



Aliph

**GENERAL ELECTROMAGNETIC MOVEMENT SENSOR
[GEMS]**

USER'S MANUAL

Revision B Version 2

1 **TABLE OF CONTENTS**

1	TABLE OF CONTENTS	2
2	INTRODUCTION	4
2.1	GENERAL DESCRIPTION	5
2.2	SENSOR UNIT	5
2.3	CHARGER.....	8
2.4	ANTENNAE.....	9
2.5	PARTS LIST	10
2.6	GETTING STARTED	11
3	SPECIFICATIONS	12
4	PERFORMANCE MEASUREMENT	13
4.1	TEST SETUP.....	13
4.2	PERFORMANCE TESTS	13
4.2.1	<i>Highpass Filter Distortion Compensation.....</i>	<i>15</i>
4.2.2	<i>Measurement sheet</i>	<i>16</i>
4.3	CALCULATING THE SNR AND THE MINIMUM DETECTABLE AMPLITUDE.....	17
5	ACQUIRING GEMS DATA	19
5.1	NATIONAL INSTRUMENTS' LABVIEW VIs	19
5.1.1	<i>Installation of the software.....</i>	<i>19</i>
5.1.2	<i>Main and configuration screens</i>	<i>20</i>
5.1.3	<i>Real time data display</i>	<i>22</i>
5.1.4	<i>4 channel recording.....</i>	<i>23</i>
5.2	RECORDING DATA FROM THE GLOTTAL AREA	24
5.3	RECORDING DATA FROM THE CHEEK AREA	26
5.4	OTHER LOCATIONS	28
6	FILTER DISTORTIONS DUE TO HP FILTER	29
7	SAFETY & COMPLIANCE	31

8	FAQ.....	32
9	TROUBLESHOOTING	35
9.1	GEMS SIGNAL	35
9.2	LABVIEW PROGRAMS.....	36
9.3	TECHNICAL SUPPORT	36
10	CONTACT INFORMATION.....	38

2 INTRODUCTION

Thank you for choosing an Aliph sensor. We hope this sensor will serve you well for many years and become the basis for many discoveries.

The General Electromagnetic Movement Sensor (GEMS) was developed at Aliph for the purpose of detecting vibratory motion of human tissue. The present sensor is the third iteration of a design first constructed in 1999. It was designed to be mass-producible and easily constructed using standard parts.

The sensor is an extremely sensitive phase-modulated quadrature motion detector that accurately determines the motion vs. time of one or more moving objects in its field of view. If several moving objects are present and detectable, the GEMS signal will represent a combination of their motions. Thus the output of the GEMS is a one-dimensional voltage that represents a combination of three-dimensional velocities. Therefore, care must be taken when interpreting the GEMS signal as it is not always clear what object is responsible for the observed signal.

This manual is intended to inform a scientifically minded user how to use the GEMS to record vibratory signals associated with human speech. It is not necessary for the user to have a background in electromagnetics (EM) or radiofrequency (RF) to use the sensor effectively. Although the sensor can be used to detect any type of motion anywhere on the body, we will restrict ourselves to motion caused by voiced speech in the sub-glottal and cheek/jaw areas. As we will see, the subglottal region can yield information on the excitation function of human speech and the cheek/jaw area may contain phonetic information about the produced speech. The user is encouraged to capture signals from other parts of the body, but we will restrict this manual to the two above as they return the most reliable and repeatable signals.

Any comments on the sensor or this manual are welcome and contact information is included in chapter 10. Additional information on the sensor and its interaction with the

human body can be found in Gregory C. Burnett's doctoral thesis, available at UMI (<http://www.umi.com/hp/Products/Dissertations.html>), thesis # 9925723, or online at www.aliph.com/Burnett_thesis.

2.1 General Description

The GEMS consists of three major subsections – the sensor, the antenna, and the battery and its charger. The sensor body is installed in an empty battery charger shell, and the rechargeable battery simply slides into a receptacle at the bottom of the sensor body. On the opposite side is a belt clip that can be used to attach the sensor to a belt or similar object. The antenna plugs into the top of the sensor body with the supplied reverse polarity SMA cable. Due to FCC regulations, only the antennae supplied by Aliph can be used with the sensor. If you wish to use other types of antennas, you should contact Aliph. Aliph is not responsible for any liabilities relating to user safety or FCC compliance that may arise from connecting antennas or other components not supplied and/or certified by Aliph.

2.2 Sensor Unit

The sensor body is shown in Figures 2.1, 2.2, and 2.3 and the charger in Figure 2.4. On the bottom front of the sensor body, the power switch is flanked by two indicator lights. The red power indicator is lit when power is applied, while the battery condition light varies:

Indicator light:	Steady Green	Blinking Green	Steady Orange
Battery state:	Battery Good	Battery Charging	Battery Low

Underneath the lights and power switch are the filter selector switches, illustrated in Figure 2.2. The switches can be manipulated to select both the highpass 3-dB point (20 or 100 Hz) and the lowpass 3-dB point (500, 2000, or 8000 Hz). The use of the filters

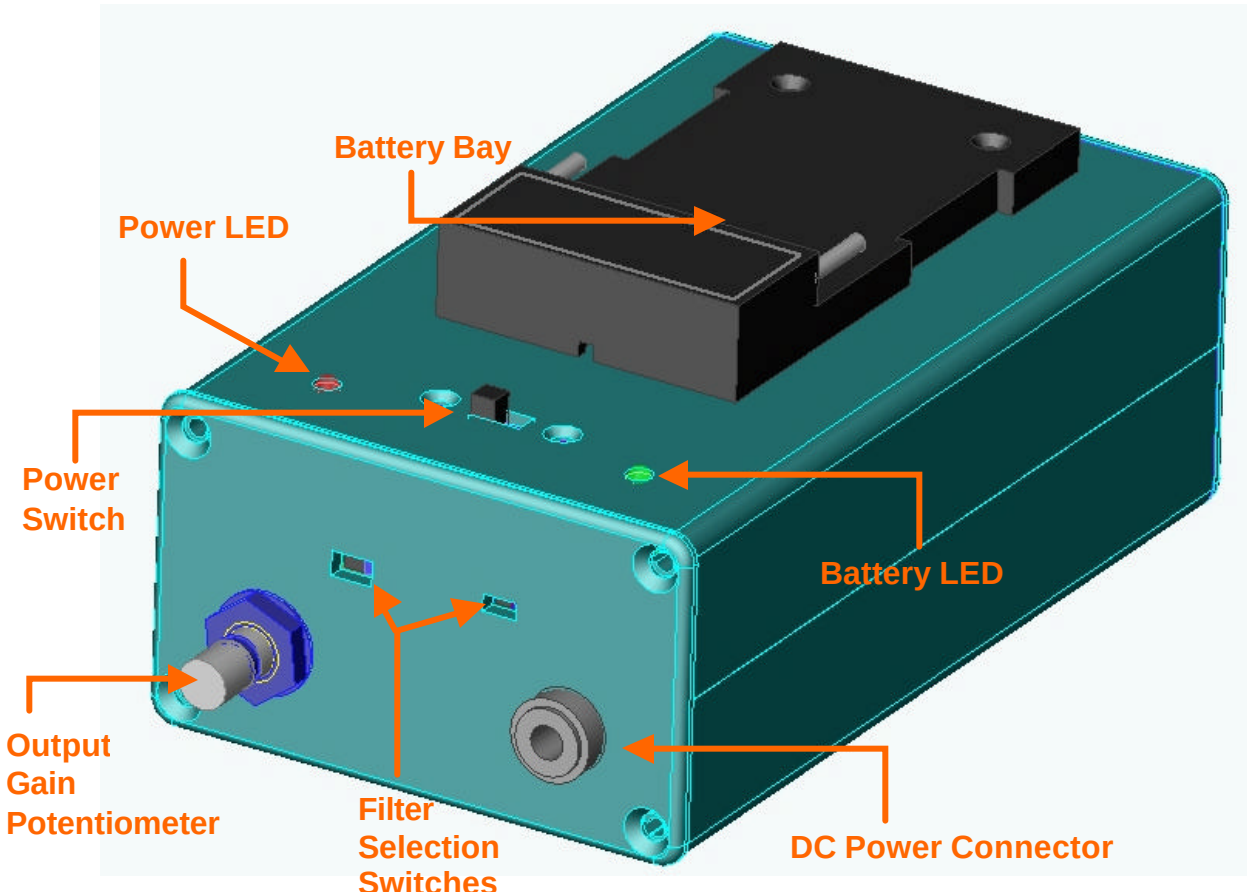


Figure 2.1. Isometric view of the bottom of the sensor body

can introduce phase distortion (see Chapter 6), so it is recommended that if low distortion is desired to use a highpass frequency of 20 Hz and a lowpass of 8000 Hz.

On the sides near the power switch there is a 3.5 mm power connector that connects to the charger, and a potentiometer that varies the gain by approximately 20 dB. The power connector is used in concert with the charger to charge the battery on the sensor, which can be used while the battery is charging. The charger itself can be used to charge an extra battery. **HOWEVER, UNDER NO CIRCUMSTANCES SHOULD A BATTERY BE USED ON THE CHARGER AND THE SENSOR AT THE SAME TIME WHEN BOTH UNITS ARE CONNECTED. IN ADDITION, THERE MUST BE A BATTERY ON THE CHARGER OR ON THE SENSOR WHEN THE**

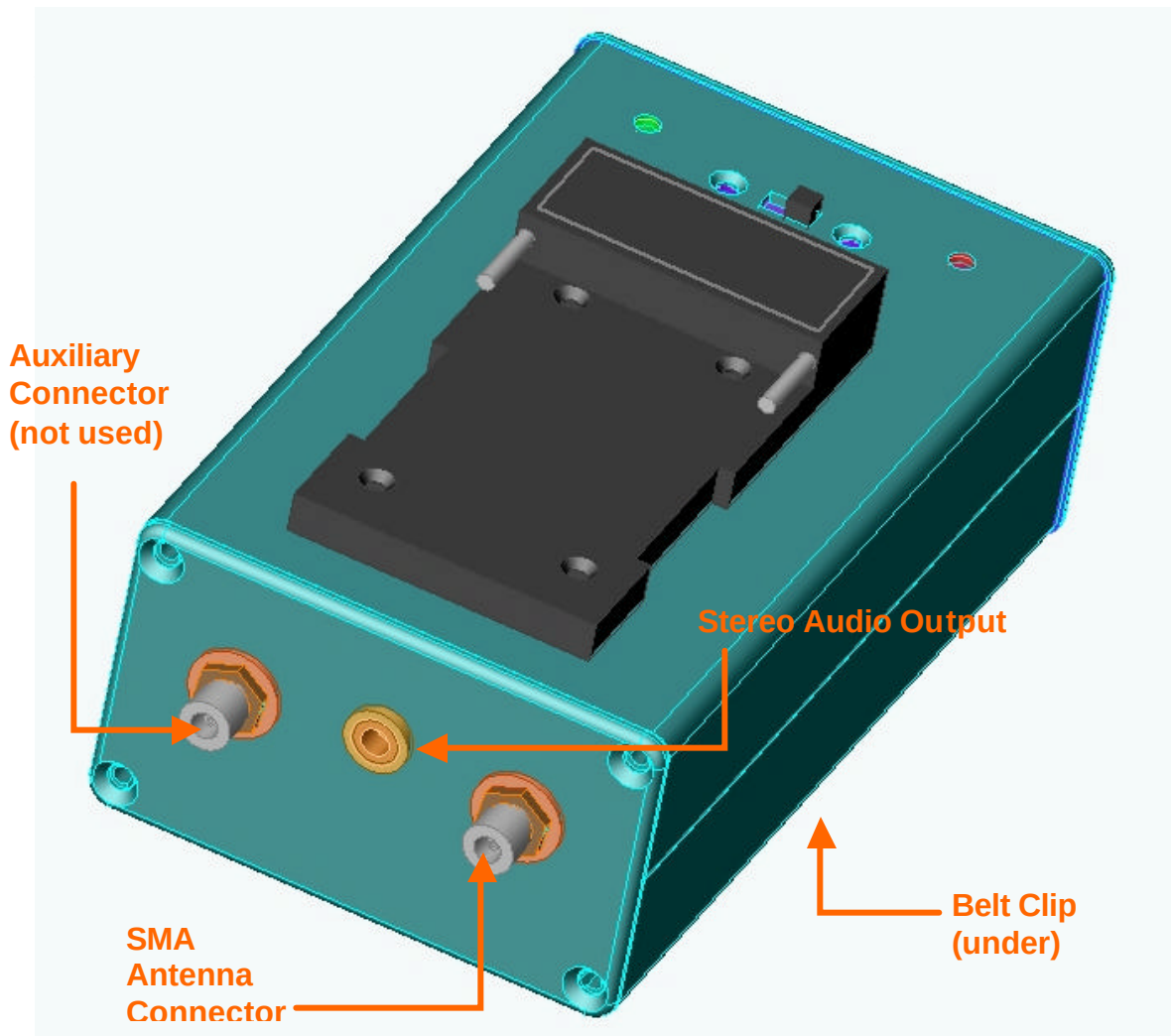


Figure 2.2. Isometric view of the top of the sensor body.

The sensor has two antenna connectors to allow a future bi-static (different transmit and receive antennae) mode. However, this is disabled in the current version and only a single antenna connection is used (mono-static configuration). Due to FCC requirements, it is not possible to use antennae not supplied or approved by Aliph. Only the supplied antennae are to be used with the supplied reverse-polarity cables. If there is a specific antenna that you wish to use with the Aliph sensor, please contact us.

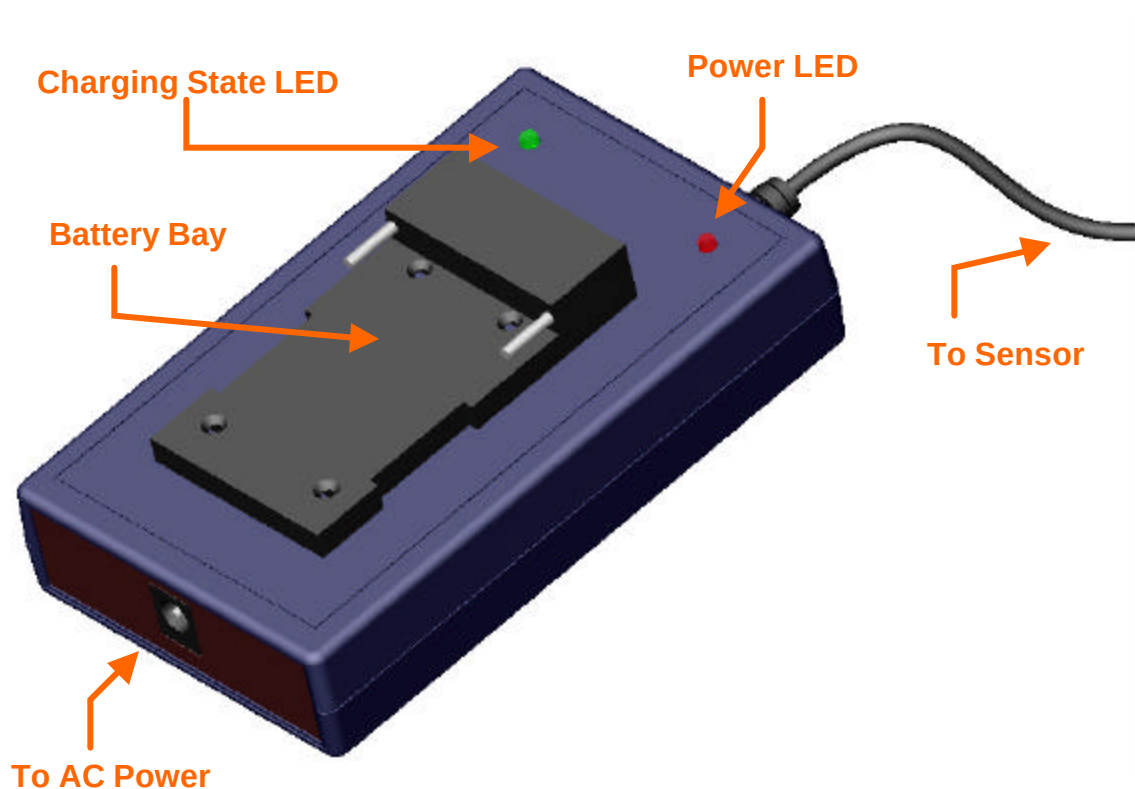


Figure 2.3. Isometric view of the battery charger. Make sure that at all times there is only one battery on either the charger or the sensor. The use of no or two batteries may damage the sensor electronics.

2.3 Charger

The charger will charge a battery in its battery bay OR a battery in the sensor's battery bay, but not both at the same time. **TRYING TO CHARGE TWO BATTERIES WITH THE SAME CHARGER WILL RESULT IN DAMAGE TO THE GEMS ELECTRONICS.** The sensor can also be used while its battery is being charged but should not be used with an AC power supply if the battery is not connected – this will introduce noise into the output signals and may damage GEMS components. The charger has two LEDs – one red LED to indicate that the AC power is connected, and red/green LED to indicate charging state. The changing state is indicated as follows:

LED:	Steady Red	Red with slow flash	Red with rapid flash	Steady Green
Charging state:	Normal charging	Minor fault, slow charging	Major fault, follow reactivation procedure	Recharging complete

“Slow flash” means 1 flash every 5 to 10 seconds, “rapid flash” is 1 flash every second. A fault may be introduced in the battery if it is deeply discharged. To reactivate a battery with a major fault (deeply discharged or shorted) follow this procedure:

Place the battery in the charger and power up the charger. Allow the battery to remain in the charger for at least 10 minutes with the Charge Mode LED flashing quickly. After more than 10 minutes, remove the battery and disconnect the charger from AC power. Re-insert the battery into the charger and power the charger unit. If this procedure does not reactivate the battery (i.e., the charging state LED is still flashing quickly) the battery has been destroyed and a new battery must be procured.

2.4 Antennae

The antennae supplied with the sensor are specially designed to work well next to human tissue. Normally, antennae are designed to function efficiently in air, which has a relative dielectric constant near unity and very low conductivity. However, at 2.4 GHz, the body has a relatively high dielectric constant (ranges from ~30-50) and significant conductivity (~2 S/m). Operation of the antenna near the body therefore affects the efficiency and resonant frequencies of the antenna and this must be taken into account during the design and testing phase.

The net effect of the operation of the antenna near the body is an overall lowering of the resonant frequencies of the antenna. For example, for one type of antenna the resonant frequency was observed to drop from 4.2 GHz (in air) to 2.7 GHz (near the body). The amount of drop is determined by several factors, including the radiating pattern of the antenna, the substrate of the antenna, and any materials present between the antenna and the body. It has been observed that even very thin materials can shift the resonance frequency 50 MHz or more, depending on the material and thickness.

Therefore the antennae can be “tuned” to operate more efficiently by placing ordinary cellophane (“Scotch”) tape on the surface of the antennae. This works best with the rectangular micropatch antennae, and will be discussed further in Chapter 5.

There are three rectangular patch antennae and one spiral patch antenna supplied with the sensor. The rectangular antennae are recommended for the neck region, and the spiral for the cheek, although they will work in both places. Insight into the selection and tuning of the antennae will also be covered in Chapter 5.

2.5 **Parts List**

The parts that were included with your Aliph GEMS kit should include the following:

Quantity	Description
1	General Electromagnetic Movement Sensor (GEMS) Unit
4	Micropatch antennae (3 rectangular, 1 spiral)
2	SMA cables (30cm and 90cm)
1	3.5 mm Stereo to RCA Cable
2	RCA to BNC connectors
1	Battery charger with AC power cable, sensor power cable
1	Li-Ion rechargeable battery
1	CD with Data Acquisition software and support materials
1	User’s manual
1	GEMS/accelerometer measurement sheet

Please take a moment to check the contents of your kit and contact us if there are any discrepancies.

Additional batteries and chargers are available and can be ordered directly from Aliph. Only the antennae supplied by Aliph have been approved with by the FCC as legal to use with this device. If you would like to use an antenna of your own design with the GEMS, contact Aliph and we will make arrangements for the necessary manufacturing and testing procedures.

2.6 Getting Started

- Step 1: Slide the battery provided into the battery bay on the sensor body
- Step 2: Attach the power cable between the charger and sensor
- Step 3: Plug in the charger's AC power supply
- Step 4: Firmly attach one SMA cable to the operating antenna port
- Step 5: Firmly attach 1 antenna (e.g. 9p6+7_80) to the SMA cable
- Step 6: Make sure the bandpass filter switches are in the desired positions
- Step 7: Insert the stereo 3.5 mm cable between the sensor and a DAQ device
- Step 8: Switch on the sensor unit
- Step 9: Apply the antenna to your trachea (and speak) to observe signals
- Step 10: Adjust the audio output gain using the sensor gain adjustment knob

Note: Please read instructions on proper battery charging routines, antenna uses, and DAQ guidelines.

3 SPECIFICATIONS

The GEMS sensor is a continuous wave phase modulated radiofrequency device that operates at a frequency of precisely 2.4 GHz. It uses a monostatic antenna configuration that uses reverse polarity SMA connectors. The maximum theoretical RF power output is 1 milliwatt while the effective power will depend on the efficiency of the antenna. It returns a voltage signal limited to ± 2.5 V that indicates the amplitude of motion of a periodic or quasi-periodic motion of a target in its field of view. It is capable of measuring very small (micron order) vibrations from 20 Hz to 8 kHz both inside and outside the body. It operates on a rechargeable 7.4 V Li-Ion battery and draws approximately 170 mA of power.

GEMS	
Maximum RF Power Output (Antenna Port)	0 dBm (1 mW)
Audio Signal Output	~5.0 V max peak-to-peak
Output Signal Operating Bandwidth	20 Hz - 8000 Hz
Maximum Sensitivity In Air (at 10dB SNR)	~5 μ m
AC Power Supply	110V - 120V AC
Input Voltage	6V - 9V DC (Regulated)
Operating Temperature (recommended)	0° to 35° C
Dimensions (approx)	115 x 60 x 32 mm
Weight	200 g

Battery	
Battery Capacity	1180 mAh
Battery Maximum Output Voltage	DC 8.4 V
Low Voltage Threshold	6 V
Operating Temperature	0° to 40° C
Dimensions (approx)	38 x 20 x 56 mm
Weight	76 g

4 PERFORMANCE MEASUREMENTS

The performance criteria for this type of device are defined by its operating characteristics and ability to directly represent the vibrational state of its targets. In this section we will explore the criteria used to determine the performance of the sensor.

The GEMS is, simply put, a vibration analysis device. It can detect very small quasi-periodic or periodic motion of targets with very little distortion in one or both of the quadrature-related channels. As the GEMS is a vibration detector, it is reasonable to use a NIST-traceable shaker table to check the accuracy of the GEMS.

4.1 Test Setup

We chose for our testing the Gilchrist Technology Model 4000 portable shaker table. Information on this table can be found at <http://www.gilchristtechnology.com>. The target was a 4 inch diameter aluminum disk, manufactured to be under the 500 gram weight limit for the shaker table. A calibrated accelerometer was included as part of the table, and the frequency and amplitude of the shaker signal can be varied from 20 Hz to 10 kHz with a maximum displacement of 0.2 mm peak-to-peak at 100 Hz. The accelerometer output was available and was compared to the sensor outputs.

For the tests, a 2.45 GHz antenna (one that is efficient in air) was connected to the GEMS of interest and placed in a test stand above the shaker head and lowered to just above the shaker table. Although the antenna is usually isotropic, normally the only vibrations in the correct frequency range are those of the shaker head, so interference was not a problem.

4.2 Performance Tests

The signals from the GEMS and the accelerometer signal were recorded using the supplied Aliph GEMS DAQ software and an analog to digital data acquisition system recording at 20 kHz. The distance measurements began at 0.8 cm ($\sim \lambda/16$) and were

increased by $\pi/16$ twice. At these distances the first measurement is taken with the I channel near its maximum, the second when the I and Q channels are about the same size, and the third when the Q channel is at its maximum. This allows us to test all of the signals at their strongest and weakest points. There was occasionally increased noise in the signals due to the proximity and perfect reflectivity of the metal target which was not observed when the antenna was placed on the skin. This caused the phase measurements to vary somewhat, but this should not be a problem in normal use.

The frequency of the shaker was set at 75 and 150 Hz, with a few seconds between recordings to allow the head to stabilize. These frequencies are slightly lower than normal male and female pitch, respectively, and were chosen mainly because above these frequencies the amplitude of the shaker head diminished rapidly to the point where accurate (± 5 degrees) phase measurements could not be made. Two different shaker amplitudes at each frequency were recorded and compared to the relative change in magnitude of the largest GEMS signal to test the linearity of the GEMS. After processing (see below), the accelerometer and GEMS signals were compared to ensure that the phase and frequency information was correct.

To compare the position measured by the sensor to that derived from the accelerometer, we can either differentiate the sensor signal twice to get acceleration or integrate the accelerometer signal twice to get position. Or, since the accelerometer signal is composed of only a single frequency:

$$a(t) = A_0 \sin(2\pi ft + \phi)$$

the actual position signal will also be a single frequency

$$x(t) = X_0 \sin(2\pi ft + \phi)$$

When we differentiate this twice with respect to time, we get

$$x''(t) = a(t) = -(2\pi f)^2 X_0 \sin(2\pi ft + \phi).$$

Setting the amplitude factors equal, we see we may derive the position signal from the accelerometer signal quite simply:

$$x(t) = \frac{-A_0}{(2\pi f)^2} \sin(2\pi ft + \phi)$$

This requires only a sign change (180 degree phase shift) and division by $(2\pi f)^2$. We are not, however, ready to compare the signals directly – we still need to account for the phase distortion of the inherent GEMS 20 Hz HP filter.

4.2.1 Highpass Filter Distortion Compensation

The GEMS has a built-in HP filter with a 3-dB point of about 20 Hz, and several other selectable filters to allow the user to examine several frequencies of interest. These filters change not only the magnitude but the phase of the signal that passes through them, distorting the resulting filtered signal. Therefore if we want to compare the accelerometer and GEMS signals directly, we can either attempt to remove the filter effects from the GEMS data, or we can filter the accelerometer signal with models of the GEMS filters that have similar magnitude and phase responses. The second method is much simpler and is what we will employ.

The measured response of the 20 Hz filter is shown in Chapter 6 in Figures 6.1 and 6.2. It is a relatively simple 2nd order analog highpass filter coupled with a delay of about 150 μ sec. The only real distortion is caused by the highpass filter below about 300 Hz. Above that, the phase is linear. To compensate for this phase distortion in our tests the accelerometer data was filtered with a model constructed using Matlab. This compensation assures that both the accelerometer and sensor signals have been distorted in the same manner, making a meaningful comparison possible. Once the differentiation and highpass filter distortion compensation operations were performed on the accelerometer signal, the result was compared directly with the sensor signals.

4.2.2 Measurement sheet

After the data at each frequency, antenna-to-target distance, and amplitude was recorded it was processed to determine the following:

1. Dominant GEMS channel (dG)
2. Frequency of vibration as recorded by the accelerometer (Hz)
 - a. Calculated using a PSD, 0.1 Hz resolution
3. Frequency of vibration as recorded by the dG (Hz). This should be exactly the same as that recorded by the accelerometer.
 - a. Calculated using a PSD, 0.1 Hz resolution
4. Strength of the fundamental signal compared to the 1st harmonic (dB). This is an indication of distortion and 30 dB or greater is preferred.
5. Signal to noise ratio (SNR, dB). This should be 30 dB or more at every distance and frequency. The GEMS normally is around 40-50 dB but can go as high as 90 dB.
6. Calculated shaker amplitude (mm, peak-peak). This is the amplitude calculated from the accelerometer signal given the accelerometer frequency of vibration from step 2. This did not always match up with the amplitude set on the shaker, as its accuracy can vary +/-3%.
7. GEMS RMS-derived amplitude (V, p-p). The RMS amplitude of the GEMS was calculated in Volts and then transformed to peak-peak.
8. Minimum amplitude detectable (μm , p-p). See below for details. A measurement independent of target amplitude that describes the sensitivity of the GEMS. 1-10 μm is good, 0.1-1.0 μm is great, and $< 0.1 \mu\text{m}$ is superlative.
9. Phase difference between the filter-compensated accelerometer signal and the dG signal (degrees). We would like to see differences of less than +/-20 degrees, although there are some cases where we observed slightly more than that, usually at the lower frequencies. For the most part, though, even a difference of 20 degrees is negligible and should not affect the performance of the device on the skin. The reasons that there is some variation in the phase are:
 - a. Slight differences in the components that make up the 20 Hz HP filter and the 8000 Hz LP

- b. Noise due to the large reflected signal of the metal disk
- c. Poor model fit

10. Linear amplitude error (percent). This is calculated at the same distance and frequency but for different target amplitudes using the information from Steps 6 and 7. If the change in amplitude is perfectly linear, the error should be 0%. We are looking for errors less than 10%. Possible reasons for error are slight differences in distances, rounding errors, and low amplitude resolution. For example, we can only measure the shaker amplitude reliably to 3 significant figures (i.e. 0.095 and 0.191 mm). We can also only measure voltage to 2 significant figures (i.e. 0.80 and 1.58 V).

$$\text{error} = \frac{1.58 - \left(\frac{0.191}{0.095} \cdot 0.80 \right)}{\frac{0.191}{0.095} \cdot 0.80} \cdot 100 = 1.8\%$$

An error in the GEMS measurements of only ± 0.02 V can increase the error to 5.4%, and ± 0.04 V can lead to an error of 8.9%. Therefore, considering the accuracy of our system, $\pm 10\%$ is reasonable.

4.3 Calculating SNR & Minimum Detectable Amplitude

At each test frequency the SNR was calculated using a background noise file (no shaker motion) as the noise level. The result was then extrapolated back to what the signal level would be at 10 dB SNR (amplitude of the signal would be 3.16 times the amplitude of the noise). This allows us to determine the minimum amplitude that can be reliably detected at that frequency. Of course, this test is in air, so any extrapolation to vibrational amplitudes in tissue will have to account for conductive losses, imperfect reflections, and scattering losses. The minimum amplitude for which a 10 dB SNR is possible is calculated by

$$\text{min_ amp} = S_0(\text{mm}) \frac{3.16(N_1(\text{V}))}{S_1(\text{V})}$$

where S_0 is the observed accelerometer amplitude in mm, N_1 is the noise amplitude in volts, and S_1 is the signal amplitude in Volts. We may use either peak-to-peak or RMS voltages in the amplitude calculations, as we are dealing with ratios of amplitudes. For

example, if the observed voltage for an amplitude of 0.1 mm was 2 Volts, and the background noise amplitude was 20 mV, then the initial SNR would be

$$\text{SNR}_0 = 20 \log \left(\frac{2000}{20} \right) = 40 \text{ dB}$$

and the smallest detectable signal with an SNR of 10 dB would be

$$\text{min_ amp} = 0.1 \text{ mm} \frac{3.16(0.02)}{2} = 0.003 \text{ mm} = 3 \text{ } \mu\text{m}$$

which corresponds to a voltage of 60 mV, three times that of the noise level of 20 mV.

This measurement is a convenient way to view the SNR independent of target amplitude.

5 ACQUIRING GEMS DATA

The GEMS is a useful device, allowing us to sense motion inside the human body. However, it requires some practice and finesse to operate correctly and robustly. The sensor itself is usually not at fault, it is normally the combination of antenna placement and cable movement that give new users the most problems. The cables will contribute noise to the system if they are moved or vibrated during data acquisition. If your subject is to move during the experiment, make sure that the cables are secured and not allowed to move freely. This will minimize the noise in the GEMS signal.

5.1 National Instruments' Labview VIs

To assist users in visualizing and recording GEMS data, stand-alone and regular Labview virtual instrument files are included as part of the GEMS package. These files can display the GEMS data plus two more data channels and record them in a binary or text file. To use the software, data acquisition hardware and software from National Instruments (the E series at <http://sine.ni.com/apps/we/nioc.vp?cid=1038&lang=US> is recommended, it uses NI-DAQ software) must be installed and correctly configured. To test your configuration after installation, try the “Test Panel” option using the NI Measurement and Automation Explorer.

This software is provided as a courtesy by Aliph and has only been tested on National Instruments hardware running under Windows 2000 and Windows 98.

5.1.1 Installation of the software

The installation routine for the executable software is on the CD. Simply place the CD in your CD drive. If the setup screen does not automatically start, open the CD and select “setup”. The executable files will be copied into a directory of your choice, and a directory called “Aliph GEMS DAQ” will be created on your Start→Programs menu. Clicking on “Aliph GEMS DAQ” will launch the program. Remember that you must have the NI hardware and software installed before you can use the Aliph software.

As a courtesy to those that may wish to customize the VIs, the source code is included in the \source directory. To use these files, you must have at least the Professional version of Labview 6.1 installed on your computer. Otherwise you may use the stand-alone applications described above.

5.1.2 Main and configuration screens

In Figure 5.1, the main menu of the Labview program is shown. Before data can be recorded or displayed, the hardware must be configured. This is why some of the buttons are disabled (grayed out) – because in this screen the hardware has not yet been configured. To configure the hardware for the first time, press “Configure DAQ” to open



Figure 5.1. Main screen of the Aliph data acquisition package.

the hardware configuration screen. If you have saved a configuration default or other file, you can press “Load config default” or “Load config file” to save time. You must load a config file or manually enter a configuration every time the program executes.

The configuration screen is shown in Figure 5.2. Here, you can load the default setting (Load default), load any configuration file (Load...), save the current settings as the default setting (Save as default), save the current settings to a file (Save...), do nothing and leave the program (Cancel), or use the current settings for the current DAQ session without saving them to a file (OK). The configuration files can be named anything; they are stored in text format. A help menu explains all the settings available.

Hitting “OK” or “Cancel” will return the user to the main menu. If a valid configuration has been chosen, the previously unavailable options will be enabled. In the future, you may load the default file or any saved configuration file from the main screen and skip the manual configuration entry.

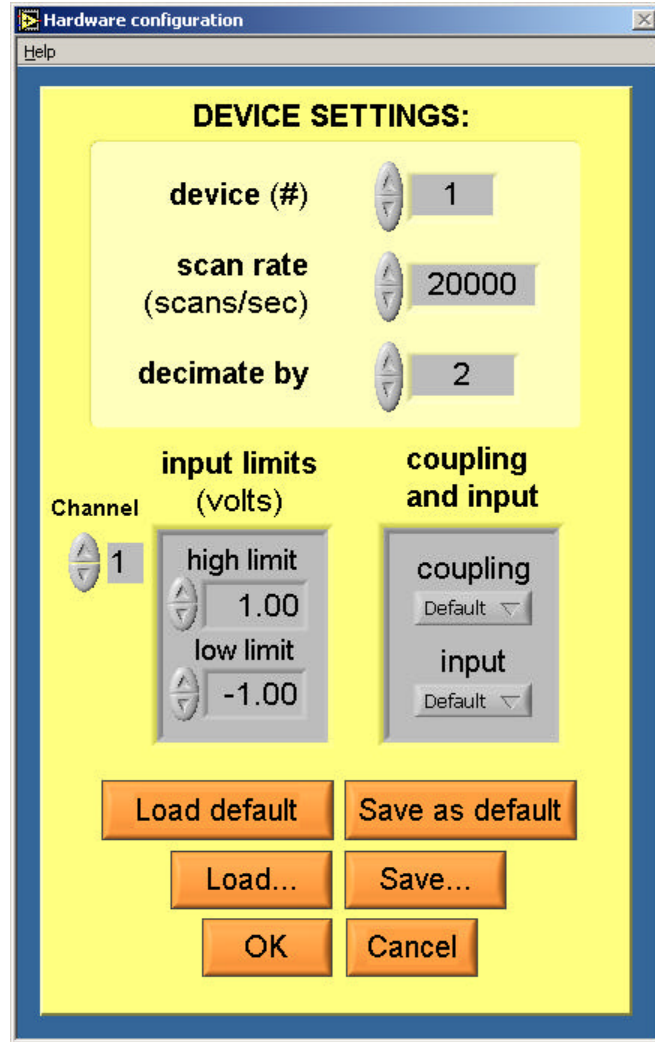


Figure 5.2. The hardware configuration screen.

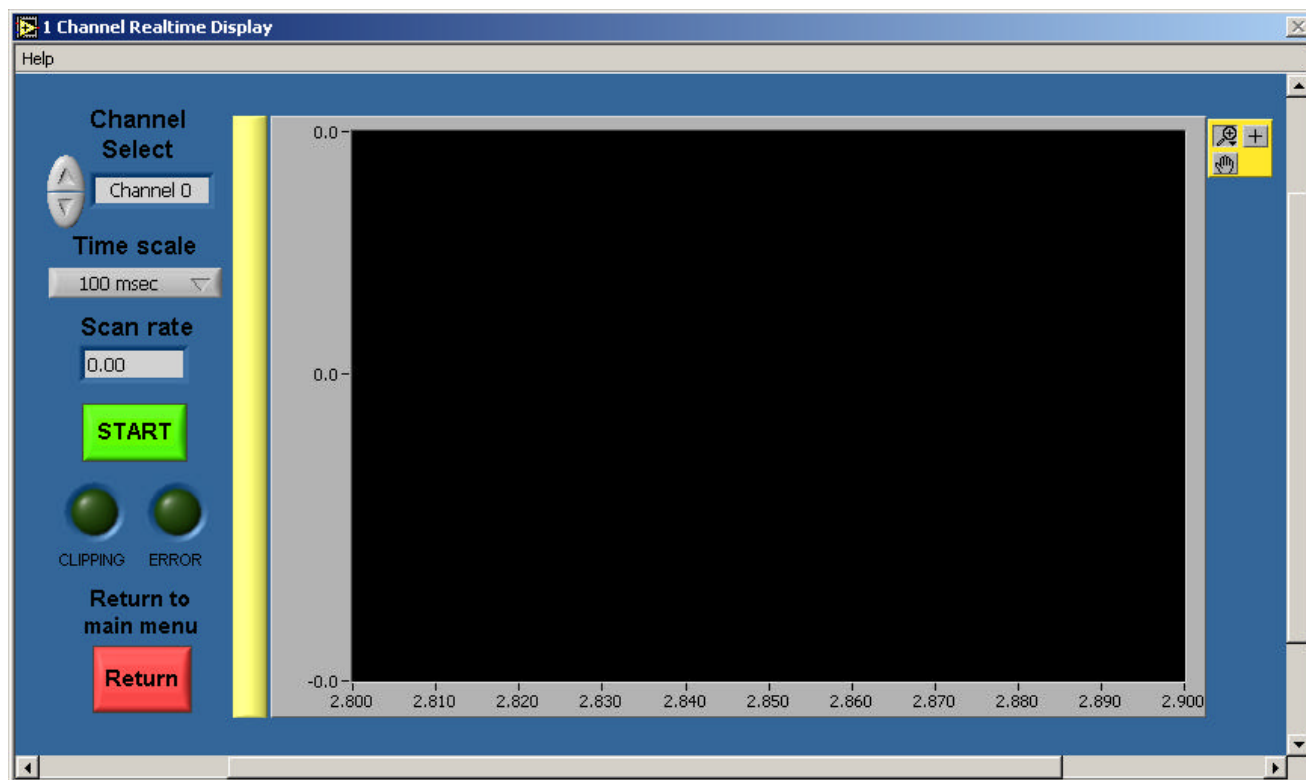


Figure 5.3. Real time configuration screen.

5.1.3 Real time data display

Two options are given for real-time data display – a 1 channel display and a 4 channel display. They work in the same way, so we'll go through just the 1 channel, shown in Figure 5.3. First, select a channel to display and a time scale to display it with. Values from 5 msec to 1000 msec may be chosen, and that amount of data will be displayed at once. This value also controls the refresh rate. The scan rate in Hz is displayed below the time scale, and is set in the hardware configuration screen (see Figure 5.2). The scan rate is the entered scan rate divided by the decimation factor.

Press “Start” and the screen will display the channel selected. If the time scale is grayed out, it cannot be changed when data is being acquired. When the display is no longer needed, press “Stop” and then the data that was being displayed is available to view. Use the palette on the right side of the plot to zoom in and out of the data. When finished,

press “Start” again to restart the data display, or press “Return” and the window will close and you will be back at the main program (Figure 5.1).

The 4 channel real time display system works the same way, except that all four channels (from 0-3) are displayed simultaneously. The sampling rate is again set in the configuration screen.

5.1.4 4 channel recording

The final algorithm offers 4 channels of data recording in either binary or text format. All four data streams are stored in the same file. The binary is recommended due to its smaller size, and a Matlab file is included (see the readme.txt file on the CD) that will translate the .bin file to a Matlab matrix. The interface is shown in Figure 5.4. To begin, enter the filename of the file you want to save the data in and the amount of time you want to record (a setting of zero here will record until you press “Stop”). The type of file recorded will be determined by the “Data file format” drop down menu. If you have specified a file suffix (like .bin) in your filename, this will override the selection on the drop down menu. If you specify a three letter extension in your filename but it is not .bin or .txt, the program will return an error and terminate. The simplest thing to do is to just specify a filename without suffix and choose the type of file you want to save from the drop-down menu.

Now press “Start”, and the “Recording” light will come on and the program will begin to record the data. You can stop the data acquisition at any time by pressing “Stop”. When the data acquisition is complete, the “Recording” light will go out and the data will be displayed. Displaying the data can take a while if the file is long. You will now be able to examine the data in greater detail using the graph palettes on the right side of the graphs. When you are satisfied with the data, you may take more data by pressing “Start” again (be sure to change the filename first if you want to save the data!) or you can return to the main menu by hitting “Return”.

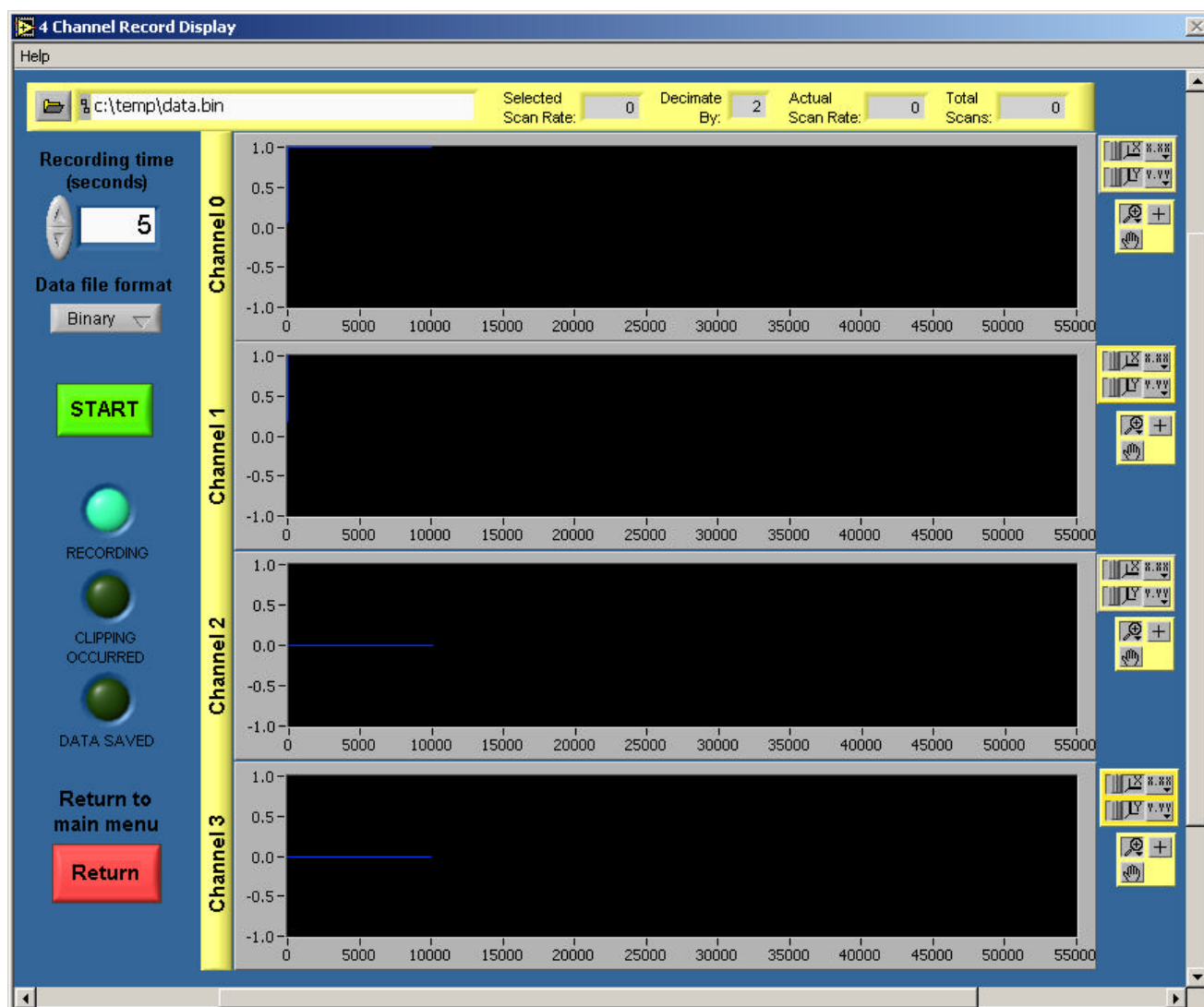


Figure 5.4. 4 Channel Data recording screen.

5.2 Recording Data from the Glottal Area

The glottis is the area between the vocal folds, and has been the subject of most GEMS research until now (see Chapter 2). It was observed that the rear subglottal tracheal wall responded readily to the pressure pulses caused by the operation of the vocal folds and glottis and the largest GEMS signal was obtained directly under the laryngeal notch (Adam's apple). This signal represents the motion of the rear wall of the subglottal trachea, and can be used to determine when the voiced excitation pulses occur. The

subglottal signal can be picked up further below the laryngeal notch, but the sharpness of the pulses decreases due to damping by the tracheal tissue. The trachea also recedes into the neck as it approaches the chest, decreasing the size of the signal due to conductive loss. A similar signal may be picked up at the side of the neck, although it is usually smaller and less robust (that is, more sensitive to antenna placement and contact).

For maximum signal strength and robustness, the antenna should be placed flat on the skin just below the laryngeal notch (see Figure 5.5). The long dimension of the antenna should be placed in the horizontal position for the best signal. The resulting signal (using the filters at 20 Hz and 8 kHz) should look similar to the data in Figure 5.6, although it will vary with user and type of voicing. Remember to use the modulation that has the most energy, and that the signal may be upside down (multiplied by -1). It is essential that there be no air gaps between the antenna face and the skin. This will result in an inappropriate shift of the resonance frequency of the antenna and signal strength will be poor. The antenna may be affixed to the neck using Velcro fasteners or masking tape. The user should start with the 9p6+8_80 antenna and test the return with the GEMS gain as high as it will go. If a sizeable signal is returned, that antenna should be used. If not, proceed to the 9p6+7_80 and 9p6+6_80 antennae. One of the three should work with almost any subject. It is imperative during these tests that the antenna face be flush with the skin. It may be difficult to achieve this with women, children, or anyone with a small trachea. Once a good sized signal is observed, tune the gain to restrict the signal so that clipping is not observed.



Figure 5.5. Approximate placement of the antenna for subglottal tracheal detection.

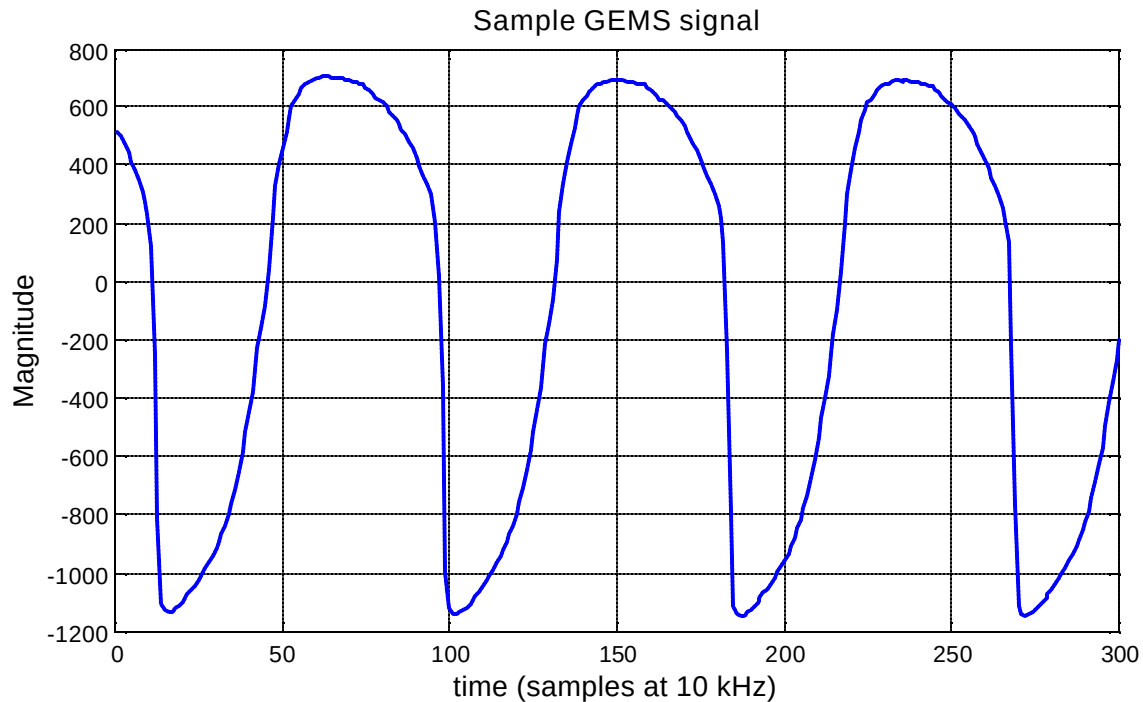


Figure 5.6. Example of a GEMS signal sampled at 10 kHz.

If you are not getting a good signal using the above technique, you should move the antenna up and down from the original position while speech is being produced. This will allow you to find an area that works well with your subject. It is very easy to get a signal from most male subjects due to the larger and more prominent trachea, but sometimes can be difficult for those with smaller and more recessed tracheas. If all else fails, you can try to tune the 9p6+6_80 antenna using pieces of cellophane (“Scotch” brand) tape. Place one piece of tape over the antenna and see if that improves the amplitude of the signal. Keep adding pieces until the amplitude decreases again, and then use the number of layers of tape that resulted in the largest signal. Add no more than about 5-6 pieces of tape – after that, the effects are minimal.

5.3 Recording data from the cheek area

In this area, there is a lot more leeway in terms of antenna location, but the amplitude of vibration of the cheek is far less than the trachea, and it can be a lot more difficult to get a good signal. The recommended area for cheek antenna placement is shown in Figure 5.7,

although signals may be detected in a variety of areas around the cheek, jaw, and nose.

Again, the antenna may be affixed using masking tape, but the headset configuration shown in Figure 5.7 is more comfortable, although it may require more care to ensure that the antenna is flat against the skin. The spiral patch antenna should be used for the cheek area, as it has the potential of a much better match against the skin. However, this sensitivity means that it may not work for all people, and it may be necessary to tune the antenna using cellophane tape as described above. Even then, there is a chance that it will not match well and it may be necessary to use a rectangular patch antenna that, although less sensitive, matches better with a wider range of people. Again,

experimentation is the key here – try adjusting the position of the antenna while the user says “mm” – this should result in the largest signal. Be sure that the antenna is flat against the skin, but don’t press it too firmly into the cheek.



Figure 5.7. One method of obtaining GEMS cheek data.

Keep in mind that the data from the cheek area reflects directly on the speech being produced, so both the shape and amplitude of the wave will vary with the speech being produced. For example, an “ee” results in a large signal, as there is a significant amount of energy reflected at the mouth back into the oral cavity. In contrast, an “ah” results in a small signal, as there is a more efficient coupling to the air at the mouth and little energy is left over to vibrate the cheek. You may need maximum gain to observe the signals at the cheek, as they are normally much smaller than the glottal signals.

5.4 Other Locations

The GEMS is sensitive enough to pick up vibrations from a number of places on the body, including the back and sides of the neck and the chin and jaw. Vibrations from different areas can contain different information – for example, the glottal area signal reflects the pressure pulses that become the speech, and the cheek area contains more information about the sound being produced. Experiment with the sensor and the antennae, and you may be surprised at what you find!

The GEMS electronics includes a simple analog HP filter to reduce low frequency noise. This filter has a 3-dB point at approximately 20 Hz. The measured response of the filter is shown in Figures 6.1 and 6.2. It is clear that there is some non-linear phase distortion of the filtered signal for frequencies below about 300 Hz. Above that frequency, the only phase response is a linear phase, which translates directly to a simple delay. In this case, the delay is about 150 μ sec. This delay does not in any way affect the shape of the GEMS signal, and therefore does not need to be removed. For those desiring absolute accuracy for signals with components greater than 300 Hz, simply advance the GEMS signal by 150 μ sec. However, remember when comparing the GEMS and acoustic signals that the GEMS signals are traveling at the speed of light and the acoustic signals at the speed of sound. A pressure pulse produced at the glottis will have to travel about 20 cm to get to a close-talk microphone near the lips, and at 330 m/s that will take about 600 μ sec. For all intents and purposes, the GEMS signals are generated and reflected instantly. Adding in the 150 μ sec delay means that for proper alignment of the acoustic and GEMS information, the GEMS should be delayed approximately 450 μ sec. In practice this is rarely an issue.

Removing the nonlinear distortion of the 20 Hz filter for the frequencies of interest (~40 Hz and up) can be done, but will not be covered in this manual. An example is given in Burnett's thesis (see Chapter 2), but will not be needed for the vast majority of applications, as the phase distortion is insignificant for most frequencies and does not in any way affect the frequency content of the signal. The 100 Hz HPF option, however, can cause significant phase distortion and should not be used if it is not needed. Once again, it is recommended to select the 20 Hz and 8 kHz filter options for minimum phase distortion.

If you feel that you must remove the phase distortion from the 20 Hz filter, contact us and we will supply you with a Matlab program that will be able to remove a significant

amount of the distortion. Perfect removal is not likely due to normal variation in the filter response.

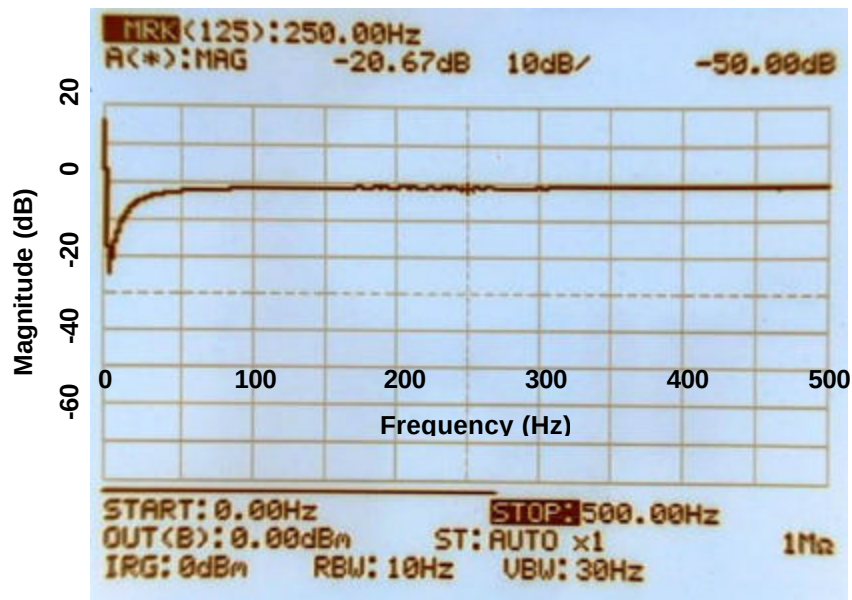


Figure 6.1. Magnitude response of the intrinsic 20 Hz filter of the GEMS. The frequency range here is from DC to 500 Hz. The spike near DC is not real, but rather an inaccuracy of the instrument.

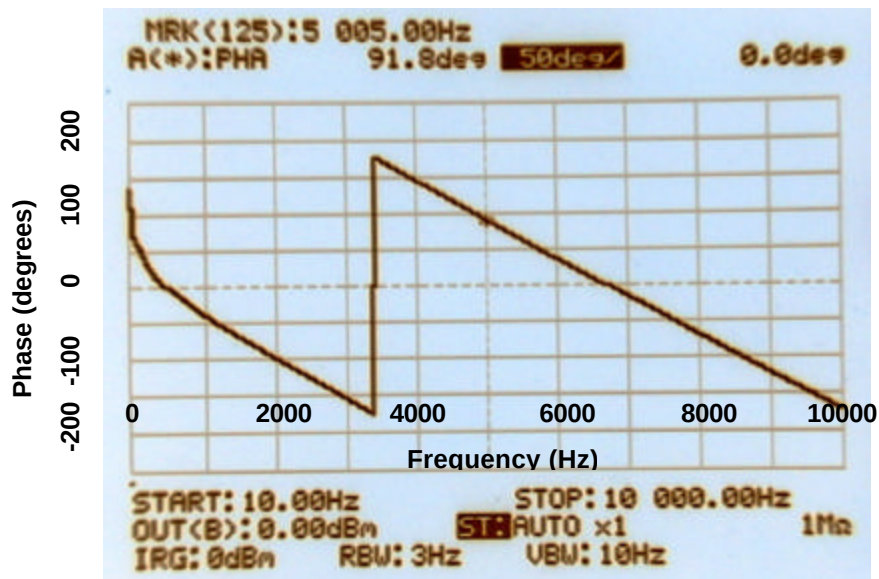


Figure 6.2. Phase response of the intrinsic 20 Hz GEMS filter. The rapid change at 3347 Hz is simply the phase wrapping around to stay between ± 180 degrees. This phase response has the characteristics of both an IIR and FIR filter. The frequency range is from DC to 10000 Hz.

Your GEMS device is a transmitter and a receiver. In operation, it transmits less than 1 mW (0 dBm) of power in the frequency range of 2400-2500 MHz. Your GEMS device is designed to operate in compliance with the RF exposure guidelines and limits set by the national authorities (FCC) and international health agencies when used as instructed in this manual.

The GEMS complies with Part 15 of FCC regulations concerning the use of intentional and unintentional radiators in the 2.4GHz ISM band.

For additional information concerning interference or safety issues, please refer to the “Aliph GEMS Safety and Compliance Report”, which will be provided to GEMS owners upon request.

The user is cautioned that changes made to this equipment that are not authorized by Aliph may void the user's authority to operate this equipment.
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Does the GEMS “image” the vocal folds?

No. The GEMS is a vibration detector and simply returns a signal that is proportional to the movement of a target in the area. If there are several vibrating surfaces, the resulting signal will be a nonlinear combination of all of the movements of the surfaces. Since the GEMS only detects signals above about 20 Hz or so and the skin depth (depth in tissue that the EM wave is reduced in energy to $1/e$) is only a few cm, normally there will only be one major contributor to the signal. However, care must be taken when interpreting the signal.

Is the GEMS safe to use?

The GEMS is a radiofrequency (RF) device that emits electromagnetic (EM) energy at a frequency of 2.4 GHz, the same frequency many cordless phones and wireless headsets use. However, the GEMS emits less than 1/1000 of the power of a mobile phone and complies completely with all US and foreign standards for continuous exposure to EM energy at this frequency. Future versions of the GEMS will emit even less energy.

Does the antenna have to be touching the body to get a signal?

No. The use of normal, in-air antenna held off the skin can return a useable signal. However, for this study the emphasis has been for on-body antenna to reduce the power output as much as possible and to make the signal as robust and repeatable as possible.

Does the GEMS directly sense the motion of the vocal folds?

No. The vocal folds are too small and their surfaces poorly positioned to reflect EM energy. Their action, though, causes pulses of air to be formed and propagate both above and below the glottis (the airspace between the vocal folds). These pulses cause the surrounding tissues to pulse, and this motion is easily detectable.

How do I go from tracheal motion to glottal pulse location?

Once the tracheal wall position has been detected by the GEMS, the pulses may be located as the places where the position changes rapidly. For most people, the closure of the folds has a much larger effect on the signal than the opening, but normally both may be detected. For more information see Gregory C. Burnett's thesis:

http://www.aliph.com/Burnett_thesis

We don't have a data acquisition (DAQ) PC card, we only have a DAT tape player (or similar). Can we still use the Aliph Labview programs to collect data?

Aliph only supports PC-based data acquisition. We recommend any of the E-Series National Instruments DAQ boards (such as the PCI-6023E or the PCI-6034E) as well as their line of BNC based connector boards such as the BNC-2110.

What sampling frequency should we use to capture the GEMS data?

Although the GEMS allows signals as high as 8 kHz to be detected, the response of the tissue to the speech pulses is poor above 2-3 kHz and it is unlikely that any significant energy will be in the GEMS above 4-5 kHz. Still, to ensure that aliasing is not present, we have found that recording the data at 24 or 32 kHz and then digitally filtering and decimating to 8 kHz has been quite successful in capturing the GEMS signal without aliasing. In a pinch, 16 kHz will do, but is not recommended.

Does the GEMS sensor work on all people?

We have been able to get a useful subglottal signal from all of our subjects. This does not mean that all people will return one, but the vast majority of people should yield a useable subglottal signal. However, the cheek signal is not as reliable. If the subject is a soft speaker or if the tissue of the cheek is incompatible with our antenna, a useful cheek signal is sometimes not available. We are working on a more sensitive version of the GEMS that will ensure a cheek signal for all subjects.

Does the subglottal GEMS signal contain phonetic information?

No; or at the most, very little. The subglottal pulses detected by the GEMS do not contain significant phonetic information. Since the phoneme is generated by the rearrangement of vocal articulators in the supraglottal region (including the larynx, pharynx, and oral cavity) and the reflection of acoustic energy at every change in cross-sectional area in the vocal tract, there is undoubtedly some phonetically shaped air pressure leakage from the supra- to the subglottal region. However, it will be quite small, as the glottis (the air space between the vocal folds) is small compared to the vocal folds and most energy will be reflected back to the vocal tract. In addition, the large pulses of air that excite the vocal tract will be many times stronger than the small amount of leakage past the folds. That is not to say that with concentrated effort some phonetic information may not be obtained.

What about the cheek/jaw information? Is that phonetically related?

Yes. The vibrations of the cheek and jaw are caused by oral cavity air pressure fluctuations, which are the result of the shaping of the glottal pulses by the vocal tract. Depending on the phoneme, the vibrations should have different frequency content and amplitude. The frequency content comes from the frequency content of the phoneme being produced, and the amplitude variations are related to how well the phoneme being produced couples with the air. An “ee”, for example, does not couple well with air and there is ample energy inside the oral cavity to vibrate the cheek and jaw. An “ah”, on the other hand, couples very well with air and there is little oral cavity energy left to vibrate the cheek and jaw.

9 TROUBLESHOOTING

9.1 GEMS Signal

The GEMS is a relatively simple device to use, especially in the subglottal area. Try that area first, as that is the area where the signal is the largest and most robust. If there is still no signal from the subglottal area, try the following troubleshooting guide:

- Check the gain potentiometer to make sure it is all the way up (full clockwise).
- Ensure that the battery is charged or charging through the supplied AC supply.
- Make sure there is only 1 battery in the charger/sensor system. The system cannot charge two batteries at once and the use of two batteries may damage the sensor. If connected to the AC power supply, ensure that there is a battery in the GEMS unit.
- Check the antenna connection to make sure it is firmly connected to the sensor.
- If using a rectangular patch antenna, make sure the long edge of the patch is perpendicular to the trachea.
- Try a different antenna and make sure that it is flat against the skin.

If a signal is returned from the trachea, but not the cheek, try the following:

- Use the spiral antenna. It has the potential to match better with the cheek.
- Vary the position of the spiral antenna while you make the sound “mm” with your mouth closed. This should result in the largest signal amplitude possible.
- Vary the amount of pressure used to press the antenna to the cheek. Vary it from lightly touching to firmly touching.
- Try to match the skin better using cellophane tape, as described in Chapter 5.

9.2 Labview Programs

Since we are not supplying any data acquisition (DAQ) hardware with the GEMS, support for DAQ hardware issues is not included in your package, but may be available on a pay-per-time basis. Support for problems you may be having with the Labview software is included, BUT ONLY FOR SOFTWARE THAT HAS NOT BEEN MODIFIED. If you modify the included Labview VIs for your own use, as is allowed, you are responsible for the results. Don't come crying to us.

Before calling us with software questions, you must make sure your hardware system is working correctly by using the Test Panel in the Measurement and Automation Explorer, part of the NI-DAQ software series (available with any hardware purchase or download from www.ni.com). Input a signal from a synthesizer or frequency generator on the channels that you want to use and check to make sure that they are being correctly received by the DAQ card. Common mistakes include connecting the incoming signals to the wrong DAQ inputs and not ensuring tight cable connections. The Aliph software uses channels 0, 1, 2, and 3 to input data. It is not necessary to use all of these channels, but the signals you want to record should be connected to one of the above four channels.

If you are detecting these known signals on the correct channels, then the next step is to see if the GEMS is producing a signal. You can use an oscilloscope or input to a computer soundcard to see if GEMS signals are being produced from the subglottal region. The subglottal signal can be recorded and sounds like muffled speech with no phonetic information. If these signals are being recorded correctly, and the input to Labview is working correctly, the system should function.

9.3 Technical Support

If you are still having problems, please feel free to contact us. Five hours of support time, which should be scheduled in advance, are included with the purchase of a new

sensor. Contact us and we'll be glad to go through your problem with you. After the included support time is exhausted, we would be happy to provide more support although this may result in additional fees.

10 Contact information

You may contact Aliph in the following ways:

Phone: 415-512-9191

Fax: 415-512-9190

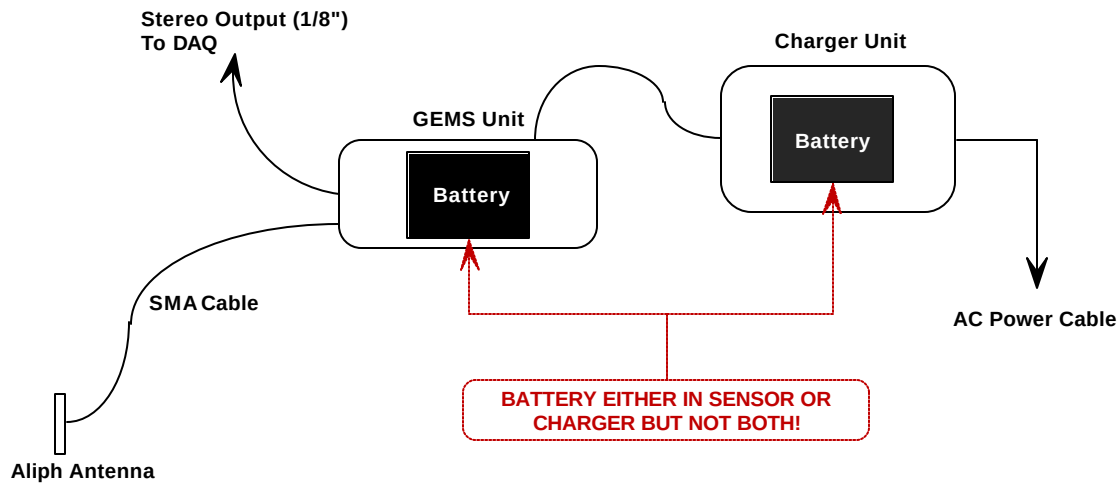
Email: support@aliph.com

Mail: Aliph

410 Jessie Street, Unit 601

San Francisco, CA 94103

Aliph GEMS Quick Reference



Quick start:

- Step 1: Slide the battery provided into the battery bay on the sensor body
- Step 2: Attach the power cable between the charger and sensor
- Step 3: Plug in the charger's AC power supply
- Step 4: Firmly attach the reverse polarity SMA cable to the antenna port
- Step 5: Firmly attach 1 antenna (e.g. 9p6+7_80) to the SMA cable
- Step 6: Make sure the bandpass filter switches are in the desired positions
- Step 7: Insert the 3.5 mm stereo cable between the sensor and a DAQ device
- Step 8: Switch on the sensor unit
- Step 9: Apply the antenna to your trachea (and speak) to observe signals
- Step 10: Adjust the audio output gain using the sensor gain adjustment knob

Note: Please read instructions on proper battery charging routines, antenna uses, and DAQ guidelines. **ONE AND ONLY ONE BATTERY CAN BE USED AT A TIME. OPERATING THE GEMS WITH EITHER TWO BATTERIES OR NO BATTERIES CAN DAMAGE IT!**