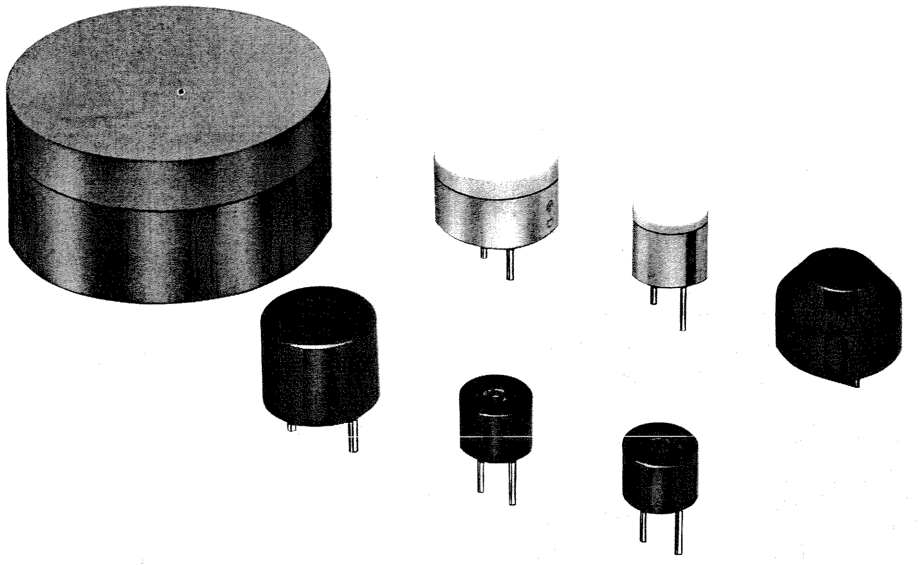


# ULTRASONIC SENSOR

## *APPLICATION MANUAL*

# Contents

# 1 Characteristics of Ultrasonic Waves

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

## 1. Wavelength and Radiation

Velocity of wave propagation is expressed by multiplication of frequency and wavelength. The velocity of an electromagnetic wave is $3\times10^8$m/s, but the velocity of sound wave propagation in air is as slow as about 344m/s (at 20℃). 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.
$c=331.5+0.607t$ (m/s) where t=temperature (℃)
That is as sound velocity varies according to circumferential 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.

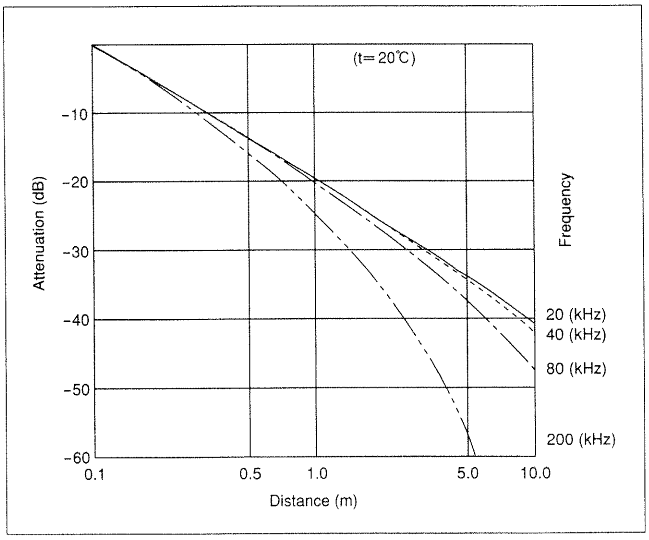



Fig.1 Attenuation Characteristics of Sound Pressure by Distance

# 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 called a bimorph, constructed of 2 sheets of piezoelectric 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 bimorph, 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 bimorph 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.

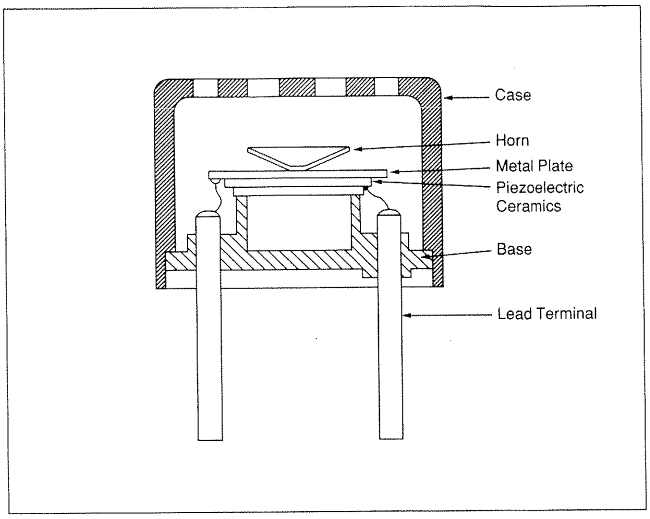


Fig.2 Construction of Open Structure Type Ultrasonic Sensor

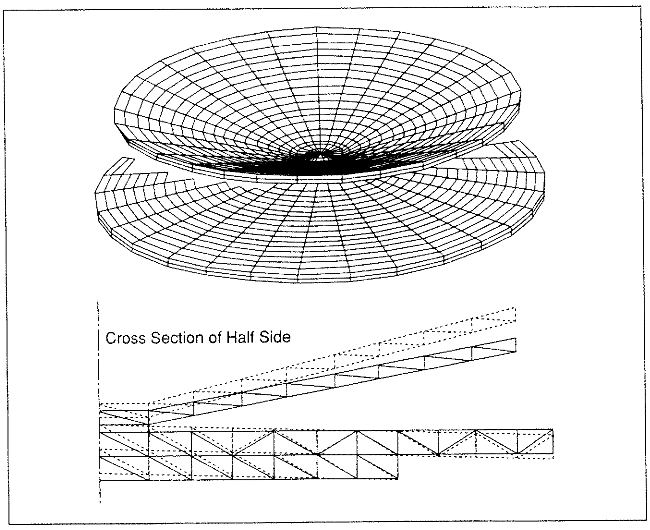


Fig.3 Simulation of Vibration

## 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 base is then mounted at the entrance of the case and is then covered with resin. (See Fig. 4.)

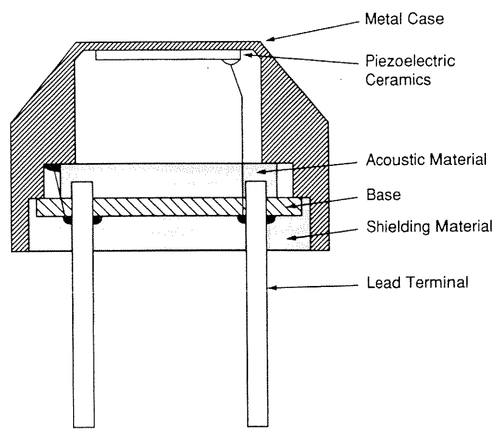



Fig.4 Construction of Enclosed Type Ultrasonic Sensor

### 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 bimorph 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 $2.6\times 10.7kg/m^2s$, while that of air is $4.3\times 10.2kg/m^2s$.
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.

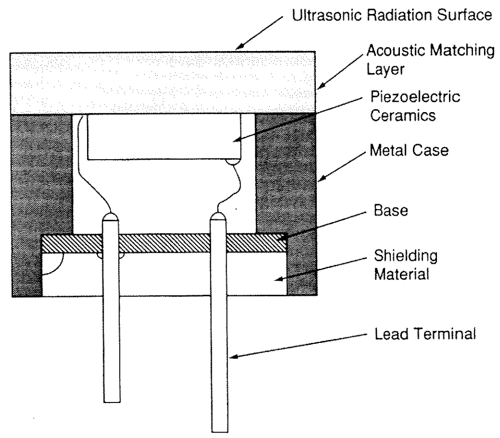



Fig.5 Construction of High Frequency Ultrasonic Sensors

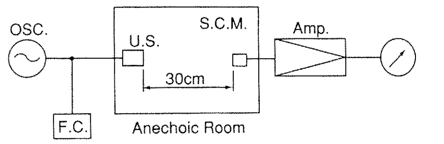
# 3 Electrical Characteristics

## 1. Sound Pressure Characteristics

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

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

where "P" is effective sound pressure ($\mu$ bar) and "Pre" is reference sound pressure ($2\times10^{-4}\ \mu$ bar) .
Fig.6 shows a sound pressure measuring circuit.




| | | |
|---|---|---|
| U.S. | : Ultrasonic Sensor | |
| S.C.M. | : Standard Capacitor Microphone | (Brüel & Kjær 4135) |
| Amp. | : Amplifier | (Brüel & Kjær 2610) |
| Input Voltage | : 10Vrms | |
| F.C. | : Frequency Counter | 0dB= $2\times10^{-4}\ \mu$ bar |

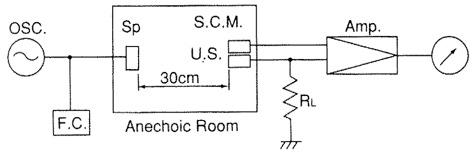
Fig.6 Sound Pressure Measuring Circuit

## 2. Sencitivity Characteristics

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

$$Sensitivity=20\log\frac{E}{P}\ (dB)$$

where "E" is generated voltage (Vrms) and "P" is input sound pressure ($\mu$ bar) .
Fig.7 shows a sensitivity measuring circuit. The 3.9k$\Omega$ resistor connected with the electrode terminal of the sensor is used to avoid the influence of outside noise.




| | | |
|---|---|---|
| RL | : 3.9k$\Omega$ | |
| U.S. | : Ultrasonic Sensor | |
| S.C.M. | : Standard Capacitor Microphone | (Brüel & Kjær 4135) |
| Amp. | : Amplifier | (Brüel & Kjær 2610) |
| OSC. | : Oscillator | |
| Sp. | : Tweeter | |
| F.C. | : Frequency Counter | 0dB= 1Vrms/ $\mu$ bar |

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 $\theta^{1/2}$.

## 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.

| Item \ Part Number | MA40E7R/S | MA40S4R/S | MA40B8R/S | MA40B7 | MA40E6-7 |
|---|---|---|---|---|---|
| Construction | Water proof type | Open structure type | | | Water proof type |
| Using Method | Receiver and Transmitter (Dual use) type | | | Combined use type | |
| Nominal Frequency (kHz) | 40 | | | | |
| Overall Sensitivity (dB) | – | – | – | $-45^{+4}_{-5}$ | – |
| Sensitivity (dB) | -74 min.* | -63±3 | -63±3 | – | -82 min. |
| Sound Pressure (dB) | 106 min. | 120±3 | 120±3 | – | 108 min. |
| Directivity (deg) | 100 | 80 | 50 | 44 | 75 |
| Capacitance (pF) | 2200±20% | 2550±20% | 2000±20% | 2000±20% | 2200±20% |
| Operating Temperature Range (°C) | −30 - +85 | | | | |
| Detectable Range (m) | 0.2 - 3 | 0.2 - 4 | 0.2 - 6 | 0.2 - 4 | 0.2 - 2 |
| Resolution (mm) | 9 | | | | |
| Dimension (mm) | 18 ϕ ×12h | 9.9 ϕ ×7.1h | 16 ϕ ×12h | 16 ϕ ×12h | 18 ϕ ×12h |
| Weight (g) | 4.5 | 0.7 | 2.0 | 2.0 | 4.5 |
| Allowable Input Voltage (Vp-p) (Rectangular wave) | 85 (40kHz)<br>Pulse width 0.4 ms<br>Interval 100 ms | 20 (40kHz)<br>Continuous signal | 40 (40kHz)<br>Continuous signal | 100 (40kHz)<br>Pulse width 0.4 ms<br>Interval 100 ms | 140<br>(40kHz Sine wave)<br>Pulse width 0.4 ms<br>Interval 100 ms |
| Packaging Quantity (Pcs.) | 90 | 540 | 150 | 150 | 90 |

* Distance : 30cm, Overall sensitivity : 0dB=10Vpp, Sensitivity : 0dB=1Vrms/μbar, Sound pressure Level : 0dB=2×$10^{-4}$ μbar1 μbar=0.1Pa
* 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, Detectable Range and Resolution is typical value. It can be changed by application circuit and fixing method of the sensor.

| Item \ Part Number | MA80A1 | MA200A1 | MA400A1 |
|---|---|---|---|
| Construction | High frequency type | | |
| Using Method | Receiver and Transmitter (Dual use) type | | |
| Center Frequency (kHz) | 75±5 | 200±10 | 400±20 |
| Overall Sensitivity (dB) | -47 min.<br>0dB=18Vpp<br>(at 50 cm) | -54 min.<br>0dB=18Vpp<br>(at 20 cm) | -74 min.<br>0dB=18Vpp<br>(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 |
| Resolution (mm) | 4 | 2 | 1 |
| Dimension (mm) | 47 ϕ ×24.5h | 19 ϕ ×10.6h | 11 ϕ ×10.5h |
| Weight (g) | 93 | 6 | 2 |
| Allowable Input Voltage (Vp-p) (Rectangular wave) | 120 (75kHz)<br>Pulse width 600 μs<br>Interval 50 ms | 120 (200kHz)<br>Pulse width 250 μs<br>Interval 20 ms | 120 (400kHz)<br>Pulse width 125 μs<br>Interval 10 ms |
| Packaging Quantity (Pcs.) | 5 | 90 | 224 |

* 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, Detectable Range and Resolution is typical value. It can be changed by application circuit and fixing method of the sensor.

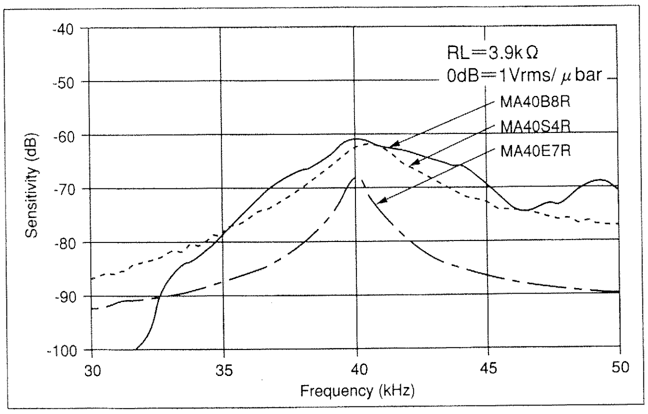



Fig. 8 Sensitivity

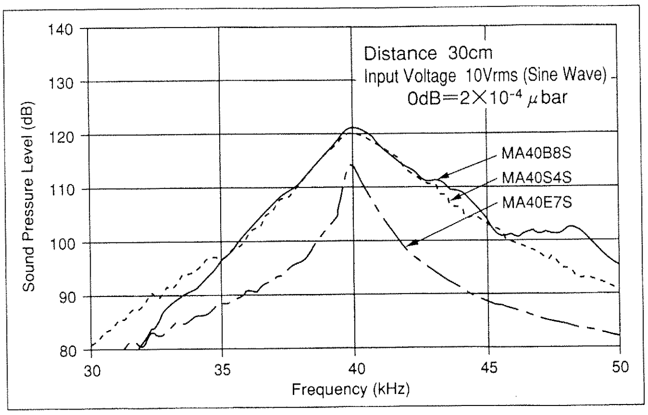



Fig. 9 Sound Pressure

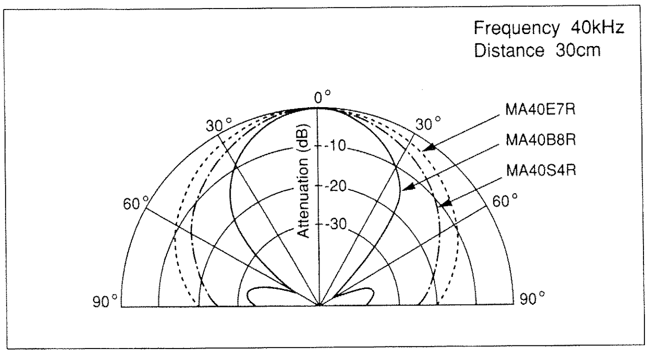



Fig.10 Radiation Characteristics (Receiver)

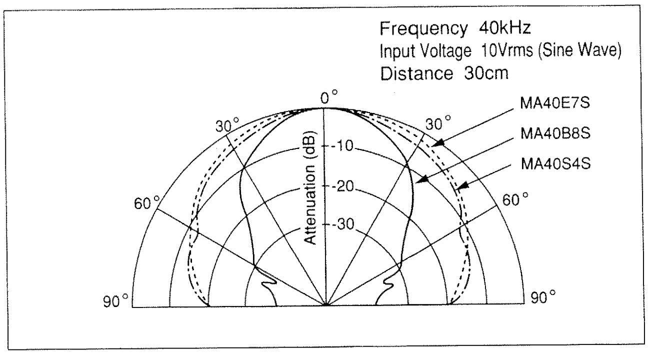



Fig.11 Radiation Characteristics (Transmitter)

# 4 Applications

## 1. Examples of Applications

Ultrasonic sensors are utilized for many purposes such as measurement applications for communications.
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 ultrasonic application for communication purposes whereby several types of signals can be produced by changing the oscillating frequency, the transmitting time, or the amount of transmissions. This type is used for remote control applications.
Example 5 is an application utilizing the change of sound velocity according to the density of a gas. Flow speed and flow rate of gas can be measured by the Doppler effect.
Example 6 is a method used to count the number of Karman vortex generated against air flow and utilize phenomena that ultrasonic signals level are reduced as Karman vortex passes into the sensor.

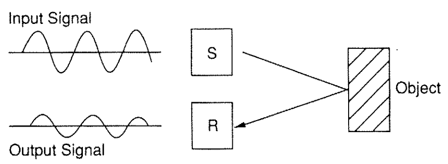
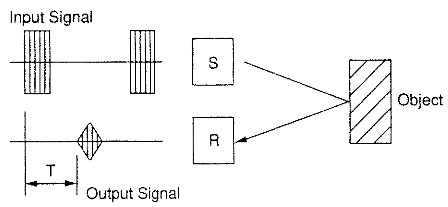
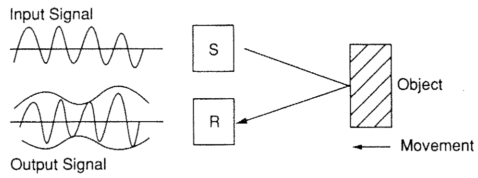
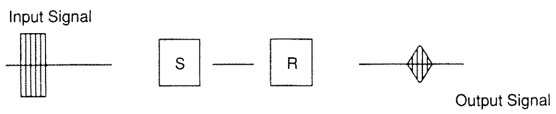
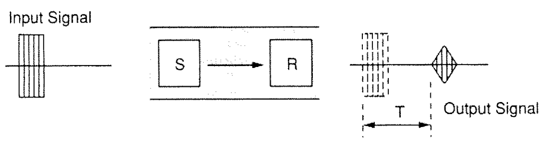
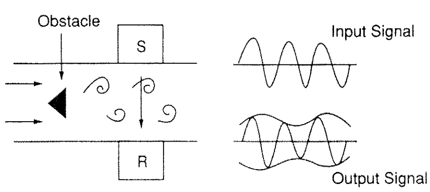
| No. | Function Method | Performance Principle (S : transmitter, R : receiver) | Applications |
|---|---|---|---|
| 1 | Detection of Signal level of continuous wave |   | Counting instruments<br>Access switches<br>Parking meters |
| 2 | Measurement of pulse reflection time |   | Automatic doors<br>Level gauges<br>Automatic change-overs of traffic signals<br>Back sonars of automobiles |
| 3 | Utilization of Doppler effect |   | Intruder alarm systems |
| 4 | Transfer of signal |   | Remote controls |
| 5 | Measurement of direct propagation time |   | Densitometers<br>Flowmeters |
| 6 | Measurement of Karman vortex |   | Flowmeters |

Table 2 Application Examples

## 2. Transmitting and Receiving Circuits

Examples of transmitting and receiving circuits using MA40B8R/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.

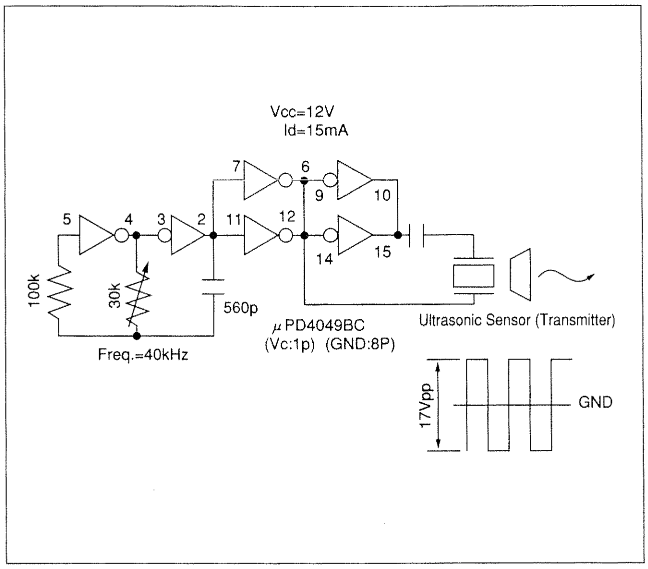



Fig.12 Example of Continuous Wave Transmitting Circuit

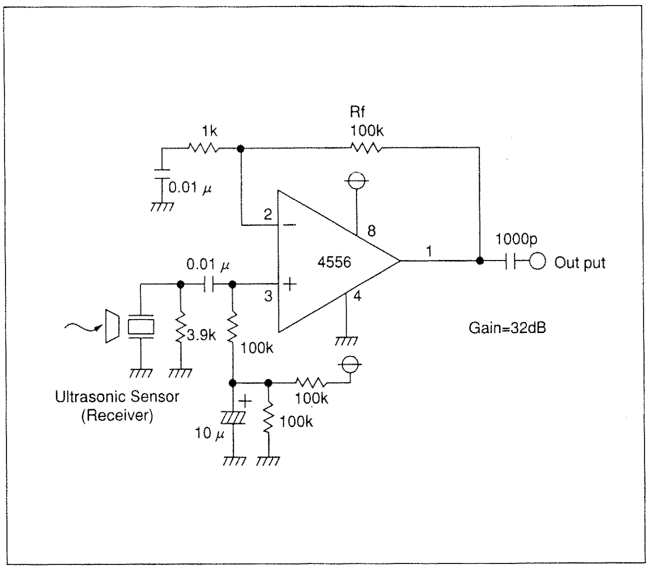



Fig.13 Example of Receiving Circuit

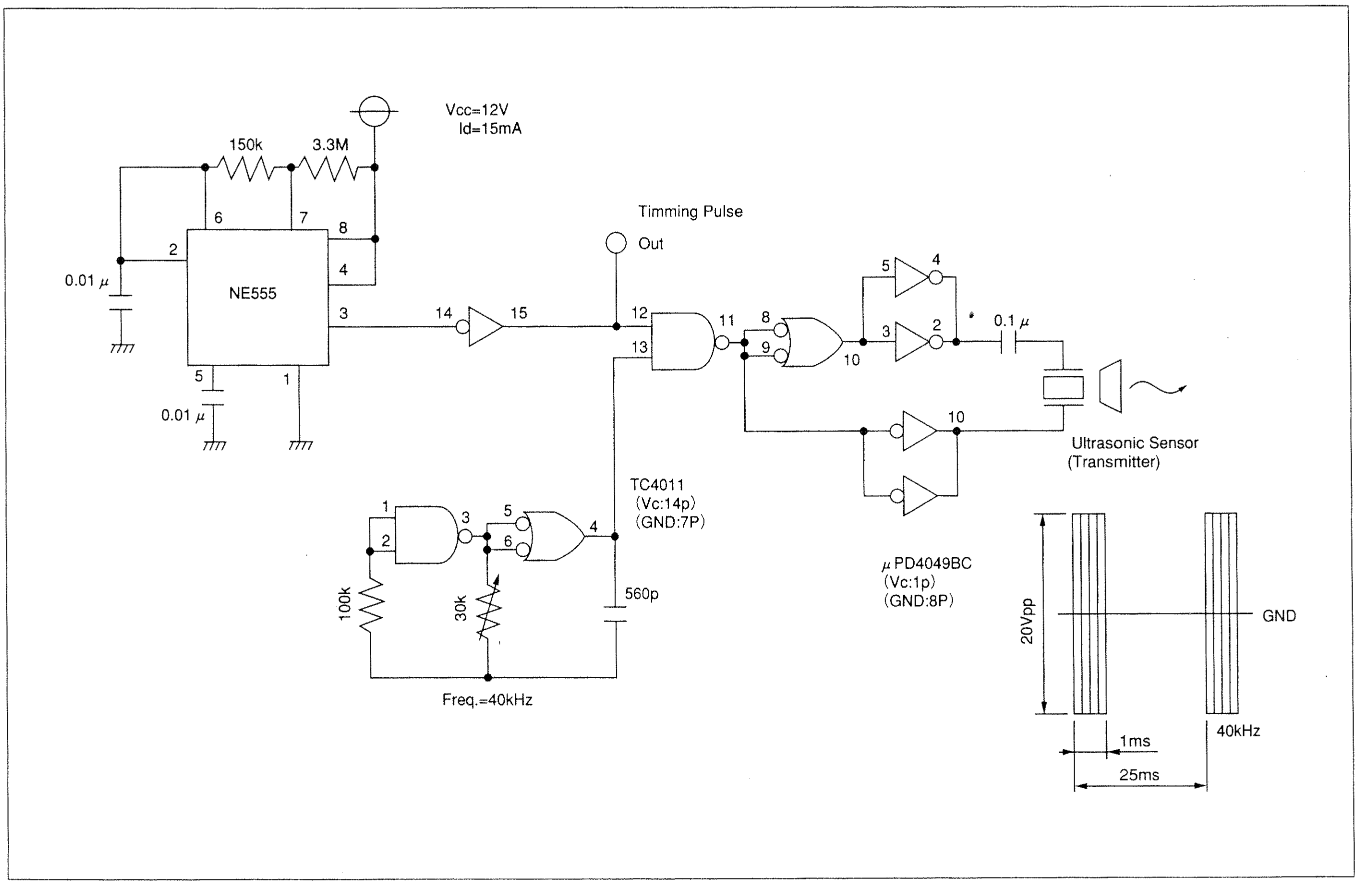



Fig.14 Example of Pulse Transmitting Circuit

Fig.15 is an example of circuit using combined use type ultrasonic sensor (MA40E6-7).
Fig.16 shows wave forms of each part of the circuit when aluminum board (10cm×10cm) located at 20cm in front of the ultrasonic sensor is measured.
In the case that a single sensor function as both transmitter and receiver, reducing ringing time (decay time) of transmitted pulse become critical. This ringing time relate to shortest distance the sensor can measure. If the ringing time is too long, reflected sound signal is mixed with the ringing and they can not be separated.
The typical ringing time of MA40E6-7 in the example of Fig.15 is about 1ms as shown in Fig.16- (d).

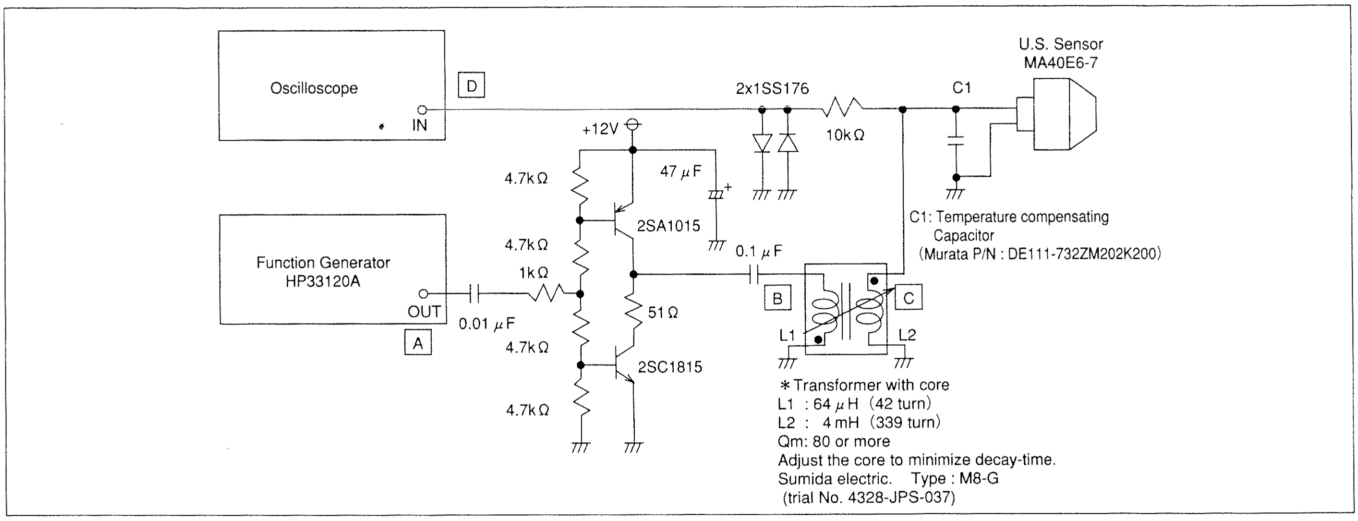
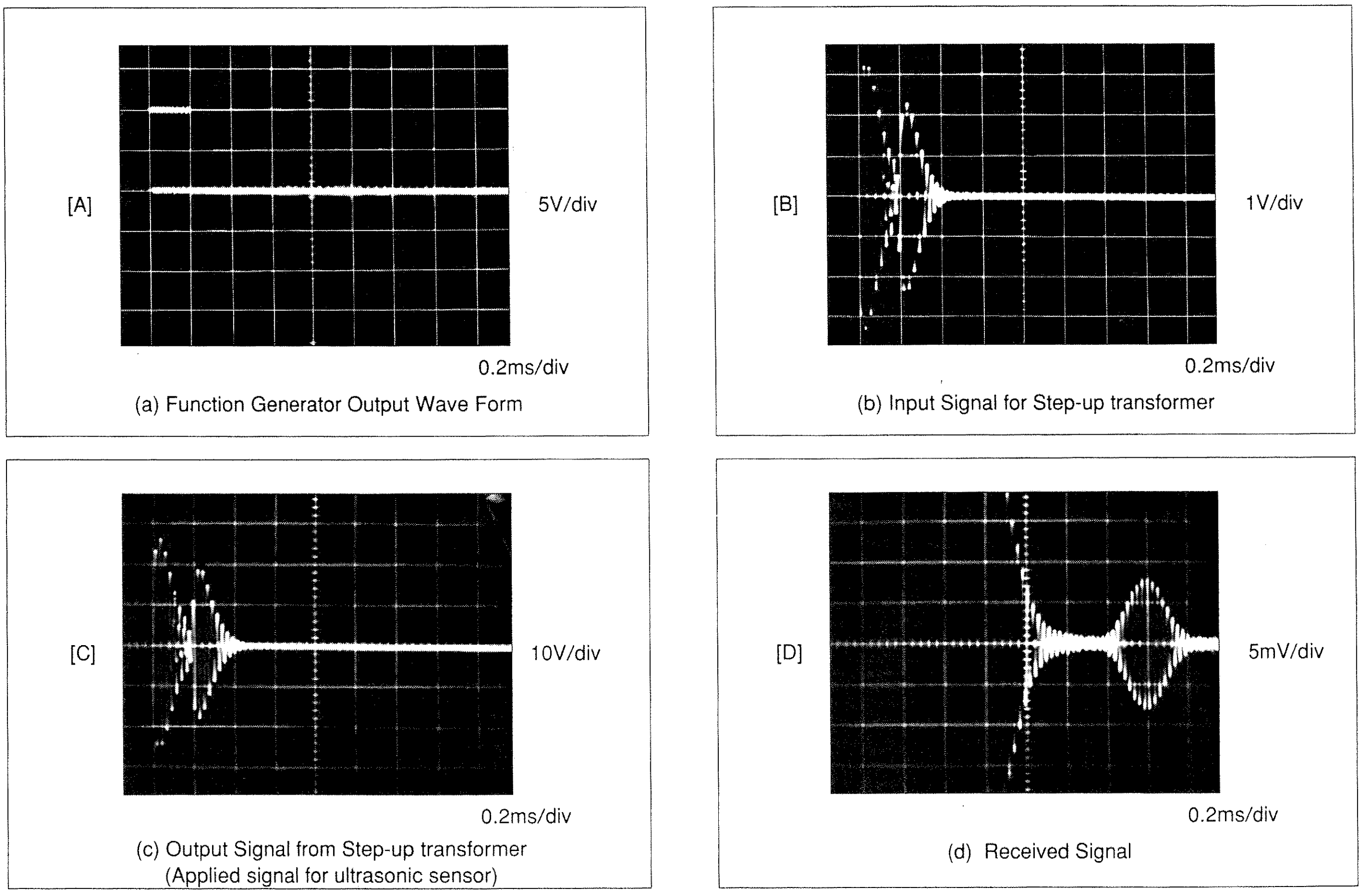


Fig.15 Example of Circuit Using Combined Use Type Ultrasonic Sensor



(a) Function Generator Output Wave Form

(b) Input Signal for Step-up transformer

(c) Output Signal from Step-up transformer (Applied signal for ultrasonic sensor)

(d) Received Signal

Fig.16 Wave Form of Each Part of Circuit

# 3. Applications for Distance Measurement

Fig.17 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 :

$L = C \cdot T/2$ where C 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.18 shows an example of a distance measuring circuit using MA40B8R/S.

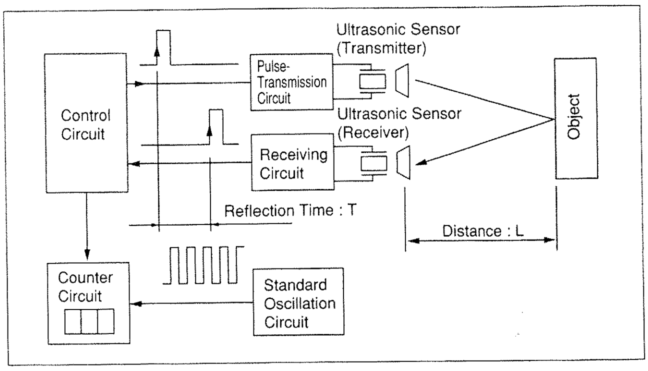



Fig.17 Principles of Measuring Distance

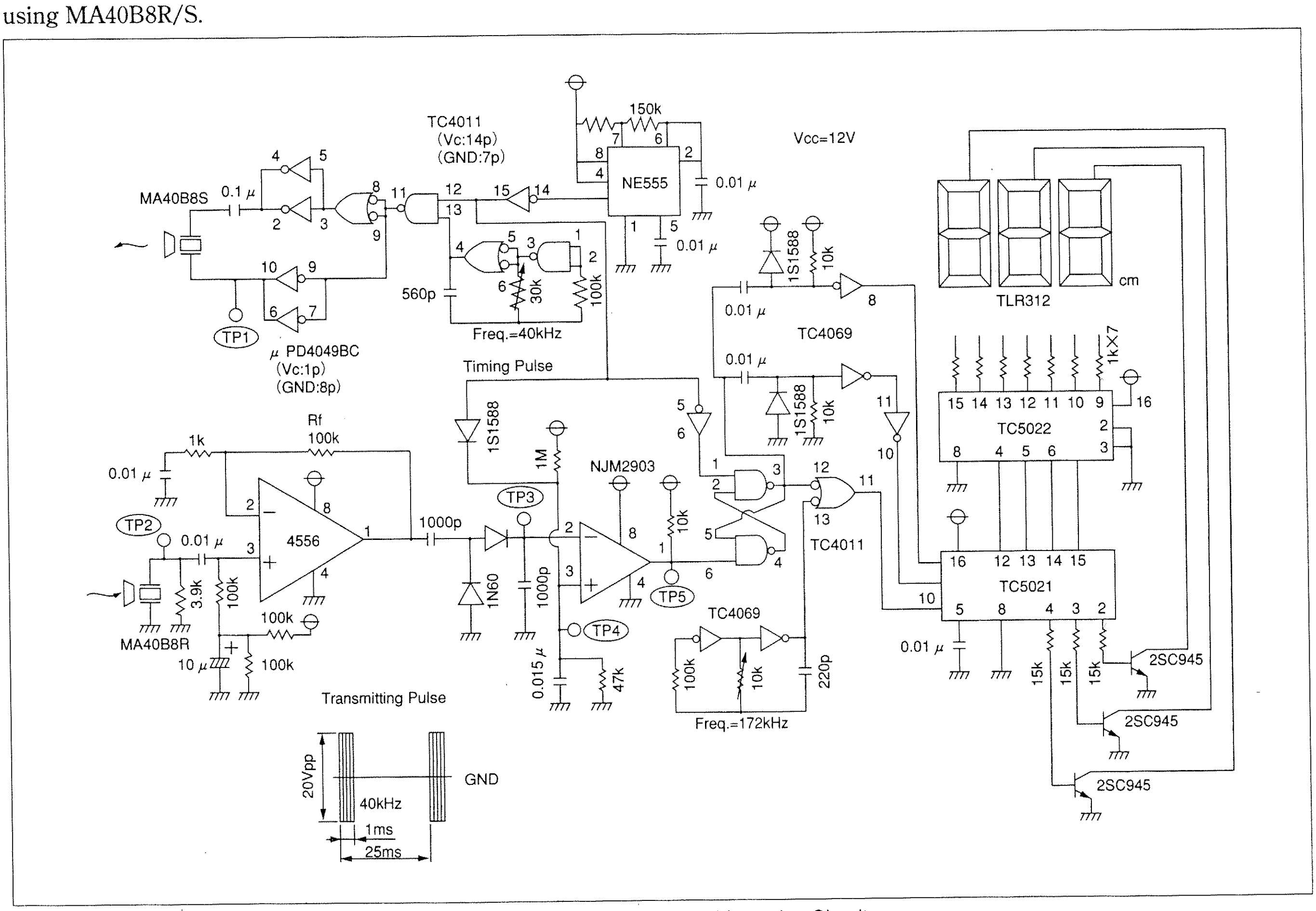
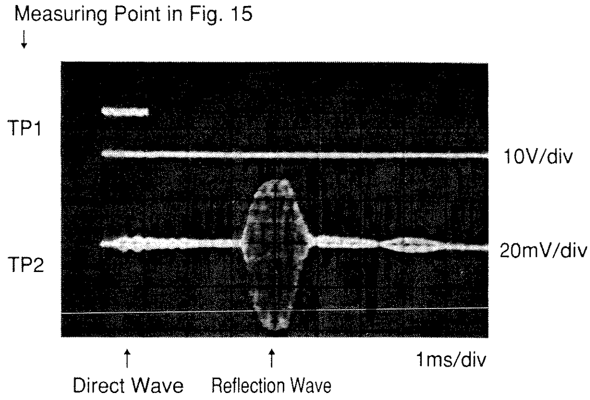
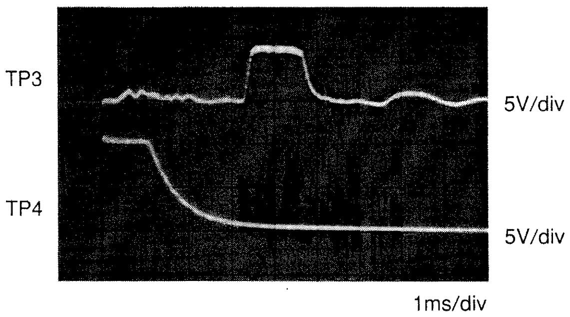



Fig.18 Example of Distance Measuring Circuit

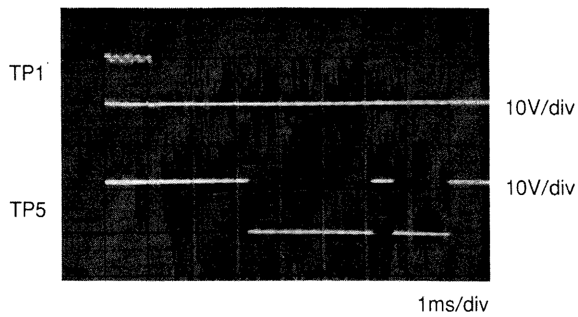
Fig.19 shows the wave forms of each part of a circuit.
This figure is the result of measuring distance to a corrugated board (10cm×10cm) located 50cm in front of the ultrasonic sensor mounted on a PC board with transmitter and receiver 3cm away from each other.
As the ultrasonic sensor has radiation, 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.19 (b), comparison will be made with the comparative voltages that attenuate exponentially with time.
Detected reflection wave is shown in Fig.19 (c).



(a) Transmit/Receive Wave Form



(b) Receive Circuit Output Voltage and Comparable Voltage Wave form



(c) Comparable Circuit Output Wave Form

Fig.19 Wave Forms of Each Part of Circuit

## 4. Installation

Fig.20 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.

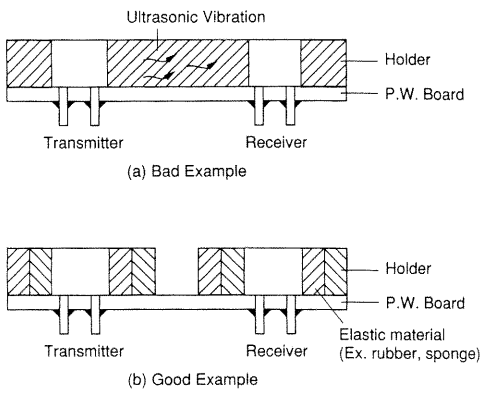
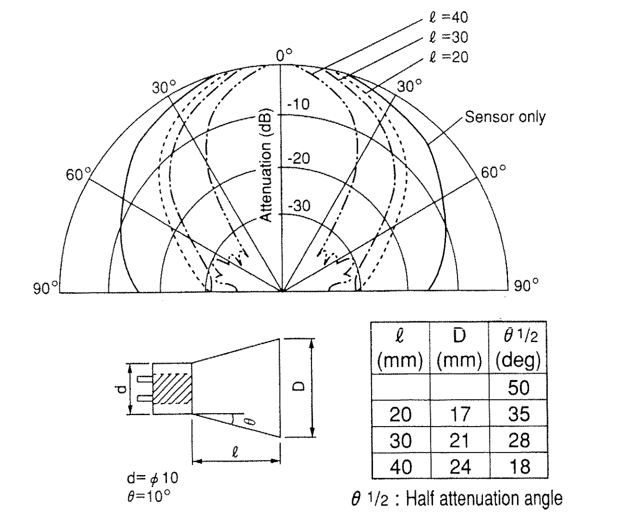



Fig. 20 Example of Installation of Ultrasonic Sensor

## 5. Sharpening of Radiation

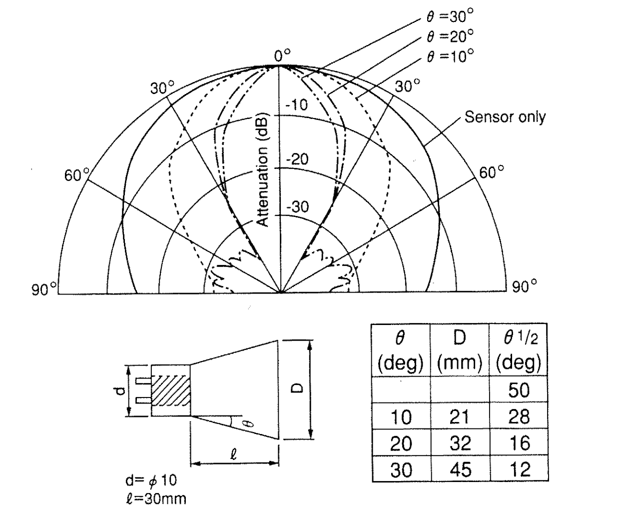
When there are objects within the sensors field that reflect ultrasonic waves but when only a specific object should be detected, more acute radiation of ultrasonic waves is advantageous. radiation is determined by the dimensions of the ultrasonic radiation surface and the frequency, but it is possible 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 MA40SR/S and the radiation characteristics is shown in Figs.21 and 22.
A similar result can be obtained regarding sound pressure radiation.




| ℓ (mm) | D (mm) | θ 1/2 (deg) |
|---|---|---|
| | | 50 |
| 20 | 17 | 35 |
| 30 | 21 | 28 |
| 40 | 24 | 18 |

θ 1/2 : Half attenuation angle

Fig. 21 Horn Length and Radiation (MA40S4R)




| θ (deg) | D (mm) | θ 1/2 (deg) |
|---|---|---|
| | | 50 |
| 10 | 21 | 28 |
| 20 | 32 | 16 |
| 30 | 45 | 12 |

Fig. 22 Horn Angle and Radiation (MA40S4R)

# 5 Other Characteristics

Typical Voltage-S.P.L. characteristics, temperature characteristics and environmental characteristics of MA40B8R/S as an example are shown in below.

■Input voltage-output S.P.L.

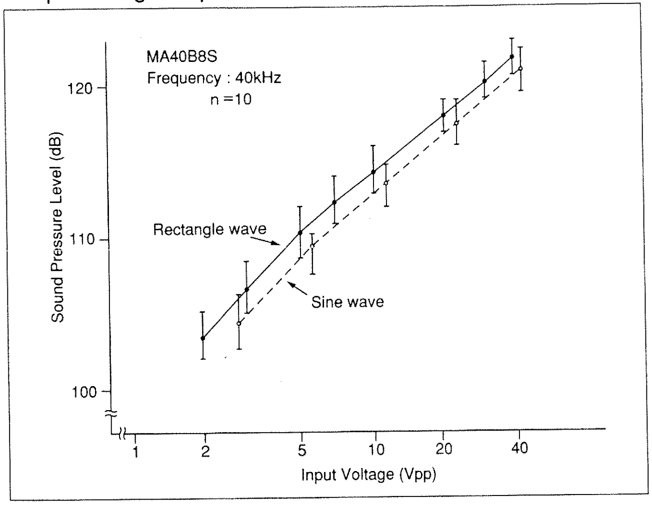



Fig. 23

■Temperature characteristics of sensitivity

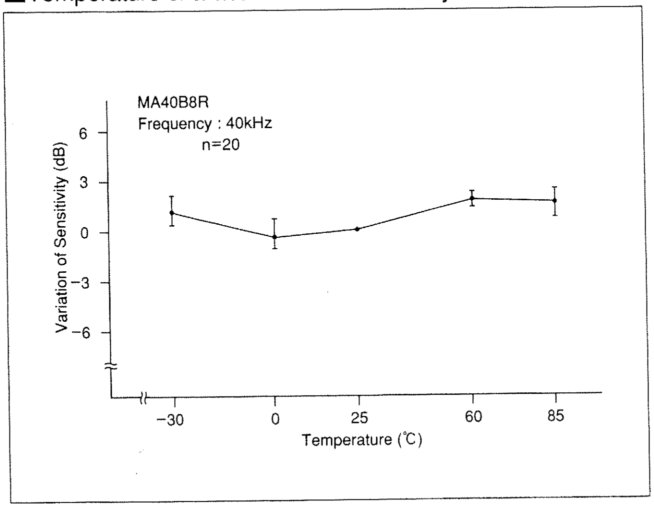



Fig. 24

■Temperature characteristics of S.P.L.

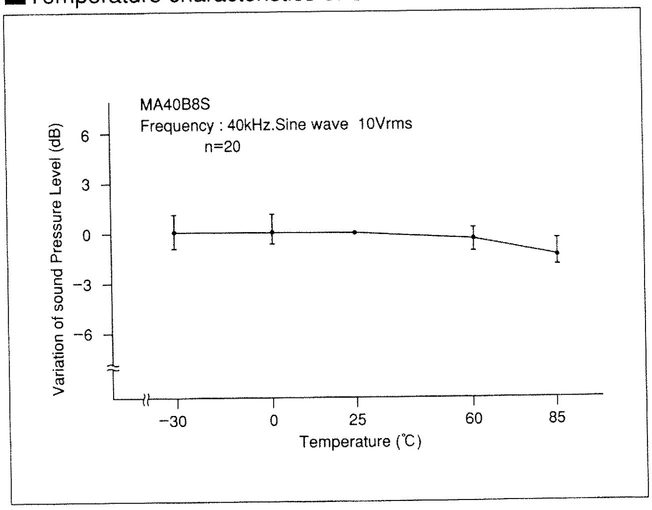



Fig. 25

■Environmental characteristics

| No. | Kind of Test | Conditions | Judgement |
|---|---|---|---|
| 1. | **Humidity Resistance** | 60℃, 90 - 95%RH, 1,000 hours | Variation of sensitivity and S.P.L is within 3dB. |
| 2. | **High Temperature Storage** | 85℃, 1,000 hours | |
| 3. | **Low Temperature Storage** | -40°C, 1,000 hours | |
| 4. | **Thermal Shock** | With -55°C (30minutes) and +85°C (30minutes) 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 3hours in each of 3 directions | |
| 6. | **Shock** | On concrete floor from 1m height, 3 times | |
| 7. | **Solder Heart Resistance** | Dipping in soldering solution at 260°C for 10 seconds | |
| 8. | **Aging** | Frequency 40kHz, Sine 40Vpp, 1000 hours | |

## ■Notice

(1) Please avoid applying DC-bias by connecting DC blocking capacitor or some other way because, otherwise, the component may be damaged.

(2) These sensors are designed for use in air ; do not use under water. Enclosed type sensors listed are constructed for use in rain, not complete submersion.

(3) Do not store sensors loosely in bulk as sensors may damage one another.

(4) Please pay attention to the mounting position as these sensors have directivity.

(5) When researching usage under special conditions such as out-of standard frequency, please advise us of service conditions, circuit, etc. so that we may comply with your specific requirements.

Please note that specification, application (especially for critical case ; ex car electronics), washing condition, and soldering condition which are not mentioned in this application manual may not be allowed to apply. Before ordering, Please consult our sales representative or engineers for details.