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Part II – Studio Design

A guide for the home recording artist

Contents

Acoustics

Introduction

So you want to setup a studio so why worry about acoustics

and what are acoustics anyway?

Let me tell you a story as I heard it from the late Dean Jensen who I stayed with in the early seventies when he was the top techo in LA. --- According to Dean in the early seventies some of the engineers of The Record Plant (one of LA's top studios) were sitting on the roof of their building after a long party. They had taken some speakers from the studio up to the roof for the party and were discussing the fact that the speakers sounded great on the roof but were pretty awful downstairs in their control room! Why?? Well, on the roof the speakers were in what is called an anechoic environment - i.e. no reflections or reverberation! The sound left the speakers, went past them and didn't come back. Try it yourself - take your favourite speakers outside and set them up in your backyard or in an open field and have a listen to them. Suddenly the bottom end will be clean and tight and the top end imaging will be amazing. The centre will be really tight and defined and you will hear all the mistakes you made in the recordings. Unfortunately your neighbours won't let you set up a control room in your backyard. I might mention here that it amazes me how much EQ front of house engineers apply to speakers when mixing outside concerts where there are no room modes etc. I remember an engineer being highly offended (and confused da!) when I suggested that JBL must make shithouse speakers when they needed +/- 12db EQ in the open air. (I was the first in Australia to add 1/3 Octave EQ my studio monitors in 1974 when I got back from LA. Within 6 months I'd removed them.)

So what is the ideal internal listening environment? Well I reckon if you did a vote you would find that over 50% would say - In the CAR!!!. I agree, I often check a mix in the car and I know a lot of other engineers who do the same. So why does the car sound so good? There are a number of factors and it is these factors that go into making a good listening environment.

The main factors in a car are:

- **The Shape:** There are no parallel walls in a car and what walls there are are thin and curved.

- **The Speakers**. In a car the speakers are almost always flush mounted. i.e. They a mounted into a flat surface like below the rear window or in the side door panels. As a result there are no out of phase signals coming from the rear of the speaker. Also the rear speakers are mounted in a big cabinet - the boot.
- **High Frequencies**: In the car the windows are the main high frequency reflectors but they are all at angles (approx. 6 - 12 degrees)and are usually curved as well. The highs also get diffused evenly throughout the cabin by the dash board. Also the ceiling, sides and floor are covered in high frequency absorption.
- **Mid Frequencies**: The seats, door panels and passengers are all low mid to high mid absorbers. Modern cars have deep pile carpet on thick underfelt which also acts as a mid frequency absorber. Most of the car's acoustic treatment for cutting down engine and road noise is also on the inside and acts as acoustic treatment for the car stereo.
- **Low Frequencies:** The beautiful thing about cars is the bottom end response. With a couple of hundred watts a side, a sub-woofer under the seat and the loudness switch on the bottom end thumps away and sounds great. Actually most of the low end goes straight through the walls and disappears, consequently it doesn't hum around the internal body causing phase problems. Any vibration is dampened by the foam lining and carpet and as far as the low end is concerned the car is equal to open air. Next time you play a tape/CD in your car get out and listen to what actually leaves the car (most of it!! especially if the windows are open)

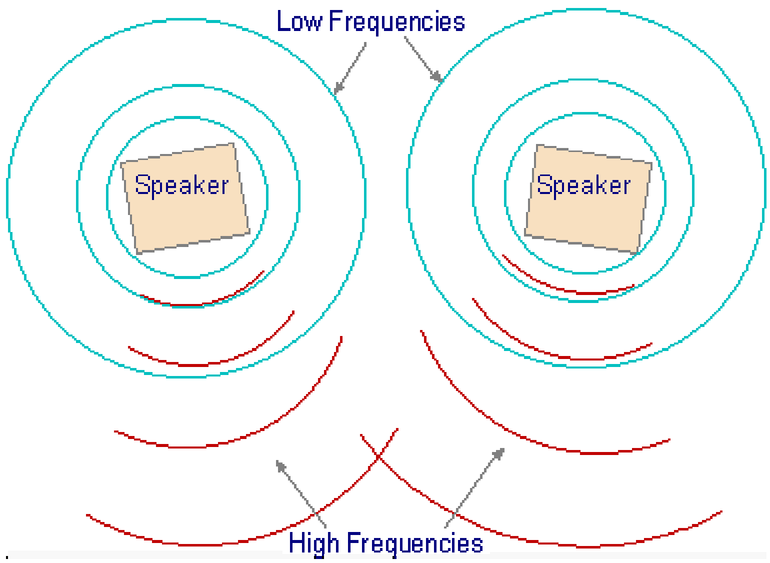
The problem with recording studios is that to keep external sounds out you land up keeping internal sounds in. People who build studios in the city have to worry about trains underneath, traffic noise outside, planes flying overhead etc. Obviously the best thing to do is to build it in the middle of a 50 acre paddock in the country where your only external noise concerns are birds, wind and rain. Then you can build a simple skin to keep the rain out and allow all the internal sound to get out so it doesn't muck up the sound within the room.

So how do you create the effect of your car, or the open air, in your studio? - **By using Acoustics!!** Treating the walls in your control room and studios so as to control the sound and thus improve the quality of the sound that you hear and record. I reckon good acoustics can beat a fancy effect unit any day and they cost about the same.

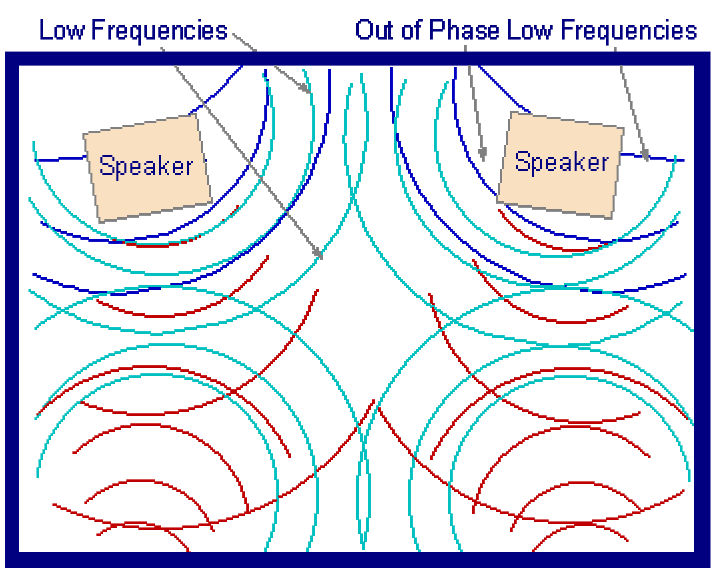
You can now select any of the topics listed in the adjacent column and progressively gain a good understanding of the basics of building a quality studio for yourself..

Acoustics – Shape & Size

So what actually happens to speakers setup in the open air? Firstly, the direct sound from the speakers is all you hear. There are no reflections coming from walls, ceiling, floor etc. Secondly no sound comes back to you a second time from a rear wall. **In open air there is no reverberation time yet every room has a reverberation time.**



Speakers Outside

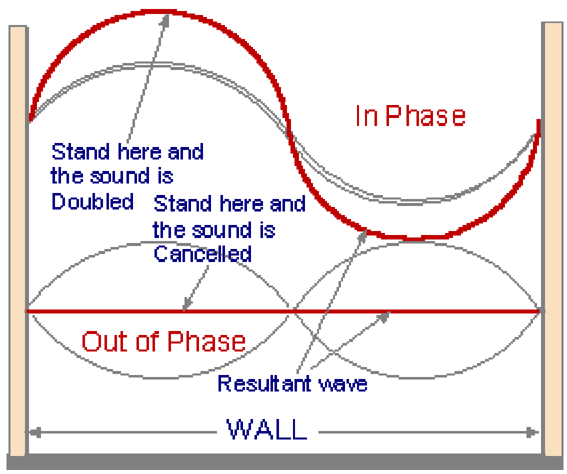


Speakers Inside

As you can see the walls really muck up the sound waves because they reflect back off the wall behind the speakers and the reflected waves arrive at the listener in and out of phase. As a result they add and subtract from each other creating confusion in the bottom end. Also the highs and mids are going to reflect off the walls and the room rear wall.

STANDING WAVES

Another problem created inside is parallel walls and standing waves. Standing waves are when a sound reflects off walls that are opposite each other and a wave equal to the distance is formed. As you move around a room with standing waves you can hear as you walk in and out of a standing wave. In one spot the bass is booming yet in another there is hardly any bass. Makes it hard to figure out how much bass you have? It works like this:



Typical Standing Waves

What happens here is that if you stand at the high point of an in phase standing wave you hear double the volume of the frequency yet when you stand at the same point in an out of phase standing wave the waves cancel each other and you hear nothing. It's pretty hard to figure out your sound frequency balance when this happens throughout your control room. It happens at all the octaves of the frequencies as well so if the frequency is 440Hz it also happens at 880Hz , 1760Hz ,3520Hz,etc. This is what creates coloration in the room. As you move around the room the frequency response keeps changing causing room coloration. It's also a problem in the studio if your mic is sitting directly in an out of phase node!! So the first thing you must do is eradicate all the parallel walls in a studio design. I believe that a wall must be at least 12 degrees off parallel to stop parallel wall standing wave interference. That's either one wall at 12 degrees or two walls at 6 degrees each. **If you can afford to make the angle bigger, do so**. Also you can **create angled walls within a rectangular room by adding acoustic treatment.** (I'll demonstrate that in the pages on wall treatment). (**Note**: having non parallel walls doesn't entirely stop standing waves - they still form within a room but along different lines of repetition). The main reason for having angled walls in a control room is because of reflection control of the high frequencies for true imaging from your speakers.

This effect also happens between the floor and the ceiling so to stop the effect you must angle one! well it's not going to be the floor is it. I must state here that putting angles into the ceiling is expensive so I would recommend that for the home studio you use the acoustic treatment to break up the ceiling. (See wall and ceiling treatment pages)

ROOM MODES

The formula for determining the fundamental frequency of a standing wave for a particular room dimension is:

$$f = V / 2d$$

- f = Fundamental frequency of the standing wave
- V = Velocity of sound (330m/sec (1130 ft/sec)
- d = Room dimension being considered in feet (length, width, or height)

Other standing waves occur at harmonics of the fundamental frequency - that is 2, 3, and 4 times the fundamental.

Fundamental Frequency Calculation

Enter the value of one of your room dimensions and you measurement system.

If you are working in:

Metric insert the speed of sound as **330 m/sec.**
Feet and inches insert the speed of sound as **1130 ft/sec.**
Then click on any other field and all fields will be calculated

Please Note: You might have trouble if you are using Netscape!!

Speed Of Sound	330 Metres/Feet/ per sec
Room Length	Meters/Feet

Fundamental	Hz
1st Harmonic	Hz
2nd Harmonic	Hz
3rd Harmonic	Hz
	RESET

Thus a room with an 6 metre dimension has standing waves forming at

- 27.5Hz (the fundamental frequency)
- 55Hz (the first harmonic),
- 82.5Hz (the second harmonic)
- 110Hz (the third harmonic)

yet a room dimension of 3 metres gives

- 55Hz (the fundamental frequency)
- 110Hz (the first harmonic),
- 165Hz (the second harmonic)
- 220Hz (the third harmonic)

In other words rooms with dimensions that are multiples of each other create similar room modes - **so avoid room shapes with dimensions that are multiples of each other.**

The Kick Drum: It is also interesting to play with the calculator in other ways. Try entering the measurement of a 24" - (2 ft) (0.600M) kick drum. A kick drum being a circle is a continuous parallel wall and it will have a fundamental frequency. You will find that the fundamental frequency of 20" - 24" bass drums is around 300Hz - wow ! do you recognise that frequency when equalising kick drums??

So what size should a control room be? These days people are building bigger and bigger control rooms because so much happens in the control room now. Often the bass player and keyboard player actually sit in the control room. I often have the vocalist singing in the control room while the bed tracks go down, so a good size control room is a good idea.

So many people think that you need a big studio and end up putting a poky little room at the end and call it a control room. I suggest that a control room ideally should be at least 6m x 5m with a minimum ceiling height of 2.4m. This size room means a good sized working area with space for the musos, friends and hangers on. Also because you don't want rear reflections to interfere it is better to start with a longer front to back dimension than the side to side dimension. i.e. 6m x 5m.

The studio, on the other hand, requires a different set of considerations. The first to consider is do you want just one room or more? The trend nowadays is for more than one studio so the you can get isolation between players and different acoustics for each room. The acoustics you want for a live drum sound is totally different than you want for a vocal for example. I recommend at least 2 rooms. You can put drums in one, guitars in the other, keys , vocals and bass (DI) in the control room or maybe the band in one and the vocalist in the other. Getting separation between guitars and drums is usually OK in a good sized room but keeping them out of the vocal track is hard if they are all in the same room. Just a note here - the kitchen is an important room to consider. Gallons of coffee and tea are drunk in studios. An engineer was once asked - how do you normally have your coffee? "Cold with a fly in it !! "- was the reply. Also a kitchen allows for a fridge for the beer and a microwave for the pizza, vital ingredients in every album recording session. Toilets (bathrooms for you in the US) are also a vital service a studio should offer. The coffee and beer has to go somewhere.

Acoustics – Diffusion

Up to this point we have discussed reflected sound off flat surfaces. There are three things that can happen when sound hits a wall. It can be reflected, absorbed, or **diffused**. If you have a multifaceted surface such as a rock wall the sound reflected will be diffused. Diffusion spreads the reverberant sound evenly throughout a room, which not only prevents standing waves but also eliminates dead spots, i.e. places where components of the sound are missing through phase cancellation as discussed in standing waves. Flat surfaces can be broken up by placing diffusers on studio walls.

Diffusion in the Control Room

I must say at this point that I have a problem with diffusion in a control room. Sure the diffuser does disperse the sound evenly within the room and it sounds impressive but I've found that when working in a diffuse control room you get a distortion of the amount of "life" in a sound. The diffusion makes everything sound airy and open but what's on tape might not have that factor.

A control room is a working environment, not a listening room

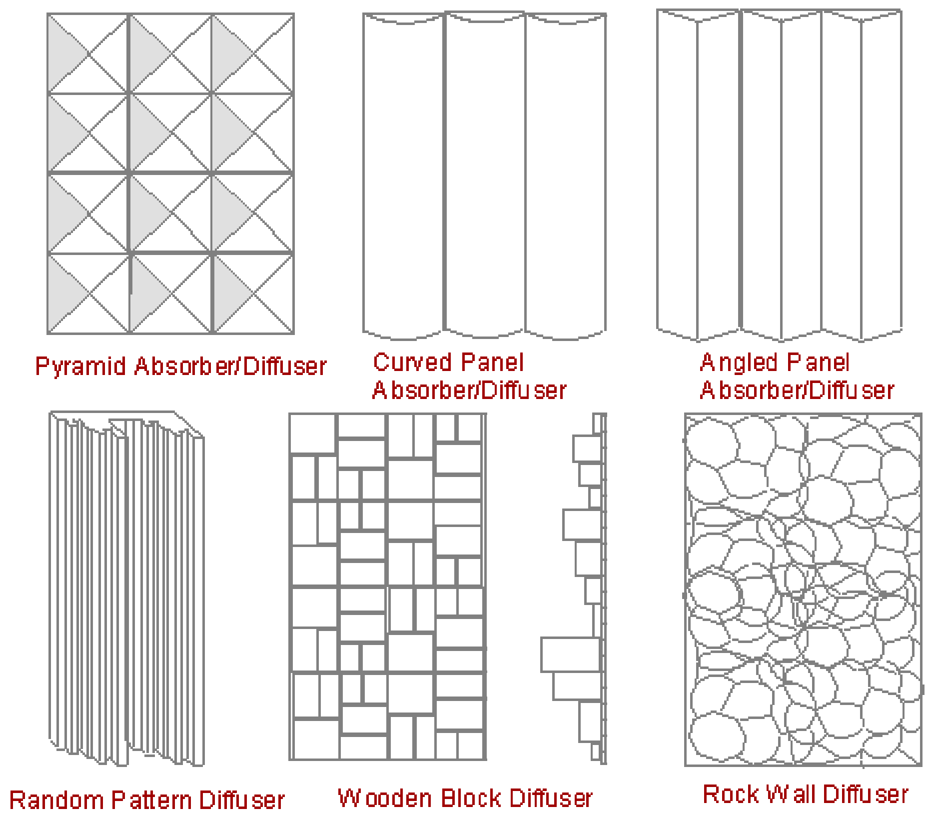
In a control room you are wanting to hear exactly what is on tape and you want to be able to analyse it completely so that you can add the necessary components such as EQ,reverberation, compression etc. Direct sound from the speaker is the aim in a control room and I feel diffusion clouds that image. I realise I'm about to be criticised for such a view soI leave it up to you.

The shapes chosen for diffusers are really a matter of taste and cost. Avoid concave curves, which focus sound instead of dispersing it, but otherwise pyramids, lattices, or computer designed random surfaces all work well. The depth of a diffuser determines the lowest frequency that will be affected. A diffuser one foot deep will scatter sound down to 160 Hz. Diffusers can be built by the home studio owner quite simply by creating a multi surface plane. The typical one is lots of blocks of wood of various sizes glued onto a backing sheet. Go to a house construction site and ask for all the 100mm x 100mm (4" x 4") offcuts. Glue the blocks of irregular lengths onto a backing sheet of plywood, spray it with paint and stick it on the wall. You will now be the owner of a new trendy studio with a diffuser on the back wall of your control room.

(Sense a bit of cynicism??)

Diffusion In the studio

Diffusion in the studio is a great idea and one of the best way to add it is to have stone walls in your studio. Not flat stone but round and irregular stones that create a rigid random diffuse surface. The reverberation created in such a room will be rich and diffuse which is what you want in a good reverb unit. (Note here that some effects units have a control over diffusion in their reverb programs)The greater the "depth" of the diffuser the lower the frequencies affected. I recommend such a wall in a drum room if you want live drum sounds. Otherwise try the wooden block system, it works really well also



VARIOUS TYPES OF DIFFUSERS

I have called the angled - curved - pyramid shapes **absorbers/diffusers** because they can be built as low frequency absorbers yet will also act as diffusers. See the section on low frequency absorbers. Today various companies manufacture pre - built diffusers that can be purchased and installed in your studio.

I must say here that the last three diffuser types are pure diffusers and perform no other function whereas the the first three types can act a low frequency absorbers. In the home studio your room sizes are usually small and low and low-mid frequency coloration is your main problem so to waste treatable wall space with just a diffuser to me is a waste of wall space. Slat resonators also act as diffusers because the slats with the gaps break up the surface and I would advise you to use them instead. The best place to use diffusers is in a live room if you have the space to dedicate a room specifically for that.

Acoustics – Reverberation

In theory, it is easy to determine the reverberation time of a room. It depends on the volume of the room and the rate at which the sound energy is absorbed by the wall surfaces and the objects in the room. In a bare room, the reverberation time is thus proportional to the ratio of volume to surface. It is customary to define the reverberation time as the time required for the sound level to decrease by 60 dB (hence the abbreviation RT60). In 1922 a pioneer in the study of room acoustics, Wallace Sabine came up with the formula which is used here by this calculator:

$$RT60 = k(V/Sa)$$

- **k** is a constant that equals 0.161 when the units of measurement are expressed in meters and 0.049 when units are expressed in feet.
- **Sa** is the total surface absorption of a room expressed in sabins. It is a sum of all the surface areas in the room multiplied by their respective absorption coefficients. The absorption coefficients express the absorption factor of materials at given frequencies.
- **V** is the volume of the room.

Absorbers

Introduction

By using different construction techniques it is possible to treat the walls so they absorb sound at various frequencies. The following pages deal with each of the frequency bands high, mid and low. By using these construction techniques you can dramatically change the acoustics of a room. High frequencies are the easiest to absorb and it gets harder as the frequency lowers. Most home studio enthusiasts only seem to treat the high frequencies in the room yet it is the mid and low frequencies that cause all the room problems.

If you study the treatment for the low and mid frequencies you will notice that the high frequencies are not effected by this construction and it is possible to have a room where all frequencies have a similar reverberation time which is the idea of the whole exercise.

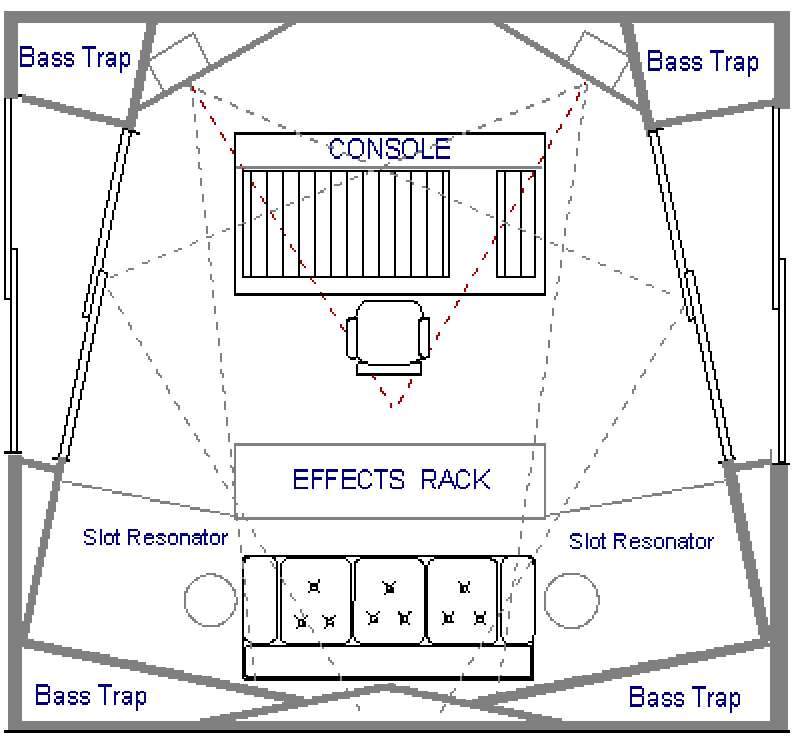
Absorbers – High Frequencies

Well just about anything absorbs high frequencies so be careful in this area. If you suck out all the high frequencies in a room your room will become lifeless. The main consideration in room acoustics is to aim to make the reverberation time near to equal in **all frequencies**. So if you put walls and walls of high frequency absorbers you will not have enough wall space to lower the low frequencies proportionately.

If you look at the coefficient of **absorption figures** for the various products you will note that whilst some attenuate the highs some also attenuate the low mids as well. 100mm (4") fibreglass for example not only absorbs high frequencies but it also works down into the low mids depending on how thick it is.

The other main factor is what are the highs in your room doing? Consider the fact that your high frequencies are coming from your speakers which have a directivity factor. In a standard multi - speaker system the highs are coming from the tweeters or horns. Both these units have a fan shaped dispersion of around 30 degrees. And create what is referred to as the on axis off axis effect. Stand in front of a speaker and you hear all the highs but go 30 degrees off axis and the highs start to reduce to the point that if you are 90 degrees off axis the highs are eliminated completely (apart fro highs that reach you my reflection from some other surface.)

Take a look at this plan of a control room:



Control Room Plan

The dotted lines indicate the axis of the high frequency projection. Note that the engineer is sitting on axis to the speakers yet someone sitting to the right of the console is off axis to the right speaker but still on axis to the left speaker. The high frequencies are reflected by the opposing walls (in this case glass doors). The idea of this control room design is make sure (by angling the walls) that the **high frequencies from the right speaker are not reflected back into your left ear.**

Once the sound passes the engineer the rear of the control room absorbs the sound and it doesn't come back to the engineer.

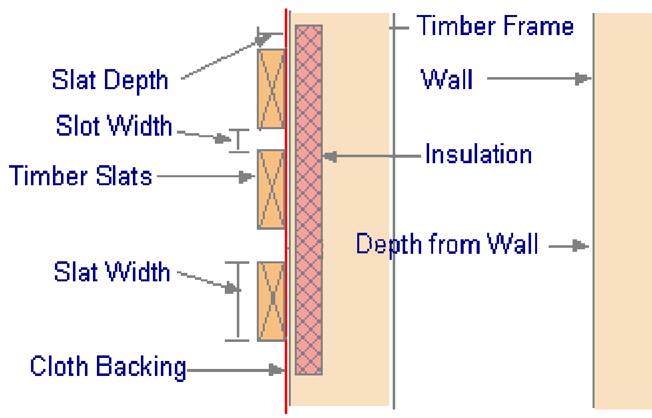
Absorbers – Middle Frequencies

If you look at the absorption coefficients of various materials you will notice that some of the fibreglass products absorb low-mid frequencies very efficiently as does a panel absorber with a fibreboard panel instead of a plywood panel. But the best low mid absorber (and the best looking) is the helmholtz resonator - often called a slat resonator.

THE HELMHOLTZ RESONATOR

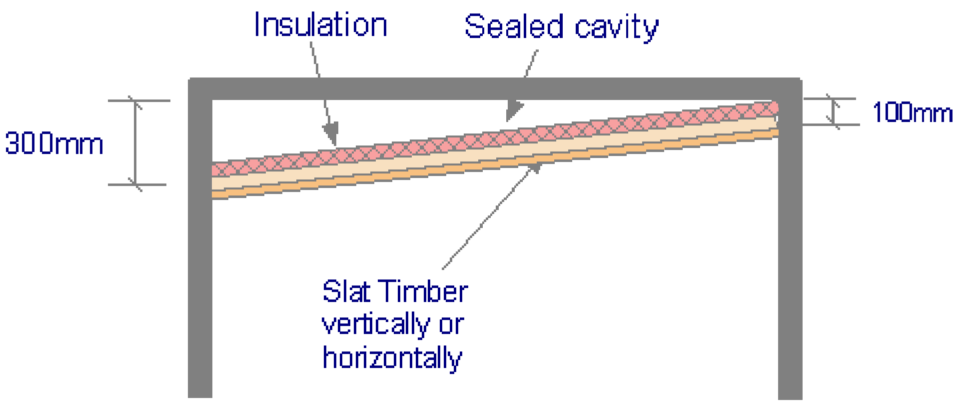
The helmholtz resonator (named after a Mr Helmholtz who discovered it) can best be demonstrated by taking a normal soft drink bottle and blowing over the mouth of the bottle - a note is produced. Now place some cotton wool in the bottle and try again. You will notice the note has reduced- well not really, the note is produced but the wool absorbs the resonance and turn the sound energy into heat! Imagine, if you lined a whole wall with bottles of various sizes, all filled with insulation material. You would now have a low-mid (200 - 500Hz depending on the bottle size) absorbing wall that as well as absorbing the low mids would also reflect or diffuse the high frequencies. I haven't tried it yet but it would be worth trying if you are short of cash because bottles are cheap. The Romans used to do it using clay jars which they placed around their theatres.

The helmholtz resonator is often called a slat or slot resonator because you can create a helmholtz resonator by building a wall with slats of timber separated by slots as in the following diagram



The timber slats can be either finished or rough sawn. If the gaps vary say 5mm, 10mm, 15mm,20mm and the wall is angled as shown below, a broad band low mid absorber is created that still keeps the the high frequencies alive. Remember the cavity behind must be sealed to an airtight container, like the bottle.

Further more, our scientists have created a formula with which we can tune the resonator to a specific frequency. If we vary the depth from the wall, slat width, slot width (and the slat depth) we can create a wall that is a broadband low-mid frequency absorber. The beautiful thing about these absorbers is that they still reflect high frequencies, in fact they will diffuse them which is even better.



The angle to the wall here can be either horizontally, as shown, or vertically with the 100mm at the bottom of the wall and the 300mm at the top.

As you can see a slat wall like this can break up parallel walls thus stopping standing waves. Because the distance from the front to the back is varying from 300mm to 100mm or around 12 degrees, the wall becomes a broadband absorber. So simple yet so effective! I've seen some beautiful looking ones where you cut the slots out of a sheet of quality particle board with a timber veneer.

Another form of helmholtz resonator is created using perforated plywood - i.e. plywood with hundreds of holes in it. We call it pegboard in Oz, you see it in hardware stores holding up tools etc. If you place a panel of this over an air cavity like in a **panel absorber** not only do the little holes act like bottle necks the whole panel acts as a low frequency panel absorber!

The formula for calculating the helmholtz resonant frequency is:

f = 2160 x sqrt (r / ((d x D) + (r + w)))

Where:

> f = resonant frequency in Hertz (Hz)
> r = slot width.
> w = slat width.
> d = effective depth of slot. (1.2 x the actual thickness of the slat)
> D = depth of box.

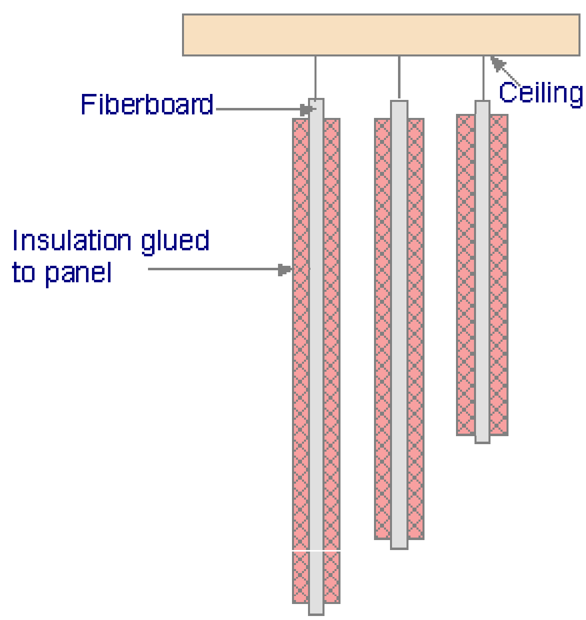
Absorbers – Low Frequencies

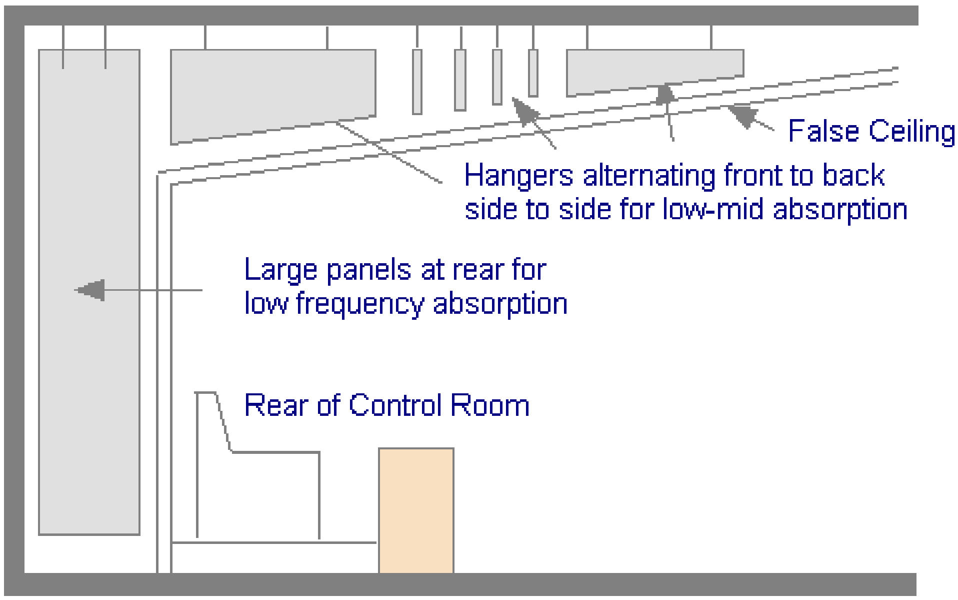
Low frequencies are big waves, consider that a 50Hz wave is 6.6m (21' 8'') and a 30Hz wave is 11m (36ft) long! That's 11m peak to peak -There's a lot of guys around here who would love to surf a wave like that! So to stop it requires special techniques.

There are basically two ways to control low frequencies.

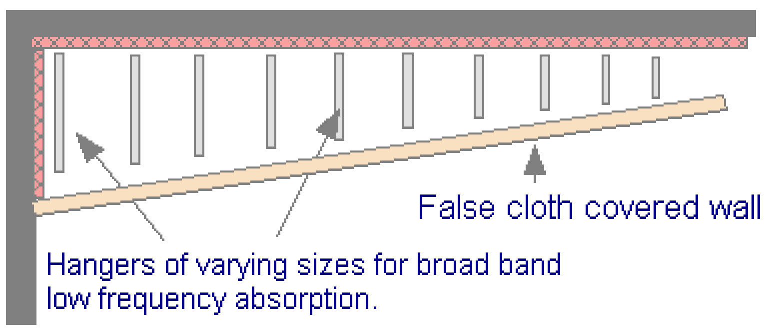
- **Acoustic Hangers**. This is a system of fibre board panels that are wrapped with insulation and are hung freely using wire or rope. The large hangers 1.8m x 500mm work in the low frequency range whilst the panels 1.2m x 300mm effect the low mid frequencies. It is common to have up to a 1.2m space at the rear of the control room with the large hangers whilst the smaller hangers are effective if suspended in the ceiling cavity created by a false ceiling.
- **Panel Absorbers**. A panel of plywood or particle board is placed over an air cavity with insulation glued to the back of the panel. The panel has a resonate frequency and when it occurs in the room it resonates and the insulation absorbs the energy.

Acoustic Hangers





The above drawing shows the rear of a typical control room design. The fibreboard panels are suspended from the ceiling with the sizes varying to give a broadband absorption field. They can also be hung behind a false wall in the studio as in the following drawing.



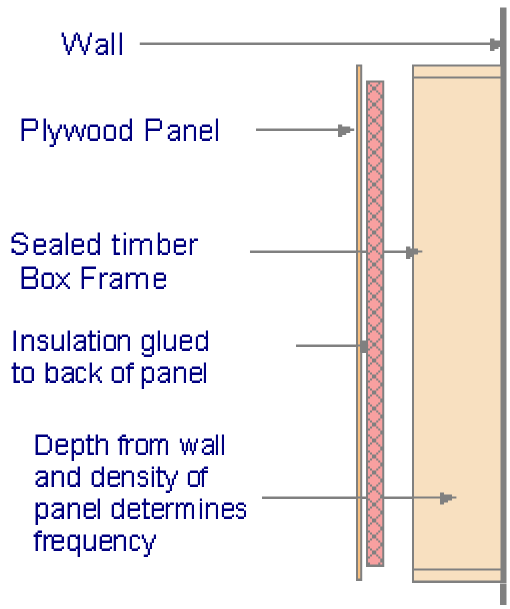
False Wall with Acoustic Hangers

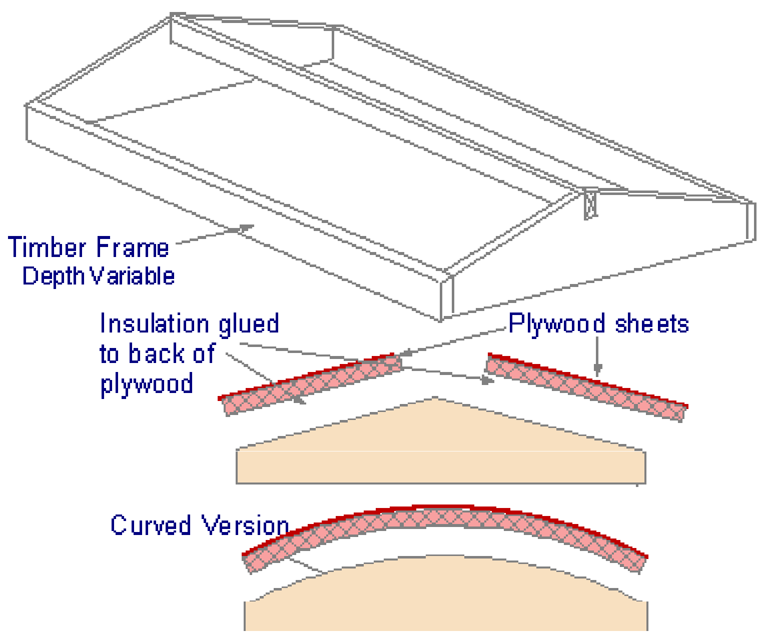
Panel Absorbers

A panel absorber is created when you place a sheet of plywood or fibreboard, with insulation glued to the back of it, over an air cavity. The panel will have a resonate frequency of its own, tap it and you will hear it. When it is placed over a **sealed cavity**, and insulation is attached to the back, everytime it hears its own note it resonates and the air in the cavity resonates and the insulation absorbs the resonance, hence absorbing the frequency! It is important to note that here we have an absorber that reflects the high frequencies and attenuates the low. With the hangers all that exposed insulation absorbs the high frequencies as well so the panel absorber has a place in the studio. The two factors determining the frequency of absorption are:

- The mass or density of the panel.
- The depth of the air cavity, i.e. depth of the sealed timber frame.

A panel absorber is made like this:





You can apply different shaped front panels

The other great advantage of panel absorbers is that they can have angled or curved fronts so when mounted on a wall or the ceiling they stop parallel wall interference and prevent standing waves creating **diffusion.**

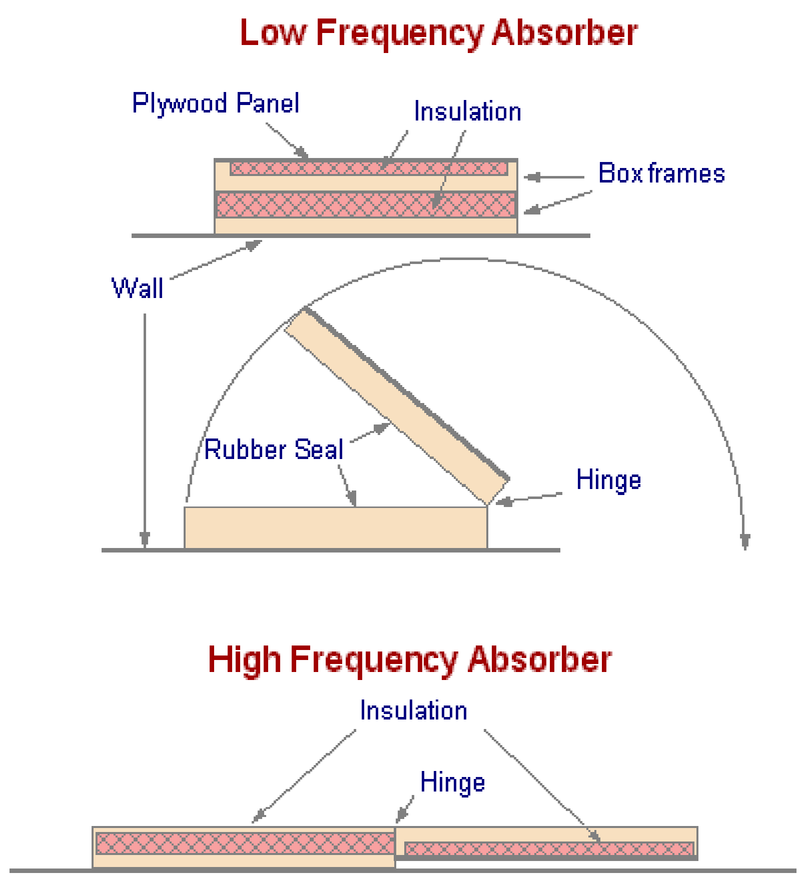
You can even tune this absorber by placing a contact microphone on the plywood panel which is plugged into a real-time analyser and blasting the panel with white noise or a swept tone with a speaker. When the frequency = the panel's resonate frequency the panel will vibrate and the frequency will show up on the real-time analyser. The thicker the plywood the lower the frequency and the greater the depth (depth of the timber box) from the wall the lower the frequency. **Using fibreboard as an alternative tends to create a low-mid absorber.**

You can create a broadband low frequency absorption wall by building a series of sealed boxes with different depths with each box being only 1m x 1m (3' x 3'). With a variety of different thickness of plywood you can cover the whole low frequency range. It looks good too. You can also alternate the fronts between panels and slats. (**See helmholtz resonators)**

For absorption coefficients and panel thickness check out the absorption coefficient **chart**.

Variable Panel Absorber

You can create a variable panel absorber by splitting the box into two boxes and placing hinges on one side so that it opens fully as per the following diagram:



VARIABLE PANEL ABSORBER

The variable panel absorber allows you to change the acoustics in a room. A wall of these absorbers can quickly change a room's acoustics from live to dead. A variation is to have a slat resonator in the bottom box so that when the box is opened it reveals a slat resonator so you end up with a wall of alternating low-mid absorbers and high frequency absorbers. If you can only afford the space for one studio this is an excellent addition as you can change the room acoustically to cover all situations.

Absorbers – Coefficient Chart

I got this chart off the web and it gives you an idea of how the different materials absorb sound at different frequencies.

Remember that full absorption is 1 whilst full reflection is 0

Absorption coefficients of common building materials and finishes

Floor materials	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
carpet	0.01	0.02	0.06	0.15	0.25	0.45
Concrete (unpainted, rough finish)	0.01	0.02	0.04	0.06	0.08	0.1
Concrete (sealed or painted)	0.01	0.01	0.02	0.02	0.02	0.02
Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02
Vinyl tile or linoleum on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Wood parquet on concrete	0.04	0.04	0.07	0.06	0.06	0.07
Wood flooring on joists	0.15	0.11	0.1	0.07	0.06	0.07
Seating materials	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**
Benches (wooden, empty)	0.1	0.09	0.08	0.08	0.08	0.08
Benches (wooden, 2/3 occupied)	0.37	0.4	0.47	0.53	0.56	0.53
Benches (wooden, fully occupied)	0.5	0.56	0.66	0.76	0.8	0.76
Benches (cushioned seats and backs, empty)	0.32	0.4	0.42	0.44	0.43	0.48
Benches (cushioned seats and backs, 2/3 occupied)	0.44	0.56	0.65	0.72	0.72	0.67
Benches (cushioned seats and backs, fully occupied)	0.5	0.64	0.76	0.86	0.86	0.76
Theater seats (wood, empty)	0.03	0.04	0.05	0.07	0.08	0.08
Theater seats (wood, 2/3 occupied)	0.34	0.21	0.28	0.53	0.56	0.53
Theater seats (wood, fully occupied)	0.5	0.3	0.4	0.76	0.8	0.76

Seats (fabric-upholsterd, empty)	0.49	0.66	0.8	0.88	0.82	0.7
Seats (fabric-upholsterd, fully occupied)	0.6	0.74	0.88	0.96	0.93	0.85
Reflective wall materials	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**
Brick (natural)	0.03	0.03	0.03	0.04	0.05	0.07
Brick (painted)	0.01	0.01	0.02	0.02	0.02	0.03
Concrete block (coarse)	0.36	0.44	0.31	0.29	0.39	0.25
Concrete block (painted)	0.1	0.05	0.06	0.07	0.09	0.08
Concrete (poured, rough finish, unpainted)	0.01	0.02	0.04	0.06	0.08	0.1
Doors (solid wood panels)	0.1	0.07	0.05	0.04	0.04	0.04
Glass (1/4" plate, large pane)	0.18	0.06	0.04	0.03	0.02	0.02
Glass (small pane)	0.04	0.04	0.03	0.03	0.02	0.02
Plasterboard (12mm (1/2") paneling on studs)	0.29	0.1	0.06	0.05	0.04	0.04
Plaster (gypsum or lime, on masonry)	0.01	0.02	0.02	0.03	0.04	0.05
Plaster (gypsum or lime, on wood lath)	0.14	0.1	0.06	0.05	0.04	0.04
Plywood (3mm(1/8") paneling over 31.7mm(1-1/4") airspace)	0.15	0.25	0.12	0.08	0.08	0.08
Plywood (3mm(1/8") paneling over 57.1mm(2-1/4") airspace)	0.28	0.2	0.1	0.1	0.08	0.08
Plywood (5mm(3/16") paneling over 50mm(2") airspace)	0.38	0.24	0.17	0.1	0.08	0.05
Plywood (5mm(3/16") panel, 25mm(1") fiberglass in 50mm(2") airspace)	0.42	0.36	0.19	0.1	0.08	0.05
Plywood (6mm(1/4") paneling, airspace, light bracing)	0.3	0.25	0.15	0.1	0.1	0.1
Plywood (10mm(3/8") paneling, airspace, light bracing)	0.28	0.22	0.17	0.09	0.1	0.11
Plywood (19mm(3/4") paneling,	0.2	0.18	0.15	0.12	0.1	0.1

airspace, light bracing)						
Absorptive wall materials	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**
Drapery (10 oz/yd2, 340 g/m2, flat against wall)	0.04	0.05	0.11	0.18	0.3	0.35
Drapery (14 oz/yd2, 476 g/m2, flat against wall)	0.05	0.07	0.13	0.22	0.32	0.35
Drapery (18 oz/yd2, 612 g/m2, flat against wall)	0.05	0.12	0.35	0.48	0.38	0.36
Drapery (14 oz/yd2, 476 g/m2, pleated 50%)	0.07	0.31	0.49	0.75	0.7	0.6
Drapery (18 oz/yd2, 612 g/m2, pleated 50%)	0.14	0.35	0.53	0.75	0.7	0.6
Fiberglass board (25mm(1") thick)	0.06	0.2	0.65	0.9	0.95	0.98
Fiberglass board (50mm(2") thick)	0.18	0.76	0.99	0.99	0.99	0.99
Fiberglass board (75mm(3") thick)	0.53	0.99	0.99	0.99	0.99	0.99
Fiberglass board (100mm(4") thick)	0.99	0.99	0.99	0.99	0.99	0.97
Open brick pattern over 75mm(3") fiberglass	0.4	0.65	0.85	0.75	0.65	0.6
Pageboard over 25mm(1") fiberglass board	0.08	0.32	0.99	0.76	0.34	0.12
Pageboard over 50mm(2") fiberglass board	0.26	0.97	0.99	0.66	0.34	0.14
Pageboard over 75mm(3") fiberglass board	0.49	0.99	0.99	0.69	0.37	0.15
Performated metal (13% open, over 50mm(2") fiberglass)	0.25	0.64	0.99	0.97	0.88	0.92
Ceiling material	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**
Plasterboard (12mm(1/2") in suspended ceiling grid)	0.15	0.11	0.04	0.04	0.07	0.08
Underlay in perforated metal panels (25mm(1") batts)	0.51	0.78	0.57	0.77	0.9	0.79
Metal deck (perforated	0.19	0.69	0.99	0.88	0.52	0.27

channels,25mm(1") batts)						
Metal deck (perforated channels, 75mm(3") batts)	0.73	0.99	0.99	0.89	0.52	0.31
Plaster (gypsum or lime, on masonary)	0.01	0.02	0.02	0.03	0.04	0.05
Plaster (gypsum or lime, rough finish or timber lath)	0.14	0.1	0.06	0.05	0.04	0.04
Sprayed cellulose fiber (16mm(5/8") on solid backing)	0.05	0.16	0.44	0.79	0.9	0.91
Sprayed cellulose fiber (25mm(1") on solid backing)	0.08	0.29	0.75	0.98	0.93	0.76
Sprayed cellulose fiber (25mm(1") on timber lath)	0.47	0.9	1.1	1.03	1.05	1.03
Sprayed cellulose fiber (32mm(1-1/4") on solid backing)	0.1	0.3	0.73	0.92	0.98	0.98
Sprayed cellulose fiber (75mm(3") on solid backing)	0.7	0.95	1	0.85	0.85	0.9
Wood tongue-and-groove roof decking	0.24	0.19	0.14	0.08	0.13	0.1
Miscellaneous surface material	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**
People-adults (per 1/10 person)	0.25	0.35	0.42	0.46	0.5	0.5
People-high school students (per 1/10 person)	0.22	0.3	0.38	0.42	0.45	0.45
People-elementary students (per 1/10 person)	0.18	0.23	0.28	0.32	0.35	0.35
Ventilating grilles	0.3	0.4	0.5	0.5	0.5	0.4
Water or ice surface	0.008	0.008	0.013	0.015	0.02	0.025

RT60 relates to intelligibility. Diffractors reduce pronounced reflection by breaking up the sound wave before reflecting it back. This does not reduce reverberant energy, but does reduce echo spikes that may otherwise exceed -60db of direct, thus lowering RT60 and improving intelligibilty, **but not necessarily improving the listening environment for music**.

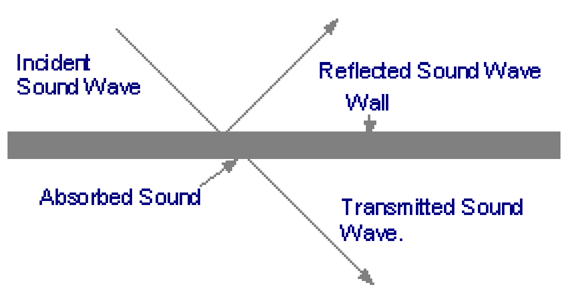
Contruction

Introduction

Isolation

Before you can consider your construction you must consider your isolation requirements. Pages could be written on this subject but you must consider how much isolation you really want. The idea of perfect isolation from external noise started in the days when loose miking techniques were used. One microphone suspended over a string section meant the mic was wound up fully and was extremely sensitive to ambient noise. Nowadays a mic 6" from a marshal amp is a totally different story. At Big Toe Studios I often have a window open and the artist will say -" Hey I can hear the birds, should I close the window?" To which I reply, "No, the only person who will hear it is some stoned out freak with headphones on who will remark excitedly - wow man I can hear birds on this track!" But if you have problem neighbours who don't like drums pounding all day I suggest you apply a certain amount of sound isolation.

The acoustic term here is **Transmission Loss.** When sound hits a wall there is a certain proportion of the sound reflected back into the room, some is lost in the absorption of the wall and the rest travels through the wall and is called the transmission loss.



TRANSMISSION LOSS

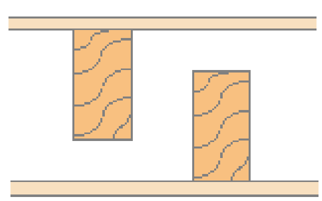
The amount of sound that is transmitted through the wall is called the:

Sound Transmission Class- **STC**

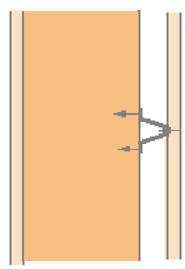
The transmission loss obviously varies relative to frequency - the **STC** is a specially weighted reading across all frequencies and is centred around 500Hz.. Every different wall construction has a different transmission class.

When sound hits a wall the energy is transferred through the plasterboard to the other side via the connection to the stud. This problem can be reduced via two ways:

- **Staggered Studs**. Here you use two studs for each side of the wall. The plasterboard on one side is attached to one stud and the plaster on the other side is attached to the other stud. The two studs are connected to a common base and top plate.



- **Flexible Channel**. Here a metal channel is attached to the stud and the plasterboard attached to the metal channel thus reducing the connection to the stud. The channels are mounted horizontally at 600mm (2 feet) centres. This system is extremely effective - check out the figures in the **STC Chart**.



Studs:

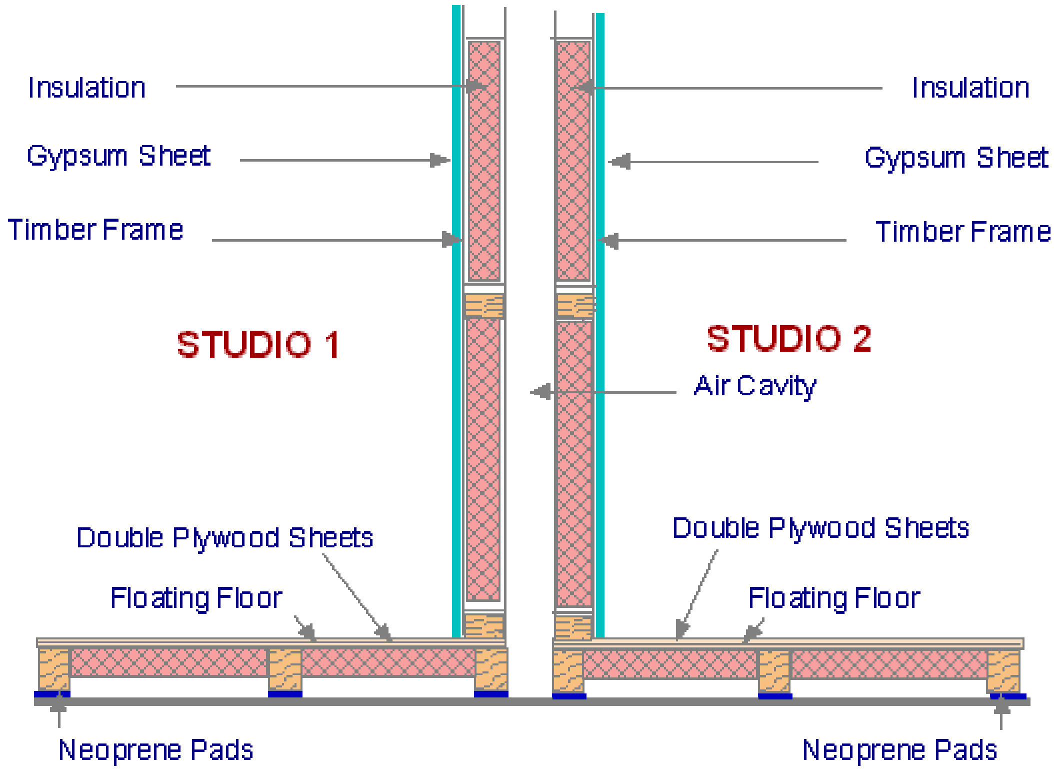
- Except for staggered stud systems, **substituting timber studs for steel studs** generally results in a significant **decrease** in sound isolation.
- Increasing the thickness of steel studs from 0.55BMT to 0.75BMT or 1.15BMT will decrease sound isolation
- Decreasing the stud spacing will decrease the sound isolation.

It is also interesting to note here that the higher the transmission loss the less reflected sound. In other words in a tent there is a high transmission loss but also a low amount of reflected sound so a tent makes a good recording room!! So people in the country who can afford a high transmission loss because there's no close neighbours can allow their sound to get away thus reducing the amount of treatment required to handle the reflected sound.

The standard gypsum wall in a house has a high transmission coefficient at 100Hz as well as a high absorption figure because the gypsum panel's resonate frequency is around that figure. Therefore the reverb in the room is low around 100Hz but higher around 300Hz where the transmission and absorption are lower. That is why most rooms in a house have a reverb peak around 300Hz. (You know the one you keep taking out of kick drums and toms.) Check it out on the **reverberation calculator.**

Perfect isolation can cost heaps because there is only one thing that will stop sound and that is **MASS**. The following solutions apply:

- **Floating the rooms**. A typical construction consists of creating new rooms within your existing rooms. This means building a floor on top of the existing floor with neoprene isolation pads and Rockwool on the underside and then building walls and a ceiling using the new floor as a base. This is the ideal system for total isolation because the new room is not mechanically connected to the main room but it is also the most expensive system. The main advantage of floating rooms is the low frequency isolation it gives. If you are building in a block of flats it would be essential as it is the only real way of achieving total sound isolation but if you are building a garage studio it really would depend on how much isolation you require. If you are an acoustic folk band - forget it - if you are a heavy metal power band it is essential because it is the only way you will stop the bass and kick drum from annoying your neighbours.
- **Double Walls**. This basically means building two timber/gypsum sheet walls between each room with Rockwool in the cavity. If you wish to go further you can double the layer of gypsum and even further by sandwiching a layer of fibre board between the two sheets of gypsum. (This is extremely effective because sound doesn't like going through changing medium densities). There are some companies who make sound isolation gypsum which is thicker and heavier than normal gypsum sheet. In Australia it's called Soundcheck and is 16mm(5/8") thick. The hollow concrete block -(Besser Block) is an excellent wall construction as it attenuates sound efficiently and cheaply.
- **Sealed Environment.** There is one important factor that must be understood about sound isolation. If you build a beautifully sealed wall between two rooms you will get good isolation **BUT** if you put one nail hole in the wall you will loose a lot of the isolation!! Sound is really not the waves we keep on describing but air pressure difference so if you allow the two air masses to join at any point the pressure gradient will transfer, so **make sure that all walls are sealed tightly**. Also make sure all joints around doors, windows and air-conditioning ducts are sealed.



Double Wall with Floating Floor

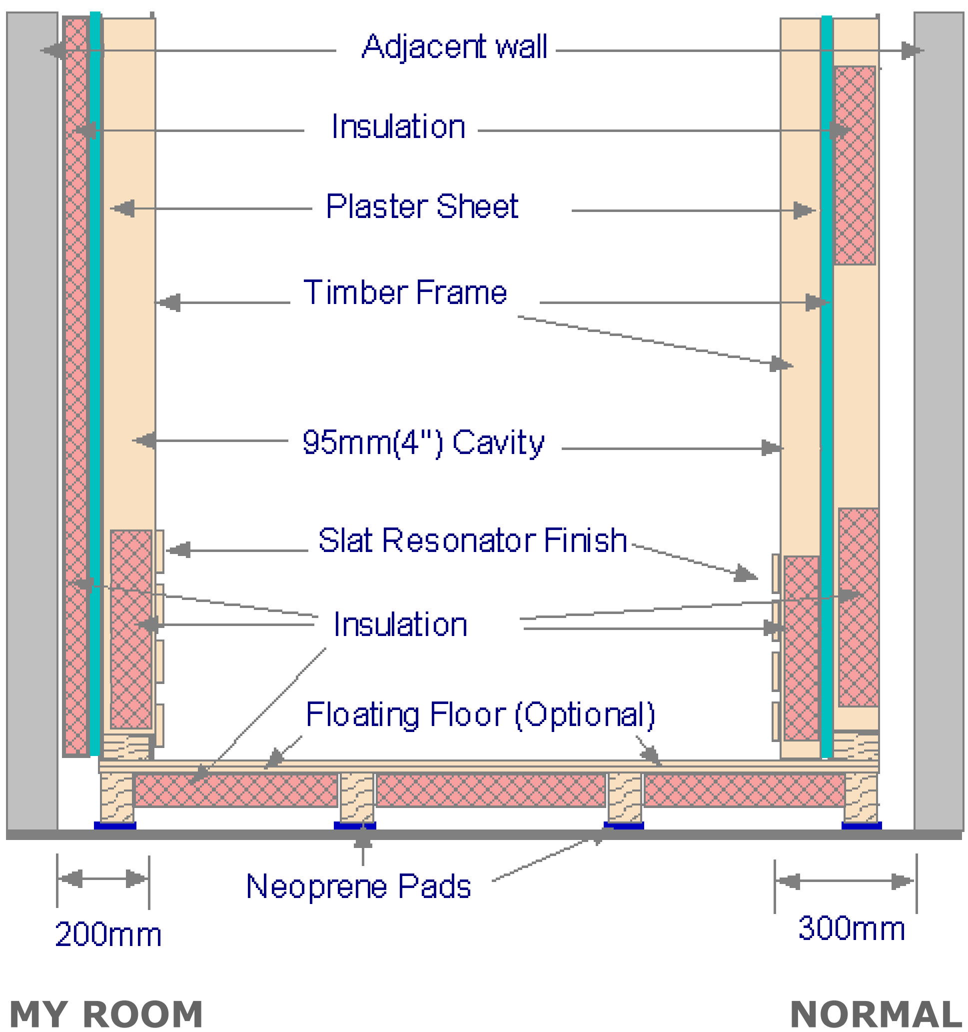
In the drawing above I've drawn a single gypsum (pale blue) layer but adding to the layer can dramatically increase the transmission loss. The options are

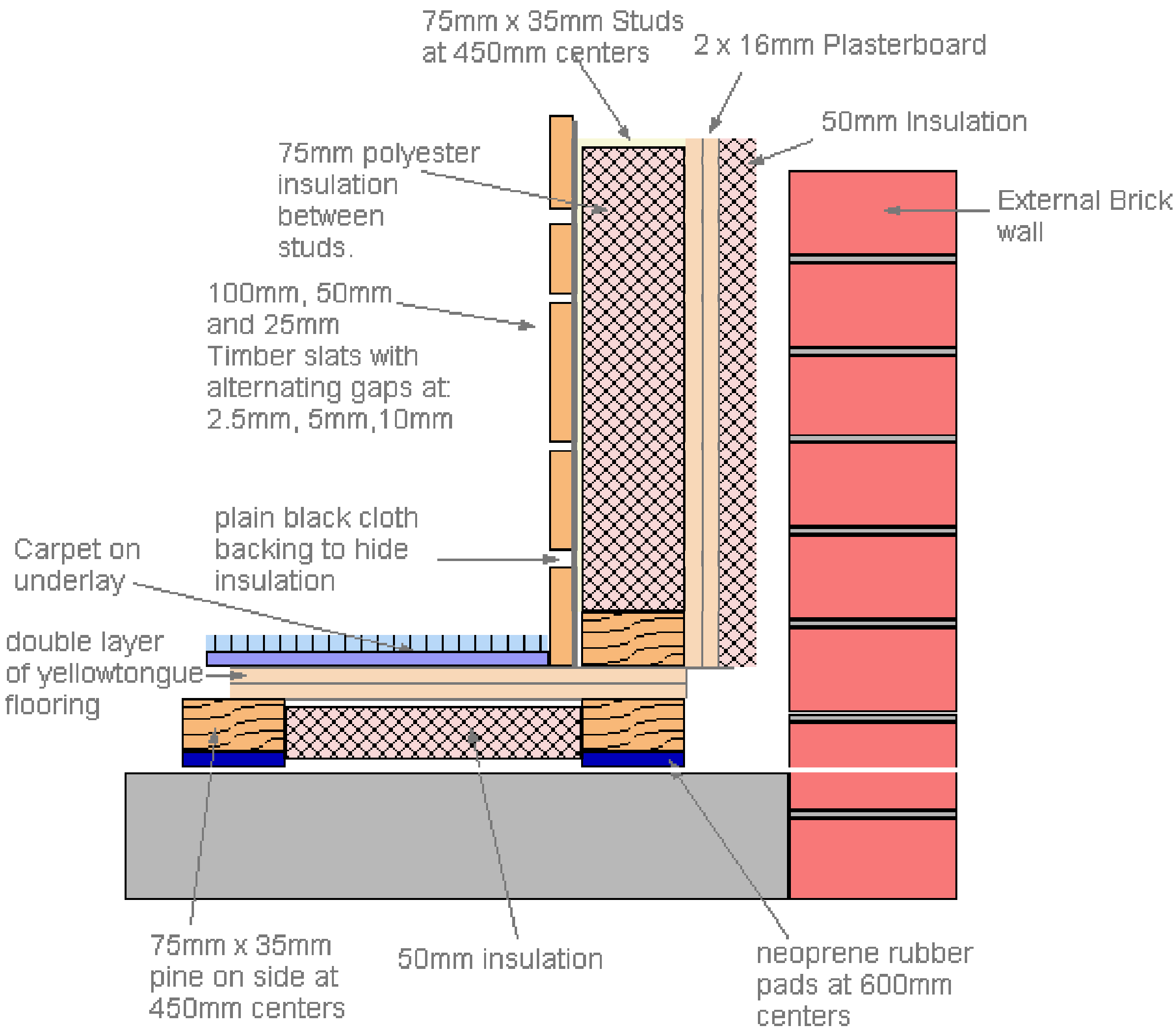
- Adding another layer of gypsum which is glued (not nailed) to the first sheet and should be a different thickness than the first sheet. i.e. 16mm (5/8") and 12mm (1/2")
- sandwiching a layer of fibreboard between the two sheets.

This really works well, a double wall with a triple layer as described above on a **floating floor** will create a room that will allow you to set up a band and not hear it outside the room! Just remember that all the sound is now trapped inside the room and heavy acoustic treatment is required to control it all.

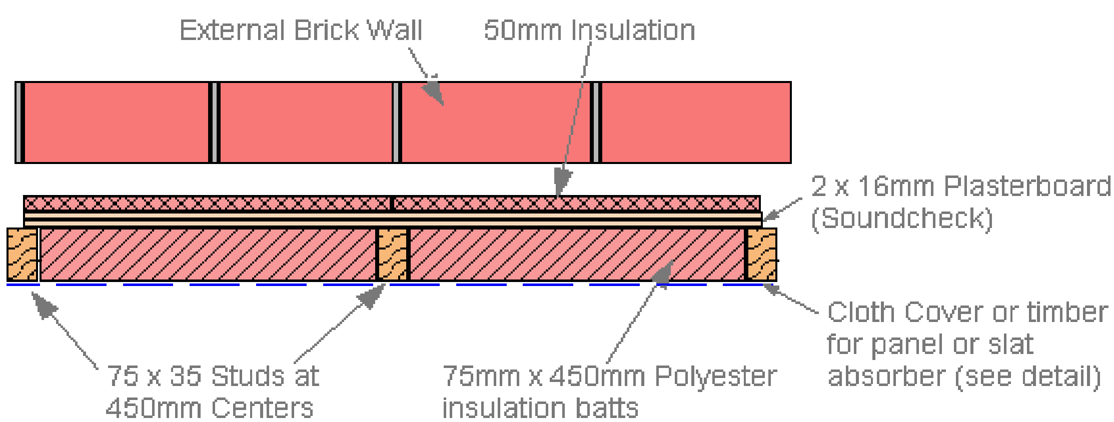
Construction – Walls and Ceilings

In the page on isolation I describe the standard double wall construction on a floating floor with a resultant wall thickness of 300mm.(1ft). That is 100mm (4")for each wall and a 100mm (4")air space between. The finished room then has a wall surface of plasterboard that requires further acoustic treatment to handle the reflected sound within the room. If you then put 100mm of treatment on each wall you end up with a wall 200mm(8") thick and a total wall thickness including the air space of 300mm (24"). In the home studio space is precious so a small saving of wall thickness can really help. So I have developed a simple and cost effective solution.

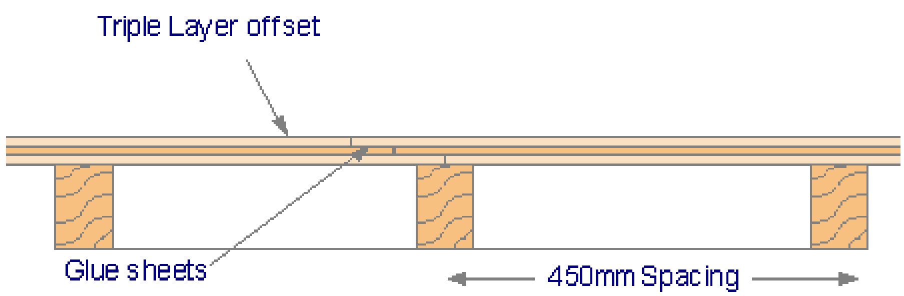




Wall Detail with Slot Resonator finish



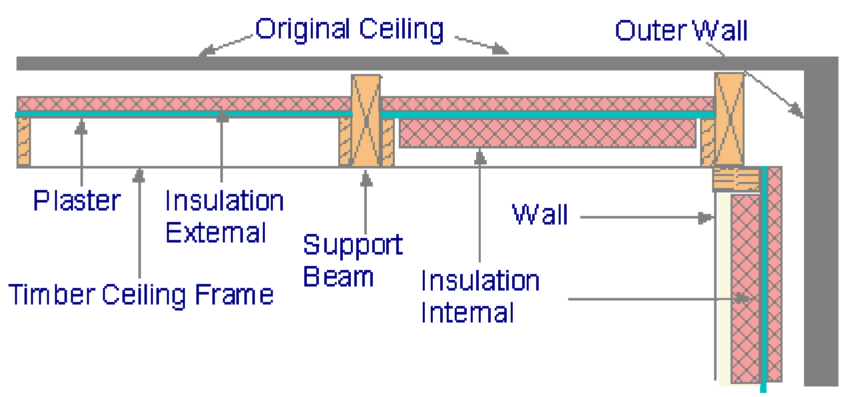
This system halves the thickness of the wall (100mm(4") instead of 200mm(8")) and makes the 95mm(4") cavity in the wall available for acoustic treatment. (Slat resonator depicted in drawing) Construction requires building the wall panels on the floor, applying the outer cladding and gluing the insulation to it then standing the wall panels up into place. You end up with a wall with the cladding on the outside and a 100mm (4") cavity for internal acoustic treatment. Obviously the panels must be sealed when connected to each other and if you are using a double or triple layer you can seal it like this.



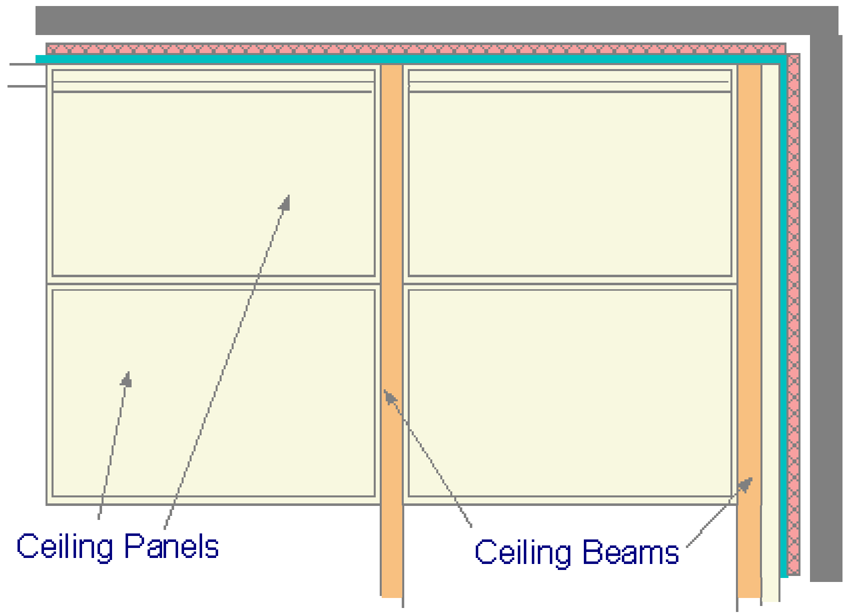
Offsetting Sheets for a good seal

CEILINGS

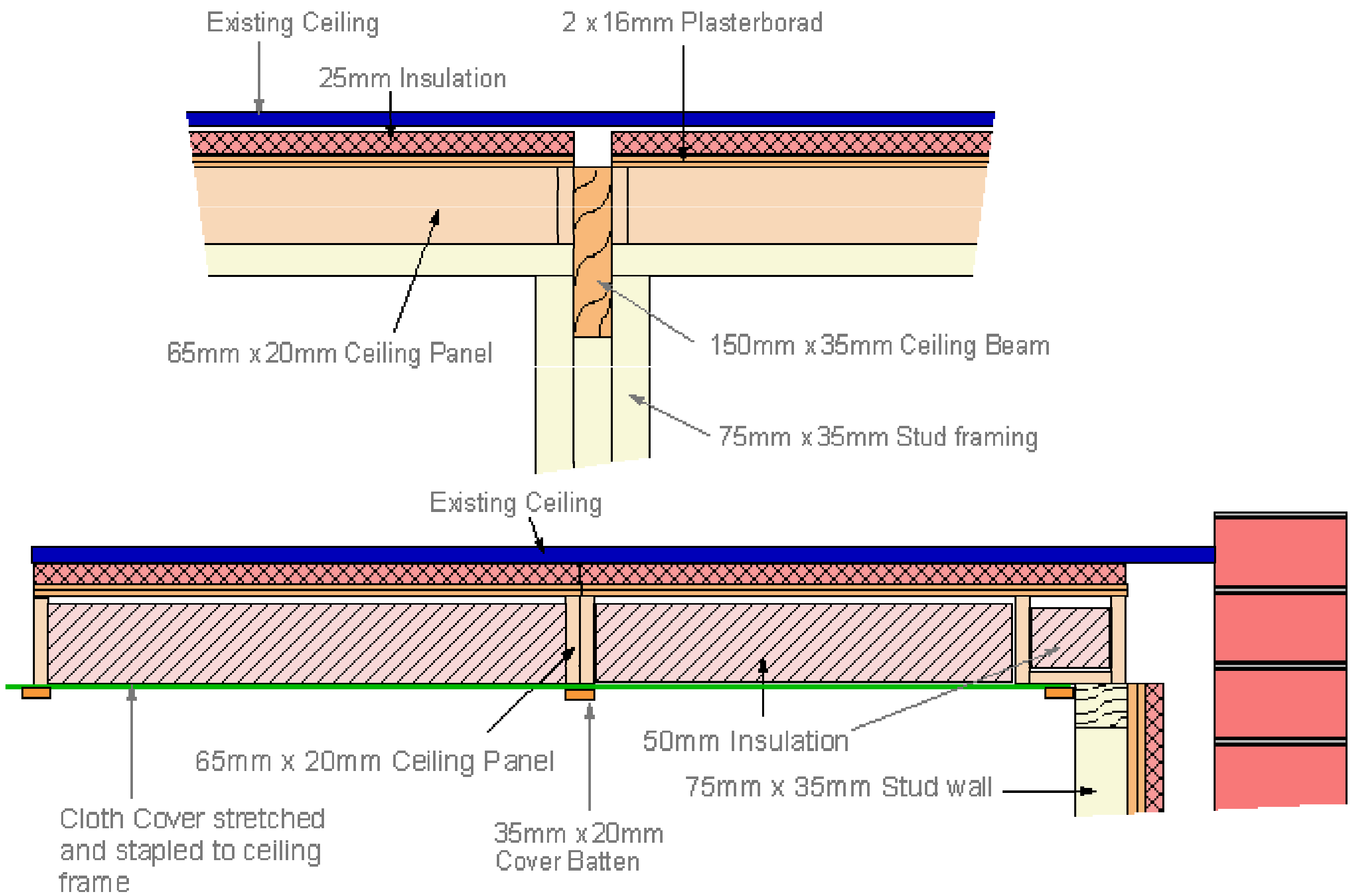
A ceiling can be built using a similar system. Here again any savings in height can benefit the home studio builder. Support beams are placed on the inner walls and ceiling panels are attached to the beams thus:



CEILING ELEVATION



CEILING PLAN



CEILING DETAIL

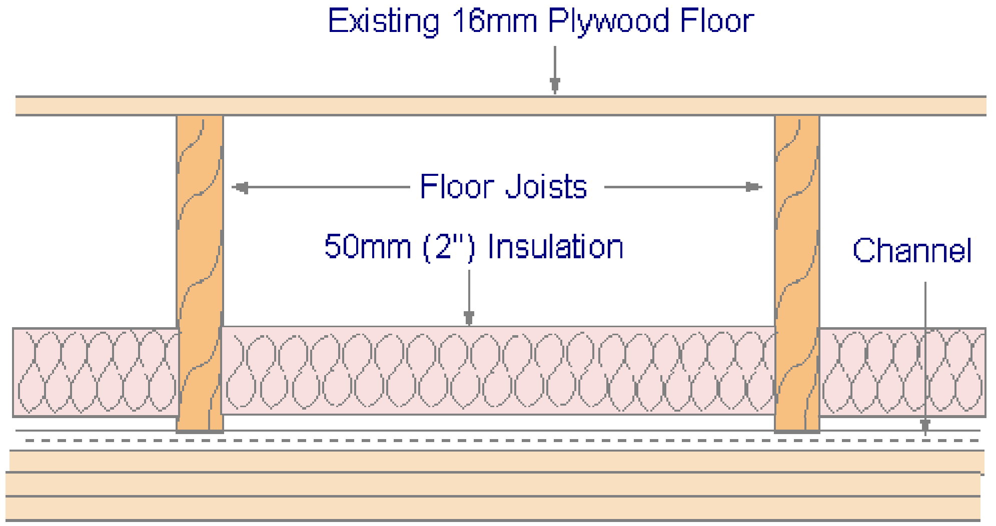
This is similar to the wall construction where the gypsum is on the outside thus freeing the 95mm(4") cavity for acoustic treatment.

The beauty of this construction is that it can be made modular. The wall and ceiling panels can be made on the floor then placed in position and joined together with a silicon seal between panels and screwed together and to the floor. They could also be made in a joinery factory and then screwed together at the site. This means it can be disassembled and moved. If you are renting, or shift house, you can take it with you!

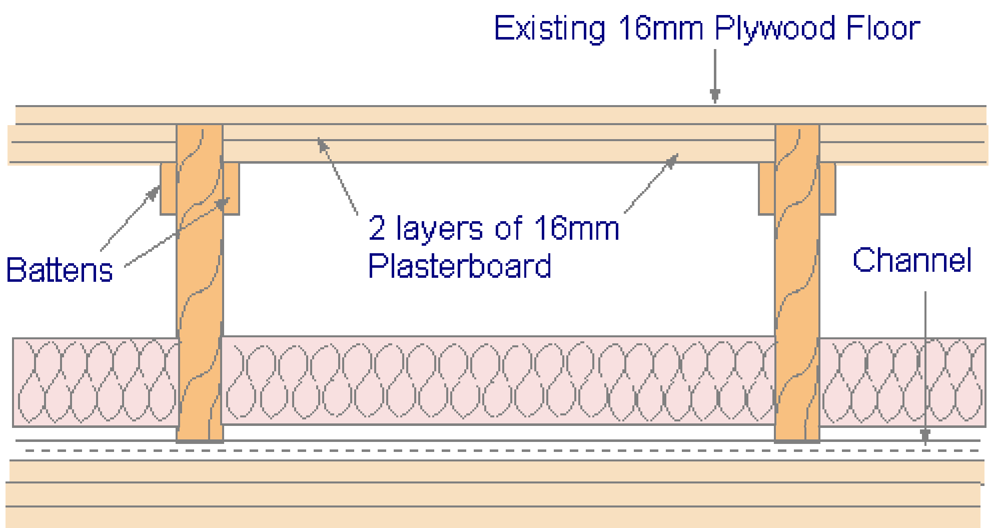
The individual wall and ceiling panels can be treated acoustically using different treatments as described in the acoustic treatment pages.

Sealing an Existing Ceiling

Plans and STC ratings for sealing an existing ceiling can be found on the **STC Chart** page.



The above drawing shows a typical system for sealing an existing ceiling. The plasterboard is attached to a flexible channel thus mechanically isolating it from the existing ceiling. For even more isolation you can add an extra lining under the existing floor thus:



This system gives an STC rating of around 60 which should stop you from annoying the rest of the house and your neighbours.

Construction – Floors

Adding a floating floor can dramatically increase your sound isolation because it disconnects the whole room structure from the rest of the building. This is especially necessary when isolation of low frequencies such as bass drums and bass amps is required.

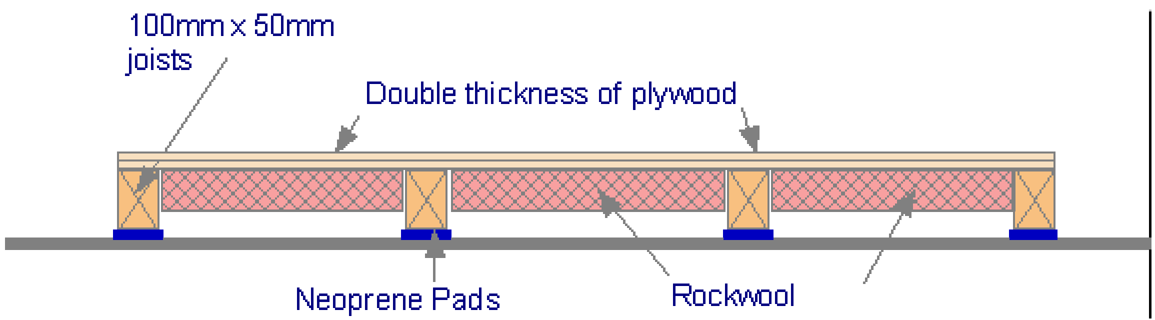
There are two ways of floating a floor.

- **Floating Timber Floor**
- **Floating Concrete Floor**

The floating timber floor is the more typical for a home studio whereas commercial studios (usually built in commercial buildings) usually opt for the floating concrete floor.

Floating timber floor

This consists of laying a double layer of 16mm (5/8") plywood or particle board flooring on 100 x 50 (4" x 2") joists that have neoprene pads placed at the points where the original flooring joists are. Rockwool is placed in the cavity between the joists to dampen any resonance.

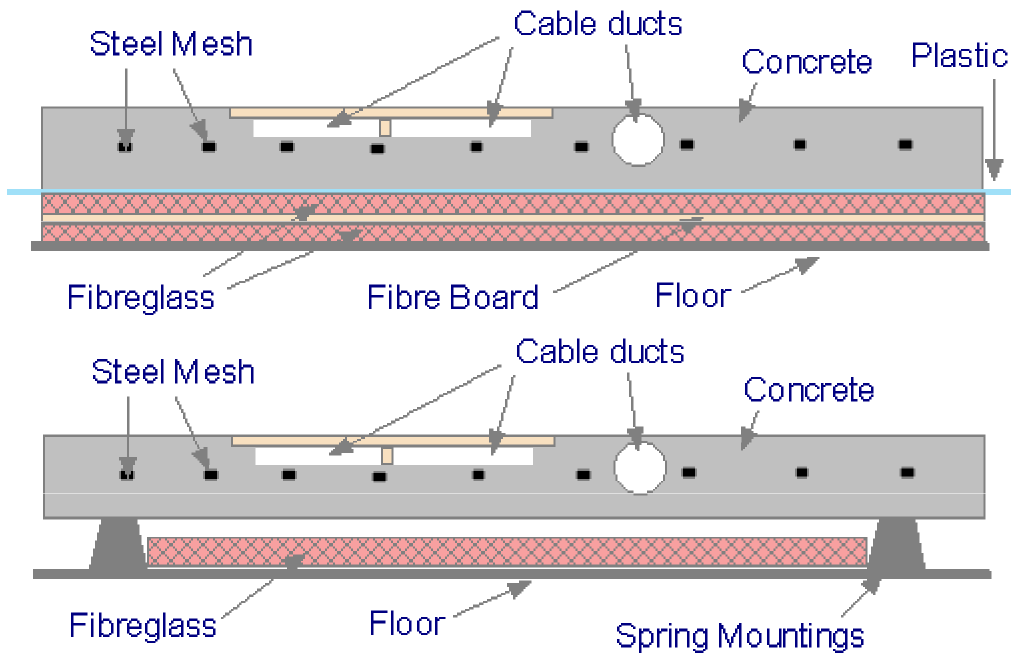


FLOATING TIMBER FLOOR

Floating Concrete Floor

Floating a concrete floor also gives excellent isolation. You can suspend the floor:

- on proprietary spring loaded suspension pads that are commercially available
- or you can float it on plastic which sits on a double layer of fibreglass with a layer of fibreboard sandwiched between the sheets.

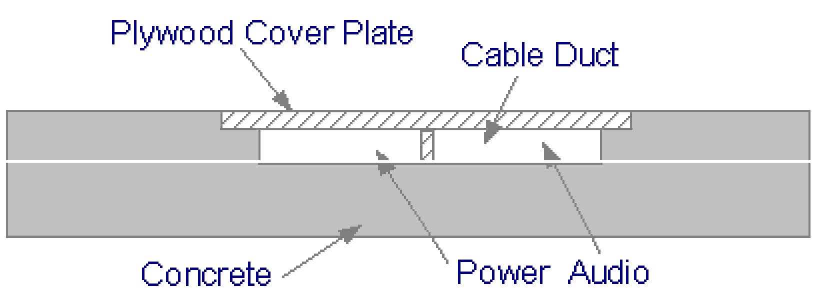


FLOATING CONCRETE FLOOR

As you can imagine the concrete compresses the fibreboard between the sheets of fibreglass and creates a multimedium isolation barrier. The concrete has a reinforcing steel mesh laid in it.

Cable Ducts

Don't forget to place your cable ducts in whatever floor structure you choose. There is nothing worse than cables all over the floor in a studio because they forgot to lay proper cable ducts. The ducts can be standard poly drain pipe or you can create a wide shallow duct in your formwork. It is advisable to run your power down one duct and your audio down another or split your one duct into two as shown.



CABLE DUCT

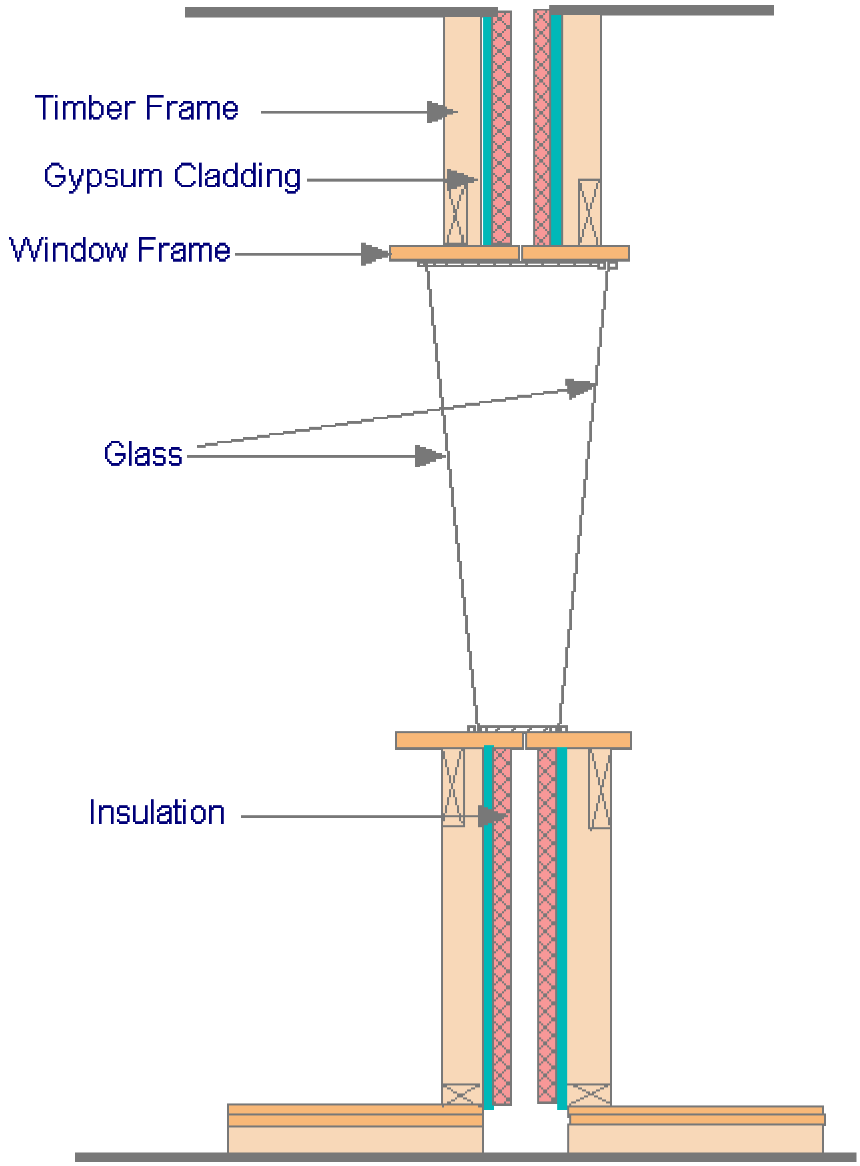
When your cables go through walls make sure that you seal around them or all the work you put into creating a sealed room will be lost.

Construction – Windows & Doors

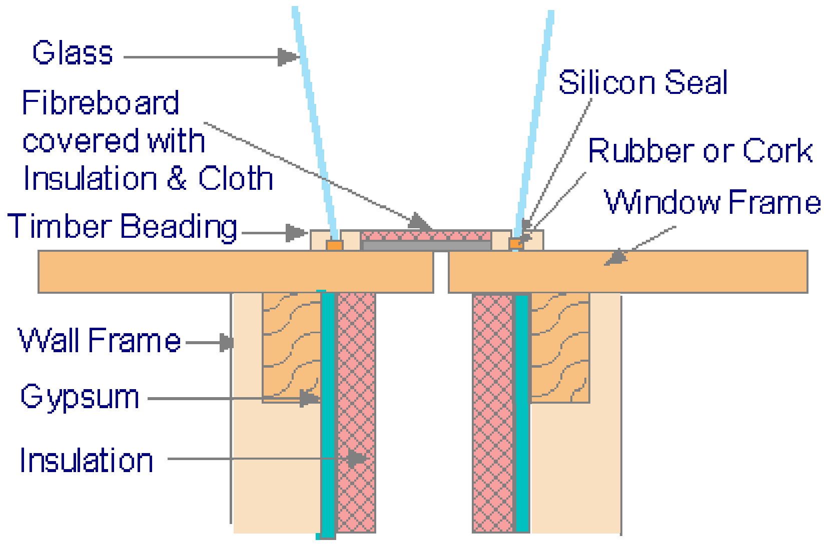
Windows and doors require special construction because no matter how much you seal your walls if the windows and doors aren't built correctly your isolation will be ruined. The main thing with windows is that they must have the following features:

- **Different Glass Thickness**. It is essential that the two sheets of glass be different in thickness. I recommend that you put the thicker of the two panes on the control room side. The thicker the glass obviously the better the sound isolation plus the thicker glass has a lower resonate frequency. Unfortunately thick glass is expensive. I would suggest you try 8mm and 10mm glass. (5/16", 3/8"). Any thinner and you are going to start getting resonate frequencies from the glass and inadequate sound isolation.
- **Angles.** The two sheets of glass must be at an angle to each other else the two sheets will interact in a resonate sympathy and the sound reduction properties will be reduced. You can angle the glass as in the following drawing but don't forget that the glass can also be angled in the horizontal plane as well as the vertical plane.
- **Silica Beads.** Because the windows are sealed the cavity created is a different temperature and humidity than your rooms which are probably air conditioned. It is therefore possible for the glass to steam up as in your car but not quite as dramatically. It is therefore recommended that you purchase some silica beads (like you get in a little sachet when you purchase a quality camera or the like) and put them in the cavity between the glass.
- **Insulation.** The cavity between the glass is like any space and will have a reverberant field so you must line around the cavity with insulation. The easiest way to do this is to cut sheets of fibreboard to the shapes and then glue thin fibreglass to it. Then you can wrap cloth around it for aesthetics and glue it into place. It is also a good idea to drill 25mm - 50mm (1" - 2") holes in the fibreboard in which you can put the silica beads.

The following drawing shows how to construct your windows.



WINDOW CONSTRUCTION



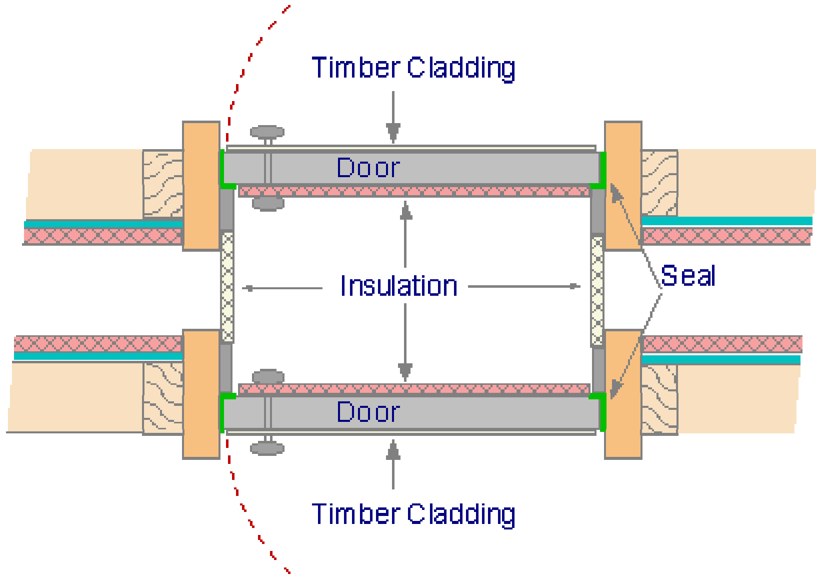
WINDOW CONSTRUCTION DETAIL

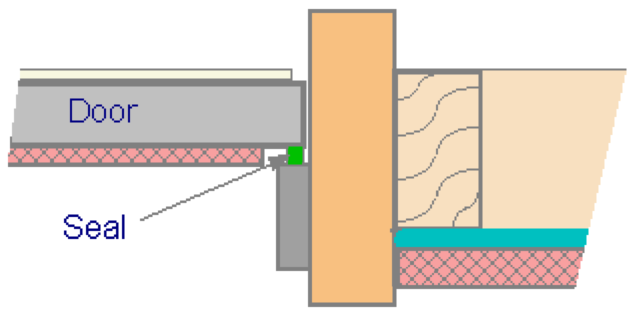
DOORS

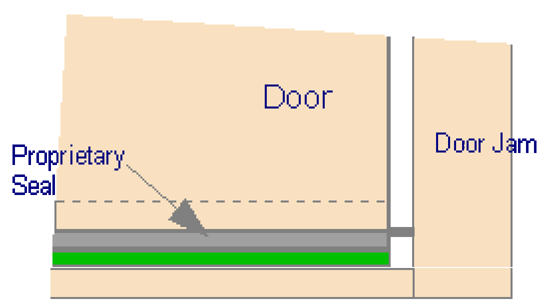
You can use two types of doors in a studio. Solid core doors or glass doors. Obviously if you wish to use glass doors the glass, like in the windows above, must be of a reasonable thickness to stop resonance. I'd suggest a minimum thickness of 8mm (5/16") yet obviously the thicker the better. Glass doors are good because they increase the communication factor which is important in a studio but if you are to use a two door sound lock you must have the doors at an angle to each other or you will get standing waves between them that will reduce isolation.

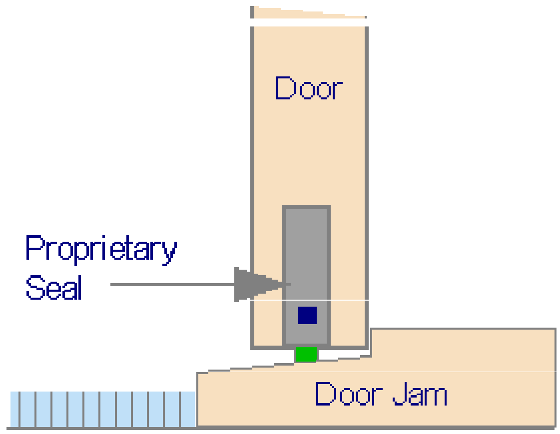
Hinged Doors

- **Seals.** As with windows once again correct sealing of doors is the main determinant that effects the sound isolation. Doors must be sealed all round and it is advisable to purchase proper commercially made door seals. There are a number of different manufacturers of door seals and I suggest you contact your local supplier. The most important seal is the one at the bottom of the door as it is the hardest seal to make. Some commercial manufacturers make a seal that has a spring loading so that when the door is closed a lever is compressed that causes a rubber seal to be forced downwards on to the door jam. When the door is opened the seal is lifted again.
- **Thickness**. It is recommended that you purchase solid core doors. If you wish to isolate you can clad the room side with extra timber that gives a nice finish and increases the effective sound isolation.
- **Insulation**. Like the window the two doors create a resonate cavity when closed so it is advisable to line the cavity and the doors with some insulation and cover with cloth.


Timber Cladding
Door
Insulation
Seal
Door
Timber Cladding


Door
Seal


Door
Door Jam
Proprietary
Seal



SEALING DOORS

You can purchase proprietary door seals that fit into the base of the door. The unit has a sprung button that when the door is closed forces a rubber seal down onto the door jam. When the door is opened the spring releases the seal.

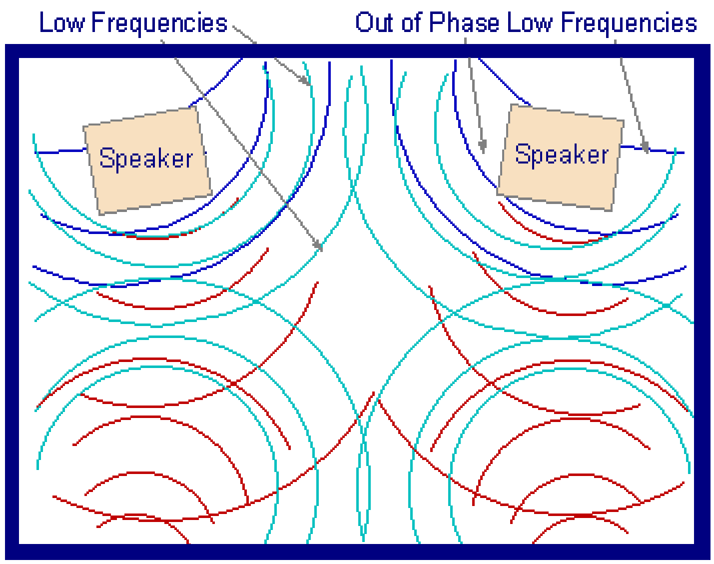
Sliding Doors

I personally like sliding glass doors in studios because of the visual communication they afford. Like windows they can't be parallel so I always put them at an angle in the horizontal plane. (The vertical plane creates unbelievable problems with runners and seals.) Sliding doors can be made of either timber or aluminium.

- **Seals.** Naturally a glass sliding door will not have the sound isolation of a hinged door purely because of the construction complexity but if you use a quality door and discuss the seal problems with your local manufacturer you can come up with a pretty good seal.
- **Thickness**. I recommend you use at least 8mm (5/16") glass but here again the thicker the better but too thick makes the door extremely heavy to slide.
- **Insulation.** Once again the cavity between the doors must be lined with insulation to stop the reverberation within the cavity. The same method as in the window (i.e. cloth over fibreglass over fibreboard is the simplest system.)

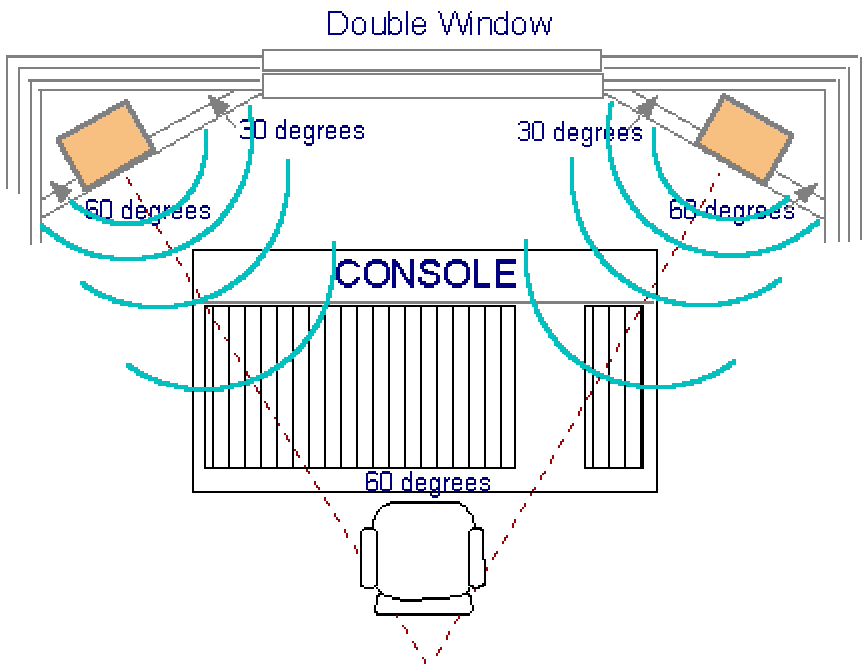
Construction – Speakers

As discussed in the opening page, the car and open air are good listening environments because they have either no reverberation or a controlled reverberation field. One of the key points was the flush mounting of the car speakers. By building your speaker boxes into the wall you can tighten the bottom end of the whole system because you eliminate the reflections that emanate from the back of the speaker, hit the wall and then come back to you in and out of phase.



Here the sound from each speaker comes back off the walls and creates a general mayhem of frequencies in the middle **where the engineer would probably be sitting.**

In the open air the sound waves are passing you and never come back.



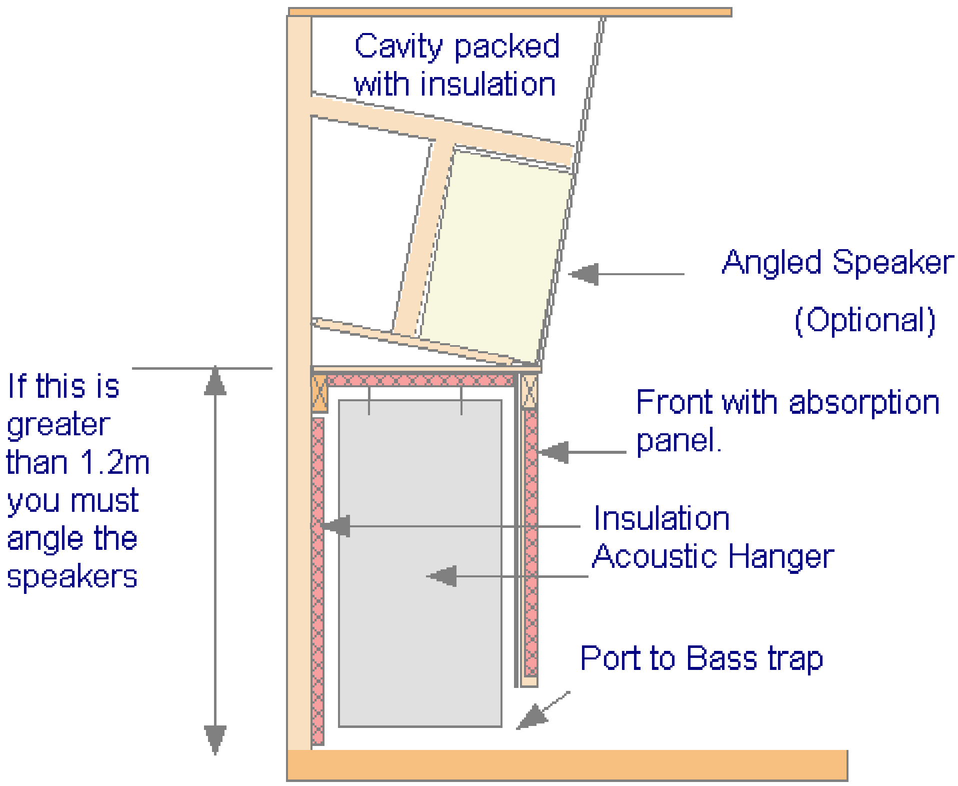
Flush Mounted Speakers

Look what a difference the flush mounting makes to the speaker wave fronts. The difference to the ear is even more dramatic.(As with most techniques in the modern studio in the past 3 decades **Tom Hidley** was the acoustician who started it.) The angles give what is referred to as a 60 degree monitoring system. Some studios played with 90 degree monitoring which gave a wider image and is an option you may experiment with. I used it at Music Farm Studios and I really liked it as the image was really wide yet the centre was still tight.

As far as the construction is concerned it has to be solidly built. As with all studio construction glue and screw as you go. Usually a frame is made and then a box 2mm bigger than the speaker box is built so the speaker slips in tightly so you are in fact pushing hard against the air pressure when you place the speakers in it. Some people line it with rubber pads so that the speakers are suspended and are mechanically isolated from the whole frame. You could build them in concrete which would be ideal but expensive.

The angle of the speakers is set so that they create a 60 degree angle at the focus. If you want to mount them high you must angle them down so that they point at the engineer. I find it annoying when I go to a studio and sit at the console and the speakers are pointing over my head. Whilst that effect looks good it is expensive and complicated to build so don't attempt it unless you've got a good carpenter as the resultant angles are complicated especially if you have a window between the speakers.

The area underneath the speakers makes a good bass trap and the front face should be absorptive so that reflections from the front of the console are eliminated.



Flush Mounted Speakers Elevation

The port is using the area under the speaker as a bass trap which is a good idea because there is a lot of bass frequencies generated in the front of the control room but you may use the area for

- **A rack for your power amps**. This option is popular because it is generally recognised that the shorter your speaker leads the better and the cavity if lined with insulation absorbs the fan noise. You may also consider putting your computer stack there for the same reason.
- **Have a tape recorder there**. This is a good option because you can always see the machine and observe its operation and meters.
- **Have a window to the studio**. This is an option I've seen in a few studios. I personally have a problem with having glass in this area because of the reflections off the back of the console can cause all sorts of problems when it interacts with the glass and if you have a window to the studio between the speakers you can land up with too much interference in the front area.
- Personally I reckon you should have a flat absorptive surface and a trap behind! It completes the flat surround of the speaker.

REAR REFLECTIONS

If a signal is placed equally in each speaker (panned centre) you will hear it as if it were coming from a centre speaker, (sometimes referred to as the Phantom Centre).

It is good practice to establish the phantom speaker in your room. If your system is correctly setup you will hear a third (phantom) speaker coming from the centre between your speakers. There was a record label on New York during the early 60's that even promoted their recordings because they had a phantom speaker in their recordings. They called their recordings Dimension D and their main artist was Enoch Light and the Light Brigade. They were spectacular recordings for their time though!.

If you have a recording setup try this experiment. Bring the same signal up into the console twice with one of the signals sent through a delay unit. Now pan one left and one right with no delay. You should hear the signal coming from the centre. Now slowly add delay to the delayed signal. You will find that something occurs around 18 -20 milliseconds. Suddenly you will start to perceive the signals as two separate signals one from the left and one from the right yet when the delay was below 18ms the ear couldn't tell the difference between the delayed and the direct so they both created a centre image. (Good way to create a doubletracked guitar effect) In other words your ears can't distinguish delay below 18ms or so. (It is different if that delay is changing as in a flanger or phaser)

Now if you have a room with a reflective rear wall the signal from the speaker will pass you and then be reflected back. Sound travels at approx. 330mm (1 ft) per millisecond so if you are 3m (9ft) from your back wall you will hear the sound as a 18ms delay and your ears will be confused and think that there is another speaker behind you. Most home studios have a back wall closer than that so it shouldn't be a problem but I really recommend you don't try that system unless you are fully aware of the technical problems involved. I have seen lots of LEDE pulled out and rebuilt because the designers didn't fully understand the geometry involved and the room sounded weird.

You could try this test. Sit in front of your speaker system and cup your hand behind your ears to block the sound coming from behind you. If you notice the sound tighten significantly you have a rear wall problem.

Fitting Out / Electrics

Power and Lights

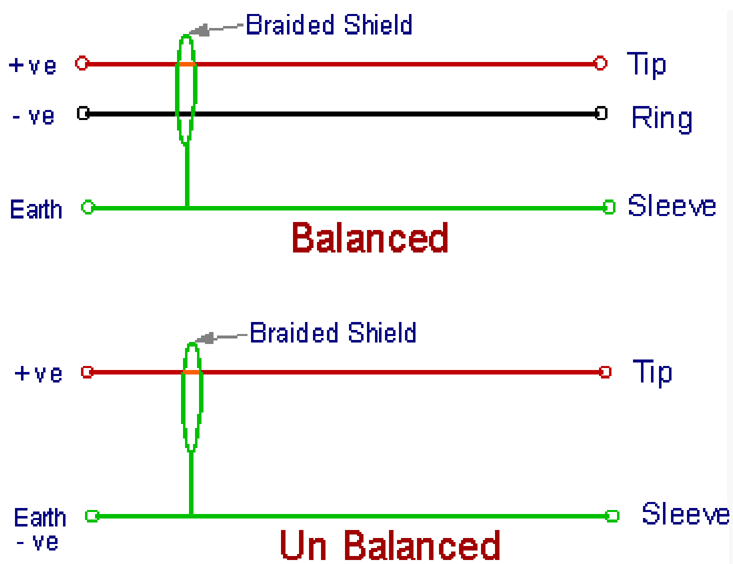
POWER & LIGHTS

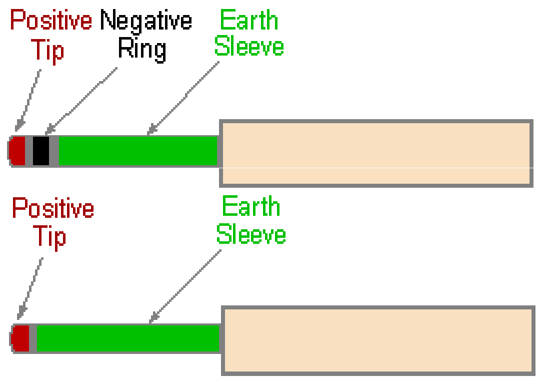
I'll deal with power first because the audio wiring comes after the power installation and because they both interact we'll sort the power out first. The important thing about power is not

- **how much is coming in** or
- **do I have enough grunt**
- **but " Is it earthed correctly??"**

Balanced and unbalanced electrical circuits

We use balanced and unbalanced leads all the time in the studio but what does it mean? The following diagram illustrates the difference.

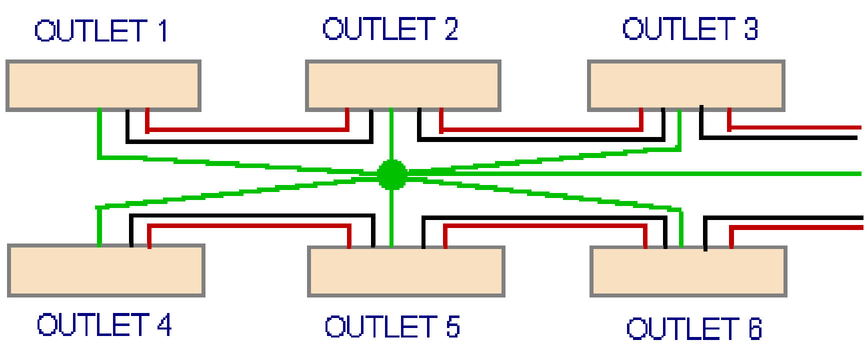




Here we have the two standards. The mic lead and the guitar lead. Balanced and unbalanced. Three wire system and two wire system. Note that in the mic lead the positive and the negative don't contact the earth whereas in the guitar lead the negative and the earth are one in the same thing. The earth - (ground) is exactly that. The green earth wire goes to a copper stake in the ground so that any short circuit between the positive and earth will send the current to ground. But because the positive and the negative don't contact the earth it is said to be **floating above ground.** The shield acts as a protection from interference by sending any extraneous electrical interference like hum, to ground. Unfortunately in the unbalanced circuit negative is ground!

So you would expect that your standard electrical feed from your power supplier would be balanced. Well unfortunately here in Australia it's not. Sure we get a red positive and a black negative from the power companies transformer but by Australian regulations the electrician must link the negative to the earth so we become unbalanced. I understand that is not the system in the US which is why Marshall amps hum in OZ but don't in the US. I would be interested in any information I could receive on this matter from anyone from the US.

The system designed to get around this is called the Star Earthing System where you ask your electrician to earth each power outlet individually like this:



STAR EARTHING OF MAINS POWER

In this setup each power point sees the same ground directly and a unit earthed to outlet 1 and connected with a patch lead to something earthed to outlet 2 won't see outlet 2 as it's earth because it has it's own more direct route to ground.

The earth, as stated before, is connected to a copper stake in the ground. It is definitely advisable to increase this factor by getting your electrician to put two or more stakes in the ground and connecting them together to increase your ground connection. I've seen systems where designers have put a whole web of copper stakes under the concrete slab before it is poured to ensure a good ground connection. In this country where it gets very hot the ground around the stake can dry out and the connection gets weaker and weaker. It can be solved to a certain extent by pouring salty water around the stake but two or more stakes is a better solution.

Lighting: It is advisable to have your light circuit separate from your power circuit. This decreases the chance of lighting interference in your power circuits. (See **lighting** further down this page)

Three Phase Power: Ideally you should have three phase power into your studio. Obviously the home studio owner won't have it but if you are looking at a professional facility it is a beneficial addition. The advantage of three phase power is that you can spread your electrical circuits over the three phases:

- **Phase 1:** Equipment and studio power.
- **Phase 2:** Lighting.
- **Phase 3:** Air-conditioning

Transformer Isolation/Power Conditioning: It is now becoming common to install a power conditioner in a studio. The advantage here is that you have a transformer between you and the supplier so that spikes are smoothed and with additional circuitry you can have a voltage stabiliser that keeps your power voltage stable no matter what the supplier is giving you. You can also have an added feature that adds battery backup in the case of power failure. This is great when you have computers as it allows you to save your current work. All these features are advantageous but can be **very expensive!** In a three phase setup you can put the conditioner over your equipment and studio power phase only. One of the common annoying items is the fridge. **Fridges** are prone to sticking spikes in the power so watch out for that one.

For more detailed info regarding grounding try this excellent web site:

http://www.hut.fi/Misc/Electronics/docs/groundloop/

It gets really tricky setting up your earthing requirements but if you start with your mains power installed correctly you've got a better chance when it comes to your **audio wiring.**

LIGHTING

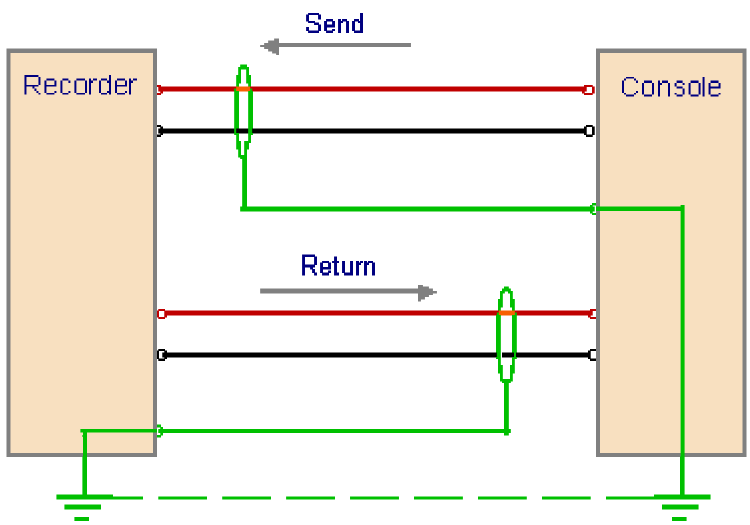
Good lighting is essential in a studio and ideally a separate circuit should be allowed for it. Downlights over the console and effects area are advisable plus additional downlights for the client etc. Lighting dimmers can also make for a comfortable environment but **be careful here**. You will probably find that the standard light dimmer will cause a buzz interference in your electrical circuits. I suggest you discuss this with your electrician. There are light dimmers available (zero crossing) that don't interfere with your electrics but they **can be expensive**!! It's not a bad idea to test a few different dimmers before you purchase the full set. In a studio situation you often require full lighting if the musicians are reading charts through to low mood lighting when the vocalist is performing a soft ballad. **I believe dimmers are the only way to go.**

It's not a bad idea to have control over your studio lights from the control room with a lighting panel mounted somewhere in your control room. That way you can control your lighting from one place.

A recent addition to the lighting system is the 12 volt lighting system. This is a good idea in a studio as these lights are already transformer isolated through the power supply which delivers the 12 volts.

Fitting Out / Electrics – Audio Wiring

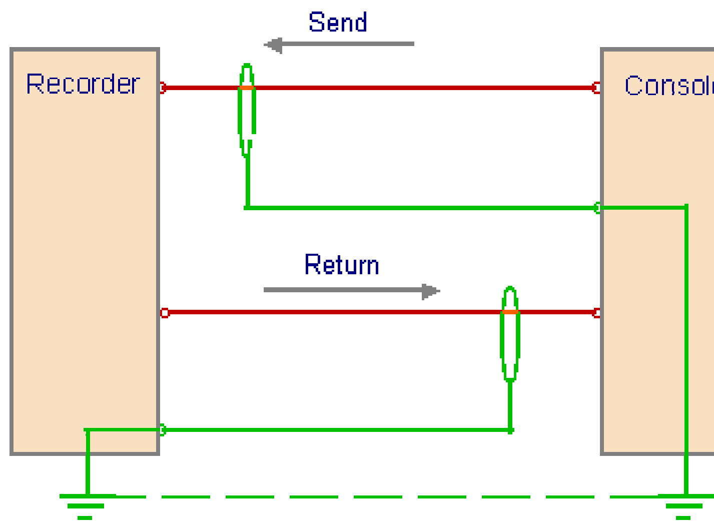
The main thing about audio wiring is understanding how the earthing works. Lets take the connection of a 24 track analogue recorder as and example. You send a balanced lead from the balanced output of the console to a balanced input on the recorder. You then return to the console with another balanced lead. Now remember, in the balanced system the audio runs through the +ve and -ve leads. The earth is just a shield established to drain unwanted interference off to ground. But if you connect the shield at both ends of each lead you are establishing the potential for an earth loop. It is in fact joined to itself in a loop. In fact it's two loops because each machine is connected to an earth as well. If on the other hand you disconnect the shield going to the recorder at the recorder end any interference generated in the shield must go to the console earth. Now if you disconnect the shield in the return lead but disconnect it at the console end any interference will be drained to the recorder's earth. No loop! Because the recorder and the console both have mains power in their circuits there must be a link to earth for safety so **don't de-earth** to get rid of the hum when **there is a safe way** such as this.



BALANCED

Now the same problem but with unbalanced leads.

Remember that the earth is now the negative as well as the ground



UNBALANCED

As you can see the recorder has a connection with the positive but also a connection to the negative but via the earth (ground) and once again there is no loop and both machines are earthed safely.

In the modern studio there are lots of simple external power supplies that just feed a single unit like a reverb unit (wall warts we call them). Have you ever noticed that they are not earthed to ground. Their mains connection has only two pins. These units allow the circuit to float above ground so the **shield must be connected** for the unit to receive the negative feed.

Some may say that by not earthing the wall warts it is dangerous but as they don't feed high voltage (typically 9 - 12 volts) to the units it's not necessary. If you did disconnect the shield in this circuit, because there is no negative, the sound would become what they call **one legged** and the sound would be thin and low in level.

So when you start wiring up your studio think of what is earthed and what is not and then you can establish when it is safe to de-earth a unit to minimise ground loops.

Additional things to consider

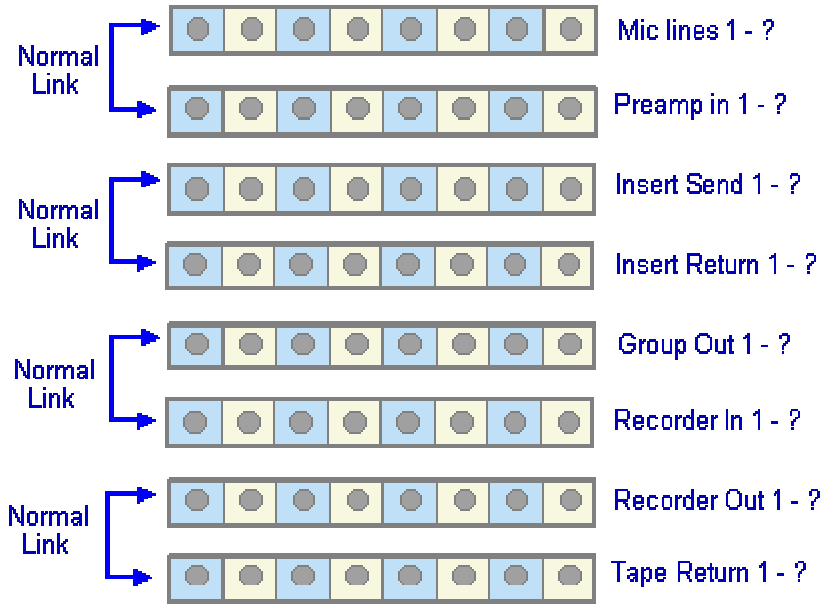
- **Maintaining Phase:** It is essential that your wiring maintains constant phase. With unbalanced leads it's pretty obvious - the centre wire is positive and the shield is negative/earth. But with balanced leads you can run into problems. Unfortunately the world has two standards. On your standard microphone plug (often called by the brand name Cannon) Europe uses pin 3 as the positive and pin two as the negative and pin 1 is earth. On the other hand the US has pin 2 as the positive and pin 3 the negative. The same applies to inputs and outputs on equipment. It is essential that you check each piece of gear and work out which pin is positive and which is negative and wire accordingly. Pin 1 is always earth and is usually a little longer so it connects first. In ring, tip and sleeve plugs the tip is always positive, the ring negative and the sleeve earth. A handy little piece of gear is a microphone line phase checker that has three lights that check the three lines in the lead for continuity and phase.

- **Guitar Lines:** It is advisable to incorporate guitar leads between rooms. This allows you to plug a guitar into a jack in the control room and pick it up in the studio and plug it into an amplifier. Guitarists often like to play in the control room, especially if you are using effects, so a cable between rooms saves having to run leads through doorways. I have seen ads for a product that has a battery powered amplifier in the cable that compensates for the high frequency loss experienced when running long unbalanced guitar leads.
- **Speaker Leads:** There is a lot of discussion on this topic and proprietary speaker cable can be purchased, but it is expensive. If you can't afford it use the standard power cable as used by your electrician. When running your speaker leads run at least two sets per side. This allows for a replacement if one cable gets damaged also it allows you to go BI-amp later should you want to without having to climb behind the speakers to add the extra cable.
- **Transfer Lines:** It's a good idea to have some standard line level lines between the control room patchbay and the other rooms. You can feed line level instruments like keyboards down them and plug them straight into the line inputs on your console.
- **Telephone Lines:** It is a good idea to incorporate a telephone line into your control room, especially now that computers are common and you may need to hook up to the web for software update downloads. We are not far off having the ability to record in real-time down these lines and can now transfer Wave and MP3 files.
- **Direct Boxes:** Direct boxes are designed to match impedance between your guitar and the microphone input. Without going into the full electronic detail here basically what happens is that a guitar is designed to plug into a high impedance input whereas a microphone input is a low impedance input. Plugging a high impedance magnetic pickup into low impedance results in a loss of highs. Direct boxes can match the impedance by either using a **transformer (passive)** or using a **circuit (active)**. Active direct boxes are identified by the fact that they have power - either as a battery or powered by the phantom power system. DI boxes also have a pad switch to reduce the level of a line level instrument down to the lower microphone input level.

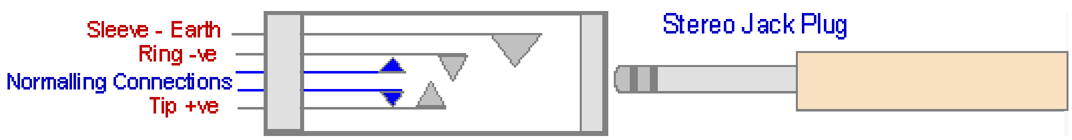
Patchbays

Patchbays can save a hell of a lot of trouble when interfacing your recording equipment. Even if you only have a bedroom studio it is a lot easier if all your gear appears on a patchbay and you can easily patch one thing into another. Patchbays can be cheap or expensive depending on the style and construction. They can also come in balanced (Ring tip and sleeve) or unbalanced (tip and sleeve). It really depends on the gear you have and your requirements but don't overlook the advantage of having a patchbay.

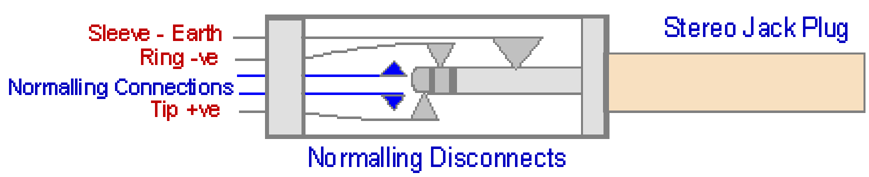
Lets look at the standard layout of a patchbay:
The inputs and outputs usually go like this:



The main idea here is that each row is normaled to the next. i.e. microphone line 1 is directly connected into preamp in 1. Insert send 1 is directly connected to Insert return 1 - group 1 is directly connected to recorder in 1 and recorder out 1 is directly connected to line input (tape return) 1.
In other words, with no patch leads the circuit is complete and you only use a patch lead if you wish to change from the normal - that's why it's called **normalling**

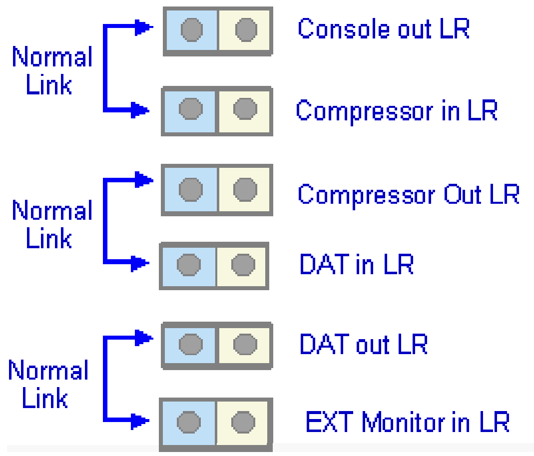


Here we have a standard stereo plug and socket. When the plug isn't inserted the +ve and -ve pins are shorted to the two normalling pins. The normalling pins then connect to the through connections.



As you can see the insertion of the plug breaks the normalling and allows the new connection. Prebuilt patchbays often have the normalling as an option. Tascam have some excellent unbalanced ones but fully balanced normalling patch rows are expensive. A simple check is to count the pins - 3 pins are standard and a normalling patch bay has 5 pins. (Earth is common)

Other normalling areas to consider are your console outputs being normalled to your master compressor input and its output is normalled to the input of your DAT recorder. Then the output of your DAT recorder is normalled to your External Monitor input. That allows you to start mixing without having to setup a huge patch . If you need to access your master compressor you just patch into it and break the normalling.

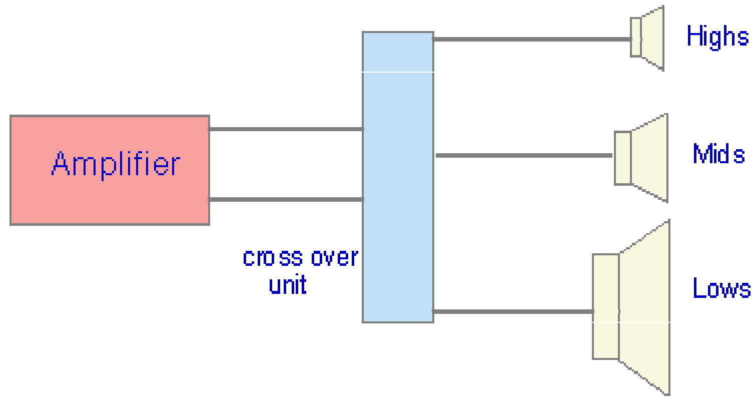


Another area is your Aux Sends. It is advisable to normal your regular setup - such as 1 &2 to your headphone amp, Aux 3 & 4 to your stereo reverb, Aux 5 to your effect unit 1 and Aux 6 to your effect unit 2. You can go further by normalling the returns of your three effects units into tape/line returns 23 - 28. With such a setup you can start a mix without having to patch a thing!!

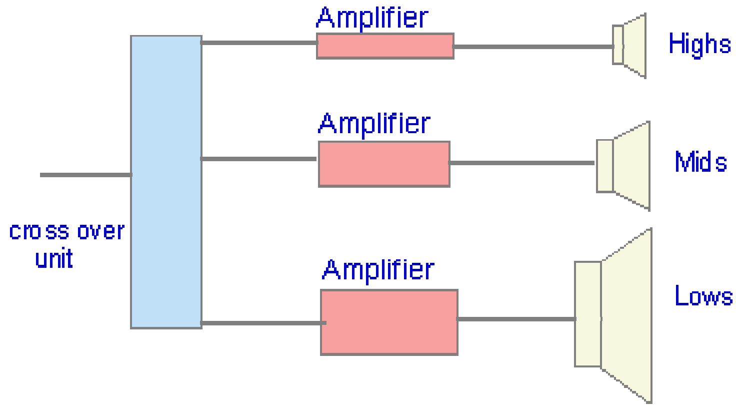
If you are the only user of your studio it is probably not really necessary to label the patch bay fully but if you have **outside clients it must be labelled clearly.**

BI and Tri - Amping

In a standard speaker the various components,(woofer, midrange and tweeter) and divided from each other with what is referred to as a crossover unit. What actually happens is the crossover divides the frequency response into 2 or 3 bands. The lows drive the woofer, the mids drive the midrange speaker (often a horn) and the highs drive the tweeter.



Here the signal from the console goes to the amplifier and then to the speaker. Within the speaker the crossover circuit splits the frequencies into to three and feed to each speaker.



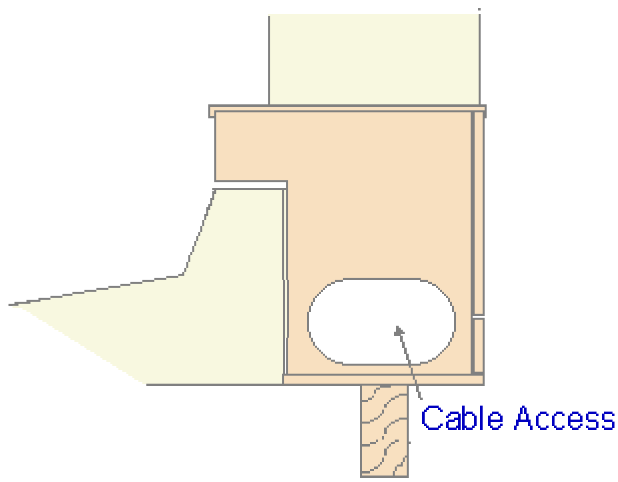
Alternatively here the output of the console goes to the electronic crossover unit that then feeds to each amplifier that drives a speaker independently. Although you need three amplifiers the amps don't need to be as big. Big PA systems run on this system and are described as being 2 way, 3 way and 4 way - bi - amped, tri - amped, and quad- amped. The additional crossover in the 4 way system feed the low mids.

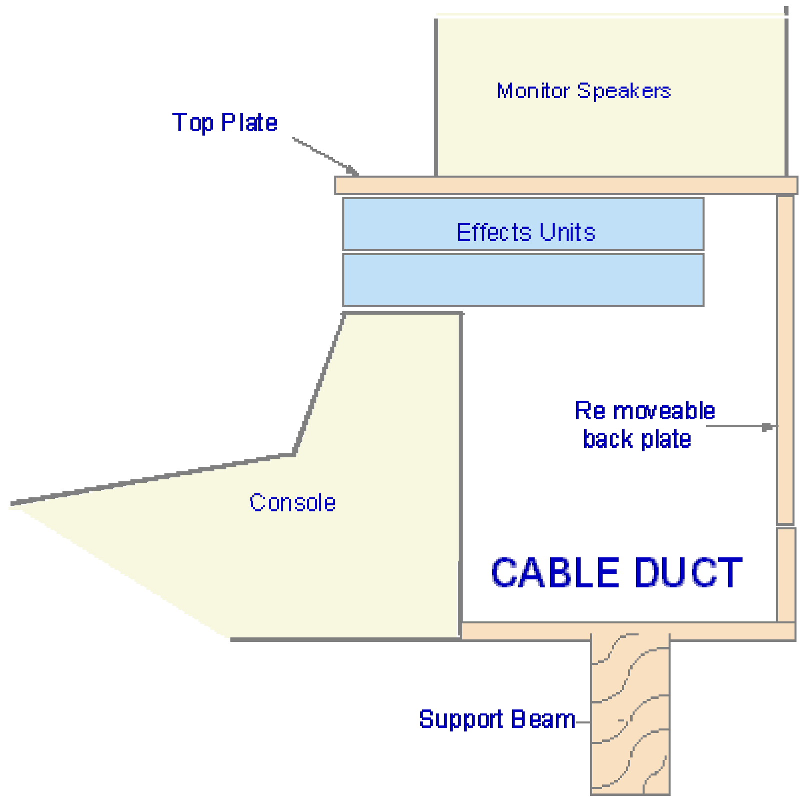
You can now buy small near field monitors that have the electronic crossover and the amps built in - all you need to do is connect the output of the console into the rear and you are away. The multi crossover multi amping system is extremely efficient and you don't need huge 500 watt amplifiers etc.

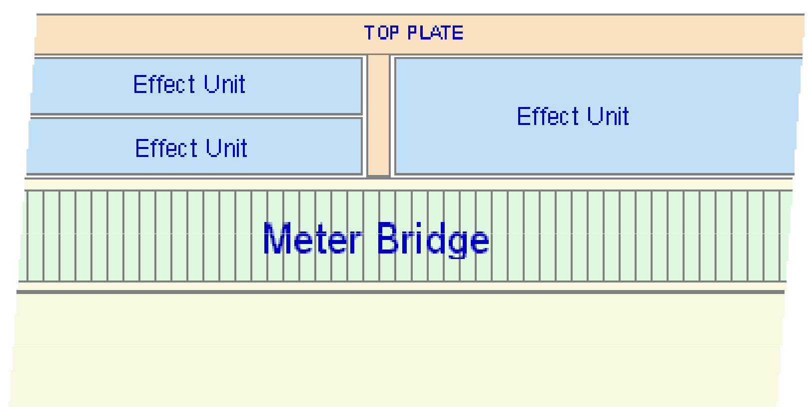
Fitting Out/Electics – Fittings

The Control Room

Fitting out the control room is an important part of the construction process. The correct ergonomic layout of equipment and machines can make the room a pleasant place to work. The position of the console is set because of the position of the speakers but how the effects units recorders etc. are arranged is a variable. It is important that effects units can be accessed from the rear so that cables etc. can be accessed. I have found that the area above the meter bridge on most consoles is a good place to have at least one rack unit space for effects:

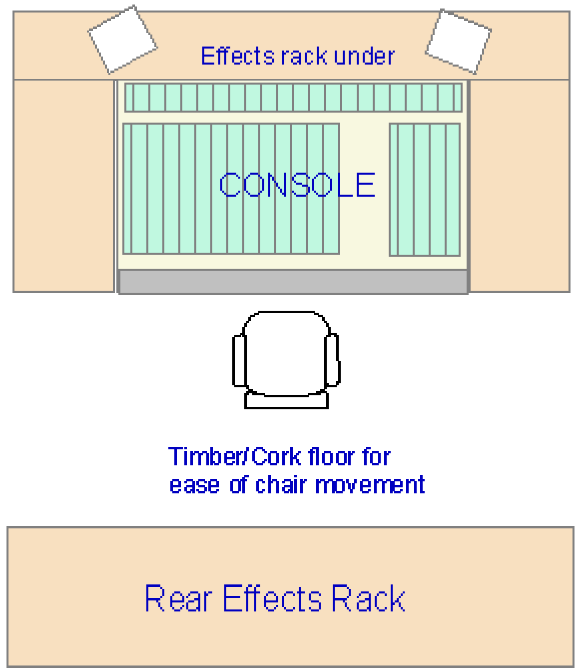




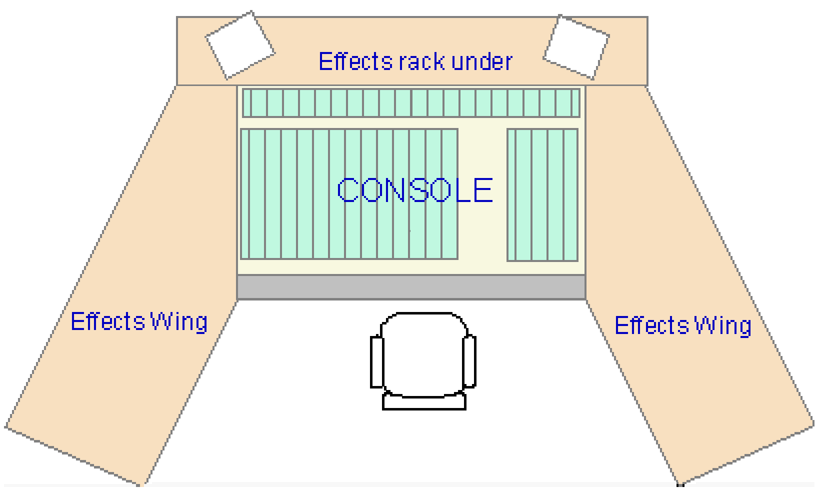


This system is great for the commonly used effects that you need to see operating such as compressors, gates, reverbs etc. It also tends to bring the nearfield monitors up to ear height with consoles like the Mackie 8 buss, Tascam 3500, Yamaha O2R etc. The cable duct at the rear also cleans up all those stray leads that normally hang around the rear of the console. The leads can be bought up into the duct through one port at the end through a simple timber duct. The back plate can be hinged so access to the rear of the console is available. Most effects units will fit into this system and these days they seem to be getting smaller and smaller. Your normal Mackie 8 Buss will allow 6 - 8 single rack space effects units to be mounted this way.

Further effects units can be mounted either in side wings or in a full effects rack behind you.

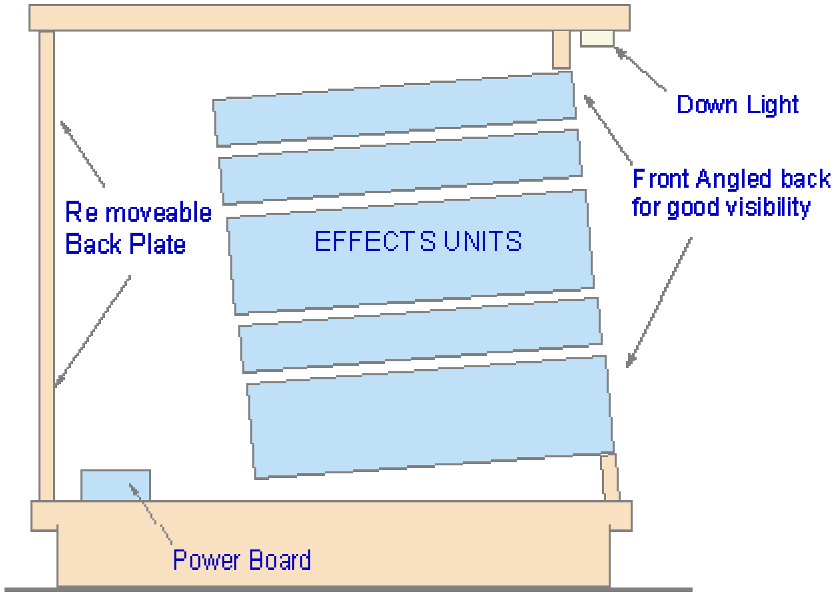


THE REAR EFFECTS UNIT



EFFECT RACK WINGS

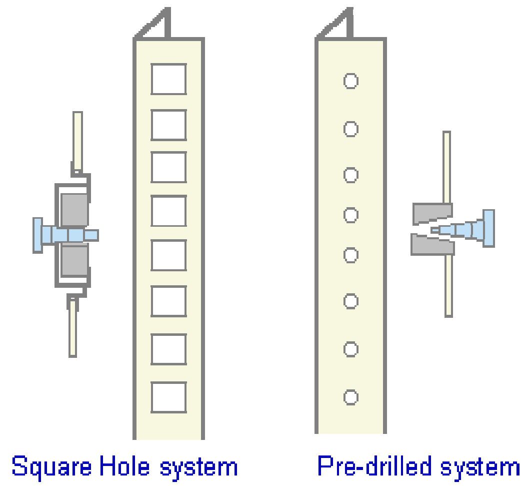
The effects wing rack construction is the same as for the rear effect unit. With this system the cables can all run within the racks and access to the rear of the equipment can be gained through removable panels at the rear. These wings are also good for computers or keyboards or any additional effects added for the session. Visually they can be glanced at quickly which is more friendly than the rear units.



It is a good idea to put air grills in the back plate to allow air circulation to keep the units cool. (Never underestimate the heat generated by effects units. 10 x 50 watt units equals a 500 watt heater!!) For large powered units, especially valve units it is advisable to space the units in the rack to allow for total air circulation. Single rack spacers with grills can be purchased for this from your local equipment supplier. **Down lights** mounted above the effects racks are a simple but effective addition - why do the manufacturers make their units black?? Power outlets can also be built into the rear of the unit which should be installed as per the directions on **star earthing.** The cable duct in the flooring can be bought up within the unit so cables are hidden.
The rear effects unit system is good because it provides a work bench for keyboards or additional equipment. It is therefore advisable to have some **tie-lines** to the console patchbay so that the keyboards/effects can be accessed at the console. Some people mount these on the rear of the unit while others prefer to have plugs mounted in a single rack unit strip on the front with the other effects.

The height of these units is a matter of comfort but I find that **720mm (2 '41/2")** is a good starting point as it's not too low for the tall and not too high for the short.

The mounting of effects units is a matter of budget. You can screw them into timber if you don't intend shifting them around or proprietary rack mounting strips can be purchased. There are two different types of rack mounting strips. One system has square cut-outs that a nut clips into and then you screw into it. The other type has holes with a screw thread welded into it. I prefer the latter.



The square hole system is designed to give latitude for the sizes but these days the manufacturers build rack units to a set standard and I always seem to loose those little sprung square nut fittings!

Fitting Out/Electrics – Air Conditioning

If you've built all the rooms of your studio correctly you will have airtight sealed rooms so the opportunity for external air to enter the building has been totally eliminated. You must therefore have some form of air-conditioning to not only keep your air temperature constant but to supply fresh air. An air conditioner consists of three components.

- **The compressor unit** that creates the cool/heat.
- **The fan unit** that moves the air.
- **The Ducts** that distribute the air.

These units can be assembled in three ways

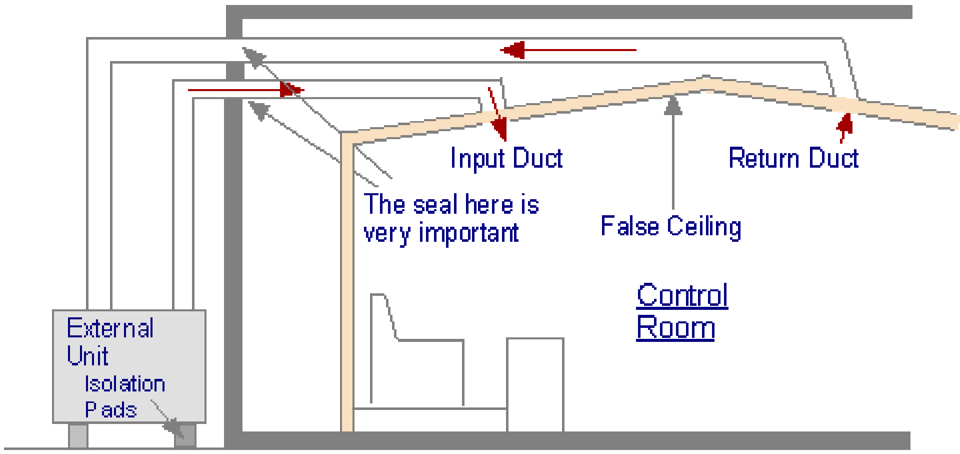
- The standard free standing unit that has all units in one.
- The split system where the fan unit is in the room and the compressor unit is outside.
- The fully external system where the fan and the compressor are external and the air is circulated via ducting.

The following must be considered.

- **Number of units.** You must have one unit for the control room and a separate unit for the studio. I've found that when you use one unit for both you land up with a nice temperature in one room whilst the other room freezes. Never underestimate how much heat normal recording equipment produces. If you add up the wattage of all your gear and imagine a heater of the same wattage you will find that you have around a 2000 watt heater going in your control room all the time whereas in the studio the only heat is the occasional guitar amp and body heat. Consequently if the thermostat is in the control room when the control room is fine the studio freezes. I recommend two separate units.
- **Type of unit.** There are three types of air-conditioners available as previously stated. The main difference here is that **only the fully external system can add fresh air.**
- **Noise Factor.** Obviously having an air-conditioner grinding away in a studio is not much good if you are recording quiet instruments but if you've got a metal band in there who cares!! Lots of home studios have a split system (That's when the compressor is external and the fan unit is in the room) There is no air exchange and if you are recording quiet instruments you just turn it off for a while. It is the cheapest system and, to be honest, the most common. Fresh air is achieved by leaving the doors open when isolation is not required.

I think that if you check your local building codes you will find that because your rooms are totally airtight they will require you by law to have a fully ducted system which adds fresh air.

To install this system you will have to breach the air seal that you have carefully created but there are ways to get around this. The typical ducted system works like this.



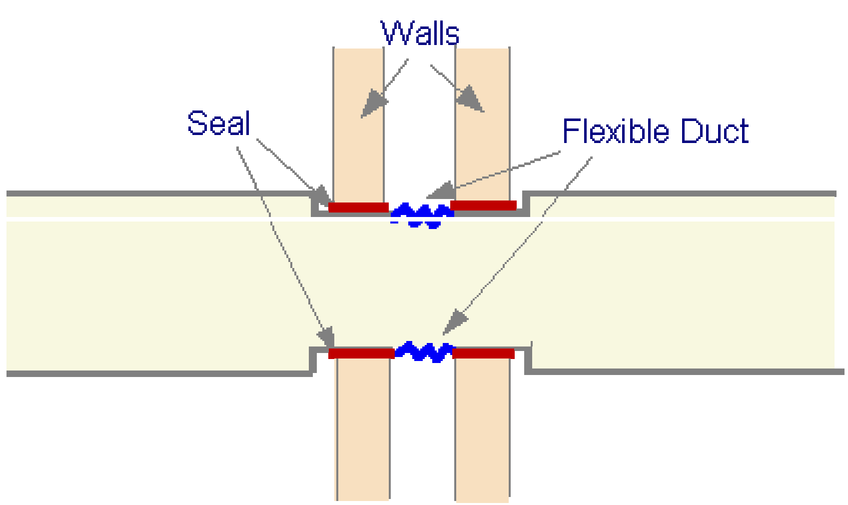
TYPICAL AIR-CONDITIONING UNIT

The above drawing shows a typical external system. The compressor and fan are in the unit externally and the ducts send and return the conditioned air.

The Ducts. The typical duct found in a home air-conditioning unit are OK for the standard home studio. They normally consist of a aluminium foil pipe wrapped in fibreglass and plastic. The external ducts on the other hand must be soundproof and are typically made from galvanised iron boxes lined internally with sound absorption material. Just remember that the larger the duct the quieter it will be.

The Noise Factor: The slower the air in the duct the quieter the air-conditioning system will be. Some of the top studios have ducts which are 1 - 2 M (3 - 6ft) wide and the air moves slowly within the duct. This stops the hiss you get when the air enters the room via a duct.

As stated the seal between the external duct and the internal duct is very important. The common way is to join the two ducts with a flexible join so that the two ducts aren't mechanically linked.



FLEXIBLE JOIN BETWEEN DUCTS

The important factor here is to make sure that it is totally sealed. The flexible joint can be made out of a product that is made from vinyl impregnated with lead. Ask your air-conditioning company about it, they will know. This gives a flexible soundproof seal.

Fresh Air: I must say something here about adding fresh air to a system. I have found that the formula used by most companies for adding fresh air doesn't add enough. When you have a control room with a producer, engineer, musos and a few hangers on the amount of fresh air added is usually insufficient and by halfway through the session everyone is yawning. They usually add about 15% fresh air to the system but I would urge you to consider adding up to 25 - 30%. This is more important when you have a fully sealed system in a city building where there is usually no external windows and the outer office/hallways etc. are fed by the buildings own system. Creativity requires plenty of fresh air!!!

Obviously the air-conditioning can be extremely expensive.

No doubt your budget will be the determining factor.

Studio Plans

I really could go over the top here. What I've tried to do in this site is to go through all the fundamentals so that you can fully understand all the acoustic ramifications and thus be in a position where you can design your own studio. Layout of rooms etc. is really up to the basic room shapes you are starting with so instead of me sweating over my computer to give you a whole lot of inappropriate shapes I will give you the basic styles that have worked for me. If you follow the basic directions of what you need to acoustically treat each room you can take any shaped room and come up with a plan. I have not included dimensions as it is not necessary and it would obviously change for each situation. The proportions are near enough though and the angles are what make it work.

Important thing to remember are:

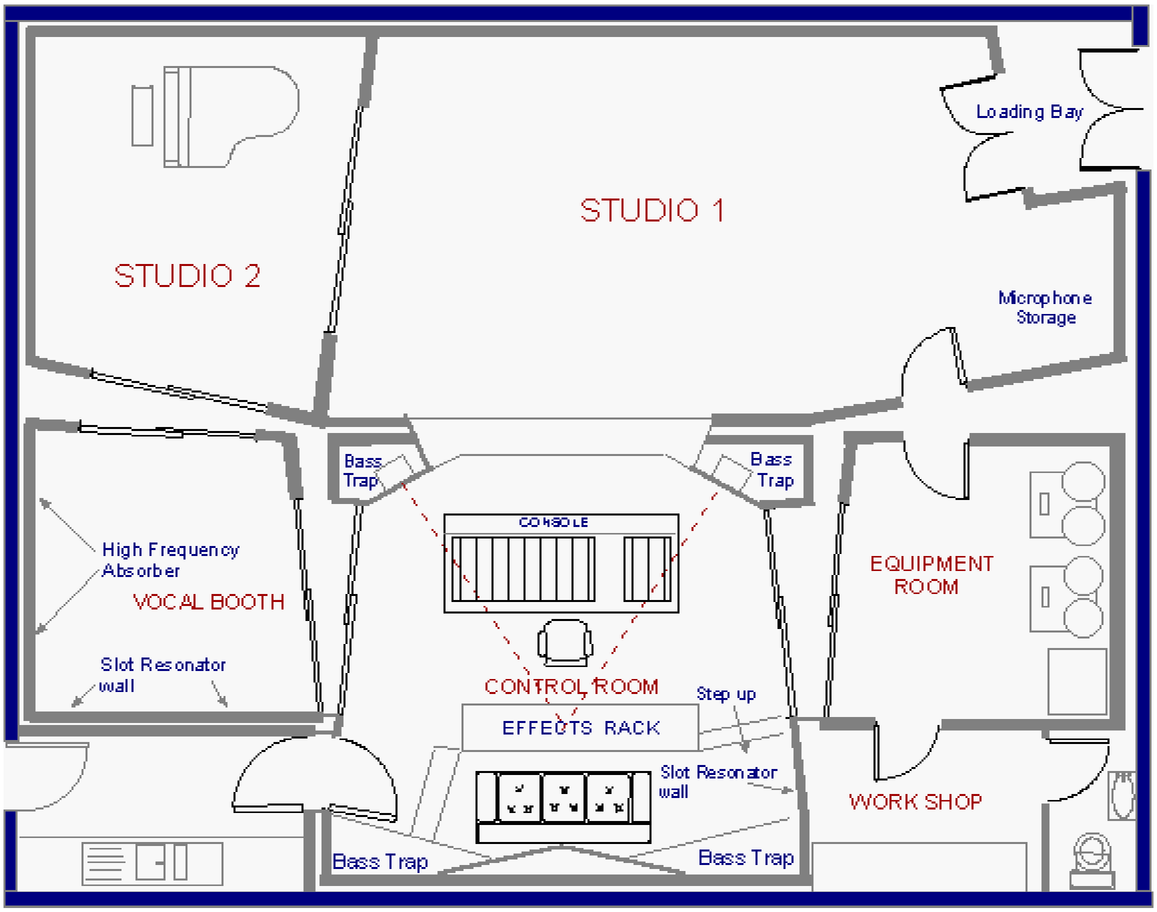
- Stereo room symmetry around your speakers.
- Glass windows or doors for communication.
- Low-mid frequency absorption from 150 -550Hz.
- High frequency absorption.
- Absorption across the rear of the control room wall.
- Whatever low frequency absorption you can fit in the space.

Things to avoid are:

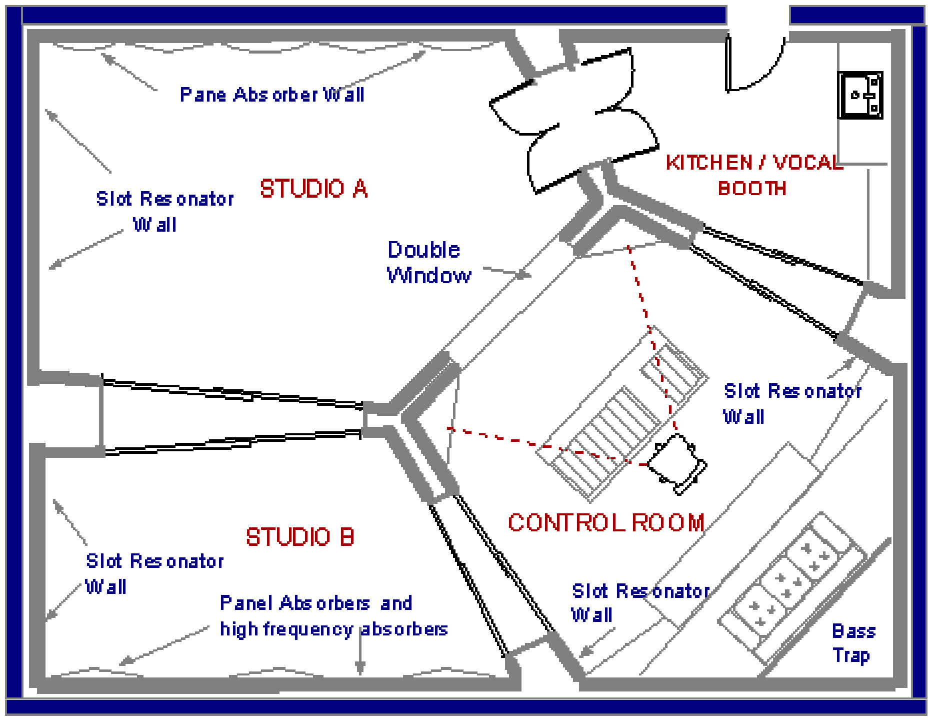
- Having to go through the studio to get to the control room!! (I hate this because you always get interuptions as people move in and out of the studio)
- Creating studios with no visual communication. There is nothing worse than recording someone you can't see.
- Big studios with a small pokey control room and visa versa.

So here are a few ideas that might start you off, use the selector for the different options. You can check out photos of some of the studios I've designed some of which are based on these layouts. You'll find them at my **home page.** (http://www.lis.net.au/%7Ejohnsay/Pages/Studios.htm)

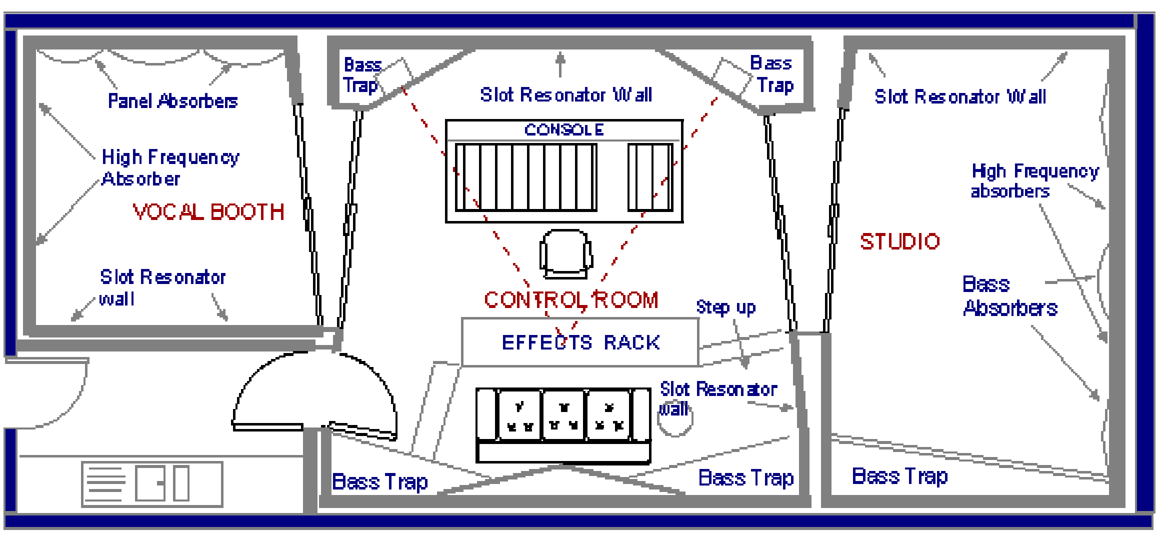
THE BIG FACILITY



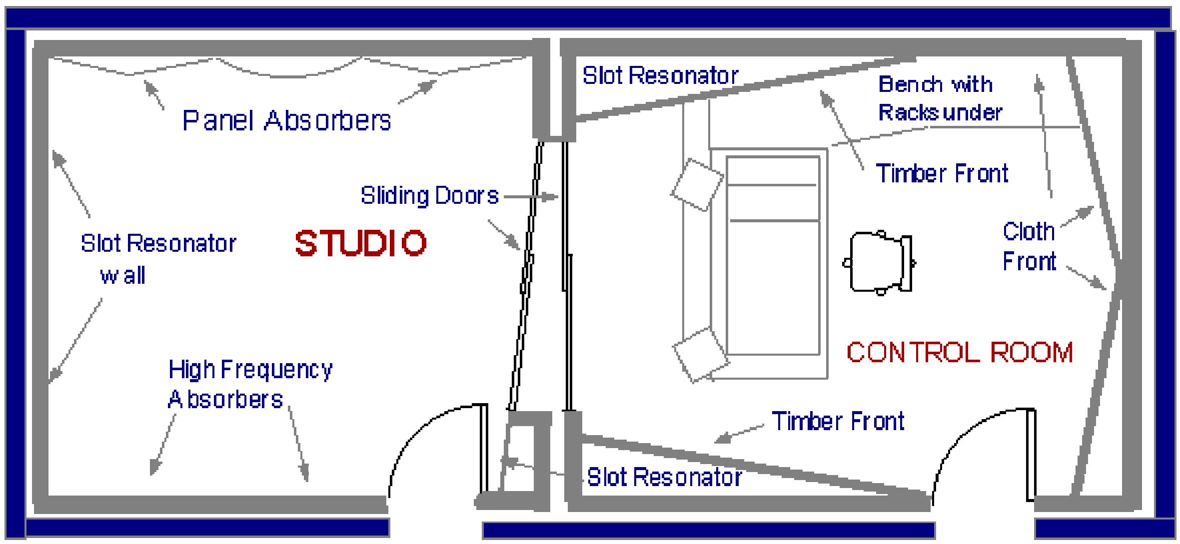
THE CORNER CONTROL ROOM



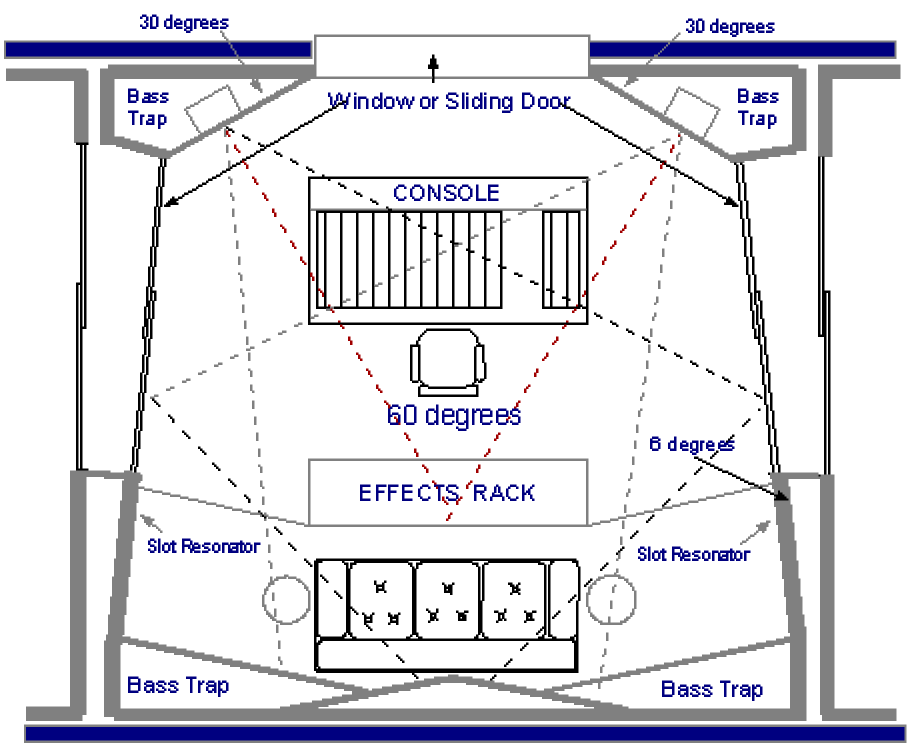
THE GARAGE STUDIO 1



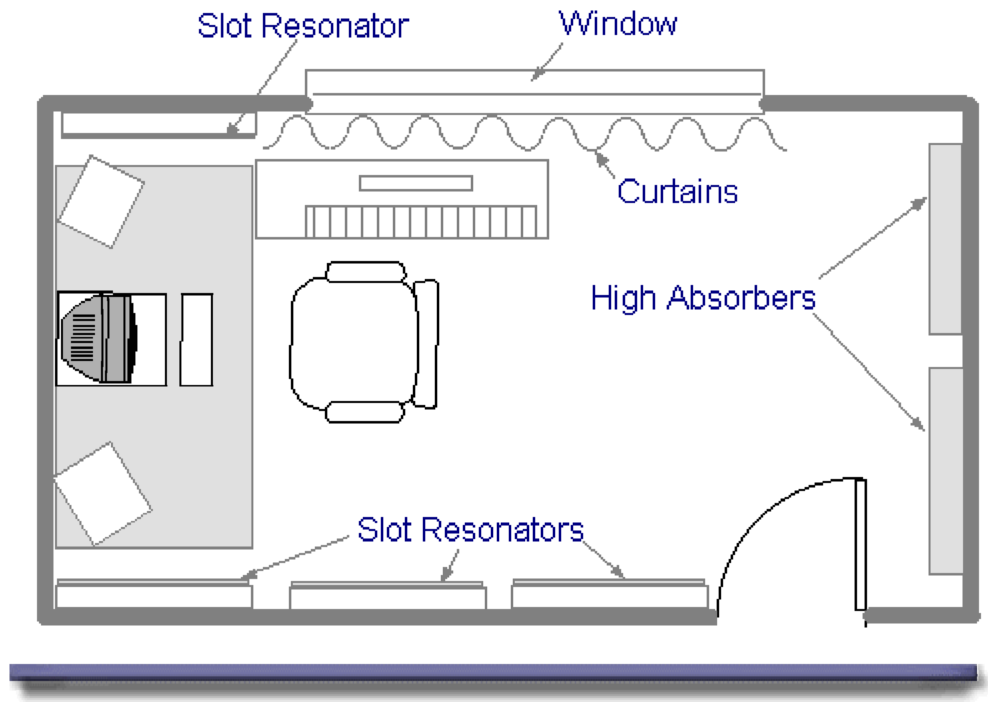
THE GARAGE STUDIO 2



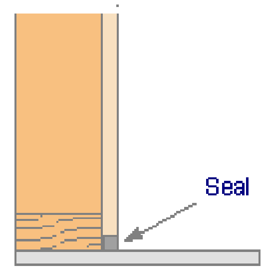
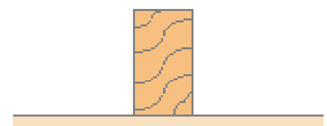
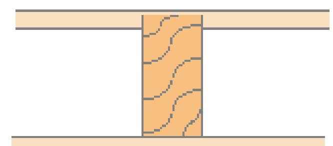
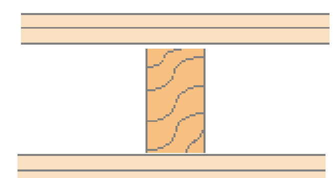
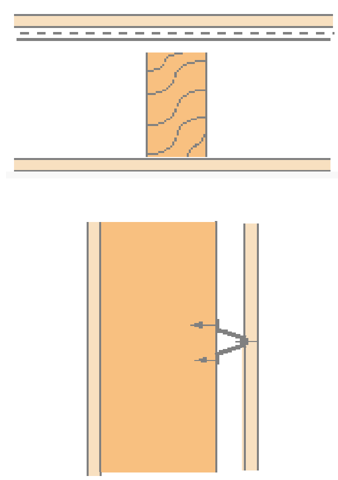
THE CONTROL ROOM

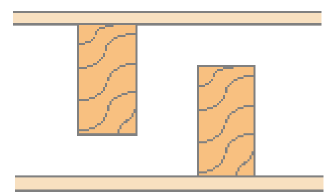
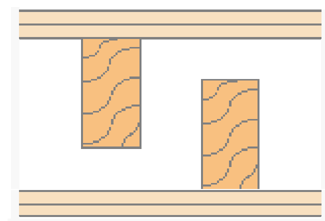
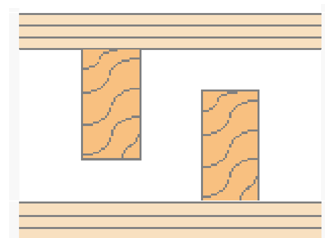
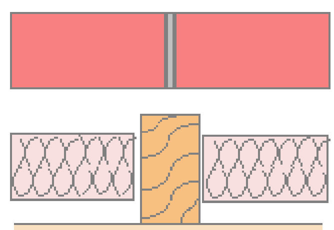
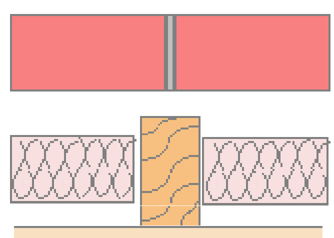


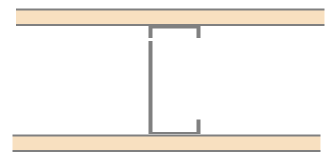
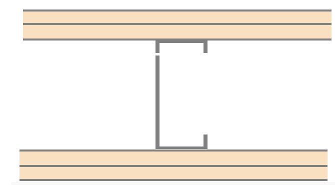
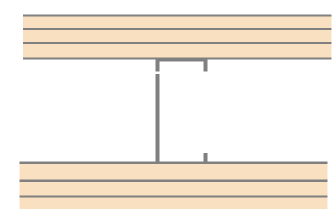
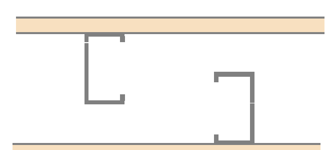
THE BEDROOM STUDIO

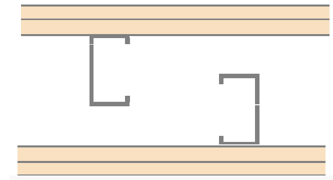
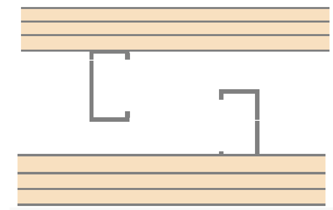
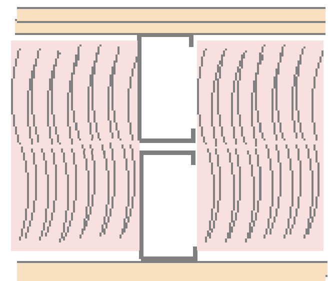
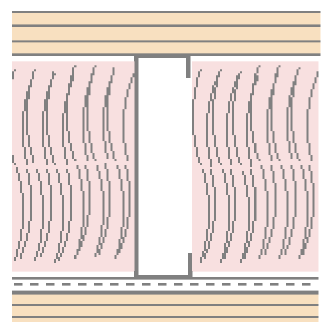
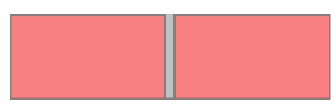
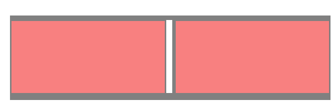

Slot Resonator
Window
Curtains
High Absorbers
Slot Resonators

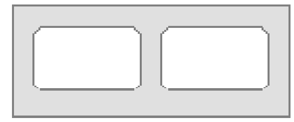
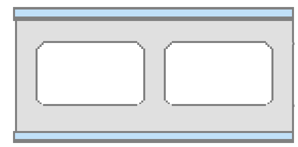
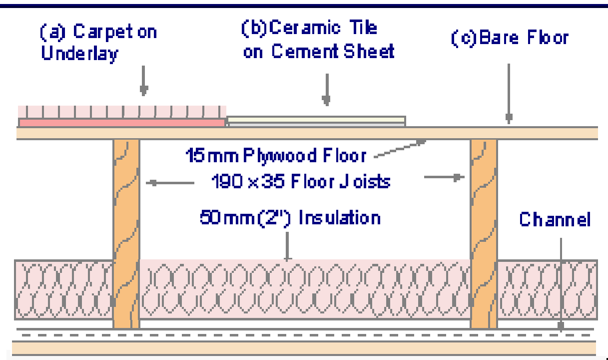
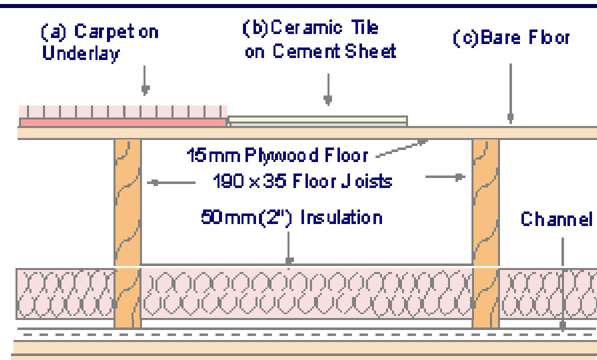
Stc Chart

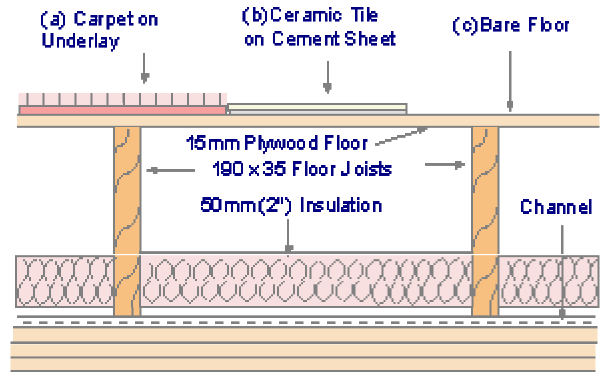
	STC CHART	HOME
In the following charts all plasterboard joins and edges are sealed with an appropriate acoustic sealant. The figures given below are based on all surfaces being sealed to airtight.		
TIMBER STUD	**STC RATING**	
Standard stud wall with one layer of 16mm (5/8") Plasterboard	No Insulation 28	
Typical wall construction with 1 layer of 16mm(5/8") Plasterboard on each side of 95x35mm (4 x 11/2") timber studs.	No Insulation 35 With Insulation 38	
Typical wall construction with 2 layers of 16mm(5/8") Plasterboard on each side of 95x35mm (4 x 11/2") timber studs.	No Insulation 41 With Insulation 45	
The Flexible Channel Single 95x35mm (4"x2")Stud wall with 1 layer of 16mm (5/8") Plaster board on one side and 1 layer of 16mm on the other side on a horizontal flexible channel at 600mm (2ft) centres screwed to the stud.	No Insulation 40 With Insulation 47	

Staggered stud wall construction with 1 layer of 16mm(5/8") Plasterboard on studs of 95x35mm (4 x 11/2") on a 120mm (4 3/4")common base.	No Insulation 42 With Insulation 48	
Staggered stud wall construction with 2 layers of 16mm(5/8") Plasterboard on studs of 95x35mm (4 x 11/2") on a 120mm (4 3/4")common base.	No Insulation 50 With Insulation 54	
Staggered stud wall construction with 3 layers of 16mm(5/8") Plasterboard on studs of 95x35mm (4 x 11/2") on a 120mm (4 3/4")common base.	No Insulation 56 With Insulation 61	
BRICK VENEER		
The typical Brick Veneer construction with a layer of 10mm (3/8") plasterboard. This is the standard Australian house construction.	No Insulation 53 With Insulation 55	
Brick Veneer construction with a layer of 16mm (5/8") plasterboard.	No Insulation 54 With Insulation 56	
STEEL STUD		

1 layer of 16mm (5/8") plasterboard each side of a steel stud. **Stud sizes** • 51mm • 64mm • 76mm • 92mm • 150mm	No Insulation • 37 • 38 • 39 • - • 42	With Insulation • 42 • 42 • 43 • 46 • 46	
2 layers of 16mm (5/8") plasterboard each side of a steel stud. **Stud sizes** • 51mm • 64mm • 76mm • 92mm • 150mm.	No Insulation • 46 • 46 • 48 • 48 • 51	With Insulation • 51 • 52 • 53 • 53 • 55	
3 layers of 16mm (5/8") plasterboard each side of a steel stud. **Stud sizes** • 51mm • 64mm • 76mm • 92mm • 150mm.	No Insulation • 50 • 51 • 52 • 53 • 55	With Insulation • 54 • 55 • 56 • 57 • 58	
1 layer of 16mm (5/8") plasterboard each side of a **staggered steel stud**.	No Insulation • 41	With Insulation • 47	

2 layers of 16mm (5/8") plasterboard each side of a **staggered steel stud**.	No Insulation • 52	With Insulation • 58	
3 layers of 16mm (5/8") plasterboard each side of a **staggered steel stud**.	No Insulation • 55	With Insulation • 60	
Double steel studs opposite each other with 2 layers of 16mm (5/8") plaster board on each side.(Insulation is 125mm (5") glass wool 25kg/m2)	No Insulation 55 With Insulation 59		
Single 150mm (6") Steel stud with 3 layers of 13mm (1/2") plasterboard on one side and on the other side another 3 layers on a flexible channel screwed horizontally onto the steel stud. (Insulation is 125mm (5") glass wool 25kg/m2)	No Insulation 55 With Insulation 64		
BRICK and CONCRETE BLOCK			
Standard house brick unrendered.	39		
House brick rendered both sides (13mm (1/2") 1:1:6,Cement:Lime:Sand)	45		

8" Concrete Block, hollow core, no wall finish	45	
8" Concrete Block , hollow core, painted 2 coats, 2 sides	48	
CEILINGS		
1 x Layer of 16mm (5/8") Plasterboard fixed to a flexible channel fixed at 400mm (16") centres. (a) 45 (b) 49 (c) 45		
2 x Layers of 16mm (5/8") Plasterboard fixed to a flexible channel fixed at 400mm (16") centres. (a) 56 (b) 58 (c) 55		

3 x Layers of 16mm (5/8") Plasterboard fixed to a flexible channel fixed at 400mm (16") centres. (a) 56 (b) 59 (c) 55	
BORAL	**I am indebted to the people at Boral for their excellent web page and the TecSYS CDROM they sent me free for the figures presented above for plasterboard installations.**