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Increase piezoelectric transducer acoustic output with a simple circuit

SEPTEMBER 11, 2019 < HTTPS://WWW.EDN.COM/INCREASE-PIEZOELECTRIC-TRANSDUCER-ACOUSTIC-OUTPUT-WITH-A-SIMPLE-CIRCUIT/>
BY DAVE CONRAD < HTTPS://WWW.EDN.COM/AUTHOR/DAVE-CONRAD/>

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There have been many different ideas presented for increasing the acoustic output of a piezo buzzer or ultrasonic transducer. Most of them involve rather complicated circuitry that drives up the total solution cost; such as boosting the low-voltage logic power supply to a higher voltage or using an H-bridge topology.

In contrast, this Design Idea shows how the acoustic output of a piezoelectric transducer can be increased while minimizing the parts count and cost. Before we look at the new approach, let's look at some of the most commonly-used piezo-acoustic designs and their drawbacks.

The simplest piezo drive circuit consists of a transducer and a switching transistor (**Figure 1**). The voltage across the transducer cannot be greater than the supply voltage, which places an upper limit on the acoustic output. The resistor R2 serves to discharge the capacitance of the transducer. The RC time constant should be short relative to the period of the resonant frequency of the transducer. Low resistor values decrease electrical efficiency while damping the mechanical (acoustical) resonance of the transducer, which of course reduces the acoustic efficiency.

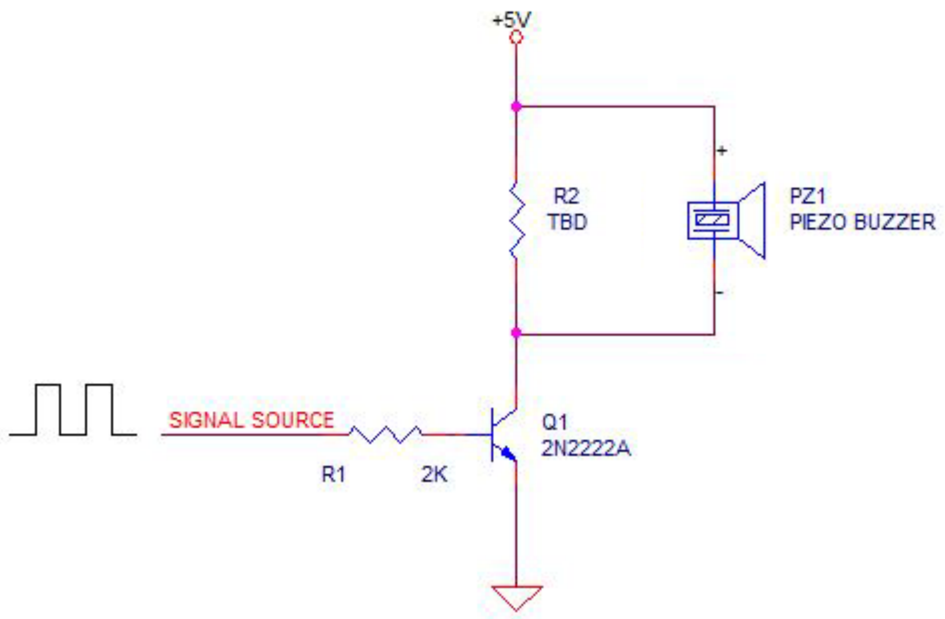

Figure 1 While this piezo drive circuit is simple, it is very inefficient.

A common enhancement to this circuit replaces R2 with an inductor as shown in **Figure 2**.

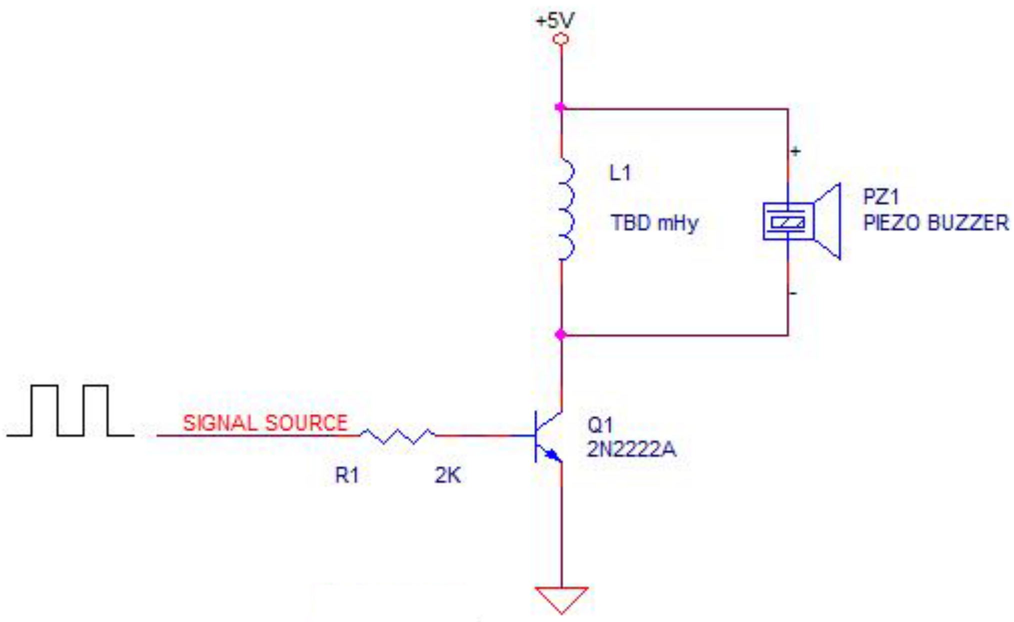

Figure 2 Substituting an inductor for R2 improves the piezo driver's output and efficiency.

Often the inductance value is selected to electrically resonate with the capacitance of the transducer (buzzer) at the acoustic resonance of the transducer. This approach can provide more acoustic output than the parallel resistor approach, but there is still a lot of room for improvement. At best, the peak-to-peak voltage across the transducer may reach 40Vppk, while 20Vppk is more typical with a 5V power supply.

That's because the transistor collector-base junction is forward biased on the negative swing of the parallel resonant circuit formed by the inductor and transducer capacitance, which clamps the voltage swing, limiting acoustic output.

Adding a diode decouples the C-E junction (or if a FET is used, the body diode junction) from this negative swing, providing a much larger voltage swing across the transducer, increasing the acoustic output (**Figure 3**). Although the forward voltage of the diode does reduce the applied power supply voltage, the increased resonance voltage more than makes up for this small loss.

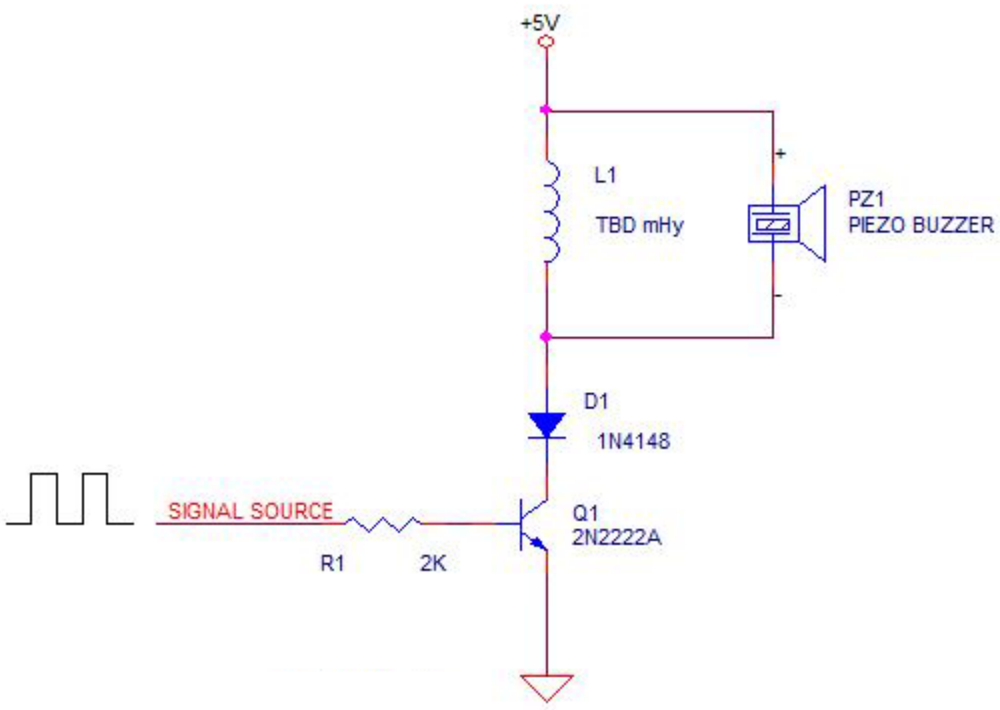

Figure 3 Using a diode can eliminate the circuit's negative swing.

To achieve any further improvements, we need to consider that there are actually two resonances at work in this small system:

1. Acoustic resonance of the transducer, mechanical and cavity resonances apply
2. Electrical resonance of the inductance and transducer capacitance

The electrical resonance frequency need not be the same as that of the acoustic resonance. In fact, if it is roughly 2× the acoustic resonance, the peak voltage across the transducer can be greatly increased.

This is demonstrated in **Figure 4**, where the waveforms are derived using the following circuit parameters:

1. Power supply = 5VDC

2. L1 = 3.2mHy
3. C(piezo) = 2nF
4. Signal source frequency = PZ1, resonant frequency = 40KHz
5. Signal source duty cycle is adjusted to eliminate a large current spike on turn-on

Note that item #5 identifies a potential problem lurking within this new solution that must be addressed. If the signal source can turn on the transistor after the transducer voltage goes positive, there will be a large narrow current spike, which can reduce electrical efficiency and potentially degrade the transistor over time. Increasing the duty cycle to cause transistor turn-on while the resonant voltage is slightly negative eliminates this spike.

With all that sorted out, let's look at how our circuit behaves in real life using our handy four-trace smart oscilloscope:

- Yellow = drive voltage, ~48% duty cycle, 5Vppk. at 40KHz
- Violet = electrical resonance voltage across the transducer, 92Vppk. at 80KHz
- Green = transistor emitter current, ~80mA peak at 40KHz
- Blue = acoustic output of the transducer, measured with a MEMS mic

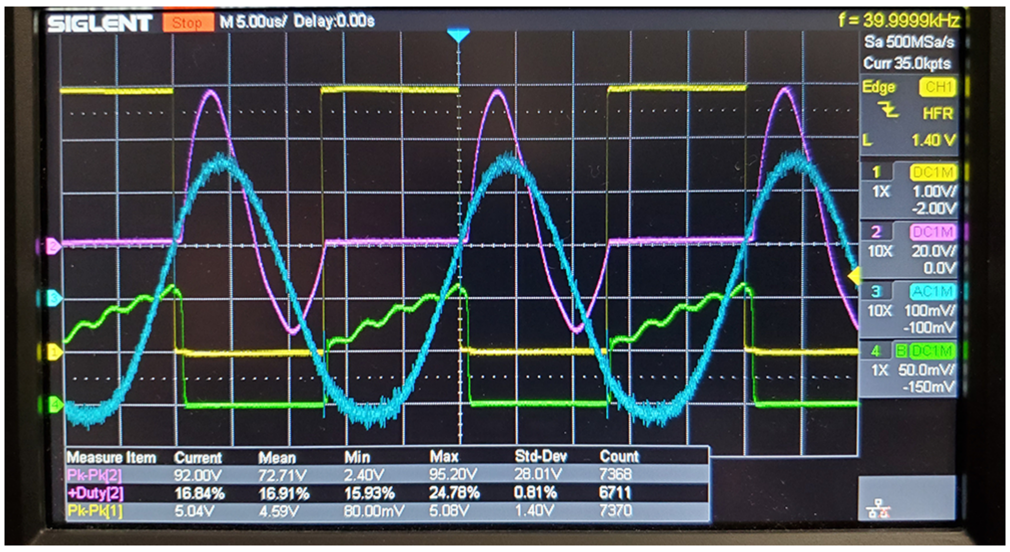

Figure 4 Here is how the circuit behaves in real life.

The high peak voltage across the transducer is achieved by using a smaller inductor than one which would resonate at 40KHz, allowing current to rise about twice as fast, in this example, providing twice the current to "charge" the inductor's magnetic field.

The peak voltage is analogous to pushing a swing, where the higher the peak voltage available, the harder the push that's delivered. In this system, this translates to a larger displacement of the transducer surface, resulting in greater acoustic output.

This Design Idea is not meant to be an exhaustive treatise on resonant circuits. Instead, it demonstrates a procedure by which any resonant piezoelectric transducer or buzzer can be driven to high acoustic output with a very simple, low-cost circuit.

The procedure can be summarized like this:

1. Determine the acoustic resonant frequency of the transducer
2. Create a drive pulse train at that same frequency, starting at a 50% duty cycle
3. Tune the duty cycle to eliminate current spikes at turn-on as needed
4. Determine the capacitance value of the transducer
5. Choose an inductance value that will electrically resonate at approximately double the acoustic resonance.

 It can be difficult to duplicate the acoustic/electrical circuit presented here in simulation, since the transducer consists of two or more potential resonant elements. These include the mechanical resonance of the transducer element, the acoustic resonance of the transducer enclosure (reference Helmholtz resonance), and of course the electrical resonance of the transducer capacitance with the external inductance.

The acoustic loading by radiation from the transducer port or diaphragm adds yet another difficulty to simulation. A simple electrical simulation of this circuit produced 240Vppk across the transducer, which is more than double that created in the real circuit. Acoustic loading may represent the majority of losses that reduce peak transducer voltage in this system, compared to the simulated results.

By using this simple procedure, one can easily maximize transducer output with minimal time and effort.

Dave Conrad is a retired electronics engineer with experience in power, video, analog, digital, mixed signal, and software design.

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12 COMMENTS ON "INCREASE PIEZOELECTRIC TRANSDUCER ACOUSTIC OUTPUT WITH A SIMPLE CIRCUIT"

Thinking_J

September 17, 2019

"I like it. With so many products with modest available voltages to work with, this solution will indeed produce much higher acoustic pressure levels. However, I do have a few reservations: this solution will require a more engineering and experimentation.. for a given application. (NRE vs BOM)- I am surprised by the cost of some inductors these days.. often additional transistors are much cheaper. Not likely a primary issue, as most products can tolerate a dime's difference in BOM costs. Most of the likely resonances found.. will be in the ultrasonic region. Making it harder to force the resonance to be at the desired frequencies for a human to hear or establish the balance between amplitude and freq. the end user may desire. (addressing the biggest application market – louder warning buzzers) I still like it's simplicity, it even has a bit of elegance to the solution."

↪**Log in to Reply**

Light Dave

April 28, 2020

Hi, the solution is quite simple, really. The trick is to use a smaller inductor to allow current to build up faster, thus building up more magnetic field energy, which is then released as a higher voltage. One downside I saw was that the resulting electronic ringing, as opposed to acoustic ringing in the transducer, was at the resonance of the transducer capacitance and the external inductance… which is higher than the acoustic resonance of the transducer. Problem? I didn't see any really, I saw no evidence in acoustic measurements that there was appreciable response by piezo receivers to this electrical resonance. The high Q of the transmitter seems to reject it well. One possible improvement, replace the 1N4148 with a Schottky diode for lower conductance losses and a gain in drive voltage.

↳**Log in to Reply**

Light Dave

September 17, 2019

“Hi, Thank you for the kind words. The point of the method is to use a small inductor, which allows for a faster rate of rise of the current. It doesn’t need to resonate at, or even near, the resonant frequency of the transducer. For instance, I had tried using half the inductance value of that given in the article, 1.6 in place of 3.3mHy. The voltage across the transducer went up to 180Vppk, the acoustic output increased proportionately. For an audible piezo buzzer, all that matters is that the repetition rate is the same or very close to the resonance of the transducer. It’s very much like pushing a swing, if you push at the resonant frequency, the amplitude can be large. Summary: store magnetic energy quickly in a smaller inductor (cheaper, your point well made), pulse at the resonant frequency of the transducer, 7KHz, 40KHz, 100KHz, no matter. thanks for commenting! Dave\n”

↳**Log in to Reply**

Light Dave

September 17, 2019

“Just a thought, while the value of the inductor controls the rate of current rise, the pulse width controls the peak current (shorter, less peak current and so on) and hence the peak to peak voltage pulse “kicking” the transducer. Controlling the acoustic power is just a matter of adjusting the width of the drive pulse. The pulse repetition rate is matched to the resonance of the transducer. Dave”

↳**Log in to Reply**

Brian park

September 18, 2019

“You can increase the output without increasing the movement of the diaphragm. Put a acoustic tuned circuit on the transducer. Bond on a piece of thin-wall aluminum pipe just slightly smaller then the transducer’s diameter with silicone sealant. The length of the pipe sets the tuning frequency. 3/4 inch long pipe will tune at 6KHz (perfect for making locust or cicada bug sounds). Longer pipes will tune lower. You can extend the effective frequency capabilities, especially on the high end, where the diaphragm’s inertia limits the motion.”

↳**Log in to Reply**

Brian park

September 18, 2019

“Yes matter! You get a higher peak voltage, but it is the AREA, not the peak (as long as the pulse’s duration is short compared to the half-period of the audio), that counts. Unless you have a circuit to trap that peak (charge) on the transducer for a significant part of the audio’s half-period, all you are doing is stressing both the transducer and the transistor, and making a nice big burst of EMI at the LC resonance frequency. Only the power that is NOT orthogonal to the audio gets converted. You have built a Tesla coil. Transducers are made of high-K dielectric and have low breakdown voltages. Most transducers have an upper cutoff (unless you acoustically tune them). With 2 more diodes and another transistor, you can trap the charge and achieve higher output. But you are defeating the purpose in that you are essentially building a flyback DC\/DC converter and boosting the voltage, and then using that to drive the transducer. You had better select a more robust transistor than 2N2222, as not only is there high voltage, there us a huge current spike (at high voltage) discharging the transducer on turn-on. You need separate logic drives for the 2 transistors; the charging one being pulsed briefly just long enough to \”charge\” the inductor, the other pulsed (or turned on during the entire discharge half-period, your choice).”

↳**Log in to Reply**

Light Dave

September 21, 2019

“Hi Brian, That’s a good idea for bare transducers. Most audible buzzers use an enclosure, which enclosure volume and port opening make a Helmholtz resonator. Adding a duct to that would substantially lower the resonant frequency of the buzzer. That’s a good thing if it’s your goal to do that. You have a good point about the width of the inductive kick from the resonance of the inductor and the capacitance of the transducer. There will be a sweet spot as one decreases the inductance in search of higher voltage, where you get maximum acoustic output, beyond which there may be higher voltage in the flyback pulse, but the \”kick\” is too short to be more effective.”

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imreac

November 14, 2019

“Simply replace the 2N2222 with a 2N7002. No Vce drop = higher V to transducer. nNot all 2n7002 are the same. Choose from reputable mfg. with RDS ~ 3 Ohm, should be 3-4 cents.”

↳**Log in to Reply**

Light Dave

November 15, 2019

“Hi imreac, Going to an FET is a good idea for reducing on losses. But the 2N7002 is perhaps not the best choice because the Vgth is 5V, too high for getting lowest R(DS)on from this device with 5VDC supply voltage. A better choice might be a logic level gate threshold device, where Vgth is around 1V. R(DS)on can be in the milliOhm range for many devices. Cost might be higher…\n\nNote that 5 Ohm on resistiance times 0.15Amps, V(DS)on is 0.75V! the 2222 can be as low as 0.5V. \n\nGood suggestion! One needs to calculate the on losses, though to help select the best device.”

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rogermija

April 28, 2020

How do I see the complete comment? My screen shows a snippet.

↳**Log in to Reply**

Jessica MacNeil

April 28, 2020

The comments should be displaying properly now, thanks for letting us know.

↳**Log in to Reply**

Tella

October 28, 2022

Hallo

I am a student and as part of my Thesis project I have question regarding piezo speakers.

As a part of my Thesis I have to build a sound generator with help of speakers(buzzers or piezoelectric speakers) with frequencies 20Khz, 40Khz, 40-100Khz, I have selected three speakers with frequency ranges(20Khz, 40Khz, 60khz) from Digikey

So my question How to make the speakers sound(one after another) at those particular frequencies?

should I have to select amplifiers or driver circuit or any other suggestions will be helpful.

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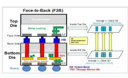

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