The Harmonica

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This essay contains embedded JPEG diagrams to help the flow of the narrative. It was written using OpenOffice 3.6 in .doc Word 97/2003 format and has been tested for essential compatibility (i.e. only minor formatting differences observed) with Microsoft Word 2000 and 2013 in which all 12 pictures display consistently correctly. It should display similarly correctly in Word 2003 and 2007 but these have not been tested. Similar inconsistencies are known to exist between different versions of Word and as the only alternative for the EMA submission is to include all diagrams as separate files, which creates it's own logistical problems both for creating and assessing, I chose to use embedded diagrams along with this statement.

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a. Introduction, historical development and present-day usage

i Choice of instrument

I chose this instrument for several reasons. It is arguably the most widely played instrument in the world (Bahnson et.al., 1998) and although mentioned (p. 75, Block 3:2), it is not considered in detail in the course notes so primarily, it gave me the opportunity to apply the techniques learned there to a different instrument. Additionally, it is one of the instruments I play and I wanted to find out more about the extraordinary range of tonality available due to the interplay between the instrument, the player's hands and the vocal tract, and in particular how notes are “bent”. Ever since managing to achieve this for the first time after a great deal of fruitless practice when learning the instrument some years ago, I had always wondered exactly what is involved.

In what follows, all screen dumps, photographs, drawings and sample recordings were made by myself, the latter using the course microphone.

ii Outline description

The instrument is a few inches long, hand-held, cheap and consequently very widely available. It has a series of holes on the long side through each of which individually or in combination, the player blows or draws, giving different notes via it's internal structure. It does not need to be tuned. It's mechanism of sound production is related to the concertina, employing only *free reeds*, (free in the sense of not being attached to an air column). It's most common forms are the *chromatic* harmonica (capable of playing all twelve tones of the octave) which can usually be found with 10, 12, 14 or 16 holes and the 10-hole *diatonic* harmonica (which plays only the tones of a selected and usually major scale, inscribed on the end of the harmonica). The chromatic harmonica is distinguished by having a lever at one end used to give access to all 12 tones of a scale.

Harmonicas are typically available in nearly all keys and also in bass forms. Figures 1, 2 illustrate two Hohner harmonicas, the eponymous “Marine Band” diatonic and a 10-hole chromatic where the pitch shifting lever can be seen on the right.

Figure 1. 10-hole diatonic “Marine Band” harmonica.

Figure 2. 10-hole chromatic harmonica.

The harmonica is played by blowing or drawing air through the holes which causes the reeds to vibrate producing a characteristic rather plaintiff sound.   There are two reeds to each channel or hole, giving separate notes on blow and draw.

Unusually, the tuning of the harmonica allows both single notes and chords to be played giving both melodic and harmonic possibilities.   The blow/draw tuning of a standard 10-hole C major diatonic harmonica numbered from 1 to 10, left to right, is

Blow	C_4	E_4	G_4	C_5	E_5	G_5	C_6	E_6	G_6	C_7
Draw	D_4	G_4	B_4	D_5	F_5	A_5	B_5	D_6	F_6	A_6

The tuning is known as *Richter-tuning* named after Joseph Richter a 19th century Bohemian instrument maker credited with inventing the blow/draw concept facilitating this compromise between diatonic melody and harmony.

The hands can be used to cup the harmonica and 'shape' the sound producing vibrato for example by opening and closing the hands. It is very often amplified electronically, with the microphone, hands and harmonica fusing into one acoustic system. It is most commonly used in country, rock and blues music but in its chromatic form has featured in jazz and classical contexts.

iii Historical origins and development

The harmonica is a *free reed* instrument, (free in the sense of not being attached to an air column). The reeds vibrate when air passes over them.

Free reeds first appeared in Asia, (Field, 2000, p. 20) several thousand years ago with instruments such as the *sheng* but the modern hand-held harmonica, (also known as the mouth organ, Mississippi saxophone and others), is a relatively modern invention dating back to 1821, where it was patented by Christian Friedrich Buschmann in Vienna.

An important musical development occurred a little later in around 1825 when Richter, a Bohemian, created what is effectively the modern diatonic harmonica. This had two significant features; first it featured separate plates for blow and draw reeds; and second the tuning was arranged to provide a complete major scale in the middle of the instrument and scales with missing notes on either side allowing both single notes and chords to be played.

Technologically, mass production gradually came into play and in 1857, a 24 year old Matthias Hohner starting manufacturing them full time and with great business acumen, bought out competitors and built his business. Other innovations followed such as using metal plates with elaborately engraved graphics to help differentiate his products as seen in Figures 1, 2.

The Hohner company continued to expand in the 20th century building its export markets, fuelled with unlikely sources of large numbers of customers in the First World War where initiatives aimed to supply every soldier on both sides with a harmonica, (Field, 2000, p. 27). The diatonic harmonica became very popular, although to this day, they retain the Richter tuning dating back to 1825.

The next important technological advance was to provide a harmonica with a chromatic range to cater for a wider set of musical genres. A diatonic harmonica is based on a particular key so any chromaticism or modulation makes them very difficult to use, even if the player is equipped with a range of harmonicas in relevant keys. The most common form contains two reed plates a semitone apart with a spring-loaded button which switches between them allowing all the notes of an octave to be played. Other technological innovations have included bass and chordal harmonicas, made for harmonica bands, and also tremolo harmonicas where one set of reeds is tuned slightly sharper than the other.

Although sales of harmonicas have ebbed and flowed in the last 150 years, musical innovation such as the ability to bend notes by up to a tone on the harmonica and hold the so-called blue note (flattened fifth), led to a massive expansion in sales in the 1960s blues/rock era of music and today the Hohner company still manufacture some 2 million a year.

iv Usage

The harmonica has been used as a solo instrument, played with other instruments and also as part of novelty harmonica bands. In the 19th century, it was mostly a solo instrument playing popular or folk melodies and in the USA, it become associated with African-American folk blues. Following the appearance of the more versatile chromatic harmonica, it began to appear in other genres and also contexts. In the 20th century, the chromatic harmonica opened up the jazz and classical genres and the great American harmonicist Larry Adler, apart from being a consummate jazz musician, had classical compositions composed for him by Vaughan Williams and Malcolm Arnold amongst others. Others such as the Belgian Toots Thielemans (also famous for his whistling), and the Dutchman Max Geldray carved out formidable reputations as jazz musicians. Alongside this, in the middle part of the 20th century, there was a surge in novelty harmonica bands such as Borrah Minevitch and the Harmonica Rascals (USA, 1930s), the Harmonica Gentlemen (USA, 1940s), Jerry Murad's Harmonicats (USA, the 1950s) and the Madcaps (Austria, 1960s).

Arguably the biggest impetus to the visibility of the harmonica gradually grew from the early-mid 20th century with players such as Sonny Terry, Jimmy Reed and Junior Wells, until it accelerated in the great blues/rock boom of the late 20th century with performers as diverse as Cyril Davies, Paul Butterfield, Jerry Portnoy, Bob Dylan, Mick Jagger and Stevie Wonder.

In the 21st century, the instrument has developed further in the hands of virtuoso harmonicists such as the Grammy Award winning Howard Levy (http://levyland.com, accessed 20-May-2015) who with others has perfected *overblow* and *overdraw* techniques to extend the range of notes of the humble diatonic harmonica to the full chromatic range.

b. Construction and operation

i Geometry and component parts

By far the commonest diatonic harmonica consists of a sandwich of two ornamental metal plates which help both to protect and advertise it on the upper and lower side, two brass plates with a series of free reeds, (tongues of metal which stand proud of an exactly matching hole), the upper plate for blow notes and the lower for draw notes. Finally the centre of the sandwich is the "comb", named because of it's physical appearance and manufactured usually in wood or composite but sometimes metal and even titanium, (http://patmissin.com, accessed 04-May-2015). The wood of choice is cedar for it's rot-resistant properties.

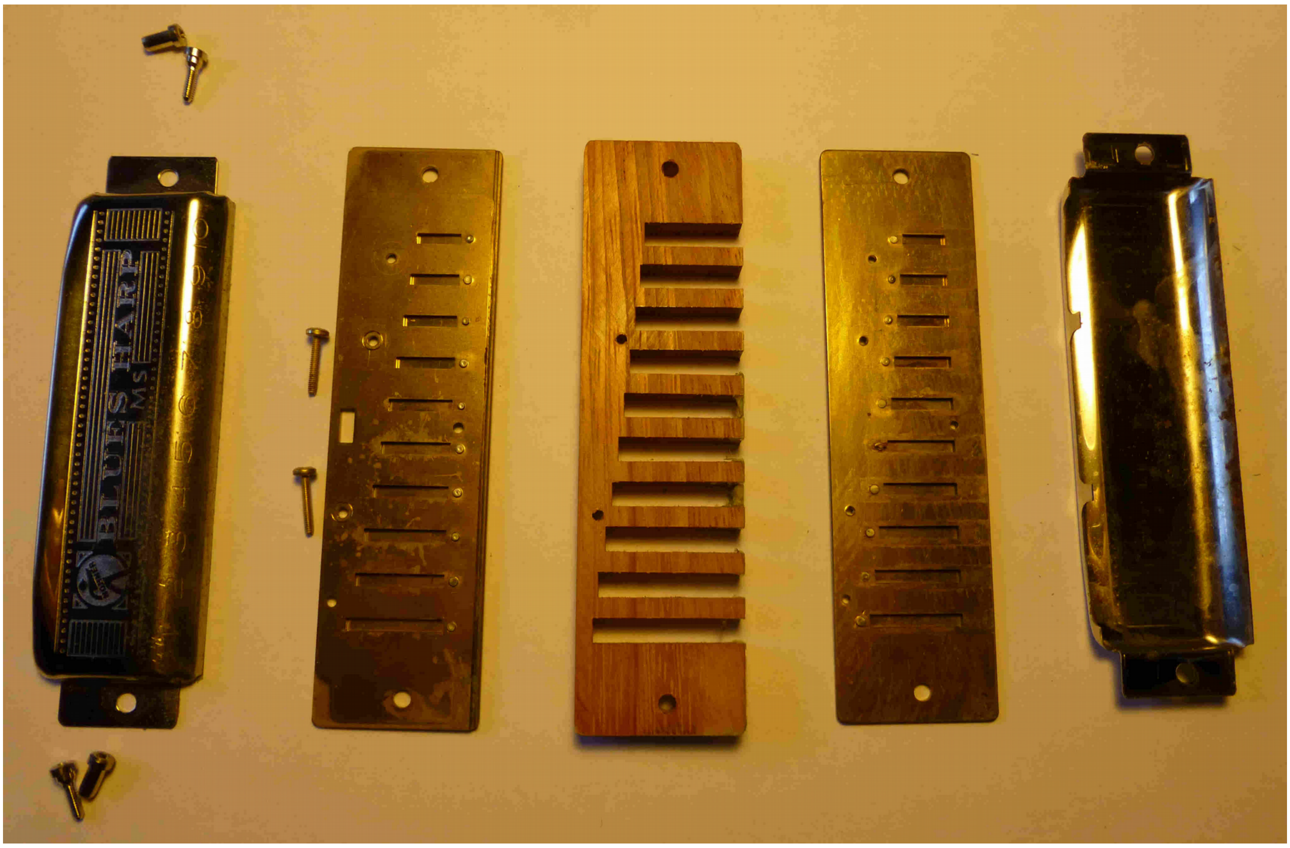

Figure 3. An exploded form of the diatonic harmonica of Figure 1. From the left is, the ornamental upper metal cover, the blow reed plate consisting of 10 reeds, the 10-slot cedar "comb" which channels the air, the draw reed plate with a further 10 reeds and the lower metal cover.

The flow of air is indicated in Figure 4.

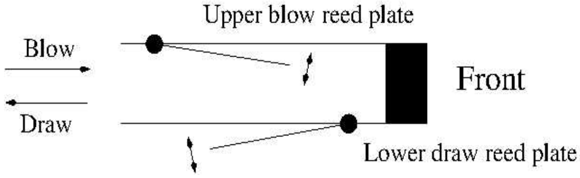

Figure 4. Geometry of the air-flow in blow and draw through the double reed plates of a diatonic harmonica.

The reed plates are worthy of most attention. They consist of tongues of a brass alloy (i.e. a non-corrosive mixture of copper and zinc for durability) which stand proud of a matching slot in a plate of the same material to prevent metallic interaction. The pitch of each tongue depends on its length, which varies from the longest and therefore lowest at the bottom of Figure 3, to the shortest and therefore highest at the top. The mass and stiffness of the tongue also affects the pitch. Sometimes both upper and lower reed plates are combined on a single plate with 20 reeds but still two per hole or channel. The reeds may be fine tuned by hand by filing off material from the far end of the tongue (to raise pitch) or the attachment end of the tongue (to lower pitch).

Unlike some other musical instruments, the materials need no special sourcing and the whole thing is joined together with screws also shown in Figure 3.

The chromatic harmonica is rather more complicated and typically several times more expensive. The basic construction is the same as the diatonic but the slider which engages the sharp notes might either be a simple baffle on two sets of holes, or may mechanically select either of the normal or sharp reed plates internally in a number of ways.

ii Method of sound production and radiation

In a fixed reed instrument such as the clarinet or saxophone, the pitch is altered by keys which change the length of the attached air column. A free reed instrument is not attached to an air column and vibrates when air is blown over it. Another example of a free reed instrument is the piano accordion. The free reed vibrates in several modes (Cottingham, 2011, 2013) with a pitch dependent on its mass, length and elasticity.

Very little was known theoretically about sound production with the harmonica as recently as the late 1980s, previous studies being confined to instruments such as the clarinet and saxophone, (Backus 1963), (Clinch, Troup and Harris, 1985). This section is therefore based largely on theoretical studies since then, (Johnston 1987), (Bahnson et.al, 1998), (Cottingham 2011, 2013), who analyse and model pitch production of free reeds with particular detail of the diatonic and to a lesser extent, the chromatic harmonica.

The results are intriguing to say the least. The harmonica turns out to have almost unique properties in that the free reed system acting as a vibrating oscillator (the secondary vibrator), is alternately upstream and downstream of it's resonating volumes or primary vibrators, the *vocal tract* and the player's cupped hands respectively. Furthermore, the fact that there are two reeds per channel leads to sympathetic and rather subtle vibration modes between them, (Bahnson et.al, 1998).

The main motivation for Johnston's landmark 1987 work is the observation, known by the African-American players in the southern USA since the late 19th century, that the notes of a diatonic harmonica can be bent down continuously by up to 3 semitones in some parts of the instrument. This is due to the complex interplay between the blow and draw reeds in each channel and the vocal tract. The general observation is that the bent pitch was achieved by "pulling down" the pitch of the upper register reed, (the blow reed in holes 1-6 and the draw reed above), whilst pulling up the pitch of the lower register reed. The net effect is a continuous pitch change of up to 3 semitones. Johnston confirmed the following:-

- Notes can only be bent down
- The only notes that can be bent are those where there is a lower-register note in the same channel, (blow or draw)
- The degree of bend is related to the pitch of the lower note in the channel, with a maximum bend about a semitone sharp of the lower note.
- The change is continuous for continuous change in mouth geometry.

These observations are often expressed in terms of "speaking" through the harmonica's voice imparting it's unique character, (Bahnson et.al, 1998) and indeed the influence of the vocal tract and different vowel sounds with the voice, (Block 3:2, p.105) are very closely related to the skills necessary to bend harmonica notes, (Baker, 1991, p. 20-). Originally, sounds were produced by blocking holes with the tongue, but the tongue turns out to be fundamental in the bending process and the discovery that the harmonica could be played by "kissing" the holes, as described by the original African American players frees up the tongue, transforming the instrument.

The vocabulary used to describe this action varies from the anatomical "bending the air column down to the front part of the lower jaw" to the more gnomic "take in air from your shoes" (Bahnson et.al, 1998). From personal experience, it is simply experimentation until one day it seems to happen and then you wonder why you could not do it before.

Given that the two primary vibrators, the vocal tract and the hands are very different, the sound production will change according to the balance between them and the degree of bending necessary for the style of music.

The sound of a harmonica radiates like the human voice and like the human voice it can be very penetrating even without amplification, although this does not appear to be in the same sense as the formants of the trained human voice. Harmonica players do not seem to rely on any sub-glottal features, (Johnston, 1987). The hands assist in sound radiation either damping it or acting as a horn. They can also be used to produce an amplitude vibrato and even a pitch vibrato.

iii Pitch range

The pitch range of a harmonica is complicated by the possibilities of overblowing but nominally, the standard 10-hole Richter-tuned C-major diatonic harmonica has a range of 3 full octaves C_4- C_7, corresponding to 22 diatonic tones. However there are only 20 reeds and one note is repeated, so there are three missing natural tones in the 3 octaves. Chromatic harmonicas are traditionally tuned differently to the diatonic (*solo* rather than *Richter* tuning) and have no missing tones but will have duplications and their pitch range depends on the number of holes. A 12 hole chromatic covers C_4- C_7, and sometimes C_4- D_7, and a 16 hole chromatic adds an octave on the bottom, C_3- C_7, and sometimes C_3- D_7.

Other tunings exist. The so-called Irish tuning for a 16-hole chromatic is B_2-B_6 whilst classical tuning for the same harmonica would be C_4-$C\#_7$.

iv Timbre and other musical or playing features

Descending notes and scales have long been associated with relative sadness compared with their ascending versions, (c.f. Collier and Hubbard 2001). Given the ease with which harmonica notes can be bent down in skilful hands, the plaintiff somewhat sad sound of a harmonica can easily be understood and often dominates the timbre of the instrument.

From the musician's point of view, the harmonica is considered in terms of *positions*. Some positions suit certain styles of music better. For example, the technique of *cross-blowing* or playing in the second position, (one sharp higher than the harmonica's natural key), gives a Mixolydian mode characterised by a flattened seventh and very common in blues and rock music. In practice, this mode involves a much higher percentage of draw bending, giving dominance to the vocal tract resonator and the very precise pitching which can be achieved by the tongue, (Bahnson et.al, 1998). Complemented by advanced techniques such as *overdrawing* and *overbending* which involve higher pressures in the mouth, fully chromatic playing of a diatonic harmonica can be achieved by virtuosos like Howard Levy who deploy an astonishing range of methods of sound production between the two vibrators.

c. Note analysis

i Waveform analysis

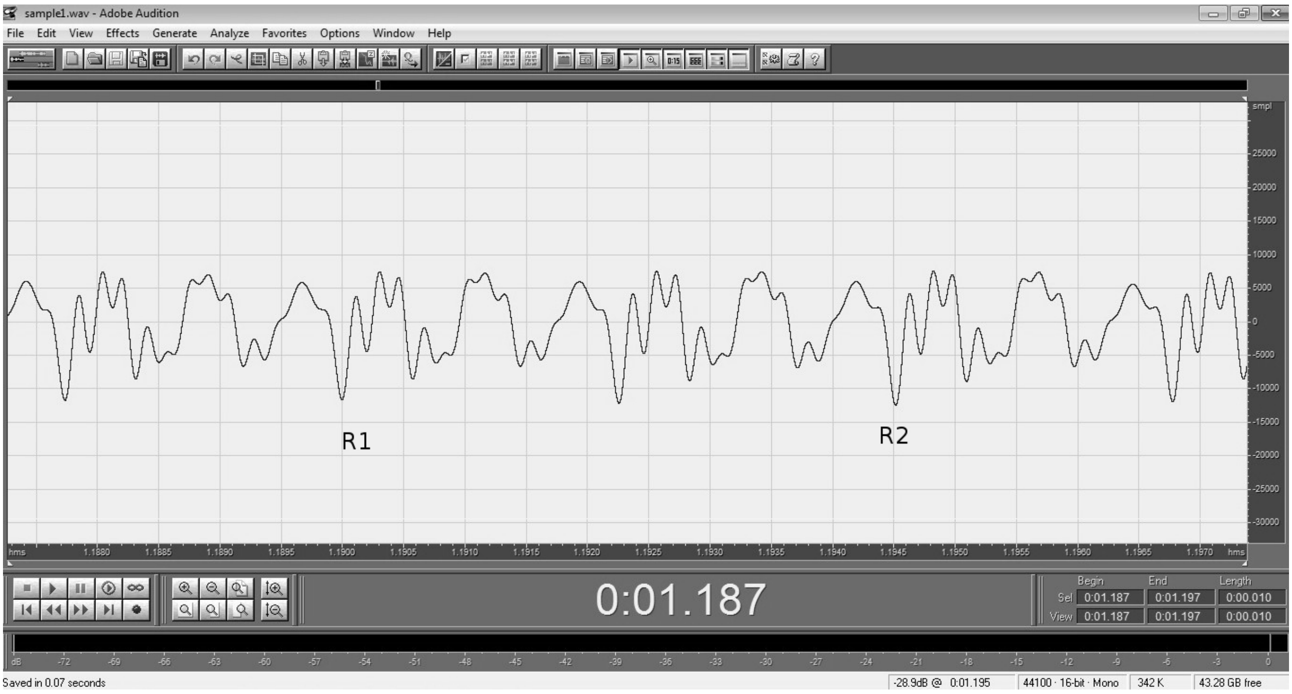

Figure 5. Approximately 4 cycles of a simple drawn A_4 (sound file TA212-14_EMA_G9025437_Q1_sample1.wav) using zoom to selection (Audition, 44.1kHz recording).

Figure 5 shows 4 complete cycles of a waveform generated from a simple drawn A_4 (hole 2) of the concert D diatonic harmonica shown in Figure 1. The duration between the 2 complete cycles at references R1, R2 is about 1.1945 – 1.1900 = .00450s., which gives a single cycle period of about 0.00225s. corresponding to a frequency of about 444Hz which is very close to the standard A_4 440Hz pitch.

Although clearly periodic, the waveform is subtle due to the complex coupled interaction between the blow and draw reeds vibrating in sympathy in the same channel, (Bahnson et.al, 1998), contributing to the instrument's singular timbre.

ii Frequency analysis

The unusual nature of harmonica construction with two reeds per channel or hole, redundancy of some notes in draw and blow, and ability to bend notes suggested the following comparisons.

Same note in draw and blow

The harmonica allows for some repetition of notes with different reeds. Here, using Audition frequency analysis, the amplitude spectrum of a blown A_4 (hole 3) is shown as Figure 6. A drawn A_4 (hole 2) is shown for comparison in Figure 7. Comparing the first 4kHz of Figures 6 and 7 reveals that although there are some differences in harmonic ratios, they are broadly similar. Such differences are expected as these two notes use different air-flow excitation as well as different holes and reeds. Both Figures show that there is a rich set of harmonics all the way through most of the audible range, although there is a marked drop in amplitude much above 6kHz. Furthermore, the second and third harmonics dominate the first harmonic, particularly in the drawn note.

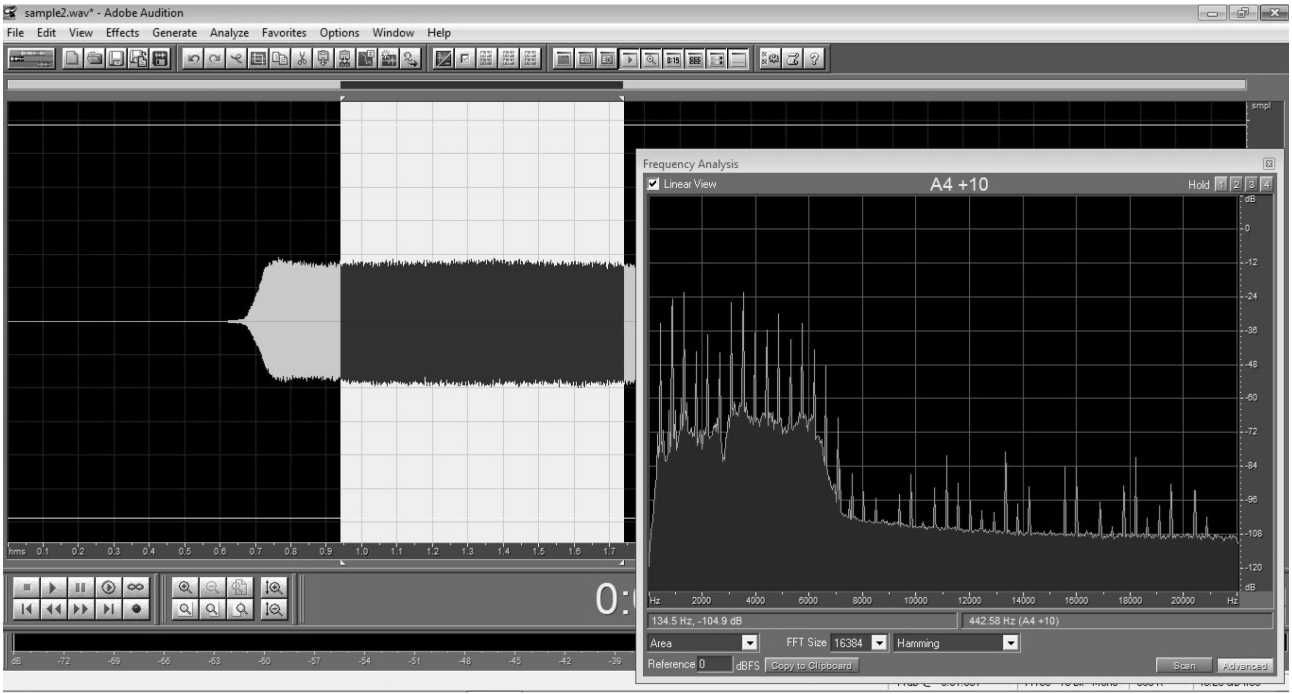

Figure 6. A blown A_4, (sound file TA212-14_EMA_G9025437_Q1_sample2.wav), (Audition, 44.1kHz recording).

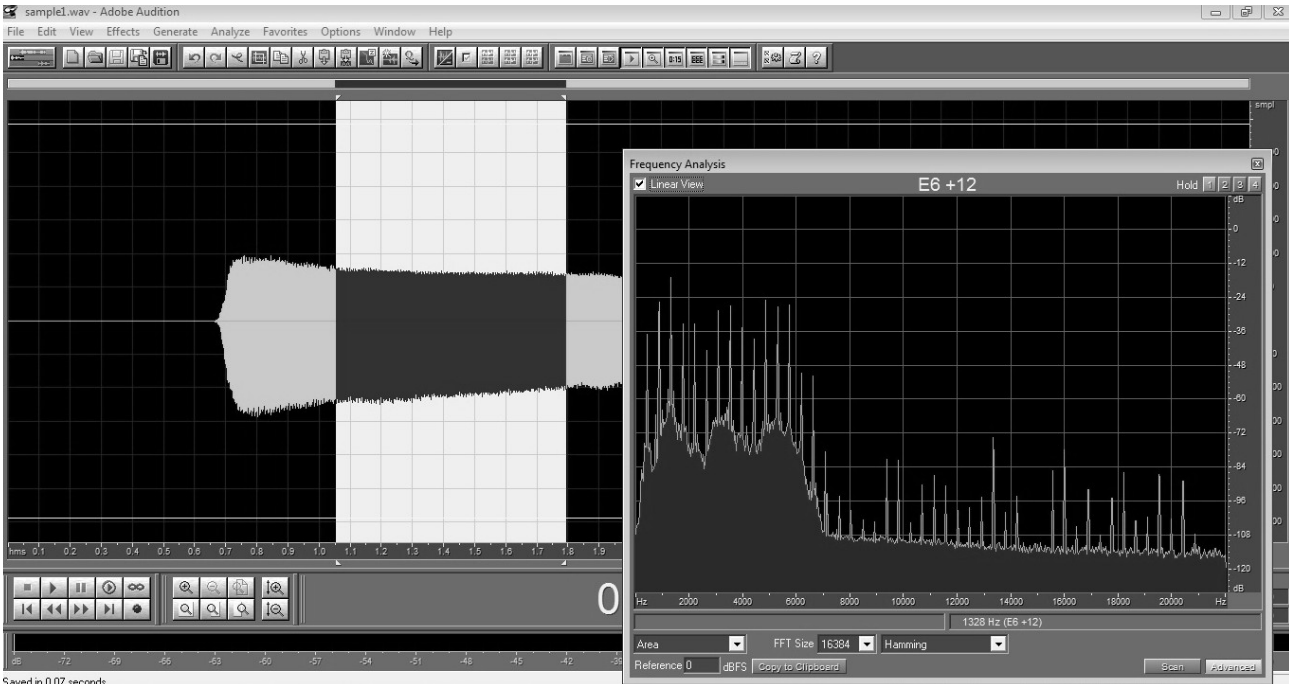

Figure 7. A drawn A_4 (sound file TA212-14_EMA_G9025437_Q1_sample1.wav).

Different blow note

Figure 8 shows the same pitch class, a blown A_6, (hole 9) nominal frequency 1760Hz (2x2x440). The amplitude spectrum shows this a little high at around 1780Hz but these reeds being much smaller are rather harder to tune accurately. They may also be worn – this is a much gigged harmonica. The first three harmonics are well established and then again above around 6kHz, the amplitude drops rapidly.

The accompanying sound file TA212-14_EMA_G9025437_Q1_sample3.wav corresponds to this note.

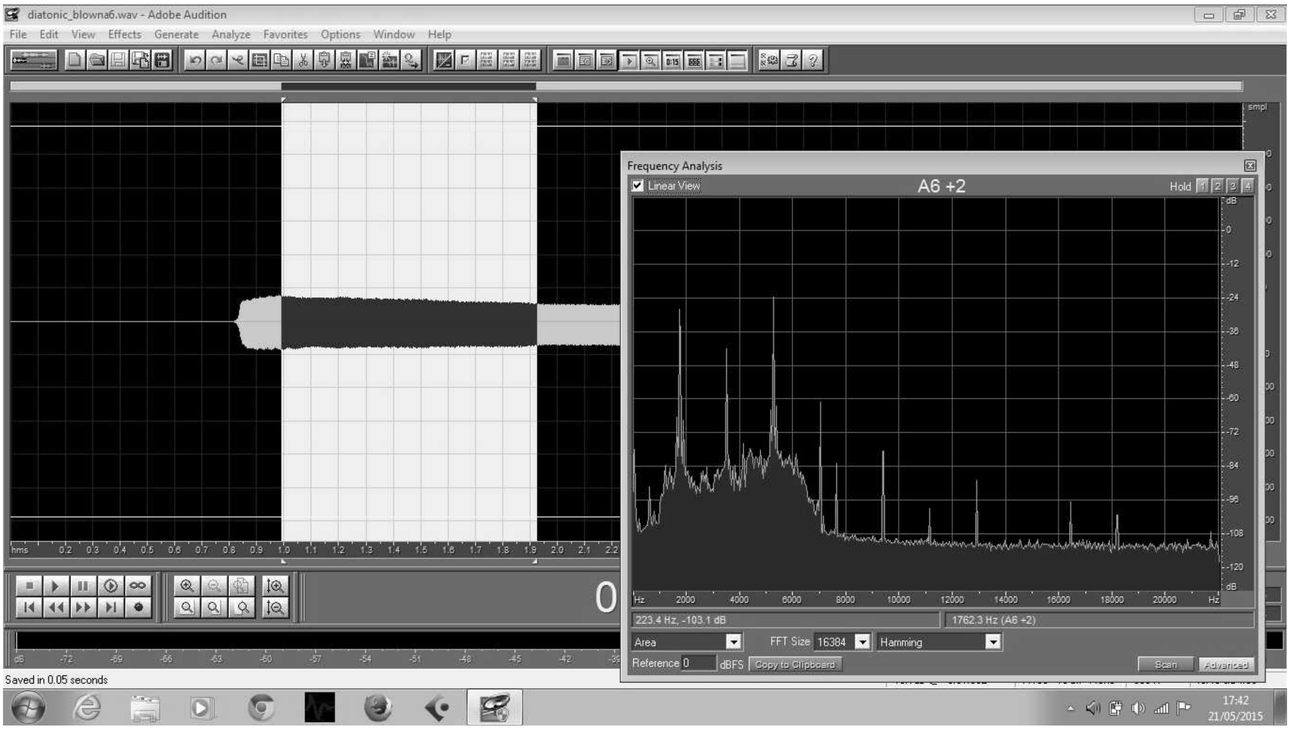

Figure 8, blown A_6, (sound file TA212-14_EMA_G9025437_Q1_sample3.wav), (Audition, 44.1kHz recording)

The first three harmonics are well developed and thereafter rapidly and suddenly decay in amplitude.

Draw bend by 1 tone

The accompanying sound file TA212-14_EMA_G9025437_Q1_sample4.wav (Audition, 8kHz) is a recording of a draw bend of E_5 (about 659Hz) down to D_5 (about 587Hz) using hole 4 whose Audition spectrogram is shown in Figure 9.

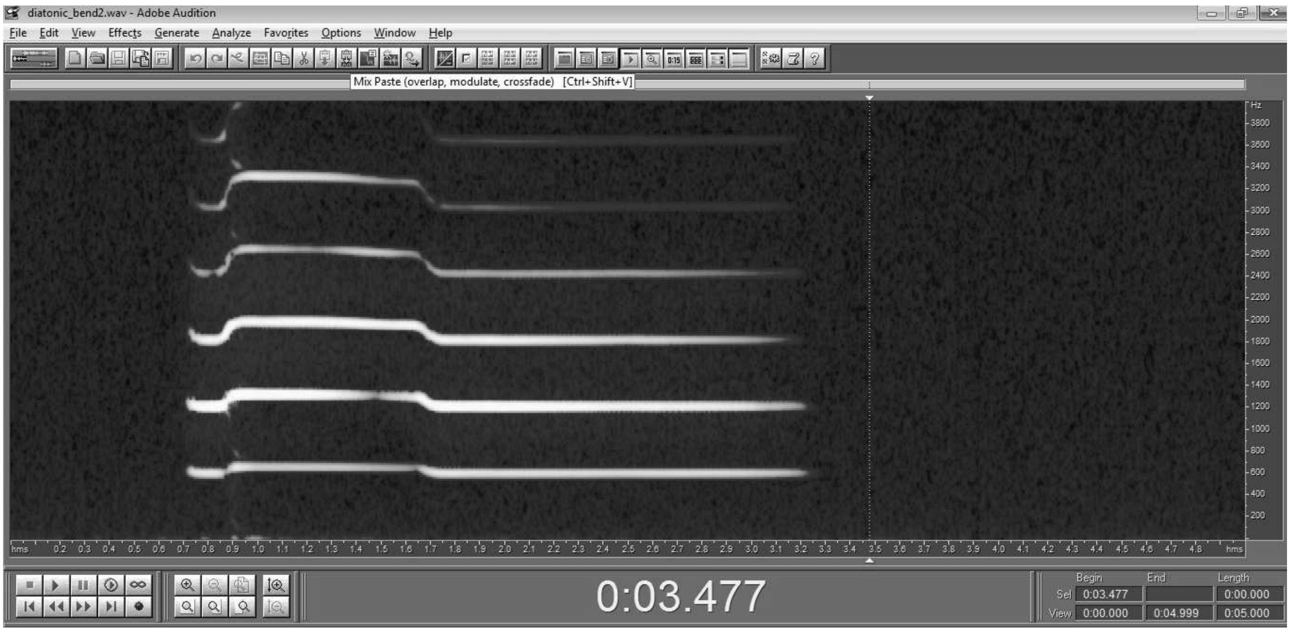

Figure 9. A spectrogram of a draw bend from E_5 to D_5, (sound file TA212-14_EMA_G9025437_Q1_sample4.wav), (Audition, 8kHz recording)

Figure 9 shows the harmonics up to 4kHz and the drop from E_5 to D_5 is shown at 1.6-1.7s. Note that this drop is continuous and can be spread over a much longer period by manipulation of the vocal tract, in particular the tongue. This bending is caused by both reeds being forced to vibrate sympathetically at a frequency determined by the vocal tract.

Figure 10 gives a frequency analysis view over a window containing both notes, (0.9-2.8s). The two peaks at each harmonic corresponding to E_5 and D_5 can clearly be seen, as can the smooth transition between them, (in-filling between peaks). The frequency separation can be seen to increase as expected with each harmonic, (the separation = n x separation at the first harmonic where n is the harmonic number).

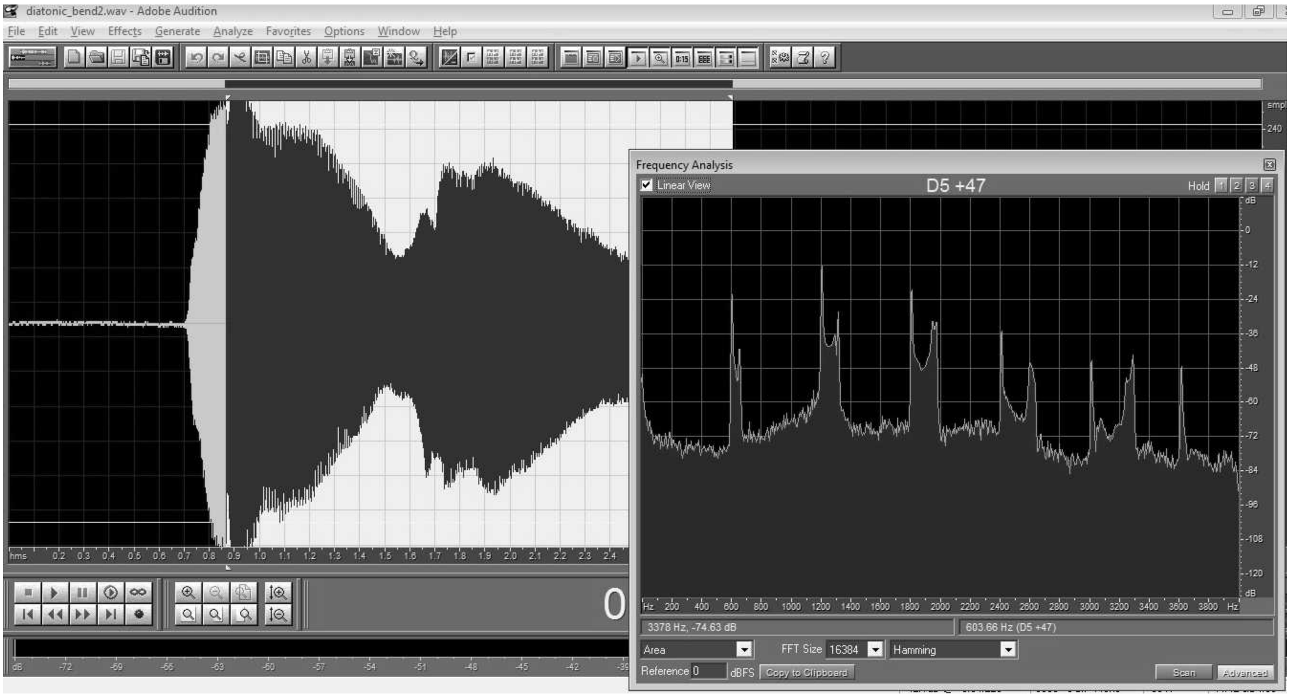

Figure 10. Frequency analysis of draw bend from E_5 to D_5.

iii Envelope analysis

Figure 11 is the full amplitude envelope of the drawn A_4 (hole 2). The envelope has some interesting features. The negative amplitudes during the attack and sustain parts of the waveform are larger than the positive giving an asymmetric waveform from the onset through the stable phase until around 2.2s and is thereafter symmetric. This is presumably because of differing responses of the blow and draw reeds whose vibrations develop initially at different rates and remain so until the latter stages as the draw pressure decreases away.

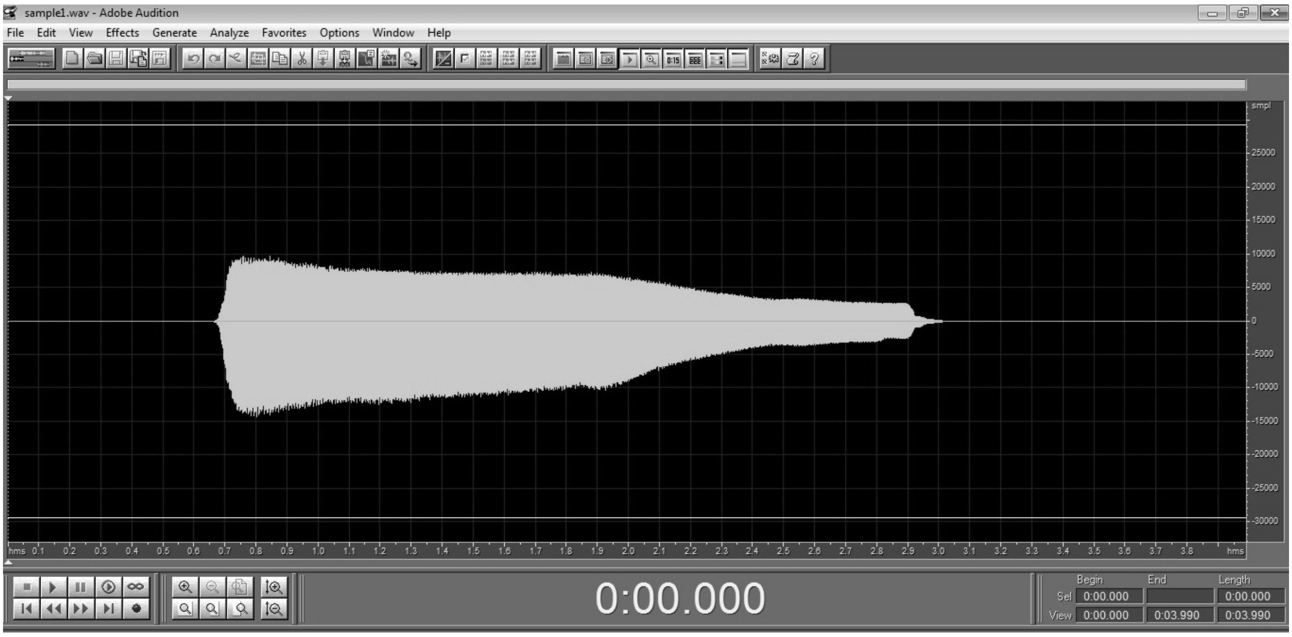

Figure 11. The full waveform of the drawn A_4.

To throw a little more light on this amplitude asymmetry, Figure 12 shows the very early stages of the waveform attack.

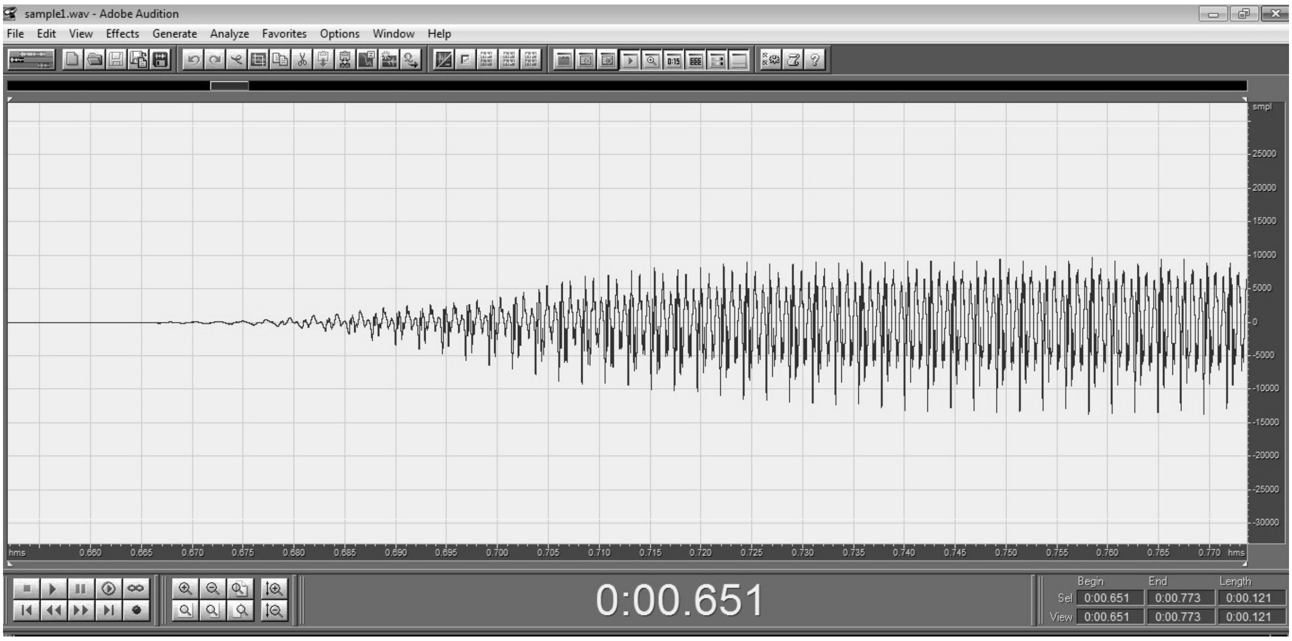

Figure 12. The attack phase of the drawn A_4.

Here the differential development of positive and negative peak can clearly be seen in the first 0.1s. of the waveform attack as the sympathetic vibrations between the two reeds establish themselves first in the draw reed and then sympathetically in the blow reed. This sympathetic vibration adds much to the fundamental timbre of the harmonica. The amplitude envelope may be affected by variable wind pressure as well as hand and vocal tract shaping. Neither was used here to attempt to get the 'pure' envelope.

d. Summary and conclusions

The apparent simplicity of the harmonica belies a subtlety and astonishingly wide range of tones in the hands of skilled players past and present such as Larry Adler, Toots Thielemans and Howard

Levy in the chromatic classical and jazz worlds, all the way to the emotionally highly charged and soulful playing of the Delta blues players such as Sonny Terry and the characteristic bending of a cross-blown diatonic harmonica.

As shown above, the unique relationship between the two sympathetically vibrating free reeds and the two resonators, the vocal tract and the player's hands giving micro-tonal movement between defined notes and both pitch and amplitude vibrato, is fascinating.

There are a number of things I would have liked to explore more. The *overdraw* and *overbend* techniques exploited by modern players such as Howard Levy was simply outside the time I had available, (nor can I do it !). I would also have liked to compare the bending characteristics of the classic diatonic harmonica with the chromatic harmonica.

The general agreement between what I expected and the values I measured seemed good. However, keeping harmonicas clean is difficult, particularly with the snug fit demanded of free reeds. It is very easy for some moisture to remain or particles to prevent one or both of the reeds from vibrating correctly. In spite of this, the fact that A_4 was so close to 440Hz in a fairly battered and well-gigged D diatonic harmonica, was gratifying. Maintaining smooth wind control avoiding hand and vocal-tract shaping was also difficult and may have affected some of my results, although I made numerous recordings to mitigate this.

Finally, this study had a big personal effect on me. I have played one for years in complete ignorance of the above subtleties and I couldn't find much available on the TA212 library resources. This study and it's background reading really opened my eyes to the astonishing relationship between this unassuming instrument, the vocal tract and the hands, and I feel as though I have barely scratched the surface of it's tonal qualities. I am now beginning to understand why so many great players talk of speaking with the harmonica's voice.

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