be elegant and metal body, Fig-2. There is an increased demand of metal back cover mobile devices such as mobile phones even though several multiband antennas are required with sufficient isolation between them to support multiple radios, which constrains the antenna design and leaves very small area for antennas, along with the electrical requirements such as large battery, high resolution display and camera etc. In an attempt to overcome that the authors in [13] used metal body of the device itself as an antenna.

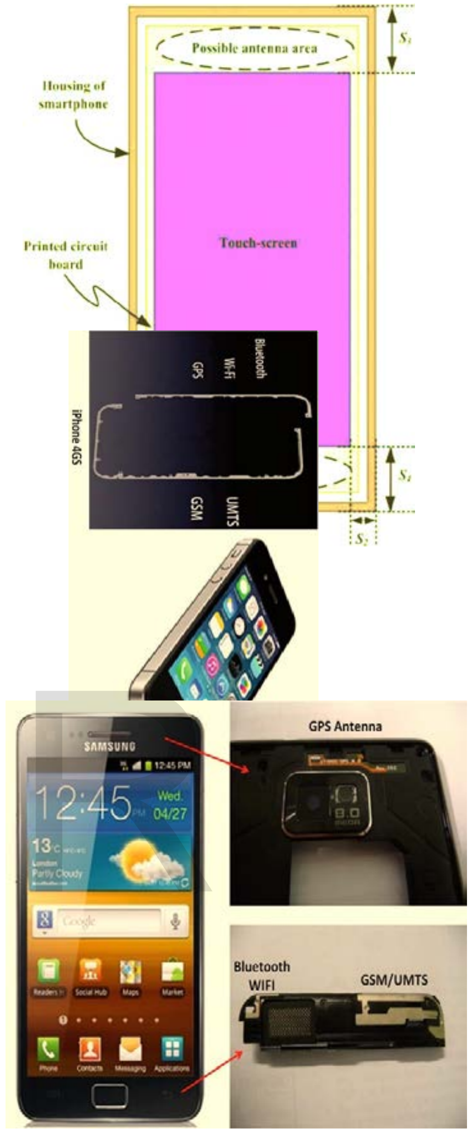

Fig1: Space/positon and antenna types

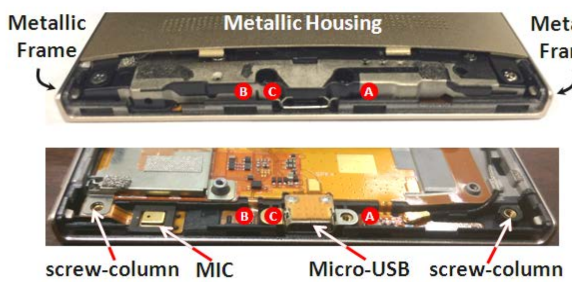

Fig2: Metal frame & other components

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Fig3: Mobile generations

With the market trend toward internal antennas for mobile terminals, the space restriction about antenna placement started to be one of the main concerns from the antenna design point of view. Dealing with newer standards, another requirement is to obtain more broadband antennas in this limited space. These newly added frequency bands form a key aspect from the antenna design point of view because they increase the design challenges of the implementation of broader-frequency antennas within a limited space (mainly reduced height). Some technologies like the possibility of using CA techniques is also of high importance from the antenna side, since they might need to cover simultaneously two or more frequency bands which might not be possible with band-switching reconfigurable antenna topologies.

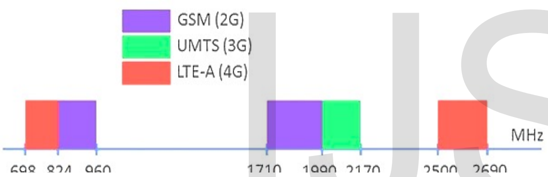

Fig4: GSM, UMTS and LTE-A bands

But with the current trend of larger touchscreens and thinner smartphones, the antennas again need to be shrunk not really in terms of size but rather of height. This current constraint results in electrically small antennas mainly because of low LTE bands, though causing challenges in terms of antenna design. With the rapid development of the 3G/4G wireless mobile communication, the 5G phone antenna must realize the multiband/multi-antenna operation with a small size/volume, dealing with the important characteristics showed in the fig 5, which are the main challenge.

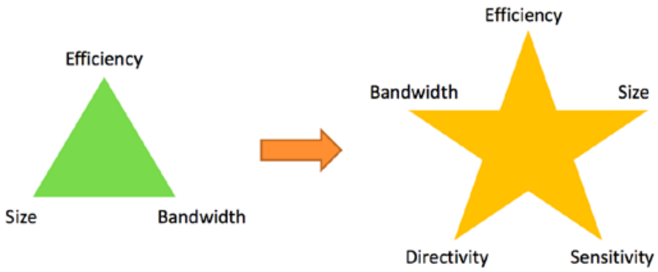

Fig5: Multidimensional Constraints

III. MIMO and Massive MIMO Implementation

Multiple-input multiple-output (MIMO) systems have remained a subject of interest in wireless communications over the past decade due to the significant gains they offer in terms of the spectral efficiency by exploiting the multipath richness of the channel. The increased spatial degrees of freedom not only provide diversity and interference cancellation gains but also help achieve a significant multiplexing gain by opening several parallel sub-channels. The designing of MIMO antennas for mobile terminals faces two challenging problems. The first problem is that the space for integrating multiple antennas inside a mobile terminal is quite limited. Therefore, the antennas should be compact but this in turn hampers the fulfilment of the requirements for the handset MIMO antennas (large bandwidth, good efficiency and low correlation). MIMO technology has successfully been implemented in wireless routers. However, its implementation in mobile handsets, in particular in mobile phones, is not yet successful due to the compact volume of mobile handset which largely correlates the MIMO antennas in the far field. This introduces coupling problems thus reducing the radiation performance [14,15]. The second problem is the electromagnetic interaction between the mobile phone antennas and human body which is discussed in the next section. Moreover, pioneer works in MIMO area has shown that under certain channel conditions, the system capacity can potentially scale linearly with the minimum number of transmit and receive (Tx-Rx) antennas [16,17], This has led to the emergence of Massive MIMO systems, that scale up the conventional MIMO systems by possibly orders of magnitude compared to the current state-of-art [18]. The question here is will it be possible to be used in mobile phone taking account battery's life and the energy consumption constraints? The development of MIMO antennas with vast cellular coverage and acceptable isolation and radiation performance is thus an area of intense research.

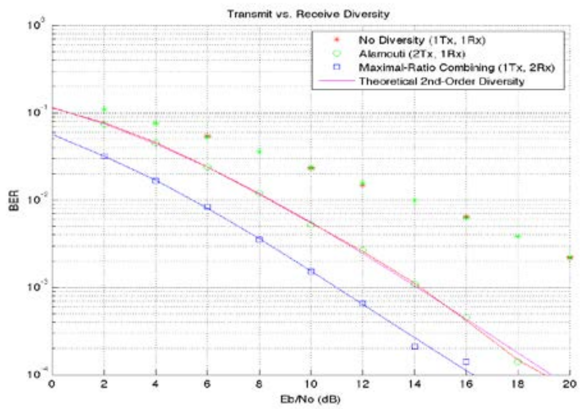

Fig6: MIMO

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In mmWave, as a trend, higher frequencies, with their shorter wavelengths, make the implementation of dense antenna arrays for massive MIMO systems much more practical than the equivalent for lower-frequency systems. For example, with lower frequencies, the same array of multiple antennas would render the physical towers for cellular networks extremely impractical.

IV. Full Duplex

Two-way wireless has been of interest over a relatively long period of time and there have been some several works addressing this problem [19,20,21] and it is often referred to as Full Duplex (FD). It has attracted an intensive attention, for its potential to double the spectral efficiency. FD wireless system can maximally achieve doubled spectral efficiency by transmitting and receiving signals at the same time and frequency. Due to advances in both radio and digital processing, FD can now be implemented at reasonable cost and without complex radio hardware. Moreover, due to the close proximity of transmit antenna to its receive antenna, the self-interference is large. However, many interference reduction methods have been proposed to make it feasible by exploiting various combinations of antenna cancelation, radio frequency (RF) cancelation, and baseband signal cancelation, [22,23]. A lot of work of FD concentrated on the link level self-interference mitigation in WiFi and LTE system with antenna isolation, analog cancellation, and digital cancellation techniques. In [24], the authors described and presented a systematic view of the FD system level issues such as deployment scenario, frame structure, reference signals (RS), interference mitigation in FD network, and transceiver structure/calibration issues, which are the challenges facing FD adoption in cellular network. However, with the advances done in FD era, in a cellular network, in particular a terminal side, mobile phone, still represent a challenge to antennas design engineers, due to the limit available space for antennas (see section II). Moving to mmWave frequencies introduces several challenges. First, the current full-duplex systems have the bandwidth at the order of 40 MHz [20], and the practical implementation of the full-duplex systems for the mmWave communications with a bandwidth of several GHz should be investigated and demonstrated. However, the current research on the full-duplex systems mainly focuses on the omnidirectional communications in the low frequency bands. Since mmWave communications are inherently directional, the directional full-duplex systems with directional transmission and reception need to be developed. So, node architecture should be redesigned to take the characteristics of mmWave communications into account. For more insight, the reader can refer to a full-duplex node architecture with directional transmission and omnidirectional reception based on the full-duplex architecture in [20] proposed by Miura and Bandai [36].

V. Challenges of MmWave Antenna design for 5G

Wide bandwidth is the most effective and straightforward method to provide the foreseen data demands for 5G cellular services expected to be commercially available in 2020 and beyond. As the additional availability of spectrum for cellular usage in the lower frequencies becomes scarce, the significant amount of underutilized spectrum in the mmWave bands could potentially provide the answer to the very large bandwidth requirements for 5G [25]. The main characteristics of mmWave are short wavelength/high frequency, large bandwidth, the interference levels are much lower compared to the congested 2.4 GHz and 5 GHz bands, high interaction with atmospheric constituents such as oxygen, and high attenuation through most solid materials. However, generating and receiving mmWaves is a challenge, but the biggest and most challenging factor with these high frequencies is the traveling media. The biggest challenges are atmospheric and free-space loss. To combat severe propagation loss, directional antennas are employed at both transmitter and receiver to achieve a high antenna gain [26]. Another issue is the manufacturing challenges associated with mmWave designs. It was found and clearly demonstrated by the work of Klohn et al that a 0.1mm change in the perturbation period led to a shift in scanning angle of approximately 8°. Moreover, microstrip patch antennas are widely used because of their several advantages such as light weight, low volume, low fabrication cost. But high losses in the dielectric and ground plane of mictrostrip circuits offer a substantial challenge at mmWave. Another negative side that is, the higher power levels which are necessary to overcome the huge path loss. If we consider 60 GHz mmWave communications, the coverage is typically up to 10 to 20 meters, even though some test implementation confirms coverage of 2 km [27] at reduced rates. The blockage problems may be frequent because of attenuation levels for certain building materials such as brick and concrete which keep mmWave transmission confined, requiring line of sight (LoS) communication [28]. The compact design of mmWave antennas, which can include thousand antenna elements in a small radio chip, allows the use of massive multiple-antenna solutions. This permits transmissions by narrow beams, which overcomes high path loss attenuations, and drastically reduces interference and contentions to access the channel [29]. However, narrow beams imply small coverage and introduce high directionality that may have the detrimental effect of deafness if beams are not correctly aligned.

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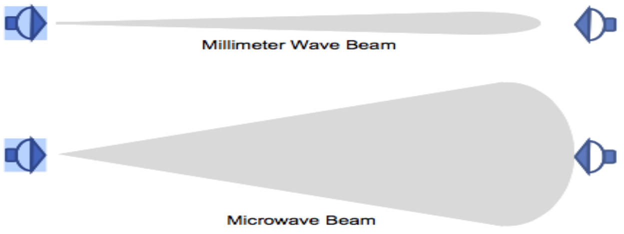

Fig7: Millimetre/ Microwave beam

Unlike microwave links, which cast very wide footprints reducing the achievable amount of reuse of the same spectrum within a specific geographical area, mmWave links cast very narrow beams, as illustrated in Fig-7. The narrow beams of mmWave links allow for deployment of multiple independent links in close proximity. As implied by the mmWave, at the higher frequencies in which mmWave operates, the small wavelengths enable the use of a large number of antenna elements in a relatively small form factor. This characteristic of mmWave can be leveraged to form narrow directional beams that can send and receive more energy to overcome the propagation / path loss challenges. These narrow beams can also be utilized for spatial reuse.

VI. Health Concern

Wireless operations permit services, such as a long-range communication, that are impossible or impractical to implement with the use of wires. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g. radio transmitters and receivers, remote controls etc.) which use some form of energy (e.g. radio waves, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances. The electromagnetic energy absorption of the biological tissue has drawn a great amount of attention due to the potential health risks. The human exposure level of mobile terminals is always a critical issue for wireless communication systems since the maximum output power of mobile terminals is limited by the strength of the human exposure. Today, the human exposure level of mobile terminals in cellular bands is evaluated by Specific Absorption Rate (SAR). SAR is limited by the U.S. Federal Communications Commission (FCC) and E.U.CE. There are two maximum allowed SAR widely adopted standards SAR. The first is U.S. FCC SAR limitation and has a value of 1.6 W/kg (1-g body tissue) and the second is E.U. CE SAR limitation which is 2.0 W/kg (10-g body tissue). The FCC limitation is stricter than the CE limitation. It can be told that a mobile phone compliant with the US SAR limit is almost always automatically compliant with the European SAR limit. For a given electric field E, SAR in human body can be expressed by Equation:

$$\mathrm{SAR} = \frac{\sigma E^2}{\rho}$$

where σ is the electric conductivity of the biological tissue (S/m), E is the root mean square of the electric field (V/m), and ρ is the density of the biological tissue(kg/m^3).

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It can be told that the SAR of a mobile phone antenna depends on the wave properties like frequency and polarization, the body characteristics like the shape and electrical properties of the tissue, the distance between the antenna and the tissue, and last but not least the antenna concept. The inherent operation of the mobile devices in a close proximity to the user, usually located in the antenna near-field zone, affects the antenna parameters and cause electromagnetic energy absorption in the human body [30,31]. The human tissue is a dielectric material with losses and its interaction with the antennas has to be viewed from two perspectives: 1) the influence of the user on the antenna performance as the presence of the user in the antenna near-field region causes changes in the input impedance of the antenna and therefore in its bandwidth. These changes are a consequence of the dielectric loading introduced by the tissue. Also, the absorption in the human body decrease the radiation efficiency of the antenna.

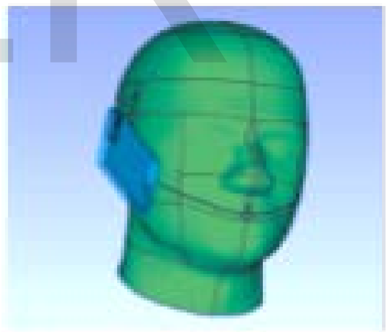

Fig8: head model

2) the exposure of the human tissue to antenna electromagnetic radiation. What is being debated in the scientific and political arenas is just how much radiation is considered unsafe, and if there are any potential long-term effects of cell-phone radiation exposure. However, since nowadays LTE main antenna is mostly positioned at the bottom of phone, the head and hand not only absorb the radiation but also detune the antenna, especially at low band. Studied showed that antenna resonance at low band was shifted 150 MHz away from free space, this will significant affect the user experience in the communication signal quality. However, most are passive antennas, or even it is tunable antenna, it is mainly used to switch bands or increase bandwidth to have better coverage [32]. In industry, the

carriers want antenna to perform well in both free space and user case in the head and hand position [33]. Generally, high antenna efficiency increases the SAR. Antenna engineers need to achieve the multiband/wideband and both high antenna efficiency and low SAR characteristics at the same time is a serious challenge. In the mmWave band, the electromagnetic coupling between antennas and the human body as well as the possible perturbations of antenna characteristics due to the body require more study [34]. Some studies have been done by researchers around the world, in [35], the authors demonstrated that the impedance matching and the antenna gain were virtually unaffected by the presence of the body, using a skin-equivalent phantom, by investigating the interaction between a 60-GHz microstrip patch antenna array and the human body both numerically and experimentally. However, based on [35] analysis in the "Modern mmWave Example Suggesting Temperature-Based Compliance" section, such high values may not lead to substantial temperature elevation at mmWave frequencies and may thus be safe.

VII. Conclusion

In this work, we tried to give an overview of the main challenges that will have to be addressed by antenna engineers. In order to achieve the 5G goals, and in shortening the time-to-market. Several technologies have been identified as candidate 5G technologies, including FD, device to device (D2D), WiFi convergence, new network architecture, multiple antenna technologies, new signal processing, high-frequency bands, and cognitive radio. Innovative frontend solutions will be needed, with focus not only on the antenna, but also on the whole RF system. To do that, inter-disciplinary approaches, new technologies and new paradigms have to be integrated in the design of antennas for UE. The absorption of electromagnetic energy by the human tissue has to be viewed not only from antenna performance point of view, but also the exposure of the biological tissue needs to be evaluated due to the potential health risk. We also believe that until scientists know much more about cell phone radiation, it's smart for consumers to buy phones with the lowest emissions.

VIII. Acknowledgment

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I. References

[1] Y. El Gholb, N. El Amrani El Idrissi, H. Ghennioui, « 5G: An Idea Whose Time Has Come" International Journal of Scientific & Engineering Research, Volume 8, Issue 3, March-2017.

[2] J.Anguera,I.Sanz,A.Sanz,T.Condes,D.Gala,C.Puente,andJ.Soler, "Enhancing the performance of handset antennas by means of groundplane design," presented at the IEEE Int.Workshop on Antenna Technol.: Small Antennas and Novel Metamater. (iWAT 2006), New York, Mar. 2006

[3] E. Antonino, M. Cabedo, M. Ferrando, and J. I. Herranz, "Analysis of the coupled chassis-antenna modes in mobile handsets," presented at the IEEE Antennas Propag. Society Int. Symp., Monterey, Jun. 2004

[4] Y. X. Guo, M. Y. W. Chia, and Z. N. Chen, "Miniature built-in multi-band antennas for mobile handsets," *IEEE Trans. Antennas Propag.*, vol. 52, no. 8, pp. 1936–1944, Aug. 2004.

[5] D.LiuandB.Gaucher,"A new multiband antenna for WLAN/cellular applications," in *Proc. IEEE. Veh. Technol. Conf.*, Sep. 2004, vol. 1, pp. 243–246.

[6] P. Ciais, R. Staraj, G. Kossiavas, and C. Luxey, "Design of an internal quad-band antenna for mobile phones," *IEEE Microw. Wireless* Compon. Lett., vol. 14, no. 4, pp. 148–150, Apr. 2004.

[7] Y.-X. Guo and H. S. Tan, "New compact six-band internal antenna," IEEE Antennas Wireless Propag. Lett., vol. 3, pp. 295–297, 2004.

[8] Sun, L., B.-H. Sun, J.-Y. Li, Y.-H. Huang, and Q.-Z. Liu, "Reconfigurable circularly polarized microstrip antenna without orthogonal feeding network," Journal of Electromagnetic Waves and Applications, Vol. 25, No. 10, 1352–1359, 2011.

[9] Nikolau, S., R. Bairavasubramanian, C. Lugo, Jr., I. Carrasquillo, D. C. Thompson, G. E. Ponchak, J. Papapolymerou, and M. M. Tentzeris, "Pattern and frequency reconfigurable annular slot antenna using PIN diodes," IEEE Trans. on Antennas and Propagat., Vol. 54, 439–448, 2006.

[10] Yang, X.-S., B.-Z. Wang, W. Wu, and S. Xiao, "Yagi patch antenna with dual-band and pattern reconfigurable characteristics," IEEE Antennas Wireless Propagat. Lett., Vol. 6, 168–171, 2007.

[11] Kamarudin, M. R. B., P. S. Hall, F. Colombel, and M. Himdi, "Electronically switched beam disk-loaded monopole array antenna," Progress In Electromagnetics Research, Vol. 101, 339– 347, 2010.

[12] Zhang, S., G. H. Huff, J. Feng, and J. T. Bernhard, "A Pattern reconfigurable microstrip parasitic array," IEEE Trans. on Antennas and Propagat., Vol. 52, 2773–2776, 2004.

[13] Yong-Ling Ban and Joshua Le-Wei Li, "Multiband LTE/WWAN Phone Antennas", International Workshop on Antenna Technology, Seoul, South Korea, 4-6 March , 2015.

[14] hoaib, S.; Shoaib, I.; Shoaib, N.; Xiaodong Chen; Parini, C.G., "Design and Performance Study of a Dual-Element Multiband Printed Monopole Antenna Array for MIMO Terminals," Antennas and Wireless Propagation Letters, IEEE , vol.13, no., pp.329,332, 2014.

[15] Y. L. Ban, S. Yang, Z. Chen, K. Kang, and L. W. Li, Decoupled planar WWAN antennas for smartphone applications, IEEE Antennas and Wireless Propag. Lett., vol.13, pp.483-486, 2014.

[16] E. Telatar, "Capacity of multi-antenna Gaussian channels," European Trans. Telecommun., vol. 10, no. 6, pp. 585–595, Nov./Dec. 1999.

[17] G. J. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi- element antennas," Bell Labs Technical Journal, vol. 1, no. 2, pp. 41–59, 1996.

[18] E. Larsson, O. Edfors, F. Tufvesson, and T. Marzetta, "Massive MIMO for next generation wireless systems," IEEE Communications Magazine, vol. 52, no. 2, pp. 186–195, Feb. 2014.

[19] A. K. Khandani, "Methods for spatial multiplexing of wireless two-way channels," US Patent number: 7817641, Filing date: Oct 17, 2006, Issue date: Oct 19, 2010, Application number: 11/581,427.

[20] M. Jain, J. Choi, T.Kim, D. Bharadia, S. Seth, K.Srinivasan, P. Levis, S. Katti, P. Sinha, "Practical, Real-time, Full-Duplex Wireless", Mobicom, Sept. 2011.

[21] J. Choi, M. Jain, K. Srinivasan, P. Levis, and S. Katti, "Achieving single channel, full duplex wireless communication," in Proc. 2010 ACM MobiCom, pp. 1–12.

[22] M. Duarte and A. Sabharwal, "Full-duplex wireless communications using off-the-shelf radios: feasibility and first results," in Proc. 2010 Asilomar Conf. Signals, Syst., Comput., pp. 1558–1562.

[23] M. Duarte, C. Dick and A. Sabharwal, "Experimental-driven Characterization of, Full-Duplex Wireless Systems", IEEE Transactions on Wireless Communications, December 2012,Vol: 11, Issue:12,P 4296-4307. DOI: 10.1109/TWC.2012.102612.111278.

[24] Shuangfeng Han; I. Chih-Lin; Zhikun Xu; Chengkang Pan; Zhengang Pan, "Full Duplex: Coming into Reality in 2020?", IEEE Global Communications Conference, 2014.

[25] T. Rappaport et al., "Millimeter Wave Mobile Communi- cations for 5G Cellular: It Will Work!," IEEE Access, vol. 1, May 2013, pp. 335–49.

[26] Y.Niu, Y.Li, D.Jin, L.Su and A.V.Vasilakos," a survey of millimeter wave communication for 5G: Opportunities and Challenges" DOI 10.1007/s11276-015-0942-z.

ISSN 2229-5518
[27] W. Roh, J. Seol, J. Park, B. Lee, J. Lee, Y. Kim, J. Cho, K. Cheun, and F. Aryanfar, "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Teoretical feasibility and prototype results," IEEE Commun. Mag., vol. 52, no. 2, pp. 106–113, Feb. 2014.

[28] Wonil Roh, Ji-Yun Seol, JeongHo Park, Byunghwan Lee, Jaekon Lee, Yungsoo Kim, Jaeweon Cho, and Kyungwhoon Cheun "Millimeter - wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility and prototype results" IEEE Communications Magazine Vol: 52, Issue: 2, February 2014.

[29] F. Khan and Z. Pi, "mmWave Mobile Broadband (MMB): Unleashing the 3–300GHz Spectrum," IEEE Sarnoff Symp. 34th, 2011.

[30] L. Vallozzi, W. Vandendriessche, H. Rogier, C. Hertleer, and M. L. Scarpello, "Wearable textile GPS antenna for integration in pro- tective garments," in Proc. IEEE 2010 4th European Conf. Antennas Propagation, 2010, pp. 1–4.

[31] M. M. Khan, Q. H. Abbasi, A. Alomainy, C. Parini, and Y. Hao, "Dual band and diverse radiation pattern antenna for power ef- ficient and reliable on-body and off-body communications for healthcare applications," in Proc. IEEE Int. Symp. Antennas Propaga- tion, 2011, pp. 396–399

[32] P. Liu and A. Springer, Tunable antenna impedance matching for 4G mobile communications," Proceedings of the International Symposium on ISAP, Vol. 2, 863- 866, 2013.

[33] Ming Cai, Hanyue Xia, Hao Wang, Guangli Yang "A Closed Loop WAN Antenna to Reduce Head and Hand Effects for Mobile Phone Applications", IEEE International Symposium on Antennas and Propagation, 2016, P 2169 – 2170.

[34] Ting Wu, Theodore S. Rappaport, and Christopher M. Collins, "Safe for Generations to Come" IEEE Microwave Magazine, March 2015

[35] N. Chahat, M. Zhadobov, L. Le Coq, S. I. Alekseev, and R. Sauleau, "Characterization of the interactions between a 60-GHz antenna and the human body in an off-body scenario," IEEE Trans. Anten- nas Propagat., vol. 60, no. 12, pp. 5958–5965, 2012.

[36] Miura, K., & Bandai, M. (2012). Node architecture and MAC protocol for full duplex wireless and directional antennas", 23rd IEEE international Symposium on personal, indoor and mobile radio communications (PIMRC), pp. 369–374.

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