

A Custom Vibration Test Fixture Using a Subwoofer

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Abstract

There are many engineering applications for a source of controlled vibrational excitation. Popular applications include fatigue testing of mechanical components and ruggedness and survivability testing of electronic assemblies for harsh environments. Other applications include vibrational energy harvesting device testing, and accelerometer testing and calibration. There exist several piezoelectric- based energy harvesting devices that are designed to capture random and/or single frequency vibrational energy. Testing of these devices requires a source of controllable vibration. The static characteristics of micro electro-mechanical system (MEMS) accelerometers can often be tested using the earth's gravity or centrifuge apparatus. Testing the dynamic characteristics, however, requires the application of known vibrational acceleration inputs. Single frequency acceleration inputs are very useful to characterize the performance of accelerometers. The applied frequency can also be swept to determine the frequency response performance of the device under test. Commercial vibration systems, often called shakers or shaker tables, typically use an electromagnetic voice coil assembly to move the test fixture. Voice coils can also be found in common audio loudspeakers. The construction of automobile subwoofers is particularly rugged. A very useful vibration test fixture can be created by modifying a subwoofer to include a table area to which a reference accelerometer and the component under test can be mounted. This paper describes the design, construction and application of a subwoofer-based vibration testing system in an undergraduate engineering technology education environment. Some experimental results from testing of energy harvesting devices and low-g MEMS accelerometers are also described. System component selection, performance and future enhancements are also presented and discussed.

Introduction

As part of an investigation into vibrational energy harvesting devices, the need arose for a controllable source of vibration. Initially, some salvaged automobile sound system speakers were evaluated for their performance as transducers for creating the controlled vibrations. From this evaluation, it was determined that with the proper speaker and driving signal, a useful, inexpensive vibration test system could be created. Therefore, a custom vibration system using a car stereo subwoofer as the transducer was designed, built and implemented in an undergraduate engineering technology laboratory.

Figure 1 shows the custom vibration system equipment diagram. Car audio subwoofer speakers are robust acoustic transducers with performance capabilities well suited for low frequency vibration excitation. An area to which test specimens can be mounted was glued onto the speaker cone. The excitation signal is produced by a laboratory function generator. A unity gain power amplifier is used to provide the current required to drive the low impedance of the subwoofer. A wideband accelerometer is used as the reference acceleration measurement device. An oscilloscope is used to measure and display the accelerometer output signal.

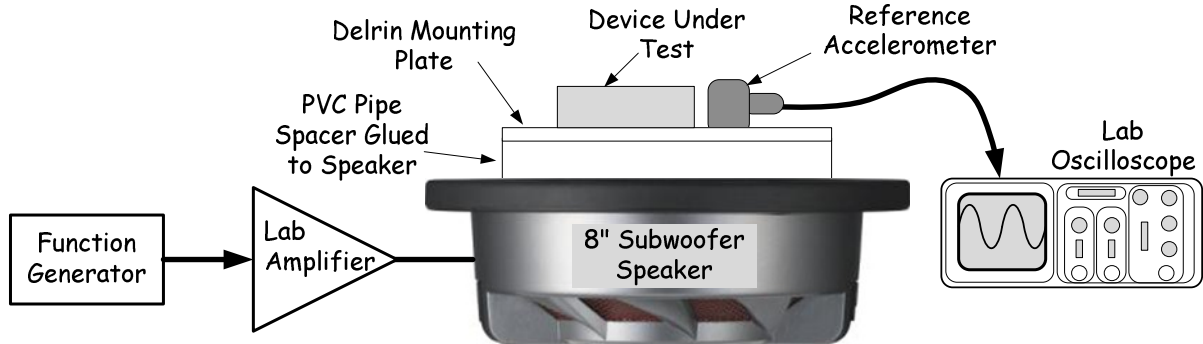


Figure 1. Vibration system equipment diagram

System Construction

The shaker table was fabricated using an automobile audio subwoofer speaker as the transducer element. The frequency response range of a subwoofer is appropriate for the desired range of the vibration table. A subwoofer was chosen for its large size and rugged construction. The suitability of the speaker cone area for accepting the intended modifications was also an important consideration. In particular, the Pioneer® model TS-SW841D, 8-inch subwoofer was selected. Some key specifications of the chosen subwoofer are given in Table 1.[1] Figure 2 shows the subwoofer before modification.

Table 1. Pioneer subwoofer specifications

Music Power, Max	500W
Nominal Power Handling	120W
Frequency Response	30 – 1500 Hz
Nominal Impedance	4Ω
Dimensions	8-7/8" x 3"

The subwoofer was modified to create a flat shaker table surface. First, a short length (about 1 inch) of 3-inch diameter PVC pipe was bonded directly to the speaker cone material with Goop® adhesive. Goop adhesive bonds well to PVC and the speaker cone material. The PVC spacer helps to raise the test surface above the recessed cone area and also provides separation from the influence of the speaker’s very strong magnet. A 0.25 inch thick disk of



Figure 2. Pioneer Subwoofer

Delrin® acetal resin was used as the shaker table mounting surface. The disk is fastened to the PVC pipe using eight machine screws arranged in a bolt circle around the edge. The Delrin disk provides an interchangeable and replaceable surface with excellent stiffness and machining properties. The device to be tested is mounted to the shaker table using machine screws as needed. Figure 3 shows a photograph of the completed vibration system. The subwoofer is shown mounted in a custom cabinet constructed of medium-density fiberboard (MDF). Figure 4 shows a close up photograph of the vibration table area to reveal the construction details.

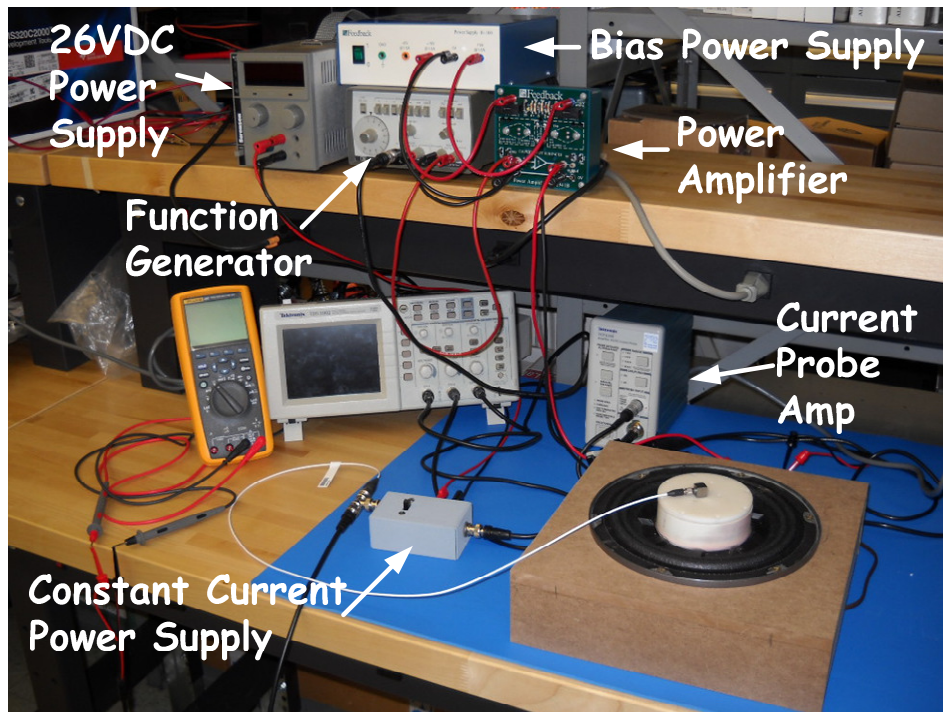


Figure 3. Vibrational test system



Figure 4. Subwoofer shaker table detail

The vibration amplitude of the shaker table is measured by a calibrated reference accelerometer. The PCB Piezotronics model 333B30 accelerometer was chosen for this application due to its low cost, sensitivity and small size and mass. The 333B30 can be seen mounted to the shaker table surface in Figure 4. Table 2 shows an excerpt from the 333B30 datasheet.[2]

Table 2. 333B30 accelerometer specifications

<u>PARAMETER</u>	<u>ENGLISH</u>	<u>SI</u>
Sensitivity($\pm 10\%$)	100 mV/g	10.2 mV/(m/s ²)
Measurement Range	± 50 g pk	± 490 m/s ² pk
Frequency Range($\pm 5\%$)	0.5 to 3000 Hz	0.5 to 3000 Hz
Resonant Frequency	≥ 40 kHz	≥ 40 kHz
Excitation Voltage	18 to 30 VDC	18 to 30 VDC
Constant Current Excitation	2 to 20 mA	2 to 20 mA
Output Bias Voltage	7 to 12 VDC	7 to 12 VDC

The accelerometer requires a constant current power supply with a compliance voltage between 18 and 30 VDC. The accelerometer then produces an output DC level of 7 – 12 VDC. The dynamic acceleration output signal is superimposed on the DC bias output. The power supply was also custom-designed and built in the engineering technology laboratory. Figure 5 shows the schematic diagram of the constant current power supply.

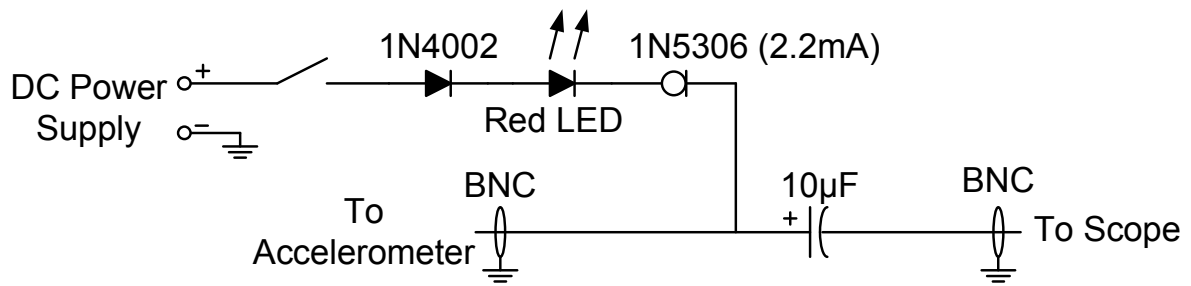


Figure 5. Constant current power supply schematic

As shown in Figure 5, the current regulator diode, 1N5306, provides the required constant current bias for the accelerometer. In operation, the DC input voltage is set to 26VDC while the DC output voltage is monitored with a DVM. The DC output voltage typically settles at about 10.9VDC. When the DC output voltage settles, the accelerometer is ready for use. The 10µF capacitor allows only the AC part of the accelerometer output to pass to the oscilloscope input. The user can also access the combined DC and AC output of the accelerometer at the port which is normally connected to the DVM as shown.

The magnitude and frequency of vibration is controlled by a function generator. The function generator is set to produce a sine wave output with zero offset. A power amplifier is needed to provide the current drive required by the low impedance of the subwoofer. The vibration system will find application at frequencies below the audio band therefore a DC-coupled amplifier was desired. The Feedback® model TK2941B unity voltage gain power amplifier was used. The amplifier was part of an educational sensors package already in use in the engineering technology laboratories.

System Performance

To characterize the performance of the subwoofer vibration system, the frequency response of the table acceleration versus speaker input voltage was measured. The input voltage was held nearly constant at about 400 mVrms for each frequency tested. Figure 6 shows a plot of the measured frequency response. The data shows a distinctive resonant peak near 45Hz. Therefore, care must be taken when applying signals with frequency components around 45Hz. The frequency response also indicates that the system has a useful in excess of 180 Hz.

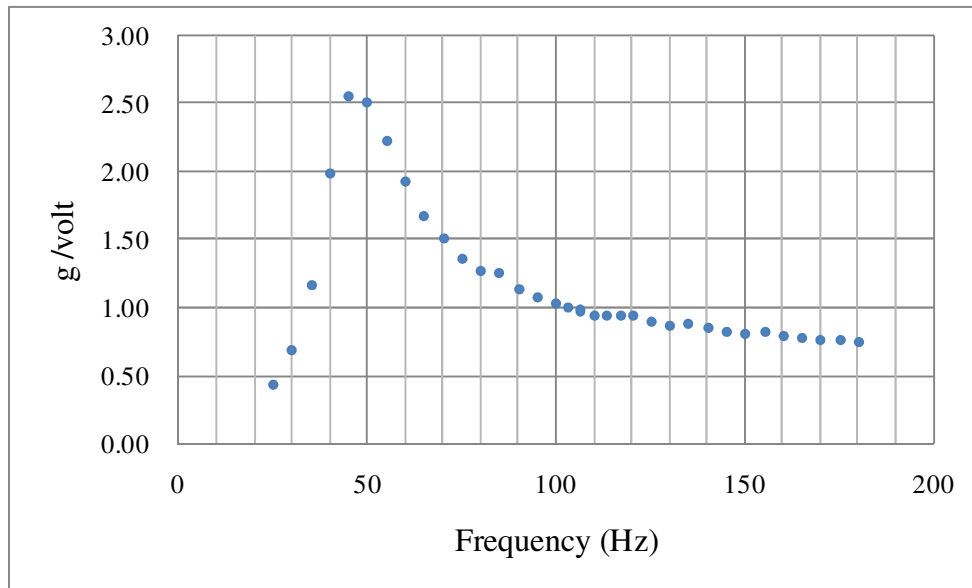


Figure 6. Vibration table acceleration frequency response

The input impedance frequency response was also measured. A Tekronix® active current probe was used to measure the subwoofer input current. The speaker input voltage was measured using a standard voltage probe. Again, the input voltage was held nearly constant at 400 mVrms. The frequency response of the magnitude ratio of measured speaker input voltage to input current (input impedance) is shown in Figure 7. The input impedance data indicates a distinct, high-Q, electrical resonance near 42Hz.

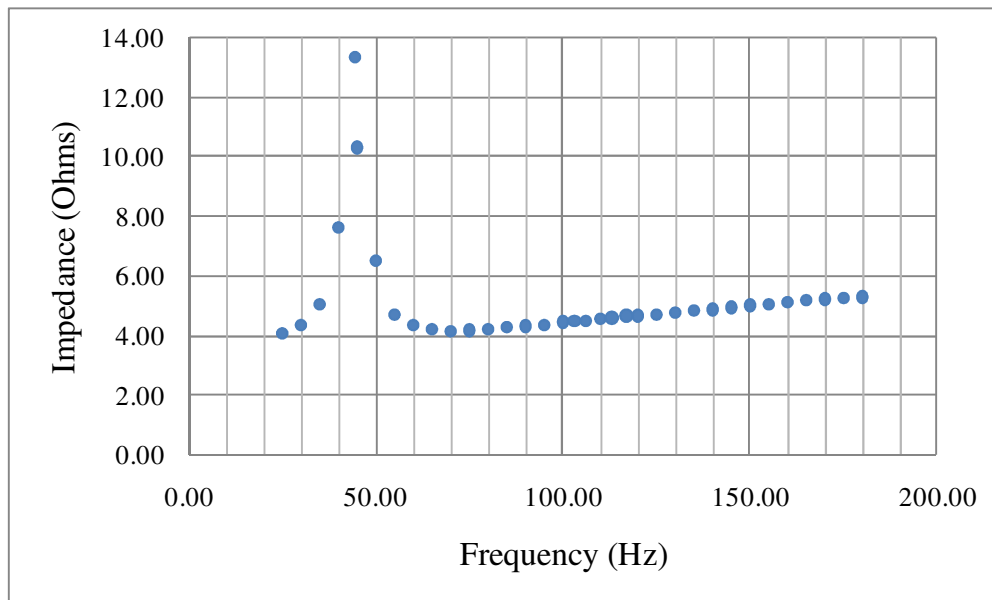


Figure 7. Subwoofer input impedance frequency response

Example Applications

Energy Harvesting

The Joule-Thief™ JTRA-e5mini energy harvesting module manufactured by AdaptivEnergy is a random vibrational energy capturing and storage device. It finds application in vehicular vibration powered sensor systems. The JTRA-e5mini contains a tuned cantilever spring-mass system with an integral piezoelectric generator. To investigate the performance of this device, the evaluation kit was used. As shown in Figure 8, the evaluation kit contains a micro-power wireless communication board, USB communication dongle and application software. The evaluation kit allows the user to remotely monitor and chart the average power output of the JTRA-e5mini.[3]



Figure 8. Joule-Thief™ JTRA-e5mini Evaluation Kit

The Joule Thief JTRA-e5mini energy harvesting unit was mounted to the subwoofer shaker table using a top clamping bar arrangement as shown in Figure 9. The performance of the energy harvester was evaluated for several levels of sinusoidal vibration at about 15 Hz. The output of the reference accelerometer was measured using a digital oscilloscope to determine the vibration level. Figure 10 shows a plot of the data obtained from this test.

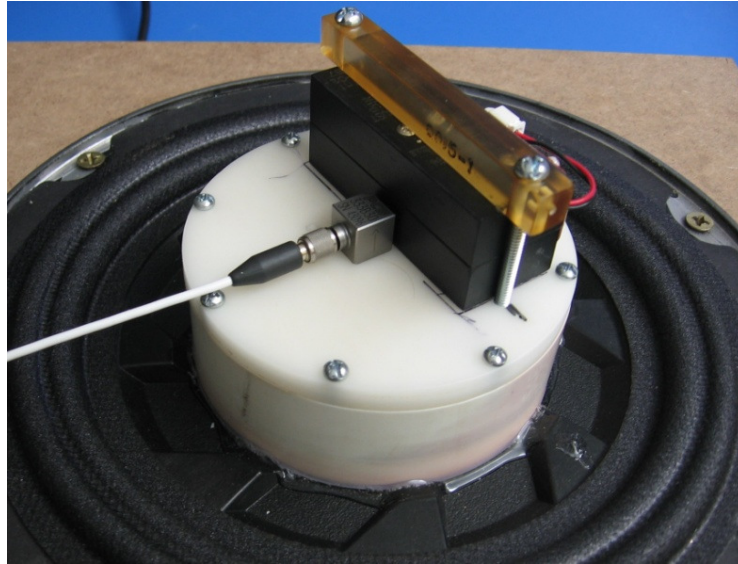


Figure 9. Joule Thief JTRA-e5mini mounted to shaker table.

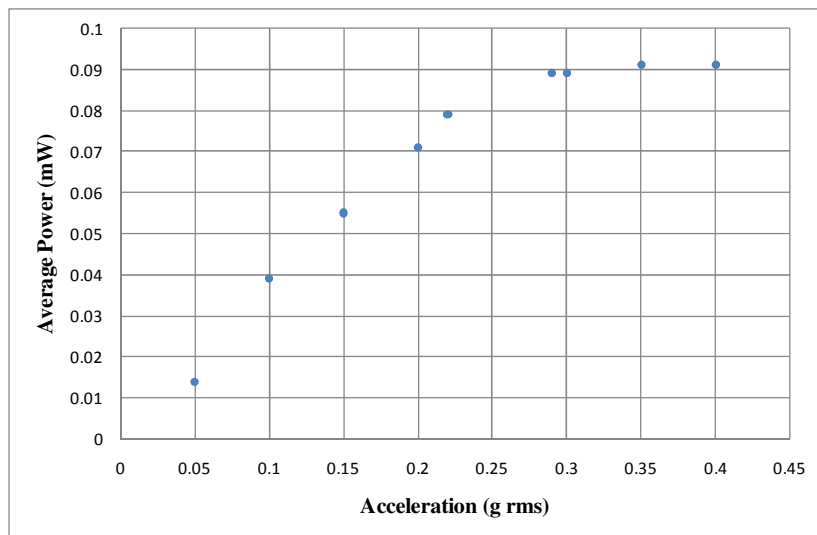


Figure 10. Joule Thief JTRA-e5mini evaluation data plot

MEMS Accelerometers

A custom centrifuge system for the evaluation of the static performance of MEMS low-g accelerometers has been presented in [4]. To evaluate the dynamic performance, the accelerometers were mounted to the subwoofer shaker table. The output for each accelerometer was compared with that of the reference accelerometer. The Freescale MMA2201D ($\pm 40g$) and MMA2260D ($\pm 1.5g$) MEMS accelerometers were tested. Figure 11 shows the test setup for the MEMS devices.

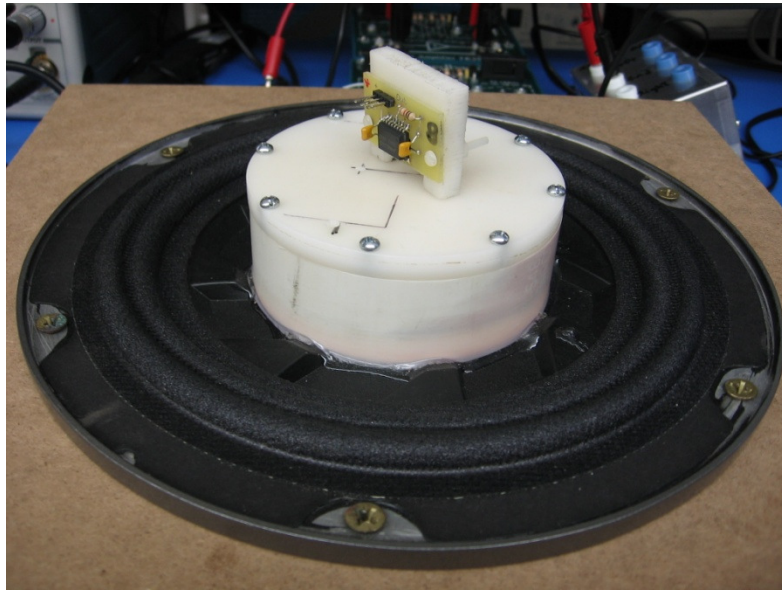


Figure 11. MEMS accelerometer test setup

The MMA2201D has a nominal sensitivity of 50mV per g. The acceleration output signal is superimposed on a zero-g bias voltage of 2.5V when powered from 5V. The frequency response of the MMA2201D versus the reference accelerometer is shown in Figure 12. The MMA2201D was found to have a very flat frequency response with excellent bandwidth.

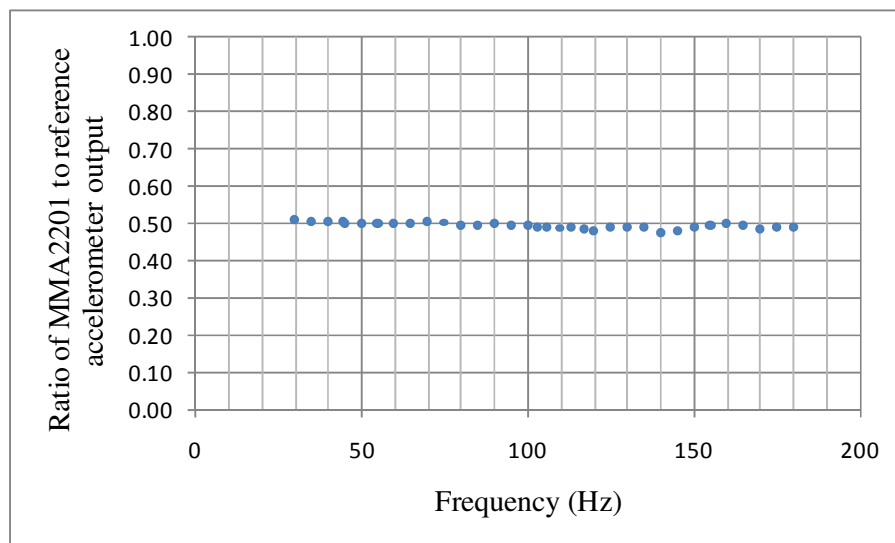


Figure 12. Frequency response data for MMA2201D

The MMA2260D has a nominal sensitivity of 1.2V per g. The acceleration output signal is superimposed on a zero-g bias voltage of 2.5V when powered from 5V. The frequency response of the MMA2260D versus the reference accelerometer is shown in Figure 13. The

MMA2260D was found to have a bandwidth of about 50Hz which is the nominal value given in the manufacturers datasheet.

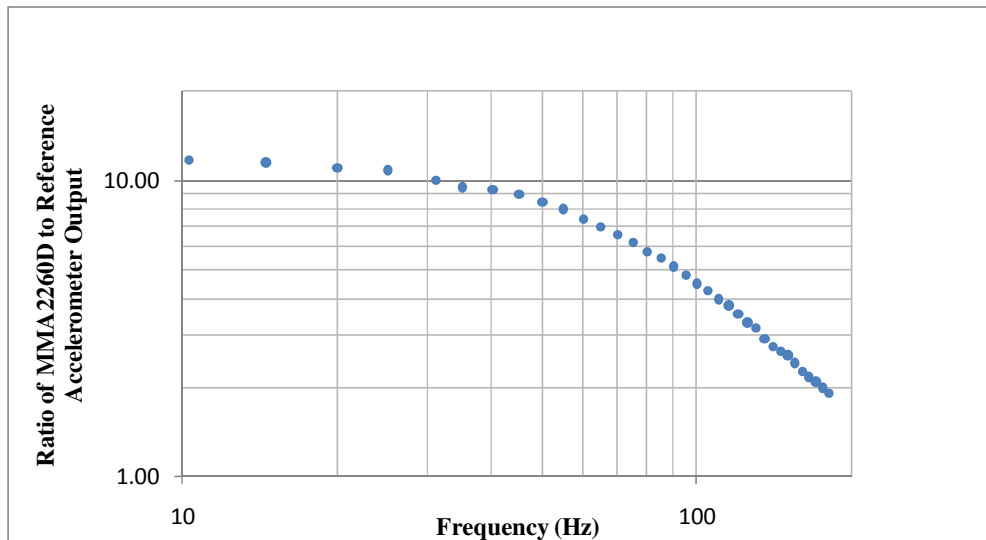


Figure 13. Frequency response data for MMA2260D

Future Work

Work continues with making the vibration test system more useable by students with less supervision. This includes developing LabView software to create the subwoofer input signals from a USB sound card device. This software will allow for the creation of complex waveforms and vibration profiles.

Some nonlinear vibrational behavior was observed at lower frequencies, especially those below 10Hz. Work is continuing to test various methods of correcting the nonlinear behavior to obtain more repeatable acceleration waveforms.

Conclusions

A vibration test apparatus using a modified subwoofer speaker was designed and fabricated. The modifications were quite simple and inexpensive. The vibration system was characterized and found to have very acceptable performance. The system was used to evaluate the performance of an energy harvesting device. MEMS accelerometers were also tested using the system with excellent results.

Acknowledgments

The author would like to thank Jordan Waite for his help in developing hardware and software for this project. Jordan is a third-year student in the electro-mechanical engineering technology program at Penn State Berks.

References

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available:http://www.adaptivenergy.com/docs/WP_AE_01_RandomVibeWSN.pdf
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Biography

DALE H. LITWHILER is an Associate Professor at Penn State, Berks Campus in Reading, PA. He received his B.S. from Penn State University, his M.S. from Syracuse University, and his Ph.D. from Lehigh University, all in electrical engineering. Prior to beginning his academic career, he worked with IBM Federal Systems and Lockheed Martin Commercial Space Systems as a hardware and software design engineer.