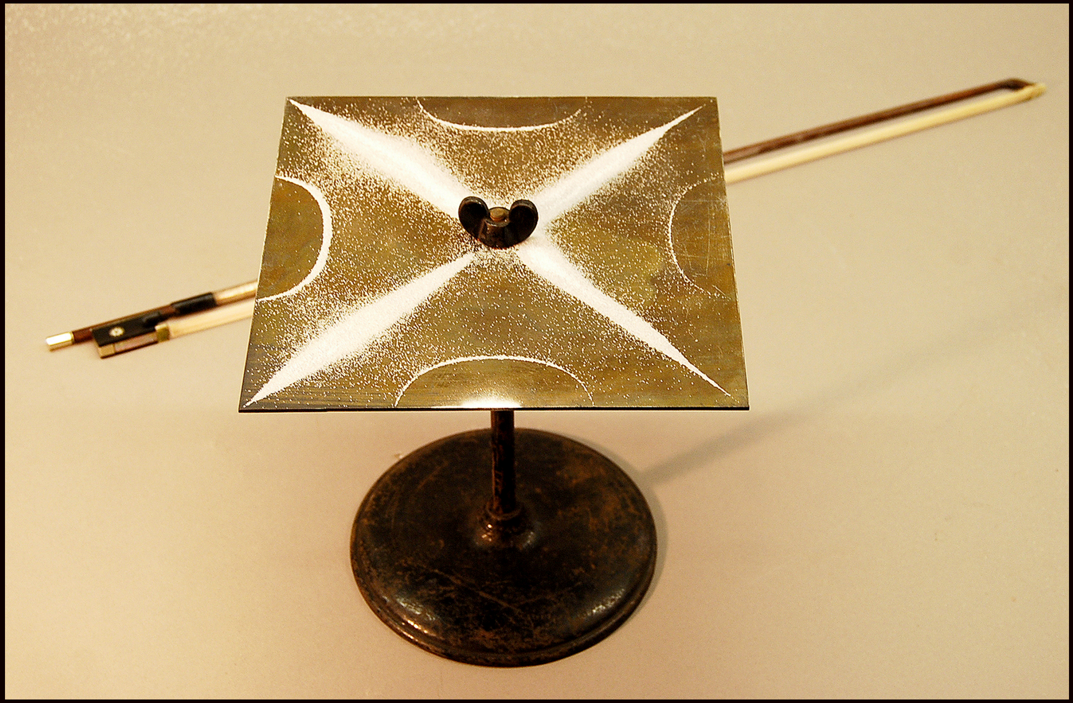
$(2,0)_a$ 484 Hz
$(2,0)_b$ 587 Hz
$(3,0)_a$ 1399 Hz
$(3,0)_b$ 1535 Hz
$(4,0)_a$ 2626 Hz
$(4,0)_b$ 2705 Hz
$(5,0)_a$ 4113 Hz
$(5,0)_b$ 4108 Hz
$(2,1)_a$ 1671 Hz
$(2,1)_b$ 1493 Hz
$(3,1)_a$ 1886 Hz
$(3,1)_b$ 1867 Hz
$(4,1)_a$ 2850 Hz
$(4,1)_b$ 3381 Hz
$(5,1)_a$ 4765 Hz
$(5,1)_b$ 4879 Hz
$(2,2)_a$ 3276 Hz
$(2,2)_b$ 3240 Hz
$(3,2)_a$ 3062 Hz
$(3,2)_b$ 3178 Hz
$(4,2)_a$ 3775 Hz
$(4,2)_b$ 3854 Hz
$(5,2)_a$ 5774 Hz
$(5,2)_b$ 5378 Hz
$(2,3)_a$ 4328 Hz
$(2,3)_b$ 4441 Hz
$(3,3)_a$ 4176 Hz
$(3,3)_b$ 4076 Hz
$(4,3)_a$ 4964 Hz
$(4,3)_b$ 5028 Hz

2D, 3D Resonating Bodies

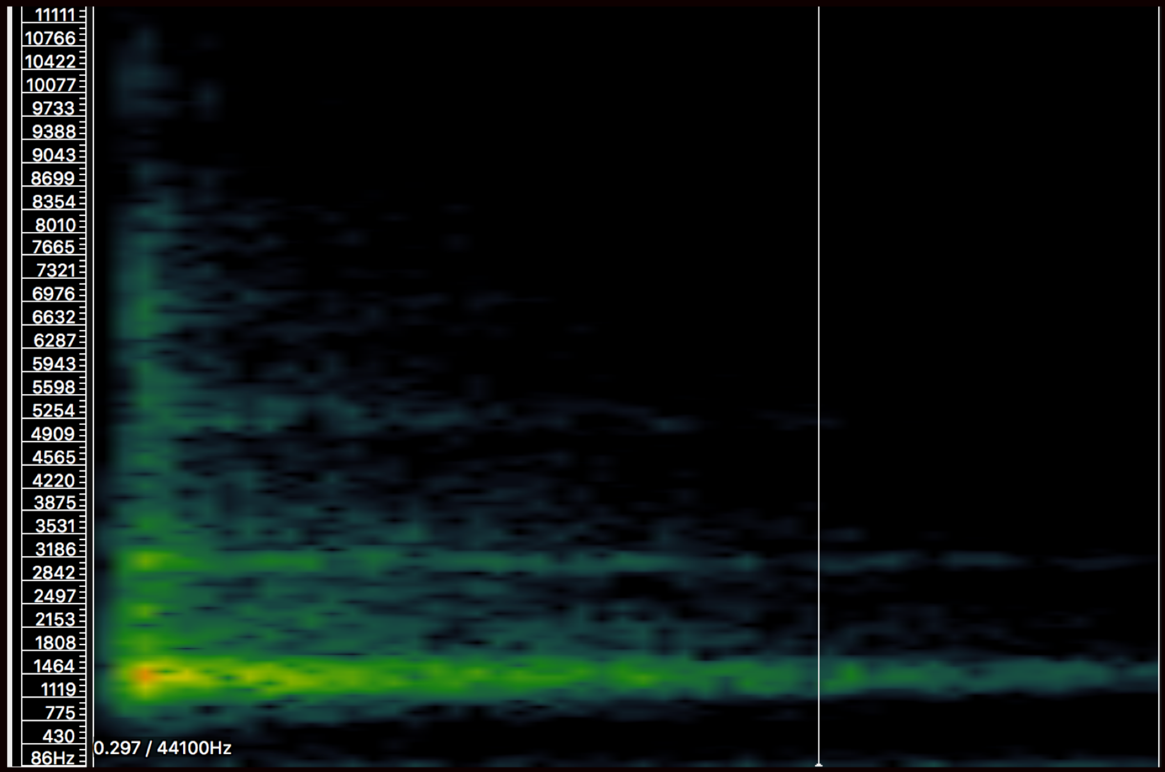
- Modelling a vibrating string using a one dimensional waveguide is easy as its fundamental wavelength is twice the length of the string and overtones follow at integer ratios.
- Two dimensional (and three dimensional) vibrating bodies will exhibit complex networks of waves. Nonetheless, carefully engineered shapes using rigid materials will exhibit coalescences of waves forming resonant partials.



Chladni plate

Modal Synthesis

- When we strike or bow such an object it is essentially filtering the broadband energy impulse we have injected into it into a series of discrete resonances.
- If we have information about the frequency locations, strengths and damping of these resonances then we can model each of them individually using bandpass filters



Struck wood block

Modal Synthesis

- Modal synthesis is a form of physical modelling synthesis in which the resonant modes of an instrument can be modelled one-by-one using filters and subsequently mixed.
- The idea is that the model remains as a static resonator until agitated by a signal of excitation.
- A range of filters are possibilities but one that is particularly stable when resonanting is the biquadratic bandpass filter of which the **`mode`** opcode is an example.
    - [a biquad/biquadratic filter‛s Z domain transfer function is described by the ratio between two quadratic equations.]

```
aout mode ain, xfreq, xQ [, iskip]
```

Modal Synthesis

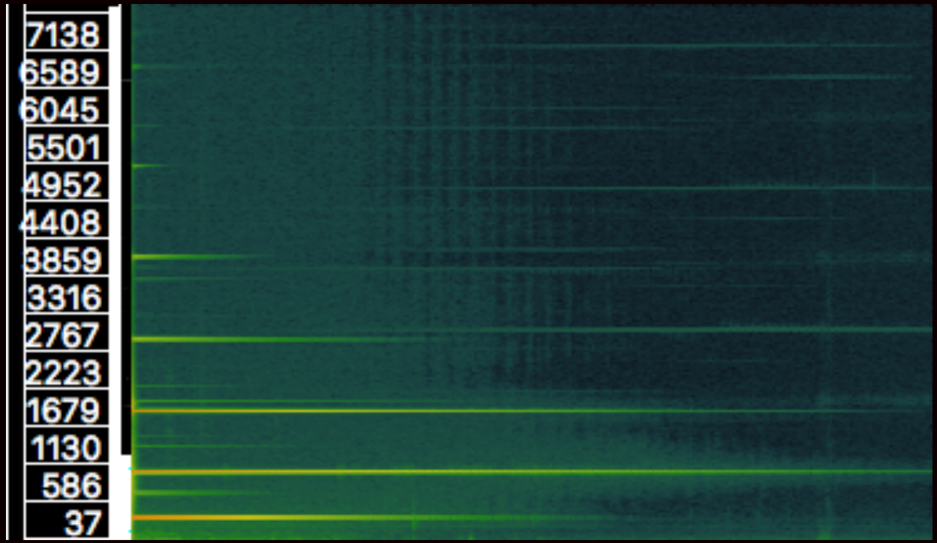
```
aout mode ain, xfreq, xQ [, iskip]
```

- **`ain`** - the input signal; some sort of impulse or signal of excitation.
- **`xfreq`** – the resonant frequency of the filter.
- **`xQ`** – the ‘quality’ of the filter. This controls the resonance of the filter. Higher values provides longer resonances and narrower bandwidths but internal feedback greater than 100% is impossible. Should be greater that 1 and can be in the thousands for simulation of metallic resonators. Q is related to bandwidth as shown below:

$$Q = \frac{\sqrt{2^{BW}}}{2^{BW} - 1}$$

- Q is often a preferred expression with filters that are acting as resonators.
- Resonating time will be approximately Q/Freq. We can see that as frequency gets higher resonating time reduces – this is what we would expect in nature.

Modal Synthesis Example: Spectral Analysis



Frequency	Amplitude
364	0.009
368.926	0.002
727	0.002
1028.4	0.027
1035.54	0.020
1908	0.004
2050	0.071
2951	0.071
3090	0.002
3097.14	0.008
4149	0.005
5476	0.001

http://www.sonicvisualiser.org/

mode * *N*

- The modes (inharmonic partials) contained within a source sound can be derived manually from a spectrogram or automatically using FFT techniques.

```
a1 mode aImpulse*0.009, 364,     kQ
a2 mode aImpulse*0.002, 368.926, kQ
a3 mode aImpulse*0.002, 727,     kQ
...etc.

aMix = a1 + a2 + a3 ...
```

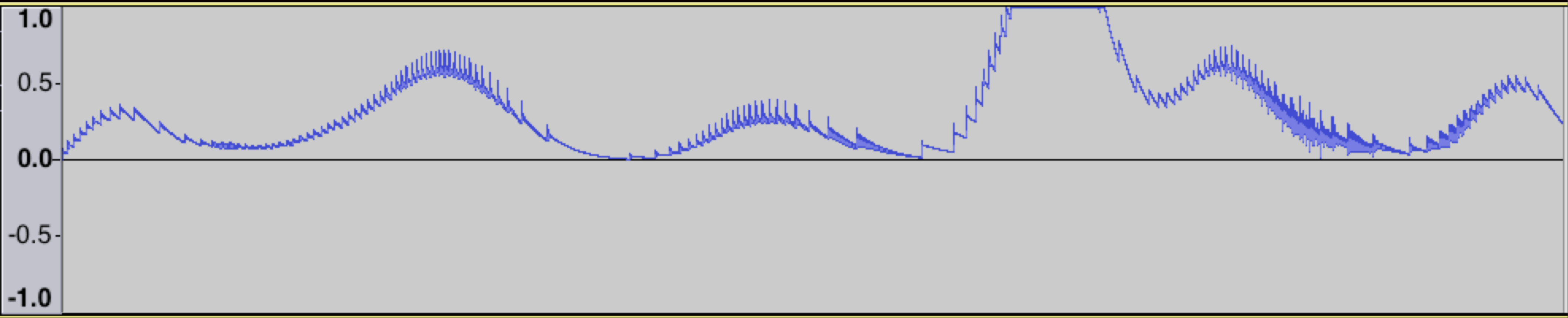
- Impulse sound could be a short burst of noise, a short sine sweep, a filtered single sample impulse, a sound file etc.

WARNING! `mode` has a frequency limit of **sr/pi** above which it will blow up. Since ver. 6.12 Csound will limit frequency in order to prevent this. In older versions you should implement protection using a conditional.

Modal Frequencies

- Beyond making your own analyses, there is modal frequency data in the Csound Manual appendix E:
- https://csound.com/docs/manual/MiscModalFreq.html
- Some datasets give just frequency ratios whereas others give both ratios and the specific frequencies of the object analysed.
- Csound manual appendix instruments:
    - Dahina tabla, Bayan tabla, Red Cedar wood plate, Redwood wood plate, Douglas Fir wood plate, Uniform wooden bar, Uniform aluminum bar, Xylophone, Vibraphone 1, Vibraphone 2, Chalandi plates, Tibetan bowl (180mm), Tibetan bowl (152 mm), Tibetan bowl (140 mm), Wine Glass, Small handbell, Spinel sphere with diameter of 3.6675mm, Pot lid
- Native Instruments Prism uses modal synthesis:
    - https://www.youtube.com/watch?v=zqU3_KwQp_g

DC Offset

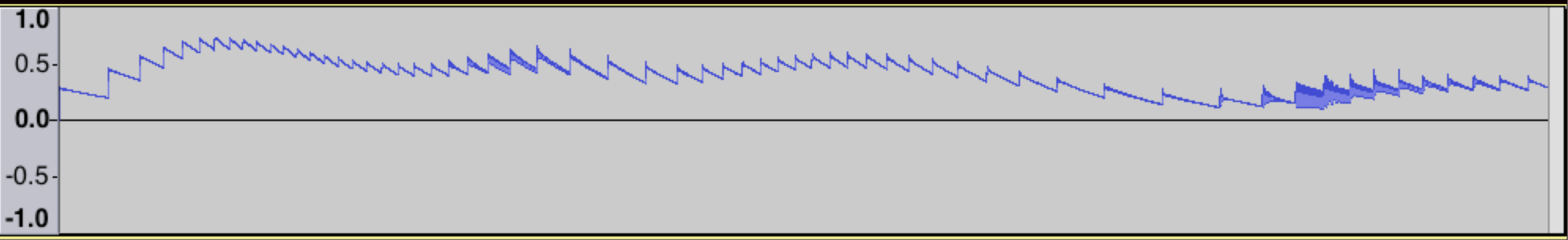


- Delays and feedback, as commonly employed in physical modelling (often through filtering), can produce DC offsets or low frequency components on account of overlapping, similar waveforms.
- As shown above, this can cause clipping even when the audible amplitude is low.
- DC offsets can be removed using steep highpass filters set at frequencies below our limit of hearing so that they don’t remove desired audio components.
- **`dcblock2`** is a opcode that performs this task.

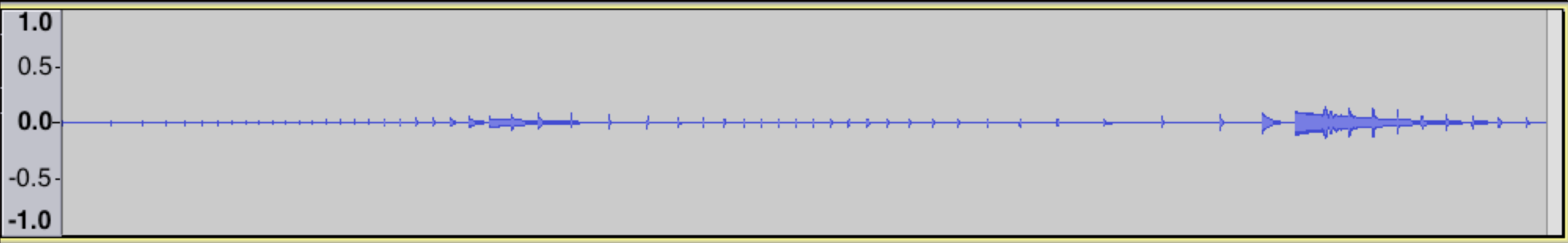
```
aout dcblock2 ain
```

DC blocking

- before DC blocking:



- after DC blocking:



- Consider applying DC blocking if:
  - The output distorts or disappears while still at a relatively low level of audibility.
  - The output amps reported in the console don’t align with the low audibility heard.
- DC blocking might be necessary in both waveguide and modal synthesis physical modelling.