INTERNATIONAL JOURNAL OF AERONAUTICS AND ASTRONAUTICS
IJAA
2020, Vol.(No): 1(1), 33-41

Research Article

Microcontroller based simulation of the very high frequency omnidirectional radio range (VOR) system in aircraft

Fatih Alpaslan Kazan*

Department of Aviation Electrical and Electronics, School of Civil Aviation, Selçuk University, Konya, Turkey

ARTICLE INFO

* Corresponding author
akazan@selcuk.edu.tr

Received December 10, 2020
Revised December 29, 2020
Accepted December 31, 2020

F. Alpaslan Kazan
0000-0002-5461-0117

ABSTRACT

As it is known, different navigation systems, such as Non-Directional Beacon (NDB), Automatic Direction Finder (ADF), Very High-Frequency Omnidirectional Radio Range (VOR), Instrument Landing System (ILS) and Distance Measurement Equipment (DME), are used for the aircraft to take off, travel and land safely. This study aims to motivate students, who educate in aviation electricity and electronics departments of aviation schools established to meet the needs of the aviation industry, to learning the microcontroller course better. To achieve this aim, the VOR receiver, which shows the aircraft's radial according to the VOR station from which receives its signal, has been simulated. Since the microcontroller to be used in simulation and the compiler to be used in programming the microcontroller may vary, only flow diagrams and basic calculations are given. In the simulations, it was seen that the phase difference between the reference and variable signals sent by the VOR station were correctly detected, and thus the aircraft could accurately determine the radial relative to the VOR station.

Keywords: Magnetic bearing; Microcontroller; Radial; Simulation; VOR

1. Introduction

Aviation has become a rapidly developing and growing sector due to the fact that air transport provides a very important time saving, the increase in international trade and the increase in people's income levels. The rapid growth of the sector has also increased the need for people trained in this field. The qualified personnel lack required by the sector is tried to be eliminated by establishing schools serving in this field.

Different navigation systems, such as Non-Directional Beacon (NDB), Automatic Direction Finder (ADF), Very High-Frequency Omnidirectional Radio Range (VOR), Instrument Landing System (ILS) and Distance Measurement Equipment (DME), are used for the aircraft to take off, travel and land safely. Through these systems, the position, head, direction, speed, and altitude information of the aircraft can be obtained. Some of these systems are placed both at the airports and on the routes that the aircraft will follow. In this way, aircraft can perform safe navigation by processing the information sent from navigation systems the electronic equipment they have.

Undoubtedly, the most basic elements of these systems used in aircraft are high-speed microcontrollers that evaluate the signals sent from the stations and present them to the pilot as simple as possible. For this reason, lessons on the structure of microcontrollers and how they are programmed are also given to students in aviation schools. However, students in the microcontroller lesson need more motivation compared to students in other lessons. Performing this motivation by simulating the VOR system, which has an important place in aviation, will enable students to be more motivated to the microcontroller lesson and to understand the VOR system better.

In the literature review made to examine the studies in this scope, many different publications on the VOR system were reached. For example, testing the VOR in the stratosphere [1], investigating the effect of the diameter and ground clearance of the VOR station on the system stability [2], measuring the signals emitted from the VOR station using unmanned aerial vehicles [3], analysing of errors in the signals emitted from the VOR station [4-6] are just a few of them.

But a study, which would motivate for the lesson the students of the department of aviation electrical and electronics by simulating the systems related to aviation in the microcontroller lessons, has not been encountered. The motivation needs of the students were tried to be met with this study. In this study, the VOR receiver, which displays the magnetic radial on the aircraft by processing the signals sent by the VOR station, is simulated as microcontroller based. In this way, it is aimed at students both gain the motivation they need during microcontroller programming and comprehend the working principle of the VOR system, which has an important place in aviation.

2. Very High Frequency Omnidirectional Radio Range (VOR) System

'The VOR system was accepted as standard by the United States in 1946 and later adopted by the International Civil Aviation Organization (ICAO) as an international standard. The system provides a widely used set of radio beacons operating in the VHF frequency band over the range 108 - 117.95 MHz. Each beacon emits a Morse code modulated tone which may be provided to the flight crew for beacon identification. The ground station radiates a cardioid pattern that rotates at 30 rev/min, generating a 30 Hz modulation at the aircraft receiver. The ground station also radiates an omnidirectional signal which is frequency modulated with a 30 Hz reference tone. The phase difference between the two tones varies directly with the bearing of the aircraft.'[7]
VORs are classified as follows according to their usage areas [8];

- Conventional VOR (CVOR)
- Broadcast VOR (BVOR)
- Doppler VOR (DVOR
- Terminal VOR (TVOR)
- Test VOR (VOT)
- Co-located VOR and TACAN (VORTAC)

The VOR station has a circular structure. One of the antennas in the station is located in the centre of the circle, while the others are on the circle. (Figure 1).

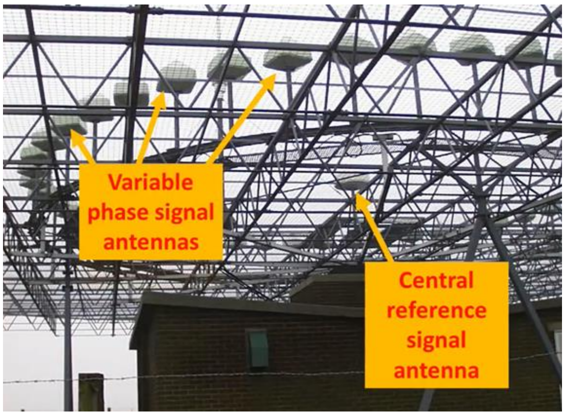

Fig. 1. Antennas in the VOR system [9]

While the antenna in the centre of the circle always radiates a zero-phase signal, each antenna on the circle is switched sequentially and radiates variable phase signals. The states of the reference and variable signal are shown in Figure 2.

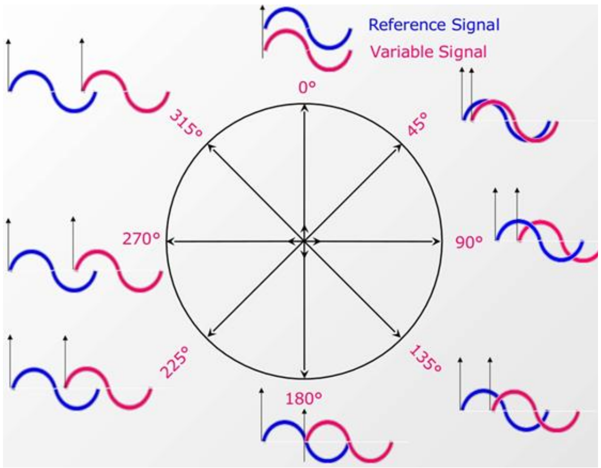

Fig. 2. Changes of reference and variable signals radiated from the VOR station [10]

The VOR station generates 360 linear lines called "Radial" at 1° interval. The aircraft can receive only one of these signals, which are 1° phase different. Through the signal it receives, it can easily detect the magnetic bearing according to the VOR station it receives the signal. In this way, it can continue its navigation safely. But, it should not be forgotten that the radial where the aircraft is located, is expressed in terms of magnetic north and VOR station. As known, a radial (QDR) is a magnetic bearing from a VOR beacon can be shown as in Figure 3.

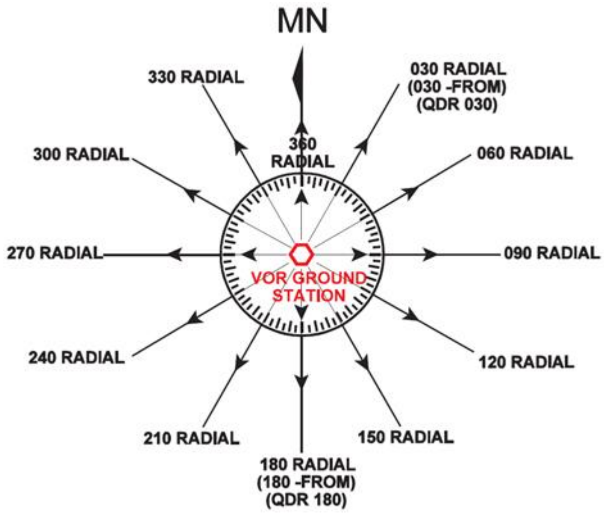

Fig. 3. The direction of the variable phase signals radiated from the VOR station and demonstration of the radial (magnetic bearing) [11]

3. Simulation of the VOR

Whether the codes written in microcontroller applications work as desired can be tested using different simulation programs. In the simulation to be done in this study, the program named Proteus belonging to Labcenter Electronics will be used.

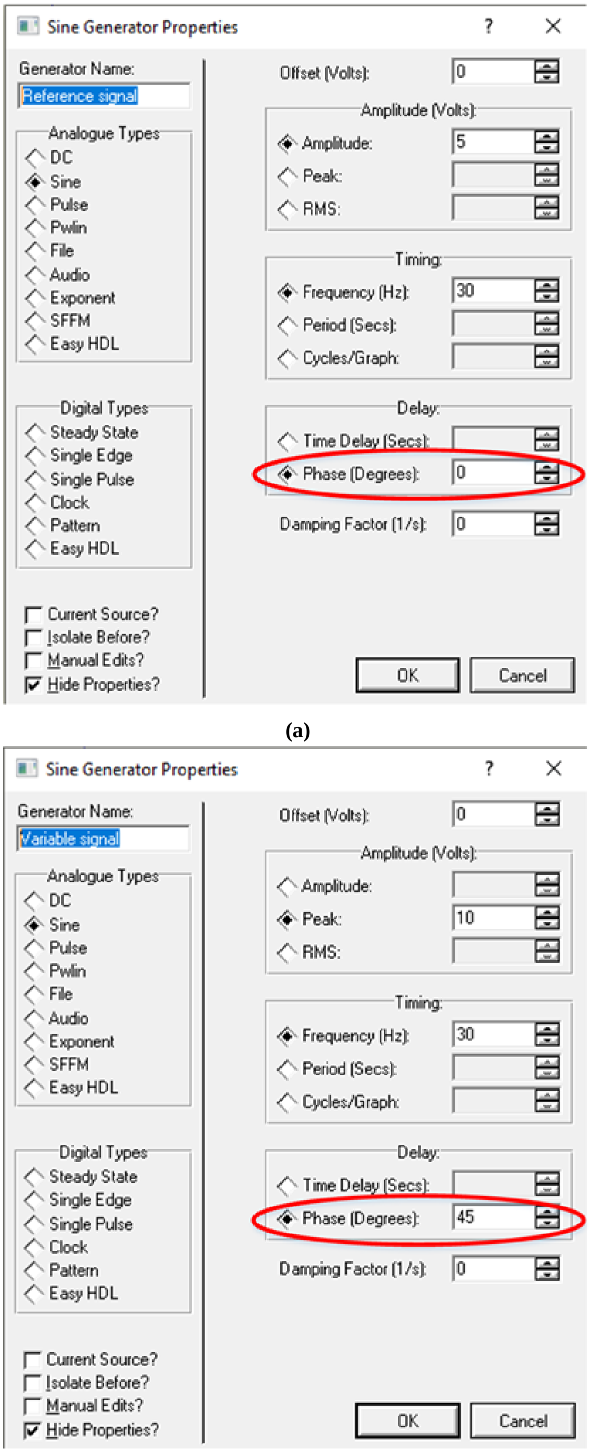

Fig. 4. Adjusting the sine generator to generate signals with the same frequency but phase different **(a)** Phase angle of the reference signal is 0°, **(b)** Phase angle of the variable signal is 45°

The main purpose of this study is to motivate students studying in the department of aviation electrical and electronics to the microcontroller lesson. Therefore, in the simulation to be made, it should be provided that students focus their attention on programming rather than hardware. Just because of this reason, reference and variable signals will be obtained directly by using sine generators in the simulation program. The interface shown in Figure 4 is used for adjusting these signals with the same frequency but different in phase. When Figure 4 is examined, it will be seen that the frequency of the signals to be produced will be 30 Hz as in the VOR system. But the phase angles can be changed as desired. The sections, where the phase angles of the reference and variable signals are adjusted in degrees, are highlighted in Figure 4. In all simulations, the phase angle of the Reference signal will remain 0 ° (Figure 4.a). However, to test the accuracy of the created algorithms and the written program, the phase angle value of the variable signal will be changed (Figure 4.b).

The block diagram of the hardware section of the simulation is given in Figure 5. As can be seen in Figure 5, reference and variable phase signals, which coming from the VOR station on the ground and separated as a result of demodulation, are first given to the zero-cross detector. Square wave signals obtained from the zero-cross detector are entered into the microcontroller to calculate the phase difference between them. After the microcontroller calculates the phase difference between the square wave signals, it transfers the information of the radial to the indicator.

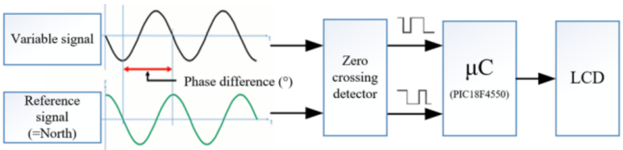

Fig. 5. Block diagram of the simulation's hardware section

In the simulation, the circuit diagram given in Figure 6 will be used. Actually, this circuit is a zero-cross detector. Therefore, this circuit is also used for determining the power factor [12].

The LM358 in the circuit is supplied by ± 12V dc. The reference and phase-different variable signals produced using a sine generator are entered on pins 2 and 6 of the LM358. When the instantaneous values of these sinusoidal signals are zero, the states of the logic signals generated at the LM318 outputs change. That is, if the previous state of the output is logic-0, the output changes to logic-1 when the instantaneous value of the signal becomes 0. The same is true for the opposite. These signals in the LM358 output are given to the Capture / Compare / PWM (CCP) pins of the microcontroller to calculate the phase difference between signals. PIC18F4550 was preferred as the microcontroller on the simulation and was operated at 8 MHz.

As it is known, Timer hardware of microcontrollers can be used as a counter or timer [13]. They are used in counter mode when calculating the period of a signal. Whether used as a counter or timer, they can be operated in 8 or 16-bit mode. In this simulation, it will be run in 16-bit mode. Therefore, it will be able to count up to a maximum of 65535. After reaching this value, it will start counting from 0 again.

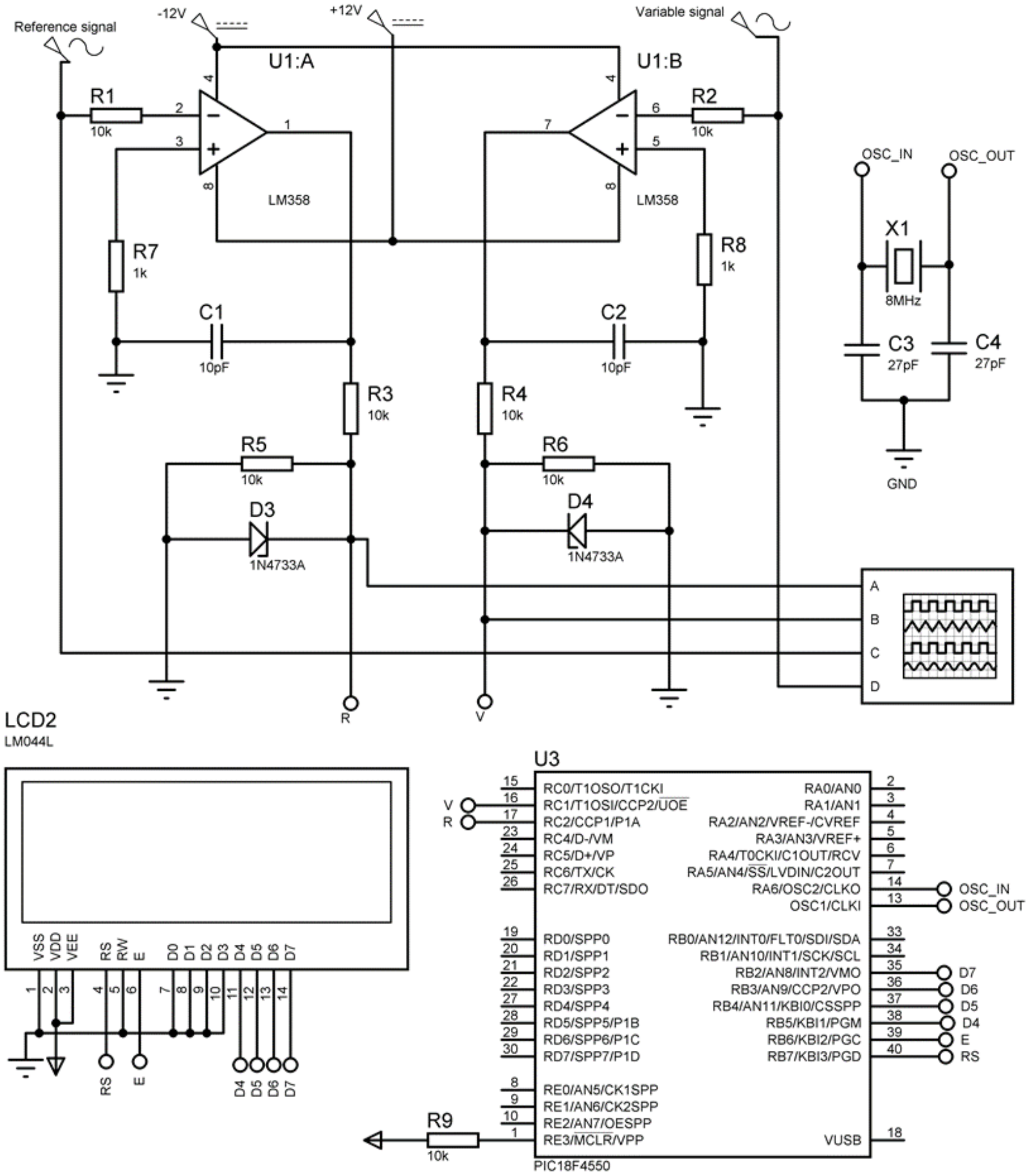

Fig. 6. Circuit diagram to be used in the simulation.

When high-frequency oscillators are used in time measurements, the Timer reaches this value in a much shorter time. Similarly, if the time to be calculated is too long, the value 65535 may not be sufficient to measure this time. In such cases, when the Timer reaches 65535, the value of a previously defined variable should be increased, and the total value counted by the Timer should be calculated correctly. This method will be implemented during the period measurement of the signals in this study.

To measure and calculate the period of a signal or the phase difference between two signals by using the Timer, firstly, a reference time such as 1 ms is determined. Then, what value the Timer reaches during this reference time is determined. Finally, the phase difference or period in terms of time is calculated by dividing the Timer value corresponding to the time to be measured by the Timer value of the reference time.

In classical power coefficient measurement applications, the phase difference between the two signals is between 0 ° and 90 °. But in the VOR system, this value varies between 0 ° and 360 °. Therefore, conventional phase difference measurement algorithms cannot be a direct solution for VOR. The first thing to do is determine which signal was logic-1 first. After this determination is made, two separate loops are used to calculate the phase difference.

The first loop is used to calculate the phase differences between 0 ° and 180 °. The operating condition of this loop is; while the reference signal is logic-1, the variable signal must be logic-0. The second loop is used to measure phase differences between 180 ° and 360 °. The operating condition of the second loop is that the reference signal is logic-0 while the variable signal is logic-1.

The timer is activated when the reference signal is logic-1, to find phase differences between 0 ° and 180 °. To disable the timer, the variable signal is expected to be logic-0. When the variable signal is logic-0, the Timer is inactivated and its value assigned to a variable. Similar procedures were repeated on the falling edge to make the measurement more accurate. But this time, Timer is active and passive, when the signals are logic-0. (Figure 7).

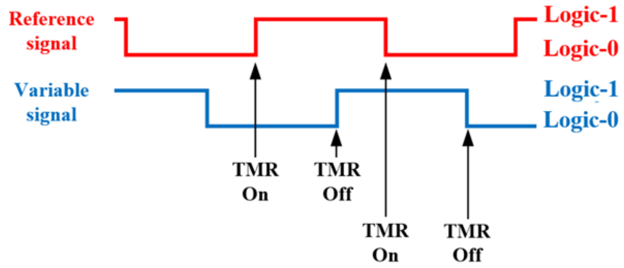

Fig. 7. The use of Timer in detecting the phase difference betw. 0°-180°

While detecting phase differences between 180 ° and 360 °, the Timer is activated and passivated as in Figure 8.

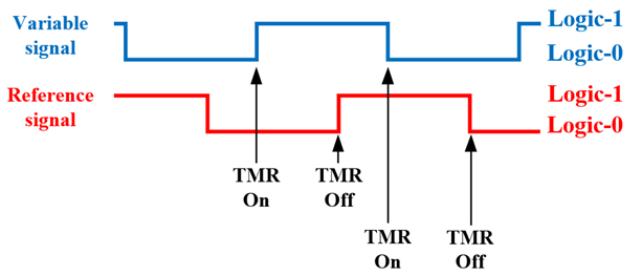

Fig.8. The use of Timer in detecting the phase differ. betw. 180°-360°

The flow diagram of the code written for the process given in Figure 7, is presented in Figure 9. Due to the possibility of the microcontroller making an error while capturing the signal edges, this process is repeated a certain number of times in a loop.

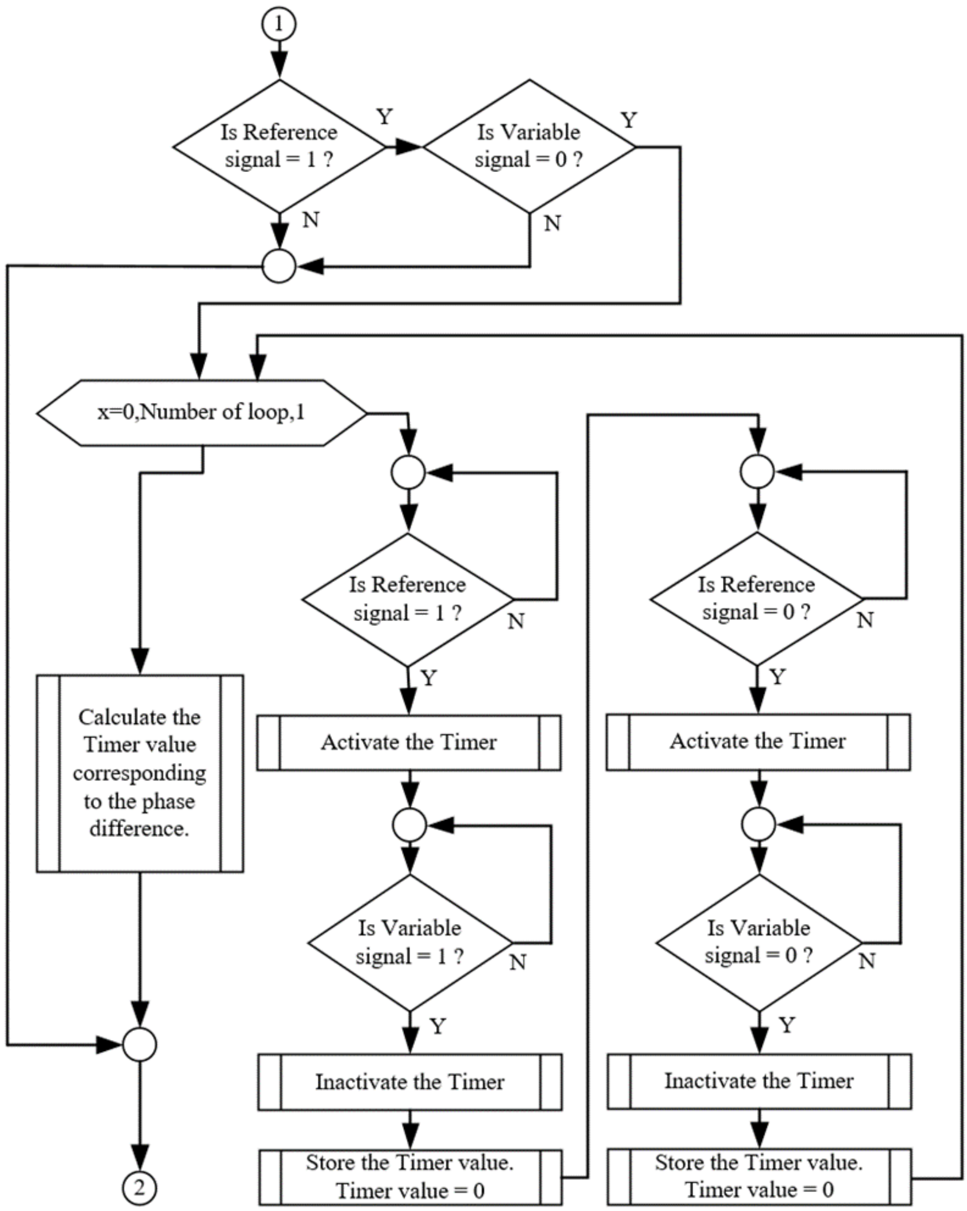

Fig. 9. Flow diagram of the piece of code written to detect the phase difference between 0 ° - 180 °

The algorithm that should be used for the process given in Figure 8 is shown in Figure 10. When the differences between Figures 9 and 10 are examined, it will be seen that the terms of reference and variable in Figure 9 have changed in Figure 10. To accurately calculate the phase difference obtained at the end of this algorithm, it is necessary to subtract the phase difference value in degrees from 360. This operation will be given during the mathematical calculation of the phase difference.

In the second step of the code written, the period of the signals has been calculated. Although the periods are certain since the signals in the VORs have a fixed frequency of 30 Hz, it is necessary to ensure that students develop different perspectives on different problems. For this reason, one of the signals was chosen and its period has been measured. The frequency will be calculated using the period. During the measurement, the Timer was activated and passivated, as shown in Figure 11.

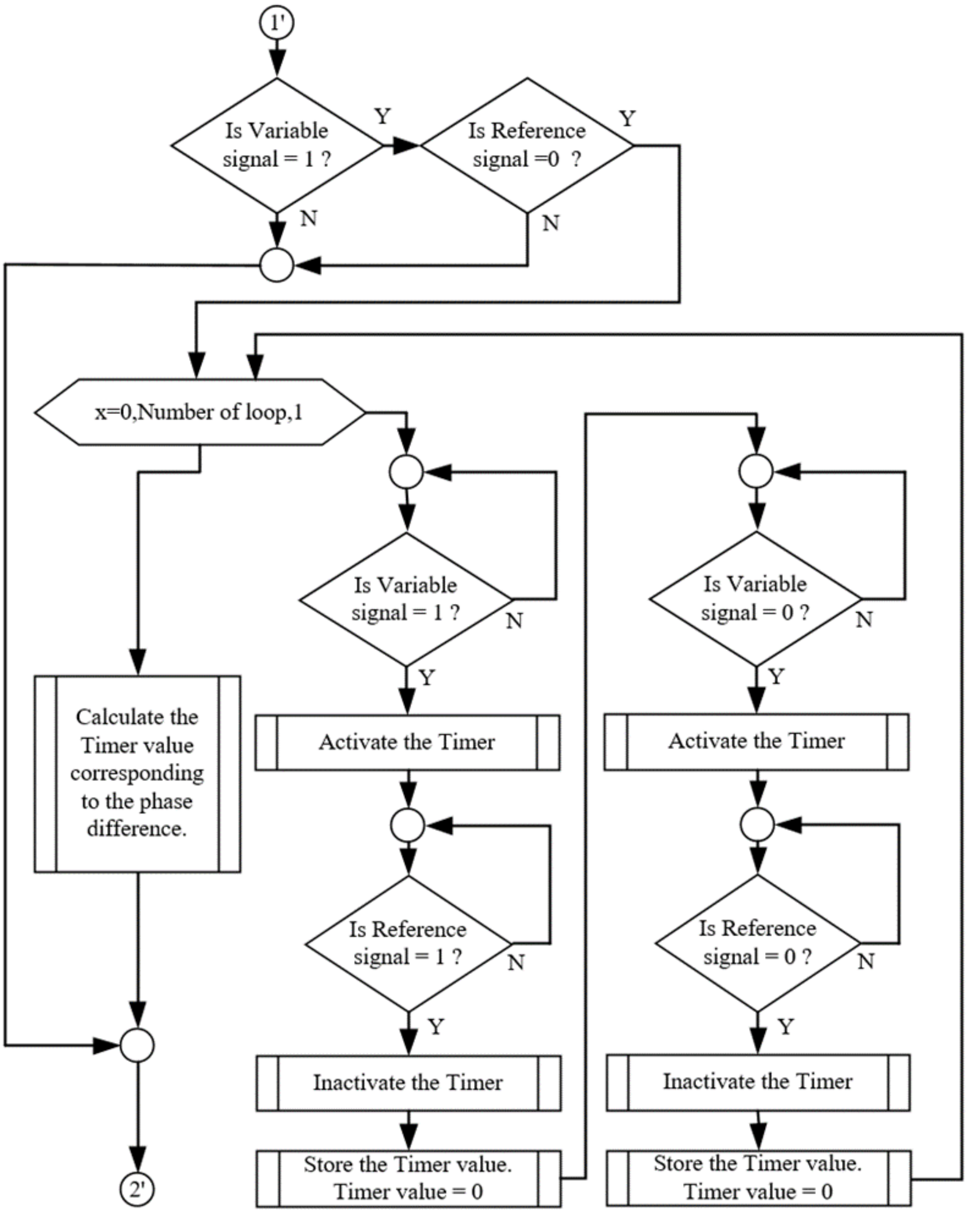

Fig. 10. Flow diagram of the piece of code written to detect the phase difference between 180 ° - 360 °

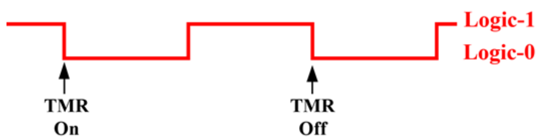

Fig. 11. The use of Timer in detecting the period and frequency

The flow diagram of the code piece written for the period measurement process is presented in Figure 12. During the measurement, it was checked whether the Timer value exceeds 65535 in both logic-0 and logic-1 states. If the timer goes down to zero, 1 is added to the value of the counter. In this way, it is ensured that the period calculation is made correctly in the case of long time measurement or high-frequency oscillator use.

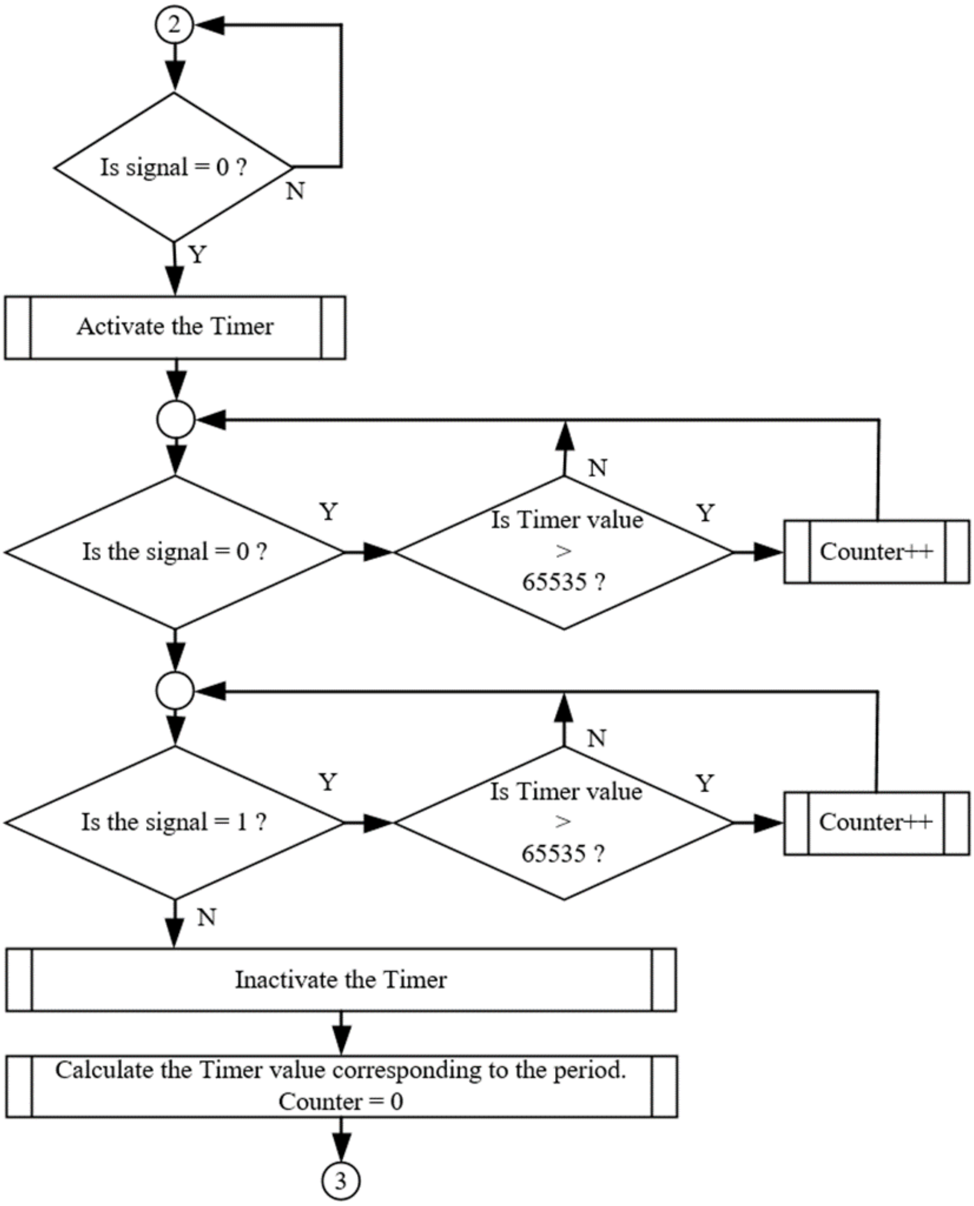

Fig. 12. Flow diagram of the piece of code written to determine the period

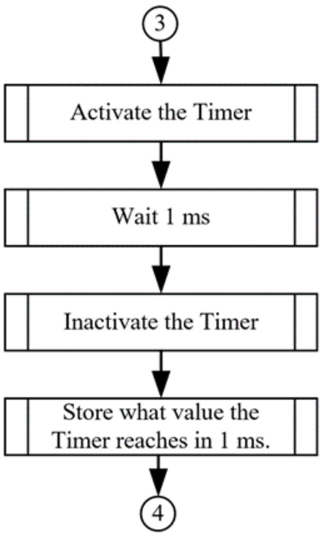

Fig. 13. Determining the value reached by the timer in 1 ms

The reference time needed for both calculating the phase difference between two signals in terms of time and determining the frequencies of the signals was taken as 1 ms. The flow diagram of the code piece written to determine the value, which the Timer will reach in the reference time, is shown in Figure 13.

After all the values specified in the flow charts are found, it is necessary to calculate the phase difference between the two signals in degrees to display on the screen the radial information received from the VOR station. These calculations in the simulation are given in Equations 1 and 2. Equation 1 is used to calculate the phase difference between 0 ° and 180 °, while Equation 2 is used to calculate the phase difference between 180 ° and 360 °. In both equations, φ symbolizes the phase difference in degrees; T_φ symbolizes the Timer value corresponding to phase difference; T_T symbolizes to the Timer value corresponding to the period.

$$\varphi = \frac{T_{\varphi}*360}{T_T} \tag{1}$$

$$\varphi = 360 - \frac{\varphi_t*360}{T_T} \tag{2}$$

Although the frequency of the signals from the VOR station is equal and 30 Hz, it is also still calculated using Equation 3. In Equation 3, f symbolizes the frequency, T_{1ms} symbolizes the value reached by Timer in 1ms.

$$f = \frac{T_{1ms}*1000}{T_T} \tag{3}$$

The information to be displayed on the LCD screen as a result of all these operations is seen in Figure 14. It should be noted that the mathematical expression on the first line of the LCD screen is equal to the number in the second line.

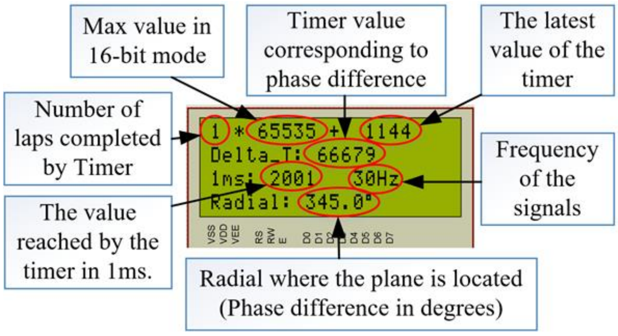

Fig. 14. Information to be seen on the LCD when the simulation starts

4. Simulation Results

Before testing the system, whether the desired phase-different signals are produced by the signal generator was checked with an oscilloscope (Figure 15). During the controls, it was seen that the signal generator produced the desired phase-different signals. However, since it is not possible to see the phase difference in degrees on the oscilloscope screen, it should be kept in mind that the time equivalent of the phase difference should be checked.

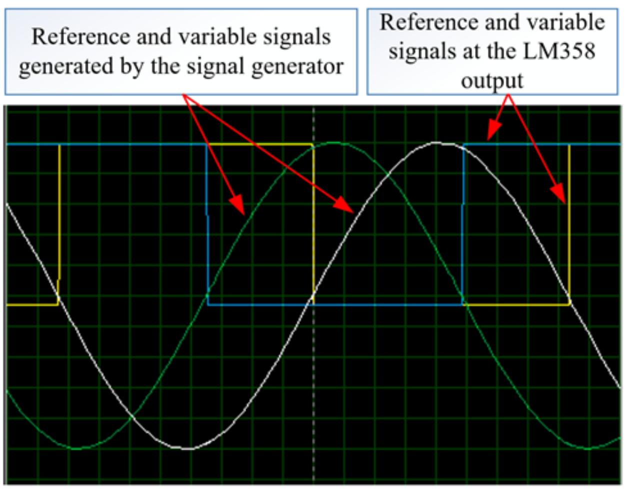

Fig. 15. Sine waves with a phase difference generated by the signal generator

The accuracy of the circuit diagram and the algorithms have been tested by entering different phase degrees from the window shown in Figure 4.b. Signals with phase-different of 5, 45, 179, 246, 300 and 359 ° were generated randomly. The simulation was repeated for each phase-different signal generated.

The screenshot taken during the 5 ° test is given in Figure 16. The simulation results obtained for other signals are also shown in Figure 17-21. While sharing the results of other signals, only the LCD section was given.

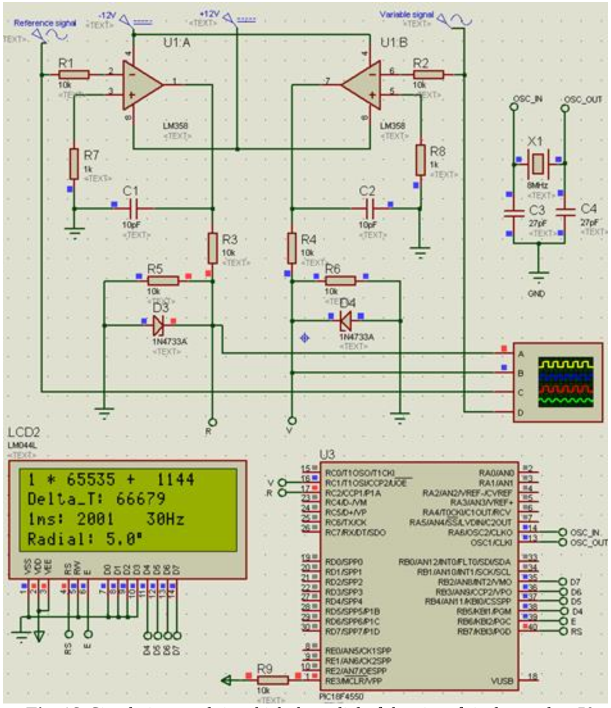

Fig. 16. Simulation result in which the radial of the aircraft is detected as 5°

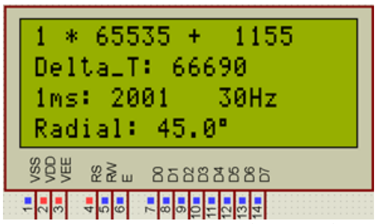

Fig. 17. Simulation result in which the radial of the aircraft is detected as 45 °

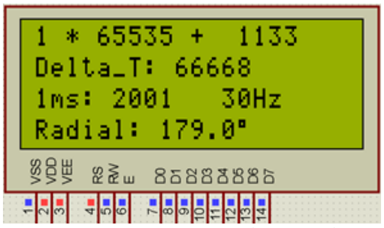

Fig. 18. Simulation result in which the radial of the aircraft is detected as 179°

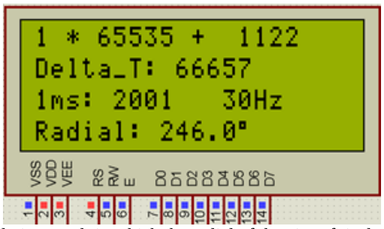

Fig. 19. Simulation result in which the radial of the aircraft is detected as 246°

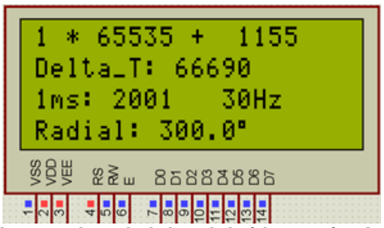

Fig. 20. Simulation result in which the radial of the aircraft is detected as 300°

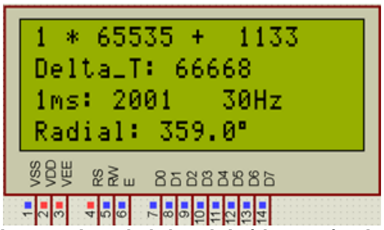

Fig. 21. Simulation result in which the radial of the aircraft is detected as 359°

5. Conclusion

In this study, the VOR receiver, which has an important place in aviation, has been simulated to ensure that the students, who educate in aviation electricity and electronics departments of aviation schools are better motivated to the microcontroller lessons. Since the microcontroller to be used in the simulation and the compilers to be used in the programming of the microcontroller may vary, only flow diagrams and basic calculations are given.

The phase difference of the variable phase signal in the VOR system was obtained by using the sine generator in the simulation program. 6 different simulations were made to test the accuracy of the created algorithm. In the simulations, it was seen that the phase differences between the reference and the variable signal were correctly detected, and thus the radial where the aircraft was located in according to the VOR station, was determined without error.

References

[1] Marzioli P, Pellegrino A, Valdatta M, et al. Testing the VOR (VHF Omnidirectional Range) in The Stratosphere: STRATONAV Experiment. In: *2016 IEEE Metrology for Aerospace (MetroAeroSpace)* 2016, pp.336-341. IEEE.

[2] Fei L, Yue H and Yuankai L. Research on Height and Diameter of Doppler VHF Omnidirectional Beacon in Complex Environment. In: *IOP Conference Series: Materials Science and Engineering* 2019, p.012005. IOP Publishing.

[3] Schrader T, Bredemeyer J, Mihalachi M, et al. High-Resolution Signal-in-Space Measurements of VHF Omnidirectional Ranges Using UAS. *Advances in Radio Science: ARS* 2019; 17: 1-10.

[4] Kara M. Ground Error Curves Formulas for VHF Omnirange Radio Beacon Antenna System. *Microwave and Optical Technology Letters* 1997; 15: 369-373.

[5] Wakabayashi R, Kawakami H, Sato G, et al. Analysis of Course Errors on CVOR Antennas (Including Effects of Mutual Coupling Between Elements). *IEEE transactions on vehicular technology* 1998; 47: 392-405.

[6] Amalu P. Analysis of Error in a Very High Frequency Omni-Directional Radio Range (VOR) Station in An International Airport in Nigeria. *The Pacific Journal of Science and Technology* 2020; 21.

[7] Moir I and Seabridge AG. *Civil Avionics Systems*. Professional Engineering Publishing, 2003.

[8] The Central Flying School (CFS) Manual of Flying.

[9] Miet PL. The Technical Wizardry of VORs - How they work. 2016.

[10] https://www.slideshare.net/btinus/vor-ppt (accessed 9.12.2020).

[11] *Radio Navigation* CAE Oxford Aviation Academy, 2014.

[12] Çolak İ and Bayındır R. Güç Katsayısının Bir Mikrodenetleyici Kullanarak Ölçümü. *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi* 2003; 19: 50-58.

[13] *Kazan* FA, Ağaçayak AC, Arslan C, et al. *MikroC İle PIC18F4550 Uygulamaları*. 1th ed. Konya: Mesleki Akademi, 2014.