

APPLICATION NOTE – AP050830

Selection and use of Ultrasonic Ceramic Transducers

The purpose of this application note is to aid the user in the selection and application of the Ultrasonic ceramic transducers.

The general transducer design features a piezo ceramic disc bender that is resonant at a nominal frequency of 20 – 60 KHz and radiates or receives ultrasonic energy. They are distinguished from the piezo ceramic audio transducer in that they produce sound waves above 20 KHz that are inaudible to humans and the ultrasonic energy is radiated or received in a relatively narrow beam. The “open” type ultrasonic transducer design exposes the piezo bender bonded with a metal conical cone behind a protective screen. The “enclosed” type transducer design has the piezo bender mounted directly on the underside of the top of the case which is then machined to resonant at the desired frequency. The “PT and EP” type transducer has more internal damper for minimizing “ringing”, which usually operates as a transceiver – oscillating in a short period and then switching to receiving mode.

Comparative Characteristics

When compared to the enclosed transducer, the open type receiver will develop more electrical output at a given sound pressure level (high sensitivity) and exhibit less reduction in output as the operating frequency deviates from normal resonant frequency (greater bandwidth).

The open type transmitter will produce more output for a specific drive level (more efficient).

The enclosed type transducer is designed for very dusty or outdoor applications. The face of the transducer must be kept clean and free of damage to prevent losses.

The transmitter is designed to have low impedance at the resonant frequency to obtain high mechanical efficiency. The receiver is constructed to maximize the impedance at the specified anti-resonant frequency to provide high electrical efficiency.

Sound Propagation

In order to properly select a transducer for a given application, it is important to be aware of the principles of sound propagation. Since sound is a wave phenomenon, its propagation and directivity are related to its wavelength (λ). A typical radiation power pattern for either a generator or receiver of waves is shown in Figure 1. Due to the reciprocity of transmission and reception, the graph portrays both power radiated along a given direction (in case of wave production), and the sensitivity along a given direction (in case of wave reception).

The angular, half-width ($\theta/2$) of the main beam is given by:

$$\theta/2 = \sin^{-1} (0.51 \lambda / D) \text{ for } -3\text{dB}$$

$$\theta/2 = \sin^{-1} (0.7 \lambda / D) \text{ for } -6\text{dB}$$

$$\lambda = c / f$$

Where “D” is the effective diameter of the flexure diaphragm, “ λ ” is the wavelength, “c” the velocity of sound (344 meter/second in air at 20° C), and “f” is the operating frequency. The above relationship applies if $\lambda < D$. For $\lambda > D$, the power pattern tends to become spherical in form. Thus, narrow beams and high directivity are achieved by selecting “D” large in relation to λ .

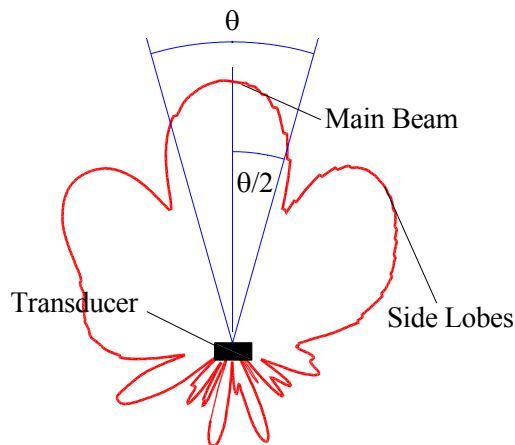


Figure 1

As an example of a typical situation, a transducer of 400ET250 has an effective diameter of 23 mm (1mm wall thickness) will produce a main beam (-6dB) with full width of 30° at a frequency of 40 KHz. For open type transducers, the beam is decided by the angular and diameter of conical cone attached on the bender inside of housing and the opening diameter so it can not be simply calculated by the diameter of the housing.

The intensity of sound waves decrease with the distance from the sound source, as might be expected for any wave phenomenon. This decrease is principal a combination of two effects. The first is the inverse square law or spherical divergence in which the intensity drop 6dB per distance doubled. This rate is common to all wave phenomena regardless of frequency.

The second effect causing the intensity to decrease is the absorption of the wave by the air (see figure 2). Absorption effects vary with humidity and dust content of the air and most importantly, they vary with frequency of the wave. Absorption at 20 KHz is about 0.02dB/30 cm. It is clear that lower frequencies are better suited for long range propagation. Of course, the selection of a lower frequency will result in less directivity (for a given diameter of source or receiver).

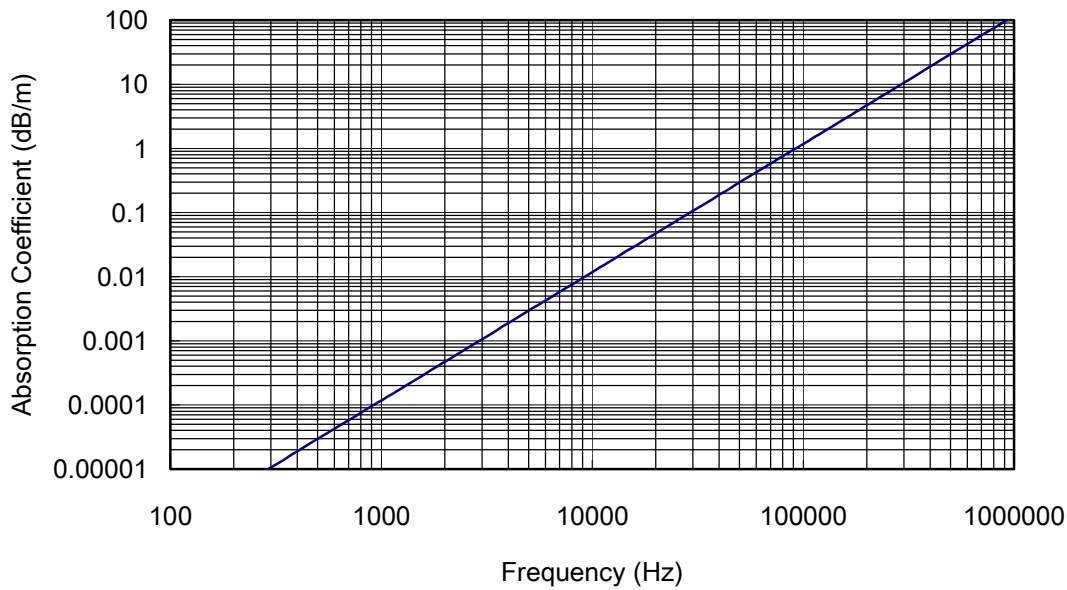


Figure 2

Transmitter Drive Considerations

The ultrasonic transmitters can dissipate 200 mw rms continually. Assuming a typical minimum series impedance of 500 ohms, the driver must source 20 mA at 10 V rms. A sine wave drive should be used to minimize harmonics that may excite the transducer in an overtone mode (vibrate at a multiple of the resonant frequency). For most models the maximum amplitude of the drive waveform should be limited to 50 V pp. The transmitter dissipation must be limited to an effective or average level of 200 mW by reducing the duty cycle when the transmitter is dissipating more than 200 mW.

There are several oscillator circuits suitable for driving our ultrasonic transmitter, which have been widely used on security systems, remote control and other applications. Please bear in mind that the circuits we suggest sometimes need to be modified according to the different characters of impedance, phase angle and resonant frequency while driving different type of transmitters. Please refer to “Impedance Characteristics” carefully.

Suggestion Oscillating Circuits:

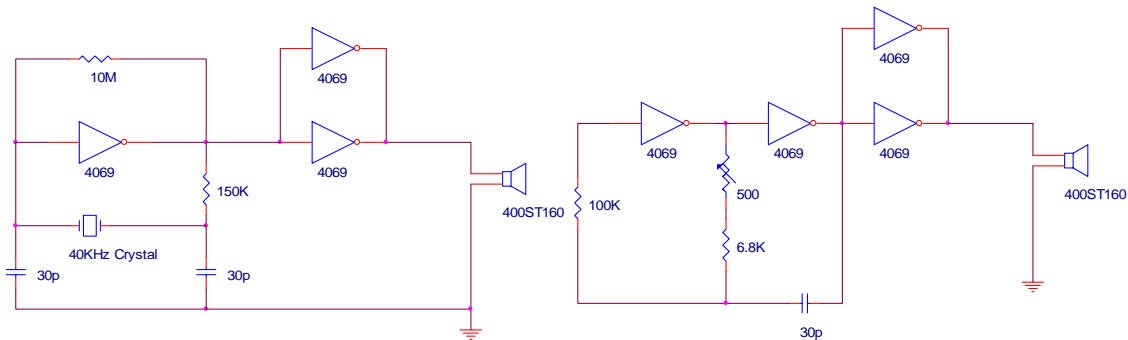


Figure 3

Figure 4

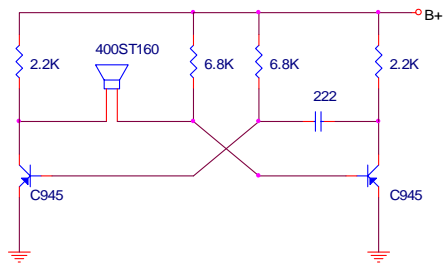


Figure 5

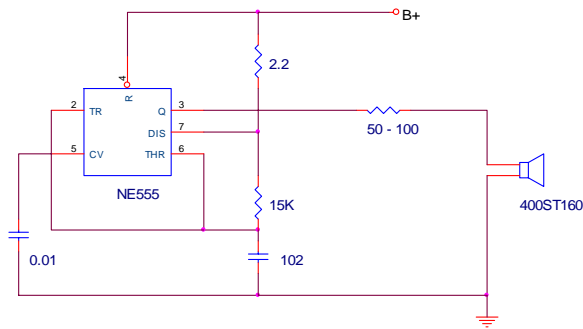


Figure 6

The ultrasonic transmitters may also be driven with a pulse waveform. Application of a DC Pulse of 10 – 20 volts will cause the transducer to “ring” at the selected resonant frequency. The ultrasonic output will be a damped ringing waveform as illustrated in the figure as follow.

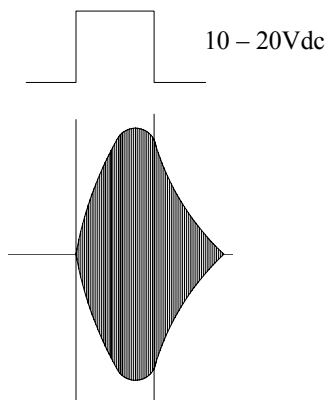


Figure 7

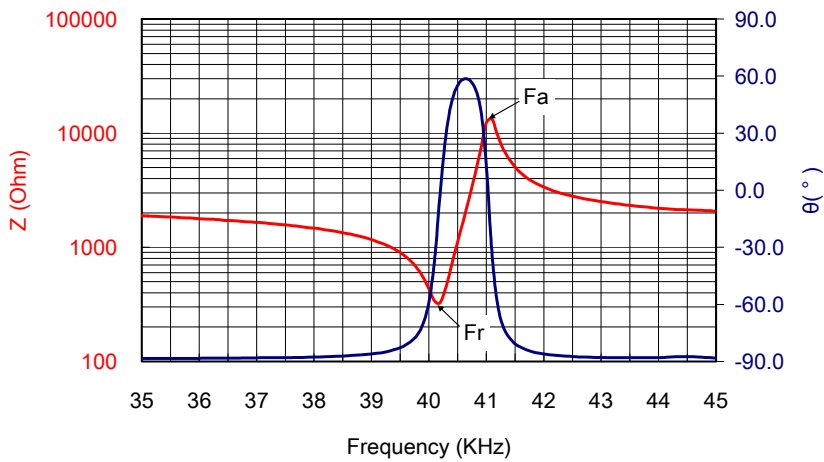
Impedance Characteristic

Ultrasonic transmitter impedance characteristics vary with operating frequency and temperature in complex manner that is different for each construction.

In general, for frequencies approximately 0.1 octave on either side of the resonant frequency, the transmitter looks like a capacitor. The current through the transmitter will lead the voltage developed across the transmitter by 90 degrees.

As the resonant frequency is approached, the voltage drop across the transmitter will decrease to a minimum at the resonant frequency (minimum series impedance) and the current will increase proportionally. The phase lead to this current relative to the voltage will decrease to zero near the resonant frequency and the transmitter will then appear to be a pure resistance.

As the frequency is increased above the resonant point, the current may now lag the voltage by an increasing amount (maximum of 90 degrees) as the voltage across the transmitter climbs to a peak which is defined as the anti-resonant frequency. During this transition, the transmitter appears to have an inductive characteristic.



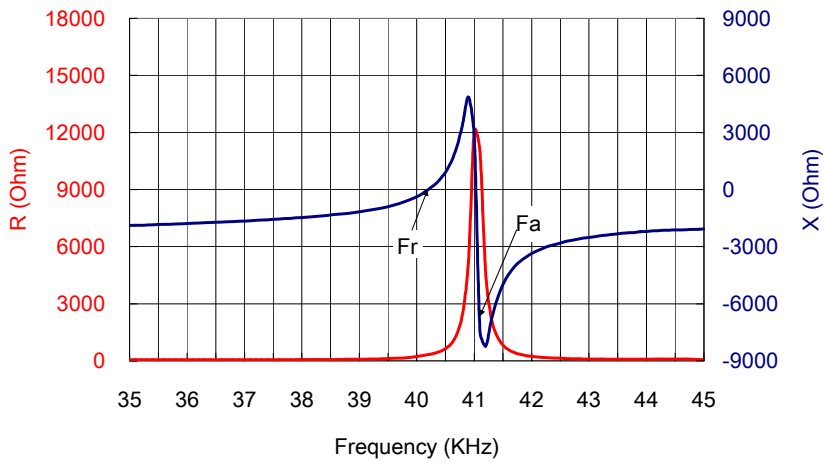
Impedance at resonant frequency (Fr):

$$Z = 329 -j0.5^\circ$$

Impedance at anti-resonant frequency (Fa):

$$Z = 13300 -j34^\circ$$

Figure 8



Impedance at resonant frequency (Fr):

$$R+jX = 329-j3$$

Impedance at anti-resonant frequency (Fa):

$$R+jX = 11026-j7437$$

Figure 9

Increasing temperature will lower the resonant frequency and thus the point at which the phase changes will occur

The test circuit shown as below may be used to measure the resonant, anti-resonant frequencies and impedance characteristics of our piezo ceramic type ultrasonic transducers.

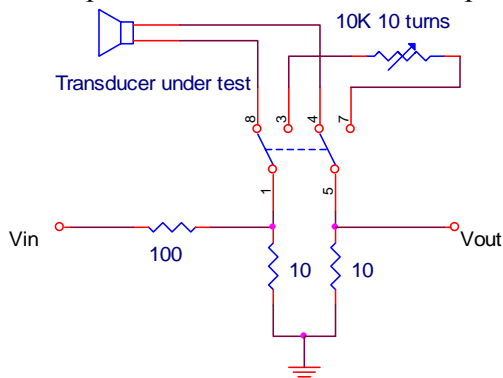


Figure 10

Adjust input frequency to obtain maximum V_{out} , Switch in variable resistor and adjust to obtain same voltage output. The value of variable resistor now equals to the minimum series impedance.

Adjust frequency to obtain minimum V_{out} . Switch in variable resistor and adjust to obtain same voltage output. The value of variable resistor now equals to the maximum series impedance at the anti-resonant frequency.

The resistor values of voltage divider, 100 and 10 ohms, probably need to be modified for better V_{out} resolution while measuring anti-resonant impedance.

How Far the transducer could reach?

One of the most frequently asked questions is “How far the transducer could reach?”. This question can be answered by a simple calculation that is based on the published specifications in the Ultrasonic Ceramic Transducer Data Sheets.

The basic procedure is to first determine the minimum sound pressure level developed at the front end of the receiver for a specific transmitter driving voltage and distance between the transmitter and receiver (transceiver has double distance between reflect target). This SPL must then be converted “Pa” (Pascal) or “μbar” (microbar) units.

The sensitivity of the receiver must then be converted from a dB reference to an absolute mV/Pa or μbar level present to obtain the final output.

Assume a 400ST160 transmitter is driven at a level of 20Vrms and a 400SR160 receiver is located 5 meters from the transmitter and loaded with a 3.9K Ohm resistor (loaded resistor value varies receiver sensitivity, please see “Acoustic Performance” of transducer data sheet).

Data sheet of 400ST/R160 shows:

Transmitting Sound Pressure Level at 40.0Khz; 120dB min.

0dB re 0.0002μbar per 10Vrms at 30cm

Receiving Sensitivity at 40.0Khz 0dB = 1 volt/μbar -65dB min.

Determining SPL at the front end of Receiver

SPL Gain for 20Vrms driving voltage = $20 * \log (20V / 10V) = 6 \text{ dB}$
SPL Reduction at 5 meters = $20 * \log (30 \text{ cm} / 500 \text{ cm}) = -24.4 \text{ dB}$
Wave absorption (refer to Figure 2) = $0.1886 \text{ dB/m} * 5 = 0.94 \text{ dB}$
The SPL at 5 meters becomes = $120 + 6 - 24.4 - 0.94 = 100.6 \text{ dB}$

Converting SPL to μbar:

$$100.6 \text{ dB} = 20 * \log (X / 0.0002 \text{ } \mu\text{bar})$$
$$X = 21.4 \text{ } \mu\text{bar}$$

Determining Receiver Sensitivity in Volts/μbar

Converting Sensitivity to Volt/μbar:

$$-65 \text{ dB} = 20 * \log (X / 1 \text{ Volt} / \mu\text{bar})$$
$$X = 0.56 \text{ mV} / \mu\text{bar}$$

Voltage generated under 21.4 μbar = $0.56 * 21.4 = 11.98 \text{ mV}$

This is the calculated voltage developed under the assumed conditions. The actual voltage output will be varied depending on the environmental conditions and absorption or reflection characteristics of target materials in or near the emanating beam. Users, then, have to judge whether this receiving voltage level is large enough for electronic processing.

The analysis is necessary to the fundamental understanding of the principals of sound wave propagation and detection but it is tedious. The figure 10 below is a graphical representation of previous analysis which may be used once in the SPL at the receiver is determined. Enter the graph from the SPL axis and proceed upward to an intersection with $-dB$ sensitivity level of the receiver using the $1V/\mu\text{bar}$ referenced data. Follow a horizontal line to the “Y” axis to obtain the receiver output in μV .

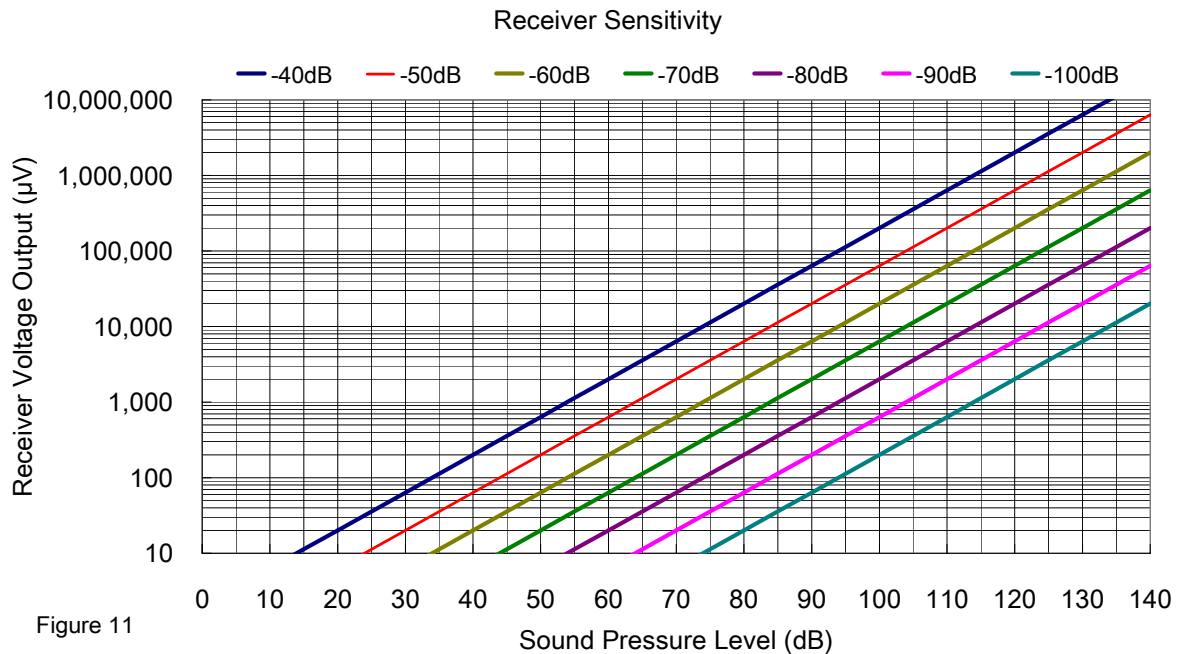


Figure 11

Ultrasonic Echo Ranging

Ultrasonic ranging systems are used to determine the distance to an object by measuring the time required for an ultrasonic wave to travel to the object and return to the source. This technique is frequently referred to as “echo ranging”.

The distance to the object may be related to the time it will take for an ultrasonic pulse to propagate the distance to the object and return to the source by dividing the total distance by the speed of sound which is 344 meters/second or 13.54 inches/millisecond.

Below is a block diagram that illustrates the basic design concept and functional elements in a typical ranging system.

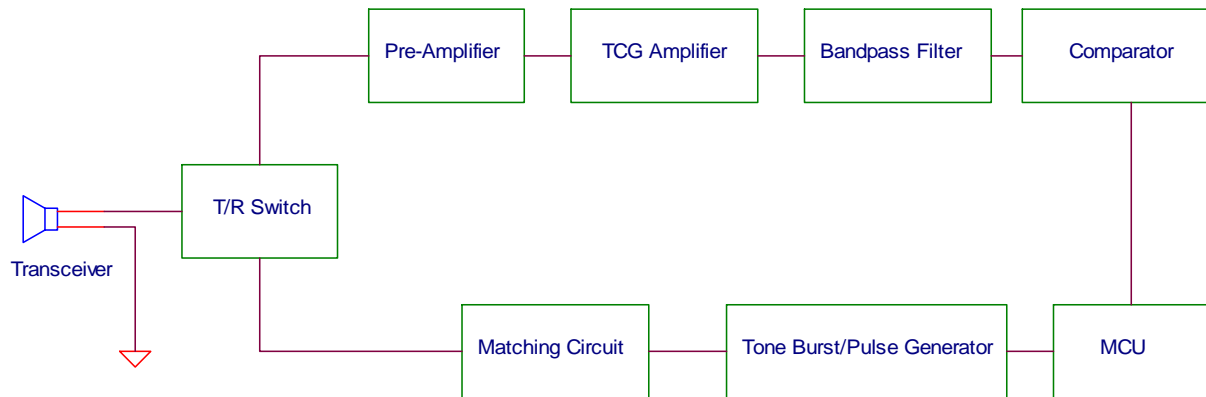


Figure 12

The driving signal can be either a tone burst of suitable burst number, which depends on the rising time of transceiver, or a pulse that will result in the transmission of a few cycles of ultrasonic energy. MCU starts a counter when tone burst starting, which is stopped by the detected returning echo. The count is thus directly proportional to the propagation time of the ultrasonic wave.

The matching circuit tunes out the imaginary part of transceiver and also plays as an impedance matching bridge for maximizing energy transfer.

The returning ultrasonic echo is usually very weak and the key to designing a good ranging system is to utilize a high “Q” tuned frequency amplifier stage that will significantly amplify any signal at the frequency of the ultrasonic echo while rejecting all other higher or lower frequencies.

Another useful technique is to make the gain of the echo amplifier increase with time such that the amplifier gain compensates for the proportional decrease in the signal strength with distance or time. This amplifier is called as TGC (Time Controlled Gain) Amplifier.

For more detail information of Ultrasonic Echo Ranging please refer to the data sheet of our Sonar Ranging IC, PW-0268 and other recommend circuit diagrams.