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DESIGN AND SIMULATION OF CONTINUOUS WAVE RADARFORAUTOMOTIVE APPLICATIONS

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ABSTRACT
The radar was in use for more than 80 years and now it is widely used both in military and civilian applications. Today's radar system uses highly innovative and specialized technology to meet all growing demands. With the advances in the radar spectrum and electronic warfare technology the capabilities of testing and measuring the system must be continuously enhanced. Automotive industries are being equipped with these radar systems to assist drivers in critical situations in order to avoid accidents.
Radar system makes it possible to measure the range, velocity and azimuth of multiple objects. This paper addresses the design and simulation of continuous wave (CW) radar system in SystemVue for automotive applications. Measurement and test accuracy plays a vital role in development and launch of any new radar system. Transmitter and receiver configuration were discussed and was found most suitable and used for the simulation. The variable parameter configuration was used and transmitter frequency can be made cover to any arbitrary frequency range. Target trajectory model was used to compute the trajectory of moving target by generating the time delay and to get the value of echo signal. Heterodyne receiver architecture was simulated for conversion of radio frequency (RF) signal to intermediate frequency (IF) signal and to demodulate it. The system performance was tested by comparing transmitted signal with received signal and clutter added.
Keywords: Continuous Wave Radar,

1 INTRODUCTION

In military applications one of the most commonly used radar is Continuous Wave (CW) radar. These radars are designed to estimate range and velocity. A CW radar system utilizes coherent transmission, reception and uses a high pulse repetition frequency (PRF) to avoid unambiguous range thereby enhancing the detection [1]. This paper covers the design and simulation of CW radar using SystemVue. SystemVue is both time domain and frequency domain system simulator for design and analysis of mathematical, scientific and engineering systems.
SystemVue is a dynamic system analysis environment for design and simulation of scientific and engineering systems. It is a powerful sink calculator of both time domain and frequency domain analysis of signals. In the SystemVue large systems can be simplified by meta system [2]. Meta system represents a complete system or subsystem. It also provides sop histicated analysis of analog, digital signal processing, control system, filter design, communication systems to mathematical models. In this paper CW radar is simulated in SystemVue and it is typically comprises of CW generator, RF transmitter, Antenna system, target trajectory model and receiver.

2. MOTIVATION

Radar is used for measurement of range, velocity and echo from all the objects in its observation area [3]. Radar covers all the defence and commercial applications by a variety of system designs using specific frequency of operation, transmit duration, bandwidth, waveform antenna and many more. Now a day's only radar provides information about range and velocity and it allows determining azimuth and elevation angles [4]. This feature of radar has allowed its use in automotive industry. Various researches [5] have shown the CW modulation offer better transmitter power, spectral control, dynamic range than equipment modulation system. This has become motivation to design and simulate CW radar for automotive applications.

3. CONTINUOUS WAVEFORM

CW radar is used for target illumination. Due to constant transmission with low power, CW radar is harder to detect compared to pulse Doppler radar [6]. Fully coherent CW radar is designed consisting

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of RF subsystem that connects to an antenna containing the signal conditioning equipment and power supplier. The continuous waveform is defined as:

$$f_1 = \text{Cos } w_0 t \quad (1)$$

Where $w_0 = 2\pi f_0$

The signal bandwidth is the range of frequency over which the signal has a nonzero spectrum. In general, any signal can be defined using its duration (time domain) and bandwidth (frequency domain). A signal is said to be band limited if it has finite bandwidth. Signals that have finite duration's (time-limited) will have infinite bandwidths, while band-limited signals have infinite duration's. The energy density distribution of a CW wave can be determined using statistical analysis. The extracted wave data are usually discontinuous and independent and cover a very short period of the total data-recording period [7].

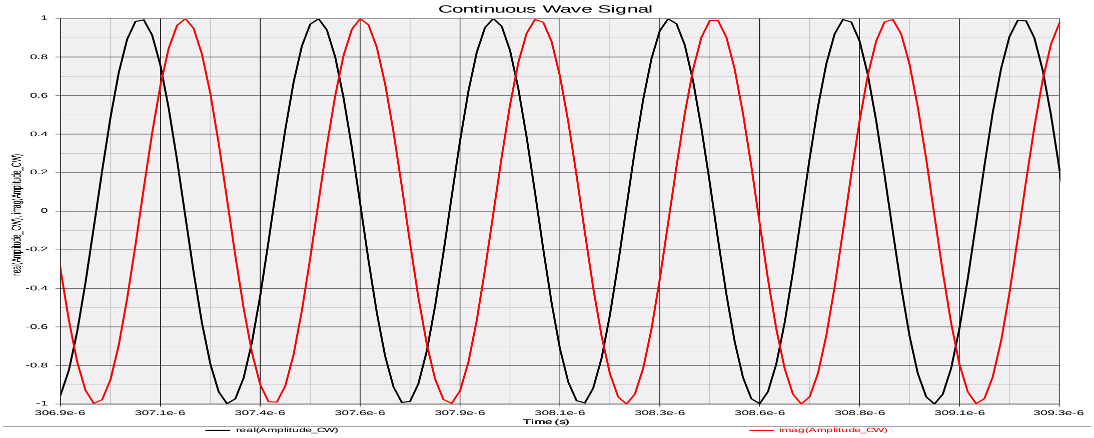

Fig 1. Time domain representation of CW waveform at a start and stop time at 0 and 1000 µs respectively

The height and period of CW waves change randomly in both time and place. It is therefore essential from an engineering viewpoint to determine and express the various characteristics of CW waves as functions of time and place. The frequency domain representation of the CW waveform generated is shown in Fig 2.

performance parameter depends on the properties of the dielectric material. The minimum dielectric constant is proven practically to give higher gain and improved isolation for automotive radar systems '[9]'. Over the years '[3,11]' have shown that for dielectric constant 1, the gain and directivity of antenna is high, but due to the complexities in connecting the modules of transceiver, these type of antenna are a great challenge. Therefore the search for a low dielectric constant material is one of the prominent areas of research.BCB is promising material and claim a dielectric constant ε_r= 2.65 between 10GHz to 1.5THz '[12]'.

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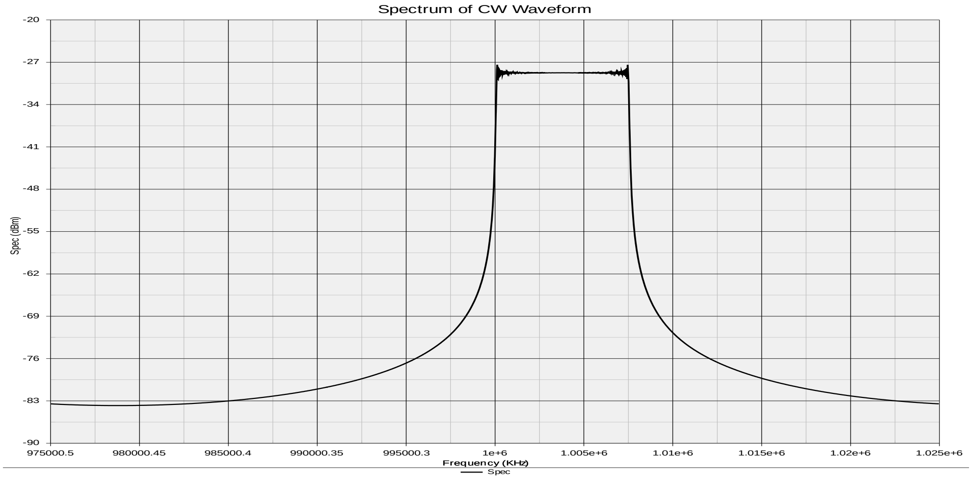

Fig 2. Spectrum of CW waveforms

4. RF Design Process:

In radar scenario a transceiver is a radio communication system which is composed of transmitter and receiver as shown in the below Fig. 3. Transmitter converts a baseband data into an RF signal and transmits it through antenna. A transmitter basically performs three functions: Modulation, Frequency translation and Amplification [8].

A receiver in radar scenario is used to receive echo signals in the range of frequencies and process them to recover the transmitted data. It consists of antenna, RF front end and baseband signal processing. Most common architecture used in received is super heterodyne receiver [9].

Receiver power (dBm) = Transmitter power (dBm) + Gain (dBm) – Losses (dB) (2)

5. Building blocks of Transmitter:

All the transmitters and receivers are composed of various RF building blocks which carry out functions like frequency translation and selection, power amplification [10]. A simplified block diagram of transceiver is shown in Fig. 3.

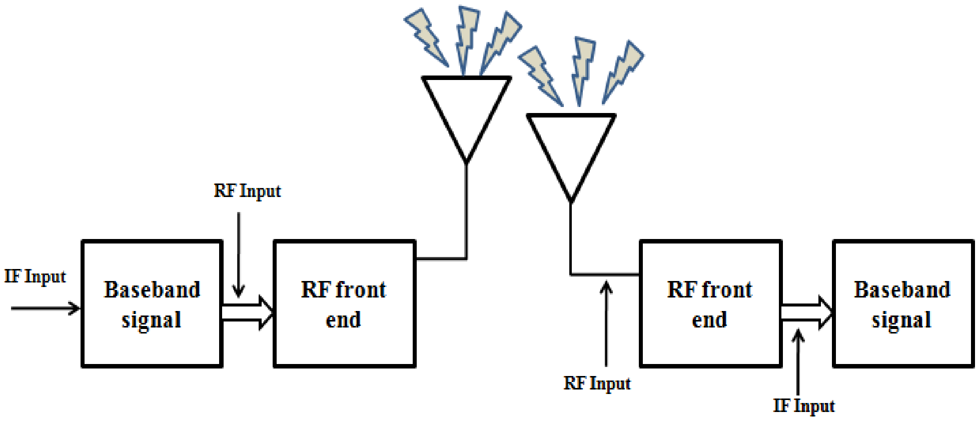

Fig 3. Block diagram of transceiver

5.1. Amplifier:

An amplifier is a device that strengthens the signal to the maximum allowed linear output. In the receiver, amplifier is required to bring the input signal to an acceptable level for processing [11]. One of the main parameters of the amplifier is gain and is chosen to be 0.5 in this work.

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5.2. Filter:

Filter is a device which does the frequency selection by passing the desired range of frequencies, the unwanted signals are attenuated. In this paper bandpass butterworth filter is used. This filter consumes one sample from the input and produces one sample to the output in every execution. SystemVue filter part incorporates various filter models in terms of frequency response, design methods both IIR and FIR [12].

5.3. Local oscillator:

A local oscillator is a device that generates a reference signal to be used as one of the mixer input and serves for up conversion [13]. Local oscillator is characterized by the parameter such as phase noise, tuning range and frequency stability. Heterodyning is used so widely in communications engineering to generate new frequencies which move information from one frequency channel to another. it is used in radio transmitters, modems, satellite communications and set-top boxes, radar, radio telescopes, telemetry systems, cell phones, cable television converter boxes and headends, microwave relays, metal detectors, atomic clocks, and military electronic countermeasures (jamming) systems, analog tape recorder and music synthesis and here LO are used for frequency conversions .

5.4. Mixer:

A mixer is a non linear device which is used for frequency translation from IF to RF and vice versa. Mixing of two signals generates sum and difference signals and to select there a low pass or a high pass filter is required [13]. In general local oscillator is used as input to up convert or down convert a signal.

In this section we summarized some of the basic components of RF design used in CW radar in detail. This paper is not intended to given an in depth course of RF design but here these components are briefed as they play a vital role in the design of CW radar.

6. Building blocks of Receiver:

The transmitter plays a vital role in CW radar system. This paper deals with simulation design and performance of transmitter. It is generally used to transform a baseband signal into RF signal, later transmits it through antenna.

There are several methods to simulate radar transmitter. Moreover, simulation is done in two ways:

- Frequency translation and
- Power amplification.

A radar transmitter must possess three main features for better performance, they are:

- Accuracy,
- Spectral emission and
- Output power level.

The below represented Fig. 4 shows the transmitter of CW radar system, which is composed of different RF building blocks.

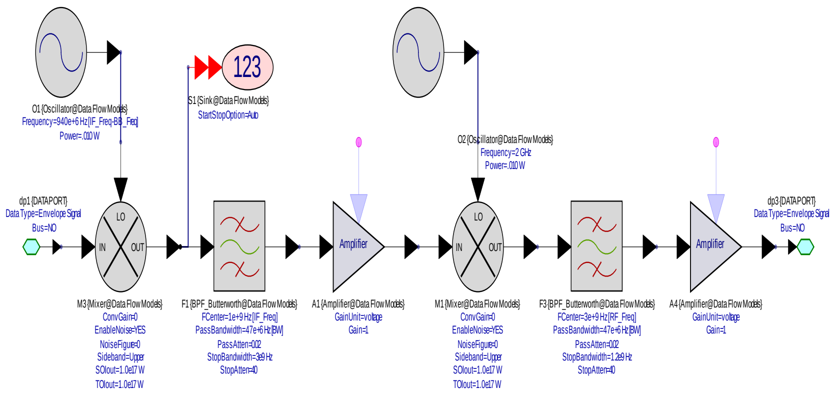

Fig 4. Transmitter of PD radar system

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Generally there are two types of transmitter architectures, which are based on mixer. One is Heterodyne and the other is Homodyne. Here we use heterodyne model, this model uses two frequencies f_1 and f_2, both together undergoes a non linear mixer and gives a new frequencies. The newly obtained frequencies are the sum and difference of the given frequencies that are f_1+f_2 and f_1-f_2 respectively. In many of the cases one of these frequencies is generally used and the other is left out at the mixer output. Here f_1+f_2 frequency is transmitted [14].The Fig.4 shows the architecture of radar transmitter where baseband part of the transmitter consists of CW waveform generator. Table 1 gives the CW waveform configuration.

Table 1. CW waveform configuration

S.No	Parameter	Value
1	Amplitude	1V
2	Period	1s
3	Low frequency	$10e^3$Hz
4	Delta frequency	300MHz
5	Sampling rate	$1e^6$MHz

In the RF subsystem the generated waveform is up converted using mixer. The Fig. 5 is the time domain representation of the waveform transmitted from the transmitter section with amplitude of 4.996 over a range of 1 to 100µs.

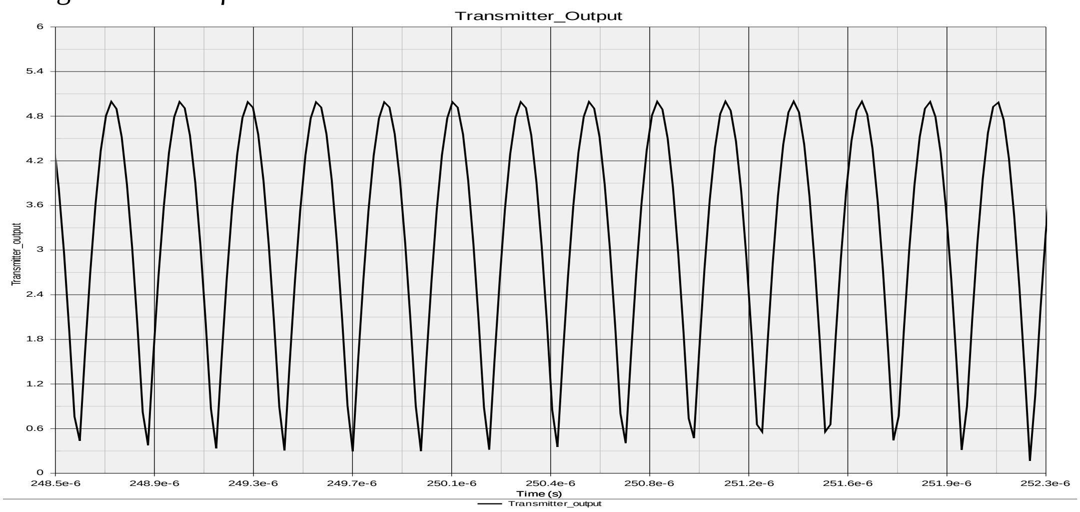

Fig 5. Time Domain Representation of transmitted waveform

7. Radar cross section(RCS)

The target is modeled by changing the Radar Cross Section (RCS). To a great extent work has been done over the years in the field of radar cross-section (RCS) calculation and a number of investigative techniques for its determination are now available [15]. The scattering of electromagnetic energy from a target depends on a number of factors (target geometry, size, shape, orientation (aspect), altitude with respect to radar antenna etc.) whose values are often practically unknown and even time-varying. For these reasons, it has been advantageous to treat the target RCS as a random variable whose characterization has always been a problem of primary concern among radar engineers interested in development of suitable models to be exploited for target detectors analysis. The first target fluctuation models were introduced by Swerling [16] in the 1968 [Note 1] in order to account for random variations in the target RCS. Moreover, since they proved inadequate in describing certain targets, they were generalized in [17] through the use of the chi square distribution. Other kinds of fluctuations have been also proposed in the open literature. Among them mention are the lognormal and the

Weibull distributions. In particular the coherent lognormal and Weibull models are first introduced to characterize both target and clutter returns.
Among all RCS models Swerling Chi target fluctuation model introduced in 1966 by swelling has been used here. In Swerling models Probability Density Function (PDF) and time correlation properties of the radar backscatter from a complex target are modelled [1]. The Swerling models apply to a finite group of pulses. The radar cross section which is used to describe the echo of the target fluctuates as a function of radar grazing angle, polarization and frequency. The parameter and value for Radar target are shown in below table 2.

Table 2. Parameters and Value for Radar Target

S.No	Parameter	Value
1	Type	Chi distribution
2	T step	0.0001s
3	Y (duration)	1s

8. Envelop delay

A delay of 10s is introduced to the output of transmitter. This delayed waveform is the input of the receiver. The purpose of introducing the delay is to simulate a single target at a constant range corresponding to the delay of the transmitted waveform before entering into the receiver [18]. Setting up the delay at the simulation help the designer in two ways:

8.1. Laboratory conservation: Setting up this radar on vehicle for test is time consuming and expensive procedure. The delay introduced will easily verify the basic operation of radar in the laboratory with less cost.

8.2. Control on environment: A delay generated using SystemVue is free from multiple effects and noise from external interferences.

9. Radar clutter generation

Radar clutters are clutters from the objects that are of no interest to the radar mission [17]. The model is timed model to generate the radar clutter, with specified Power Spectral Density (PSD) and Probability Density Functions (PDF). Clutter is used to describe the disturbances from any object that may generate unwanted radar echoes [18]. Clutter is statistically described by PDF which again depends on radar operating frequency and nature of the clutter. The clutter parameter chosen are shown in below table 3.

Table 3. Model parameter for radar clutter simulation

S.No	Parameter	Description	Value
1.	RF frequency	RF carrier frequency	$2.5e^9$
2.	PDF	Clutter amplitude probability density	Ray Leigh
3.	PSD	Clutter power spectral density	Gaussian
4.	Fd	Doppler frequency of PSD	100Hz
5.	Filter length	The PSD filter length	64
6.	Type of clutter	The clutter is coherent or non coherent	Coherent

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In this paper Ray Leigh distribution is used to describe the clutter. This is composed of many small scatters and is given by

$$f(x) = \frac{2x}{V_A}\exp\left(\frac{-x^2}{V_A}\right) : x > 0 \qquad (3)$$

Where V_A is mean square value of x and its value chosen here is 1.
The clutter PSD is periodic with $f_r$as shown in below Fig., Where f_r = 100Hz
The clutter PSD consider here is Gaussian distribution and is given as below:

$$S(f) = \exp\left(\frac{-f_r^{\,2}}{2P_A^{\,2}}\right) \qquad (4)$$

Where P_A is clutter power
The clutter is introduced is shown in the below Fig. 6:

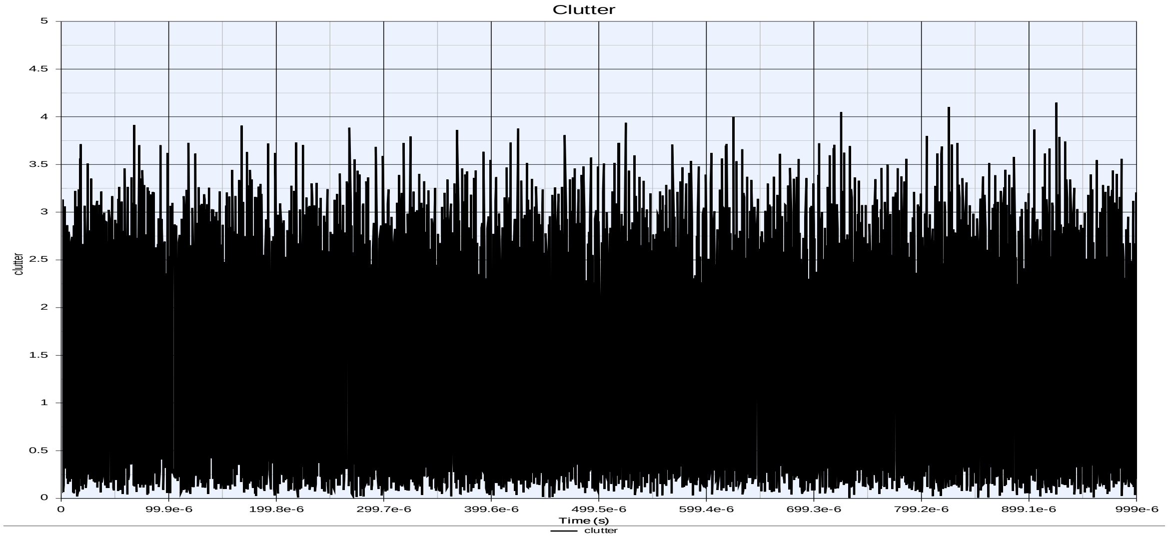

Fig. 6. Time Domain Representation of Clutter

10. Receiver

The receiver takes incoming RF signal and down convert to IF signal. The ability to recollect signal depends on number of factors such as atmospheric noise, competing signals, multi path etc. The main difference between transmitter and receiver is carrier and signal recovery [21]. The frequency and phase (or timing) must be correct in the receiver to recover the transmitted information. In transmitter the RF carrier is generated inside the transmitter, whereas in receiver it approximates where the RF carrier is without having information of the phase (or timing). In general creating a receiver is just like creating an inverse transmitter [22]. Both transmitter and receiver is mirror to each other. SystemVue with more advanced functions is hassle free alternation to create receiver system for CW radar. The CW radar receiver is super heterodyne receiver that collects the echo signal. The echo signals which are in RF range are down converted to IF range using local oscillator. This frequency translation does the heterodyning which gives its name as super heterodyne. It changes incoming signal frequency to IF frequency.

The band pass filter and amplifier supplies most of the gain and narrowband filtering for the received signal. At the receiver the radar clutter and the delay output from transmitter are added and then it is down converted to IF signal. IF signal is again band limited and once again amplified.

The receiver is shown in the below Fig. 7

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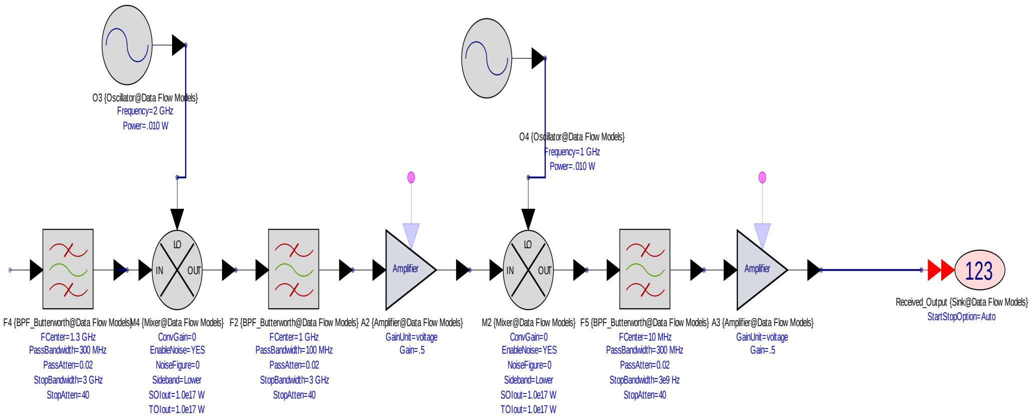

Fig. 7. Receiver of CW radar system

The output of the receiver must be lower than the transmitter because of the clutter introduced and the time domain representation is shown in Fig. 8.

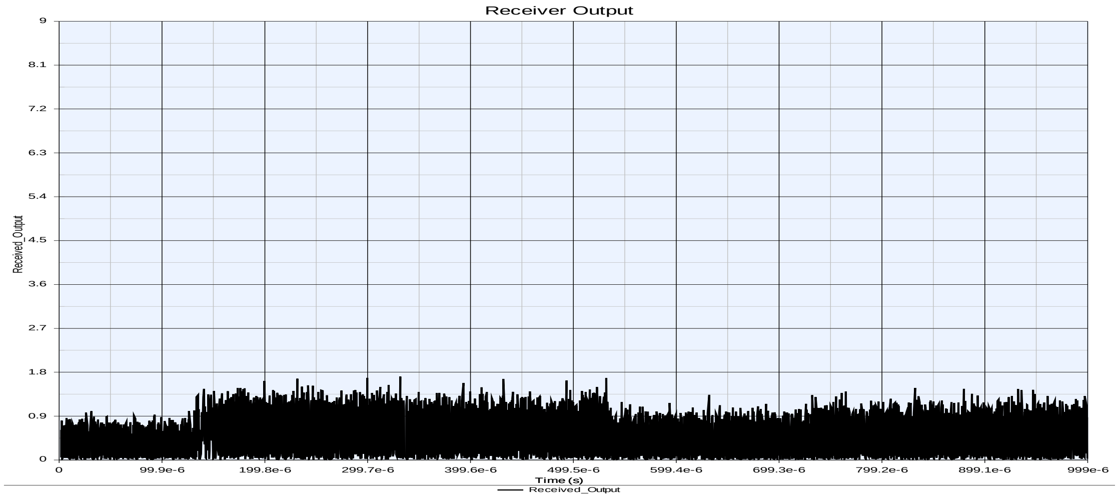

Fig 8. Time domain representation of received signal

11. Simulation results

In this section the results of comparison of transmitter, receiver and clutter are presented. In previous sections the performance of the transmitter, clutter, RCS and receiver were discovered and the results with respect to their performances were shown. For the transmitter its performance is shown in section 6, clutter in section 9 and the receiver performance in section 10. Therefore those results are not repeated here.

After designing, simulating the CW radar system the final response is plotted in Fig. 9 and it shows time domain version of the output's at each stage. As expected the receiver output has less strength because of incorporation of single target RCS and clutter.

The plot in Fig. 9 represents four signals transmitter output, information of clutter, input to the receiver, output of the receiver.

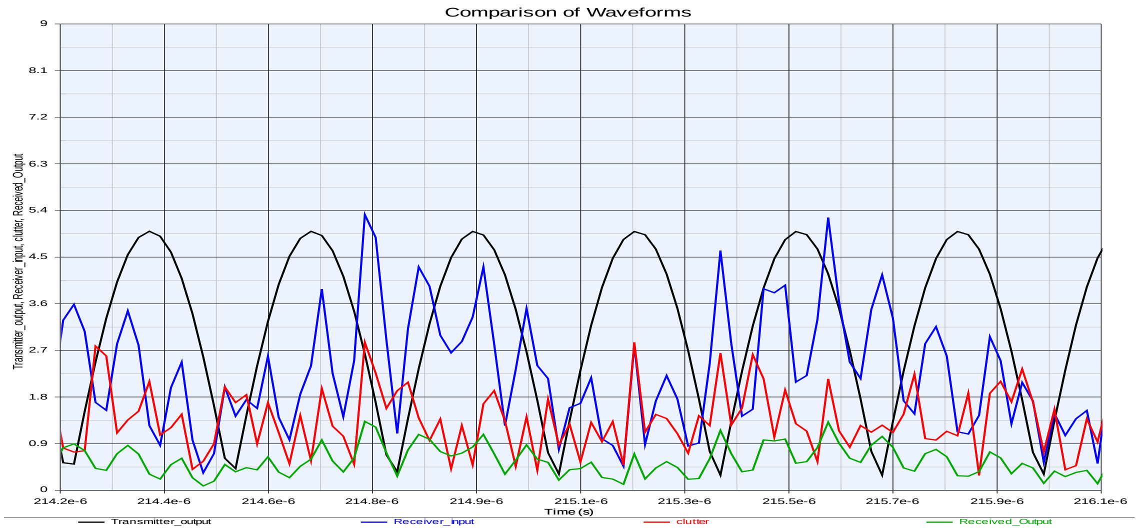

Fig. 9. Comparisons of waveforms

The results in the range 0 - 1000µs showed that receiver output has to b further processed for detection of targets. Some of the signal processing techniques can be introduced in future for processing the receiver output after 2 stage IF amplification. Integrating all the parts in radar provides a small size, low cost, low power consumption and portable solution for design of CW radar system has high range that ensures high performance operation in the presence of clutter. By this one can conclude that the CW radar system operates with high immunity against clutter in automotive applications.

12. Conclusions

Based on the design and simulation of CW radar in this paper the following conclusions can be drawn.

1. CW radar was designed and simulated using SystemVue and found to operate satisfactorily.

2. A CW transmitter was simulated using the variable parameter method and its performance was tested and is exceptionally good. The spectral representation of transmitter led to good signal at the transmitter output. The transmitter simulation was complete with local oscillators, mixers, band pass filters and amplifiers.
3. In real time applications there are more complicated targets and this design of CW radar cannot be observed exactly. Since radar has extended its application in automotive industries where it is very difficult to find real time data. However in SystemVue there are some measurements for Radar Cross Section which helped to model realistic target model.
4. The detailed performance analysis of the proposed CW radar is provided for single target. The results presented so far are based on the fact that the waveform generated is known with single target and need to be analyzed for multiple targets in future.
5. It is a system level simulation; behavioural models are used to describe the clutter. The Chi-Square distribution model and Gaussian Probability Densities are used to model the clutter.
6. Delay of 10s is introduced at the transmitter to verify proper operation of CW radar.
7. A super heterodyne architecture receiver system was chosen because of its capabilities. A 1-1000µs CW receiver using double IF system was simulated and the performance is plotted.

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