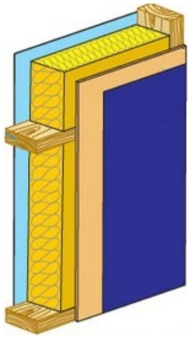
Room Acoustics

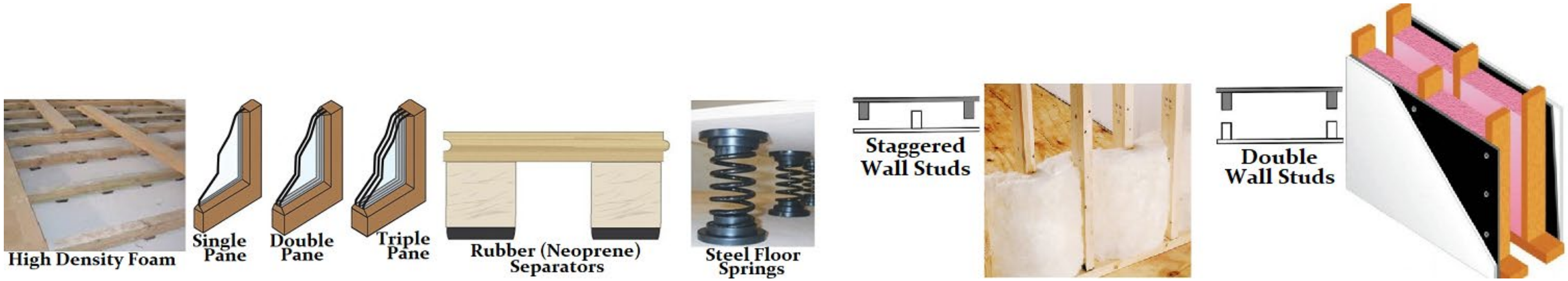
Church Audio

Isolation



When sound is played in a room, all the walls, ceiling and floor become large vibrating diaphragms. Their vibrations cause the whole structure to vibrate.

This results in the walls on the outside vibrating slightly as well. This is how we can hear something in the next room… the sound transmits mechanically through the vibrating building structure.



If we don't want our sound to transmit then we need to isolate from the outside, what we call *a room inside a room*. We need our inner room to be physically separated, as much as possible, from the outer wall structure so that we don't vibrate it and the sound won't transmit.

This is not easy if the building already exists, but if you have noise pollution problems then you need to reduce the sound vibrating the building structure.

Reverberation

ROOM REVERBERATION

As sound travels around a room it bounces off the reflective surfaces it encounters. This causes echoes. This all happens very quickly, and there are hundreds of reflections occurring in milliseconds. Our ear recognises this mass of reflections as a boomy ambient effect we call reverberation. *Stand in the middle of a room and clap your hands and you will hear it.*

If a room has too much reverberation, such as a highly reflective Cathedral or Gymnasium, it is practically impossible to hear speech or play music without getting a muddy confusion of reverberation flooding the sound, making everything unintelligible.
Reverberation is controlled by the linings on the walls, floor and ceiling. By choosing how we cover walls and surfaces, we can make the room as dry or reverberant as we wish.

Every material has an absorption factor (α). This is how much sound it will absorb (and consequently how much will reflect away). Materials absorb different frequencies differently. Here are some examples of materials with their absorption coefficients (α) at various frequencies:

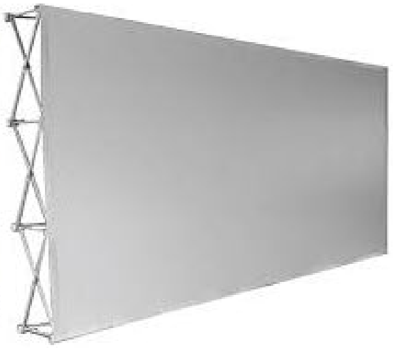
	Frequency (Hz)					
Surface	125	250	500	1000	2000	4000
Acoustic tile, ridged mount	.2	.4	.7	.8	.6	.4
Acoustic tile, suspended	.5	.7	.6	.7	.7	.5
Drywall, gypsum, 1/2 inch on studs	.3	.1	.05	.04	.07	.1
Plywood, ¼ inch, on studs	.6	.3	.1	.1	.1	.1
Concrete block, unpainted	.4	.4	.3	.3	.4	.3
Concrete block, painted	.1	.05	.06	.07	.1	.1
Concrete, poured	.01	.01	.02	.02	.02	.03
Brick	.03	.03	.03	.04	.05	.07
Vinyl on concrete	.02	.03	.03	.03	.03	.02
Heavy carpet on concrete	.02	.06	.15	.4	.6	.6
Padded carpet	.1	.3	.4	.5	.6	.7
Window glass	.3	.2	.2	.1	.07	.04
Drapes, medium	.07	.3	.5	.7	.7	.6
Upholstered seats, unoccupied	.2	.4	.6	.7	.6	.6
Upholstered seats, occupied	.4	.6	.8	.9	.9	.9
Wood or metal seats, unoccupied	.02	.03	.03	.06	.06	.05
Wood or metal seats, occupied	.4	.4	.7	.7	.8	.7

Look at your room. Add the total square metres each material, and multiply each by their particular Absorption Coefficient (α). The answer is in '*Sabines*'.
If an area (totalled up from everywhere) of Drapes totals 4m x 5m (20 sq m) and has an $\boldsymbol{\alpha}$ *of 0.6 then that is 12 Sabines.* Add all Sabines.

$$\textbf{Room Reverberation} = \frac{\textbf{0.163 x cu metres of room}}{\textbf{total Sabines (sq m)}}$$

When you add all the Sabines in a room, the answer is in ***Seconds***. It is called the $\mathbf{RT^{60}}$ (*Reverb Time 60dB*). This is the seconds for the room reverberation to fall by 60 decibels (silence). A suitable reverb time for churches should be around 2 to 2.5 seconds of reverb.

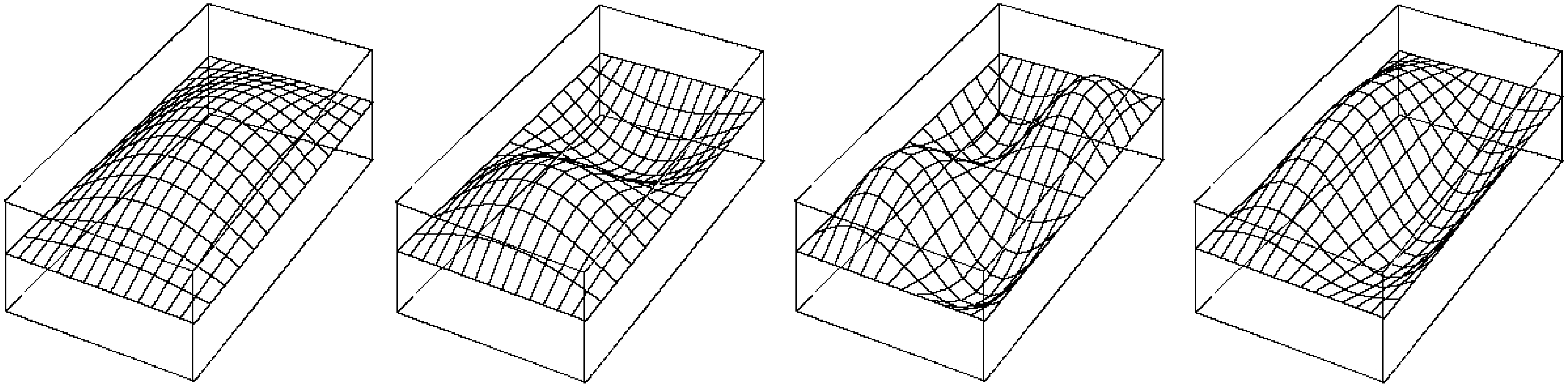




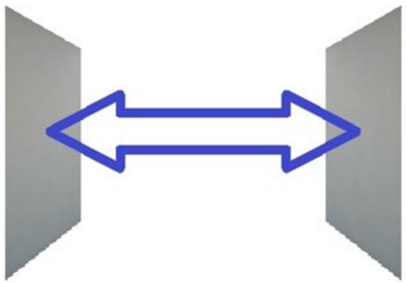
One effective way to dampen sound vibrating off the walls is to hang drapes or banners out from the wall (not touching the wall). When sound hits a suspended fabric, it will act like a shock absorber. It stops parallel walls being able to reflect back and forth**.** Simple, and a great chance to add some elegance to the room.

Reflection

ALL PARALLEL WALLS REFLECT SOUND BACK AND FORTH (RESONATE)



Wall reflections are called **Standing Waves**, or **Stationary Waves** or **Eigen Tones**.



$$\text{FREQUENCY (Hz)} = \frac{\text{Speed of Sound}}{2 \times \text{Distance (m)}}$$

The exact frequency of resonance is double the wavelength (physical distance) between two parallel surfaces.

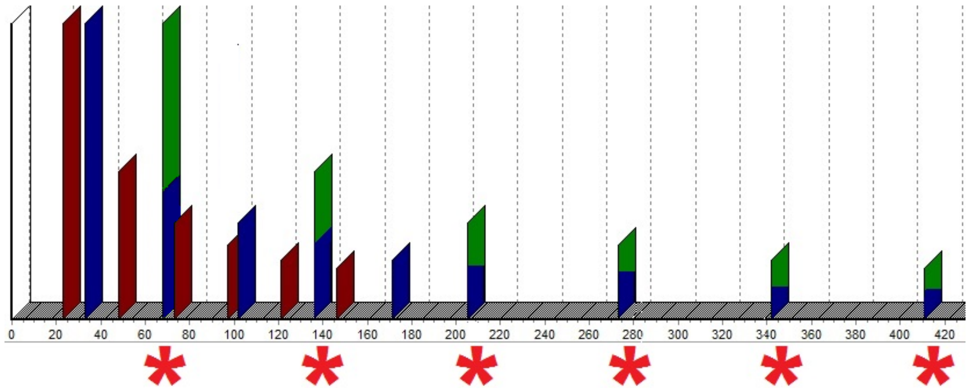
Every rectangular room will have three reflections (length, width, height). This means every room has three resonant frequencies.

In our example room (7m x 5m x 2.5m), any time music is played, the 24.5 Hz, 34.3 Hz and 68.6 Hz frequencies in the music will be amplified (as if they were raised by an equaliser) because the room will resonate and sustain them. This means the room will boost your sound at those three frequencies.

As if that wasn't bad enough… whenever frequencies vibrate in the air, they automatically double and triple and quadruple. These ripples (**Harmonics**) are lower in power than the three **Fundamental** frequencies of the room, but the first few still have a strong effect on your sound. So… let's take another look at our room.

	1st	2nd	3rd	4th	5th	6th
7m *Length* =	**24Hz**	49Hz	74Hz	98Hz	122Hz	147Hz
5m *Width* =	**34Hz**	69Hz	103Hz	137Hz	172Hz	206Hz
2.5m *High* =	**69Hz**	137Hz	206Hz	274Hz	343Hz	412Hz

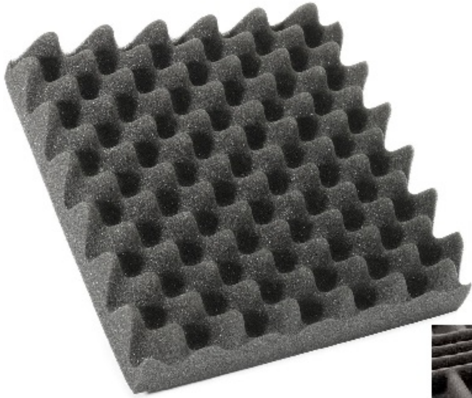
So you see that the fundamentals plus their harmonics contribute quite a lot of sound material that mixes in with your original music.

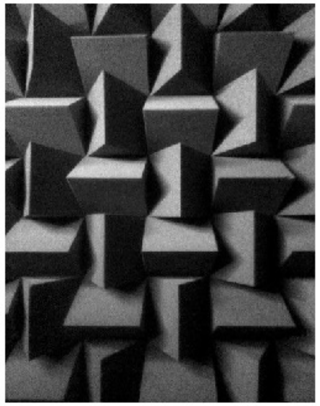


Notice on the list above how some of the harmonics generated from the different walls have the same value (137Hz and 206 Hz).
Those two frequencies will have double the effect on our sound and could be quite a sound problem. Doubling up of any reflections in a room is the worst-case scenario.

One way of taming wall reflections is to **scatter (diffuse)** the sound in all directions. This stops the sound from bouncing back and forth between the same two parallel points.

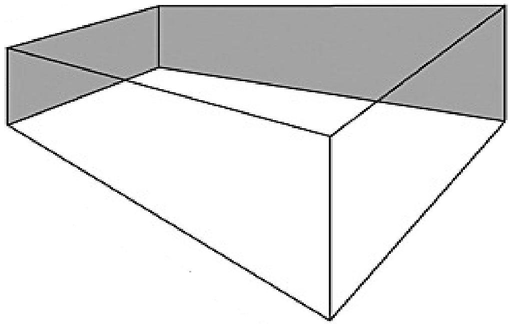
The exact profile (shape) of **wall diffusers** is not crucial, some prefer random profiles, some uniform profiles.



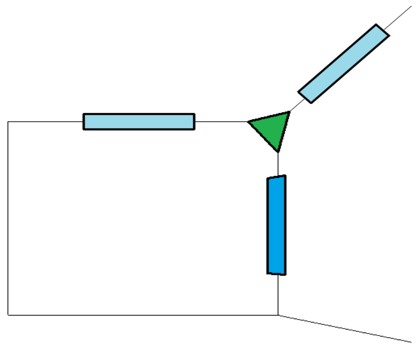



Acoustic Foam, although it looks cool, does little to *diffuse* as foam has no real acoustic power and sound passes through it (think of a microphone wind sock). The diffusers you place on walls must be hard and solid, not soft!

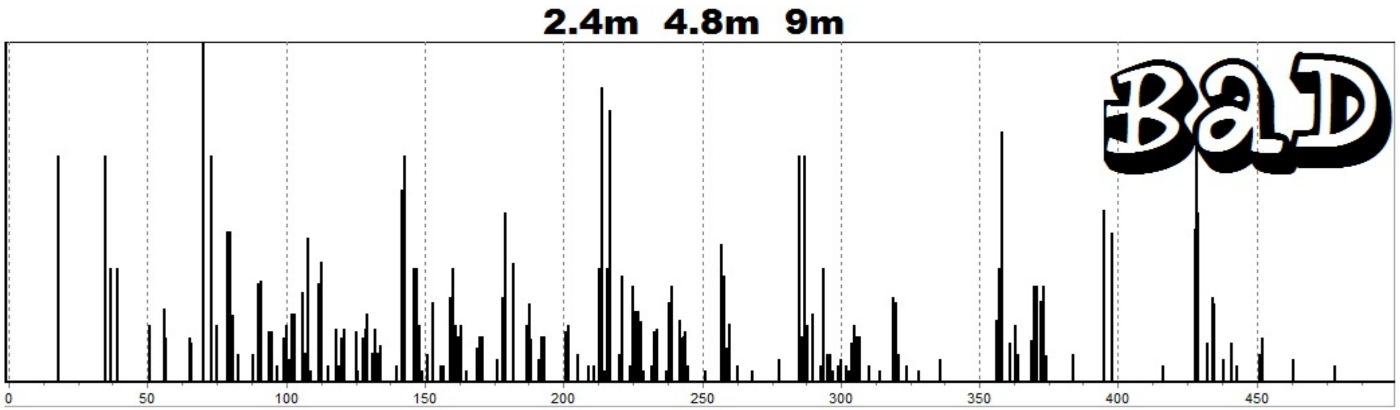
Another way of taming wall reflections is to angle (splay) the walls. This could mean using a second, false wall.

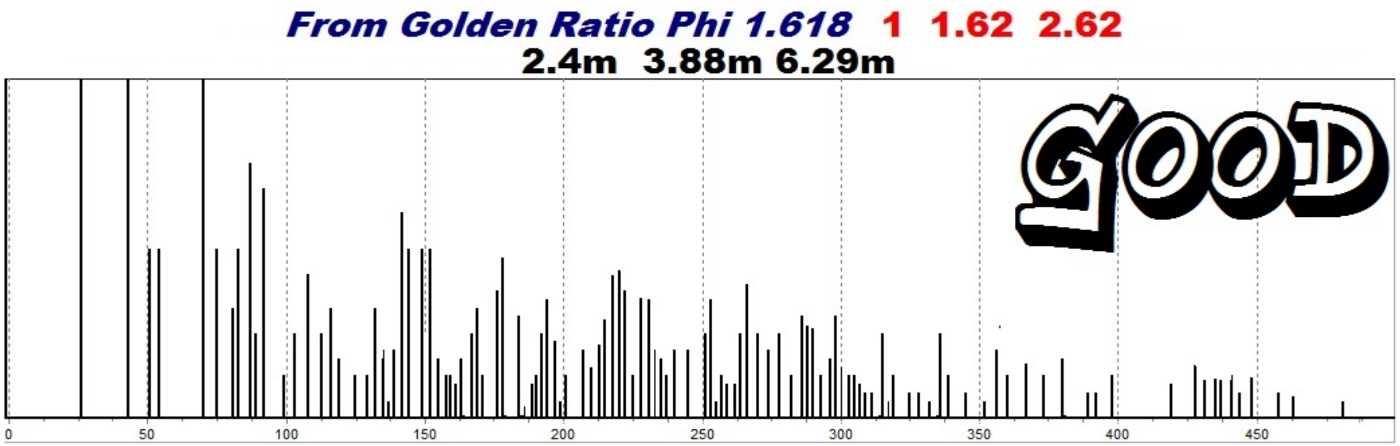


Modern mathematics says splaying all walls by 12° (6° per wall) will remove any parallel surfaces.
Another approach is the ratio of the height at one end of a wall to the other end of the same wall is 1.272 to 1 (1.272 is the square root of Golden Ratio 1.618).



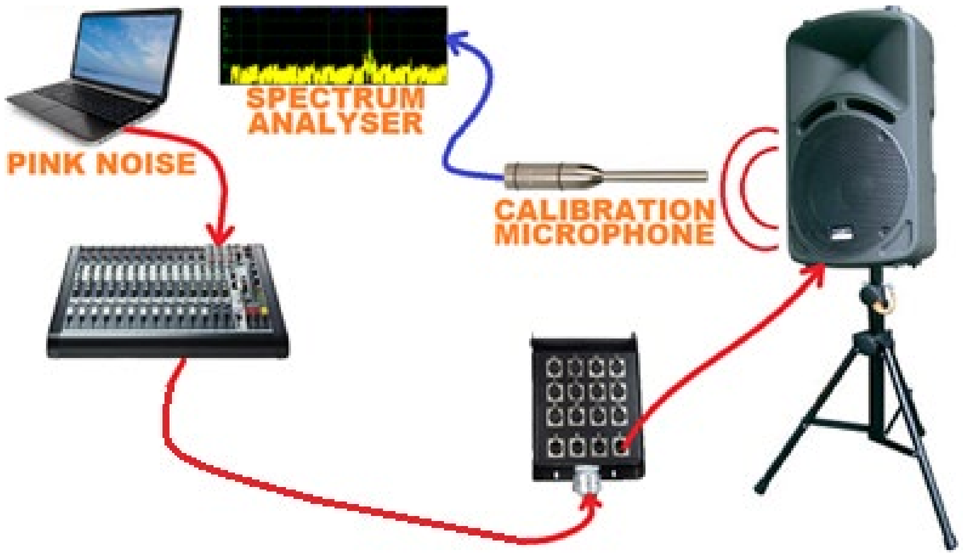
Sometimes the corners of walls can cause strange reflections (flutter echoes). We eliminate these by putting a hard triangle over the corner, and for further diffusion of corner echoes we can place strips to eliminate the angles altogether.





Usually we inherit a venue to use, and we don't have control of the length, width and height. On those occasions that you can plan a room beforehand, or you can put in a false wall, always choose a **room ratio** that spreads out the resonances (**room modes**) evenly.

The BAD example shows all the frequencies caused by room reflections. See how many frequencies cluster close together. This will result in serious colouring of your sound. The GOOD example has a 'clever' combination of length, width and height, chosen so the harmonics of each of the three fundamentals never clash with each other. It will still colour your sound, but it will be smoother and less disturbing to the ear.



So how do I determine what frequencies are being generated by the room?

Connect a Pink Noise source (*it just means all the frequencies are playing at once*) from a Laptop or Spectrum Analyser to a channel, and send (assign) it out to a Loudspeaker cabinet. Make sure that the channel EQ is flat (not filtering the Pink Noise).
Position a Spectrum Analyser near the Mixer and connect a Calibration microphone. Point the microphone at a Loudspeaker cabinet down the other end of the room.

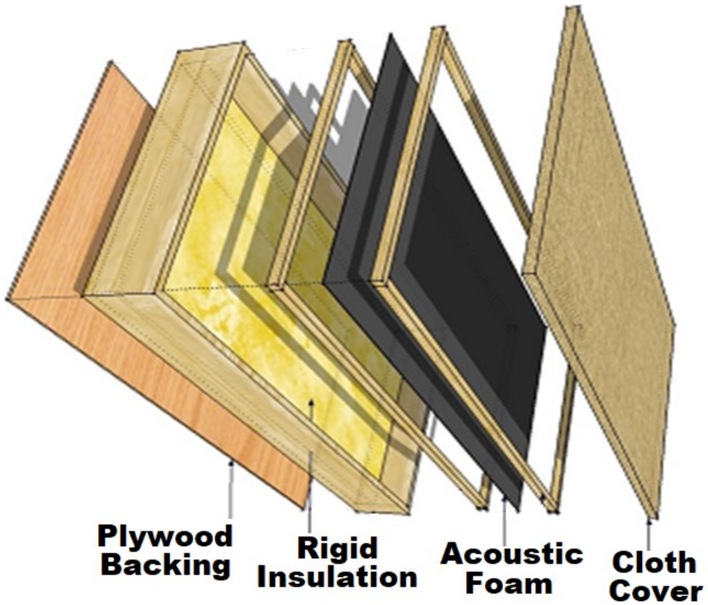
When you play Pink Noise out through your Sound System, and back to the microphone, the pink noise curve should look the same as when you sent it (because you haven't filtered it). The result will never be the same as when you sent it. This will show you what resonances the church building has added to your sound.

Absorption

SOUND TREATMENT

When a room is too reverberated, or ringy, it becomes necessary to place sound baffles on the walls. These are specially designed, and are positioned strategically, to absorb the excess frequencies that the room is generating.

They consist of containers with acoustic material suspended inside at a precise distance. This makes them become ***frequency absorbers***.



Here is an example of a **Broad-band Membrane Absorber**.

This captures a reasonably large band of frequencies.

Here is an example of a **Med Freq Membrane Absorber.**

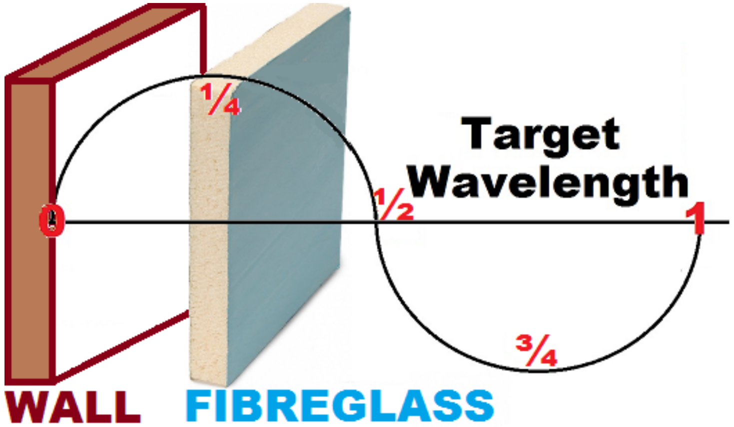
It is quite simply a panel of rigid fibreglass covered with some fabric.

The frequency that it will absorb (trap) is controlled by it's distance from the wall (the air-gap).

The distance is calculated using the *wavelength* of the target room frequency you want to lower.

$$\textbf{Wavelength} = \frac{\textbf{Speed of Sound}}{\textbf{Frequency}}$$

The trap also affects the harmonics of the target frequency.



The ideal air gap (out from the wall) is ¼ of the target wavelength.

Sound Absorption Coefficients - Type "A" Mounting)

Thickness		Frequency (Hz)						
in.	mm	125	250	500	1000	2000	4000	NRC
1.0	25	0.06	0.29	0.75	0.99	1.04	1.02	0.75
2.0	51	0.24	1.00	1.11	1.08	1.06	1.05	1.05

Here is an example of a **Panel Trap Absorber.**

These are great for lowering bass frequencies. The box is closed, air-tight, so any movement on the front panel increases internal pressure. The fiberglass converts the acoustic energy into heat. A huge advantage is they don't have to be thick to absorb very low frequencies. The wooden front is reflective at higher frequencies so treating a room properly for low frequency problems will not make the room too dead sounding at higher frequencies.

The target frequency of a panel trap is determined by the surface density of the panel, and by the depth of the sealed cavity behind the panel.

If you build it using the image above, then the formula is…
Resonant frequency = 600 / sqrt (m*d)
*where **m** is membrane (plywood) surface density **kg/sq.m**, and **d** is frame depth **cm**.*

If you put porous sound-absorbing material inside, then the formula is…
Resonant frequency = 500 / sqrt (m*d)
Filling the inner volume with sound-absorbing material reduces the (Q) of the absorber, which leads to a larger bandwidth that it will absorb.

MDF (particle board) is too light (no mass), be sure to use use dense wood eg plywood.

A trap four inches deep with a 1/4-inch-thick plywood front absorbs 100 percent at around 90 Hz, which is more than the same thickness of rigid fiberglass at that frequency.

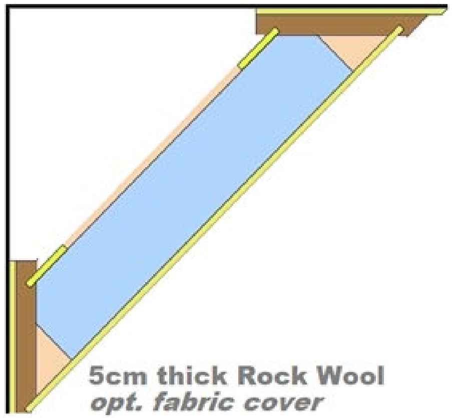
The ideal would be Panel Traps tuned differently, mixed with fibreglass Membrane Absorbers.

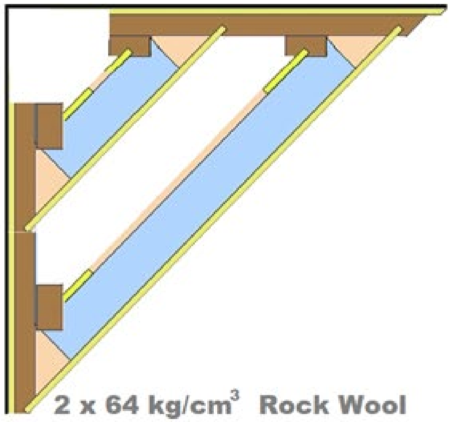
Placing Absorbers, Drapes or Diffusers in the centre of long flat surfaces is similar to placing your finger on the centre of a drumskin, it blocks the principal vibrations.

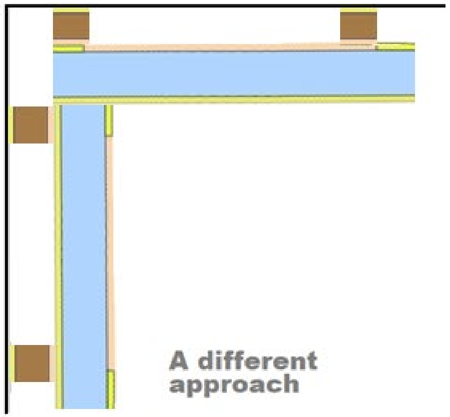
Please note: The formulae in this document are all theoretical. You always do well to place a calibration microphone near any Absorber or Resonator you are constructing, and play some pink noise across it to see what it actually absorbs and reflects.

Here is an example of a **Corner Bass-Trap.**

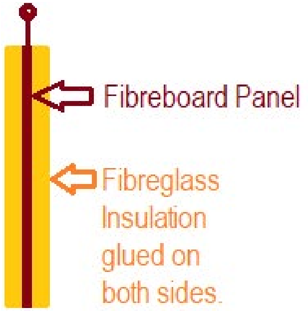
All room reflections ripple along walls, ceiling and floor and end up in the corners. It is a great place to trap the basses. There are plenty of methods…



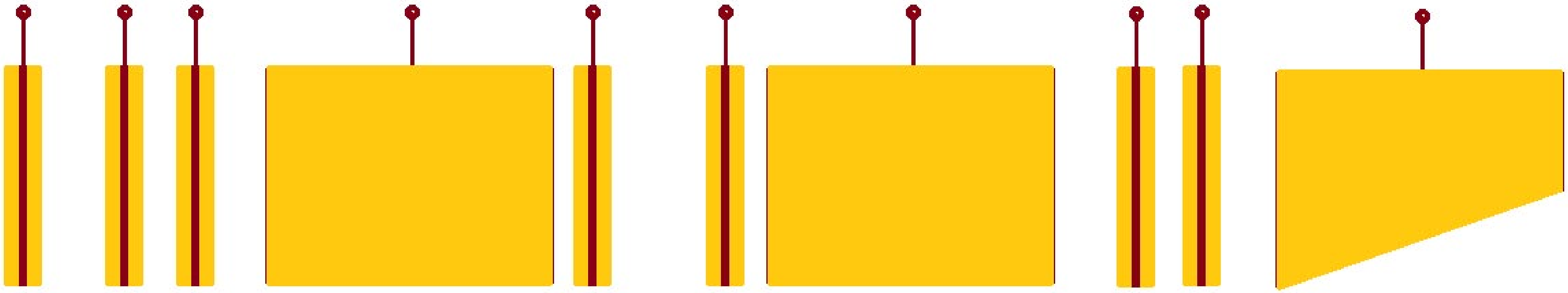




Here is an example of suspended **Acoustic Panels.**



When suspended in the ceiling, place a false ceiling of cloth underneath. This is a great low frequency eliminator.



Use random spacing between panels to influence a wider band of frequencies.

For example- large panels 1.8m x 500mm suit the low frequency range, and smaller panels 1.2m x 300mm suit the lower mid frequencies.

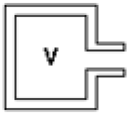
Resonators

The Roman Historian Vitruvius wrote about large copper vases he saw in Greek Amphitheatres. They were placed in chambers under the rows of seats in accordance with mathematical reckoning. The Greeks called them ***Echeia***. He noted that the sound became fuller and reached the audience with a richer and sweeter note.

For many centuries we have known that very large vases or Jars trap bass frequencies, making the sound cleaner.

Here is a ***Resonance Amphora*** found embedded in the wall of the Church of the Chartreuse Notre-Dame du Val-de-benediction.

In more modern times, a man named **Helmholtz**, gave us mathematical understanding about what resonators are actually doing.



$$\text{freq (hz)} = 54\sqrt{\frac{A}{LV}}$$

A is the cross-sectional area of the neck (cm squared).
L is the length of the neck (cm).
V is the volume of the body (cubic cm).

A Resonator is a tuned cavity that can be designed to absorb **very low frequencies**. It is very efficient, but the downside is that it absorbs a fairly narrow range of frequencies (narrow band) and needs to be rather large to absorb very low frequencies.

The ‘range’ can be widened by filling the cavity with fiberglass, or by creating several openings with different size necks.

One popular design today uses a box filled with fiberglass with its front opening partially covered by a series of thin wood boards separated by air spaces. This is called a **slot resonator**.

A similar design uses a box filled with fiberglass but has a cover made of pegboard containing many small holes, called a **hole resonator**.

Slot Helmholtz Resonator responds to one definite frequency. Their distinctive feature is low-frequency vibration, where wavelength is much bigger than the resonator's size. In general, construction is a timber framing erected on a wall or a ceiling .

A set of slats with slots between them is put on the framing.
Inner space is filled with sound-absorbing material.
Resonant frequency = (c/(2*PI))*sqrt(r/((d*1.2*D)*(r+w))),
where

w is slat width, r is slot width, d is slat thickness, D is frame depth, c is speed of sound in the air.

If you use different width slats and adjust them to different slots, or use a frame with variable depth, it's possible to build an effective absorber to work in wide range of frequencies.

CREDITS

This material is offered freely to the Christian Churches; downloadable at Pietango.com

Text: *Original, by the Author, a Christian Recording Engineer.*
Images: *Designed by the Author. Some photographs were sourced from the Internet, then re-worked.*

Ever since the creation of the world, God's invisible attributes and divine nature have been evident. They are clearly understood through his workmanship, and all the wonderful things that he has made. Therefore, those who fail to believe and trust in him are without excuse, or defence. **Romans 1:20**

All of us have sinned and fallen short of God's glory, but God treats us much better than we deserve.
Because of Christ Jesus, he freely accepts us and sets us free from our sins. God sent Christ to be our sacrifice. Christ offered his life's blood, so that by faith in him we could come to God. **Romans 3:23**

If you declare with your mouth, "Jesus is lord," and believe in your heart that God raised him from the dead, you will be saved. For it is with your heart that you believe and are justified, and it is with your mouth that you profess your faith and are saved. **Romans 10:9**

For the Scripture (*Isaiah 28:16*) says, "Whoever believes in Him will not be disappointed." **Romans 10:11**

These things have been written so that you may believe that Jesus is the Christ, the son of God; and that by believing, and relying on him, you may have new life in his name. **John 20:31**