Attenuation Due To Rain in Wireless Technology

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Abstract*- The Doppler effect due to the rainwater in hilly areas leads to an interference in the received signal. In addition to the Doppler shift created by the mechanical movement of the radar-dish, the frequency shift produced by the rainwater affects the connectivity when the received signal wavelength matches with that of the diameter of the raindrop. This shift is analyzed using transforms like Fast Fourier Transform (FFT), Short Time Fourier Transform (STFT) and Wigner-Ville Distribution (WVD). In this paper, the methods of extraction and mitigation of Doppler are explained with viable algorithms and results.*

Keywords- Doppler, Fast Fourier Transform (FFT), Short Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD).

I. INTRODUCTION

A radar transmits a signal towards the target, which interacts with the target and then returns to the receiver. The returned signal is affected by the characteristics of the target. The frequency shift produced in the returned signal due to the target interaction is known as Doppler Effect. [1] In places of heavy rainfall, especially in hill-stations, this frequency shift is accompanied by micro-motions due to the raindrops falling on the radar dish or simply due to the interaction of the signal with the raindrops in the atmosphere. This kind of frequency shift caused due to micro-motions is known as Doppler Effect. If we consider a duplexer, where the transmitter and the receiver are together in the same place, the total distance covered by the signal will be twice of the distance between the transmitter and the target. The frequency can be produced in the form of the wavelength of the signal and the distance between the transmitter and the target as:

$f_d = 2\lambda v$ where $\lambda = c/f$ acts the wavelength of the signal.

The Doppler frequency shift obtained due to the raindrops can be used to estimate the velocity of the raindrops. While we can get a lot of information from these Doppler results, they might interfere with the returning signal and can affect the inverse synthetic aperture radar (ISAR) image of the main signal. [3] This can lead to a vague interpretation of the main signal. Hence, it is important that the Doppler is properly extracted and removed. Furthermore, post the extraction, the signal becomes disturbance-free and as per requirement, the signal propagation can be altered.

The Doppler extraction is done in order to locate the micro-motion taking place on the radar dish. For the error-free analysis, several methods have been employed involving the frequency domain. The most common one stands as the Fast Fourier Transform (FFT). [4] In this report, we present the idea of utilizing Short Time Fourier Transform (STFT), Wigner-Ville Distribution (WD) and Pseudo Wigner-Ville Distribution (PWD) for the accurate extraction of the fine Doppler projections. [5] The resolution offered by these methods in the frequency domain analysis is better than the commonly used transform.

The paper is organized as

1) Introduction of the concept of rain-induced Doppler
2) Explaining in detail what all mathematical methods have been used in the past in order to capture the Doppler produced by such micro-motions?
3) Instead of using the conventional method of FFT, new methods shall be introduced which increases the precision of the Doppler extraction mathematically
4) Algorithms to show the results due to the transforms
5) When the Doppler is extracted, necessary measures need to be taken in order shift the radar frequency to a suitable frequency to receive uninterrupted connectivity
6) Real- life simulation of the mentioned methods in hardware with appropriate results.

II. RAIN FADE

The frequency bands allocated by International Telecommunication Union (ITU) as Broadcasting Satellite Service are

1) 10.7 - 12.75 GHz in ITU Region 1 (Europe, Russia, Africa)
2) 12.2-12.7 GHz ITU Region 2 (North and South America)
3) 11.7-12.2 GHz in ITU Region 3 (Asia, Australia) [6]

The microwave frequency exists between 300MHz to 300GHz. [7] All microwaves are transmitted in this frequency range. As a result, during a condition of storm, heavy rainfall and heavy clouds, the microwave radio frequency (RF) signal mainly in the range of 11GHz and above frequencies are absorbed by the water molecules. This phenomenon is commonly known as Rain Fade or Rain Attenuation. Most of the satellite communication is carried out in the form of electromagnetic radiation spectrum. The situation where the mean distance between water droplets or crystals is comparable to the wavelength of the electromagnetic signals, severe attenuation occurs. The range of disruption taking place in the signal connectivity depends on three factors – 1. Regional rainfall measure (yearly), 2. Location of the satellite footprint, 3. Altitude of the satellite. [8] Usually the disruption is short-lived and connectivity is restored in no-time. However, the main difficulty arises in the hilly regions where rainfall is a near-daily occurrence and the users face the sudden blackouts every now and then. Though mini-satellite dishes are being optimized to work against the weather adversity, large dishes are recommended in such areas for the signal compensation. There are cases of rain fade under no-rain conditions too. This happens when the radiations pass through precipitations from a long distance. This usually happens when the dish is at a low-look angle. Some amount of signal scattering takes place due to diffusion, diffraction and refraction of electromagnetic waves around the raindrops.

The frequency shift produced due to this interference is known as Rain-Induced Doppler. It is a form of Doppler which when detected creates difficulties in the signal propagation.

A. Rain Fade in 5G Connection

The latest new technology where scientists all over the world are working on is the 5th Generation Network (5G). The 5G technology involves a short and high frequency band of 15GHz and can transfer a huge data in a matter of milliseconds. The wavelength of the 5G signal is in the range of millimeters. The 5G wavelength is known as the millimeter wave (MW). [9] Hence, when this signal is transmitted in a heavy cloud or rain day, the wavelength and the diameter of the raindrops may be similar countering each other. This eventually leads to disturbance and more scattering. The movement of the rainwater droplets in the atmosphere can cause corresponding frequency shifts as mentioned earlier as the Rain Induced Doppler. This is a serious problem in the discovery of 5G which can cause connection breakage whenever such a weather change occurs. This paper simulates and emulates the real life condition of the weather and presents efficient methods to shift the frequency to that of the 4G type from 5G so that the connection doesn't break.

III. MATHEMATICAL METHODS EMPLOYED FOR EXTRACTION

The micro-motion analysis is done on the frequency spectrum and the Doppler extraction can be done on the basis of the cure results. The frequency analysis is usually carried out using FFT. However, FFT results are vague and accuracy is needed in order to detect such light motions. Hence, the paper introduces WD and PWD.

A. Fast Fourier Transform (FFT)

The FFT is basically the fastest method of finding the Discrete Fourier transform (DFT). This is mathematically presented as:

$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{i2\pi n}{N}}$$

Here, k = 0,1…N-1. An FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse (mostly zero) factors. [4] [10]

This method though a start doesn't satisfy the need in this paper. It cannot detect the micro-motions for further analysis.

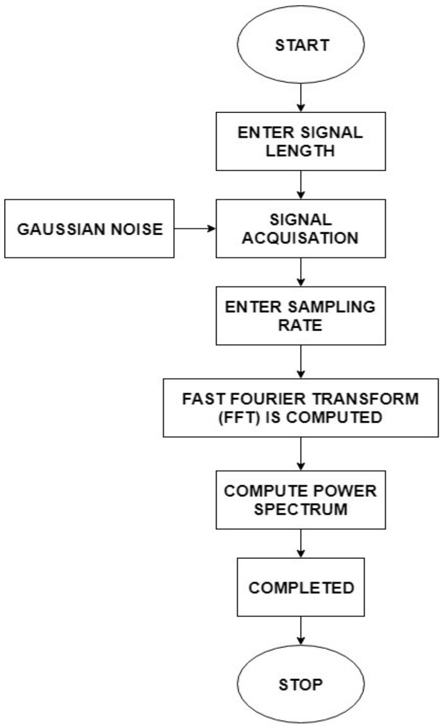

Figure 1. FFT flowchart

This flowchart presents the computation of the Fourier transform of the signal acquired with the Gaussian noise and then produce it on a power spectrum. The power spectrum gives output on an x-y graph as amplitude-vs.-time. This helps in attaining the maximum intensity of the signal acquired for further usage.

B. Short-Time Fourier Transform (STFT)

This procedure breaks a time span into smaller parts and finds the frequency of each part separately. This method increases the resolution when compared with the Fast Fourier Transform. Finally, it presents the spectra in frequency domain. The transform of the signal is a two-dimensional representation. Mathematically, it is represented as:

$$STFT = X(t,\tau) = \int_{-\infty}^{\infty} x(t)w(t-\tau)e^{-j\omega t}dt$$
$$= \int_{-\infty}^{\infty} x(t)w(t-\tau)e^{-j2\pi ft}dt$$

Here, w(t) is the window function which produces the 2-D effect and x(t) is the signal which needs the transformation. [11] However, for micro motion detection, this method doesn't stand out. For the minute details, this method is redundant.

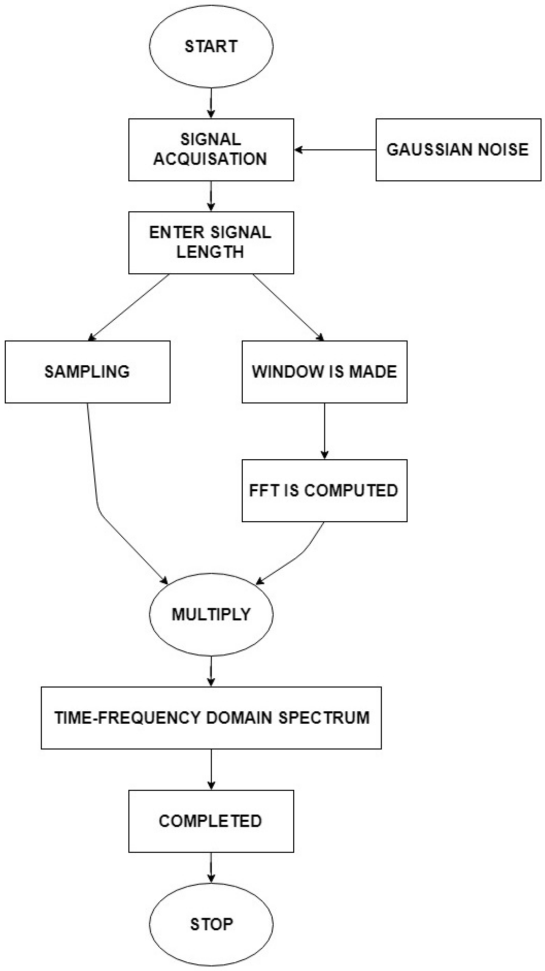

Figure 2. STFT flowchart

This flowchart presents the manner in which the short-time Fourier transform for the signal acquired. The original signal is used as two different entities – one copy is used for the sampling depending upon the signal length and sampling rate. The second copy is used for window calculations. The results are multiplied and then presented on a time-vs-frequency spectrum.

C. Winger-Ville Distribution (WVD)

The WVD does not suffer from leakage effects as the STFT does. Hence, the WVD gives you the best spectral resolution. The mathematical representation is as follows:

$$W_x(t,f) = \int_{-\infty}^{\infty} x\left(t+\frac{\tau}{2}\right).x(t-\frac{\tau}{2})^* e^{-j2\pi f\tau}d\tau$$

Here, the result is for a mean-zero-time segment. The profit of Wigner function is that it reduces to the spectral density function at all times t for stationary processes even though it is fully equivalent to the non-stationary autocorrelation function. [12]

However, if you have signals with several frequency components, the WVD suffers from the so called cross terms. [13] These cross terms can be (partly) suppressed by extending the WVD - this results in the so called Smoothed Pseudo WVD (SPWVD). Hence, for most practical applications you would (and should) use the SPWVD.

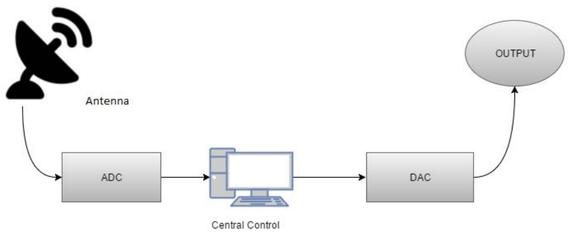

Figure 3: Overall Block Diagram of the experiment

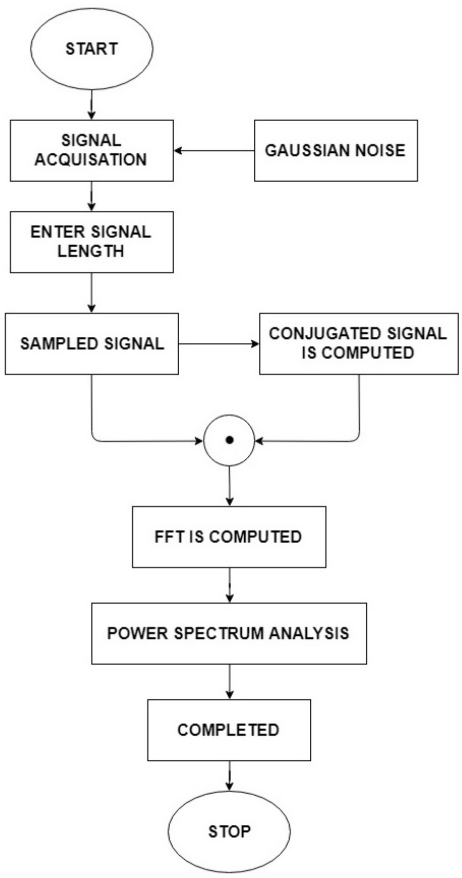

Figure 4. WVD flowchart

The flowchart explains the Wigner-Ville distribution working. Here, instead of the window computation as seen in STFT, the conjugation of the signal is computed. This aids the mean-zero computation which increases the resolution of the output.

IV. SIMULATION PROCEDURE AND BLOCK DIAGRAM

1. Antenna: The radar has been constructed in a manner to receive the signal from the real- time conditions (for example, the rain condition) and this signal is received in the form of an analog signal. After this, the analog signal is fed into the ADC (Analog-Digital Converter).
2. ADC (Analog-Digital Converter): It is an electronic device which converts a continuous analog quantity (physical quantity like voltage or current) to a digital number (in the form of 0s and 1s) which will represent the quantity's amplitude. This is done using quantization of the input in order to lower-down the error possibility. The conversion is done periodically and not continuously. Sampling of the input is done in order to convert. In this simulation process, the Digital Signal Oscilloscope acts as the ADC.
3. Central Control – this is basically the computer where the manipulation of the digital output is carried out. The manipulation Is done using either of the following software's: MATLAB or LabVIEW. The manipulated digital data is then transferred to the DAC (Digital-Analog Converter).
4. DAC (Digital-Analog Converter): This electronic device works opposite to that of an ADC. Its function is to convert the digital output transferred from the PC is the digital bus (), to a physical quantity (analog). This analog output is carried out using the hardware of either of the following: NI Card or SG. The physical quantity output is in the form of RF (Radio Frequency). The radio frequencies available for the different types of connections are as follows:

Table 1. Respective Carrier Frequencies of the different types of connections [16]

TYPE OF CONNECTION	RF CARRIER FREQUENCY
FM NETWORK	100 MHz
2G MOBILE NETWORK	900 MHz
3G MOBILE NETWORK	2100 MHz
4G MOBILE NETWORK	2600 MHZ

A phenomenon which can help in the hilly regions during rains or storms is "Frequency Hoping"[12]

Frequency Hopping: This phenomenon is the process of shifting of frequencies depending on the surrounding conditions. For future purposes, connectivities via 5G gives the users the ability to change the "carrier frequency" as and when the weather condition changes. [19] 5G has two different carrier frequencies as follows: [20]

Table 2. Carrier Frequencies of 5G network [21]

TYPE OF CONNECTION	RF CARRIER FREQUENCY
5G MOBILE NETWORK	3GHz OR Millimetre Wave (above 30GHz)

When the sky is clear, the chances of an interference by the water-droplets in the atmosphere is not possible. Hence, the carrier frequency of the millimetre wave (mmW) can be used. This gives the user the ability to communicate with the satellite in the fastest way with a frequency of 30GHz (approximately).

However, during the condition of rain, or heavy clouds etc. the conditions slightly change. The water droplets in the atmosphere can cause a "Rain Fade" as discussed earlier due to the size of the droplet comparable with the wavelength of the carrier frequency. When such a case arises, the carrier frequency should automatically shift from the mmW to 3GHz which reduces or nearly nullifies the chances of such a difficult.

V. SIMULATIONS USING TEST SIGNALS

The simulation of the test signals (for example, chirp signal and sine signal) was carried out using MATLAB 2014a.

A. MATLAB Simulations

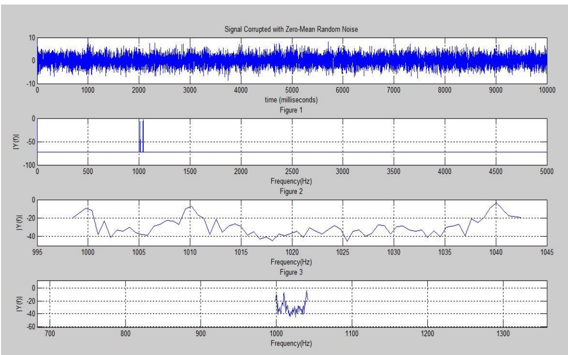

Figure 5. MATLAB output for FFT simulation with test signal

The O/P for the chirp signal after STFT is as follows:

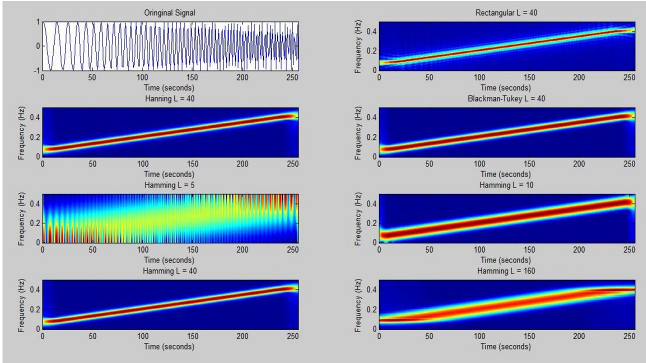

Figure 2. MATLAB output for STFT simulation with test signal

The **WVD** O/P for a chirp signal is as follows:

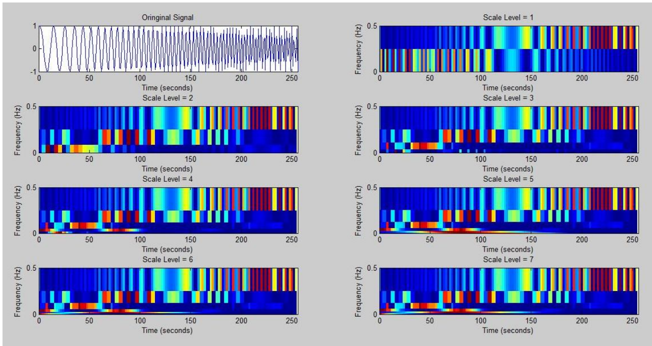

Figure 3. MATLAB output for WVD simulation with test signal

B. LabVIEW Simulations

The platform allows the virtual implementation of the hardware components on a software platform. Using the transform on the test signals, the outputs are nearly the same as that of MATLAB.

For **FFT**, the LabVIEW implementation using a sine wave with Gaussian noise is as follows:

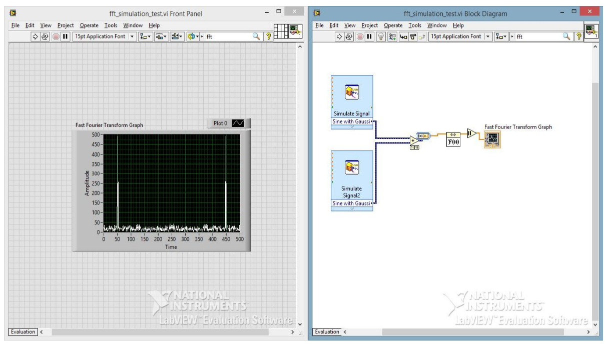

Figure 4. LabVIEW Front Panel and Block diagram for FFT of test signal

For **STFT**, the O/P is as follows for a chirp sine signal:

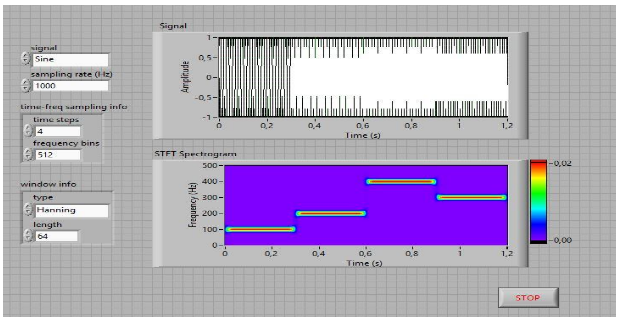

Figure 5. Front Panel of STFT output.

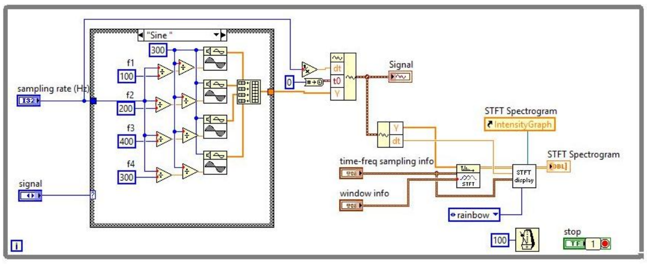

Figure 6. Block Diagram of STFT for chirp signal

For **WVD**, the O/P is as follows:

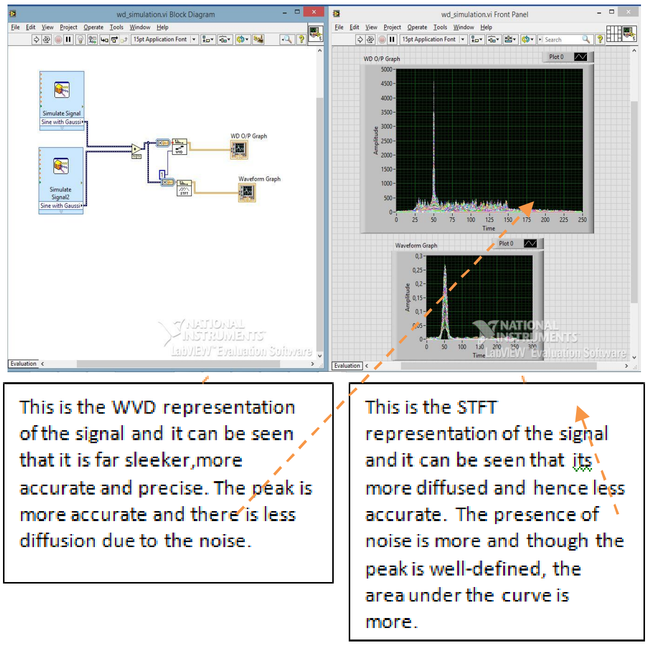

Figure 7. The WVD versus the FFT result for the a sine wave with Gaussian noise as signal

VI. RESULTS WITH REAL-TIME SIGNALS

A. LabVIEW Simulations

The test signals are now replaced with real-time signals from the surroundings and the values are taken. For this, NI Data Acquisition card works along with LabVIEW to produce the output.

For **FFT**, the O/P is as follows for real-time signal:

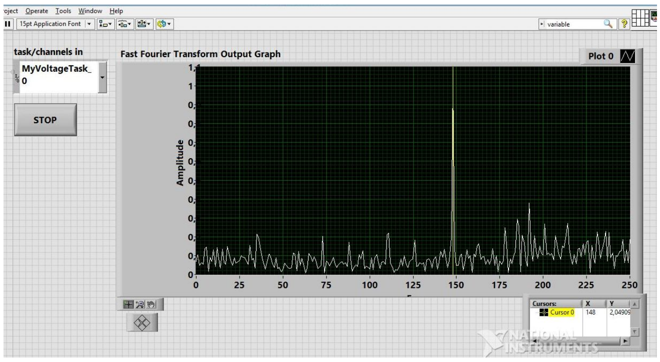

Figure 8. FFT of slower real time signal

By increasing the velocity of the moving body we notice that the Doppler shift keeps increasing. This has been successfully extracted using FFT. The values of a slower and a faster moving body have been shown in the figures 12 and 13. Table 3 depicts the values of Doppler shift in hertz with the corresponding changes in velocity of the body in motion. This shows more the velocity more is the Doppler shift.

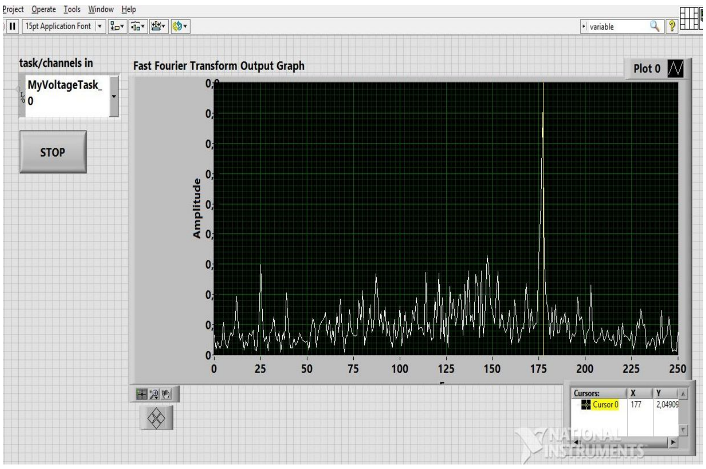

Figure 9. FFT of a faster signal

Rotations per minute (RPM)	Velocity (m/s)	Doppler Shift at 24GHz C.F (Hz)
591	3.52	283.56
521	3.10	249.72
499	2.977	239.25
482	2.87	231.19
451	2.69	216.69
335	1.99	160.31
284	1.69	136.14

Table 3. Measured RPM with respective Doppler shifts in Carrier Frequency (C.F)

The **STFT** O/P for real time signals is as follows:

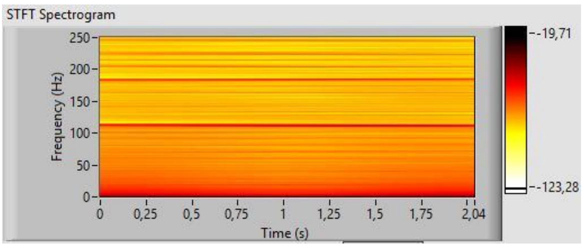

Figure 10. STFT output in Hanning window

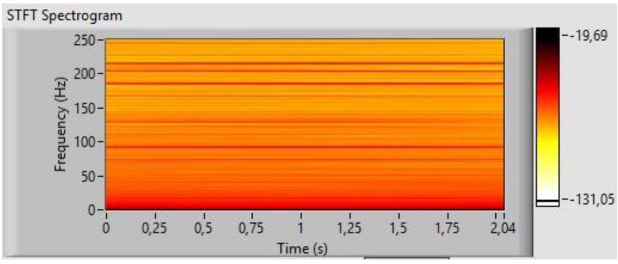

Figure 11. STFT output in Hamming Window

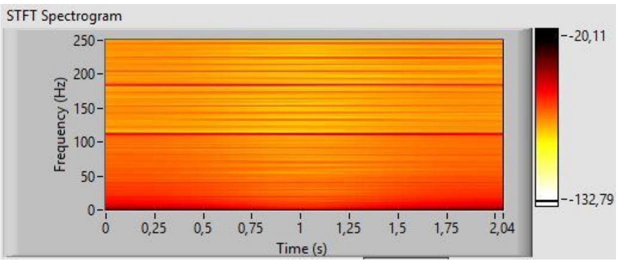

Figure 16. STFT output in Flat-Top Window

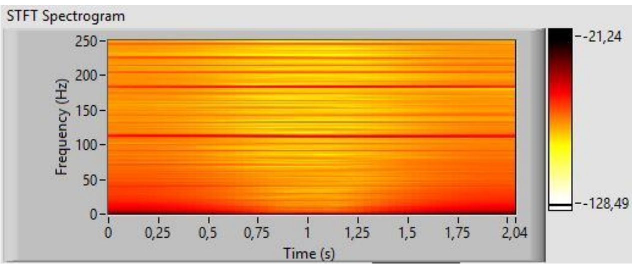

Figure 17. STFT output in Blackman-Harris Window

Figures 14-17 depict the different results for different windows for the STFT output for real time signals. We find that the values are more scattered (at around 90Hz, 180Hz,210Hz where the darker red lines appear). We receive the range accurately (90 Hz to 210Hz) but too many values.

After attaining values for the different windows for the STFT transform, we found that the **Blackman-Harris Window** gives more precision and narrows down the values to a more workable range. The range now becomes more precise (110Hz – 170Hz).

The WVD results for a real time signal are as follows:

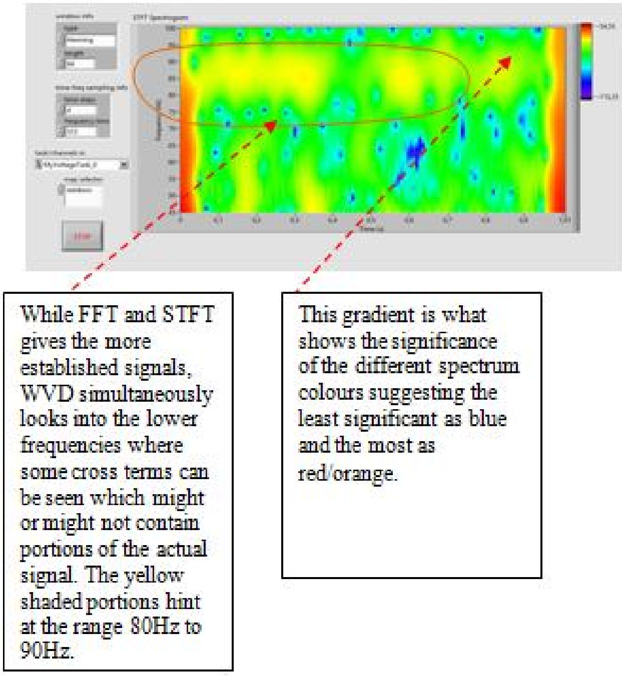

Figure 18. WVD output in Hanning Window

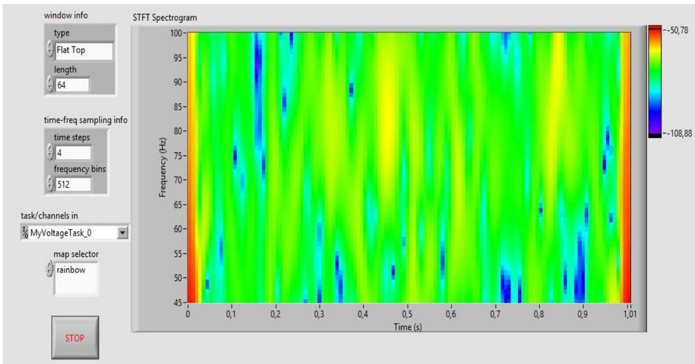

Figure 19. WVD output in Flat-top Window

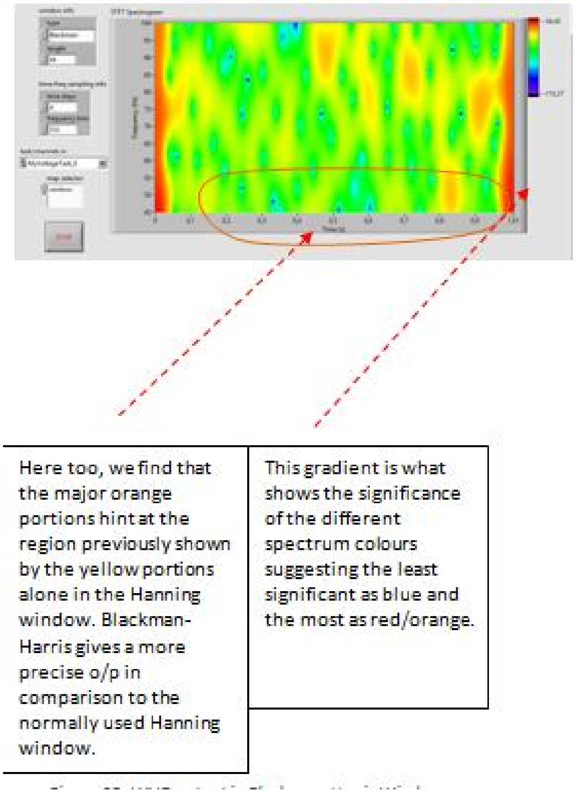

Figure 120. WVD output in Blackman-Harris Window

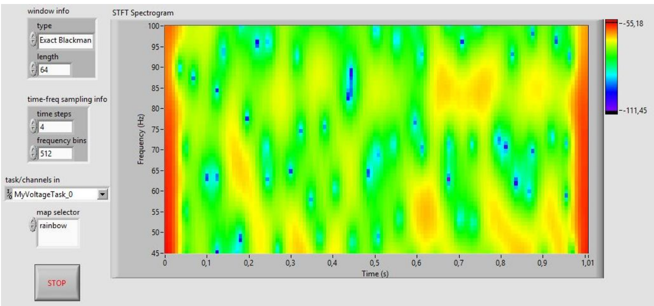

Figure 21. WVD output in Exact Blackman Window

While FFT and STFT gives the more established signals, WVD simultaneously looks into the lower frequencies where some cross terms can be seen which might or might not contain portions of the actual signal. The yellow shaded portions hint at the range 80Hz to 90Hz.

Here too, we find that the major orange portions hint at the region previously shown by the yellow portions alone. **Blackman-Harris** gives a more precise output in comparison to the normally used Hanning window.

VI. CONCLUSION

From multiple real-time scenarios, we have successfully been able to extract the frequency ranges of the slightest changes in the frequencies of the signal. We have also realized that The Blackman-Harris Window gives the best output presentation.

This method of detection and extraction of Doppler shift can help in knowing the deviation from the original signal and can be later used for formulation new antennae for hilly regions which can rule out any shifts for seamless signal transfer.

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[9] However, if you have signals with several frequency components, the WVD suffers from the so called cross terms. These cross terms can be (partly) suppressed by extending the WVD - this results in the so called Smoothed Pseudo WVD (SPWVD). Hence, for most.

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