

AN ACOUSTIC ANALYSIS OF EXTENDED VOCAL TECHNIQUES IN SINGING AND BEATBOXING

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ABSTRACT

“Extended Vocal Technique” is a blanket term used to refer to any sound produced using the primary or false vocal folds that doesn’t fall into the M-classification system of registers; M0 for vocal fry, M1 for chest voice, M2 for falsetto or head voice, and M3 for whistle register. These four registers make up almost all of the singing that can be found in popular music of any genre, and have been considered for generations of Western culture to be the extent of what singing can be. However, many other means of pitched vocalization cannot be classified by any of these terms, or anything in between them, such as a mixed voice. Ingressive phonation produces sound from the true or false vocal chords that resonates powerfully in the chest cavity of the performer and creates a powerful sound with much more stability in its relative inwards M0. Subharmonic singing uses precise control of airflow and individual vocal folds in order to manipulate each fold to vibrate at slightly different frequencies and sound a lower pitch as a result. Throat and vibration singing use both the true and false vocal folds working together to create a similar effect to subharmonic singing, where each set of vocal folds is adducting at different frequencies, inducing a new frequency an octave or more below the “true” fundamental [2].

This paper is an analysis of these four extended vocal techniques used in the *basso profundo* register in order to compare and contrast their respective spectra over a range of common vowel shapes and pitches. Several vocalists specializing in these techniques provided recordings, which were then converted to frequency data via Fast Fourier Transforms and analyzed quantitatively and qualitatively. This experiment required a thorough understanding of audio recording and sampling, as well as how to properly configure an FFT to produce accurate and viable data.

1. MATERIALS AND METHODS

Several relevant terms must be established and defined in order to aid the clarity and ability to draw conclusions from this research. The term *true fundamental* as written above will be used to refer to the pitch being sung by the vocalist, regardless of technique. For ingressive phonation, the true

fundamental is the same pitch as the perceived (or, false) fundamental; this technique does not generate any subharmonic series. For subharmonic and throat bass, the perceived fundamental frequency sounds an octave lower than the true fundamental—that is to say, a vocalist who wishes to perform an A1 with either of these techniques will sing an A2 and then utilize the technique, at which point an A1 will be heard. Vibration bass takes this concept to the next level, and produces a perceived fundamental a whole 19 semitones below the sung pitch, also known as an octave and a perfect fifth. This paper will involve both technical physical descriptions of intervals, as well as some common musical terms, as it seeks to create a resource for the researcher and the performer alike. An octave is defined as a doubling or halving of frequency, and a perfect fifth is a frequency ratio of 3 : 2.

Continuing on, the term “subharmonic” singing originates from the concepts of harmonics, also known as overtones or partials, of a pitched sound. Any pitched sound besides a pure sine wave is made up of many frequencies organized in a specific way. The lowest of these frequencies is perceived as the “pitch”, and the rest of the frequencies will sound at whole number intervals of the lowest, or *fundamental*, frequency and be perceived as its quality or *timbre*. Since they will always be at whole number intervals of the fundamental, a complete series of overtones will always follow the same intervals: first an octave above then fundamental frequency, followed by a perfect fifth above that, then a perfect fourth above that, then a major third above that. . . the intervals get smaller and smaller as the harmonic series continues into higher and higher frequencies above the fundamental. This series of pitches is something that exists naturally, and is heavily related to how the western 12-tone diatonic scale was created in the first place [3]. The equation for harmonics of a frequency is defined as

$$f_n = (n + 1) \cdot f_0 \quad (1)$$

where f_n is the n th harmonic of the fundamental frequency f_0 for any integer n .

Conversely, the *subharmonic* series, also known as the undertone series, consists of the same intervals but is mirrored over the fundamental frequency. Therefore the first subharmonic is an octave below the fundamental, the second is a perfect fifth below that, the third is a perfect fourth below that, and so on, following the exact same pattern as the harmonic series in the opposite direction. The equation

for *subharmonics* of a frequency is defined as

$$f_n = f_0 / (n + 1) \quad (2)$$

where f_n is the n th subharmonic of the fundamental frequency f_0 for any integer n .

An integral concept to the techniques used in this paper is that of Giuseppe Tartini’s seemingly mystical *combination tone*. Tartini found that combining certain pitches, specifically those exactly a fifth apart, will produce a third resultant tone an octave below the lower of the two sounded pitches [4]. This mechanism is the basis for throat and vibration bass, which utilize both sets of vocal folds, known as the *true* and *false* folds to produce such an interval that generates a resultant undertone the desired subharmonic interval below the true fundamental.

To gather data for this analysis, three vocalists each recorded one to two techniques with which they are proficient. Robert Waters recorded subharmonic bass, Lucas Faria de Sá Tucker recorded ingressive phonation, and Melody Henrich recorded both throat bass and vibration bass. Each of these vocalists have years of experience with their respective techniques, as well as years spent in the bass vocalist or beatbox communities, within which similar techniques are quite popular. Each vocalist was asked to record five descending scales with each technique they were recording, each one on a different vowel shape. This was done in order to observe how vowel shaping affects the prominent overtones for each analyzed technique, something that would turn out to be especially of note in the case of ingressive phonation, though bore significance for all four techniques. Vocalists were instructed to record a scale ranging from roughly seven to 12 semitones, and to sustain each note briefly to ensure enough data was available to produce an accurate FFT. A fast Fourier transform is a specific case of the discrete Fourier transform

$$A_k = \sum_{n=0}^{N-1} e^{-i \frac{2\pi}{N} kn} a_n \quad (3)$$

where a signal of discrete steps a_n from $n = 0 \dots N - 1$ is converted to a frequency spectrum A_k . The fast Fourier transform uses an FFT size of 2^n points, allowing for a greatly optimized computation [1]. This is because a discrete Fourier transform for a time domain signal with N samples takes $O(N^2)$ total adds and multiplies to compute, whereas a fast Fourier transform with the same amount of samples only needs to make $O \cdot (N \log N)$ adds and multiplies—a difference which becomes massive for large N . Using a large N is necessary in order to get sufficient frequency resolution to tell apart extremely low notes, as the frequency step size of a semitone becomes increasingly small when working with increasingly lower notes. This is why sustained notes were requested from participating vocalists, as more data is required to get accurate results from an FFT of a larger size. FFT sizes of 16384 and 32768 were used in this experiment to analyze data in various frequency ranges. All FFTs performed in this

analysis were computed using Adobe’s Audition 2024 audio analysis software using Hann windowing.

Each vocalist recorded independently using their own recording hardware and software. Waters recorded with a RODE NT1–A Cardioid Condenser Microphone through a RODE interface into Apple’s Logic Pro digital audio workstation (DAW). Faria de Sá Tucker recorded with a Shure SM7B dynamic microphone through a Scarlett Solo interface into Adobe’s Audition 2024 audio editor software. Henrich recorded with a Shure SM58 dynamic cardioid microphone through a Boss RC–505 Loopstation into Ableton’s Live 12 DAW. All recordings were taken at a sampling rate of 44.1kHz and a bit depth of 24 to ensure high quality audio, and exported as wav files. It is important to use a sampling rate greater than 40kHz when recording most audio, as the resulting cutoff of the *Nyquist frequency*

$$f_{Nyquist} = \frac{f_{sampling}}{2} \quad (4)$$

will still include the full range of human hearing, up to 20kHz. Using a lower sampling rate can result in aliasing if frequencies above the Nyquist should be recorded. This means that instead of recording the frequency as it originally sounded higher than the Nyquist, an aliased frequency would instead show up as a frequency below the Nyquist separated from the Nyquist by the same value. This is defined as follows:

$$f_{alias} = |f_{Nyquist} - |f_{Nyquist} - f_{wave}|| \quad (5)$$

Once data from the vocalists was acquired and spectra generated using Adobe Audition, the data was imported to a spreadsheet to perform various analyses. The most prominent partial of each note was found by identifying the greatest amplitude present in each spectrum, and its corresponding frequency. The fundamental frequency of each note was also identified alongside its amplitude in order to compare volume across vowel shapes, techniques, and between fundamental and the loudest overtone. In several cases, the fundamental frequency itself was the most prominent part of the note’s harmonic series, which led to some interesting visual effects when graphs were produced. Visualizations were created to show one sample FFT each from every technique performed, as well as plots of the amplitudes of the loudest harmonic and fundamental frequency over fundamental frequency for each vowel shape and technique, and a second set of technique–specific specialized plots. For the ingressive phonation, this was a plot of the frequency of the loudest harmonic over the frequency of the fundamental sung. For subharmonics, throat bass, and vibration bass, this was a plot of the ratio of the frequency of the loudest harmonic divided to the fundamental frequency.

2. DISCUSSION

(Note: all figures are included at the end of the document for formatting purposes). The results produced by these

analyses are fascinating to say the least, though it may not be immediately apparent from the above slew of graphs. There are five main takeaways from our analyses: the surprising weight of vowel shape in the timbral quality of ingressive phonation, the consistency of the true fundamental as the loudest partial in subharmonic and throat bass, the so-called throat bass tone appearing as the most prominent harmonic in vibration bass, the case of octavized ghost Tartini resultant tones an octave below the false fundamental in vibration bass, and the overwhelming ease of perception and performance with the “OH” vowel shape across techniques due to spectral content.

When it comes to ingressive phonation, a very interesting phenomenon is observed. While singing through a range of frequencies—specifically an octave in the case of this study—the frequency of the most prominent harmonic remains almost exactly the same across all performed notes. Observe Figures 7 and 10 for prominent examples of this occurring. This is possible because the higher up through the harmonic series one progresses, the smaller the intervals between the harmonics become. Therefore at very high frequency values nearly 10 times that of the fundamental frequency, the most prominent overtone can remain within the same 50–90Hz range, depending on the frequencies of the fundamentals performed. This suggests that it is the shape of the vowel more than the fundamental frequency being sung that affects the spectrum of a note performed with ingressive phonation. This aligns with other known properties of the technique, such as its aforementioned significant volume as a whole due to the ability to resonant powerfully in the chest cavity of the vocalist performing it. It is reasonable to extrapolate that another property of the sound waves being created inwards is an especially prominent influence by the shaping of the vocal tract; or, in other words, the vowel shape being used.

On the other hand, subharmonic singing and throat bass produce more typical results, better highlighted in their respective plots of the loudest harmonic’s multiple of the fundamental frequency over fundamental frequency. This can be observed on nearly every vowel shape tested; for reference, see Figures 21, 22, 30, 31. These plots all show that the frequency of the loudest harmonic is nearly exactly double the frequency of the false fundamental for both of these techniques. This reflects the fact that these techniques create perceived tones an octave beneath the “true” fundamentals being sung, and gives these techniques a more natural quality perceptually. It is not uncommon for the second harmonic to be the loudest in standard modal singing registers used in a majority of singing; this parallel gives subharmonic singing and throat bass a more modal quality that aligns with what most listeners expect singing to sound like. As a result, expert utilization of these techniques simply gives the effect of a vocalist having an incredible low and well controlled vocal range.

Additionally, it was noted in one vowel shape of throat bass that Henrich, the vocalist for said technique, was able to produce a tone with a false fundamental louder than even the true fundamental (Figure 33). This shows a phenomenal level of skill and control, and shows the versatility

of these techniques in producing various notably different timbres. The use cases of extended vocal techniques are currently quite esoteric, but they certainly deserve a place in the spotlight with how many possibilities they can create.

Moving on to vibration bass, it can be observed that it follows the expected pattern of the same most prominent partial regardless of false fundamental frequency for most vowel shapes (Figures 42, 44). However, this consistent loudest harmonic is not the true fundamental. Since vibration bass creates a false fundamental an octave and a fifth below the true performed fundamental, its true fundamental can be found two harmonics “above” the sounded pitch. From Equation 1, two harmonics above requires multiplying by a factor of $2 + 1 = 3$, not the 1.5 that was most prominent. In fact, the most prominent harmonic was actually the pitch that would be sounded if the same true fundamental was performed with throat bass; in other words, the note an octave below the true harmonic. This is interesting for a number of reasons. First of all, it is further evidence that it is very possible to perform these EVT’s in a way that creates false fundamentals (or, in this case, false harmonics!) that are more prominent and impactful to the sound than the true fundamental being sung. However, it also begs an interesting question: if the false fundamental is only a fifth below its first “harmonic”, what does the rest of the series of overtones look like? The definition of a harmonic series established via Equation 1 makes it clear that the first interval between a fundamental and harmonic will be an octave, regardless of the pitch of this fundamental. The same goes for the subharmonic series (Equation 2). And fascinatingly enough, the FFT of vibration bass reflects this conundrum with an incredible result; a faint ghost subharmonic an octave beneath the false fundamental completing the harmonic series (Figure 34). The furthest left spike on this plot is not the perceived pitch, but a pitch an entire octave lower. Considering the uniquely low frequency ranges vibration bass can already reach, this discovery speaks volumes to the possibilities of this technique in contemporary music. This “ghost tone”, however, is not an unknown phenomenon; this is simply another case of Tartini’s combination tones [4]. The perfect fifth created between the first and second subharmonics produced by vibration bass creates a resultant tone an octave below as expected.

Finally, it was found across all techniques analysed within this study that the standard open “OH” vowel shaping produces the most pleasant and viable results. That is to say, the upper partials in the “OH” vowel shape are particularly subdued and do not draw significant attention away from the fundamental (or false fundamental). This is especially important when using EVT’s, as there are often competing parts of the spectra, such as the true fundamental of a subharmonic technique or the prominent upper partials of ingressive phonation. The “OH” vowel does the best job of eliminating these distracting elements across all of the EVT’s studied.

3. CONCLUSIONS

The extended vocal techniques of ingressive phonation, subharmonic singing, throat bass, and vibration bass were recorded and their respective spectra analyzed across a range of vowel shapes. It was found that ingressive phonation has prominent upper partials which are predominantly shaped by choice of vowel. Subharmonic and throat singing both tend to have the sung true fundamental as their most prominent harmonic an octave above the sounded false fundamental, though they can be manipulated to produce a perceived fundamental louder than the true fundamental, giving a very natural vocal quality. Vibration bass has its loudest harmonic only a fifth above the perceived fundamental, giving it a distinct vocal quality and producing a Tartini combination tone an octave lower than the technique sounds.

Future extensions to this research could be envisioned to involve additional EVT's such as inwards bass and further descent into the subharmonic series with true fold subharmonics. Additionally, providing a vocalist to demonstrate modal singing for comparison would be valuable to highlight the differences between EVT's and standard singing.

Acknowledgments

This project could not have been possible without recordings provided by Robert Waters, Melody Henrich, and Lucas Faria de Sá Tucker.

4. REFERENCES

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<https://www.jstor.org/stable/843046>

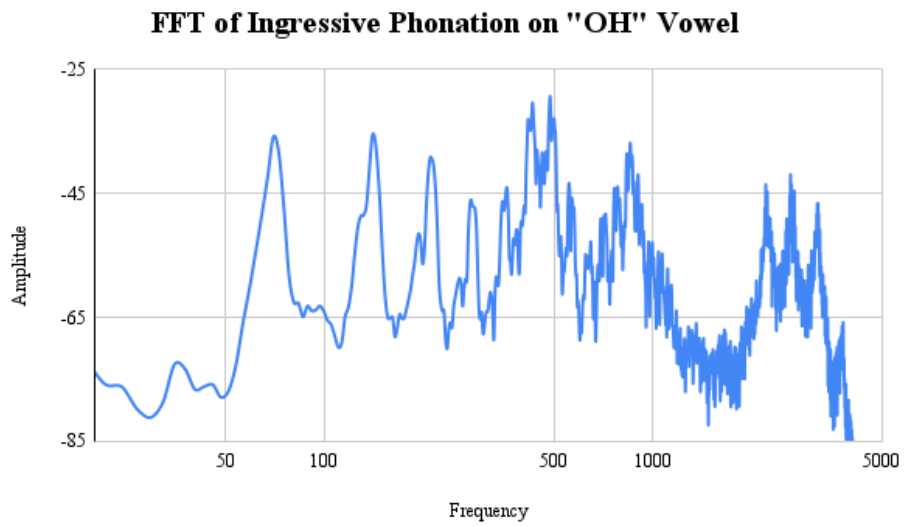


Figure 1. Fast Fourier Transform plot for ingressive phonation at a representative pitch.

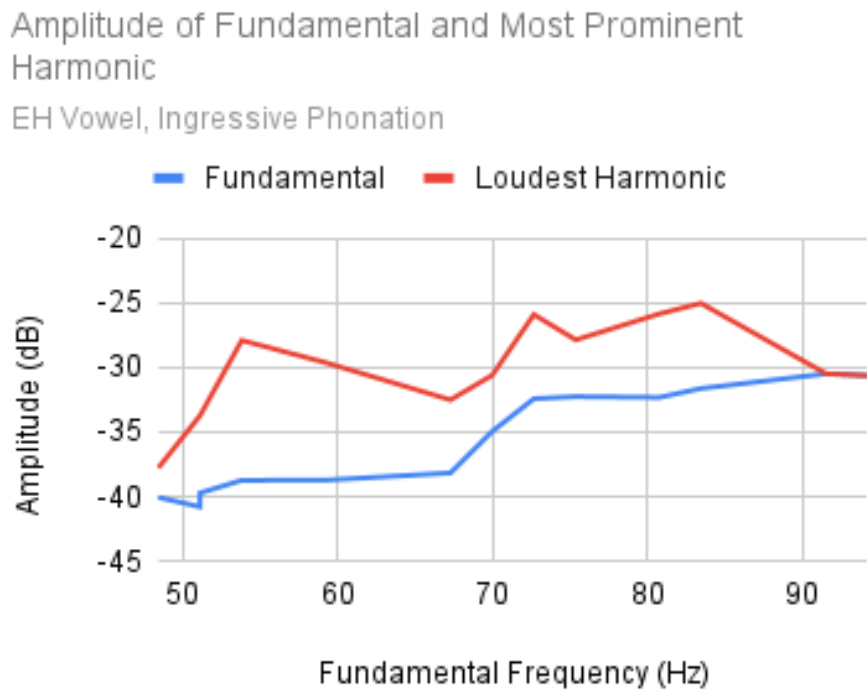


Figure 2. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for ingressive phonation performed on an "EH" vowel.

Amplitude of Fundamental and Most Prominent Harmonic

EE Vowel, Ingressive Phonation

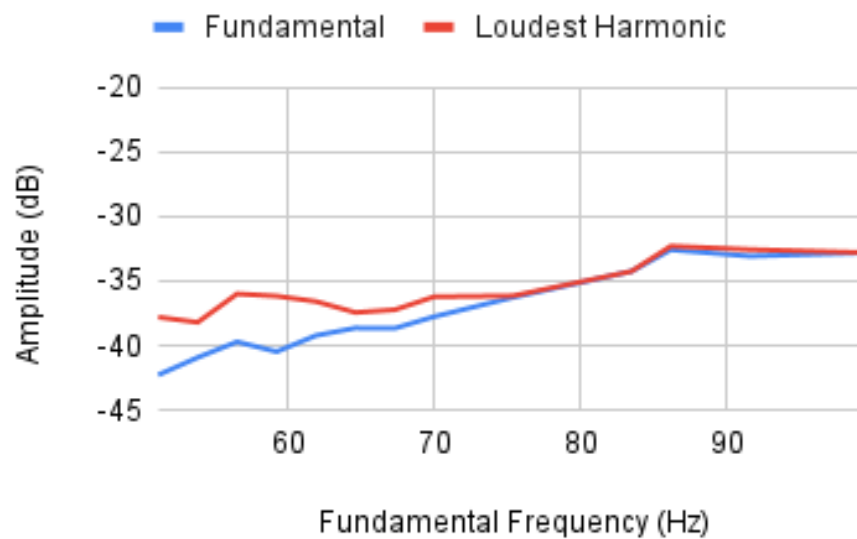


Figure 3. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for ingressive phonation performed on an “EE” vowel.

Amplitude of Fundamental and Most Prominent Harmonic

AH Vowel, Ingressive Phonation

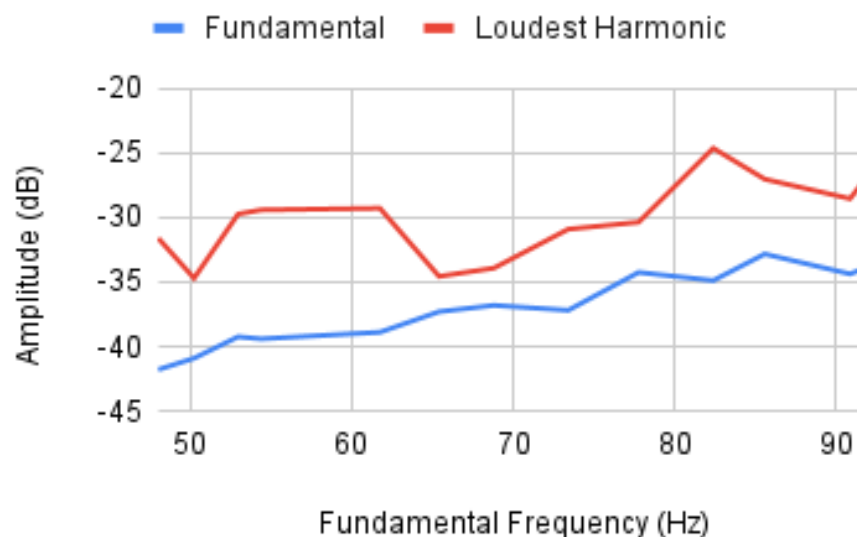


Figure 4. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for ingressive phonation performed on an “AH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic

OH Vowel, Ingressive Phonation

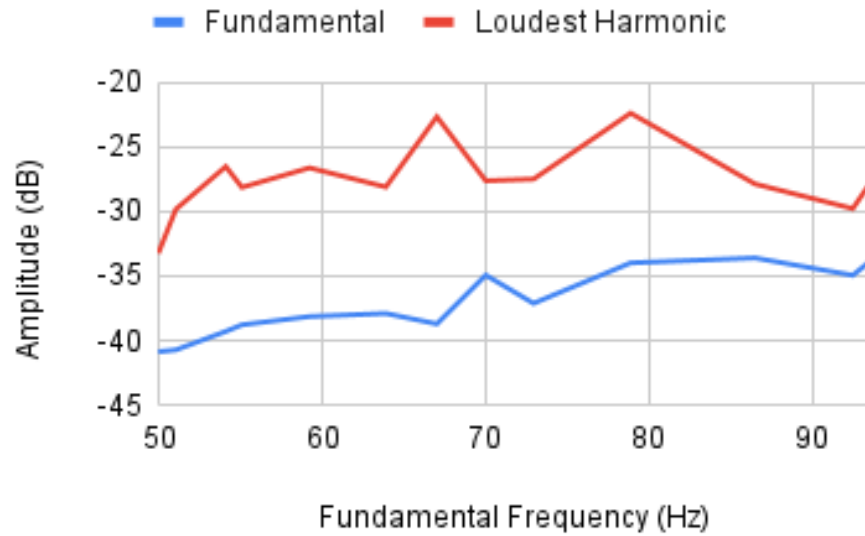


Figure 5. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for ingressive phonation performed on an “OH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic

OO Vowel, Ingressive Phonation

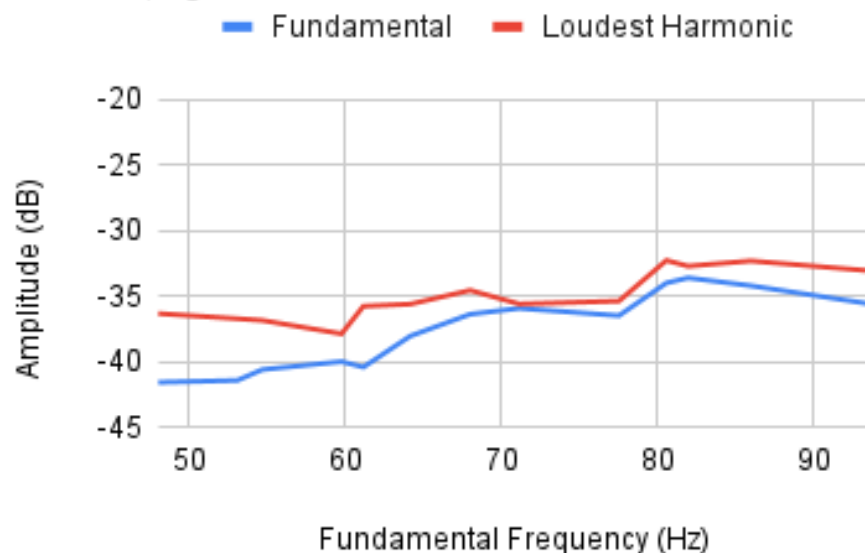


Figure 6. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for ingressive phonation performed on an “OO” vowel.

Loudest Harmonic vs Fundamental Frequency
EH Vowel, Ingressive Phonation

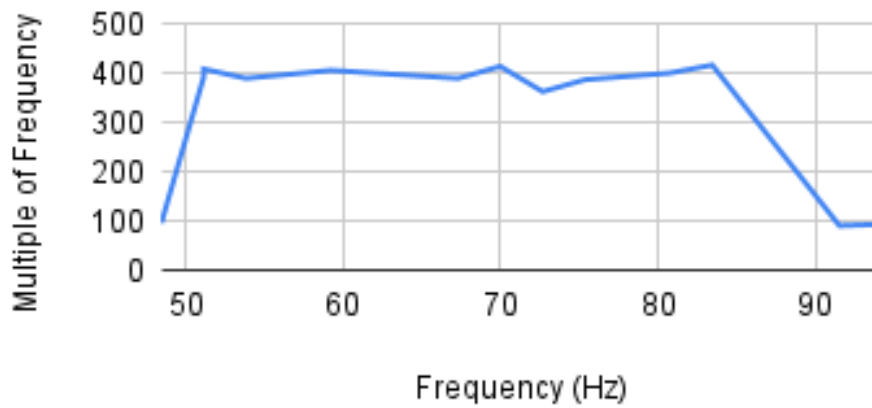


Figure 7. Plot of frequency of loudest harmonic over fundamental frequency for ingressive phonation performed on an “EH” vowel.

Loudest Harmonic vs Fundamental Frequency
EE Vowel, Ingressive Phonation

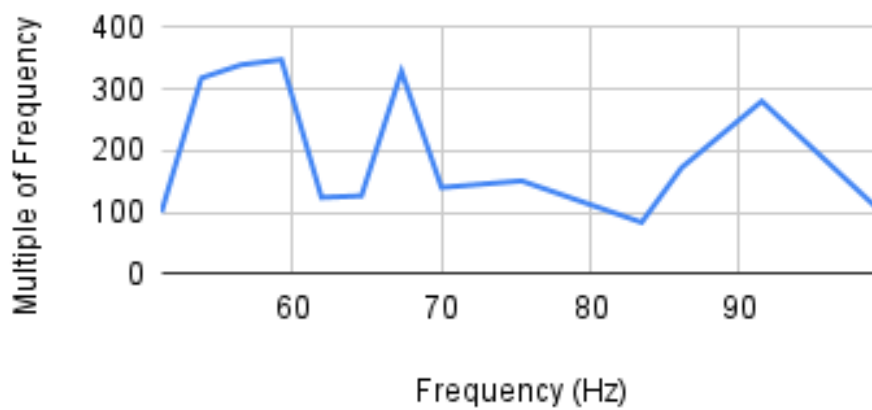


Figure 8. Plot of frequency of loudest harmonic over fundamental frequency for ingressive phonation performed on an “EE” vowel.

Loudest Harmonic vs Fundamental Frequency
AH Vowel, Ingressive Phonation

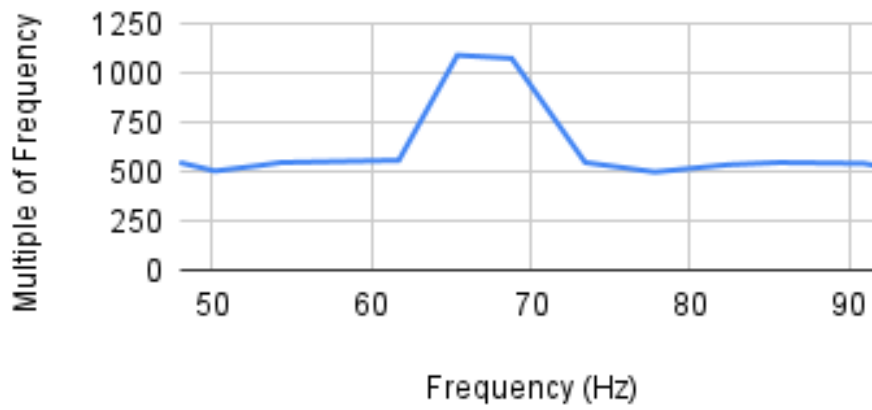


Figure 9. Plot of frequency of loudest harmonic over fundamental frequency for ingressive phonation performed on an “AH” vowel.

Loudest Harmonic vs Fundamental Frequency
OH Vowel, Ingressive Phonation

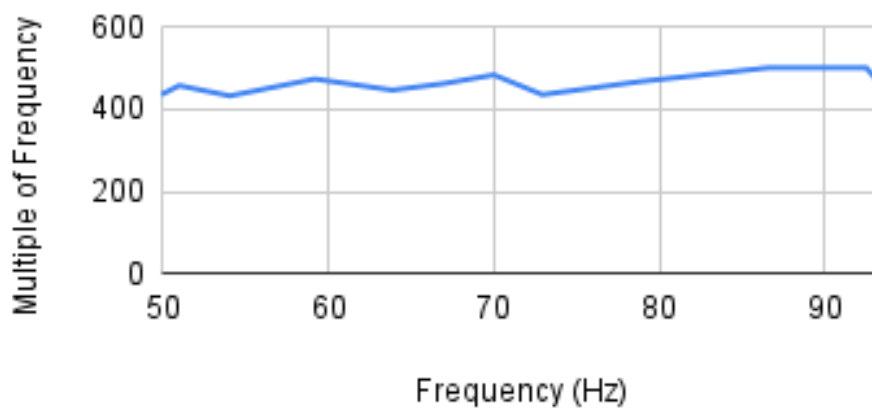


Figure 10. Plot of frequency of loudest harmonic over fundamental frequency for ingressive phonation performed on an “OH” vowel.

Loudest Harmonic vs Fundamental Frequency

OO Vowel, Ingressive Phonation

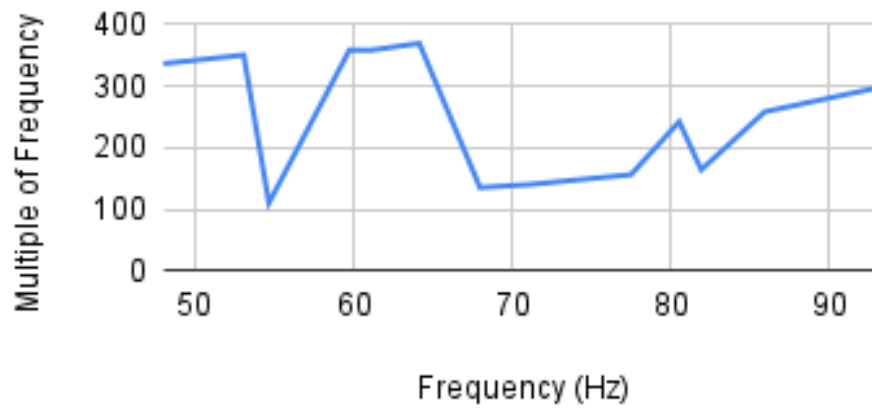


Figure 11. Plot of frequency of loudest harmonic over fundamental frequency for ingressive phonation performed on an “OO” vowel.

FFT of Subharmonic Bass on "OH" Vowel

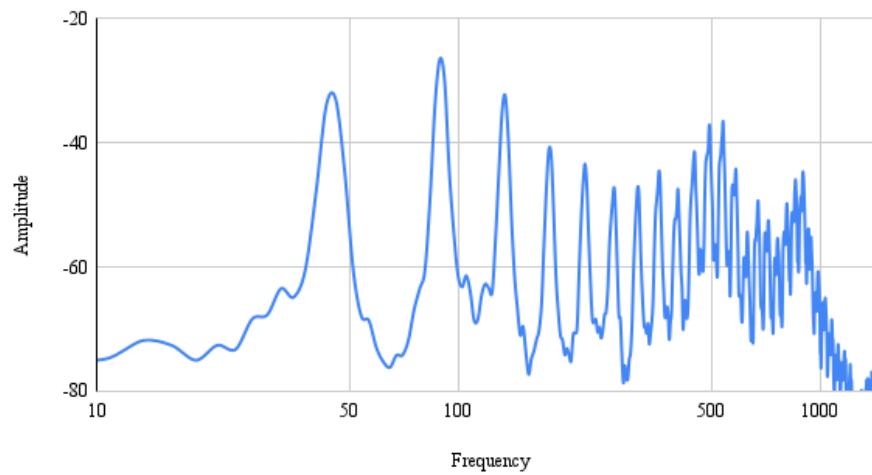


Figure 12. Fast Fourier Transform plot for subharmonic singing at a representative pitch.

Amplitude of Fundamental and Most Prominent Harmonic

EH Vowel, Subharmonics

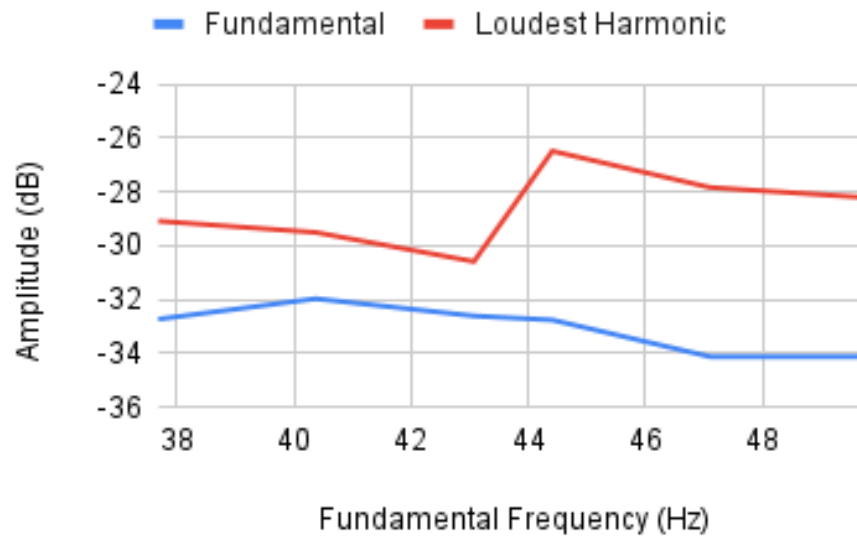


Figure 13. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for subharmonic singing performed on an “EH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic

EE Vowel, Subharmonics

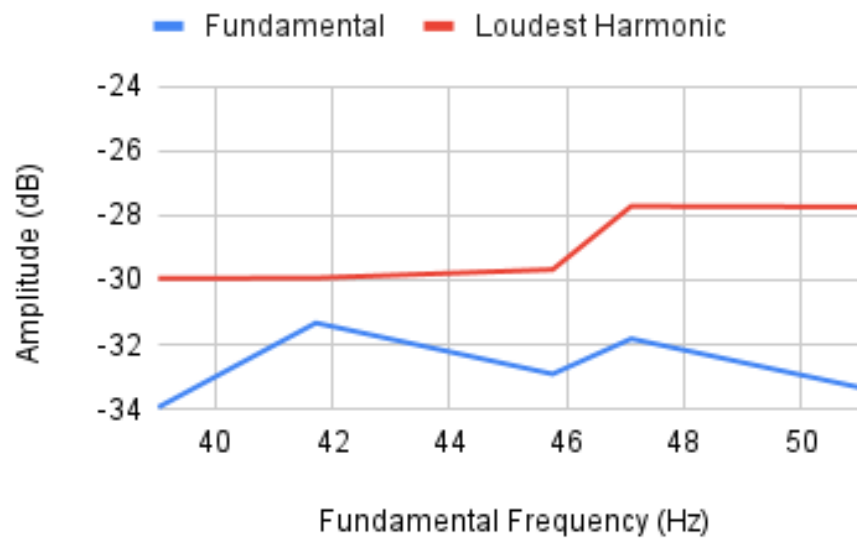


Figure 14. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for subharmonic singing performed on an “EE” vowel.

Amplitude of Fundamental and Most Prominent Harmonic

AH Vowel, Subharmonics

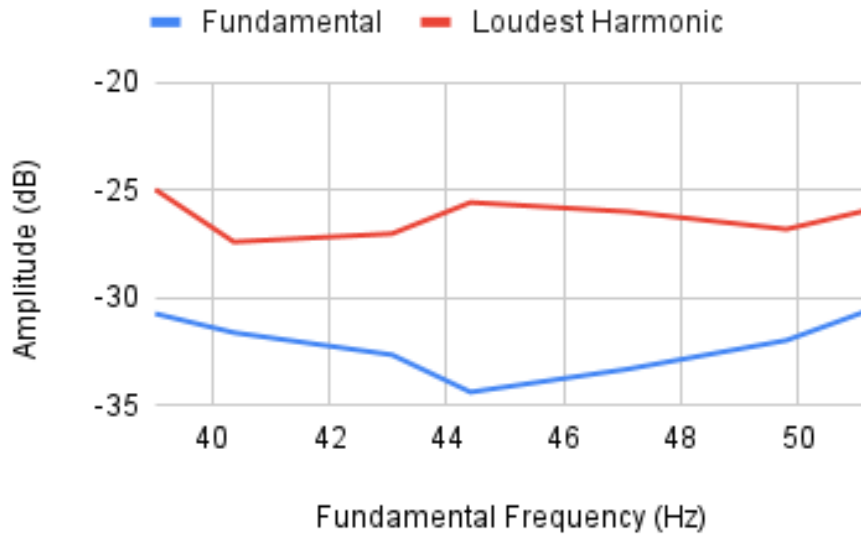


Figure 15. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for subharmonic singing performed on an “AH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic

OH Vowel, Subharmonics

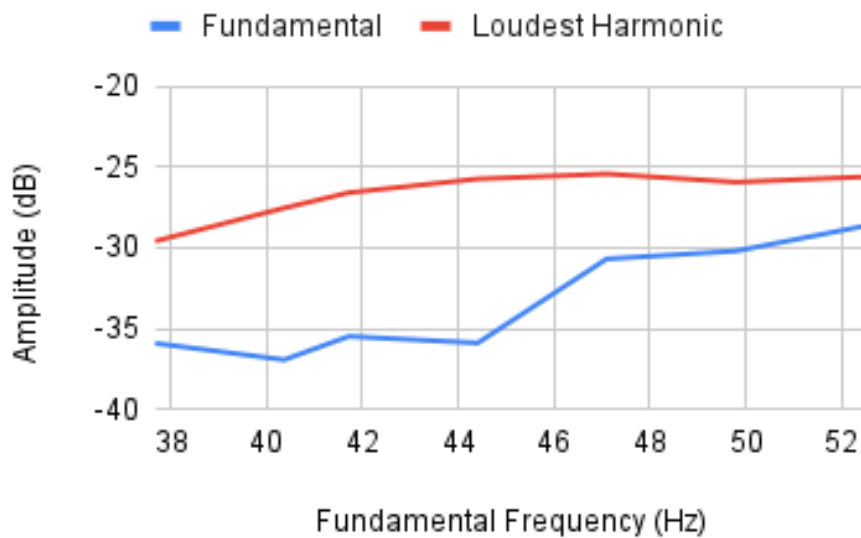


Figure 16. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for subharmonic singing performed on an “OH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic OO Vowel, Subharmonics

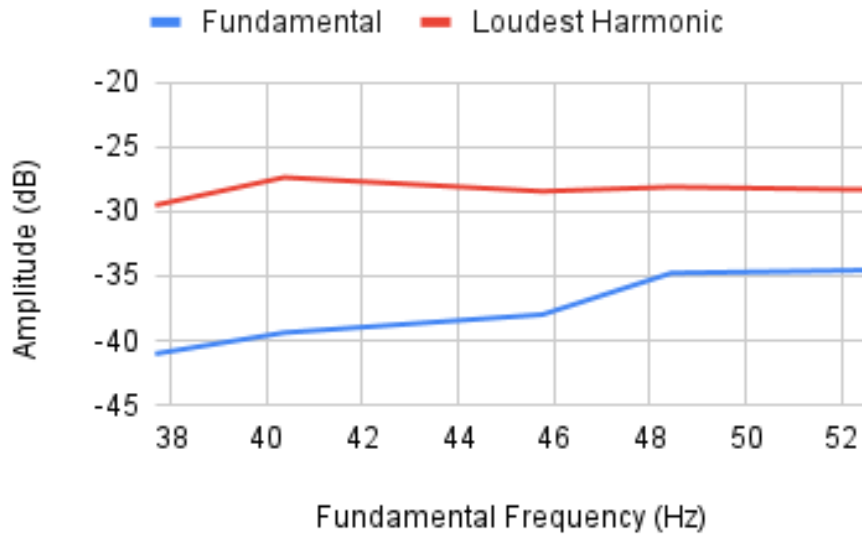


Figure 17. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for subharmonic singing performed on an “OO” vowel.

Multiple of Frequency vs Frequency

EH Vowel, Subharmonics

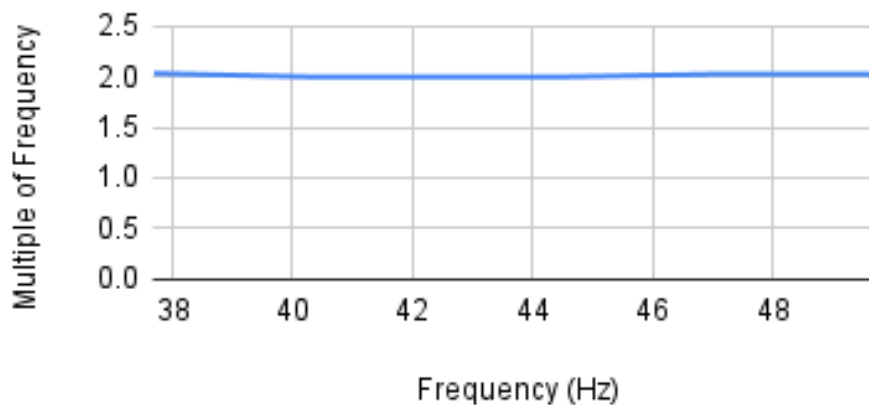


Figure 18. Plots of multiple of fundamental frequency of the loudest harmonic for subharmonic singing performed on an “EH” vowel.

Multiple of Frequency vs Frequency

EE Vowel, Subharmonics

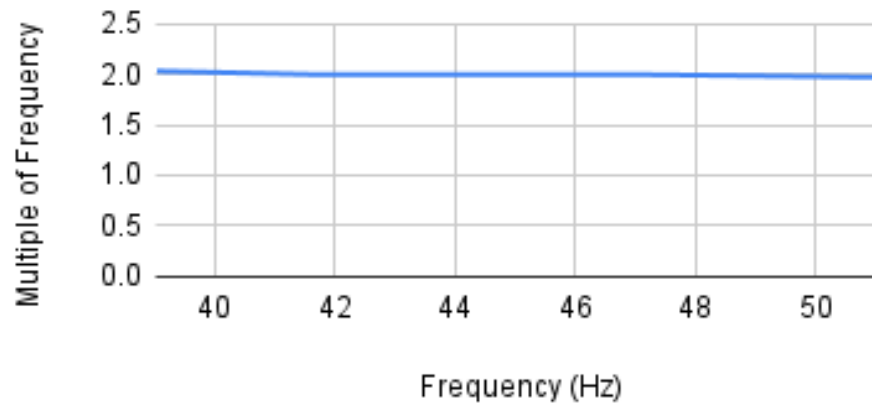


Figure 19. Plots of multiple of fundamental frequency of the loudest harmonic for subharmonic singing performed on an “EE” vowel.

Multiple of Frequency vs Frequency

AH Vowel, Subharmonics

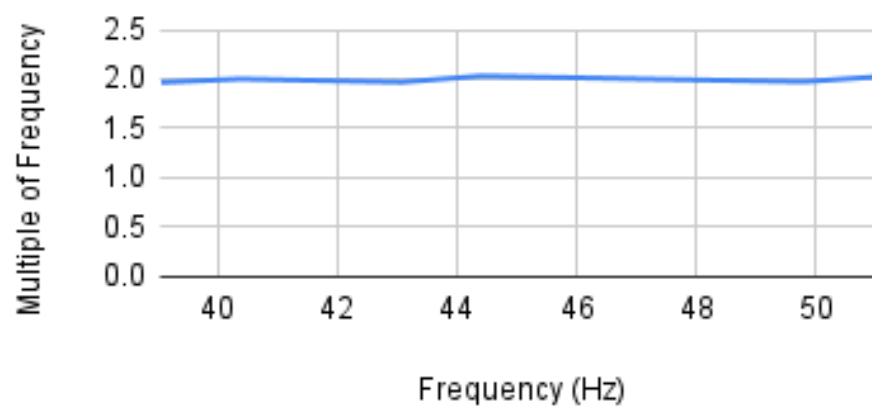


Figure 20. Plots of multiple of fundamental frequency of the loudest harmonic for subharmonic singing performed on an “AH” vowel.

Multiple of Frequency vs Frequency

OH Vowel, Subharmonics

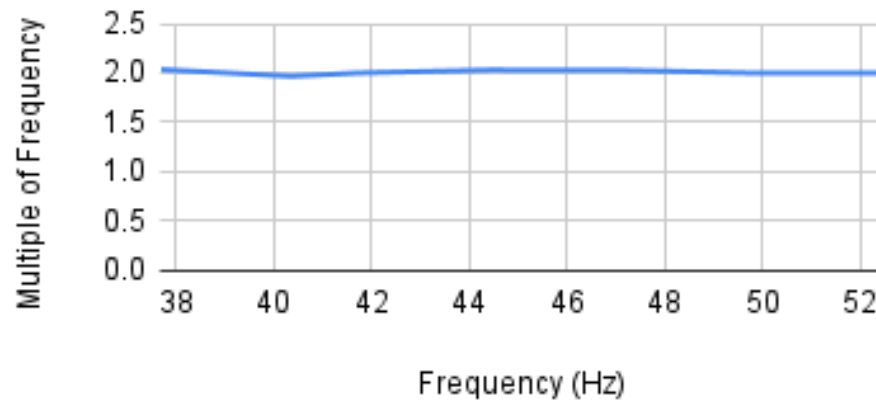


Figure 21. Plots of multiple of fundamental frequency of the loudest harmonic for subharmonic singing performed on an “OH” vowel.

Multiple of Frequency vs Frequency

OO Vowel, Subharmonics

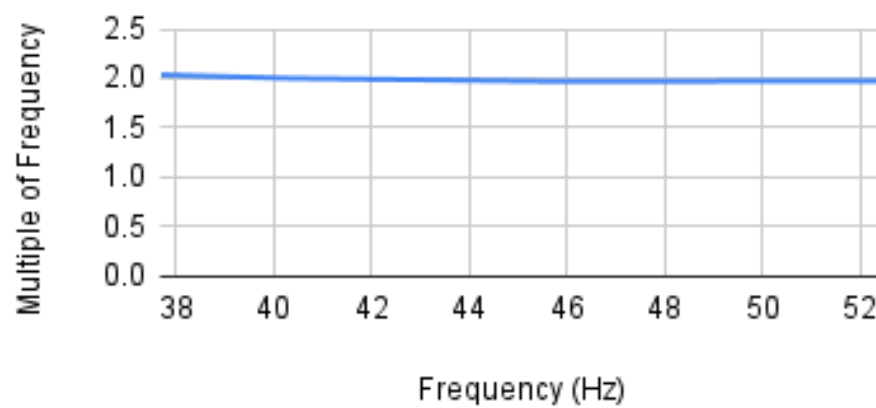


Figure 22. Plots of multiple of fundamental frequency of the loudest harmonic for subharmonic singing performed on an “OO” vowel.

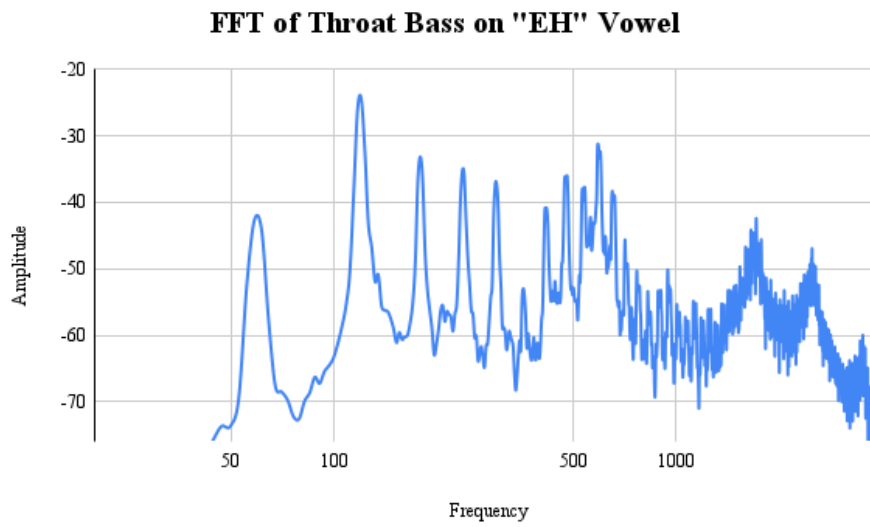


Figure 23. Fast Fourier Transform plot for throat bass at a representative pitch.

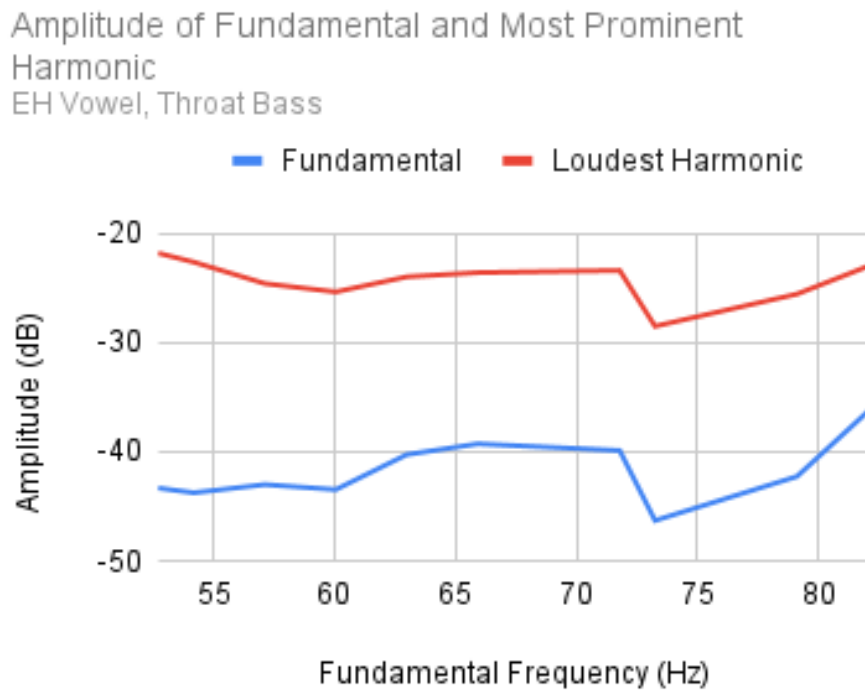


Figure 24. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for throat bass performed on an "EH" vowel.

Amplitude of Fundamental and Most Prominent Harmonic
 EE Vowel, Throat Bass

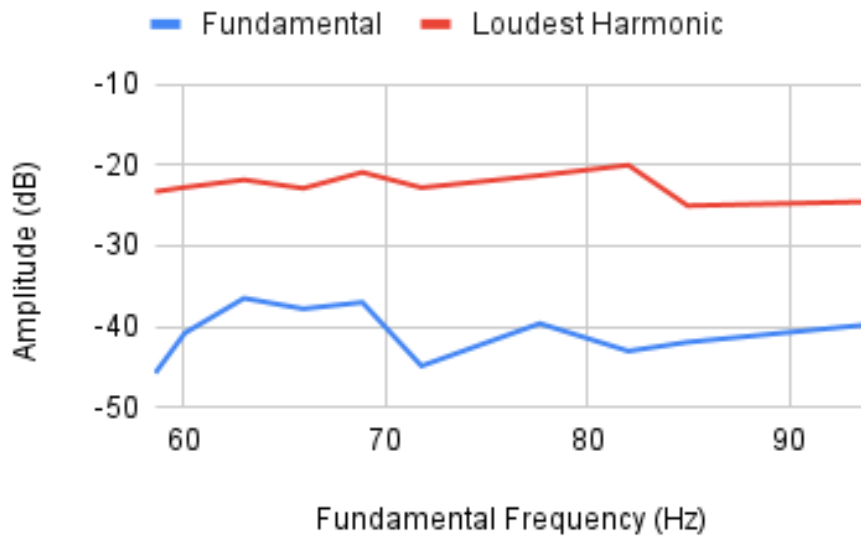


Figure 25. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for throat bass performed on an “EE” vowel.

Amplitude of Fundamental and Most Prominent Harmonic
 AH Vowel, Throat Bass

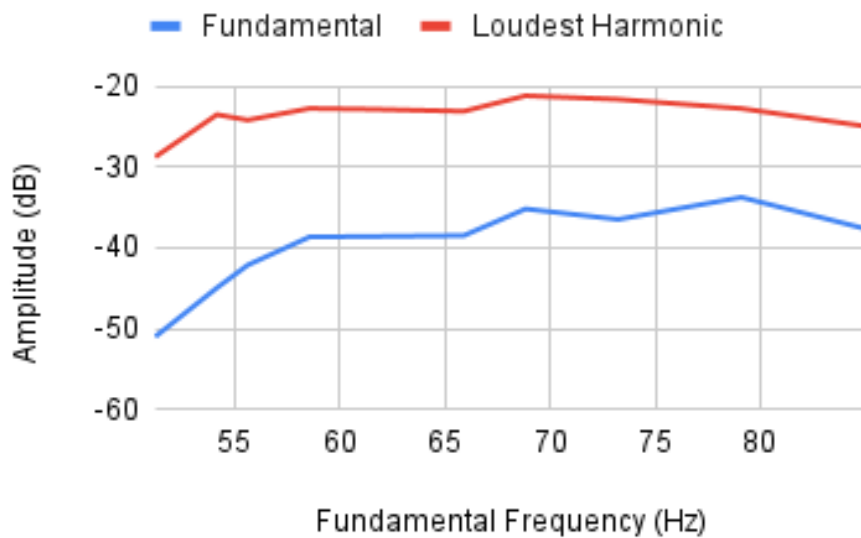


Figure 26. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for throat bass performed on an “AH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic
OH Vowel, Throat Bass

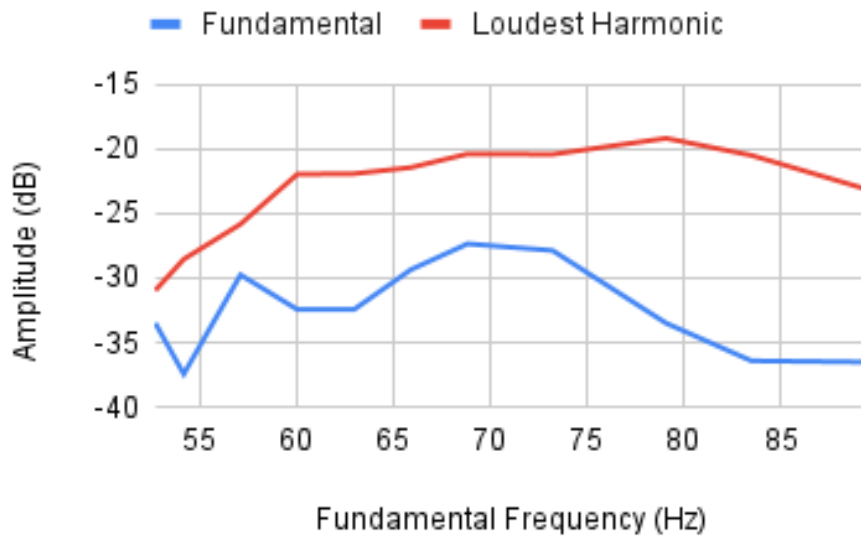


Figure 27. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for throat bass performed on an “OH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic
OO Vowel, Throat Bass

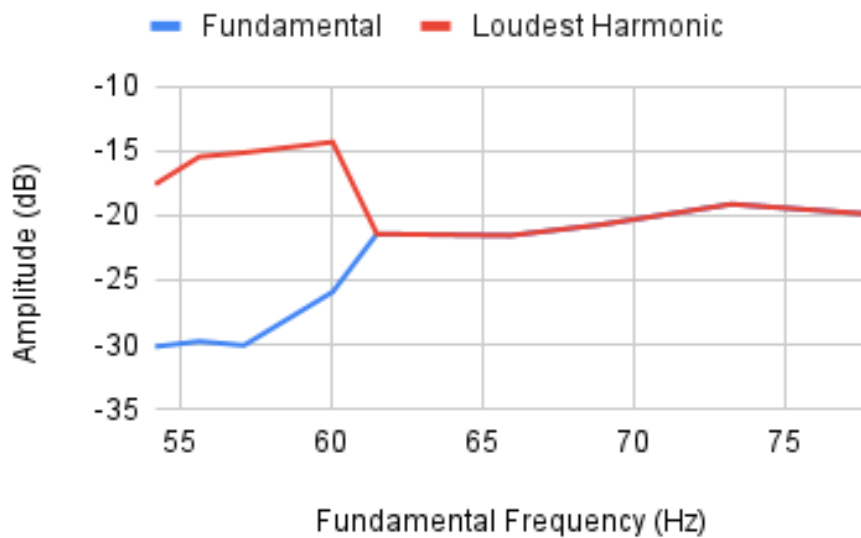


Figure 28. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for throat bass performed on an “OO” vowel.

Multiple of Frequency vs Frequency

EH Vowel, Throat Bass

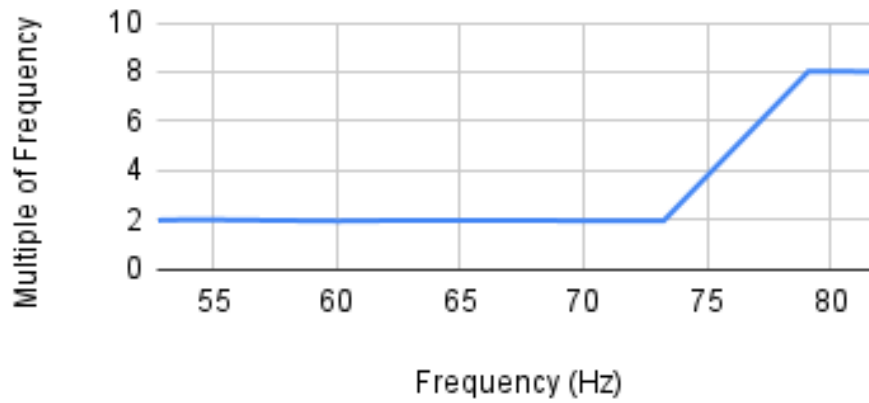


Figure 29. Plots of multiple of fundamental frequency of the loudest harmonic for throat bass performed on an “EH” vowel.

Multiple of Frequency vs Frequency

EE Vowel, Throat Bass

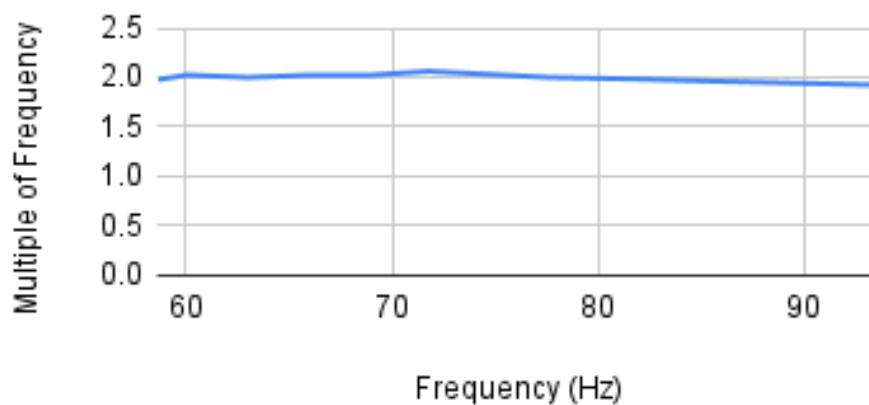


Figure 30. Plots of multiple of fundamental frequency of the loudest harmonic for throat bass performed on an “EE” vowel.

Multiple of Frequency vs Frequency

AH Vowel, Throat Bass

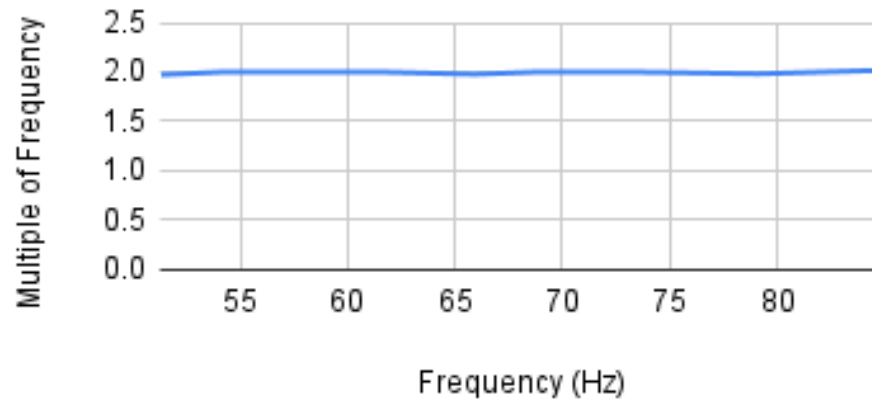


Figure 31. Plots of multiple of fundamental frequency of the loudest harmonic for throat bass performed on an “AH” vowel.

Multiple of Frequency vs Frequency

OH Vowel, Throat Bass

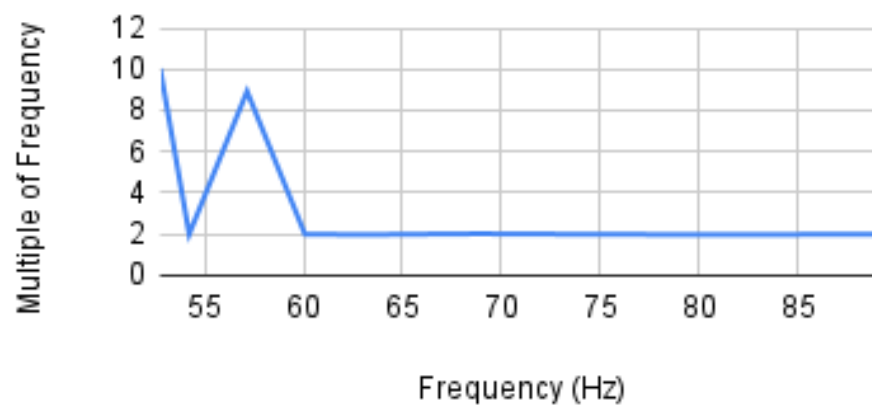


Figure 32. Plots of multiple of fundamental frequency of the loudest harmonic for throat bass performed on an “OH” vowel.

Multiple of Frequency vs Frequency

OO Vowel, Throat Bass

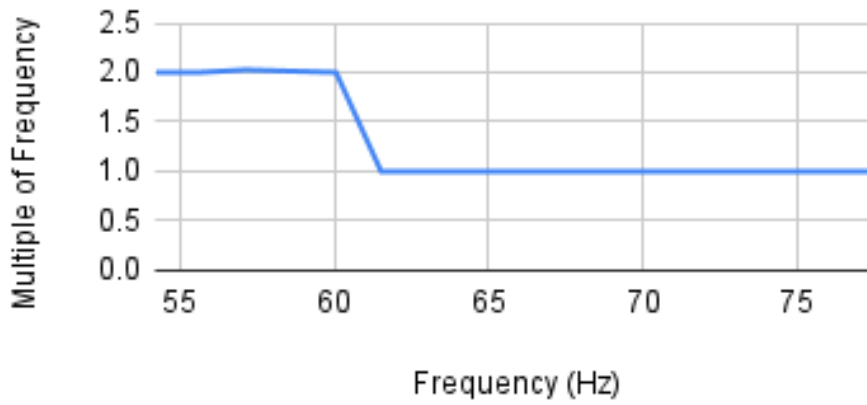


Figure 33. Plots of multiple of fundamental frequency of the loudest harmonic for throat bass performed on an “OO” vowel.

FFT of Vibration Bass on "AH" Vowel

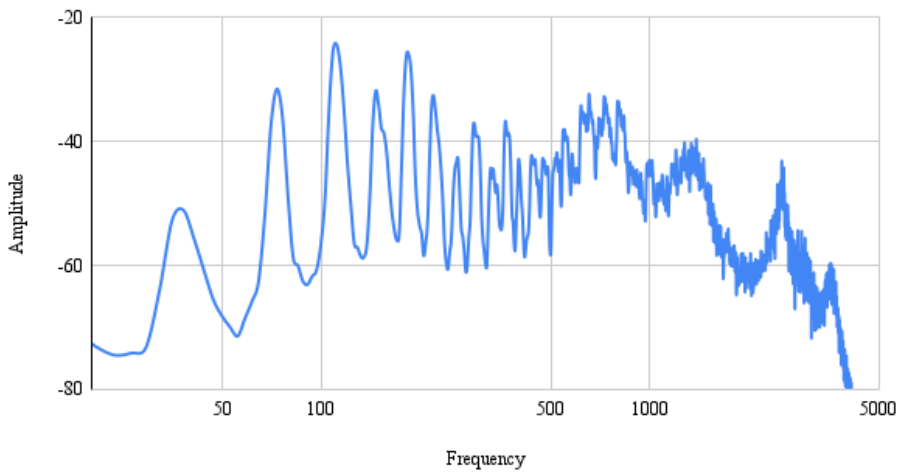


Figure 34. Fast Fourier Transform plot for vibration bass at a representative pitch.

Amplitude of Fundamental and Most Prominent Harmonic
EH Vowel, Vibration Bass

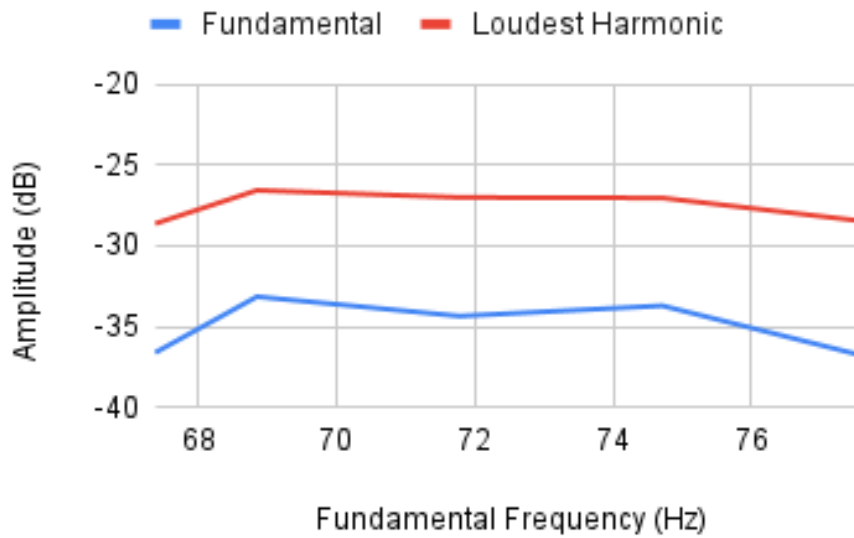


Figure 35. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for vibration bass performed on an “EH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic
EE Vowel, Vibration Bass

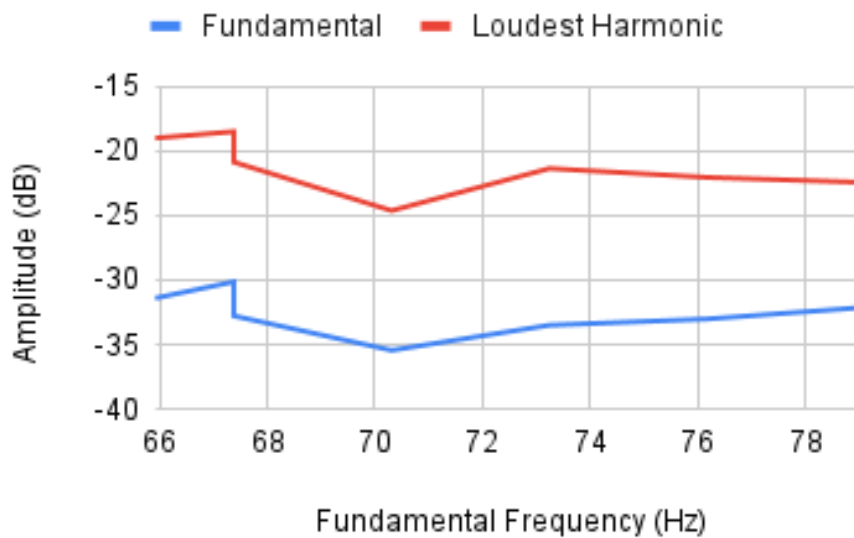


Figure 36. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for vibration bass performed on an “EE” vowel.

Amplitude of Fundamental and Most Prominent Harmonic
AH Vowel, Vibration Bass

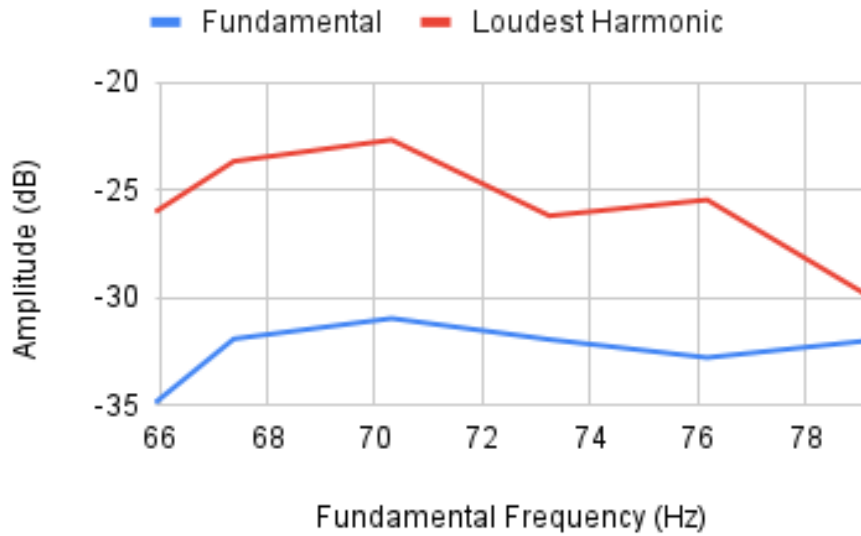


Figure 37. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for vibration bass performed on an “AH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic
OH Vowel, Vibration Bass

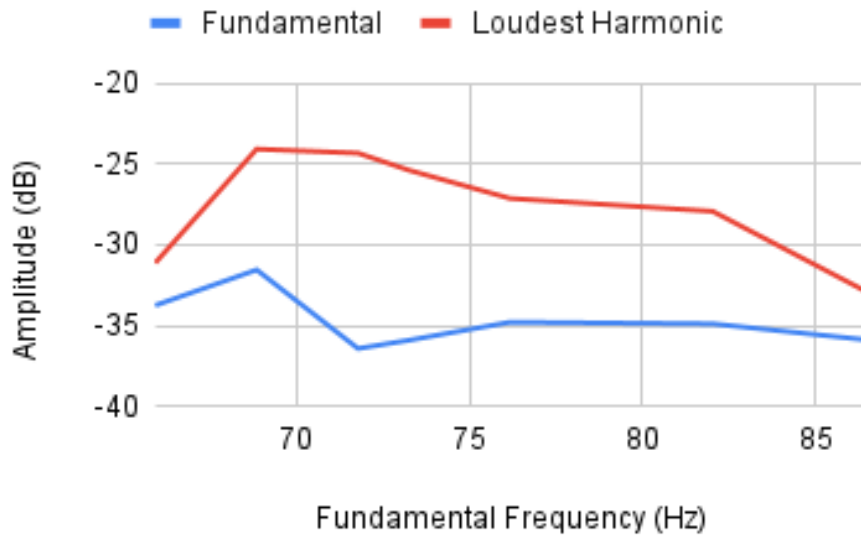


Figure 38. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for vibration bass performed on an “OH” vowel.

Amplitude of Fundamental and Most Prominent Harmonic
OO Vowel, Vibration Bass

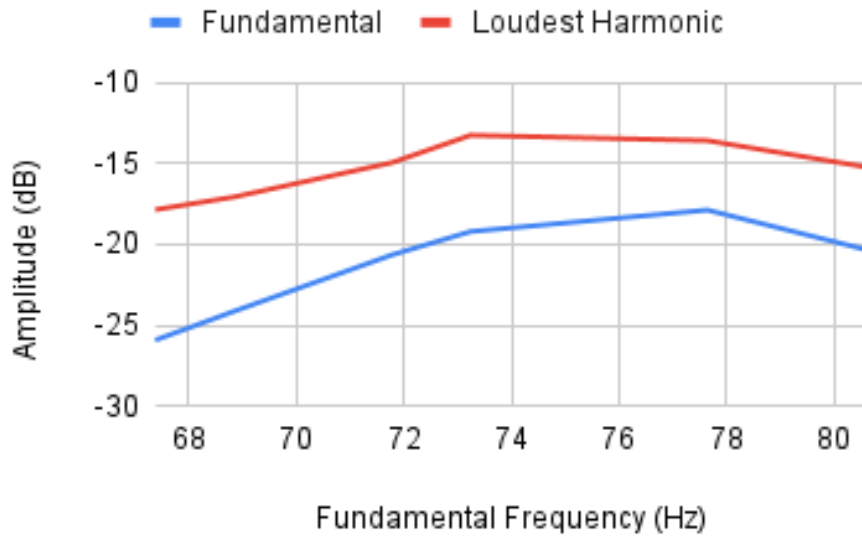


Figure 39. Plot of amplitudes of both the loudest harmonic and the fundamental frequency over fundamental frequency for vibration bass performed on an “OO” vowel.

Multiple of Frequency vs Frequency

EH Vowel, Vibration Bass

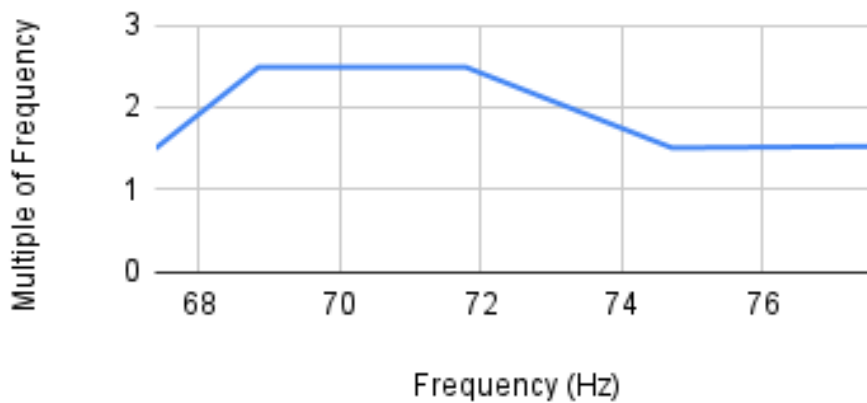


Figure 40. Plots of multiple of fundamental frequency of the loudest harmonic for vibration bass performed on an “EH” vowel.

Multiple of Frequency vs Frequency

EE Vowel, Vibration Bass

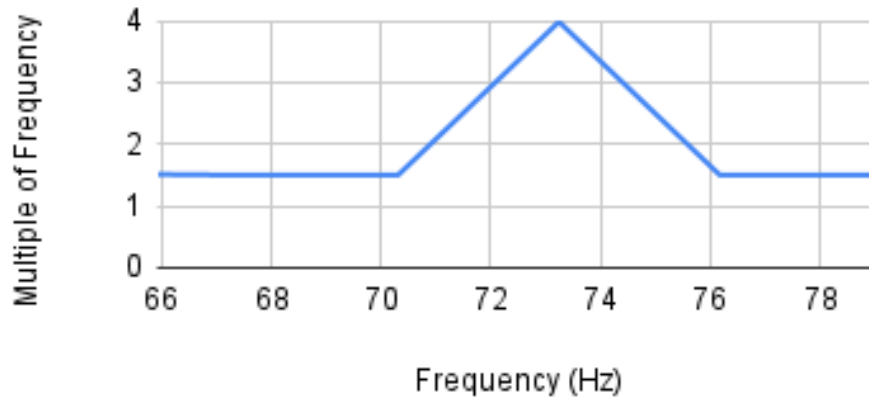


Figure 41. Plots of multiple of fundamental frequency of the loudest harmonic for vibration bass performed on an “EE” vowel.

Multiple of Frequency vs Frequency

AH Vowel, Vibration Bass

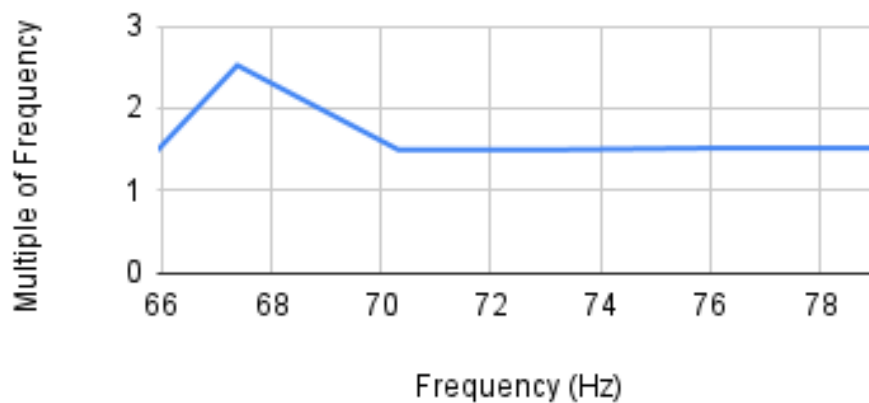


Figure 42. Plots of multiple of fundamental frequency of the loudest harmonic for vibration bass performed on an “AH” vowel.

Multiple of Frequency vs Frequency

OH Vowel, Vibration Bass

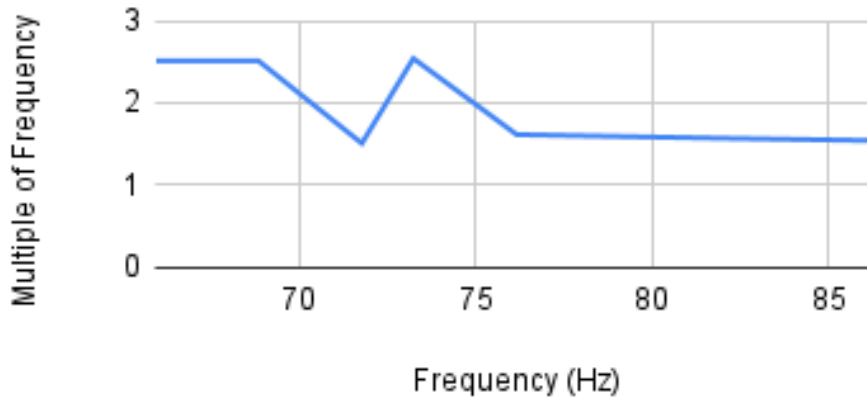


Figure 43. Plots of multiple of fundamental frequency of the loudest harmonic for vibration bass performed on an “OH” vowel.

Multiple of Frequency vs Frequency

OO Vowel, Vibration Bass

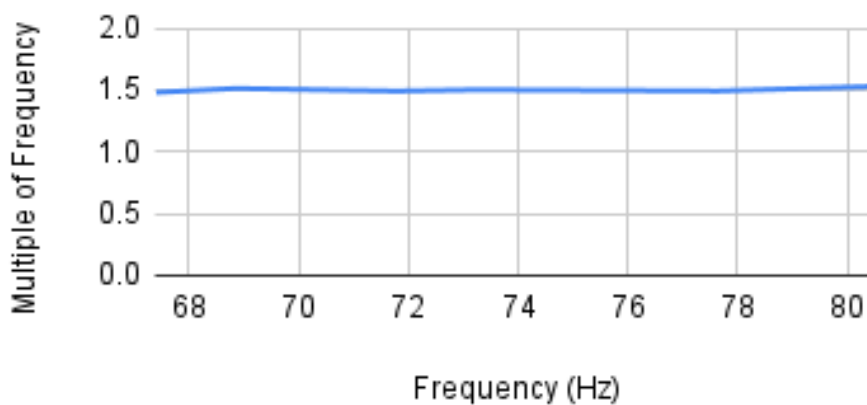


Figure 44. Plots of multiple of fundamental frequency of the loudest harmonic for vibration bass performed on an “OO” vowel.