Microphone Array Analysis for Multichannel Sound Recording

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Michael Williams
Independent Audio Consultant
Paris, France

Guillaume Le Dû
Ecole Nationale Supérieure Louis Lumiére
Marne La Vallée, France

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MICROPHONE ARRAY ANALYSIS for MULTICHANNEL SOUND RECORDING

Michael Williams[1] and Guillaume Le Dû [2]
1 - Independent Audio Consultant, Paris, France
2 - Ecole Nationale Supérieure Louis Lumière, Marne La Vallée, France

Abstract :
The development of microphone array systems for recording both stereo and multichannel sound is directly dependent on the configuration of the reproduction system. This paper describes the intersection between the psychoacoustics of the multichannel listening environment and the physics of the microphone array in the context of univalent recording/reproduction systems, and how realistic natural reproduction of the sound field can be achieved.

Introduction

Multichannel sound recording systems are as much subject to the basic rules of sound recording as any other recording system, be it monophonic or stereophonic. The microphone or microphone array will need to be nearer the sound source to obtain the same sound perspective compared with perception by normal hearing of the actual sound source. The perception of distance is as usual a function of direct to reverberant sound and therefore directly influenced by the directivity of the microphones used in the system. The advantage of the multichannel surround sound environment is that we are able to « envelope » the listener as much as we consider desirable. In achieving this aim we are not limited to the front facing triplet of microphones and loudspeakers to create our main sound stage, for this would create limits to the main sound stage and be little better than the traditional stereophonic reproduction. However this front perception zone of about 60° seems to satisfy approximately our needs as to the angular size of the main sound stage, but with multichannel continuous sound field recording and reproduction, we have the freedom to be able to widen this sound stage if we feel the need.

The stereophonic listening configuration severely limits the sound recording engineer in the reproduction of early reflections and of course in the reproduction of the surrounding reverberant sound environment (4). The object of this paper is to show how it is possible to design multichannel arrays that are capable of giving complete freedom for the sound engineer to spread the main sound stage over any desired angle, and to integrate both first reflections and reverberation and maintain their natural acoustic structure. This is another major step towards achieving seemingly perfect reproduction of the sound environment. We must also be able to use this type of sound recording system in the recording of contemporary music which will often make use of the surrounding sound space, and of course sound effects and ambiance where sound should be localised correctly within the total surrounding sound field.

But don't be deceived, the achievement of this aim needs very careful adjustment of the parameters of the microphone array, and a clear understanding of the fundamental characteristics of each segment of the array. It must also never be forgotten that, as with stereo, the microphone array will pick up not only sound in the horizontal plane around the array, but both above and below the system. This sound will obviously be reproduced only in the horizontal plane of the reproduction system. We must therefore not loose sight of the fact that even multichannel surround sound recording and reproduction systems still have some limitations to the impression given of natural reproduction of the total sound field.

Segmentation of the Sound Field

At the 91st AES Convention (New York - 1991) in a paper entitled "Microphone Arrays for Natural Multiphony" - preprint 3157, the author (Michael Williams) described the development of three microphone arrays suitable for recording/reproduction systems using four, five or six channels. At this time the author considered the associated loudspeaker layout to be perfectly symmetrical, the reproduced surround sound field being generated by loudspeakers placed on a circle divided into equal segments in the horizontal plane. Also the recording/reproduction system was based on a univalent or one to one microphone/loudspeaker relationship. The characteristics of a specific microphone array covering a given number of segments, was determined from the intersection of the physics of the microphone array with the psychoacoustics of the listening configuration. This approach was conceived, for the four channel system, purely as an extension and improvement of the original Quadraphonic Recording/Reproduction System, and it seems, was somewhat in advance of the multichannel systems now required.

Although a similar approach by segmentation of the sound field is used in this paper, it is shown how almost complete freedom can be obtained in the relation to the physical angle between the microphones with respect to the corresponding segment coverage angle. A detailed analysis will show how to "link" segments without overlap, and obtain a smooth continuous reproduction of the total sound field.

The standardisation in the context of multichannel reproduction in relation to surround sound for audio-visual applications, has since modified considerably the layout of the sound field segments. This, together with an ever increasing interest in the use of multichannel systems for the reproduction of music as a purely audio media, has shown the need for a clear and unambiguous analysis of the psychoacoustics of reproduction in a multichannel environment, in order to help in the development of microphone arrays that can meet the need for specific sound field segment pick-up and reproduction.

In Stereophony, considerable use has been made of Intensity Difference, Time Difference and combined Intensity/Time Difference systems to produce reasonably satisfactory microphone systems for the recording and reproduction of the sound field. In previous papers(1)(2)(3)(4) the author has shown how a multiplicity of dual microphone arrays can be developed to enable the sound recording engineer to choose the best configuration for optimum stereophonic results in a given set of conditions. In this paper this same approach has been applied to microphone arrays for multichannel systems.

It is a convention established in a previous papers (1)(2) that the Stereophonic Recording Angle is always specified as +/- 50° to avoid confusion with the angle between the microphones. However in the case of Multichannel Microphone Arrays we no longer have a symmetrical recording/reproduction sound stage in relation to each of the array segments, so it would seem necessary to change terminology and use the idea of **Coverage Angle** to mean the total coverage of the Stereophonic Recording Angle of a single pair of microphones making up part of the total Multichannel Array. In the example cited the SRA of +/- 50° becomes a Coverage Angle of 100°.

Back to Basics

It should not come as any surprise to the initiated that we must first deepen our knowledge of the characteristics of a simple pair of microphones, reproduced evidently by two loudspeakers. In the context of stereophonic reproduction, left/right symmetry of the reproduced sound field is, in general, obviously desirable. The sound field reproduced by the loudspeakers can be either smaller or larger than the physical angle between the axis of directivity of the microphones, and disposed usually symmetrically on each side of the physical axis of the pair of microphones.

However in the design of multichannel microphone arrays we must have complete control over the **angular offset** of the reproduced segments of the sound field in relation to the axis of symmetry of the microphone pair covering each specific segment. In the design of the front facing triplet of microphones covering the left and right front segments, we must be able to **offset** the reproduced sound field segments so that the side limits of the left and right sound fields correspond to the axis of the front facing centre microphone. For the lateral segments however we need to be able to rotate freely the coverage of the side segments, without any coincidence between the physical axis of the microphones and the limits of each of the sound field segments. And finally, for the back segment we return to the simple symmetrical segment as used in stereophony.

Offset and Linking

The application of **Offset** is illustrated in Figure 1 to 6.

- Figure 1 shows the standard Stereophonic Recording Angle (SRA) where it is less than the physical angle between the microphones.
- Figures 2 & 3 show how this same sound field coverage can be rotated in an anti-clockwise direction, that is using an **negative angular offset**.
- Figure 4 shows an SRA that is larger than the angle between the microphones.
- Figures 5 & 6 show the same principle of offset, but using, this time, a clockwise rotation or **positive angular offset.**

In these Figures (1 to 6) the Stereophonic Recording Angle has been drawn with its true origin on a line between the two microphone capsules. In Figure 2 and Figure 5 we see that the left limits to the SRA are aligned (or parallel) with the axis of the left microphone.

The process of **linking** is represented in Figures 7 to 10. As the sound source is relatively far away compared with the distance between the microphones, it is an acceptable approximation from now on, to draw the graphical origin of the SRA coverage at the intersection between the microphone axes. This enables us in Figure 8 & 9, and thereafter, to illustrate more clearly the process of **linking** that is an essential characteristic in the design of a multichannel microphone array for smooth and continuous coverage.

- Figure 7 shows the front triplet of a Multichannel Microphone Array. We can see that we have microphones facing both towards the left-hand side and right-hand side, forming left facing and right facing pairs by sharing the centre microphone.
- In Figure 8 & 9 we show how to link the SRAs of each pair to produce continuous coverage of the front sound stage. Figure 8 uses the link between two SRAs that are each smaller than the physical angle between the microphones that make up their respective pairs. We need to use Positive Angular Offset on the left segment and Negative Angular Offset on the right segment to **critically link** the two segments. However in Figure 9 the link is between the two SRAs that are larger than the angle between the microphones, we therefore use Negative Angular Offset on the left segment and Positive Angular Offset on the right segment for correct linking. By this process we can create a front triplet with any desired coverage angle, thereby giving more flexibility to the sound recording engineer in setting up the coverage of the main front sound stage.
- Figure 10 shows how this process of linking is applied for the complete Multichannel Microphone Array. Only the front facing centre microphone is aligned with the linking of two segments i.e. the link between the Front Left Segment (FLS) and the Front Right Segment (FRS). The Back Segment (BS) is usually symetrical with respect to the back axis of the system.

Intensity and Time Offset Generation

The method used to produce this offset technique is in fact remarkably simple, both in theory and practice. The difficulty comes in the choice of specific offsets so that « critical linking » is obtained, and smooth and continuous sound field reproduction is achieved. Basically there are four different types of offset that we can apply :

- **Electronic Intensity Offset** – addition of a constant Intensity Difference to the Intensity/Time Difference function between two microphones
- **Electronic Time Offset** – addition of a constant Time Difference to the Intensity/Time Difference function between two microphones
- **Microphone Position Intensity Offset**
- **Microphone Position Time Offset**

These last two offsets are one and the same, as it is just a question of one type of offset relative to the other. By creating a Microphone Position Intensity Offset in one direction, it is equivalent to creating a Microphone Position Time Offset in the other direction.

Figure 11 illustrates the analysis of this Microphone Position Offset, but seen from two different points of view :

- Using the microphone diaphragm as the centre of rotation for each microphone, we can consider that both microphones have been rotated 15° in an anticlockwise direction (Figure 11b), thereby also rotating the Intensity Axis (ΔI=0) anticlockwise by the same amount i.e. Negative Microphone Position Intensity Offset.
- Or we can think of the right hand microphone as having been moved backwards whilst maintaining the same distance between the microphones (Figure 11c) - the time axis (ΔT=0) has therefore been rotated 15° in a clockwise direction i.e. Positive Microphone Position Time Offset.

It is sure that the trigonometric analysis of these two interpretations is somewhat complicated, but the practical end result is exactly the same i.e. the orientation of the Intensity axis relative to the Time axis is the same..

There is however a subtle difference between **Electronic Offset** and **Microphone Position Offset**.

- Electronic Offset is simply the addition of a constant value of Intensity Difference or Time Difference to the Intensity/Time function of a pair of microphones covering a particular segment.
- Microphone Position Offset is created by changing the physical position of the microphones forming the pair, thereby creating an angular difference between the Intensity and Time axes.

Let us be clear on the convention that has been adopted for Positive and Negative Offsets :

<u>POSITIVE</u> OFFSET IS DEFINED AS THAT OFFSET WHICH PRODUCES A ROTATION OF THE COVERAGE ANGLE IN A <u>CLOCKWISE</u> DIRECTION.

- **This is obtained in the case of a Positive Electronic Time Offset by introducing a delay in the right hand microphone in relation to the left hand microphone.**
- **Similarly with Positive Electronic Intensity Offset the right hand microphone is attenuated in relation to the left.**
- **With Positive Microphone Position Time Offset the right hand microphone is rotated clockwise (i.e. backwards) using the centre of the left microphone diaphragm as the centre of rotation whilst maintaining the same distance between the microphones and angle between the axes of the microphones.**

Each of these different **positive** offsets will produce a shift in their respective Intensity/Time function graphs either <u>to the left</u> for Positive Time Offsets, or <u>downwards</u> for Positive Intensity Offsets. This can be a little disconcerting at first, however the sound position coordinates show the relative position of the Coverage Angle and this leaves no room for ambiguity. The values of the Sound Position Coordinates are shown in ellipses superimposed on the Intensity/Time Difference function in each graph. The table shown in Figure 25 will help in following the analysis and practical implementation of each type of Offset.

OFFSET FUNCTIONS – (COVERAGE ANGLE > PHYSICAL ANGLE BETWEEN MICROPHONES)

Electronic Offset

- Figure 12 shows the Intensity/Time Difference Function for a pair of microphones at 25cm/70° between the microphones without any Offset of any sort.
- Figure 13 however has a **Positive Electronic Time Offset** of -0.28 mS (the right hand microphone has been delayed in relation to the left), i.e. the whole of the Intensity/Time Difference function has been displaced towards the left by 0.28 mS, we can see that the origin (0°) of sound source position in this diagram is also at –0.28 mS.
- In Figure 14, **Positive Electronic Intensity Offset** of -2.5 db has been applied (the right hand microphone has been attenuated in relation to the left). In relation to Figure 12, the Intensity/Time Difference function has been translated downwards by 2.5 db. Again the origin of the sound source position has followed suit, and is at –2.5 db on the Intensity Difference axis.

It can be clearly seen in these examples the influence of the two types of offset on the Stereophonic Recording Angle. In Figure 12 the SRA is about +/- 50° (a total angle or Coverage Angle of 100°). Whereas in Figure 13 the offset has created a SRA with an overall coverage of about 103°, but now with an asymmetrical coverage from –35° (to the left) to +68° (to the right). In Figure 14 the Intensity Offset is –2.5 db covering about 105° in all, but with an asymmetrical coverage from –35° (to the left) to +70° (to the right). It is to be noted that the use of offset can modify slightly the total coverage angle of the system in relation to the SRA without offset. This will have to be taken into account in the final design of the complete microphone array.

It is easy to see how we can adjust both positive and negative intensity and time offsets to obtain almost any position of the coverage, within reason. A word of warning however, excessive values of offset will produce some unexpected effects :

- There **must** be intersection between the Intensity/Time Difference function and the Psychoacoustic curves for +/- 30° otherwise we will not be able to produce correct linking.
- Angular Distortion is normally just a function of intersection of the Intensity/Time Difference function with the psychoacoustic curves (at 10°, 20° & 30°) representing the reproduced position of the various sound sources as virtuel images between the loudspeakers. As can be seen in Figures 13 & 14, with excessive values of offset, the non-linearity of the Intensity/Time Difference function can perceptably increase the Angular Distortion.
- We must also be careful not to introduce too much Electronic Intensity Offset, as this will cause an imbalance in the general energy distribution around the system. Unfortunately there is at present too little published information concerning the psychoacoustics of energy perception when in the presence of complex summation of Intensity/Time Difference signals.

In Figure 15 we can see that it is also possible to apply a combination of Electronic Intensity and Time Offset so that the Intensity/Time Difference function passes through the Intensity/Time origin (0 db / 0 mS). This has no magical significance as it is perfectly possible to exploit the two other sectors of Intensity/Time Difference graph, especially if we are concerned only by values reasonably close to the Intensity/Time origin. Some preliminary research (7) has been done to be sure that there are no surprises when the Intensity/Time function passes close to the origin, however it would seem that there is some dispersion of localisation of the virtual image when crossing these sectors. It would be interesting to have a complete mapping of this area ; this is yet another area where more psychoacoustic research is necessary.

Microphone Position Offset

Figure 16 shows the effect of Microphone Position Time Offset using an angular rotation of +37° (37° of clockwise rotation of the right microphone, the centre of the diaphragm of the left microphone is the centre of rotation and the same angle is maintained between the microphone axes).

Combined Offsets

In Figure 17 the same Coverage Angle Offset is obtained with a combination of both Microphone Position Offset and Electronic Intensity Offset, i.e. a combination of +13° Microphone Position Offset and –1.3 db Electronic Intensity Offset. This produces a Coverage Angle Offset of +15° (compared with Figure 12 where no Offset is applied) and is explained in detail in the next paragraph.

Linking of the Front Triplet

In Figure 18, the Front Facing Triplet is represented with 25cm/70° between the microphones, the SRA is +/- 50°. The angle between the microphones is 70°, the Coverage Angle is 100°, so we need 15° of Angular Offset to align the edge of the Coverage Angle with the axis of one of the microphones. Instead of a symmetrical coverage of +/- 50° we are looking for coverage from –65° to +35° or –35° to +65° according to whether we have to apply Negative Angular Offset to the Left Front Segment or Positive Angular Offset to the Right Front Segment, in order to obtain critical linking as shown in Figure 19.

The examples in Figures 13, 14,15, 16 & 17 have been chosen to illustrate the application of offset in the design of the Front Facing Triplet. In each of these examples, each pair of microphones making up the Front Triplet has an angle of 70° between the axis of the microphones and 25cm between the centre of the microphone diaphragms. From these examples we now have a disconcerting choice of methods to use, in order to obtain a desired offset with the edge of the Coverage angle of each segment aligned with the centre microphone axis.

- Figure 13 : Positive Electronic Time Offset of –0.28 mS (right hand microphone is delayed in relation to the left).
- Figure 14 : Positive Electronic Intensity Offset of –2.5 db (right hand microphone is attenuated in relation to the left).
- Figure 15 : Combined Positive Electronic Time and Intensity Offsets of –1.15 db and 0.145 mS respectively.
- Figure 16 : Microphone Position Time Offset of +37° .
- Figure 17 : Combination of Microphone Position Offset of +13° and Positive Electronic Intentensity Offset of –1.3 db;

OFFSET FUNCTIONS – (COVERAGE ANGLE<PHYSICAL ANGLE BETWEEN MICROPHONES)

The coverage angle used for Figures 13 to 17 is wider than the physical angle between the microphones. To have the complete picture of the application of this offset technique for linking in the final Multichannel Microphone Array, we must also look at the opposite situation, i.e. when the Coverage Angle of a pair of microphones is less than the angle between the microphones.

It is not be necessary here to make a detailed analysis of Figures 20 to 24, suffice it to say that, in each of these illustrations, Negative Offset has been applied to rotate the Coverage Angle anticlockwise, which is the case when the pair is being used to cover the Right Facing Segment of the Front Triplet (the opposite offset is applied when the pair covers the Left Segment of the Front Facing Triplet).

☞ WARNING - Any use of Electronic Intensity Offset must be done with caution, as this may effect the smooth energy distribution around the system. However in the case of Negative Electronic Intensity Offset we are in fact decreasing the relative level of the centre microphone of the triplet and there are quite a number of people who consider this already to be necessary in a multichannel system to achieve a balance in energy distribution around the system!

Linking in the Front Triplet

In Figures 20 to 24 and 26 & 27, both microphone pairs used to illustrate the process of Linking in the Front Facing Triplet are 25cm/110°, the SRA is +/- 40°, the total Coverage Angle is 80°. Using the same analysis as previously, the angle between the microphones is 110°, the Coverage Angle is 80°, so we need 15° of Angular Offset to align the edge of the Coverage Angle with the axis of one of the microphones. Instead of a symmetrical coverage of +/- 40° we are looking for coverage from -25° to +55° or –55° to +25° according to whether we have to apply Positive Angular Offset to the Left Front Segment or Negative Angular Offset to the Right Front Segment.

Again we have a wide choice of different forms of Offset that can be applied to each segment to produce Critical Linking :

Figure 20 : Negative Electronic Time Offset of 0.31 mS

Figure 21 : Negative Electronic Intensity Offset of 2.5 db

Figure 22 : Combined Negative Electronic Time and Intensity Offsets of 0.12 mS and 1.38 db resp.

Figure 23 : Microphone Position Time Offset of -32°

Figure 24 : Combination of Negative Microphone Position Offset of -10° and Negative Electronic Intensity Offset of 1.6 db

LOUDSPEAKER POSITIONING IN THE MULTICHANNEL CONFIGURATION

Opinions have often been expressed concerning the relation between the reproduction of sound with loudspeakers at 30° as in the Multichannel configuration, and the reproduction with 60° between the loudspeakers as in the Stereophonic configuration. We can also ask the same question regarding the other segments of the Multichannel configuration, where the angle between the louspeakers is 80° in the Lateral Segments and 140° at the back. Preliminary research (7) has shown that the closer the loudspeakers, the better is the Angular Distortion characteristic, but that the overall SRA changes very little. This has certainly been our experience when listening to stereo either too near or too far away from the loudspeakers. This means that in the standard configuration for Multichannel Sound, we can expect a much more regular distibution of the sound sources within the main sound stage of the Front Triplet, whilst Angular Distortion will be more predominant on the side and especially the Back Segment. This is of little consequence in the reproduction of lateral reflections and reverberation, but obviously becomes more difficult to integrate into total surround sound reproduction, where a more even distribution of loudspeakers would obviously be advantageous.

SEGMENT DESIGN OF THE MULTICHANNEL MICROPHONE ARRAY (MMA)

There are three distinct stages in the design of the complete MMA :

1) Design of the Front Facing Triplet
2) Choice of the Back Segment Coverage
3) Critical Linking of the Lateral Segments

Front Facing Triplet

The Coverage Angle (CA) of the Front Facing Triplet (FFT) is probably the most important parameter that must be determined right from the start of the process of design of the MMA. The physical position of the microphone system i.e. its distance from the sound source, will obviously determine the angular size of the sound source as 'seen' by the MMA. On the other hand the choice of Coverage Angle will determine the reproduced angular 'size' of the sound source. A large CA will reduce the reproduced sound image – a small CA will, on the contrary, widen the reproduced sound image, even to the extent of overlapping into the Left and Right Lateral Segments.

This is part of the personal choice of the sound engineer in the effect that he wishes to produce. The main sound stage formed by the front three loudspeakers is responsable for the reproduction of the FFT. Overlap into the Lateral Segments will envelope the listener in a wider sound stage, but one should not expect to have precise localisation over the total width of these Lateral Segments, as our natural perception shows a gradual loss towards the sides. However this is not a reason for rejecting totally the possibility of overlap, and do not forget that we have the freedom to turn the head during listening, which in itself changes our perception of the different segments of sound reproduction.

With the reproduction of a wide sound source such as a Symphony Orchestra, the overlap can be a definite advantage. The stereophonic recording of this type of sound source has always been a compromise between the spread of the centre of the orchestra and the cut-off on the sides of the sound surface of violins on the left, and cellos and double-basses on the right. With MMA a new field of experiment is opened up into the amount of overlapping into the Lateral Segments that is desirable.

MMA DESIGN PROCESS

There is one basic rule that will avoid difficulties in the later stages of the design process : it is advisable to choose microphone distance/angle combination so that the coverage angle is as near as possible the same as the angle between the microphones. This means that only small offset values will be needed. It is **not** necessary to choose a Coverage Angle that is similar to the angle between the loudspeakers of the corresponding reproduction segment, quite the contrary !

Front Triplet Design

We will start by designing a system with a Front Facing Triplet Coverage of a total of 120° i.e. each Front Segment covers 60°. We will therefore look for a combination of microphone distance/angle with 60° coverage and an angle between the microphones of as near as possible 60°. These conditions are satisfied with a combination of 50cm/70° having a 60° Coverage as can be seen in the SRA diagram reproduced here from reference (2) as Figure 28. The Front Facing Triplet is illustrated in Figure 29 & 30, with linking achieved with only 7° of Microphone Position Offset (-7° for RFS and +7° for LFS).

Back Segment

The combination chosen for the back segment covering generally the reverberant field is relatively arbitrary. It has been our experience that too heavy a sound field in the back segment can be disturbing. However as the spacing of the back segment loudspeakers is 140°, there is considerable angular Distortion associated with this segment, and therefore the reproduced sound field has a tendancy to widely spread in the centre part of the field. The choice of a reasonably small SRA would also tend to accentuate this effect. The SRA chosen in our example is 56cm/48° - a SRA of +/- 30°. This choice also obviously has the advantage of facilitating the linking with the Lateral Segment Coverage. Figures 31 & 32 show the coverage at the second stage of design of the MMA.

Lateral Segments

Having determined the coverage required for the Front Triplet (FT) and the Back Pair (BP), we must vary the distance between these two components (FT & BP) so that the coverage angle of the Lateral Pairs (LP) corresponds to the angle of coverage needed for the Lateral Segments (LS). For the time being this is not necessarily correctly orientated. Each of the pairs covering the lateral segments will have an inherent time offset due to the physical position of the back facing microphones in relation to the side facing microphones of the pairs. This must be compensated by Simple Intensity Difference Offset so that the segment orientation critically links with its front & back facing neighbours.

The Coverage Angles remaining are 90° on each side [(360° - 60°*3)/2]. The angle between the microphones, afortiori, is 86° [(360° - 48° - 70°*2)/2]. We are therefore obliged to adopt a distance between the side microphones of 26cm to satisfy a segment coverage of 90°, +/- 45° read from the SRA diagrams in Figure 28 and illustrated in Figures 33 & 34. The position and orientation of all the microphones is now determined, the only parametre to be adjusted is the Electronic Intensity or Time Offset to be applied to the Lateral Segment Pairs to produce Critical Linking with their neighbour segments.

Lateral Segment Compensation Offset

In order to determine the value of this Electronic Offset we have to map out the specific coordinates and orientation of each microphone. The position of the Front Triplet and its distance from the Back Pair determines the distance separating the microphones in each of the Lateral Pairs. This distance enables us to determine the coordinates of each microphone forming the lateral microphone pairs, and thus to be able to calculate the inherent Microphone Position Time Offset created by their position. It is then just a question of determining the amount of Electronic Intensity offset needed to obtain Critical Linking with the neighbour segments.

In the example chosen we need to apply 2.4 db of Negative Electronic Intensity Offset as illustrated in Figure 35 .We must therefore attenuate the three front microphones of the Front Triplet by 2.4 db. This means that we keep the same Intensity/Time Difference relationship within the Front Triplet and also within the Back Pair, but we create a Negative Intensity Offset between the side microphones making up the Left and Right Lateral Pairs. This attenuation of 2.4 db may have its limitations in certain acoustic environments, however many other possibilities exist without this specific characteristic, and will be fully developed in later publications.

The Completed Multichannel Microphone System Specification (illustrated in Figure 36) :

Front Facing Triplet – microphones are placed at 50cm between the capsules and 70° between the axes of directivity, with a consequent Coverage Angle of 60° on each side of the centre axis.

Microphone Position Time Offset is created by a 7° advance of the side microphone positions.

Back Pair – microphones are placed at 56cm apart and 48° between the axes.

The distance between the lateral pairs is 26cm.

This gives the following coordinate values for all components of the system (all coordinate values are with respect to the front facing centre microphone) :

Left side microphone has x/y coordinates of (–44cm,-23cm), orientation 290°.

Right side microphone has x/y coordinates of (+44cm,-23cm) with orientation of 70°.

Back left microphone has x/y coordinates of (-28cm,-46cm), orientation 204°.

Back right microphone has x/y coordinates of (+28cm, -46cm) orientation 156°.

There is 2.4 dB attenuation of the Front Triplet in relation to the back pair.

CONCLUSION

The Multichannel Design Process demonstrated in this paper can be used to produce a multitude of combinations that will satisfy the different conditions experienced in multichannel sound recording.

Critical Linking becomes a reality, and the resultant smooth continuous reproduction of the sound field maintains the original structure of the sound source and its acoustic environment. The concept of different types of Offset is a major tool in improving the performance of this type of multichannel microphone system. It is the intention of the authors of this paper to develop both a graphical representation system and computer software that will facilite this design process. The number of channels used in the examples studied in this paper is only illustrative, as any number of channels within reason, can be catered for. The same can also be said for the loudspeaker configuration, where almost any desired loudspeaker placement can also be taken into account. It must be reiterated however that the design process presented in this paper is only applicable, for the time being at least, to a univalent (one to one) microphone loudspeaker recording/reproduction context.

Practical recordings have already been made (7) to test the validity of this design process - the multichannel systems tested have been, up to now, very favourably received. It is also the intention of the authors to publish at a later date the analysis of the recording technique used during these sessions, and discuss the various conclusions reached concerning the quality of restitution obtained.

Vocabulary and Abbreviations

Multichannel Microphone Array (MMA) is any group of microphones forming a coherent sound recording microphone system.

Sound Field Segmentation – The sound field is divided into angular segments or sectors, covered by a specific microphone pair. Each segment is analysed in relation to the characteristics of the relative microphone pair and with respective to the corresponding loudspeaker positions.

Coverage Angle (CA) is the total angle covered by a dual microphone system, which will be reproduced as a virtual sound field in the reproduction configuration. The Coverage Angle is equivalent to the total Stereophonic Recording Angle (SRA) of a single pair of microphones. The SRA is usually specified with the prefix +/- (for example +/- 50° becomes a Coverage Angle of 100°).

Angular Offset or Offset is the angular rotation of the Coverage Angle.

Positive or Negative Offset is used to refer to the direction of rotation of the Coverage Angle, positive being clockwise, negative being anticlockwise, when some form of offset is applied.

Critical Linking or Linking is the use of angular offset on two neighbouring Coverage Angles, so that the side limits of each Coverage Angle link up with each other, without overlapping or leaving an uncovered space.

Electronic Intensity Offset is the addition of a constant Intensity Difference to the Intensity/Time Difference function.

Electronic Time Offset is the addition of a constant Time Difference to the Intensity/Time Difference function between two microphones.

Positive Microphone Position Time Offset is applied when the right hand microphone is rotated clockwise (i.e. backwards) using the centre of the left microphone diaphragm as the centre of rotation whilst maintaining the same distance between the microphones and angle between the axes of the microphones.

Negative Microphone Position Time Offset is applied when the right hand microphone is rotated anticlockwise (i.e. forwards) using the centre of the left microphone diaphragm as the centre of rotation whilst maintaining the same distance between the microphones and angle between the axes of the microphones.

Front Facing Triplet (FFT) is the group of three microphones normally covering the main sound stage.

Front Left Segment (FLS) is the segment of the sound field covered by the left pair (centre microphone + left side microphone) of the Front Facing Triplet.

Front Right Segment (FRS) is the segment of the sound field covered by the right pair (centre microphone + right side microphone) of the Front Facing Triplet.

Left Lateral Segment (LLS) is the segment of the sound field covered by the left side pair (left side microphone + left back microphone) of the microphone array.

Right Lateral Segment (RLS) is the segment of the sound field covered by the right side pair (right side microphone + right back microphone) of the microphone array.

Back Segment (BS) is the segment of the sound field covered by the pair of microphones facing the back of the microphone array.

References :

(1) 1984 : 74th AES Convention in Paris – preprint 2072 (D1) « The Stereophonic Zoom, A Practical Approach to determining the Characteristics of a Spaced Pair of Microphones » by Michael Williams.

(2) 1987 ; 82nd AES Convention in London – preprint 2466 (H6) « Unified Theory of Microphone Systems for Stereophonic Sound Recording » by Michael Williams

(3) 1990 : 88th AES Convention in Montreux – preprint 2931 (K3) « Operational Limits of the Variable M/S Streophonic Microphone System » by Michael Williams

(4) 1991 : 91st AES Convention in New York – preprint 3155 (R4) « Early Reflections and Reverberant Field Distribution in Dual Microphone Stereophonic Sound Recording Systems » by Michael Williams

(5) 1991 : 91st AES Convention in New York – preprint 3157 « Microphone Arrays for Natural Multiphony » by Michael Williams.

(6) 1992 : 92nd AES Convention in Vienna (2TD1.04) « Frequency Dependent Hybrid Microphone Arrays for Stereophonic Recording » by Michael Williams.

(7) 1999 : Memoire de Recherche de l'Ecole Nationale Supérieure Louis Lumière « Conception de systèmes de prise de son multicanaux » by Guillaume Le Dû.

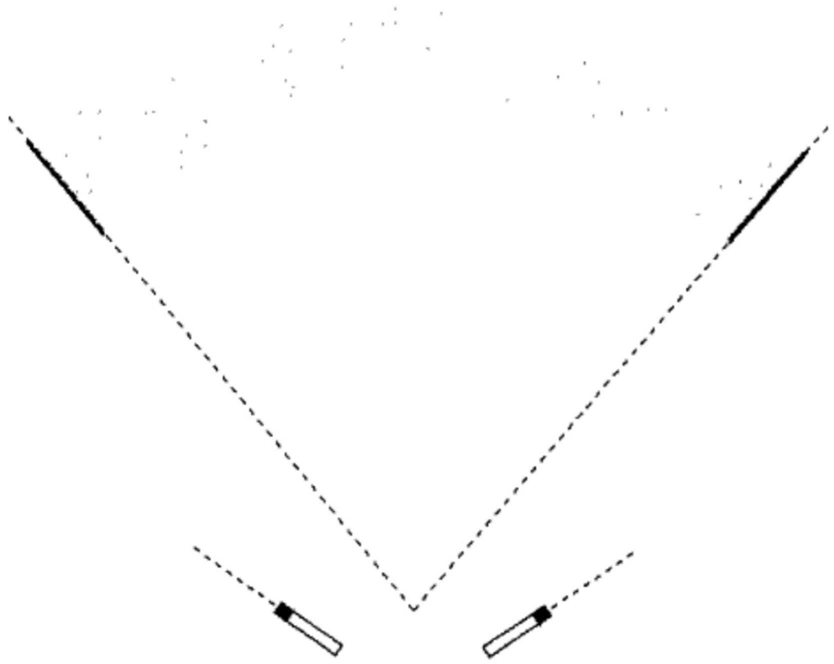


Figure 1 : Stereophonic Recording Angle (SRA) less than Angle between Microphones

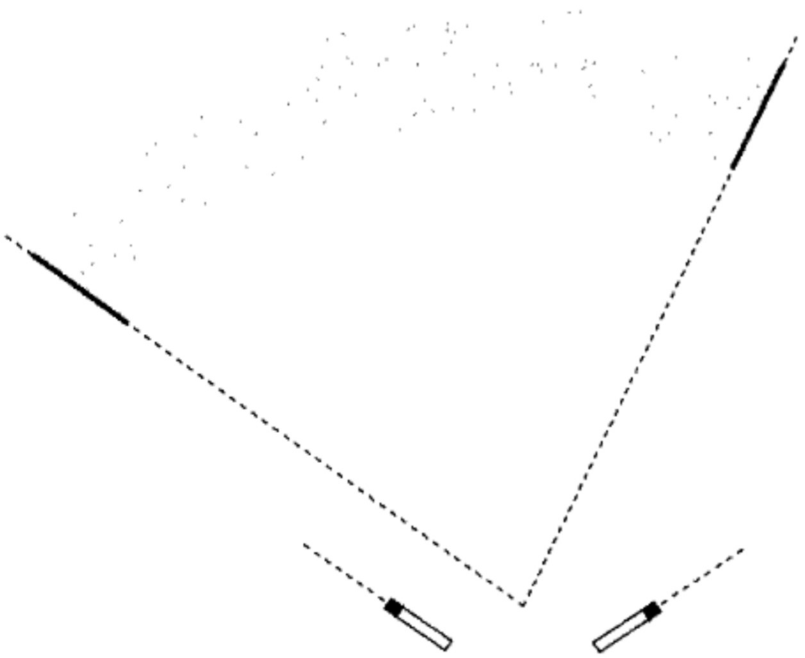


Figure 2 : Negative Offset of -15° (Left Limit of SRA aligned with Microphone Axis)

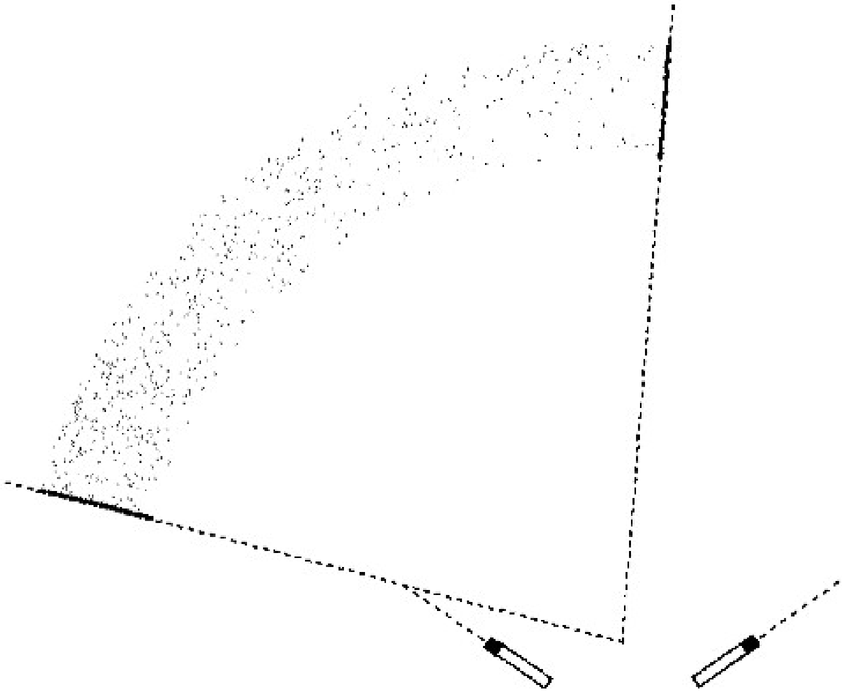


Figure 3 : Negative Offset of -35° : Axis left microphone now within the SRA

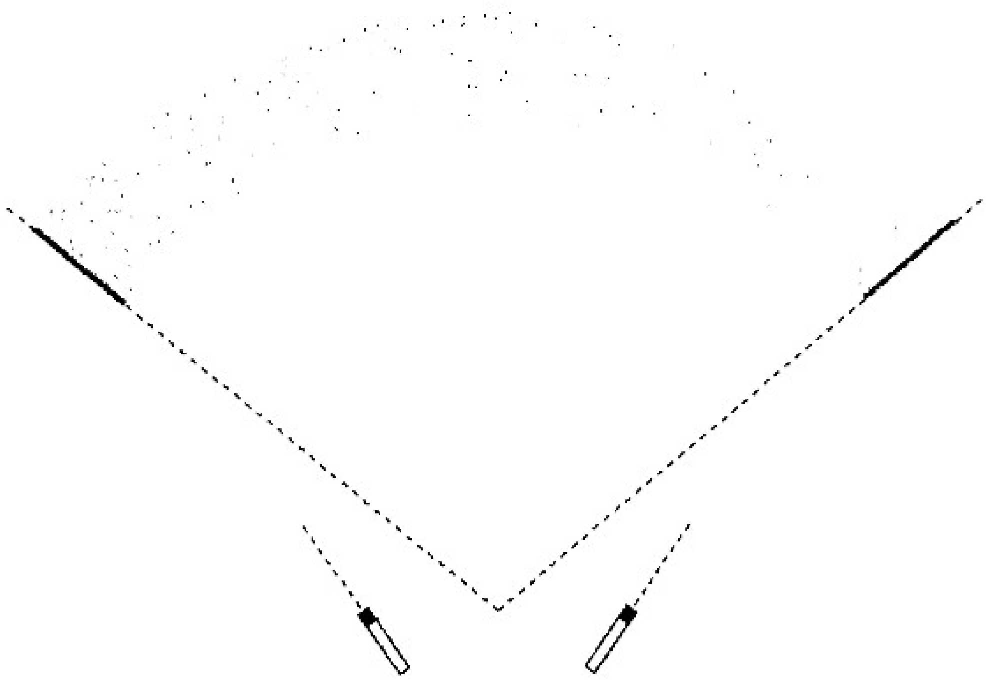


Figure 4 : Stereophonic Recording Angle is Greater than Angle between Microphones

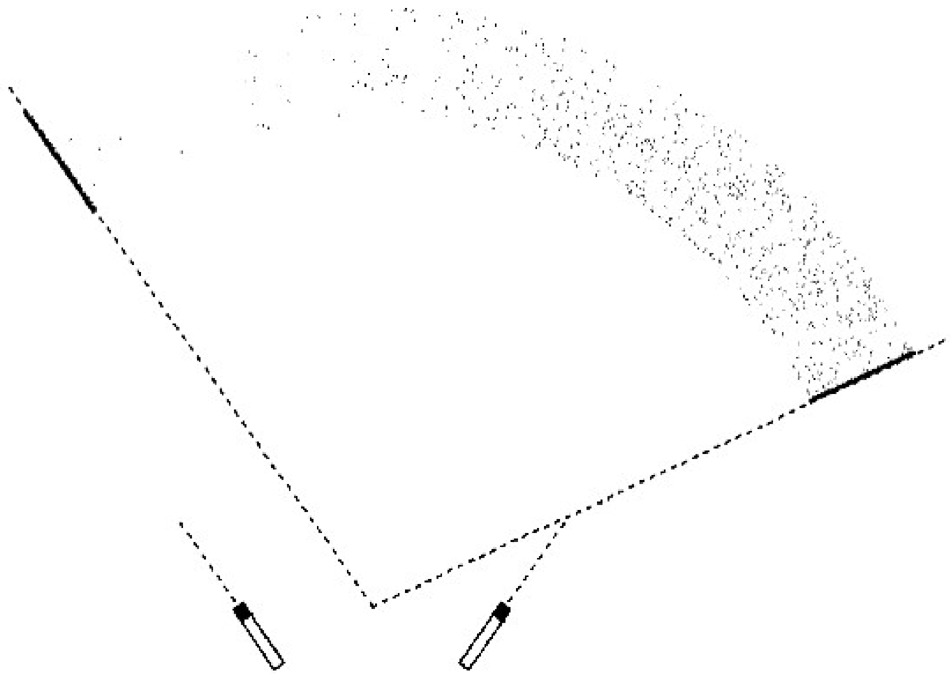


Figure 5 : Positive Offset of 15° (Left Limit of SRA aligned with Microphone Axis)

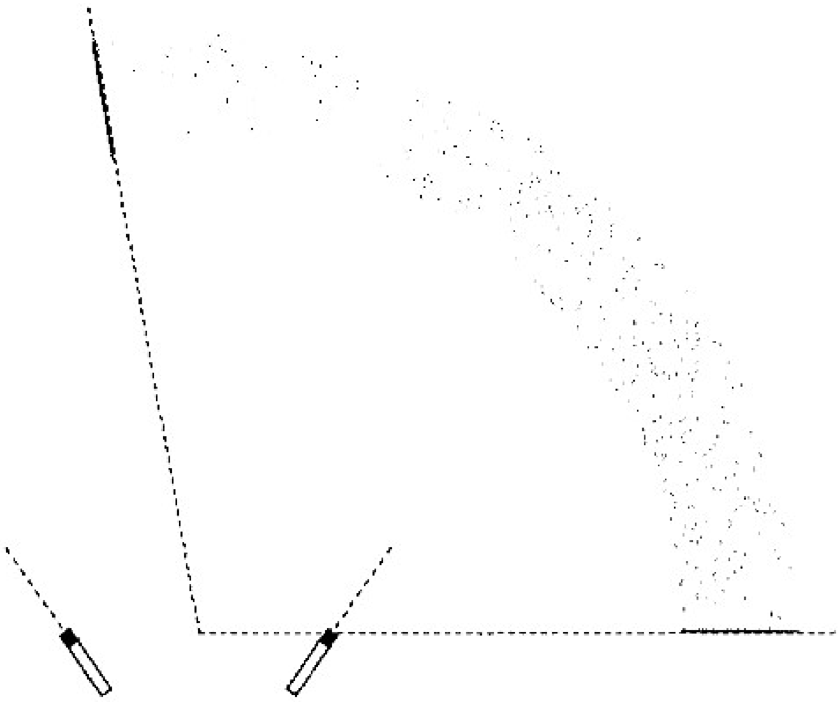


Figure 6 : Orientation of SRA with Positive Angular Offset of 40°

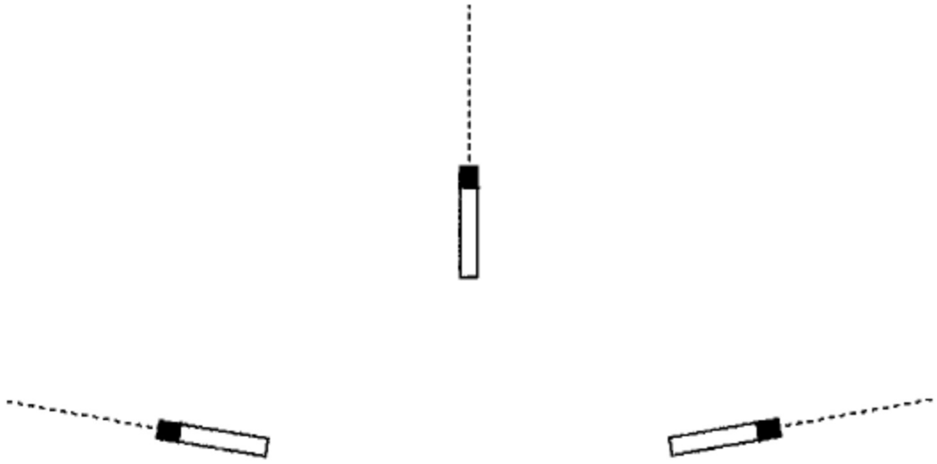


Figure 7 : The Front Facing Triplet

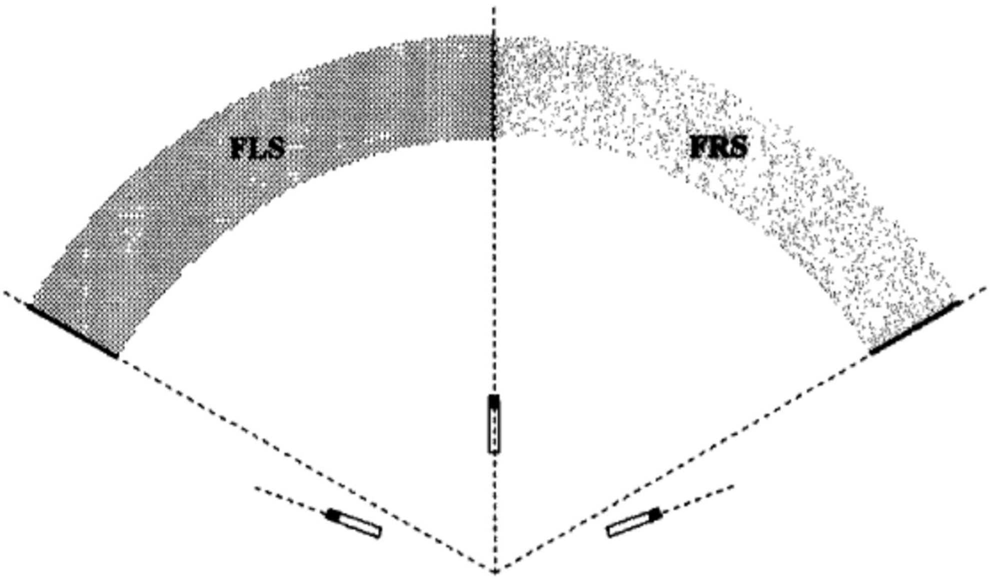


Figure 8 : Critical Linking of Front Left Segment (FLS) and Front Right Segment (FRS)
(Left & Right Coverage Angles < Angle between microphones)

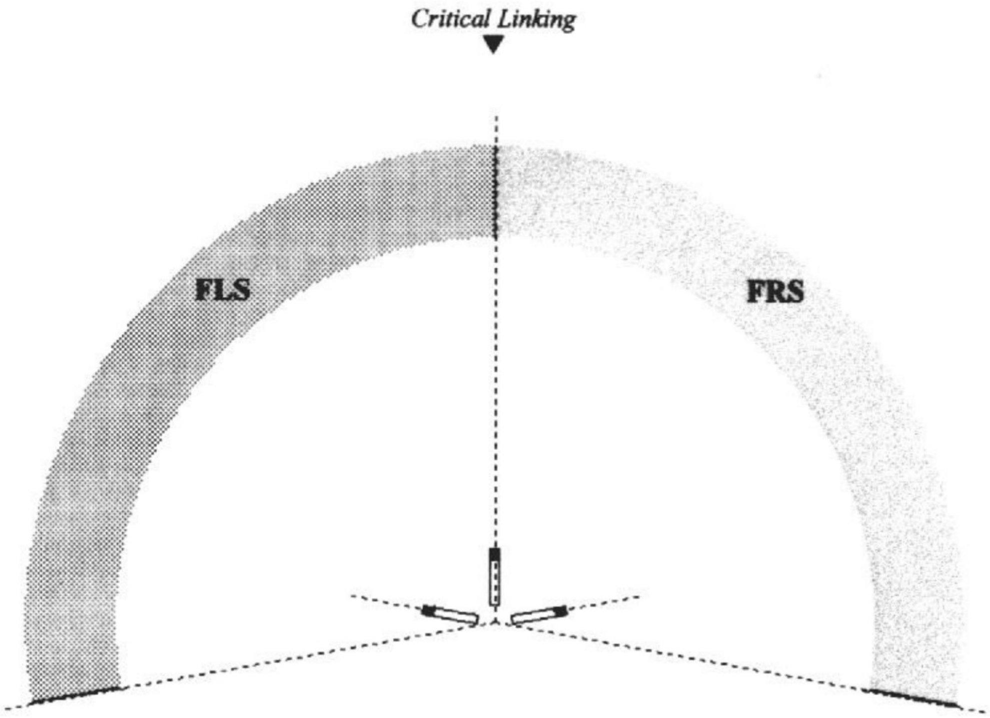


Figure 9 : Critical Linking of Front Left Segment (FLS) and Front Right Segment (FRS) (Left & Right Coverage Angles > Angle between microphones)

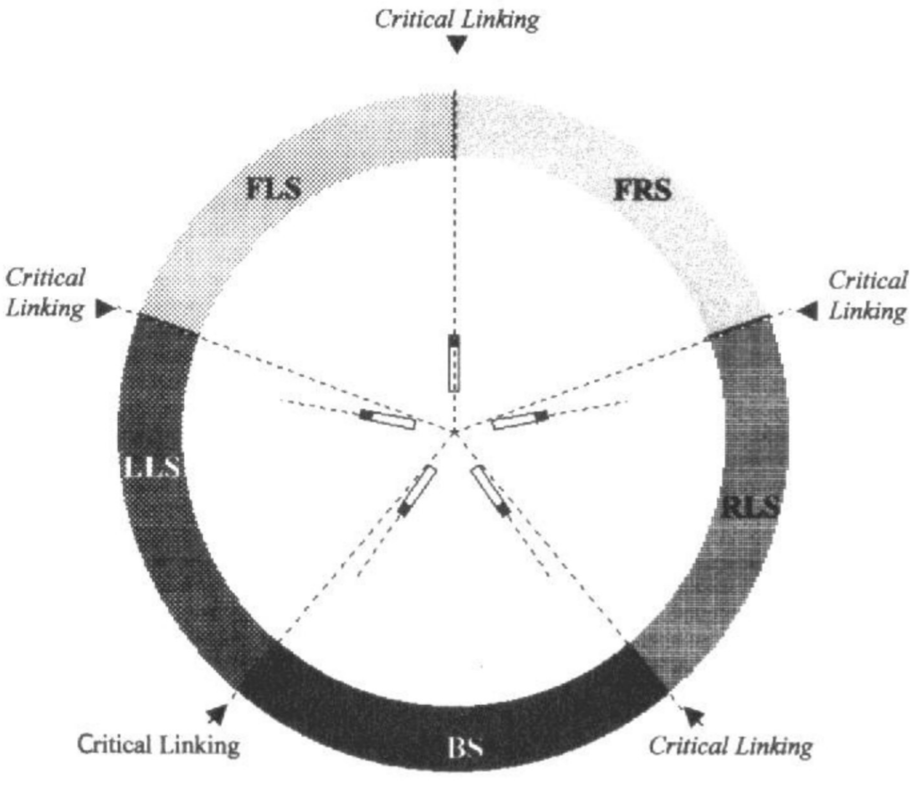


Figure 10 : Critical linking between all segments of a Multichannel Microphone Array

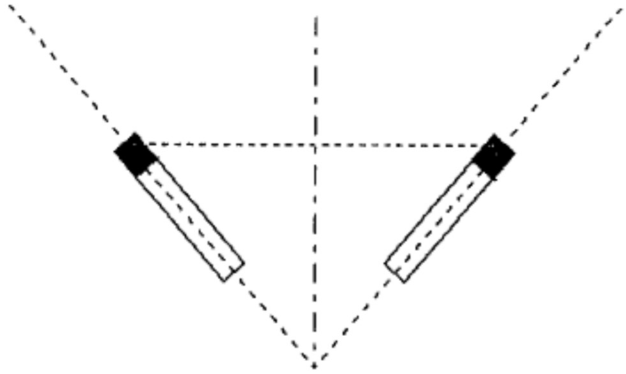


Figure 11a : No Offset

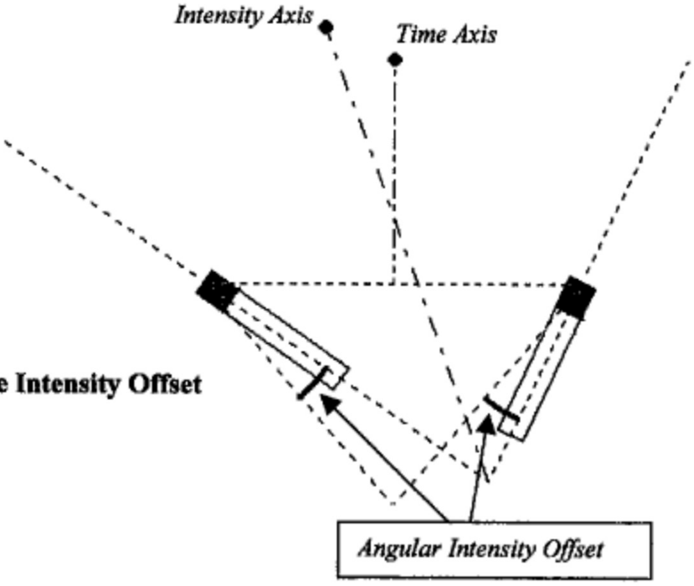


Figure 11b : Negative Intensity Offset

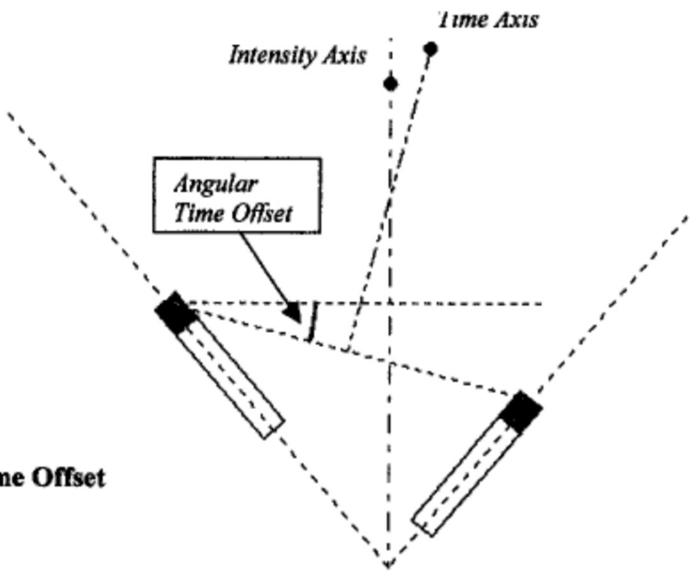


Figure 11c : Positive Time Offset

Figure 11 : Microphone Position Intensity Offset and Time Offset

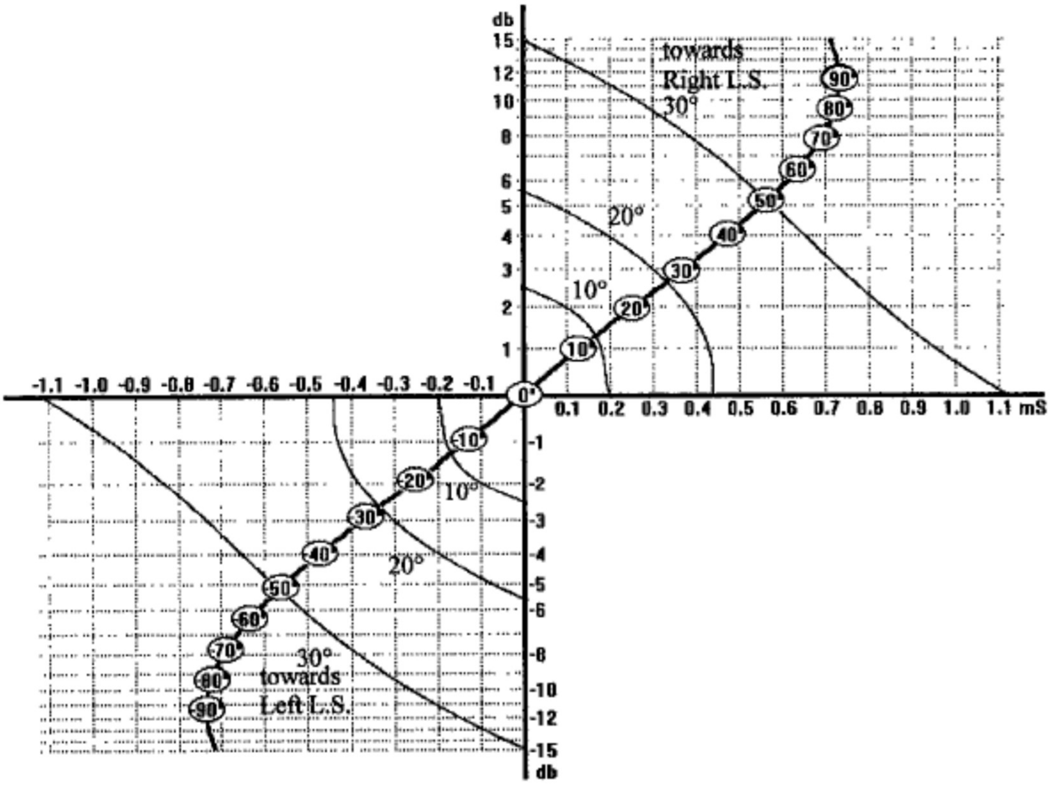


Figure 12 : Intensity / Time Difference Function without Offset

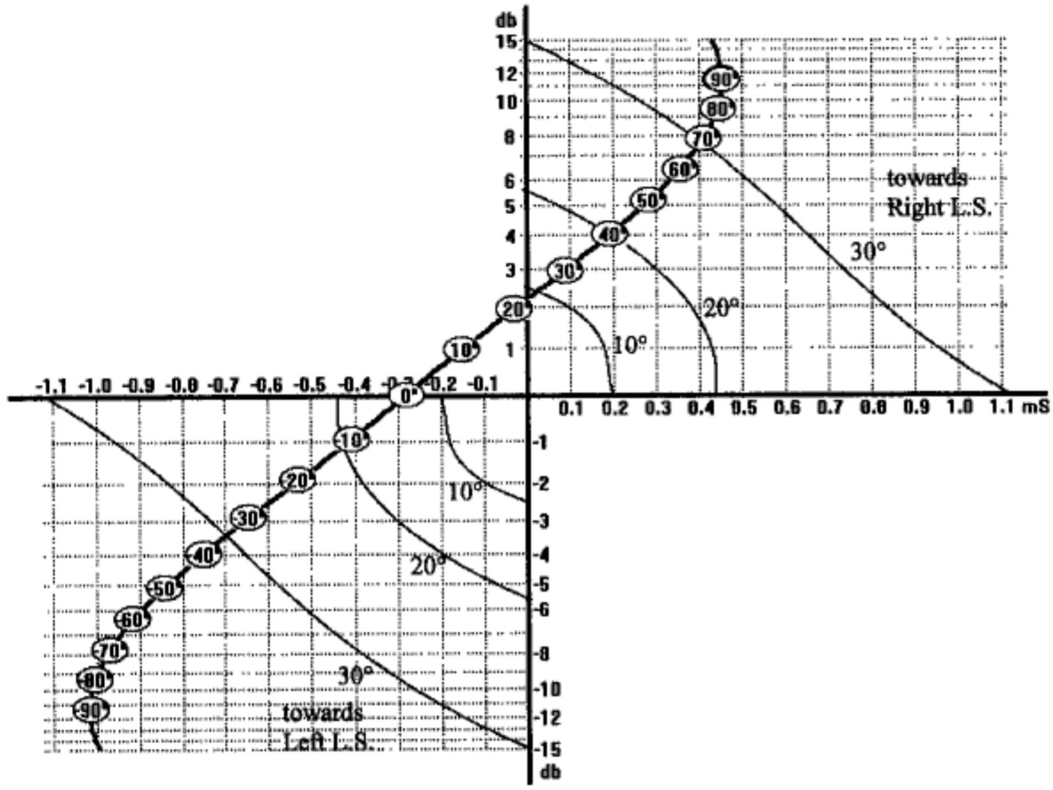


Figure 13 : Intensity/Time Difference Function
with <u>Positive</u> Electronic Time Offset of -0.28 mS

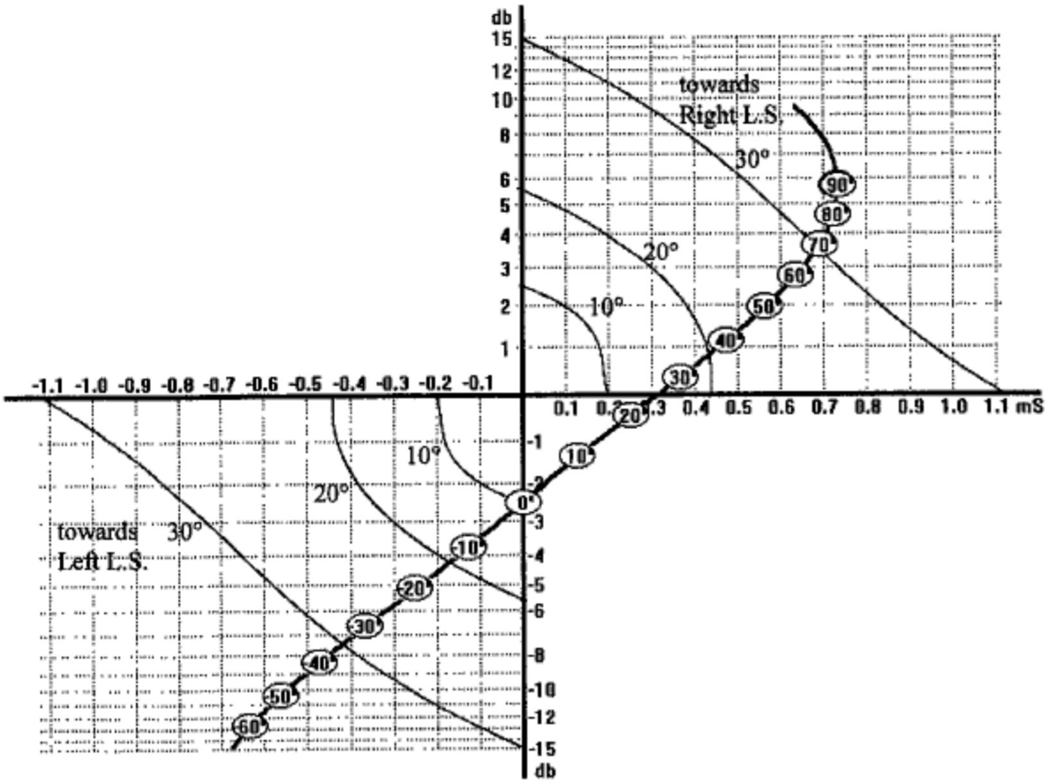


Figure 14 : Intensity/Time Difference Function with Positive Electronic Intensity Offset of -2.5 db

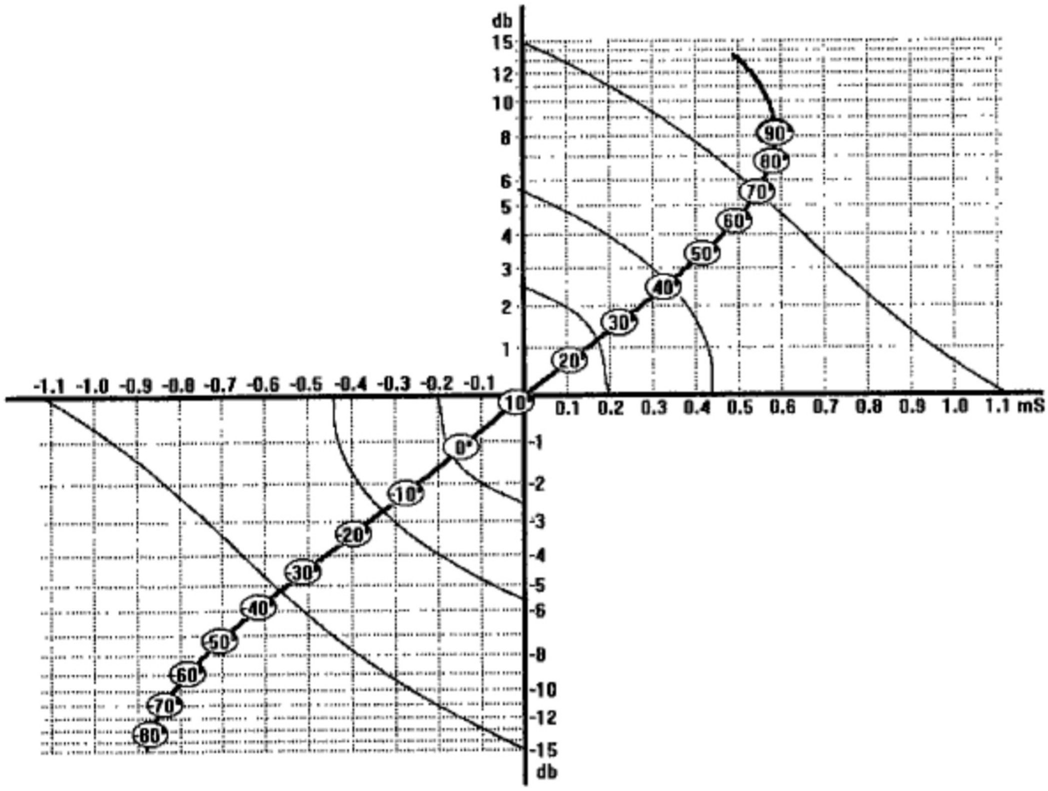


Figure 15 : Intensity/Time Difference Function : Positive Electronic Intensity Offset of –1.15 db and Positive Electronic Time Offset of -0.145 mS

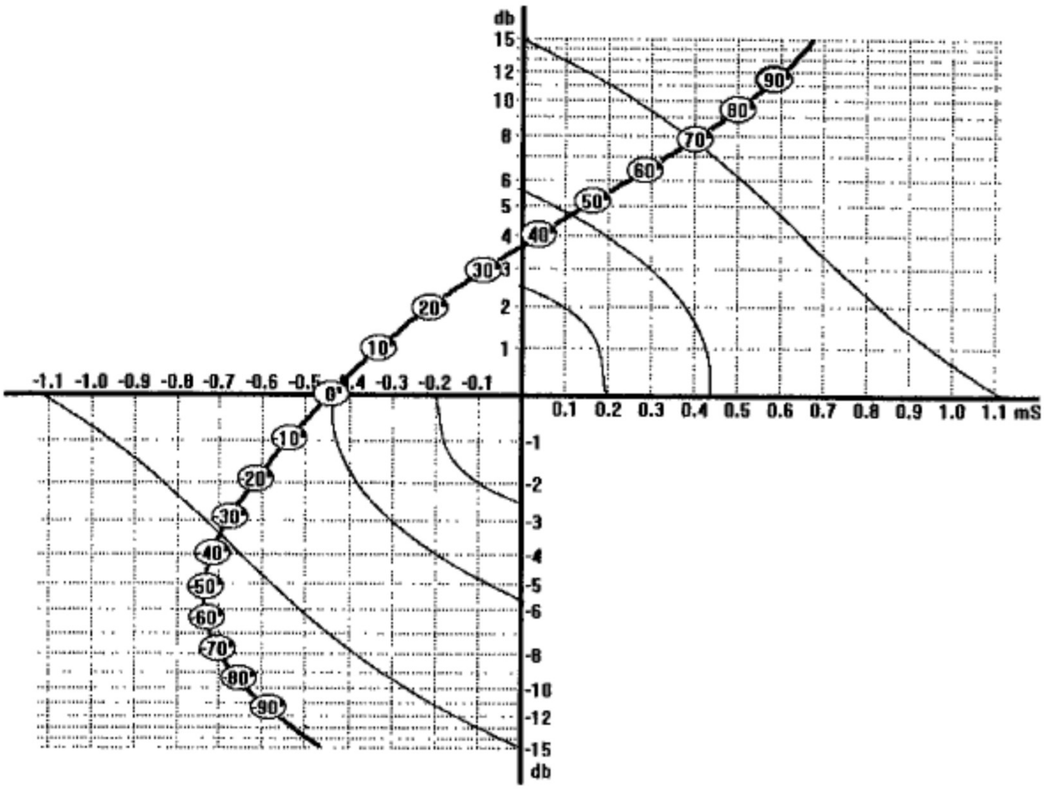


Figure 16 : Intensity/Time Difference Function
with Positive Microphone Position Time Offset of +37°

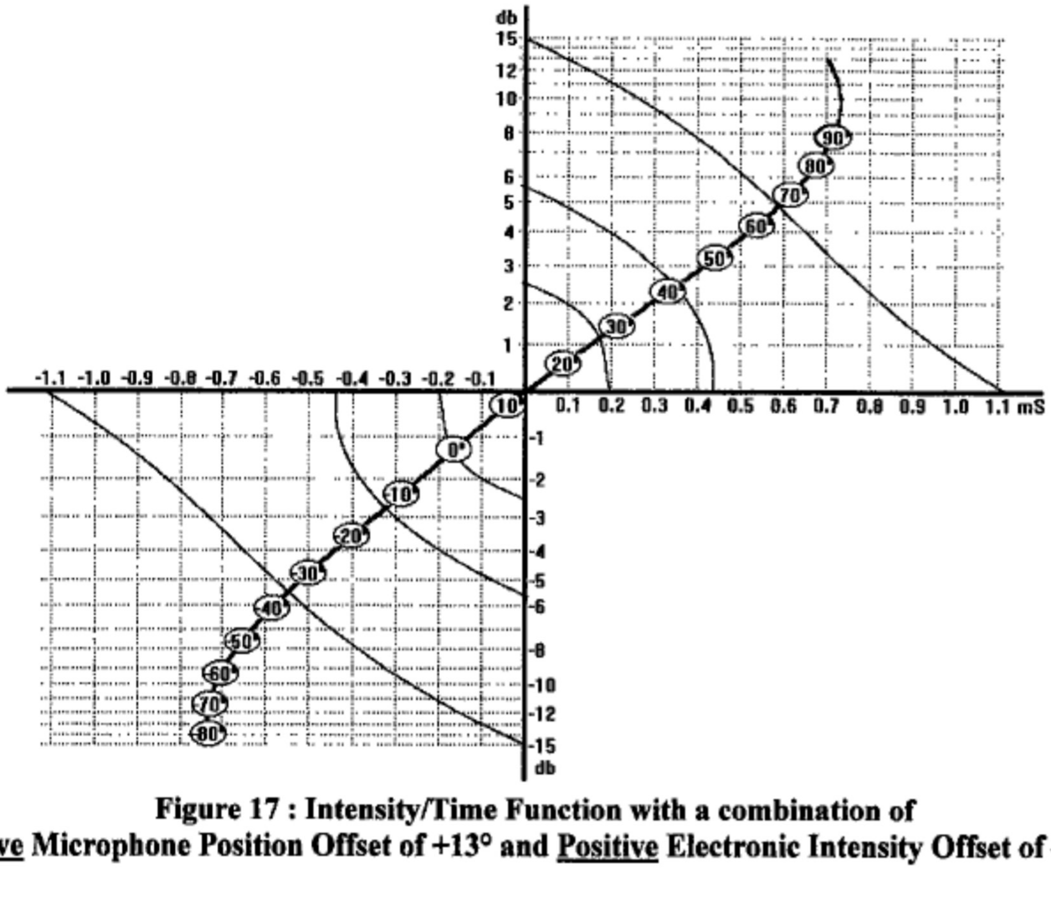


Figure 17 : Intensity/Time Function with a combination of
Positive Microphone Position Offset of +13° and Positive Electronic Intensity Offset of –1.3 db

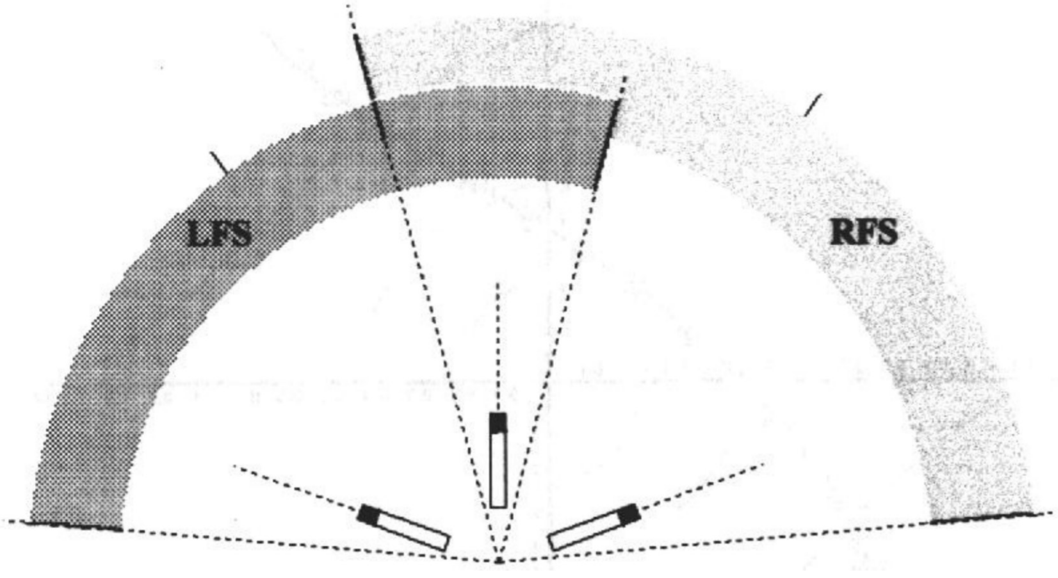


Figure 18 : Front Triplet 25cm/70° - Coverage Angle 100° for each Segment – No Offset

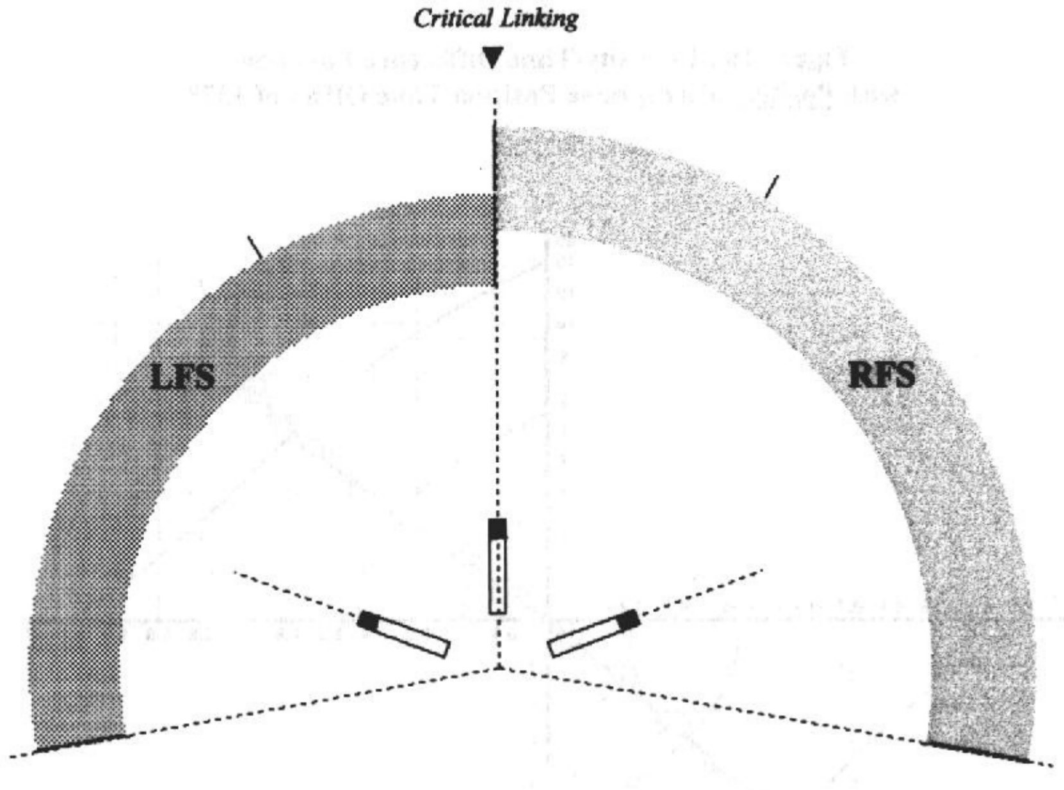


Figure 19 : Front Triplet 25cm/70° - Coverage Angle 100° for each Segment with Negative Offset of –15° on Left Front Segment and Positive Offset of +15° on Right Front Segment

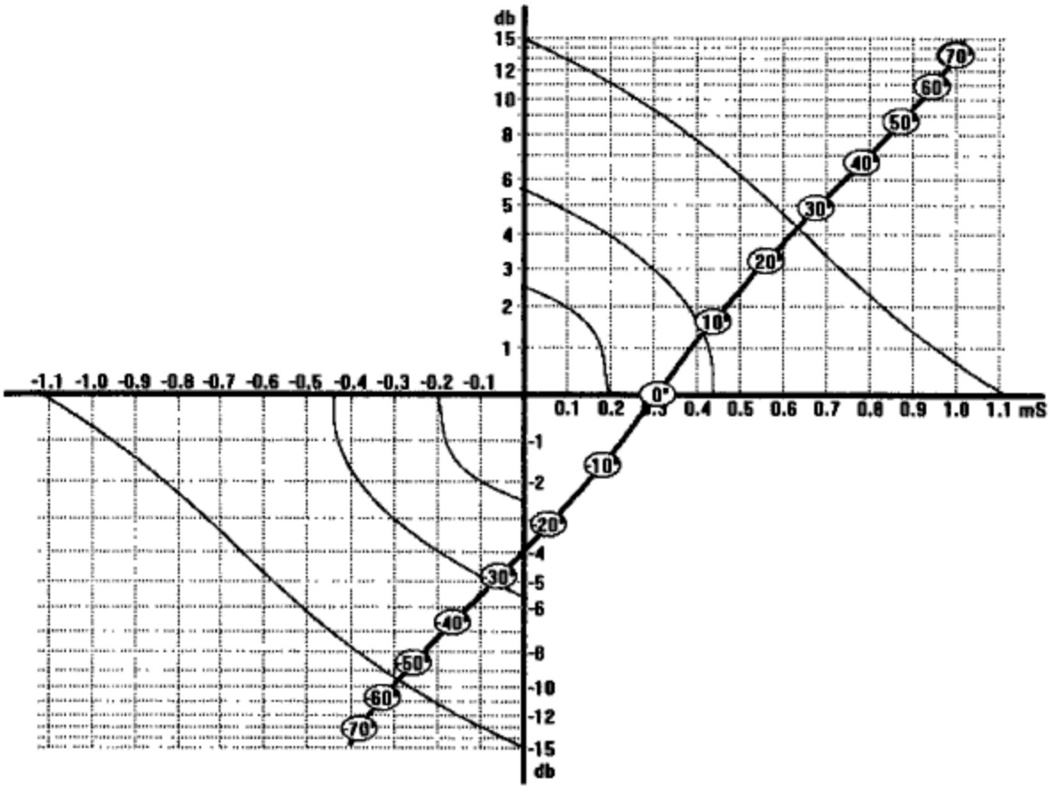


Figure 20 : Intensity/Time Difference Function with Negative Electronic Time Offset of 0.31 mS

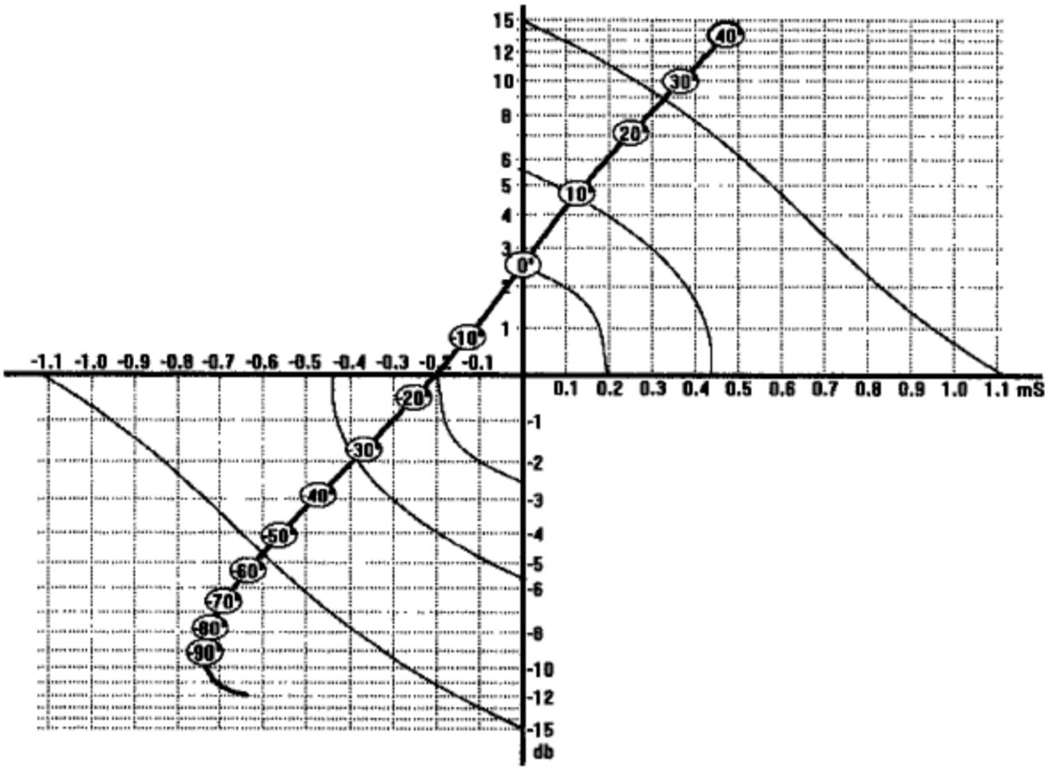


Figure 21 : Intensity/Time Difference Function with Negative Electronic Intensity Offset of 2.5 db

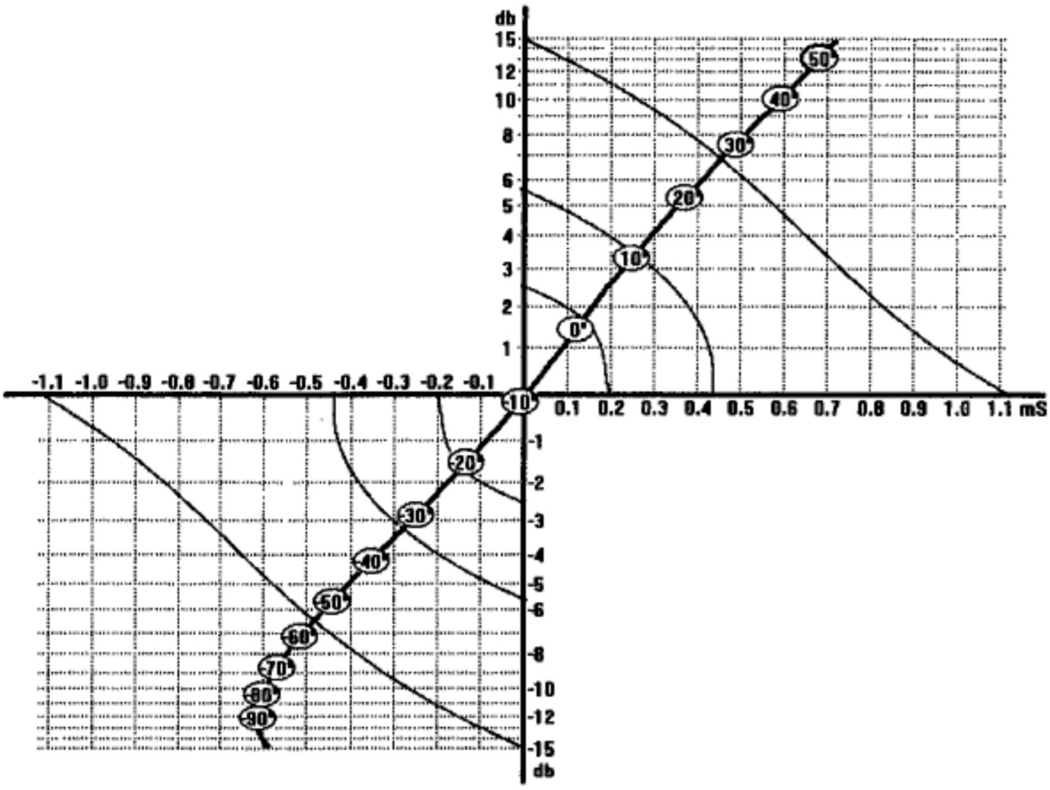


Figure 22 : Intensity/Time Difference Function with Negative Electronic Intensity Offset of 1.38 db and Negative Electronic Time Offset of 0.12 mS

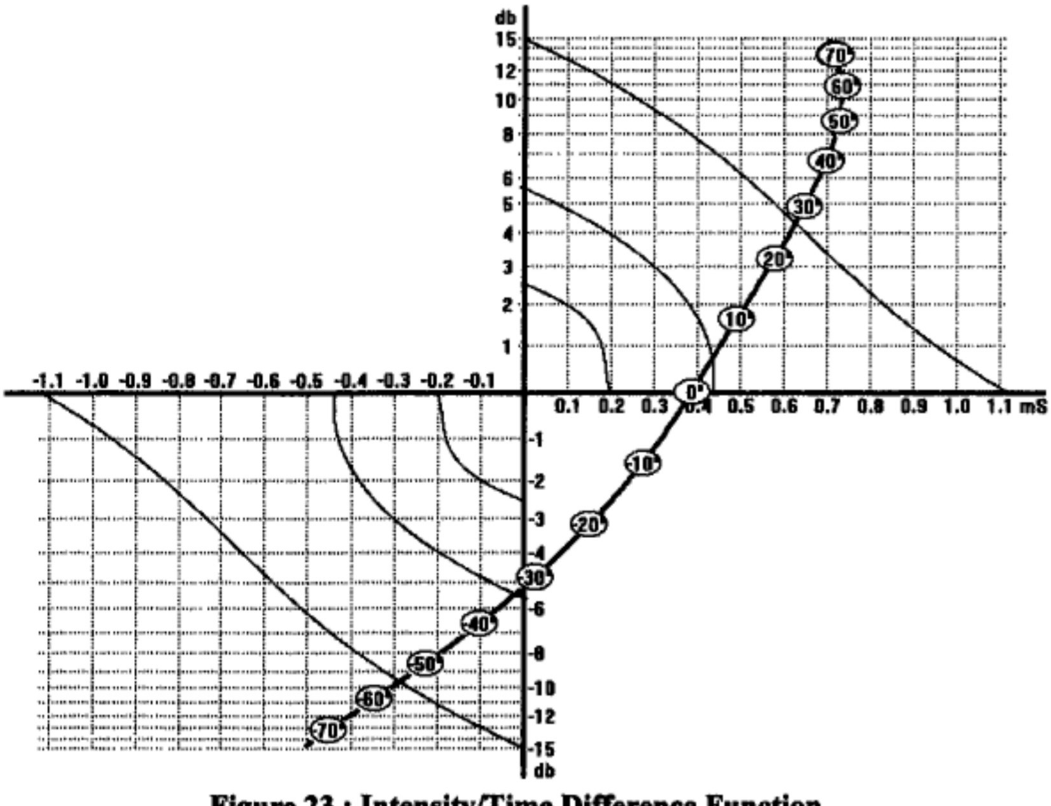


Figure 23 : Intensity/Time Difference Function with Negative Microphone Position Time Offset of –32°

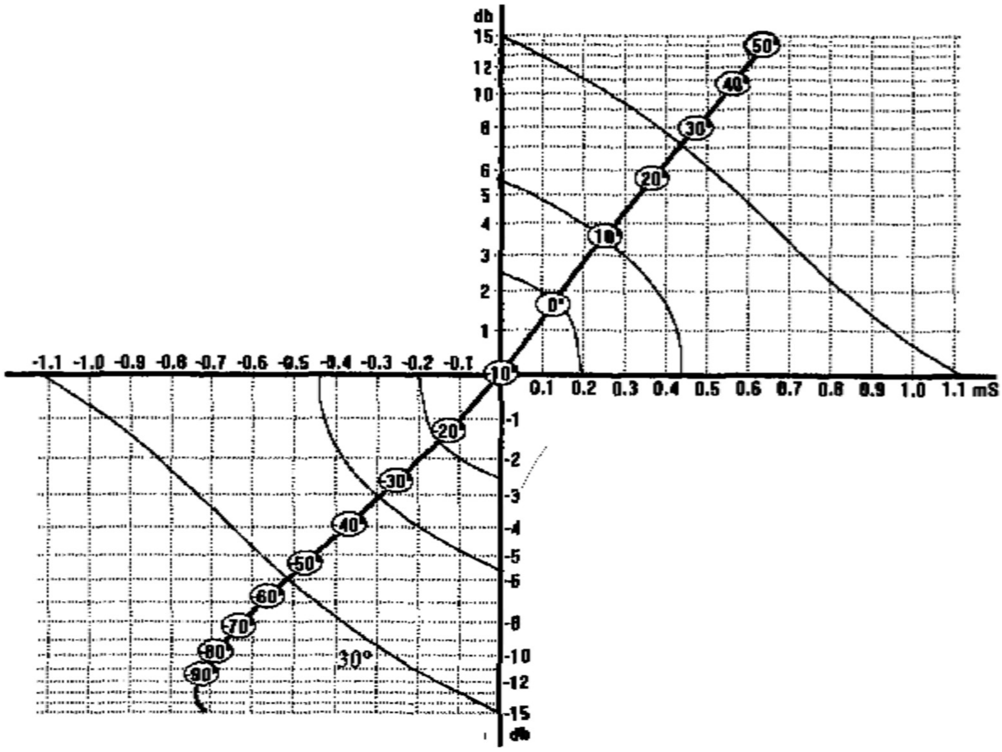


Figure 24 : Intensity/Time Difference Function with a combination of <u>Negative</u> Microphone Position Time Offset of –10° and <u>Negative</u> Electronic Intensity Offset of 1.6 db

Figure 25 : Offset Types, Physical Effect, Graphical Representation and Practical Implementation

Angular Offset	Coverage Angle Rotation	dI/dT shift	Right-hand Microphone
Positive Electronic Intensity Offset	Clockwise (Positive Rotation)	Downwards (- 'y' db)	attenuated
Positive Electronic Time Offset	Clockwise (Positive Rotation)	to the left (- 'x' mS)	electronic delay
Positive Microphone Position Time Offset	Clockwise (Positive Rotation)	to the left (+ angle°)	delayed (by physical position)
			Left-hand Microphone
Negative Electronic Intensity Offset	Anticlockwise (Negative Rotation)	Upwards (+ 'y' db)	attenuated
Negative Electronic Time Offset	Anticlockwise (Negative Rotation)	to the right (+ 'x' mS)	electronic delay
Negative Microphone Position Time Offset	Anticlockwise (Negative Rotation)	to the right (- angle°)	delayed (by physical position)

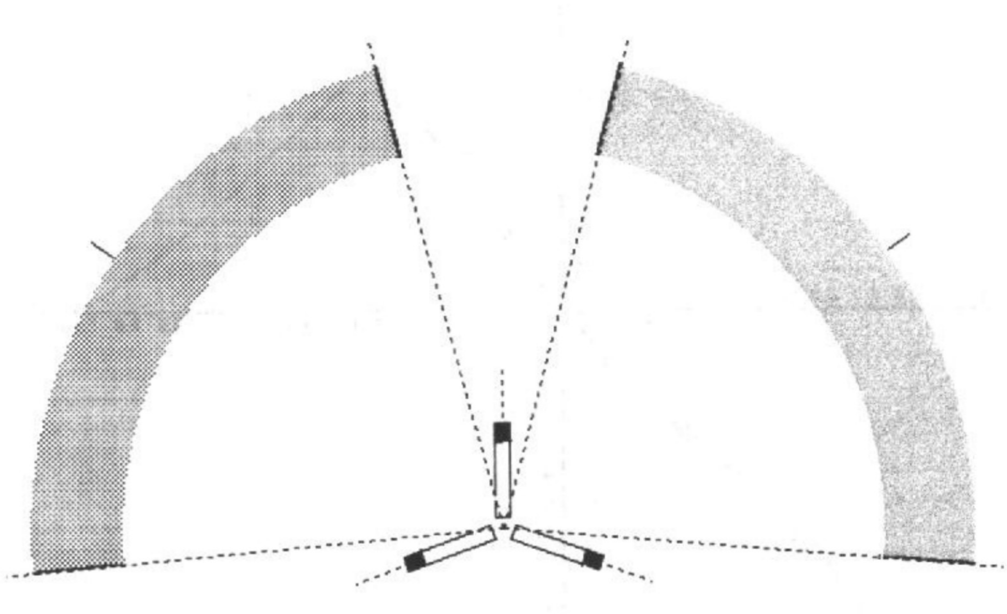


Figure 26 : Front Triplet 25cm/110° - Coverage Angle 80° for each Segment – No Offset

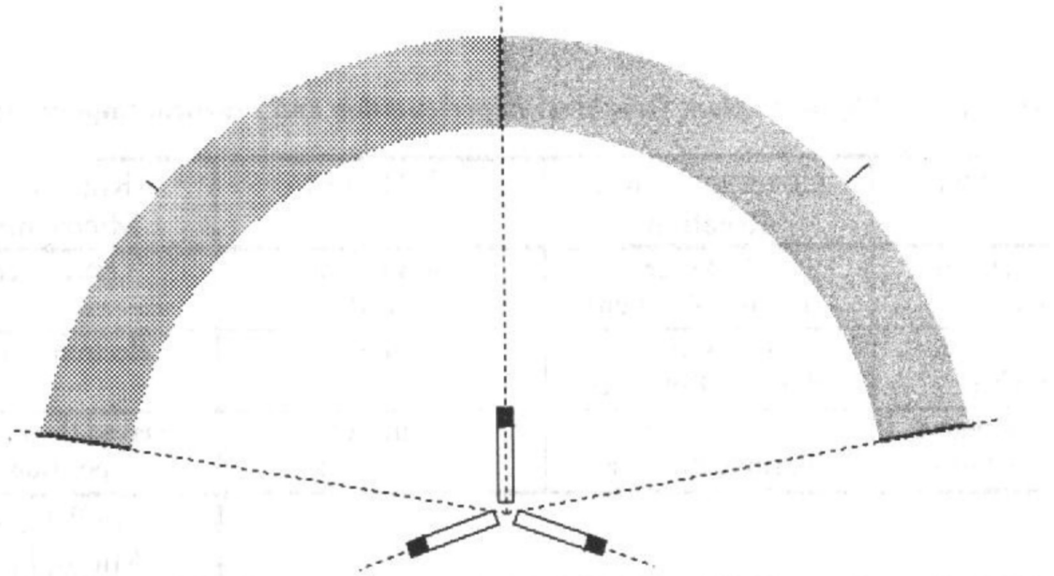
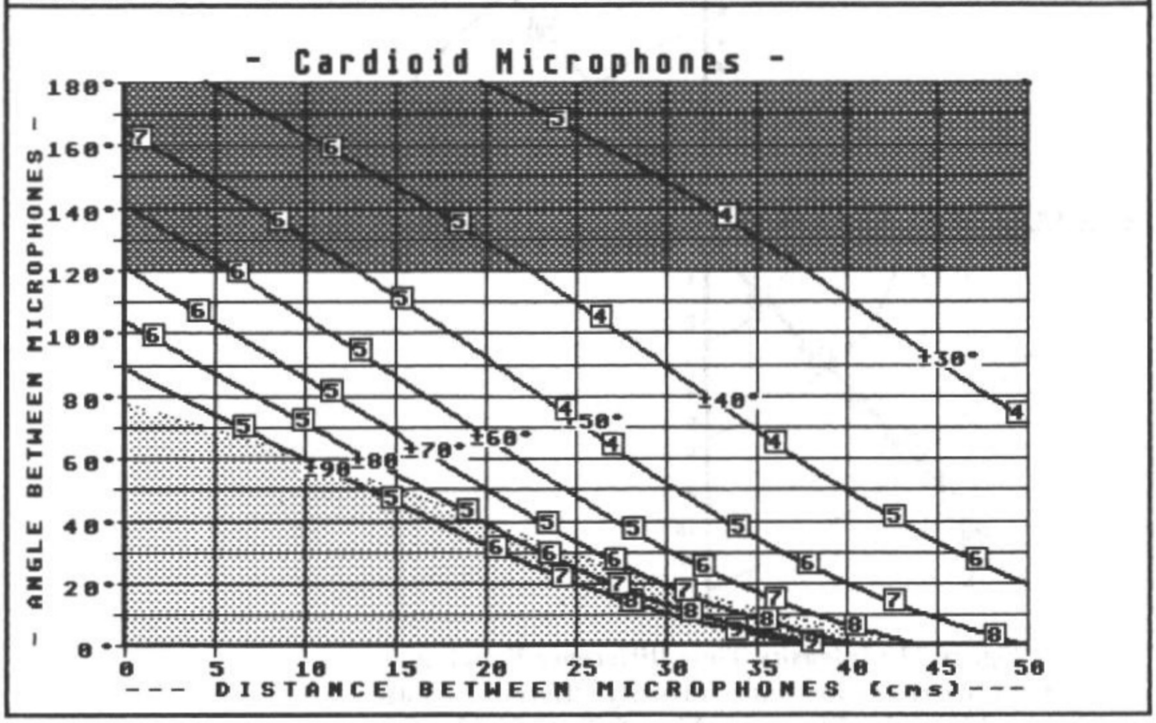


Figure 27 : Front Facing Triplet 25cm/110° - Coverage Angle 80° for each segment Offset of +15° on Left Front Segment / Offset of –15° on Right Front Segment

FIGURE 28 - STEREOPHONIC RECORDING ANGLE IN THE REFERENCE PLANE



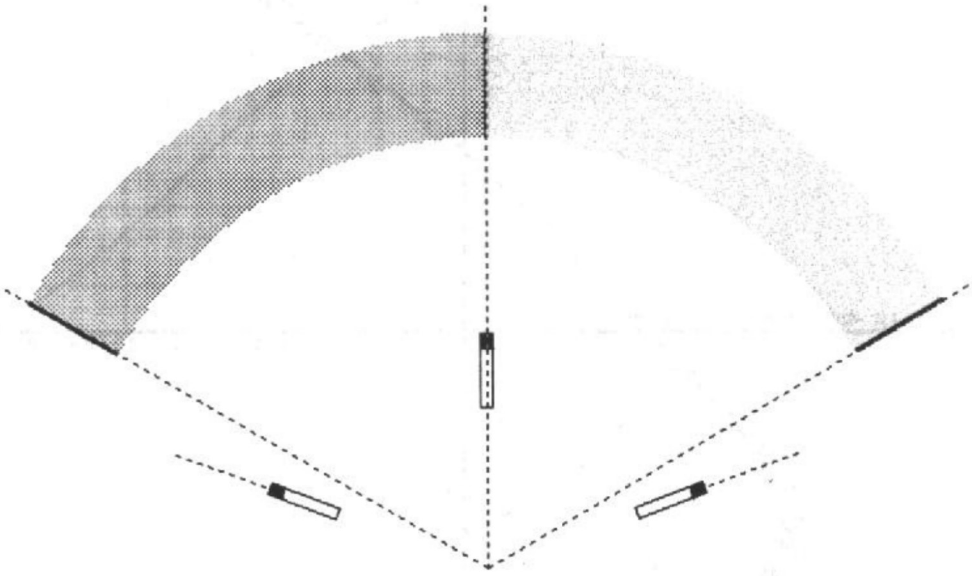


Figure 29 : Front Triplet – 50cm/70° - Coverage Angle 60° left / 60° right Critical Linking with Microphone Position Offset 7° (-7° RFS, +7° LFS)

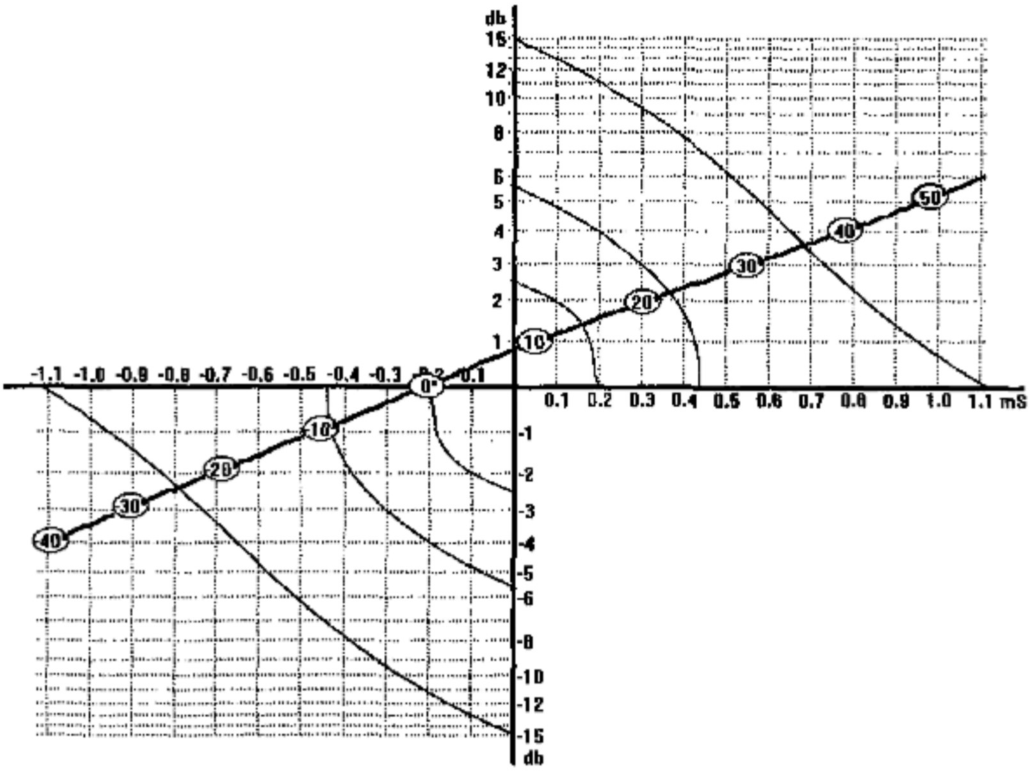


Figure 30 : Intensity/Time Difference Function
Front Triplet - 50cm/70° - Coverage Angle 60° left / 60° right
Microphone Position Time Offset 7° (-7° RFS, +7° LFS)

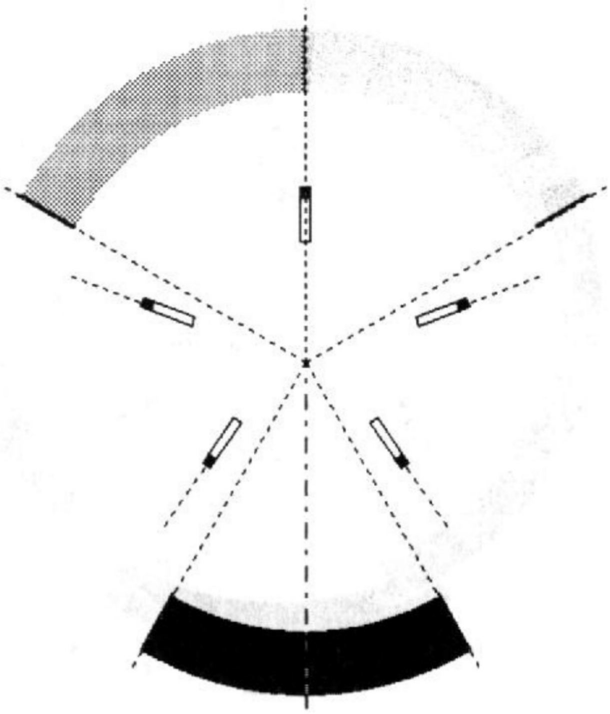


Figure 31 : Back Segment – 56cm/48° - Coverage Angle +/- 30° (a total of 60°)

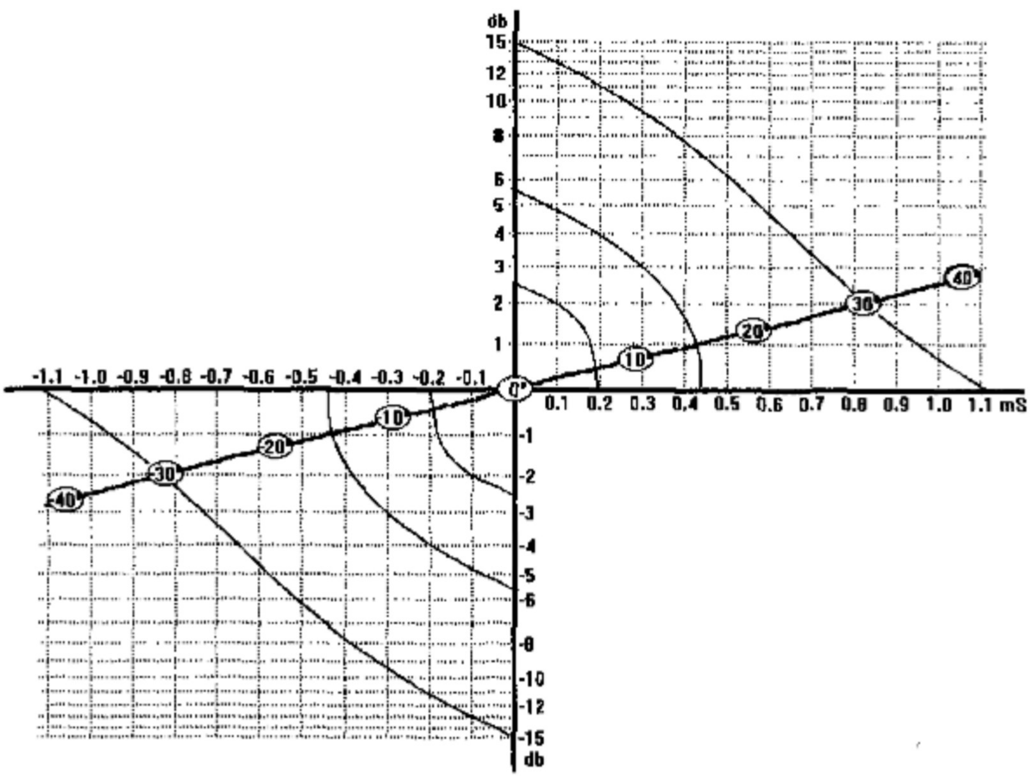


Figure 32 : Intensity/Time Difference Function
Back Segment – 56cm/48° - Coverage Angle +/- 30°

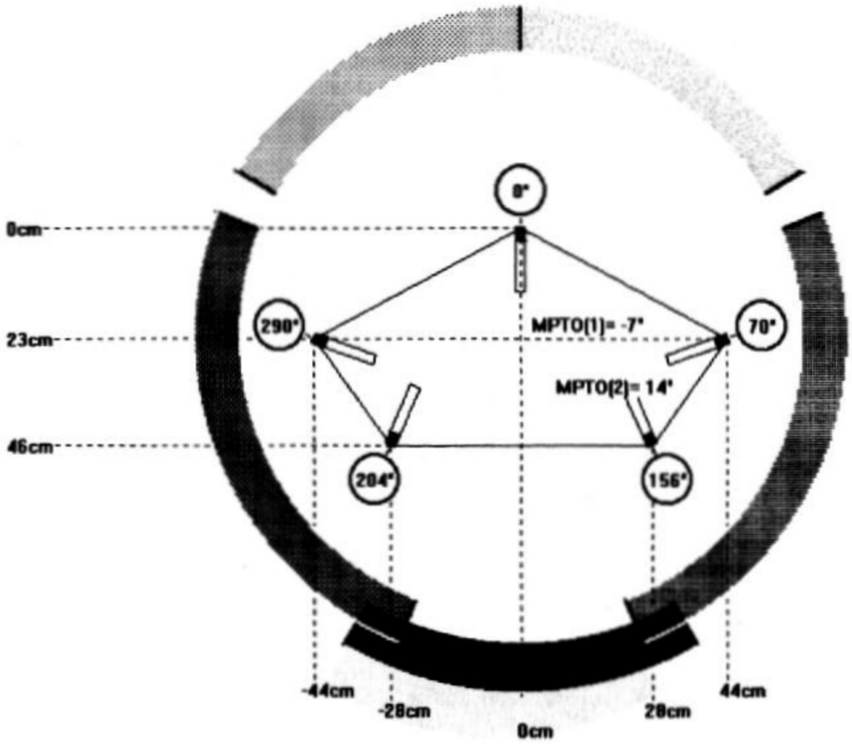


Figure 33 : Third Stage of MMA Design
Lateral Segments with Positive Microphone Position Time Offset (MPTO) overlapping with Back Segment Coverage

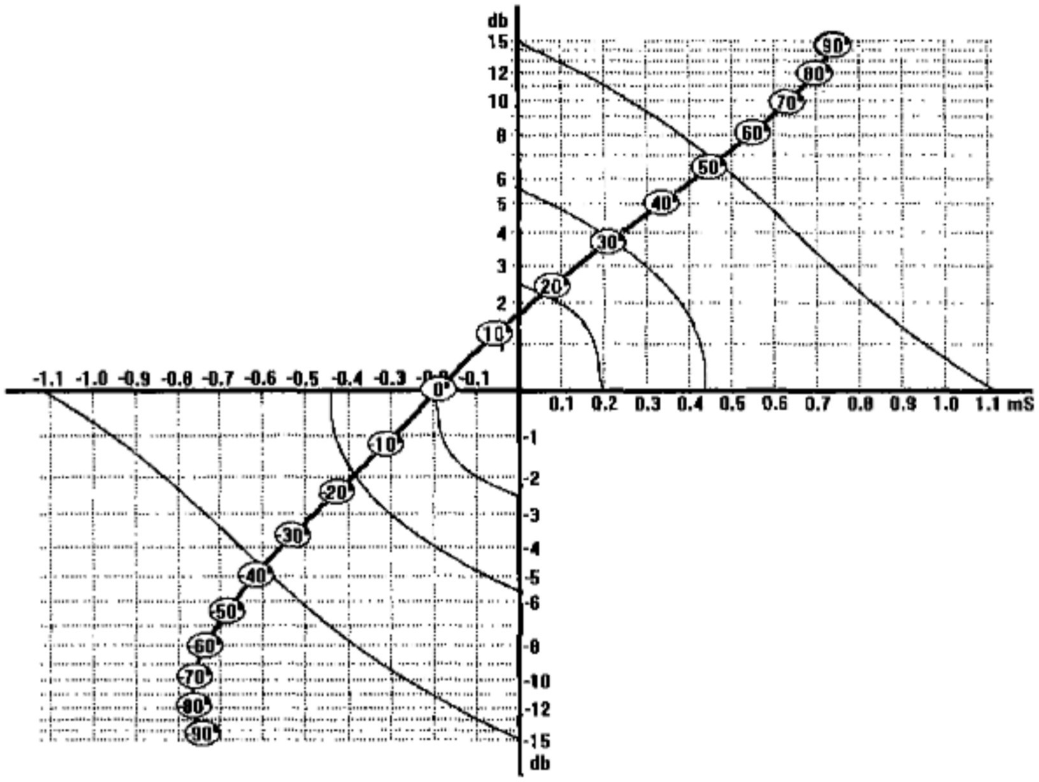


Figure 34 : Intensity/Time Difference Function for Right Lateral Segment with Positive Microphone Position Time Offset of 14°

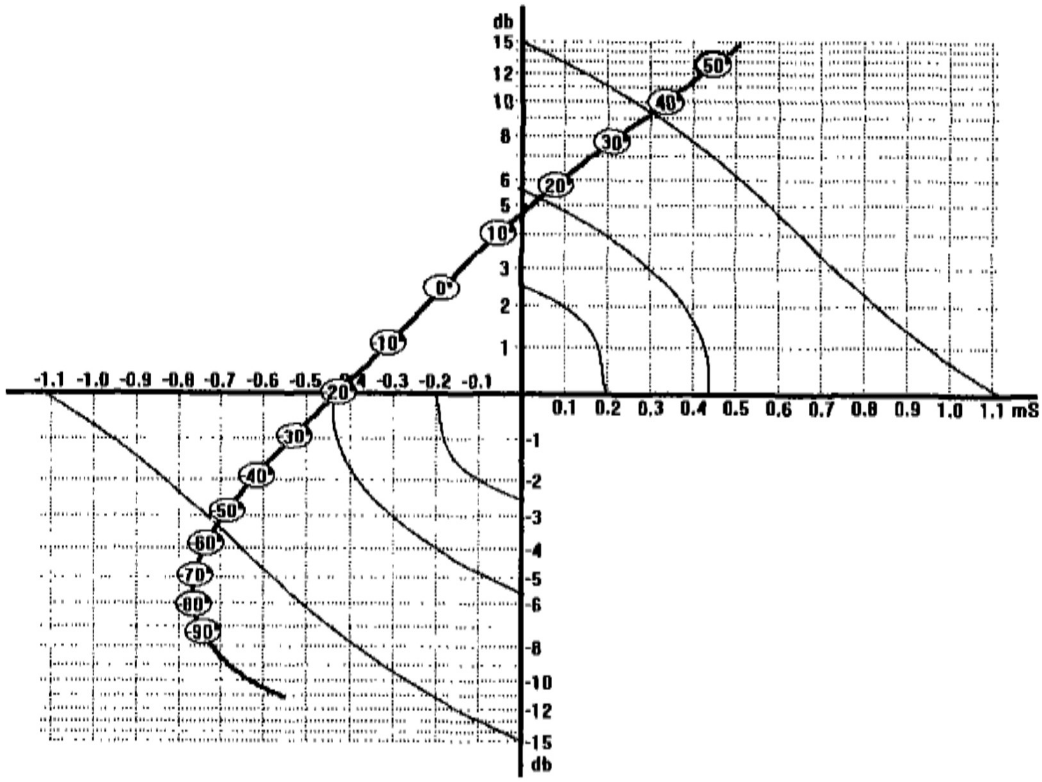


Figure 35 : Intensity/Time Difference Function with same Positive Microphone Position Offset as in Figure 34 (14°) but compensated by Negative Electronic Intensity Offset of 2.4 db Coverage Angle of – 53° to + 38°

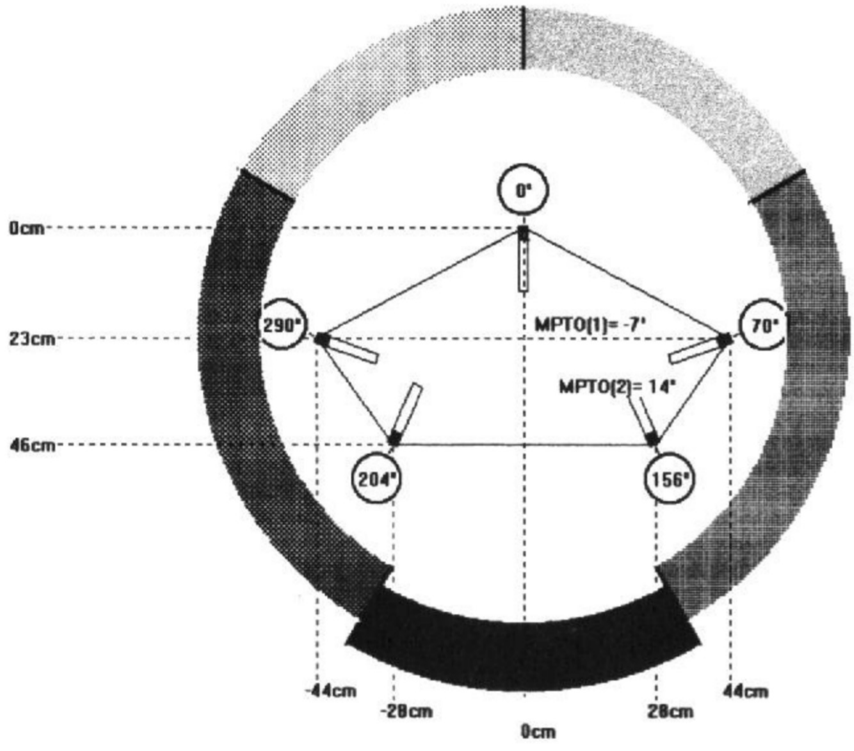


Figure 36 : Critical Linking of all segments of the Multichannel Microphone Array