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THE ULTRASOUND SPECTRUM

Xtal Set Society

Sound waves with frequencies above those used by humans are called ultrasound. Sounds generated or heard by humans range from above zero to near 20 kHz. The useful range of ultrasound pressure waves is from 20 kHz to roughly 10 MHz. Medical applications, such as ultrasound imaging, are probably the most familiar to the general public. Many insects, rodents, bats, and fish make use of portions of the ultrasound spectrum for feeding, communication, and navigation. Some species use both audio and ultrasound. Except for structural and medical testing, ultrasound use is nil above about 160 kHz for biological use, due to the near total absorption of the wave over short distances through the air. Table 1 notes a brief listing.

Table 1: Ultrasound Users

Band	**Freq range** kHz	**Users**
audio	0-20	humans, insects, animals, fish, sonar
ultrasound	20-30	rodents
ultrasound	20-75	insects
ultrasound	20-160	bats, dolphins
ultrasound	100-2000	structures testing
ultrasound	1K-10K	medical applications
radio	30-up	low freq radio to mm-wave applications

Sound pressure levels (SPL) emitted across species, recorded at about a foot, are from about 70 to 110 dB. Signals emitted vary from simple sine waves to complex waveforms with bandwidths and center frequencies as high as 120 kHz. With frequency-divider and frequency shift (direction conversion) receivers, we hear most of this activity as a pattern of clicks.

SPL is defined as follows:

(1.1) $$L_P = 20\log(\frac{p_{signal}}{p_{ref}}) \text{ dB},$$

where P_{signal} is the pressure of the signal in Pa [n/sq-m] and P_{ref} is the reference sign at 20 μPa – the threshold of hearing. 1 Pa is equal to (perhaps the more familiar) 10^{-5} bar. Rearranging, 1 Pa is equal to 10 μbar.

At 40 kHz, absorption of the signal by the air is about 0.2 dB per foot; not too bad. Hence a very strong signal at 110 SPL would represent a pressure at the source of:

(1.2) $$p_{signal} = p_{ref}(10^{SPL/20}) = (20e-6)(10^{110/20}) = 6.3 \text{ Pa.}$$

Since the pressure of an acoustic point source is reduced by a factor of 1/r at a distance r, one can say that the signal is reduced 6 dB for each doubling in distance from the source reference point. Hence a 7 times doubling would result in a distance of 128 feet. The resulting signal would be 110 – 6*7 or -68 dB. This is still a strong enough signal to hear in a moderate gain direction conversion receive using a 40 kHz front end and 8-ohm headphones. Adding a parabolic dish to boost gain only adds range as noted below.

The speed of sound in air at 0 deg C is 330 meters/second, or 1,082 ft/sec. In general it is dependent upon the combination of gases making up the media and is a function of temperature, increasing about 0.2% per degree C above 0 deg C. The velocity of sound in air can be calculated from the following:

(1.3) $$v_P = \sqrt{\frac{\gamma_g p_A}{\rho_V}},$$

where γ_g is the ratio of the specific heats of the gases at constant pressure and constant volume, p_A is the ambient pressure, and ρ_V is the density of the gases. These values for air at 0 deg C are as follows : 1.4, 10^5 n/sq-m, and 1.29 kg/m^3. Thus the velocity of sound for air is:

(1.4) $$v_P = \sqrt{\frac{1.4*10^5}{1.29}} = 330 \text{ m/s.}$$

Many of the formulas you are likely familiar with for radio projects apply to acoustic projects. For example, the velocity of a wave in a medium is equal to the produce of its frequency and wavelength. Hence:

(1.5) $$f\lambda = v,$$

where f the frequency in Hz, λ is the wavelength in meters, and v is the velocity of propagation.

Using this equation, we've listed the wavelength of several ultrasound signals at different frequencies in Table 2. Note that the wavelength at the popular 40 kHz experimental frequency is just 0.05 feet or about one-third of an inch. Given this fact, it is clear that a one or two foot parabolic dish can be used effectively to boost weak signals in conjunction with a piezo transducer (PZT) receiver. So, you can think of ultrasound kind of like light rather than the usual dimensions for radio projects!

Table 2: Ultrasound Parameters

Band	**Freq**	**velocity**	**wavelength**	**wavelength**
	kHz	meters/sec	meters	feet
audio	1	330	0.3300	1.0827
ultrasound	20	330	0.0165	0.0541
ultrasound	40	330	0.0083	0.0271
ultrasound	120	330	0.0028	0.0090
ultrasound	1000	330	0.0003	0.0011
radio	7000	3.00E+08	42.8571	140.6071