

# The HZX Headphone Adapter

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**Looking for a pair of high-quality, high-impedance headphones for that crystal radio project? Build the HZX headphone adapter and use your Walkman-style headphones instead!**

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Despite the relentless march of technology, there's been a resurgence of interest in crystal radio experimentation and construction. A recent *QST* article [1] by Dave Evison, W7DE, described how to build a beginner's crystal set. And Steve Ford, WB8IMY, reviewed a book published by the Crystal Set Society, a club exclusively devoted to designing and building crystal radios! [2] I find this renewed interest in crystal radio construction very encouraging. Understanding how crystal sets actually work encompasses virtually all the radio theory needed by beginning hams!

Although most of the components required to build crystal sets are readily available, quality high-impedance headphones are hard to find. Decent low-impedance "Walkman style" headphones, however, abound. Devising a way to use these low-impedance headphones with crystal radios—which "work for free" and require no external power—is the challenge.

## The Passive Approach

The most direct approach to using low-impedance headphones with crystal sets is to use an audio transformer with a high-impedance primary winding (several thousand ohms) and a lower-impedance secondary to match the impedance of the phones. Unfortunately, this type of transformer is rather difficult to find.

Radio Shack offers a 1 k $\Omega$  to 8- $\Omega$  transformer (273-1380), but that particular transformer loads the crystal detector severely. I have used it with several crystal sets and, as expected, only strong AM stations can be heard. Also, the excessive loading ruins the set's tuning.

In experimenting I also noticed that the type of low-impedance headphones I used had a significant impact on how well they worked with the transformer. I had assumed that "low-impedance" headphones were 8  $\Omega$  or 16- $\Omega$  devices. After some measurements on an impedance analyzer, however, I was amazed to find that the higher-quality (and better performing) headphones were actually 50 to 60  $\Omega$  per phone, while the lower-quality, poorer-performing units ranged from about 4 to 18  $\Omega$  per phone.

Because I was using the phones in series, the better-performing units were actually presenting an impedance of 100 to 120  $\Omega$ . When used with the Radio Shack transformer, the transformed impedance of the 120- $\Omega$  phones was about 2.8 k $\Omega$ , as compared to the 1 to 1.5-k $\Omega$  impedance presented by the lower-impedance phones. The higher-impedance units caused less detector loading and, therefore, greater audio output. The transformer loading, however, was still too great to allow proper receiver tuning.

After researching additional transformers, I found a family of quality, low-power audio transformers from Pico Electronics. [3] Although somewhat expensive, these transformers seemed to be exactly what I needed. I chose a transformer with a primary impedance of 100 k $\Omega$  and a secondary impedance of 100  $\Omega$ . [4]

Using this transformer with the Walkman headphones and a crystal set provided some encouraging results, with good audio and tuning when I used a large wire antenna (more than 300 feet long). The audio level from the same crystal set when tested with a more realistic antenna (about 60 feet long) was disappointing. The same set worked well, however, with the shorter antenna and a "no-name" brand of 1960-era high-impedance magnetic headphones.

To resolve this problem, I reviewed as much literature on high-impedance headphones as I could turn up. Reportedly, the penultimate headphones for crystal sets were produced by the C. Brandes Company in the 1920s. A trip to a large antique radio show yielded two sets of Brandes *Superior* headphones in "very good to excellent" condition at a combined cost of \$60. Brandes headphones in "working to good" condition ranged in price from \$15 to \$25. I also collected several additional "working" high-impedance headphones, which included magnetic and "ceramic" (piezo-electric) types, to gather test data on impedance, sensitivity and frequency response.

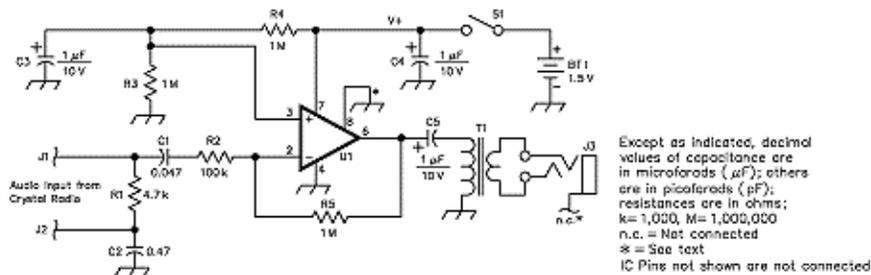
In summary, I found that there is not necessarily a direct relationship between the impedance of the headphones and their sensitivity. Some headphones with a 1.6-k $\Omega$  impedance at 2 kHz had greater sensitivity than phones with a 25-k $\Omega$  impedance at the same frequency. In most cases, however, there was a direct relationship between the sensitivity and the frequency response of the

phones. The more sensitive the phones, the narrower the frequency response, with most of the more sensitive units having a low-frequency limit of about 1.5 to 2 kHz. The lower audio frequencies require more energy to produce the mechanical movement of the diaphragm required to reproduce the lower frequencies. This is why the newer Walkman headphones, which have a low-frequency response of less than 50 Hz, do not have the same apparent sensitivity, even with the proper impedance matching, as do high-impedance headphones.

Additionally, I found that the Brandes headphones did indeed offer the best overall combination of impedance (about 15 kΩ at 1 kHz), sensitivity and frequency response of the nine high-impedance headphones I tested, both in the lab and on the air with a crystal radio. The difference in the apparent "gain" between the Brandes and Walkman headphones (with a matching transformer) is about 12 dB. Therefore, to have the Walkman headphones emulate the performance of the Brandes units, I needed more power.

## The Hybrid "HZX" Phone Adapter

Although considering a "powered" accessory for a crystal radio may sound like heresy to crystal set enthusiasts, it may make the difference between success and failure for beginning builders. Additionally, if the required power is so low that a AA-size battery can power it for a year or more, I feel that the "spirit" of crystal radio design is well preserved. Shown in **Figure 1** is the design of the HZX phone adapter. The name derives from "high impedance" (Hi-Z) and Xtal, the abbreviation for the word crystal.



**Figure 1—Schematic diagram and parts list for the HZX headphone adapter. Radio Shack part numbers shown unless otherwise noted.**

**C1—0.047  $\mu\text{F}$  ceramic (272-134)**

**C2—0.47 $\mu\text{F}$  ceramic (RSU11298320)**

**C3, C4, C5—1  $\mu\text{F}$ , 10 V electrolytics (RSU11297850)**

**J1, J2—binding posts (274-662)**

**J3—phone jack (274-249)**

**R1—4.7 k $\Omega$  (271-1124)**

**R2—100 k $\Omega$  (271-1131)**

**R3, R4, R5—1 M $\Omega$  (271-1356)**

**S1—SPST switch (275-634)**

**T1—audio transformer, 1 k $\Omega$  primary/8  $\Omega$  secondary (273-1380)**

**U1—TLC251 op amp (Tech America no. 900-6362. Order line: 800-877-0072.)**

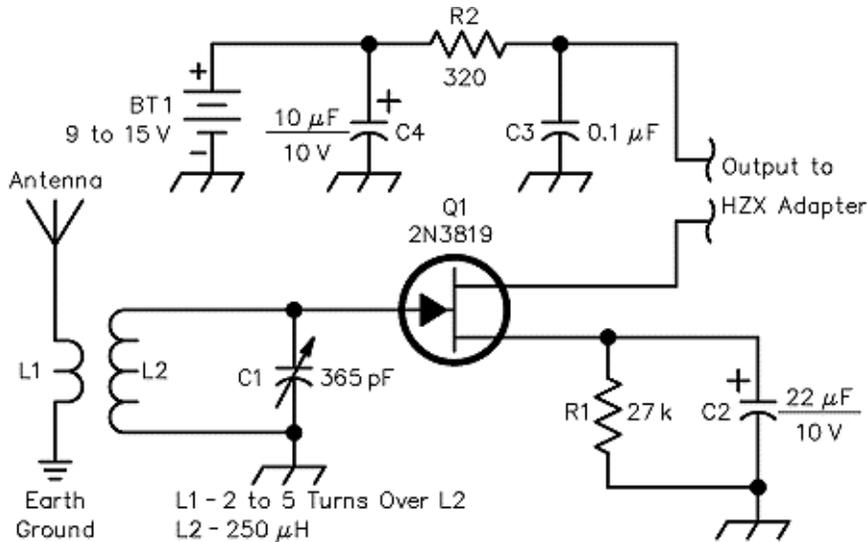
The design is a "hybrid," using active component U1 for gain and passive component T1 for impedance matching. The unique feature of the design is op-amp U1, a TLC251. This device can operate with single supply voltages as low as 1.4 V and can be programmed to consume very little power supply current.

In this application, the output of U1 drives T1, the same low-cost Radio Shack transformer used in earlier experiments. While T1 is specified as a 1 k $\Omega$  to 8- $\Omega$  transformer, it still works well with the 100 to 120- $\Omega$  headphones at the low power levels used in this

design. To provide the drive required by T1, the TLC251 is operated in its high bias mode (pin 8 of U1 is grounded).

U1's voltage gain is set to 10 (20 dB) by the ratio of R5 to R2. These values were selected by modeling the op-amp to give a required audio frequency response of about 100 Hz to 10 kHz. When operating the op-amp at low supply voltages, smaller values for R5 and R2 degrade U1's frequency response.

The 4.7-kΩ input resistor, R1, was selected to set overall circuit gain to emulate the performance of the Brandes *Superior* headphones. Placing R1 as a series element and ac-coupling the input (via C1) and the ground (via C2) lets us use the HZX in the drain circuit of an infinite-impedance detector for those graduating from pure crystal sets to "active" detector circuits. This application is shown in **Figure 2**.



**Figure 2—A typical crystal receiver modified for use with an "active" detector.**

With a 1.5-V supply, U1 consumes about 50 μA with the headphones plugged in and a 0.01-V, 2-kHz signal applied, for a total power of about 75 μW. This is less power than the crystal radio itself "draws" from a received RF wave to produce an audible audio signal!

To estimate battery life when using a 1.5-V AA cell, I consulted Duracell's Web site.<sup>[5]</sup> The listed capacity rating for standard AA batteries is 2.85 A/h. Duracell's site indicated that a 0.8 derating factor should be used when estimating battery life down to an end-of-life voltage of 0.8 V. Scaling this to the 1.4-V minimum operating voltage for U1 gives a derating factor of about 0.15. Therefore, at 50 μA, the battery should last about a year with continuous use!

I have roughly confirmed this estimate on several prototype HZX units where the battery voltage drops about 0.6 mV per day. At this rate, the battery would last about 11 months. Assuming a usage of only a few hours per day, the AA battery could last for several years.

For those seeking the ultimate in low-power operation, T1 can be replaced by the 100-kΩ Pico Electronics transformer. In this application, U1 can be operated in its low bias mode (pin 8 is connected to V+). When operating in this mode, U1 typically uses about 2 μA at 1.4 V, for a total circuit power of less than 3.5 μW!

## Building the HZX

There is nothing critical in the construction of this design. Units have been built on perf-board with point to point wiring, "dead-bug" style on scraps of copper-clad board, and using prototyping PCBs from Radio Shack (RS 276-149 or similar). All methods work equally well. The connecting hardware (J1, J2 and J3) and S1 are chosen by the builder.

In my prototype units I used binding post connectors for J1 and J2. This allows easy connections to most crystal sets. Notice that

the common, or ground connection on headphone connector J3 is not used. As always, check your work before applying power for the first time.

It's easy to determine if your Walkman-style headphones will work well with the HZX adapter. It turns out that the dc resistance and ac impedance of most Walkman-style headphones are about the same. They have very little reactance between dc and audio frequencies. Simply measure the dc resistance of the phones. If it's greater than 30 or 40  $\Omega$  per phone, your phones should work well.

All of the parts are available from Radio Shack except U1, which is available from Tech America. As of this writing, the total cost for all new components is less than \$9. A low-cost headphone that works well with this design is Radio Shack's *NOVA 42*.

## Check-out and Operation

To quickly verify the operation of the HZX, touch pin 2 of U1 with a short piece of bare hook-up wire. A 60-Hz hum should be heard in the headphones. A simple test I use to determine if high-impedance headphones are *sensitive* can also be used with the HZX adapter. Connect two short lengths of bare wire to J1 and J2. While holding one bare wire with one hand, touch the other bare wire with a quarter held in your other hand. A faint crackling noise caused by the small galvanic voltage (only a few hundred *microvolts*) developed between your hand and the quarter should be heard in the headphones. Remember, the HZX is designed to *emulate* the performance of classic crystal radio high-impedance phones, so the volume will be no greater than that from a set of good high-impedance headphones.

Often, when using the HZX on your crystal set, the audio will sound "louder" than when using typical high-impedance phones. This is not because of the amplifier, but because of the improved frequency response. If you have some high-impedance phones available, it's interesting to do an "on-the-air" comparison. You'll usually find that the peak volume will be about the same, but the high-impedance phones will sound very "tinny" because of the lack of low-frequency response. On strong signals, the HZX may overload more quickly than high-impedance phones, however. In this case, simply reduce the antenna coupling. This will improve the set's audio quality and selectivity.

## Summary

For many of us, building crystal radios was the start of our ham radio hobby. I think it's still one of the best ways to get started. It embodies much of what new hams need to know in terms of theory and practice. All components are readily available—except high-impedance headphones. I hope this little project helps many beginners to successfully build crystal sets of their own. Users will be impressed with the HZX's fidelity—and the newer "Walkman" headphones are much more comfortable than 70-year-old antique headphones! If you have never built a crystal set, or haven't played with one for the last 20 or 30 years, give it a try. There is still something magical about broadcast-band DXing with a crystal set and a good antenna.