Antenna Array Construction on a Mobile Terminal Chassis at 3.5 GHz for LTE Advanced

Syrytsin, Igor A.; Zhang, Shuai; Pedersen, Gert F.

Published in:
2017 11th European Conference on Antennas and Propagation (EUCAP)

DOI (link to publication from Publisher):
10.23919/EuCAP.2017.7928134

Publication date:
2017

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Syrytsin, I. A., Zhang, S., & Pedersen, G. F. (2017). Antenna Array Construction on a Mobile Terminal Chassis at 3.5 GHz for LTE Advanced. In *2017 11th European Conference on Antennas and Propagation (EUCAP)* (pp. 2695 - 2699). IEEE (Institute of Electrical and Electronics Engineers). https://doi.org/10.23919/EuCAP.2017.7928134

Antenna Array Construction on a Mobile Terminal Chassis at 3.5 GHz for LTE Advanced

Igor Syrytsin, Shuai Zhang, Gert Frølund Pedersen
Department of Electronic Systems, Aalborg University, Aalborg, Denmark, {igs,sz,gfp}@es.aau.dk

***Abstract*—This paper proposes a method of constructing an antenna array on the typical ground plane of the modern mobile terminal. An IFA and a slot in a metal frame antenna elements have been used to illustrate the proposed method. The radiation pattern of the element is recorded at the chosen number of the discrete locations on the ground plane. Antenna elements at the positions, where the boresight is similar and the maximum gain is high are combined into an array. The performance is verified by comparing performance of the one antenna element to the performance of the constructed arrays. The proposed method works both in free space and in data mode for two types of antenna elements. The method shown that a maximum gain of the constructed array is 1 to 2.5 dB higher then the gain of a single element both in free space and in data mode.**

***Index Terms*—Mobile terminal antenna, antenna array, LTE advanced, radiation pattern, antenna element.**

I. Introduction

In the last few years multiple high frequency bands, such as band 42 ($f_c = 3.5\,\text{GHz}$) have been relisted for the application of LTE advanced [1]. At a frequencies between 2.6 – 4 GHz a ground plane has significant influence on the radiation properties of the antenna elements. For the frequencies higher then 3 GHz a phased array could be a feasible solution for the link quality improvement, as described in [2]. In [3]. It has also been shown that an antenna array can achieve enormous capacity gains over a single-antenna systems by exploiting a multipath in the rich-scattering wireless channel. A system of multiple phased arrays can improve the link quality by making use of the beamforming in a weak fading environment with a low SINR, multi-beam MIMO in a strong fading environment with a high SINR and an antenna diversity in a strong fading environment with a low SINR. Because of the strong ground plane influence the basic antenna array theory, described in [4], is not directly applicable for mobile applications. A range of specific antenna elements at the specific positions on the ground plane has to be chosen in order to create an efficient array. This paper will focus on explaining the method of finding and combining a specific antenna elements into an array.

In [5] a dual band 2x2 U-slot rectangular patch antenna array has been designed for wireless sensor network applications, however the distance between antenna elements has been found experimentally as it is also described in [6]. A Bidirectional Planar Monopole Antenna Array for WiFi/Bluetooth and LTE Mobile Applications has been proposed in [7], where the distance and placement of the array elements has also been found experimentally. A Dual-band Linear Phased Array Antenna for WiFi and LTE Mobile Applications has been designed in [8], where the optimal value of the inter-element spacing for the proposed array is found by simulating an array with a three different values of inter-elements spacing. In the [9] an eight ports dual band antenna array for 2.4/3.5 GHz for MIMO applications has been proposed. The mutual coupling between two IFA antenna elements and hence their diversity performance at 3 GHz has been evaluated and investigated in [10], however the element performance in an array has not been studied. Furthermore all of those studies does not take in account the influence of the ground plane on the radiation pattern of an antenna element.

In this paper a systematic method of finding the optimal position of the antenna elements for the use in an array at 3.5 GHz is proposed. An IFA and a slot in a metal frame antenna elements are used as an example. The proposed method is useful at the frequencies, where a ground plane has a considerable influence on the radiation pattern of the antenna. Method proposes combining the antenna elements with the same boresight and a high gain in an array. In this paper the proposed method will also be applied to create an antenna system, consisting of the two sub-arrays. The constructed arrays are also simulated in the data mode with a left PDA hand to investigate how efficient the proposed method works with user effects involved in the simulation setup.

II. Geometry and Setup

The dimensions of an IFA and a slot antenna elements are shown in Fig. 1. A location of the feeds is marked with the green dots. Both of the antenna elements, presented in this paper, have at leas 200 MHz of the −6 dB bandwidth. It has been found, that a right and left oriented antenna element will produce different currents and this a different radiation pattern when placed on a ground plane. The orientation of the antenna elements is shown in Fig. 2 and a position of the feed is represented by the red circles. All of the antenna elements are placed on the edges of the ground plane. Ground plane size is chosen to $60\,\text{mm} \times 120\,\text{mm}$ with copper thickness of 0.034 mm and a FR-4 substrate thickness of 1.3 mm.

Method proposes moving the antenna element around all of the edges of the ground plane in a number of discrete steps. The gain pattern of an element is recorded at the each position. Both right and left antenna elements are used for this investigation. The distance between steps is chosen depending on the resonating frequency of the element, the ground plane size and an amount of influence of the ground plane on the

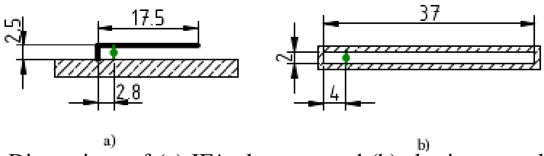


Fig. 1. Dimensions of (a) IFA elements and (b) slot in a metal frame antenna element.

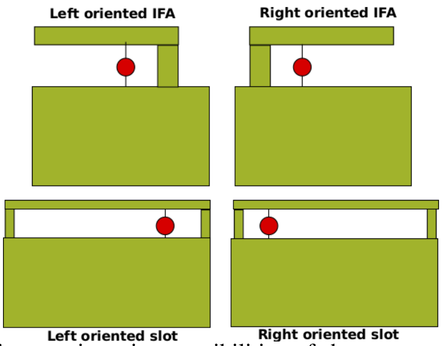


Fig. 2. Different orientation possibilities of the antenna element on the ground plane.

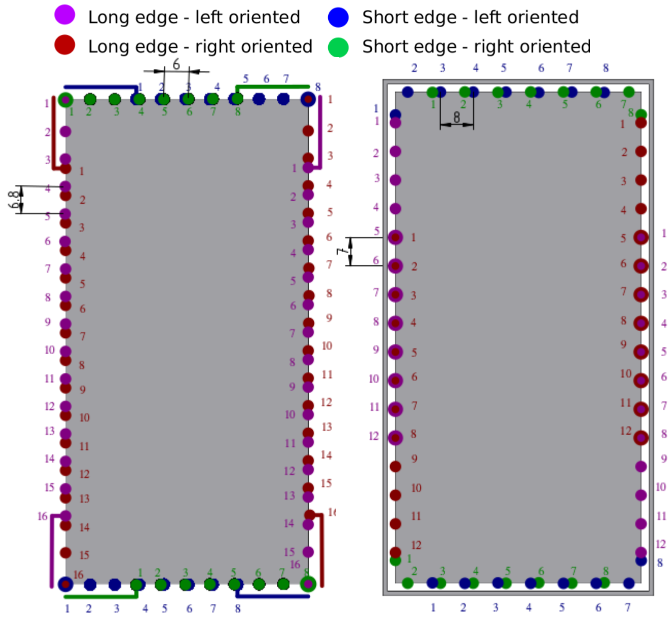
radiation pattern of an element. All of the IFA and slot antenna element positions are shown in Fig. 3. The dots represent a position of the short pin for an IFA element and a position of the feeding pin for a slot element. Green dots represent a right oriented antenna element and blue dots represent left oriented antenna element on the short edge of the ground plane. Red dots represent a right oriented element and magenta dots represent a left oriented element on the long edge of the ground plane.

III. Radiation Pattern Investigation

In this section the simulated results will be presented and discussed.

a) Free Space: The θ and ϕ boresight and a maximum gain for each of the antenna element locations are shown in Fig. 4. Only results for the top short edge and long left edge are shown. Results for the short bottom edge and long right edge will be similar, but mirrored because of the symmetry in a ground plane and a metal frame geometry. Antenna element's position for the use in an array is chosen, such so boresight of the element is similar and maximum gain is high. The optimal number of the antenna element for an array depends on the frequency, ground plane size and element orientation. To illustrate the proposed method a maximum of 2 antenna elements have been chosen to be combined into an array.

b) Data Mode: Antenna element on the all of the edges of the ground plane has been simulated in data mode. Because of the user hand asymmetry a Matlab post-processing can not be used for simplifying the simulations. The boresight and the maximum gain of the antenna element are shown in Fig. 5 for an IFA antenna element and in Fig. 6 for a slot antenna element. Because of the asymmetry of the simulation setup a curve for a right oriented element is not symmetrical to a curve of the left oriented element. In this particular case it is



(a) (b)

Fig. 3. Positions of (a) IFA element – circles represent short positions and (b) slot element – circles represent feed positions.

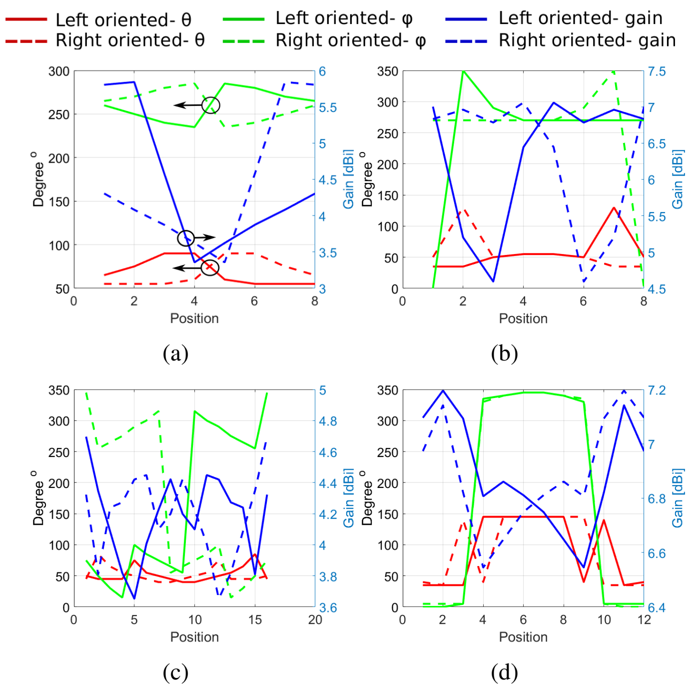
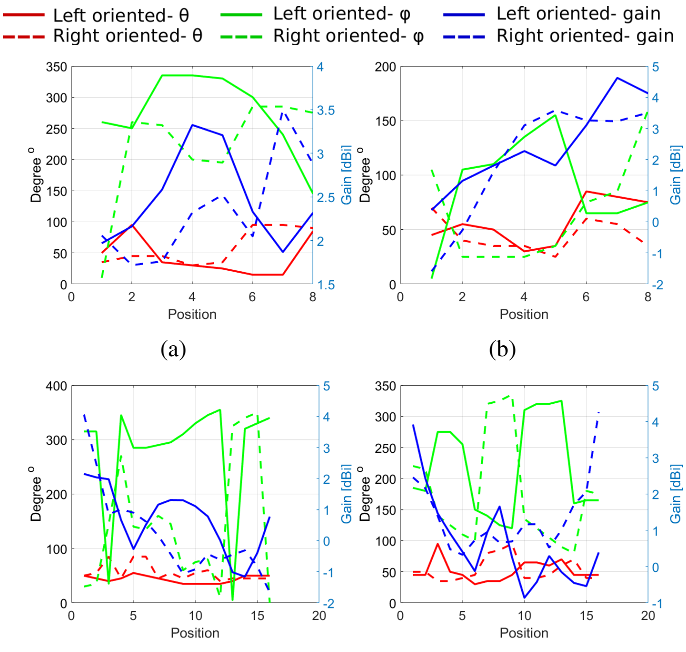


Fig. 4. θ and ϕ boresight and maximum gain for each position of (a) IFA element on the top short edge, (b) slot element on the top short edge, (c) IFA element on the left long edge and (d) slot element on the left long edge.

more challenging to find two widely spaced elements with a similar boresight and a high gain characteristics.



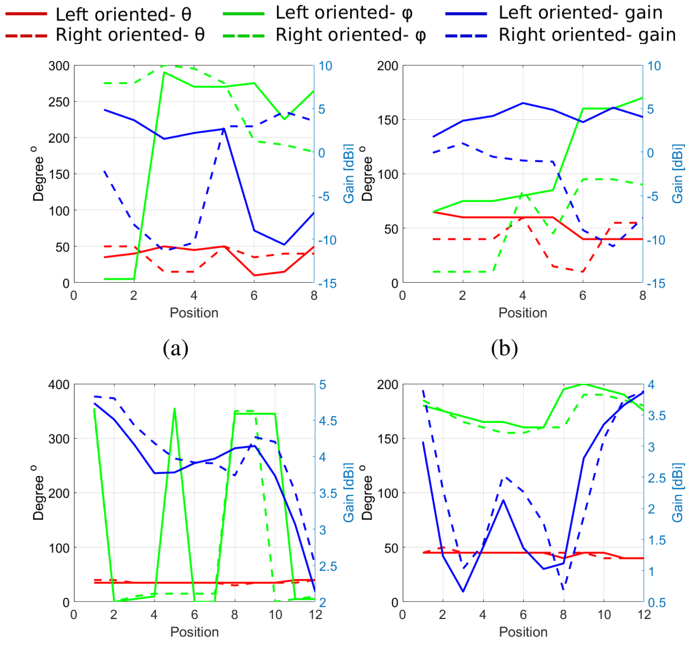
(a) (b) (c) (d)

Fig. 5. θ and ϕ boresight and maximum gain for each position of an IFA element on the (a) top short edge, (b) bottom short edge, (c) left long edge and (d) right long edge.

IV. Array Construction

Six antenna systems have been constructed with IFA elements and six antenna systems have been constructed with slot elements to demonstrate the proposed method. The antenna elements has been chosen, based on the results illustrated in Fig. 4. Antenna systems constructed with proposed antenna elements are shown in Fig. 7 and Fig. 8. The antenna systems of two sub-arrays have been constructed to study impact of the coupling on the efficiency of the proposed method.

a) Free Space: Right oriented element at the position 8 and a left oriented element at the position 1 have been chosen for an IFA array on top short edge, shown in Fig. 7 (d). Right oriented element and a left oriented element at the position 5 have been chosen for a slot array on top short edge, shown in Fig. 8 (d). Right oriented element at the position 1 and a left oriented element at the position 16 have been chosen for an IFA array on left long edge, shown in Fig. 7 (a). Left oriented element at the position 1 and a right oriented element at the position 12 have been chosen for a slot array on left long edge, shown in Fig. 8 (a). Arrays on the long right edge and a short bottom edge have been constructed using the same procedure. Sub-arrays on both long edges and sub-arrays on the both short edges is combined into an antenna system to investigate a performance of the constructed arrays when multiple elements are present. In a such antenna system each array can be switched on or off, depending on the incoming power direction, or can be used simultaneously in a 2x2 multi-beam MIMO system. Geometries of the antenna systems are shown in Fig. 7 (c), Fig. 7 (f), Fig. 8 (c), and Fig. 8 (f).



(a) (b) (c) (d)

Fig. 6. θ and ϕ boresight and maximum gain for each position of slot element on the (a) top short edge, (b) bottom short edge, (c) left long edge and (d) right long edge.

The simulation results for an IFA array configurations are shown in Tab. I. The maximum gain for a single array on the long edge is 1.18 dB higher then a sub-array on the long edge in the antenna system. The maximum gain for a single array on the short edge is 0.32 dB higher then a sub-array on the short edge in the antenna system. The ϕ and θ boresight does not change from a single array to the sub-array in an antenna system. The simulation results for a slot antenna array configurations are shown in Tab. I. The maximum gain for a single array on the long edge is 1.11 dB higher then a sub-array on the long edge in the antenna system. The maximum gain for a single array on the short edge is 0.9 dB higher then a sub-array on the short edge in the antenna system. The ϕ boresight does not change from a single array to the sub-array in an antenna system. The θ boresight changes for an array on the long edge, because the radiation pattern have two main lobes. Overall the gain of a slot array is higher, but loss in gain, when used in the antenna system configuration, is lower for the IFA array.

b) Data Mode: For the antenna array construction in data mode it has been chosen to use: right oriented IFA at the position 1 and a left oriented IFA at the position 9 for the left long edge in Fig. 9 (a), right oriented IFA at the position 16 and a left oriented IFA at the position 1 for the right long edge in Fig. 9 (b), right oriented IFA at the position 8 and a left oriented IFA at the position 2 for the top short edge in Fig. 9 (d) and a right oriented IFA at the position 5 and a left oriented IFA at the position 8 for the bottom short edge in

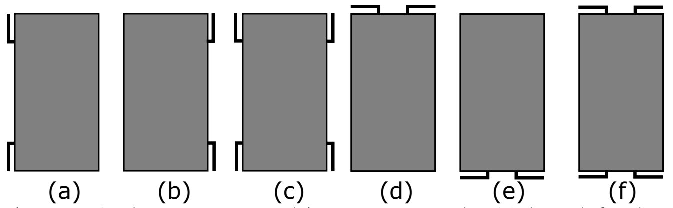


Fig. 7. IFA elements arranged in an array on the (a) long left edge, (b) long right edge, (c) both long edges, (d) short top edge, (e) short bottom edge, (f) both short edges.

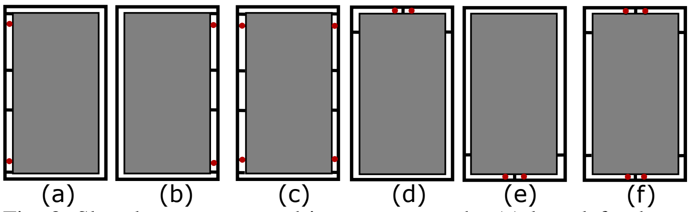


Fig. 8. Slot elements arranged in an array on the (a) long left edge, (b) long right edge, (c) both long edges, (d) short top edge, (e) short bottom edge, (f) both short edges.

Tab. I. Boresight and maximum gain of a different IFA and slot array configurations.

Type	Location	θ	ϕ	Max. gain
IFA array, Fig. 7 (a)	Long left	40°	0°	6.04 dBi
IFA sub-array, Fig. 7 (c)	Long left	40°	0°	4.86 dBi
IFA array, Fig. 7 (b)	Long right	40°	180°	6.04 dBi
IFA sub-array, Fig. 7 (c)	Long right	40°	180°	4.86 dBi
IFA array, Fig. 7 (d)	Short top	55°	270°	5.42 dBi
IFA sub-array, Fig. 7 (f)	Short top	55°	270°	5.1 dBi
IFA array, Fig. 7 (e)	Short bottom	55°	90°	5.42 dBi
IFA sub-array, Fig. 7 (f)	Short bottom	55°	90°	5.1 dBi
Slot array, Fig. 8 (a)	Long left	35°	0°	9.55 dBi
Slot sub-array, Fig. 8 (c)	Long left	140°	0°	8.44 dBi
Slot array, Fig. 8 (b)	Long right	35°	180°	9.55 dBi
Slot sub-array, Fig. 8 (c)	Long right	140°	180°	8.44 dBi
Slot array, Fig. 8 (d)	Short top	50°	270°	8.06 dBi
Slot sub-array, Fig. 8 (f)	Short top	50°	270°	7.16 dBi
Slot array, Fig. 8 (e)	Short bottom	50°	90°	8.06 dBi
Slot sub-array, Fig. 8 (f)	Short bottom	50°	90°	7.16 dBi

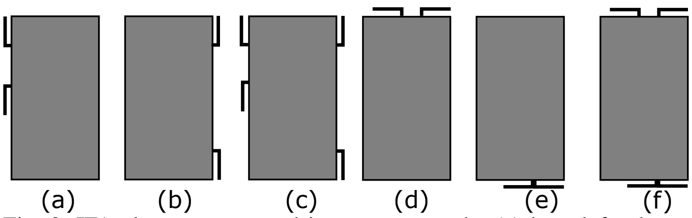


Fig. 9. IFA elements arranged in an array on the (a) long left edge, (b) long right edge, (c) both long edges, (d) short top edge, (e) short bottom edge, (f) both short edges.

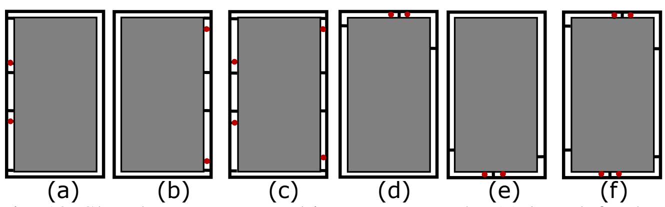


Fig. 10. Slot elements arranged in an array on the (a) long left edge, (b) long right edge, (c) both long edges, (d) short top edge, (e) short bottom edge, (f) both short edges.

Tab. II. Boresight and maximum gain of a different IFA and slot array configurations in data mode.

Type	Location	θ	ϕ	Max. gain
IFA array, Fig. 9 (a)	Long left	45°	0°	3.8 dBi
IFA sub-array, Fig. 9 (c)	Long left	45°	0°	2.86 dBi
IFA array, Fig. 9 (b)	Long right	40°	180°	6.05 dBi
IFA sub-array, Fig. 9 (c)	Long right	45°	180°	5.5 dBi
IFA array, Fig. 9 (d)	Short top	90°	285°	1.91 dBi
IFA sub-array, Fig. 9 (f)	Short top	90°	285°	1.66 dBi
IFA array, Fig. 9 (e)	Short bottom	70°	75°	4.27 dBi
IFA sub-array, Fig. 9 (f)	Short bottom	70°	75°	3.85 dBi
Slot array, Fig. 10 (a)	Long left	35°	0°	7.01 dBi
Slot sub-array, Fig. 10 (c)	Long left	35°	0°	6.45 dBi
Slot array, Fig. 10 (b)	Long right	45°	180°	5.44 dBi
Slot sub-array, Fig. 10 (c)	Long right	45°	180°	4.02 dBi
Slot array, Fig. 10 (d)	Short top	55°	300°	2.98 dBi
Slot sub-array, Fig. 10 (f)	Short top	75°	290°	2.92 dBi
Slot array, Fig. 10 (e)	Short bottom	65°	70°	3.45 dBi
Slot sub-array, Fig. 10 (f)	Short bottom	55°	95°	3.47 dBi

Fig. 9 (e).

The boresight and maximum gain for the all configurations shown if Table II for the IFA arrays and in Fig. 10 for the slot arrays. Loss due to mutual coupling of an IFA array is 0.94 dB for the array on the left long edge, 0.55 dB for the array on the right long edge, 0.42 dB for the array on the top short edge and 0.25 dB for the array on the bottom short edge. Loss due to mutual coupling of a slot array is 0.560 dB for the array on the left long edge, 1.42 dB for the array on the right long edge, 0.06 dB for the array on the top short edge and 0.98 dB for the array on the bottom short edge. Boresight of a top and bottom slot arrays will change when those arrays are combined into an antenna system.

V. Conclusion

The paper has been shown a method of constructing an antenna array on the mobile terminal chassis. The boresight of the antenna array can be predetermined when choosing the right antenna elements to use in the array. The method can be used to construct an array on the ground plane of a chosen size both is free space and with user influence. Such an array can be used as a phased array, which has been shown in [2] in detail. The method can also be used when constructing a multi-beam MIMO antenna array system.

A presented method showing promising results with an array, constructed in a metal frame around the ground plane, where a gain of 9.55 dBi has been achieved. The method shown that a maximum gain of the constructed array is 1 to 2.5 dB higher then the gain of a single element. The same conclusion can be also drawn for the array performance in the data mode, however it is challenging to optimize an array for use in data mode in the right and left hand, with a user head, or in dual-hand mode at the same time.

References

[1] RP-152158, "RAN4 CRS for LTE Advanced intra-band contiguous Carrier Aggregation in band 42 for 4DL," Nokia Networks, CATT, RAN4#70, Sitges, December, 2015.

[2] I. Syrytsin, S. Zhang, and G. Pedersen, "Performance investigation of a mobile terminal phased array with user effects at 3.5 ghz for lte advanced," *IEEE Antennas and Wireless Propagation Letters*, vol. PP, no. 99, pp. 1–1, 2016.

[3] C. N. Chuah, G. J. Foschini, R. A. Valenzuela, D. Chizhik, J. Ling, and J. M. Kahn, “Capacity growth of multi-element arrays in indoor and outdoor wireless channels,” in *Wireless Communications and Networking Confernce, 2000. WCNC. 2000 IEEE*, vol. 3, pp. 1340–1344 vol.3, 2000.
[4] C. A. Balanis, *Antenna Theory: Analysis and Design*. Wiley-Interscience, 2005.
[5] M. Ali and B. A. Khawaja, “Dual bandmicrostrip patch antenna array for next generation wireless sensor network applications,” in *Sensor Network Security Technology and Privacy Communication System (SNS PCS), 2013 International Conference on*, pp. 39–43, May 2013.
[6] W. Swelam, M. A. Soliman, A. Gomaa, and T. E. Taha, “Compact dual-band microstrip patch array antenna for mimo 4g communication systems,” in *2010 IEEE Antennas and Propagation Society International Symposium*, pp. 1–4, July 2010.
[7] W. Zhou and T. Arslan, “A bidirectional planar monopole antenna array for wifi/bluetooth and lte mobile applications,” in *Antennas and Propagation Conference (LAPC), 2013 Loughborough*, pp. 190–193, Nov 2013.
[8] M. S. R. Bashri, T. Arslan, and W. Zhou, “A dual-band linear phased array antenna for wifi and lte mobile applications,” in *Antennas Propagation Conference (LAPC), 2015 Loughborough*, pp. 1–5, Nov 2015.
[9] Y. qiang Xia, X. rong Chen, and T. Tang, “A novel eight ports dual band antenna array for 2.4/3.5 {GHz} {MIMO} applications,” *Optik - International Journal for Light and Electron Optics*, vol. 126, no. 11–12, pp. 1175 – 1180, 2015.
[10] M. K. T. Al-Nuaimi and W. G. Whittow, “Performance investigation of a dual element ifa array at 3 ghz for mimo terminals,” in *Antennas and Propagation Conference (LAPC), 2011 Loughborough*, pp. 1–5, Nov 2011.