International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 12, Issue 2, pp: (10-15), Month: April - June 2024, Available at: www.researchpublish.com

FPGA Board Ramp Generation for 2 GHz RF Bandwidth in X-Band Application

Vaishnavi D. Kanzarkar[1], Kshitija S. Kayat[1], Akanksha B. Jadhav[1], Pranav kumar Tingare[2], Sampurna De[2], Chinchu Joseph[2], Vineeth Kumar[2], Vanita. P. Patil[1], A Arockia Bazil Raj[2]

[1]Electronics and Telecommunication Engineering, Smt. Kashibai Navale College of Engineering, Vadgaon, Pune, India– 411 041.

[2]Radar Systems Laboratory, Electronics Engineering, Defence Institute of Advance Technology, Pune, India– 411 025.

DOI: https://doi.org/10.5281/zenodo.11112310

Published Date: 04-May-2024

Abstract: **The novel approach to FPGA-based ramp generation adapts for X-Band applications, achieving a remarkable 2 GHz RF bandwidth. The study outlines the design methodology, emphasizing the FPGA's flexibility in generating complex waveforms crucial for X-Band systems. Through extensive experimentation, the proposed solution demonstrates its efficacy in meeting the requirements of X-Band applications, such as radar and communication systems. The research highlights the performance advantages of the FPGA – based ramp generator, including enhanced system agility, reduced hardware complexity, and improved scalability. Furthermore, potential applications and benefits of the developed solution are discussed, showing its significance in advancing the capabilities of FPGA technology in high-frequency RF domains. Overall, this work contributes to the ongoing evolution of FPGA-based solutions for X-Band applications, promising improved performance and versatility in future systems likes wireless communication.**

Keywords: **Field-Programmable Gate Arrays (FPGA), radar, sweep signal, large bandwidth, Linear frequency modulated signal.**

1. INTRODUCTION

High Bandwidth is crucial in RF applications such as radar systems, broadcasting, wireless power transfer, remote sensing, etc. Firstly, it enables faster data transmission rates, which is essential for applications such as wireless communication & data networking [1-3]. With higher bandwidth, more data can be sent and received within a given period, leading to improved performance, reduced latency, and enhanced user experience. Moreover, in crowded RF environments with multiple users or devices accessing the network simultaneously, higher bandwidth helps to alleviate congestion and maintain quality of service for all users. This is particularly important in densely populated areas of busy network environments where efficient spectrum utilization is essential [4-6]. Furthermore, high bandwidth enables the implementation of advanced modulation schemes such as Quadrature Amplitude Modulation (QAM) and Orthogonal Frequency Division Multiplexing (OFDM), which can achieve higher data rates and improved spectral efficiency. Overall, high bandwidth in RF applications ensures efficient data transmission, supports multimedia content, alleviates congestion, and enables the implementation of advanced modulation techniques, thus meeting the growing demands of modern communication systems [7-9].

Radar, short for Radio Detection and Ranging, is a technology that uses radio waves to detect and determine the range, angle, or velocity of objects such as aircraft, ships, spacecraft, vehicles, or even weather formations. It operates by transmitting electromagnetic wave, typically in the microwave frequency range, and then detecting the reflected signals from objects in the environment [10-13]. The system calculates the distance to the target by measuring the time it takes for the signal to return. Radar systems vary in complexity and application, from simple handheld devices for speed enforcement to sophisticated systems used in air traffic control, military surveillance, weather monitoring, and navigation [14-16]. Modern radar systems incorporate advanced signal processing techniques, such as pulse compression and Doppler processing, to enhance their performance in detecting and tracking targets with high accuracy and reliability, even in challenging environments. Radar technology plays a crucial role in various fields, including transportation, defence, meteorology, and scientific research, contributing to safety, security, and efficiency in numerous applications [17-19].

FPGA

It allows for the implementation of complex digital circuits that can be reconfigured on-the fly. Unlike traditional ASICs (Application-Specific Integrated Circuits) which are fixed once manufactured, FPGA circuits can be modified and updated as needed, making them highly adaptable to changing requirements and allowing for rapid prototyping and iteration.

Vivado is a comprehensive design suite developed by Xilinx for designing and programming FPGA and Complex Programmable Logic Devices (CPLDs). It provides a user-friendly interface for designing, implementing, and verifying digital circuits on Xilinx FPGA platforms. Vivado supports various hardware description Language (HDLs) such as VHDL and Verilog, along with high-level synthesis tools for accelerating design productivity. Additionally, it offers advanced features for timing analysis, debugging, and optimization, enabling efficient and robust FPGA designs[20-21].

Basys 3 Board

It’s popular FPGA development board manufactured by Digilent, designed for educational and prototyping purposes. It features a Xilinx Artix-7 chip, which provides a balance of performance, power efficiency, and affordability. The Basys 3 board offers a range of built-in peripherals including switches, LEDs, push-buttons, and seven-segment displays, making it suitable for a wide variety of digital projects. It also includes connectors for expansion modules, enabling users to extend its functionality further. The Basys 3 board is widely used in university courses, hobbyist projects, and professional prototyping due to its ease of use, affordability, and versatility.

2. THEORY & PRINCIPLE

In RF applications, Linear Frequency Modulated (LFM) signals, particularly Linear Frequency Modulated Continuous Wave (LFMCW) signals, plays a major role, notably in radar systems. LFMCW signals are prized for their ability to offer high range resolution, making them indispensable in various applications. These signals are commonly used in Frequency Modulated Continuous Wave (FMCW) radar systems, where their linear frequency variation over time enables precise distance and speed measurements. By analysing the frequency shifts of the reflected signal, LFMCW radars accurately determine the distance to objects, essential for applications such as distance measurement and collision avoidance systems in automotive contexts. LFMCW signals offer distinct advantages such as straightforward hardware implementation, low power consumption, and exceptional resolution, making them a preferred choice for RF systems where precise range and velocity measurements are paramount, solidifying their significance in radar technology and beyond.

Ramp Generation

The ramp function, a real unary function, resembles a ramp in its graph. It can be defined in various ways, such as being 0 for negative inputs and equal to the input for non-negative ones. Additionally, the term “ramp” applies to other function achieved by scaling and shifting, while the specific function discussed here is the unit ramp function, with a slope of 1 and starting at 0.

In mathematical contexts, the ramp function is alternatively referred to as the positive part.

$$r(t) = \{1 \; for \geq 0 \; 0 \; for \; t < 0 \qquad (1)$$

Also

$$r(t) = t\,u(t) \qquad (2)$$

From the above equation, it is clear that the ramp signal is a signal whose magnitude varies linearly. The graphical representation of the continuous-time unit ramp signal is shown in fig.1.

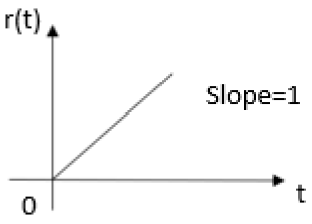

Fig. 1 Ramp Signal

3. EXPERIMENTAL SETUP

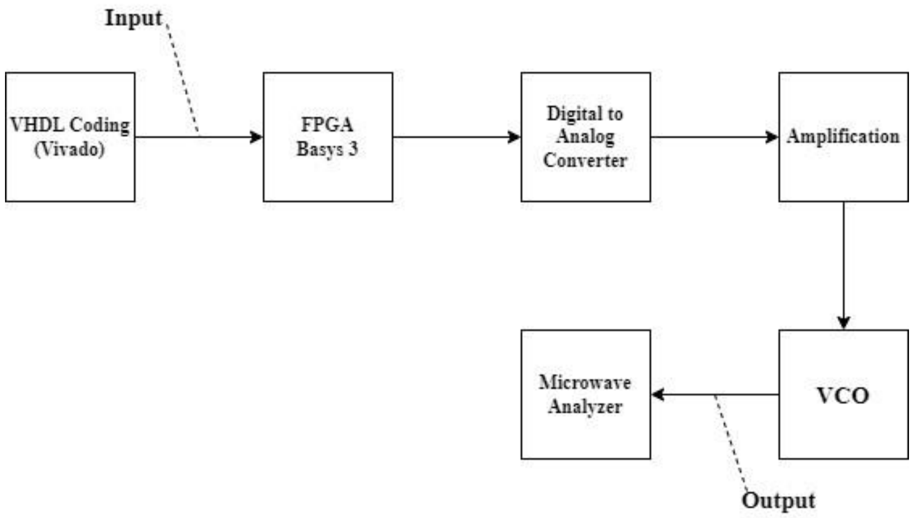

Fig. 2 Block Diagram of Ramp Generation

In the above fig 1, generated the Ramp Signal through Vivado according to the requirement of 8-bit ramp in the VHDL coding. Also, the clock divider code is included in the ramp generation program because the DAC is not capable of handling such high frequency clock. After Synthesizing the code and generating the bit stream file, executed it in the Basys 3 board of FPGA. From these we receive the 8-bit digital output that is further given to the DAC which works like Digital-to-Analog Conversion. An op-amp amplifier circuit is used to amplify the 5 volts ramp signal to 10 volts. We can see the input signal and the amplified signal in the fig 2.

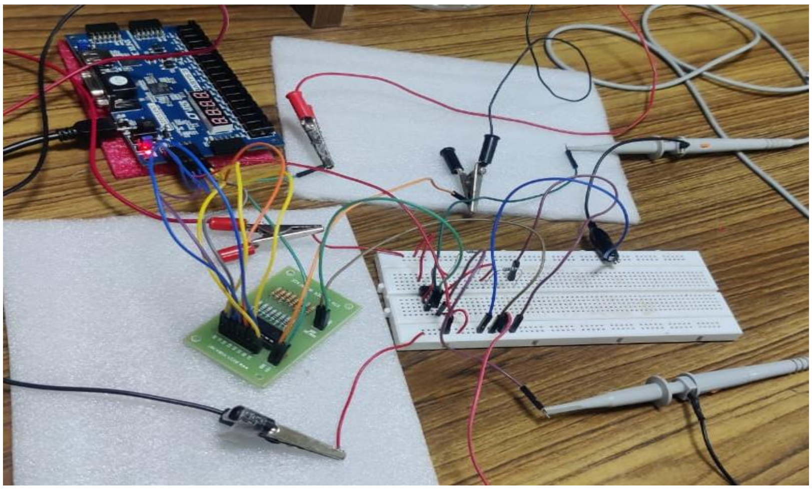

Fig. 3 Experimental Setup

TABLE I Subsystem Details

Sr. No.	Component list	Specification
1.	FPGA Board	Basys 3
2.	DAC	74HC573N
3.	Op-amp IC	LM4558
4.	Resistor	2Kohm
5.	VCO	ZX95 -5400 –S+
6.	DSO	--
7.	Power Supply	--

4. RESULTS

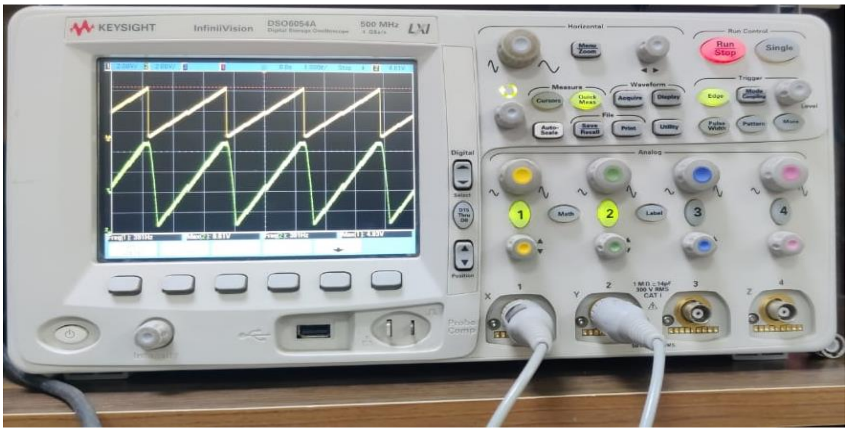

Fig. 4 Ramp Signal Output on DSO

In the DSO output, we observe two distinct ramp signals. The first ramp signal represents the output of the DAC before undergoing any amplification, with a voltage level of 5 volts. This initial signal reflects the raw output generated by the FPGA and converted into an analog voltage waveform by the DAC. Following this stage, the ramp signal undergoes amplification to achieve the desired voltage levels. Upon amplification, the voltage of the ramp waveform is boosted from 5 volts to 10 volts, as evidenced by the second ramp signal visible in the DSO output. This amplified output fulfils the specified requirements, aligning with the intended voltage levels for the application at hand. The clear distinction between the two ramp signals in the DSO output illustrates the effectiveness of the amplification process in achieving the desired voltage amplification, thereby meeting the performance criteria set for the system.

Fig. 5 Bandwidth on Microwave Analyzer

From the above fig. we can observe the 2 GHz bandwidth from the range of 3.5 GHz to 5.5 GHz which is achieved from the Voltage Control Oscillator (VCO). The amplifier output is fed to the VCO and from that VCO we have connected that signal to the Microwave Analyser. The VCO has 3 terminals from which the 2 terminal are of V_{cc} and ground with the supply applied to it was 5 volts. And the third terminal with V_{tune} which is from the amplification circuit. The output voltage which we have received after amplification from the voltage we got the 4 GHz to 5 GHz Frequency.

Fig 6. Bandwidth of X-Band

From the above fig. we can see the X-band frequency which is obtained after the VCO by connecting the multiplier to it. The VCO output frequency is around 3.5 – 5.5 GHz, from the frequency band we generated the X-band range using the multiplier by which received the doubled frequency range which from 7.5 – 11 GHz range.

5. CONCLUSION

Demonstrated the development of the FPGA board ramp for 2 GHz RF bandwidth in X-band applications represents a significant achievement. Through rigorous design and testing, we have successfully demonstrated its capability to efficiency manage the demanding requirements of X-band frequencies. The FPGA technology offers a versatile solution, providing a wide bandwidth while maintaining high performance and reliability. Its implementation opens avenues for enhanced signal processing and improved system efficiency in various industries, including telecommunication and radar systems. Moving forward, continued research efforts should focus on optimizing the FPGA technology, exploring additional functionalities, and extending its applicability across different frequency bands. By leveraging the capabilities of FPGA, we can continue to advance RF engineering and unlock new possibilities in communication and sensing systems.

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