Journal of Physics Special Topics
An undergraduate physics journal

A1_7 Holes in the Sound

Y. Davis, N. Drewes, T. Lomax, S. Norman

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 13, 2020

Abstract

In this paper we investigated the effect of sound holes in electric guitars on the sustain based on our model of solid body and chambered body guitars. The resonant frequency of the air in the sound hole is found through the Helmholtz frequency, and if this is not too far from the chord it can dramatically reduce the sustain. We found that for the high E note the sustain is reduced by a factor of 100-300 as the body resonance approaches the note.

Introduction

So far, we have examined the sustain of an electric guitar due to the vibrational response of a solid body guitar and a chambered guitar and its enclosed air in Paper I and Paper II respectively [1, 2]. In Paper II we looked at a Gretsch Jet Firebird as was played by AC/DC's Malcolm Young. In fact, he heavily modified his model – nicknamed "The Beast" – by taking out the neck pick-up as well as middle pick-up that was added by his older brother, leaving him with two holes in the body [3]. Here, we will examine the effect this has on the sustain of an electric guitar by analysing a model of an acoustic guitar.

Theory

To examine the impact of the holes in the body, we must look at how the air resonates in the body. This is the working principle of an acoustic guitar, in which the sound is made by the resonating air and especially in the air column created by the sound hole. When this vibrating air column descends a small distance into the air contained by the guitar body, it compresses it. This creates a pressure difference on either side of the air column, with the higher pressure in the body. Therefore, a restoring force aims to equalise these pressures and the air column oscillates outwards again, setting up a pressure difference in the opposite direction. The resonant frequency of this oscillation is the Helmholtz frequency, given by

$$\omega_{0,air} = c_s \sqrt{\frac{S}{V_{air} L}}, \tag{1}$$

where S is the surface area of the air column, L is its vertical height, and V_{air} and c_s are the volume of air in the body and the speed of sound as previously discussed [4]. This frequency is now the resonant frequency of the air inside the body, and can be used as such in the relevant equation for the oscillation energy of the air E_{air} [2]. As aforementioned, this body has two holes where the pick-ups used to be, but as the frequency depends on the physical size of the holes, we only consider the effects of one of the two holes. The surface area is independent of shape, so for a rectangle with width w_h and length l_h the radius of a circle with the same area is $r = \sqrt{w_h l_h/\pi}$. In addition, the length L is more complicated than here assumed, as an extra volume above and below the column moves with it. Accordingly, the final length L is given by

$$L = \Delta d + 1.6r, \tag{2}$$

where Δd is the original height of the column which is the thickness of the top plate of the guitar [2, 4].

Results

Next, we calculate the impact of this air resonance on the sustain of the string using the method described in Paper I. Essentially, for each cycle, we find the dampened amplitude of the string and take away the energy caught in the oscillation of the body and the air inside of it. Through this, we can find the final amplitude of the string at each time step, and then finally take the sustain as the time 2τ it takes the amplitude of the string to decrease by a factor of e^{-1}.

Here, we use all the values for the string, body, and air oscillations from Papers I and II, again leaving the body resonant frequency at 325 Hz. The dimensions of the pick-up hole are $w_d = 3.5\,\mathrm{cm}$ and $l_d = 7.5\,\mathrm{cm}$ such that $r = 4.1\,\mathrm{cm}$ [3]. According to Eq. 1 and 2, this gives the resonant frequency of the air as $\omega_{0,air}/2\pi = 204\,\mathrm{Hz}$.

This time we only focus on the high E string at 330 Hz. In Fig. 1 the amplitude as a function of time for the 325 Hz body resonance is shown in blue, which goes to zero instantaneously in the body with the hole (dashed). To be able to examine the effect of the hole, we also looked at bodies with resonances 320 Hz (red) and 315 Hz (green). The sustain for the hole at 320 Hz is 0.003 s (one cycle) versus the chambered sustain of 0.9 s and for 315 Hz it is 0.009 s (three cycles) versus 1.2 s.

Conclusion

While in acoustic guitars sound holes and their air vibration drive the sound, in electric guitars they tend to be a nuisance since the sound is extracted directly from the string vibration. Fig. 1 shows that they decrease the sustain by a factor of 100-300, depending on the body resonance. As the body resonance approaches the driving frequency, the air is driven with a higher force and gains more energy in its vibration. These small sustains lead to very sharp but slightly inaccurate notes as the pickups will vibrate with the body and its air. This is the source of the characteristic rock and roll sound of hollow body guitars: the lightness and air will lead the pickup to vibrate as well as the string, leading to smeared out chords in the frequency space. Without a doubt, the modifications of Malcolm Young's guitar drove his unique sound in part.

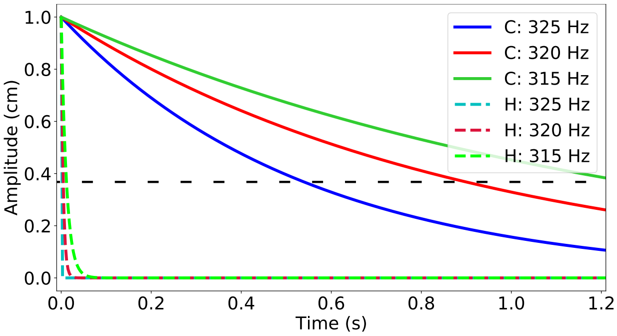

Figure 1: The amplitude of the high E string as a function of time and various body resonances, for chambered (solid) guitar and with a sound hole (dashed). The black dashed line is at e^{-1}, where $A = A(2\tau)$.

References

[1] Y. Davis, N. Drewes, T. Lomax, S. Norman *A1_3 Modelling the Sustain of an Electric Guitar*, PST 19, (2020).

[2] Y. Davis, N. Drewes, T. Lomax, S. Norman *A1_4 The Sustain of a Chambered Electric Guitar*, PST 19, (2020).

[3] `https://www.gretschguitars.com/gear/family/jet/g6131-my-malcolm-young-signature-jet/2411916821` [Accessed 1 December 2020].

[4] `http://newt.phys.unsw.edu.au/jw/Helmholtz.html` [Accessed 1 December 2020].