Digital Beam Forming Vehicular Radar at 77 GHz

D.Mondal, R.Bera, P.Dey, S.Hazra, M.Mitra

Abstract—In this paper Authors are trying to develop Digital Beam Forming Vehicular Radar at 77 GHz. At the transmitter side antenna beam pattern is digitally controlled by the DBS Transmitter having DBF planar structure 4X4 elemental patch antenna and at the receiver end receiving antenna beam pattern is digitally controlled by DBS Receiver having identical 4X4 elemental antennas. From this model we are able to measure the target motion and accurate ranging in presence of hostile environment successfully. The performance of this innovative model in range and velocity resolution are better with respect to other conventional Radar system.

Index Terms—DBF (Digital Beam Forming), CSWAP (Cost Size Weight And Power), CALM (Continuous Air interface for Long and Medium distance), DS-SS (Direct Sequence Spread Spectrum), RCS (Radar Cross Section)

I. INTRODUCTION

Over the last few year it has been comprehended that the complexity of the Radar design is increasing day by day in the sense Cost, Size, Weight and Power according to the social and industrial demands. There are so many radar have been developed specially for transportation system using efficient technology like SDR,MIMO based Pulse Doppler radar[1], Analog[2] as well as Digital Beam forming Radar[3] as per requirement to the social needs. Now for vehicular safety authors are try to develop a special type of Radar that will be maintain by Cost, Size, Weight and Power [4] that can be mount at the vehicle. Basically this radar is operated in searching mode. This DBF radar will sense nearest car and its dynamic range and velocity. However according to ETSI[5] and CEPT[6] author have simulated the complete radar system at 77 GHz carrier frequency with band width of 500 MHz This radar system will search Vehicle up to 150 meters. A survey report from world health organisation (WHO)[7-8] over all countries shows that 1.3 million people are killed on road accident every year or more than 3,500 people per day. This is one of the motivation of Authors towards implementation of SSDBF Radar [9] for collision avoidance. The major objectives of milli-metre (77GHz) wave radar technology are clutter free and short distance vehicle detection and classification using DS-SS Radar and its extension to Digital Beam Forming Spread Spectrum Radar (SS-DBF)[9].Lot of experimental studies is going on based on Matlab, ADS, SystemVue software simulation and hardware realization towards the implementation of SS-DBF Radar. In this paper we are focusing towards SS-DBF using SystemVue. Now using Spectral spreading technique with Digital Beam synthesis in both side Transmitter as well as Receiver specially we emphasized on velocity, range estimation and the applied orthogonal code detection on the road side. Simulation results are shown in different section of this paper. Complete simulation Model is shown in Fig.1

Revised Manuscript Received on December 22, 2015.

D.Mondal, R.Bera, Department of Electronics and Telecommunication Engineering Indian Institute of Engineering Science and Technology, Shibpur, Howrah-711103, W.B, India.

P.Dey, S.Hazra, [2]Department of Electronics and Communications Engineering Sikkim Manipal Institute of Technology, Majitar, Sikkim, INDIA

M.Mitra, Department of Electronics and Communications Engineering Future Institute of Engineering and Management, Sonarpur, Kolkata, INDIA

II. DEVELOPMENT OF DBF RADAR MODEL USING SYSTEMVUE SOFTWARE

Using SystemVue software entire simulation model of Digital Beam Forming Radar at 77 GHz is shown in Fig.-1. After running the overall model in SystemVue, we can estimate all the above phenomena and also do the analysis. The analysis are shown in different section of this paper .

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

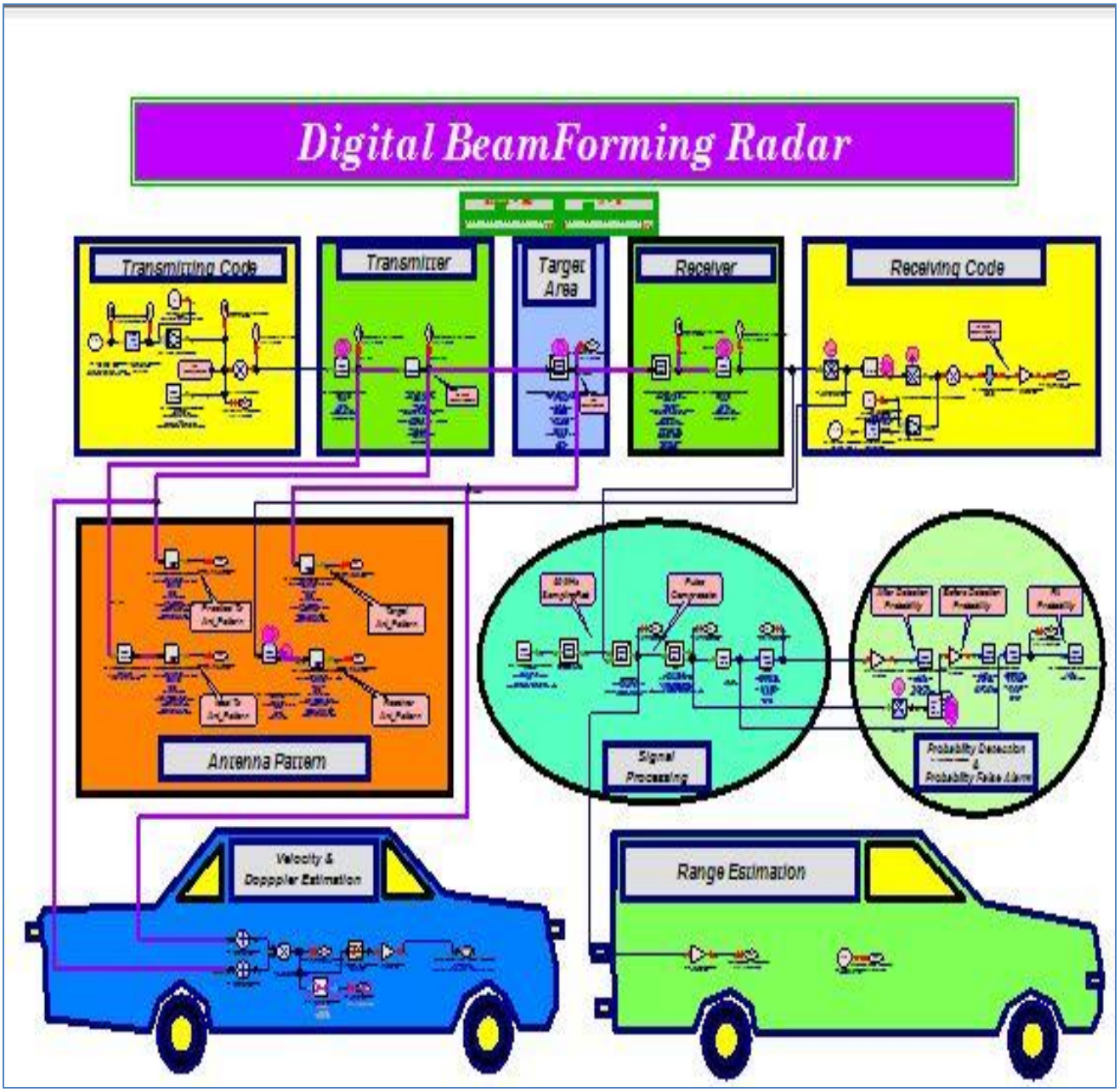

Fig.- 1: Simulation Model of Digital Beam Forming Radar using SystemVue

III. ANALYSIS USING DIFFERENT TRANSMITTING CODE

Lot of Matlab simulation have already done on different orthogonal codes like Barker, Gold, Hadamard, OVSF and different length PN Sequence [10], Frank, P1,P2,P3,P4,Px Codeon Doppler and Delay Ambiguity test .Performance test of ambiguity on Frank code shows better with respect to other orthogonal codes. Frank code is basically a type of Polly-Phase code, used as a CDMA-technique[11] in this model for target detection.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

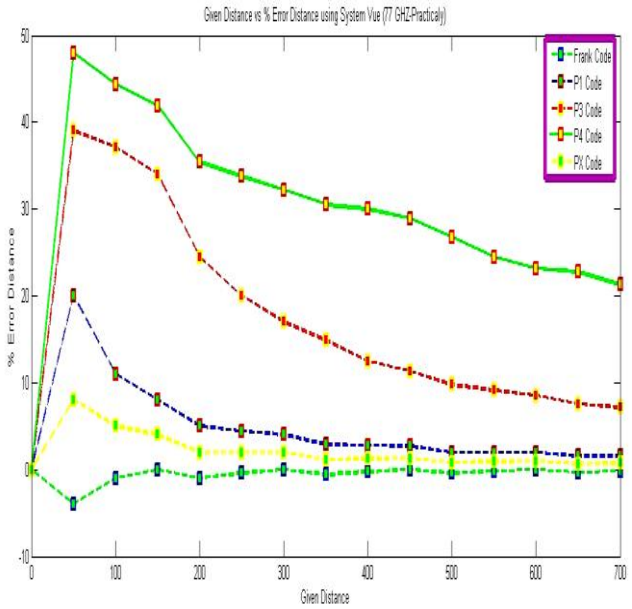

Fig.-2: Assigned Distance Vs Error distance Graph Using Different Codes.

From Fig.-2 it would be shown that the Frank Code is better than other Polynomial Code and PN Sequence Code for this model. So it is justified to used Frank Code rather than other code as a transmitting code. Maximum distance error by Frank Code is 2%, which is to be negligible. So Frank Code is more efficient than other code for this model.

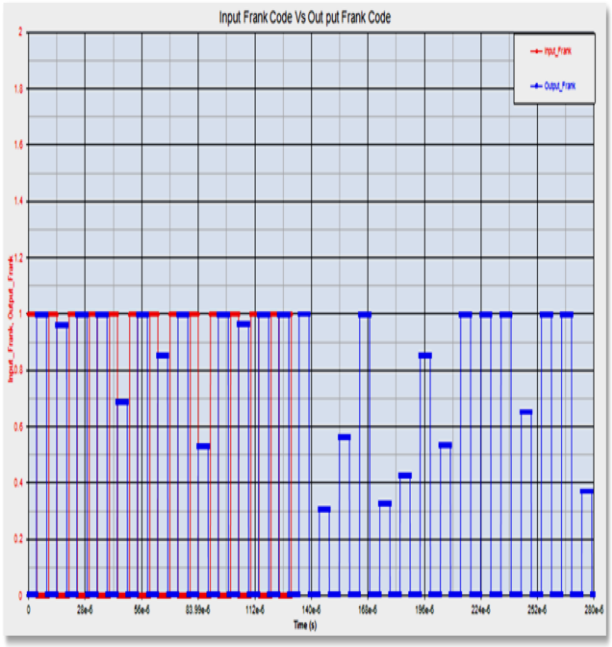

Fig.-3: Input Frank Code (in Red) Vs Output Frank Code (in Blue) corresponding 10MHz Sampling Rate.

From Fig.-3 it is cleared that output Frank Code is the delayed version of input with some distortion. Distortion is present for clutter & also might be present some noise for other block in the SystemVue Software and delay is present for time taken by the signal to reach receiver end. Here we have used 4X4 rectangular array elements which give the output of the 2D rectangular array antenna as a combination of 16 channels. From that we have sent the signal through a multichannel transmitter of 4X4 elements, where each element is a combination of digital radar up converter, an amplifier, a mixer with a local oscillator of 77GHz, a band pass filter and a delay envelope.. So Digital Beam Synthesise pattern of the SystemVue output is shown in figure Fig.-3.Which represent 16 channel data's digital beam synthesise output.

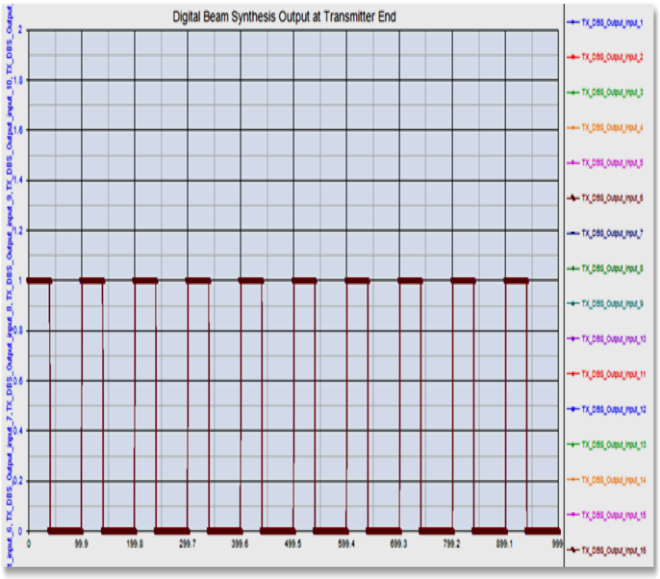

Fig.-3: Digital Beam Synthesise of the transmitted signal.

It is necessary to know how the model is performed using Frank Code or other Polynomial Code or PN Sequence Code. Detail analysis of this model is described in Section III,IV and V.

IV. DETECTION OF TARGET RANGE USING FRANK CODE.

To estimate detection range of the target we have used Pulse Compression technique. It is generally a FFT based implementation which detects the sample delay. In this technique two inputs are used, one of them is reference input and another is the received input. Different 'Window ' is used to control the compressed pulse side lobe. In the sample domain, maximum peak occurred in between the range of the number of samples per PRI, which gave the sample delay.
Now from there we get time delay as:
Time Delay = Sample Delay/Sampling Frequency
Now from time delay we can get the range of the target as:

$$Target\ Range = \frac{C \times \Delta t}{2}$$

Where $C = 3\times 10^8$ m/s (Light Speed).

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

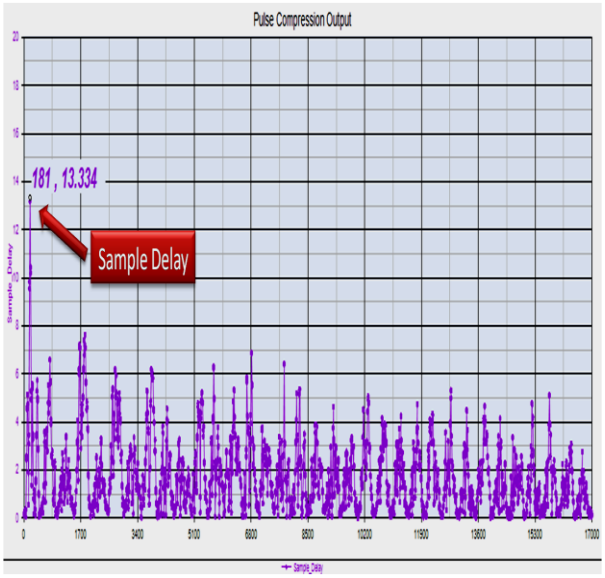

Fig 7: Pulse Compression Output.

From the above graph, sample delay is 181.So from equation-16, we get,

$$Time\ Delay\ (\Delta t) = \frac{181}{50\times10^{6}} = 3.62\ \mu s.$$

[∵ Sampling Freq.=50 MHz]

So, from equation (17)&(18), detected target range can be written as 543 meters. In this model, the PRI is 10e-5sec.So from there, we get PRF =1/PRI. So PRF is 100 KHz. Now, the maximum detectable range is:

$$R_{max} = \frac{C}{2\times PRF}$$

$$\Rightarrow R_{max} = \frac{3\times 10^{8}}{2\times100\times10^{3}}$$

= 1500 meters

Due to duplex wireless channel the maximum detectable range of this model is half of the maximum detection range as 750 meters. But Practically, the model measured the maximum distance up to 700 meters.

V. ESTIMATION OF VELOCITY USING FRANK CODE

Now to estimate the velocity of the target we have to measure the Doppler shift. So, to measure the Doppler shift we have multiplied the transmitted and received signal through low pass filtering which is shown in Fig.-1 of the simulation model. Using spectrum analyser we get directly the Doppler shift and target velocity can be written as:

Vehicle Velocity=(f_d*c/2*f_c)

Where, f_d = Doppler frequency; c = Velocity of light $= 3 \times 10^{8}$ m/s; λ = Carrier wavelength= c/f_c;f_c = Carrier frequency = 77GHz;

- **Maximum Detectable Velocity of This Model**

With the PRF 100 KHz and RF Frequency at 77 GHz evaluated the maximum detectable velocity of this model. Now, the maximum detectable velocity equation is:

$$V_{max} = \frac{C\times PRF}{4\times R_F}$$

$$\Rightarrow V_{max} = \frac{3\times10^{8}\times100\times10^{3}}{4\times77\times10^{9}}$$

$$\Rightarrow V_{max} = 97.4\ meters/sec$$

Practically, the model measured the velocity which is beyond the maximum detectable velocity with the technique that has used to detect the velocity estimation. Here in the below, given a Table-1 of theoretical velocity corresponding practical velocity.

Table-1

SI NO.	Assigned Velocity (m/s)	SystenVue Evaluated Velocity(m/s)	Velocity Error (%)
1	10	9.74	-2.6
2	20	19.481	-2.595
3	30	29.221	-2.596
4	40	40.909	2.27
5	50	50.649	1.298
6	60	60.39	0.65
7	70	70.13	0.185
8	80	79.87	-0.16
9	90	89.61	-0.433

From the table, it is to be shown that the percentage of velocity error is varying in the range between -2.5% to 2.5%.So it is to be negligible as it is too small.

VI. PERFORMANCE OF THIS MODEL

A. Using CFAR Technique

As we see at the time of range detection that, the pulse compression output (See Fig: 7) shows multiple peak with different amplitude due to hostile environment or dynamic channel of the model. From there it is very difficult to get the actual target peak. So to get the desired peak, we have used CA-CFAR [12] based algorithm, which compress or eliminate the other unwanted peak and gives only one or some peaks which have desired target . Obviously from here probability of detection of target is improved. Here CA-CFAR model firing Cell Size number of inputs is consumed and the same amount of outputs is generated. The value of Cell Size is same as the number of samples per PRI.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Here the number of reference cells is 32, which used to specify the number of reference cells in each side. Threshold is used to specify the CFAR detection . Generally CFAR has some different types of algorithm. Like CA algorithm, GOCA algorithm, SOCA algorithm etc. the CA algorithm can be described as,

$$\frac{x_0}{z} \geq \frac{T}{M}$$

Where, x_0 is the value of test cell ,z is the summation of the value of all reference cell ,M is the size of the reference cell, T is the detection threshold. If $\mathbf{z_l}$ is the sum of the left reference cell and $\mathbf{z_r}$ is the sum of right reference cell.
For basic cell averaging CA as $\mathbf{Z=z_1+z_r}$.For GOCA (Greater Of Cell Average), $\mathbf{z=max(z_l,z_r)}$ For SOCA (Smaller Of Cell Average), $\mathbf{z=min(z_l, z_r)}$.The FAR (False Alarm Rate) can be written as

$$FAR = \frac{False\ Targets\ Per\ PRT}{Number\ of\ Range\ Cells}$$

Now to avoid multiple peaks of pulse compression output, a CFAR block is used which gives a desired target response at particular sample value.

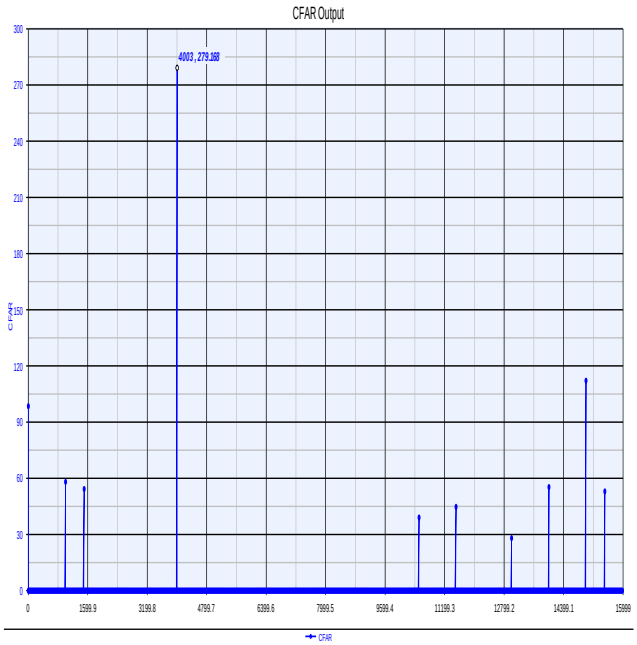

Fig.- 8: CFAR Output at Probability of False Alarm (Pf=1e-6)

B. Using Monta Carlo Simulation Technique

For estimation of detection probability using the radar's video output signal is used. The total simulation sample length is PRI_NUM* FFT_Size* Detection_Num, where PRI_NUM is the number of samples in a PRI, FFT_Size is the number of pulse in a CPI(Coherent Processing Interval),Detection_Num is the number of detections. The detection probability P_d is estimated based on Monte Carlo estimation as

$$P_d = \frac{1}{N}\sum_{j=1}^{N} D(t)$$

And the indication function D (t) is defined on the detection event as

$$D(t) = \begin{cases} 1 & target\ detected\ with\ target\ input \\ 0 & no\ target\ detected\ with\ target\ input \end{cases}$$

Here used two block before and after CFAR block. By which, we can see the difference of the detection probability from pulse compression output and from CFAR output. Now we have to set the target threshold from 0 to 1 and measuring the practical value of target threshold. If it is much high like more than 0.7 or 0.8 then the model's detection probability is good.

C. Comparison of Probability of Detection (Pd) between DBF Radar and Normal Radar:

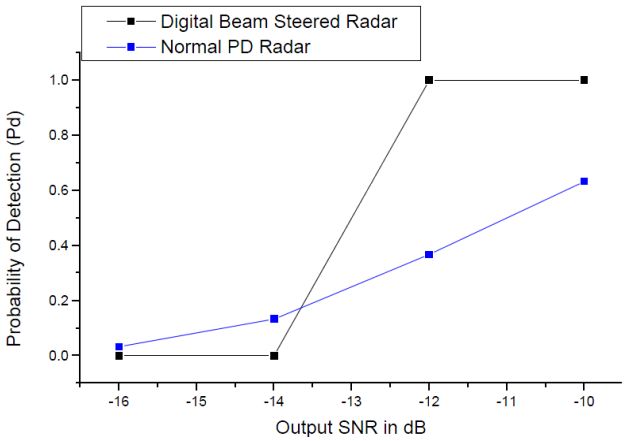

Fig.-9 The Probability of Target Detection is 100% ambiguity free in case of a Digital Beam Former Radar w.r.t a normal Radar within the negative SNR zone of -12 dB to -10dB

VI. CONCLUSION

- Using of 4X4 planar elemental array antennas, it would be much more complex, to handle the entire system performance in the sense measuring the delay involve in the reflected target signal because collection of peak sample value is very difficult task from which it can measure delay.
- Without presence of clutter, output detected code is still distorted.
- Maximum target range detected 700meters.But as a theoretically, it can measure 1500meters which is not possible in practical way.
- Not CSWAP enabled.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

REFERENCES

1. SKOLNIK,M.I: 'Introduction to radar systems'(McGraw-Hill Book Company, Singapore,1980,2nd edn) & Radar Signal Processing by Bassem R. Mahafza Huntsville , Alabama
2. D. Mondal, et.all ,"Vehicular Communication and Safety in Realization of Intelligent Transport System"IEEE international conference on.[Computer and Devices for Communication, 2009 held in Kolkata, INDIA]
3. NICKEL,U., and WIRTH,W.D.:"Beam forming and array processing with active arrays". IEEE Antennas and propagation symposium, Ann Arbor, USA, 1993,pp.1540-1543
4. A MULTI-BEAM AND MULTI-RANGE RADAR WITH FMCW AND DIGITAL BEAM FORMING FOR AUTOMOTIVE APPLICATIONS S.-H. Jeong , H.-Y. Yu, J.-E. Lee , J.-N. Oh, and K.-H. Lee -Progress In Electromagnetics Research, Vol. 124, 285{299, 2012
5. ETSI EN 302 264-1 v1.1.1 (2009-06) Europen Standard (Telecommunications series) Short Range Radar equipment operating in the 77 GHz to 81 GHz band, Part-1: Technical requirements and methods of measurement,
6. CEPT Report 37 , Report from CEPT to the European Commission in response to Part 2 of the Mandate on " Automotive Short-Range Radar Systems(SRR), Electronic Communication Committee(ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT)
7. Source:http://www.who.int/violence_injury_prevention/road_safety_status
8. World Health Organization (WHO), *"World report on road traffic injury prevention"*, Geneva,2004
9. Spread Spectrum Digital Beam forming (SSDBF) Radar Dr. Marcos A. Bergamo Applied Radar Inc. 200 Wheeler Road Burlington, MA 01803, USA
10. C. Andren, "Short PN Sequences for Direct Sequence Spread Spectrum Radios", Harris Semiconductor, November 1997.
11. S. Hara and R. Prasad, Overview of multicarrier CDMA, "IEEE Comm. mag., no. 12, Vol. 35, pp 126-133, Dec 1997.
12. M. A. Habib, M. Barkat ,B. A"ıssa and T. A. Denidni, CA-CFAR DETECTION PERFORMANCE OF RADAR TARGETS EMBEDDED IN "NON CENTERED CHI-2 GAMMA" CLUTTER Progress In Electromagnetics Research, PIER 88, 135–148, 2008

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication