# Peak and Harmonic Analyzer ver.1.0.0 User Manual

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This program displays the power spectrum of an input sound (sound file) and shows, at a glance, the positions (frequencies) of the many peaks in that spectrum, or the positions of the fundamental (f0) and its harmonics.

A power spectrum usually has countless peaks, so the program offers two filters to choose which peaks are shown : "Prominence" and "Min Peak Height". Prominence is how much a peak stands out from its surroundings; only peaks that stand out more than this value are shown. Min Peak Height is the level (decibels) of the peak top; only peaks higher than this value are shown.

For sounds with harmonics, such as instrument tones, the fundamental (f0) and the harmonics are found and shown separately, independently of the peak filters. For two or more tones sounding together, such as a double stop or a chord, a harmonic set is found and shown for each tone (up to 5 sets). Peaks and harmonics can each be shown or hidden. Up to 8 sounds can be drawn in one graph to compare them.

The calculation goes as follows. For a sound A,

1. The middle part of A, as long as the Analysis Length, is taken and its frequency spectrum (FFT : Fast Fourier Transform) is calculated.
2. If a mic calibration is selected, the frequency response of the microphone is corrected in the spectrum.
3. Only the peaks that stand out more than the Prominence and are higher than the Min Peak Height are taken, and their frequencies are shown at the peak tops.
4. If the sound has harmonics, the fundamental (f0) and the harmonics are found and shown. For two or more tones, a harmonic set is shown for each tone.

# 1 Usage

The program can be used to see the peaks or harmonics of a sound at a glance, or to compare the peaks or harmonics of several sounds in one graph.

Examples for the violin :

- Checking and comparing the tap tones of modes 1, 2 and 5 while working on the top and back plates
- Checking the fundamental (f0) and the positions and levels of the harmonics of played notes
- Checking the harmonics of each note of a double stop or chord, and the harmonics they share
- Recording the same note under different conditions (instrument, string, setup ...) and comparing peaks and harmonics

# 2 Install

The program is a portable version, so no installation is needed. Unzip the file and double-click "`Peak_and_Harmonic_Analyzer_v.X.X.X.exe`" in the "`Peak_and_Harmonic_Analyzer_v.X.X.X`" folder to start the program. Depending on the computer, starting may take some time.

# 3 Preparations

## 3.1 Preparing the sound files

Up to 8 sounds can be loaded and analyzed, so prepare the sound files as needed.

## 3.2 Conditions of the sound files

Points to keep when preparing or recording the sound files :

- Accurate tuning and accurate pitch
- Uncompressed wave files (extension : wav). 8, 16, 24, 32 bit integer and 32 bit float formats are all supported
- Mono (1 channel) is recommended. The two channels of a stereo file are averaged into mono for the analysis
- A sampling frequency of 44.1 [kHz] is recommended
- The file should be longer than the Analysis Length (default 1.0 s). 1 s or longer is recommended

## 3.3 Precautions

When recording, keep the resonances of the room out of the recording as much as possible. The best place is an anechoic chamber; otherwise, a quiet place outdoors (e.g. a field without buildings that reflect the sound) or a room well damped with curtains is recommended. If room resonances could not be avoided, take them into account when judging the results.

Sounds to be compared must be recorded with the same microphone, at the same position, distance and recording level. Any difference in these conditions shows up directly in the peak heights.

# 4 Screen layout

When the program starts, the window of Figure 1 appears. It is divided into two columns by a vertical line : the sound files and analysis settings on the left, the mic calibration and calculation buttons on the right. The numbers of the sections roughly follow the order of use.

| No. | Section | Contents |
|---|---|---|
| 1 | SELECT SOUND FILES | Sound files to analyze (up to 8) |
| 2 | FFT SETTINGS | FFT Size, Window, Analysis Length |
| 3 | PEAK SETTINGS | Show/hide peaks, filters choosing the peaks shown |
| 4 | HARMONICS | Show/hide harmonics, number of harmonic sets etc. |
| 5 | AXIS SETTINGS | X-axis (Linear/Log, range) and Y-axis range |
| 6 | MIC CALIBRATION | Microphone calibration |
| 7 | CALCULATION | Graph windows, calculation buttons, result table |

Table 1: *Screen layout*

The color of a button shows its state.

| Color | Meaning |
|---|---|
| Sound 1 | Input needed (no file loaded yet) |
| Sound 1 | Loaded / ready to calculate |
| Calculate Sound 1 | Not available now |

Table 2: *Meaning of the button colors*

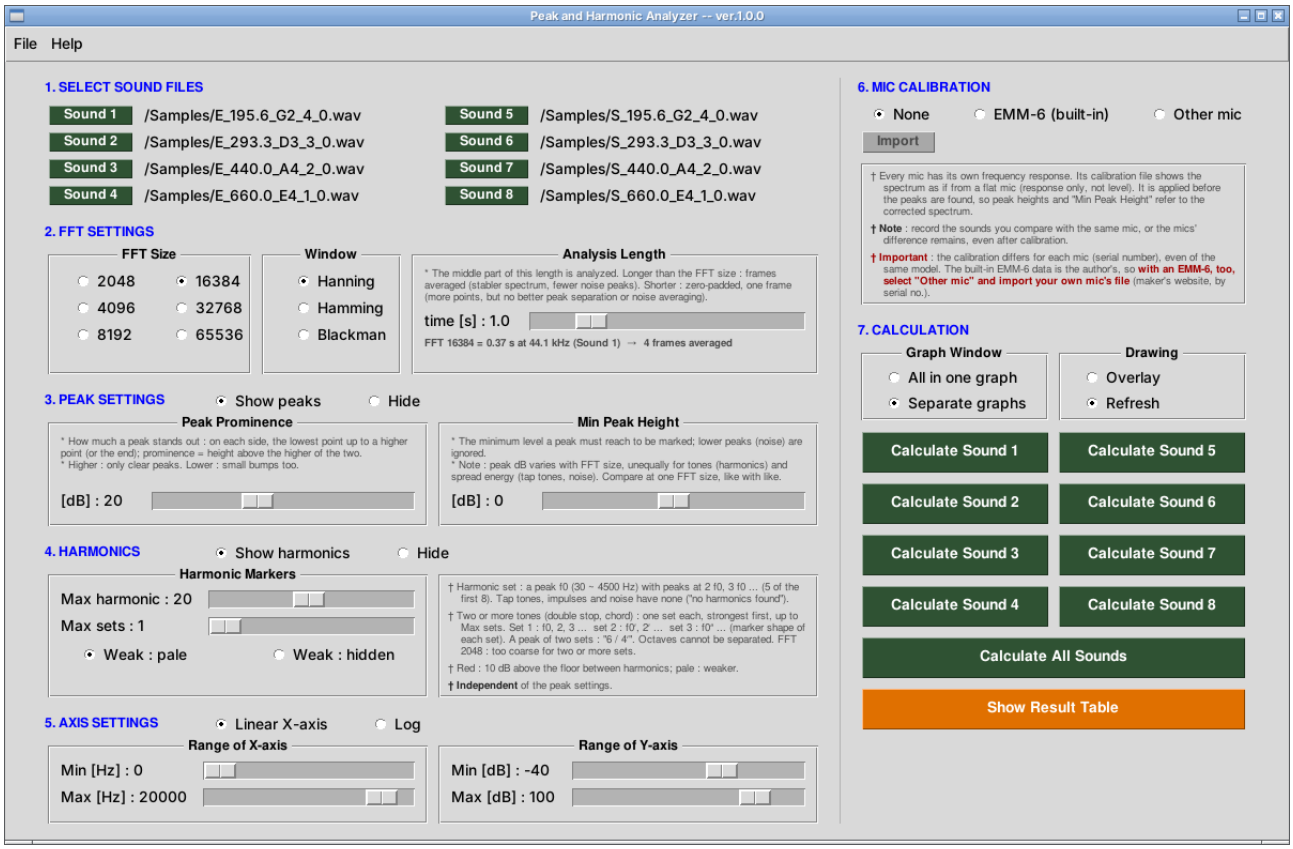


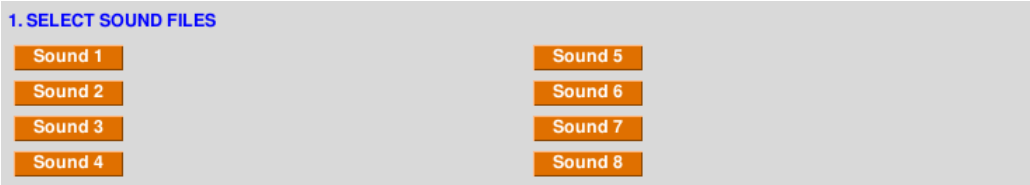

Figure 1: *Program window (8 sound files loaded)*

# 5 How to use

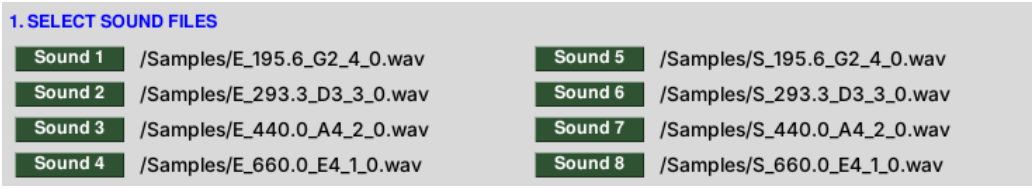
## 5.1 1. SELECT SOUND FILES

Click [Sound 1] to load a prepared sound file, and load the other files in the same way. When a file is loaded, its button turns from orange to green and the path and name of the file are shown on the right (Figure 2). A long path is shortened in the middle with '...'. A message appears on loading in the following cases :

- Stereo file : the channels are averaged into mono. If one channel is empty, a warning that the level is about 6 [dB] lower
- Silent file (all samples are zero)
- File shorter than the Analysis Length : the whole file is analyzed
- Unreadable file : an error message appears and the previously loaded file is kept




(a) *Before loading*




(b) *After loading*

Figure 2: *Loading the sound files*

## 5.2 2. FFT SETTINGS

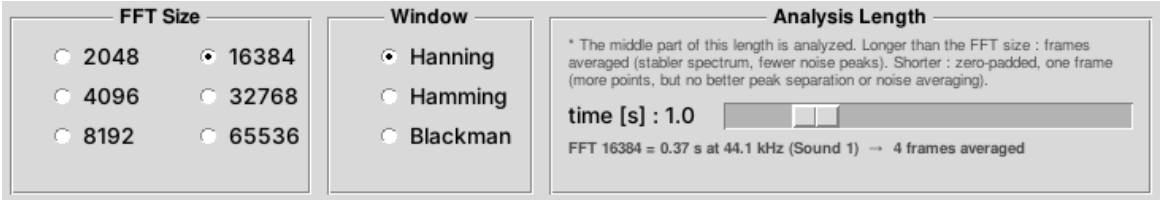
■ **FFT Size** : The FFT (Fast Fourier Transform) is what is usually called "frequency analysis". The FFT Size is the number of samples analyzed at once; the larger it is, the finer the frequency resolution (when the analyzed part is at least as long as the FFT Size). Choose from 2048 ∼ 65536 (default 16384). At 44.1 [kHz], 16384 is 0.37 s and 65536 is 1.49 s.

■ **Window** : The shape with which the data are cut out. It makes only a very small difference to the result. Hanning (default) is commonly used.

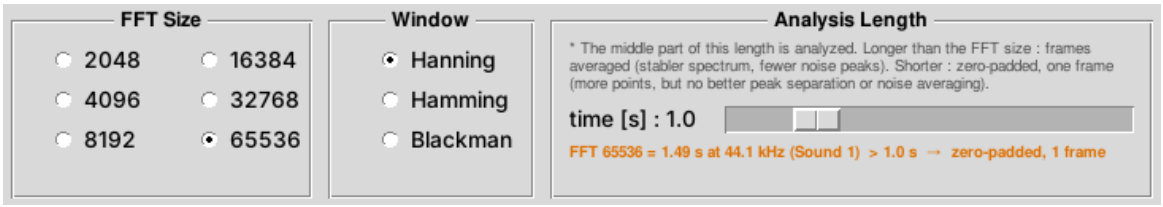
■ **Analysis Length** : Only this length (0.1 ∼ 5.0 s, default 1.0 s) is taken from the middle of the sound file and analyzed. If the part is longer than the FFT Size, frames of the FFT Size (50% overlap) are averaged, so the spectrum is stable and there are fewer noise peaks. If it is shorter, it is zero-padded to the FFT Size and analyzed as one frame; the spectrum then has more points, but close peaks are not separated better and the noise is not averaged. If the file is shorter than this length, the whole file is analyzed.

For sustained sounds such as played notes, the default (1.0 s) is suitable. For sounds that die out quickly, such as tap tones, set it to about the time until the sound has mostly died out.

The status line under the slider shows the duration of the FFT Size and how the part is analyzed, at the sampling frequency of the first loaded file (without a file, 44.1 [kHz] is assumed and "(assumed)" is shown). The number of averaged frames is shown in gray, "1 frame (no averaging)" when only one frame fits, and "zero-padded" in orange when zeros are added (Figure 3). If it is orange, a smaller FFT Size or a longer Analysis Length is better.




(a) *FFT 16384 : 4 frames averaged*




(b) *FFT 65536 : zero-padded*

Figure 3: *FFT SETTINGS and the status line*

## 5.3 3. PEAK SETTINGS

[Show peaks] / [Hide] next to the title turns the peaks on and off (default Show). With Hide, the peak markers and frequencies are not drawn and the two sliders below are grayed out; use it to see only the harmonics. The two filters below choose which of the many peaks are shown; only peaks meeting both conditions are shown (Figure 4).

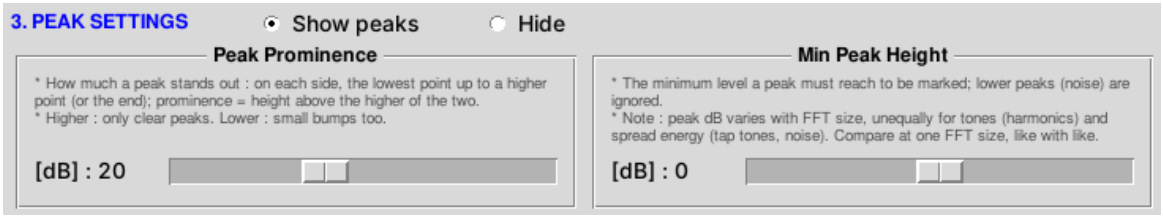



Figure 4: *PEAK SETTINGS*

■ **Peak Prominence** : How much a peak stands out from its surroundings. Only peaks that stand out more than this value are shown ($1 \sim 50$ [dB], default 20 [dB]). A higher value shows only clear peaks, a lower value also small bumps.

Prominence is calculated with find_peaks of the scipy module, as follows (Figure 5).

1. From the top of the peak, draw a horizontal line to the left and to the right. Each line extends until it first meets **a point higher than the peak** (or the end of the graph), passing over any lower peaks in between.
2. The range covered by each line (from the peak to where the line stops) is the left and the right interval. In each interval, find **the lowest point of the whole interval** : not the valley right next to the peak, but the minimum within the interval.

3. The **higher** of the two minima is the reference level, and Prominence = peak height − reference level. The vertical lines in the figure run from each peak down to its reference level, i.e. they show the prominence.

In mountaineering terms, prominence is the least you must descend from a summit to cross over to a higher summit.

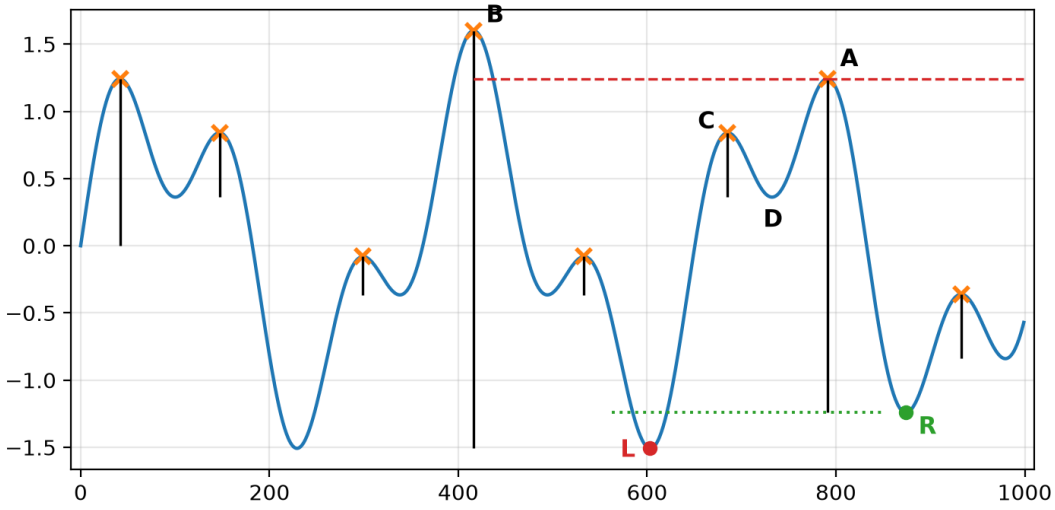



Figure 5: *Calculation of the prominence (vertical lines : prominence of each peak)*

Figure 5 is drawn from the example signal of the scipy documentation[1]; the vertical lines are the prominences of the peaks.

- Peak A (1.24) : the left line stops at the higher peak B, so it passes over the small peak C and the valley D, and the minimum of the left interval is L (−1.51). The right line goes to the end, and its minimum is R (−1.24). The higher one, R, is the reference, so the prominence is $1.24 - (-1.24) = 2.48$.
- Peak B (1.60) : the highest peak, so both lines go to the ends of the graph, and both minima are −1.51. Its prominence, 3.11, is the largest.
- Peak C (0.84) : the left line goes to B and its minimum is L (−1.51); the right line stops at A and its minimum is D (0.36). The higher one, D, is the reference, so the prominence is $0.84 - 0.36 = 0.48$.

So a small peak on the shoulder of a large peak has a small prominence even if it is high, while the highest peak in its neighborhood is measured from the minimum of a wide range and has a large prominence. In a spectrum, a larger prominence means a peak that stands out more clearly from its surroundings. Figure 6[2] shows the same method with colors.

[1]Source : `https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.peak_prominences.html` (redrawn from the example figure of this page, with A, B, C, D, L, R and the horizontal lines added)

[2]Source : `https://www.mathworks.com/help/signal/ug/prominence.html`

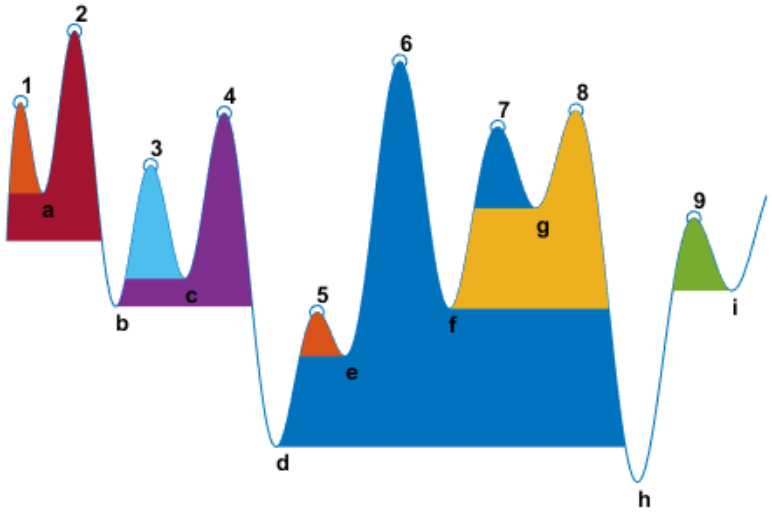



Figure 6: *Prominence : how much a peak stands out*

■ **Min Peak Height** : Only peaks whose top is higher than this value are shown ($-120 \sim 120$ [dB], default 0 [dB]). With three peaks at 10, 20 and 30 [dB], a value of 15 shows only the 20 and 30 [dB] peaks. Figure 7 (0 [dB]) shows all peaks above 0 [dB], while Figure 8 (40 [dB]) shows only the peaks above 40 [dB] (both with the harmonics hidden, X-axis Max 6,000 [Hz]).

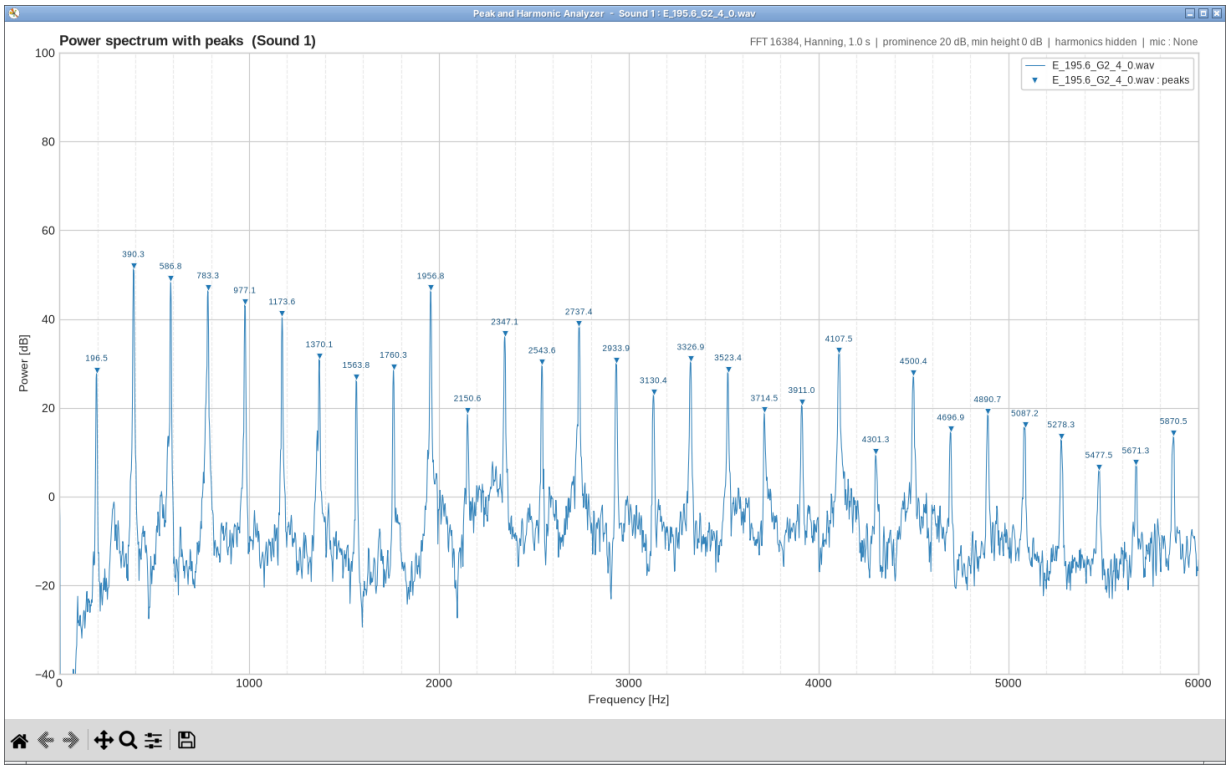



Figure 7: *Min Peak Height = 0 [dB]*

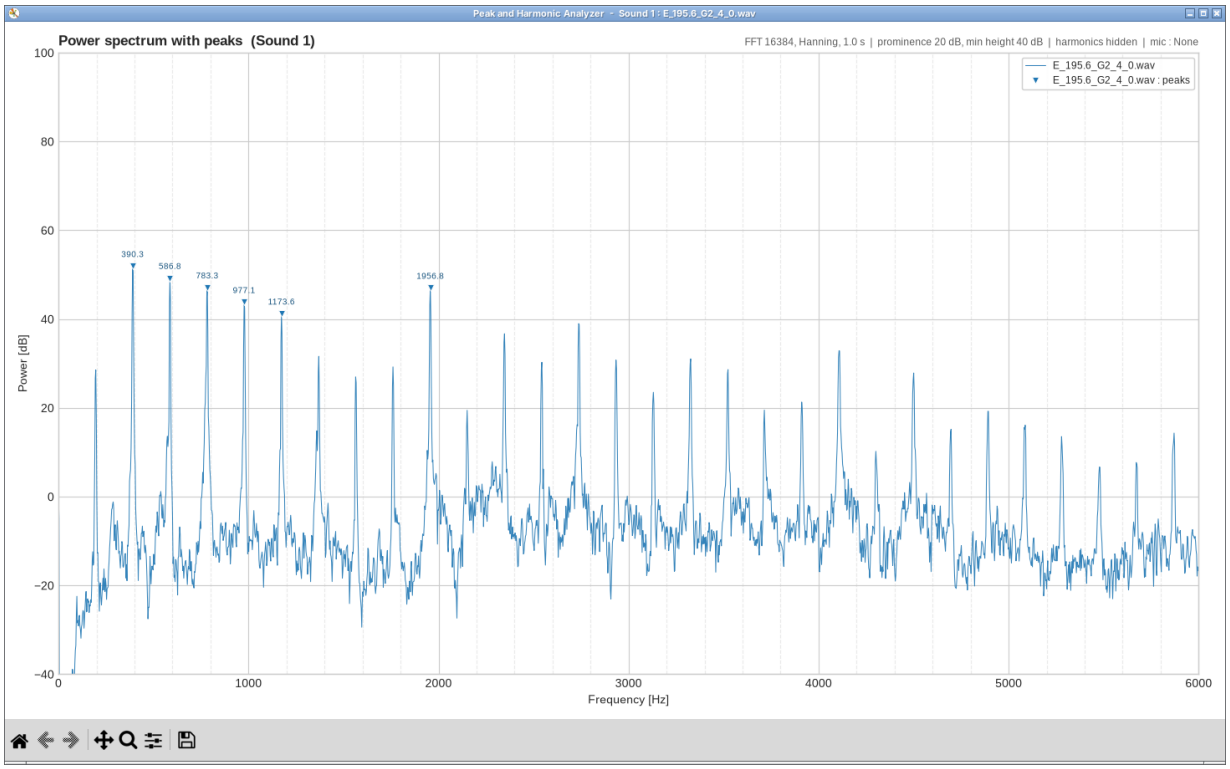



Figure 8: *Min Peak Height = 40 [dB]*

■ **Note :** Peak heights (dB) change with the FFT Size, and by different amounts for sounds with harmonics (played notes) and for sounds whose energy is spread out (tap tones, noise). The energy of a harmonic is concentrated almost in one point, while for spread energy, the larger the FFT Size, the less of it falls into one point. Therefore compare peak dB values only between sounds of the same kind, calculated with the same FFT Size.

## 5.4 4. HARMONICS

For sounds with harmonics, such as instrument tones, the positions of the fundamental (f0) and the harmonics are shown (Figure 9). This works independently of the peak settings, so harmonics are shown even if they are not shown as peaks because of the filters, or if the peaks are hidden.

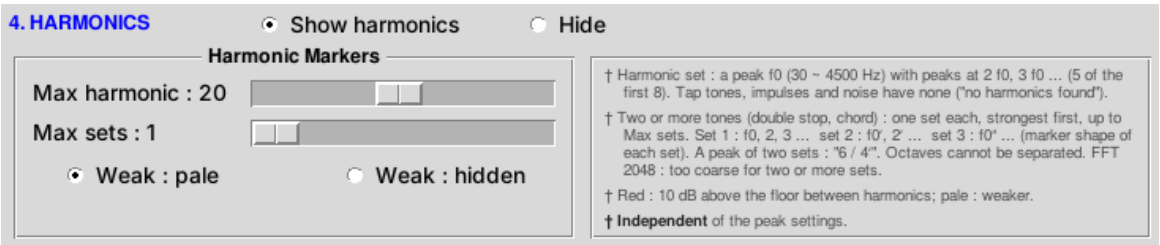



Figure 9: *HARMONICS*

- [Show harmonics] / [Hide] : next to the title, turns the harmonics on and off (default Show). With Hide, the options below are grayed out.
- [Max harmonic] : the highest harmonic number shown (1 ~ 40, default 20).
- [Max sets] : the largest number of harmonic sets to find (1 ~ 5, default 1). 2 for a double stop, 3 for a triple stop.

- [Weak : pale] / [Weak : hidden] : weak harmonics are drawn pale (default) or hidden.

Harmonics are marked in red above the peaks, and the numbers f0, 2, 3, ... above them are the harmonic numbers (f0 = 1st harmonic). The marker edge has the line color of the sound, so the sounds can be told apart in one graph. The f0 found is shown in the legend. Harmonics standing 10 [dB] or more above their surroundings are dark red; weaker ones are pale red.

■ **Harmonic sets** : A harmonic set is the fundamental of a tone together with its harmonics. A single note has one set, a double stop two, a triple stop three. The sets are numbered 1, 2, 3 ... from the strongest tone, and are told apart by the marker shape and the way the numbers are written (Table 3).

| Set | Marker | Harmonic No. | Legend |
|---|---|---|---|
| 1 | Triangle | f0, 2, 3, ... | harmonics 1 (f0 ... Hz) |
| 2 | Diamond | f0′, 2′, 3′, ... | harmonics 2 (f0 ... Hz) |
| 3 | Square | f0″, 2″, 3″, ... | harmonics 3 (f0 ... Hz) |
| 4 | Circle | f0‴, 2‴, 3‴, ... | harmonics 4 (f0 ... Hz) |
| 5 | Pentagon | f0⁗, 2⁗, 3⁗, ... | harmonics 5 (f0 ... Hz) |

Table 3: *Display of the harmonic sets (with one set, the legend is "harmonics (f0 ... Hz)")*

When two sets share a peak (e.g. in a G and D double stop, the 2nd harmonic of D = the 3rd harmonic of G), the markers are stacked and the numbers are written together on one line, as "2 / 3′".

■ **How they are found** : Each peak of the spectrum (30 ∼ 4500 [Hz]) is tried as f0, checking whether there really are harmonic peaks at f0, 2f0, ... 8f0. Only if at least 5 of these 8 positions, f0 itself included, have a peak standing 10 [dB] above its surroundings and within 60 [dB] of the largest peak, is it accepted as a candidate harmonic set. The following candidates are then dropped :

- Candidates whose harmonics are all explained by the harmonics of other candidates : for example, a G and D double stop looks like harmonics 2, 3, 4, 6, 8 of the note an octave below G, but they are really the harmonics of G and D.
- Candidates that are a harmonic (2f0, 3f0 ...) of another candidate

Of the remaining candidates, the one with the most energy in harmonics not yet in another set becomes set 1, then set 2, and so on. A set more than 30 [dB] weaker than set 1 is taken as noise or resonance and is not shown. Then harmonic k is the highest point within ±1% of k×f0; since string harmonics are slightly higher the higher they are, f0 is recalculated from each harmonic found before looking for the next one.

■ **Limits** : Sounds without a harmonic structure, such as tap tones, impulses, noise and pure sine waves, show "no harmonics found" in the legend, and no harmonics are drawn. Sounds whose fundamental is below 30 [Hz] or does not appear as a peak in the spectrum cannot be found either. Other limits :

- Two notes an octave apart (e.g. G3 and G4) appear as one set, because all harmonics of the upper note coincide with harmonics of the lower note.
- With a small FFT Size, the harmonics cannot be separated, so they are not shown (e.g. 2048 for low notes), or two or more sets are not found correctly. For two or more sets, use an FFT Size of 4096 or more, preferably the default (16384) or more.
- When harmonics overlap closely, as in a four-note chord, some notes may not be found.

The f0 in the legend is interpolated at the peak top, so its decimals may differ slightly from the frequency shown at the peak.

## 5.5 5. AXIS SETTINGS

[Linear X-axis] / [Log] next to the title selects the X-axis scale (default Linear). Below, set the range of the X-axis (Min, Max : 0 ∼ 22,050 [Hz] in steps of 50 [Hz], default 0 ∼ 20,000 [Hz]) and of the Y-axis (Min −120 ∼ 0 [dB], Max 0 ∼ 120 [dB], default −40 ∼ 100 [dB]). The scale and ranges only change how the results are shown, not the analysis. On a Log scale with Min 0, the axis starts at 20 [Hz]. If Min is equal to or larger than Max, an error message appears when a calculation button is pressed and nothing is calculated.

## 5.6 6. MIC CALIBRATION

Every microphone has its own frequency response. With a calibration file, the response of the microphone is corrected and the spectrum is shown as if measured with a flat microphone. Only the deviation with frequency (the shape of the curve) is corrected, not the absolute sound pressure level. The calibration is applied before the peaks are found, so peak heights and the Min Peak Height refer to the corrected spectrum.

- [None] (default) : no calibration
- [EMM-6 (built-in)] : the built-in Dayton Audio EMM-6 calibration (the author's own measurement microphone)
- [Other mic] : import the calibration file of another microphone with [Import]. The button is orange without a file and turns green when a file is imported correctly (Figure 10).

**[Important] The calibration differs for each microphone (each serial number), even of the same EMM-6 model. The built-in EMM-6 data are the author's own microphone, so even with an EMM-6, select [Other mic] and [Import] the calibration file for your own microphone's serial number.** The file can be downloaded from the maker's website by entering the serial number of the microphone.

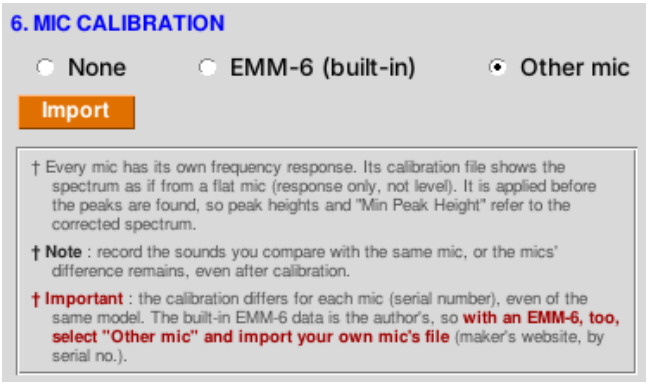



Figure 10: *Other mic selected (before importing a calibration file)*

A calibration file is a text file (.txt, .cal, .frd) with two columns : frequency (Hz) and calibration (dB). Lines starting with *, ", #, ; and lines that are not numbers are ignored. The contents are checked on import : if it is not a text file, uses commas as decimal points (e.g. "20,00 -3,3", European number format), has fewer than 10 data lines, has frequencies not in ascending order or repeated, does not include 1 [kHz], or has values beyond ±30 [dB] (absolute level data), an error message appears and the previous file is kept. If the data do not cover 20 ∼ 20,000 [Hz], a message says that the end values are used outside the range.

■ **Format of the calibration file** : one line per point, [frequency (Hz) dB value] separated by spaces or a tab, as below. This is the format commonly used by REW and others.

```
* Mic Model : xxxxxx xxx-xx
* Freq(Hz)  dB
10.000      -1.717
10.481      -1.717
...
23594.406   -5.440
24000.000   -5.440
```

The dB value is how much louder (+) or quieter (−) the microphone records at that frequency than a flat microphone. The program reverses the sign and adds it to the spectrum. For example, if the value at 24,000 [Hz] in the file above is −5.440, +5.440 [dB] is added at that frequency. Between the frequencies of the file, values are interpolated on a logarithmic frequency axis. Some makers provide correction values with the sign already reversed instead of deviations; in that case the sign is the opposite, so check the description of the file.

## 5.7 7. CALCULATION

■ **Graph Window** : [Separate graphs] (default) draws each sound in its own graph window. [All in one graph] draws all sounds together in one window, "All sounds", to compare their peaks.

■ **Drawing** : [Refresh] (default) erases the previous result of the same sound before drawing, so curves do not pile up while you change the options. [Overlay] draws over without erasing; when the same sound is drawn again, it gets a new color and #2, #3 . . . in the legend. A closed graph window is opened again.

■ **Calculation buttons** : [Calculate Sound 1] ∼ [Calculate Sound 8] are active (green) only for loaded sounds. [Calculate All Sounds] calculates all loaded sounds at once, the same as pressing every green calculation button (Figure 11).

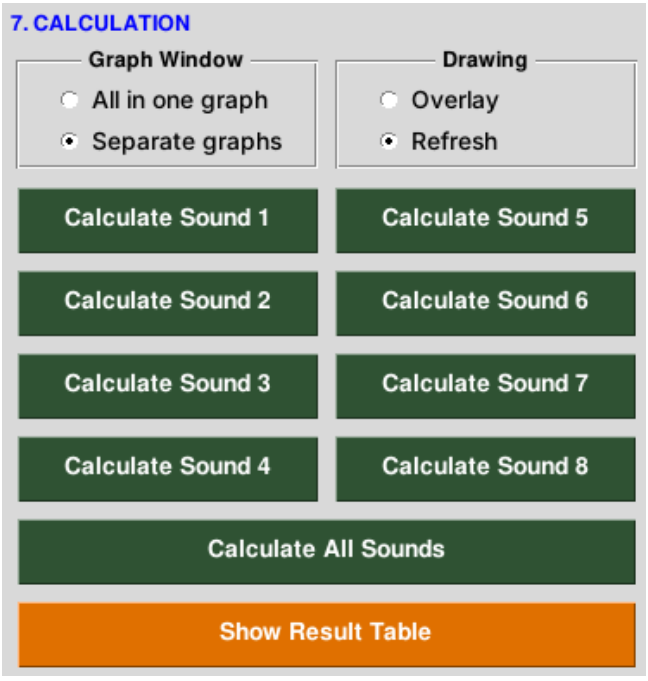



Figure 11: *CALCULATION (8 files loaded)*

When a calculation button is pressed, a message appears first in the following cases; press [OK] to go on with the calculation. [Calculate All Sounds] shows the messages of all sounds together in one message box.

- The file is shorter than the Analysis Length (the whole file is analyzed)
- The analyzed part is shorter than the FFT Size (zero-padded, one frame)

If [Other mic] is selected and no calibration file is imported, an error message appears and nothing is calculated.

■ **Result graph** : The left side of the graph title shows what is drawn (peaks, harmonics), and the right side shows the settings used : FFT Size, Window, Analysis Length, Prominence and Min Peak Height ("peaks hidden" if the peaks are hidden), the highest harmonic number and the number of sets ("harmonics hidden" if hidden), and the mic calibration. The window title shows the number and file name of the sound.

Peaks are marked with a different marker for each sound and their frequency [Hz]; harmonics with red markers and harmonic numbers. The legend shows the spectrum, peaks and harmonic sets (f0) of each sound; with many entries it uses smaller text in two columns. With the toolbar under the graph, the graph can be zoomed or saved as an image file. When the program is closed, the open graph windows close with it.

■ **Result table** : [Show Result Table] under [Calculate All Sounds] opens a window with the peaks and harmonics of the calculated sounds in tables, as in Figure 12. The graph shows only the frequencies of the peaks and harmonics; the table also gives their levels [dB]. This button is always orange; if no sound has been calculated yet, a message appears.

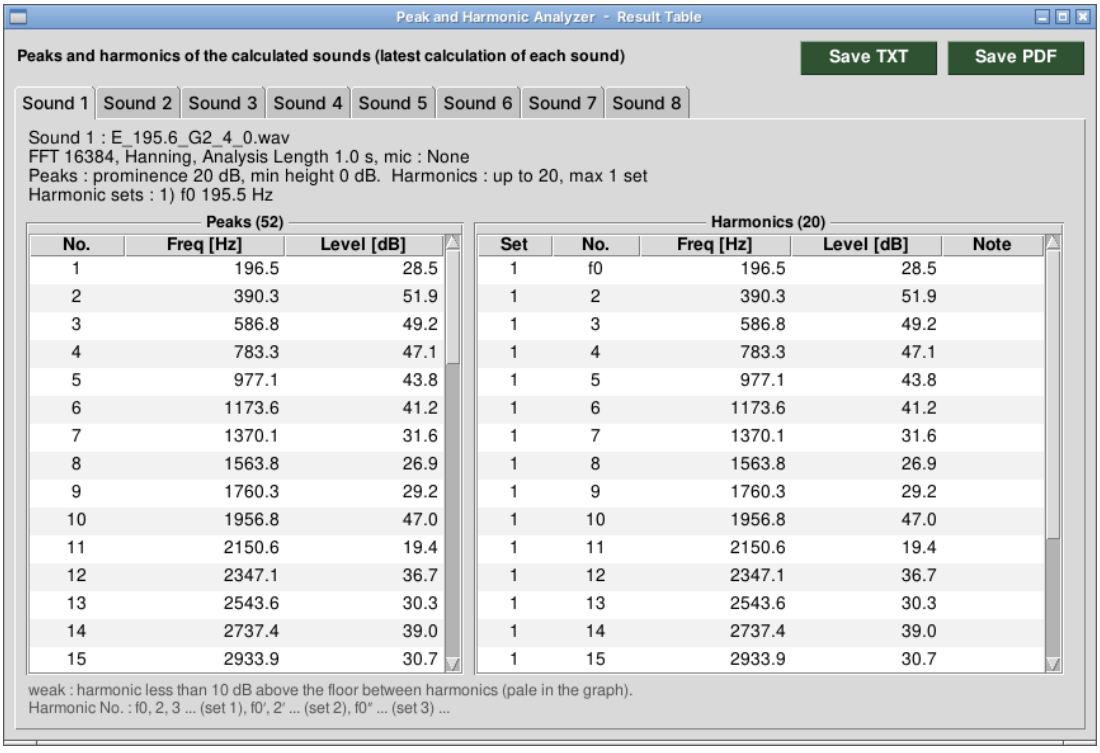



Figure 12: *Result Table (after calculating 8 sounds, Sound 1)*

- There is one tab for each calculated sound, showing its latest calculation. The top of the tab shows the file name, the settings used and the f0 of the harmonic sets found.
- The left table lists the peaks (No., frequency [Hz], level [dB]); the right table the harmonics (set, harmonic No., frequency [Hz], level [dB], Note). Weak harmonics (less than 10 [dB] above their surroundings) are in

gray with “weak” in the Note column.

- Peaks and harmonics hidden in the graph are still listed in the table, so the peak levels can be read even when only the harmonics are drawn.
- If a sound is calculated again while the table is open, the table is updated at once; if a sound file is replaced, the tab of that sound disappears.
- [Save TXT] / [Save PDF] at the top right save the tables of all calculated sounds as a text file or a PDF file (A4, each sound on a new page).

# 6 Examples

An example with the open G string of a violin. Load the sound of the string mounted on the violin (`E_195.6_G2_4_0.wav`) into [Sound 1] and the sound of the string alone without a body (`S_195.6_G2_4_0.wav`) into [Sound 5], and the D, A and E strings in the same way (Figure 1). Change only the X-axis Max to 6,000 [Hz] and leave the other options at their defaults.

## 6.1 Peaks and harmonics of one sound

Pressing [Calculate Sound 1] gives the result of Figure 13. The blue line is the power spectrum; peaks are marked with ▼ and their frequency, harmonics with red triangles (▲) and harmonic numbers. The f0 in the legend is 195.5 [Hz].

In this sound, the 2nd harmonic (390.3 [Hz]) is about 23 [dB] stronger than f0 (196.5 [Hz]), and harmonics 2 ∼ 6 and the 10th (1956.8 [Hz]) are especially strong. All harmonics up to the 20th (about 3.9 [kHz]) are dark red, so they are all clear harmonics. Above 4 [kHz], harmonics from the 21st on are shown only as peaks (Max harmonic 20).

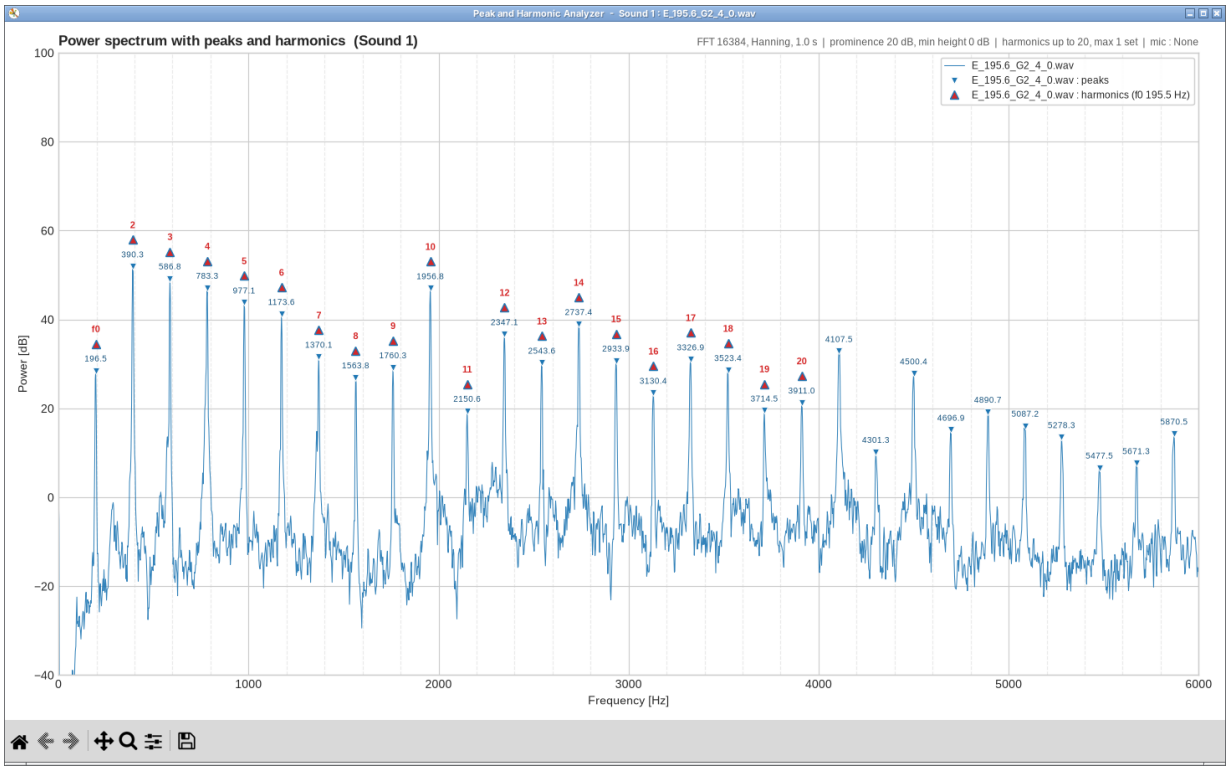



Figure 13: *Result (G string, Sound 1)*

## 6.2 Comparing two sounds

Select [All in one graph] and press [Calculate Sound 1] and [Calculate Sound 5] in turn; the two sounds are drawn together in one graph, as in Figure 14. Blue is the string mounted on the violin, brown the string alone; the edge color of the harmonic triangles shows which sound a harmonic belongs to.

The sound on the violin is stronger than the string alone in all 20 harmonics. In particular, the 2nd harmonic (390 [Hz]) is very weak in the string alone (−3.6 [dB]) but is the strongest harmonic on the violin (about 52

[dB]). The string alone, on the other hand, has its strongest harmonic at the 4th (783 [Hz]). Here the 2nd harmonic of the string alone is below the Min Peak Height (0 [dB]) and is not shown as a peak, but it is shown as a harmonic : the harmonic display works independently of the peak filters. The difference in level between the two sounds is meaningful only if they were recorded with the same microphone, position and recording level (section 3.3).

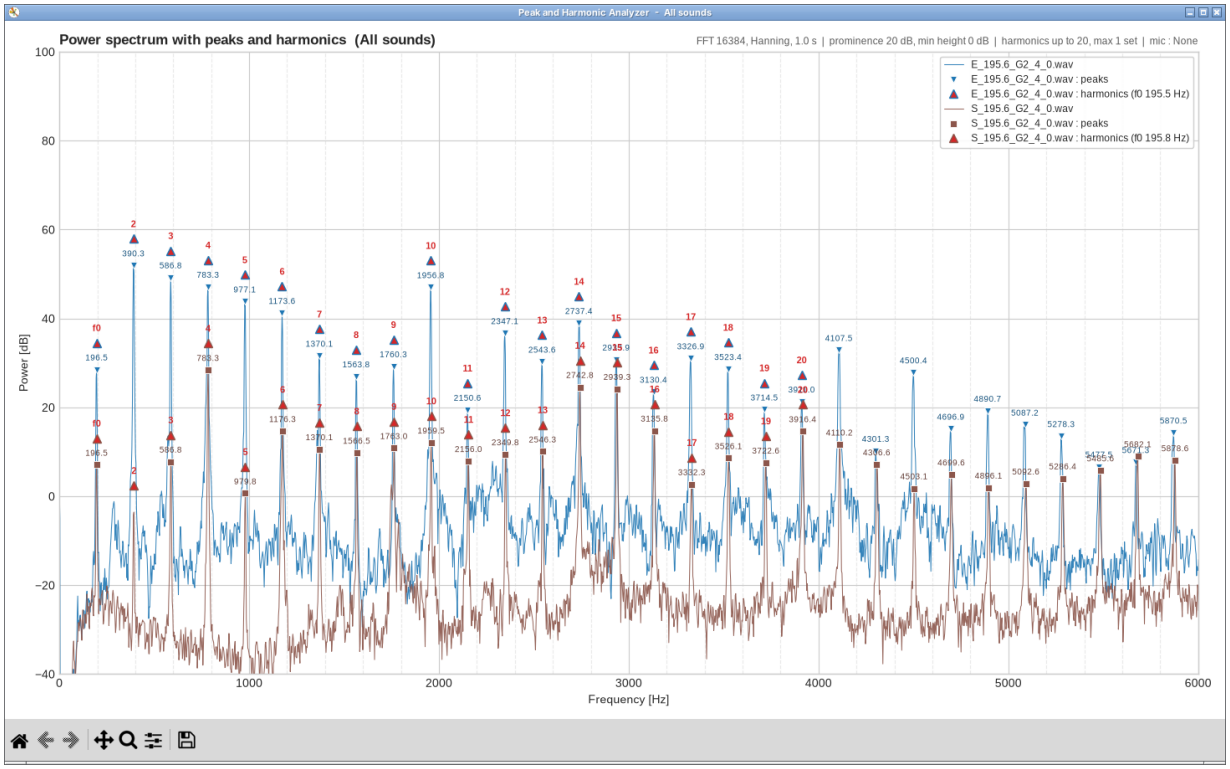



Figure 14: *Result (G string, mounted on the violin vs. the string alone, All in one graph)*

## 6.3 Harmonic sets of a double stop

An example of a double stop on the G and D strings. Here, a file made by mixing the G string sound of [Sound 1] and the D string sound of [Sound 2] at equal levels (`E_GD.wav`) is loaded into [Sound 1]. Set the Graph Window back to [Separate graphs] and keep the X-axis Max at 6,000 [Hz].

With Max sets 1 (default), only the harmonic set of the stronger D (f0 293.1 [Hz]) is shown. With Max sets 2, the harmonic set of G (f0 195.5 [Hz]) is also shown as the second set (diamonds, f0′, 2′, . . .), as in Figure 15.

G and D are a perfect fifth (2 : 3) apart, so the even harmonics of D are the same peaks as the harmonics of G whose numbers are multiples of 3. The numbers of both sets are therefore written together and the markers stacked : “2 / 3′” at 586.8 [Hz], “4 / 6′” at 1173.6 [Hz], “6 / 9′” at 1760.3 [Hz].

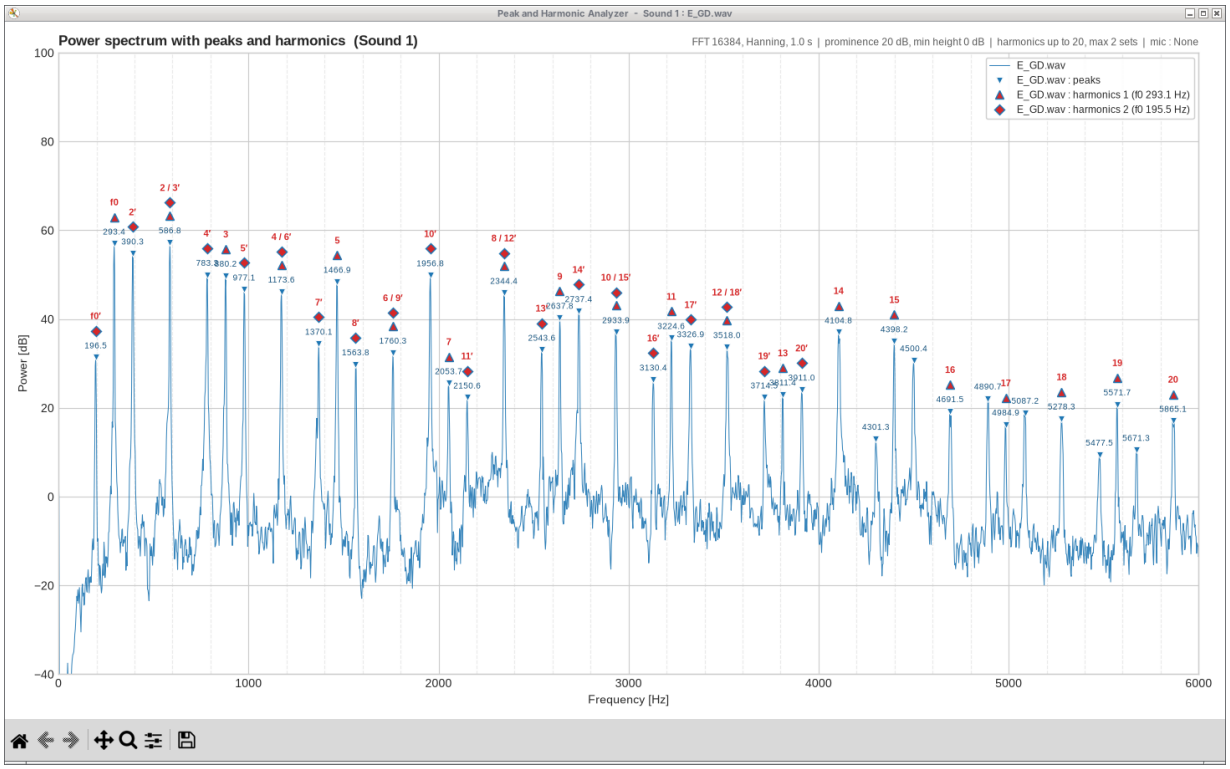



Figure 15: *Result (double stop on the G and D strings, Max sets 2)*

Selecting [Hide] in PEAK SETTINGS shows only the harmonics, without peak markers and frequencies, as in Figure 16, which makes the harmonic structure of the two notes easier to see.

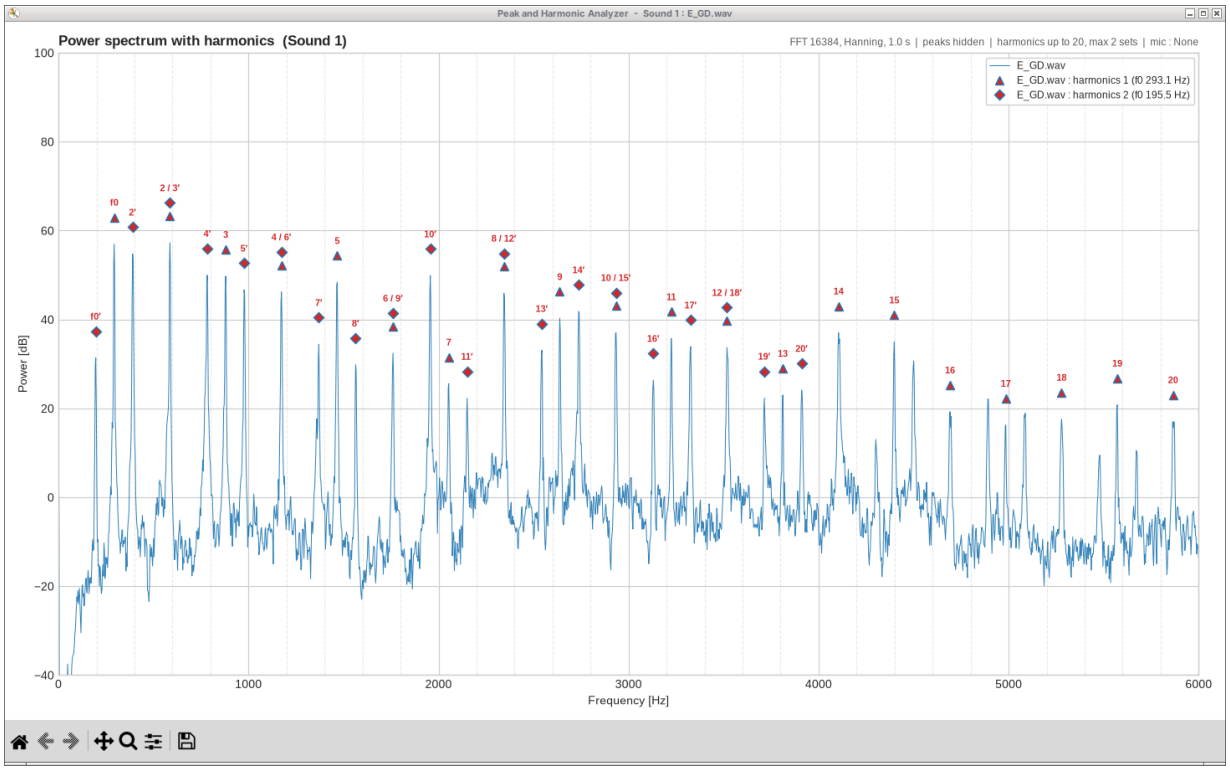



Figure 16: *Result (double stop on the G and D strings, Max sets 2, peaks hidden)*

# 7 Main features

- Peaks : positions and frequencies of the peaks chosen by Prominence and Min Peak Height
- Harmonics : positions of the fundamental (f0) and the harmonics, independently of the peak filters
- Several harmonic sets : a harmonic set for each note of a double stop or chord (up to 5), shared harmonics shown together
- Peaks and harmonics shown or hidden independently
- Result table : frequencies and levels [dB] of the peaks and harmonics in tables, one tab per sound, saved as TXT / PDF
- Up to 8 sounds in one graph or in separate graphs, Refresh / Overlay, [Calculate All Sounds]
- Frequency analysis : averaged frames over the whole Analysis Length, FFT Size 2048 $\sim$ 65536, status line and messages
- Mic calibration (built-in EMM-6, import and check of other calibration files)
- 8/16/24/32 bit and float wav files, stereo files (converted to mono)
- Two-column layout, button colors showing the state, resizable window with scroll bars, mouse wheel for the sliders

# 8 Development and environment

The program was developed with “Python 3.11 + Tkinter” (NumPy, SciPy, Matplotlib) and tested on “Windows 11”.