Indoor ultrasonic positioning system transceiver modules

D V Morohin
Volga State University of Technology, Lenin Sq., b. 3, Republic of Mari El, Yoshkar-Ola, 424000, Russia

E-mail: dvmitry@mail.ru

Abstract. Positioning systems allow you to determine the position of an object. Global positioning systems use signals from satellites for this purpose, and local (indoor) positioning systems use a wide range of physical phenomena that can transmit signals. In particular, one of these phenomena is ultrasonic. The author of this article propose a solution in the form of devices for emitting and receiving an ultrasonic pulse with high sensitivity and a wide solid angle of reception/ emission of ultrasonic, which can be successfully applied in an indoor positioning system.

1. Introduction
Positioning systems allow determining the objects position in space. Global positioning system uses a network of satellites to determine the object location on the planet surface. Local positioning systems solve another problem: they carry out the positioning in places where global positioning is not possible (warehouses and any other enclosed spaces) and the accuracy of global positioning systems (1-2 m) is insufficient. Local positioning systems can based on a wide range of technology [1].

Distributed indoor positioning system determining the position of an object using RFID technology. It is possible to determine the location to use a cellular network and a Wi-Fi network. In addition, positioning system can based on infrared radiation and on ultrasonic. One of the advantages of ultrasonic method is high precision (about centimeters). This article is the result of the ultrasonic transceiver system development.

Many developers using ultrasonic type of indoor positioning system [2, 3]. However, often, for radiation of the ultrasonic pulses used ultrasonic rangefinders (HC-SR04 for example). The objective of this rangefinder is essentially a measurement of distance, and the ultrasonic wave radiated in a narrow beam.

Therefore, these modules can be used to build a positioning system, but greatly limits its working area, since the transmitters and receivers should always must directed towards each other. To eliminate this drawback it is possible to go the path of increasing the number of modules and radial alignment of the transmitters and receivers. However, this way is not optimal, because to cover a full circle is need 12 rangefinders that is large enough quantity, and increases the cost of system.

In addition, if you use many rangefinders on the receivers, it can be connection difficulties. The author of this article developed the modules of the radiation and reception of ultrasonic, in which these disadvantages eliminated or significantly mitigated.
2. Requirements for the modules

Modules must meet the following requirements: a large solid angle works (both receivers and transmitters), suitable sensitivity (the signal is received at a distance of 6 m), ease of connection to modern microcontrollers, ability to easily modify the circuit if you need other features.

To fulfil the first condition, it was decided to use ultrasonic sensors/transducers with a wide solid angle of reception/emission of ultrasonic. In this case, the modules MA40S4R and MA40S4S were used respectively. They provide solid angle of 80 degrees. In addition, these modules have good sensitivity.

As known, the microcontrollers work primarily with discrete signals. Therefore, for receivers it would be convenient to implement a sampling of the input signal, bringing it to digital form. For the transmitters it would be effective to realize switching of generation of ultrasonic waves by the discrete potential signal and not to perform high-frequency generation directly under the microcontroller. In this case, the microcontroller load will be minimal.

3. Ultrasonic transmitter module

Ultrasonic transmitter diagram shown in figure 1. Its main part is a timer of 555 series, in particular, NE555. It wired as generator [4, p.303] in this case. The timer R contact is a reset signal, and it is a control signal connected to the microcontroller. Feeding him a low-level voltage, the timer starts to generate vibrations. Timing chain consists of resistors Ra and Rb and capacitor C1. Calculated period of oscillation is \( T = 0.693(Ra+2Rb)C1 \). This circuit of timer generation principle is as follows. Contact DIS (discharge), depending on the level of the output signal, can be in two States: in the z-state, or connected to ground. When you turn on the circuit and the capacitor is discharged, the timer is in a state where the output signal has a logic one level; in this case, the contact DIS is translated in the z-state and the capacitor C1 begins to charge through resistors Ra and Rb. Upon reaching the capacitor voltage equals \( 2/3 Up \) the entrance THR (threshold) switches, and the output goes into a state logic level of "0". Simultaneously, the contact DIS is transitioned to the connection state with the ground, and the capacitor C1 discharged through the resistor Rb and the contact DIS. When lowering the voltage on the capacitor to \( 1/3 Up \) contact THR switch again, the output returns to the logic level of "1", the contact DIS moves in the z-state and the generation cycle begins again.

![Ultrasonic radiation module Diagram](image)

Figure 1. Ultrasonic radiation module Diagram.

Ultrasonic vibrations modules MA40S4S for optimal generation necessary discrete periodic signal with a fill factor as close as possible to 50%. Since the charging of capacitor C1 takes place via a serial connection of resistors Ra and Rb and discharge only through the resistor Rb such a ratio can be obtained only in the case when \( Rb = 0 \), in the presence of the resistance Rb in this circuit, the fill factor will always be greater than 50%. But \( Rb = 0 \) in the case of the connection of the DIS contact with the ground
short circuit occurs. Therefore, the resistor \( R_a \) selected so that as low as possible, but it significantly limits the current from the power source to the ground during the phase of discharge of the capacitor.

It is possible to connect the ultrasonic modules directly to the generator output in theory. However, it is not optimal for two reasons. The first reason is that the radiation modules are piezoelectric elements, which by their properties similar to capacitors, and when connected they create an oscillating system. The capacity of each module have some variation, and oscillations connected modules will not interfere with the vibrations of each other, and the increases the difference of their parameters. The second reason is that the output of the NE555 timer designed for a small limit output current of 225 mA. Connecting several modules, as a capacitor, creates a significant burden for the timer output at the initial moment of charging, which is an undesirable effect. To solve these problems operational amplifiers are used. In this and the following circuit were used operational amplifier MCP6022. They were chosen because they meet the following requirements: output voltage swing from ground level to the level of the power supply (rail to rail) wide bandwidth (10 MHz), as well as the need for low voltage operation (2.5 V to 5.5 V). In this case, the operational amplifiers are used. This connection maintains the voltage at the output of op-amp is equal to the voltage at the non-inverting input. The essence of this connection in our circuit is that the input op amp presents a very large resistance (typically on the level Megohm) that unloads the timer output from the low impedance load in the form of the directly connected modules radiation. On the other hand, the radiation modules now are not connected, so do not interfere with the vibrations of each other.

4. Ultrasonic receiver module

Ultrasonic receiver circuit is show in figure. 2. Ultrasonic signal is been amplified and is sampled, and the results of sampling several modules are combined using the Boolean OR.

![Figure 2. Ultrasonic receiver circuit.](image)

Operational amplifier \( DD1.1 \) in this circuit creates whole diagram "virtual ground". A feature of operational amplifier is that if the device is connected to the supply voltage to op-amp the voltage level of the land automatically becomes the voltage level equal to half of the supply voltage (relative to the
point with zero potential). For this reason, amplification of the signals necessary to implement such a circuit, the voltage that is equal to the power supply and its input impedance was low. Operational amplifier DD1.1 connected via repeater, previously discussed, but its non-inverting input voltage applied to the voltage divider, with the same shoulders. This circuit implements a point the voltage of which is equal to half the supply voltage, which grounds for one of the subsequent circuits, in particular amplifiers.

Wiring diagram DD1.2 and DD2.1 represents non-inverting amplifiers [4, p. 185]. The gain of these amplifiers is equal \( T_{\text{ous}} = 1 + R7/R5 = 11 \). This circuit was preferable to an inverting amplifier because it provides very high input resistance, which is preferable, when working with weak signals generated by the reception module.

After amplification, the signal enters a comparator circuit. This circuit is operational amplifier without any feedback. For this reason, the output of op-amp very quickly saturated in the positive or the negative direction (i.e., becomes equal to one of the supply voltages). If the voltage at the inverting input greater than non-inverting, the output voltage becomes equal to the negative supply, otherwise - positive. In our circuit the non-inverting input the voltage from the amplifier, and the inverting - threshold voltage operation circuit created by the voltage divider. When ultrasonic come the voltage at the non-inverting input was half of the period will exceed the voltage at the inverting input and the comparator output will appear logic level of "1", the rest of the output will appear a logic level of "0". You may notice that the voltage divider lower shoulder slightly more of the upper shoulder. This is for the following reason. In the absence of ultrasonic received by the receiving unit, the signal amplifier will be approximately the voltage level of the "virtual ground" equal to half the supply voltage. However, there will be some noise. If the shoulders are the same, then the slightest voltage fluctuations due to noise at the non-inverting input will cause the constant transitions of the comparator output the negative saturation to positive and back. It has not desired. This difference in the shoulders of the voltage divider generates a threshold of protection against noise and false positives of the circuit for him.

Since one receiver is covered a little corner, it requires consolidation of several such circuit. Because signal presence indicated by a logic level of "1", to merge the operation of these circuit is best suited for the chip operational amplifier logic. When at least one module for receiving ultrasonic vibrations output of this circuit will be installed in the logic level of "1", regardless of whether that signal other modules receiving or not.

5. Conclusion

Devices Prototypes were assembled and tested. They ensure the capture of the ultrasonic signal at a distance of 6 m. and when using 2 transmitters and receivers in the circuit of permissible angles of radiation and reception of 140 degrees. These modules were applied to build a positioning system using ultrasonic [5].

References
[1] Brena R F, Garcia-Vazquez J P, Galvan-Tejada C E, Munoz-Rodriguez D, Vargas-Rosales C and Fangmeyer J 2017 Evolution of Indoor Positioning Technologies: A Survey Journal of Sensors 2017 2630413
[2] Draghtici I C, Vasilateanu A, Goga N, Pavaloiu B, Guta L, Mihaiescu M N and Boiangiu C A 2017 Indoor positioning system for location based healthcare using trilateration with corrections Proc. Int. Conf. on Engineering, Technology and Innovation (Madeira Island, Portugal: IEEE) 2018 pp 169-72
[3] Ananth S K, Anusha R B and Surekha T P 2018 Indoor Positioning System using Ultrasound International journal of engineering research & technology (IJERT) 6(13) 1-7
[4] Horowitz P and Hill W 2015 The art of electronics, 2nd ed. (Cambridge, UK: Cambridge University Press)
[5] Morohin D V and Totisky A A 2018 Development of a Scalable Local System for Determining the Location of a Mobile Object International Journal of Advanced Studies 8(1-2) 105-14