A study on acoustics of critical audio control rooms

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Transfer Report

A Study on
Acoustics of Critical Audio Control Rooms

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1.0 Introduction

Since the advent of Radio Broadcast that acoustic designers have tried to define a standard for control rooms. Although many years have passed since the first control rooms were built and many different solutions have been tried and tested, a final standard design has not yet been devised.

The purpose of this report is to define and demonstrate that a proposed route of investigation will present novelty, address an important issue in this industry and fulfil the necessary requirements for the attainment of a PhD degree.

The report is subdivided in chapters.

Chapters 2 and 3 are an extended Literature Review of Designs (Chapter 2) and Specifications (Chapter 3) previously published on this type of listening spaces. A detailed description of each paper is given. This is done in order to better identify problems and reasons for specific requirements on Critical listening spaces.

Chapter 4 is a personal view of the author on critical listening spaces. It is an organisation of the ideas brought forward in previous chapters, and its relevance is on the identification of generally accepted concepts and their application on the successful design of a critical listening space. Currently accepted design steps are listed.

Chapter 5 presents results from a survey performed by the author on a panel of professional recording engineers and producers in the UK. This represents the main subject of this project during the past year.

The result of this survey gives an indication of research routes that are important in order to solve eminent problems on the design of critical listening spaces.

Finally, Chapter 6 gives a plan of investigation detailing a specific area of research in order to continue this project with the objective of attaining a PhD degree.

In this chapter, the author feels that a short literature review should be presented. The reason for another literature review at this stage of the report is mainly to show that previous research done in the field is not comprehensive and therefore leaves scope for further investigation.

Additionally, it also indicates which publications will be the basis to start from on the current research.

This chapter also presents the relevant points to be investigated, expected results and explains how this will bring originality and novelty to the academic community.

Methods to be used, practical work to be carried out and possible problems are described.

A time plan chart is submitted.

2.0 Review on different philosophies for Control Room Design

2.1 Introduction

This chapter focuses on the different design concepts that have been used over the years to achieve the best critical listening environment.
It follows a brief description of some of the reported types of design commonly used to address these features.

2.2 "Non Environment"

This design has been introduced by Tom Hidley in the 80's. Hidley and other designers still make use of it or a variant form based on the same principles[1,2,3].
This room was an attempt to simulate outdoor acoustic behaviour in an indoor space, with the benefits of not having any environmental noise. This was achieved by controlling all sound within the room using very powerful absorption on all reflective surfaces. This way all reflections that would be introduced by the walls of the room were effectively removed leaving a condition very close to anechoic. Although they do not "simulate" normal domestic listening conditions, these rooms provide a very strong and precise stereo imaging when sitting at the focal point. A neutral condition is achieved given that no extra acoustic effects were added by the room boundaries. Therefore, different size control rooms using this design would generally "sound" the same.
However, such an environment can be disconcerting due to its unnaturalness and lack of reflections, which are important in providing us some information on the space that surrounds us. Some users would describe them as not being conductive to the mood for recording or mixing.
The front wall and floor were then made totally reflective to add some "naturalness" to the acoustics inside the room. This way, the speakers would radiate into an effectively anechoic room, whilst people speaking somewhere in the centre of the room would perceive some reflections from the floor and hard front wall making the ambient sound more natural. The speakers are

usually flush mounted on the front wall removing the possibility of any comb filtering effects.

One drawback is the need for large physical space to accommodate large sized absorption material. This makes this type of design take up a considerable area of floor space and not very suitable for most projects where customers try to “squeeze” the control room into smaller spaces.

These rooms are designed to have very short reverberation times, which enable any reverberation or distinct delays in the original signal to be monitored.

This type of room often has a limited area where the sound is best. This is the corner of an equilateral triangle between the two speakers and the listener, for a stereo set-up.

2.3Live-End-Dead-End™

In 1980, Davis, D. and Davis, C. published a paper on a novel design for a control room that was an attempt to standardise control room design[4]. The Live-end-dead-end consisted of the front part of the room being fully absorptive whilst the back part of the room was fully diffusive. This design relied heavily on a new “tool” for the designer, the diffuser.

One of the first issues this design addresses is the *Initial Time Delay Gap* between the direct sound from the speakers and high-level reflections from nearby walls. These reflections inform the listener that he or she is in a small enclosure. They also make it impossible to hear the ITD of the studio itself because of the time masking effect. Therefore, in order to control these early reflections the front part of the room near the speakers is treated with absorptive materials to “remove” any reflections. This also enhances the frequency response coupling between the speakers and the room, as comb-filtering effects are reduced.

The “live” part of the room, behind the listener position, is treated with diffusive and scattering materials. This prevents any specular reflections from the back of the room. By making the rear wall diffuse the reflections are smeared in time and therefore their amplitude decreases reducing the risk of a high level distinct reflection that may distract the listener.

Furthermore, the actual ITD of the control room can be controlled by moving the listening position into the front (dead) part of the room in order to increase ITD (i.e.: longer reflection time).

"The psychoacoustic effect of the LEDE design technique is to give the mixer's ears the acoustic clues of the larger space, thus allowing the perception of hearing the studio rather than the control room."[4]

The LEDE room attempts to simulate a sound field closer to normal domestic listening conditions. By providing the listener with a clear first pass of the sound wave followed by diffuse reflections it is intended to give the perception of a "natural" room whilst trying to enable similarity between rooms designed in this way. Due to its diffuse late reflections these rooms often exhibit a larger area where the perceived sound is similar.

The sound of these rooms may be more conducive to work in due to the extra "liveliness" they, but large reverberation times and 'lobing' introduced by arrays of diffusers are a problem that should not be overlooked. Also the longer RT introduced by the room may mask any effects and unwanted reverb tails in the original signal.

2.4Reflection Free Zone

This type of design addresses the use of redirection in order to make any early reflections to "miss" the listening position. It is therefore achieved a time period where the signal at listener's ears is free from any room interactions. The redirected reflections will eventually hit other room boundaries and by the time they arrive at the listener's ears they will either be low in amplitude or late in time and perceived as the usual reverberation tail of any sound indoors. This reverberation period should be very diffuse and therefore requires many reflections spread in time.

Initial time delay gap is adjusted by controlling and redirecting all reflections that will fall within the early reflections time zone (usually up to around 20ms).

Reverberation time is adjusted by introducing more or less absorption.

Variations of this type of design can be seen as a Hybrid between the two types of design described above.

In this type of room, there is usually one single position where stereo image and time distribution of the signal is perceived at its best. This is the position to which the reflection control was designed.

2.5Conclusion

The previous chapter listed some of the current designs used to address the issue of Control Room for critical listening purposes. Three main design philosophies in common use are explained. However, hybrid types of rooms are very common. This is a mix of any procedures of the designs above.
E as an attempt to meet requirements gained from subjective experiments on room acoustics.

3.0 Review on Specifications for Control and Listening Rooms

3.1 Introduction

This chapter focuses on published standards, recommendations and measures for the correct design of control rooms and listening rooms for critical audio monitoring.

Some reference is made to publications on different factors that affect the perception of sound in a room.

Most of the accepted standards, measures and recommendations are a result of experiments made on the subjective perception of sound in enclosed spaces.

This chapter does not attempt to cover the entire list of publications both on the subject of specifications for audio rooms or on subjective preferences. It is a mere reference to a few guidelines and requirements that any acoustic designer should be aware of when projecting a room.

At this point a serious differentiation should be made between *Listening Room* and *Control Room*.

A *Listening room* is used for the enjoyment of listening to music. There is no assumption that these rooms will be used with the purpose of producing a recording, mix-down or post-production work. Listening rooms are also designed and used for the qualification of Loudspeakers, where a panel of listeners will rate differences between sets of Loudspeakers, which are usually concealed behind a curtain. These rooms will generally try to emulate the sound field of a domestic environment, although keeping some acoustic parameters under control.

A *Control room* is designed with the sole purpose of critically monitoring a signal, which is being recorded, broadcast mastered. It is therefore very important that this room is designed in such a way that the person or persons that are listening have a clear and real perception of the monitored sound without any distortions introduced either by the electronic equipment or the room itself.

Given the differences above, Listening rooms and Control rooms will have to be designed to different specifications although its use may appear to be similar.

The subject of multichannel control rooms is also approached, although this is a field where much research is still needed.

3.2Listening Rooms

The British Standard BS6840: Part 13[6], describes how a listening test for loudspeakers should be conducted. Along with definitions for an experimental procedure and evaluation, it also describes the physical set-up, room's characteristics and measures that should be obeyed to achieve credible results.

The room should simulate a standard listening room. Average RT should be within the range 0.3 s to 0.6 s in the frequencies 250 Hz to 4KHz. Individual measurements should not deviate more than 25% of the average value. Outside the specified frequency range the measured RT may vary more than 25%, as long as it is not higher than 0.8 s below 250 Hz. A further and more strict recommendation indicates that average RT should be 0.4 s ± 0.05 s. Flutter echoes between parallel surfaces, including scattering objects, should be prevented. The back wall should be treated to prevent strong coherent reflections, especially at mid and high frequencies.

Loudspeakers should be placed 1.25 m above the floor and pointed towards the listening position. Separation should be at least 2m and loudspeakers should be at least 1m from the sidewalls and 0.70m from the front wall. The listening position should be 2m away from the line joining the loudspeakers. The angle from the listening position and the loudspeakers should be within 55° and 65°. For good stereo image the arrangement should be symmetrical along the axis of the room.

3.3Control Rooms

3.3.1 Stereo

In 1998, Voelker wrote about the importance of the first 15ms in optimum listening conditions of control rooms[6]. Concentrating on the arrival of sound at the listener position, the interference of reflections is analysed. For a quality sound recording, the monitored sound at the control room should not be disturbed by acoustical influences of the room. “The control room should therefore be neutral”[6]. The author goes on to quote that a considerable shift in stereo localisation is produced by a reflection with a delay of as least as 0.021ms. This supports the idea that very early reflections will cause changes in the stereo imaging and should therefore be avoided. Furthermore, distortions on a first pressure front like delays and phase shifts are considered dangerous for optimal sound perception and can also cause fatigue during long term listening.

The sound being recorded at the studio area is composed by a direct sound from the instrument, but also of many short-term reflections from various objects near the path between the instrument and the microphone. When listening in a control room the sound within the first 15ms of a pressure front should reach the listener’s ears without being affected by reflections introduced by the room. If these reflections are not removed the impression caused will be that of a smaller room, distracting the listener from being able to hear exactly what is being recorded in the studio room.

As a consequence, in the control room no other contributions to a clear first pressure front are permitted, except for later reflections arriving after 15ms. Later reflections after 15ms are actually desired. This fact raises a very important question on how good monitoring speakers should be. Some of the models tested on the referred paper show another surge of a high-level pressure front, some 1ms after the first impulse. This can cause unwanted distorted information than can lead to listening fatigue.

For multi-channel sound reproduction the same criterion applies. First reflections within the first 15ms gap should be avoided. The room should be equally absorbed. Another solution is presented as the use of near-field monitors as an attempt to exclude the acoustics of the room.

3.3.2Multichannel

In 1998, Munro wrote a paper on a standard for audio-visual mixing theatres[7]. This paper sets out the specification of a room to be used in the monitoring of sound recorded in the 5.1 format. Munro states that there should be a correct balance between direct sound from each speaker, room reflection and reverberant energy. This is controlled by speaker directivity, distance and angle of the speaker to listening position, room volume and geometry and room acoustic treatment.

The practical set-up of the speakers has the left and right speaker at an angle of 60 degrees with the listener, and the centre speaker straight-ahead. The surround speakers should be at an angle of 110 degrees from the centre line. All speakers should be at the same distance from the listening position. However, if this is a problem for the surround speakers, these should be "equalised" in time by the use of time delays. All speakers should be identical. In terms of acoustics some consideration should be given to the design of the room. The room should be symmetrical about the centre line axis, which is where the centre speaker is placed. Windows and doors should be placed to redirect sound reflections away from the listening position. Reflections within 15ms should arrive the listener at a level of 10dB below the direct sound, especially within 250 Hz and 2KHz. Speakers should be placed at least 1m away from the walls and not equidistant to two or more walls. The sound field should be made as diffuse as possible. Reverberation time should be (0.25(V/100)^1/3)+/-0.05 s. Room ratios should be calculated in order to achieve good low frequency performance without any dominant modes. Attention should be given to noise levels that should be low.

The paper by Walker[8] describes the design of a control room for multichannel monitoring. The design of the room follows closely the International Recommendations ITU-R BS1116 and EBU Rec. R22 (Tech. Doc. 3276).

For the measurement of early reflections, the author used a MLSSA set-up with a bandwidth 10Khz (30 KHz sampling), a half hann FT window of 128 samples giving a half amplitude time resolution of about 2ms and a frequency domain sample spacing of 234 Hz. The results were further filtered at third octave bands.

To follow the published recommendations the level of reflections within 15ms of the direct sound should arrive the listener's ears at levels of 10dB below that of the direct sound (in the frequency range 1KHz – 8KHz).

The first order reflections are the most important to be addressed, due to the fact that second order reflections usually have to travel a longer distance and are therefore attenuated by air absorption and attenuation caused by hitting more than one wall. Furthermore, some consideration is given to the directionality of the speakers. All sources are considered omni directional. However, above 1KHz, which is the frequency above which the author claims to be important for directionality, all loudspeakers are generally quite directional. For this reason the immediate reflections of surfaces near the speakers are of controlled amplitudes.

To achieve enough reduction of level with the use of absorption would mean too large sections of absorptive material. An alternative solution is to angle the relevant portions of the walls in order to redirect first order reflections away from the listening area. A 2m exclusion area around the listening position would generally suffice. This dictates which angles to use on the walls. The rear wall can be a more difficult problem, for the angled portion would project too far into the room. Diffusers and flat panels that redirect reflections either to the floor or the ceiling can be used.

RT is adjusted by introducing additional absorption. The absorptive material should preferably be placed in and around the corners of the room.

Recommendations are:

RT=0.25 (Volume / Ref. Volume (100))$^{1/3}$.

3.4Conclusion

Most designers and acousticians have defined a clear need for having the very early part of the sound arriving from the speakers unmarred by any type of reflections or interference introduced by the room or phase non linearity from the equipment. This cross line is defined as being within 15 to 20 ms of the arrival of the direct sound. Therefore, a gap between direct sound and first reflection of at least 15ms should exist. This not only allows the early reflections in the studio to be heard, but also gives the impression of being in a larger space. Additionally, the stereo image is not affected by early lateral reflections that may have a confusing effect.

To address this, three main options are put forward:

- To use redirection of reflections in order to force them to "miss" the listening position. This is useful in the case of low RT due to the fact that no energy is removed from the room. It is rather redirected towards other surfaces, so that when it reaches the listening position its intensity has been decreased due to air and surface absorption.
  This method can lead to a very small *reflection free zone* or *sweet spot*, which is undesirable.
- To remove the reflection by means of absorption. This usually requires very bulky and large absorption, especially at low frequencies. It can be used in large rooms where RT tends to be large and space is available. The main advantage is that the reflection is effectively removed, thus leaving no possibility for a second order reflection to reach the listening position. However, if used in small rooms this can turn out to be a problem given that RT will be too low and bulky absorbers will take too much space.
- To use diffusion in order to smear the reflections in time thus reducing their amplitude, whilst scattering them in two or three dimensions. This option is usually preferred when used in conjunction with one of the methods above. Using diffusion is effective in reducing the effects of a strong specular reflection, but by adding randomness it can blur the image positioning created in stereo or multichannel set-up.

4.0 Personal View on Critical Listening Spaces

4.1 Introduction

This brief chapter is the author's personal view on requirements on control rooms and a few guidelines to achieve them.

The relevance of this chapter in the Transfer Report is to define the place for the proposed investigation. It will show that whilst most of the requirements of Control Room design have been addressed, low frequency control in rooms, although widely studied has not yet been successfully understood.

Most requirements and subsequent recommendations will emerge from papers described in the previous chapter and some practical work carried out.

4.2 Purpose of Control Rooms

The main purpose of a Control Room for recording, mastering or broadcast studios is to give a clear and very detailed representation of sound in order to allow critical monitoring of the signal.

However, there may be disagreement in terms of what type of acoustical sound field a listener should be exposed to.

The final product will most invariably be listened to in a multitude of environments. Domestic living rooms, in-car listening, headphones and compact stereo systems to name a few.

For an acoustic designer the main question that has to be dealt with is:

Should or should not a Control Room introduce any acoustical effects at the listeners ears?

If there are any effects introduced by the room then these should be controlled in such a way that the listener is not distracted from the signal being monitored. To try and emulate domestic listening conditions and set standards for control room design may prove difficult given that there is no average living room and listening environments are getting more and more diverse. Furthermore, the introduction of many reflections and large reverberation time, as it is common in domestic environments, may prove too distracting for an accurate monitoring of sound.

If the room is *not* to introduce any effects at the listener's ears, then any reflections from room boundaries should be removed. In this case the sound at listener's position is exactly what the speakers are reproducing and there will be no other reflections from nearby walls. However, this listening experience is not representative of "what it will sound like" in a domestic environment. Additionally, carrying a days work in a room which is constantly giving the brain "clues" that it is not used to can prove very stressful and uncomfortable (we perceive our enclosing environment not only from visual but also from auditory clues). Another problem may arise from the fact that in such a room the sound will differ considerably in different positions in the room. Stereo image will also collapse as soon as the listener moves from the listening position.

More over, in today's music industry, many control rooms are designed to be built in small spaces. These exhibit inherent problems due to size and proximity of boundaries. It is impossible to use large quantities of acoustic treatment, making the control of low frequencies a problem.

4.3 Requirements and Recommendations for Control Rooms

In order to define a procedure or guideline to achieve good accurate acoustics in a room it is necessary to define the full objective of a control room.

A control room is to be used in the critical monitoring of recordings made at an adjacent live room, in a performance space or recorded previously in some format. It can also be designed for broadcast or mastering.

For the above to be adequately performed the following list of requirements should be met:

- A flat frequency response should be perceived in the largest possible area within the room.
- Background levels should be low and follow published recommendations.
- The user should be able to monitor at the largest possible frequency range and without any phase distortions.
- The user should be able to listen exactly what is being reproduced by the monitors at a comfortably loud level.

- The room should not interfere in the experience of the listener by introducing predominant resonant frequencies (room modes).
- The Stereo Image should be very accurate, so that, the user can pinpoint where a certain instrument is placed, being it in a stereo or multichannel set-up.
- The user should be able to hear any very early reflections that may be recorded or happening in the performance area, without any masking from reflections in the control room.
- The control room should present some degree of “naturalness”. This means the RT should be at a recommended value across the whole frequency range and some perceptional cues of an enclosed space should be present but not predominant or distracting.
- The room should be a comfortable and inducing environment to work in.

To achieve the requirements pointed above a list of recommendations is certainly helpful as a starting point:

- Monitors should be of high quality, producing constant levels at the largest frequency range and phase linearity, preferably flush mounted allowing better coupling between monitor and room boundaries.
- The outer dimensions of the room should not be in small integer ratios ensuring Low Frequency modal behaviour is close to diffuse. This will prevent colouration or masking arising from predominant modes.
- The recommendation above is generally not enough to ensure even power distribution at low frequencies. Additional means of mode control should be used.
- Reflections within the 15 to 20 ms period should be controlled so that, if they arrive at the listening position their level is at least 10dB lower than the level of direct sound. The preference however is for these very early reflections not to arrive at the listener position at all.
- The point above is usually dependent on the longest Time delay gap that may occur in the performance space. The time gap between the direct

sound and the first high-level reflection in the control room should be greater than that in the performance area.

- Reflections from surfaces very near the monitors may alter the stereo or multichannel localisation and should therefore be controlled.
- Some late reflections (>30 to 40 ms) should be provided to add a degree of room impression, naturalness and control RT. (There may be disagreement regarding this recommendation given that some designers may defend long RT (~0.4s) may mask any noises in the original signal)
- RT should be "tuned" to be constant across all frequencies using extra absorption if necessary.

Along with the above indications, some common sense should also be present when designing the control room. A common addition to the room after the design is tall racks of equipment on either side of the listener position and even in the path between monitors and listener. As a rule, all items that are to be placed in the room should be taken into consideration at the design stage. After the final measurements and necessary adjustments any additional items should only be added with the advice of the acoustic consultant and monitoring sources if not fixed should not be moved.

5.0 Preferences and Opinions of Professional Audio Control Room Users – A field study

5.1 Introduction

This chapter focuses on the views and preferences of a panel of Professional Studio Control Room users in the UK. The panel was comprised of 18 professionals that work in recording, mastering or broadcast for at least one year. The average working experience was around 10 years. 15 of these professionals worked mostly with recording and mastering at professional recording studios, 2 worked in live recording of classical performances and 1 in broadcast for a major British broadcast company. The range of musical styles was varied and included classical, pop, rock and dance.

All these professionals were invited to participate in a 30 minutes interview about their views and preferences on the sound of Control Rooms for Music Recording, mastering or broadcast.

This was carried out as a first and important step on the development of the design of Control Rooms. The aim is to identify common language, important specifications and requirements by the people that regularly use a Control Room for professional purposes.

This survey took the form of a semi-structured interview where the answers were recorded for a later analysis. All interviewees agreed to the recording of the interview.

The interview aimed at 8 different aspects of sound in Control Rooms and the outcomes of work carried out in them.

The next section presents the general views about these aspects. The conclusions are taken from the results of the interviews, and there is no input from the author. They represent the general idea from the panel regarding different acoustic features. Answers are qualitative and their results are not an attempt to derive fixed quantitative measures. Appropriate quotations are given.

A copy of the interview can be found at the Appendix. Transcription of the interviews is available.

5.2Views and Preferences

Reverberance

Most people prefer rooms that have less Reverberance. This induces more confidence when monitoring.

"I'd prefer a dry room"

"I think the room should be neutral in the sense that you shouldn't be aware of it"

However, almost everyone finds that working in a room that is almost anechoic may become stressful, uncomfortable and sounds unnatural.

"I find dead rooms very tiring, I think it seems the sound changes quite a lot when you move around"

"I think a completely dead room is very claustrophobic"

Some ambience will help to have a better understanding on how the final work will sound at the end users' system.

"you need a room to be slightly reverberant because the end listener, the person in the living room at home has a reverberant room"

Reverberance should be set to a minimum before it makes it uncomfortable and unnatural to work.

Stereo Image

Best Stereo Image is described as enabling different clear positioning areas within the speakers. Instruments will be easily pinpointed in a whole image. Phantom sources have a defined, narrow (when applicable) and imaginable position.

"Yes, I think so, defined imagery yes, so that if you've got a series of images in a stereo field then they're clearly defined, discernable."

Some people refer that Near Field Speakers may give better stereo image although smaller in horizontal width due to their separation compared with Main Room Monitors. However, this is not a common feeling among the panel.

"Often times the stereo imaging on large control room monitors is not very good you know which is, most of the time as an engineer you're usually working on near fields anyway so you're choosing near fields to hopefully you know make the stereo image happen for you"

In a good stereo set-up, panoramic movements are clearly reflected in the positioning of the sound. In poor systems, panoramic movements have to be extreme for the effect to be noticed.

"you tend to find or what I find that badly set up systems before things start moving off that central image you have to be panning, and then there's a lot you know, a lot further out yes."

Focus/Envelopment

Most people prefer sound focused on the speaker field. Reflections or sound arriving from other directions can be distracting and make user feel uncomfortable.

"if it's a stereo operation then you certainly shouldn't be surrounded by the sound"

If the room is introducing too many reflections the user can find it difficult to translate how it will sound in other environments. He/She would not know if their perception is the sound being monitored or the particular room-speaker interaction.

"it would make me worry if I heard things coming from say the sides or the back, I'd wonder what it sounded like outside the room"

Most users refer that some controlled reflections or ambience will add to the naturalness of the sound.

Common feeling is that the focus should be on the speakers allowing also a certain depth of the stereo field behind the speaker plane.

Frequency Balance

Most people prefer a room which enables them to hear the full frequency range (20Hz – 20KHz) without any alterations. This means that the loudness level of reproduced signal should be even at all frequencies.

"A room that doesn't colour the sound."

A great number of people in the panel mention that a good room enables an increase in volume (loudness) without added colouration being added.

Most of the interviewees mention Low Frequency problems happening in rooms where they usually work. This takes the form of rooms that either enhance the Bass response or reduce it. Low Frequency should be detailed and precise without the effect of room modes (resonances).

"the main problem I think that we have with this room is the bass response of the room which changes drastically depending on where you sit."

"there's something in the walls that causes the bass to boom and reverberate and do strange things"

Some people mention that the room and system should not introduce any colourations that may elude the correct perception of sound. This would confuse their understanding on how it would sound elsewhere.

A small percentage of the panel mention great differences on frequency problems between using Near Field or Main Monitors.

<u>Sound Area</u>

All interviewed people have felt that the sound varies as they move to different positions in the room. Problems are described as vast differences in the frequency spectrum, blurry stereo image, a difference in transient sounds and an increased difficulty to hear different components of the signal properly.

All people mention that the most common problems are a rise of Low Frequency sound at the rear of the room, Low Frequency changes across the mixing desk and Low Frequency "Hot-Spots" in the room.

"You must sit in the operating position in the room to do any serious work."

"There's always a change in the frequency response, the transient is different depending on where you are you know, obviously that's partly to do with frequency and phase cancellation etc, I think the bigger the neutral space that can be created the better."

"Yes, the worst thing is if the bottom end"

Main concern is when Recording/Mastering Control Rooms are used as commercial facilities and the customer is not listening correctly to the sound being monitored due to its positioning in the room, most often not in the listening position.

"It is reasonably important because it gives the people you're working with a wrong impression, because generally they're not sitting at the desk all day"

"it has to sound good everywhere in the room because band members aren't going to come up and sit you know and make sure they're sat in the right place"

Some users also find it extremely difficult to translate their work to other environments because they are not sure if their perception is correct.
Sound is commonly described as not being homogeneous around the room.
Most users prefer a larger homogeneous sound area. However a slight rise in Low Frequencies towards the rear of the room is acceptable.
Middle and High frequencies are described as usually unaffected by this problem.

<u>Monitors</u>

Most people will generally use Near Field speakers for monitoring mixes. The reasons for this being that these speakers are more illustrative of end users' systems (Generally Hi Fi). It is also more difficult to make something sound good on this type of speakers and they are described as being less tiring when used for long hours.

"At least 80 percent on near fields."

"It's just because they're more like hi-fi speakers really"

"Virtually all the mixing and the long hours of programming and working are done on the near fields."

Main Monitors are generally used for recording, when loud levels are required and also when there is a need to check for extended frequency response.
Sound on Main Monitors is also more representative of Clubs and Bars. Most people feel uncomfortable using them because sound of main monitors is so exciting and make everything sound too good.

"I find it difficult to make decisions about the balance of instruments on big speakers, it sounds to good"

Although main monitors will almost invariably give a better detail of sound, near field monitors will show up problems arising from restricted frequency response and give a better view on how it will sound at domestic environments.
Main monitors are the election when it comes to show a product to record companies, due to their "bigger, stronger and more exciting" sound.
Four professionals of the interviewed panel always use main monitors, usually on stands, for classical music recording or for radio broadcast.

Learning The Room

Most users agree that they get used to how a certain room “sounds” after using it for a while. This learning process can take the form of listening to previously recorded material and hear how it sounds in a particular control room they will be using. Another common procedure is to take some work out into other environments and listen how it translates. Professionals evaluate if final work sounds as it was intended in the control room, when listened elsewhere. If there are any major differences, the work is brought back into the control room and the mix is compensated. This procedure will improve until final work is achieved to a satisfactory level without the need of later readjustments. Finding problems and slowly solving them is also part of this learning process.

“I'm use to our mix room now and you can be fairly sure you know what you're getting out”

“It does take you a while to get used to”

“I mean the first thing you do is to play a reference tape, a tape of mixes or music that you're familiar with and you know what it's supposed to sound like or you know what you're familiar with and so immediately you hear something strange like too much treble or a resonance at 1 kHz or too much bass or a fuzziness in the stereo image or something like that”

Some professionals mention that if they were using a well-known mixing console or outboard equipment, they would expect certain behaviour of the EQ section or gain. If this does not happen they will use this as a clue to how the acoustics of the room and monitoring system is affecting their perception. Ultimately, being used to the sound of a specific room is being able and making sure that work that is taken out will sound consistently similar in other environments.

“that's the main thing is that your work may be different from what you did in another control room but it's still is OK so it's a question of confidence, it's a gradual acceptance of those characteristics.”

Consistency with Other Environments

Most interviewees will take mixes out into other rooms and systems (Hi-Fi, Car, Ghetto Blasters, etc) in order to check if it sounds as they intended in the control room. Invariably, these systems will have lower quality sound.

“Is the best way to go about it and at the end of the day as long as it sounds similar in that control room and then probably the most important thing to do is after you've finished the section or the mix is take it home and listen to it at home, listen to as many different speakers as you can”

Professionals check for consistency in frequency, balance of instruments, missing notes, masking of important sounds, loss of detail, perspective of stereo image and reverberance and mono compatibility.

“Well I hear at home, I'm looking to hear that it's as I remember it sounding in a control room.”

“I listen to, one is the kind of what I'd call the technical frequency bands which is just how much bass, how much treble but then the other more musical aspect is the question of the musical aspect of a mix for example, the balance of the instruments and the perspective of the instruments, reverberation is important as well”

Control rooms that have problems in the frequency response will turn into problems in final mixes when heard in other systems.

“And the subtleties involved and how a little bit in a room can turn into a lot or not enough”

A common comment is that low frequencies do not translate well and there will be either a loss or an increase of low frequency when replayed in other systems.

These problems may usually be readjusted by remixing or at a later mastering stage.

<u>Optimum Control Room</u>

The panel was asked for a description in their own words how an optimum control room should be. The aim of the question was for sounding qualities of the room. However, most people felt appropriate to include preferences on other factors such as decorating, lighting, temperature, staff, etc. These are commonly seen as more important than the actual acoustic facilities.

In terms of acoustic factors, the author finds more appropriate to include transcriptions of some of the comments made in order to convey the full meaning to the reader.

“Clean, clear, detailed, strong”

"have enough separation, have enough, enough depth “

"you've got to have a dynamic range, you need to hear everything, you want to hear as much detail as possible, all the information possible, as wide a frequency range as possible, flat unless you know the room, and at least two pairs of monitoring sources…"

"Yes, balanced across the frequencies sure, you don't want it to be getting excessively bottom endy when you turn the speakers up.
you don't want the high frequencies to be reflected."

"a neutral environment where you can make informed decisions about the recording you're making, this environment is purely a tool to let you do the job which is making the decisions about the mix , a control room should be somewhere which I can go and I can make my mix decisions and the decisions I make will be based on what's going on in the hall not, you know nothing to do with the control room, I don't want to be bothered with the control room, I'm not there to listen to the control room. I don't want to be thinking about the control room, I'm making all my decisions, my balance decisions on the sound which comes from those speakers.
I should be able to forget about the monitoring environment.
I don't want an environment which is fatiguing in terms of being able to you know, being able to
In terms of being able to listen and any acoustic problems with the room, if they're constantly nagging at you then that is really going to get on your nerves.
anechoic environment is not normal you know, it's, so I guess that's one of the reasons why I wouldn't like it.

"a room with a flat response that doesn't mislead you, you want a large working area where there is very very little alteration in the sound you hear, so you can actually be fiddling around in front of the desk and you're hearing it real, there's nothing worse than having one little zone where you can hear it for real then you move over and you do your alteration then you move back to see what it's done, and it doesn't matter where I sit listening to it…"

"I guess clarity, clarity is a big thing, I suspect a lot of reflections make a confusing space
I think you've got to have a real clear, neutral space so that you can really hear what the sound is that's in the speakers as opposed to the sound of the room we're in today because the room the listener's going to be in tomorrow is not going to be here."

"it needs to sound natural, it needs to sound like you're not aware of the room, the acoustics of the room at all so that you feel like you're just listening to the music that's coming out of the speakers so yes I wouldn't want to hear any resonances or, a clear stereo image, well balanced across the room if possible, if it was possible for it to sound exactly the same everywhere in the room that would be really good, it needs to be a sound that's not tiring as well, it should be a comfortable sound but transparent, yes transparent and without any real character,

"as long as I take a mix out of a control room that you know that I'm happy with then that's when the control room is a good control room, it's not guessing again it's like a control room that stays true to what I'm doing in it so everything that I'm trying to achieve on particular mix will you know happen in other systems, it's important that that happens.
Again it's the bass end, I think it's an important one, the mix I think is very important as well, Well it's got to be loud to start with, I would like a big control room for the reasons that I explained before, my control room has to have nice big speakers, the main monitors have to be quite good.
Mainly because it's the way I listen to music I suppose you know and because of what I do, doing, I like the bass end of it to be live and punchy so it's very important for me to make sure that it is and I don't find small control rooms and near fields good enough for that so it has to have a nice monitoring, a nice big monitor system yes."

"A room without resonances, back to the equal frequency, the flat frequency idea, So it's flat and clear. Non-resonant, something that doesn't lie that's all…"

"It sounds comfortable, put on CDs that you know and like, put them on the main monitors and go wow that sounds like I expect it to sound, should give you good stereo imaging, you want it to be detailed, you've got to be able to work in it for fourteen hours a day on the monitors and not get tired so if the room's boomy then again it makes you tired because you're constantly having to think and fight against what you're hearing or what you want to hear, if it's too reverberant, if it's too dead you know, just horrible…
Yes, ideally yes it would be nice to have a reasonably cohesive sound up and down the board, not necessarily stereo imaging because you know that tends to collapse fairly quickly as you move off axis but to be able to stand at one end of the desk and know that if you're EQ'ing something, it's sounds reasonably similar to what it sounds like in the middle of the board even though you're completely way off axis.

"Punchy bass drum and I prefer to hear lower bass and punchy bass drum rather than a sort of woolly ??? from the bass.
So definition in the bass but definitely bass drum and punchy kick from the drums…"

"loudness is very much something should be a natural sounding loudness, stereo image should be tight and accurate you know if something is central it should be central like I was saying before if something's slightly right, it should appear to be you know, what a room should sound like…
I really do like very accurate rooms, a good sounding room should be accurate with regards to image, I don't think a room should have any sort of imposed character, well that's impossible but a room should have the minimum amount of imposed character as to keep it natural.
About frequency and time delaying which are hugely inter-related so you can't separate them really can you I mean but with regard to both sort of domains you know what I mean.
it's not like walk into an anechoic chamber, put a pair of speakers up it probably will sound fantastic you know but turn round and have a conversation with somebody it can be quite bizarre and you shouldn't have

to shout, so on and so forth, should be enough reverberation for something to sound natural but it shouldn't affect the character of the room."

"speakers with a good frequency range, I like to be able to sit in a good position, get a good stereo position, I do like the room to be quite wide, I find reflections off the side walls quite confusing sometimes, I do like a bit of reverberation…
I always have to say I think the clarity, getting a nice sound out of things, not getting too disturbed, there is a need for warmth, a little reverb."

5.3 Conclusion

The previous sections will have conveyed the opinions and preferences of professionals that use a Control Room most days of their working life.
Reverberance and reflections are factors that should be kept at a minimum. However, ambience, which gives the user, some perceptual clues of the enclosed space he/she is in are important for comfort and confidence in the consistency of work.
Stereo Image is described as best within the speaker field preferably projecting some depth in the region behind the speakers.
Throughout the interviews it became increasingly clear that there is a major problem at Low Frequencies with most control rooms. Most users complain about problems in translating work out of the room into other environments especially when listening to low frequencies. The reason for this may be due to the fact that most rooms are not controlling low frequencies to a desirable standard.
There is also a general idea across the panel that spatial irregularities are happening mostly at low frequencies. The inability to perform a certain task when you are in a position away from the main listening position becomes a problem. Adjustments on outboard equipment are usually away from the listening position and the engineer then has to come back to accurately listen to the result. This is clearly far from the best working conditions. Another problem arises when customers are in the room and wish to evaluate how the work is being carried out. Most users find it uncomfortable to constantly having to remind their customers that what they are hearing may not necessarily be the truest representation of the sound being monitored.

Near field monitors are the election when it comes to performing long hours of work and making sure it is going to be consistent at other environments. The reasons for this being the closest frequency response when compared to domestic systems and the added difficulty of making the sound better using smaller monitors. However, it should be pointed out that rooms are generally designed to be used with specific main monitors. Using near-fields in these rooms means that the listener may not be taking the full advantage of the acoustic design of the room. In fact, as near-field monitors are usually placed on the top of the meter bridge, the pattern of early reflections may be completely different of that to which the room was designed for. Comb filtering and altered stereo image may be some of the unwanted effects of monitoring using near field in a control room designed for a specific pair of main monitors. On the other hand, being smaller and less powerful, near field speakers do not excite the room in the same way as large main monitors and given their reduced frequency response, the interaction room-speaker is not as noticeable. The problematic effects of room modes may not be as noticeable given that they are not excited at the same points (as with main monitors) or to the same amplitude.

The extended frequency response and usually the better specifications of main monitors make them too flattering which can be deceiving for the user. Main monitors are used for extended frequency response checks and as a “show-off” tool for record companies and A&R. Main monitors are also important when recording, where detail and loud levels are required. Most users will have their own set of near field monitors, which they take with them into the room where they will be working. Because they are well used to their system, they can perform their task more confident of what they are hearing. All users will undergo a stage where they adapt to how a certain room sounds and how this affects their perception. This is usually done by playing some well-known recordings and also by taking some work out and listening at some other system/environment. This procedure is a learning process that, when perfected, enables final work to be taken out into other environments and still sound consistent to how it was intended in the control room.

6.0 Proposed plan of investigation

6.1 Introduction

This chapter reports the plan of investigation to be carried out in order to attain the PhD degree.

It is widely known among the acoustic research field that the sound field of a small room at Low Frequencies exhibits maxima and minima (peaks and troughs) that can vary as much as 15dB. These are caused by what is known as “room modes”. When sound is bouncing between two parallel walls the effect of a one-dimensional standing wave is set up (axial mode). These cause resonant frequencies, which are dependant on the distance between the walls. Inside a rectangular room, there are 3 sets of parallel walls that will cause this effect. Tangential (2 dimensions) and Oblique (3 dimensions) modes also exist although these are usually less noticeable than axial modes. If a room is used for critical monitoring the audible effects of room modes will affect the correct perception of sound at low frequencies. Furthermore, the spatial variation that these modes cause can make two different positions in the same room have a very different frequency response.

As concluded from the previous chapter, on the investigation of subjective preferences in control rooms, the Low Frequency response and spatial variance of sound inside the room are the most obvious problems in nowadays state of the art control rooms. It is therefore necessary to address this issue in order to enable control rooms, especially those of smaller dimensions, to be designed in such a way that normal room modes do not affect the correct perception of reproduced sound.
A section on previous published work in this field is presented in order to identify the novelty in this line of research. It may appear strange to the reader to find another literature review at this chapter, however it is very relevant to identify what type of investigation has been done into the control or description of low frequencies in rooms.

Some work published on Distributed Mode Loudspeakers is also presented, given that this type of transducer will also be under investigation.
A brief description of investigation methods and a time plan is discussed.

6.2Work previously done in the field

In 1988 Morimoto et al wrote a paper on the effects of low frequency on spaciousness[16]. Results lead to the conclusion that one should pay attention not only to making Inter Aural Cross Correlation lower, but also to providing low frequency components, especially below 200 Hz, to increase spaciousness.

In 1988 Toole and Olive reported on the effect of resonances in the perception of timbre[9]. The paper is very comprehensive and covers various experiments that attempt to identify thresholds for the detection of resonances added to pink noise, pulses and music signals. Frequency range is as low as 200 Hz and up to 20KHz. Findings show how factors like frequency, Q-factor, type of signal, reverb and delay affect the perception of resonances. The results give useful information on how low frequency resonances should be quantified in terms of their disturbance level and the necessity or not of controlling them.

In 1994, Olive et al present a paper on the detection of low frequency resonances[10]. The results are very much in line with the results of above described paper by Olive and Toole. The difference in this experiment is that the tests are carried out with frequencies ranging from 50 Hz to 500 Hz, therefore concentrating on lower frequencies. The audibility of notches as well as peaks is also studied. This paper unveils more important information on the Human perception of low frequencies.

In 1995 Herzog et al wrote a paper reporting on Low Frequency room modes and the use of passive and active absorption in order to control room modes[5]. Details on the technique of modal decomposition are given. Placement and effective use of passive absorption is described.

Also in 1995, Darlington and Avis produced a publication presenting a method of actively controlling room modes[11]. Spatial and Frequency irregularities introduced by room modes are studied and a solution in the form of a cone loudspeaker designed to radiate negative power is shown to effectively control a Low Frequency mode.

In 1996, again Darlington and Avis present the use of active absorption to control room modes[12]. Investigation into wave-guide and real size measurements is done.

So far, most work published on Low Frequency modes in rooms has been done using conventional cone Loudspeakers. Follows a reference to some publications on a novel type of transducer being developed, the *Distributed Mode Loudspeaker*.

In 1997 Azima and Harris write about DML radiation and interaction with nearby boundaries[13]. Due to its diffuse nature, reflections originating from boundaries near DML speakers are said to be less distracting. Some comments are also made on the ability of DML to generate a more even power distribution across a larger area of the room.

In 1998, Azima and Mapp produced a paper comparing the interaction between DML and normal cone transducers and nearby reflective walls[14]. This paper concentrates on the effects of early reflections. The sound field created by DML is here said to be less influenced by nearby boundaries.

In 1999 Azima and Panzer report on placing a DML panel flush mounted in a box, much like the cone of a conventional cabinet loudspeaker[15]. This is proven to eliminate undesirable effects of DML when placed parallel and very near (less than 50cm) to a wall. The effect of placing a DML in an enclosure is described as having an improvement in performance whilst removing the dependence on positioning.

6.3 Points to investigate, Results and Novelty

As seen from the previous section and previous chapters, it is widely published that small-enclosed spaces exhibit Low Frequency discrepancies at audible frequencies. These problems are in the form of *Frequency* and *Spatial* irregularities such that:

- Two persons in the same room at different positions will experience a different hearing perception for the same sound being monitored.
- One person will perceive a difference in tonality when moving around in a room
- The perception of sound at Low Frequencies will differ substantially when listened to in rooms of different dimensions

In rooms used for critical listening the effects listed above are highly undesirable and should be avoided.

The proposed route of this research is to investigate solutions to the problems of Low Frequencies in critical audio listening rooms.
Therefore, by addressing the problem of room modes, the even spatial distribution of pressure is also improved.
As a novel line of research the interaction between Distributed Mode Loudspeakers and rooms at Low Frequencies will be carried out.
DML radiate sound in a different way to that of a conventional cone Loudspeaker. Therefore, it is expected that when placed in a small room, DML will excite the modes differently, due to its diffuse radiation. There is a necessity to investigate how a large size DML generating only low frequencies would excite the low end of the spectrum in a small room. By understanding this, a better insight into solving or controlling low frequency problems will be gained. The objective is to provide a more even frequency response at low frequencies and therefore a more even power distribution at all locations inside the room.
DML Sub-Woofers and rooms could be designed in conjunction in order to provide a space that would enable critical listening to be performed at its best.

There are large areas of space available in a control room that could accommodate such a Sub-Woofer. It would be commercially viable and desirable.

The theory involved would include understanding of low frequency modal behaviour, modal decomposition techniques, sound pressure spatial distribution in an enclosed space and a brief insight on the behaviour of DML at low frequencies. Some computer modelling will be required.

Results expected are a better understanding of the interaction between a diffuse source and an enclosed space and a further contribution to the knowledge of source-room interaction at low frequencies. A better knowledge of this could lead to the design of Sub-Woofer systems using DML or multiple low frequency sources placed at specific locations all with the final objective of enabling control rooms to be designed and built with a more even low frequency response and spatial distribution.

A more efficient use of passive absorption methods would also benefit from the results of this investigation.

The novelty in this line of research is on the fact that at the moment DML have not been investigated as low frequency sources. Additionally, the interaction between diffuse sources and room modes has not been comprehensively researched. A novel and successful use for this type of transducer in conjunction with improving the design methods for professional standard control rooms will benefit the academic knowledge in this field.

6.4 Methods to be used and Practical Work

In order to achieve the results proposed above there will be a methodical approach to carry the research.

The first step will be to investigate the difference in using DML rather than conventional transducers when exciting the room modes. This will be achieved by measuring the low frequency response of a very small room (e.g.

2m X 3m X 3m) when excited both by a large size DML panel and a conventional studio monitor. Some scale model measurements will also be required.
Different behaviour will be investigated placing the source at relevant locations in the room.

Having measured a frequency response using a DML as a source it will be suitable to model how source size, behaviour location and positioning affect the response in the room. The effects of room boundary conditions, size and shape should also be investigated.
The most effective way to achieve this appears to be computer simulation using different techniques such as *Modal Decomposition* or *Boundary Element Modelling.*
The interest will be on investigating how modes of the panel and modes of the room couple together.
A computer simulation is a fast and non-expensive way to gain a better understanding of the interaction between a given source and a room.
If a process of *auralisation* is modelled, a further subjective investigation of the effects of low frequency modes can be performed.
After a better knowledge of source-room interaction, a design of a Distributed Mode Source for low frequencies may be attempted.
Further measurements of this type of source in a specific room configuration should be tried.
Again, some subjective perception experiments may be carried out in order to identify if the effects are audible and desirable.
A design procedure for extended area of even power distribution should be the result of these experiments.

6.5 Problems

The inability of DML to radiate as a diffuse source at very low frequencies can pose a problem to this investigation.

DML generally behave as a bipolar almost pistonic source at its low-end performance. At very low frequencies the modal vibration of the plate is of first and second order making it a non-diffusive source. The way to overcome this problem seems to be to design a DML that exhibits higher order modal behaviour at very low frequencies. This problem is highly dependant on the material of which the panel is made of.

Additionally, to generate very low frequencies it is believed that the panel needs to be of very large dimensions, and these are not commercially available.

These problems can be overcome by performing scale measurements and using normal, commercially available DM Loudspeakers in scale size rooms. This way, the source would behave as a diffuse radiator at the frequencies of interest.

Another problem is the power handling capacity of DML, which may make them unsuitable for Control Room use.

Using computer modelling is an effective way to simulate some results without the physical problems associated with real size measurements. However, the model needs to be very accurate and this may scale up computational time, depending on method and programming language.

Coupling between source and room should not be overlooked and incorporated at some advanced stage of the simulation. This can be done using a Finite Element Method approach.

6.6 Time plan

7.0 Conclusion

Control Room design is a science that is still under development. The choice between a neutral room, a completely anechoic room or a room that has its own ambience is still not clear.

Many different philosophies of design are currently in use, and all have advantages and disadvantages.

A field research on a panel of professionals working in Studio Control Rooms in the UK has shown different factors that affect the perception of sound in these rooms. It stands out as a common problem that most professionals are disturbed by the effects of resonances at low frequencies especially in small control rooms. This effect is parallel to a spatial irregularity in the room that makes two different positions in the room sound completely different.

A proposed plan of investigation is put forward in order to further investigate low frequency problems in rooms and how type of source can influence this. It is believed that a novel type of source currently under investigation may excite the room modes in a different way and therefore create a different perception of low frequencies in small rooms. It is suggested that the investigation into how a Distributed Mode Loudspeaker excites modes in a room may give a further insight into behaviour, excitation and control of low frequencies in rooms. This is highly desirable from both an academic and commercial point of view.

It is the belief of the author that the scope of the investigation presents originality and will provide further contribution to the research field.

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Appendix

Structure of Interview

Introduction and first checks

1. Introduce and talk vaguely about interview and its purposes, stressing that research is about acoustics but their views and preferences is what we need to know about. Should last about 30, but ask if there is a time dead line.
2. Confidentiality means that no specific names will be presented anywhere.
3. Ask permission to record on DAT, and start recording.
4. Start interview by picking up on one of the questionnaire answers as an introduction.

Points to identify:

1. Reverberance
2. Stereo Image
3. Envelopment/Focus
4. Sound around the room
5. Frequency Balance
6. Learning the room
7. Near Field monitors/headphones
8. Consistency with other listening environments
9. Optimum conditions

Favourite Conditions:

- How do you feel a room should be in terms of reverberance?
- Do you find it easy to work in a control room that sounds very dry?
- Do you find it easy to work in a control room that sounds very live?

- What is your description of a good Stereo Image?
- What type of stereo image do you prefer? (eg: Narrow, wide, very wide, contained within the speakers, etc.)

- When you are working do you like being surrounded by sound or do you prefer a more focused sound within the speakers? Please explain.

- What happens to the sound as you move around the room?
- Are there any positions in the room where factors like Stereo Image, Frequency Balance and Localization are best? Where is best? Where is second best?

- In terms of tonal balance, how would you describe the sound of a good room?
- Do you find that sometimes you feel the sound is bass or treble heavy and this is being introduced by the room rather than by what is on tape?
- Does this happen at localized positions in the room? Where?

- During the time you have been working, have you found that you get used to how a certain control room sounds, and you adapt your mixing/recording decisions to it?
- Have you ever found that you were compensating for a specific feature? Which one(s)?
- How would you describe this “learning the room” process?

- Do you find that the system with which you work (including desk, amp, speakers and room) is faithful to what has or is being recorded?

- Do you compare your final work on other systems, like car stereo, small tape player, other rooms?
- What are your comments on how the final work sounds on other systems?

- Do you use near field monitors on your mixes? Why?
- Can you specify the situations when you would use near field monitors?
- And the main monitors?

- How would you describe the sound in the control room of the studio where you usually work? If you work in more than one control room please describe the one you prefer.
- Could you describe how would your optimum control room sound?

<u>Closing:</u>

- I believe I have taken too much of your precious time. I would like to thank you for your availability. Would you like to be informed about possible outcomes of this study? Do you know of anyone that may be of interest to this study?