

Mechanical Oscillator

User Manual

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Olin-NASA Research Group

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Table of Contents

1 – Quick Start Guide.....	3
2 – Oscillator Assembly.....	5
3 – Amplifier Circuit and Transformer.....	7
4 – Software.....	9
5 – Troubleshooting.....	11
6 – Components.....	12
7 – Frequency Response Report.....	18
8 – Drawing Files.....	21
9 – Suppliers.....	23
10 – Acknowledgements.....	23

1 – Quick Start Guide

1 - Mount oscillator to target object with 6-32 size screws

The oscillator assembly should be mounted to the target object using 6-32 size screws. The base plate of the assembly has four through holes, one at each corner, dimensioned to accommodate these screws. The assembly should be attached using all four of these holes to ensure a strong connection.

2 - Connect blue and green transformer leads to orange leads on amplifier circuit

The blue and green leads coming from the transformer, which is mounted to the base plate, must be attached to the orange leads coming from the bottom of the amplifier circuit. Since the amplifier circuit was designed to function at normal room conditions, these connections must be made via a feedthrough to the outside of the dewar.

3 - Attach ± 18 V power supply to amplifier circuit

Connect a ± 18 V power supply to the amplifier circuit via banana clips. The +18 V lead should be plugged into the red port labeled with a “+”. The -18 V lead should be plugged into the red port labeled with a “-”. A grounded lead should be plugged into the black port.

4 - Attach the amplifier circuit to a computer via a 3.5 mm mono audio cable

Plug a 3.5 mm mono audio cable into the small black audio port on the amplifier circuit. The other end of this cable should be plugged into the audio port of a computer that supports MATLAB 7.0.

5 - Open MATLAB 7.0 and run *control.m*

Open MATLAB 7.0 and navigate its current directory to the folder containing *control.m* and *control.fig*. Type `control` into the MATLAB interface to launch the program.

6 - Calibrate the output of the control program

Set the sound card volume on the computer at a value that corresponds to the normal listening volume of the computer if head phones were in use. Set the output amplitude to 1 by opening the “Adjust Output” window in the “Calibrate” pull down menu. Close the “Adjust Output” window. Select the top line in the program window. Enter 2000 in the “Frequency (Hz)” field and 5 in the “Duration (s)” field. Connect a floating scope across the two output wires of the amplifier circuit in order to measure the output waveform. Click “Test Selected Line” and observe the output waveform. If the wave form is clipping, open the “Adjust Output” window again and reduce the output amplitude. The oscillator functions best at the greatest amplitude that does not result in clipping. This calibration should be done at the beginning of each use.

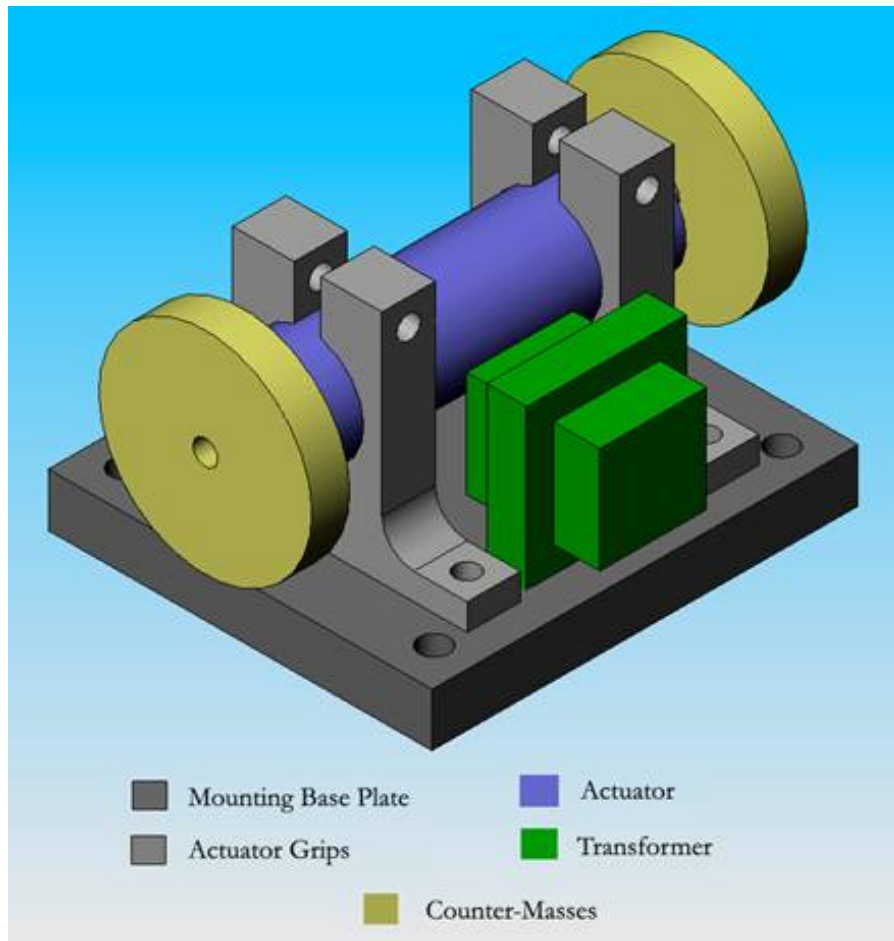
7 - Run program with desired frequencies

In the control program window, input the desired frequency and time duration of the signal. Up to five signals can be played sequentially. Click “Run Program” to begin driving the oscillator. The frequency currently being played should become green.

2 – Oscillator Assembly

Assembly Overview

The solid model shown below is graphical representation of the oscillator assembly. This assembly is intended to be placed inside the dewar and operate at 4 K. This assembly was tested at temperatures as low as 77 K, at which it was still fully functional. At room temperature, the oscillator was found to be able to produce vibrations that, when attached to a 10 kg mass, would have magnitudes on the order of mG's. The assembly was found to have resonances at 530 Hz as well as 2500 Hz. At these frequencies, vibrations of approximately 30 mG's were predicted. Details of the experimental data can be found in Section 7.



Oscillator System

The actuator used in this system is a moving magnet linear actuator purchased from H2W Technologies. This actuator functions on the principle of a voice coil. The lead counter-masses mounted to each end of the moving magnet are approximately 25 g. This mass is great enough to produce accelerations on the order of mG's on a 10 kg mass.

Compression springs were placed along the magnet between the counter-masses and the end of the actuator casing. These springs keep the magnet centered within the voice coil without substantially affecting its travel. The transformer connects the actuator to the amplifier circuit, which is kept outside of the dewar. Details about the function of the transformer can be found in Section 3. Specs for all of these components are available in Section 6.

Mounting System

The mounting system for the oscillator assembly consists of three main parts, two actuator grips and a base plate. These pieces were cut from 1/4" 1018 steel. This is the same steel of which the casing of the actuator is made. This prevents any damage to the actuator that may have otherwise occurred due to thermal contractions. Drawing files for these parts are in Section 8.

Assembling the Oscillator System

To begin assembling the oscillator system, the actuator should be placed through both of the actuator grips. The grips should then be generally positioned over the threaded holes in the base plate. Two 1/4" long, size 4-40 screws may be used to attach the grips to the base plate. Each screw should be screwed in to half its length before any of the screws are tightened. A size 4-40 Belleville washer should be placed between the head of each screw and the grip to ensure tight connects after thermal contractions.

The actuator can be secured in the grips by placing a 1" long, size 4-40 screw through the holes in the top of the grip and tightening a nut on the other end of the screw. Belleville washers should be placed between the heads of the screws and the grips as well as between the nuts and the grips.

After the actuator is secured, the centering springs may be placed along the moving magnet as described previously. Next, the counter-masses should be attached. These masses are held on to the magnet via 3/8" long, 2-56 size screws. Size 2-56 Belleville washers should be placed on either side of the mass before screwing the mass to the magnet.

Attaching the Assembly to the Target Object

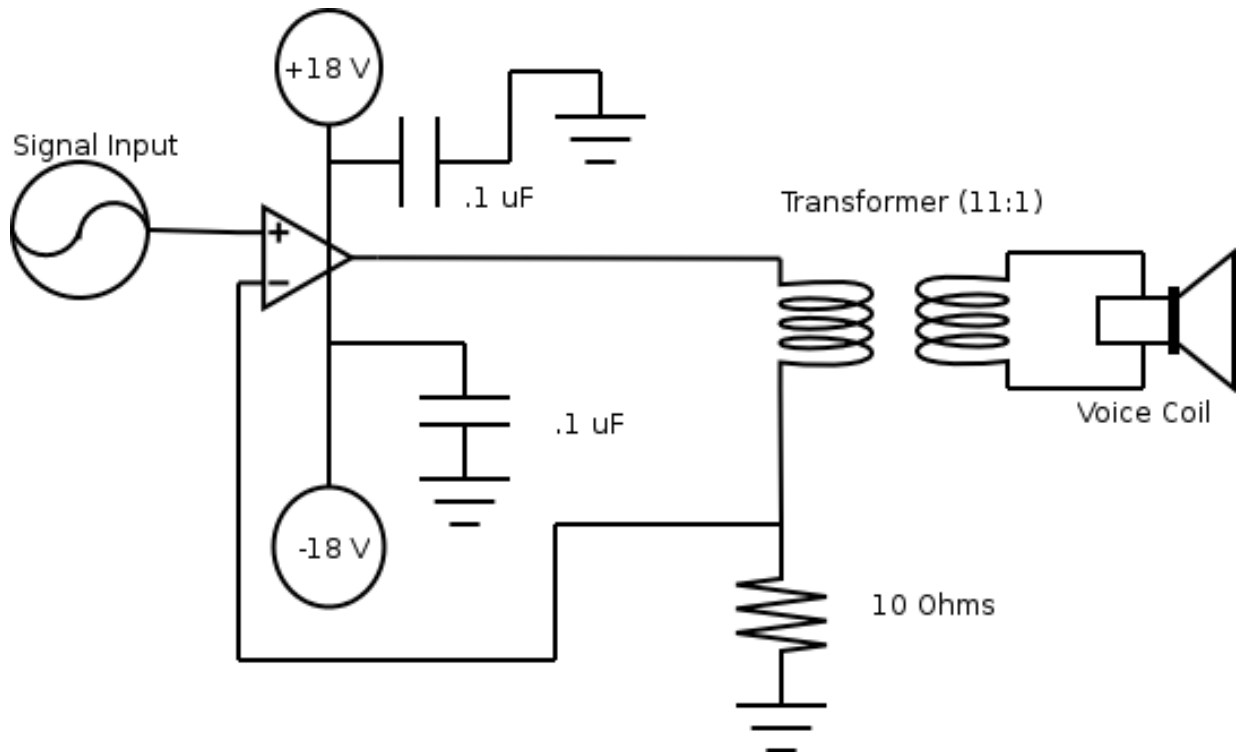
The oscillator assembly should be mounted to the target object using 6-32 size screws. The base plate of the assembly has four through holes, one at each corner, dimensioned to accommodate these screws. The assembly should be attached using all four of these holes to ensure a strong connection.

3 – Amplifier Circuit and Transformer

Circuit Overview

The circuit diagram below is a graphical representation of the amplifier circuit. This circuit is a current driven operational amplifier circuit. A current driven circuit was desirable because it prevents the voice coil current from varying as the resistance of the feed through wiring varies. The op-amp used in this circuit was an OPA551 (See op-amp specs in Section 6). The transformer shown in the circuit diagram is actually separate from the amplifier circuit. It is attached to the base plate of the oscillator assembly and is placed inside the dewar. This transformer was necessary to connect the voice coil to the high impedance wiring within the dewar. This is because the voice coil works more efficiently with a high current and a low voltage.

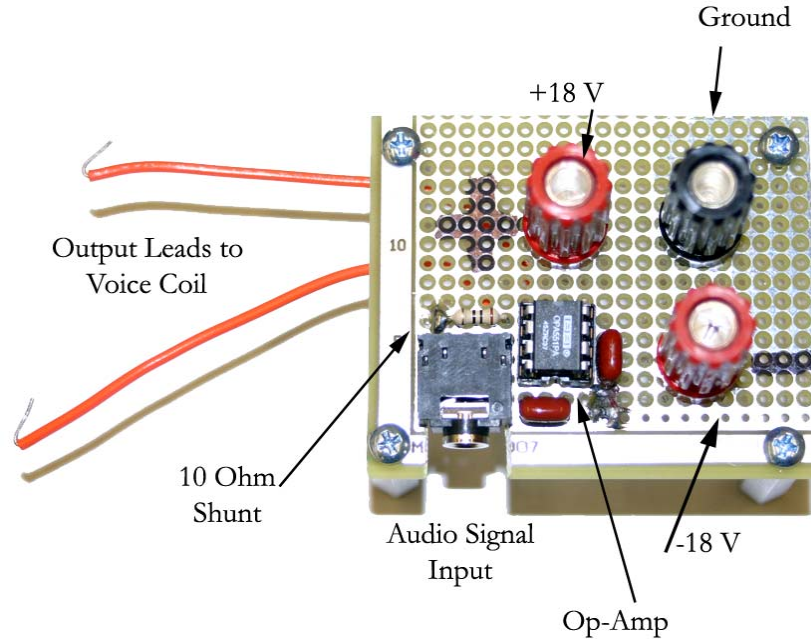
Circuit Diagram



Connecting the Circuit

The amplifier circuit should be connected to a ± 18 V power supply via banana clips. Higher voltages may result in op-amp failure even though it is rated to ± 30 V. A 3.5 mm mono audio cable should be plugged into the signal input port. The other end of this cable should be plugged into the audio output port of the computer that is supporting the oscillator control software.

The orange output leads of the amplifier circuit should attach to the blue and green leads of the transformer via a feed through on the dewar. Each connection port/wire is labeled in the diagram below.



Performance

In room temperature testing, the circuit was found capable of delivering high quality waveforms to the oscillator over the majority of the desired frequencies (60-2000 Hz). This waveform had an amplitude of approximately 400 mA. Details of experimental data can be found in Section 7. The quality of the voice coil current waveform should improve significantly at cryogenic temperatures (4 K) because the resistance in the wiring of both the transformer and the voice coil becomes negligible. This improvement may allow for high quality waveforms at frequencies as low as 20 Hz.

Replacing Components

Note: Before making changes to the circuit or adjusting components, be sure that it is disconnected from the computer and the power is off. Otherwise, power may be inadvertently back-fed into the computer.

Over the course of its use, some components in the circuit may burn out or otherwise break. The OPA551 can be replaced by simply pulling out the damaged one and pushing a new one into its place. It is important to orient the replacement op-amp such that the semicircular notch on the op-amp is close to the positive input terminal. All other components must be removed by melting away the solder that holds them in place.

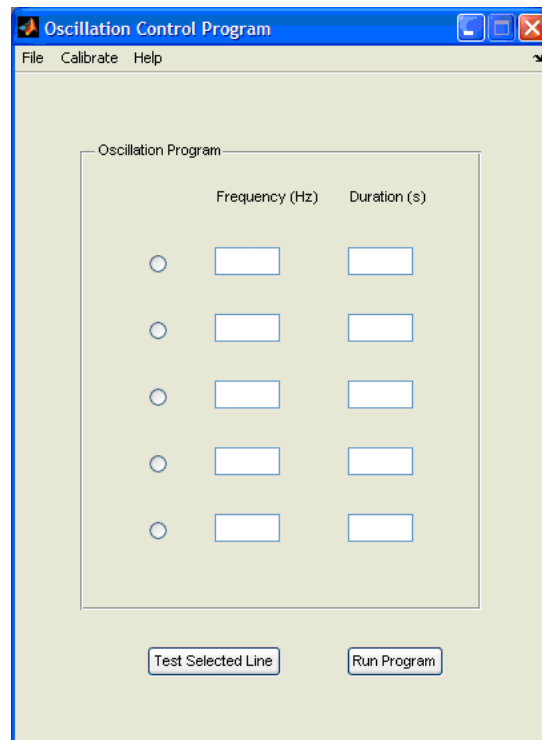
4 – Software

Control Program Overview

The control software was designed to be easily customized and to operate within multiple operating systems. Developing the application and interface using MATLAB permits the software to be run from any system that supports this program (OSX, Windows XP, etc.). The output from the software was directed through the audio output port of the computer because the sound card on a computer outputs a relatively accurate reproduction of sound sources in the range of ± 1 V. Since sound cards on different computers may output waves of different amplitudes, a configuration option was included that would alter the amplitude of the output wave as to provide similar output conditions regardless of which computer is used.

Launching the Application

The application was developed in GUIDE, so it consists of two files, *control.fig* and *control.m*. To launch the application, navigate MATLAB's current directory to the folder containing both of these files, then either type `control` into MATLAB or run the *.m* file. This causes the following window to be displayed.

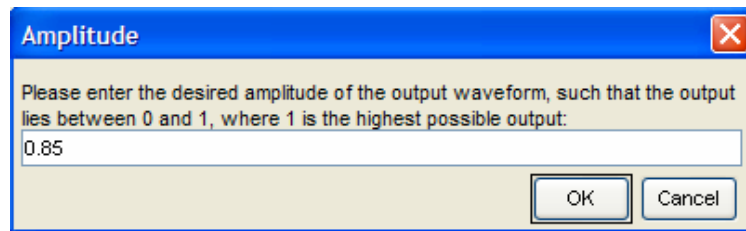


Calibrating the Output

Set the sound card volume on the computer at a value that corresponds to the normal listening volume of the computer if head phones were in use.

The calibration tool scales the output of the program by a factor between 0 and 1, where 1 is the maximum output possible. The value of 1 will roughly correspond to ± 1 V output, but this might vary from computer to computer.

To calibrate the output amplitude of a specific computer, open the “Adjust Output” window (seen below) in the “Calibrate” pull down menu. Set this value to 1, and Close the “Adjust Output” window. Select the top line in the program window. Enter 2000 in the “Frequency (Hz)” field and 5 in the “Duration (s)” field. Connect a floating scope across the two output wires of the driving circuit in order to measure the output waveform. Click “Test Selected Line” and observe the output waveform. If the wave form is clipping, open the “Adjust Output” window again and reduce the output amplitude. The oscillator functions best at the greatest amplitude that does not result in clipping. This value will not be saved onto the hard drive, so each time the application is launched, this value will need to be set. To edit the default amplitude of the output wave see *Customizing the Application*.



Running the Application

The frequency and the length of the output can be set in the “Frequency (Hz)” and the “Duration (s)” fields. There are two options for outputting sound waves with the program: either one specific line or all five lines sequentially. Using the “Test Selected Line” command may be helpful for configuring the oscillator before testing begins. Lines may be selected by clicking the round button on the left of the desired line. For substantial data collection, the “Run Program” command will be useful. When the “Run Program” button is pressed, the application will progress through each line that contains a frequency and duration. If these parameters are not present, it will move on to the next line. The button of the current line will be selected and the parameter fields will be green while that line is being played. The image below demonstrates how an active line will appear.



Customizing the Application

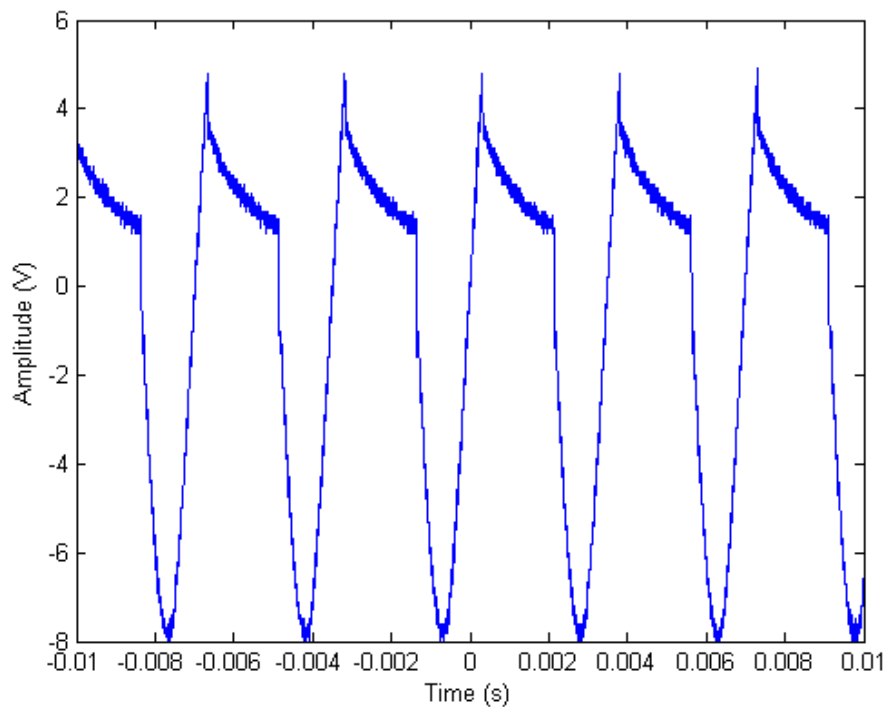
To edit the graphical layout of the application, type `guide` into MATLAB, and this will launch the GUI development tool. To edit the default amplitude of the output wave, change the value on lines 22 and 201 to the desired value. This will be the amplitude that the program will run at upon launch.

5 – Troubleshooting

Unusual Waveform

In some cases, the output of the amplification circuit appears as below. When this happens, the op-amp is not functioning properly and must be replaced. When replacing the op-amp, it should be positioned so that the semicircular notch is closest to the positive voltage port. Replacing this component should solve the amplification circuit's problems.

Note: Before making changes to the circuit or adjusting components, be sure that it is disconnected from the computer and the power is off. Otherwise, power may be inadvertently back-fed into the computer.



Clipping Waveform

If clipping is noticed on the output waveform of the circuit, follow the instructions in Section 3 under *Calibrating the Output*.

Choppy Voice Coil Movement

If the moving magnet in the voice coil clicks or no longer moves smoothly, this may mean that it is dirty or otherwise clogged. The voice coil may be opened and cleaned. Before opening the voice coil, the counter-masses and springs should be removed. To open the voice coil, note that there is a snap ring on one side of the oscillator. Removal of the snap ring with pliers allows access to the inside of the assembly.

6 – Components

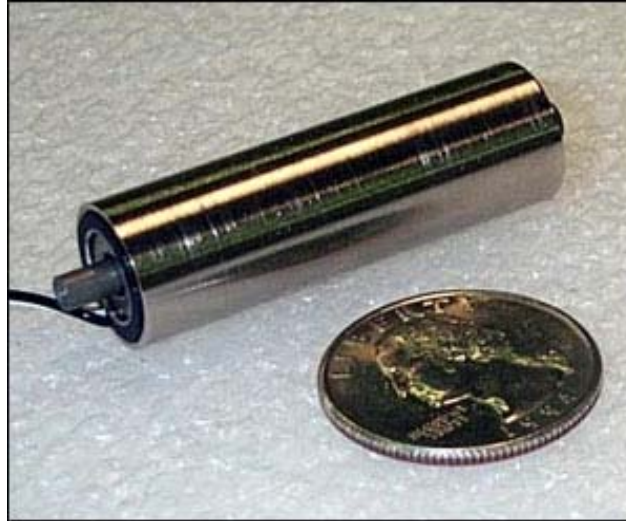
Oscillator System

Actuator

Non-Commutated Direct Current Moving Magnet Linear Actuator from H2W Technologies

P/N: NCM02-05-005-4JB

Serial: G501



See Section 8 for drawing and dimensions

- Power Rating: 3.5 W
- Voltage Rating: 3.5 V
- Current Rating: 1 A
- Casing Material: 1018 Steel
- Magnet Travel: 0.15"
- Max. Acceleration: 20 G
- Continuous Force: .5 lbs.
- Peak Force: 1.5 lbs.
- Average Km: 0.27 lbs./W^{1/2}
- Total Mass: 0.067 lbs.
- Moving Mass: 0.026 lbs.
- Inductance (Room Temp.): 0.2358 mH
- Inductance (77 K): 0.2262 mH
- Resistance (Room Temp.): 3.38 Ω
- Resistance (77 K): 0.649 Ω

Centering Springs

Compression Springs from Century Spring Corporation
P/N: 10572



- $k = 1.1$ lbs./in.
- OD: 0.234"
- ID: 0.210"
- Free Length: 0.310"
- Max. Deformation: 0.250"
- Max Load: 0.270 lbs.
- Wire Diameter: 0.012"
- Number of Turns: 4.5

Counter-masses

Lead from McMaster-Carr
P/N: 9054K23



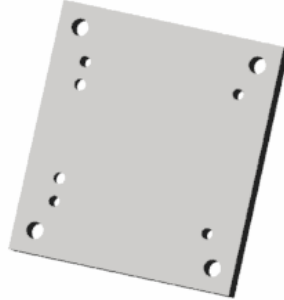
- Weight: 0.054 lbs. each
- OD: 0.95"
- Thickness: 0.18"
- Through Hole: 2-56

Mounting System

Base Plate

1018 steel from McMaster-Carr

P/N: 8910K598



See Section 8 for drawing and dimensions

- Thickness: 0.25"
- Thickness Tolerance: ± 0.003 "
- 1018 Carbon Steel
- Finish/Coating: Unpolished (Mill)
- Maximum Attainable Hardness: Rockwell B72
- Yield Strength: 55,000 psi
- Four (4) 6-32 through holes for mounting
- Four (4) 4-40 through holes for actuator mounting
- Two (2) countersunk holes for transformer mounting

Actuator Grips

1018 steel from McMaster-Carr

P/N: 8910K598



See Section 8 for drawing and dimensions

- Thickness: 0.25"
- Thickness Tolerance: ± 0.003 "
- 1018 Carbon Steel
- Finish/Coating: Unpolished (Mill)
- Maximum Attainable Hardness: Rockwell B72
- Yield Strength: 55,000 psi
- Two (2) 4-40 holes for baseplate mounting
- One (1) 4-40 hole for grip tightening

Fasteners

Screws

Size 4-40 Screws from McMaster-Carr

P/N: 90272A115, 90272A106



- Length: 1.0” for mounting grip
- Length: 0.25” for grip attachment
- Material: Steel – Zinc Plated
- Head Style: Pan
- Drive Style: Phillips
- Thread Size: #4-40
- Decimal Size: 0.112”
- Head Diameter: 0.219”
- Head Height: 0.080”
- Thread Point Style - Standard Machine
- Rockwell Hardness: B70
- Minimum Tensile Strength - 60,000 psi

Size 2-56 Screws from McMaster-Carr

P/N: 90022A096



- Length: 0.375”
- Material: Steel – Zinc Plated
- Head Style: Pan
- Drive Style: Allen
- Thread Size: #2-56
- Decimal Size: 0.068”
- Head Diameter: 0.167”
- Head Height: 0.062”
- Thread Point Style: Standard Machine
- Rockwell Hardness: B70
- Minimum Tensile Strength: 60,000 psi

Nuts

Size 4-40 for mounting grips from McMaster-Carr

P/N: 90760A005



- Undersized Machine Screw Hex Nut
- Height: 0.0625"
- Width: 0.1875"
- Material: Steel – Zinc Plated
- Grade 2
- Thread Size: 4-40
- Right-Hand Thread
- Standard Threads
- Rockwell Hardness: Maximum C44

Washers

Size 4-40 Belleville Washers from McMaster – Carr

P/N: 9712K53



- Material: Steel
- Non-Serrated
- Inside Diameter: 0.125"
- Outside Diameter: 0.25"

Size 2-56 Belleville Washers from McMaster – Carr

P/N: 95221A101



- Material: Steel
- Non-Serrated
- Inside Diameter: 0.09"
- Outside Diameter: 0.20"

Circuit

Op-Amp

OPA551PA from Digikey

P/N: OPA551PA-ND



- ± 30 V
- 200 mA
- Slew Rate: 15 Vms
- Bandwidth: 3 MHz

Transformer

Audio Output transformer for high impedance wires from Radio Shack

P/N: 273-1380



- Turn ratio: $\sim 11:1$
- Input: $1\text{ k}\Omega$
- Output: $8\ \Omega$
- Tested at 77 K

Mono Audio Cable

P/N: 42-2387

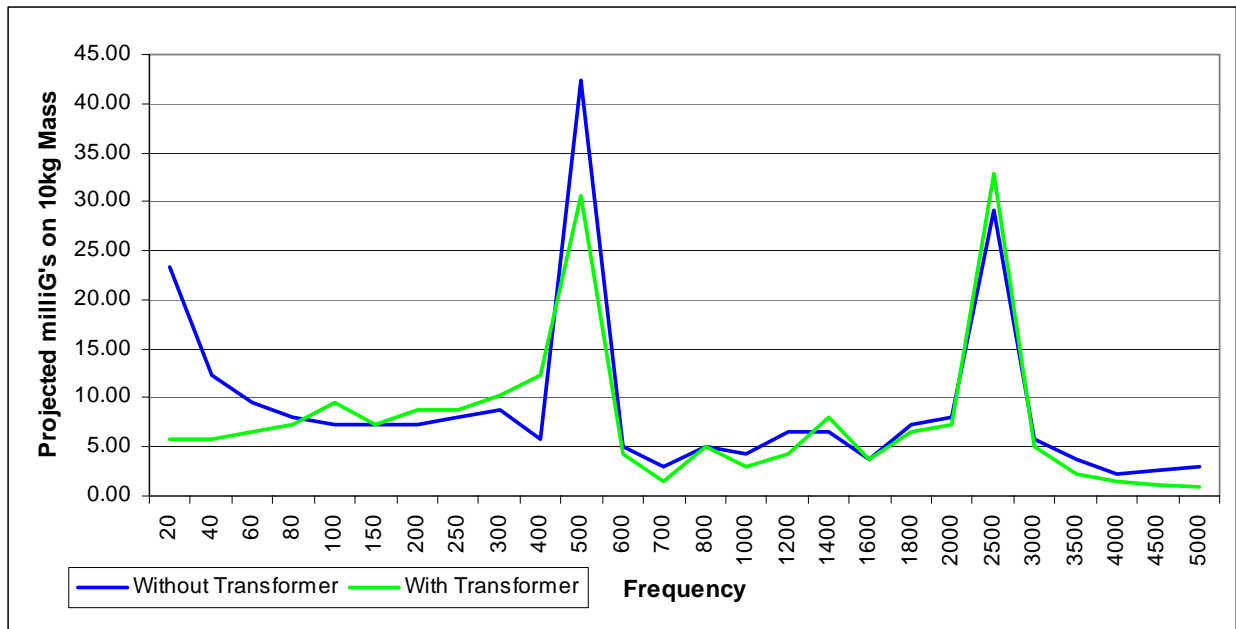


- Connection size: $1/8''$ to $1/8''$
- Length: 6 ft.

7 – Frequency Response Report:

The performance of the oscillator assembly was tested at various frequencies at room temperature (296 K). The accelerations output by the oscillator assembly were measured using an Endevco 2272 Accelerometer, which was calibrated to output 3 V per G. The accelerations on the test mounting were used to calculate the accelerations that would occur if the assembly was mounted on a 10 kg mass. The magnitudes of these accelerations along with the input parameters of the experiment were recorded in the tables at the end of this section.

A plot of the projected acceleration as a function of frequency is shown below. Frequencies below 60 Hz resulted in jagged acceleration waveforms, particularly in the trials that included the transformer. The waveforms, both with and without the transformer, improve at colder temperatures due to decreased resistance and inductance in both the actuator coil and the transformer. This decrease in resistance is also predicted to result in greater maximum accelerations. Therefore, more force will be exerted by the assembly at 4 K than at the room-temperature.



At low frequencies, the force produced in the trial by the oscillator assembly with the transformer has noticeably lower amplitudes than the trial without the transformer. This variation in amplitude is due to some properties of the transformer. The discrepancy between the setups disappears when the assembly was subjected to cryogenic temperatures because the resistance of the transformer becomes significantly reduced. This, in effect, reduces the magnetizing inductance of the coils, which yields higher quality output at low frequencies.

Two resonances are apparent at approximately 500 Hz and 2500 Hz. It is believed that these are due to properties of the mounting system and testing setup.

Warm Testing Calibration Without Transformer

Power Supply Voltage (V)	Voltage to G's Scaling Factor	Shunt Resistor In Circuit
+/- 5	0.33	1 Ohm

Frequency (Hz)	Audio Output (mV)	Voice Coil Current (mA)	Accel. Voltage (V)	Output G's	Projected mG's on 10 kg mass	Notes:
20	300.00	195.00	3.20	1.07	23.36	Irregular Wave Form
40	300.00	195.00	1.70	0.57	12.41	Irregular Wave Form
60	300.00	195.00	1.30	0.43	9.49	
80	300.00	195.00	1.10	0.37	8.03	
100	300.00	195.00	1.00	0.33	7.30	
150	300.00	195.00	1.00	0.33	7.30	
200	300.00	195.00	1.00	0.33	7.30	
250	300.00	195.00	1.10	0.37	8.03	
300	300.00	195.00	1.20	0.40	8.76	
400	300.00	195.00	0.80	0.27	5.84	
500	300.00	195.00	5.80	1.93	42.34	
600	300.00	195.00	0.70	0.23	5.11	
700	300.00	195.00	0.40	0.13	2.92	Irregular Wave Form
800	300.00	195.00	0.70	0.23	5.11	
1000	300.00	195.00	0.60	0.20	4.38	
1200	300.00	195.00	0.90	0.30	6.57	
1400	300.00	195.00	0.90	0.30	6.57	
1600	300.00	195.00	0.50	0.17	3.65	
1800	300.00	195.00	1.00	0.33	7.30	
2000	300.00	195.00	1.10	0.37	8.03	
2500	300.00	195.00	4.00	1.33	29.20	
3000	300.00	195.00	0.80	0.27	5.84	
3500	300.00	195.00	0.50	0.17	3.65	
4000	300.00	195.00	0.31	0.10	2.26	
4500	300.00	195.00	0.35	0.12	2.56	
5000	300.00	195.00	0.40	0.13	2.92	

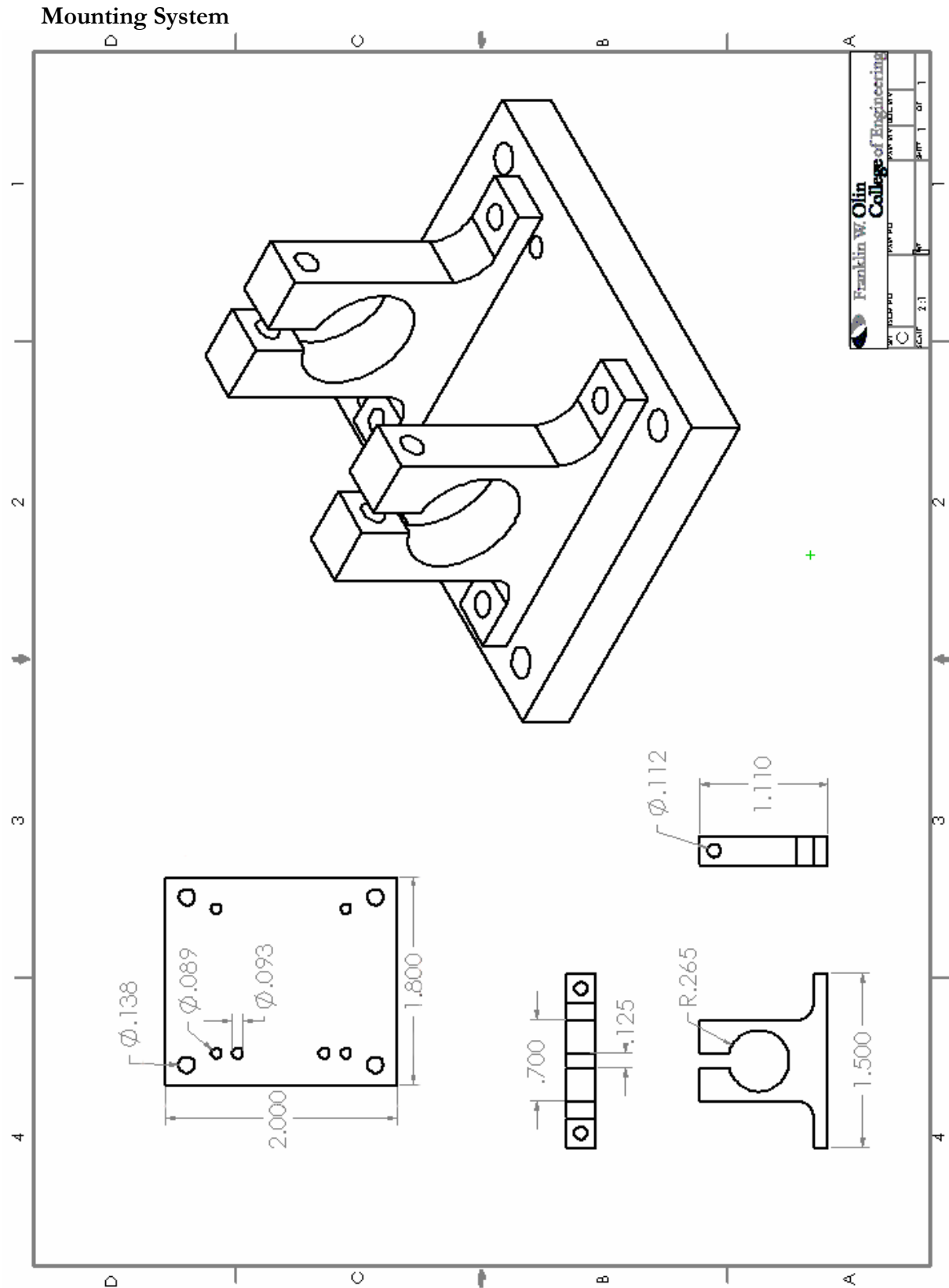
Warm Testing Calibration With Transformer

Power Supply Voltage (V)	Voltage to G's Scaling Factor	Shunt Resistor In Circuit
+/- 19	0.33	10 Ohms

Frequency (Hz)	Audio Output (mV)	Voice Coil Current (mA)	Accel. Voltage (V)	Output G's	Projected mG's on 10 kg mass	Notes:
20	300.00	400.00	0.80	0.27	5.84	Irregular Wave Form
40	300.00	400.00	0.80	0.27	5.84	Irregular Wave Form
60	300.00	400.00	0.90	0.30	6.57	
80	300.00	400.00	1.00	0.33	7.30	
100	300.00	400.00	1.30	0.43	9.49	
150	300.00	400.00	1.00	0.33	7.30	
200	300.00	400.00	1.20	0.40	8.76	
250	300.00	400.00	1.20	0.40	8.76	
300	300.00	400.00	1.40	0.47	10.22	
400	300.00	400.00	1.70	0.57	12.41	
500	300.00	400.00	4.20	1.40	30.66	
600	300.00	400.00	0.60	0.20	4.38	
700	300.00	400.00	0.20	0.07	1.46	Irregular Wave Form
800	300.00	400.00	0.70	0.23	5.11	
1000	300.00	400.00	0.40	0.13	2.92	Somewhat Irregular
1200	300.00	400.00	0.60	0.20	4.38	
1400	300.00	400.00	1.10	0.37	8.03	
1600	300.00	400.00	0.50	0.17	3.65	
1800	300.00	400.00	0.90	0.30	6.57	
2000	300.00	400.00	1.00	0.33	7.30	
2500	300.00	400.00	4.50	1.50	32.85	
3000	300.00	400.00	0.70	0.23	5.11	
3500	300.00	400.00	0.30	0.10	2.19	
4000	300.00	400.00	0.20	0.07	1.46	
4500	300.00	400.00	0.15	0.05	1.10	Irregular Wave Form
5000	300.00	400.00	0.13	0.04	0.95	Somewhat Irregular

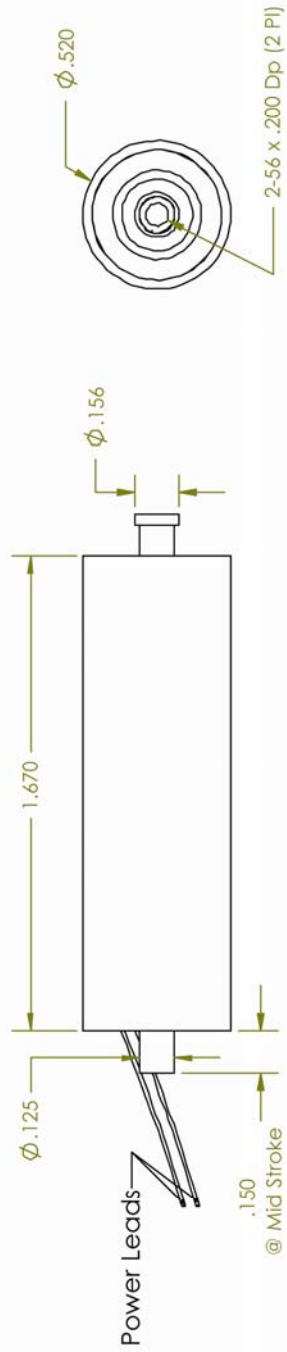
Note: All Volt, Amp, and 'G' data values in the chart are "+/-".

8 – Drawing Files



Actuator

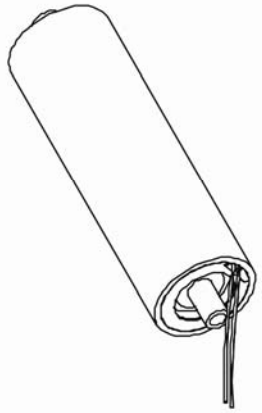
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SPECIFICATIONS	
Motor P/N	NCM02-05-005-4JB
Stroke	0.15"
Bearing Type	Jeweled Sapphire
Moving Mass	12 grams
Total Mass	49 grams
Resistance	3.3 Ω
Force Constant	0.32 LBS/(Watt) ^{1/2}
Continuous Force	0.50 LBS
Peak Force	1.50 LBS
Power In @ 100% Duty	3 WATTS

H2W Technologies, Inc.
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 Tel: (661)-702-4444
 www.h2wtech.com

MATERIAL		TITLE	
FINISH SPECIFIED OTHERWISE: All dimensions are in inches XX = .005 ANGLE XX = .020 CORNERS X = Remove All Burrs and Sharp Edges		NCM02-05-005-4JB	
FINISH	DATE	DWG #	REV
XXXX	2-25-02	30-0097	---
DRAWN	APPROVED	TCN	
COG	PGW		



9 – Suppliers

Century Spring Corporation

222 East 16th Street
Los Angeles, CA 90015
Toll Free: 800-237-5225
Ph: 213-749-1466
Fax: 213-749-3802
www.centuryspring.com

H2W Technologies

28310-C Ave Crocker
Valencia, CA 91355
Toll Free: 888-702-0540
Ph: 661-702-9346
Fax: 661-702-9348
www.h2wtech.com

McMaster-Carr

P.O. Box 440
New Brunswick, NJ 08903-0440
Ph: 732-329-3200
Fax: 732-329-3772
www.mcmaster.com

Radio Shack

Marshalls Plaza
241 Needham St.
Newton, MA 02464
Ph: 617-796-7761

You-Do-It Electronics

40 Franklin Street
Needham, MA 02494
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Fax: 781-449-1009
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10 – Acknowledgements

Team

Joe Roskowski (Project Manager)
Madge Dodson
Conor Frackleton
Kyle Rader
Simone Sequeira
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Dr. Stephen S. Holt

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