Ikshana : A FMCW Radar Module
Abstract

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I. Introduction

Advancement of technology in various fields like Signal Processing and millimeter-wave (mm-wave) semiconductor technology has led to significant improvements in the automobile industry. Recently, a lot of path-breaking research done for enhancing the performance of Autonomous Vehicles, has given a colossal boost to Advanced Driving Assistance Systems (ADAS). In this context, automotive radar has emerged as a low-cost system that provides robust performance in inclement environmental conditions, such as heavy precipitation, pollution, or bad illumination.

Frequency Modulated Continuous Wave (FMCW) radars are becoming increasingly popular in a variety of industries and applications, including Self-Driving Cars. The reasons for their popularity are because of their accurate short-range measurements, low sensitivity to clutter, low cost, robustness and easy integration. The FMCW Radar Module, *Ikshana*, proposed in this abstract, is planned to be developed using the Vajra(C64-A100, Shakti C-class) SoC developed by IIT Madras. *Ikshana* is a low cost solution, which can be utilized for developing many useful indigenous products, including autonomous vehicles, Night-Vision goggles (for soldiers) etc. (See Section V).

The prospected module will be implemented on Xilinx Arty A7 FPGA using BSV. It is also planned to add some soft-core extensions[1] to the *Swadeshi* processor, like the FFT Block and CSI Block, as the performance and speed are crucial for this module.

II. Review

Rapid advances in technology has given rise to the development of several Automated and autonomous vehicles technologies. One of the most crucial part of the automation is acquiring the knowledge of its surrounding i.e. perception of other vehicles. This is done using ultrasonic sensors, RADARS, LiDAR and cameras or even combination of these. From table I, we can see that RADAR has high range, quiet good Resolution and accuracy, low maintenance and affordable price. And also, with the current research in RADAR technology such as 3D Antenna, Sub-Terahertz & 4D Imaging[1], RADAR alone can be used for perception purpose giving an edge over other technologies[2].

	Ultrasonic	**RADAR**	**LiDAR**	**Cameras**
FOV	Low	Medium	Medium or High	Medium or High
Max Range	Low	High	High	Medium or High
Accuracy	Low	Medium	High	Medium
Resolution	Low	Medium	Medium	High
Size	Small	Small	Medium	Small
Weather Affection	Low	Low	Medium	High
Maintenance	Medium	Low	Medium	Medium
Price	Low	Medium	High	Medium or High

Table I: Main features of sensors used in perception systems in Automated and autonomous vehicles technologies[3][4]

From figure 1 we can see maximum range and FOV of current RADAR technology for different types of RADAR. As we already know that range resolution of radar is inversely proportional to the chirp BW, and most of the automotive RADAR uses 4GHz BW which has a resolution of 3.75cm, which is quiet a good value. Angle resolution is inversely proportional to number of receivers (which is limited in most of the cases), so virtual antenna concept can used here for increasing the resolution. This can be done using the following Multiplexing techniques.

- Time division multiplexing[5] – Velocity resolution decreases.
- Frequency Multiplexing[5] – Requires a larger spectrum (which is not available).
- Binary Phase Modulation[5] – Requires much higher computing power.

[1]Note that these extensions can be utilized for many different applications

III. Theoretical Background

FMCW Radar stands for Frequency Modulated Continuous Wave (FMCW) Radio Detection And Ranging (Radar). It is transmitting a continuous carrier modulated linearly increasing frequency with time known as *Up-chirp* and similarly, linearly decreasing frequency known as *Down-chirp*.[6]

Frequency is modulating over carrier frequency f_c with bandwidth as B as shown in the figure 2. The signal is being transmitted over chirp time T_s from the transmitting antenna, same will be reflected from the object and received at receiver after few delay of time $t_d = \frac{2R}{c}$ [6] as shown in the figure 2.

In the case of stationary target, difference between transmitted and received signal contains single frequency component named as beat frequency f_b which is almost constant for certain amount of time but in the case of moving targets, Doppler Frequency shift[2] f_d should be considered along with Beat frequency f_b[6] that will lead to two different frequency for both Up-chirp and down chirp known as f_{bu} and f_{bd} respectively but that can't be distinguished properly in FFT plot because of smaller difference.[7] By equating slope in the figure 2,

$$\frac{B}{T_s} = \frac{f_b}{(\frac{2R}{c})}$$

$$\implies \boxed{R = \frac{f_b T_s}{2B} c}$$

where,
B is sweep bandwidth
T_s is chirp time
R is Relative distance between Radar and object **Range**
f_b is beat frequnecy measured from FFT plot
c is speed of light

For measuring velocity, need to detect change in the phase value on multiple chirps because phase can be sensitive enough to detect minor change in the range as shown in the figure 3.[7]

Here,

[2]Doppler shift can cause frequency shift of amount f_d depends on relative motion of Radar and object.

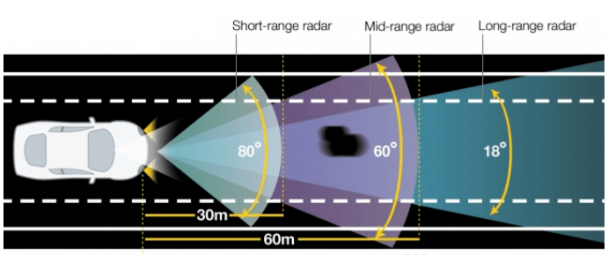

Figure 1: Current RADAR Technology[1]

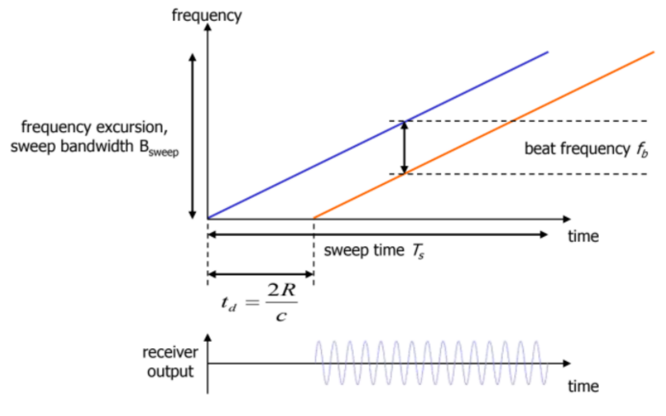

Figure 2: Frequency chirp diagram of FMCW radar[6]

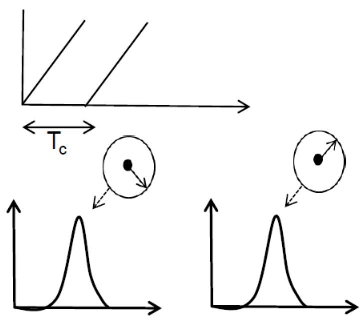

Figure 3: Frequency chirp diagram of FMCW radar for velocity measurement[7]

$$\Delta\phi = \frac{4\pi}{\lambda}(V_r T_c)$$

$$\implies \boxed{V_r = \frac{\lambda \Delta\phi}{4\pi T_c}}$$

where,
T_c is chirp time
V_r is relative velocity of Radar and object **(Relative Velocity)**
$\Delta\phi$ is the difference in the phase value on multiple chirp measured form FFT plot
λ is wavelength corresponds to carrier frequency

Similarly Angle can be measured by phase difference between *multiple receiver data* as shown in the figure 4.[7]

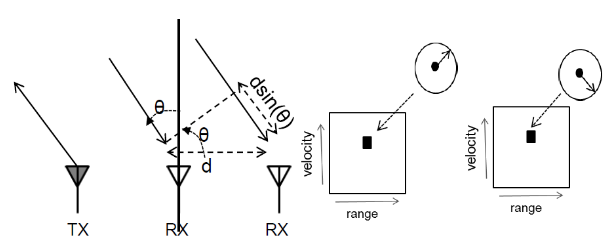

Figure 4: Receiver antenna part of FMCW radar for angle measurement[7]

Here,

$$\Delta\phi = \frac{2\pi d sin(\theta)}{\lambda}$$

$$\implies \boxed{\theta = sin^{-1}(\frac{\lambda\Delta\phi}{2\pi d})}$$

where,
$\Delta\phi$ is the difference in the phase value on multiple receiver data measured form FFT plot
θ is **Angle of Arrival** of signal coming from object as shown in figure 4
d is distance between two consecutive receiver antenna
λ is wavelength corresponds to carrier frequency

IV. An Outline of the Methodology

Ikshana consists of two major modules, namely: Transceiver module and SoC module (consisting of *Swadeshi Processor*), as can be seen in Fig. 6. The generated frame of chirps is modulated and transmitted using the transmitter antennae present in the transceiver module, after filtering and amplifying it. The received signal consists of the required information encoded in it, about the objects present in its *immediate* surroundings (See Section III). This received data is filtered, amplified and is given as an input to a mixer, whose output is an IF (Intermediate/Beat Frequency) signal after being filtered again. The signal is then *digitized* in the ADC of the transceiver module before it is sent to the SoC through the CSI2 interface[3]. The received data is sent to the *CSI2* block in the SoC module, where it is preprocessed (data depacketization and segregation) and sent to the *FFT* block for computing the Range FFT (See Section III).

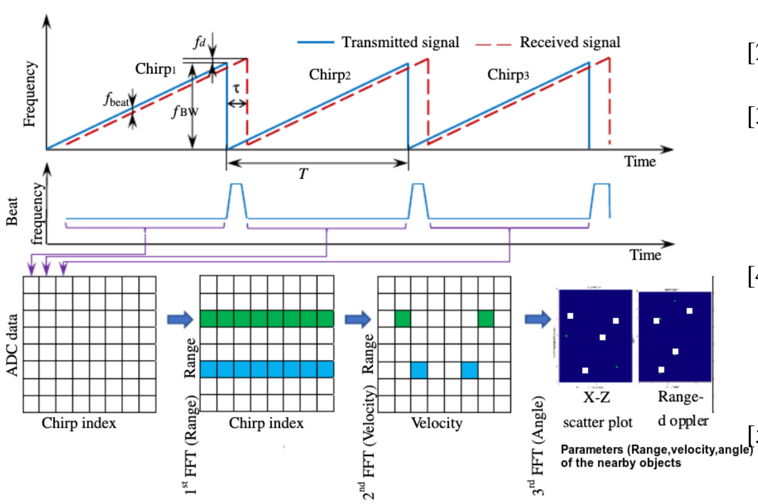

Figure 5: An example describing the various steps involved in the process of the methodology, being discussed in section IV [8]

[3]Note that, the SPI interface is used for interrupt signals and control signals, from SoC to Transceiver module and vice versa

A peak detection of this sequence of Range FFT data (for each chirp) is performed. Then, the Range-Velocity FFT (Doppler FFT or 2D FFT) is performed on the sequence of phasors corresponding to these peaks, whose peaks give us a list of possible *Range-Velocity* pairs[4]. Further to estimate the azimuthal angle (θ) of the objects in vicinity, a similar process involving computation of another level of FFT called Range-Velocity-Angle (3D FFT) is performed on the corresponding phase data of peaks[5]. This process at the end results in a list of (R, V, θ) tuples, corresponding to the *Range*,*Velocity* and *Azimuthal angle* of possible targets. These parameters are then sent to the Display unit which is planned to be displayed dynamically(using scatter plots and tables) on the monitor by using VGA connector.

V. Applications

Ikshana can be used in wide variety of applications in innumerable fields, some of which are being discussed below:

- *Autonomous Vehicles*: Parameters estimated can be additional inputs to DL/AI models, which can help in collision detection, cross-traffic alert, adaptive cruise control etc., even in harsh conditions.
- *Assistance for Visually-impaired*: Low cost and portable multitarget warning systems can be built using *Ikshana* and RGB-depth sensors[8].
- *RADAR Altimeter*: Data from *Ikshana* can prove to be inexpensive during landing of aircrafts and spacecrafts.
- *Non-Contact Measurement*: Applications like Liquid Level measurement, wall-penetrating radar for imaging and detection, human vital-sign detection and measurement etc.

References

[1] FutureBridge, "Advancements in automotive radars," https://www.futurebridge.com/uncategorized/advancements-in-automotive-radars/, 2020.
[2] Maria S. Greco, "Automotive radar," *2012 IEEE Radar Conference, May 7-11, Atlanta*, vol. 8, 2012.
[3] F. Rosique, P. J. Navarro, C. Fernández, and A. Padilla, "A systematic review of perception system and simulators for autonomous vehicles research," *Sensors*, vol. 19, no. 3, p. 1–29, Feb 2019. [Online]. Available: https://www.mdpi.com/1424-8220/19/3/648/pdf
[4] Dr. Stéphane Elisabeth, Cédric Malaquin, "How will radar sensor technology shape cars of the future?" https://www.electronicdesign.com/markets/automotive/article/21806443/how-will-radar-sensor-technology-shape-cars-of-the-future.
[5] Tutorials Point, "Digital communication - phase shift keying," https://www.tutorialspoint.com/digital_communication/digital_communication_phase_shift_keying.htm.

[4]Peaks in the 2D *RV* plot
[5]Peak Detection on 2D FFT data from spatially distributed multiple receivers

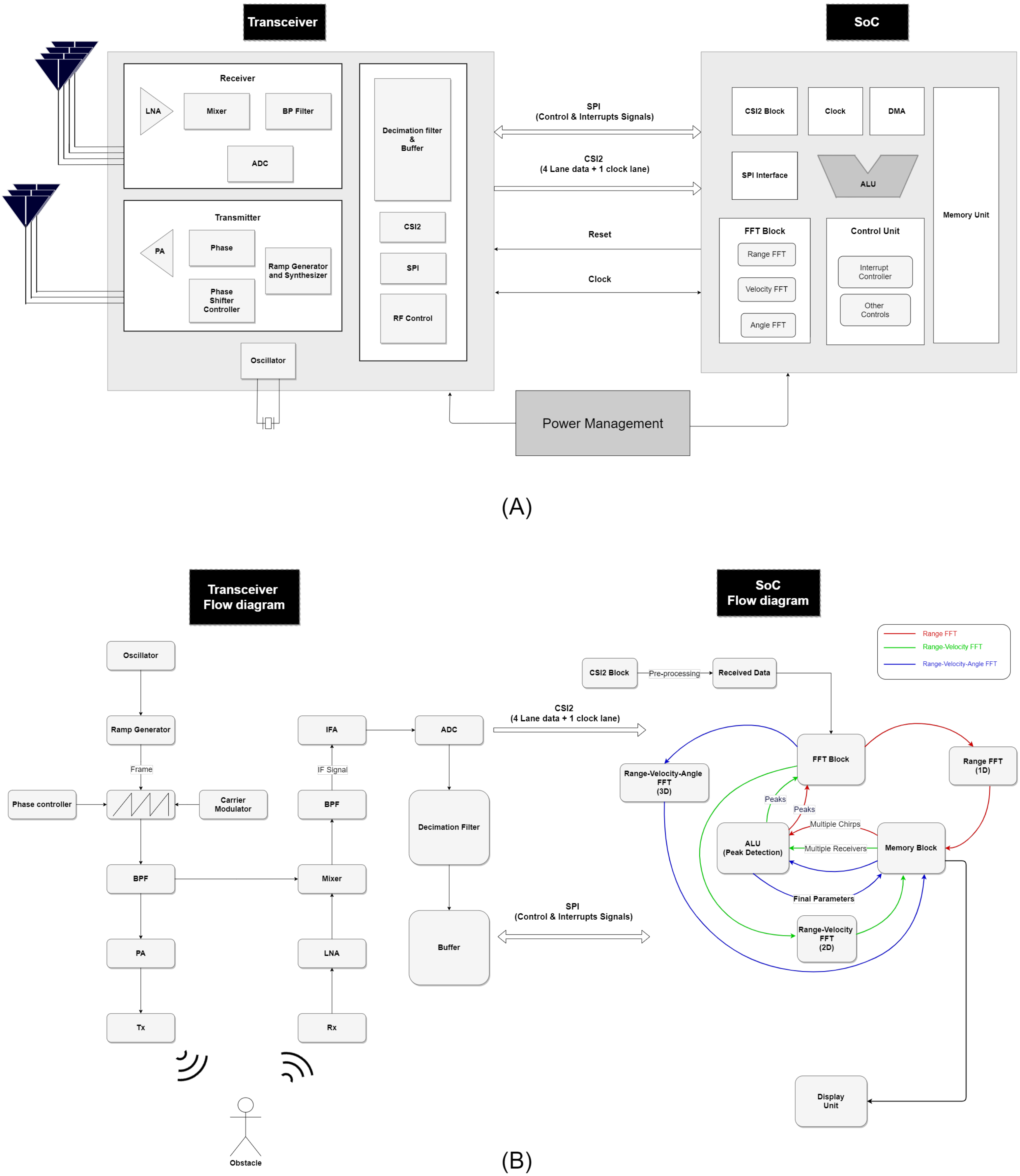

Figure 6: (A) High Level Block diagram representation of the Transceiver and SoC Modules in *Ikshana* (B) Flow Diagram representation of various steps involved in the working of Transceiver and SoC Modules of *Ikshana*

[6] Tobias Otto, "Principle of fmcw radars," https://www.slideshare.net/tobiasotto/principle-of-fmcw-radars, 2018.

[7] Sandeep Rao, "Introduction to mmwave sensing: Fmcw radars," https://training.ti.com/sites/default/files/docs/mmwaveSensing-FMCW-offlineviewing_3.pdf, 2018.

[8] N. Long, K. Wang, R. Cheng, K. Yang, H. Weijian, and J. Bai, "Assisting the visually impaired: Multitarget warning through millimeter wave radar and rgb-depth sensors," *Journal of Electronic Imaging*, vol. 28, p. 1, 02 2019.