ADVANCED ELECTROMAGNETICS, VOL. 7, NO. 4, AUGUST 2018

Design of High Gain Novel Dielectric Resonator Antenna Array for 24 GHz Short Range Radar Systems

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Abstract

in this work we present a 16x1 array' elements of a high gain Novel shape designed Dielectric Resonator Antenna (NDRA), having a low dielectric constant value of 18, for wide band (WB) 24 GHz automotive Short Range Radar (SRR) applications. The proposed NDRA array is feed by an efficient microstrip network feeding mechanism and presents wide impedance bandwidth (426 MHz), high gain (20.9 dBi), high efficiency (96%) and directional radiation pattern at 24 GHz with narrow angular beam-width of 6.4°. Computed NDRA array results allow the proposed design to be practical for the next automotive radar generations. Parametric studies have been analyzed using the Finite Difference Time Domain (FDTD) method of the CST-MW time domain solver and results, of the optimal structure, have been validated by the Finite Element Method (FEM) used in HFSS electromagnetic (EM) simulator.

Keywords--DRAs; High gain; SRR; LRR; Anti-collision automotive radar.

1. Introduction

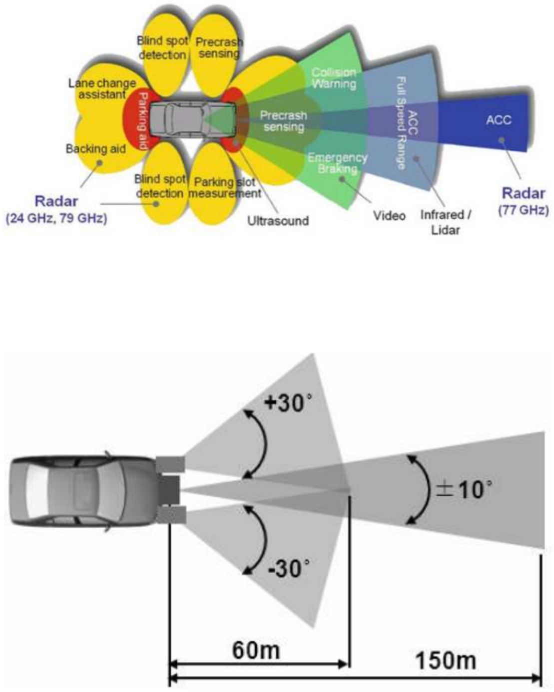
Automotive anti-collision radar systems have experienced remarkable development over the past ten years [1-5] thanks to the extensive and fast improvement in antenna R&D domain [6-8].

After the second world war radar' technology has covering many civilian domains especially the automotive industry where high-end vehicles applications, based on the electromagnetic radars, have been appeared in the last decade [9]. However the demand for higher performances radar systems is increasing since they will play more significant roles in next generations of safety and autonomously driving projects.

Anti-collision automotive radar systems are divided into two categories depending on range and beam width: short range radar (SRR) and long range radar (LRR) as shown in table 1. The SRR category is covering the most of automotive radar standardized frequency bands (24 GHz, 26 GHz and 79 GHz) in Narrow Band (NB) and UWB. The 24 GHz band has attracted many radar systems applications, summarized in figure 1 (a, b), like ACC support with Stop & Go functionality, collision warning, collision mitigation, blind spot monitoring, parking aid (forward and reverse), Lane change assistant and rear crash collision warning [2, 9].

Table 1: Automotive radar applications summary [11].

	Application	Center Frequency	Band Width
24 GHz NB	SRR/ACC	24.2 GHz	0.2 GHz
24 GHz UWB	SRR	24.5 GHz	5 GHz
26 GHz	SRR	26.5 GHz	4 GHz
77 GHz	LRR/ACC	76.5 GHz	1 GHz
79 GHz	SRR/MRR	79.0 GHz	4GHz



possible
automotive applications of SRR technology [9], (b) A
go system with max range of
width critical for SRR and LRR [10].

First radar' systems generations and the most of actual ones are designed using microstrip antennas technology because of some advantages such as low cost of fabrication and the ease of design and test during R&D phase. However this technology is suffering from energy losses because of Joule effect when using metallic radiator and less design flexibility compared to their competitors: dielectric resonator antennas (DRA).

DRAs were introduced by Long et. al. [12] in 1983, and since then they have been widely studied [13]. Before that, dielectric resonators were used for filter applications in microwave circuits [14]. The DRAs are very attractive for millimeter wave applications as they exhibit very low losses. Different shapes can be used to design DRAs such as rectangular, cylindrical, and hemispherical geometries. DRAs can also be excited with different feeding methods, such as probes, micro-strip lines, slots, and co-planar lines [15]. They are also fabricated from a high relative permittivity (ε_r=10-100). As compared to the microstrip antenna, the DRA presents several advantages such as small size, light weight, low cost, diversity in shape and feeding mechanism, simple structure, easy fabrication as well as an ease of excitation. Moreover, it offers a low dissipation loss and high radiation efficiency at high frequencies due to the absence of conductors and surface wave losses [16, 17]. DRAs don't excite surface waves, which create a mutual coupling in the case of microstrip antenna arrays and is responsible of the scan blind problem for large phased patch antenna arrays [18]

In this paper, based on a previous work done in 2016 [19], we will present the design of novel high gain DRA structure which we managed to develop and adopt to be used for automotive radar systems. The single antenna is simulated to achieve radars' requirements for vehicle applications at 24 GHz, then an effort has been carried out to design a suitable feeding network array using 16x1 antennas elements while keeping minimal return loss value around 24GHz and enhancing the radiation pattern performances such as high efficiency and narrow half power beam-width (HPBW) to make the finale NDRA array structure oriented to 24 GHz WB and NB SRR applications.

2. Design of single NDRA

2.1. Configuration of NDRA

The novel DRA structure is composed by a rectangular shape (axbxh) and three semi-cylindrical shapes, having a radius (r) and height (h), glued against three lateral sides of the rectangular shape as illustrated in figure 2. The hybrid structure, which is placed on a Lossy Rogers-5880 substrate of thickness hs, is fed by 50 Ω micro-strip line as a feed-line technique, having a width of W_f=0.8mm and a length of L_f=5mm, through the fourth lateral rectangular side.

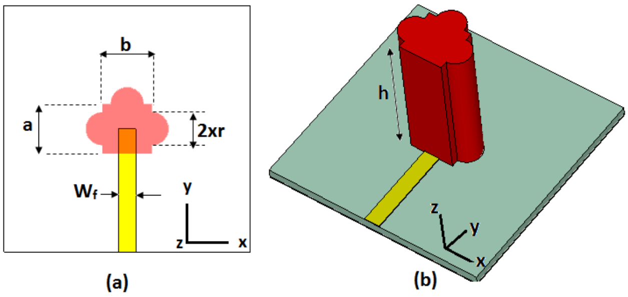
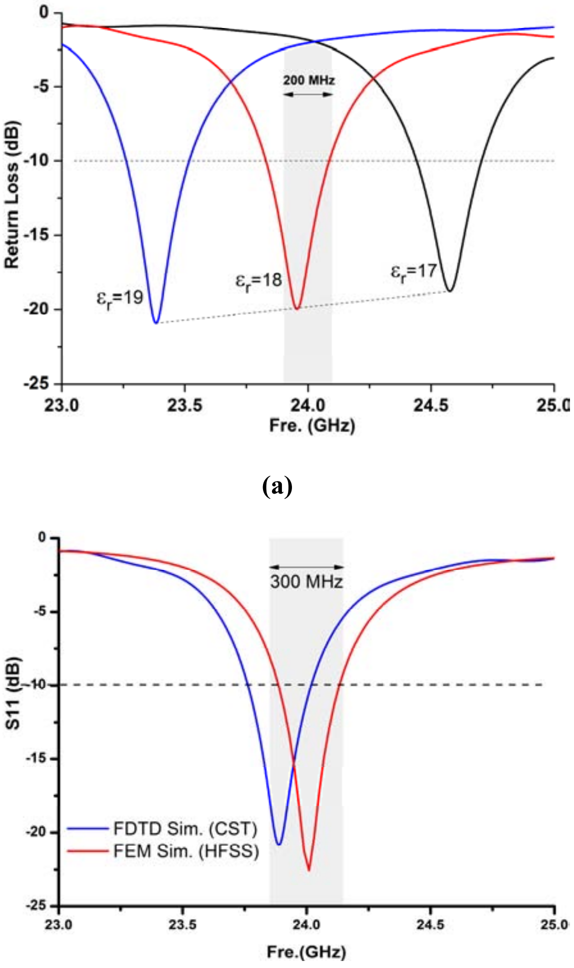


Figure 2: Geometry of the proposed NDRA, (a) top view, (b) 3D view.

2.2. Reflection coefficient

To validate our proposed single NDRA design, simulation has been carried out, using the commercial software MWS CST, with a=2mm, b=2mm, r = a/3, h=6.03 mm and hs=0.1mm and DRA' material permittivity is chosen to be 18. Both the ground plane and the substrate have the same length (Ls=10mm) and width (Ws=10mm). The previous geometrical quantities was an output of many simulation works carried out to get the present antenna structure, figure 3(a), as example, shows the effect of material permittivity on the resonant frequency shifting when hs=0.1mm and h_{DRA}=6.1mm. Through S_{11} plotted results we can confirm, in this case, that DRA resonant frequency is, approximately, inversely proportional to the dielectric resonator material permittivity. Return loss parameter' results of the optimal structure are plotted in figure 3(b) where lower values are obtained, and they are about -22.5 dB, around the desired resonant frequency 24 GHz.



(a)

(b)

Figure 3: Reflection coefficient: (a) CST parametric study and (b) optimal NDRA where h_s =0.1 mm and ε_r =18.

2.3. Radiation pattern and Gain Characteristic

The gain radiation pattern of the proposed NDRA is illustrated in figure 4, in linear scale; the maximum value corresponds to 12.3 dBi, with horizontal HPBW of 92.3 degrees. The simulated gain versus frequency of the proposed single NDRA is plotted in figure 5; higher values of simulated gain are noted around 24 GHz reaching values up to 12.25 dB, and it is exactly 12.24 dB at 24 GHz. The structure presents encouraging unidirectional pattern properties which can be enhanced, by developing an array with suitable placement of single antenna elements, in order to obtain a thinner angular beam width (HPBW) especially in the horizontal plane (xy-plane) for automotive radar purpose, this will increase the antenna gain and will improve the SRR' angular resolution.

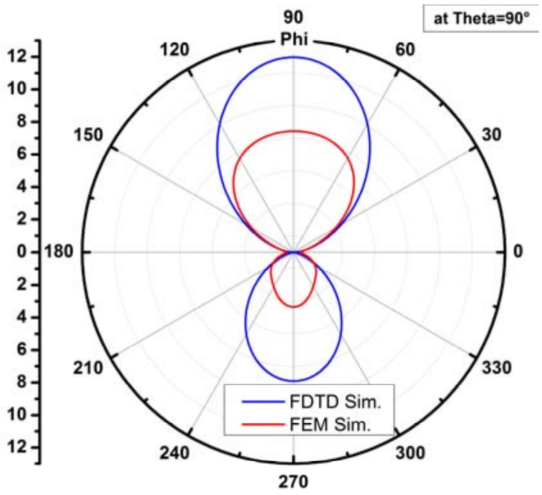


Figure 4: Radiation pattern of the proposed single NDRA at 24 GHz in linear scale at xy-plane (theta = 90).

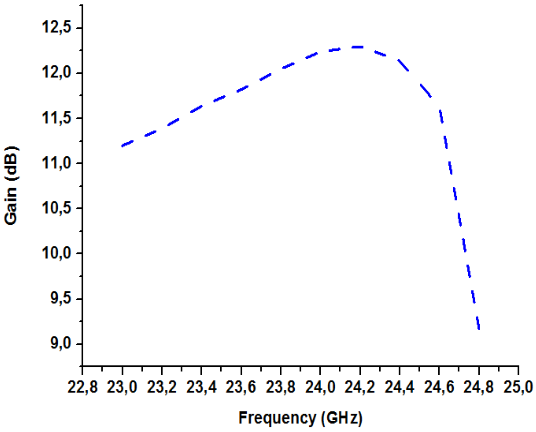
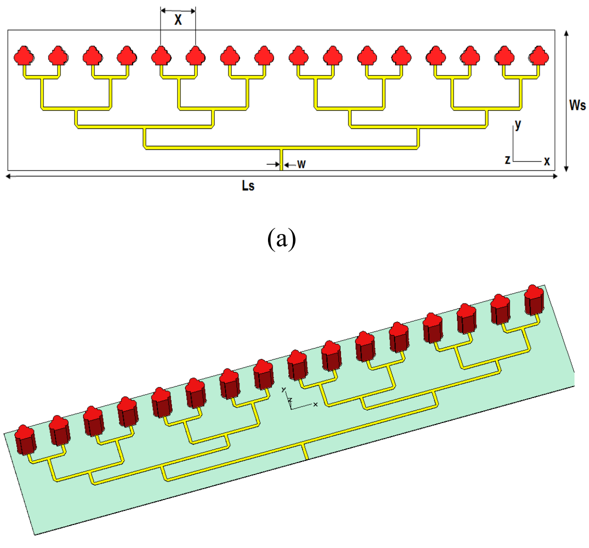


Figure 5: CST simulated gain versus the frequency of the proposed single NDRA.

3. Design of NDRA array

3.1. Configuration of NDRA array

Antenna array structures are required to achieve high gain, high efficiency and better radar angular resolution with a narrow beam width for high accuracy target position determining, hence, we have proposed a simple structure array design whose geometry is shown in figure 6; it is a linear 16 NDRA array elements excited by a 50 Ω micro-strip feed-line. The proposed optimal antenna structure is mounted on Lossy Rogers-5880 substrate with fully grounded plane, the Lossy Rogers-5880 substrate has a thickness of h=0.1mm, a length of L_S=96 mm and a width of W_S=20 mm. The single antenna elements are spaced from each other by a distance x and fed through a simple feeding network topology where the optimal feed-line width has been found to be W = 0.5mm



(a)

(b)

Figure 6: Geometry of the proposed NDRA array, (a) top view (b) 3D view

3.2. Parametric study

3.2.1. *Effect of antenna elements' spacing on S_{11}*

Different physical and geometrical parameters can be investigated to get the optimal feeding network ensuring a radiating structure operating around 24 GHz for SRR applications. In this section we present only the effect of antenna' spacing parameter (x) which is decisive for array DRA performances enhancement.

Figure 7 shows the simulated S-parameter for different values of antenna elements spacing (x). By altering the x value, significant variation in resonant frequency can be observed. In the case of x = 6.25 mm the proposed DRA array is resonating exactly around 24 GHz where this value of x (6.25mm) is equal to 0.5λ (λ/2) and λ is the wave length corresponding to 24 GHz in free space.

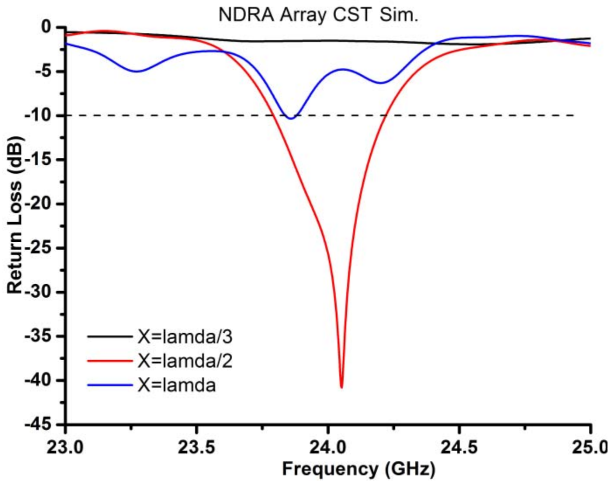
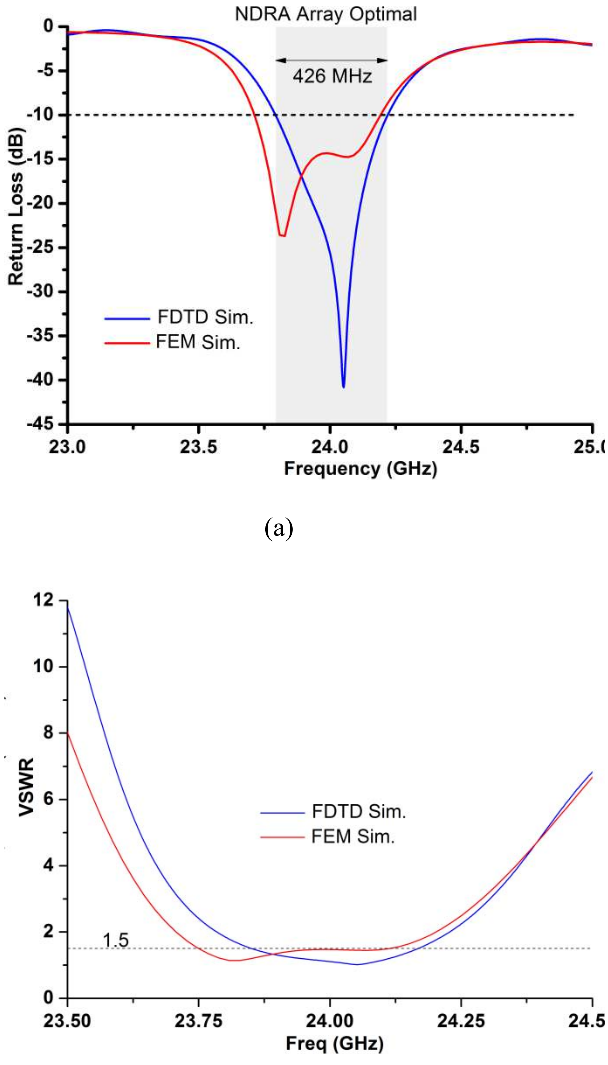


Figure 7: Return Loss for various antenna elements' spacing (X) of NDRA array.

3.3. Optimal structure

Based on the above parametric study, the antenna array structure, with calculated optimal geometrical dimensions, has been simulated also with HFSS software to check the results obtained with CST-MW. Return loss' curves show a good agreement, at least for impedance bandwidth at -10dB, which is approximately 426 MHz around 24 GHz, according to CST results (Fig. 8a); simulated VSWR values are less than 1.5 for the considered bandwidth (Fig. 8b). The high meshing procedure followed in CST-MW Time Domain solver (more than 8.5 million mesh cells) makes us so confident about its results, while in HFSS we have used the default meshing mechanism because of expensive memory resources required when requesting small edges of the tetrahedral finite elements used by the FEM, this is why we observe a slight difference between the two graphs when S_{11} is less than -10dB.



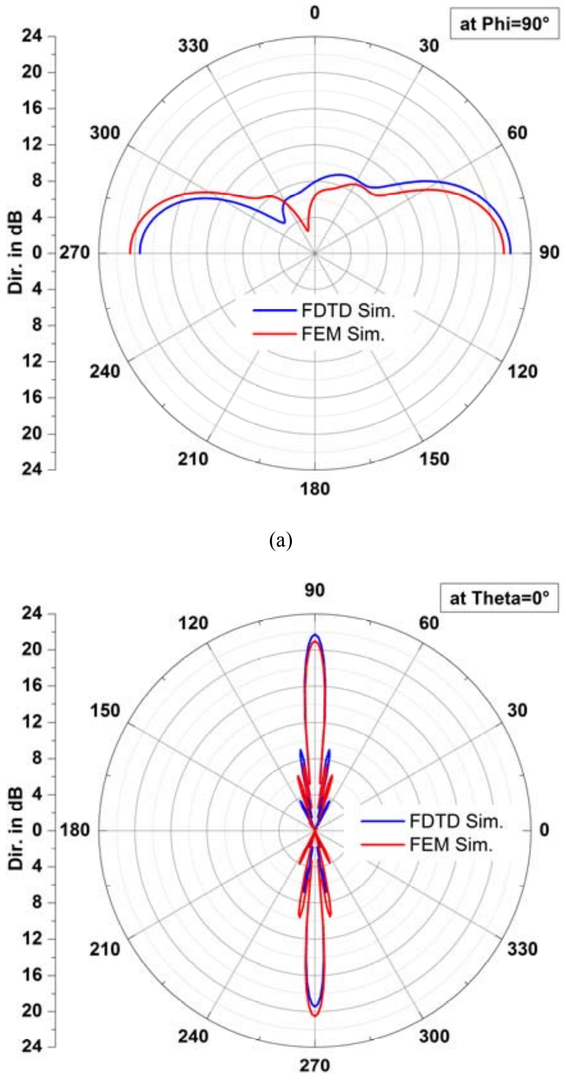
(a)

(b)

Figure 8: (a) S_{11} and (b) VSWR of the proposed optimal NDRA array.

3.4. NDRA array radiation patterns

The gain radiation patterns at 24 GHz, at xy (Theta=90°) and yz (Phi=90°) planes, are shown in figure 9.For better viewing the diagram has been plotted. We can say that the linear array of 16 elements has led to a sharpener radiation pattern antenna at desired resonant frequency (24 GHz) with a HPBW of 6.4° in both xy-plane and yz-plane; this will improve significantly the resulting radar angular resolution.



(a)

(b)

Figure 9: Radiation patterns in dB scale of the proposed NDRA array at 24 GHz: (a) YZ-plane and (b) XY-plane.

3.5. Gain, directivity and radiation efficiency of the 1x16 element NDRA array

Simulated gain and directivity versus frequency of the proposed NDRA array are plotted in figure 10, where gain and directivity are reaching, respectively, values up to 20.9 dB and 21.7 dBi at 24 GHz. As result the investigated DRA array structure with just 16 linear elements spaced by 6.25 mm is presenting very high gain and directivity quantities. The efficiency of our proposed NDRA antenna is well above 90% in the frequency range and it can go up to 96% at 24 GHz as shown in figure 11.

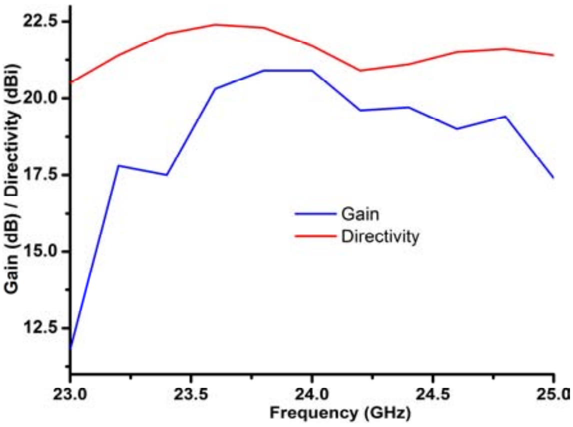


Figure 10: CST simulated gain and directivity of the proposed NDRA array.

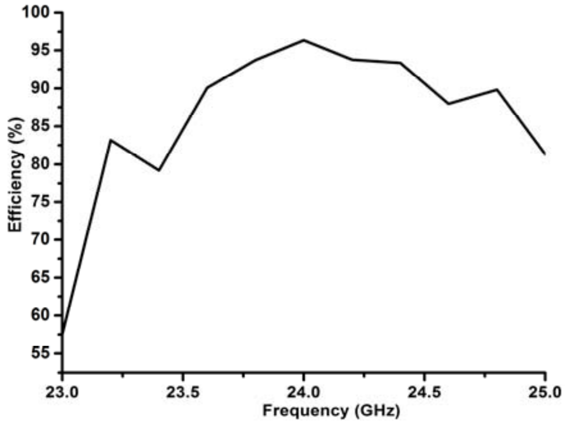


Figure 11: CST Simulated radiation efficiency of the proposed NDRA array.

CONCLUSION

The NDRA array for 24 GHz wide band (WB) SRR applications [11] has been designed and simulated using two leader EM simulators: CST-MW and HFSS. Simulations show encouraging and promising results: around 24 GHz the return loss is less than -35 dB, the gain and the directivity of the linear 16 NDRA elements array are respectively about 20.9 dB and 21.7 dBi. Narrow angular beam width of 6.4 degree is noted which leads to higher radar angular resolution performances; high radiation efficiency is achieved (96%) thereby ensuring higher power radiating capability and longer range radar. The proposed NDRA array has attractive features and can be practically used for 24 GHz NB and WB SRR anti-collision applications.

References

[1] W. Weidmann and D. Steinbuch, “A high resolution radar for short range automotive applications”, *in 28th Eur. Microw. Conf., Amsterdam, Netherlands*, 1998, pp. 590–594.

[2] H.-L. Bloecher, A. Sailer, G. Rollmann, and J. Dickmann,” 79 GHz UWB automotive short range radar – Spectrum allocation and technology trends”, *Adv. Radio Sci*., 7, 61–65, 2009.

[3] Wixforth, T. and W. Ritschel, \Multimode-radar-technologief˜ur24 GHz," *Auto Elektronik*, Vol. 3, 56-58, 2004

[4] Victor Rabinovich, Nikolai Alexandrov, BasimAlkhadeep, “Automotive Antenna and Design
Applications”, *CRC Press*, 2010.

[5] D. Thiripurasundariand D.S. Emmanuel ,“Switchable Ultra Wideband Antenna for Indoor and Automotive Vehicular Band Applications”, *International Journal Of Microwave And Optical Technology*, VOL.8 NO.1, JANUARY 2013.

[6] M. Slovic, B. Jokanovic and Kolundzija, “High efficiency patch antenna for 24 GHz anticollision radar*,” in Telecommunications in Modern Satellite, Cable and Broadcasting Services*, 2005. 7th International Conference on, 2005, pp. 20-23 vol. 1

[7] V. Cojocaru et al., “24GHz low-cost UWB front-end design for short range radar applications,” *European Microwave Conference*, Amsterdam 2004.

[8] M. Park et al., “Technology Trends of 77GHz Automotive Radar Components,” *ETRI Journal*, Vol.27, No.1, Feb. 2012, pp.101-112.

[9]White Paper, WP-01183-1.3, “Implementing Digital Processing for Automotive Radar Using SoCs”, *Altera Corporation*, December 2013

[10] S.-H. Jeong , H.-Y. Yu , J.-E. Lee , J.-N. Oh , and K.-H. Lee “A Multi-Beam And Multi-Range Radar with FMCW and Digital Beam Forming for Automotive Applications”; *Progress In Electromagnetics Research*, Vol. 124, 285-299, 2012

[11] Dr. Rudolf lachner ,“Development Status of Next Generation Automotive Radar in Eu” *ITS Forum 2009*, TOKYO, February 26th, 2009.

[12]Long, S. A., M. W. McAllister, and L. C. Shen, “The resonant cylindrical dielectric cavity antenna,"

IEEE Transactions on Antennas and Propagation, Vol. 31, No. 5, 406{412, May 1983.

[13] G. Almpanis, C. Fumeaux, and R. Vahldieck, “Offsetcross-slot coupled dielectric resonator antenna for circular polarization,” *IEEE Microwave and Wireless Components Letters, vol. 16, no. 8, pp. 461–463, 2006.*

[14] Kajfez, D. and P. Guillon, Dielectric Resonators, *Artech House*, Norwood, MA, 1986.

[15] A. Petosa, “Dielectric Resonator Antenna Handbook”, *ArtechHouse Publishers*, 2007.

[16] A. Kishk, “Dielectric Resonator Antenna, a candidate for radar application”,*Proc. Of the 2003 Radar Conference*, pp. 258–264, May 2003.

[17] K. M. Luk and K. W. Leung, Dielectric Resonator Antennas.Hertfordshire, *U.K.:Research Studies* Press Ltd., 2002

[18] A. A. Kishk, “Dielectric resonator antenna, a candidate for radar applications”, *Proceedings of the 2003 IEEE Radar Conference*, 5-8 May 2003, USA

[19] A. Haddad, M. Aoutoul, K. Rais, M. Essaaidi, “A High Gain Novel Dielectric Resonator Antenna (NDRA) for Anti-collision Short Range Radar (SRR) Application”, 5th International Conference on Multimedia Computing and Systems, ICMCS’16, 29 September-1 October 2016, Marrakech, Morocco.