APPLICATION NOTE – ULTRASONIC CERAMIC TRANSDUCERS

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.

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 a 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 the case of wave production), and the sensitivity along a given direction(in case of wave reception).

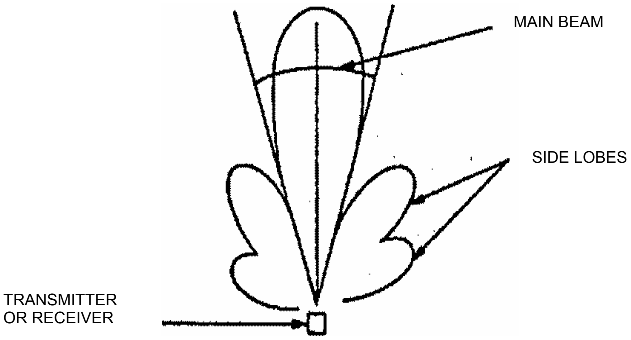


FIGURE 1 ULTRASONIC BEAM PATTERN

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

$$\text{Sin}(\alpha/2) \approx \lambda/D = V/DF$$

Where "D" is the effective diameter of the flexure diaphragm, "V" is 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 $\lambda \geq D$, 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.

As an example of a typical situation, a transducer with an effective diameter of 25 mm will produce a main beam with full width α of 40° 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 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 in the absorption of the wave by the air. 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 of receiver).

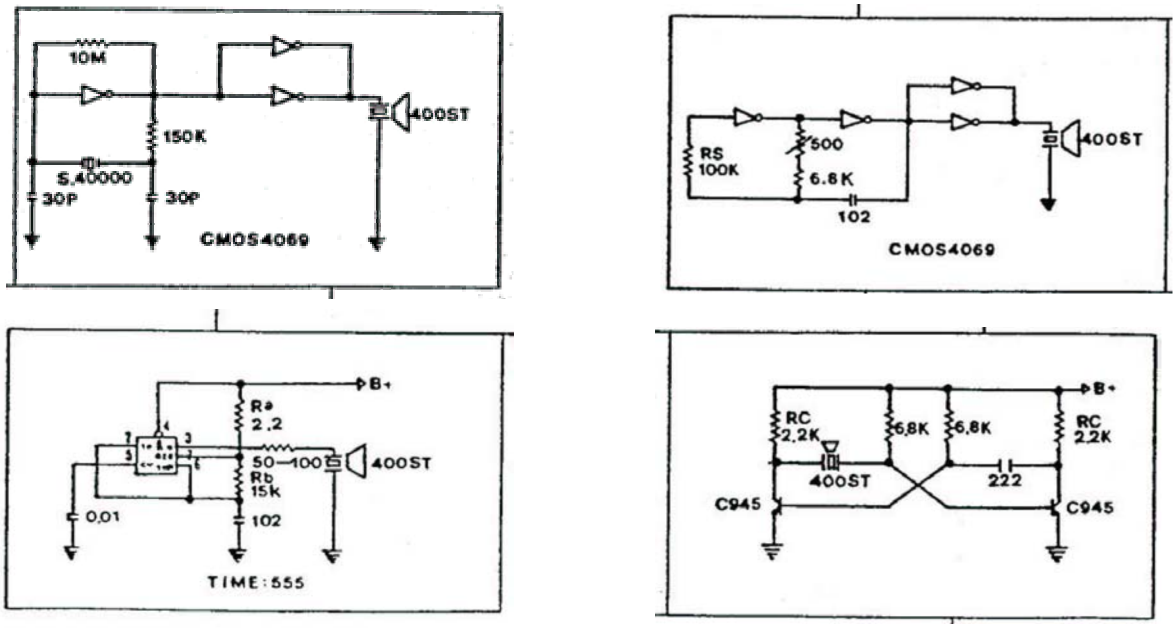
Transmitter Drive Considerations

The ultrasonic transmitters can dissipate 200 mw rms continually. Assuming a typical minimum series impedance of 500 ohms, the driver must source 20 mA rms at 10 V rms.

A sinewave drive should be used to minimize harmonics that may excite the transducer in an overtone mode (vibrate at a multiple of the resonant frequency). 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.

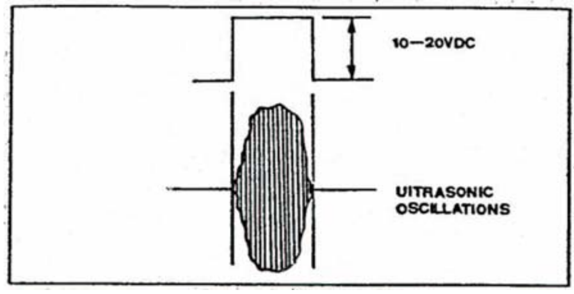
There are several oscillator circuits suitable for driving our ultrasonic transmitter which have been widely used on security systems, remote control and other applications. Please bear in mind that the circuits we suggest sometimes need to be modified according to the different characters of impedance,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

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.



SUGGESTED OSCILLATING CIRCUITS

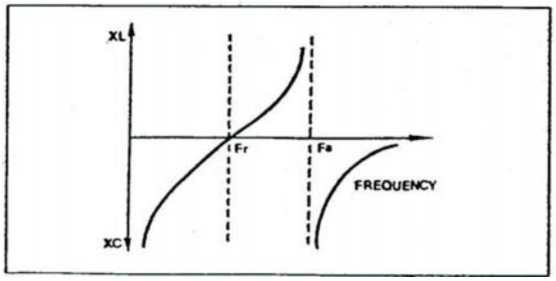
Transmitter Impedance Characteristics



Ultrasonic transmitter impedance characteristics vary with operating frequency and temperature in a 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.

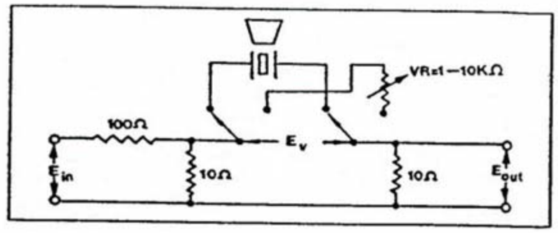
As the resonant frequency is approached, the voltage drop across the transmitter will decrease to a minimum at the resonant frequency (minimum series impedance) and the current will increase proportionally. The phase lead to this current relative to the voltage will decrease to zero near the resonant 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 point. During this transition, the transmitter appears to have an inductive characteristic.

Increasing temperature will lower the resonant frequency and thus the point at which the phase changes will occur. The rate and magnitude of phase change is more stable than the resonant frequency.

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



Adjust frequency to obtain maximum E_{OUT}. Switch in VR and adjust to obtain the same output. VR now equals the minimum series impedance.

Adjust frequency to obtain minimum E_{OUT}. Switch in VR and adjust to obtain same output. VR now equals the maximum series impedance at the anti-resonant frequency.

Measure phase between voltage E_U and E_{OUT} to determine impedance characteristics.

Ultrasonic Receiver Characteristics

Ultrasonic receivers develop an electrical output in proportion to the sound pressure level at the receiver. One of the most frequently asked questions is “What output can I expect from a receiver at a specific distance?” This question can be answered by a simple calculation that is based on the published specifications in the Ultrasonic Ceramic Transducer Data Bulletin.

The basic procedure is to first determine the minimum SPL at the receiver for specific transmitter drive voltage and distance between the transmitter and receiver. This SPL must then be converted to “Pa” (Pascal) or “μbar” (microbar) units.

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

Assume a 400ST160 receiver is located 2 meters from the transmitter and loaded with a 3.9K resistor (resistor placed across the terminals of the receiver).

Determining the SPL at the Receiver

Transmitter SPL: 119 dB at 40KHz, refer to 0 dB = 0.0002 μbar at 30 cm when driven with 10V rms.

Receiver Sensitivity: -65 dB at 40KHz refer to 1 volts/ μbar.

SPL Reduction at 2 meters = 20 log (30cm/200cm) = -16.47 dB

SPL Gain for 14 Vrms Drive = 20 log (14V/10V = 2.92 dB

The SPL at 2 meters = 119 dB + 2.92 dB – 16.47 dB = 105.5 dB

Converting SPL to μbar:

SPL = 105.5 dB
= 20 log (SPL in μbar = “X”/0.0002 μbar @ 0dB)

Dividing by 20 and taking the anti-log yields:

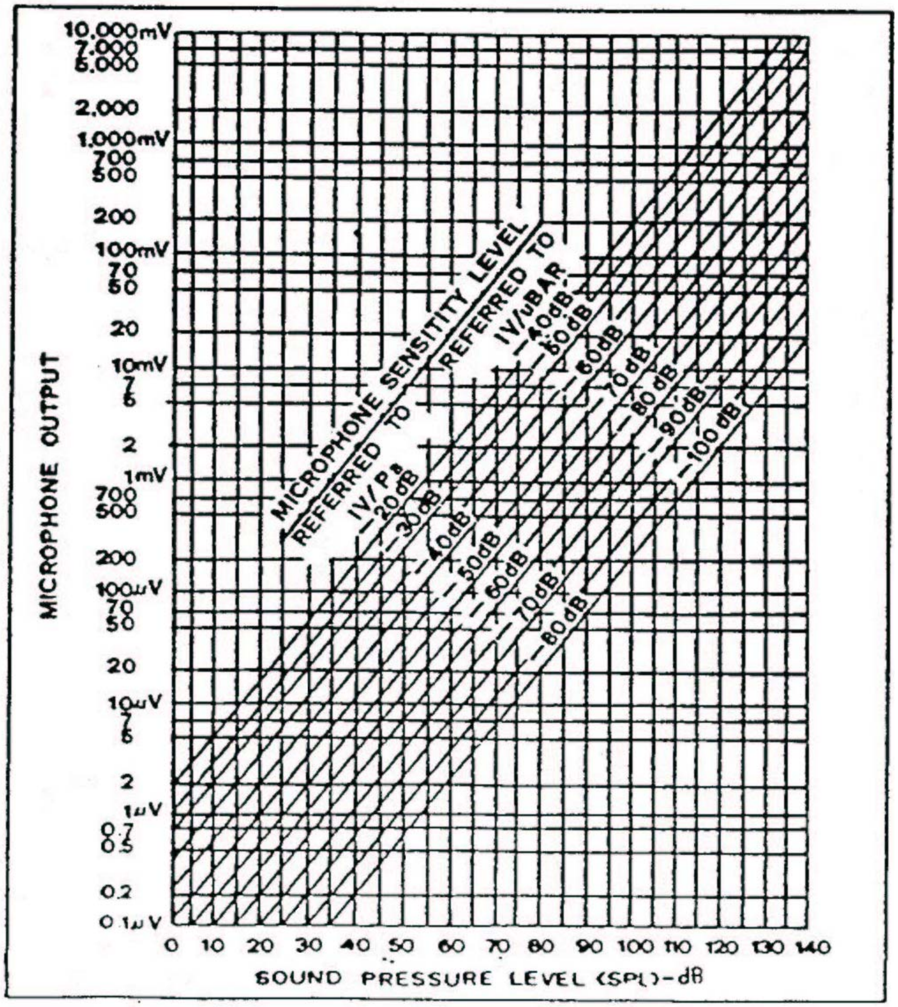
188364.9 = “X”/0.0002 μbar = 37.64 μbar

Determining Receiver Sensitivity in volts/μbar

Sen. = -65 dB
= 20 log (Output Voltage at a Specific SPL ÷ 1 Volt/μbar)
= 0.0005623 Volts/μbar x 37.67 μbar
= 0.0212 Volts = 21.2 millivolts.

This is the minimum output that should be developed under the assumed conditions. The actual output may be much greater depending on operating frequency versus matching frequency between transmit and receive, environmental conditions, and reflective or absorption characteristics of materials in or near the emanating beam.

The analysis is necessary to the fundamental understanding of the principals of soundwave propagation and detection but it is tedious. The figure below is a graphical representation of the 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/μbar referenced data. Follow a horizontal line to the “Y” axis to obtain the receiver output in mV.



Ultrasonic Ranging

Ultrasonic ranging systems are used to determine the distance to an object by measuring the time required for an ultrasonic soundwave 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.

The oscillator output is gated to the ultrasonic transmitter for a brief period that will result in the transmission of a few cycles of ultrasonic energy.

The gate signal also starts a counter which is stopped by the detected returning echo. The count is thus directly proportional to the propagation time of the ultrasonic sound.

The frequency of the clock that is driving the counter is selected to produce a count which represents the distance to the object in the desired engineering units.

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.

The most common approach is to utilize the counter state outputs to drive a digital programmable amplifier such that the gain is automatically related to distance the sound travels.