1.0 Introduction

This document presents a study of the sound radiated by different guitar designs. Six designs have been studied for different archtop and flat top guitars:

- Traditional flat top and archtop guitars without side sound hole:

  ![Trad. Archtop](image1.png) ![Trad. Flat top (000)](image2.png)

- Modern flat top and archtop Kasha inspired guitars with one sound hole on the side and one sound hole on the soundboard:

  ![Kasha Archtop](image3.png) ![Kasha Flat top](image4.png)
Modern flat top and archtop guitars with two sound holes on the side and no front hole (NFH):

This study is based on the use of a new acoustical instrument, which produces an acoustical image: the I-Track from Soft dB (http://www.softdb.com/acoustic-products-itrack.php).

The study has yielded the following conclusions:

- The low frequencies are mainly generated by the sound holes of the instruments.
- As the frequency increases the sound is progressively generated by the soundboard itself and at high frequencies the sound hole contribution on the sound is negligible. During the transition, a dip is observed on the sound power spectrum.
- The presence of sound holes on the soundboard limit the vibration surface and the power at mid frequencies.
- At low frequencies, the guitar acts more like an omnidirectional source and the sound hole placement seems to have little influence on the sound that the instrument projects.

The next sections present in details the measurement techniques and the measurement results.
2.0 Measurement technique

The measurement is based on a sound intensity probe coupled to with a 3D positioning system and a camera. During the measurement, a device is attached to the bridge of the guitar to generate the sound in a controlled manner:

![Archtop guitar with the excitation device (shaker)](image)

The device, an inertial actuator, is like a loudspeaker without cone. This device (or shaker) is driven by a white noise generator and a simple audio amplifier.

While the shaker drives the guitar, a sound intensity probe is used to scan the surface of the guitar. During the scan, the instrument logs the sound intensity and the position for each discrete measurement point. The probe is positioned about 3 inches above the guitar during the scan. It means that only the near field sound is measured. This measurement provides information about the sound propagated by the instrument but since only the near field is measured, caution must be exercised during the interpretation of the images. The next image schematizes the camera and all the measurement points taken over the soundboard of the guitar during the test:
After the measurement, a PC analysis software builds an acoustical image from the data logged during the scan. Since a white noise is used, a spectral analysis can be done to isolate a specific frequency or a group of frequencies. For instance, the next figure presents the image for the 125 Hz 1/3-octave band (low B) for a traditional archtop guitar:
3.0 Measurements

3.1 Archtop images

The measurements have been done in a semi-anechoic chamber with the guitar suspended 4 inches off the floor. For the guitar with a sound hole on the side, two inches of fiberglass absorbent have been added under the guitar in order to simulate the presence of the player. For each image, the color scale is set to cover 10 dB from the maximum dB(A) value in the image. It means that an absolute sound power comparison cannot be done based on the color of the images. However, the sound power spectrum for each kind of guitar will be presented later in this document (section 3.2).

The next figures present the results at each 1/3-octave band from 125 Hz (low B) to 630 Hz (higher Eb) for the following guitars:

**Left guitar:**

[Benoit Lavoie Jazz Traditional](#) 17 inches archtop, maple back, sitka spruce top and parallel bracing.
Middle guitar:  
**Benoit Lavoie Jazz Kasha inspired** 17 inches archtop, Bubinga back, red spruce top, one sound hole on the side, one sound hole on the soundboard and parallel bracing.

Right guitar:  
**Benoit Lavoie Jazz No Front Hole (NFH)** 16 inches archtop, maple back, sitka spruce top, two sound holes on the side and a X/parallel hybrid bracing.
Sound mapping for the 125Hz 1/3-octave band

Sound mapping for the 160Hz 1/3-octave band
Sound mapping for the 200Hz 1/3-octave band

Sound mapping for the 250Hz 1/3-octave band
Sound mapping for the 315Hz 1/3-octave band

Sound mapping for the 400Hz 1/3-octave band
Sound mapping for the 500Hz 1/3-octave band

Sound mapping for the 630Hz 1/3-octave band
From the last images, we can conclude that the sound is coming from the holes at low frequencies. As the frequency increases the sound is progressively generated by the soundboard itself. At high frequencies, the sound holes do not contribute to the sound emission. This transition seems to occur at lower frequencies for the Kasha design and for the no front hole (NFH) design.

Between 315 Hz and 500 Hz, we can see that the F holes on the traditional design break the vibrations of the soundboard and almost no sounds are generated between the side and the F holes. For the modern designs, the vibration and the sound seem to cover a larger portion of the soundboard. The sound power spectrum presented at section 3.2 indicates that the two guitars with the modern design have a better response in the mid frequencies resulting in a flatter frequency response.

The hybrid X/Parallel bracing design of the NFH guitar seems to have an impact on the sound pattern at 630 Hz. Actually, the small oblique brace on the treble side is visible on the image. This bracing design changes the orientation of the dipole in comparison with the kasha and the traditional guitars. Also, the sound power for this frequency band is lower for the NFH guitar (see section 3.2).

At low frequencies (125 Hz and 160 Hz), we can see light gray zones: these zones represent negative intensity. Positive intensity is sound that travels from the guitar toward the listener while negative intensity is sound that travels towards, and is absorbed by the guitar. This indicates that the sound that coming out the sound holes acts like an omnidirectional source at low frequencies. It means that the location of the sound holes is not critical. At mid and high frequencies, the sound radiated by the soundboard is more directional and no negative intensity is observed. The next figure present the positive and negative sound intensities for the three guitars at 125 Hz:
Positive sound intensity for the 125Hz 1/3-octave band

Negative sound intensity for the 125Hz 1/3-octave band
3.2 Archtop sound power

The next figure presents a comparison of the sound power for all the three archtop guitars. The legend presents the overall power in dB(A) for each guitar. All three guitars have similar global sound power but the traditional one is a little bit louder principally because of the high frequencies. The traditional guitar measurement has been done without additional absorbent under the guitar. This can explain the difference at high frequencies. Also, the traditional archtop has a dip between 275 and 375 Hz while both modern archtop guitars have a flatter response in the mid frequencies. At 200 Hz, the NFH guitar has a large and sharp power reduction that can be explained by the fast transition of the sound emission location (from the sound holes to the soundboard). See the images at 200 Hz and 250 Hz for this guitar at the section 3.1. This phenomenon is clear for the NFH archtop but can also be observed on all other guitars (flat top or archtop): when the sound emission location goes from the sound hole to the soundboard, a dip in the sound power spectrum is observed.
3.3 Flat top images

For the archtop and flat top measurements the same set-up has been used. The next figures present the results at each 1/3-octave band from 125 Hz (low B) to 630 Hz (higher Eb) for the following guitars:

**Left guitar:**
Standard 15 inches 000 flat-top, brazilian rosewood back, sitka spruce top and X bracing.

![Guitar Image]

**Middle guitar:**
Benoit Lavoie Flat top Kasha inspired 16 inches flat-top, Goncalo Alves back, sitka spruce top, one sound hole on the side and one sound hole on the soundboard and Kasha inspired bracing.

![Guitar Image]
Right guitar:

Benoit Lavoie Flat top No Front Hole (NFH) 17 inches flat-top, Bubinga back, red spruce top, two sound holes on the side and Kasha inspired bracing.
Sound mapping for the 125Hz 1/3-octave band

Sound mapping for the 160Hz 1/3-octave band
Sound mapping for the 200Hz 1/3-octave band

Sound mapping for the 250Hz 1/3-octave band
Sound mapping for the 315Hz 1/3-octave band

Sound mapping for the 400Hz 1/3-octave band
Sound mapping for the 500Hz 1/3-octave band

Sound mapping for the 630Hz 1/3-octave band
As for the archtop guitars, we can conclude that the sound is coming from the holes at low frequencies. As the frequency increases the sound is progressively generated by the soundboard itself. At high frequencies, the sound holes do not contribute to the sound emission. The transition seems to occur earlier for the kasha design and for the no front hole design.

In general, the modern design guitars use a larger part of the soundboard to emit the sound. This can be explained by the absence or a better placement of the sound hole on the soundboard. The bracing on the NFH guitar is more solid close to the neck joint and it seems to reduce the soundboard vibration and the sound emission in this area (see images at 315, 400 and 500 Hz). Also, for both modern guitars the sound pattern at 500 Hz changes and looks more like a dipole while the traditional flat top shows no change in its sound pattern. At 630 Hz, the modern guitars show a dipole pattern but in the longitudinal direction while the traditional flat top continues to show the same sound pattern. This can be explained by the fact that the modern flat top guitars have a Kasha inspired bracing pattern while the traditional flat top uses the standard X bracing pattern. However, the sound power at 500 Hz for both modern guitars is not affected (see the section 3.4).

Like the archtop guitars, the sound holes act like an omnidirectional source at low frequencies. The next figure present the positive and negative sound intensities for the three guitars at 125 Hz:

**Positive sound intensity for the 125Hz 1/3-octave band**
Negative sound intensity for the 125Hz 1/3-octave band
3.4 Flat top sound power

The next figure presents a comparison of the sound power for all three flat top guitars. The legend presents the overall power in dB(A) for each guitar. Both modern design guitars are louder than the traditional design. All guitars have a dip in the mid but for the modern guitars this phenomenon happens at lower frequencies. This can be explained by the fact that the shift of the emission location (from the sound holes to the soundboard) happens at lower frequencies than the traditional design. The transition frequency is 315 Hz for the traditional design, 250 Hz for the kasha design and 200 Hz for the NFH design.
4.0 Conclusion

The initial aim of this study was simply to evaluate objectively some modern guitar designs developed by luthier Benoit Lavoie. For this purpose a simple listening test can validate new guitar concepts, but it is difficult to figure out what is good or bad in the design, and a listening test does not provide an objective measure of the instrument's sound power and frequency response.

Because it illustrates in a very visual way how the underlying structure and construction of the guitar combine to produce its acoustical properties, the iTrack-based methodology that we describe here, goes beyond simple validation. It represents a very powerful tool to guide the luthier in the design of new guitar concepts.