

# From the Didgeridoo to the Opendidge\*

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## The Open Didge

A tube that is open at both ends, for example a flute, produces a different timbre of sound in comparison to that produced by a tube that is open at just one end as is typical in reed instruments such as the didgeridoo, trumpet, tuba, clarinet, oboe etc... This difference is largely due to the restrictions on standing waves as a consequence of the boundary conditions at the two ends of the tube. This division leads to an apparent dichotomy of instrument types. A flute is a tube with both ends open as the sound hole is of course open as are the finger-holes. The second family of instruments are distinguished by the fact that the reed needs large pressure variations to function, the type of variations that occur at the closed end of a tube. Without the feedback from this pressure anti-node (point with maximal pressure variations) the reed will not vibrate effectively and little or no sound can be produced.

This dichotomy does not exist for stringed instruments as the string is necessarily fixed at both end points, these points correspondingly being displacement nodes (points with zero displacement). However a different factor comes into play for stringed instruments, this being the point at which the string is struck, plucked or bowed, and one can of course change the timbre of a stringed instrument by exciting it at different points along its length. One may have thought that you should pluck or bow at displacement nodes but in general this is not true as you can easily see by observing a players fingers or bow.

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It is also generally true that for any musical instrument with finger holes or other types of keys, the size of the hole is comparable to the internal diameter of the tube at the hole position. Finally the bell on the instrument is generally necessary for a good coupling between the resonant cavity and the surrounding air thus making the instrument into an efficient radiator of sound waves - an obvious necessity for acoustic instruments to be heard.

The new class of wind instruments that we are proposing here come from a reconsideration of these various features together with a novel amplification system. It generally consists of two or more cylindrical tubes attached to a central mouthpiece. The amplification is obtained by the use of a piezo-electric contact microphone positioned close to the lip reed and before the main body of the instrument. This form of amplification obviates the need for a bell that couples the instrument to the environment and as such there is no need for any tapering of the resonant cavity. As a further consequence of the cylindrical form of the instruments various tubes it is perfectly reasonable (without sacrificing sound quality) to add finger-holes allowing a single instrument to play more than one note. Furthermore one can modify the sound of the instrument by closing the ends of some of the tubes (obviously not all at once..).

The acoustics of such an instrument is significantly different from any of the above examples as the driving impulse is in general applied at a point that does not precisely correspond to either a pressure node (brass and woodwinds apart from the flute) or a pressure antinode (flutes). From this point of view it is quite similar to a bowed string instrument as we have a continuous vibrational excitation applied to the air column at some intermediate point along its length.

The lengths of the various tubes attached to the central mouthpiece is of fundamental importance for the creation of good quality resonances and can significantly influence the harmonic quality of the entire sound spectrum. The placement of finger-holes enables one to play simple melodies (very good for bass lines) but once again the exact location of the finger holes is very important, bad placement leading to weak resonances and some notes or their overtones difficult to intonate and play.

Using the transmission line model for standing waves in a series of tubes we find the equation that governs the resonant frequencies  $f$ , for the case of two tubes (of equal radius) and a mouthpiece;

$$A_0 \tan(2\pi f L_0/c) = A(\cot(2\pi f L_1/c) + \cot(2\pi f L_2/c))$$

where  $c$  is the speed of sound in air (we will take  $c = 34500\text{cm/s}$  for air tem-

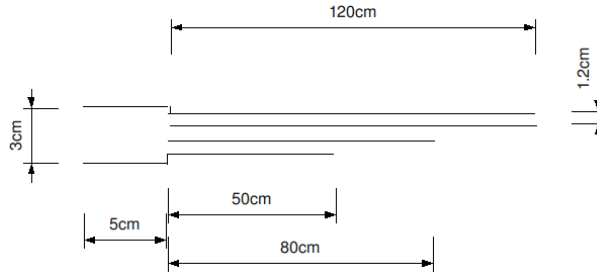


Figure 1: Side view of an open-didge showing  $L_0 = 5\text{cm}$ ,  $L_1 = 50\text{cm}$ ,  $L_2 = 80\text{cm}$ ,  $L_3 = 120\text{cm}$ ,  $D_0 = 3\text{cm}$  and  $D_1 = D_2 = D_3 = 12\text{mm}$ .

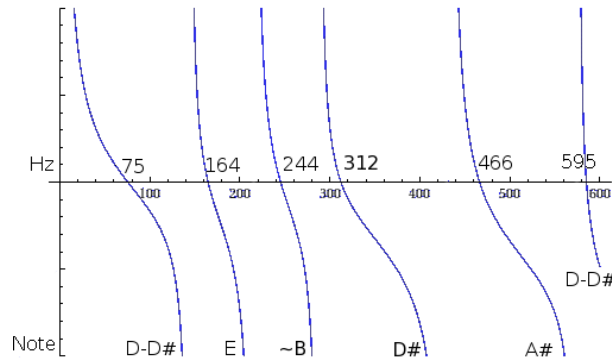


Figure 2: An example of the frequency spectrum (indicated by the points where the curve crosses the horizontal axis) for the case where  $L_1 = 80\text{cm}$  and  $L_2 = 120\text{cm}$ .

perature of  $23^\circ$ ),  $A = \pi D^2$  is the cross-sectional area of the tubes (assumed equal), and  $A_0$  is the cross-sectional area of the mouthpiece.  $L_0 = 5\text{cm}$  is the length of the mouthpiece and the  $L_i$  are the lengths of the attached tubes. In general  $L_0$  will be small (about  $5\text{cm}$ ) compared to  $L_1$  and  $L_2$ , and one can easily see that in this limit the wavelength of the fundamental resonance is  $2(L_1 + L_2)$  as one would expect for a tube that is open at both ends. The special case of  $L_1 = L_2$  is equivalent to an open-closed tube of length  $L_1$  and cross-sectional area  $2A$  attached to the mouthpiece. Figure 2. shows a plot

of this curve together with the predicted spectrum of fundamental note and overtones.

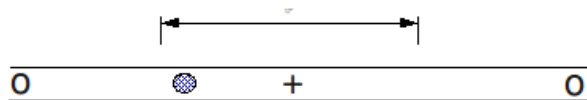


Figure 3: The fundamental standing wave with pressure nodes denoted by  $o$  and anti-nodes by  $+$ . The range of good insertion points for the mouthpiece are indicated and a possible mouthpiece has been added.

For three tubes of cross-sectional areas  $A_1, A_2, A_3$  and of lengths  $L_1, L_2, L_3$  this equation generalises to;

$$A_0 \tan(2\pi f L_0/c) = A_1 \cot(2\pi f L_1/c) + A_2 \cot(2\pi f L_2/c) + A_3 \cot(2\pi f L_3/c)$$

This curve together with the corresponding spectrum can be seen in Figure 4.

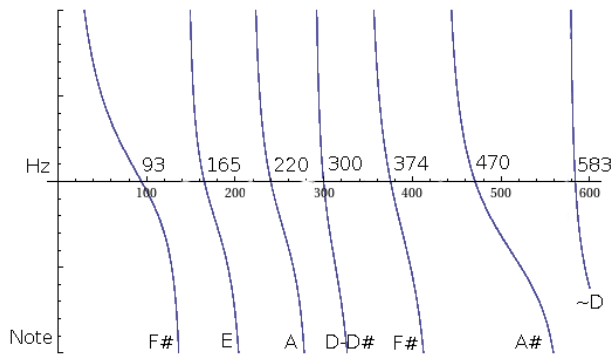


Figure 4: Resonant frequencies for the example with  $L_1 = 50\text{cm}$ ,  $L_2 = 80\text{cm}$  and  $L_3 = 120\text{cm}$ .

If we close the end of one of the tubes (say tube 1) the equation is modified to

$$A_0 \tan(2\pi f L_0/c) + A_1 \tan(2\pi f L_1/c) = A_2 \cot(2\pi f L_2/c) + A_3 \cot(2\pi f L_3/c)$$

This curve together with the corresponding spectrum can be seen in Figure 5.

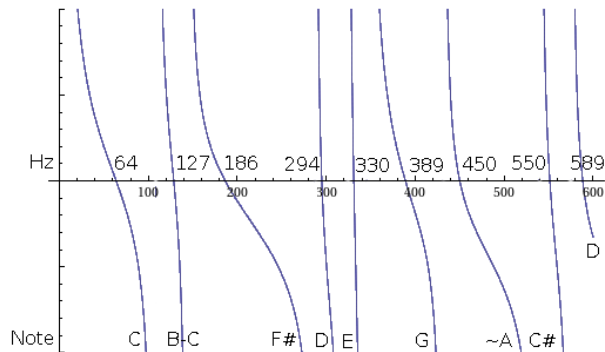


Figure 5: Resonant frequencies for the example with  $L_1 = 80\text{cm}$ ,  $L_2 = 50\text{cm}$  and  $L_3 = 120\text{cm}$  and with tube 1 closed. Notice the shift towards lower frequencies in comparison to the above case where all three tubes were open.

## Amplification

In general wind instruments are not efficient radiators of the energy in standing waves that are formed inside them. Studies on trumpets and trombones have shown that the air pressure variation near the mouthpiece end is many orders of magnitude (up to 175 dB!) greater than the pressure variation present at the bell. To amplify the open didge we take these sound vibrations directly from the mouthpiece by using a piezo-electric transducer which

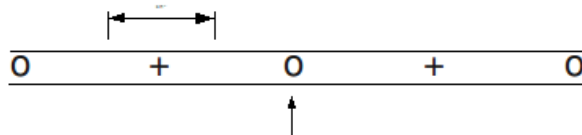


Figure 6: The first overtone resonance. The range of good insertion points for the mouthpiece are indicated while the single arrow indicates a mouthpiece insertion point that will not excite this harmonic.

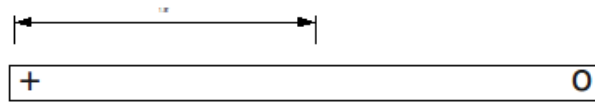


Figure 7: The fundamental resonance for a tube that is closed at one end showing the range of possible mouthpiece locations.

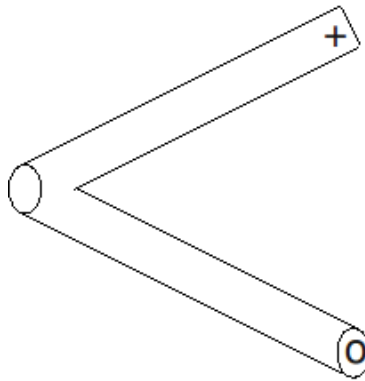


Figure 8: A bent didgeridoo corresponding to a tube closed at one end, but with the playing position located half way along the tube.

picks up the vibrations of the air inside the mouthpiece - maybe filtered by the walls or other objects in such a way as to fine tune the particular sound that one would like to create. One could also try to insert into the mouthpiece a small condenser microphone with moisture resistant screen. I have initially used the piezo-electric mics as they are completely moisture resistant and cost an order of magnitude less than an appropriate condenser mic.

As a final comment I would like to point out that this technique also obviously provides us with a novel way to amplify a didgeridoo. One can simply attach the mouthpiece with pickup as an extension to the mouthpiece of the didgeridoo with very interesting results.

## Some Dimensions and other details

We have found by experimenting with many different possibilities that for a decent air-flow it is sufficient to have a mouthpiece of internal diameter about 30mm and then about 5cm from the mouthpiece (which includes the piezo pick-up for amplification) a junction to a number of tubes each with an inner radius of about 12mm. Finger holes should then have a radius of 10-12 mm or so. For two tubes an easily playable configuration is  $L_1 = 2L_2$ . For three tubes the most interesting combination found so far has  $L_1/L_2 = L_2/L_3 = 5/8$  and plots of the resonant frequencies for a case very similar to this one are given above.

Very cheap piezo-electric microphones can be found in small buzzer type door bell alarms. They are inside a small plastic capsule. Carefully pry open the capsule and you will find the piezo transducer inside. These work surprisingly well when coupled with an appropriate preamp. It should be noted that the strongest signal from the pickup is attained when there is a hole (in our prototypes of diameter 8mm) in the side of the mouthpiece above which the pickup is fixed. One can filter the signal by leaving a small amount of wood under the pickup, or filling the hole with different pastes or materials - there is ample room for experimentation here.

Any piezo transducer needs to be attached first to a preamp before entering a mixer or effects units. The preamp should be one specifically designed for high-impedance pickups.

## Experimental Results

In this section we will present the final results of an analysis of the spectrum of the opendidge. We then will confront this spectrum with the expected theoretical spectrum that we discussed in the second section.

We have two slightly different instruments at hand, each with tubes of lengths 50, 80 and 120 cm long. Instrument I has a 30mm mouthpiece attached directly to three tubes each 12mm in diameter. Instrument II has a 30mm mouthpiece attached to a hole of 12mm which then branches into three tubes each 12mm in diameter.

For the instrument (II) with two tubes of lengths  $L_1 = 80\text{cm}$  and  $L_2 = 120\text{cm}$  the expected resonant frequencies in Hz (Fig 2) are 75, 164, 244, 312 ... and the playable notes were measured to be at 79, 161, 239, 308, quite a good agreement.

For the instrument with tubes of length  $L_1 = 80\text{cm}$ ,  $L_2 = 50\text{cm}$ ,  $L_3 = 120\text{cm}$  the expected resonant frequencies in Hz (Fig. 4) are 93, 165, 220, 300, 374, .. On instrument I the playable notes were at frequencies 92, 160, 236, 295 while the resonance near 374 was very difficult to intonate. On instrument II the playable notes were at frequencies of 97, 163, 236, 296 and 360 Hz. Again this displays a good agreement with the theoretically expected frequencies.

For the instrument with tubes of length as in the previous example but closing the end of the 80cm tube the expected resonant frequencies are 64, 127, 186, 294, 330, 389 ... On instrument I the playable notes were at frequencies of 66, 123, 174, 290, 378 while the expected note at around 330 was difficult to intonate. On instrument II the playable notes were at frequencies of 66, 125, 178, 230, 375. The notes expected at 294 and 330 were difficult to intonate while the extra frequency at 230 was not amongst the notes of the theoretical prediction.

For instrument I the differences between theory and experiment are negligible taking into account that the tube length measurements are only accurate to within 1cm. For instrument II there were several discrepancies. We should recall that for instrument II the theoretical model was not precise due to the narrowing of the mouthpiece to 12mm before the branching to the other tubes. We should add this modification to the theoretical model to see if the predicted frequencies then agree with theory as one expects to find.

## Transferring Vibrational Energy

If one plays the instrument shown in figure 8. where the closed end is closed by your hand, you can directly experience the vibrations in the air column as a massage on the palm of your hand. This may be useful for therapies/massage where the inducement of vibration is important.

## The Open Didge Project

The basic principles of an open didge are

- didge style mouthpiece with pickup
- two or more tubes attached to the mouthpiece
- finger-holes, keys, slides added to one or more of the tubes to enable the playing of more than one note.

There are however many many variables.

- The lengths of the tubes and locations of finger holes determines the tuning of the instrument and there are many possible variations.
- The diameter of the tubes changes the playability and energy structure of the standing waves. One can further have all tubes of the same diameter or also some tubes larger and some smaller.
- The exact type of pickup that is used. It could also be a small water resistant dynamic or condensor microphone.
- The placement of the microphone, there being obviously the possibility of using also multiple microphones.
- The material from which the various tubes are made will also have some impact on the sound produced.

For the photos of various opendidges, including instruments I and II used in the study of the spectrum, for the latest version of this document and for further material on the OpenDidge please go to <http://martino.fluiditj.com/opendidge.html>

## Appendix: Tunings - Theory and Experiment

Here we present a list, in an easily readable form for reference, of the theoretical and measured spectrum for various opendidge configurations. Instrument I and II are as referred to in the text.

Theoretical	Instrument I	Instrument II
75	ND	79
164	ND	161
244	ND	239
312	ND	308

Table 1: Spectrum (in Hz) for a two tube instrument with  $L_1 = 80$  and  $L_2 = 120$ , ND = No Data.

Theoretical	Instrument I	Instrument II
93	92	97
165	160	163
220	236	236
300	295	296
374	ND	360

Table 2: Spectrum (in Hz) for a three tube instrument with  $L_1 = 80$   $L_2 = 50$  and  $L_3 = 120$ .

Theoretical	Instrument I	Instrument II
64	66	66
127	123	125
186	174	178
294	290	230?
330	ND	ND
389	378	375

Table 3: Spectrum (in Hz) for a three tube instrument with  $L_1 = 80$ ,  $L_2 = 50$  and  $L_3 = 120$ . The end of tube 1 is held closed.