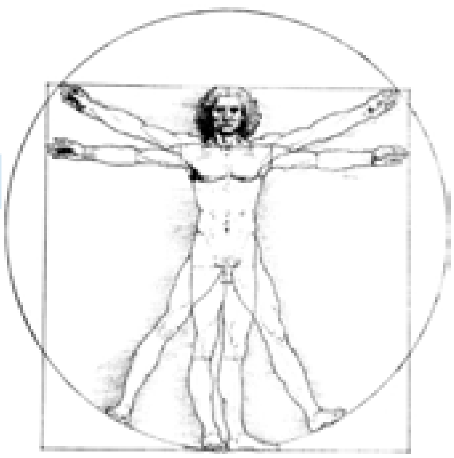
Monitoring Ultrasound

By Phil Anderson, WØXI

Each time I see a rendering of Leonardo da Vinci's Vitruvian Man, exploring the relationship between man and nature, I'm reminded of thoughts I had while taking a course in electro-magnetism many years back:

Wouldn't it be neat if we had glasses that allowed us to "see" magnetic fields, and

If there's a shadow behind a pole due to sunlight, wouldn't there also be an electro-magnetic shadow due to incoming radio waves?



You might counter that we do see radiation already; we see sunlight with the naked eye. As humans, we see the visible, hear and produce audio, feel and give off heat, perceive smells by excitation of our olfactory nerves, and we can produce and sense pressure as well.

With technical assistance, we can see *infra*red using night vision goggles, hear detected radio signals, watch reconstituted images on TV, see inside the body, and view distant galaxies.

So wouldn't it be neat to hear ultrasound – those frequencies high above the limits of human hearing? We could hear what dogs can hear, listen in on bat conversations, or even monitor multi-mile conversations by elephants using infrasound below human hearing range.

We can, and a small handful of folks already do!

❖ An Ultrasound Receiver

I ran across an article some months back about a bat detector a fellow hobbyist in the UK had built. (I guess they like bats in their belfries there.) I got fired up and decided to investigate, design, and build my own units to listen to and transmit ultrasound and infrasound. I've finished my first 40 kHz ultrasound receiver, described here briefly, and have a transmitter working on the bench.

As you'll see, the architecture of the receiver is direct conversion, which should be familiar to radio amateurs. The front end could easily be converted to listen to radio signals in the ELF (3-30Hz), VLF (3-30kHz), and LowFER (under 500 kHz) bands as well.

Before describing the receiver, a short introduction/refresher about sound is in order. Humans hear from about 20 Hz to 20,000 Hz. The useful range for pressure waves (which is what sound waves are) actually extends far above that, all the way up to roughly 10 MHz! Medical applications, such as imaging sonograms, are probably the most familiar use.

Many insects, rodents, bats, and fish utilize portions of the ultrasound spectrum for feeding, communication, and navigation. Some use human-range audio, too, of course. Except for structural and medical testing, the use of ultrasound above about 160 kHz by living organisms is virtually non-existent, since air is so absorptive to these pressure waves.

Elephants and whales use infrasound – signals below 20 Hz. It's been documented that elephants can communicate over tens of miles at these low frequencies.

Arguably, some humans use infrasound, too: teenagers with their car stereos thumping at low frequencies as they drive by, mesmerized by the pounding sound. This habit will, no doubt, become a new source of patients for audiologists, if not already! More elegantly, concert-goers feel the deep pulse of a base drum, evoking a primordial response in the psyche of the listener.

Table 1 summarizes the frequency ranges and their inhabitants. Note the overlap between the high end of the pressure waves and our AM broadcast band. The difference is, of course, that the pressure waves are an upper extension of acoustical sound – vibration of air molecules – while radio signals are electromagnetic.

TABLE 1

Band	Frequency Range	Users
infrasound	0-20 Hz	Elephants, whales
audio	20 Hz-20 kHz	Humans, insects, animals, fish, sonar
ultrasound	10-30 kHz	Rodents
ultrasound	20-75 kHz	Insects
ultrasound	20-160 kHz	Bats, dolphins
ultrasound	100-2000 kHz	Structures testing
ultrasound	1-10 MHz	Medical applications
mediumwave	0.5-1.6 MHz	AM radio

Figure 1: The Direct-Conversion Ultrasound Receiver, RX1

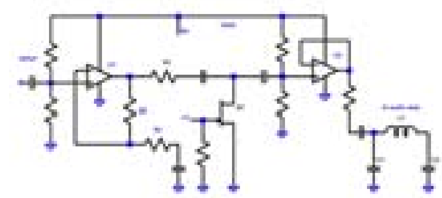


Figure 1-A: Simplified Schematic

❖ The Receiver

A block diagram for the Ultra-RX1 receiver is displayed in Figure 1. A simplified schematic of the pre-amp, mixer, and low-pass filter is shown in Figure 1-A. Power supply and audio components are not shown. R2 and R3 set the gain of U1; the +5 volt TTL signal of the LO turns on and off Q1, the N-channel FET; and the U2 buffer sets the drive impedance for the first section of the low-pass filter.

A Kobitone 400SR16 piezoelectric transducer (PZT) – essentially a high frequency microphone – takes the place of the usual RF antenna. Pressure variations arriving at the PZT generate a low voltage signal, which is then amplified by a 34-dB operational amplifier.

The amplified signal is mixed with a frequency-adjustable local oscillator (LO) using a conventional N-channel field effect transistor (FET) as a "chopper" mixer. The mixer output is a collection of signals: the PZT output, the LO, harmonics of each, and products of the two (sums and differences – "beat" frequencies).

Without filtering, the final detected signal could sound more like the simultaneous audition of 20 American Idol contestants – and amplified at that! For this reason, a two-stage, passive, low-pass filter was added, removing all but the desirable product.

The final step, an audio amplifier, consists of two stages, a 27 dB op-amp with filter feedback, and a common, 8-pin, DIP audio

Figure 3: Two Ultra-RX1 Kits, assembled and in the case

IC. For listening, I use a set of 24-ohm iPOD headphones, but an 8-ohm ear bud or even high impedance phones will work, too. Basically, if it's an earphone or a headset, plug it in!

❖ A little theory

So, what's the frequency range of the receiver? What pressure and voltage levels are involved? What can one hear on a calm sunny day in the spring? (Winter is a dead-zone for bio-ultrasound listening.)

PZTs are inherently narrow-banded with a typical 3-dB bandwidth of about one kHz. While their circuit model resembles that of an RF quartz crystal (see Figure 2), the Q is much lower. By adding an inductance in parallel as noted in figure 2, the response bandwidth can be expanded to over 10 kHz. Since many bats and insects chat at or about 40 kHz, I chose a PZT with a series resonant frequency of just that.

The receiver is made to listen from at least 35 to 45 kHz; by tuning the LO through this range, the human-range audio can hear the entire band of ultrasonic signals. In a way, the RX1 is actually a mini-ultrasonic spectrum analyzer!

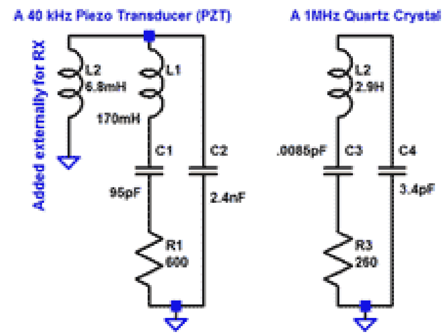


Figure 2: Typical Electrical Models of a Piezo Transducer and a Quartz Crystal

Many insects, bats, and some mammals produce sound pressure levels (SPL) of 70 to 110 dB as measured at one foot distance. SPL is defined as 20 times the logarithm of the signal pressure divided by the pressure for the threshold of human hearing, about 20 micro-pascals (20 uPa).

Since sound pressure dissipates at a rate inverse to the distance, the signal pressure at 50 feet will be dissipated to 1/50th that at 1 foot in front the emitter. Thus, the pressure heard at 50 feet would be reduced 34 dB. A strong signal of 110 dB would thus be less than 70 dB at the receiver. The corresponding pressure would be 0.06 uPa. That is a strong signal for our receiver!

❖ Applications

To first check out the unit, turn it on with the volume control set low (this receiver has tremendous gain!) and tune the oscillator adjustment while jingling keys nearby. You should hear the ultrasonic overtones converted to audio. Now listen to your fingers and hands rubbing each other, a comb through your hair, water dripping, cellophane crumpling – you'll think of other sources as well! But let's get practical.

While bats hibernate during the winter months, expect them to start coming out in the early spring. Listen for them during feeding time – early and mid-evening. Expect to hear their "clicking" song as they come up to you – unexpectedly, checking you out!

As soon as the ground is warmer, expect to hear many types of bugs chatting endlessly – "eek, eek, eek," in the trees and in your lawn. And don't forget to check out the brush piles and ground holes for rodent communication between mom and the kids!

Credits

Thanks go to Philip Tate (UK), M1GWZ, Joe Eisenberg, NØNEB, and Bob Grove, W8JHD, for beta testing the Ultra-RX1. The receiver is available in kit form from the Xtal Set Society, **www.midnightscience.com/ultra-sonics.html** (or call 1-405-517-7347, or write The Xtal Set Society, PO Box 3636, Lawrence, KS 66046): $69.96 for the full kit, or $24.95 for the PCB and instructions only.

Ultra-Rx1 Ultrasonic Receiver Kit

Review by Bob Grove

The website at **www.midnightscience.com/ultra-kits.html** says, "You can DX the alien nations – insects, rodents, bats, and more – in the *35 to 45 kHz ultrasound band*, listening to their feeding, communication, and navigational signals." Since anything out of the ordinary has always been a fascination of mine, I decided to order the Ultra-RX1 kit from the Xtal Set Society.

❖ Let's assemble the kit

The parts are separated in groups which match the steps in the accompanying manual, and all are adequately marked for recognition. You should plan on several hours for the complete assembly and testing, including drilling and filing holes for the controls in the panel. An accurate drilling template is provided.

The manual is an informational, step-by-step set of instructions with excellent background information, technical details, and appropriate assembly order. The parts are of good quality, as is the professional layout and etching of the circuit board, which is well marked with parts placement legends.

There are three successive points in the assembly where you can verify operation up to that point, reassuring the kit builder that if the final instrument doesn't work right, it probably wasn't one of those steps!

For the tests, you will need at least a VOM (volt-Ohm-milliammeter) or DVM (digital voltmeter), and it wouldn't hurt to have an audio signal generator as well. An oscilloscope would disclose the injection oscillator operation and waveform, and you will need earphones or a speaker, too.

Upon completion, you will be eager to turn the Ultra-RX1 on to find out what you can hear. Don't switch it on with the earphones on or in your ears, however! The audio output is extremely high, and you will want to first adjust it while away from your ears for safe comfort.

❖ Switching it on

After completing the assembly, I carefully inspected all my solder joints under a magnifying glass, snipping suspiciously long leads and looking for solder shorts on the circuit traces. All was well. I switched the instrument on, and lo! I beheld sounds coming out of the earphones!

Turning the gain down comfortably and putting the earphones in place, I began tuning the frequency control through its near-40 kHz range. I had been told that jingling keys had extremely high overtones, so out of my pocket they came.

As I gently allowed them to collide in front of the ultrasonic transducer (that's techie talk for high frequency microphone!), the unmistakable clatter of church bells assailed my ears. Next I rubbed my fingers together in front of the mike and, to my amazement, the high frequency components of skin rubbing sounds like grating sandpaper! Rubbing my fingers through my hair disclosed the rough sound as well.

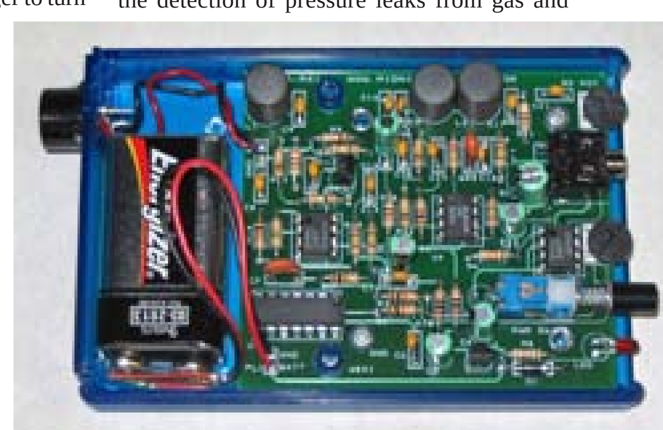
❖ Wide and varied uses

Ultrasonic detectors have vital application potential in biology, commerce, and industry. Biologists monitor the ultrasonic emissions of a variety of insects to relate the sounds with mating, eating and communications. The ability to directionally locate specific destructive insects can provide clues to the propagation of invasive colonies that threaten crops, ornamental plants, trees, and animals as well. The distinctive sounds from each species permit identification of those intruders.

Perhaps the most widely publicized uses for wildlife monitoring using ultrasound is the tracking of bats. Since they are only active at night, visual studies are nearly impossible. Infrared provides some good imaging, but their ultrasonic communications, used for echolocation, is a distinct advantage in chronicling the activities of these fascinating creatures.

Commercial industrial applications include the detection of pressure leaks from gas and steam lines, providing an immediate alert to the possibility of a pending explosion. The high pressure release passing over the edge of the break produces a loud sound above the range of human hearing that only the ultrasonic detector can hear to activate an alarm.

Intrusion alarms abound with a variety of technologies including radio, infrared, visible light, and sound. One of these techniques employs bathing a protected area with an ultrasound, setting the detector to monitor the stable level. Anyone entering the area offsets the level by reflecting or absorbing the ultrasonic waves, thus alerting the detector to the presence of an intruder.



❖...and other titillating experiments

Decades ago, a Sarasota, FL scientist performed a variety of studies employing a sonic detector with a simple dipole antenna which he immersed in rivers, lakes and ocean waters. He repeatedly detected sonic emissions over a wide band of frequencies from fish, enabling their identification from the analysis of the sounds as well as their direction from the position of the antenna.

Sadly, the scientist died before his data could be shared widely, but it is rumored that the U.S. Navy took note of his work and continued the project separately, under the cloak of secrecy, for tactical applications. His files still remain undisturbed in a relative's home.

And how about the sounds from our own earth? Seismic geologists have been monitoring earthquake sounds and their precursors for decades. Are they missing something? The vast majority of studies are done at sub-sonic frequencies – typically 1 Hz and below. Yet we know that the Piezo effect, so widely studied for frequency stabilizing oscillators and filters, is also present when pressures are imposed on rocks, especially quartz-bearing varieties. Could it be that the secret for earthquake prediction actually lies in the ultrasonic spectrum?

If you're tired of shortwave static and pager tones, give ultrasound a try! See the accompanying article by Phil Anderson on page 68 for contact and ordering information.