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Intelligent Transportation System using Automotive WiMAX Radar Networks

Samiran Pramanik, Nirmalendu Bikas Sinha, Chandan Kumar Sarkar, Rabindranath Bera

Abstract*— This paper addresses the development efforts towards realization of vehicle to vehicle cooperative collision warning system for ITS. In this intelligent system either the vehicle or the infrastructure can communicate its location or other information to surrounding vehicles or nearby infrastructure for its implications in cooperative driving and vehicle safety deserve closer investigation. Commercial vehicles with multiple radars has the limitation of more false detection as the detection technology is based on ' skin' mode of radar operation and the radar receives its transmitted energy after reflection from the body of the target vehicles. The 'transponder' mode of radar operation will definitely improve the false detection leading to collision warning and warning system. The vehicles will be the 'friends' to each other by integrating the local radar mounted on each vehicle with vehicular communication. The goals of this paper are twofold: providing an engineering argument of possible functional architectures of such systems and presenting a possible example of the proposed future-trajectory-based design, which estimates and communicates vehicle positions and predicts and processes future trajectories for collision decision making using WiMAX waveforms. The authors have developed automotive WiMAX radar networks for Skin and Transponder mode utilizing the VLSI based advanced development platforms. This paper will highlight the achievements and limitations of the developed model.

Index Terms*— AWG, VSA, WiMAX, ITS, TCF, FCF, Skin mode and Transponder mode.

I. INTRODUCTION

Scientists and Technologists involved in the development of communication and remote sensing systems all over the world. Exploring the advantage of the above mentioned technologies authors are trying to develop an intelligent transport system by reutilizing their previous concept in 60 GHz WiMAX waveform [1][2]. Large scale national ITS projects began in Europe, the US and Japan in the mid-1980s but recent ITS efforts have seen a markedly greater focus on communication and safety grown tremendously over a few years. The EU's Safety initiative [3], announced in November 2002, aims to halve the number of annual traffic accident fatalities in the EU by 2010. The United States' ITS Ten-Year Plan [4], announced in January 2002, talks about achieving a 15% reduction in the number of annual traffic fatalities by 2011.The collision avoidance sensor, which is a part of AVCS can identify nearby vehicles and other obstacles in order to prevent collisions.

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Dr. Nirmalendu Bikas Sinha, corresponding author is with the Department of ECE and EIE, College of Engineering & Management, Kolaghat, K.T.P.P Township, Purba- Medinipur, 721171, W.B., India.

Prof. Samiran Pramanik, author is with the Department of ECE and EIE, College of Engineering & Management, Kolaghat, K.T.P.P Township, Purba- Medinipur, 721171, W.B., India.

Dr. Chandan Kumar Sarkar, author is with the Department of ETCE, Jadavpur University, Kolkata- 700032, W.B., and India.

Dr. Rabindranath Bera, author is with the Department of ECE, SMIT Sikkim Manipal University,Rangpo, East Sikim.,India.

A study shows that 90% of rear-end and 60% of head-on collisions could have been prevented if the driver could have been warned [5][6]. Recently Passive radars have attracted much attention in the international radar community and are becoming popular in the field of ITS. It is essentially, receiver-only radar that usually dissociates the receiver antenna away from the transmitter. Containing no transmitter, the benefits that passive radar can offer are numerous. Most importantly, passive radar is virtually undetectable to surveillance receivers and there is no constraint in spectrum allocation and thus can effectively be used for target detection. In most cases, passive radar is smaller, easily portable and is of lower cost compared to conventional active radar. Lots of research has also been initiated towards Multi-static Passive radar Networks. In fact, it is the reuse of communication technology to characterize the target. Development efforts towards individual and separate communication and radar systems are progressing a lot for utilization in vehicular application [7]-[11].

Collision avoidance in ITS can be avoided by either skin mode or transponder mode. On road condition, the vehicles should have both modes of radar operation. Transponder mode is set by default. The vehicle will send an interrogating signal to distant vehicle and if not answered, then it will set its mode to skin mode of operation. Mercedes Benz S class vehicle is available with such technology. This S class vehicle is fitted with several sensors for safety applications including radar and also enriched with latest communication. The major limitations of such vehicles are that firstly, enormous amounts of power must be radiated to ensure returns from the target. This is especially true if long range is desired. Secondly, because of the small amount of energy returned at the receiver, returns may be easily disrupted due to such factors as changes of target attitude or signal attenuation due to heavy rain. This may cause the displayed target to 'fade'. Thirdly, correlation of a particular radar return with a particular vehicle requires an identification process. Finally communication is not so reliable. The challenge is therefore, a careful selection of a latest high speed wireless technology like WiMAX to be embedded for safety and communication purposes in skin mode or transponder mode of operation in order to avoid collision on road. In this paper, the authors deal with such types of embedded system when radar is in skin mode and transponder mode using WiMAX waveform.

II. WIMAX RADAR DEVELOPMENT WITH SKIN MODE

The code transmission and its autocorrelation at the receiver used in WiMAX radar is the major achievement. Further performance improvement is possible with the use of FCF (Frequency correlation function) and matched filtering at the receiver.

The three major radar signal processing may be more useful in defining the target with fewer false alarms and less clutter. With this aim a new development of the WiMAX radar is also tried by the authors and an interesting development results. But, FCF implementation is more effective in frequency domain mode of radar operation. Therefore, for FCF realization, the WiMAX mode is changed to FHSS (Frequency hopping spread spectrum) mode.The background information on noise and clutter rejection techniques is described as follows.

Matched Filtering

Matched filtering refers to waveform matching at the receiver with that of transmitted waveform. This transmitted waveform may be used as reference at the receiver for matched filter design. So, the matched filtering will be more effective in reducing out of band noise from the received waveform. It may not be effective for in band noise and clutter reduction. FCF may be utilized for such in band noise reduction. The Matched filtering and the FCF together will be effective in reducing noise and clutter from a radar system. Additional performance improvement is possible using TCFTime Correlation function) function at the receiver and auto-correlated values at the output of TCF will be used for the calculation of target range and velocity information. Position of the filter is shown in the Figure 1.

Let Where G(f) denote the Fourier transform of the known signal g(t), and H(f) denotes the frequency response of the filter. Then the Fourier transform of the output signal can be mathematically expressed as

$$g_o(t) = \int_{-\infty}^{+\infty} H(f)G(f)\exp(j2\pi f t)\, df \;\ldots\ldots\ldots(1)$$

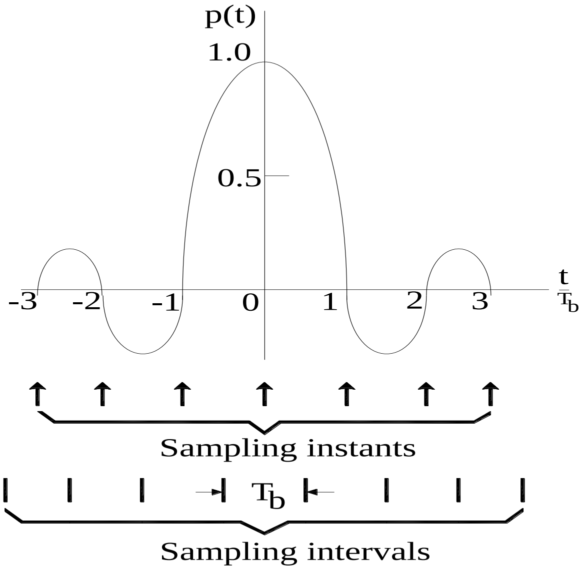

Figure 1: Ideal basic pulse shape.

Nyquist Sampling

Nyquist introduced a novel method of sampling at the receiver, where receive sampling will differ from transmit sampling. It aim is to peak detect the wanted signal and reject the side lobes or unwanted noise which prevails outside the main impulse response lobe. The concept is further elaborated in Figure 2. The concept is further elaborated in Figure 3 with reference to actual code where the waveform can be divided into two zones.

Zone 1: [marked with green border] where signal peak is detected by Nyquist sampling.

Zone 2: [Marked with red border] where unwanted signal will be rejected.

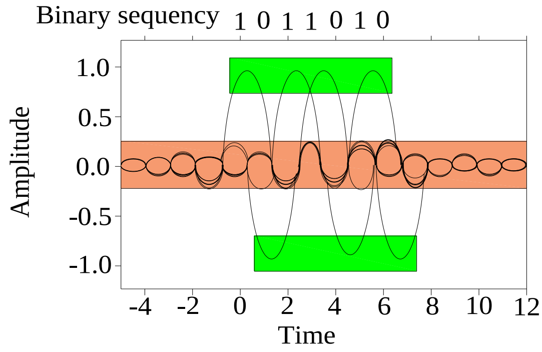

Figure 2: Series of Sinc pulses corresponding to the sequence 1011010.

FCF Function

FCF is defined as a correlation function generated by convolving the frequency response of a target X (f) with a conjugated, shifted version of the same response, $X^*(f+\tau$,

$$\mathrm{FCF_X}(\tau) = \int_{-\infty}^{\infty} X(f)X^*(f+\tau)df \;\ldots\ldots\ldots(2)$$

FCF will be helpful in defining the target very precisely from its surroundings; the detail will be discussed later.

D. TCF function

TCF (Figure 3 and Figure 4) is defined as a autocorrelation function of a periodic signal c(t) of period T_b is

$$R_c(\tau) = \frac{1}{T_b}\int_{-T_b/2}^{T_b/2} c(t)c(t-\tau)dt \;\ldots\ldots\ldots(3)$$

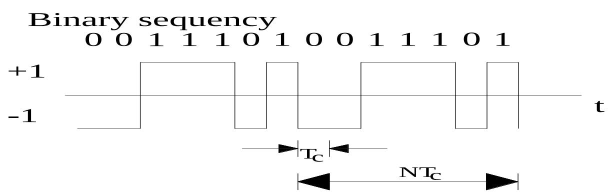

Figure 3: Waveform of maximal length sequence for length m=3 or period N=7.

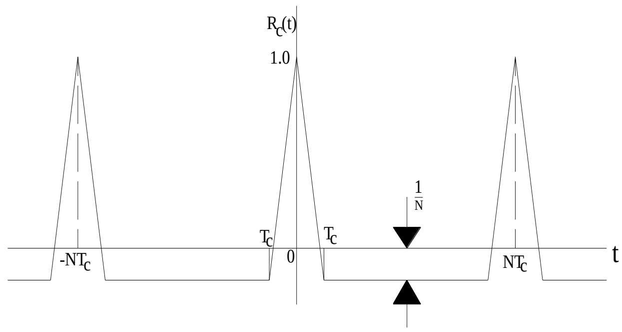

Figure 4: Autocorrelation function

In our FHSS radar design we should look for the generation of G(f),H(f) and c(t) function in cascade form. At the receiver their counterpart in the form of either multiplication or convolution obeying Equ.1to

Equ.3.These is additional blocks we should try to implement in our FHSS radar in addition to conventional transmitter and receiver.

III. IMPLEMENTATION OF WIMAX RADAR SYSTEM IN SKIN MODE

To generate the sharp antenna beam width, a dish antenna with prime focus horn is used both at the transmitter and the receiver. At the receiver, one Ku-band LNBC (Low Noise Block Converter) having a nose temperature of 4^0K is used. The block diagram of the said radar in skin mode is as shown in the Figure 5.A GUNN diode at X band is used as the main carrier oscillator tunable between 8 to 12 GHz. A PIN modulator is used as a modulator connected in series with the GUNN.

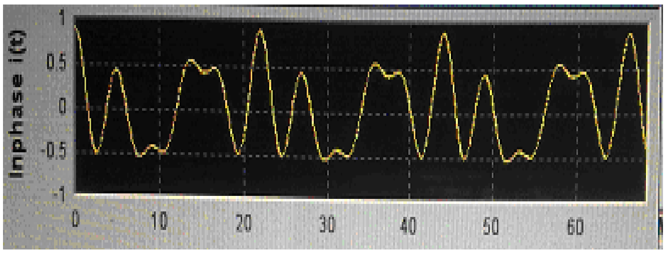

Figure 6: Barker code +++---+--+- generation using AWG

But for radar operation pulse barker waveform is preferred over CW Barker. The waveform is passed through a gating function which results in a pulse Barker waveform as shown in Fig.7. The following Fig.8 show the 6% duty cycle i.e. 2200 ns on time of the pulsed 11-bit Barker code, where PRI is set at 36666.67 ns.

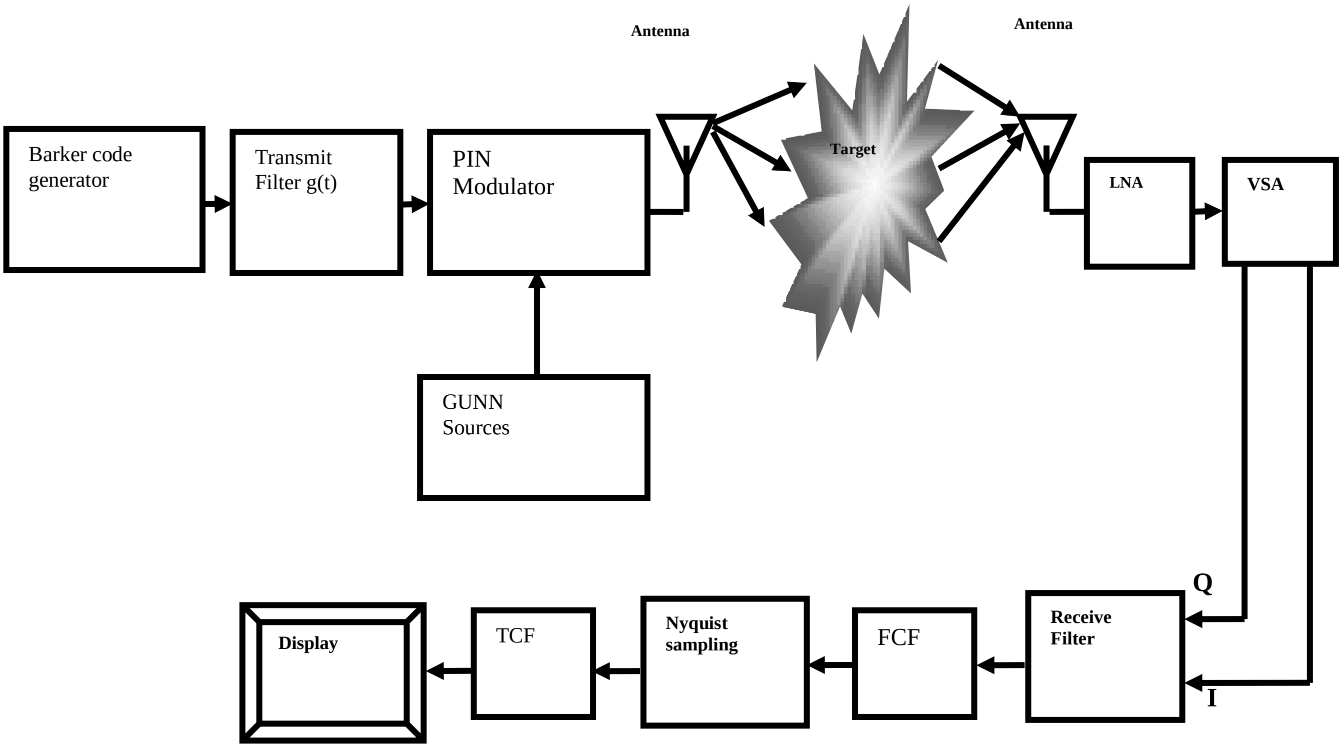

Figure 5: Block diagram of the FHSS mode of WiMAX radar

The other end of the PIN is connected to a VSG model no R&S SMBV100 which is programmed for the Barker code generation. The entire transmitter sub system is mounted at the focus of a Dish antenna achieving a beam width of 2 degrees. The receiver composed of another dish having a LNBC connected at its focus. The LNBC output is connected to one RTSA receiver.

IV. EXPERIMENTAL RESULTS

A. Waveform generation of Barker code and Transmit Filter design

A program is written on PC and ported to AWG for the generation of Barker code. The code is then passed through an in-built raised cosine transmit filter. The total transmitted waveform is shown in the Fig.6.

Figure 7: Generation of pulsed barker waveform in AWG with off time = 34466.67 ns [94% of the PRI]

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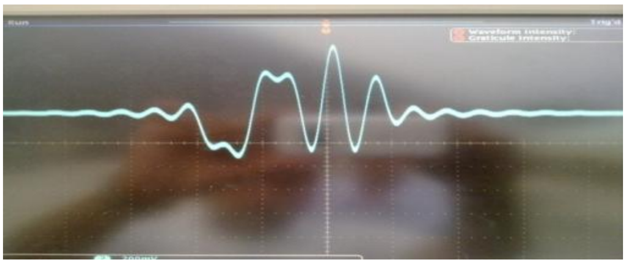

Figure 8: Generated 11-Bit Barker code pattern from the I output of the AWG [The Barker code pattern is: -1-1-1+1+1+1-1+1+1-1+1]

In the above section authors successfully realize the FHSS mode of WiMAX radar operation. Therefore, this development is extended towards transponder mode of operation as diagrammed in Figure 10. The FHSS block is repeated for two vehicles namely object and target vehicle with transmitter and receiver implemented in each vehicle. The baseband transmit portion for barker code generation and the IVL data and the baseband receiver portion for FCF, TCF and others are implemented using SDRs.

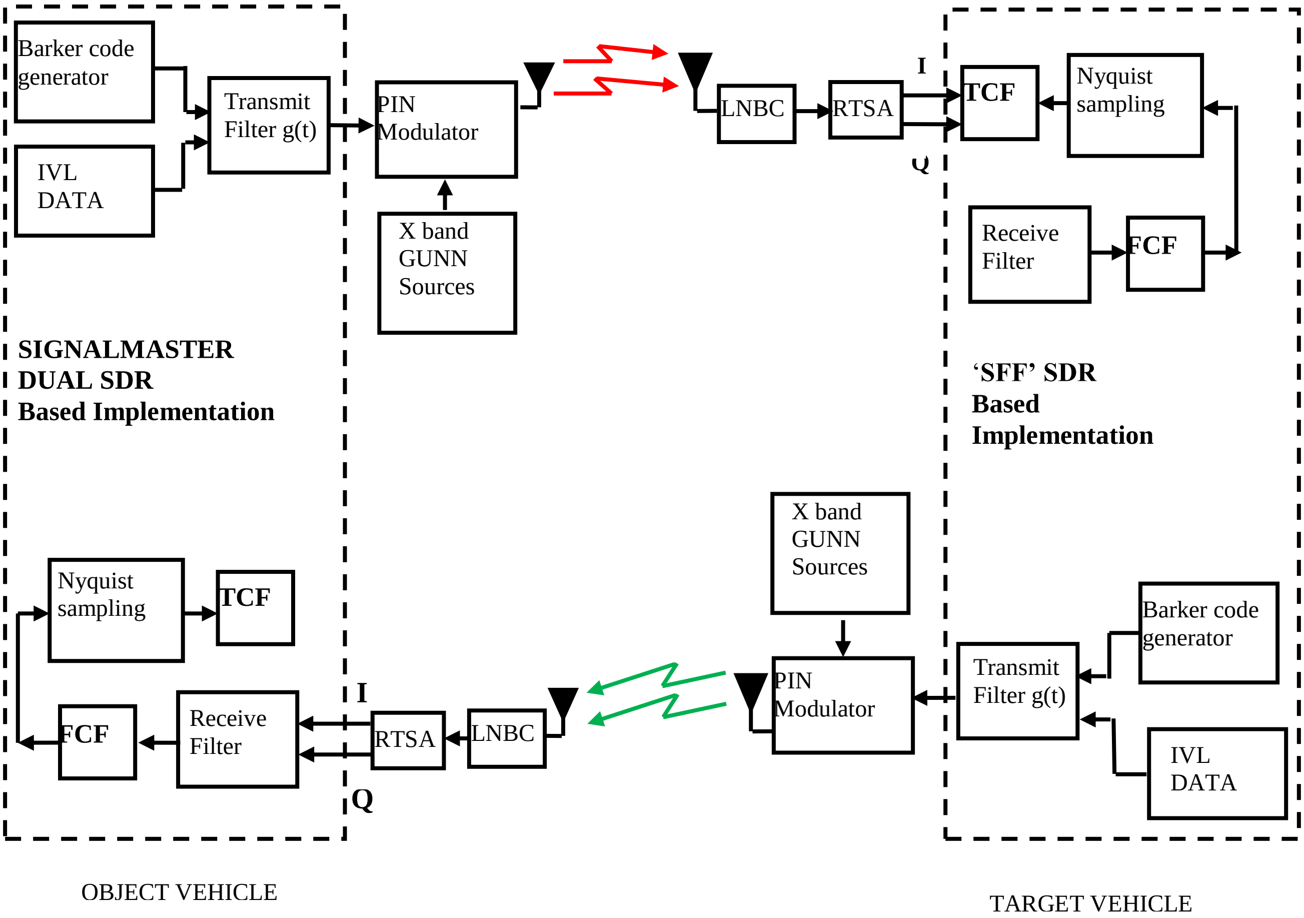

Figure 10: Block diagram of the Transponder mode withWiMAX radar.

B. ***Reception of Pulsed barker waveform at the RTSA (Through Target Return):***

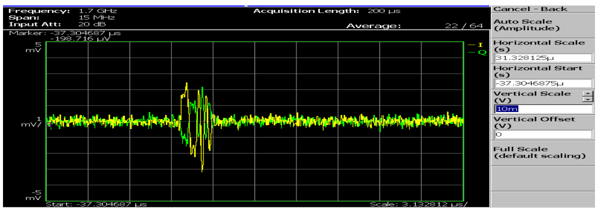

Figure 9: Received Pulsed barker waveform at the RTSA

V. IMPLEMENTATION OF WIMAX RADAR WITH TRANSPONDER MODE.

VI. EXPERIMENTAL RESULTS

The following plots of target return in frequency domain are evolved out of the experiment and shown in Fig.11. The conditions of environment are also indicated in the plots.

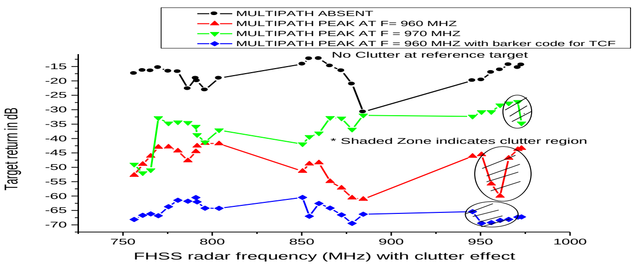

Figure 11: Target return vs. radar frequency

The raw frequency domain data are processed through IFFT operation and processed results are indicated below:

Case- 1: Single circular flat target (metallic) kept at a distance = 7.5 m (Fig. 12)

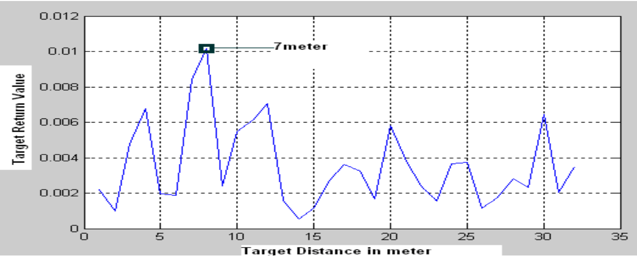

Figure 12: Single target detection with FHSS mode radar operation

Only one circular flat target metallic, radius (r) = 0.381 m;
Transmitter power from the AWG = 8 dBm;
Receiver power at the VSA = -78 dBm;
Start frequency = 1.7 GHz;
Frequency step size = 5 MHz;

VII. CONCLUSION

This paper is intended towards developing collision avoidance architecture for the latest Intelligent Transport System. We have investigated and thoroughly explored automotive WiMAX radar networks for skin mode and transponder mode for vehicle to vehicle cooperative collision warning system. It is then noticed that on road condition skin mode is better than transponder mode if two vehicles embedded with radar. The clutter and multipath are the major issues in actual implementation of the system. The performance of the system will be highly degraded under those channel conditions. Therefore, this paper critically analyzed and evolved clutter and multipath using proper DSP techniques for restoration of performance under worst channel conditions. Finally skin mode and transponder mode systems using WiMAX waveform is being implemented using VSG and RTSA. Hardware was programmed from Work Station using Matlab/Simulink for its vehicular realization. Putting brains i.e. intelligence into the above embedded system, the system should be cognitive dynamic system. Majority of the problems will be solved by this cognitive technique and we look forward for the improved society with intelligent vehicles.

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AUTHORS PROFILE

Prof. Samiran Pramanik, received the B. Tech degrees in Electronics and Communication Engg. from W.B.U.T, West Bengal and M. Tech degrees in Electronic and communication Engg. (Specialization in microwave) Burdwan University, India, in 2007 and 2009 respectively. He is currently working towards the Ph.D. degree in Electronics and Telecommunication Engineering at Jadavpur University, W.B. Since 2010, he has been associated with the College of Engineering and Management, Kolaghat. W.B, India where he is currently an Asst.Professor is with the department of Electronics & Communication Engineering & Electronics & Instrumentation Engineering. His current research Interests are in the area of MIMO, multiuser communications, Wireless 4G communications and Digital Radar, RCS Imaging. He has published large number of papers in different international Conference and journals.

Dr. Nirmalendu Bikas Sinha received the B.Sc (Honours in Physics), B. Tech, M. Tech degrees in Radio-Physics and Electronics from Calcutta University, Calcutta, India, in1996,1999 and 2001, respectively. He has received Ph.D (Engg.) degree in Electronics and Telecommunication Engineering from Bengal Engineering and Science University, Shibpur in 2012. Since 2003, he has been associated with the College of Engineering and Management, Kolaghat. W.B, India where he is currently an Associate Professor is with the department of Electronics & Communication Engineering & Electronics & Instrumentation Engineering. His current research Interests are in the area of signal processing for high-speed digital communications, signal detection, MIMO, multiuser communications,Microwave /Millimeter wave based Broadband Wireless Mobile Communication ,semiconductor Devices, Remote Sensing, Digital Radar, RCS Imaging, and Wireless 4G communication. He has published more than fifty papers in different international Conference, proceedings and journals. He is presently the editor and reviewers in different international journals.

Dr. Chandan Kumar Sarkar (SM'87) received the M.Sc. degree in physics from the Aligarh Muslim University, Aligarh, India, in 1975, the Ph.D. degree from Calcutta University, Kolkata, India, in 1979, and the D.Phil. degree from the University of Oxford, Oxford, U.K., in 1983. He was a Research Fellow of the Royal Commission for the Exhibition of 1851 at the Clarendon Laboratory, University of Oxford, from 1983 to 1985. He was also a Visiting Fellow with the Linkoping University, Linkoping, Sweden. He joined Jadavpur University, Kolkata, in 1987 as a Reader in electronics and telecommunication engineering and became a Professor and the Head of the Department of Physics, BESUS, India, in 1996. Since 1999, he has been a Professor with the Department of Electronics and Telecommunication Engineering, J.U. He has served as a Visiting Professor in many universities and has published around 100 papers in referred journals. Dr. Sarkar is the Chair of the IEEE Electron Devices Society (EDS), Calcutta Chapter. He serves as a Distinguished Lecturer of the IEEE EDS.

Rabindranath Bera is a professor and Dean (R&D), HOD in Sikkim Manipal University and Ex-reader of Calcutta University, India. B.Tech, M.Tech and Ph.D. degrees from Institute of Radio-Physics and Electronics, Calcutta University. His research areas are in the field of Digital Radar, RCS Imaging, Wireless 4G Communications, Radiometric remote sensing. He has published large number of papers in different national and international Conference and journals.