# ULTRASONIC LISTENING DEVICE

# UltraScope

# User's Manual

Firmware Version 2.0

*"Technology to Make Listening Easier"*

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## USER'S MANUAL

## Firmware Version 2.0

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## 1.0 BACKGROUND

Ultrasonic vibrations are above the range of human hearing. Ultrasound is typically considered to be all acoustic energy above 20,000 Hz. Although humans cannot hear such high frequencies, a number of other creatures, including insects, dogs, and whales, can. Ultrasound is also exploited in various electronic products, including sonar, medical imaging, high-tech cleaning systems, and industrial materials testing equipment.

Ultrasound can also be used to transmit signals through the air, in a manner very similar to radio or infrared transmissions. Signals containing audio, data, or other intelligence can be modulated onto ultrasonic acoustical carriers, amplified, and transmitted using specialized high-frequency transducers. If the transmitted acoustical signal is sufficiently strong, it can travel outside the building, where it can be recovered with the proper receiving equipment. At the receiver, the recovered signal can be demodulated and the audio or intelligence revealed.

Note that ultrasound produces no electromagnetic energy that would be detectable using an RF “sweep” receiver; the vibrations are purely mechanical. Since ultrasound is completely inaudible to the human ear, the only way to detect ultrasound is thorough the use of electronic equipment.

The traditional approach for sniffing out transmitters of this type is to connect an ultrasonic microphone to a general purpose spectrum analyzer and look for line spectra in the ultrasonic region. The difficulties with this approach are twofold: first, though the spectrum analyzer can determine if an ultrasonic signal is present, it cannot determine whether it is a benign signal, such as that produced by a motion sensor, or a malicious one that is being used as a covert communications path. Second, the equipment is generally bulky and AC-powered, which is difficult to manage and transport from room to room as needed for a thorough sweep.

To address these difficulties, DAC has developed the UltraScope product. UltraScope is a handheld, battery-powered, ultrasonic acoustical analyzer which incorporates an ultrasonic mic and precise FFT spectrum analyzer, along with a unique feature: the ability to select a 10 kHz region of signal to demodulate to the audible band for listening. This is a dramatic improvement over traditional technology, because it allows the user to listen to the ultrasonic signal in question and determine its nature or origin.

Other features of the UltraScope include a Line Out connector (to allow the user to record any signals of interest), a large, backlit LCD display for viewing the frequency spectrum and setting operating parameters, a large user-friendly keypad with rotary controls, and a NiMH rechargeable battery pack with charger.

## 1.1 Dual and Single Side Bands

A signal modulated onto an ultrasonic carrier will most likely take on one of two main forms. These forms are referred to as Single Side Band (SSB) and Dual Side Band (DSB) amplitude modulation. To explain these two forms of modulation, some background in spectrum analysis is needed.

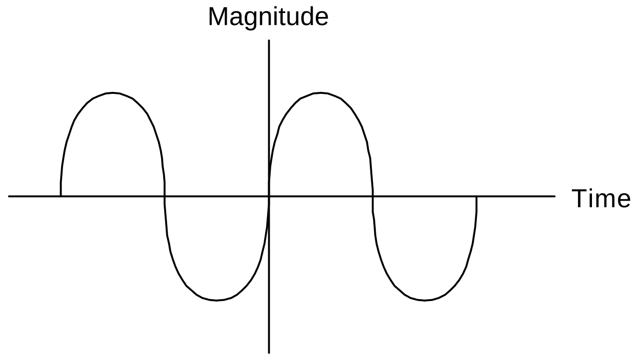


**Figure 1: Simple Sine Wave**

Figure 1 shows a simple sine wave. In the frequency domain (spectrum) this sine wave is represented by two spikes about the zero axis representing the energy concentrated at the frequency of the sine wave. A 1 KHz sine wave would be represented in the frequency domain by a single spike at 1 KHz above and below the baseband (0 Hz) axis, as shown in Figure 2. A more complex audio signal would have energy at many frequencies.  An example audio spectrum is shown in Figure 3.

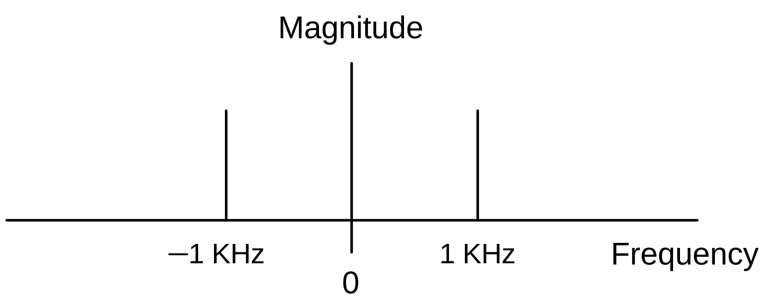


**Figure 2: 1 KHz Sine Wave Representation in the Frequency Domain**

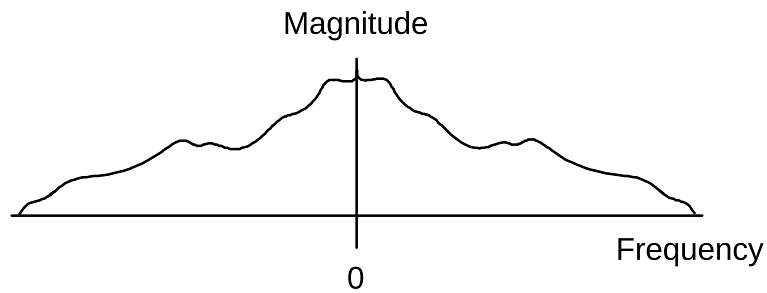


**Figure 3: Example Audio Spectrum**

An ultrasonic carrier looks very similar to the 1 KHz Sine Wave in the frequency domain, except it will be at a much higher carrier frequency ($f_c$), generally one well in excess of 20000 Hz so that it is completely inaudible to humans.

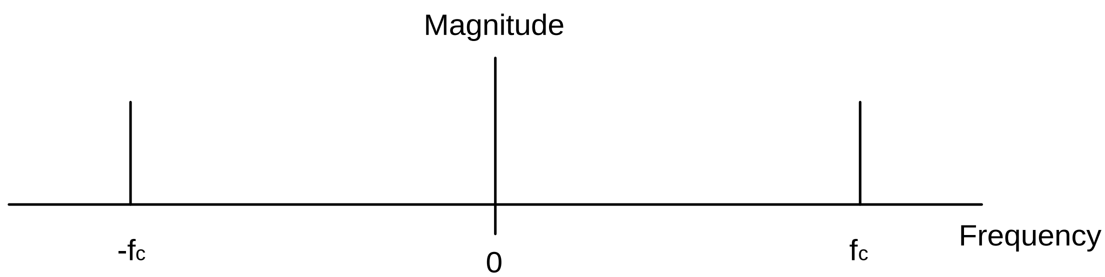


**Figure 4: Ultrasonic Carrier Frequency Spectrum**

Modulated audio on an ultrasonic carrier will look similar to Figure 5. This type of modulated audio is DSB, as both the positive and negative frequency information is centered on the carrier frequency ($f_c$).

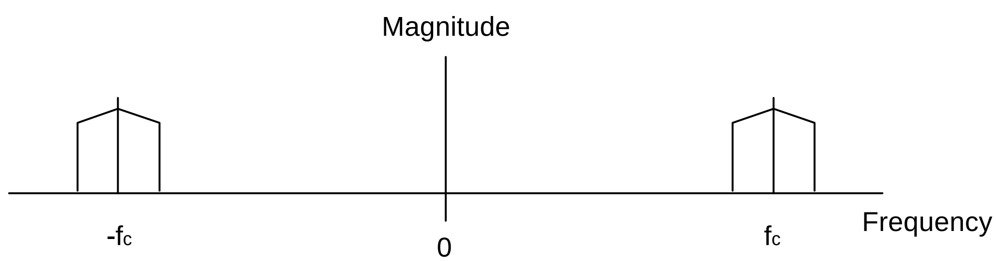


**Figure 5: Dual Side-Band Modulated Audio**

Note that the complete signal spectrum is symmetric about 0 Hz. The UltraScope takes advantage of this symmetry and displays only the positive frequency spectrum on the LCD display, since the negative frequency information is identical and contributes nothing extra to the analysis. UltraScope's display plots the signal spectrum over a range of 0 Hz to 220 kHz, which is approximately 10 times the range of human hearing.

Note also that the DSB signal that is centered about $f_c$ is also symmetrical; in effect, an extra copy of the desired audio signal is being transmitted. This duplication of information can be eliminated using SSB modulation, thus improving the spectral and power efficiency of the transmission system. SSB modulation is represented in the following figures; Figure 6 shows upper side band (USB) modulated audio, and Figure 7 shows lower side band (LSB) modulated audio.

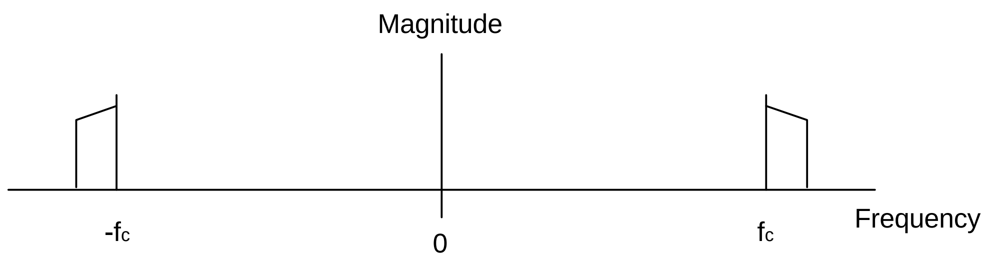


**Figure 6: Upper Single Side-Band Modulated Audio**

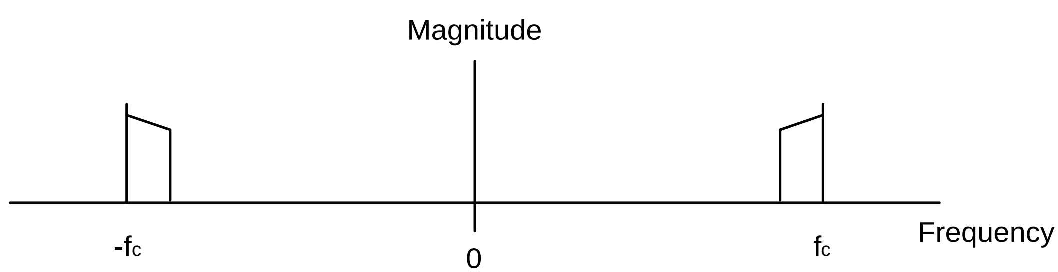


**Figure 7: Lower Side Band Modulated Audio**

Note that USB-modulated audio (Figure 6) is a clear signal, and simply needs to be frequency shifted to baseband (0 Hz) for listening. However, LSB-modulated audio is always spectrally inverted, meaning that low and high frequency signals are transposed. For intelligible listening, then, LSB-modulated audio must be frequency inverted once it is frequency shifted to baseband.

UltraScope supports all three types of amplitude modulation (DSB, USB, and LSB). These modes can be selected via the UTILITY MENU.

## 1.2 Ultrasonic Acoustical Intensity

Practical ultrasound communication systems require a high-intensity acoustical carrier, particularly if the intent is to convey an audio signal from the inside of a building to the outside. This carrier, though completely inaudible, can be in excess of 110dB SPL, or roughly the same intensity as a burglar alarm when it is activated. This means that any effective detection equipment needs to have sufficient dynamic range that it can accept the extremely intense acoustical signal that is present within the building, as well as the relatively weak (40dB SPL or less) residual acoustical signal that may be present outside the building. The Ultrascope system offers approximately 100dB of dynamic range, and is capable of distinguishing acoustical energy in the range of 20dB SPL to 120dB SPL.

High-intensity sources of ultrasonic acoustical energy include such items as motion sensors, insect repellers, and audio countermeasures devices that are intended to defeat microphones. Computer equipment, as well as rotating machinery, can also emit ultrasonic energy. Such signals are highly directional in nature, which means that detection devices need to be pointed directly at such a device, perhaps even within a narrow angular “window”, in order to acquire the signal. Hence, a handheld, portable device such as UltraScope is highly desirable, as it is easily moved around and pointed in different directions.

To support operation in high-intensity ultrasound environments, UltraScope can accept acoustic energy as loud as 124dB SPL without clipping. Also, to allow additional gain to be applied to just the ultrasound in high audible noise environments, UltraScope includes a 20kHz highpass filter, which can be switched in and out of the circuit, ahead of the preamplifier. This allows the user to apply up to 30dB of additional gain to the ultrasound, via the UTILITY MENU, without introducing clipping distortion.

## 2.0 ULTRASCOPE OPERATION

### 2.1 Top Panel Functions

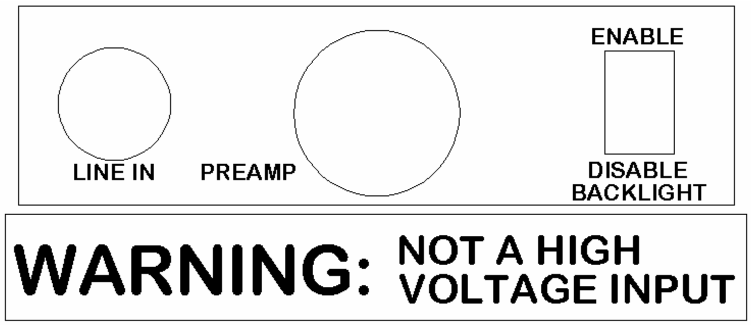


**Figure 8: UltraScope Top Panel**

The top panel allows connection of the inputs to the UltraScope as well as control of the backlight for the LCD. The **Line In** connector allows attachment of an 3.5 mm stereo plug to input an alternate signal (other than the **Preamp** signal) to be analyzed by the UltraScope. If a signal source is connected to the **Line In** connector, this input will be used instead of the **Preamp** connector signal. The **Line In** expects a “line level” signal of approximately of 800mV$_{rms}$ or less

The **Line In** connector allows the UltraScope to be used with other signal detection and countermeasures products like Digital Audio Corporation’s ProbeAMP. By routing the line output from the ProbeAMP into the line input of the UltraScope, carrier-current devices can be detected on power lines and telephone lines, and demodulated for listening. If a stereo 3.5mm plug is used to connect a signal to the **Line In** connector, note that only the left channel signal is actually accepted; the right channel signal will be ignored by the unit.

The **Preamp** connector allows connection of the included ultrasonic microphone and/or extension cable. The connector is an industry standard Lemo microphone connector, which provides an extremely reliable connection and is easily mated and unmated. The microphone simply “snaps” into place as if it were an antenna.

The **Enable/Disable Backlight** switch is used to allow or disallow illumination of the built-in backlight on the front panel LCD. To allow the backlight to be turned on and off via software control, put the switch in the **Enable** position. To ensure that the backlight remains off at all times, put the switch in the **Disable** position.

## 2.2 Bottom Panel Functions

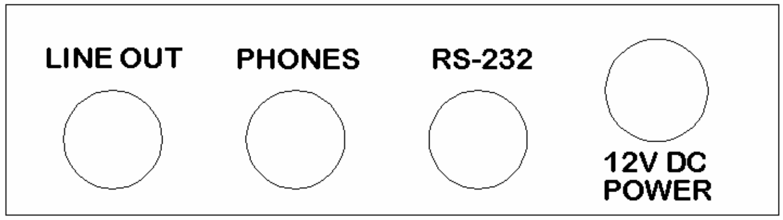


**Figure 9: UltraScope Bottom Panel**

The bottom panel allows for connection of the output audio signals, RS-232 communications, and 12V DC power. The **12V DC Power** connector is for powering the UltraScope unit with the included power supply unit. The external power supply can both power the UltraScope unit and charge the rechargeable NiMH battery packs. The batteries will continue to be charged when the unit is powered off.

The **Line Out** connector attaches to any 3.5mm mono or stereo plug. For stereo plugs, the signal will be present only on the left channel. The output signal is a line level (approximately $1V_{rms}$ maximum level) signal containing the demodulated audio of the selected frequency (selecting the frequency is discussed in the Front Panel Functions section).

The **Phones** connector attaches to any standard 3.5mm stereo headphone connector. To listen to the demodulated audio, simply attach a standard pair of stereo headphones to this connector and adjust the loudness using the **Volume** connector on the front panel.

The **RS-232** connector is for attaching the included RS-232 cable that has a standard 9 pin D-shell connector on one end and a 3.5 mm stereo plug on the other. This connector allows the connection of UltraScope to a PC for advanced data logging applications (see Section 4.0 DATA LOGGING for further details on this feature).

## 2.3 Front Panel Functions

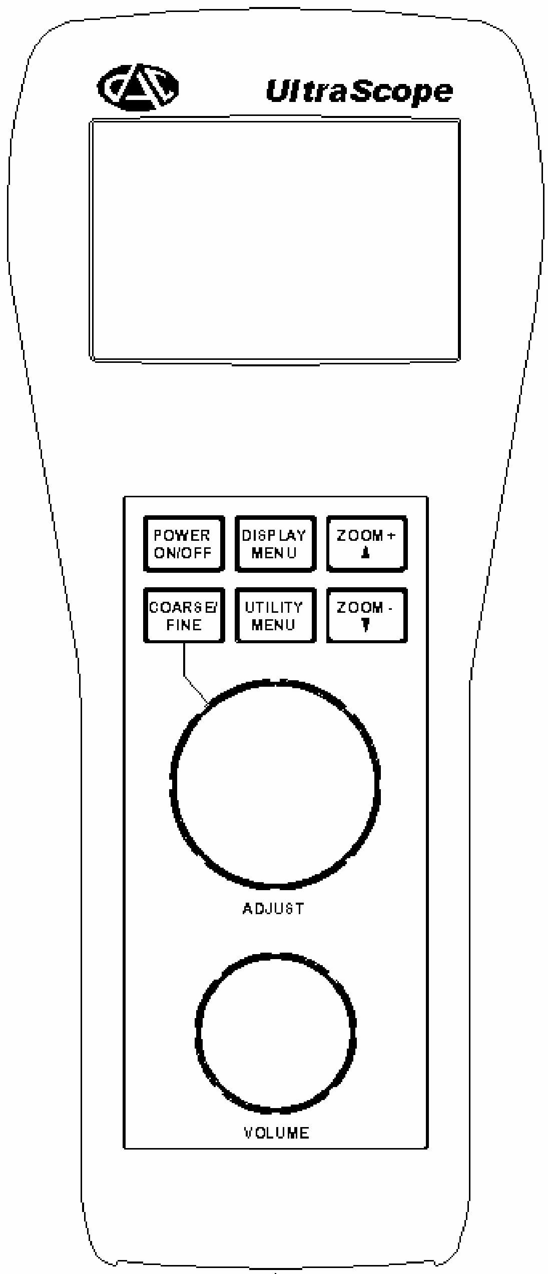


**Figure 10: UltraScope Front Panel**

The front panel provides control for each of the UltraScope's features. The **Power On/Off** button is used to turn the unit on or off. To turn on the unit, depress the **Power On/Off** button. To turn off the unit, depress the **Power On/Off** button again.

When the unit is initially powered on, the first screen to appear momentarily on the LCD will be the “splash” screen (Figure 11) displaying the firmware version number (currently Version 2.0). An introductory audio clip will also be played on the headphone and line outputs. The *firmware* is the software that runs internally on the UltraScope. After the “splash” screen has disappeared the Spectrum Viewing Screen will appear.


**Figure 11: UltraScope Splash Screen**

### 2.3.1 <u>Spectrum Viewing Screen</u>

The Spectrum Viewing Screen, shown in Figure 12, displays the current spectrum of the input signal. The current range of frequencies graphed is displayed in the upper left corner of the LCD display. The frequency and instantaneous level of the band that is currently being demodulated (and output via the headphones and line output) is shown in the upper middle portion of the display; the frequency and level are alternatively displayed at 2 second intervals. The overall dB level of the input signal is displayed in the upper right corner of the display, as well as graphically by the thick bar on the far right of the display. If the input signal becomes too strong and an overload condition occurs, **INPUT** will appear at the top of the LCD display.

The spectrum of the input signal is plotted using the remainder of the display. This spectrum is the frequency domain representation of the input signal, and on a band-by-band basis shows the peak energy level of frequencies from 0 to 220,000 Hz (at its lowest “zoom” level). Using this display, any ultrasonic carrier frequency will show up as a spike of higher energy within a particular band.

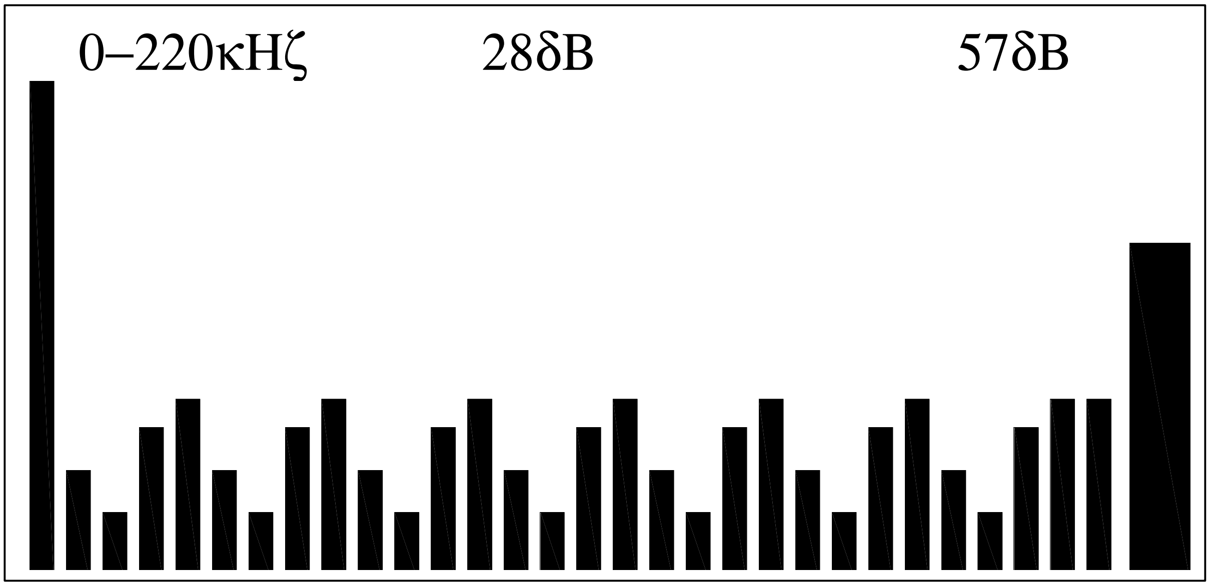


**Figure 12: UltraScope Spectrum Display**

Use the **Adjust** knob to select which frequency is demodulated and output to the headphones and line output. The “cursor”, which is a vertical bar the full height of the display area, can be moved using the **Adjust** knob, and will graphically display the currently selected frequency and peak level. To increase the currently selected frequency, turn the **Adjust** knob in the clockwise direction. To decrease the selected frequency, turn the knob in the counter-clockwise direction.

To change the step size by which the selected frequency is changed by the **Adjust** knob, use the **Coarse/Fine** button. Each time the **Coarse/Fine** button is depressed, the step size will change and the new step size will be displayed on the LCD display. Supported step sizes vary from 4 Hz (finest adjustment) to 10000 Hz (most coarse adjustment).

The **Zoom +** and **Zoom –** buttons expand the viewed spectrum around the current cursor region. This new range of frequencies being viewed is shown in the upper left corner of the LCD. To “zoom in” (increase the frequency resolution around the current cursor position) depress the **Zoom +** button. To “zoom out” (decrease the frequency resolution) depress the **Zoom –** button. When initially powered on, the UltraScope defaults to the lowest zoom level (all frequencies displayed).

The second, smaller **Volume** knob is used to change the listening level of the signal routed to the headphone jack. To increase the listening level, turn the knob clockwise. To decrease the listening level, turn the knob counter-clockwise. The new listening level (as a percentage of maximum) will be displayed momentarily on the LCD display each time the **Volume** knob is turned.

### 2.3.2 <u>Display Menu</u>

The **Display Menu** button is used to access the menu which allows the user to alter how information is displayed on the graphical LCD. Depressing this button will cause the Display Menu to appear as shown in Figure 13. From this menu, the user can adjust the LCD contrast, and the backlight mode.

```
BACK LIGHT    AUTO
CONTRAST   100
```

**Figure 13: UltraScope Display Menu**

To select the Display Menu options, use the **Zoom +** and **Zoom –** buttons. Once the desired menu option is selected, use the **Adjust** knob to change the value.

The **Backlight** mode option determines how the backlight is applied when the top panel **Backlight** switch is in the **Enable** position. In the "Auto" mode, the backlight will stay illuminated for 30 seconds after any knob or button activity. To manually control the backlight, simply set to "On" or "Off" as needed. To ensure that the backlight remains off at all times, simply set the **Backlight** hardware switch on the rear panel to the **Disable** position.

The **Contrast** option allows adjustment of the LCD display's contrast. Increasing the contrast percentage will darken the LCD display while decreasing the percentage will lighten the display. Adjust the contrast as needed for different lighting conditions.

Depressing the **Display Menu** button again will return the user to Spectrum Viewing Screen. All **Display Menu** values will be retained in the UltraScope's flash memory upon power down.

### 2.3.3 Utility Menu

The **Utility Menu** button is used to access a menu that allows the user to alter settings that affect the global operation of the device. Depressing this button will cause the Utility Menu to appear as shown in Figure 14. From this menu the user can enable or disable the Low Cut filter, adjust the Microphone Gain, select the type of demodulation to be applied to the selected 10kHz region, or select the number of averages to apply to the FFT analysis.

```
MIC GAIN   30
LOW CUT   OFF
DEMODULATION    DSB
AVERAGING     0
```

**Figure 14: UltraScope Utility Menu**

To select the Utility Menu options, use the **Zoom +** to and **Zoom –** buttons. Once the desired menu option is selected, use the **Adjust** knob to alter the value.

The **Mic Gain** setting adjusts the preamplifier gain for the mic input; it has no effect on the Line Input. Selectable values include **0, 10, 20,** and **30** dB. Reducing the gain allows greater sound pressure levels to be accepted without clipping, while increasing the gain allows lower sound pressure levels to be detected. The input level options are listed below:

| Applied Mic Gain | Maximum Input SPL |
|---|---|
| 0 dB | 124 dB |
| 10 dB | 114 dB |
| 20 dB | 104 dB |
| 30 dB | 94 dB |

**Table 1 Mic Gain vs. Maximum Input SPL**

The **Low Cut** setting selects whether the built-in 20kHz highpass filter is **On** or **Off**. If on, the filter is applied to the input signal and attenuates all human-audible signals that are input from the mic, **before** preamplification as specified by the **Mic Gain** setting. This feature allows the gain to be applied to ultrasonic frequencies only, thus avoiding clipping distortion in loud audible noise environments. Note that like the **Mic Gain** setting, the **Low Cut** setting has no effect on signals applied to the Line Input.

**Demodulation** selects whether double side band (DSB), upper side band (USB), or lower side band (LSB) amplitude demodulation is applied to the selected 10kHz frequency band. Normally, the DSB setting is recommended, as better low-frequency response can be obtained on the demodulated audio output. In cases where single sideband modulation is suspected and/or there are adjacent noise signals near the carrier frequency, either LSB or USB should be used, with the understanding that the demodulated audio will sound somewhat “tinny” due to low-frequency rolloff below approximately 2.5kHz.

**Averaging** selects the amount of smoothing to apply to the FFT spectral data as it is being displayed. Range of values is **0-10**, in increments of 1, with **0** indicating no smoothing applied and **10** indicating that the average of the last 10 FFT frames is being displayed. Note that the averager is peak sensitive; in the case where 10 averages are applies, if any of the last 10 FFT frames has a level that is higher than the current average value, the average value gets set to that peak, so that it is not missed by the user.

Depressing the **Utility Menu** button again will return the user to the Spectrum Viewing Screen. All **Utility Menu** values will be retained in the UltraScope’s flash memory upon power down.

## 2.4 Powering the Unit

The unit can powered from either a rechargeable NiMH (nickel metal-hydride) battery pack (one included), by the 12 VDC AC adaptor (included), or by a 4-cell AA alkaline battery pack (optional accessory). Contact DAC for replacement battery packs, AC adaptors, or other optional accessories.

While the unit is being externally powered, the NiMH battery pack, if installed, will also be recharged. Four standard AA alkaline batteries can be used in the optional accessory battery pack.

Whenever the unit is powered by batteries and the battery voltage level becomes too low, the **LOW** [battery] indicator will be shown at the upper left corner of the LCD display.

## 3.0 ULTRASCOPE CALIBRATION

UltraScope is factory calibrated, and should remain accurate as long as the supplied ACO Pacific ultrasonic mic is utilized with the unit. If other mics are to be used, or if the accuracy of the level measurements ever becomes suspect, please return the unit, along with the microphone, to DAC for proper calibration.

## 4.0 DATA LOGGING

UltraScope's RS-232 interface allows computer logging of the FFT spectral data for subsequent analysis. To utilize this feature, simply connect the supplied DB-9 to 3.5mm adaptor cable to the RS-232 jack, and connect the DB-9 end to the serial port of your PC. Your logging software will need to be configured to operate as follows:

| | |
|---|---|
| Baud Rate: | 9600 |
| Number of bits: | 8 |
| Parity: | None |
| Stop Bits: | 1 |
| Handshaking: | None |

To receive FFT data on the PC, the logging software will need to send a single character to the UltraScope to trigger the data transmission. The data will be configured as follows:

***Microphone {or "LineIn"}***
***Gain***
***30 {preamplifier gain setting in dB}***
***Each Bin is 1220.7Hz***
***12345 {first of 256 FFT points, each one a 5-digit decimal integer}***
***23456***

- 
- 
- 

***32100 {256th FFT point}***

The first FFT point output represents the DC (0 Hz) band, while subsequent points represent subsequent frequency bands at intervals of 1220.7 Hz (e.g., 0Hz, 1220.7Hz, 2441.4Hz, ….., 312.5kHz). Note that UltraScope only has 220kHz usable signal bandwidth available, due to limitations of the analog anti-alias filters. Therefore, only the first 180 values are meaningful, the rest fall into the analog filter transition band.

To convert each 5-digit FFT value to dB SPL (sound pressure level), use the following formula:

dB(SPL) = (integer value) * G / 30500,

where G is dependent upon the preamplifier gain setting that is output as part of the sequence. G is also dependent upon whether the Microphone or Line Input is used, which can also be determined from the sequence. Select G according to the following table:

| Input | Gain = 0dB | Gain = 10dB | Gain = 20dB | Gain = 30dB |
|---|---|---|---|---|
| Microphone | 124 | 114 | 104 | 94 |
| Line Input | 100 | 100 | 100 | 100 |

**Table 2: "G" Value Lookup Table**

Note that the value of G does not change as a function of preamplifier gain when the Line Input is used, since the preamplifier gain is not applied to the Line Input. Also, the dB SPL calculation will most likely NOT be accurate when the Line Input is used, since the actual sensitivity of the connected device cannot be known. However, when the supplied ACO Pacific mic is used, the calculated dB SPL will be fairly accurate, generally within +/-2dB.

## 5.0 SPECIFICATIONS

| | |
|---|---|
| Input Connections: | Industry standard Lemo™ connector on Preamp Input<br>Standard 3.5 mm stereo connector on Line Input. Accepts either mono or stereo plugs |
| Line Input: | 800mV$_{rms}$, maximum input level<br>>100 kilohm input impedance<br>Only left channel connected when stereo plug used |
| Preamp Input: | Typical 3mV or less input level from supplied ACO Pacific ultrasonic microphone<br>15 kilohm input impedance<br>Supplies required 28VDC and 200VDC polarization voltages required by ACO Pacific mic |
| Input Gain Stage: | +24dB to +54dB, adjustable in 10dB increments<br>Applied to preamplifier input only |
| Input Highpass Filter: | 20 kHz cutoff frequency<br>Can be switched in and out as desired<br>Applied to preamplifier input only |
| Equivalent Input Noise: | Less than 1000 nVrms |
| Bandwidth: | 100 – 220,000 Hz |
| Frequency Selectability: | Any 10kHz region from 0 to 220kHz can be selected for listening. Minimum step size of 4Hz allows precision tuning. Either DSB, USB, or LSB demodulation can be selected |
| Line Output: | 1V$_{rms}$, nominal output level<br>Capable of driving 1 kilohm or higher impedance load<br>Standard 3.5 mm stereo connector, accepts mono or stereo plugs<br>Signal on left channel only when stereo plug is used |
| Phones Output: | 3.5 mm stereo phone jack, drives standard 8 Ohms stereo headphones. Monaural signal applied to both ears |
| Power: | 9-18 VDC external DC power input,<br>2.1 mm barrel plug, positive tip.<br>NiMH battery pack,<br>Four AA standard alkaline batteries (requires optional accessory pack) |
| Packaging: | Rugged ABS plastic housing, approximately 1 lb.<br>2.1” H x 9.0“ L x 3.7” W<br>Optional Pelican carrying case and accessory kit |
| RS-232: | 9600 baud rate, 1 stop bit, no parity bits<br>Outputs measurements in ASCII format in response to any character input (see Section 4.0)<br>Adaptor cable for connection to standard PC COM port supplied |