

# Sonic Microscope/Telescope Uses a MEMS Microphone

By Jerald M. Cogswell

Wildlife photographers using 2000 mm lenses can add close-up sound to their videos with this sonic telescope. Biologists can use the same device as a sonic microscope to listen to insects and burrowing animals. A precision MEMS microphone mounted in a satellite dish's focal point (or an elliptical chamber) can feed its signal to an amplifier that enables simultaneous recording and monitoring via headphones.

## How It Works

Figure 1 shows the complete schematic. We will discuss the microphone, preamp, output amp, and power supply.

**Microphone Stage:** Tiny MEMS microphones such as the ADMP504 give inventors much more flexibility than the old electret or condenser microphones. MEMS devices have better Signal-to-Noise Ratios, higher sensitivity, much smaller size, and easy integration into small mobile devices. Their specifications are also more consistent, unit to unit. Maximum supply voltage is +3.3V. Capacitor C1 is required in the microphone signal path to block the 0.8VDC offset produced by the device.

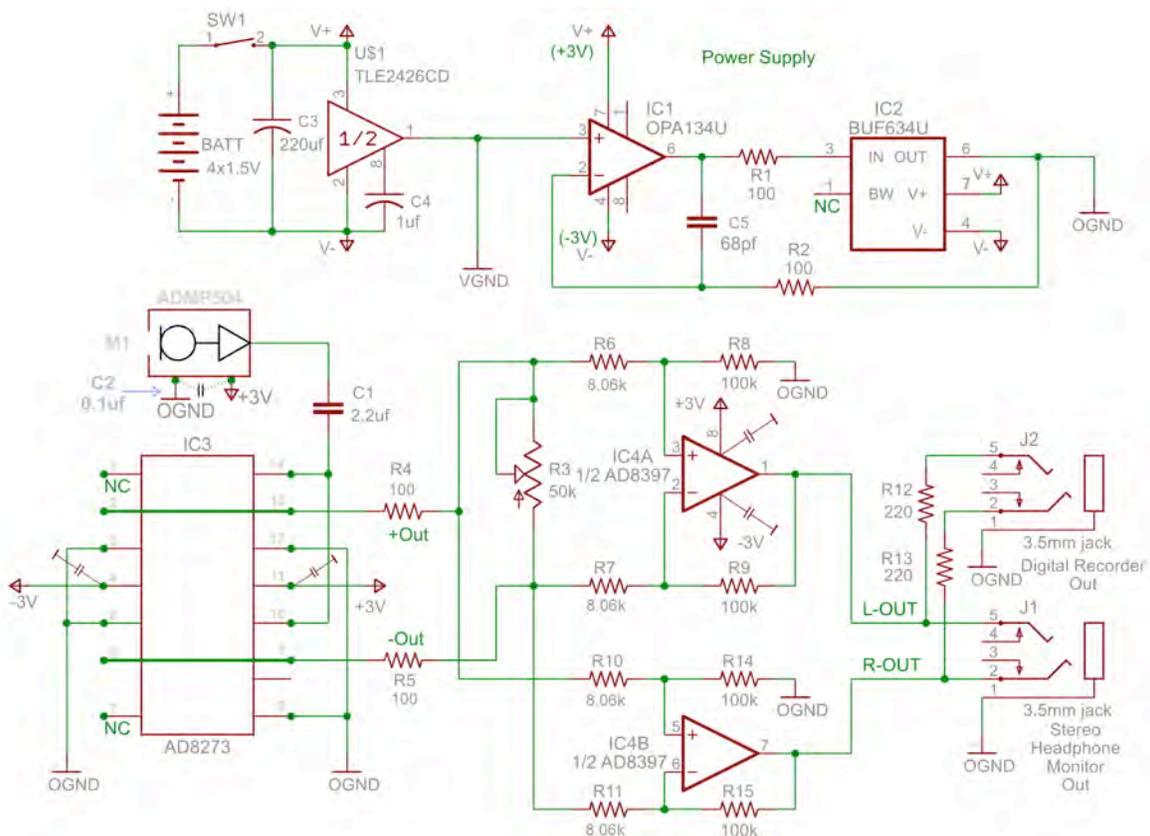


Figure 1

**Preamp Stage:** For a microphone preamp, we use an AD8273 dual difference amplifier which offers very low noise and distortion. The balanced line configuration shown in Figure 2 is redrawn from the MEMS Application Note 1165 (see: [http://www.analog.com/static/imported-files/application\\_notes/AN-1165.pdf](http://www.analog.com/static/imported-files/application_notes/AN-1165.pdf)), page.5. The microphone signal is applied to one inverting and one non-inverting input of the preamp. C1 removes the 0.8VDC offset from the microphone and we have a balanced line output. Notice that the AD8273 has internal resistors we can use to configure the gain. We simply jumper the external pins to obtain our choice of gain from 1/2 to 4. These internal resistors are far more precise than any external resistors and they have more consistent thermal coefficients, thus, they assure excellent Common Mode Rejection (CMR). They also reduce the parts count and cost of the board. We configure the resistors here for a gain of +2 and -2 for a combined gain of 4.

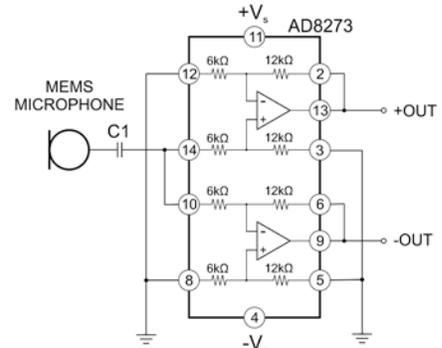


Figure 2

Figure 3 shows the same wiring layout with actual pin positions.

**Output Stage:** Since we have a balanced line preamp output we cannot ground either of its output pins. Our headphone amplifier must be a differential amplifier. This is much different from the popular non-inverting headphone amp circuits. The CMoy amp will not work here. IC4 amplifies the difference between the two signal lines from IC3.

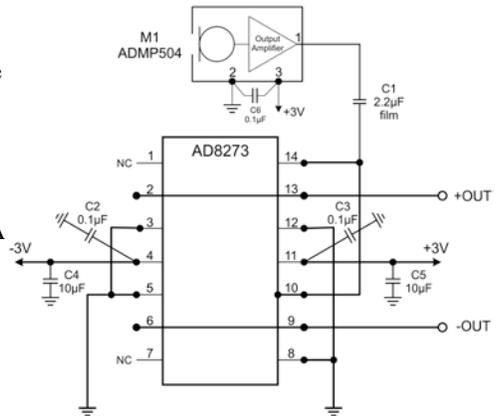


Figure 3

The output stage employs an AD8397. This device can drive loads as low as 35Ω. I recommend that headphones of around 250Ω be used, *e.g.*, Bose noise canceling headphones. Do not use 16Ω earbuds. We add a second 3.5mm jack to drive a digital recorder so that we can monitor and record simultaneously. A digital recorder presents about 2k impedance so the total load is well within our amplifier's capability. We need a gain of only 6 because the MEMS microphone outputs 250mV at a sound pressure level (SPL) of 120db. The preamp gain of 4 gives us 1V, so a further gain of 6 or so will drive the output to clipping using a 6V power supply. We will give it a gain of 12 to 14 and use the volume control to limit as necessary.

Typical volume control designs that put the potentiometer in series with the signal cause resistor noise that increases at low volume. Our volume control is placed across IC4's input lines so that resistor noise gets rejected as Common Mode. R4,R5 limit current load for the preamp output when the volume control is at CCW. At the CW position of R3, its resistance is much larger than R4,R5 and most of the preamp output is delivered to IC4. As the volume control wiper arm slides to the low (CCW) end, the inputs to IC4 are shorted, thus, there is no signal voltage to apply to IC4. The gain of differential amplifier IC4 is the ratio R9/R7. We have only one microphone channel so we deliver the output of the preamp to IC4A and IC4B to drive stereo headphones. Use precision resistors for R4 through R15 to avoid phase distortion and to preserve CMR. That is: R4=R5; R6=R7; R8=R9; R10=R11; R14=R15.

In the case of the sonic telescope, using a parabolic dish, we are concentrating sound collected over 300,000 square centimeters down to a few square millimeters. Do not aim this device at any sound levels you can easily hear, such as traffic noise, as you could destroy the MEMS microphone. Using a vacuum cleaner sound (about 70db SPL) at 1 meter distance with no reflector, the author measured the output of the ADMP504 at 19mV peak-to-peak. Even a whisper at one foot was clearly audible in the headphones! In the case of the sonic microscope using a small elliptical reflector, we can increase the output amplifier's gain to 40db by decreasing precision resistors R6,R7,R10,R11 to as low as 1k though that's probably pushing the noise floor limit and risks oscillation and DC offset. We could consider changing the gain between telescope and microscope applications by using male headers and shorting blocks to select bias resistors. We could also consider mounting the microphones into the earpieces of a conventional stethoscope.

**Power Supply Stage:** Power is supplied by four AAA batteries. We obtain a dual ±3V supply by implementing a virtual ground concept. The TLE2426 Rail Splitter accurately splits the voltage into ±3V supplies by offering a virtual ground reference at 1/2 V<sub>s</sub>. The rail splitter does this without use of external current-robbing divider resistors.

Note: It would be a good idea to order a bunch of these devices as an inexpensive alternative to building dual power supplies for your projects. The Rail Splitter can handle voltages from 4V to 40V and can sink and source 20mA – adequate for many projects without the BUF634. The TLE2426 comes in a 3-pin TO-226AA package, a low-noise SOIC-8 package, or a low-noise DIP-8 package.

We need more current here than the 20mA of the Rail Splitter. We'll deliver its output to a buffer driven by an op amp. The OPA134 was chosen because it is unity gain stable and can operate on a ±3V supply. The BUF634 provides the high current we need while the op amp provides precise control. The op amp/buffer combination is configured as a unity gain ground stage. The power supply schematic is adapted from one used in the PIMETA v2 headphone amp circuit. See <http://www.tangentsoft.net/audio/pimeta2/>. Also see the BUF634 data sheet <http://www.ti.com/lit/an/sboa065/sboa065.pdf>.

**Reflector:** Both DishTV and DirecTV satellite dishes are available for a hundred dollars or less without the LNB from various online vendors. The parabolic shape is suitable for use as a sonic telescope. Development of the device as a

microscope requires the use of an elliptical reflector. You might have stood in an elliptical room sometimes called a whisper chamber. When two people stand in the respective focal points of the room, they can whisper to each other and hear clearly. The following examples are cited in <http://en.wikipedia.org/wiki/Ellipse>.

“Examples are the National Statuary Hall at the United States Capitol (where John Quincy Adams is said to have used this property for eavesdropping on political matters), at an exhibit on sound at the Museum of Science and Industry in Chicago, in front of the University of Illinois at Urbana-Champaign Foellinger Auditorium, and also at a side chamber of the Palace of Charles V, in the Alhambra.”

For our sonic microscope we made an elliptical chamber about the size of a football. One end of the chamber is truncated, perhaps at an angle through one of the foci. The microphone is placed in the other focus. Any objects or insects in focus can be amplified by reflection off the walls of the chamber.

## Build Instructions

**Microphone:** I didn't have the patience and resources to mount the tiny MEMS device to an SMT circuit board so I ordered the *MEMS ADMP504 Evaluation Board* (Analog Devices part EVAL-ADMP504Z-FLEX). While the MEMS microphone costs only five dollars or so, the task of soldering the 2.5mm x 3.5mm device to a PCB is a bit daunting. It involves having a solder paste stencil cut, applying solder paste (a perishable item), etching a very tiny PCB pattern, drilling a #75 hole, and baking the assembly, perhaps in a toaster oven, to somewhat exacting specifications – all with a possibility of failure. Now you see why I ordered the evaluation board at less than a hundred dollars. The assembled board even includes the power supply decoupling capacitor and three wire leads. For those with access to professional SMT soldering equipment, the ADMP504 data sheet includes all the specifications required for soldering at [http://www.analog.com/static/imported-files/data\\_sheets/ADMP504.pdf](http://www.analog.com/static/imported-files/data_sheets/ADMP504.pdf).

**The Amplifier Board:** We opt here for the SOIC surface-mount versions of the integrated circuits IC3, IC4. Some readers might be reluctant to try a project that involves soldering SMT SOIC chips. That's why I selected the SchmartBoard 204-0004-01 as an introduction to soldering these small parts. We need two of these. Snap off the 28-pin section of the SchmartBoards as we only need the 8 and 18-pin sections as a unit. The SchmartBoards provide a breakout to 0.10” (1.27mm) pitch male headers which stack onto a solderless breadboard or a solderable protoboard. The product even comes presoldered and provides the male headers! SchmartBoard's website offers video instruction on the use of the product at [http://www.schmartboard.com/index.asp?page=resources\\_howto](http://www.schmartboard.com/index.asp?page=resources_howto). The manufacturer recommends a solder tip temperature of 800°F (427°C) for the unleaded solder. This seems high but it works very well. If you're just getting into SOIC chips, this would be a good time to invest in a soldering station. Be sure to use water-soluble flux or water-soluble flux pen. Rosin flux does not give reliable results on the SchmartBoard. Use a fine solder point. You will gain confidence in your ability to use SOIC in more projects. After soldering the SOIC chips, drop the point temperature to 518°F (320°C) for work on the protoboard. Wash off the soluble flux with distilled water within an hour after soldering.

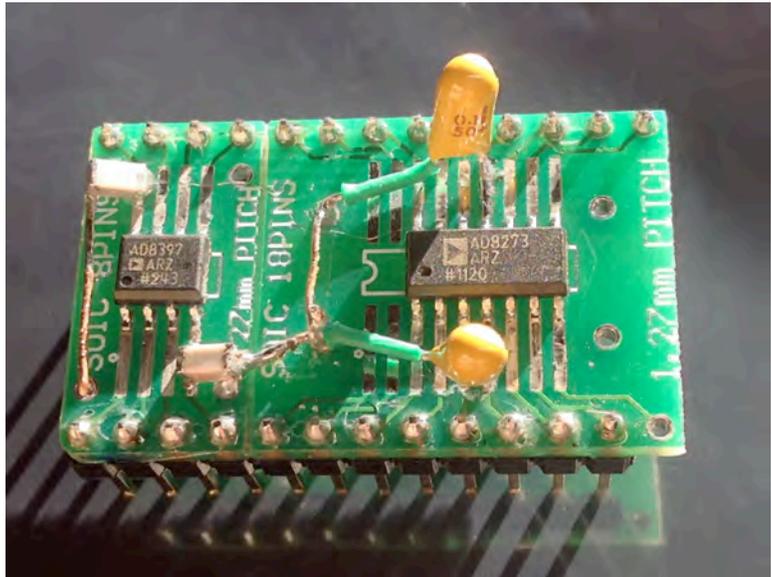


Figure 4

The placement of the 0.1µF capacitors on the schematic reminds us that we must decouple the ICs from the power supply by soldering the capacitors very close to the IC pins. The SchmartBoard offers a way of doing this for SMT capacitors. See their video. [http://www.schmartboard.com/schmartboard\\_dc\\_bypass.pdf](http://www.schmartboard.com/schmartboard_dc_bypass.pdf). I used tantalum capacitors on the preamp IC and 1206-package surface-mount ceramics on the OPA134. We cannot pick just any point on our PCB as a “ground.” Remember that not all ground points are equal. Try to tie all your grounds to a single point using a spider configuration of wiring. Here is an excellent tutorial on ground points. [http://www.analog.com/static/imported-files/application\\_notes/AN-202.pdf](http://www.analog.com/static/imported-files/application_notes/AN-202.pdf). If you intend to change the feedback gain between microscope and telescope functions, consider wiring bias resistors to pin headers so that shorting blocks can change values.

Notice that the Record Out jack has 220Ω series resistors. This is to prevent overloading the amp in case someone tries to plug a second pair headphones into it.

Any capacitors in an audio signal path should be of high quality film. If ceramic capacitors are used, select C0G/NP0 temperature coefficients. Use top-screw terminal blocks to attach the microphone wires to the preamp or, if you prefer, attach female jumpers to the microphone leads and connect them to male pin headers at the preamp as I did.

One more thing; It's a good idea to do all your layout and soldering on a static-free surface. If you don't want to purchase a static-free mat, just use one of those static-free packaging bags that the ICs came in. It's also a good idea to have a "helping hands" clamp or a desk vice to hold the boards while you solder. An illuminated magnifying glass is also very helpful for checking your solder joints. Use a dry transfer lettering kit to label the output jacks as *Record Out* and *Headphones 250Ω*. Label the three microphone lead attachments.

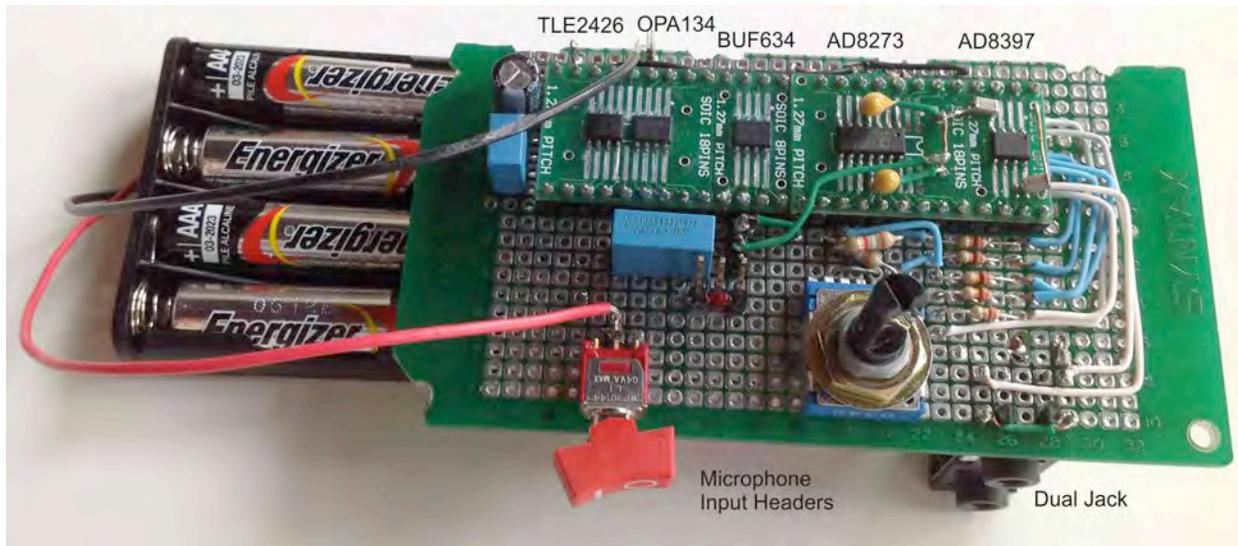


Figure 5

**Power Supply Board:** Using the same technique as used for the amplifier board, solder the Rail Splitter, the OPA134, and the BUF634 to a second SchmartBoard. Solder on the long pin headers as well. Though not shown in the schematic, add power supply decoupling capacitors to the BUF634. Mount the board to a solderless breadboard and wire the power supply circuit. Test the TLE2426 output voltage before connecting it to the op amp and buffer. Jumper wires and 1/8 Watt resistors fit under the SchmartBoard between the header rows. Check output with a multimeter. Positive and negative voltages should agree within 3 or 4 millivolts. After you are satisfied that the power supply works properly, you are ready to solder all components to a through-hole prototype board.

**Elliptical Chamber:** For the sonic microscope we need an elliptical chamber. One could draw this and print it in 3D. A somewhat crude method is to make a mold of balsa bulkheads and stringers and cast the shell in resin or plaster. I used Foamcore board for the inside mold instead of balsa. I drew the ellipse shape using the pins and string method. The pins were 80mm apart and the string length was 216mm. Make five or six semi-ellipses that meet along the major axis. Cut each ellipse through one of the foci parallel with the minor axis. Lay this on a flat surface to make one half of the clamshell. These would be the bulkheads in model airplane terminology. Run 1/16" balsa stringers across the bulkheads to make a mesh of the curved surface. Cover the shell with strips of tissue paper and varnish. Apply wax or petroleum jelly. Smear a layer of plaster over the mold and reinforce it with thread. Remove the shell when dry and make a second (optional) half shell. Attach the two halves together and you have your elliptical chamber. When recording insects it might be interesting to lower the recorded sound by an octave using software such as Sony SoundForge Pro-10 to see if there is any content in the high frequencies. I plan to experiment with this. You could increase the amplifier gain to as high as 200 (46db) for tiny sounds but be careful of outside noise. Use shorting blocks or DIP switches on R6, R7, R10, R11 values to offer gain options.



Figure 6

**Parabolic Reflector:** For the sonic telescope use a TV satellite dish without the LNB. Mount the MEMS microphone PCB in the focal point where the LNB would go. It's possible to hold the dish by hand but you might want to purchase a dish tripod for hands-free operation.

**Protecting the microphone:** One application note advises protecting the microphone from dust intrusion into the tiny opening. A thin sheet of plastic wrap should be adequate.

**Testing:** Test the assembled circuit before plugging in expensive headphones. Especially check for DC of more than a few millivolts on the output. If you measure any large DC output you likely have a wiring error either in the power supply or the amplifier section. Smaller DC offsets result from imprecise bias resistor matching. Consider making a simple sine wave generator with a dual op amp and using its signal in lieu of the MEMS microphone for testing. An oscilloscope is always a big help in diagnosing signal circuits. Also consider using a 3.5 mm stereo plug with the barrel removed to give access to output during signal and voltage checks.

#### Reference

MEMS Sensors datasheet: [http://www.analog.com/static/imported-files/data\\_sheets/ADMP504.pdf](http://www.analog.com/static/imported-files/data_sheets/ADMP504.pdf)

MEMS Sensor Application Notes: <http://www.analog.com/en/mems-sensors/products/index.html>

Linear amps datasheets and application notes: <http://www.analog.com/en/amplifiers-linear/products/index.html>

Preamp: MEMS Application Note 1165 (see: [http://www.analog.com/static/imported-files/application\\_notes/AN-1165.pdf](http://www.analog.com/static/imported-files/application_notes/AN-1165.pdf))

OPA134 datasheet: <http://www.ti.com/lit/ds/symlink/opa2134.pdf>

BUF634 datasheet: <http://www.ti.com/lit/ds/symlink/buf634.pdf> and <http://www.ti.com/lit/an/sboa065/sboa065.pdf> .

Power Supply: <http://www.tangentsoft.net/audio/pimeta2/>.

