

IMPLEMENTING AN AUTOMATED POSITIONING AND MEASUREMENT SYSTEM
FOR THE STUDY OF A HYPERSONIC SPEAKER

by

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A senior thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Bachelor of Science

Department of Physics and Astronomy

Brigham Young University

April 2008

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DEPARTMENT APPROVAL

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This thesis has been reviewed by the research advisor, research coordinator,
and department chair and has been found to be satisfactory.

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ABSTRACT

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The implementation of an automated positioning and measurement system in the fully anechoic chamber at Brigham Young University is described. The system is employed to study the frequency generation of a hypersonic speaker. The general positioning system design consists of suspended rails for planar motion which are moved using stepper motors controlled by a computer. Considerations for mounting, acoustically absorptive insulation, system error handling, and automated measurement techniques are addressed. Software design and necessary functionality is outlined in detail. This system is useful for high-resolution measurements in stationary sound fields that could not be carried out with a reasonable number of channels or in a reasonable amount of time. The system is used to measure hypersonic speaker frequency generation of using driving signals of 500 Hz, 3 kHz, 10 kHz and all of those frequencies combined. The speaker is also studied using a white noise input signal.

ACKNOWLEDGMENTS

I would like to thank Dr. Kent L. Gee for his help in designing the system and suggesting necessary features needed by the BYU Acoustics Research Group. I would also like to thank Ryan Chester for the many hours he spent helping assemble the various mechanical components of the system and assisting in basic testing and development.

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Chapter 1

Introduction

1.1 Purpose of this Study

Hypersonic speakers are designed using a parametric array of speakers that output hypersonic frequencies. Multiple frequencies are output in such a way that the difference frequencies generate audible sounds in the acoustic far field. This method of audible sound generation provides for a very directional sound field and a relatively flat frequency response over the middle region of the audible spectrum. The nonlinear nature of this sound generation suggests that a single input frequency may produce a certain frequency response in the acoustic near field for various input frequencies; however, combining several input frequencies may not yield a superposition of the singular responses. This nonlinear sound generation would differ from the traditional treatment of assumed linear loudspeaker systems. In order to correctly characterize the nature of a hypersonic speaker, it is necessary to verify whether or not the assumed nonlinear response is indeed a relevant factor in making measurements with the speaker. If it is verified that a simple superposition of frequency responses is not possible with hypersonic speakers, the way in which researchers use such speakers in

measurements will be altered to account for this difference.

1.2 Purpose of the System

Many acoustical measurements require a careful examination of an acoustic field. This includes measuring subtle variations in the field, variations which may not be easily detected unless the spatial measurement resolution is sufficiently high. In larger planar fields exceeding 0.25 m^2 and three dimensional spaces, such high resolution measurements can be difficult to make due to the problems associated with manual positioning of a microphone. An array of microphones can be used to facilitate the measurement process; however, equipment costs stipulate the limits of such a configuration. Although increasing the number of microphones in an array allows for the acquisition of data in a more reasonable amount of time, such setup becomes impractical when the field size needing to be measured is increased. Extending the field size creates the same problem that called for the creation of a measurement array; the time required to measure all the necessary positions becomes unreasonably large. A better method of positioning a microphone or array thereof is needed to expedite the process without reducing the number of measurement positions and spatial resolution. This need suggests that a system can be employed to automatically move the measurement array within the sound field and acquire measurement data systematically. Such a system would be needed to extend the measurement abilities of most acoustical research facilities allowing for faster, higher resolution measurements over larger regions. We have implemented this type of system at Brigham Young University in the university's fully anechoic chamber. In order to aid in the study of a hypersonic speaker system, this positioning system has been constructed to streamline the measurement process.

Chapter 2

System Design

2.1 Mechanical Design

The design uses a hanging gantry fitted with a moveable cross arm which provides motion in what we define as the x axis. The cross arm is fitted with a moveable cart capable of moving in a direction perpendicular to the x axis. This provides y axis motion for a microphone boom attached to the cart. Together this gantry system enables planar positioning of a boom anywhere within the perimeter of the gantry. The system dimensions are 8.53 m by 5.21 m with a useable measurement area of approximately 32 m². Figures 2.1 and 2.2 show illustrative details of the gantry design. The cross arm and cart are moved using two stepper motors. Each stepper motor is also fitted with a brake mechanism to ensure that the boom is locked into position when measurements are begun. The stepper motors are adjusted to vary the position of the boom and the speed at which the boom moves between positions and the system acceleration parameters. Accurate position control is essential to the system's purpose. Speed and acceleration considerations are also an important feature of the system. It is useful to be able to vary speed and acceleration parameters

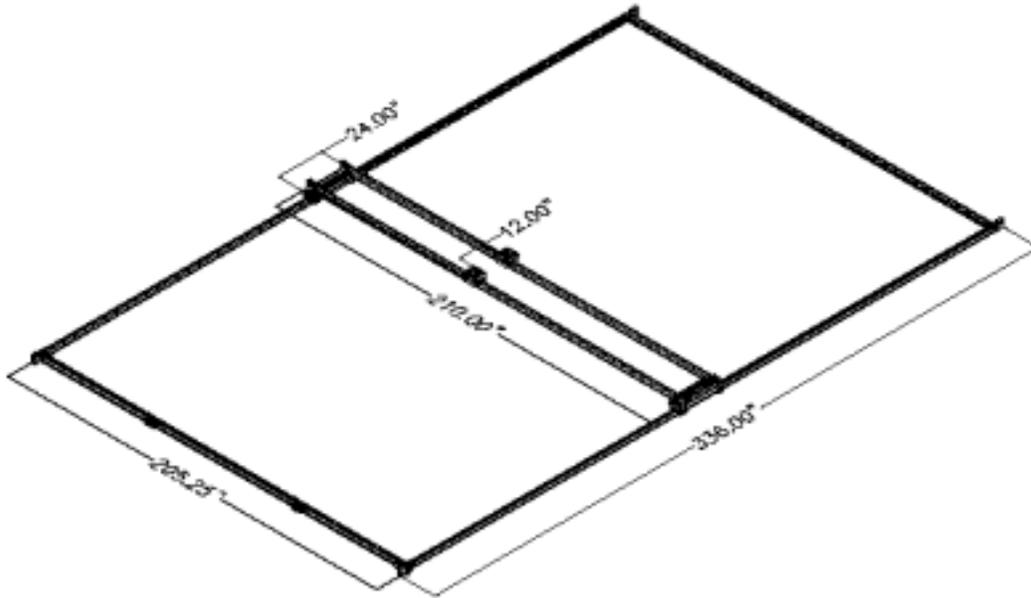


Figure 2.1 Technical drawing isometric view of the gantry system hanging in the anechoic chamber. [1]

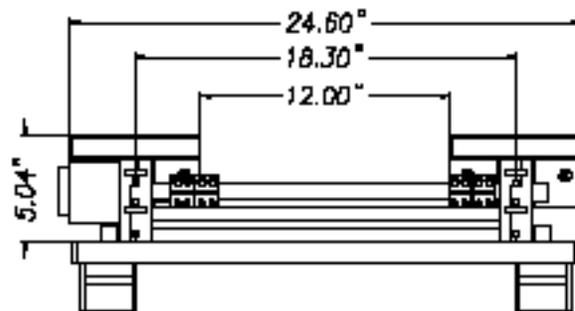


Figure 2.2 Technical drawing right side view of the gantry system cross arm. [1]

because the load attached to the boom may vary from a single microphone to a much larger array of microphones. When a larger load is attached, a lower speed or acceleration may be used to help minimize the system settling time - the amount of time it takes for the microphones attached to the end of the boom to stop swaying as a result of the movement stop. The stepper motors are controlled simultaneously with computer hardware designed for such a task. The hardware is simply required to send pulses/steps to the motor signaling that the motor should move in a given direction. More advanced motor operation may require use of a relative encoder, a mechanical, optical device used to track actual motor movement with precision. We use a 2000 count/revolution encoder. In our setup the motor is attached to a 25:1 ratio gear head which provides the torque needed to move the cross arm and cart. A key design element in the system takes into account the acoustic cross-section of the gantry system and cart. The system must be designed such that it does not reflect sound; a feature of the anechoic chamber which if altered would make the chamber useless. We use small acoustically absorptive wedges specially designed to attach to and cover the gantry system support frame and cross arm. These wedges attach directly to the beams. The wedges attached to the cross arm are carried with the arm as it moves. This maintains the anechoic nature of the chamber; however, it also adds additional weight to the whole design which will reduce overall system acceleration. Figure 2.3 shows what the installed wedges look like.

The wedges we chose weigh approximately 5 lbs/ft. The weight of such wedges should be considered beforehand to avoid potential problems related to required motor torque and ceiling support. When combined, the motor, gear head, and gantry system pitch experimentally yield an average system movement of 5.95×10^{-3} and 6.05×10^{-3} m/rev for the x and y axes respectively. These experimentally derived values differ from the theoretical values which are determined to be 5.6×10^{-3} m/rev for



Figure 2.3 Photograph of the acoustical absorptive wedges installed on the gantry.

Measurement	X m/rev	Y m/rev
1	5.900E-03	6.000E-03
2	6.208E-03	5.905E-03
3	5.910E-03	6.096E-03
5	5.902E-03	6.223E-03
6	5.902E-03	6.033E-03
7	5.936E-03	6.033E-03
8	5.902E-03	6.127E-03
Average	5.951E-03	6.059E-03
Standard Deviation	1.139E-04	1.012E-04

Figure 2.4 Table of measured motion distance/revolution values.

each axis. Since these values are important to determining how accurate the system is, some statistical analysis is provided below using a characteristic sample of 8 measurements. This information is found in Figure 2.4. Measurements were made over distances ranging from 2 inches to 10 feet. A set number of revolutions and steps were executed followed by a measurement of the actual distance traversed. The distance per revolution values were then calculated from this data. The standard deviation indicates that using an averaged value to calculate distances can lead to appreciable position offset after several measurement positions. This is because the uncertainty in each move varies leading to propagation of error over time. We use two methods to correct the position of the boom aligning it to the actual desired position. The first method involves system realignment to an absolute position in the room. The computer requires an absolute position, preferably in the corner of the room, to realign the software defined coordinate system with the actual position. We employ this absolute reference using physical limit switches - switches fixed to the gantry system - that are stationary relative to the axis movement. After several movements, the system

will seek this position and realign the coordinate system to eliminate propagation of position error. Limit switches also help to protect the system from damaging itself. If the user tries to drive the cart or cross arm into the perimeter of the gantry, limit switches prevent the system from moving beyond their position. This is a hardware check that the motors won't burn out trying to drive the hardware into itself. The second method requires the use of encoders. Instead of using a software side count of how far the system has moved, the computer monitors the system position strictly based on the encoder response. This means that if the motor used has 50,800 steps per revolution as our does, we can identify the actual position to within 26 steps. This translates to a system accuracy of roughly 3 micrometers and a precision of 0.1 micrometers. Despite this high accuracy and precision actual experimentation with software positioning techniques indicates a best accuracy of about 100 micrometers or 0.1 mm. System speeds which yield efficient movement with minimum stress on the motor were determined empirically after the final wedges were in place. The high torque motors used coupled with the 25:1 ratio gear head gave best results with maximum single axis speeds of 12 revolutions per second. This is the ideal speed for system motion with a minimum amount of weight attached. As weight is increased, maximum speed may need to be decreased to prevent stressing the support boom and motor. Acceleration and deceleration may also need to be adjusted for the same reasons. With these values, initial estimates and measurements indicate time savings of approximately 500%. Another important issue when constructing the system involves the proper treatment of motor control cables and data cables that attach to the boom microphones. In the case of our system we also considered brake and limit switch cables. We employed cable carriers to ensure that the cables would remain bundled and not catch on anything during motion. Cable carriers are designed to bundle and folder cables as an axis moves. The cable carrier must be long enough to

account for the full span of the system. Both the x and y axes have a cable carrier to ensure proper movement in both directions.

2.2 Software Overview

The automated positioning and acoustic measurement system is controlled with computer software written in LabVIEW version 8.2. The virtual instrument (VI), a name given to programs written in LabVIEW, makes use of several toolkits which are not part of the basic installation. The software is designed to interface with data acquisition hardware called the PXI. The PXI uses data acquisition cards and a motion control card to acquire data from the microphones and control the motion of the system. The automated positioning and acoustic measurement system software is named “Motion Control” and uses the filename “MOCON”. It contains the following general features listed below.

Main Program

This primary interface allows the user to observe and control motion parameters. The user can define a list of data points where the system will acquire data, change motion and measurement settings, and view alarm indicators to verify that the system is functioning properly.

Remote Positioning

This separate software component called a SubVI allows the user to connect an external analog control device, such as a joystick, to the computer. The analog control device can then be used to manually position the system aligning the boom to the desired initial position. The Remote Positioning SubVI can be accessed from within

the Main Program.

Channel Configuration

The PXI hardware requires the user to define information about the type of measurement that it will be used for. The user can employ the Channel Configuration SubVI to set up the desired data acquisition channels for the PXI hardware. Once the channels have been activated, the software will automatically record information on the selected channels when the measurement is executed.

Selected Measurement Module

The software is capable of making certain common measurements that have been preprogrammed. Measurements that the software can automatically perform include Waveform, Waveform and Complex FFT, Autospectrum, Transfer Function, and Complex Pressure. Custom measurements are also possible, but require knowledge of LabVIEW programming. The user can select a measurement type to be performed. When the measurement is executed, the appropriate measurement control screen associated with the selected measurement type will become available allowing the user to see the microphone data as it is acquired.

Setup and Execution Phases

When the program is run, there are two main phases for the software. The first phase is called the Setup Phase. During this phase the user accesses data point setup, measurement properties, remote positioning, and channel configuration. The second phase is called the Execution Phase or simply “execution”. During this phase the system will proceed to make the specified measurements at locations determined by the specified data points. The data points can form a complex 2-Dimensional or

3-Dimensional grid of points. Larger grids correspond to a longer execution phase duration. The selected measurement module will also become available during this phase. When the LabVIEW Virtual Instrument (VI) is executed, meaning the “run” button is pressed in LabVIEW, the user enters the Setup Phase, first of the two main phases for the software. During this phase the user is able to set up the following measurement properties.

Grid Setup - The user can input a sequence of Cartesian points which will be used as the positions to be measured when the second phase begins.

Measurement Setup - The type of acoustic measurement can be selected along with sampling parameters and experiment descriptions.

Remote Positioning - The initial measurement position which is identified as the Cartesian origin (0,0,0) can be selected using an external control device such as a joystick.

Channel Configuration - The user can choose which Data Acquisition channels are used in the measurement and adjust the various properties of those channels (including microphone calibration) before any data is recorded.

Motion Settings - A variety of system options are available to the user.

After all the appropriate settings have been selected during the Setup phase, the user can begin the measurement. The program will then enter the Execution Phase. During this phase the system will proceed to make the specified measurements at locations determined by the measurement grid. The user can monitor measurements in real time and either choose to repeat measurements at select points or request that the computer automatically accept measurements and record that information. If the user opts to let the computer automatically accept measurements, the motion will be completely automated. It is still recommended that the user remain near the control computer should an emergency shutdown be necessary.

Version Control and Program Modification

Changes are frequently made to the motion control software to improve system reliability. Each version is accompanied by a changes log that outlines major and minor fixes and differences from the previous version. Within the main program, the version number is located directly below the program title “Motion Control”. The customizable nature of the software implies that it is not possible to compile a read-only version of the program. This means that the version held by a user can be modified and even destroyed if carelessly handled. Before modifications are made to the program, the user should make a backup copy to ensure that permanent damages are not incurred to the base copy. If the base copy of the software is corrupted, a backup of the most current version is available on the shared network drive.

2.3 Software Design and Functionality

This section describes the function of the major monitor and control featured in the software. The main program uses a tab control to organize the various control options. This manual organizes the controls and monitors in a similar fashion grouping the components by SubVI and tab.

Main Program

The Main Program is the screen the user sees when the program is first run. It consists of various tabs that organize the controls of the program by function. These tabs include: Monitor Tab, Data Setup Tab, Data Monitor Tab, Settings Tab, Measurement Setup Tab, Help Tab. The Data Monitor Tab only becomes available during the Execution Phase after the measurement has started. The Measurement Setup Tab

is invisible during this phase rendering it unavailable while the system is in motion. Each tab contains a number of components which allow the user to either observe information about the system or control some aspect of the motion and measurement.

Monitor Tab

The Monitor tab allows the user to observe the position of the microphone boom, its velocity, the current data point being sought, and various alarms. The current position monitor relies on the use of encoders attached to the motor. The encoder monitors the actual position of the microphone and relays that information to the monitor. Various indicators exist to help the user understand the current state of the system. A list of indicators and their purpose are listed below:

Position Monitor - This displays a visual representation of the measurement field and the microphone position in that field.

Seeking Data Point Number - These numerical indicators indicate which data point is the current target of motion and measurement

Seeking Position - This display indicates the data point being sought. This means that the boom is either traveling towards this coordinate or recording data there.

Current Position - This indicates the current position of the microphone as it moves.

Planar Arm Velocity - This indicates the speed of boom motion through the chamber.

Run Progress - This is a progress bar which allows quick observation of the percent progress made in the measurement sequence.

Time to Completion - This monitor estimates how long the system will take to finish the measurements. It is a rough estimation to within several minutes.

Status - A text box which indicates the next steps to be completed by the user.

System Initialized - This status indicator affirms that the settings needed for proper function of the system have been initialized.

XY Motion - This indicates that the system is moving in the X-Y plane.

Z Motion - This indicates that the system is moving in the Z plane.

Correcting Position - This indicates that minor adjustments are being made to the position of the microphone to ensure that the desired position is reached to within a precision of 100 micrometers.

Motion Settling - This indicates that the user defined motion settling time has begun. Motion settling time is the time the system rests after making a move but before making a measurement. It can be used to verify that vibrations in the support rod have damped out before the measurement is made.

Measurement - This indicates that the user defined measurement is being executed.

Alarm - This indicator signals that the motor has “faulted” or has an “alarm”. This occurs when the motor stalls by either running into a physical object or having a poorly connected encoder cable. When this signal is received, motion shuts down to avoid damaging the system.

Limit Error - This indicates that there was a problem associated with the limit switches installed in the chamber. This means that either the motion system has run outside the prescribed software boundaries or that a limit switch was encountered unexpectedly.

Motion Shutting Down - This indicates that the final stage of motion is initiated and that the system will quit momentarily.

Finding Reference - This indicates that the system is moving and seeking the reverse or home limit switch to zero itself physically in the chamber. During this phase, position information is not available because no absolute reference has been defined. Once the reference position is found, position information becomes available.

System Paused - This indicates that the user has selected the “pause after move” button and that the system is awaiting further instructions. Motion Settling and

Measurement will take place once the user unpauses the motion.

Start Measurement - This will begin the Execution Phase utilizing the measurement parameters that have been entered. If there are any problems with settings, the user will be informed at this point and motion will not begin.

Quit - This button will end VI execution.

End Program After Move - This button is only available after the Execution Phase as begun. Selecting this button allows the system to finish its motion and then exits the Execution Phase after the measurement has been made at that position.

Emergency Kill Program - This button is only available after the Execution Phase as begun. Selecting this button immediately ends motion and exits the program. Data previously saved remains untouched, but the Execution Phase ends. Emergency Kill is recommended if problems requiring immediate attention occur in the anechoic chamber. This includes situations wherein a collision is eminent and the user has enough time to stop the system before it occurs.

Pause After Move - This button is only available after the Execution Phase as begun. This option will halt program execution (but not terminate the program) after the motion phase has been completed. At this point the user can enter the chamber to make any necessary changes. Once the system resumes motion, the program will make the appropriate measurement and then continue to the next position.

The Monitor Tab contains the “Emergency Kill Program” button which makes it one of the more important tabs to leave open while running the measurement. If the program needs to be killed for any reason, a feature exists which allows the user to resume measurement from the last position. This feature is called “Resume”. More information about how to use this feature can be found in the description of the Settings Tab.

Data Setup Tab

The Data Setup tab allows the user to customize the set of data points which collectively form the measurement grid. A list of prominent features contained on this tab are listed below.

Position Matrix - A list of all the data points to be measured in this experiment. The list can be saved for later use using the “Save Grid” button. You can load a saved list using the “Load Grid” button. The measurement grid can be manually entered or loaded from a file in which the X,Y and Z coordinates are tab delimited and each coordinate occupies a single line of the file.

Measurement Geometry - This window displays the entire measurement grid. The points are connected with a dark line that indicates that order in which points are sought.

Remove Duplicates - This button removes any duplicate points found in the positions matrix.

Clear Data Points - This button deletes all points from the Position Matrix. This operation cannot be undone.

Advanced Setup - This button loads a separate coordinate editor. The data points are imported into the editor. The advanced editor allows you to select groups of points for mass editing. It also provides access to the Z List which is explained below.

Z List - This is a list of points found in the Advanced Setup coordinate editor. Each point specified in the list defines the beginning of a new plane. When a point in the Z List is encountered during the Execution Phase, before moving to that point, the program will lift the Z motion to its highest position. The planar move (in the XY plane) is made followed by another Z motion (vertical) move. This is useful when making measurements around equipment because the user can specify where to lift the microphone over equipment so that collisions are avoided. It takes time to raise and lower the microphone so it would not be wise to enter every point into the Z List.

Custom Offset - This coordinate indicates where the relative zero of the measurement grid is located. It may be set using the “Set Custom Origin” button under the measurement setup tab. When using a custom offset, the origin specified in the measurement grid will be located at this location in the absolute chamber coordinate system.

Predefined Data Plot - A section of the Data Setup Tab dedicated to automated measurement grid creation. See table 3.6 for more details.

Auto-create - This button determines the type of measurement grid to be created. Available options include the creation of a plane, line, or arc.

Plane - Once a planar grid type is selected, options related to creating that plane become available. Point resolution in each dimension can be entered to define the spacing between points. The plane can be defined in either the XY plane, XZ plane, or YZ plane. The height field indicates the offset of the plane in the dimension normal to the plane orientation. The domain can be set to limit the grid expanse in the selected plane.

Line - A line measurement can be made between any two positions. The “number of points” field determines how many data points will be measured between those two points. The minimum number of points is two, a case which would define the two listed positions as the initial and final measurements points.

Arc - This measurement type defines an arc in space. “Arc Center” determines the position of the arc’s center in the XYZ coordinate system. Once the center has been defined, that point will serve as the origin for a spherical coordinate system within which the user may define the arc. In spherical coordinates the $(1, \pi/2, 0)$ vector points in to +x direction according to the anechoic chamber’s Cartesian coordinate system. The user can define the initial and final positions in spherical coordinates and generate the data set. The “Pi calculator” button provides a calculator for con-

verting integer and fractional multiples of pi into a floating point value. This is useful since decimal values are required for the angular portion of a coordinate position in spherical coordinates. It is recommended that 6 decimals of precision be used when entering those values.

Generate Data Points - Once the appropriate grid auto-creation parameters have been entered in the options section, this button will generate the desired measurement grid. The system can either append the newly generated data set to the current set found in the Positions Matrix or replace the current set altogether. The choice between these options is available after pressing this button.

Domain Truncation - Checking this button causes the data point generator to truncate points outside the selected domain for the planar measurement. This means that if the resolution is such that a data point cannot be created on the boundary of the desired domain, the points that lie just outside the domain are removed from the data set that is generated.

Data Monitor Tab - This tab is only visible during the execution phase of the program. It gives the user the ability to add or delete points from the measurement grid. It also lets the user manually override the automated positioning by either delaying motion or jumping to another position in the measurement grid. This tab also graphically displays measurement progress during the execution phase by displaying the measurement grid points and highlighting the points that have already been measured. Prominent features contained on this tab are listed below.

Position List - This field lists all positions at which a measurement is to be made. The current position that is target for measurement has a diamond selector next to it. Positions that have already been measured are marked with a check mark.

Position View - Graphically displays all points to be measured.

Add New Position - This button allows the user to add new points to the measurement grid during the Execution Phase. In order for an added position to be successfully measured, it must be added before the system has targeted the last point in the current list.

Delete Selected Position - This button will delete selected points from the Position List during the Execution Phase. Points with check marks or the target diamond icon cannot be removed because the number of the points to be measured is associated with a coordinate. If the user deletes the first point in the list, this will shift all subsequent points in the list and give a false association between the position number and coordinate.

Manual Override - Once this button is selected, the system will continue to the current target point and make a measurement. If the “Pause between measurements” button is selected, the system will wait until the user selects either “Repeat Measurement” or “Keep measurement and continue”. “Repeat Measurement” executes the selected measurement type VI again. “Keep measurement and continue” does not execute the VI again, but instead moves on to the next point in the position list.

Jump to selected point - When this button is impressed, a number associated with the currently selected point in the Position List is saved. Once the current measurement is finished, execution will move to the saved point in the list. Once the jump to another point is made, the button will automatically turn off and execution will continue from that point onward normally unless another jump made.

Settings Tab

The settings tab contains display and motion settings available to the user. Examples of the features available on this tab include speed and acceleration control, limit settings, encoder options, and custom positioning moves. Some of the settings avail-

able on this tab are only modifiable during the Setup Phase while others may be changed during any program phase. If a settings control passes from being available to unavailable, its text will be dimmed and the button or icon associated with it will become grey and inaccessible. Several fields involved with system timing are available on this tab as well. Prominent features of the settings tab are listed below.

Resume - If execution was prematurely terminated during the previous run using the emergency kill button, activating resume will remember where execution was terminated and begin measurements from that point. If Resume is turned off then previous measurement history is deleted and the system begins from the first position.

Clear Faults on Start Up - If a motor fault or alarm occurs, the physical hardware will need to receive a “clear fault” command to resume normal functionality. Choosing “Clear Faults on Start Up” sends this clear fault command to the hardware before beginning the motion. If a fault from a previous execution, this option must be selected in order to begin the program again.

Pause Motion on Alarm - This option causes the execution to shut down if an alarm is detected. Normal execution requires that it remain activated; however, in special situations there may be a need to disable it.

Emergency Stop - This determines the type of stop that occurs when “Emergency Kill” program is pressed. “Decelerate” provides the normal motion deceleration speed. “Hard Stop” initiates an immediate halt of the system with maximum deceleration. “Hard Stop” may cause the momentum of the system to be transferred to the hanging rails causing shaking and possible damage.

Display Entire Field - When this option is enabled, the entire field of measurement is displayed on the Monitor Tab. This is the default view mode. When disabled, the user is allowed to see a more detailed view of the boom position on the Monitor Tab, but sacrifices a global picture.

Enable Fast Draw - When the visual displays of the measurement grid are rotated and dragged, it can sometimes require significant computing power to dynamically update the positions of all the points in real time. If the data field has too many points to be moved effectively with the given computer specifications, enabling fast draw can help alleviate processor strain. Enabling fast draw sacrifices the aesthetics of the rotation for speed.

Use 3D Acceleration - This option employs 3D acceleration using the default video card to render the position field and measurement grid. *Use Manual Override* This option determines whether manual override is on or off when the program first enters the Execution Phase.

Speed Control - The system is designed to operate at a fixed maximum speed. If the apparatus being moved is heavier than the ideal weight, the user may lower the planar and vertical speeds to values which reduce stress on the support arm. Acceleration and deceleration control is also available.

Monitor Refresh Rates - This field determines how often the front panel updates the position of the system. For “Display Entire Field” display settings, 10ms is recommended. When that option is deactivated, 500ms is recommended.

Motion Settling Time - This field determines how long the system waits between a completed move and the start of a measurement. It is used to eliminate vibrations from the support arm before a measurement is made. Heavier apparatuses may require a longer settling time.

Measurement Time - This field indicates how long a measurement is estimated to take based on the selected measurement parameters. It is used in estimating the total time for a measurement to be completed. *Position Reset Rate* This is a number indicating after how many measurements the system should again find the absolute origin of the room and correct for position drift unaccounted for by the encoder. A

default value of 100 measurements is recommended. Setting the Position Reset Rate to “0” sets the system to never reset itself after the initial home finding phase.

Limit Switch Settings - Limit switches prevent the system from running off the track by stopping motion if they are encountered during motion. Limit switches may be either a physical switch placed on the gantry rail or software settings that define permissible boundaries of motion. The default settings may be used by selecting “Use default”. Otherwise the user may customize the boundaries by selecting “Use custom settings”.

Software Limits - Software Limits are positions that defined an allowed region of system motion. Should the unlikely case arise that the system malfunctions and attempts to move outside this region, motion will cease and a limit error will be signaled. Software limits are relative to the absolute chamber Cartesian coordinate system and can be used to assure that the motion cannot move beyond the limit region.

Home Settings - When the position reset rate is a nonzero value, the system will attempt to find the home limit switch of all axes before continuing the measurement. If the measurement field is in a single plane or line, it would be an ineffective use of time to try and reset axes that have not been moving. To disable home-finding of these axis, you can uncheck them under the home settings panel. When unchecked, a home-finding sequence will not attempt to zero those unselected axis.

Special Moves - If the user has saved a previous measurement setup and wants to place hardware in the chamber at the same location where it was previously located. By choosing the button labeled “Offset Position”, the system will move to the selected offset position allowing the user to identify that location. To move the system back into its corner storage position, the user may select the button labeled “Storage Position”.

Measurement Setup Tab

The Measurement Setup Tab contains data acquisition parameters and file information. This tab is only visible during the Setup Phase. As information is recorded from the anechoic chamber, it is recorded to a computer location specified by the user in this section. The type of measurement made by the computer can also be selected from this tab. Sampling parameters, averaging, and other measurement specific information can be entered here. Once all measurement information and the measurement grid have been entered, this information can be saved from this tab in a single file called a "Measurement". Various components of this tab are listed below.

Folder Path - This field identifies the root computer directory to which acquired data will be saved.

Root Folder

File Name - This field identifies the desired file name of the measurement folder. This folder will contain structured data files sorted into various folders.

Test Description - This field contains a description of the data that will accompany data files. It should contain averaging and sampling information.

Custom Settings Field - This field contains various parameters for the different types of measurements. It can be edited by the user for a custom VI if desired.

Channel Setup - This button opens special PXI channel setup information to be used by a premade or custom measurement VI. It activates the Channel Setup SubVI.

Set Custom Origin - This button allows the user to use joystick control to position the system at a specific location which will then be considered the Cartesian origin for the data field. It activates the Remote Positioning SubVI.

Measurement Type - This drop down list allows the user to select the type of measurement that will be used during the Execution Phase.

Save Measurement - This button saves measurement settings including software limits, data points, custom offset, channel settings and test information.

Load Measurement - This button loads a previously saved measurement file.

Help Tab

The help tab contains a drop down list of help topics which can be accessed during any phase of the program. To access a help topic select the desired topic and then press the “Display” button. The contents of the help file associated with that topic will then be displayed in the large field. System alarms are displayed in an error monitor located at the bottom of this tab. Summarized content of this tab is listed below.

Remote Positioning System

The Remote Positioning System is a SubVI that allows the user to specify the origin of the measurement using an analog USB game pad or joystick. This SubVI can also be used to arbitrarily move the microphone boom within the anechoic chamber without having to set up a measurement grid. Two tabs are available within the window of this SubVI: the Device Configuration Tab and the Acquire Position Tab.

Device Configuration - This tab allows the user to verify that the input device is functioning properly. This tab includes a virtual layout of the default control device, device ID selector, and a test option. Figure 3.9 displays the contents of this tab.

Device ID is a number that the operating system uses to identify the device that is connected to the computer. The default value for one external device connected to the computer is ID 0. If there are multiple devices, the user may need to select the appropriate ID until device detection occurs. A device ID may not be changed while a test is in progress. To begin a test, press the “Begin Test” button under the Device Configuration tab. Device detection information is made available immediately after a test has begun. To end a test, press the “End Test” button on the acquire position

page. The “End Test” button is visible available while a test is being performed. After a device is detected during a test, the device inputs become active for test purposes only. No motion occurs during this test. When the user presses the various inputs on the external USB device, the lights on the virtual controller will illuminate indicating that the corresponding button functions properly. Should a button fail to illuminate, this could indicate a hardware problem with the attached device.

Acquire Position - The process of acquiring a custom origin or simply moving the microphone boom occurs in two phases: the Home Finding Phase and the User Input Phase. The first step is optional and can be disabled by unselecting the “Find Home First” button under the Acquire Position tab. To begin this two step procedure, press the “Begin Acquisition” button under the Acquire Position Tab. Figure 3.10 displays the contents of the Acquire Position Tab before the User Input Phase.

Home Finding and User Input Phases - In Home Finding phase, the hardware will automatically locate the home position of the system. This is a position in the room that is used as the absolute origin of the anechoic chamber. This phase involves motion movement so the chamber must be obstruction free before beginning this phase. During the User Input Phase the joystick becomes an active control for positioning the system. Once the user has positioned the boom in the correct relative origin position, the save buttons must be pressed simultaneously to record that position into the computer. The save buttons are labeled on the virtual gamepad located on the Device Configuration Tab. After setting a custom origin, select the button labeled “Done” at the bottom of the control panel to save the selected position. The button labeled “Cancel” will close the Remote Positioning SubVI without saving any information. The button labeled “Go to Saved Position” moves the system to the previously saved position offset. The button labeled “Go to Home Position” will move the microphone boom back to the anechoic chamber corner so that hardware setup

will not be impeded by the presence of the microphone boom.

The operating system is sensitive to removing devices during operation. If the device is unplugged during the User Input Phase, the Remote Positioning VI must be closed and reopened to properly detect the controller again.

Chapter 3

Hypersonic Speaker Measurements

3.1 Measurement Setup

Measurements were made starting up against the speaker and backing the microphone away in 2 cm increments up to 2 meters. The carrier frequency of the speaker was given as roughly 40 kHz and the measurement sampling rate was 120 kHz. Frequencies of 500 Hz, 3 kHz, and 10 kHz were each driven separately through the speaker and time waveform data was acquired. A combined waveform containing equal amounts of 500 Hz, 3 kHz, and 10 kHz was then driven through the speaker to analyze the combined effect of different frequencies. White noise was then driven through the hypersonic speaker to see the general features of the frequency response.

3.2 Measurement Results and Analysis

The most interesting results were found in the near and far fields. The transition between the two resulting power spectra are as easily predictable from the surrounding spectra and so those intermediate results will not be presented here.

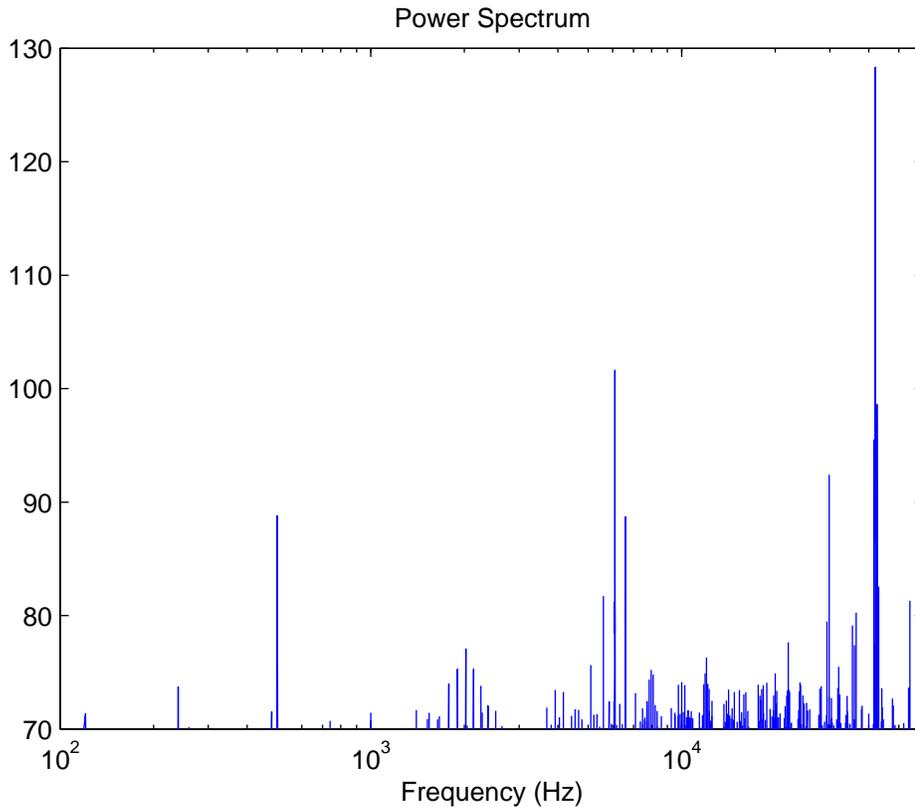


Figure 3.1 Plot of the power spectrum for a 500 Hz input signal measured at 2m from the speaker.

The 500 Hz sine wave produced an expected 500 Hz frequency component when measured at 2 meters as indicated by Figure 3.1. In the near field, the spectrum was generally characterized by more noise as seen in Figure 3.2, but still presents a small yet visible 500 Hz peak suggesting that the nonlinear 500 Hz frequency generation occurs much closer to the parametric array than measurable by the current setup. The frequency difference can be seen in Figure 3.3. As expected the difference between these primary peaks in the vicinity of the carrier frequency is 500 Hz, the desired output frequency.

The 3 and 10 kHz signals yielded similar results. Figure 3.4 shows a 3 kHz frequency difference between the carrier and surrounding components. Figure 3.5 shows a 10

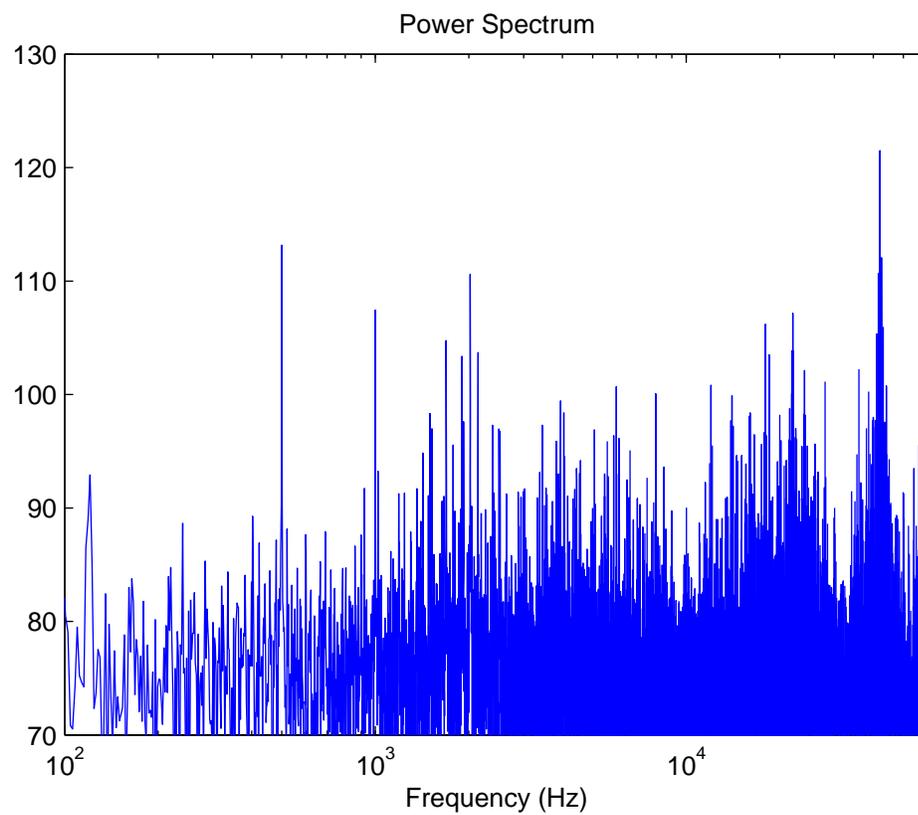


Figure 3.2 Plot of the power spectrum for a 500 Hz input signal measured at 0m from the speaker.

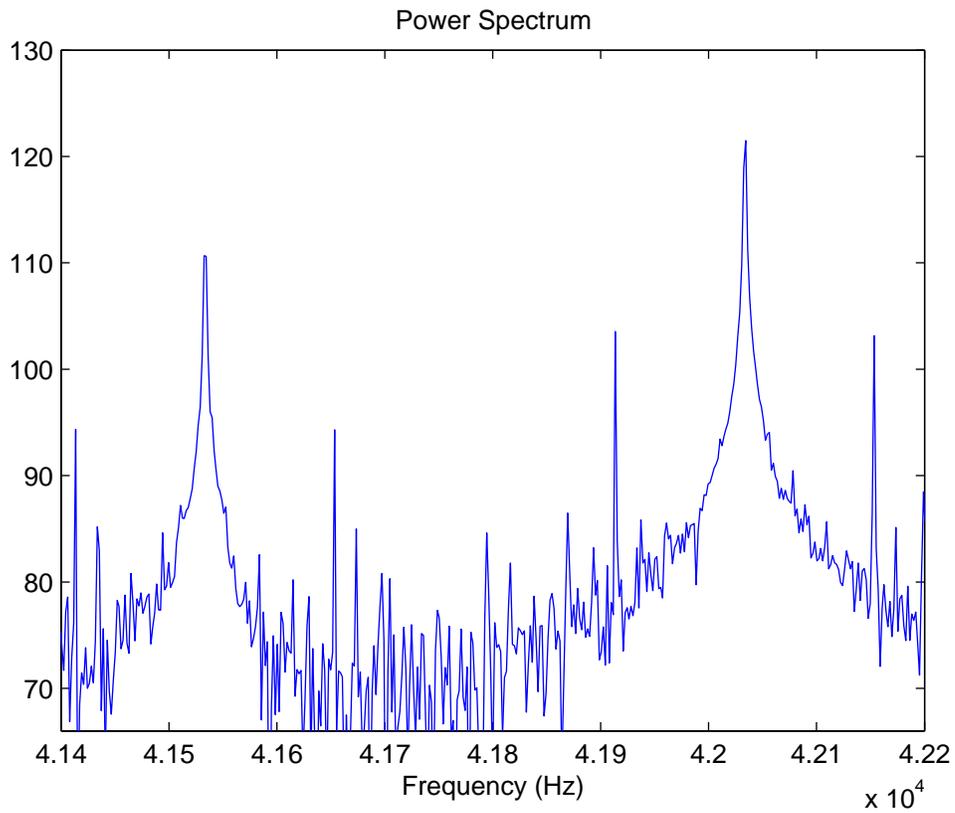


Figure 3.3 Plot of the power spectrum difference frequencies for a 500 Hz input signal measured at 0m from the speaker.

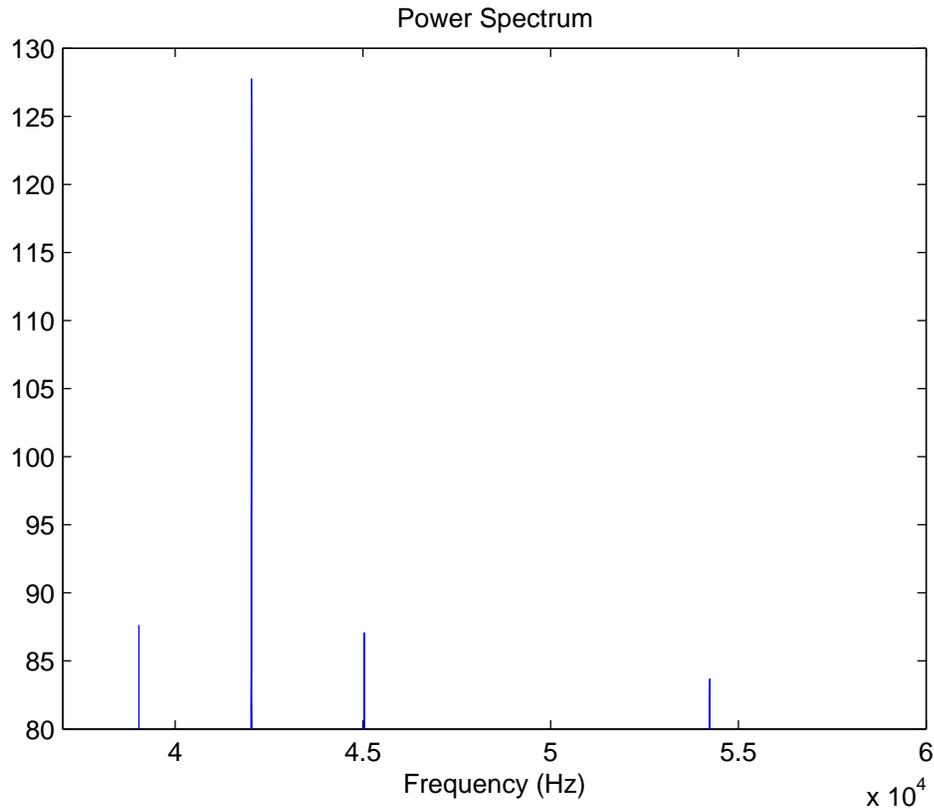


Figure 3.4 Plot of the power spectrum frequency difference for a 3 kHz input signal measured at 2m from the speaker.

kHz frequency difference between the carrier frequency and the nearest prominent peak; however, other peaks seem to dominate which may be an indication of nonlinear distortion. Further evidence of this distortion can be seen in Figure 3.6 as it is apparent that the single 10 kHz frequency is dominated by other component frequencies. This distortion is much more severe than in the 3 kHz counterpart found in Figure 3.7. This suggests that the hypersonic speaker suffers from strong harmonic distortion effects at frequencies as low as 3 kHz.

The combination of the three frequencies yields an unusual power spectrum near the carrier frequency. Figure 3.8 shows a variety of frequency peaks, the differences match any of the 3 expected frequencies, but include several other strong peaks which do

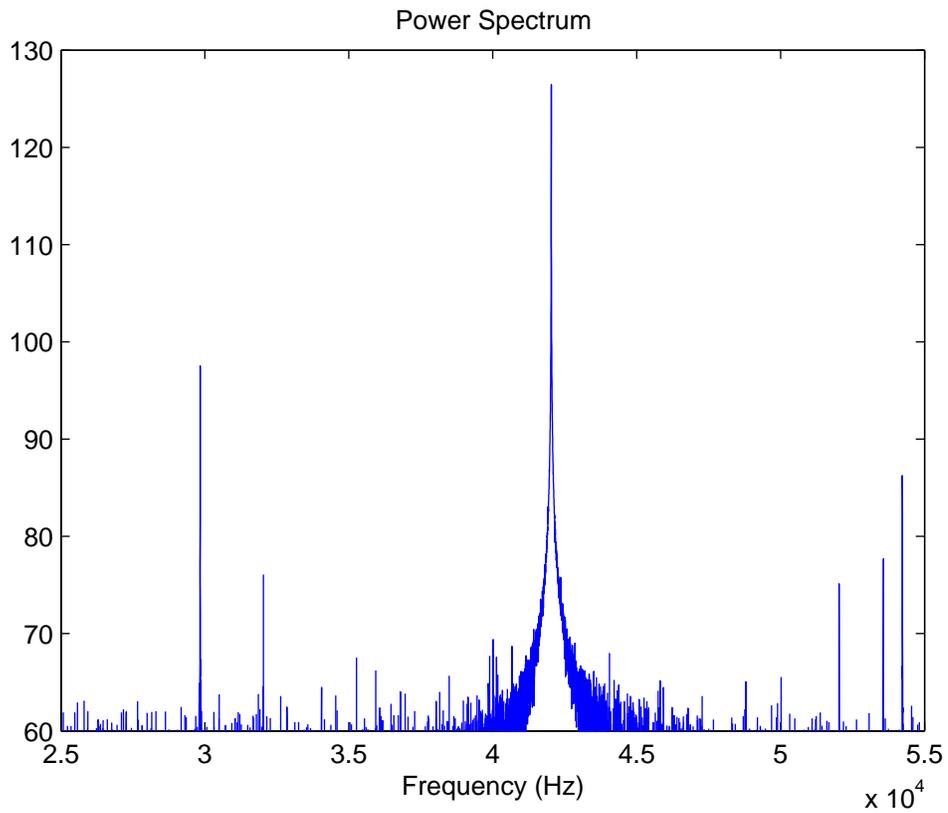


Figure 3.5 Plot of the power spectrum difference frequencies for a 10 kHz input signal measured at 2m from the speaker.

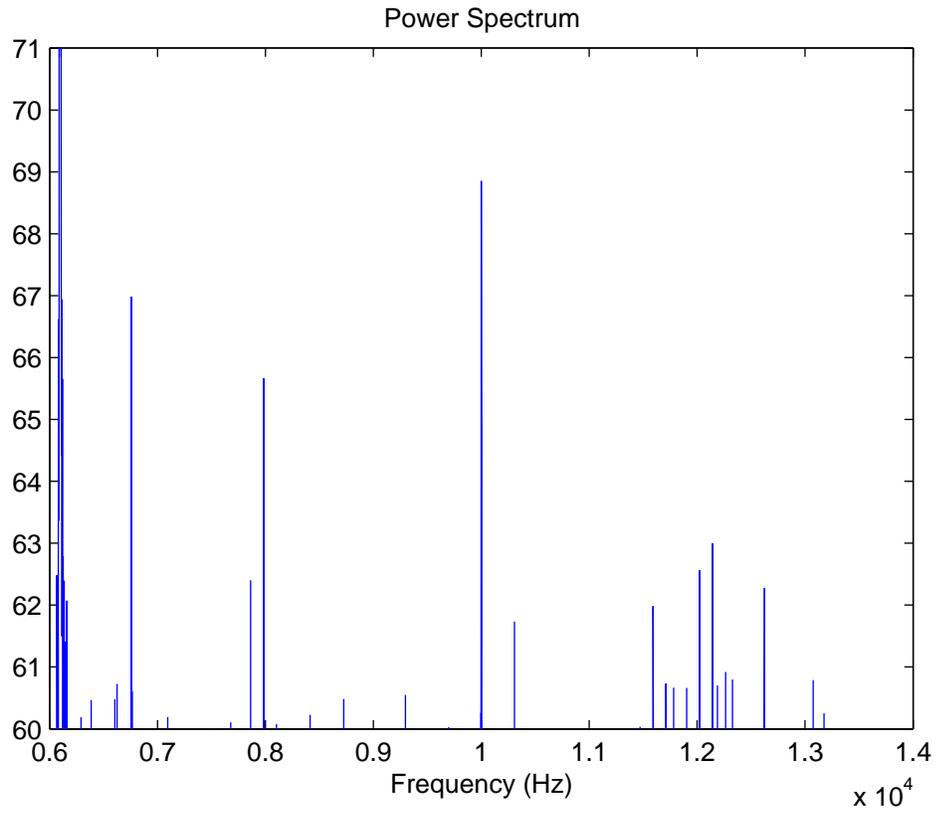


Figure 3.6 Plot of the power spectrum for a 10 kHz input signal measured at 2m from the speaker.

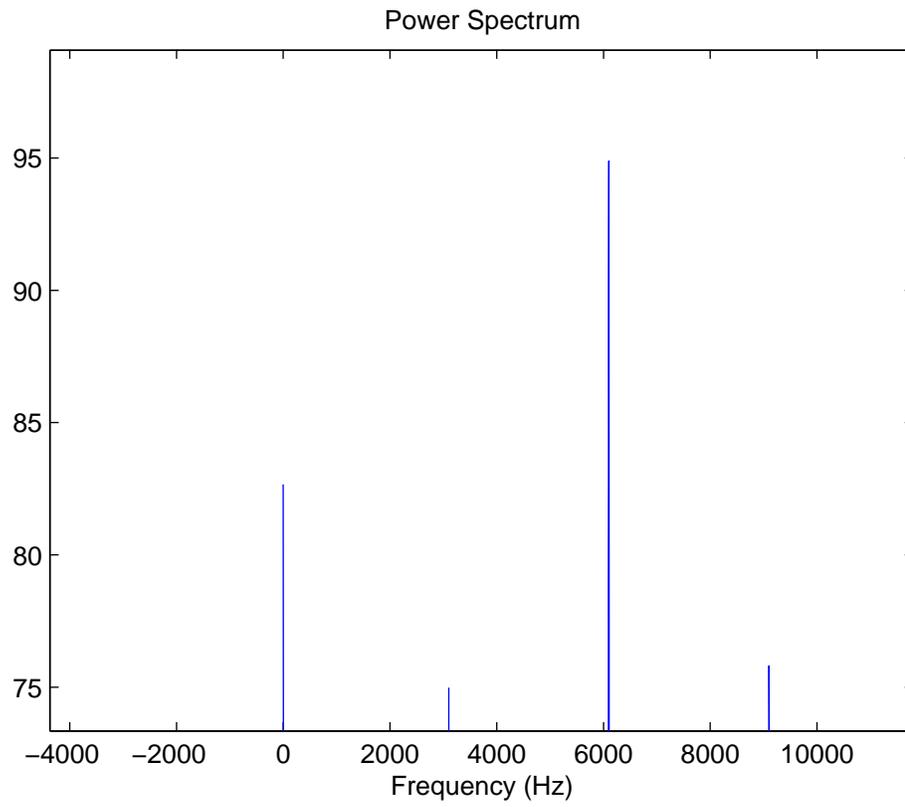


Figure 3.7 Plot of the power spectrum for a 3 kHz input signal measured at 2m from the speaker.

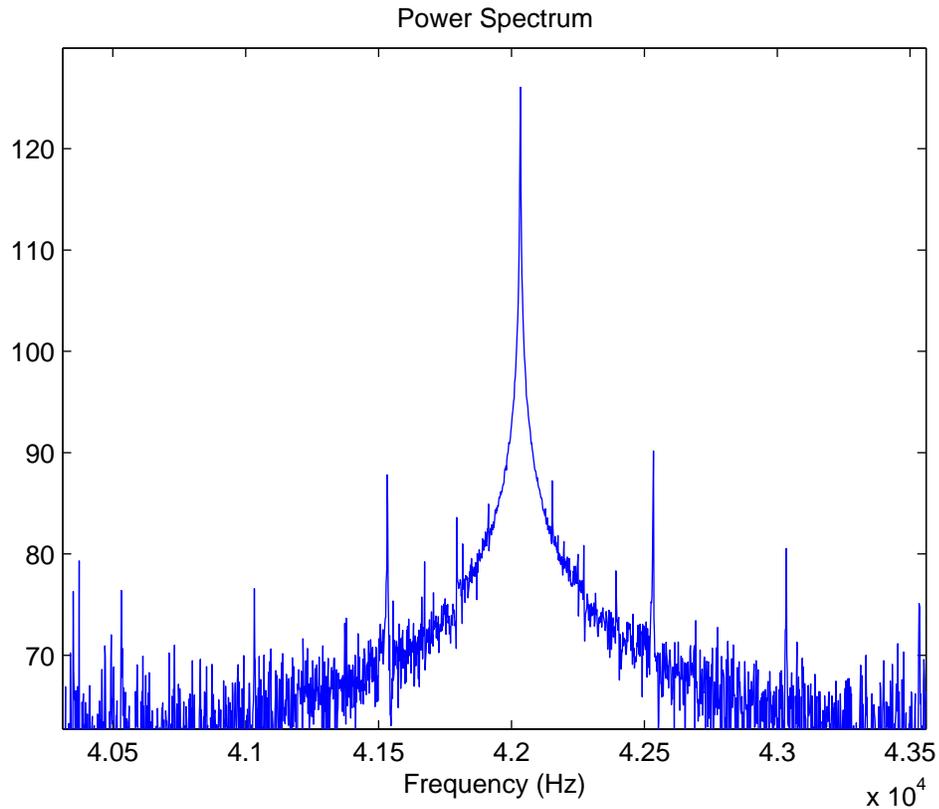


Figure 3.8 Plot of the power spectrum frequency difference for a 500 Hz, 3 kHz, and 10 kHz combined input signal measured at 2m from the speaker.

not appear as prominently in the individual frequency power spectra as seen in Figure 3.5. This suggests that the system is indeed nonlinear and cannot be treated as a superposition of individual power spectra. The system also displays strange behavior over the desired frequency range as none of the desired frequencies are dominant. Figure 3.9 shows unusual bands of varied response along with expected peaks at 500 Hz, 3 kHz, and 10 kHz. The overall power spectrum for white noise as seen in Figure 3.10 indicates that there are indeed frequency bands that appear more strongly than others.

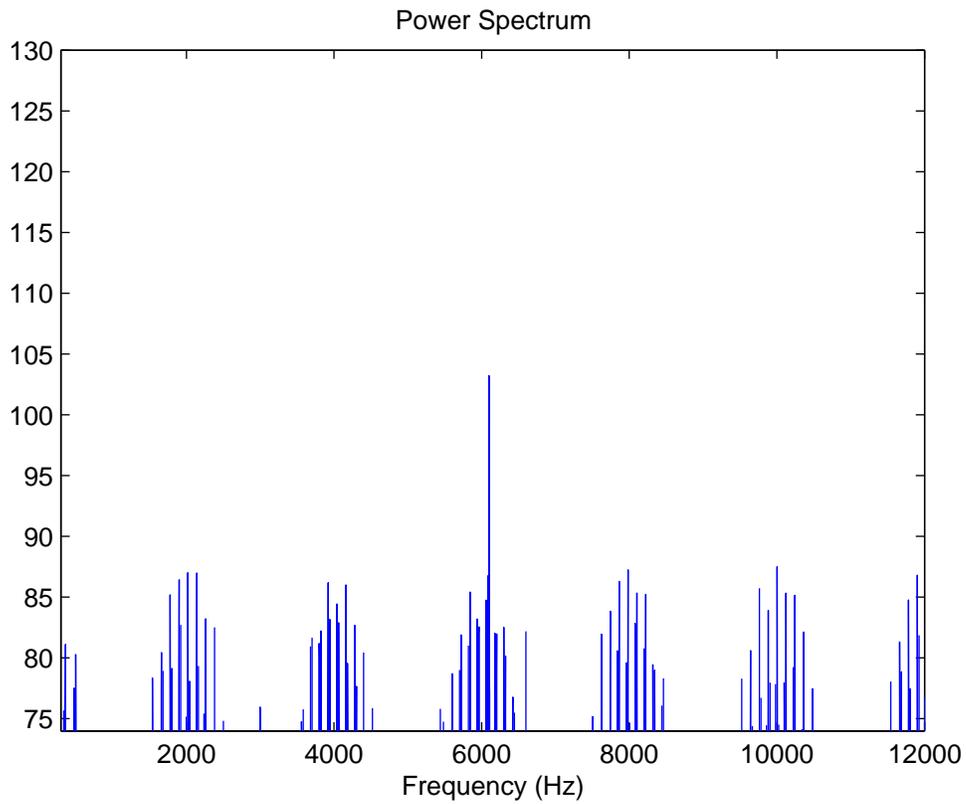


Figure 3.9 Plot of the power spectrum for 500 Hz, 3 kHz, and 10 kHz combined input signal measured at 2m from the speaker.

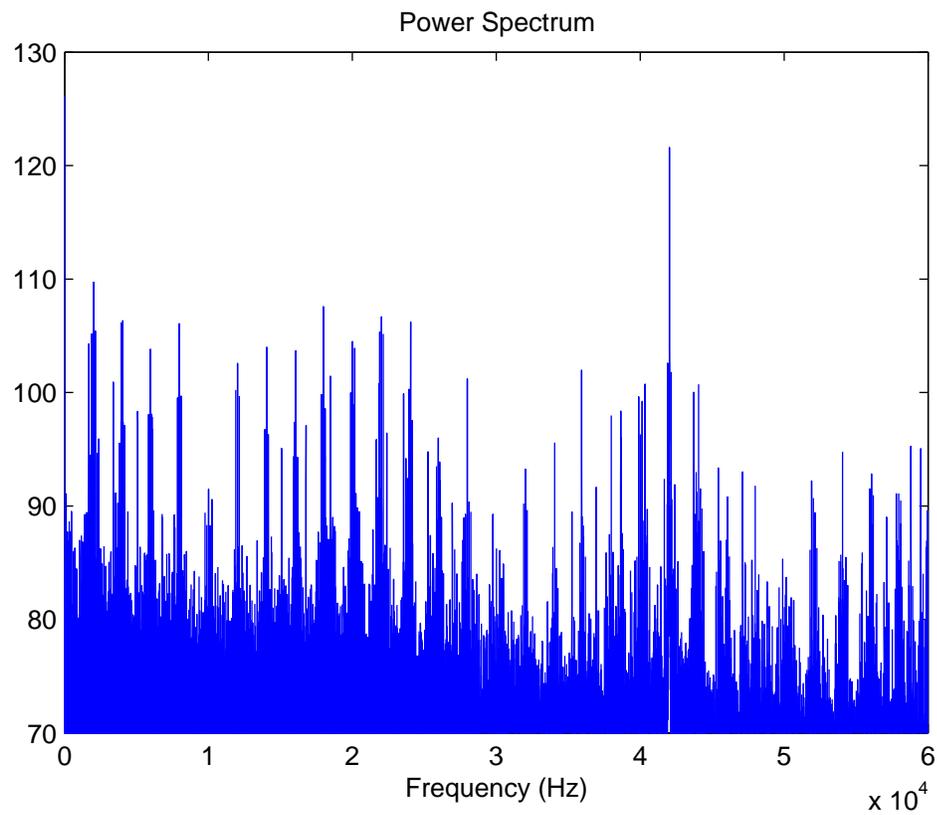


Figure 3.10 Plot of the frequency response of the hypersonic speaker using white noise.

Chapter 4

Conclusion

4.1 Positioning System Conclusion

The design of an automated positioning and measurement system allows for high-resolution measurements in stationary sound fields that could not be carried out with a reasonable number of channels or in a reasonable amount of time. Results thus far indicate a successful implementation of the system. Hardware torque, speed, acceleration, weight, and acoustically absorptive properties must be taken into consideration when installing the positioning system in an anechoic chamber. There are several methods of position error correction including resetting the system to an absolute reference and using relative encoders to determine actual position. Software considerations include position adjustment, measurement duration calculations, automated measurement, field generation, relative origin acquisition, and predefined measurements

4.2 Measurement Conclusion

The hypersonic speaker system appears to use a nonlinear method of generating audible frequencies. The cost of this includes undesired distortion at relatively low audible frequencies, as well as a characteristic noise production. This suggests that hypersonic speakers would be less than ideal for system requiring clean, crisp sound such as music playback. The power spectra of system involving more than one frequency component do not follow a simple linear treatment of wave mechanics and require a more rigorous treatment to be properly analyzed and used in theoretical applications.

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