

SIMULATION AND IMPLEMENTATION OF PASSIVE BISTATIC FM RADAR USING SDR

S. Mohandass, V. Krishnaveni and S.V. Veera Kanmani

Department of Electronics and Communication, PSG College of Technology, India

Abstract

This paper illustrates a prototype of Passive Bistatic Radar (PBR) system that uses FM radio transmitter as the Source of Illuminator. Software Defined Radio (SDR) approach is used to simulate and implement the Radar. SDR Board is used to receive the direct signal and the reflected signal from the target by means of Yagi-Uda Antenna. Signal processing operations are performed offline over the direct and reflected signal in order to detect the presence of the target and estimate the target range and speed. In order to analyse the performance of the proposed SDR based passive bistatic radar, MATLAB simulation is used with predefined target settings

Keywords:

Passive Bistatic Radar, Source of Illuminator, Software Defined Radio

1. INTRODUCTION

Passive radar is a type of bistatic radar that uses a commercial transmitter and a dedicated receiver in order to form a bistatic pair. Passive Radars use the illuminators of opportunity like Commercial TV, FM, and GSM transmissions for the detection and estimation of targets [1]. This type of radar has no dedicated transmitter and hence does not require frequency allocation. The passive radar exploits common RF energy transmitted from commercial transmitter and the RF energy reflected by the target in order to extract the range and Doppler information about the target.

In the proposed work passive bistatic radar is implemented using FM signals [2]. FM signals are preferred as they constitute adequate power needed for detecting the targets from the reflected signals and also there are plenty of FM stations available for experimentation. Software defined radio-based approach is used to implement the proposed passive radar [13]. Software radios represent a major change in the design paradigm for traditional radios in which large portion of functionality is implemented through programmable digital signal processing devices, giving the radio the ability to change its operating parameters to accommodate new features and capabilities [14]. A software radio approach reduces the content of radio frequency (RF) and other analog components of traditional radios and emphasizes digital signal processing to enhance the overall receiver flexibility [15].

Universal Software Radio Peripheral (USRP) is a low-cost hardware platform used to develop software-defined radios [3]. USRP architecture consists of a motherboard which includes subsystems like clock generation and synchronization, FPGA, ADCs DACs, host processor interface and power regulation [16]. FPGA is used to baseband signal processing after converting the signal from Analog to Digital format. Before ADC, analog operations like up/down-conversion, filtering, and other signal conditioning operations are performed using RF front-end, called a daughterboard [17]. Daughterboards are available in various

frequency ranges which permit the USRP [4] to support applications operating between DC and 6 GHz [18]-[20].

In the proposed work, two USRP boards (B200 Series) are used to receive the FM signal reflected from aircraft and to receive a copy of transmitted FM signal simultaneously. Yagi-Uda antenna is used to receive signals owing to its high gain and directivity, in order to receive a strong directional component of reference signal.

2. SYSTEM SETUP

The setup consists of two USRP boards (B200 Series) and two Yagi-Uda antennas. The USRP B200 platform supports frequency coverage from 70 MHz – 6 GHz. It has fully integrated single board architecture. The advantages of B200 include low cost SDR development with 56 MHz of real-time bandwidth, an open and reprogrammable Spartan6 FPGA, and fast and convenient bus-powered Super Speed USB 3.0 connectivity. The Fig.1 represents the USRP B200 series used to receive the FM signal. The Table.1 lists the features of B200 series.

Table.1. Features of USRP B200

Sl. No.	Features
1.	RF coverage from 70 MHz–6 GHz
2.	GNU Radio, C++ and Python APIs
3.	USB 3.0 SuperSpeed interface
4.	Standard-B USB 3.0 connector
5.	Flexible rate 12-bit ADC/DAC
6.	Grounded mounting holes
7.	1 TX & 1 RX, Half or Full Duplex
8.	Xilinx Spartan 6 XC6SLX75 FPGA
9.	Up to 56 MHz of instantaneous bandwidth
10.	USB Bus powered



Fig.1. USRP B200 Series

The block diagram of passive bistatic FM radar system is shown in Fig.2. One of the antennas connected to the USRP board

(USRP 1) is used to receive the direct signal from the FM station and the other Yagi antenna connected to another USRP board (USRP 2) is used to receive the reflected signal from the target (airplane). The reference Yagi antenna used to receive the direct signal is oriented in such a way that its main beam focuses towards the FM station and the antenna used to receive the reflected component is oriented such that its major lobe focuses towards the target and the minor lobe is directed towards the FM station [5].

There exist two channels as shown in Fig.2, one with respect to reflected signal referred to as echo channel and the other channel with respect to direct signal known as Reference/Direct channel [6]. FM station is selected in such a way that the received power from the transmitter is not so strong as to saturate the Echo Channel. The position of the USRP receivers is selected in such a way that the airport is nearby and the signal received by the Echo Channel from the reflections from the airplane is strong enough for easy detection.

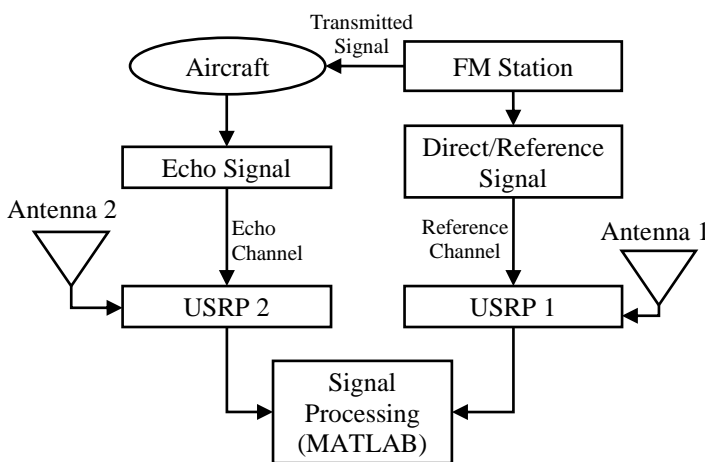


Fig.2. Block Diagram of Passive Bistatic Radar

The reflected signal from echo channel and the direct signal from the reference channel are subjected to signal processing operations which are performed offline in MATLAB Software. The signal operations can also be performed using GNU Radio [7]. In the proposed work, USRP boards are configured using MATLAB software. The Table.2 shows the FM receiver parameters which gives the information regarding USRP radio clock rate, audio sampling frequency, radio gain, frame size and stop time indicating the duration upto which the song would be played. These parameters are obtained through simulation in Matlab. FM signal reception in Matlab requires installation of USRP support package.

Table.2. FM Receiver Parameters

Parameters	Values
Radio Master Clock Rate	20000000
Radio Gain	40
Radio Sample Rate	200000
Radio Decimation Factor	100
Audio Sample Rate	48000
Frequency Deviation	75000
Filter Time Constant	7.500e-05

Radio Frame Length	4000
Buffer Size	4000
Audio Frame Time	0.02
Stop Time(seconds)	60

The radio parameters of the FM receiver which includes information regarding the number of samples per frame, channel mapping (dual or single), whether the source of generation of clock signal is internal or off board and master clock rate are illustrated in Table.3.

Table.3. Radio Parameters

Parameters	Values
Platform	B200
Serial Number	F4E5A8
Channel Mapping	1
Centre Frequency	93500000
Local Oscillator Offset	0
Gain	40
PPS Source	Internal
Clock Source	Internal
Master Clock Rate	20000000
Decimation Factor	100
Transport Data Type	Int16
Output Data Type	Single
Samples Per Frame	4000
Enable Burst Mode	False

The hardware information about the USRP board being used to receive the FM signal, parameters like centre frequency to which the board is tuned, gain and version of the board, sampling rate, minimum and maximum centre frequency are listed in Table.4.

Table.4. Hardware Information

Parameters	Values
Mother board	B200
RXSubdev	FE-RX2
TXSubdev	FE-TX2
Minimum Centre Frequency	40000000
Maximum Centre Frequency	6.01e+09
Minimum Gain	0
Maximum Gain	76
Gain Step	1
Centre Frequency	9.35e+07
Local Oscillator Offset	-0.0605
Gain	40
Master Clock Rate	20000000
Decimation Factor	100
Baseband Sample Rate	200000

3. SIGNAL PROCESSING

The reflected signal from the target and the reference signal are processed in MATLAB. The processing is however carried out offline. The FM reception by means of USRP board is also performed in MATLAB. The transmitted signal from the FM station hits the target and is reflected back towards the receiver which is received by the receiving antenna connected to USRP board (USRP 2). The FM signal with carrier frequency 93.5 MHz was used as reference signal. Hence, Hello FM, Trichy Road Coimbatore, was chosen as the transmitter in the proposed work.

One of the design challenges involved is the cancellation of direct signal in the echo channel, as there is a possibility that the transmitted signal would be directly received by the receiving antenna along the echo channel. Sequential cancellation algorithm [8] is used to eliminate the direct signal in the echo channel. This algorithm finds the correlation between the signal from the reference channel and the direct signal component present in the Echo channel.

Various amounts of delays and doppler shifts are introduced to the direct signal from the reference channel and it then correlates the signal with the reflected signal to find the strength of these signal components and hence subtracted from the echo channel signal.

Also, it is necessary to identify the static objects in the terrain and separate it from the moving target. This could be achieved by observing the Doppler shift associated with the varying objects in the environment. For the static object, Doppler frequency would be zero, hence clearly the objects with zero Doppler shift could be considered as static and could be removed from moving ones. The signal received from the echo channel and reference channel are subjected to matched filtering operation whose coefficients could be used to estimate the target range and velocity based on the initial position of the target.

4. MATLAB SIMULATION

In order to analyse the performance of the proposed passive bistatic radar, MATLAB simulation is used with predefined target settings. In the simulation work it is assumed that the direct component is completely eliminated from the reflected signal at the receiving end. For the purpose of simulation, the initial position of the transmitter, receiver and targets are assumed in order to compute the target range with respect to transmitter and receiver and target speed. Also, it is assumed that the targets are moving with constant velocity.

In the proposed simulation work, three targets are taken into consideration whose range and speed has to be estimated. Among the three, first two targets are assumed to be moving ones and the third one is assumed to be the static target. To realise the entire operation of PBR as described above the FM signal required to detect the targets is generated and an array of dipole antenna is used at the transmitting and receiving end. The environment required for the propagation of the FM signal is assumed to be free space. Also, in the simulation work it is assumed that the echo channel is free from the effects of multipath and interference. The simulation flow of passive bistatic radar beginning from the generation of FM signals till the computation of target range and speed is depicted in Fig.3.

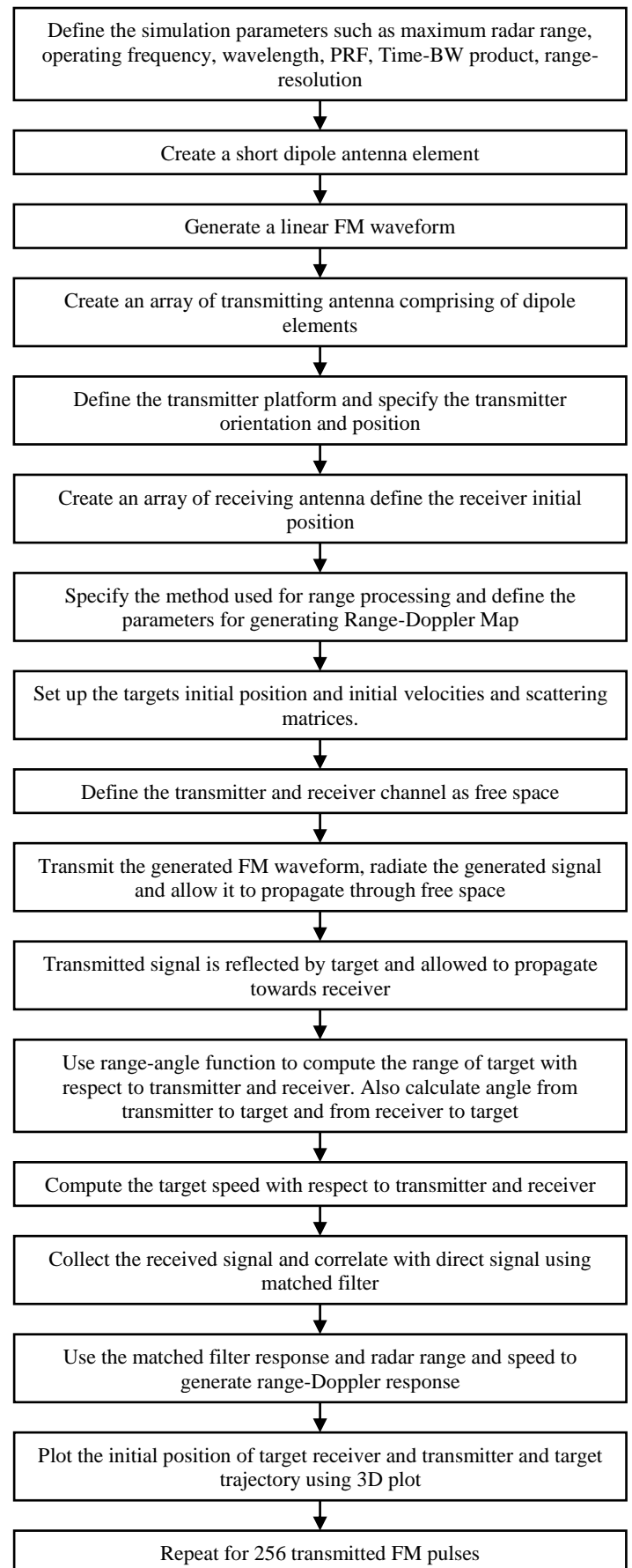


Fig.3. Simulation Flow for passive Bistatic Radar

5. SIMULATION RESULTS AND DISCUSSION

5.1 SYSTEM DYNAMICS

The Fig.4 shows the initial position of the transmitter, receiver and the three targets in three-dimensional space. The transmitter is considered to be the FM Station, ALL INDIA RADIO which is located at the origin of the three-dimensional space. The position of the receiver is fixed in accordance to the transmitter which acts as a reference.

The receiver in the proposed work is the USRP board and is located at PSG College of Technology, Coimbatore. The target is aircraft, hence the location of airport from the receiver is considered to be the target position and is shown in the three-dimensional view.

The spatial coordinates corresponding to the position of receiver and targets are obtained using the latitude and longitude information with respect to the location of receiver and target by assuming the transmitter as the reference.

The initial position of transmitter, receiver and the targets are mentioned below.

- Transmitter: (0,0,0).
- Receiver: (20000,1000,100).
- Target 1: (15000,1000,500).
- Target 2: (35000, -1000,1000).
- Target 3: (25000,2000,1000).

Targets are assumed to be moving with constant velocity as mentioned below.

- Target 1: (200,50,0).
- Target 2: (-160,0, -50).
- Target 3: (0,0,0).

This indicates the presence of static target (Target 3) which is taken into account to illustrate how to segregate static target from moving ones. Also, the trajectory of motion of target starting from their initial point to the point that they have travelled (till the listening time) is shown in Fig.4.

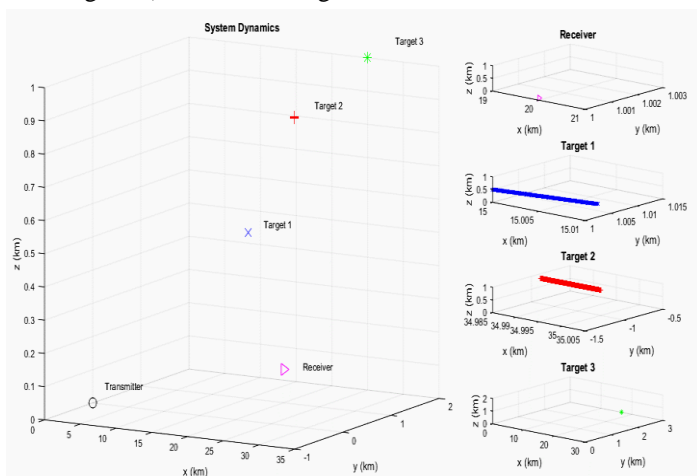


Fig.4: System Dynamics

5.2 RANGE - DOPPLER MAP

The Range-Doppler map is a plot created using matrix viewer in Matlab. This represents a plot of range of the radar (km) versus the speed (km/hr). This plot would enable to identify the moving targets and static ones. As it is well known that for static targets such as buildings, mountains and other objects surrounding the terrain the Doppler frequency is zero, hence their speed would be zero which could be observed from Fig.5. However, for moving target Doppler would be changing with respect to target motion, hence they have a finite velocity [9]. This is how the moving targets are separated from the static targets.

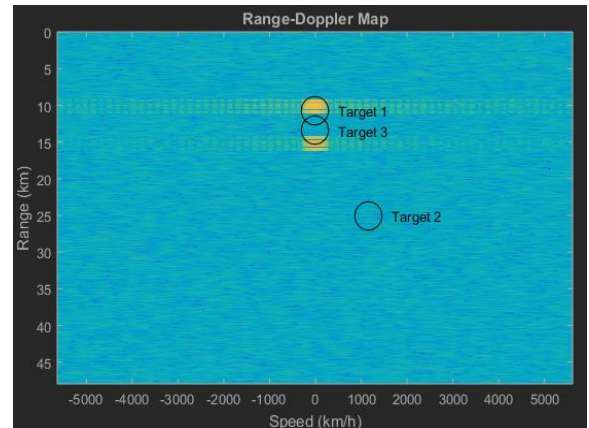


Fig.5. Range-Doppler Map

It could be observed from Fig.5 that target 3 has a speed of 0 km/hr which clearly indicates that it is a static one. The speed corresponding to target 1 and 2 are 3.5km/hr and 322km/hr respectively.

The range associated with the three targets are specified below.

- Target 1: 8.67 km.
- Target 2: 23.02 km.
- Target 3: 11.4 km.

Thus, in the simulation, the static target is removed and the moving targets are considered for further analysis according to the application.

6. CONCLUSION

In the proposed work passive bistatic radar is simulated using Matlab by generating FM signal in order to detect the presence of targets (aircrafts) and estimate their speed and range. Also, the static targets are identified and separated from moving ones using range-doppler map. The measurements made for target range and Doppler do not represent the actual location of the target rather they are known as bistatic range and the bistatic Doppler. Identification and elimination of clutters and multipath components is a great challenge in real time which needs to be tackled in the future work [10] [11].

The implementation of passive bistatic radar using multiple transmit receive pairs (diversity techniques) in order to estimate the exact location of the target would be the part of future work. The measurements from the individual pairs need to be finally

fused in order to get the final picture with the actual locations of the target [12].

ACKNOWLEDGEMENT

The authors would be thankful and grateful to Mr. L. S. Bharadwaj, Scientist C, Centre for Adaptive Sensing Technology, DRDO, Bangalore, for his support and valuable guidance.

REFERENCES

- [1] L.S. Bharadwaj, G. Manu and O.C. Vishnu, "Passive FM Radar", *Proceedings of International Radar Symposium India*, pp. 1-13, 2013.
- [2] F. Colone, A. Lauri and R. Cardinali, "Analysis and Emulation of FM Radio Signals for Passive Radar", *Proceedings of IEEE International Conference on Aerospace*, pp. 1-6, 2006.
- [3] K. Devidas, J. Murtaza and M. Sushama, "Implementation of FM Transceiver using Software Defined Radio", *International Journal of Engineering Development and Research*, Vol. 5, No. 2, pp. 225-233, 2017.
- [4] T. Thamaraimanalan and P. Sampath, "A Low Power Fuzzy Logic based Variable Resolution ADC for Wireless ECG Monitoring Systems", *Cognitive Systems Research*, Vol. 57, pp. 236-245, 2019.
- [5] C. Venkatesan, P. Karthigaikumar and R. Varatharajan, "FPGA Implementation of Modified Error Normalized LMS Adaptive Filter for ECG Noise Removal", *Cluster Computing*, Vol. 22, No. 5, pp. 12233-12241, 2019.
- [6] Matt Ettus, "USRP User's and Developer's Guide", Available at https://www.olifantasia.eu/gnuradio/usrp/files/usrp_guide.pdf, Accessed at 2021.
- [7] P.E. Howland, D. Maksimiuk and G. Reitsma, "FM Radio based Bistatic Radar", *Proceedings of IEEE International Conference on Radar Sonar and Navigation*, pp. 107-115, 2005.
- [8] H.D. Giffiths, C.J. Baker and M. Baubert, "Bistatic Radar using Spaceborne Illuminator of Opportunity", *Proceedings of IEEE International Conference on Radar*, pp. 15-17, 2002.
- [9] GNU Radio, Available at <https://wiki.gnuradio.org/index.php/Tutorials>, Accessed at 2021.
- [10] F. Colone, R. Cardinali and P. Lombardo, "Cancellation of Clutter and Multipath in Passive Radar using a Sequential Approach", *Proceedings of IEEE International Conference on Radar*, pp. 393-399, 2006.
- [11] H.D. Griffiths and C.J. Baker, "An Introduction to Passive Radar", Artech House, 2018.
- [12] G. Chen, J. Wang, L. Zuo and Y. Wen, "Two-Stage Clutter and Interference Cancellation Method in Passive Bistatic Radar", *IET Signal Processing*, Vol. 14, pp. 342-351, 2020.
- [13] Z. Dawei, W. Jun, C. Gang and W. Jipeng, "Clutter Cancellation Based on Frequency Domain Analysis in Passive Bistatic Radar", *IEEE Access*, Vol. 8, pp. 43956-43964, 2020.
- [14] C. Bongioanni, F. Colone and P. Lombardo, "Performance Analysis of a Multi-Frequency FM based Passive Bistatic Radar", *Proceedings of the IEEE International Conference on Radar*, pp. 26-30, 2008.
- [15] T. Thamaraimanalan and P. Sampath, "Leakage Power Reduction in Deep Submicron VLSI Circuits using Delay-Based Power Gating", *National Academy Science Letters*, Vol. 43, No. 3, pp. 229-232, 2019.
- [16] S. Velliangiri, P. Karthikeyan and V. Vinoth Kumar, "Detection of Distributed Denial of Service Attack in Cloud Computing using the Optimization-based Deep Networks", *Journal of Experimental and Theoretical Artificial Intelligence*, Vol. 23, pp. 1-20, 2020.
- [17] C. Venkatesan and P. Karthigaikumar, "An Efficient Noise Removal Technique using Modified Error Normalized LMS Algorithm", *National Academy Science Letters*, Vol. 41, No. 3, pp. 155-159, 2018.
- [18] A.R. Suhas and M.M. Priyatham "Heal Nodes Specification Improvement using Modified Chef Method for Group Based Detection Point Network", *International Journal of Pervasive Computing and Communications*, Vol. 33, No. 2, pp. 1-12, 2021.
- [19] L. Niranjana and M.M. Priyatham "Lifetime Ratio Improvement Technique using Special Fixed Sensing Points in Wireless Sensor Network", *International Journal of Pervasive Computing and Communications*, Vol. 33, No. 2, pp. 33-39, 2021.
- [20] V.V. Kumar S. Ramamoorthy, V.D. Kumar and J. Balajee "Design and Evaluation of Wi-Fi Offloading Mechanism in Heterogeneous Networks", *International Journal of e-Collaboration*, Vol. 17, No. 1, pp. 60-70, 2021.