A Novel Approach for Design of Receiver front end for Radars

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***Abstract* - Development of a versatile multipurpose receiver system has become essential to meet the requirements of radars and communication systems in aerospace and defense. The existing systems are specific to an application or a system. In order to avoid designing a receiver for each application, it is worth designing a versatile configuration so that the receiver can be realized with minor changes for each requirement. Therefore, in this paper different possible receiver configurations are discussed based on the literature survey. A brief review on three different configurations of the communication receivers is presented. The main focus is made on the front-end system of the receiver. The configuration without RF-IF down converter is found to be more advantageous. Accordingly, simulations are carried out by introducing a suitable filter in C band at 5.8 GHz. The simulation results have confirmed the feasibility of development of a versatile receiver by suitably tuning the front end.**

***Index Terms* - Receiver Design; Aerospace Applications; Analog to Digital Converter; Software Defined Radio [21]; Direct RF Sampling**

1.INTRODUCTION

Radar and satellite communications is one of the important areas in the fields of aerospace and defense. Any communication system generally consists of mainly a transmitter and a receiver. The transmitters are designed based on the frequency requirement of the communication. To receive the signals from different transmission systems, the receivers need to be realized for each requirement. This has resulted in customizing the receivers or re-designing the receivers. However, the development of digital receivers offers certain advantages in terms of programmability and better tuning of the receivers as per the requirements. These digital receivers have become the main subsystems of the pulsed radars. Nowadays, most of the applications in aerospace, defense and civilian areas, pulsed radars are widely being used mainly because of the advantages it offers over other types of radars. Some of the main advantages include the high Signal-to-Noise (S/N) ratio, the rejection of unwanted clutter or echoes using Doppler filters.

With the motive of achieving good target range resolution different data processing techniques were invented and implemented in the development of digital receivers. One of the newly invented techniques is Digital Pulse Compression. This is one of the advanced techniques for processing the radar data.

In the process of digital pulse compression, Linear Frequency Modulated (LFM) signal is used to generate the chirp waveform. This processing system which generates the signal is quite a complex task for the receivers available in the present market. So, there is a need to provide a solution for design of a digital receiver that will address the problem of handling the chirp waveform. For this purpose, it is necessary to develop a generic system which is programmable and can perform multiple functions depending upon the received data and requirement.

In an effort to achieve the above multipurpose systems, there is a need to work on different modules of the system individually, namely, transmitters, receivers, synchronizing clocks, etc. This can be achieved by configuring the systems using commercially available Off-the-Shelf technologies. The study has indicated that the receiver design has to be optimized so that it takes into consideration the overall load on different receiver components including the filters, low noise amplifiers, Analog-to-Digital Converter (ADC) and other digital signal processing units. Increasing the load on any of these components will bring down the performance of the overall receiver. If this load is minimized by introducing a suitable methodology, the data can be easily handled and processed. Therefore, a filter in the RF front end is proposed to improve the SNR and the resolution of the system. Accordingly, the RF front end is redesigned with suitable filters and simulations have been carried out.

The research work that has been carried out and the development of technologies in the digital receivers over the last decade are detailed in the next section. Later, the receiver configurations and the optimization of the front end with and without RF-IF down conversion and the Commercial-Off The-Shelf (COTS) based configurations are presented in detail and the design challenges are also discussed in detail. The detailed study has indicated that without RF-IF down conversion is more advantageous than the other two configurations. In this configuration, a Band pass filter at a frequency of 5.8 GHz is introduced and the simulations are carried out. The results have confirmed that it has significantly improved return loss by 20 dB.

2.RECEIVERS IN COMMUNICATION SYSTEM

Receives are generally used to receive signals of different kinds in communication. The primary function of the receiver is to receive and decode signals and then transform them suitably to process further for the required parameters.

Receiver is an integral part of any communication system. No matter how good a transmitter can be, the receiver should be sensitive and accurate enough to decode the signal parameters. Even though both the transmitter and the receiver are equally important in communication engineering, the receiver is given higher importance as the complexity of the signal increases tremendously by the time the signal reaches from the transmitter to the receiver along with channel noise. Hence, it is the capability of the receiver, to improve the signal from the noise and process the parameters. In order to attain such high parameter accuracies and sensitivities in real time detection and analysis of the radars, system based on digital receivers are proposed in some research studies [2].

Studies have indicated that design and implementation of digital bean forming based compact and flexible L-band digital receiver can handle sampling RF inputs up to 3.3GHz. All the components like the data ports for extraction of data and the interfaces were carefully chosen with an aim to extend the concept for airborne and space-borne platforms [3]. The Field Programmable Gate Arrays (FPGAs) were also considered so that real time implementations of some algorithms are made possible. It is also demonstrated that an FPGA architecture-based approach that uses high speed Analog-to-Digital Converter at 1.5GHz for sampling and digital signal processing in an attempt to target the airborne applications. This is basically to achieve the high-speed sampling rate [4].

Software Defined Radio (SDR) using GNU Radio Platform (an open-source software development kit) and Universal Software Radio Peripheral (USRP) to develop low cost and sophisticated software defined radar is being attempted recently [5-6]. It is also emphasized a reconfigurable nature of the hardware with software based digital signal processing in the Software Defined Radio and to develop a low-cost digital beacon receiver for Ku-band measurements [7]. Further development of a multi-channel receiver system using USRP X300 and GNU Radio for Equatorial Atmosphere Radar has given consistent results by performing a full correlation analysis [8]. Development of low-cost SDR beacon receiver developed with USRP and GNU Radio passed all tests successfully, confirming that it is a reliable measuring system [9]. Thus, USRP can be considered as a possible low-cost replacement for the existing analog receivers.

Practically trade-offs are inevitable. There always exists a trade-off among two or more parameters but the success of such designs will depend on which parameter is given the priority among others. The impact noise figure of the ADC on the receiver performance was also studied to understand the compromise between sensitivity and the dynamic range of an S-band digital receiver [10]. The maximum sensitivity achieved was -85.71 dBm and maximum dynamic range limited by the ADC used was 63.22 dB. The results presented indicate high impracticality to realize a receiver with best dynamic range and sensitivity and hence a compromise was reached between sensitivity of -84.31 dBm and dynamic range of 58.46dB. A 9th order band pass filter at 5.75GHz with a 100 MHz bandwidth has contributed for direct conversion of front-end receiver for WLAN applications [11].

Literature also shows about the elimination of high-speed ADC technology using compressed sensing based random modulator pre-integrator architecture for recovery and reconstruction of the radar signal compressive sampling matching pursuit algorithm [12]. In addition to the ADC part of the digital receiver, the RF front-end should also be optimized to reduce the overall noise that reaches the digital receiver. A N-type Chebyshev 9th order band-pass filter which was optimized in terms of size with its counterpart, 9thorder Chebyshev band-pass filter [13]. Efforts are taken to optimize the RF front-end (especially the narrow band RF filters) in the form of computer simulation in an attempt to eliminate maximum noise in the initial stage without carrying it forward in the receiver chain.

Even though the antenna is not a part of receiver design, some studies have shown that the type of antenna chosen also affects the performance of the receiver [14]. A larger antenna provides better Carrier to Noise Ratio and captures more power compared to smaller antennas and directly affects the receiver performance during noisy environments, thus making the choice of antenna a trade-off between beam widths, required Carrier to Noise level. It is also estimated Half Power Beam Width and Carrier to Noise Level against Frequency and antenna dimension.

Based on the above literature survey, it is understood that different receiver configurations can be worked out to optimize the receiver and also to simplify the design while attempting for better performance.

3.RECEIVER CONFIGURATIONS AND SELECTION

The receiver can be configured in different ways depending on the requirement or application. Each receiver design consists of different stages such as pre-amplification, down-converting(mixers), Intermediate Frequency(IF) amplifiers and demodulating stages. The pre-amplification stage mostly performs the filtering and other pre-processing of the incoming signal at the receiving end.

The pre-amplification stage can be any of the available options like TRF(Tuned Radio Frequency), Regenerative or Super-heterodyne pre-amplification. The main criterion in selecting each of these pre-amplification stages is the bandwidth of the filter. In case of super-heterodyne receivers only band pass filter is used. The design of narrow band pass filter is slightly difficult, and it also tends to be unstable. Nevertheless, narrow band pass filter provides better selectivity and reduced vulnerability to interference.

In the mixers, the selection criteria include the isolation provided, drive level required for the Local Oscillator (LO), gain and production cost. The passive mixers provide good isolation and LO drive and practically no development cost. But the active mixers are available in discrete or IC form and can be built with a low cost. The factors that affect the IF amplifier performance include total IF stages (gain distribution among stages and total gain available), noise figure (sensitivity), gain (stability), bandwidth and frequency (spurious signals and gain). Coherent demodulation may allow reduced noise bandwidth and favour low IF frequency, but non-coherent demodulators have the simplest design.

Every receiver design will have trade-offs as an inherent characteristic. But based on all of the above-mentioned criteria viz., stability, bandwidth, sensitivity, etc. and the application requirements, necessary trade-offs should be made, and the receiver configuration has to be finalized. Some of the stages in the receiver can be included or excluded for the improvement in the system performance or the reduction in complexity of the overall system. So, now there are two configurations to choose. One is with RF-IF down conversion as shown in Figure 1 and the other one is without RF-IF down conversion as shown in Figure 2. RF front-end stage comprises of the low noise amplifiers and filters. The IF down converter stage consists of a mixer for down conversion and IF amplifiers. The analog signal is now digitized using the ADC’s and fed to the on-board FPGA for further processing.

The second configuration has the advantage of lesser complexity in terms of design as there is no down conversion block, but it also means that the digitizing of the analog signal must happen at C-band frequencies. Direct RF Sampling is the process of digitizing the RF signal with an ADC directly without intermediate frequency conversion or baseband conversion. In simple terms, RF signals sampling, ADC can replace a combination of mixers, Local oscillators, IF amplifiers and filters while increasing the software programmability of the system. This requires ADC to operate at very high frequencies of the order of 5-6GHz with a high sampling rate. At present, the availability of faster ADC's such as 14 bit 9 GSPS (Giga Samples Per Second) has reduced the complexity of sampling. This configuration also helps in overcoming the DC offset problem present in the Zero-IF receiver. As there are fewer stages in the receiver design shown in Figure 2, the overall noise figure improves, and the cost significantly comes down. It also eliminates the need for local oscillator as there is no down conversion to any intermediate frequency.

Even though the receiver design complexity in the Figure 1 is less, the advantages of the configuration without down conversion outweigh the advantages of the configuration with down conversion, especially, in the applications such as radar/satellite communication test equipment and can further be improved in terms of time and cost of development by employing Commercial Off-The-Shelf technologies [15] like USRP.

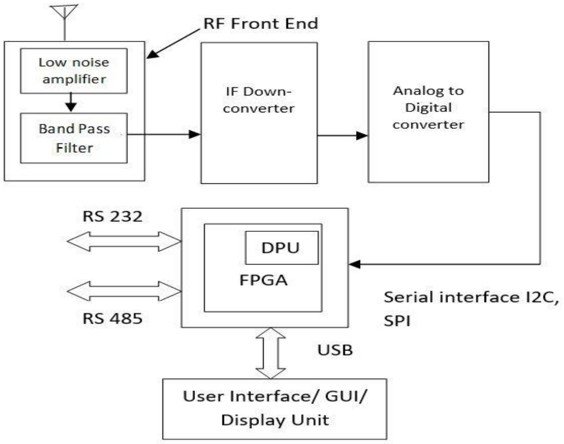

Figure 1. Receiver configuration with RF-IF down conversion.

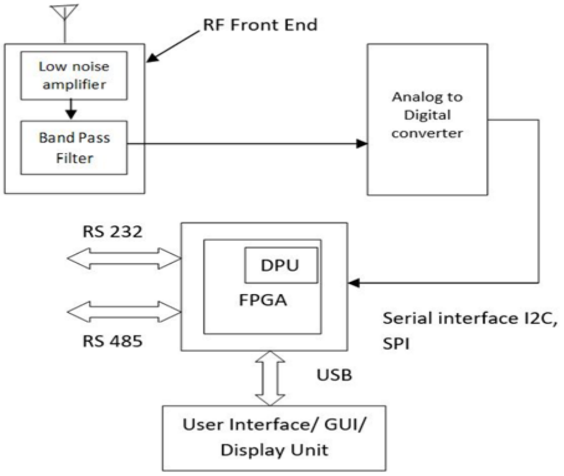

Figure 2. Receiver configuration without RF-IF down conversion.

In Figure 3, the USRP – SDR based technology is shown where the work done in firmware is reduced to a large extent, allowing the development to be done in software. The first step involves developing the independent GNU Radio block using C++ and Python responsible for generating the required waveform using parameters such as Center frequency, bandwidth, Pulse Repetition Frequency (PRF) and the waveform shape. The USRP handles the transmitted and received waveforms and GNU Radio applies the process of demodulation. The data generated is stored in a file by the USRP and is available for further signal processing applications. The USRP can also be interfaced with LabVIEW and MATLAB.

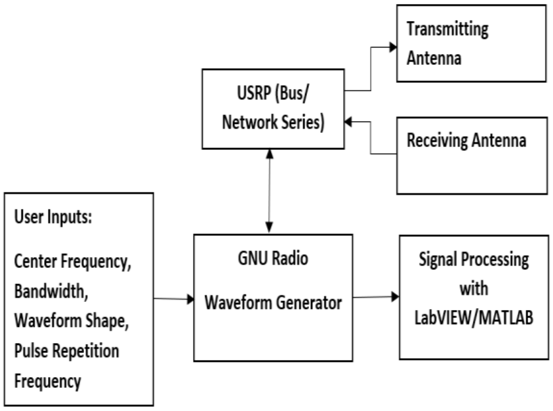

Figure 3. USRP – SDR based Transmitter Receiver architecture.

Based on the above discussions, the receiver is developed without RF-IF down converter and the simulation results are presented in the following chapter.

4.DESIGN ANDSIMULATION RESULTS

As the receiver configuration without RF-IF down conversion has significant advantages over its counterpart, design and implementation of various blocks of the receivers carried out accordingly. Since the proposed application requires working in the C-band (5.7-5.8GHz), the designing of the band pass filter, which is a part of the RF front-end, is planned and executed accordingly. The schematic is shown in the Figure 4.

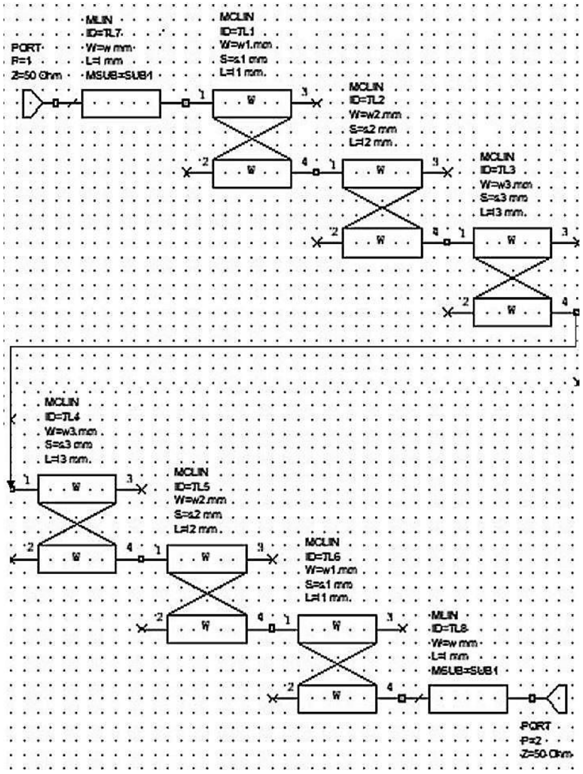

Figure 4. Band-pass filter schematic design at5.8GHz.

The input applied to the filter at the first stage of coupled line band pass filter is 0 dBm. After the 5 stages involved in the filter design, return loss of -40 dB and insertion loss of -6.23 dB is achieved.

The layout of band pass filter is shown in Figure 5. The widths and the spacing between the micro strip lines must be preserved in order to achieve the projected results. The widths of the coupled lines are 0.1822mm, 0.1974mm, 0.1971mm. The spacing between the micro strip lines are 0.6456mm, 2.137mm, 2.697mm as shown in Figure 5.

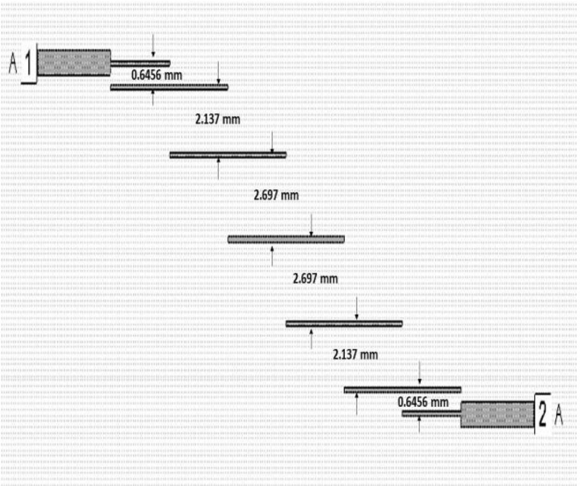

Figure 5. Band-Pass Filter Layout at 5.8GHz

Applied Wave Research (AWR) software is used to simulate the schematic of the band pass filter. A narrow bandwidth 5th order coupled line band pass filter for applications with center frequency at 5.795 GHz was designed. Alumina is considered as a substrate with a dielectric constant of 9.8.

The design of coupled line filters is composed of cascaded micro strip lines. The coupling between two transmission lines is introduced by their proximity to each other. Usually, effects of coupling are undesirable, such as crosstalk, but sometimes as in directional couplers where the objective is to transfer power from one line to the other, is desirable. Wider bandwidth filters generally require tightly coupled lines and are difficult to fabricate whereas narrow bandwidth filters are easier to fabricate.

The frequency response of the 5th order coupled line filter i.e., the measurement results for the S-parameters (S11& S21) is shown in Figure 6.

The designed filter is best matched at the frequency of 5.795 GHz. It can be seen from the Figure 6 that the return loss at this frequency is very low, approximately -40 dB. This is superior to the return losses (-14.17 dB and -11.85 dB) achieved with the 9th order Chebyshev band pass filter on TLY-5A substrate and FR-4 substrate respectively. The insertion loss of -6.23 dB achieved in the proposed design is comparable to the insertion loss of -5.23 dB achieved on TLY-5A substrate but better than -9.67 dB achieved on FR-4 substrate. The designs on TLY-5A substrate [13] and Alumina substrate is achieved similar to 3 dB bandwidth of 84 and 96 MHz respectively whereas the filter designed on the FR-4 substrate [13] has a bandwidth of 388MHz. Hence, the proposed band pass filter performed better than the existing 9th order Chebyshev band pass filter and can further be used in the RF front end part of the receiver configurations.

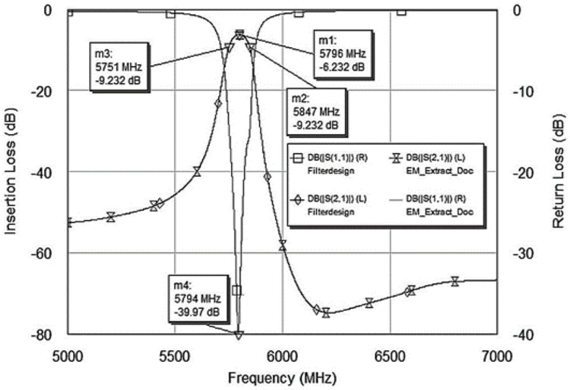

Figure 6. S21 & S11 of the band pass filter

The simulated results of the proposed 5th order coupled line band-pass filter are on par with the designs results of the 9th order band-pass filter [11]. The simulated results are tabulated in the Table 1.

Table 1. Simulated Results at 5.8 GHz

Parameter	Proposed 5th order coupled line BPF	9th order Chebyshev BPF
Center Frequency	5.795 GHz	5.8 GHz
Insertion Loss	-6.232 dB	-9.67 dB
Return Loss	-39.97 dB	-14.17 dB
Bandwidth (3 dB)	96 MHz	96 MHz

5. CONCLUSIONS

The receiver configurations for our applications have been discussed considering the pros and cons and also the availability of high-speed ADC’s for fast RF sampling. In addition to that, the 5th order band pass filter with ~100 MHz bandwidth and acceptable S-parameters has been designed and simulated. The simulated results have confirmed that the proposed receiver configuration i.e., the receiver without RF-IF down conversion and with a band pass filter for a frequency of 5.8 GHz gives a return loss of -39.97 dB and confirms that this design is versatile for different frequencies of the receiver.

Further research will include checking the compatibility of simulated results, programming the FPGA for processing the digitized information. Software Defined Radio (SDR) from Ettus Research is proposed to be utilized to accomplish this. There are different versions of SDR’s like Bus series, Network series and X-series of which Bus series can be utilized as it is a low-cost solution for testing the real time implementation [16-17]. Digital pulse compression techniques can also be used in the above system to enhance the signal detection and improve the range resolution [18].

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