

Ultrasonic Sensor



Application Manual



*Innovator
in Electronics*

**Murata
Manufacturing Co., Ltd.**

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Introduction

An ultrasonic sensor transmit ultrasonic waves into the air and detects reflected waves from an object. There are many applications for ultrasonic sensors, such as in intrusion alarm systems, automatic door openers and backup sensors for automobiles.

Accompanied by the rapid development of information processing technology, new fields of application, such as factory automation equipment and car electronics, are increasing and should continue to do so.

Using its unique piezoelectric ceramics manufacturing technology developed over many years, Murata has developed various types of ultrasonic sensors which are compact and yet have very high performance.

The information contained in this catalog will help you to make effective use of our ultrasonic sensors.

Features of Murata Ultrasonic Sensor

- (1) Compact and light-weight
- (2) High sensitivity and high sound pressure
- (3) High reliability

CONTENTS

1	Characteristics of Ultrasonic Waves	2
1.	Wavelength and Radiation	2
2.	Reflection	2
3.	Effects of Temperature	2
4.	Attenuation	2
2	Construction and Operation Principles	3
1.	Open Structure Type Ultrasonic Sensors	3
2.	Enclosed Type Ultrasonic Sensor	4
3.	High Frequency Ultrasonic Sensors	4
3	Electrical Characteristics	5
1.	Sound Pressure Characteristics	5
2.	Sensitivity Characteristics	5
3.	Radiation	5
4.	Ratings	6
4	Applications	8
1.	Examples of Applications	8
2.	Transmitting and Receiving Circuits	9
3.	Applications for Distance Measurement	10
4.	Installation	11
5.	Sharpening of Radiation	12
5	Environmental Tests	13
■	Notice	14

1	Characteristics of Ultrasonic Waves
2	Construction and Operation Principles
3	Electrical Characteristics
4	Applications
5	Environmental Tests

1 Characteristics of Ultrasonic Waves

Ultrasonic waves are sounds which cannot be heard by humans and are normally, frequencies of above 20kHz. The basic characteristics of ultrasonic waves are explained below.

1

1. Wavelength and Radiation

Velocity of wave propagation is expressed by multiplication of frequency and wavelength. The velocity of an electromagnetic wave is $3 \times 10^8 \text{m/s}$, but the velocity of sound wave propagation in air is as slow as about 344m/s (at 20°C). At these slower velocities, wavelengths are short, meaning that higher resolution of distance and

direction can be obtained.

Because of the higher resolution, it is possible to get higher measurement made large accuracy. The surface dimension of the ultrasonic device can be easily to obtain accurate radiation.

2. Reflection

In order to detect the presence of an object, ultrasonic waves are reflected on objects. Because metal, wood, concrete, glass, rubber and paper, etc. reflect approximately 100% of ultrasonic waves, these objects can be easily detected.

Cloth, cotton, wool, etc. are difficult to detect because they absorb ultrasonic waves. It may often be difficult, also, to detect objects having large surface undulation, because of irregular reflection.

3. Effects of Temperature

Velocity of sound wave propagation "c" is expressed by the following formula.

$$c = 331.5 + 0.607t \text{ (m/s)} \quad \text{where } t = \text{temperature } (^\circ\text{C})$$

That is as sound velocity varies according to circumfer-

ential temperature, it is necessary to verify the temperature at all times to measure the distance to the object accurately.

4. Attenuation

The strength of ultrasonic waves propagated into the air attenuate proportionally with distance. This is caused by diffusion loss on a spherical surface due to diffraction phenomenon and absorption loss, that energy is absorbed by medium.

As shown in Fig.1, the higher the frequency of the ultrasonic wave, the bigger the attenuation rate and the shorter the distance the wave reaches.

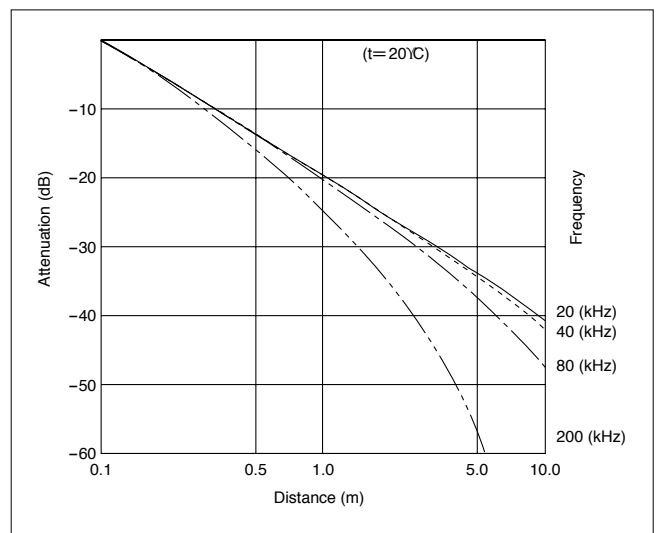


Fig. 1 Attenuation Characteristics of Sound Pressure by Distance

2 Construction and Operation Principles

When voltage is applied to piezoelectric ceramics, mechanical distortion is generated according to the voltage and frequency.

On the other hand, when vibration is applied to piezoelectric ceramics, an electric charge is produced.

By applying this principle, when an electric signal is added to a vibrator, constructed of 2 sheets of piezoelec-

tric ceramics or a sheet of piezoelectric ceramics and a metal sheet, an electric signal is radiated by flexure vibration. As a reverse effect, when an ultrasonic vibration is added to the vibrator, an electric signal is produced.

Because of these effects, piezoelectric ceramics are utilized as ultrasonic sensors.

1. Open Structure Type Ultrasonic Sensors

As shown in the diagram of an ultrasonic sensor (Fig. 2), a multiple vibrator is fixed elastically to the base.

This multiple vibrator is a combination of a resonator and a vibrator which is composed of a metal sheet and a piezoelectric ceramics sheet. The resonator is conical in order to efficiently radiate the ultrasonic waves generated by the vibration and also in order to effectively concentrate the ultrasonic waves at the central part of the vibrator.

Fig. 3 shows a finite element method simulation of the vibration of the multiple vibrators.

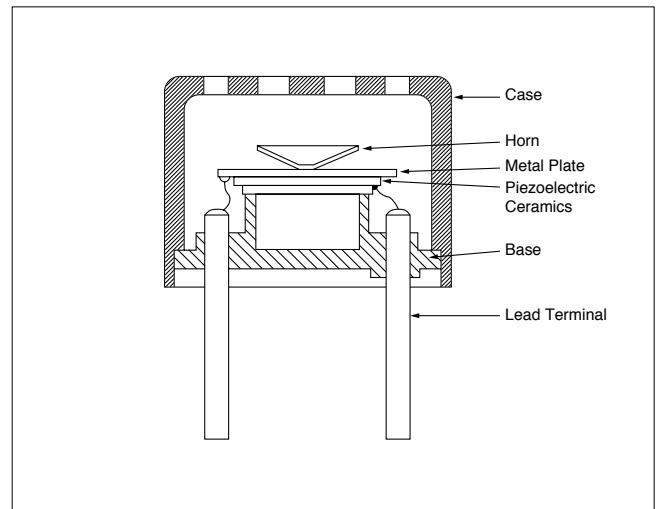


Fig.2 Construction of Open Structure Type Ultrasonic Sensor

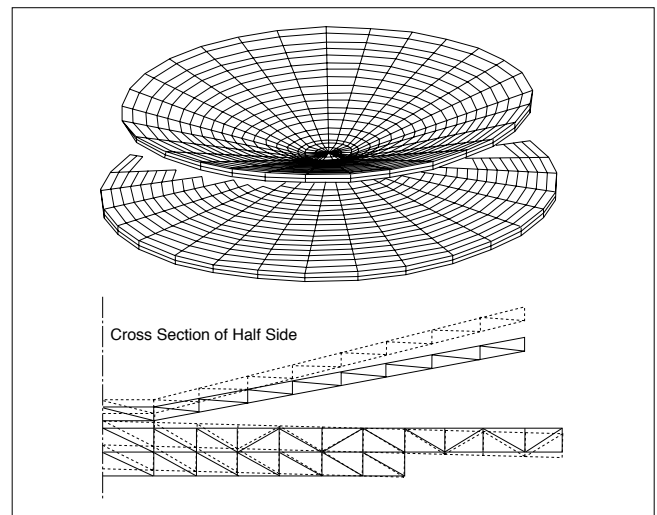


Fig.3 Simulation of Vibration

2 Construction and Operation Principles

2. Enclosed type Ultrasonic Sensor

Ultrasonic sensors for outdoors use are sealed to protect them from dew, rain and dust.

Piezoelectric ceramics are attached to the top inside of the metal case. The entrance of the case is covered with resin. (See Fig. 4.)

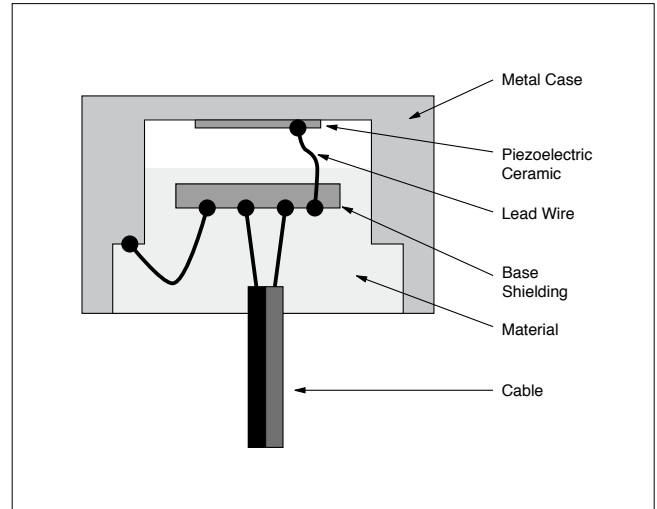


Fig. 4 Construction of Enclosed Type Ultrasonic Sensor

3. High Frequency Ultrasonic Sensors

For use in industrial robots, accuracy as precise as 1mm and acute radiation are required. By flexure vibration of the conventional vibrator, no practical characteristics can be obtained in frequencies higher than 70kHz and, therefore, vertical thickness vibration mode of piezoelectric ceramics is utilized for detection in high frequency. In this case, the matching of acoustic impedances of the piezoelectric ceramics and air becomes important. Acoustic impedance of piezoelectric ceramics is $2.6 \times 10.7 \text{kg/m}^2\text{s}$, while that of air is $4.3 \times 10.2 \text{kg/m}^2\text{s}$. This difference of 5 powers causes large loss on the vibration radiating surface of the piezoelectric ceramics.

Matching the acoustic impedances with air is performed by bonding a special material to the piezoelectric ceramics as an acoustic matching layer.

This construction enables the ultrasonic sensor to work in frequencies of up to several hundred kHz.

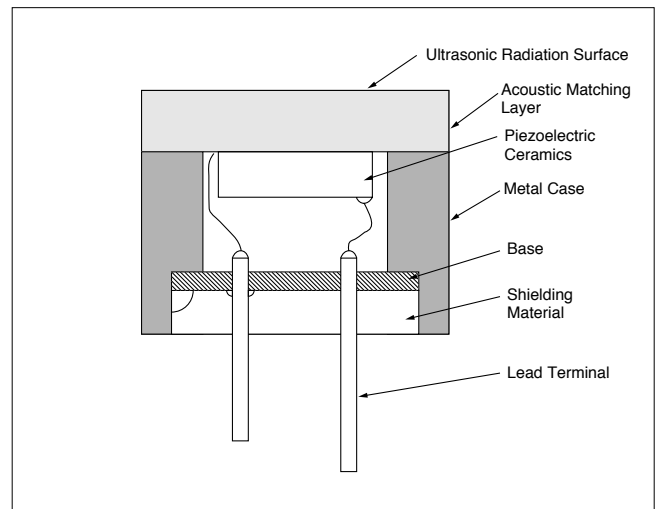


Fig. 5 Construction of High Frequency Ultrasonic Sensors

3 Electrical Characteristics

1. Sound Pressure Characteristics

Sound pressure level (S.P.L.) is unit indicating the volume of sound and is expressed by the following formula.

$$\text{S.P.L.} = 20 \log \frac{P}{P_0} \text{ (dB)}$$

where "P" is Sensor sound pressure (Pa) and "Po" is reference sound pressure (20μPa).

Fig.6 shows a sound pressure measuring circuit.

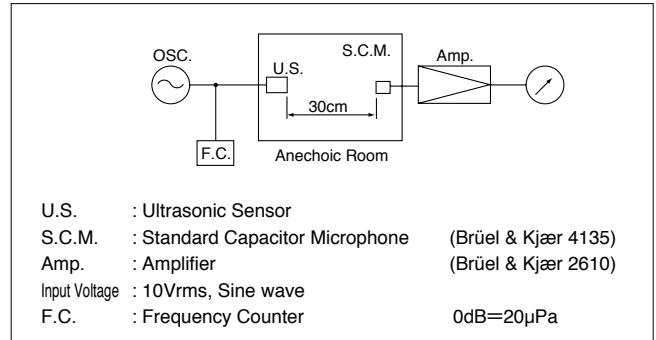


Fig. 6 Sound Pressure Measuring Circuit

2. Sencitivity Characteristics

Sensitivity is the unit indicating the sound receiving level and is expressed by the following formula.

$$\text{Sensitivity} = 20 \log \frac{S}{S_0} \text{ (dB)}$$

where "S" is Sensor voltage (V) and "So" is reference sound pressure (V/Pa) .

Fig.7 shows a sensitivity measuring circuit. The 3.9kΩ resistor connected with the electrode terminal of the sensor is used to avoid the influence of outside noise.

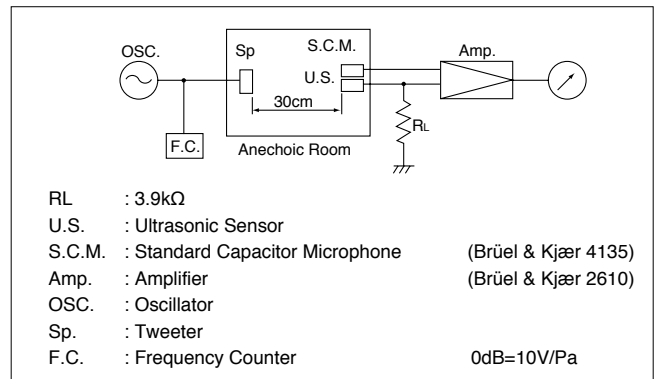


Fig. 7 Sensitivity Measuring Circuit

3. Radiation

The ultrasonic sensor is installed on a table. Then, the relationship between angle and sound pressure (sensitivity) is measured.

In order to express radiation precisely, the angle in which the sound pressure (sensitivity) level attenuates by 6dB compared with the front is called the half attenuation angle with an expression of $\theta^{1/2}$.

3 Electrical Characteristics

4. Ratings

The ratings and dimensions of representative types of these ultrasonic sensors appear in Table 1. Also frequency characteristics of sensitivity and sound pressure are

shown in Figs. 8 and 9 and their radiation characteristics Figs. 10 and 11.

Part Number	MA40S4R/S
Item	
Construction	Open structure type
Using Method	Receiver and Transmitter (Dual use) type
Nominal Frequency (kHz)	40
Overall Sensitivity (dB)	-
Sensitivity (dB)	-63±3
Sound Pressure (dB)	120±3
Directivity (deg)	80
Capacitance (pF)	2550±20%
Operating Temperature Range (°C)	-40 - +85
Detectable Range (m)	0.2 - 4
Dimension (mm)	ø9.9x7.1h
Weight (g)	0.7
Max. Input Voltage	20 Vp-p Square wave 40kHz

Part Number	MA40E7R/S	MA40E8-2	MA40MF14-5B
Item			
Construction	Water proof type		
Using Method	Receiver and Transmitter type	Combined use type	
Nominal Frequency (kHz)	40		
Overall Sensitivity (dB)	-		
Sensitivity (dB)	-74 min.	-85 min.	-87 min.
Sound Pressure (dB)	106 min.		103 min.
Directivity (deg)	100	75	100x50
Capacitance (pF)	2200±20%	2800	4400
Operating Temperature Range (°C)	-30 - +85		-40 - +85
Detectable Range (m)	0.2 - 3	0.2 - 1.5	
Dimension (mm)	ø18x12h	ø14x8h	ø14x9h
Weight (g)	4.5	2.4	
Max. Input Voltage	100 Vp-p Square waves 40kHz Pulse width 0.4 ms Interval 100 ms	160 Vp-p Square waves 40kHz Pulse width 0.8ms Interval 60 ms	

- Distance : 30cm, Sensitivity : 0dB=10V/Pa, Sound pressure Level : 0dB=20µPa.
- The sensor can be used in the operating temperature range.
Please refer to the individual specification for the temperature drift of Sensitivity/Sound pressure level or environmental characteristics in that temperature range.
- Directivity, and Detectable Range typical is value. It can be changed by application circuit and fixing method of the sensor.

Electrical Characteristics 3

Part Number	MA80A1	MA200A1	MA400A1
Item			
Construction	High frequency type		
Using Method	Combined use type		
Center Frequency (kHz)	75±5	200±10	400±20
Overall Sensitivity (dB)	-47 min. 0dB=18Vpp (at 50 cm)	-54 min. 0dB=18Vpp (at 20 cm)	-74 min. 0dB=18Vpp (at 10 cm)
Directivity (deg)	7		
Operating Temperature Range (°C)	-10 - +60	-30 - +60	
Detectable Range (m)	0.5 - 5	0.2 - 1	0.06 - 0.3
Dimension (mm)	ø47×24.5h	ø19×10.6h	ø11×10.5h
Weight (g)	93	6	2
Max. Input Voltage	120 Vp-p Square waves 75kHz Pulse width 600µs Interval 50 ms	120 Vp-p Square waves 200kHz Pulse width 250µs Interval 20 ms	120 Vp-p Square waves 400kHz Pulse width 125µs Interval 10 ms

- The sensor can be used in the operating temperature range. Please refer to the individual specification for the temperature drift of Sensitivity/ Sound pressure level or environmental characteristics in that temperature range.
- Directivity, and Detectable Range is typical value. It can be changed by application circuit and fixing method of the sensor.

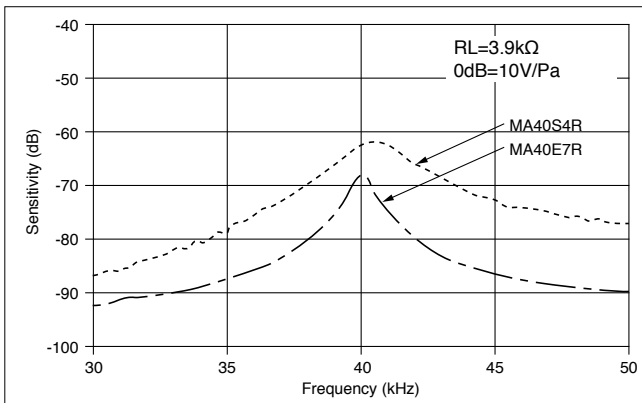


Fig. 8 Sensitivity

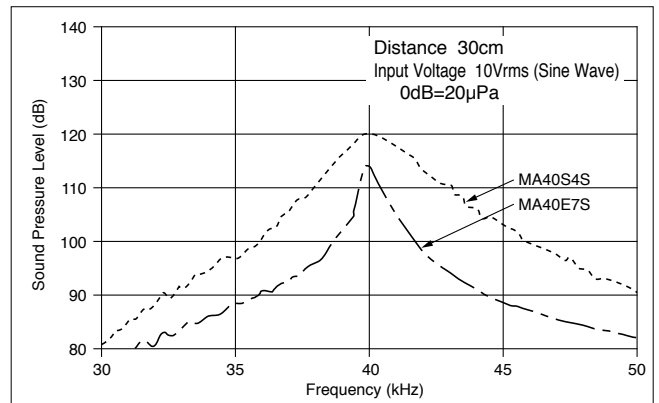


Fig. 9 Sound Pressure

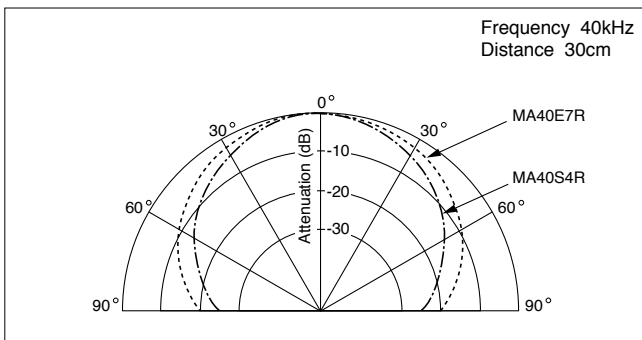


Fig. 10 Radiation Characteristics (Receiver)

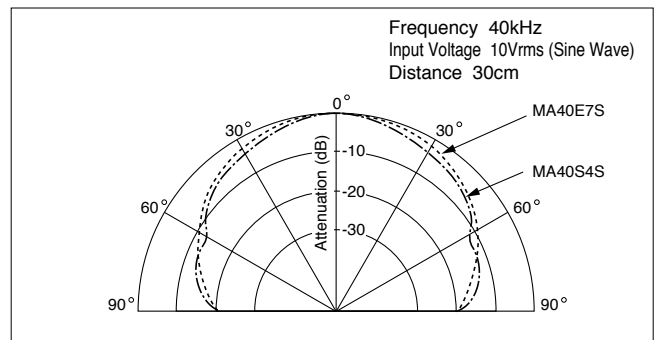


Fig. 11 Radiation Characteristics (Transmitter)

4 Applications

1. Examples of Applications

Ultrasonic sensors are utilized for many purposes such as measurement applications etc.

For examples of these applications, please refer to the examples in Table 2 and the explanations as follows.
 Level detection of continuous wave signals (Example 1) is used for counting machines and approximate switches due to the simple circuit construction of these devices.
 Example 2 is used in devices such as automatic doors where the environment is very changeable. The system is arranged so that the instrument may actuate only when a certain number of reflected pulses is detected.
 And example 2 is also used for measuring distance to an object, such as the back up sensors of cars.

Example 3 is an application utilizing the phenomenon by which the Doppler effect produces a modulated signal as an object moves closer or farther away. This is often used for intruder alarm systems.

Example 4 is an application utilizing the change of sound velocity according to the density and the flow speed of a gas.

Example 5 is a method used to count the number of Karman vortex generated against flow speed and utilize phenomena that ultrasonic signals level are reduced as Karman vortex passes into the sensor.

No.	Function Method	Performance Principle (S: transmitter, R: receiver)	Applications
1	Detection of Signal level of continuous wave		Counting instruments Access switches Parking meters
2	Measurement of pulse reflection time		Automatic doors Level gauges Automatic change-overs of traffic signals Back sonars of automobiles
3	Utilization of Doppler effect		Intruder alarm systems
4	Measurement of direct propagation time		Densitometers Flowmeters
5	Measurement of Karman vortex		Flowmeters

Table 2 Application Examples

2. Transmitting and Receiving Circuits

Examples of transmitting and receiving circuits using MA40S4R/S are shown in Figs.12 to 14. By changing a part of the constants, they can be applied for other purposes.

Fig.12 is a simple circuit using a C-MOS IC and is used

for continuously transmitting ultrasonic waves.

Fig.13 is a pre-amp circuit that amplifies the ultrasonic receiving signal.

Fig.14 is an ultrasonic pulse transmitting circuit.

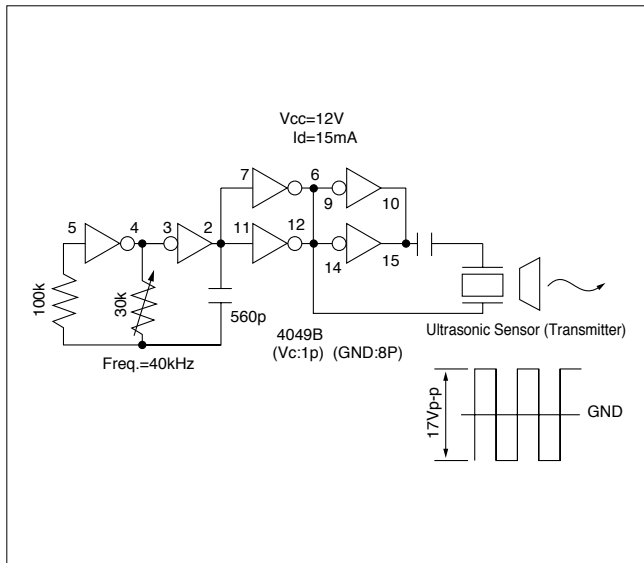


Fig. 12 Example of Continuous Wave Transmitting Circuit

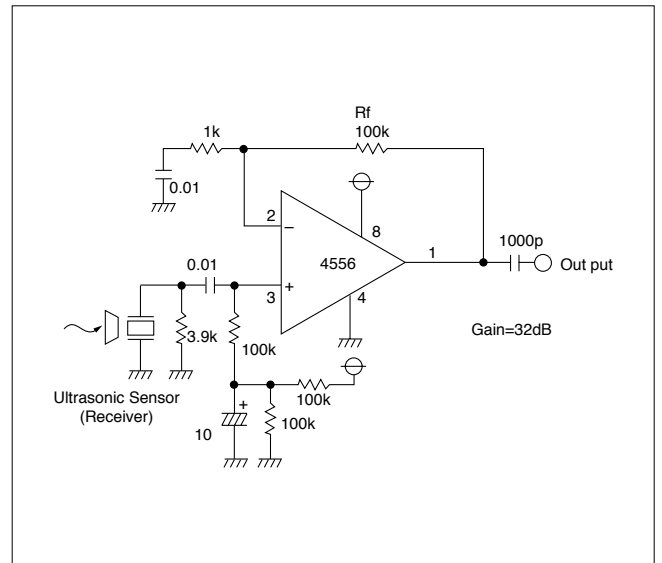


Fig. 13 Example of Receiving Circuit

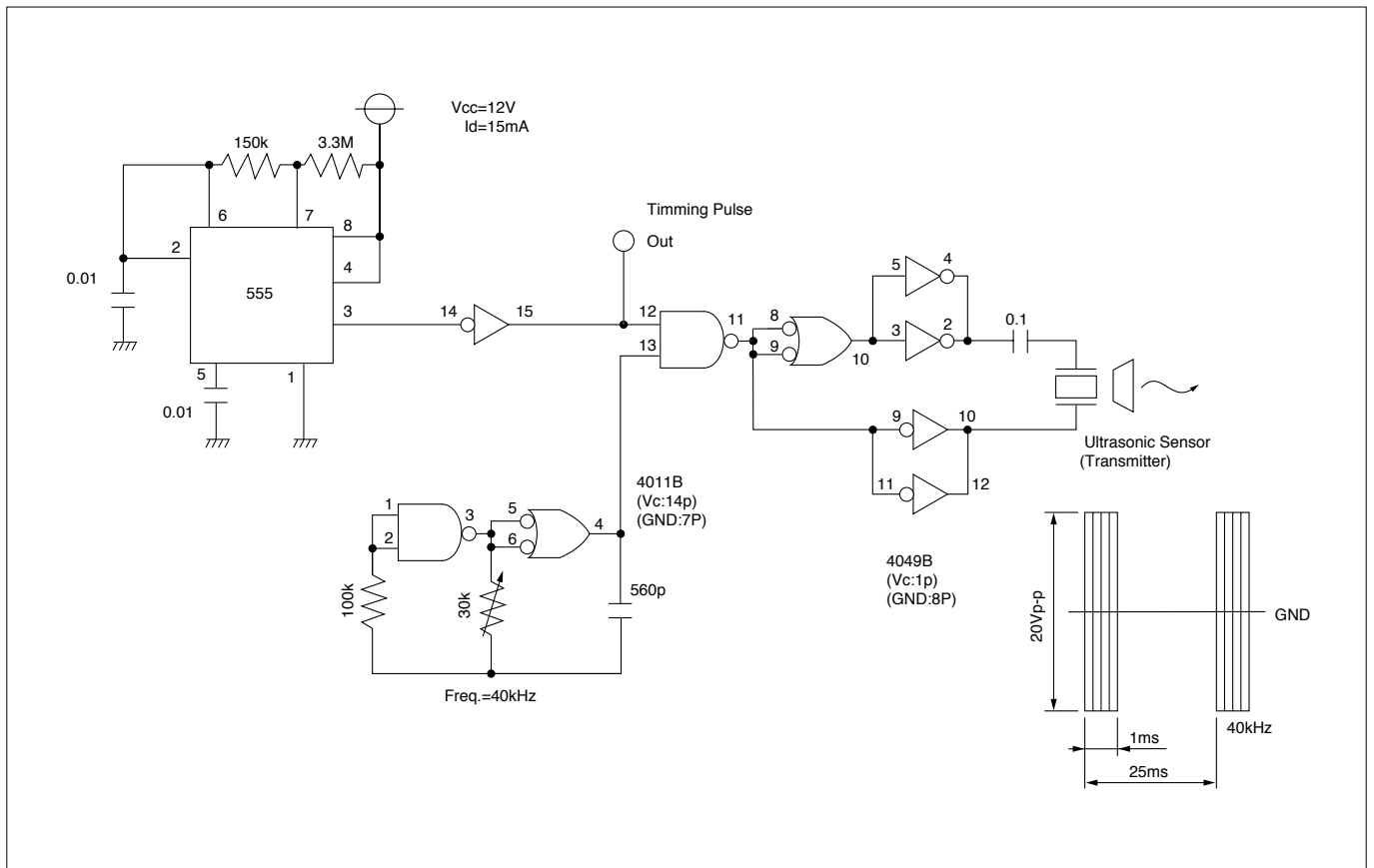


Fig. 14 Example of Pulse Transmitting Circuit

4 Applications

3. Applications for Distance Measurement

Fig.15 shows the principles of measuring distance and is called the "pulse reflection method" which makes it possible to count the number of reference pulses.

This method is used to measure reflection time up to the object between transmitting pulse and receiving pulse of the ultrasonic wave.

The relationship between the distance up to the object L and the reflecting time T is expressed by the following formula :

$$L=C \cdot T/2 \quad \text{where } C \text{ is the velocity of sound.}$$

That is, the distance to the object can be ascertained by measuring the reflection time involved in reaching the object.

Fig.16 shows an example of a distance measuring circuit using MA40S4R/S.

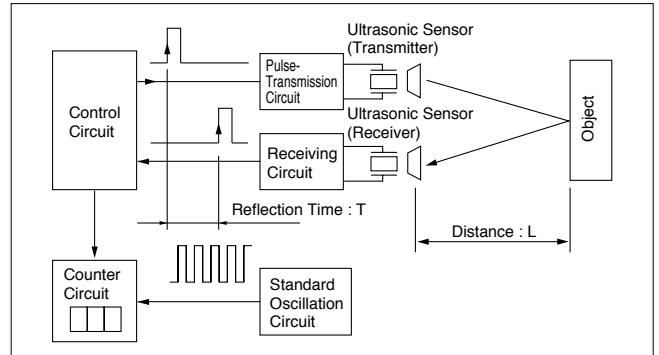


Fig. 15 Principles of Measuring Distance

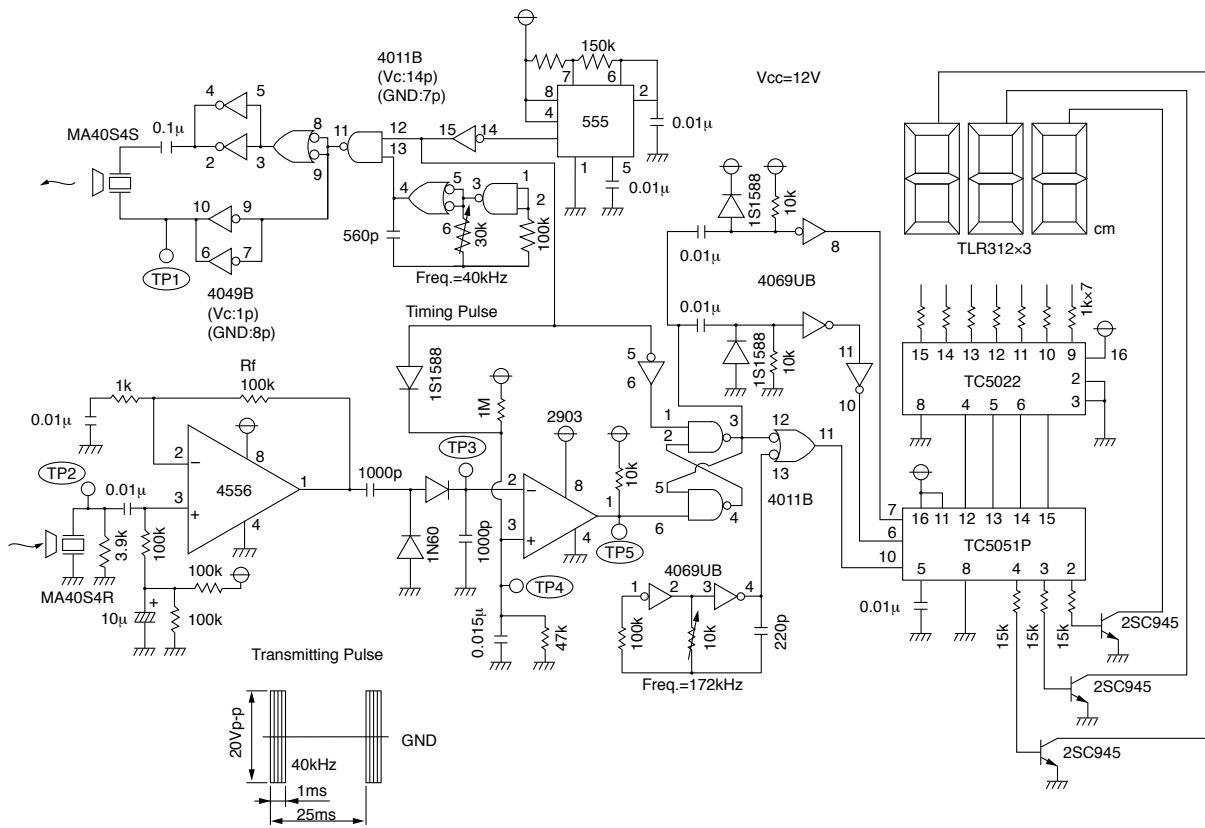


Fig. 16 Example of Distance Measuring Circuit

Applications 4

Fig. 17 shows the wave forms of each part of a circuit. This figure is the result of measuring distance to a flat board (10cm×10cm) located 50cm in front of the ultrasonic sensor mounted on a PC board with transmitter and receiver 3cm away from each other.

If the distance between the transmitter and the receiver is too close, the ultrasonic waves may reach the receiver directly from the transmitter. As shown in Fig. 17 (b), comparison will be made with the comparative voltages that attenuate exponentially with time.

Detected reflection wave is shown in Fig. 17 (c).

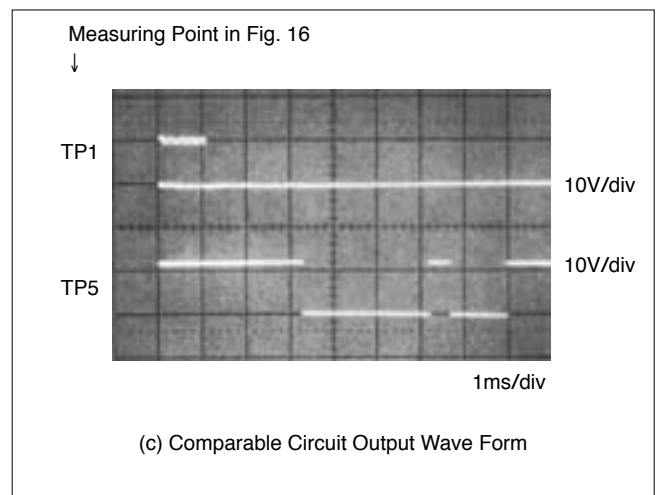
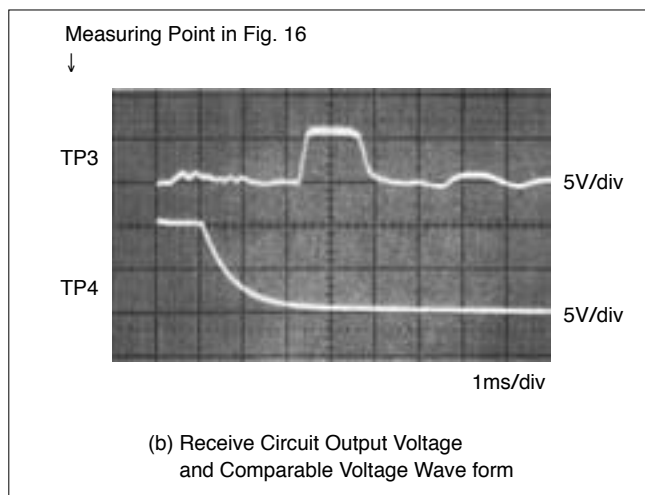
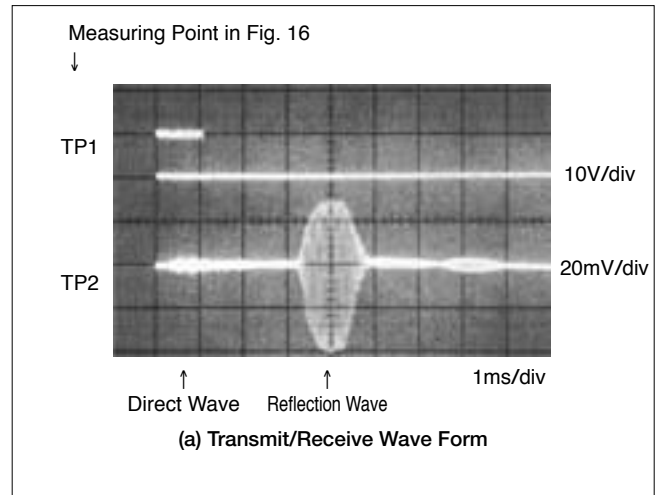


Fig. 17 Wave Forms of Each Part of Circuit

4. Installation

Fig. 18 is an example of the installation of an ultrasonic sensor.

The housing of the ultrasonic sensor should be protected with elastic material, such as rubber, sponge, etc., and care should be taken so that ultrasonic vibration is not transmitted directly to the receiver from the transmitter.

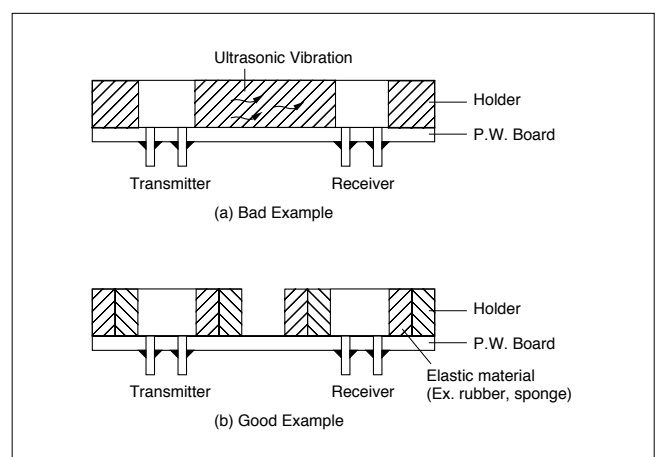


Fig. 18 Example of Installation of Ultrasonic Sensor

4 Applications

5. Sharpening of Radiation

When there are objects within the sensors field that reflect ultrasonic waves but when only a specific object should be detected, more acute radiation of ultrasonic waves is advantageous. Radiation is determined by the dimensions of the ultrasonic radiation surface and the frequency, but it is possible to make radiation more acute and measuring distance longer by mounting a horn on the outside of the ultrasonic sensor.

Regarding this horn, in general, the wider the diameter of its opening and the longer its total length, the more acute the radiation.

The relationship between the configuration of the horn using MA40S4R/S and the radiation characteristics is shown in Figs. 19 and 20.

A similar result can be obtained regarding sound pressure radiation.

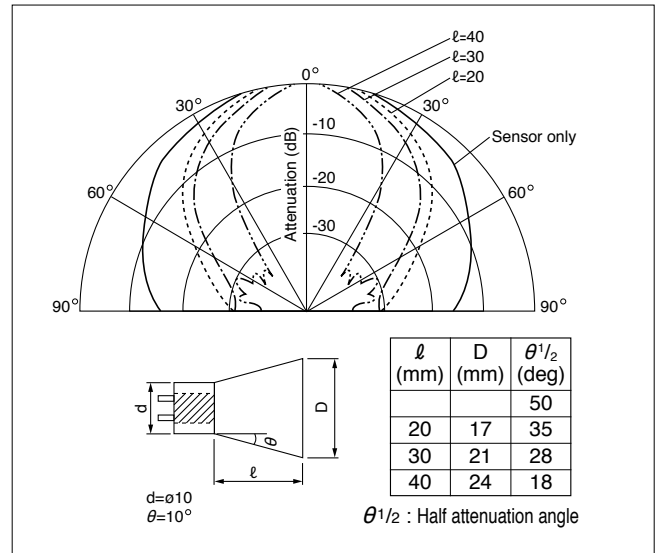


Fig. 19 Horn Length and Radiation (MA40S4R)

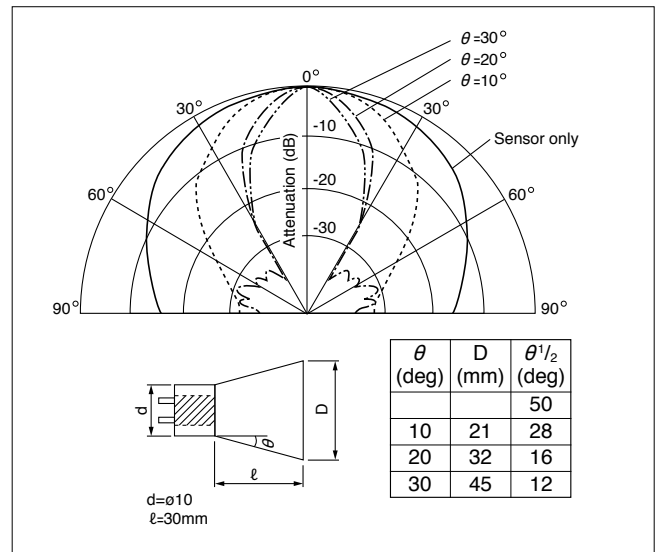


Fig. 20 Horn Angle and Radiation (MA40S4R)

5 Environmental Tests

Environmental tests of MA40S4R/S as an example are shown in below.

■Environmental tests

No.	Kind of Test	Conditions	Judgement
1	Humidity Resistance	60°C, 90 - 95%RH, 100 hours	Variation of sensitivity and S.P.L. is within 3dB.
2	High Temperature Storage	85°C, 100 hours	
3	Low Temperature Storage	-40°C, 100 hours	
4	Thermal Shock	With -40°C (30 minutes) and +85°C (30 minutes) as one cycle, 100 cycles. (Resistance of 3.9kΩ connected between terminals of sensor.)	
5	Vibration	Maximum Amplitude : 1.5mm Vibrating frequency : 10 - 55Hz Vibrating cycle : 1minute 3 hours in each of 3 directions	
6	Solder Heart Resistance	Soldering terminal up to 2mm below base at 350°C with soldering tip for 3 seconds.	
7	Operating	Frequency 40kHz, Sine 24Vp-p, 1000 hours	

■ Caution in use

1. (Notice in design)

- 1) The transducer may generate surge voltage by mechanical or thermal shock.
- 2) Please do not apply D.C.voltage for ultrasonic transducer to avoid migration.
- 3) Please do not use this ultrasonic sensor in water.

2. (Notice in handling and storage)

- 1) Please do not apply an excessve mechanical shock for this ultrasonic transducer.
Please do not apply excessive force on the top of this ultrasonic transducer and terminal pins.
- 2) The products should not be used or stored in a corrosive atmosphere, especially where chloride gas, sulfide gas, acid, alkali, salt or the like are present.
Store the products in the room where is normal temperature and humidity, and avoid the sunlight, sudden changes in temperature and humidity.
It may cause of failure or malfunction in such conditions.
- 3) Please do not use and storage this ultrasonic sensor in hev y dust and high humidity condition. Store the products where the temperature and relative humidity do not exceed -10 to 40 degrees centigrade, and 15 to 95%RH.
Use the products within 6 months after receiving.

3. (Notice in mounting)

- 1) Please do not apply excessive force for terminals, when soldering.
- 2) Use soldering iron to mount. Don't exceed 350 degC, 3second. Soldering point should be more than 2mm below from the bottom of ultrasonic transducer body.
- 3) Please do not clean by water and dissolvent.

△Note:

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|-----------------------------|--|
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| ⑨ Data-processing equipment | ⑩ Application of similar complexity and/or reliability requirements to the applications listed above |

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