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Computer Aided Design and Analysis of the *Razorblade™ Quadratic Diffuser*

(Internet version)

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Introduction

BC acoustics Consulting has been retained by Primacoustic Studio Design, a division of Radial Engineering Ltd., to conduct a computer analysis of the acoustical behavior of the Razorblade™ quadratic diffuser (fig.1).

The goal was to demonstrate, by using the latest in acoustical engineering technology, the effectiveness of the Razorblade quadratic diffuser.

Mr. Hamid Bouhioui, who holds a Masters and a Ph.D. in Acoustical Engineering, with over 10 years experience in computer modeling was in charge of this project.

Sound Diffusion and Diffusers

Sound in an enclosure can be described as a diffused if the intensity of the sound energy is equal in every location of the room, or the sound energy flows equally in every direction.

Many different factors can enhance the diffused sound. These include geometrical irregularities, absence of focusing surfaces, the distribution of absorptive and reflective elements randomly scattered through the space, and the existence of diffusing objects (furniture) or panels (diffusers).

Today, more effective diffusion can be achieved using professionally designed diffusers such as the Razorblade™ Quadratic Diffuser.

The Razorblade™ quadratic diffuser

The Primacoustic Razorblade is a quadratic diffuser that measures 24" wide and is 48" tall and is made entirely of MDF as this type of wood is both extremely rigid and very heavy which makes its resonance appear at very high frequencies (no resonance at the frequency range of interest).

The Razorblade features 16 wells in a semi-random pattern with depths to 8" (fig.2). This combination has been tested to be effective from about 400Hz to well over 10kHz where a fully diffuse field is created. In this report, we show how this diffuser actually starts to diffuse sound from 400Hz and up.

Figure 1. Razorblade™ quadratic diffuser

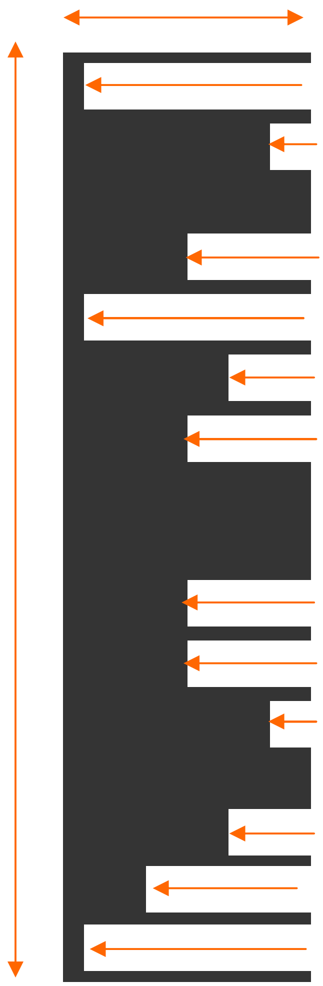


Figure 2. Two-Dimensional section of the Razorblade™ quadratic diffuser
(Depth of wells not available in this Internet version)

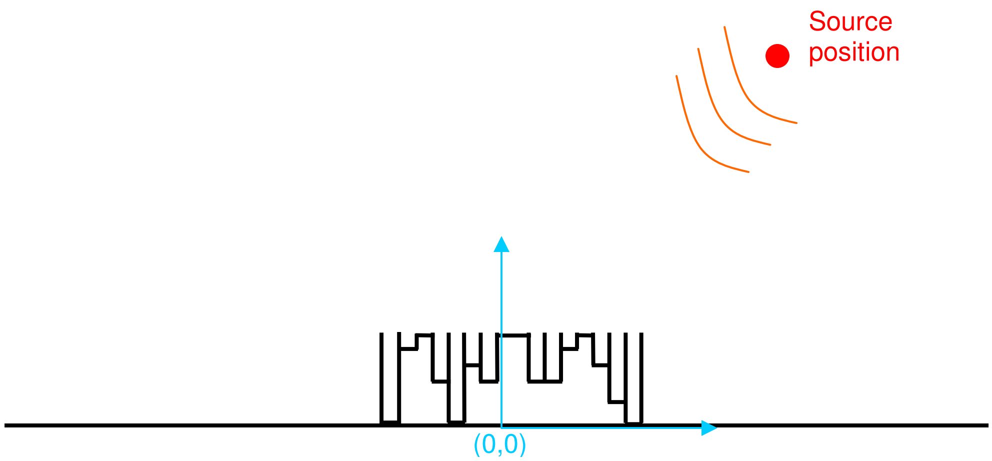


Figure 3. Two-Dimensional section of the diffuser and sound source

The computer model

A Finite-Element-Method (FEM) simulation has been performed in order to compare results with the previous analytical model. The FEM is one of the most efficient computer modeling techniques known today. It allows for accurate solution of complex problems with complex geometry.

The Razorblade™ quadratic diffuser is rigid, which means that there will be no resonance at the frequency range we are interested in (200Hz-2000Hz). This allows us not to worry about the structural vibrations (diffuser's resonance). We only need to model the air around the diffuser and analyze the generated pressure field at various frequencies.

The Razorblade diffuses sound in the horizontal direction. This direction is the significant one as the sound propagates horizontally in the studio. In order to show how the diffuser acts, we only need to model a horizontal section of the diffuser and surrounding air.

The FEM model consists of dividing the air around the diffuser into elements quadrangles or triangles (This is referred to as 'meshing' a domain or geometry). We chose quadrangles because they are more suited for the geometry of the Razorblade™ quadratic diffuser (we could have used triangles if the geometry were more arbitrary).

The properties of air (density and speed of sound in air) and the global geometry are input in the computer software. The software runs and calculates the pressure levels at any given frequency.

The size of the elements (quadrangles here) is determined by the highest frequency at which we need to predict the pressure level. In order to have a good accuracy, the largest side of each element (let's call it L) must be smaller than or equal to the quarter of the wavelength (usually denoted λ):

$$L \leq \lambda / 4$$

The wavelength λ is determined for each frequency (usually denoted f) as follows:

$$\lambda = c / f$$

Where c is the speed of sound.

Results and analysis

The computer model used here allows for prediction of pressure levels at any frequency. One must make sure that the mesh is satisfactory for the chosen frequency ($L \leq \lambda / 4$).

In this study, we have decided to predict the pressure level generated by the diffuser every 100Hz between 200Hz and 2kHz. This choice is satisfactory for the purpose of this study, i.e. to demonstrate the effectiveness of the Razorblade quadratic diffuser.

If further analysis were needed around 400Hz, then a smaller frequency step would be used around this frequency. For example, we would predict the sound levels every 5Hz or 10Hz around 400Hz, i.e. if the step is 10 Hz, calculation would be performed at 350Hz, 360Hz, 370Hz, … 400Hz, 410Hz, 420Hz, …450Hz. This level of accuracy is not necessary for the present study.

A sound source has been placed 3 meters away from the diffuser (see figure 3). The sound source generates spherical waves that are directed towards the diffuser. There is a rigid wall behind the diffuser. If there were no diffuser, the sound waves would be reflected by the wall in an unaltered shape (spherical). The results show that the Razorblade starts to diffuse sound around 400Hz. As the frequency increases, the Razorblade keeps diffusing sound at various frequencies. The diffusion continues for, virtually, all higher frequencies.

The graphics and analysis below show what happens at every 100Hz between 200Hz and 2kHz. One may need to know some of the formulae used in this analysis:

Sound speed:

Referred to as ‘c’ and is equal to 340 meters/second (m/s) in normal conditions.

Wavelength:

Referred to as ‘λ’ and is equal to c / f (unit: meters) where f is the frequency.

Sound pressure level:

A bar on the right of each graphic shows the maximum (red) and minimum pressure (blue). This pressure is expressed in Newton per squared-meter (N/m^2). The maximum (or minimum) pressure level in decibels (dB) can be calculated using the following formula:

$$PL \text{ (in dB)} = 20 \cdot \log (P / P_{ref})$$

Where: PL is the pressure-level in dB; P is the pressure in N/m^2 And P_{ref} the reference, i.e. $P_{ref} = 2.10^{-5}\ N/m^2$.

Graphic#1, Frequency=200Hz:

Frequency f = 200 Hz
Wavelength $\lambda = c / f = 340/200 = 1.7$ m

At this frequency, the graphic#1 shows that the incident wave is reflected without alteration. This means that the diffuser has no effect at this frequency. This result confirms the well-known formula used for closed-end pipes (see appendix). According to this theory, the diffuser will start to diffuse when the quarter of the wavelength ($\lambda /4$) is equal to or smaller than its deepest well (remember, that the well will only diffuse the sound for odd multiples of $\lambda /4$).

For the frequency 200Hz, $\lambda /4 = 0.425$m = 42.5cm, which is still larger than the depth of all wells (including the deepest one). That's why diffusion has not started yet.

Graphic#2, Frequency=300Hz:

Frequency f = 300 Hz
Wavelength $\lambda = c / f = 1.13$ m

At this frequency, the graphic#2 shows that the incident wave is reflected without alteration. This means that the diffuser has no effect at this frequency.

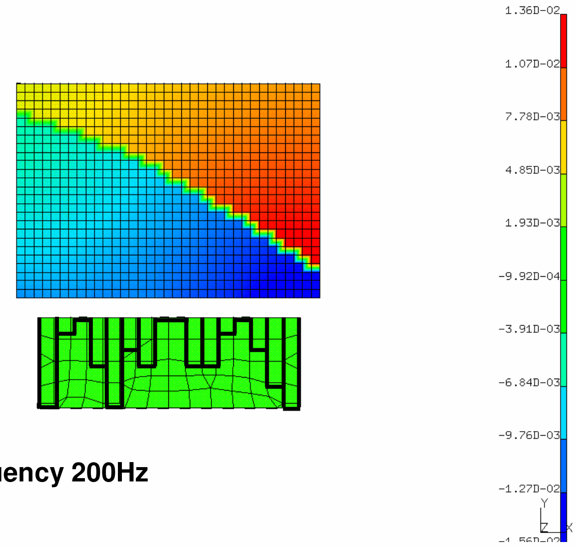
For the frequency 300Hz, $\lambda /4 = 0.283$m = 28.3cm, which is still larger than the depth of all wells (including the deepest one). That's why diffusion has not started yet.

Graphic#3, Frequency=400Hz:

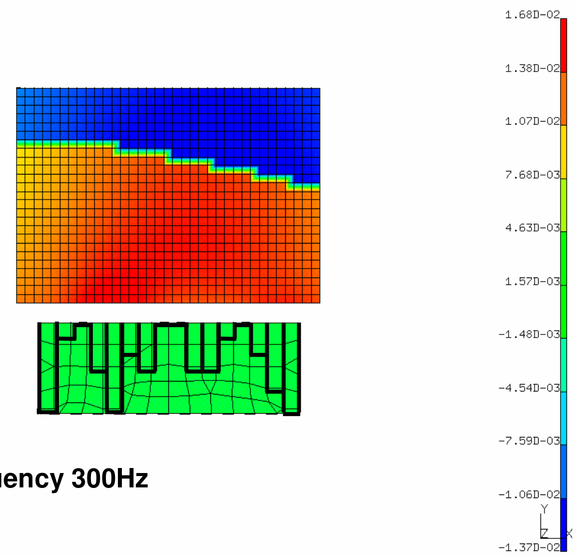
Frequency f = 400 Hz
Wavelength $\lambda = c / f = 340/400 = 0.85$ m

At this frequency, the graphic#3 shows two spots, one high-pressure (red) and one low-pressure (blue) where the diffuser *disturbs* the incident wave. This means that the diffuser starts to diffuse the acoustic field. Note that the two spots are located in front of two of the three deepest wells.

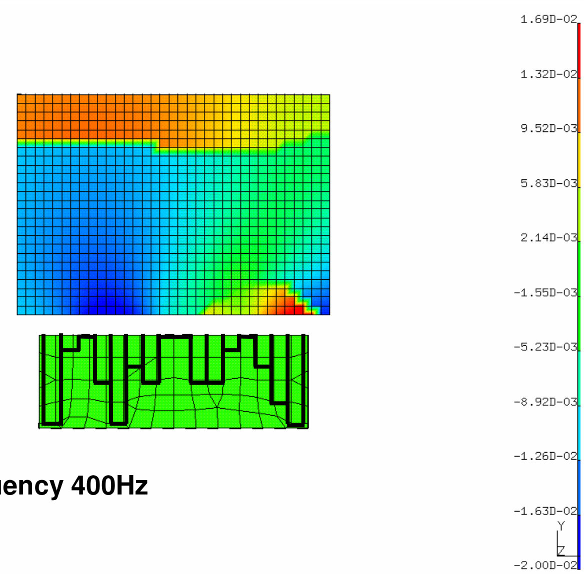
For the frequency 400Hz, $\lambda /4 = 0.212m = 21.2cm$, which is close to the depth of the deepest well. That explains why the diffuser starts to diffuse the incident sound.



Graphic#1: Frequency 200Hz



Graphic#2: Frequency 300Hz



Graphic#3: Frequency 400Hz

Graphic#4, Frequency=500Hz:

Frequency f = 500 Hz
Wavelength λ = c / f = 340/500 = 0.68 m

At this frequency, the graphic#4 shows that the acoustic field around the diffuser is partially diffused. One can still see a wave-pattern on the lower-right side of the graphic.

For the frequency 500Hz, λ /4 = 17cm. There is a spot in front of the well with a depth of …cm (…'') which shows that this well starts to diffuse the field because its depth is close to λ /4. The next odd harmonic, 3λ /4 = 51cm is still too large compared to any of the wells' depth.

If we manually measure the ½-wavelength on the graphic#4, we'll find out that it is approximately equal to 35cm, which as expected corresponds to λ=68cm=0.68m (λ/2=34cm).

Graphic#5, Frequency=600Hz:

Frequency f = 600 Hz
Wavelength λ = c / f = 340/600 = 0.57 m

At this frequency, the graphic#5 shows that the acoustic field around the diffuser is almost unperturbed. One can still see a wave-pattern, as if the incident sound wave was simply reflected by the wall behind the diffuser.

For the frequency 600Hz, λ /4 = 14cm which does not correspond to any of the wells' depth. 3λ /4 = 42cm is too large compared to any of the wells' depth.

If we manually measure the ½-wavelength on the graphic#5, we'll find out that it is approximately equal to 27.7cm, which as expected, is close enough to the unaltered wavelength λ=57cm=0.57m (λ/2=27.5cm).

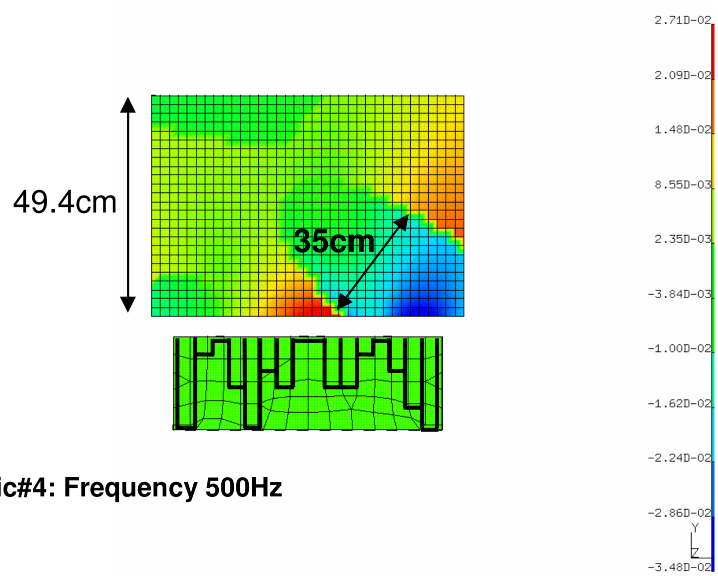
Graphic#6, Frequency=700Hz:

Frequency f = 700 Hz
Wavelength λ = c / f = 340/700 = 0.486 m

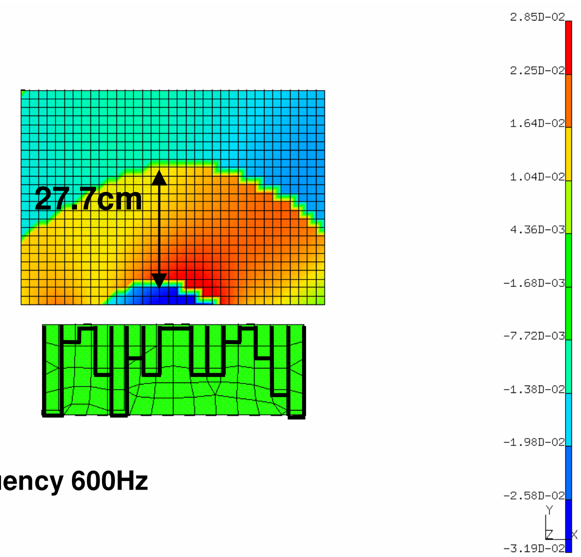
For the frequency 700Hz, λ /4 = 12.15cm. At this frequency, the graphic#6 shows that the acoustic field around the diffuser is partially diffused. This diffusion is here, due to 3 wells with depth close to ¼-wavelength, i.e. … cm (…''). One can still see a wave-pattern outside of the lower-right side of the graphic.

$3\lambda/4$ = 36.45cm is still too large compared to any of the wells' depth.

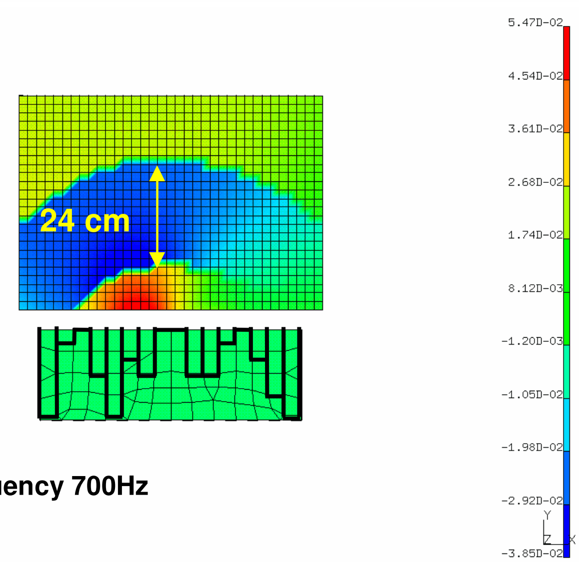
If we manually measure the ½-wavelength on the graphic#6, we'll find out that it is approximately equal to 24cm, which as expected corresponds to the unaltered wavelength λ=48.6cm=0.48m ($\lambda/2$=24.3cm).



Graphic#4: Frequency 500Hz



Graphic#5: Frequency 600Hz



Graphic#6: Frequency 700Hz

Graphic#7, Frequency=800Hz:

Frequency f = 800 Hz
Wavelength λ = c / f = 340/800 = 0.425 m
½ Wavelength λ/2 = 0.212 m
¼ Wavelength λ/4 = 0.106 m = 10.6 cm
¾ Wavelength 3λ/4 = 32 cm too large compared to any of the wells' depth.

If we manually measure the ½-wavelength on the graphic#7, we'll find out that it is approximately equal to 19.8cm, which as expected, is close enough to the unaltered wavelength λ=42.5cm.

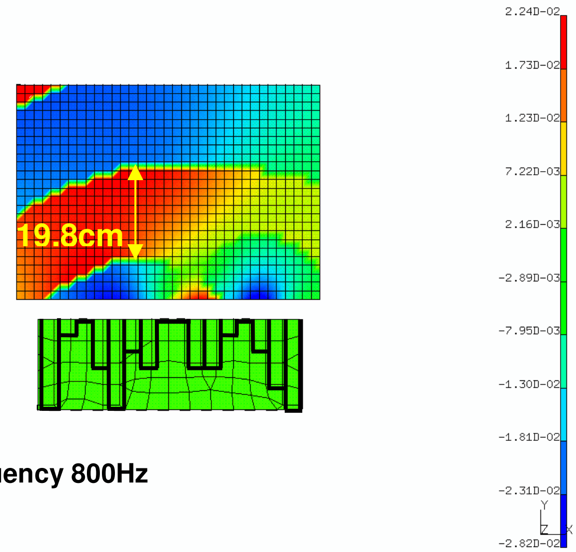
There are 3 main diffusion spots on the graphic. Note that, 2 of them (blue) are in front of the …cm-depth well (close to λ/4=10.6cm) and one (red) in front of the …cm-depth well (…'').

Graphic#8, Frequency=900Hz:

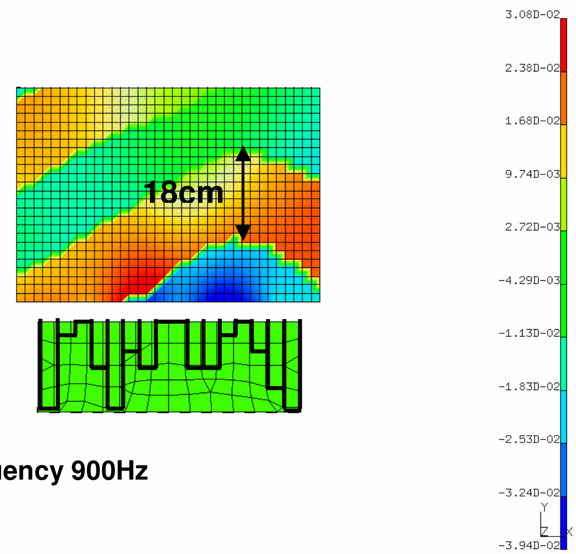
Frequency f = 900 Hz
Wavelength λ = c / f = 340/900 = 0.378 m
½ Wavelength λ/2 = 0.189 m
¼ Wavelength λ/4 = 0.094 m = 9.44 cm
¾ Wavelength 3λ/4 = 28.3 cm too large compared to any of the wells' depth.
The acoustic field is slightly diffused, mainly due to the …cm-depth wells.
The measured ½ wavelength is 18cm (see graphic#8).

Graphic#9, Frequency=1000Hz:

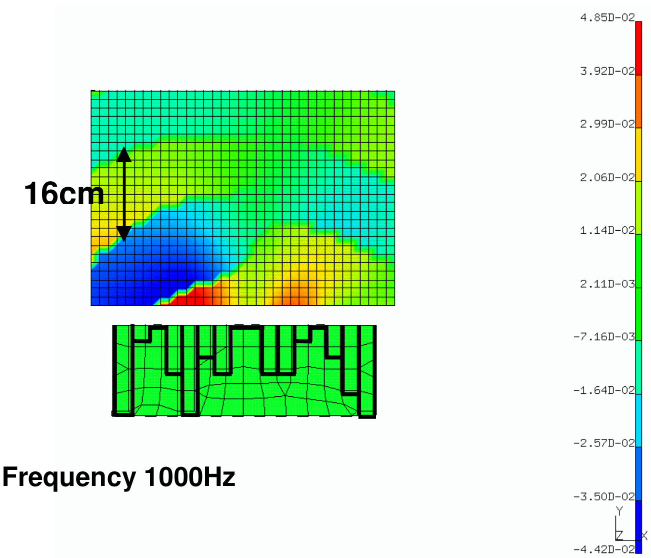
Frequency f = 1000 Hz
Wavelength λ = c / f = 340/1000 = 0.340m
½ Wavelength λ/2 = 0.17 m
¼ Wavelength λ/4 = 0.085 m = 8.5 cm
¾ Wavelength 3λ/4 = 25.5 cm too large compared to any of the wells' depth.
The acoustic field is diffused due to the …cm-depth (…'') wells and …cm-depth (…'').
Note that the difference between the high-pressure level (67.7dB) and low-pressure level (67.0dB) is small (1%), which means that the field is very well diffused.
The measured ½ wavelength is 16cm (see graphic#9), which is close to the unaltered ½ wavelength, 17cm.



Graphic#7: Frequency 800Hz



Graphic#8: Frequency 900Hz



Graphic#9: Frequency 1000Hz

Graphic#10, Frequency=1100Hz:

Frequency f = 1100Hz
Wavelength λ = c / f = 340/1100 = 0.31 m
½ Wavelength λ/2 = 0.155 m
¼ Wavelength λ/4 = 0.077 m = 7.7 cm
¾ Wavelength 3λ/4 = 23.2 cm too large compared to any of the wells' depth.

The acoustic field is diffused, mainly due to the …cm-depth well on the right hand side. The one on the left hand side coincides with a nodal line – a line where the pressure is zero (right between high and low pressure)
The measured ½ wavelength is …cm (see graphic#10), which is close to the unaltered ½ wavelength, i.e. … cm.

Graphic#11, Frequency=1200Hz:

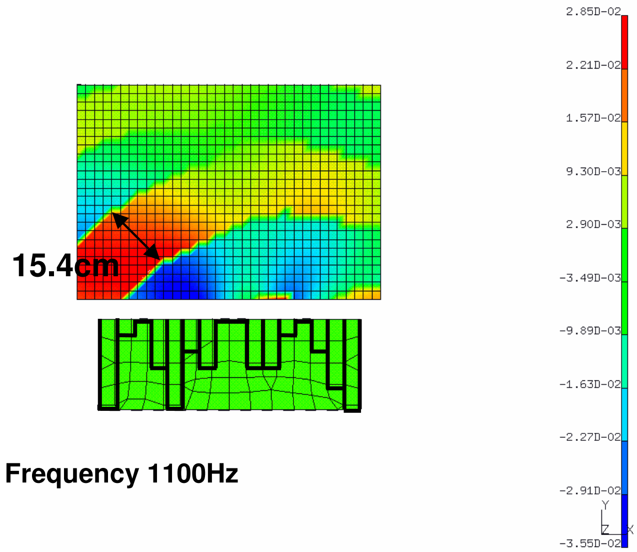
Frequency f = 1200Hz
Wavelength λ = c / f = 340/1200 = 0.283 m
½ Wavelength λ/2 = 0.14m
¼ Wavelength λ/4 = 0.07 m = 7 cm
¾ Wavelength 3λ/4 = 21 cm.

The acoustic field is diffused almost everywhere around the diffuser, due to the 6.97cm-depth wells (the well on the left hand side close but does not coincide with the nodal line) and also the …cm wells which depth is close to 3λ/4=21cm.
The measured ½ wavelength is 14cm (see graphic#11), which corresponds to the unaltered ½ wavelength, i.e. 14 cm.

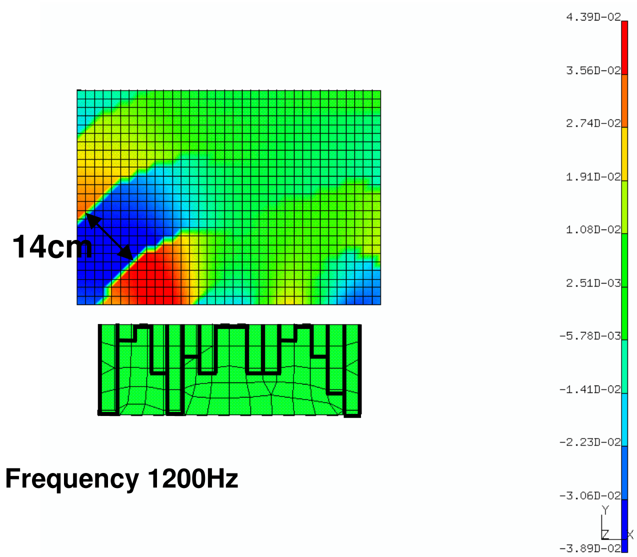
Graphic#12, Frequency=1300Hz:

Frequency f = 1300Hz
Wavelength λ = c / f = 340/1300 = 0.26 m
½ Wavelength λ/2 = 0.13m
¼ Wavelength λ/4 = 0.065 m = 6.5 cm
¾ Wavelength 3λ/4 = 19.6 cm.

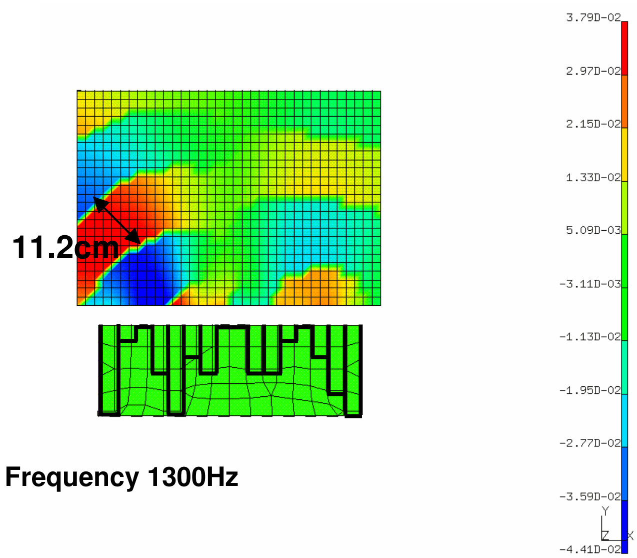
The acoustic field is diffused almost everywhere around the diffuser, due to the …cm-depth wells (the well on the left hand side close but does not coincide with the nodal line) and also the …cm wells which depth is very close to 3λ/4=19.6 cm.
The measured ½ wavelength is 11.2cm (see graphic#12).



Graphic#10: Frequency 1100Hz



Graphic#11: Frequency 1200Hz



Graphic#12: Frequency 1300Hz

Graphic#13, Frequency=1400Hz:

Frequency f = 1400Hz
Wavelength λ = c / f = 340/1400 = 0.24 m
½ Wavelength λ/2 = 0.12 m
¼ Wavelength λ/4 = 0.06 m = 6 cm
¾ Wavelength 3λ/4 = 18 cm.

For this the acoustic field is well diffused, due to the …cm-depth wells and also the … cm wells which depth is close to 3λ/4=18 cm.
The measured ½ wavelength is 9.8 cm (see graphic#13).

Graphic#14, Frequency=1500Hz:

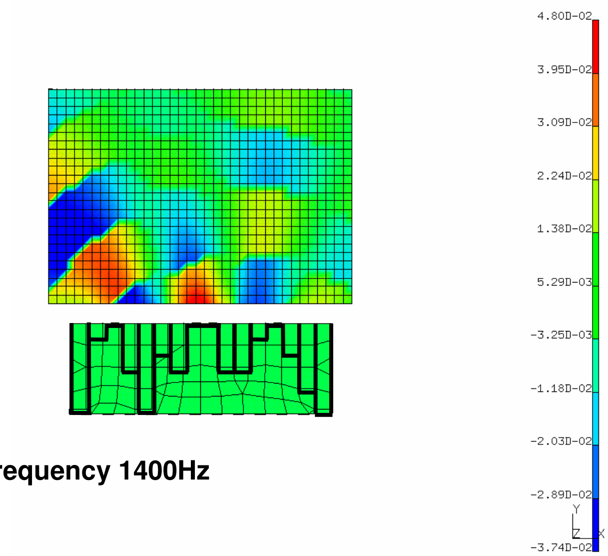
Frequency f = 1500Hz
Wavelength λ = c / f = 340/1500 = 0.227 m
½ Wavelength λ/2 = 0.113 m
¼ Wavelength λ/4 = 0.057 m = 5.7 cm
¾ Wavelength 3λ/4 = 17 cm.

At this frequency, the field is well diffused. It is the …cm-well that acts the most. Its depth equals 3λ/4 = 17 cm but the …cm-well also seems to have an effect on the incident field.

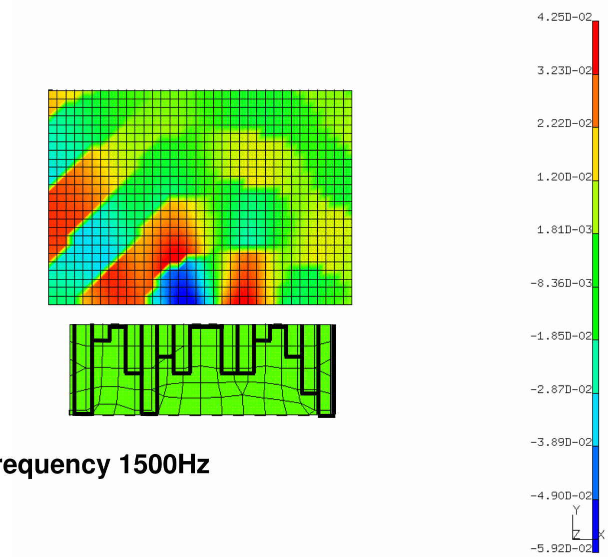
Graphic#15, Frequency=1600Hz:

Frequency f = 1600Hz
Wavelength λ = c / f = 340/1600 = 0.212 m
½ Wavelength λ/2 = 0.106 m
¼ Wavelength λ/4 = 0.053 m = 5.3 cm
¾ Wavelength 3λ/4 = 16 cm.
5/4 wavelength 3λ/4 = 26.6 cm is still large compared to any of the wells' depth.

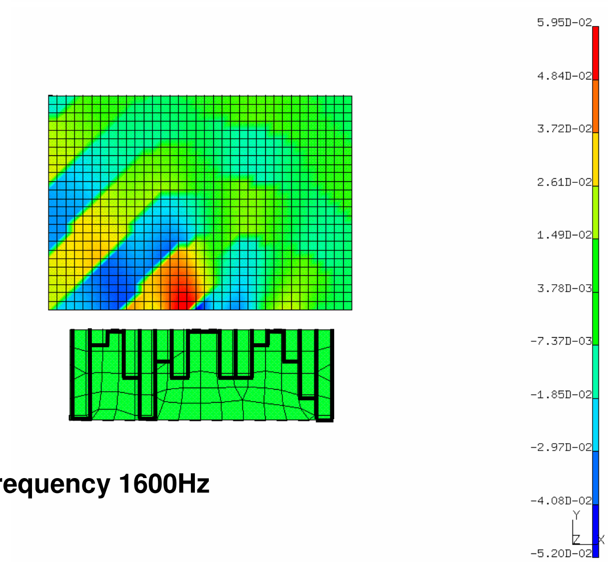
At this frequency, it is the …cm-well that acts the most. Its depth is close to 3λ/4 = 16 cm.



Graphic#13: Frequency 1400Hz



Graphic#14: Frequency 1500Hz



Graphic#15: Frequency 1600Hz

Graphic#16, Frequency=1700Hz:

Frequency f = 1700Hz
Wavelength λ = c / f = 340/1700 = 0.2 m
½ Wavelength λ/2 = 0.1 m
¼ Wavelength λ/4 = 0.05 m = 5 cm
¾ Wavelength 3λ/4 = 15 cm.
5/4 wavelength 3λ/4 = 25 cm is still large compared to any of the wells' depth.
Very well diffused field. Diffusion is mainly due to the …cm and …cm wells.

Graphic#17, Frequency=1800Hz:

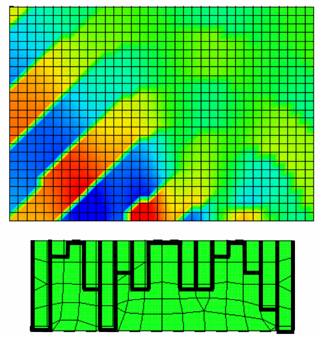
Frequency f = 1800Hz
Wavelength λ = c / f = 340/1800 = 0.189 m
½ Wavelength λ/2 = 0.094 m
¼ Wavelength λ/4 = 0.047 m = 5 cm
¾ Wavelength 3λ/4 = 14.1 cm.
5/4 wavelength 3λ/4 = 23.6 cm is still large compared to any of the wells' depth.
Very well diffused field. Diffusion is mainly due to the …cm wells.

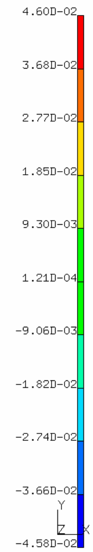
Graphic#18, Frequency=1900Hz:

Frequency f = 1900Hz
Wavelength λ = c / f = 340/1900 = 0.178 m
½ Wavelength λ/2 = 0.089 m
¼ Wavelength λ/4 = 0.0447 m = 4.47 cm
¾ Wavelength 3λ/4 = 13 cm.
5/4 wavelength 3λ/4 = 22 cm.
Very well diffused field. Several wells are responsible for diffusion at this frequency, i.e. the 3 …cm-wells and the 3 …cm-wells.

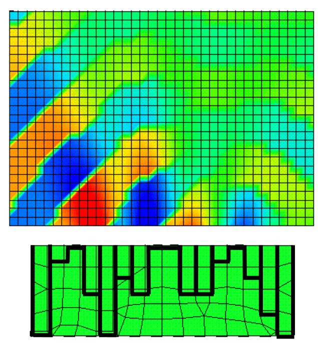
Graphic#19, Frequency=2000Hz:

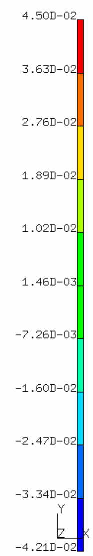
Frequency f = 2000Hz
Wavelength λ = c / f = 340/2000 = 0.17 m
½ Wavelength λ/2 = 0.085 m
¼ Wavelength λ/4 = 0.0425 m = 4.25 cm
¾ Wavelength 3λ/4 = 12.75 cm.
5/4 wavelength 3λ/4 = 21.25 cm.
Very well diffused field. Several wells are responsible for diffusion at this frequency, i.e. the 3 …cm-wells and the 3 …cm-wells. For frequencies higher than 1500Hz, the field is always well diffused.



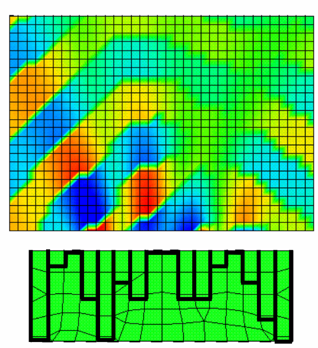


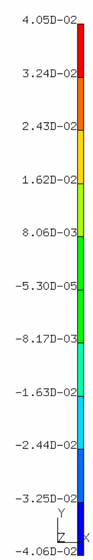
Graphic#16: Frequency 1700Hz



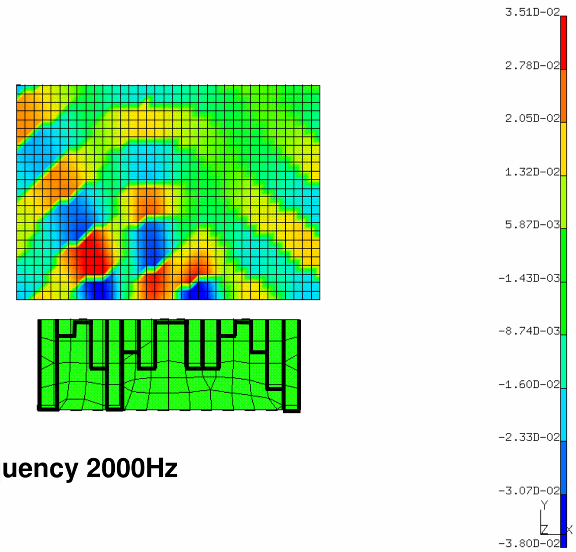


Graphic#17: Frequency 1800Hz





Graphic#18: Frequency 1900Hz



Graphic#19: Frequency 2000Hz

Conclusions

BC Acoustics Consulting, has performed a computer analysis of the acoustical behavior of the Razorblade™ Quadratic Diffuser commercialized by Primacoustic Studio Design.

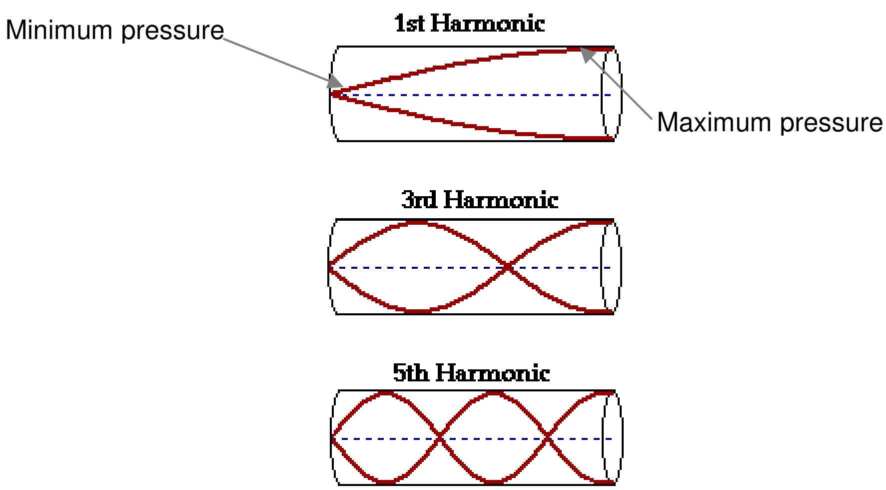
It has been shown that, as expected, this device actually diffuses sound waves for frequencies around 400Hz. This prediction model was a confirmation of the analytical prediction previously made for this diffuser.

Appendix: Closed-end pipes

For a two open ends pipe all harmonics exist. However, for a pipe with one end closed, only odd harmonics exist.

For a pipe with two open ends, the resonance frequencies correspond to n = 1 (fundamental), 2 (second harmonic), 3, etc
For a pipe with one closed end (like the 16 wells of the Razorblade), the resonance frequencies correspond to n = 1 (fundamental), 3 (third harmonic), 5, etc

There are no even harmonics in a closed-end pipe.



The relationships between the standing wave pattern for a given harmonic and the length-wavelength relationships for closed-end air columns are summarized in the table below.

Harmonic #	# of Waves in Column	# of Press. Nodes	# of Pressure Anti-nodes	Length-Wavelength Relationship
1	1/4	1	1	Wavelength = (4/1)*L
3	3/4	2	2	Wavelength = (4/3)*L
5	5/4	3	3	Wavelength = (4/5)*L