

Filtering of Volume Clutter in Pulse Surveillance Radar using Discrete Wavelet Transform

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Abstract: Moving weather systems will have a nonzero Doppler response at rate at which the rain droplets are approaching the radar system. The complete data the radar collects contain the returns of both the target and the clutter. The signal processing block in a radar system uses filtering operations to extract the target information while suppressing the clutter. Typically the filters are designed based on Doppler Frequency using a Fourier filter bank. Instead of the frequency domain, the wavelet analysis allows the time-scale domain in processing. The filter bank in this project utilizes Discrete Wavelet Transform (DWT), DWT coefficients represent the results of a multi-resolution analysis of the radar signal. The experiments indicate that the Fourier filter bank filter the volume clutter very well. However, a DWT filter bank has different time resolution for different frequency ranges. The experiments were performed in MATLAB environment as well as python and data is real radar rain clutter data from PSR, TERLS(low PRF). The objective of this paper is to develop a DWT based filtering system and to test it's operation in one situation of volume clutter and then plotting PPI.

Index Terms—DWT, PSR, RADAR, PPI, RCS, CFAR

I. INTRODUCTION

The word radar is an abbreviation for RAdio Detection And Ranging. In general, radar systems use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space

Manuscript received May 12, 2016; revised January 20, 2015; accepted June 13, 2016. Date of publication July 4, 2016; Date of current version June 11, 2016. Nimisha O A guided by Mr. Sreejith S Nair, Assistant Professor of the Electronics and Communication Engineering department Jawaharlal College of Engineering and Technology, Lakkidi, Kerala, India (e-mail: nimishaanu4@gmail.com). to search for targets. Objects (targets) within a search volume will reflect portions of this energy (radar returns or echoes) back to the radar. These echoes are then processed by the radar receiver to extract target information such as range, velocity, angular position, and other target identifying characteristics. Thumba Equatorial Rocket Launching Station (TERLS) of Mechanisms and Vehicle Integration Testing (MVIT), Vikram Sarabhai Space Centre (VSSC), Indian Space Research Organization (ISRO) is an international sounding rocket launching station for meteorological purpose. To

launch sounding rockets, the impact zone of the same needs to be cleared. To meet this requirement, a Primary Surveillance Radar with detection capability of medium sized ships upto a distance of 100km was established. The main aim of the project is filtering of various clutters using wavelet thresholding. Radars can be classified as ground based, airborne, space borne, or ship based radar systems. They can also be classified into numerous categories based on the specific radar characteristics, such as the frequency band, antenna type, and waveforms utilized. Another classification is concerned with the mission and /or the functionality of the radar. This includes: weather, acquisition and search, tracking, track-while-scan, fire control, early warning, over the horizon, terrain following, and terrain avoidance radars. Phased array radars utilize phased array antennas, and are often called multifunction (multimode) radars.

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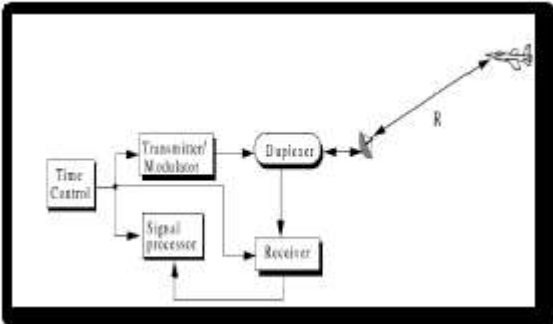


Figure 1 A simplified pulsed radar block diagram

The Doppler phenomenon describes the shift in the center frequency of an incident waveform due to the target motion with respect to the source of radiation. Depending on the direction of the target's motion this frequency shift may be positive or negative. Clutter is a term used to describe any object that may generate unwanted radar returns that may interfere with normal radar operations. Parasitic returns that enter the radar through the antenna's main lobe are called main lobe clutter; otherwise they are called side lobe clutter. Clutter can be classified in two main categories: surface clutter and airborne or volume clutter. Surface clutter includes trees, vegetation, ground terrain, man-made structures, and sea surface (sea clutter). Volume clutter normally has large extent (size) and includes chaff, rain, birds, and insects. Chaff consists of a large number of small dipole reflectors that have large RCS values. It is released by hostile aircraft or missiles as a means of ECM in an attempt to confuse the defense. Surface clutter changes from one area to another, while volume clutter may be more predictable. Volume clutter has large extents and includes rain (weather), chaff, birds, and insects. The volume clutter coefficient is normally expressed in squared meters (RCS per resolution volume). Birds, insects, and other flying particles are often referred to as angel clutter or biological clutter.

II. EXISTING SYSTEM

Thumba Equatorial Rocket Launching Station (TERLS) of Mechanisms and Vehicle Integration Testing (MVIT), Vikram Sarabhai Space Centre (VSSC), ISRO is an international sounding rocket launching station for meteorological purpose. In order to launch sounding rockets, the impact zone of the same needs to be cleared. To

meet this requirement, primary surveillance radar with detection capability of medium sized ships upto a distance of 100km is required. A coastal surveillance radar requires a 'standard' or an 'advanced' solid state radar as IALA V-128 and an X-band radar to detect small RCS and wooden boats at an extended range, at the same time meeting target separation and accuracy parameters. Coastal surveillance radar is required to ensure that the target types are detected and tracked in the designated area covered by the vessel traffic service, taking into account the visibility, precipitation rates, sea states and propagation conditions relevant for the individual radar site. The Primary Surveillance Radar has the following major subsystems, namely,

1. Antenna
2. Transmitter
3. Exciter
4. Receiver
5. Digital receiver and signal processing
6. Control console and Data processing

A. FUNCTIONAL DESCRIPTION

The Antenna transmits and receives the RF signals to and from the target. The antenna receives the High power RF signals from transmitter sub-system which in turn gets its input from the RF sub-system of the Primary surveillance RADAR. The received signal from the antenna is provided to the LNA module which in turn provides the amplified received signal to the receiver chain where the down conversion is done to convert the X band Signal to IF frequency. The down converted frequency is provided to the Data processing sub-system where the signal is digitized and processed to get the required output at the display. The RADAR also has a touch screen display and hard switches based interface for easy user control of the RADAR parameters. The entire power supply for the Radar system is derived from the 3 ϕ supply. The functional requirements of primary surveillance RADAR can be met with the following sub systems.

1. Antenna and pedestal sub system.
2. Transmitter sub system
3. RF sub-system.
4. Digital sub-system.
5. Control and console display
6. PSU sub-system.

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The Antenna and Pedestal Sub-system contains the Cossec2 pattern antenna, Motor and Antenna motor control system required for controlling the azimuth of the antenna and also has 17 bit encoder which helps in plotting of the Proper PPI Data. Features include :

- ❖ The Primary Surveillance radar uses Cossec² antenna.
- ❖ It consists of Parabolic reflector with the size of 3.5 X 2.965 Meter
- ❖ Feed Horn: Corrugated Horn
- ❖ WR112 waveguide for RF Plumbing
- ❖ Angular movement: The antenna should be capable of rotating 360 degree in azimuth with the angular rate of 1 to 10 RPM selectable from the console. Also there should be provision to fix the elevation between -2 degree to +10 degree from the user console.
- ❖ Worm Gear for Azimuth rotation
- ❖ Vertical or horizontal polarization as per operator's selection.
- ❖ Provision for mechanical stop.
- ❖ Provision for easy dismantling and re-erection.
- ❖ Blanking of RF at user defined azimuth sector.
- ❖ Facility to mount video camera and provision to display the same in operator's console.
- ❖ Should be mounted on top of a 18 m building near sea shore with flat roof top.

Antennae with cosecant squared pattern are special designed for air-surveillance radar sets. These permit an adapted distribution of the radiation in the beam and causing a more ideal space scanning. The cosecant squared pattern is a means of achieving a more uniform signal strength at the input of the receiver as a target moves with a constant height within the beam.

The transmitter sub system is responsible for the generation of high power X band (9.3 to 9.5GHz) RF signal with required power level and pulse width. The output of the transmitter sub-system is provided to the circulator from which the power is radiated by the antenna. RF sub system consists of exciter which is responsible for the generation of the C band and L band local oscillator signals. These signals are used for the up conversion in case of the transmitting mode and in down conversion of the received pulse to a IF frequency of 70MHz in case of receive mode. The exciter also generate the 60MHz ADC sampling clock signal for the digitization of the received signal from receiver module.

The receiver uses the C band LO signal (7670MHz to 7870MHz) for the down-conversion of the X band received signal to L band (1630MHz) then uses an L band LO signal (1560MHz) for the further down conversion to IF frequency for the signal processing by the digital receiver.

The functional requirements of the X Band RF subsystems can be achieved by developing the following modules:

1. Receiver The features of the receiver are
 - Built-in-test (RF Simulation)
 - Range Simulation with configurable S/N
2. Receiver Sub-System. The Receiver channel consists of a low Noise Amplifier with Noise Figure of 1 dB. It also consists of RF Simulator to simulate a target with dynamics in range to facilitate the evaluation of the subsystems and provide operator's training. The digital sub-system is responsible for the application of FFT, Doppler processing and other coherent averaging techniques for the removal of clutter and improving the SNR of the received signal for achieving proper probability of detection. It consists of the following sub-modules.
 - DP-SPL-0163 (Power Quicc Based Processor Module)
 - DP-FMC-2009 (Dual Channel 14 Bit FMC DAC Module)
 - DP-FMC-5004 (125 MHz Dual Channel 16 Bit FMC ADC)

The Digital Receiver is responsible for the Digitization of the Received data and processing the data till Coherent Integration, further processing is done by the Radar Controller. The sub system has the following functional blocks. Digital Receiver Module.

- Digital Down Converter.
- FMC ADC Module.
- FMC DAC Module.

The exciter consists of LO Generation Module which can be further classified into LO2 Module and LO1 Module. The LO2 section generate 1560 MHz signal.It receives the input frequency 60 MHz signal from the OCXO which is applied to limiter after multiplication to 120MHz for odd harmonics generation.

The RADAR control console sub system consist of a high resolution monitor driven by a graphics processor with Map overlay. Provision for

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limited zooming and sectoring (when sector scan is used) are provided. Provision for combined PPI/A scope display with weight age for PPI shall be provided. The RADAR Computer that controls all the RADAR subsystems is interfaced to Radar Controller through UDP protocol. The health of the subsystems is also monitored and display on the RADAR controller (RC). The RC acts as the main Human Machine Interface (HMI) in the RADAR. It consists of LCD for real time display and 10" control panel with soft switches. The real time display displays the A scope, PPI and important parameters of the radar for real time operation. High End PC is used for this purpose. Also it consists of IRIG-B Interface, Hard switches and Joystick for user interface. The PSU sub-system is a AC-DC converter to convert the 230Volt AC to 12VDC, 8VDC for the internal power supplies of the Digital and RF sub-system, Transmitter sub-system, Antenna Sub-system. The switching Frequency to be selected at a higher range in KHz. The 3 phase, 4 wire, 415V, 50 Hz AC power supply to the system is controlled by the Main contactor through ON/OFF momentary push button switches in the front panel of Transreceiver rack. The main contactor is a 4 pole contactor with coil control supply of 24V DC.

B. Signal Processing Techniques

The digital down conversion is one of the primary responsibility of the Digital Receiver section, which transforms high frequency RF signals to base band for further processing. The IF Digital down Converter module is responsible for down converting the IF to get the base band I and Q data. The module performs functions of signal conditioning, Digitization, IQ down conversion. This was traditionally carried out using RF signal chain. The decoding of the pulse compressed data and coherent integration need to be realized in real time. The decoding operation essentially involves cross correlating the incoming digital data with the replica of the transmit code. It is implemented by means of a correlator /transversal filter. The Barker 13 code is used for Pulse Compression. Barker Code is one of the

earliest and most popular methods of pulse compression is phase coding. The phase coded waveform is matched filtered to recover the pulse. The matched filter produces the aperiodic auto correlation function for the code. Due to the inherent nature of the codes we get both a main lobe and side lobes in the aperiodic auto correlation. Barker codes have the smallest side lobes possible for bi-phase codes. Barker codes produce the best known side lobe to main lobe ratio.

Windowing is a technique used to shape the time portion, to minimize edge effects that result in spectral leakage in the FFT spectrum. By using Window Functions correctly, the spectral resolution of your frequency-domain result will increase. Applying a window function to the acquisition that connects the waveform endpoints in a smoother fashion before computing the FFT, will result in better spectral resolution. This technique is also referred to as „applying a window“ or simply „windowing“. There are different types of window functions available, each with their own advantage and preferred application. Fast Fourier Transforms is employed for the spectrum estimation. The FFT is a computationally efficient algorithm for computing a Discrete Fourier Transform (DFT) of sample sizes that are a positive integer power of

2. The DFT $X(K)$, $K = 0, 1, \dots, N-1$ of a sequence $x(n)$, $n = 0, 1, \dots, N-1$ is defined as

$$X_k = \sum_{n=0}^{N-1} x_n e^{-j2\pi kn/N} \quad k=0, \dots, N-1 \quad (1)$$

Where N is the transform size and $j = \sqrt{-1}$. A strong DC value or Zero mean velocities may present in the spectrum after doing the FFT. This is removed by replacing the zero Doppler bins by the average of adjacent Doppler bins on either side. This is also can be removed in time series by taking out the bias in I and Q channel and do for Fourier analysis basic operation is carried out here is, $N/2$ to corresponds to Zero frequency. A false alarm is an erroneous radar target detection decision caused by noise or other interfering signals exceeding the detection threshold". The False

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Alarm Rate (FAR) is calculated as FAR = (false targets per PRT / Number of rangecells) In a track-while-scan system, target position must be extracted and velocities calculated for many targets while the radar continues to scan. Obviously, in a system of this type, target data is not continuously available for each target. Since the antenna is continuing to scan, some means of storing and analyzing target data from one update to the next and beyond is necessary. The digital computer is employed to perform this function and thus replaces the tracking servo systems.

III. FILTERING METHOD USING DWT

Moving weather systems will have a nonzero Doppler response at rate at which the rain droplets are approaching the radar system. The complete data the radar collects contain the returns of both the target and the clutter. The signal processing block in a radar system uses filtering operations to extract the target information while suppressing the clutter. Typically the filters are designed based on Doppler Frequency using a Fourier filter bank. Instead of the frequency domain, the wavelet analysis allows the time-scale domain in processing. The filter bank in this study utilizes Discrete Wavelet Transform (DWT), DWT coefficients represent the results of a multi-resolution analysis of the radar signal. A DWT filter bank has different time resolution for different frequency ranges.

Volume clutter is three dimensional and the clutter is usually measured in volume. This type of clutter has large volume and it may include rain, chaff, birds, and insects. Birds, insects, and other flying particles are often referred to as angle clutter or biological clutter. In the case of the rain clutter, the total radar cross sector (RCS) of rain clutter within a single resolution volume is VC

$$\sigma = V_c \sum_i \sigma_i \quad (2)$$

Where V_c is the resolution volume and $\sum_i \sigma_i$ is the average sum of all scatterer's RCS of rain clutter per

unit resolution volume. An empirical model for the rain reflectivity (Laws-Parsons distributed) is given by $\pi^5 D_i^6$

$$\sigma_i = \frac{\pi^5 D_i^6 \epsilon_r - 1}{\lambda^4 \epsilon_r + 2} \quad (3)$$

Where D_i is the raindrop diameter and ϵ_r is the relative permittivity of water and λ is the carrier wavelength. $\sum_i D_i$ can be approximated using Z-R (Marshall-Palmer) rainfall estimates. H is defined as RCS of the rain clutter per unit resolution volume V_c . It is defined as the sum of all individual scatterer's RCS within the volume. Coherent pulsed radar is capable to solve the phases of the reflected pulses. The most common process to create a filter bank in up-to-date pulsed Doppler radar systems is the Fast Fourier Transform (FFT). A FFT transform is executed on both the In-phase channel (I-channel) and the Quadrature channel (Q-channel) in order to create a bank of filters. In a filter banks, the number of filters formed is equal to the number of samples integrated and the total passband of the filter bank is equal to the PRF. For example, an eight-point FFT filter bank requires that eight pulses (I and Q) are processed for each coherent processing interval (CPI). That actually means that the frequency of the radar can not change for that CPI, because of the dependences of the phase. DWT coefficients represent the results of a multi-resolution analysis of the radar signal. A rough approximation of radar signal might look stationary, while at a detailed level discontinuities become apparent. DWT has many advantages over Fourier Transform in analyzing the signals containing discontinuities and sharp spikes. DWT uses certain wavelet filters to divide the data into different frequency or scale components, and then analyze each component with a resolution corresponding to its scale. Meanwhile, it retains the time information while revealing the frequency information. It is ideal for extracting information from signals that are either stationary or transient.

A. Wavelet Transform

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The wavelet transform is based on a window family generated by translations (time) and dilations (scale) of a window called a wavelet. The only difference between DWT and CWT (Continuous Wavelet Transform) is that the process of shifting and scaling is discrete. In other words, time-axis is replaced by sample-axis using integers as indices. The time interval of samples becomes not so important. Then DWT and its coefficient are defined as $Wf(s, \tau) = \langle f(t), \psi_{s, \tau}(t) \rangle = \int f(t) R \psi_{s, \tau}^*(t) dt$ (4) where $f(t)$ is the time domain signal, $\psi_{s, \tau}$ the wavelet and $*$ denotes the complex conjugation. When the signal $f(t)$ is passed through a set of filters determined by a wavelet family, we get the respective outputs as the DWT coefficients. These coefficients describe the signal content in time-scale domain. In discrete two-channel wavelet transform, the signal is also separated to the low-pass and high-pass components. We define $h(k)$ (the low pass filter) as the scaling filter and $g(k)$ (the high pass filter) as the wavelet filter. The next step transforms the approximation coefficients $cA1$ into two parts using the same scheme, replacing $cA1$ and producing $cA2$ and $cD2$, and so on.

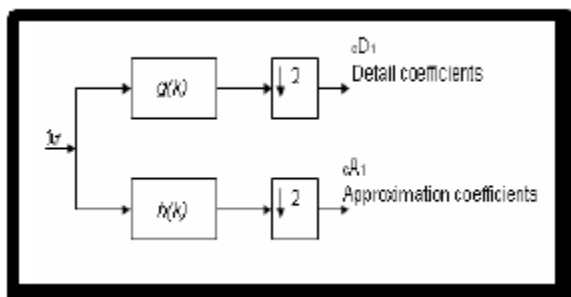


Figure 2 Mallat's algorithm for the wavelet decomposition B. **HAMMING WINDOW** Windowing is a technique used to shape the time portion, to minimize edge effects that result in spectral leakage in the FFT spectrum. By using Window Functions correctly, the spectral resolution of your frequency-domain result will increase. Applying a window function to the acquisition that connects the waveform endpoints in a smoother fashion before computing the

FFT, will result in better spectral resolution. The Hamming window is given by

$$w(n) = \alpha - \beta \cos\left(\frac{2\pi n}{N-1}\right) \quad (5)$$

$$\text{with } \alpha = 0.54, \beta = 1 - \alpha = 0.46$$

C. Clutter Filtering With Discrete Wavelet Transform

The purpose of the DWT is to detect and to locate the targets in an environment which can include volume clutter like the rain clutter. Typically radar's clutter mapping is a technique for detecting moving targets with fixed clutter or very low Doppler shift. The idea of the wavelet mapping (WM) is to separate different frequency bands without the explicit data of the radar parameters such as PRF. WM is calculated using DWT. In DWT, the bandwidths for each smaller band are not the same. They are not divided evenly by DWT filter bank even though they are also called a M-channel filter bank. Typically, M is equal to two. The purpose of our filter design is to suppress target-like returns produced by the rain clutter and allow returns from real moving targets to pass through the filter bank with little or no degradation. This requirement equals to near-zero DWT coefficients for the clutter and large coefficient values for the targets. The DWT coefficients are computed using a pair of filters, a low pass filter and a high pass filter. Due to the variable resolution of the wavelet transform, the coefficients are arranged such that the first level decomposition generates half of the total amount while further decompositions produce half of the rest. Referring to the spectrum of the target and the rain clutter and due to their different frequency ranges, we are able to separate the target from the clutter. The target appears in the lower level detail (high frequency) while the clutter exists in the high level detail or approximation (low frequency). Filtering is done in eight steps.

1. The power data from Primary Surveillance Radar is first given as input.
2. The PPI (Plan Position Indicator) plot is replicated for the given input.

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3. Windowing of the data using Hamming Window to keep side lobe level low.
4. Applying Discrete Wavelet Transform (DWT) to both I and Q channel data separately.
5. DWT coefficients are calculated.
6. Selection of the maximum response for each decomposition level.
7. Defining a threshold for output using CFAR to deal with these DWT coefficients to get filtered signal.
8. Plotting the PPI of the DWT filtered output.

IV. RESULT AND DISCUSSION

The project to remove the unwanted targets using wavelet transform was implemented after 6 months of research. The process started with the literature survey of various clutter filtering techniques in radar. After that I studied about the present Doppler filtering method used in the Primary Surveillance Radar, TERLS. The algorithm was implemented in primary surveillance radar to remove clutter effectively in order to provide danger zone clearance during sounding rocket launches from TERLS Range. The Radar can also be used for security and strategic applications and Meteorology applications.

In the programming section ,Matlab coding and later Python was used to implement the whole output of the project. The main aim of the project was to implement the PPI plot showing the required target output. First I plotted an A-scope data with the given input. The input consists of azimuthal angle ,elevation angle and range bins. Then plotted the data in x-y plane. After that a polar plot for a single angle was plotted. Then a PPI plot was plotted for 360 degree azimuth angle data .Similarly clutter plot was also plotted .Finally a Matlab program was coded for the clutter removal using wavelet transform .The same program were implemented in Python language also. Python is a widely used high-level, general-purpose ,interpreted, dynamic programming language.Its design philosophy emphasizes code readability, and its syntax allow programmers to express concepts in fewer lines of code than possible in languages such as C++ or Java. The

language provides constructs intended to enable clear programs on both a small and large scale. The radar scanning was carried out in PSR on various days to get the PPI plots for reference. The plots showed variations due to different weather conditions on each day. The results shown below includes the screen shots from the radar monitor for reference, PPI plots created from the data of the same reference plot, and the clutter filtered output.

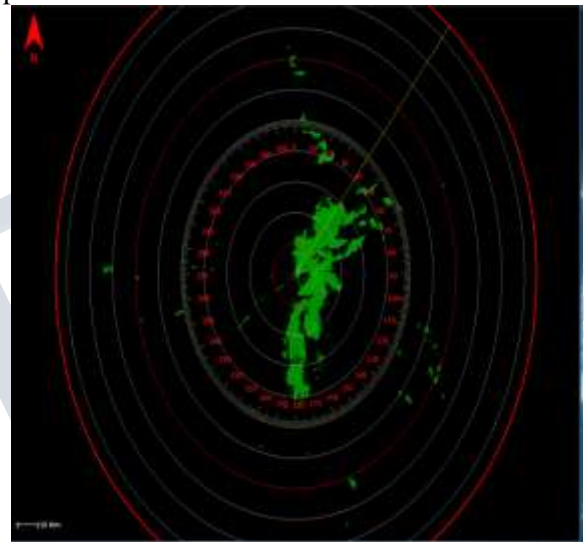
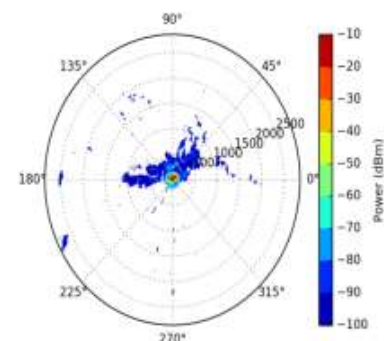


Figure 3 Screen Shot of the PSR Data Figure 3 was taken on 08/05/2016 by PSR at 14:33 hours. The weather was cloudy and it showed large clutters and the required targets were indistinguishable. Figure 4 shows the python output for the same input data in power units. The colour scale shows the various power levels in dBm units



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Figure 4. PPI Plot of Data Figure 5 shows the clutter filtered output .All the unwanted targets were removed by specifying a threshold ..

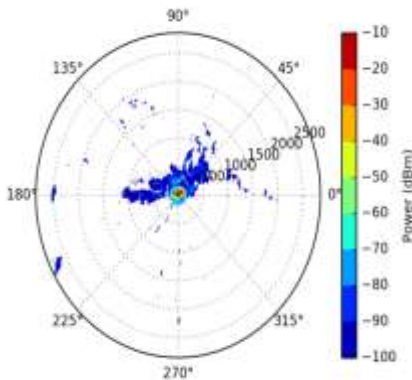


Figure 5 Doppler Filtered Output

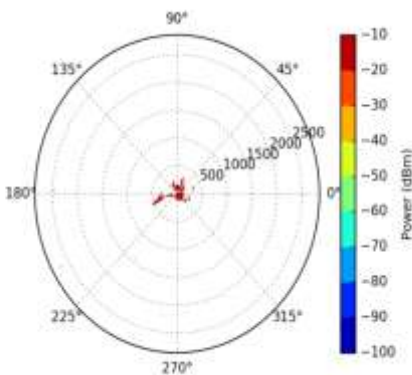


Figure 6 DWT Filtered Output

Figure 6 shows the clutter filtered output of wavelet transform. It removes the clutters more specific than the Doppler clutter filtering .It also takes less time for performing the task. So it is better than the present filtering technique. Implemented a novel clutter filtering technique using the wavelet transform to remove the clutters and detect the required targets. Here Discrete Wavelet Transform technique is used to filter all the clutters by using a CFAR threshold. This technique filters the clutter better than that of the present clutter filtering technique .It can also be performed in less running time. V. CONCLUSION This project aims to improve the clutter rejection in the target determination

algorithm of Pulse Surveillance Radar. The same has been implemented using Discrete Wavelet Transform. The wavelet mapping improves target detection in the presence of volume clutter .As the major clutter contribution in Pulse Surveillance Radar is due to sea and clouds which are volumetric targets, this method is much effective in comparison to the Fast Fourier Transform based clutter rejection technique. The Discrete Wavelet Transform based clutter filtering algorithm was evaluated with five sets of Pulse Surveillance Radar data and a better target detection was observed in comparison to Fast Fourier Transform method which is being used. A DWT filter bank has different time resolution for different frequency ranges. With very heavy rain clutter affecting to the target signatures, this technique indicates that the wavelet filter bank performs better than the Fourier filter bank. This method performs better filtering than that of the present system and it also performs faster reducing the running time. The algorithm can further be fine tuned with adaptive thresholding , using the signal strength of volumetric targets such as rain clutter in future scope.

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