Instrumentation Requirements for Measuring Traffic Noise — Pilot Study

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Abstract

To objectively measure the noise level in a residential area, the test method defined by the Federal Highway Administration (FHWA) in FHWA-PD-96-046 should be followed [1]. In this experiment, a pilot measurement with minimal instrumentation following the FHWA standard was conducted to validate the compliance. A hardware-based sound level meter (SLM) and a mobile app were used to measure the noise level of 10 sites at the convergence of Maryland Route 32 (MD 32) and the River Hill Village. The collected data were then entered into Google My Maps for interactive review. The results show that the hardware-based sound level meter offered much better accuracy than the mobile app. However, more instrumentation, including a professional-grade sound level meter and an acoustic calibrator, are required to comply with the federal standard.

Introduction

Noise, or unwanted sound, is a pollutant, disturbance, and even a health hazard for some people. About 40 million Americans suffer from a range of adverse health effects due to noise exposure, including noise-induced hearing loss, stress related illnesses, heart disease, etc. [2][3]. A 1974 Environmental Protection Agency Report recommends a 70dB(A) 24-hour average exposure limit for protecting 96% of the general population [4]. Noise measurement is important for determining the levels of environmental noise experienced by residents, which may exceed recommended levels and cause harm. In this study, an inexpensive, consumer-grade sound level meter and a mobile app were used to collect data of sound pressure levels (SPL or sound level herein) in the River Hill Village, Clarksville, Maryland.

Methods and Materials

Study Design

In this study, two measurement devices, a hardware-based sound level meter (DT-85A, CEM [5]) and a software-based mobile app (Sound Meter, Abc [6]), were used to collect sound pressure level data.

Figure 1: Two sound level meters were mounted on tripods at the same height (see Figure 2 for a closer view). Another smartphone was used to record the sound level readings shown on the meters as well as the ambient sound and the GPS location information. This reading, marked as Point #2, was taken on Grace Drive, in front of W.R. Grace & Co. on Sunday, January 20, 2020 in temperatures of 36˚ F.

Figure 2: The hardware-based sound level meter CEM DT-85A (right) and the software-based Abc Sound Meter app running on a smartphone (left) reported different readings — 68.7 dB vs. 71.1 dB.

Sound Level Meter DT-85A

The specifications of the hardware-based SLM are listed below in comparison with the federal requirements.

Specifications	**DT-85A**	**Federal Standard [1]**	**Compliant ?**
Frequency weighting method	A-weighted	A-weighted	Yes
Time weighting method	Fast mode	Slow mode	No
Microphone	½” electret condenser	½” or 3/8” condenser	Yes
Measuring level range	40~130 dB	N/A	N/A
Accuracy	±3.5dB @ 1kHz	N/A	N/A
Frequency range	31.5Hz~8KHz	N/A	N/A
Resolution	0.1 dB	N/A	N/A

Components of a sound level meter usually include: microphone with preamplifier, amplifier, frequency weighting, time averaging, and output indicator ([1], Section 3.1.3.2 Sound Level Meter). The internal components of the DT-85A SLM are shown in Figure 3.

Figure 3: Inside the DT-85A sound level meter.

The DT-85A uses the A-type frequency weighting method, the most widely used method for assessing transportation-related noise (c.f. Figure 4). A-weighting reflects human perception of various frequencies, taking into account lower sensitivities at lower sound pressures ([1], Section 3.1.3.4.2).

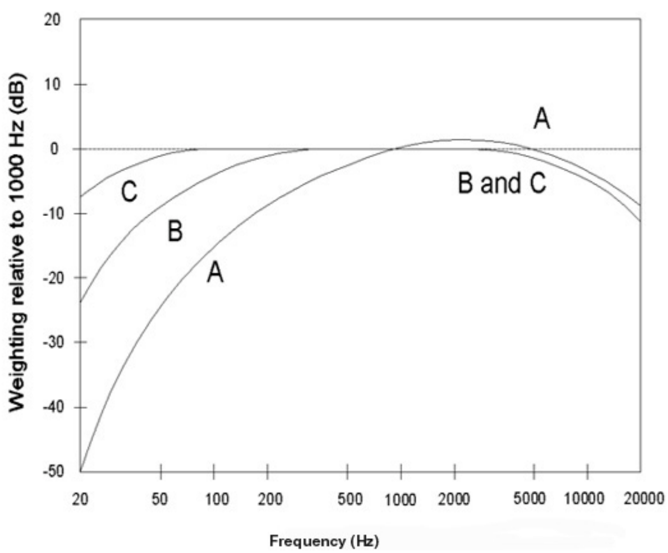

Figure 4: Frequency weighting methods. Excerpted from [1].

Two time weighting functions were discussed in the FHWA standard. In the Fast mode, exponential time averaging was used, using the fast response setting, which puts greater weighting on the measurement of short-term impacts, such as individual highway vehicle pass-bys (c.f. Figure 5). Fast weighting is not optimal, as the Slow weighting mode is recommended for the measurement of long-term impact of highway noise ([1], Section 3.1.3.4.4 Exponential Time-Averaging).

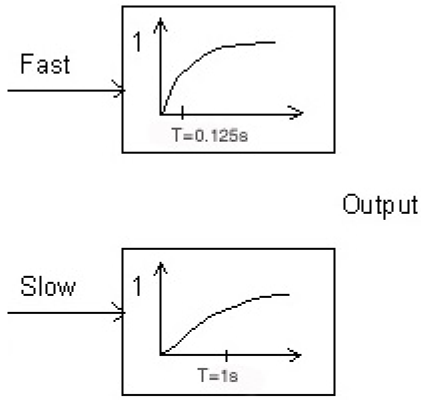

Figure 5: Time weighting methods. Excerpted from [1].

The 0.5-inch electret condenser microphone was suitable for this study since measurements at extremely low sound pressure levels were not required ([1], Section 3.1.1 Microphone Type).

The DT-85A measures sound pressures from 40~130 dB with an accuracy of ±3.5dB and a resolution of 0.1 dB. The sound level meter has a frequency range from 31.5Hz~8KHz. Data is displayed every 0.5 seconds.

Mobile App Sound Meter by Abc

A mobile app ([6] Sound Meter, Abc Apps, see Figure 6) was downloaded and installed on a Samsung Galaxy S9+ mobile phone (c.f. Figure 6). The app used the built-in microphone(s) of the smartphone to detect sound and converted the data into sound level through some undocumented calibration process.

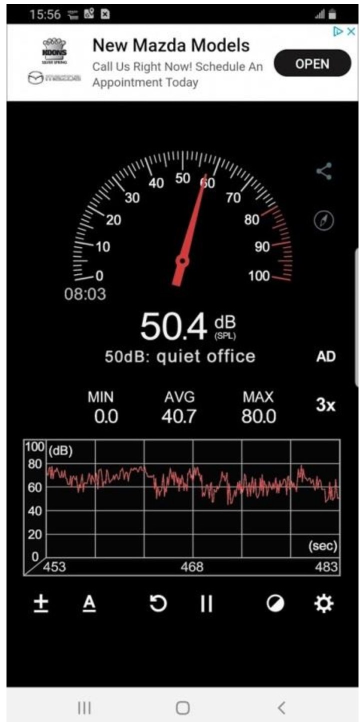

Figure 6: Screenshot of the mobile app Sound Meter.

Measurement Setup

As shown in Figure 1, the microphone was positioned with grazing (i.e., 90 degree) incidence to MD 32, which is the preferred orientation for moving measurements, such as those taken from vehicles on a highway ([1], Section 3.1.1.3 Microphone Incidence). A tripod supported the sound level meter or the smartphone about three feet above the pavement as recommended by the federal standard, with care taken to ensure the isolation of the devices from the tripod. The DT-85A included a windscreen for outdoor measurement but the smartphone did not. An acoustic calibrator, which would provide reference sound pressure level for checking the instrumentation system's accuracy, was not used in this study for budgetary reasons. A pink noise generator was not available to check the meters, either. A dummy microphone, which is an electronic circuit for emulating the microphone's output to validate the sound level meter's calibration, as suggested in the federal standard, was not used because it cannot be applied to an integrated sound level meter such as the DT-85A. Of the meteorological instrumentation, only a thermometer was used, as temperature and humidity do not affect sound levels nearly as much as wind does.

Linearity Test of Sound Level Meter DT-85A

A bench test was designed to test the linearity of the DT-85A. The detail of the test is documented in the Appendix. The test results demonstrated very high linearity as shown in Figure 3.

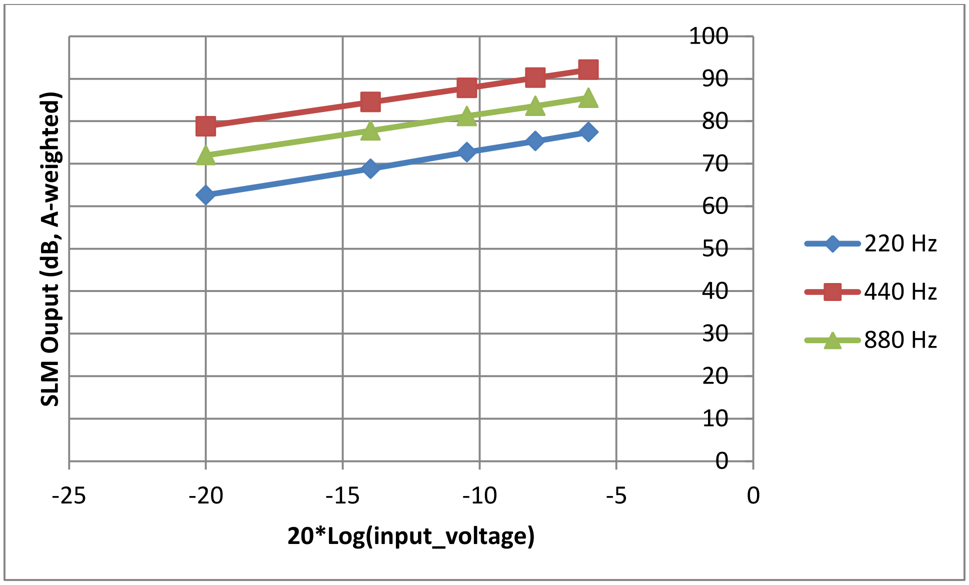

Figure 7: The relationship between the input voltage to an amplified speaker and the output dB measured by the SLM DT-85A. See Appendix for details.

Data Collection

After confirming the relative accuracy, i.e., linearity, of the DT-85A, it was used to measure the sound pressure level at five spots on Grace Drive, each about 0.1 mile apart, and five spots on Guilford Road, also about 0.1 mile apart. These measurements were taken between 3:54 and 4:14 pm, Jan. 19, 2020, The traffic on MD-32 was light on the Sunday afternoon. The temperature was about 36 ˚F, with a humidity of about 80% and winds at around 12 mph, all within the operation requirements of the DT-85A. A 10-second video clip of both the sound level meter and the Samsung's screen was taken with another smartphone for later data retrieval.

Results

The sound level data measured by the two meters at 10 different locations are listed in the following table.

Point	Location (longitude, latitude)	DT-85A (dB)	Sound Meter (dB)
1	39.19103, -76.90711	64.5	56.7
2	39.18990, -76.90525	64.7	71.8
3	39.18860, -76.90313	63.8	54.4
4	39.18752, -76.90113	68.4	71.1
5	39.18623, -76.89854	57.0	61.3

6	39.18345, -76.90035	52.8	55.0
7	39.18538, -76.90018	70.4	56.1
8	39.18707, -76.90194	68.7	61.2
9	39.18801, -76.90379	59.7	56.9
10	39.18914, -76.90632	57.8	62.5

Data Visualization

The sound level and location data were retrieved and entered as a spreadsheet, which was then automatically converted into Google My Maps [7], whose interactive interface allows users to click on a point on the map to see the recorded sound level data. Please click on the link to see the collected data on their corresponding locations [8].

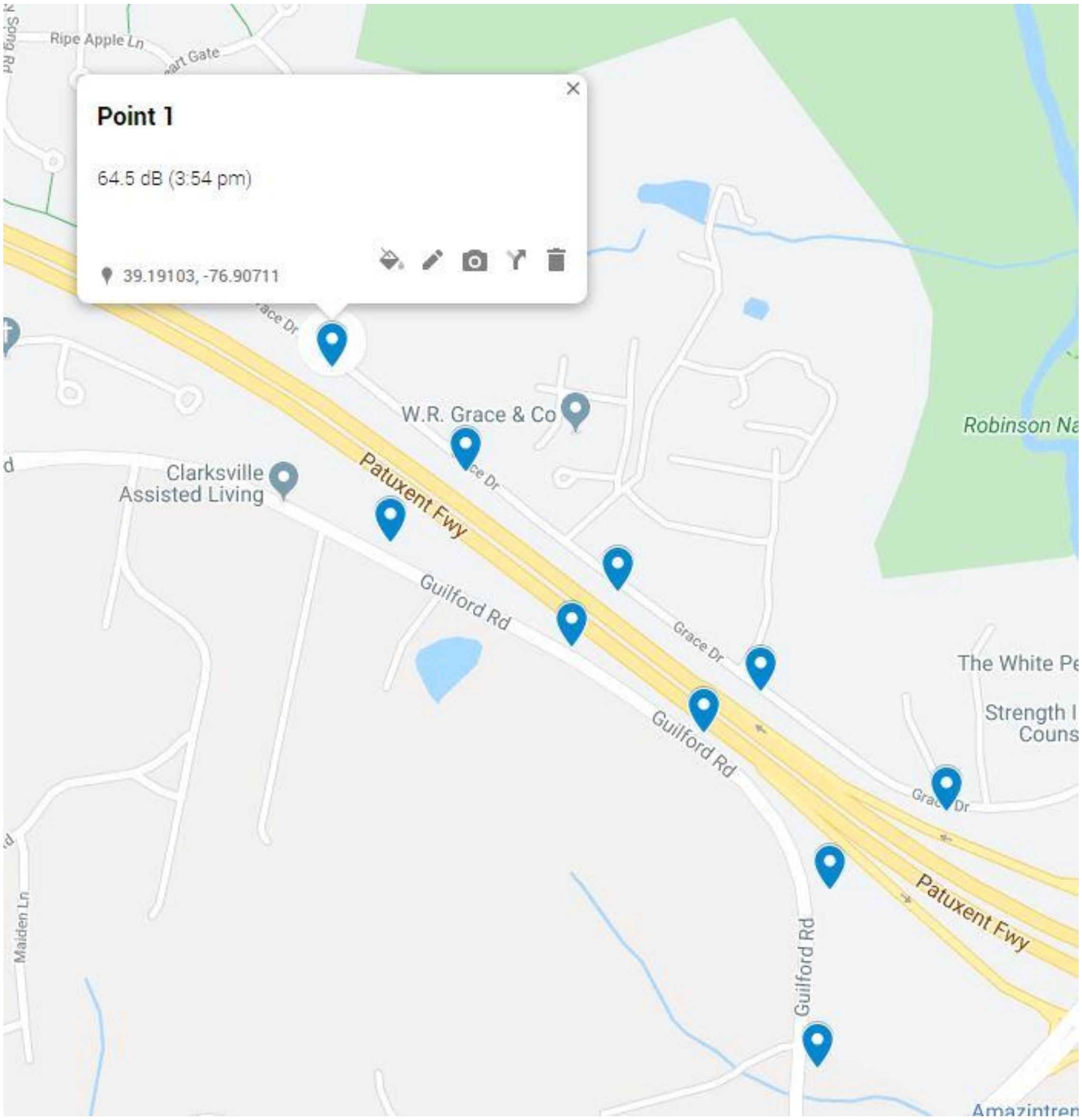

Figure 8: The collected sound level data were interactively presented as a My Maps webpage pointed by the URL in [8]. The ten balloons indicate the ten locations where the sound level data were measured. The user clicks on any ballon to open the data, which currently include the sound level, time, and location.

Discussion

The inconsistencies between the hardware- and software-based sound level meters show that the mobile app is of poor quality and requires additional calibration. Figure 9 shows the 10 pairs of data from both meters. Ideally, the 10 data points should lie on the line $x = y$ if both meters produce identical readings. However, the measured data show very poor correlation ($R^2 = 0.0762$).

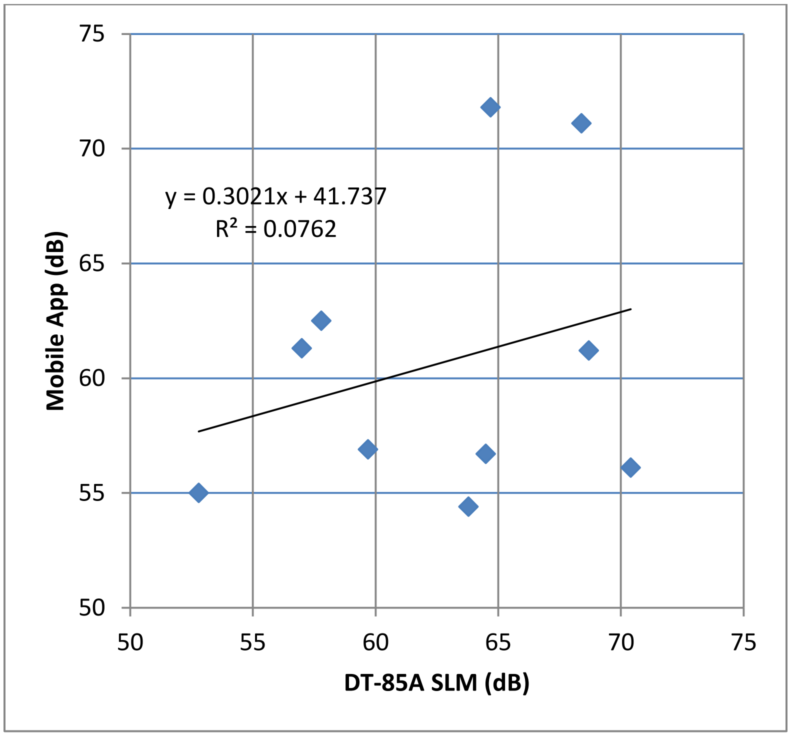

Figure 9: Poor correlation between the DT-85A and mobile app.

Limitations

This study was greatly limited by budget and time. The Maryland Department of Transportation (MDOT) requires the one-hour, A-weighted equivalent sound level for determination of noise levels and impact criteria, but the present readings were taken for only 10 seconds at each location. In addition, the Fast time-weighting method of the DT-85A, while acceptable, is not ideal, as federal regulations recommend using the Slow time-weighting method for long-term impact of highway noise ([1], Section 3.1.3.4.2 Frequency Weighting). An acoustic calibrator could not be obtained, although federal regulations require that calibrations be performed at the beginning and end of each measurement session, preferably at one-hour intervals in between ([1], Section 3.1.4 Calibrator). ANSI S1.13-1971 also requires the establishment of the electronic noise floor of the entire system with the usage of a microphone simulator, otherwise known as a microphone dummy ([1], Section 3.1.5 Microphone Simulator). However, such a simulator is not feasible for this SLM. Finally, FHWA recommends that the frequency response characteristics of the entire acoustic generator system be established each day by measuring and storing 30 seconds of pink noise ([1], Section 3.1.6 Pink Noise Generator). Pink noise, a random signal for which spectrum density is inversely proportional to the frequency of the signal, was not measured in this study.

As a result, the following additional instruments are recommended for a professional study in the future.

- Sound level meter with A-frequency weighting, Slow time weighting, and data logging. USD $45, https://www.amazon.com/Professional-Backlight-Accuracy-Measuring-30dB-130dB/dp/B01N9M9VBE

- Sound level meter calibrator, USD $110, https://www.amazon.com/Calibrator-Pressure-Microphone-Noise-backlight-function/dp/B07HWQ9B5X

Conclusions

The test method and required instrumentation defined in federal standards for measuring the sound pressure level induced by highway traffic was elaborated. A simple bench test method for evaluating the linearity of sound level meters was proposed. Consumer-grade sound level meters may be able to deliver reasonable accuracy but are insufficient for a professional study of highway noise. Using uncalibrated mobile apps seems to be unacceptable, as well. A list of required instruments was proposed for conducting subsequent measurements that comply with the federal standard.

Acknowledgments

This study could not have been done without the help of my family. I thank my dad for his generous loan of his Samsung Galaxy S9+ and retrieval of the standard documents, and my mom for retrieval of various published papers and transportation. Additionally, I would like to thank my brother for his tripod, as well as his patience during the car ride.

References

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Appendix. Linearity Test of Sound Level Meter DT-85A

Without a calibrated sound source, the relative accuracy of the sound level meter DT-85A was tested with a set-up that functions as a digitally controlled sound source as shown in Figure 10. The idea behind this set-up is to use digital input as the independent variable to generate controlled sound levels and then examine whether the sound level meter readings correlate with the digital input. The correlation between the meter's reading and the ground truth is called linearity. Testing the linearity is useful when the absolute accuracy of the meter is not available. If the sound level meter is not absolutely correct but has perfect linearity, the previously collected measurement data can be corrected by adding a constant once a sound level meter calibrator is available.

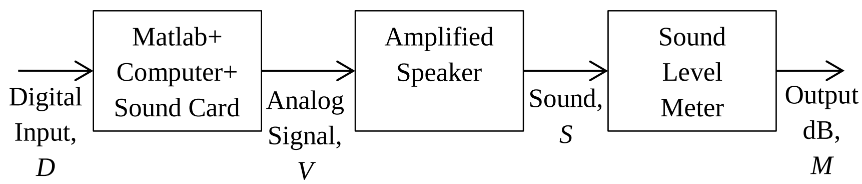

Figure 10: The experiment set-up for testing the relationship between the digital input signal and the output reading measured by a sound level meter.

The Matlab programming environment was used for this experiment. The digital input data, 12 sine waveforms, were generated with amplitudes ranging from 0.1 to 0.5 at increments of 0.1 at frequencies of 220, 440, and 880 Hz. The waveforms, as "Digital Input, *D*" in Figure 5, were played by Matlab, which drove the built-in sound card, essentially a digital-to-analog converter, in the computer to generate analog audio signals, *V*. An amplified speaker, with volume (i.e., gain) control fixed, was used to amplify the analog audio signal into audible sound, *S*. The sound level meter was secured 6 inches away from the amplified speaker with 0 degree incidence. The sound level reading of the sound level meter, in decibels (dB), *M*, was recorded as shown in the following table.

Digital Input		Output Reading		
Amplitude in Voltage	dB in Power	220 Hz	440 Hz	880 Hz
0.1	-20.0000	62.6	78.8	72.0
0.2	-13.9794	68.8	84.5	77.8
0.3	-10.4575	72.7	87.8	81.2

0.4	-7.9588	75.3	90.2	83.6
0.5	-6.0206	77.4	92.1	85.5

The digital input is a sine waveform, which is written as

$$D = A\sin(2\pi f t),$$

where *f* is the frequency of the sound (e.g., 220, 440, and 880 Hz), *t* is time, and *A* is the amplitude (0.1, 0.2,… 0.5), the independent variable in this experiment.

Assuming that the combination of Matlab, computer, and sound card is a perfect digital-to-analog converter, the analog audio signal *V* in voltage is proportional to the digital input *D*.

$$V = kD = kA\sin(2\pi f t)$$

Assuming that the amplified speaker is perfectly linear at frequency *f*, the output sound power is proportional to the square of voltage according to Ohm's law

$$P = V^2/R,$$

where *P* is power, *V* is voltage, and *R* is resistance.

Power intensity *I* is the ratio of power to area

$$I = P/E,$$

where *P* is power and *E* is area.

The power intensity of sound is equal to the product of sound pressure level and particle velocity

$$I = SPL \cdot v,$$

where *SPL* is sound pressure level and *v* is particle velocity.

Thus we have

$$\frac{(\mathrm{kAsin}(2\pi f t))^2}{R \cdot E} = SPL \cdot v$$

When *k*, *R*, *E*, *v* and *f* are constant, A^2 is proportional to *SPL*.

$$A^2 \cong SPL$$

When A^2 is represented in dB, the relationship between *A* and *SPL* becomes linear

$$dB(A^2) = 20\log(A^2) = 40\log(A) \cong SPL$$

Therefore, the relationship between sound pressure level and amplitude in dB should be linear. In other words, the data points plotted on a logarithmic scale should be linear if the sound pressure meter is accurate.

The sound pressure readings were graphed against the amplitude on a logarithmic *x* scale, yielding three lines, one for each frequency in Figure 11.

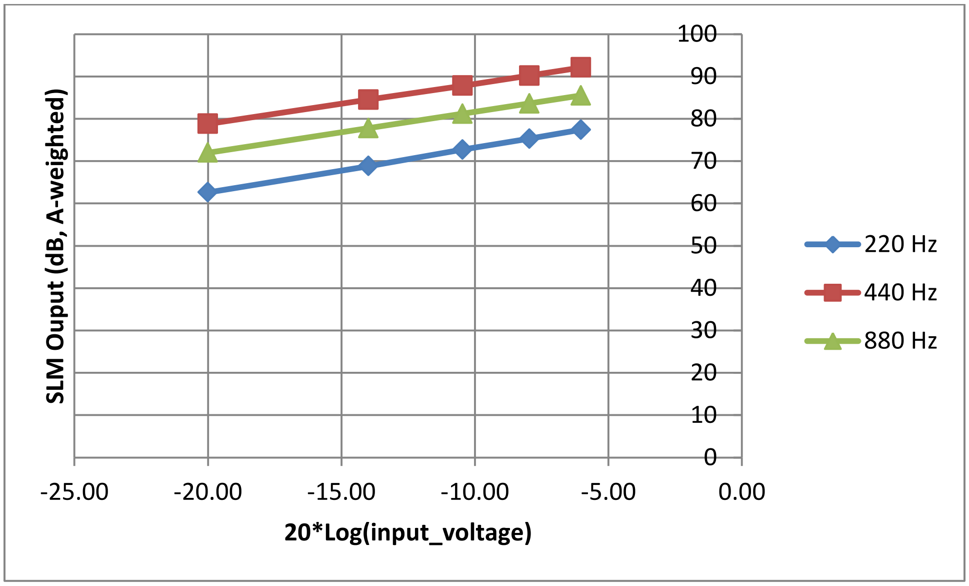

Figure 11: Linearity between the digital input and the reading from the sound level meter.

The linear regression of each line was calculated. Each line had an extremely high coefficient of determination (R^2)—0.9994, 0.9994, and 0.9997 for 220, 440, and 880 Hz, respectively—meaning that each line is nearly perfectly linear. This linearity indicates that Sound Level Meter DT-85A has excellent relative accuracy, although its absolute accuracy cannot be determined without a calibrator.