Crystal Radio Engineering
Headphones

by Kenneth A. Kuhn
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Introduction

Headphones are made using small electrical to acoustical transducers that are located very close to the human ear so that very little electrical power is required for hearing a signal. With sensitive (i.e. high efficiency) headphones it is possible to hear audio signals in the nanowatt range! A milliwatt is a huge amount of power and makes a very loud signal.

Headphone types

There are three basic types of headphones as described below

Magnetic These were the first headphones ever built and were popular for many years although modern headphones work better and have replaced them. Magnetic headphones are constructed by winding many turns of fine wire to form a coil around an iron core that includes a permanent magnet. A thin iron plate which makes the sound is held in place by the magnetic field. The center portion of the thin plate is pulled by the magnetism. As an audio (i.e. AC) current is passed through the coil the magnetic field increases or decreases in response. The variation in the magnetic field modulates the force of attraction of the iron plate which then moves slightly thus making a sound. Magnetic headphones generally have an impedance in the 2,000 to 20,000 ohm range. The impedance is not the DC resistance but is related to the inductance of the winding on the coil and the acoustical reaction of the iron plate. Some magnetic headphones are quite sensitive but others are only fair. Any old headphone set you find could vary considerably in impedance and sensitivity – you would have to make your own measurements with laboratory equipment to truly know what you have. For nostalgia there is an attraction to using magnetic headphones (if you can find them – they are old and rare now). However, modern speaker phones generally are more sensitive and work better.

Crystal These are based on the piezoelectric effect (piezo means force or pressure). A crystal physically expands or contracts in response to an electrical voltage applied across it. If the electrical voltage represents an audio signal then sound can be heard coming from the crystal. The process also works in reverse and the device is known as crystal microphone. Sound pressure causes the crystal to expand or contract which produces a voltage in proportion. Crystal earphones used to be very popular but are now rare as modern earphones work much better. Crystal earphones can be damaged by mechanical shock (such as dropping) and humidity. The sensitivity varies a lot – some are insensitive, others are fairly sensitive. Crystal earphones are high impedance (typically much greater than

50,000 ohms) devices and are ideal for use with crystal radios. DC voltages should not be applied so a coupling capacitor (typically in the 0.1 uF range) should be used to block the DC detected voltage from the rectifier diode. A resistor (often around 50,000 to 100,000 ohms) is placed across the output of the rectifier diode to ground to provide a required DC complete circuit.

Speaker These headphones are built using a tiny speaker located close to the ear. The interest in using these with modern battery powered equipment has led to the development of units that require only a very small electrical power (on the order of a milliwatt) to produce a loud sound. The typical impedance of these units ranges from around 30 to 150 ohms so some kind of transformer is always required to match into the much higher detector impedance (typically tens of thousands of ohms) of the crystal radio. If the left and right earpieces are connected in parallel then the impedance is halved. The impedance would be doubled if the units are connected in series. There is a slight issue with connecting the phones in series and that is that the phase is inverted from ear to ear – this really only matters for low audio frequencies. This would not be desirable from a high-fidelity standpoint but probably makes little, if any difference to most people particularly in a crystal radio setting as it is a thrill to hear anything at all.

Sensitivity

In modern society people are accustomed to high sound levels. People accustomed to this initially have difficulty in acclimating themselves to hear faint sounds. With practice and concentration, remarkably low sound levels can be heard. This is necessary to be able to use a crystal radio. Once you have adapted yourself to listen to weak signals the noisy world we live in will become very obvious.

It is very important to use headphones that are highly efficient. Audio quality is of no concern although just about all modern headphones have fine audio quality. A small amount of power produces a high volume in even inefficient headphones so few people care about efficiency and that data is rare. When you can find such data it is typically given in terms of dBa for one milliwatt with typical values ranging from the seventies (low efficiency) to over one hundred (high efficiency) dBa for one milliwatt. It does not make any sense to measure efficiency for this case in percent. What matters is how much acoustical power can be delivered to the ears for as little electrical power as possible – that is what we need for a crystal radio. In the case of crystal radios the amount of available audio power is incredibly small – perhaps microwatts or less so highly efficient headphones are a necessity.

We should review some facts about acoustical power and decibels. Decibels always represent a power ratio. We might derive the value from a voltage or current ratio but it is always power that matters. When we speak of a sound level of 80 dBa, then we are referring to an acoustical power density relative to the zero dBa reference level which has been established at 1 pW per square meter (note: some sources state 2 pW). Acoustical levels are very commonly measured in dBa but unfortunately, the ‘a’ subscript which refers to the particular acoustic 0 dB reference level is often dropped. There is no such thing as absolute dB as the language often sounds like. The following table provides some examples. The headphones referenced are rated for 90 dBa / mW. This does not mean 90 dBa per milliwatt but that a sound pressure level of 90 dBa is produced by one milliwatt of electrical power. The sound pressure level produced by ten milliwatts would be 100 dBa. It is hard to hear sound pressure levels less than about 30 dBa because other low level noises are in that order of magnitude and mask the sound. Table 1 indicates that with ordinary headphones one should be able to detect an audio signal in the 1 nW range. That would barely be distinguishable from background noise in the room. However, a one-hundred nW level should readily be heard in the headphones.

dBa	Power density	Headphones	Examples
0	1 pW/m2		accepted threshold of human hearing
10	10 pW/m2		
20	100 pW/m2		
30	1 nW/m2	1 nW	quiet room (background noise level)
40	10 nW/m2	10 nW	very quiet whisper conversation
50	100 nW/m2	100 nW	
60	1 uW/m2	1 uW	quiet conversation
70	10 uW/m2	10 uW	typical office and normal conversation
80	100 uW/m2	100 uW	moderately loud radio
90	1 mW/m2	1 mW	loud radio
100	10 mW/m2	10 mW	very loud radio; many complaints likely
110	100 mW/m2	100 mW	
120	1 W/m2	1 W	extremely loud dance club; threshold of pain

Table 1: Acoustical data (headphones are 90 dBa for 1 mW)