Design and Implementation of Frequency Modulation Continuous Wave Radar for Adaptive Cruise Control Interfaces with PIC Microcontroller

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Abstract – This paper, presents the design and implementation of Frequency Modulation Continuous Wave (FMCW) radar system working at 77GHz for Adaptive Cruise Control (ACC) technology which is a flexible system to estimate the speed and distance in accordance to vehicle ahead, which reduces the forces on the rate of accidents by warning the driver when two vehicles become too close. In addition, the principle of FMCW radar is presented to generate Linear Frequency Modulated Continuous Wave (LFMCW) sweep waveform through frequency bands with triangular frequency modulation using Voltage Control Oscillator (VCO), a triangle sweep pattern adopt will resolve ambiguity without Doppler processing. This improves the decision making before hardware implementation. The simulation design is achieving the desired performance, one parameter warrants further attention. In the FMCW configuration, the sweep time is about 25 microseconds. Therefore, the system needs to sweep a 140 MHz band within a very short period. Such an automotive radar may able to meet the cost requirement.

Keywords: Adaptive Cruise Control technology, Frequency Modulation Format, FMCW radar, PIC Microcontroller.

1. Introduction

The traffic accidents became significantly obsession and concern for all members of society, and has become one of the most important problems that sap physical, human resources and human potential. The researches show that the damaged property and other costs may equal 3% of world's gross domestic product, which have been required to work in finding solutions and suggestions and put them into practice to reduce these incidents.

The insertion of preventive safety applications into the car system can avoid the challenges.

Currently, computer-controlled functions in a car are increasing at a rapid rate, high-end vehicles have up to 80-100 microprocessors implementing and controlling various parts of the functionalities [1].

Applications such as Collision Avoidance or ACC are safety enhancers that deal with critical data having stringent timing requirements on freshness and involving deadline bound computations [2].

An ACC system is an automotive feature that allows a vehicle's cruise control system to adapt the vehicle's speed to the traffic environment [3]. Figure(1) illustrates ACC system operates the FMCW radar located in the front bumper sensing whether the vehicle is in forward and counting car distance and speed .

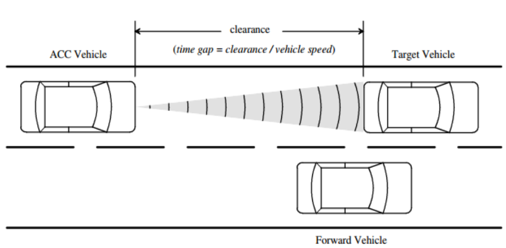

Figure 1 ACC Vehicle Relationships

2. FMCW Radar

The FMCW radars have several advantages over pulsed radars and Continuous Wave CW radars which only measures velocity for moving target, in this paper the target is vehicle, because there is no time reference, when energy is transmitted continuously in the space then the time interval between transmitted and received signals cannot detect the range (distance from Radar to vehicle).

According to Zhaolong Li and Ke Wu, in 2006, [4] studied and presented two configurations of radar front-end with a multi-chip assembly for automotive applications. Linear frequency modulation signals are used to verify the functionality of the system.

Ali Bazzi et al, in 2009, [5] presented a comparison of two strategies for FMCW radars in the presence of multiple targets based on theoretical bounds derivation is validated by Monte Carlo simulations.

Faiza Ali and Martin Vossiek, in 2010, [6] deal with a FMCW radar measurement scheme and a 2-D range-Doppler FMCW radar Fourier processing that is especially suited to detect very weak moving targets. The practical application of the described method was illustrated with a 24 GHz FMCW radar sensor system. The signal evaluation was implemented on a Field Programmable Gate Array (FPGA) to facilitate real time processing.

D.O. Handayani, et al, in 2012, [7] developed a two-dimensional FMCW radar scene generator that can be used as an aid in the ship navigation training. In this research a suitable Graphical User Interface (GUI) was also designed and progressing. Using this GUI the user can easily produce static and dynamic components of the radar scene generator.

When the frequency modulation is used in continuous wave radar, the range as well as velocity of possible vehicle can be calculated and measured to satisfy and maintain the system ACC requirement, using the time reference to measure the delay which appears in received signal as compare to transmitted signal, which is proportional to range measurement.

The advantages of FMCW against the other types of radar are:

- Low peak power.
- Less sensitive to clutter.
- Accurate short-range measurement.

Which means:

- Easier to integrate.
- Simpler algorithm for digital signal processing.
- Cheaper to manufacture.

Estimation of the above points illustrates the use of Frequency Modulated CW for the current design of the ACC radar system .

Principle of linear frequency modulated continuous wave (LFMCW) radar:

The signal is reflected from remote targets and detected by the receiver where the return signal is mixed with a copy of the transmitted signal to determine the range of the target. The propagation delay to the target and back causes a frequency difference between the transmitted signal and the received signal which is called the beat signal. Figure (2) shows the basic hardware configuration of the FMCW Radar [8].

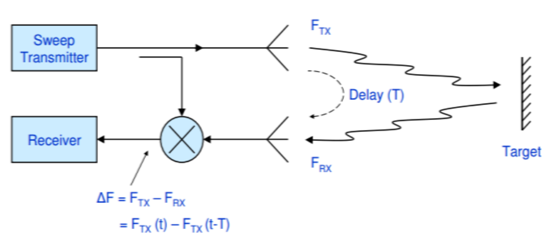

Figure 2 FMCW Radar Architecture [8].

3. Triangular Modulation

The RF signal is frequency modulation usually by a linear sweep with a sinusoidal, saw-tooth or triangular modulating waveform. If saw-tooth frequency modulation is used, only the range estimated and Doppler shift will result in an error. By using triangular modulation, both range and velocity can be extract from the measured beat frequency [9].

$$f_b = f_t - f_r \qquad (1)$$

Triangular sweep transmitted signal had been generated and examine the spectrogram of triangular sweep (time-frequency) of the FMCW signal waveform as shown in Figure (3).

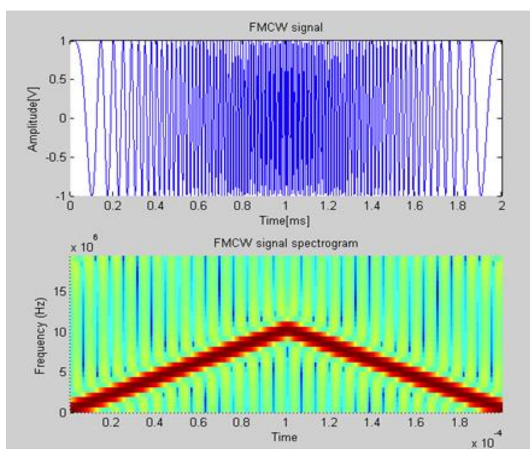

Figure 3 Triangular sweep linear FMCW Tx signal and its spectrogram

LFM signal is written as:

$$f_T(t) = f_0 + \alpha t \qquad (2)$$

where, $f_T(t)$: transmitted modulated signal.

f_0: is start of sweep signal and increase to f_1 at the end of sweep over time T.

α: is rate change of frequency(slope of signal sweeps).

B: is the difference between f_1 and f_0 [10].

When the target is moving, the received signal will include a Doppler shift term in addition to the frequency shift due to the time delay.

The beat frequency is difference between the transmitted signal and received signal and the beat frequencies for the up sweep and down sweep are denoted a respectively as (f_b^+, f_b^-). Figure (4) shows Doppler frequency effects on the beat frequencies up and down triangular sweeps.

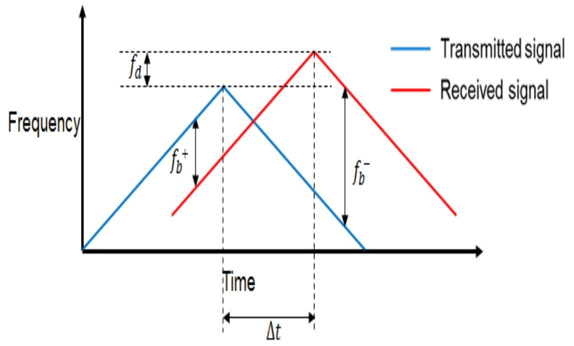

Figure 4. Transmitted, received, signals with beat frequencies and doppler shift as a function of time for a moving target.

Therefore, f_b^+ and f_b^- it have been used to estimate beat frequency f_b and Doppler shift f_d as shown in Figure (5).

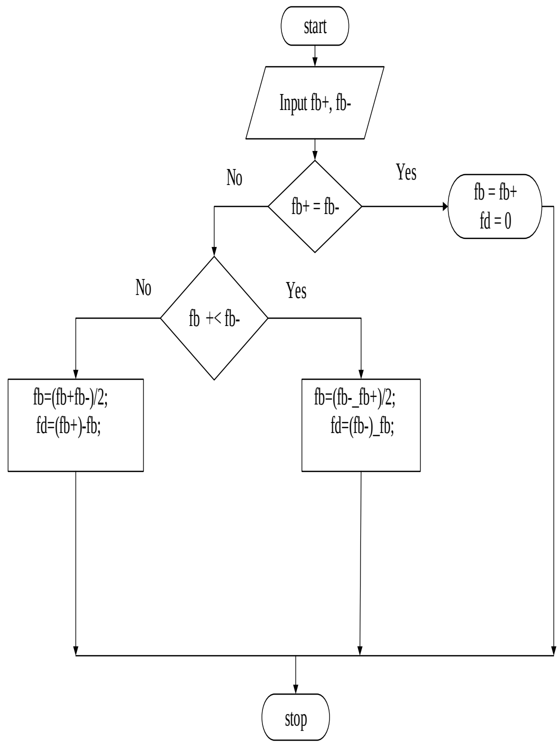

Figure 5. Flowchart of the proposed method to find fd and fb from the beat frequencies (f_b+, f_b-)

4. Design and Implementation of the Proposed System

Figure (6) describes the design and implementation process used for the proposed FMCW radar model.

To make efficient application of FMCW radar at 77 GHz as well as triangular frequency modulation and signal processing at base band frequencies. Figure (7) illustrates design of the FMCW radar system, which was applied using MATLAB for moving vehicle detection.

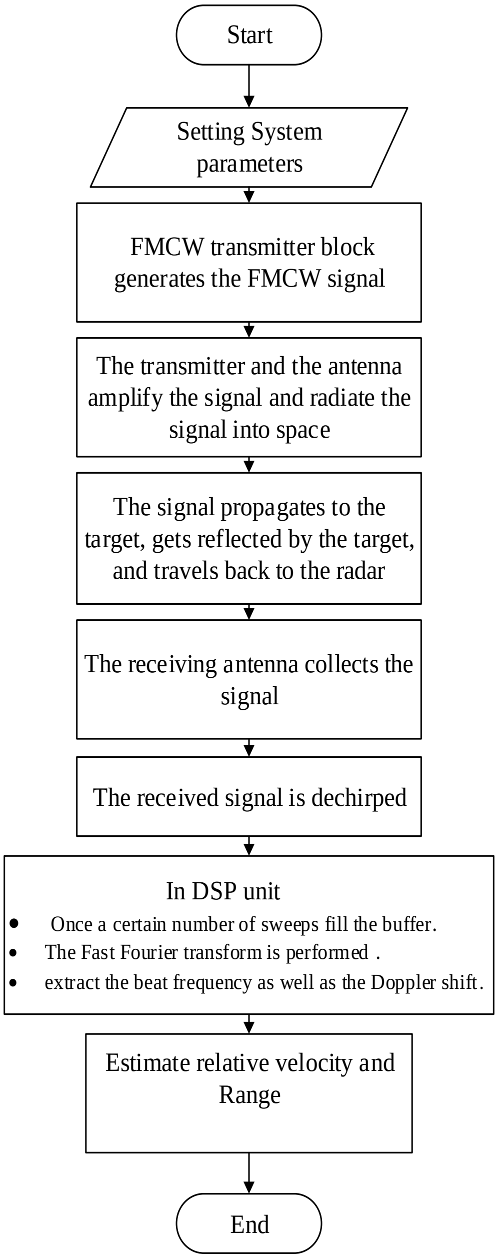

Figure 6. Flowchart of the proposed FMCW radar model

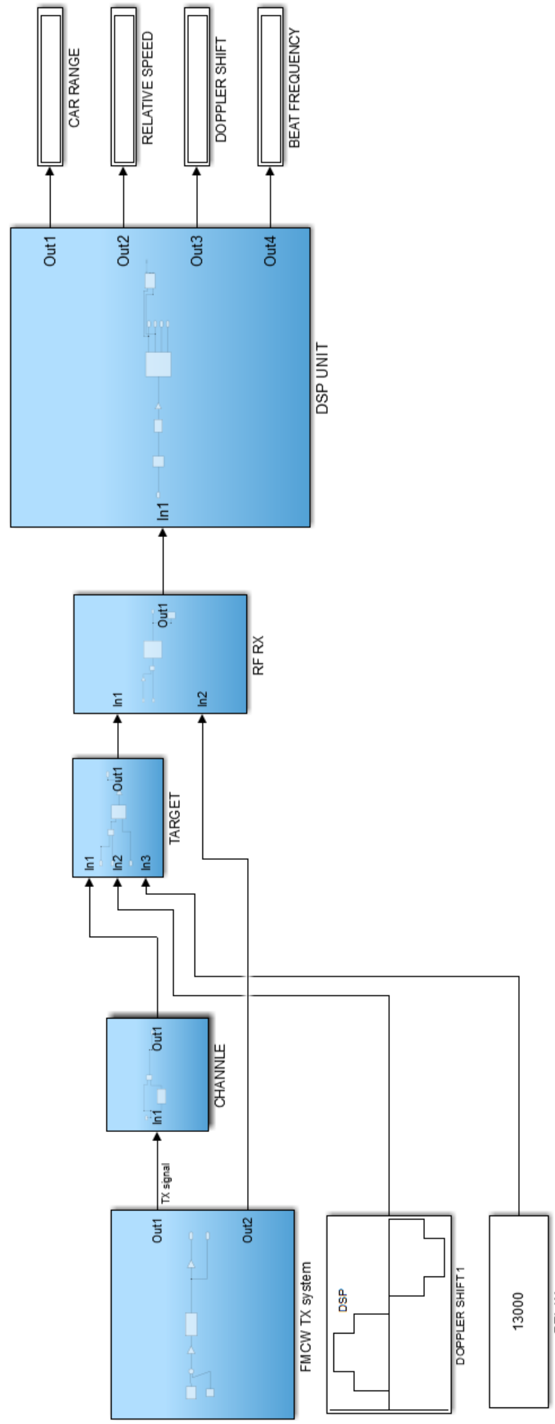

Figure 7. Proposed model of FMCW Radar for ACC application

The remainder of this paragraph devoted to clarify the mechanism of action for each block was used in the design of the FMCW radar system:

4.1. FMCW Transmitter System

The transmission simulation block has shown in Figure (8) it Indicate to an essential setup that consisting of the Voltage Control Oscillator (VCO) and a triangle wave driver.

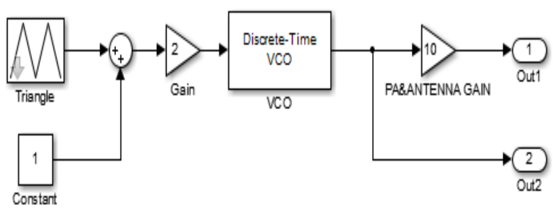

Figure 8. Transmitter FMCW radar simulation

VCO in this design is modulated by triangular frequency modulation which represented the driver of sweep (up and down) signal as shown in Figure (9).

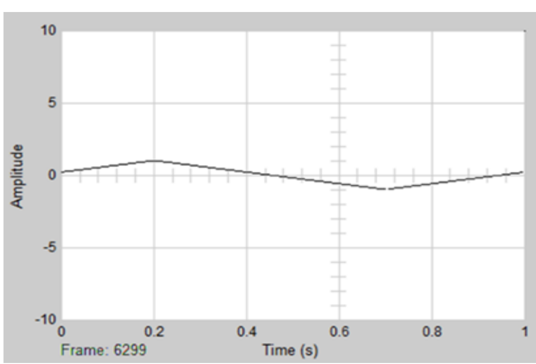

Figure 9. Triangular sweep driver

VCO parameters have been set in this system design with output amplitude (V) = 1, Quiescent frequency (Hz) = 5000, Input sensitivity (Hz/V) = 2000, Sample time (s) = 1/40000. Figure (10) shows the VCO vector scope output, which is sin waves with multiple frequencies (chirp).

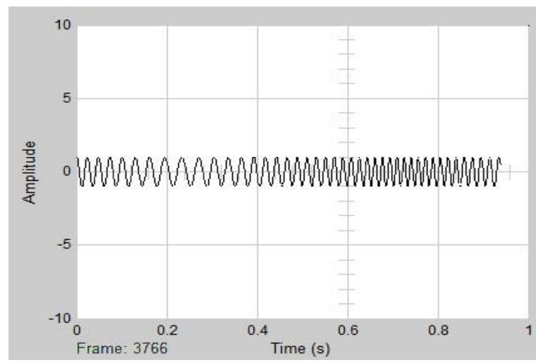

Figure 10. VCO vector scope output

4.2 Channel Model

Channel model with Additive White Gaussian Noise (AWGN) which considered as substitute the effect of many random processes that occur in nature, has been clarified in Figure (11). AWGN with signal to noise ratio Es/No (dB) =10, Symbol period (s) = 1/40000 .Manual switch is permanently closed on AWGN to apply the noise effects on the system. In addition, AWGN effects interrupted via manual switch.

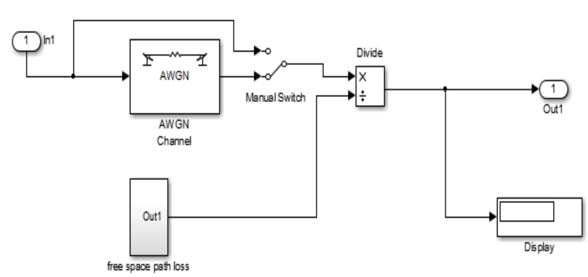

Figure 11. Channel Model

4.3 FMCW Radar Target Model

The target of FMCW Radar system for ACC application is usually vehicle ahead. Figure (12) shows target model where channel output connected to first input of target model , frequency Doppler shift from car velocity with (fd max=2500 Hz, sampling time =1/40000)connect to second input ,third input connect to delay with constant value 13000 ,as shown in overall system design Figure (7). We set the propagation delay to be free space with upper limit delay length =40000.

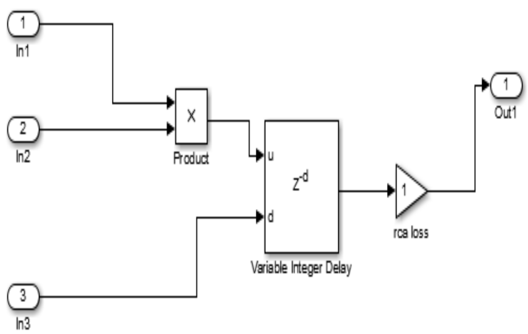

Figure 12. Target model

4.4 FMCW Receiver Signal System

The reflected signal from the target must be adjustment before Low Noise Amplifier (LNA) passes it to digital filter, which is an electronic amplifier which it is used to amplify possibly received weak signal from target which is affected by noise. By setting the gain of amplifier the effect of noise on Rx signal can be reduced.

The mixer is used to perform a time-domain multiplication of the transmitted $Tx=A_t\cos(w_t t)$ and the received Rx signal $=A_r\cos(w_r t)$ and output the sum and differences of these frequencies.

$$\{(A_t \cos(w_t\, t)) \times (A_t \cos(w_r t))\} \xrightarrow[MIXER \quad O/P]{}$$

$$\left\{\begin{array}{l} A_t \cos(w_t t) \cos(w_r t) = \\ \dfrac{A_t}{2} (\cos\left[(w_t - w_r)\right] \\ +\cos\left[(w_t + w_r)t\right] \end{array}\right\} \xrightarrow{LPF}$$

$$\frac{A_t}{2}(\cos\left[(w_t - w_r)t\right] \tag{3}$$

The output of mixer is passed to Low Pass Filter (LPF) to filter out the high frequency component, the result is Intermediate Frequency (IF) signal : = At/2(cos[(wt-wr)t] as shown in figure (13).

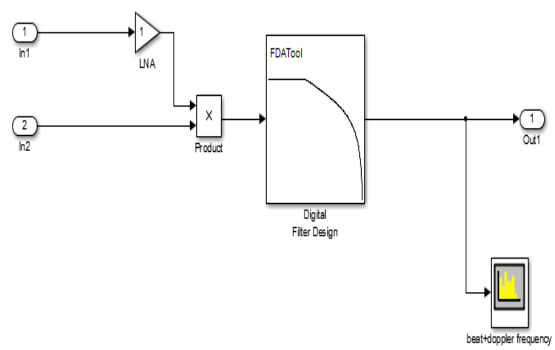

Figure 13. FMCW Receiver signal system

4.5 Digital Signal Processing of FMCW Radar System

Figure (14) shows Digital Signal Processing simulation of FMCW Radar System.

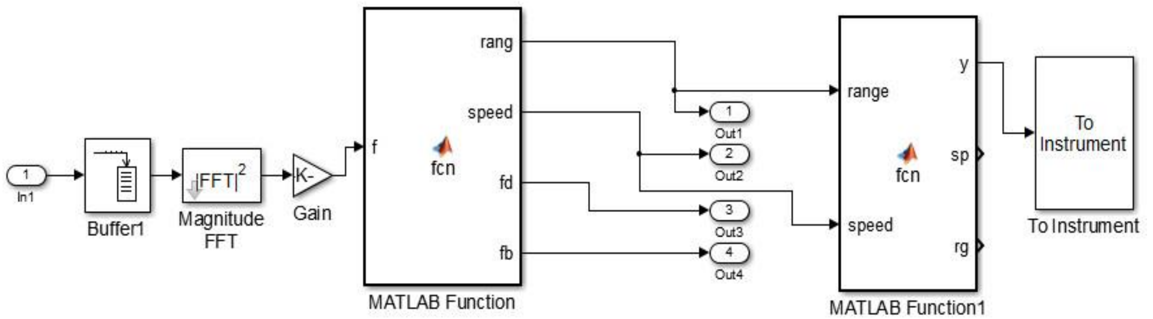

Figure 14. Digital signal processing of FMCW radar system

The range and relative velocity of target are proportion to the vehicle that utilizes FMCW radar could be found using the following equations:

*Range = round (1.5*10^8*f_b*10^7*36 / (resolution*sample rate))* (4)

*Speed = round (1.5*10^9*18/f_0*f_d/5)* (5)

The parameters adopted are described in Table 1.

Table 1. FMCW radar simulation variable values

System parameters	**Value**
Operating frequency f_0 (GHz)	77
Maximum target range (m)	201
Range resolution (m)	1
Maximum target speed (km/h)	176
Sample time (seconds)	1/40000
Sweep bandwidth (MHz)	140
Maximum beat frequency (MHz)	5.200
Sample rate	40000

4.6 Interfacing Proteus with MATLAB

In this work, PIC16F887 microcontroller was chosen because of several reasons:

- It is one of the most advanced microcontroller from Microchip.
- This controller is widely used for experimental and modern applications because of its low price, wide range of applications, high quality, and ease of availability.
- It is ideal for applications such as machine control applications, measurement devices, study purpose, and so on.
- The PIC16F887 features all the components which modern microcontrollers normally have.

The Proteus Professional v8 is used to simulate Microcontroller PIC16F887 to design forward collision warning that's typically paired with MATLAB simulation.

The collision warning and display circuit has to be designed to recognize three state with difference distance (short, middle, long) between two automobiles on the same road lane. Where, the range is measured by FMCW radar unit behind the front grille or under the bumper of the car. Where, RS-232 connector is a virtual port in proteus simulation having the ability to interface with the physical port of the PC. This attribute enables to send the data from MATLAB to the physical port and then to PIC microcontroller. For this interfacing we used additional software (Virtual serial Ports Emulator) for making virtual com port and making pairing between the ports which are used to interfacing Proteus with MATLAB.

4.6.1 Collision warning and display circuit description

After explaining the general principles of the design procedure, the next step is to simulate the hardware in Proteus ISIS Professional v8 simulation software; PIC16F887 Microcontroller, Virtual UART Terminal

used to establish serial communication, LM016L (LCD display), set of LED (D_1-D_8) and Buzzer (the buzzer needs just a DC input voltage to activate, the default is 12v), the frequency it should be 500H_Z actually with Proteus software to design collision warning and display circuit as shown in Figure (15).

To interfacing UART with PIC, Embedded C program was written in Mikcro C PRO v 6.1, which is essential software for embedded C, compile it and build the hex file of the project. The hex file is very important because microcontroller understand hex not C language.

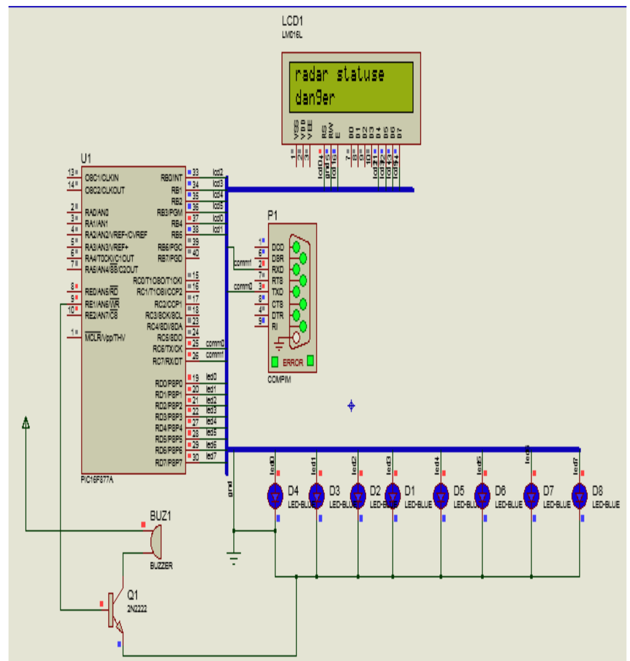

Figure 15. Collision warning and display circuit

4.7 Implemented the proposed system with EASYPIC v7 board

First**,** to make interface between the proposed FMCW radar system implemented in MATLAB with EasyPIC v7 board. RS-232 serial port can be used for this interfacing as shown in Figure (16).

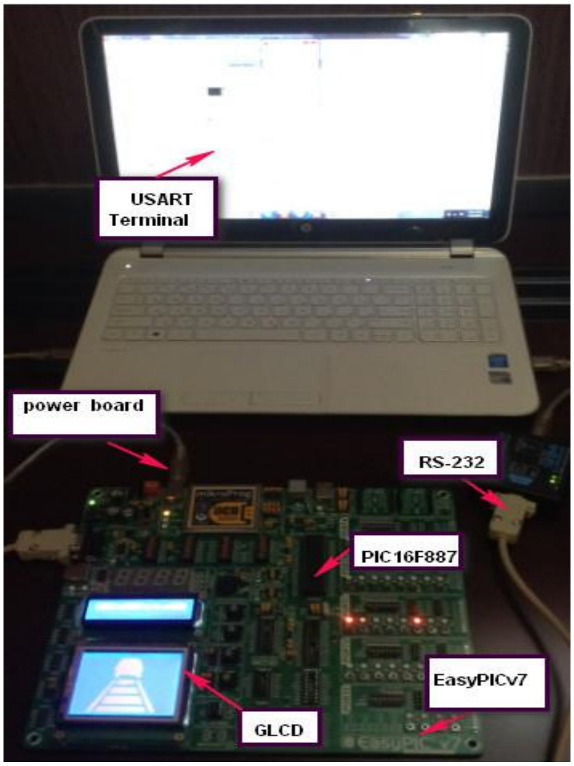

Figure 16. Easy PIC v7 board serial interface with FMCW radar

In this work, the parameter of USART terminal from compiler IDE for sending and receiving data are adjusted as follows:

Baud rate =2400 baud, Buffer size =1024, Compiled for PIC16F887 at 8 MHz external oscillator.

4.7.1 LCD Out of the Proposed System with EasyPICv7 Board

Displaying text on LCD by interfaced with PIC16F877 microcontroller in 4 bit mode. We use Micro C v 6.1 here for writing the embedded C Program and build the hex file of it USART port is used to control this interface.

Figure (17) shows LCD status according to range measurement by FMCW radar simulation.

a. For short range region from (1m) up to (20 m)

b. For middle range region from (20m) up to (50 m)

c.

d. For large range region from (50m) up to (200 m)

Figure 17. {a, b, c} Shows LCD display for (short, middle, large) range region respectively with EasyPIC v7 board.

If a fault occurs, during operation of the system in cruise or follow modes, the ACC system will be switched off and cannot be used until the fault is cleared. The message error status appears on LCD as shown in Figure (18).

Figure 18 . Error status appears on LCD when fault occurs

4.7.2 Using Graphic LCD

There are several ways for operating Graphic LCD 128x64:

- Using Visual GLCD software.
- Manually using GLCD library.
- Importing bmp image.

Graphic LCD Bitmap Editor has been adapted, which MikroC PRO for PIC includes it. The output is the MikroC PRO for PIC compatible code as shown in Figure (19).

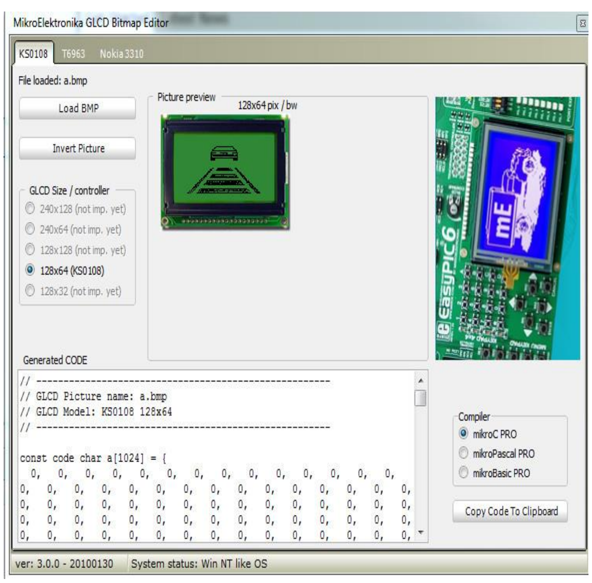

Figure .19 GLCD bitmap editor used

Figure (20) shows Graphic LCD display of proposed ACC system implement with EasyPIC v7.

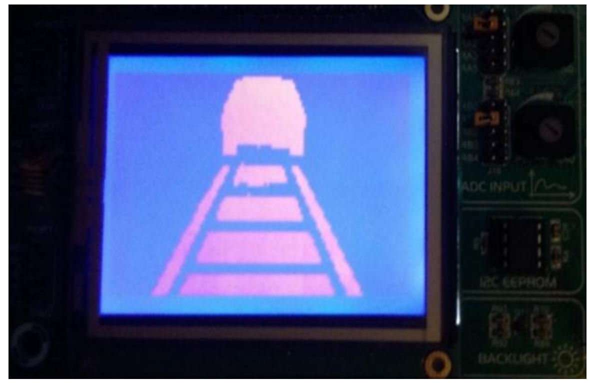

Figure 20. Graphic LCD of ACC system display target (car) and road lines

5. Conclusion

- LFM format technique has been chosen as the modulation format for this work, that's allows the handling of more complex scenarios for better beat frequency.
- DSP unit has been designed to estimate beat frequency and Doppler shift from received modulated signal. Signal was processing by FFT to convert signal in frequency domain.
- The simulation design is achieving the desired performance, in the FMCW configuration; the sweep time is about 25 microseconds. Therefore the system needs to sweep a 140 MHz band within a very short period. Such an automotive radar may able to meet the cost requirement.

- The range has been obtained with high resolution and improved error with three state range of the target for ACC system. The proposed system show high performance in range and velocity measurement accuracy. LCD shows the radar status with different vehicle range and GLCD will show vehicle position and road lines.

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