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The Principles and Design Procedure for Multi-format-compatible Microphone Arrays

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ABSTRACT

Multiple format recording of almost any production project is now becoming a basic requirement in most media – the 2 channel stereo and multichannel release formats of the same title are indeed almost a commercial necessity. At present the only solution available for a main microphone array recording is to use different microphone arrays for each of the required formats. This paper shows how this jungle of main microphone arrays can be replaced by a single 5 channel microphone array that will supply direct signals compatible with 5 standard formats : mono, 2 channel "stereo", three channel "triphony", four channel "quadraphony", and "multichannel" with 5 channels. The direct signals from this type of array design could even be transmitted as such, allowing the consumer to choose any desired diffusion format from the direct signals, with or without channel matrixing.

INTRODUCTION

As described in papers on Multichannel Microphone Array Design (MMAD) presented at various Audio Engineering Society Conventions (1), we can design microphone arrays for three specific coverage strategies:

- Front Sound Stage Coverage only
- Front and Side Sound Stage Coverage
- Surround Sound Coverage

The basic design procedure assumes that the Recording/Transmission/Reproduction chain is univalent in that there is an obligatory one to one correspondence between microphones, channels and loudspeakers.

Front Sound Coverage arrays can be designed in the context of 2, 3, 4, 5 or more microphones/channels, whereas satisfactory surround sound arrays apply only to 4 or 5 (or more) microphones/channels.

Three basic microphone array configuration systems are possible :

- Root Arrays where the orientation of the microphone also corresponds to the limit of the array coverage segments
- Natural Arrays where only Microphone Position Offset (MPO) is needed to achieve Critical Linking or seamless reproduction of the sound field (no segment steering using Electronic Time Offset (ETO) or Electronic Intensity Offset (EIO) is necessary)
- All other arrays where the array design process uses, where necessary, MPO, ETO and/or EIO to achieve Critical Linking

The multi-format-compatible array design is directly applicable to two specific situations :

- Front Sound Stage Coverage with 3 microphone channels – either two or three channel compatible reproduction being possible
- Surround Sound Coverage with a 5 microphone array – compatible with 4, 3 or 2 channel reproduction, or even mono reproduction

The normal multichannel microphone array design procedure may be divided into 3 stages :

- the design of the front segment(s) coverage
- the determination of the back pair coverage
- the configuration of the lateral pair coverage

More information on the details of the multichannel microphone array design process will be found in the series of AES preprints cited in the references.

In designing for array compatibility we must pay particular attention to the configuration of the front coverage segment or segments, whereas the side and back coverage microphone configurations correspond to the normal design procedure. Image folding of the side and back segments into the front coverage in two or three channel reproduction, called in a previous paper “twisted quad matrixing”, is of course optional.

We must adopt a very different strategy for compatibility in the design of the front coverage segments, compared to the relatively simple design procedure for the lateral and back segment coverage.

THE FRONT SEGMENT COVERAGE DESIGN FORMULA

The two segment front coverage system of a triplet array of microphones must obey the simple but fundamental coverage formula:

the Left Front Segment Coverage angle (LFSC)
formed by the left and centre microphones

PLUS

the Right Front Segment Coverage angle (RFSC)
formed by the centre and right microphones

MUST BE EQUAL TO

the Left and Right Pair Coverage angle (LRPC)
formed by the left and right microphones

LFSC + RFSC = LRPC

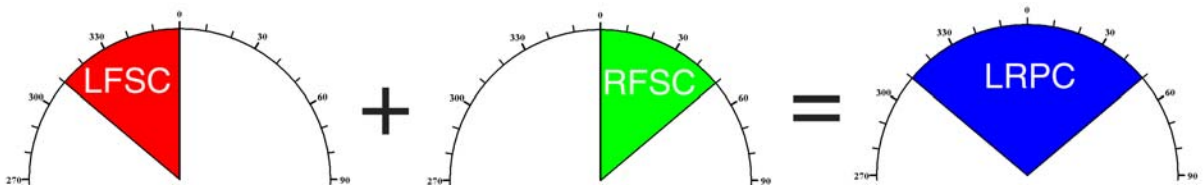

Figure 1 - The Front Segment-Coverage Design Formula

This would seem to be absolutely self evident, but only a clear understanding of the function of the centre microphone in the design of the left and right segment coverage will enable the correct design to be achieved.

This in no way implies that the front coverage segment determined by the left and right pair is superimposed upon the left front-coverage segment together with the right front-coverage segment. As described in a previous AES paper (AES preprint 6373) the "precedence effect" will limit our perception of a triplet microphone array to the coverage by the left and right front segments, whereas the stereo pair created by the left and right microphones will ONLY be perceived in the context of two channel stereo reproduction. When the precedence effect is operative this double perception of segment coverage in a triangle of microphones as superimposed segments is a pure figment of intellectual imagination and has no foundation in psychoacoustic analysis.

The ever recurring mythology concerning the function of the centre microphone of a front triplet array can only cause confusion in the mind of the sound engineer in the complex process of optimisation of the microphone array. It must be clearly understood that the adjunct of the centre microphone is not a banal addition of a centre source, but the creation of two distinct and theoretically separate segments: the left front and the right front segments. The precedence effect will assure that we perceive ONLY these two segments in spaced microphone arrays. This is one of the main advantages of spaced microphone arrays over coincident microphone systems. It is therefore necessary to design the microphone configuration so that good critical linking is achieved between the two segments, giving the impression of a smooth and continuous sound field coverage.

The starting point for the design of the front segment formula is to determine the segment coverage of the stereo pair (formed by the left and right microphones), and each segment coverage of the triplet array (left front segment coverage and right front segment coverage). From Figure 2 we can see that a combination of 70° between the microphone axes and 25 cm between the centre of the microphone diaphragms will produce a stereo pair with a Stereophonic Recording Angle (SRA) of +/- 50° (a total coverage of 100°).

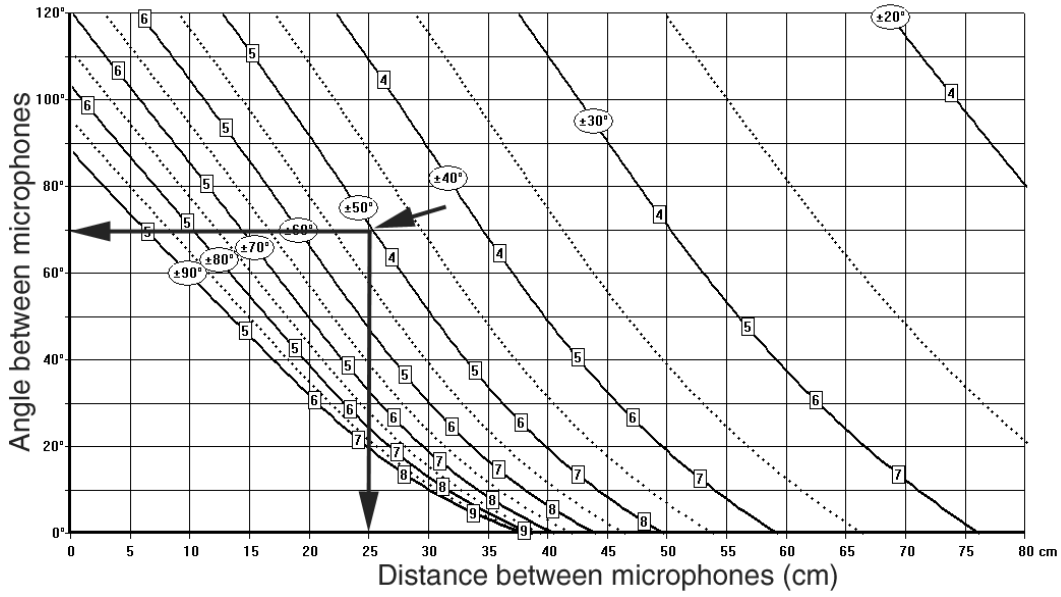

Figure 2 – SRA Diagram showing stereo pair combination: +/- 50° (70° / 25cm)

The di/dt function is shown in Figure 3.

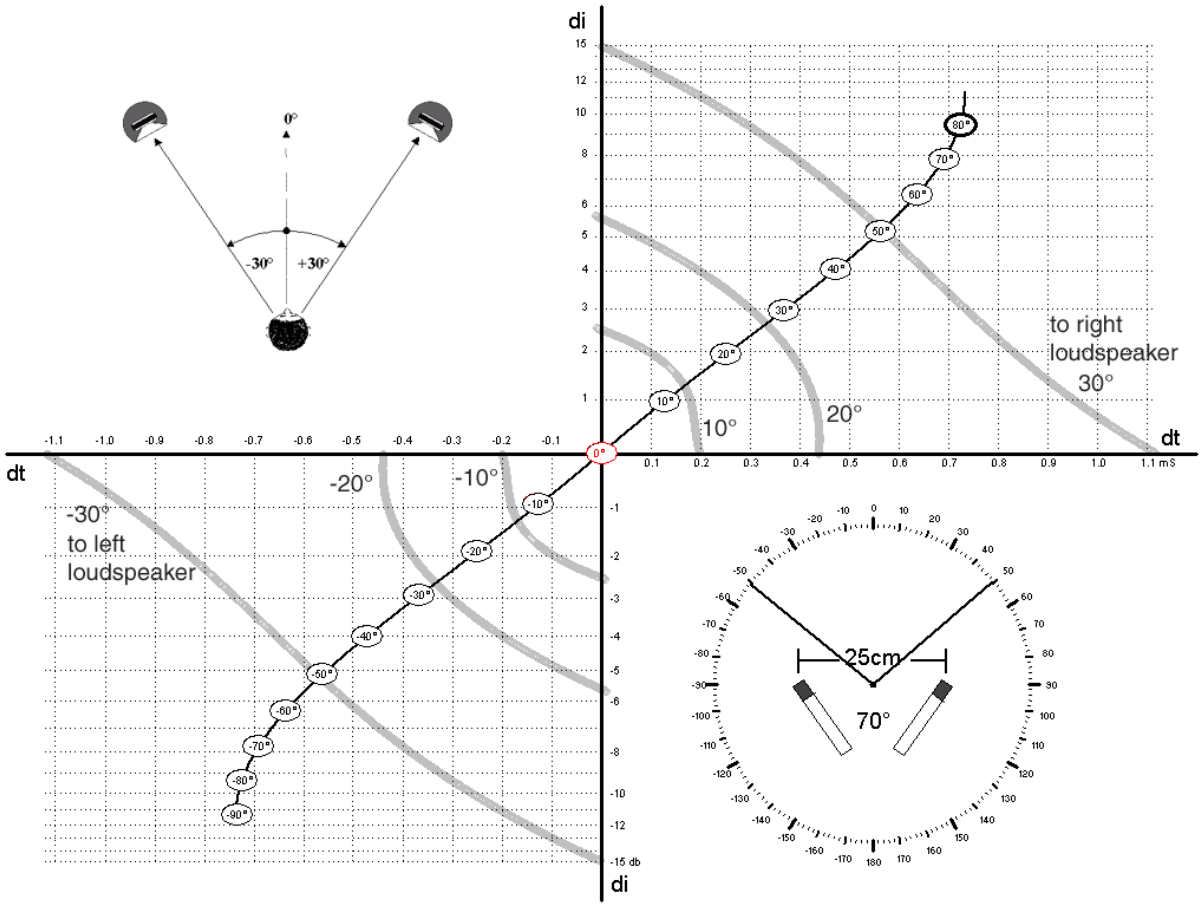

Figure 3 - di / dt function for stereo pair 70° / 25cm

If we now add the centre front facing microphone we can create a triplet array. As the stereo-pair originally had a segment coverage of 100°, then each triplet coverage segment must obviously be 50°, at least for the front segment-coverage formula to be valid.

The centre microphone of the triplet array will obviously be forward facing at 0°. The angle between the left microphone (orientation 325°) and the centre microphone (at 0°), or the centre microphone (at 0°) and the right microphone (orientation 35°), will 'per force' be 35°.

As we can see from Figure 4, to obtain a segment coverage of 50° (corresponding to a SRA of +/- 25° i.e. a total of 50°), with 35° between the microphones, we must use a spacing between the microphones of about 75cm.

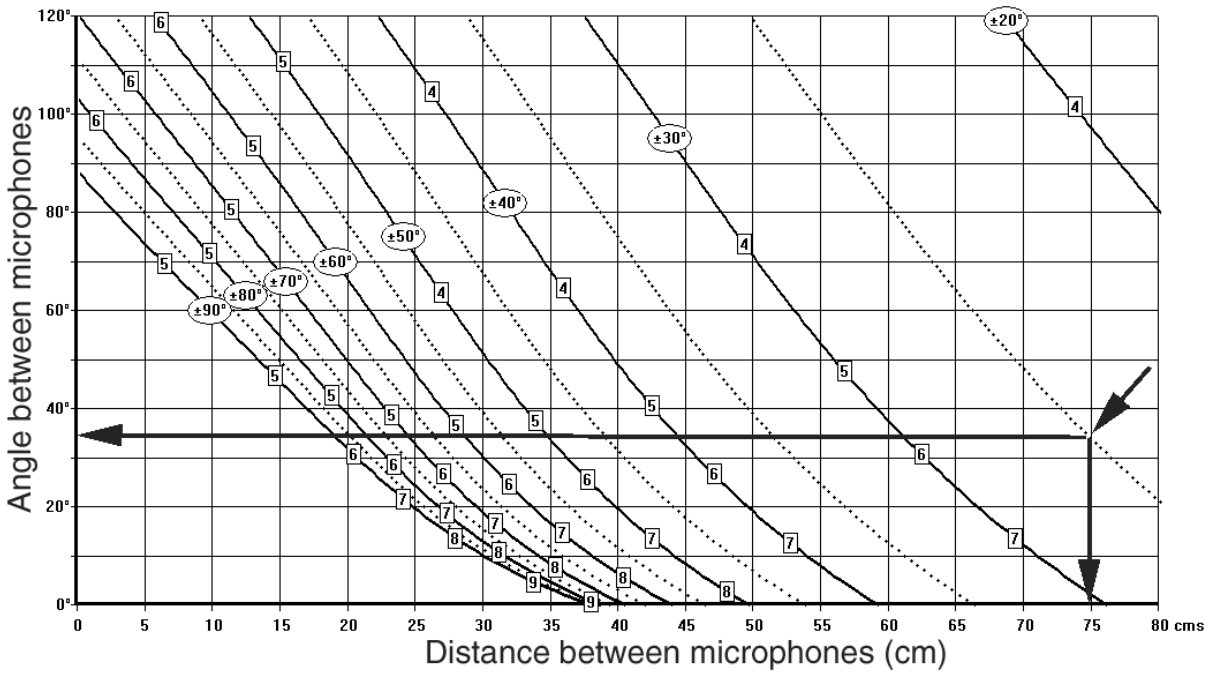

Figure 4 – SRA Diagram showing stereo pair combination: SRA +/- 25° (35° / 75cm)

The front triplet can be constructed as two side-by-side pairs of 35° / 75cm sharing the centre microphone as shown in Figure 5.

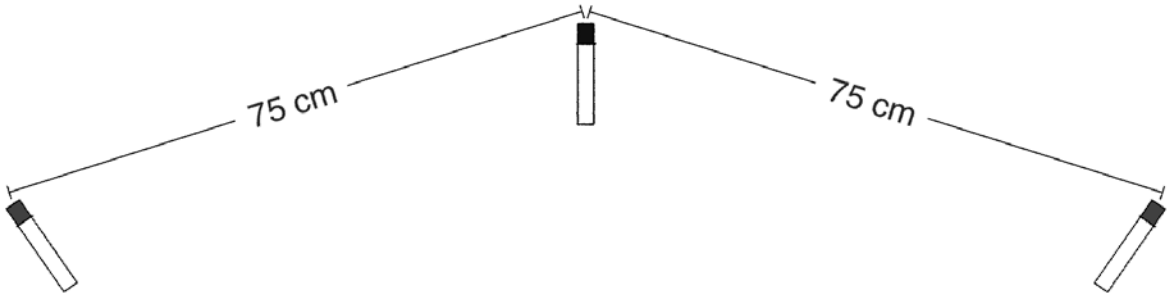

Figure 5 – Front Triplet made up from two pairs at 35° / 75cm

The coverage of each pair is 50°, but the angle between the microphones is only 35° - the coverage segments from each part of the front triplet will therefore overlap

This is also shown in Figure 6, the coverage of the left front segment will be from 320° to 10° and symmetrically the right front segment from 350° to 40° - an overlap from 350° to 10°. The left coverage segment angle is therefore not critically linked with the right segment coverage angle.

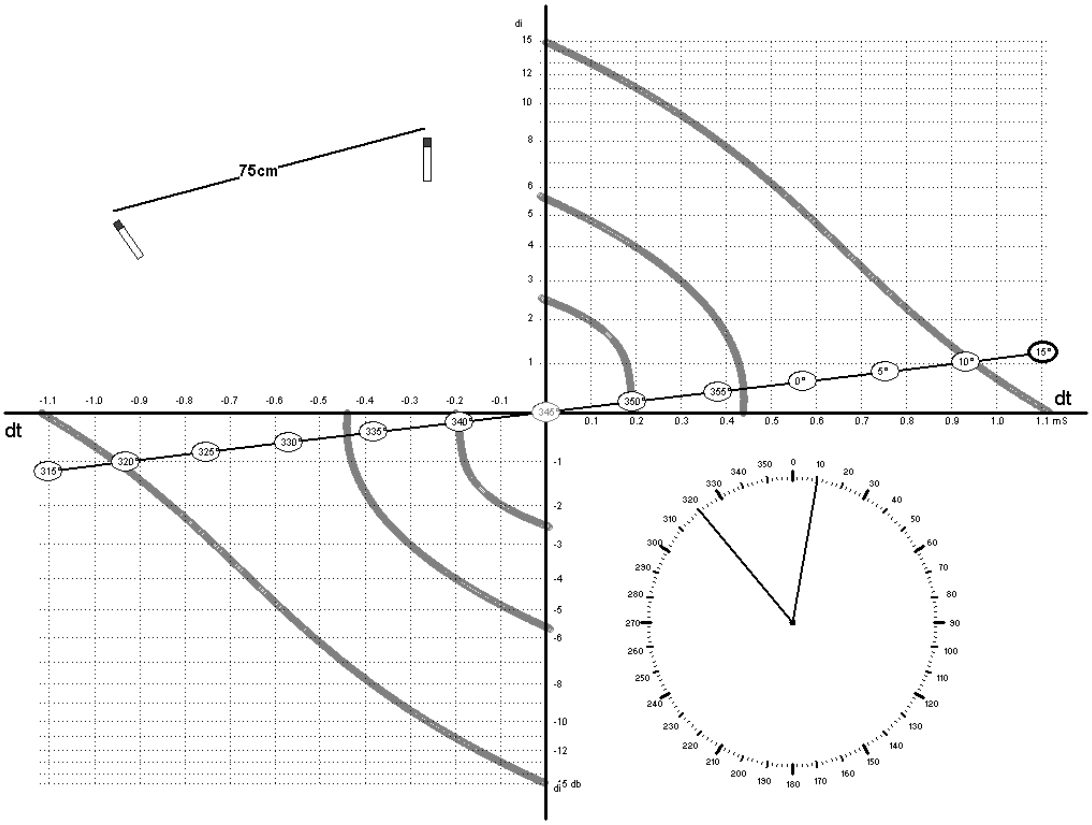

Figure 6 - di / dt function for a stereo pair 35° / 75cm

However in design for compatibility the left and right microphones must also form the left-right stereo pair - this would seem to be impossible to achieve in relation to the left-right stereo pair of 70° / 25cm as shown in Figure 3. However if we place a centre microphone at 75cm in front of the stereo pair, we obtain the same pair characteristics for each component pair except that the front triplet pair now has a microphone position offset (MPO) of about 45° as shown in Figure 7.

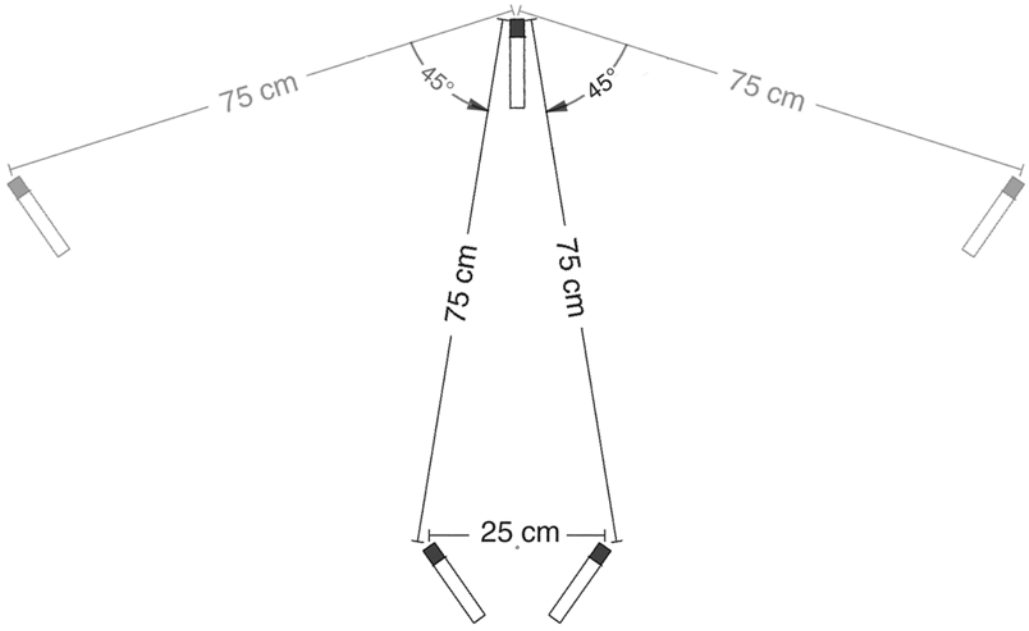

Figure 7 – Front Triplet with MPO of 45°

The di / dt function for the left front segment of this configuration is shown in Figure 8.

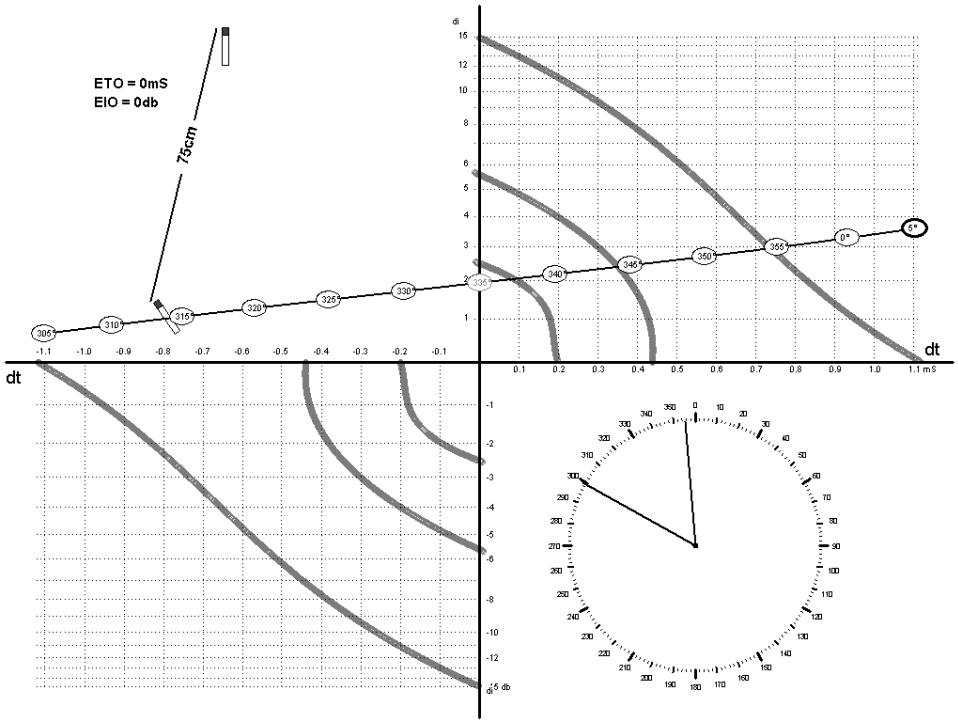

Figure 8 – di / dt for left font segment wth MPO of 45°

In the left front segment shown in Figure 7, the segment coverage is from 300° to 355°. The symmetrical coverage of the right front segment will therefore be from 5° to 60°. For perfect Critical Linking between the left and right segments about 2db of Electronic Intensity Offset (EIO) will be enough to steer the two segments to link at 0°. Figure 9 shows the di/dt function with 2db of EIO.

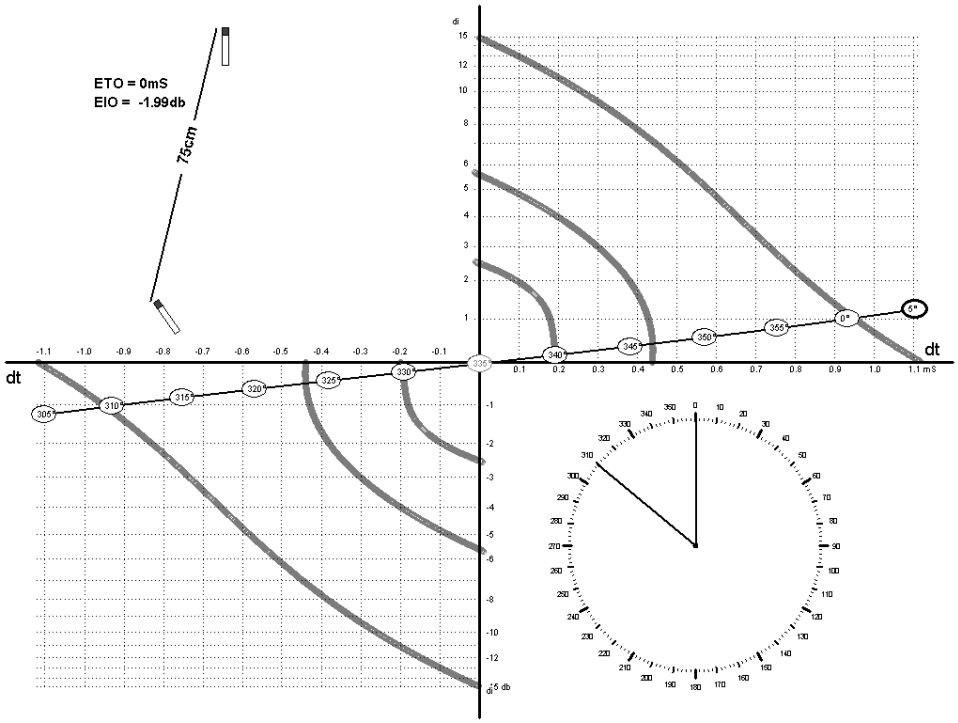

Figure 9 – di / dt for left font segment wth MPO of 45° with 2db EIO

We have thereby created a compatible two-channel / three-channel front coverage array.

Initial design of offset will tend towards a di/dt function that passes by the zero-di / zero-dt point in the di/dt function diagram. However other ratios of di and dt can be tried if the energy distribution over the front coverage is not satisfactory. It is not necessary for the di/dt transfer function to always pass through the zero point in the di/dt function diagram. However a wide offset from the zero point should be avoided – otherwise localisation can be somewhat problematic.

THE SIDE AND BACK COVERAGE SEGMENTS

A simple solution for side and back coverage with this compatible triplet array design is to use the same stereo pair configuration, as formed by the left and right microphones, but placed facing to the rear. The back pair therefore has a coverage of 100°. We must now determine the distance between the front triplet and the back pair. The coverage angle remaining on each side, is half the difference between 360° and the sum of the front triplet coverage plus the back pair coverage.

Font Triplet coverage = 50° +50°

Back Pair Coverage = 100°

Therefore the left and right lateral coverage segments are each 80° (or +/- 40° in the SRA Diagram) - the angle between the lateral segment microphones is 110° - therefore from Figure 10 we can see that the lateral segment microphone distance must be 25cm.

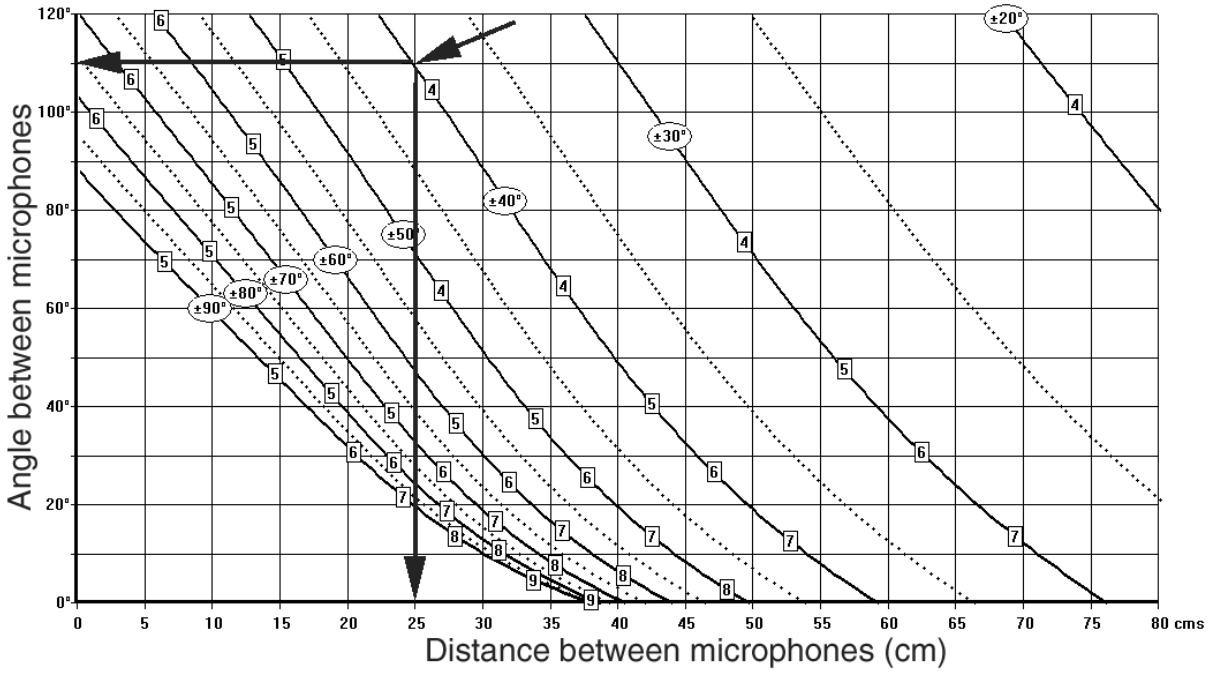

Figure 10 – SRA Diagram showing stereo pair combination: +/- 40° (110° / 25cm)

It is pure coincidence that the distance between the left-right stereo pair is the same as the lateral segment microphone distance. But from a practical point of view for the microphone support system this can but be an advantage. The final array design is therefore as shown in Figure 11.

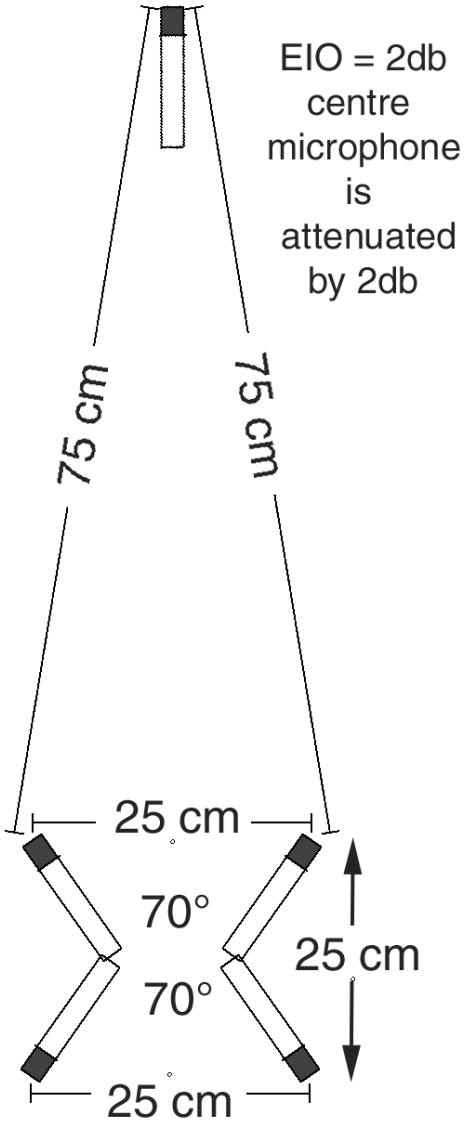

Figure 11 – A multi-format-compatible array design

From a master 5 channel recording using this array, reproduction can be chosen either as the standard 5 channel multichannel – or 4 channel quad – or 3 channels (front sound stage coverage only) – or simply the standard stereo pair or even 1 channel mono (if this still exists!). The reproduction format can be chosen at the production end or by the consumer according to their own particular listening configuration.

It is also possible to add on the additional option of Twisted Quad Mixing which folds the side and back segments into the stereo pair reproduction. This is an optional addition to the main compatibility design, but can improve considerably the spatial attributes of various reproduction formats derived from the basic 5 channel array.

The following text is taken from AES Preprint 6373 presented at the Multichannel session during the 118th Convention in Barcelona in 2005.

TWISTED QUAD RECORDING

Four and five channel arrays for front sound stage coverage were presented by the author in a paper during the session on Multichannel Sound at the 117th AES Convention. In addition a compatible multichannel/stereo microphone array recording process was presented but without any documentation in the preprint. In reply to the many enquiries for more information, here is a description of the basic principles of recording and reproduction using this type of array.

In Figure 12 we can see one example of a normal four channel recording/reproduction array system - there are many cases in multichannel recording when a four channel array system is to be preferred using only the L, R, Rs and Ls loudspeakers for reproduction. Good compatibility between stereo and multichannel is just one such case.

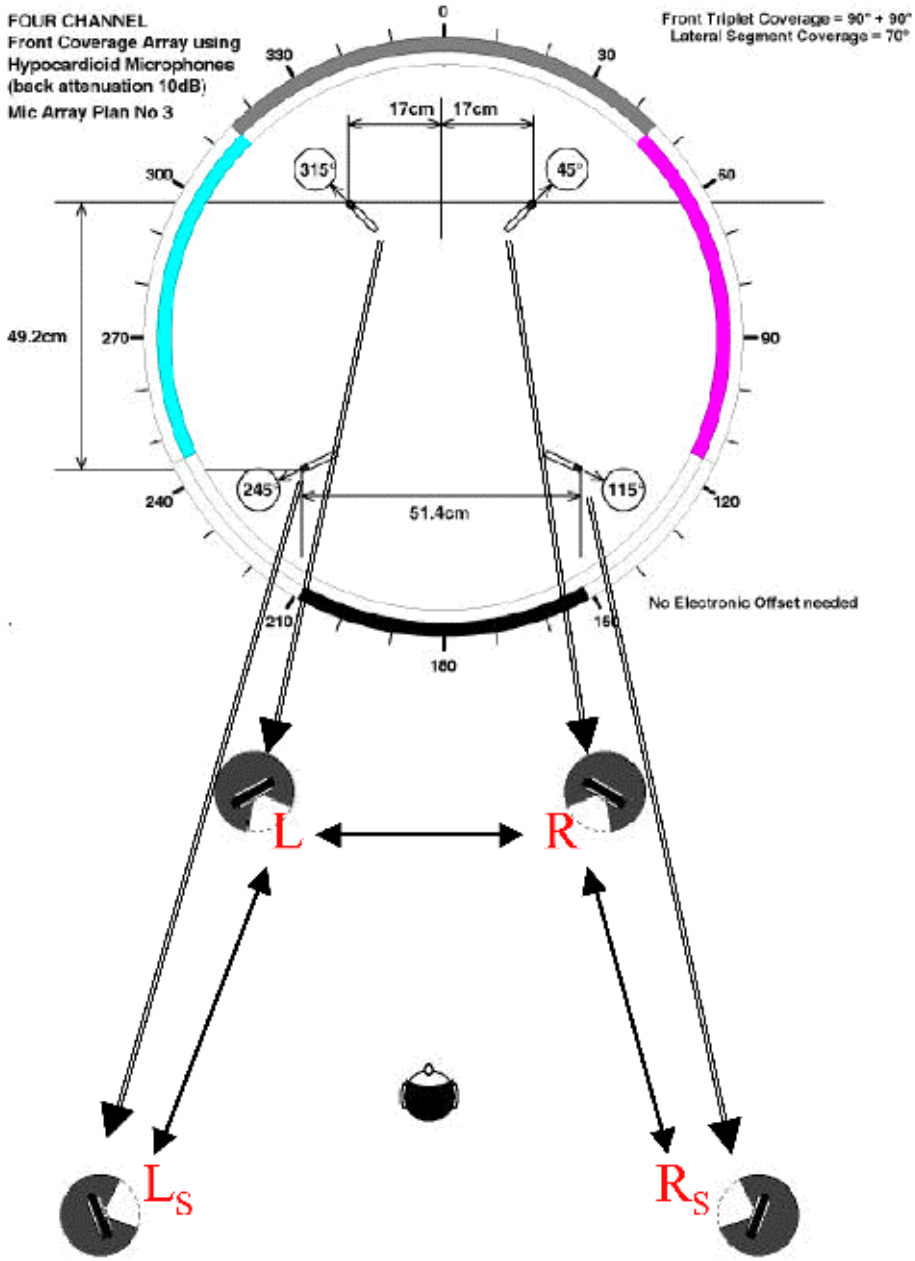

Figure 12 – Normal Four Channel Recording Array and Reproduction

Twisted Quad recording is a perfectly compatible 2-channel/4-channel recording process. The stereo component can either be the standard front facing stereo pair from the quad array or otherwise the left and right surround channels can be twisted back into the two main stereo channels as an enhancement to a normal main microphone stereo pair recording as illustrated in Figure 13. Again it must be emphasised that this is only applicable to spaced quad microphone arrays, as again no coincident quad surround sound array with first order directivity patterns can be designed with critical linking.

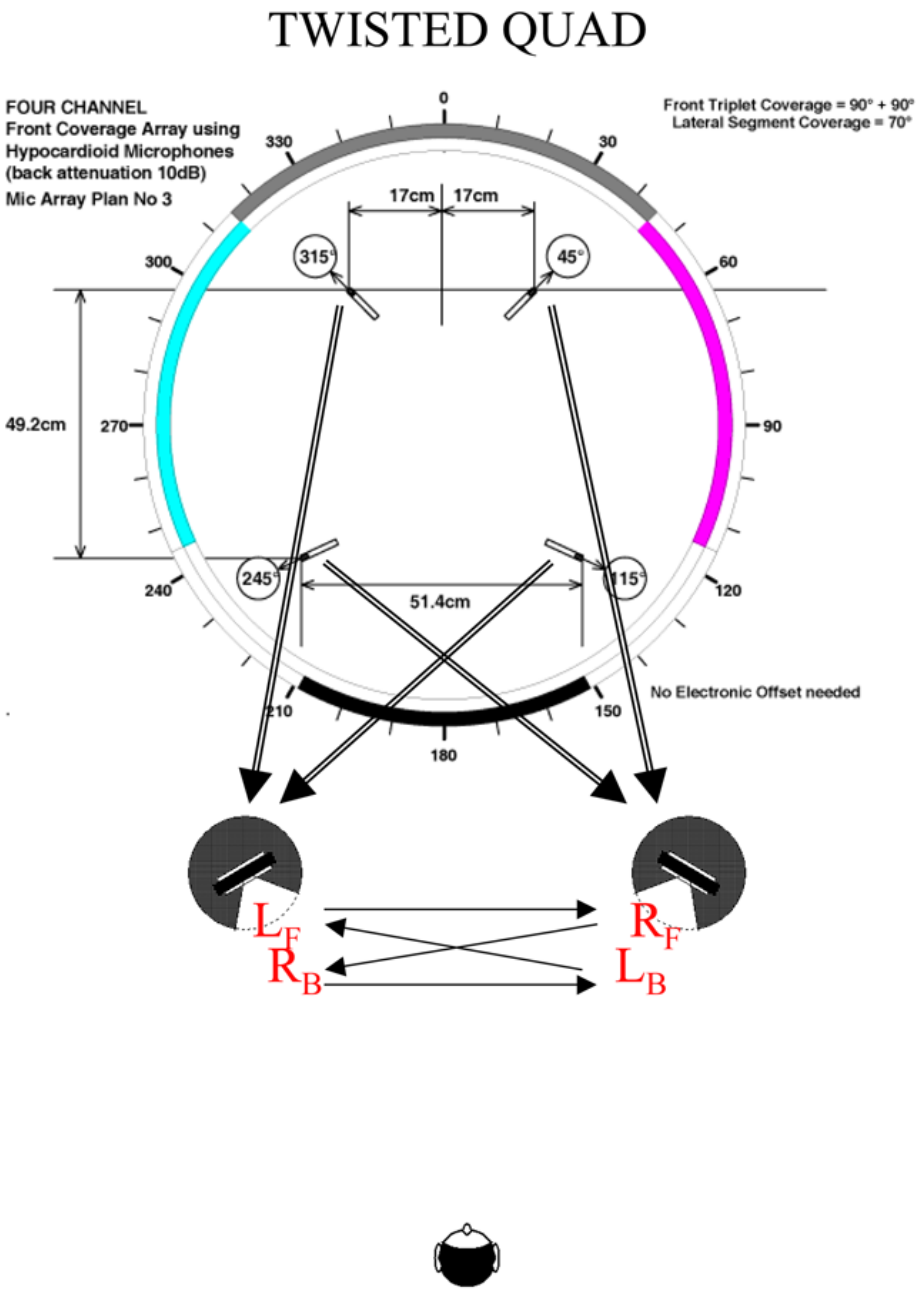

Figure 13 – A Twisted Quad Stereo Mixdown

Normal stereo recording suffers from the fact that all early reflections from the sides are reproduced as mono sources on the left and right loudspeakers, and reverberation from the side and back of the dual microphone array is also reproduced as a left and right mono source. This heavily weights the non-stereo left-right reverberation levels. If the sound source is within the Stereophonic Recording Angle (SRA), the direct sound is correctly reproduced as a virtual image in between the loudspeakers as shown in Figure 14. The same can be said for

backwall reflections, ceiling and central early reflections coloured in blue on the diagram. Reverberation however is split between stereo reverberation for that segment of reverberation that is within the SRA, and mono reverberation reproduced on each loudspeaker pole for reverberation outside the SRA. Early lateral reflections are also outside the SRA and will be reproduced as mono radiation coming from each loudspeaker pole – from the left and from the right loudspeaker (in red and green respectively in the diagram). The Twisted Quad is a simple solution to this basic defect in stereo recording, as well as being a satisfactory multichannel recording array.

Figure 14 – Stereo Reproduction Map

The major advantage of the Twisted Quad mixdown therefore is that early reflections from the sides of the array together with the reverberation field in these segments is redeployed within the stereo front sound stage. The back reverberation field will also automatically be folded back into the main sound stage but the left/right directionality is inverted to right/left. Care must be taken to adjust the position of the microphone array so that the direct to reverberant level ratio is acceptable. No adjustment of the level of the back microphones should be attempted as this will upset the critical linking between the front and side segments. Level adjustment is equivalent to applying a certain Electronic Intensity Offset (EIO) to the side segments – this could of course be compensated by the requisite amount of opposite time offset (ETO).

CONCLUSION

The addition of Twisted Quad Mixing to the basic 5 channel compatible array generates the possibility of 7 reproduction formats:

1) The standard multichannel format using the five univalent channels
2) Four channel reproduction using the left, right, left-surround and right-surround channels only
3) 3 channel reproduction using the left, centre and right channels
4) 3 channel reproduction using the left, centre and right channels, plus twisted quad mixing, which will fold the lateral and back segments sound images from the left-surround and right-surround into the stereo pair reproduction
5) 2 channel stereo from the left and right channel
6) 2 channel stereo with twisted quad mixing folding the lateral and back segments into the stereo pair
7) 1 channel or mono using the centre channel only

REFERENCES (can be ordered from **euroservices@aes.org**)

1) AES Preprints 3157, 4997, 5157, 5336, 5567, 6059, 6230 & 6373
2) 24th AES International Conference: Multichannel Audio - The New Reality