

# FPGA BASED VEHICLE TO VEHICLE COMMUNICATION IN SPARTAN 3E

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## Abstract

This paper presents economic and reconfigurable RF based wireless communication at 2.4 GHz between two vehicles. It implements digital VLSI using two Spartan 3E FPGAs, where one vehicle receives the information of another vehicle and shares its own information to another vehicle. The information includes vehicle's speed, location, heading and its operation, such as braking status and turning status. It implements autonomous vehicle technology. In this work, FPGA is used as central signal processing unit which is interfaced with two microcontrollers (ATmega328P). Microcontroller-1 is interfaced with compass module, GPS module, DF Player mini and nRF24L01 module. This microcontroller determines the relative position and the relative heading as seen from one vehicle to another. Microcontroller-2 is used to measure the speed of vehicle digitally. The resulting data from these microcontrollers are transmitted separately and serially through UART interface to FPGA. At FPGA, different signal processing such as speed comparison, turn comparison, distance range measurement and vehicle operation processing, are carried out to generate the voice announcement command, warning signals, event signals, and such outputs are utilized to warn drivers about potential accidents and prevent crashes before event happens.

**Keywords:** Vehicular communication, FPGA, Autonomous vehicle technology.

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## 1. Introduction

Vehicular communication is one of the world wide latest and popular communication methods and rapidly emerging communication system along with the evolving technologies, such as artificial intelligence (AI) and internet of things (IoT). This has revolutionized the transportation system. It is also called as smart transportation. V2V is the acronym of the vehicle to vehicle communication, where vehicles are communicated to each other, emphasizing the prevention of road accidents.

Many cars already have instruments that use radar or ultrasonic obstacles or vehicles. These sensors are limited to few car lengths, and they cannot see past the nearest obstruction (Knight, 2015). The remarkable factor of this communication is wireless communication that can be implemented at low cost with efficient wireless communication protocol.

There are many other activities, but it is certain that vehicle-to-vehicle communication has the potential to play a significant role in the future of safe driving (K. Farkas, 2006). If preventive measures are not taken road death is likely to change to the third-leading cause of death in 2020 from ninth place in 1990 (Peden, et al., 2004). A study from the American Automobile Association (AAA) concluded that car crashes cost the United States \$300 billion per year (Anon., 2011). The deaths caused by car crashes are in principle avoidable. The U.S. Department of Transportation (DOT) states that 21,000 of the annual 43,000 road accident deaths in the US are caused by roadway departures and intersection-related incidents. Studies show that in Western Europe a mere 5 km/h decrease on average vehicle speeds could result in 25% decrease in deaths. V2V is currently in active development by General Motors, which demonstrated the system in 2006 using Cadillac vehicles. Automakers working on V2V includes BMW, Daimler, Honda, Audi, Toyota, Volvo and the Car-to-Car communication consortium (Vehicles, 2015). In December 2016, the US DOT proposed draft rules that would gradually make V2V

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(Received: January 09, 2020 Accepted: August 02, 2020)



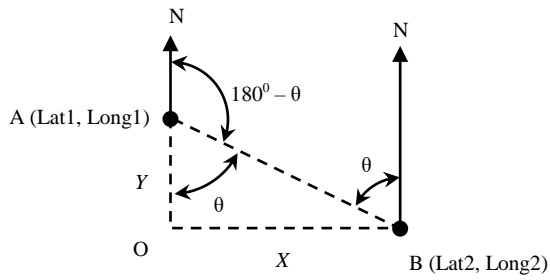


Fig. 2 Determination of bearing

$$\text{Bearing, } \theta = \text{Tan}^{-1}(X/Y) \quad (1)$$

Lat1 = Latitude of A, Lat2 = Latitude of B

Long1 = Longitude of A, Long2 = Longitude of B

$$X = \cos(\text{Lat}2) * \sin(\Delta\text{Long}) \quad (2)$$

$$Y = \cos(\text{Lat}1) * \sin(\text{Lat}2) - \sin(\text{Lat}1) * \cos(\text{Lat}2) * \cos(\Delta\text{Long}) \quad (3)$$

Distance between A and B by Haversine formula:

$$d = R * c \quad (4)$$

where, R = Radius of earth

$$c = 2 * \text{atan}2(\sqrt{a}, \sqrt{1 - a}) \quad (5)$$

$$a = \sin^2(\Delta\text{Lat}/2) + \cos \text{Lat}1 * \cos \text{Lat}2 * \sin^2(\Delta\text{Long}/2) \quad (6)$$

### Measurement of Heading

Heading gives the direction of motion of object. Heading is determined according true north by correcting using magnetic declination. Heading( $\theta$ ) is measured as:

$$\theta = \text{atan}2(m_y, m_x)$$

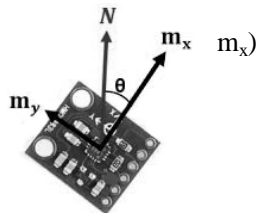


Fig. 3 Determination of Heading

### CASE I

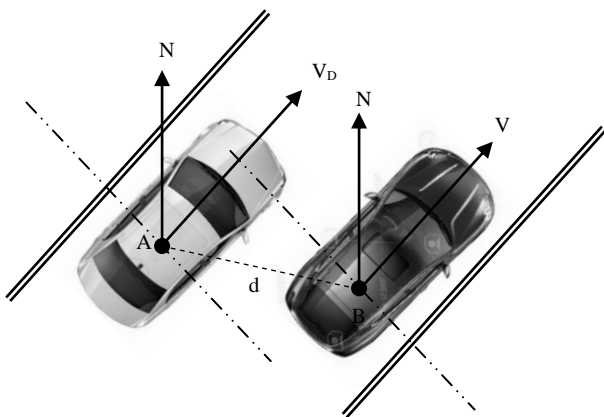


Fig. 4 Relative position between vehicles A and B

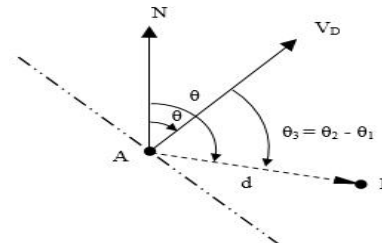
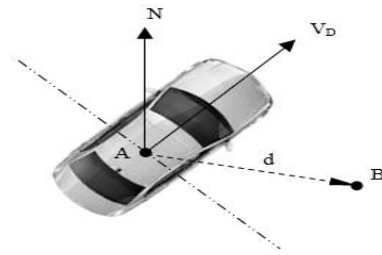


Fig. 5 Relative position of vehicle B (respect to A)

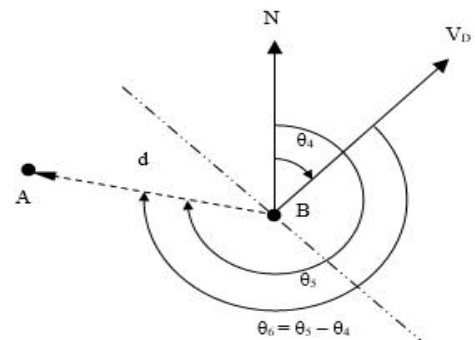
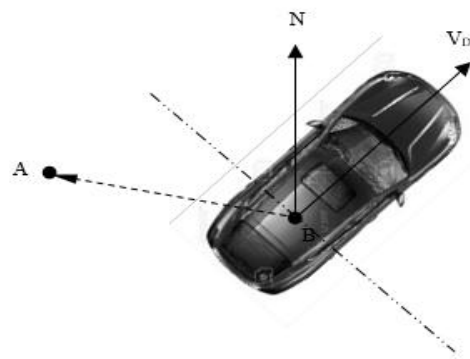


Fig.6 Relative position of vehicle A (respect to B)

Where, N = Magnetic north

VD = Vehicle Direction

d = Distance between to vehicles

A= GPS Position of vehicle A

B = GPS Position of vehicle B

$\theta_1$  = Heading of vehicle A (compass reading)

$\theta_2$  = Bearing between P and Q with respect to N

$\theta_3 = \theta_2 - \theta_1$  = location of B with respect to VD of A

$\theta_4$  = Heading of vehicle B (Compass reading)

$\theta_5$  = Bearing between P and Q with respect to N

$\theta_6 = \theta_5 - \theta_4$  = location of vehicle A with respect to VD of vehicle B

**CASE II**

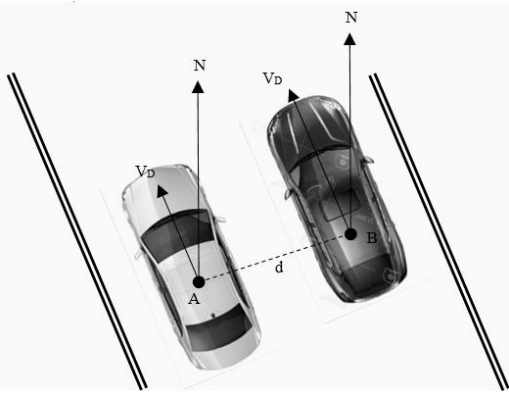


Fig. 7 Relative position between vehicles A and B

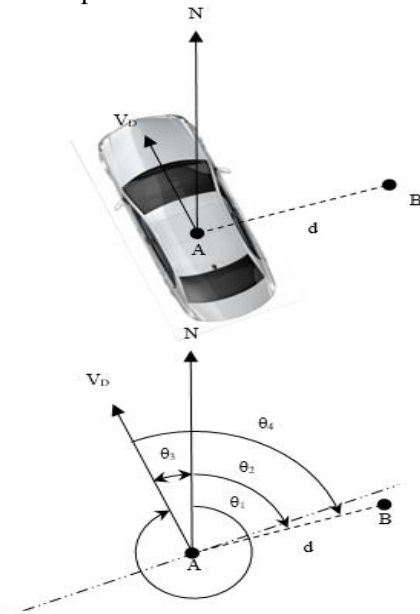


Fig. 8 Relative position of vehicle B (respect to A)

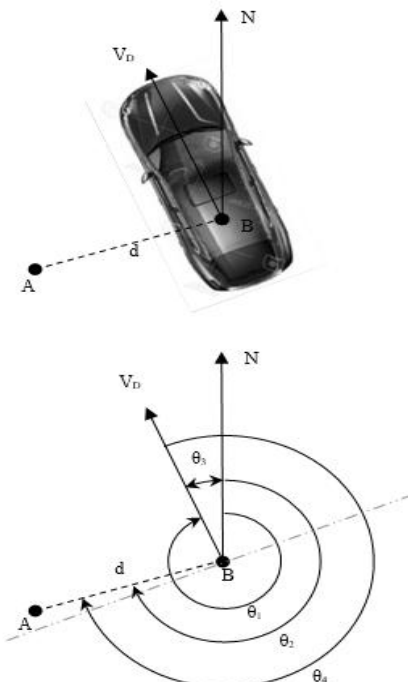


Fig. 9 Relative position of vehicle A (respect to B)

$\theta_1$  = Heading of vehicle A (Compass reading)  
 $\theta_2$  = Bearing between A and B with respect to N  
 $\theta_3 = 3600 - \theta_1$   
 $\theta_4 = \theta_3 - \theta_2$  = Location of vehicle B with respect to VD  
 Positions are 8 bit coded and then transmitted to FPGA. It is depicted as following:

Table 1: Binary coding of relative position

Position	8 bit binary code
Front	00000001
Right Corner	00000010
Right Side	00000011
Right Blind Spot	00000100
Behind	00000101
Left Blind Spot	00000110
Left Side	00000111
Left Corner	00001000

The heading difference (HD) is determined in clockwise direction and is also coded in 8 bit form and transmitted to FPGA. There are four possible heading differences, i.e. 0, 90, 180 and 270. This heading difference has its meaning. The HD 0 means both vehicles are moving same direction. HD 180 means vehicles are approaching to each other from opposite direction. HD 90 means vehicles are approaching to intersection from left side while HD 270 states vehicles are approaching to intersection from right side. If  $V_{DA}$  and  $V_{DB}$  be the heading of vehicle A and B respectively, then following cases considered before determining relative heading;

- Case 1: Relative heading, as seen from vehicle A
  - Condition 1:  $V_{DA} > V_{DB}$ ;  $HD = 3600 - V_{DA} + V_{DB}$
  - Condition 2:  $V_{DA} < V_{DB}$ ;  $HD = V_{DB} - V_{DA}$
- Case 2: Relative heading, as seen from vehicle B
  - Condition 1:  $V_{DB} > V_{DA}$ ;  $HD = 3600 - V_{DB} + V_{DA}$
  - Condition 2:  $V_{DB} < V_{DA}$ ;  $HD = V_{DA} - V_{DB}$

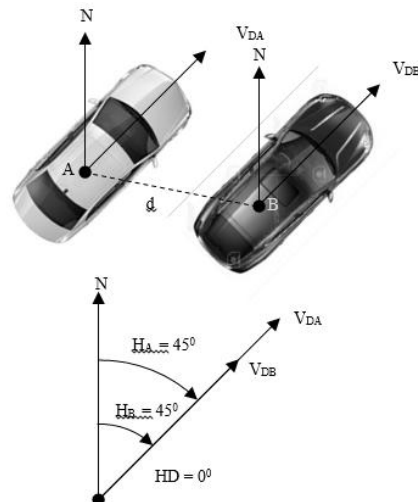


Fig. 10 Determination of heading difference

The net heading as seen from both vehicles to each other =  $450 - 450$

HD = 0

That is, vehicles are moving in same direction

**Scenario 2**

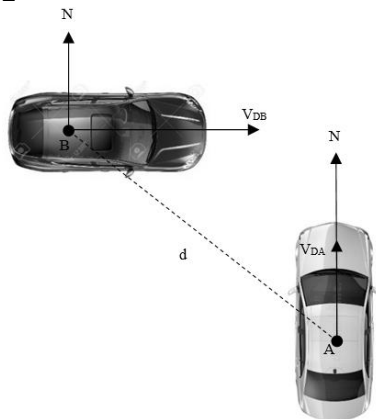


Fig. 11 Determination of HD at intersection

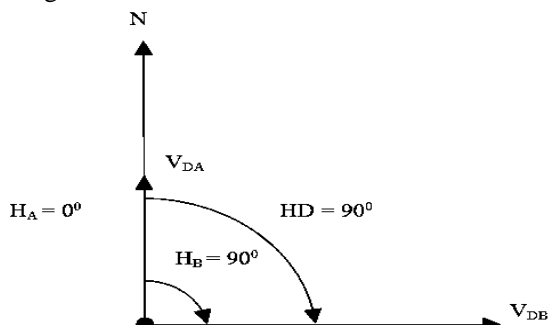


Fig. 12 Equivalent diagram of determination of HD at intersection seen from vehicle A

The net heading (seen from vehicle A in clockwise direction) =  $900 - 00 = 900$

HD = 900

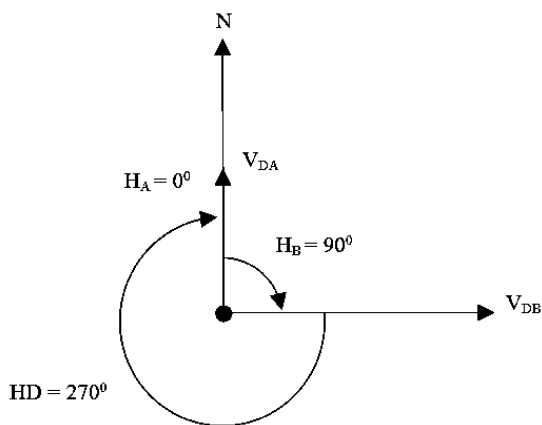


Fig. 13 Equivalent diagram of determination of HD at intersection seen from vehicle B

The net heading (seen from vehicle B in clockwise direction) =  $3600 - 900 - 00 = 2700 = HD$

i.e, vehicle A is approaching intersection from right  
**Scenario 3**

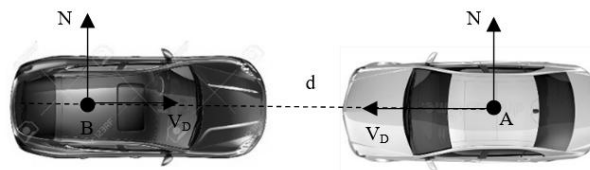


Fig. 14 Determination of HD when vehicles are approaching to each other

HD (from A in clockwise) =  $3600 - 2700 + 900 = 1800$

HD (seen from B in clockwise) =  $2700 - 900 = 1800$

Heading difference is transmitted to FPGA in coded form as shown in table.

Table 2: Binary coding of HD

Dec	8 bit binary number		Description
	HD	DR	
140	1000	1100	HD 0 ;same direction within Distance Range (DR)
172	1010	1100	HD 90;approaching intersection from left within DR
188	1011	1100	HD 180;approaching from opposite within DR
236	1110	1100	HD 270;approaching intersection from right within DR
131	1000	0011	HD 0;same direction not within DR
163	1010	0011	HD 90;approaching intersection from left not within DR
179	1011	0011	HD 180;approaching from opposite not within DR
227	1110	0011	HD 270;approaching intersection from right not within DR

**3. Result and Discussion**

**3.1. FPGA Implementation**

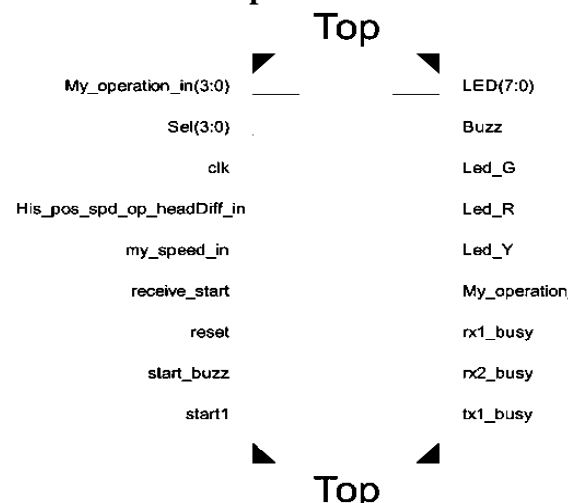


Fig. 15 Schematic of Top Module

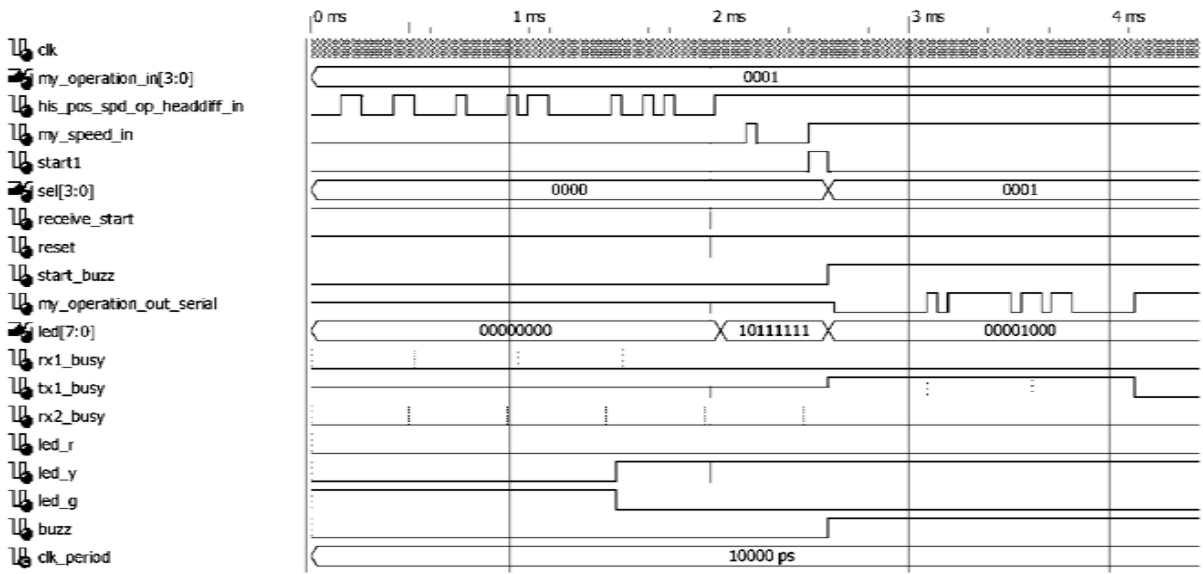


Fig. 16 Simulation output of Top module

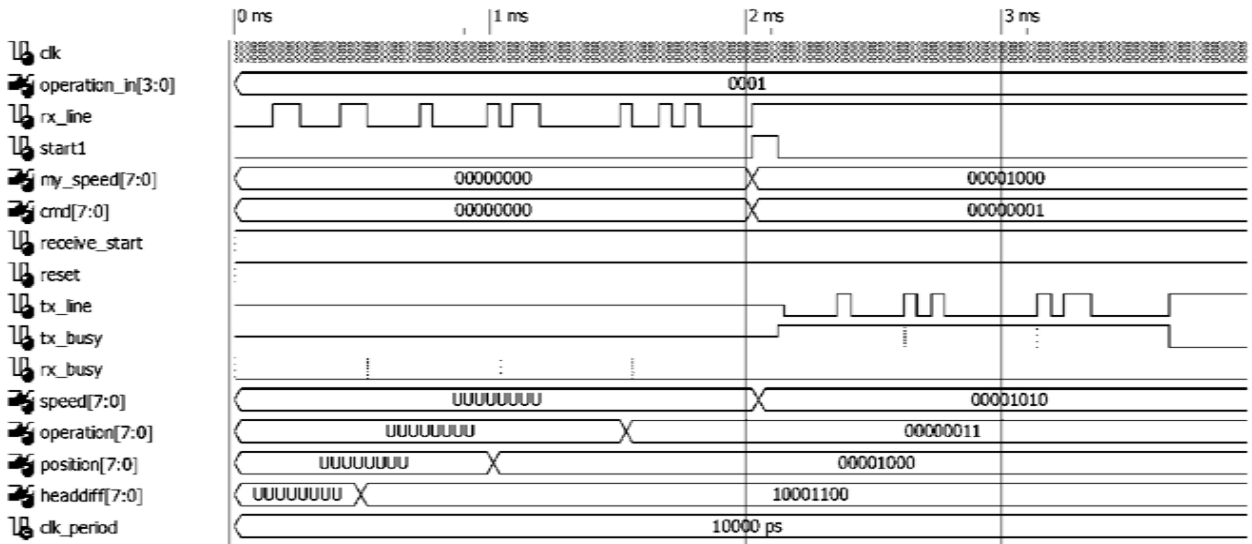


Fig. 17 Simulation output of Module 1

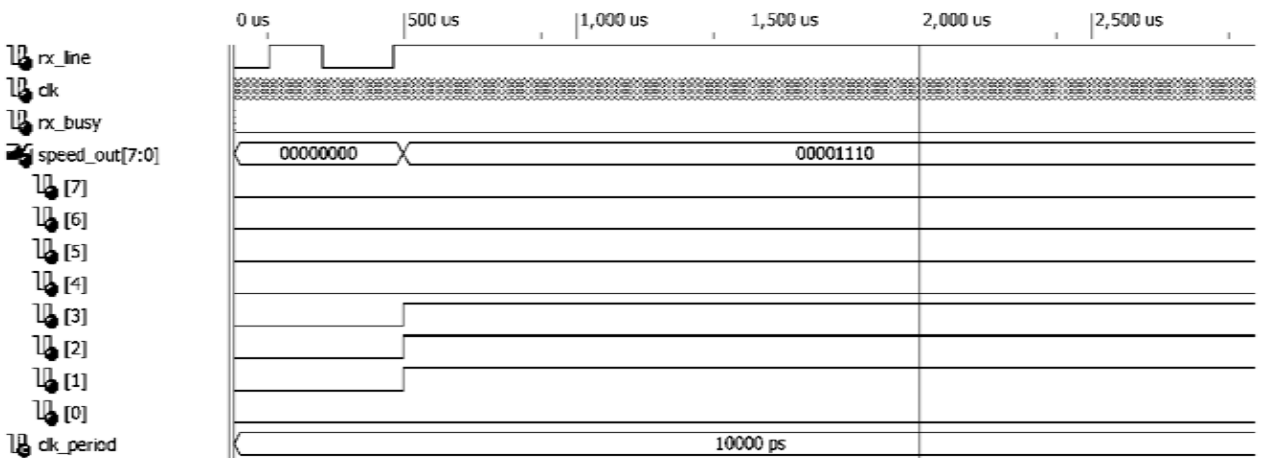


Fig. 18 Simulation output of Module 2

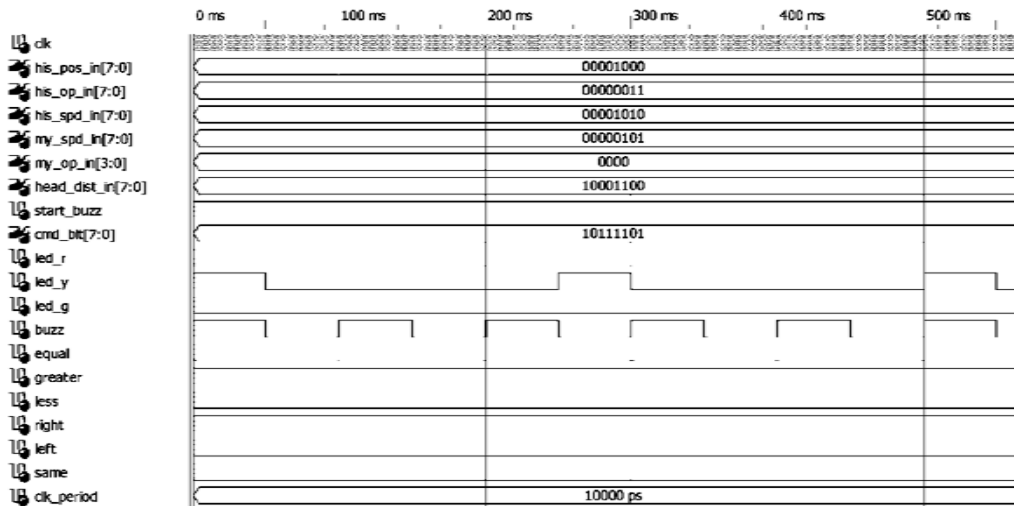


Fig. 19 Simulation output of Module 2

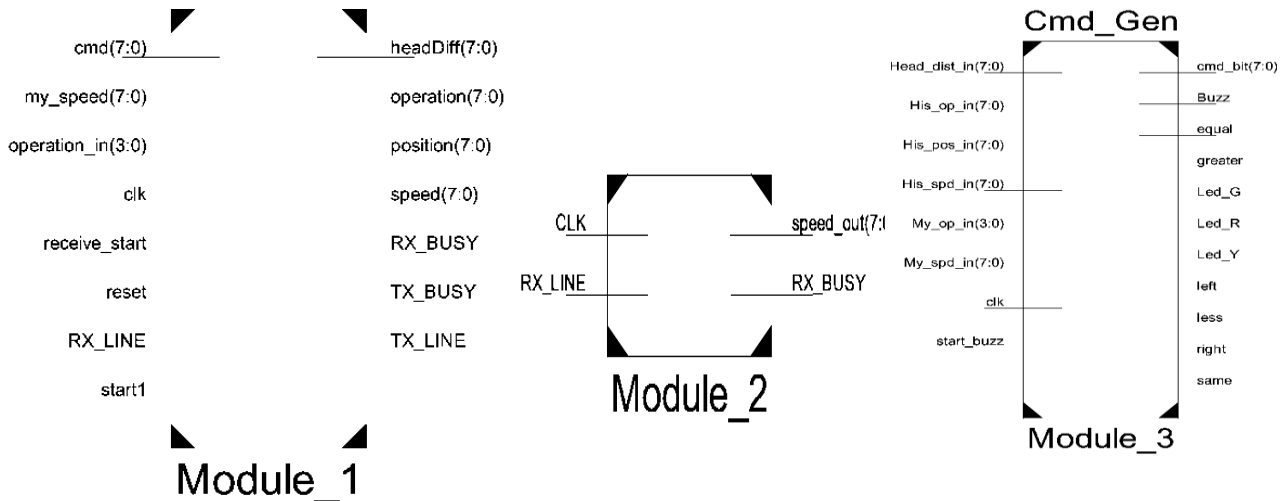


Fig. 20 Schematic of Modules 1

Fig.21 Schematic of Module 2

Fig. 22 Schematic of Modules3

### 3.2 Hardware Implementation

```

Lt1 = 27.673946 Lg1 = 85.407096
Lt2 = 27.673950 Lg2 = 85.407173
D = 7.99 m B = 87.15 PA = 6.15 H = 81.00 Spd =5 R_H = 80.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =0.00 F=0 2:RC

Lt1 = 27.673946 Lg1 = 85.407096
Lt2 = 27.673950 Lg2 = 85.407173
D = 7.99 m B = 87.15 PA = 6.15 H = 81.00 Spd =5 R_H = 80.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =0.00 F=0 2:RC

Lt1 = 27.673946 Lg1 = 85.407096
Lt2 = 27.673950 Lg2 = 85.407173
D = 7.99 m B = 87.15 PA = 6.15 H = 81.00 Spd =5 R_H = 80.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =0.00 F=0 2:RC

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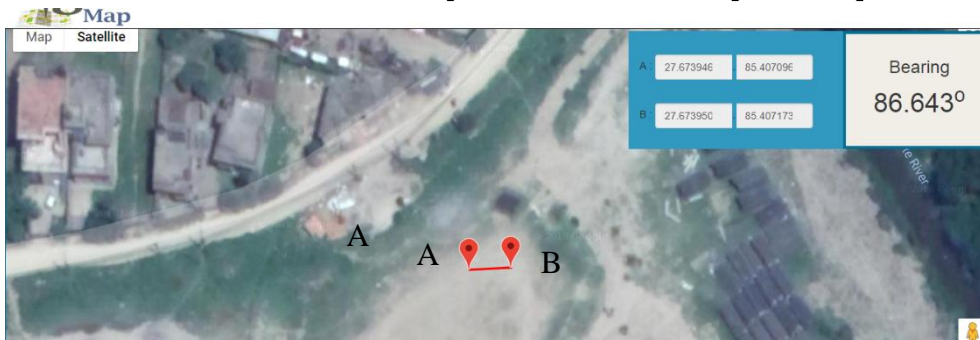


Fig. 23 Serial monitor output and vehicles PositionMap, vehicle B at right corner moving towards same direction

```

Lt1 = 27.673915 Lg1 = 85.407112
Lt2 = 27.673936 Lg2 = 85.407066
D = 5.33 m B = 296.78 PA = 216.78 H = 80.00 Spd =4 R_H = 72.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =0.00 F =0 6:LBS

Lt1 = 27.673915 Lg1 = 85.407112
Lt2 = 27.673936 Lg2 = 85.407066
D = 5.33 m B = 296.78 PA = 216.78 H = 80.00 Spd =4 R_H = 72.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =0.00 F =0 6:LBS

Lt1 = 27.673915 Lg1 = 85.407112
Lt2 = 27.673936 Lg2 = 85.407066
D = 5.33 m B = 296.78 PA = 216.78 H = 80.00 Spd =4 R_H = 72.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =0.00 F =0 6:LBS

```



Fig. 24 Serial Monitor Output and Position Map when vehicle B at blind spot moving towards same direction

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Lt1 = 27.673934 Lg1 = 85.407096
Lt2 = 27.673944 Lg2 = 85.407173
D = 8.05 m B = 82.84 PA = 8.84 H = 74.00 Spd =3 R_H = 349.00 HD = 236, 11101100 R_Spd =0.00 RX_Op =0.00 F =0 2:RC

Lt1 = 27.673934 Lg1 = 85.407096
Lt2 = 27.673944 Lg2 = 85.407173
D = 8.05 m B = 82.84 PA = 8.84 H = 74.00 Spd =3 R_H = 349.00 HD = 236, 11101100 R_Spd =0.00 RX_Op =0.00 F =0 2:RC

Lt1 = 27.673934 Lg1 = 85.407096
Lt2 = 27.673944 Lg2 = 85.407173
D = 8.05 m B = 82.84 PA = 8.84 H = 74.00 Spd =3 R_H = 349.00 HD = 236, 11101100 R_Spd =0.00 RX_Op =0.00 F =0 2:RC

Lt1 = 27.673934 Lg1 = 85.407096
Lt2 = 27.673944 Lg2 = 85.407173
D = 8.05 m B = 82.84 PA = 8.84 H = 74.00 Spd =3 R_H = 349.00 HD = 236, 11101100 R_Spd =0.00 RX_Op =0.00 F =0 2:RC

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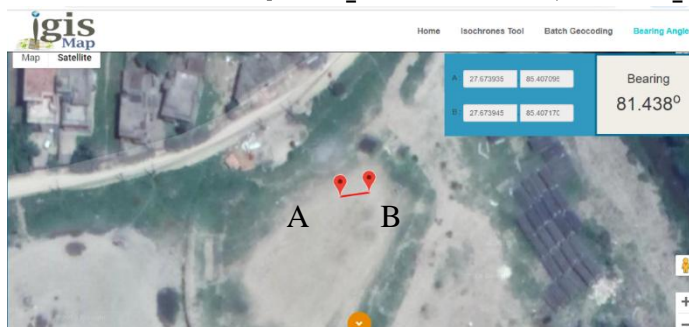


Fig. 25 Serial Monitor Output and Position Map when vehicle B at left blind spot moving opposite direction

```

Lt1 = 27.673900 Lg1 = 85.407089
Lt2 = 27.673933 Lg2 = 85.407150
D = 7.33 m B = 60.41 PA = 1.41 H = 59.00 Spd =0 R_H = 65.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =12.00 F =0 2:RC

Lt1 = 27.673900 Lg1 = 85.407089
Lt2 = 27.673933 Lg2 = 85.407150
D = 7.33 m B = 60.41 PA = 1.41 H = 59.00 Spd =0 R_H = 65.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =12.00 F =0 2:RC

Lt1 = 27.673900 Lg1 = 85.407089
Lt2 = 27.673933 Lg2 = 85.407150
D = 7.33 m B = 60.41 PA = 1.41 H = 59.00 Spd =0 R_H = 65.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =12.00 F =0 2:RC

Lt1 = 27.673900 Lg1 = 85.407089
Lt2 = 27.673933 Lg2 = 85.407150
D = 7.33 m B = 60.41 PA = 1.41 H = 59.00 Spd =0 R_H = 65.00 HD = 140, 10001100 R_Spd =0.00 RX_Op =12.00 F =0 2:RC

```



Fig. 26 Serial Monitor Output and Position Map when vehicle B at right corner coming towards the lane



Table 3: Device utilization summary

Device Utilization Summary (estimated values)			
Logic Utilization	Used	Available	Utilization
Number of Slices	62	4656	1%
Number of Flip Flops	27	9312	0%
Number of 4 input LUTs	119	9312	1%
Number of bonded IOBs	6	232	2%
Number of GCLKs	1	24	4%

For first vehicle with latitude of 27.673946 and longitude of 85.407096 and second vehicle with latitude of 27.673950 and longitude of 85.407173, distance between two vehicles is found to be 7.99m with bearing value 87.15°, relative position angle of 6.15°, heading of first vehicle to be 81° and speed of 5 kmph, heading of second vehicle to be 80° at rest which means the second vehicle is detected to be located at right corner of first vehicle. Here first vehicle is moving at same direction with respect to second vehicle. For first vehicle with latitude of 27.673915 and longitude of 85.407112 and second vehicle with latitude of 27.673936 and longitude of 85.407066, distance between two vehicles is found to be 5.33m with bearing value 296.78°, relative position angle of 216.78°, heading of first vehicle to be 80° and speed of 4 kmph, heading of second vehicle to be 72° at rest which means the second vehicle is detected to be located at left blind spot of first vehicle. So, here first vehicle is moving at same direction with respect to second vehicle.

For first vehicle with latitude of 27.673917 and longitude of 85.407119 and second vehicle with latitude of 27.673961 and longitude of 85.407127, distance between two vehicles is found to be 4.94m with bearing value 8.66°, relative position angle of 276.66°, heading of first vehicle to be 92° and speed of 3 kmph, heading of second vehicle to be 83° at rest which means the second vehicle is detected to be located at left corner of first vehicle. So, here first vehicle is moving at same direction with respect to second vehicle. For first vehicle with latitude of 27.673934 and longitude of 85.407096 and second vehicle with latitude of 27.673944 and longitude of 85.407173, distance between two vehicles is found to be 8.05m with bearing value 82.84°, relative position angle of 8.84°, heading of first vehicle to be 74° and speed of 3 kmph, heading of second vehicle to be 349° at rest which means the

second vehicle is detected to be located at right corner of first vehicle. So, here first vehicle is moving in intersecting direction with respect to second vehicle.

#### 4. Conclusion

Vehicle communication has been successfully implemented for the mentioned scenarios. FPGA processes the data and communication signals in real-time environment. Hence, this technology can prevent unfortunate accidents due to blind spots in real world. It is value addition in safety feature in the vehicles. It is also applicable in self-driving vehicles.

#### 5. References

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