WIRELESS EMBEDDED SYSTEM FOR ITS APPLICATION WITH SDR BASED CENTRAL PROCESSING AND CO-ORDINATION

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ABSTRACT

The objective of this paper is to present a development effort to ITS application carried out by the authors at SMIT towards a latest category of vehicles which embeds three technology systems viz. Radar, Communication and Radiometer for reliable ITS operation. Radar for collision avoidance and cruise control, Communication for driver assistance like positioning, navigation and passenger needs like internet, mobile TV etc. and Radiometer for sensing smoke/gas pollution.

SDR is used as the central control unit of the embedding system, exploiting it as a reconfigurable hardware to operate in three modes – radar, communication & radiometer as when required. The entire base band processing, integration, coordination of the three systems and mode of operation is carried by the SDR, where conventional methods if used would increase system complexity/size, reducing system reliability and flexibility.

Radar and Communication modes have been realized. Development efforts are being carried out for Radiometer operations.

1. INTRODUCTION

Lots of radio system development efforts have been put for the realization of systems like Radars at W-band, X-band, S-band , Wireless Communication Links at W, V, Ku, Ka, C & S , Radiometers at W, V, Ku, Ka, X, C & S Bands by the Author and his team members since 1988. The works are also extended towards radio wave propagation studies and their mitigation. The successful developments fetch a 'Bose Fellowship' for the 1st author in URSI GA at Japan in the year 1993. Those systems are operational at the two rooftop Laboratories of the Institute of Radiophysics & Electronics, Calcutta University as well as '4G&ITS' laboratory of Sikkim Manipal University. The systems are running round the clock to study the propagation impairments and their remedial measures. But the limitations of the systems are that i) they are too costly [total equipments cost for each laboratory = 50K US$ approx.] ii) no central processing and co-ordination. Recently the author came across the statement by Dr. John Chapin, Vanu, "In a world of diverse and rapidly changing radio communications requirements, organization that will adopt SDR will succeed; those that neglect SDR will be left behind". This encourages a lot to the authors and accordingly, they are gradually trying to introduce SDR in their R&D efforts.

The recent review by the authors reveals that 4G & ITS are the two major thrust areas where key challenges for putting R&D efforts are involved [1]. Category 1 of vehicles are commercially available for driver assistance system embedding 5 radars [24 GHz radars three in number and 77 GHz radars two in number] [2][3]. Category 2 of vehicles named as 'Radio Taxi' are also available fitted with GPS and GPRS to assist the driver as well as the passengers in the form of AGPS based positioning and navigation. At SMU, we are now trying for the development of the 3rd category of vehicles embedding 5 radars, GPS/ AGPS based positioning and navigation, GSM/GPRS/WCDMA/4G based communication system, mobile TV. Radiometer is to be used as passive sensing of the environment for pollution sensing of smoke, gases etc and control. Effectively the above laboratory equipments/systems will be fitted in the car to make it an ITS car to serve the user in an intelligent and better way and saving human lives from car accident. The ITS car can also be used as 'mobile laboratory' for field experiments.

Typically four simultaneous channels in the radio system operation is a mandatory requirement for reliable ITS operation. One channel will cater for user communication, 2nd channel for radar based collision avoidance operation, 3rd channel for IVL [inter vehicle link] to be used for communicating position, velocity, distance and other sensor parameters to nearby vehicles and the 4th channel for radiometer based pollution sensing.

The paper is organized in the following way:

section 2 discusses about SDR based radar development, section 3 discusses about development of communication system using SDR, section 4 discusses about the radiometer development using SDR, section 5 about integration of all. Parallel developments are also initiated for the simulation of IVL portion of the system which is elaborated in article 6.

2. DEVELOPMENT OF RADAR

2.1 Distance Measuring Processing

The distance between the vehicles to the target can be calculated from the traveling time of the reflected wave using the following formula:

$$R = C.T_d /2 \qquad (1)$$

where R is the distance, C is the speed of light and T_d is the traveling time to the target and back.. Therefore, in order to calculate the distance, it is necessary to measure T_d. In the radar system, a spread spectrum technique is adopted for radar signal processing. Therefore, the traveling time T_d is evaluated by the correlation between the received PN code and the reference PN code, which is shifted by the transmitted PN code, as shown in Fig.1.

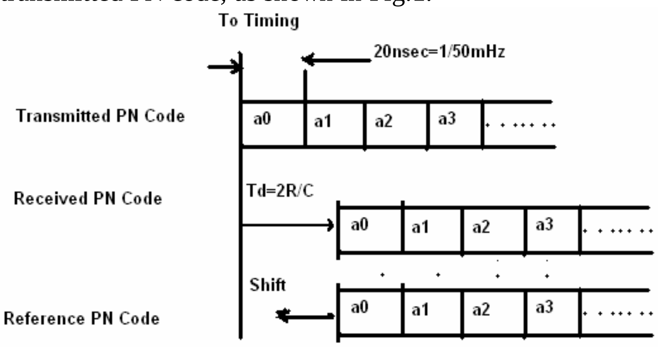


Fig.1: Correlating PN codes

In Fig.1, the sequence a0, a1, a2, a3... is the PN code. The auto-correlation function for the PN code is shown as

$$R_{aa}(\tau) = \frac{1}{T}\int_{-T/2}^{T/2} a(t)a(t-\tau)dt$$

$$= \begin{cases} 1 & for \quad \tau = 0 \\ 1 - ((n+1)/n)|\tau|/\Delta & for \quad -\Delta \le t \le \Delta \\ -1/n & for \quad otherwise \end{cases} \qquad (2)$$

where a(t) is the PN code, n is the length of the PN code. Target detection is made by the correlation characteristic of the PN code, as shown in Fig.2. In Fig.2, n is the length of the PN code, and in the case of this radar system, n is 1023. When the phase difference is zero**,** the correlation is 1 and the desired target is detected and when the phase difference is more than 1 chip, the correlation co-efficient is negative indicating the noise and clutter zone. When the phase difference is between -1 and 1, the correlation has a triangular characteristic. In other words, if a target exists and if the radar receives the reflected wave at the phase of the PN code corresponding to the distance to the target, the correlation will be O dB (normalized), and at other phases the correlation is 40dB (= $-20\log_{10}1023$).

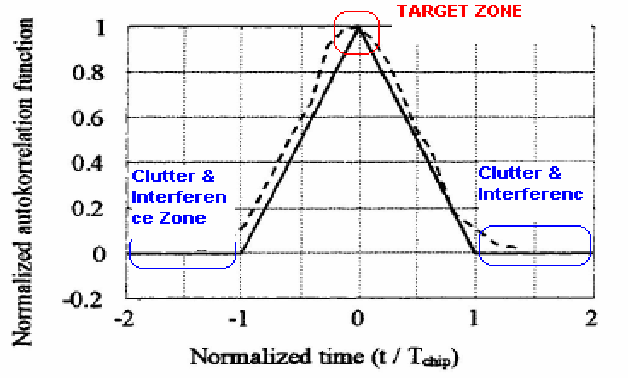


Fig.2: Calculated and measured auto-correlation function

2.2 Matched Filtering

One raised cosine transmit digital filter and one raised cosine receive filter working jointly as 'matched filter' are used for the frequency domain correlation and reduces noise, clutter & interference considerably .The FIR interpolation factor of 4 is used both at the transmitter and receiver with roll off 0.35.The down sampling by 4 will help a lot in specifying the target from other unwanted sources. The responses are shown in Fig. 3a & 3b

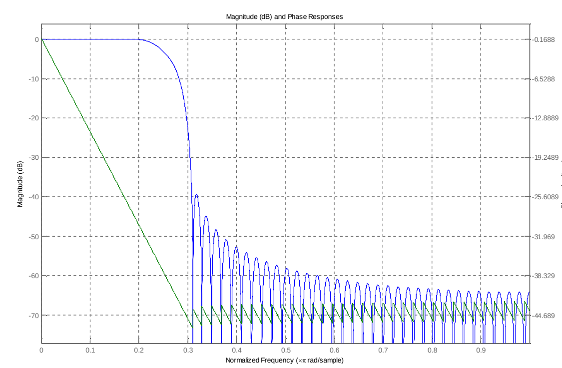


Fig. 3a: The mag. /phase response of the matched filter

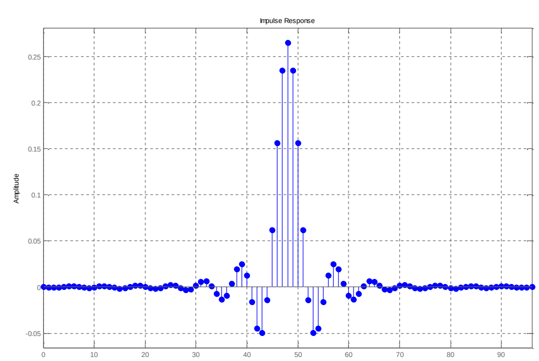


Fig. 3b: The Impulse response

2.3 SDR based approach to radar system

A Test Bed is created at SMIT for the testing of system at the outdoor as shown in the Fig. 4 below:

Fig. 4: Photograph of the System at the test Bed

2.3.1 Instruments Used

1. R&S VSG (MODEL: SMBV100A)
2. SDR: Make Lyrtech Model SFF DP
3. Spectrum Analyzer GSP 110 make: GWINSTAKE
4. Digital Storage Oscilloscope: Systronics 6100M
5. Two dish antennas (3.5m in diameter)
6. Two Helical antennas
7. One Audio Loudspeaker

The R&S VSG SMBV100A is used as transmitter and the Lyrtech make SFF SDR as receiver. SFF SDR composed of 3 tier boards:

Tier 1: Base band board having one TI 6446 SOC where both GPP and DSP are integrated in a single IC, one Xilinx Virtex 4 FPGA. PC having Matlab /Simulink is connected to the Ethernet port of the SOC and thus PC becomes the integral part of the System. The communication between the SOC and the FPGA is established using VPSS bus.

Tier 2: This board is named as ‘The ADACMASTER III’ board where two 500 MSPS DAC, two 125 MSPS ADC and one Virtex4 FPGA are involved. The communication between the Tier 1 and Tier 2 is established using LYRIO fast communication Bus supporting a data rate of 5 GBPS.

Tier 3: This RF board is analog RF board having the SPI based tuning from the base band board.

The VSG has also SDR based architecture having similar hardware configuration as SFF SDR.

2.3.2 Methodology

* One LOS path is created using Omni directional antennas
*Additionally Multi path created with two Dish antennas as in Fig.5.
* Radar operating point A is selected for its operation as in Fig.8.

*Exploitation of directional beam width of two dish antennas of size 3.5 Meter

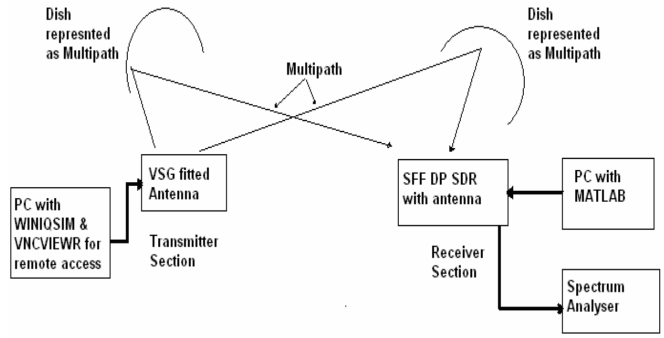


Fig. 5: Multi path created with two dish antennas

2.3.3 Results

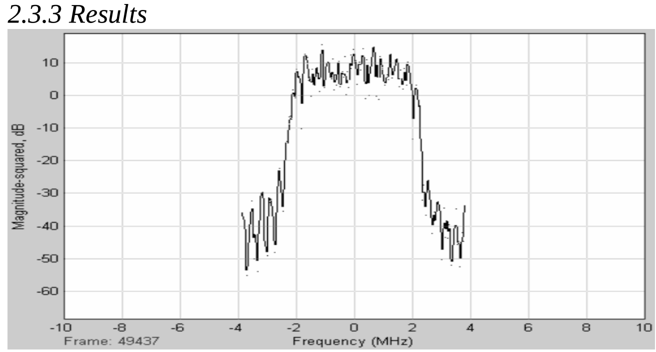


Fig.6: Spread Spectrum Waveform generation at 462 MHz with a bandwidth of 5 MHz.

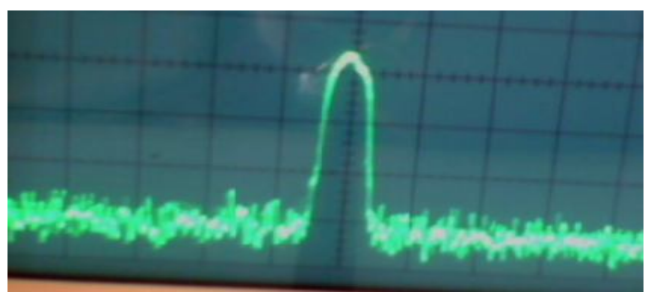


Fig.7: Reception of 30 MHz IF- frequency through SFF DP (SDR) by running simulation program and received through RX path of the RF front end of the SDR.

Fig. 8: Choice of Operating Point A for radar operation

*Setting of radar operating point to sharp point A to create silence in loudspeaker as in Fig.8.
*Operating Point A shifts to B with insertion of Target and Audio Tone will be heard at the loudspeaker.

2.4 Software for SDR based RADAR development using Simulink

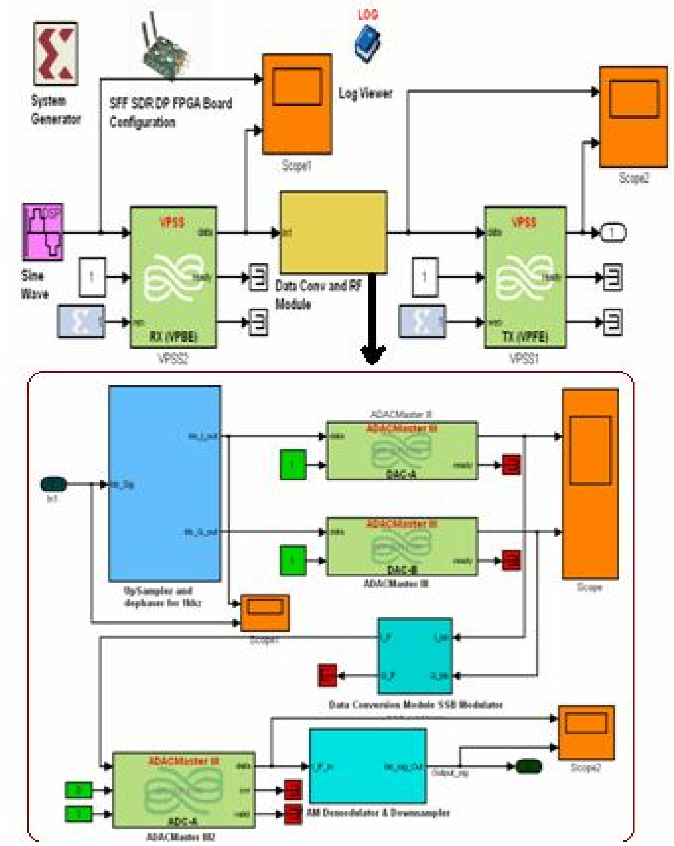


Fig. 9: Simulink Software for the DSP & FPGA processors of the SDR

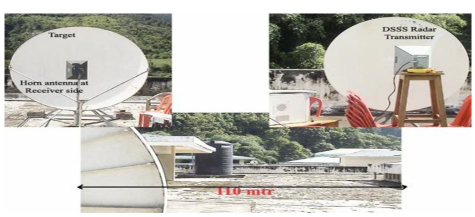


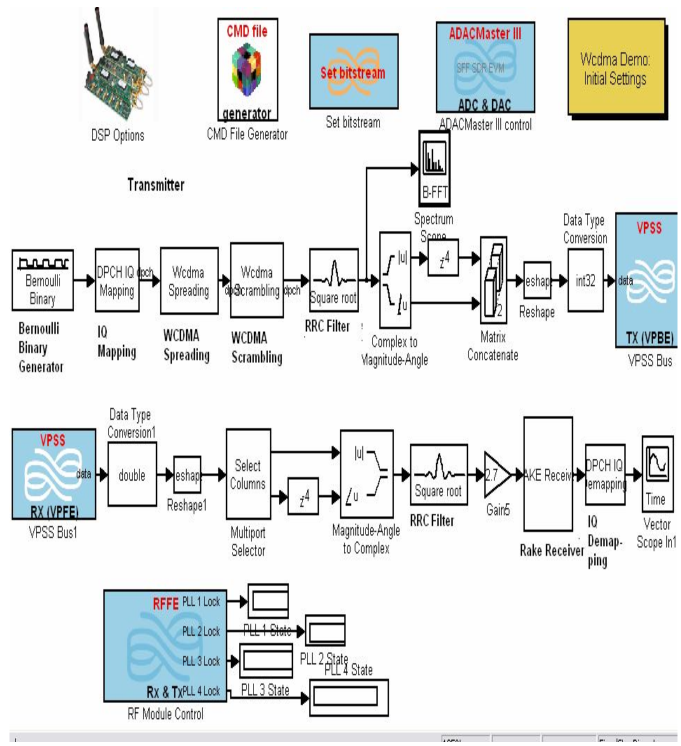
Fig. 10: Photograph of a communication Link

3. DEVELOPMENT OF COMMUNICATION SYSTEM

3.1 SDR based approach to communication system

WCDMA waveform is generated using the same VSG and the same SFF SDR and one LOS link is established over a distant of 110 meter using the same dish antenna with a separation of 110 meter between them as in Fig.10. The same WCDMA technology will be useful for IVL operation whose simulation are carried out and discussed in section 6.

DSP program



FPGA Program for IF Processing & RF Tuning

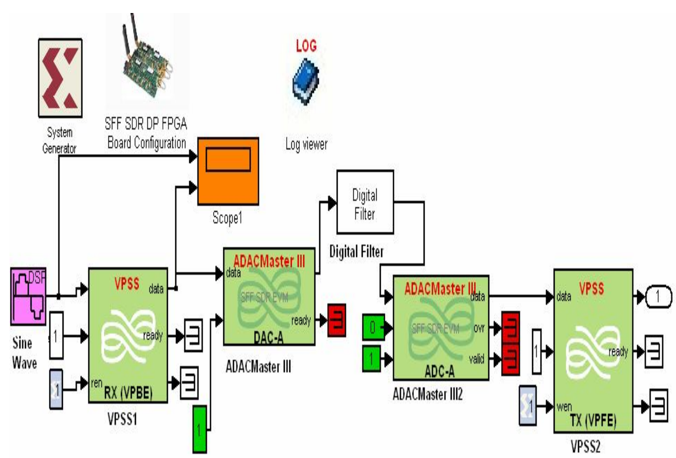


Fig. 11: Simulink Software for the DSP & FPGA processors of the SDR

3.1.1 MATLAB / Simulink based SDR program for WCDMA designed in two steps:

As shown in above Fig. 11, the total program is divided into two parts:

DSP part of the program:
*Bernoulli Binary signal used to form WCDMA waveform and further transmission to FPGA
FPGA part of the Program:
* Signal from DSP is received, up-converted and passed through DAC for transmission.
* The transmitted signal then received through Rx antenna, down-converted and processed through ADC

4. DEVELOPMENT OF RADIOMETERS

The radiometers at W, V, Ku, Ka, X, C & S Bands developed by the Authors and their group members at Calcutta University are Dicke Switched radiometers. Thermal noises in the form of brightness temperature from the distant objects / targets are picked up by the antenna front ends which are too feeble to detect having radiometric resolution of 1 degree K. The Dicke switch is introduced between the antenna and the receiver which is switched at the rate of 1 KHz to enable the receiver to receive the chopped waveform over which the outdoor brightness noise signal is superimposed. It is then passed through the cascaded 3 stages IF amplifiers and detector.

4.1 Matched Filtering

After the detector, a tuned amplifier with center frequency of 1 KHz having bandwidth of 10 Hz is used. This produces, effectively, a sampling, matched filtering, frequency domain correlation and peak detection so that only unwanted noise of the receiver will reduce and brightness temperature of the distant target is detected.

4.2 Synchronous Detector

One synchronous detector is then followed which behaves as Time domain sampling, correlation and peak detection. The signal is then integrated by a time constant of 1 sec and amplified by a DC amplifier and recorded in a PC.

4.3 Overall Performance

The performance of the radiometer is thus enhanced by two correlations [frequency domain correlation followed by time domain correlation]. It is important to note that connection of a spectrum analyzer replacing the 1 KHz tuned amplifier having RBW filter of 100 Hz is not at all effective in measuring the target brightness temperature.

4.4 SDR based approach to radiometric system

With a view to enhance the performance of the radiometers as well as central co-ordination, Lyrtech make SFF SDR is introduced in the radiometer systems by replacing the post processing units e.g. the tuned amplifier and synchronous detector, integrator and DC amplifier. At later stages, it is proposed to replace the RF & IF stages by their digital counterparts.

5. IMPLEMENTATION OF RADAR SYSTEMS, COMMUNICATION AND RADIOMETER FOR OPERATION AT THE VEHICLE

The same instruments as shown in the section 2.3.1 are used for multifunctional operations. The ARB (Arbitrary Waveform Generator) within the VSG and the SFF SDR is programmed for three simultaneous channels transmission and reception operation respectively.

5.1 RESULTS

The simultaneous 3 channel transmitter and 3 channel receivers are operating correctly for the total system. One channel is used for radar operation using spread spectrum waveform (SS_RADAR) as shown in Fig. 12, one communication channels using WCDMA is used for supporting communication to the users (WCDMA_COMM). 2^{nd} communication channel is utilized for IVL (inter vehicle link) to pass range /velocity and other information to the distance vehicles for the collision avoidance (WCDMA_IVL). They all have explored a bandwidth of 5 MHz. The total bandwidth supported by the VSG and SDR is 20 MHz.
In this way total bandwidth of 5+5+5=15 MHz out of 20 MHZ available bandwidth is utilized for three channels of radio operation. The rest of 20 MHz -15 MHz = 5 MHz is being explored for the radiometric operation. As discussed in article 4, radiometer is a receiver used for passive remote sensing application. Introduction of digital technology in its RF,IF & Base band section will improve its performance further. Developments efforts are being carried out in fruitful radiometric operation exploiting the SDR with its full digital operation.

The Simulink based SDR program is also ready for reception. The three major sections of the received SDR programs are:
i) RF down conversion to IF with tuning
ii) IF ADC section for IF gain, demodulation to base band using DDS clock, decimation & filtering etc.
iii) Base band received signal processing used for demodulation of 3 simultaneous channels and WCDMA decoding operations.

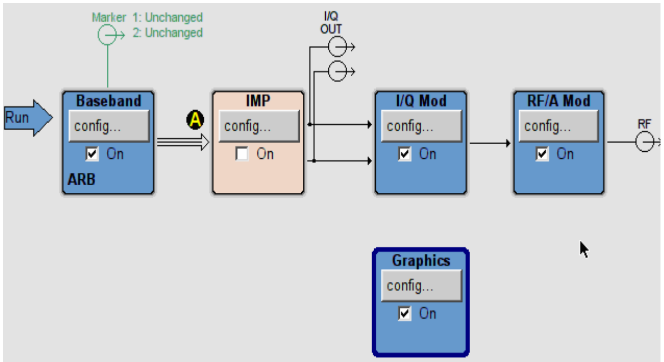


Fig.12a: The API/ Block Diagrams utilized in R&S VSG

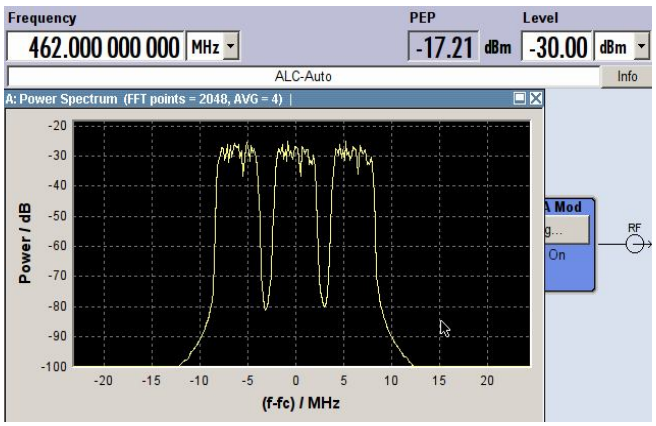


Fig.12b: The Transmitted Power Spectrum of 3 simultaneous Channels with channel names SS_RADAR, WCDMA_COMM and WCDMA_IVL on the Carrier Frequency of 462 MHz.

5.2 CHOICE OF UPGRADED INSTRUMENTS FOR FUTURE WORKS

5.2.1 Upgraded Instruments to be used in the test bed

1. Arbitrary Waveform Generator: Tektronix 7122
2. SDR: Lyrtech SIGNAL MASTER DUAL ADP
3 .Spectrum Analyzer: Tektronix RTSA
4. Digital Storage Oscilloscope: Tektronix
5. Two dish antennas (3.5m in diameter)
6. Horn antennas for broadband & MIMO operation.
7. Loudspeaker

5.2.2 Methodology

This up gradation will lead us for two tier extra achievements as compared to present developments.

1. Full Digital RF up to 5 GHz of RF frequency,

a) AWG, having a sampling rate up to 20 GSPS, will help us in introducing digital RF transmitter instead of analog RF.

b) RTSA and Signal Master SDR in conjunction with AWG will help us in realization of digital RF receiver. Better RF Filtering, RF DSP, better RF Visualization, better RF NCO are the major performance enhancements possibilities.

2. MIMO based digital beam forming will be easy for this up graded configuration.

3. Ridged horn antennas along with signal processing will lead to least interference, least multi path & least possible clutter in system operation.

6. MATLAB BASED SIMULATION OF THE SYSTEMS

The embedded system as discussed is operational in its basic operation. For actual operation at the field , others Sensor Data Fusion and communicating the fused data over a mobile communication link as IVL is also being simulated. The following simulation works are in progress:

i) Design, simulation & Implementation of GPS, AGPS system using SDR

ii) Design, simulation & Implementation of Full Digital Radar system using SDR

iii) Design, simulation & Implementation of vertical handover amongst different wireless system for realization in 4G using SDR

iv) Sensor Data Fusion and communicating the fused data over a mobile communication link as IVL.

The MBD Model Based Design approach using Simulink is being used for our software development. Text based approach using *.m files are also being used and AccelDSP is used for conversion of *.m to *.mdl files. Xilinx System generator & ISE 9.2i are being used at the final porting level. Simulations are almost ready and porting/realizations are in progress.

7. REFERENCES

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