Applying Physics Makes Auditory Sense

A New Paradigm in Hearing

Verification of calculations of residual pitch and beat phenomena by the reader

Willem Chr. Heerens

Yves Mangelinckx

and

J. Alexander de Ru

Verification of calculations of residual pitch and beat phenomena by the reader

Willem Chr. Heerens, Yves Mangelinckx & J. Alexander de Ru

This program is ONLY available for computer systems running under
Windows XP or Windows Vista

This file is a copy of the Appendix I from the booklet:

Applying Physics Makes Auditory Sense

A I.1 Introduction

Appendix I and the associated software – a calculation program designed by Yves Mangelinckx to be downloaded from Internet – together provide you with a tool to personally verify the predicted residual pitch and beat phenomena described in Chapter 3 of this booklet.

You are invited to download the software via one of the following websites:

http://www.een-andere-kijk-op-horen.nl/

or

http://www.a3ccm-apmas-eakoh.be/

This software program forms the experimental basis of the above-mentioned chapter and enables you to verify the beat and residue experiments that were explained in Chapter 3.

For each experiment described in these paragraphs: simply fill in the corresponding frequencies within the program, start the calculation. You will subsequently be able to listen to the sound fragment. The sound fragments can be heard via standard audio software programs like Windows Media Player or iTunes.

This program can easily be installed on systems running under Windows XP or Vista.

A I.2 How to use the software program after the installation

After downloading and installing this program – in a separate directory – proceed with the following 8 steps:

1. Open the directory of the program and click on the executable file named **Perception_Calculations.application**, the program fill-in screen pops up. [See for the screen display also Fig. A.1]

2. Select the duration of the sound complex to be heard in the first line. Steps of **5** seconds from **05** / **10** [default] / **15** / **20** / **25** / **30 seconds**. [However we advise you to use 20 seconds in experiments where you have to count the number of beats in that period]

3. Fill in the frequency components in the boxes indicated as **f0**; **f1**; **f2**; etc… [Boxes not in use remain empty. Maximum number of frequencies 10]

4. Select the amplitude criterion for each frequency by switching ↕ . [**1/f amplitude** [default] for equal energy contribution or **amplitude 1** for equal sound pressure contribution]

5. Fill in per frequency the extra multiplication factor to be used for the amplitude in the left box column. [**Extra multiply Amplitude 1** [default] or **>1**]

6. Select sine or cosine function for each frequency by switching ↕ . [**sin**[default] or **cos**]

7. Select the desired phase for each frequency by switching ↕ . [**0 degree** [default], otherwise between **0°** and **360°**]

8. Select how you want to hear the composed sound-complex or to store the wavelet on your PC with the buttons as shown below:

     For standard built-in sound machine under Windows XP click on:

     Build wave and Play. ! XP Only ! (Play within this form).

     For sound machine installed on your PC click on:

     Build wave and Play. (Play: System.Diagnostics.Process).

     For storing a wavelet on your PC click on:

     Write wave as ...

     and follow further instructions.

Remark

Which character to use in this program for the decimal mark depends on your computer system.
If your system has installed a dot decimal mark notation apply a dot.
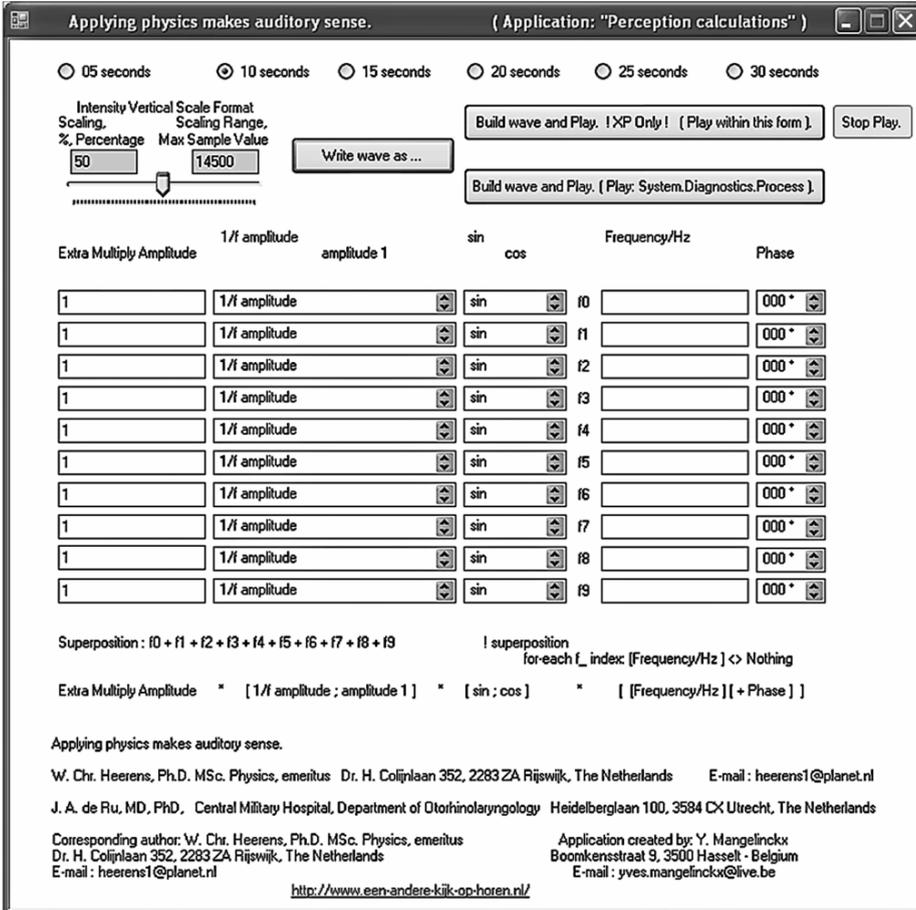*If your system has installed a comma decimal mark notation apply a comma instead of a dot.*

Fig. A.1. Lay-out of pop-up fill-in screen

A I.3 Possible calculations this program allows you to make

Of course, you can vary all the frequencies in the given examples to convince your-self that the choice of frequency combinations actually isn't that important as long as the differences between successive frequencies are equal. Because the pitch that you hear is built up from the combined difference frequencies.

You must also be sure to insert the appropriate change of the original value when a frequency disturbance of a few Hz from that equidistance is needed for the beat experiment.

Inserting a series of 5 frequencies f_0, f_1, f_2, f_3, f_4, in the computation display, while all other settings remain at default, will lead to the calculation of the sound fragment S built up by a Fourier series as function of time:

$$S = \frac{A}{f_0}\sin(2\pi f_0 t) + \frac{A}{f_1}\sin(2\pi f_1 t) + \frac{A}{f_2}\sin(2\pi f_2 t) + \frac{A}{f_3}\sin(2\pi f_3 t) + \frac{A}{f_4}\sin(2\pi f_4 t)$$

A I.4 The successive experiments

For your convenience, the following experiments have all been numbered and named according to their previous descriptions (experiments) in Chapter 3.

3.2. Pitch perception in incomplete harmonic sound complexes

Experiment 3.2.0

When you fill in the frequencies:

   $f_0 = 200$ Hz; $f_1 = 400$ Hz; $f_2 = 700$ Hz and $f_3 = 900$ Hz

you hear a harmonic tone.

Experiment 3.2.1

To the frequencies in Experiment 3.2.0 you can add the extra tone:

   $f_4 = 99$ Hz or $f_4 = 101$ Hz with Extra Multiply Amplitude 2

   [which is the test signal for pitch determination]

and you will hear a beat of 2 Hz.

   [Counting 20 dips during a 10 second sound fragment means 20:10 = 2 Hz beat]

3.3. Residual pitch perception in enharmonic tone series

Experiment 3.3.0

When you fill in the frequencies:

   $f_0 = 1400$ Hz; $f_1 = 1600$ Hz; $f_2 = 1800$ Hz

you will hear a harmonic tone.

Experiment 3.3.1

When you modify the center frequency:

$f_1 = 1600$ Hz into $f_1 = 1600.5$ Hz

the triplet becomes:

$f_0 = 1400$ Hz; $f_1 = 1600.5$ Hz; $f_2 = 1800$ Hz

you will hear the same harmonic tone as in Experiment 3.3.0, but with a 1 Hz beat.

[Counting 10 dips during a 10 second sound fragment means 10:10 = 1 Hz beat]

Experiment 3.3.2

When you modify the center frequency:

$f_1 = 1600$ Hz into $f_1 = 1599.5$ Hz

the triplet becomes:

$f_0 = 1400$ Hz; $f_1 = 1599.5$ Hz; $f_2 = 1800$ Hz

you will hear the same harmonic tone as in Experiment 3.3.0, again with a 1 Hz beat.

[Counting 10 dips during a 10 second sound fragment means 10:10 = 1 Hz beat]

3.4. Addition of harmonics and their influence on beat phenomena

Experiment 3.4.0

To the triplet in Experiment 3.3.2 you can add another contribution of two frequencies:

$f_3 = 1200$ Hz and $f_4 = 2000$ Hz

to create the 5-tone complex:

$f_0 = 1400$ Hz; $f_1 = 1599.5$ Hz; $f_2 = 1800$ Hz; $f_3 = 1200$ Hz; $f_4 = 2000$ Hz

then you will hear a harmonic tone with a 0.5 Hz beat.

[Counting 5 dips during a 10 second sound fragment means 5:10 = 0.5 Hz beat]

Experiment 3.4.1

To the triplet in Experiment 3.3.2 you can add two other frequency contributions:

$f_3 = 1000$ Hz and $f_4 = 1200$ Hz instead of: $f_3 = 1200$ Hz and $f_4 = 2000$ Hz

and again you will hear a harmonic tone with a 0.5 Hz beat, however with another timbre.

Experiment 3.4.2

To the triplet in Experiment 3.3.2 you can add two other frequency contributions:

$f_3 = 2000$ Hz and $f_4 = 2200$ Hz instead of: $f_3 = 1000$ Hz and $f_4 = 1200$ Hz

and again you will hear a harmonic tone with a 0.5 Hz beat, however with yet another timbre.

Remark

In case you find it difficult to distinguish and count a 0.5 Hz beat frequency you can also use:

$f_1 = 1601$ Hz   *or* $f_1 = 1599$ Hz

all beat phenomena will then be doubled in frequency.
The beat in the triplets will be heard as 2 Hz, while this 2 Hz beat will change into 1 Hz in the 5- tone complexes.

3.5. Modifying a beat frequency by adding a low frequency stimulus

Experiment 3.5.1

When you fill in the triplet:

$f_0 = 1400$ Hz; $f_1 = 1601$ Hz; $f_2 = 1800$ Hz

you will hear a harmonic tone complex with a beat of 2 Hz.

Experiment 3.5.2

To the triplet in Experiment 3.5.1 you can add the test signal:

$f_3 = 100$ Hz with Extra Multiply Amplitude 2

[which is the test signal for pitch determination]

you will hear the former harmonic tone complex – with a beat of 2 Hz – change into a harmonic tone complex with a much lower timbre and with a 1 Hz beat.

Experiment 3.5.3

To the triplet in Experiment 3.5.1 you can add the test signal:

$f_3 = 200$ Hz with Extra Multiply Amplitude $\geq \sqrt{2} = 1.4142$

and you will hear the former harmonic tone complex change in timbre, however the beat of 2 Hz doesn't change.

3.7.   Is pitch shift in an enharmonic tone complex with equidistant frequencies an illusion?

Experiment 3.7.0

When you fill in the frequencies of the 7-tone complex:

$f_0 = 1400$ Hz; $f_1 = 1600$ Hz; $f_2 = 1800$ Hz; $f_3 = 2000$ Hz; $f_4 = 2200$ Hz;

$f_5 = 2400$ Hz and $f_6 = 2600$ Hz

you hear a harmonic tone.

Experiment 3.7.1

To the 7-tone complex in Experiment 3.7.0 you can add the twin-tone contribution:

$f_7 = 201$ Hz; $f_8 = 402$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

to create the 9-tone complex:

$f_0 = 1400$ Hz; $f_1 = 1600$ Hz; $f_2 = 1800$ Hz; $f_3 = 2000$ Hz; $f_4 = 2200$ Hz;

$f_5 = 2400$ Hz; $f_6 = 2600$ Hz; $f_7 = 201$ Hz and $f_8 = 402$ Hz

and then you will hear a harmonic tone with a lower timbre than in Experiment 3.7.0 and a 1 Hz beat.

Experiment 3.7.2

To the 7-tone complex in Experiment 3.7.0 you can add the twin-tone contribution:

$f_7 = 199$ Hz; $f_8 = 398$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

and then you will hear an almost identical harmonic tone as in Experiment 3.7.1, again with a 1 Hz beat.

Experiment 3.7.3

When you fill in the frequencies:

$f_0 = 1430$ Hz; $f_1 = 1630$ Hz; $f_2 = 1830$ Hz; $f_3 = 2030$ Hz; $f_4 = 2230$ Hz;

$f_5 = 2430$ Hz and $f_6 = 2630$ Hz

you will hear an enharmonic tone.

Remark

Listeners who are trained in music are able to distinguish the pitch and its shift upward, as reported by De Boer and others.
In our experience the sound is rather harsh.

Experiment 3.7.4

In his thesis [A I 1] De Boer has explained that the pitch of Experiment 3.7.3 can best be compared to the pitch of the harmonic tone complex for which you can fill in:

$f_0 = 1421$ Hz; $f_1 = 1624$ Hz; $f_2 = 1827$ Hz; $f_3 = 2030$ Hz; $f_4 = 2233$ Hz;

$f_5 = 2436$ Hz and $f_6 = 2639$ Hz

and then you will hear a harmonic tone.

Remark

Here – according to previous results – the pitch is equal to 203 Hz, the first harmonic of this series.

Experiment 3.7.5

To the 7-tone complex in Experiment 3.7.4 you can add the twin-tone contribution:

$f_7 = 203$ Hz; $f_8 = 406$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

to create the 9-tone complex:

$f_0 = 1421$ Hz; $f_1 = 1624$ Hz; $f_2 = 1827$ Hz; $f_3 = 2030$ Hz; $f_4 = 2233$ Hz;

$f_5 = 2436$ Hz; $f_6 = 2639$ Hz; $f_7 = 203$ Hz and $f_8 = 406$ Hz

and you will hear a harmonic tone with a lower timbre than in Experiment 3.7.4, without a beat.

Remark

Therefore, we will attempt to search for this pitch in the enharmonic 7-tone complex of Experiment 3.7.3, by means of the pitch tracing mechanism. This mechanism consists of the addition of several different twin-tones to this tone complex, and to observe the changes in evoked beats.

In Experiment 3.7.6 we will start with the twin-tone of 203 Hz and 406 Hz because we can expect the pitch of 203 Hz De Boer has predicted.

And if he is correct you will not hear a beat with this twin-tone test.

Experiment 3.7.6

To the 7-tone complex in Experiment 3.7.3 you can add the twin-tone contribution:

$f_7 = 203$ Hz; $f_8 = 406$ Hz; with an Extra Multiply Amplitude of $\sqrt{6} = 2.449$

to create the 9-tone complex:

$f_0 = 1430$ Hz; $f_1 = 1630$ Hz; $f_2 = 1830$ Hz; $f_3 = 2030$ Hz; $f_4 = 2230$ Hz;

$f_5 = 2430$ Hz; $f_6 = 2630$ Hz.; $f_7 = 203$ Hz and $f_8 = 406$ Hz

and then you will hear an enharmonic tone with a lower timbre than in Experiment 3.7.3. However, instead of hearing an extra intensity to the pitch as is expected, you will clearly hear a 3 Hz beat.

Experiment 3.7.7

When you replace the added twin-tone in Experiment 3.7.6 by the twin-tone:

$f_7 = 202$ Hz; $f_8 = 404$ Hz

you will hear the same timbre as in Experiment 3.7.6, but with a beat of 2 Hz.

Experiment 3.7.8

When you replace the formerly added twin-tone by: $f_7 = 201$ Hz; $f_8 = 402$ Hz
you will hear a beat of 1 Hz.

Experiment 3.7.9

When you replace the formerly added twin-tone by: $f_7 = 200$ Hz; $f_8 = 400$ Hz
the beat disappears completely.

Experiment 3.7.10

When you replace the formerly added twin-tone by: $f_7 = 199$ Hz; $f_8 = 398$ Hz
the beat you will hear returns to 1 Hz.

Remark

> *As no examiner can find any trace of a shift in pitch in these beat experiments, the only possible conclusion is that the pitch shift, which is observed and reported by trained listeners in music perception, actually is an illusion.*

> *The actual pitch remains unchanged at 200 Hz, which is the smallest difference frequency in the enharmonic tone series.*

3.8. Infrasound can also be heard according to the squaring principle

Experiment 3.8.0

When you fill in the twin-tone frequencies:

$f_0 = 600$ Hz and $f_1 = 610$ Hz

you presume to hear a tone of 605 Hz with a vibrato of 10 Hz.

Remark

This is commonly explained as the beat effect of the combination of the two near-by frequencies. However that is not how it works, as can be seen in the following series of experiments.

Experiment 3.8.1

When you fill in the triplet frequencies:

$f_0 = 600$ Hz; $f_1 = 610$ Hz and $f_2 = 620$ Hz

you will hear a tone of 610 Hz with a beat in the form of a vibrato of 10 Hz.

Experiments 3.8.2 – 3.8.3

When you change the $f_1 = 610$ Hz in either 609 Hz or 611 Hz you create the triplet:

$f_0 = 600$ Hz; $f_1 = 609$ Hz (or $f_1 = 611$ Hz) and $f_2 = 620$ Hz

you will hear a tone of 610 Hz with a 10 Hz vibrato, and an extra beat of 2 Hz.

Experiments 3.8.4 – 3.8.5 – 3.8.6

When you add one of the following combinations to the triplet in Experiment 3.8.2 or 3.8.3:

$f_3 = 580$ Hz and $f_4 = 590$ Hz

or: $f_3 = 590$ Hz and $f_4 = 630$ Hz

or: $f_3 = 630$ Hz and $f_4 = 640$ Hz

you will hear that the extra 2 Hz beat is changed into a 1 Hz beat.

Remark

You also have to consider that the only frequency that can be modulated is the 10 Hz pitch.

Experiment 3.8.7

To the triplet in Experiment 3.8.2 or 3.8.3 you can add another triplet:

$f_3 = 700$ Hz; $f_4 = 710$ Hz and $f_5 = 720$ Hz

then you will hear that, apart from a change in timbre, the extra 2 Hz beat is changed into a 1 Hz beat.

Remark

The combination of the four difference frequency contributions of 9; 2 times 10 and 11 Hz results in a signal of 10 Hz with a beat of 1 Hz. . Halved compared to the beat in Experiment 3.8.2 or 3.8.3.

Experiment 3.8.8

In the added triplet in Experiment 3.8.7 you can change the frequency $f_4 = 710$ Hz into $f_4 = 711$ Hz and this triplet becomes:

$f_3 = 700$ Hz; $f_4 = 711$ Hz and $f_5 = 720$ Hz

and you will hear that the extra 1 Hz beat again changes into a 2 Hz beat.

Experiment 3.8.9

When you change the phase of the f_4 into 180° in Experiment 3.8.8 you will hear that the 10 Hz beat disappears almost completely.

Instead of that you hear a not modulated 20 Hz vibrato.

Remark

This occurs because the two difference frequencies of 9 Hz and 11 Hz (evoked out of the 600 + 609 (or 611) + 620 Hz triplet) and the same two difference frequencies of 9 Hz and 11 Hz (evoked out of the 700 + 709 (or 711) + 720 Hz triplet) are – pair by pair – practically equal in amplitude and have an opposite phase. Therefore they cancel each other's contributions almost completely.

What remains is the combination of two contributions of the difference frequency of 20 Hz as a result from the combinations 620 – 600 and 720 – 700 Hz, heard as a 20 Hz vibrato.

References

A I 1.   De Boer E. (1956) On the "residue" in hearing. Thesis; University of Amsterdam.