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Migration of 5.0 Multichannel Microphone Array Design to Higher Order MMAD (6.0, 7.0 & 8.0) with or without the Inter-format Compatibility Criteria

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ABSTRACT

The severe limitations of the 5.0 Multichannel Reproduction Standard in reproducing good quality audio-visual or stand-alone audio surround sound reproduction has increased the pressure on recording and reproduction system designers to increase the number of channels in an attempt to give an even more satisfactory envelopment experience. This paper extends the MMAD process to show how higher order channel array designs (6.0, 7.0 and 8.0) can be developed from the existing data on 4.0 or 5.0 Multichannel Front Sound Stage Coverage Array Designs with almost perfectly seamless and linear surround sound reproduction. Designing for inter-format compatibility can also be accommodated from the existing multi-format array design data described in a previous paper on Multichannel Arrays Generating Inter-format Compatibility (MAGIC arrays)(3).

1. INTRODUCTION

The Standard 5.0 Multichannel Loudspeaker Configuration Recommendation ITU - BS.775-1 was created essentially as an audio support configuration for Cinema and Home Theatre sound reproduction. Even in this environment the only segments giving satisfactory virtual sound reproduction are within the frontal sound field of 60° created by the left, centre and right loudspeakers - this is obviously the segment usually occupied in Cinema or Home Theatre reproduction by screen related sound. The lateral segments however suffer from a certain amount of angular distortion and a natural decrease in resolution at 90° and 270° with respect to the listener in the centre. Whereas the back segment, which should show reasonably good localisation, is rendered almost unusable due to the high degree of angular distortion created by the wide angular spacing of the Ls and Rs loudspeakers. Although many attempts have been made to reduce these defects by generating additional channels from the 5 channels transmitted in a 5.0 multichannel format, it has been increasingly evident that the most satisfactory solution would be to increase the number of primary channels. The arrival of the 7.1 multichannel structure with the Blu-Ray and HD DVD disc formats has obviously highlighted the need to design satisfactory higher order (6.0, 7.0 and 8.0) multichannel array systems to meet the need for a high quality audio-visual and especially stand-alone surround sound recordings.

2. HIGHER ORDER MMAD (6.0, 7.0 & 8.0)

First of all let it be clear that the title 'Higher Order MMAD' means a higher number of channels i.e. greater than the multichannel 5.0 standard of 5 channels, not a higher order directivity pattern for the microphones. The arrays designs described in this paper apply to standard 1st order directivity pattern microphones. In MMAD approach to array design it is not necessary to revert to higher order directivity patterns to obtain satisfactory localisation performance, thereby taking advantage of the excellent performance of some of the standard small diaphragm studio condenser microphones.

Three specific approaches to array design using the MMAD procedure will be described

Equal segment array design
Complimentary 'back-to-back' array design
Interformat compatible array design

2.1 Equal Segment Surround Sound Array Design

The very beginning of the Multichannel Microphone Array Design process was described in a paper presented to the 91st AES convention in New York in 1991[(1)]. This paper described the principles behind the migration of two channel stereo to equal segment microphone arrays for 4, 5 or 6 channels. Although at the time it seemed almost impossible to envisage the eventual use of higher order channel arrays, new media technology has inevitably overtaken us. The same principles of equal segmentation of the sound field can of course be applied to these new higher order equal segment designs as well as to the older designs, as shown in Figures 1, 2, 3, 4 and 5.

The extended SRA diagrams in Figures 6, 7 and 8, show how the unique values of angle and distance can be determined in order to specify the configuration of each array for 4, 5, 6, 7 and 8 channels, and for each of the usual 1st order directivity patterns. These configurations still remain a most reliable, satisfactory and compact sound recording tool for multichannel recording and reproduction - indeed a number of proprietary array systems, which conform to this design procedure, have since seen the light of day.

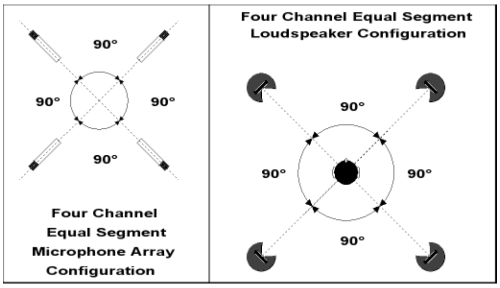

Figure 1

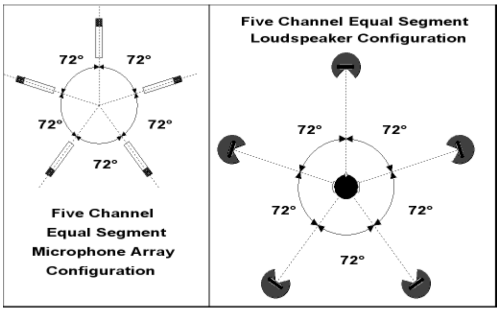

Figure 2

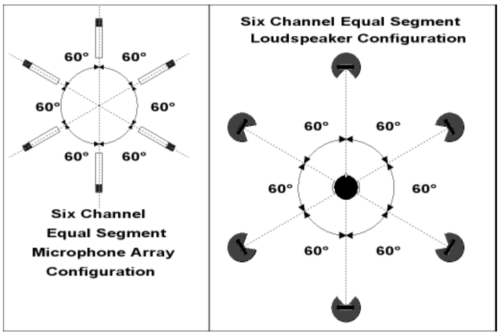

Figure 3

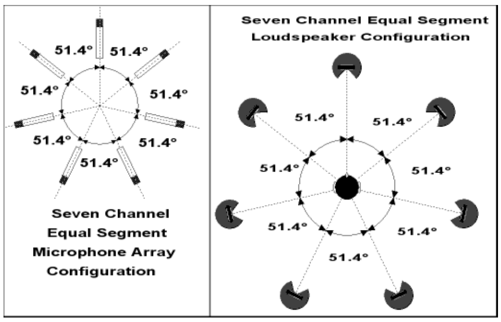

Figure 4

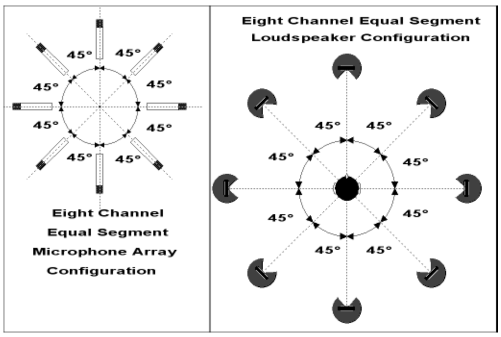

Figure 5

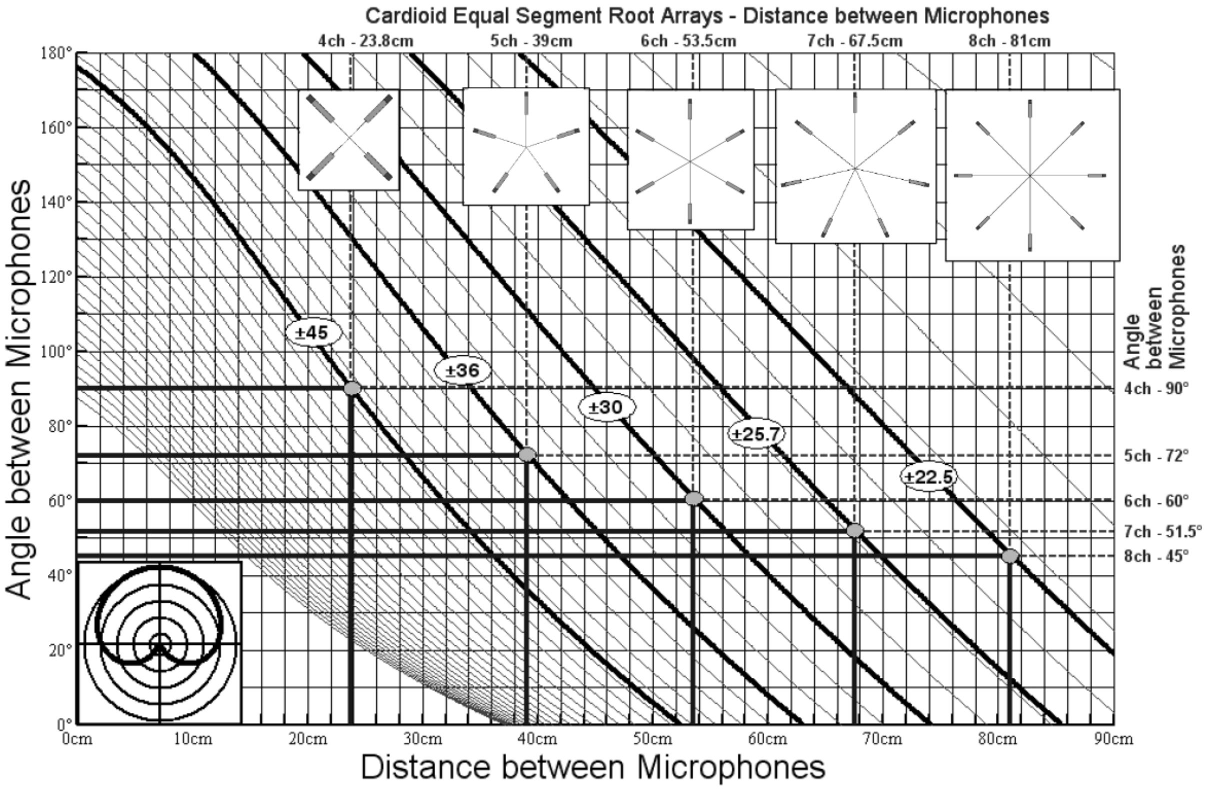

Figure 6

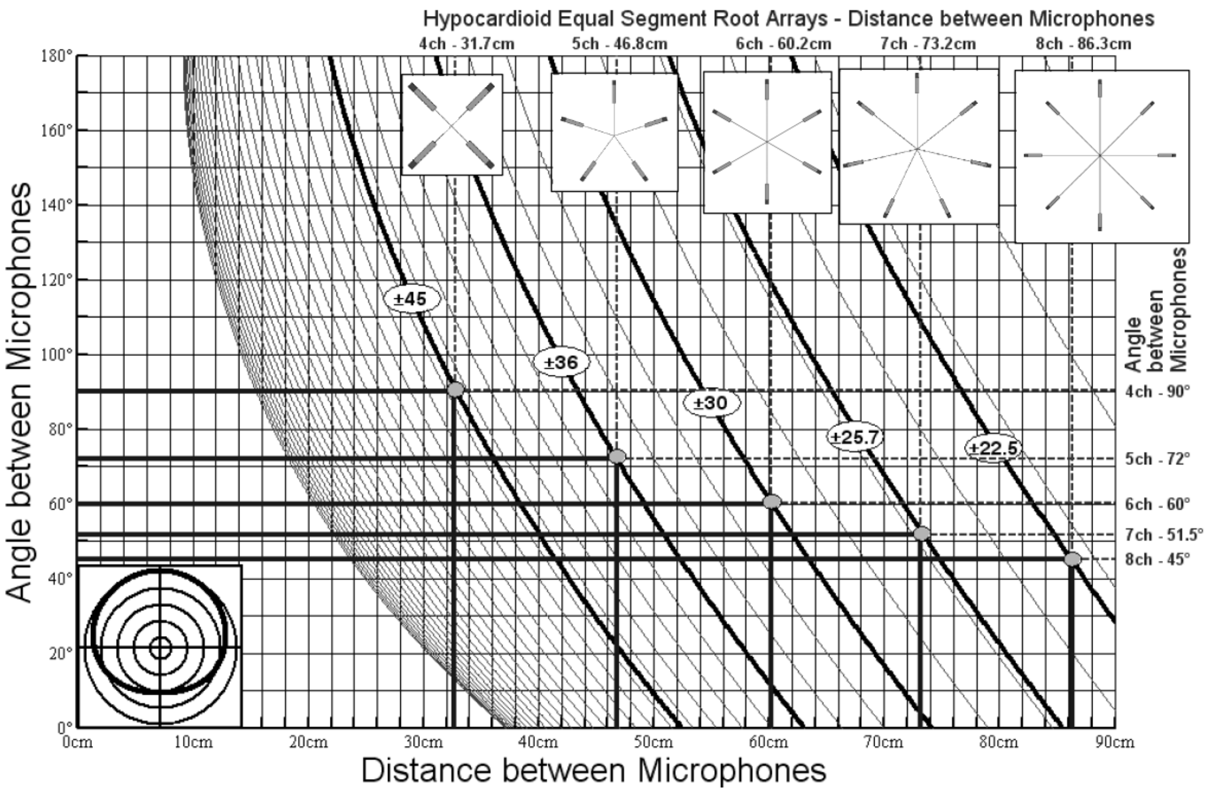

Figure 7

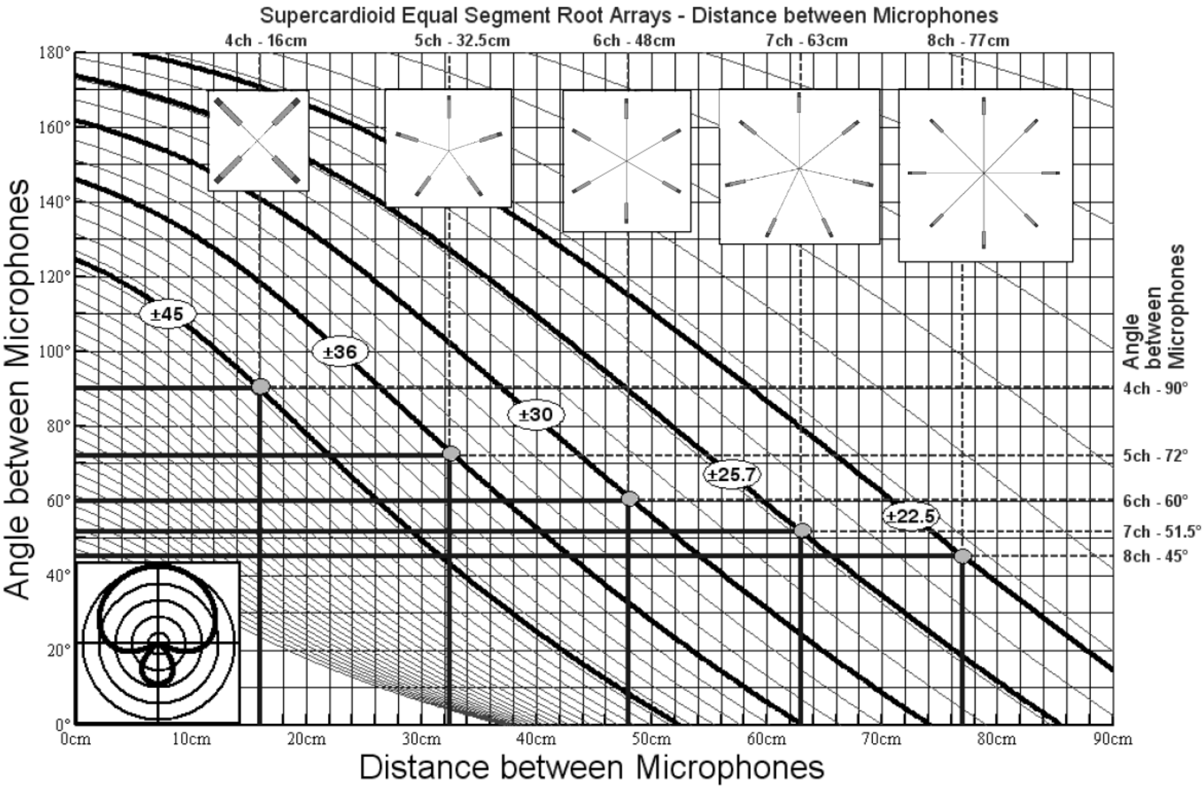

Figure 8

2.2 Complimentary Surround Sound 'Back to Back' Array Design

Multichannel Microphone Array Design procedure, as applied to both 4.0 and 5.0 Front Sound Stage Coverage (FSSC) recording configurations has been described in a previous AES paper(2). By selecting specific complimentary array designs that are available on the MMAD CD-ROM or at www.mmad.info, they can be used in a 'back-to-back' configuration to produce surround sound recording arrays that satisfy any channel configuration from 6.0 to 8.0.

The basic design procedure is to select specific pairs of MMAD FSSC configurations where the redundant back segment angular coverage corresponds to the front segment coverage of another configuration - these pairs of specific arrays can be considered complimentary and combined 'back-to-back' to produce higher order channel systems. For example a 5 channel FSSC array with a back segment of 220° can be combined with another 4 channel FSSC with a 140° front segment coverage to produce a 360° surround sound 7.0 channel array. As long as the back segment coverage of one array is equal to the front segment coverage of the other array, they can be considered as complimentary, and combined 'back-to-back' to form a higher order surround sound array. Three array combination choices can be made - the combination of two complimentary 4.0 arrays will produce a 6.0 channel system - one 5.0 array and another complimentary 4.0 array will produce a 7.0 array system, - two complimentary 5.0 arrays will produce an 8.0 array system.

It is understood that in the combined higher order array, one complimentary array system will share the back boundary microphones of the other. This however implies another constraint in that the distance between the Ls and Rs microphones also must be the same within a few centimetres. This distance criteria can, to some extent, be neglected if steering is applied to the adjacent segments. If the shared microphones are set at the mean distance between Ls and Rs and time offset is used to steer the segment to critical linking with their adjacent segments then many other configurations become available. For the purposes of this paper only configurations that do not require any segment steering, are presented.

Figure 9 shows a table of array configurations taken from the MMAD CD-ROM (or the www.mmad.info website) for 4.0 and 5.0 Front Sound Stage Coverage CARDIOID microphone arrays. Two examples of complimentary arrays are highlighted. Figure 10 shows a similar set of configurations, but for HYPOCARDIOID microphones. One complimentary array is highlighted. It is this complimentary Hypocardioid array that will be used to illustrate the process of combining the two complimentary arrays.

FSSC (Front Sound Stage Coverage) CARDIOID Root Arrays											
5 Channels						4 Channels					
Array Plan No	Front Triplet Coverage	Lateral Side Coverage	Distance between Ls and Rs	Total Back Segment Angle		Total Front Coverage	Front Coverage	Lateral Side Coverage	Distance between Ls and Rs	Array Plan No
20	40° + 40°	30°	325.8cm	220°		100°	40°	30°	294.6cm	42
19		40°	270.8cm	200°		120°		40°	268.2cm	41
18		50°	235cm	180°		140°		50°	202.6cm	40
17		60°	213cm	160°		160°		60°	170cm	39
16		70°	198cm	140°		180°		70°	146.2cm	38
15	50° + 50°	30°	235cm	200°		110°	50°	30°	257.4cm	35
14		40°	189.4cm	180°		130°		40°	212.6cm	34
13		50°	160.8cm	160°		150°		50°	169.2cm	33
12		60°	143.6cm	140°		170°		60°	138.2cm	32
11		70°	137.2cm	120°		190°		70°	116cm	31
10	60° + 60°	30°	159.2cm	180°		120°	60°	30°	225.8cm	28
9		40°	124.4cm	160°		140°		40°	182cm	27
8		50°	103.8cm	140°		160°		50°	140cm	26
7		60°	91.8cm	120°		180°		60°	112cm	25
6		70°	86.8cm	100°						

FIGURE 9

FSSC (Front Sound Stage Coverage) HYPOCARDIOID Root Arrays										
5 Channels						4 Channels				
Array Plan No	Front Triplet Coverage	Lateral Side Coverage	Distance between Ls and Rs mics	Total Back Segment Angle		Total Front Coverage	Front Coverage	Lateral Side Coverage	Distance between Ls and Rs mics	Array Plan No
20	40° + 40°	30°	345.8cm	220°		100°	40°	30°	344.2cm	42
19		40°	290.8cm	200°		120°		40°	265.8cm	41
18		50°	254.2cm	180°		140°		50°	216.8cm	40
17		60°	231cm	160°		160°		60°	184.8cm	39
16		70°	215.2cm	140°		180°		70°	162.4cm	38
						200°		80°	146cm	37
15	50° + 50°	30°	252.8cm	200°		110°	50°	30°	302.6cm	35
14		40°	206.8cm	180°		130°		40°	227.4cm	34
13		50°	117.2cm	160°		150°		50°	180.6cm	33
12		60°	158.4cm	140°		170°		60°	150.2cm	32
11		70°	146.4cm	120°		190°		70°	129cm	31
						210°		80°	113.6cm	30
10	60° + 60°	30°	174.4cm	180°		120°	60°	30°	268.4cm	28
9		40°	139cm	160°		140°		40°	197cm	27
8		50°	117.2	140°		160°		50°	152.6cm	26
7		60°	104cm	120°		180°		60°	124cm	25
6		70°	95.4cm	100°		200°		70°	84.2cm	24
						220°		80°	90cm	23

FIGURE 10

The following procedure should be followed to address the microphone array plans.

Go to the following http address:
1a) http://www.mmad.info/MMAD_04/Readme.htm
1b) or load the MMAD CD-ROM 04.

2) Select the **SOS_MMAD.htm** in the top right hand corner of the readme page.
3) Select **Microphone Array Design** in the following page.
4) Select the **5 Channel FSSC** (Front Sound Stage Coverage) link.
5) Select **Hypocardioid** microphone directivity
6) Select Front Triplet Coverage of **FTC 40° + 40°**
7) Select Lateral Segment Coverage of **LSC 70°**

This will lead you to a PDF of **Plan 16** shown in Figure 11
Return to the Microphone Array Design selection as in the previous line 3.
4) Select the **4 Channel FSSC** link.
5) Select **Hypocardioid** microphone directivity
6) Select Front Coverage of **FC 40°**
7) Select Lateral Segment Coverage of **LSC 50°**

This will lead you to a PDF of **Plan 40** shown in Figure 12

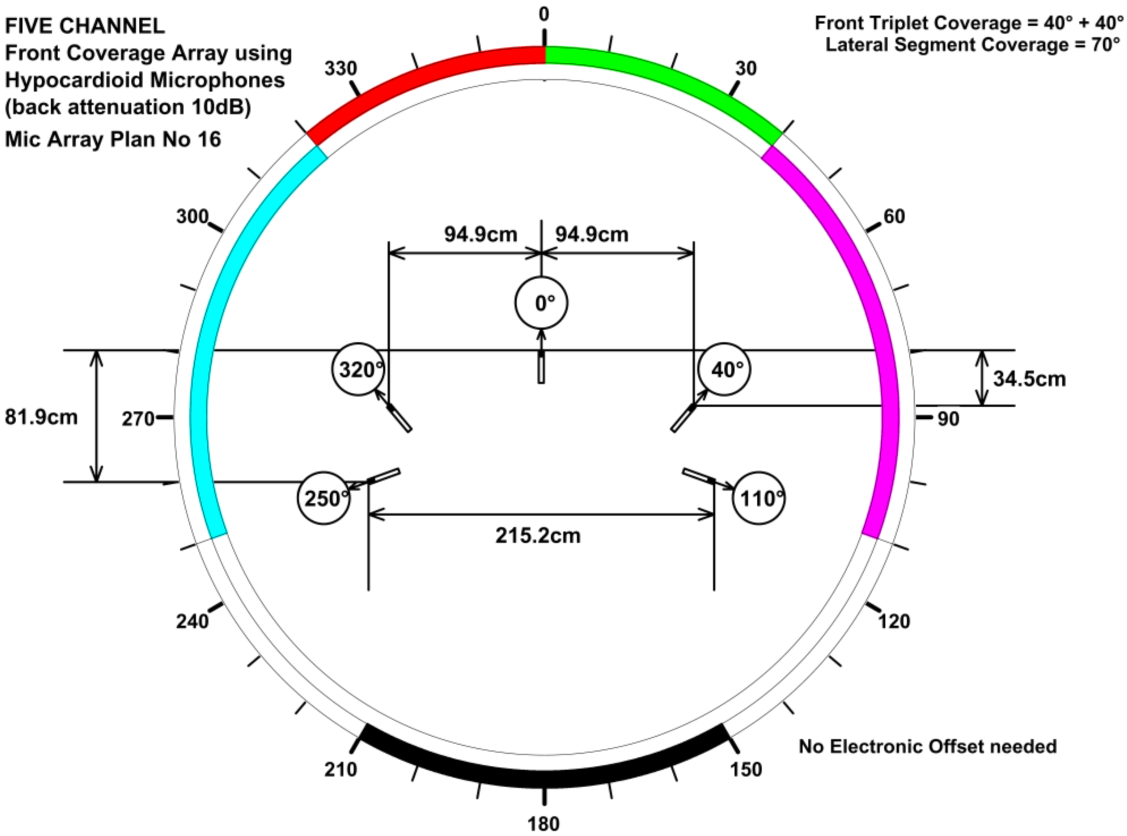

FIGURE 11

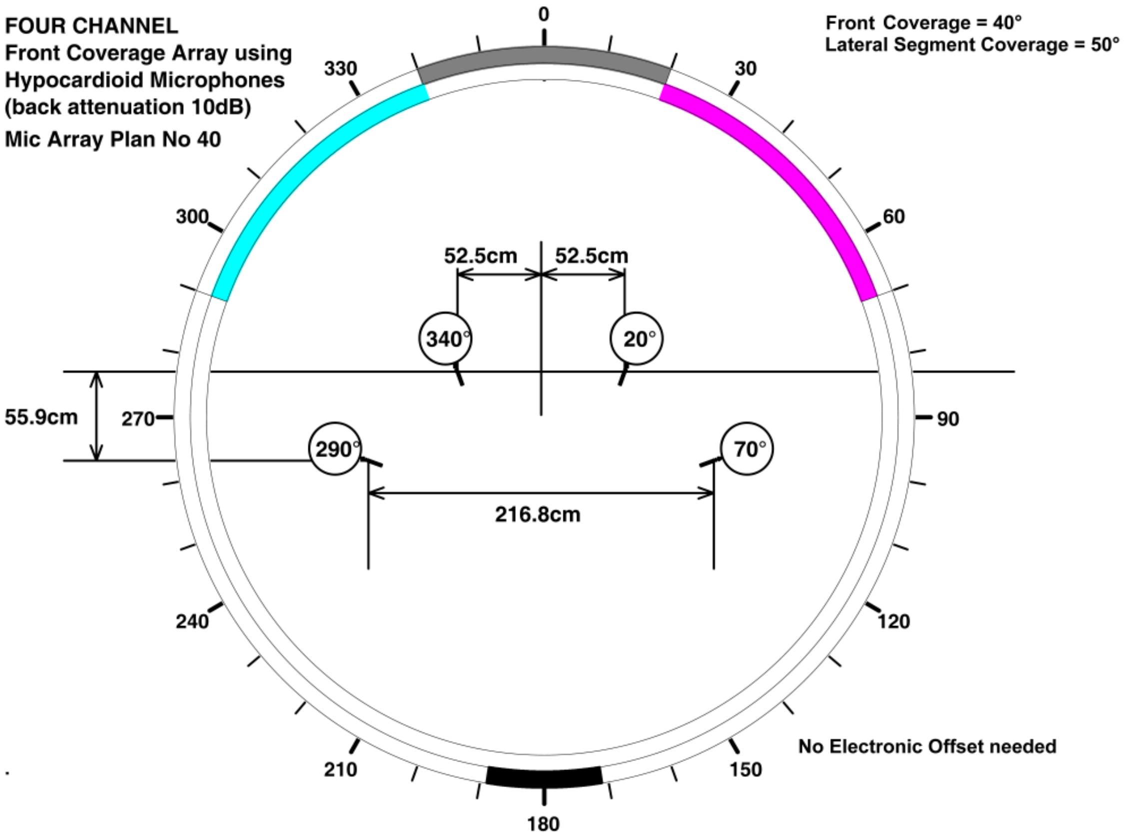

FIGURE 12

It only remains now to mount these two arrays back-to-back using a mean distance between the Ls and Rs microphones of 216 cm. The 5 Channel configuration (Plan 16) is obviously the front facing array whilst the 4 Channel configuration (Plan 40) covers the back segments - the complete 7 Channel array is shown in Figure 13

These array constructions, as has already been explained, use previously defined array configurations from the SOS MMAD CD-ROM or www.mmad.info Website. However in a start-from-scratch new array design procedure that is not confined to root arrays, i.e. that allows for segment steering, many other 6.0, 7.0 or 8.0 array designs can be produced.

For the purpose of this paper it was considered simpler to use only root arrays - root arrays are defined as arrays where the angle between each microphone pair corresponds exactly with the corresponding segment coverage angle. This facilitates any angular mapping of the sound sources that might be necessary in the planning of layout during a recording session.

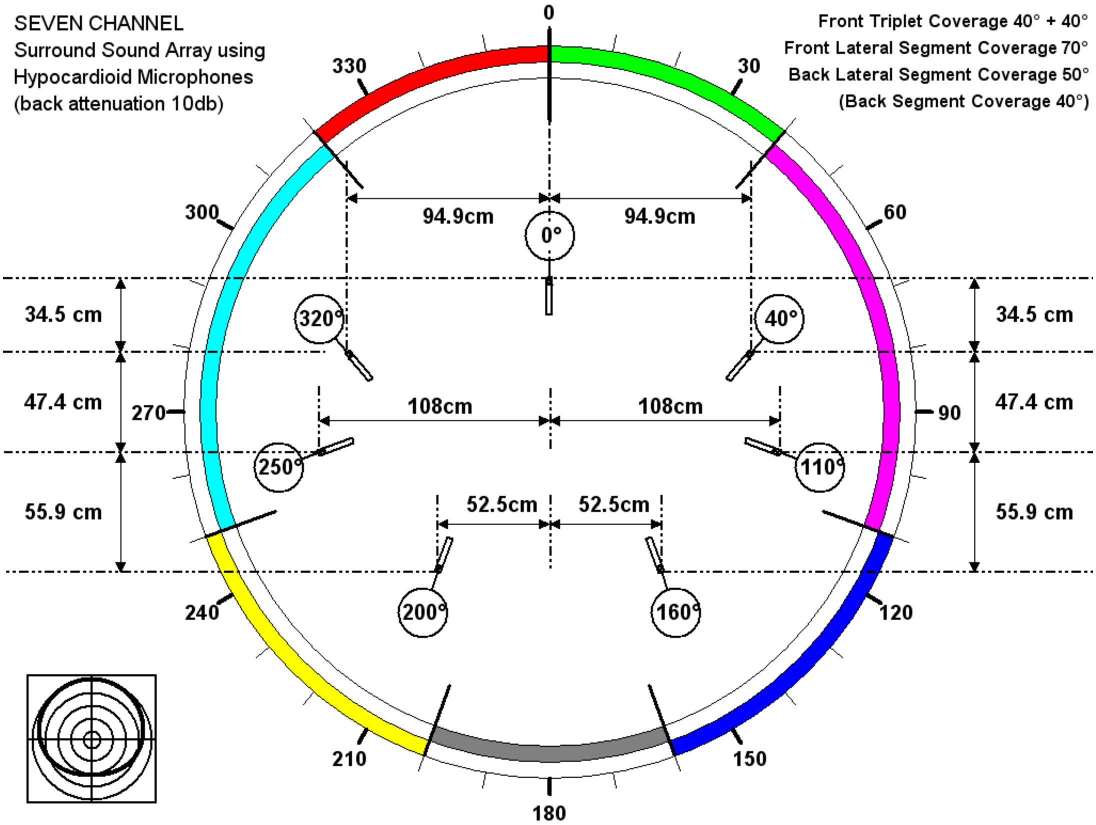

FIGURE 13 - HYPOCARDIOID 7.0 SURROUND SOUND ARRAY

The same procedure can be followed to setup a Cardioid 7.0 multichannel microphone array design by using the highlighted values in the table in Figure 9. The following Figure 14 is a back-to-back combination of Plan 16 (front facing array) and Plan 40 (facing to the rear) for Cardioid microphones.

Please note that the plan numbers may be the same as those selected for the Hypocardioid array - this is because each set of arrays for a specific directivity, contains arrays numbered from 1 to 5000. Cardioid Arrays will therefore be numbered from 1 to 5000, Supercardioid arrays will also be numbered from 1 to 5000, and the same applies to Hypocardioid arrays which are also numbered from 1 to 5000. It is therefore necessary not only to note the number of the array plan but also to check that it corresponds to the required directivity pattern. In this paper we will not be able to go into design procedure for hybrid arrays that use a combination of different directivity patterns.

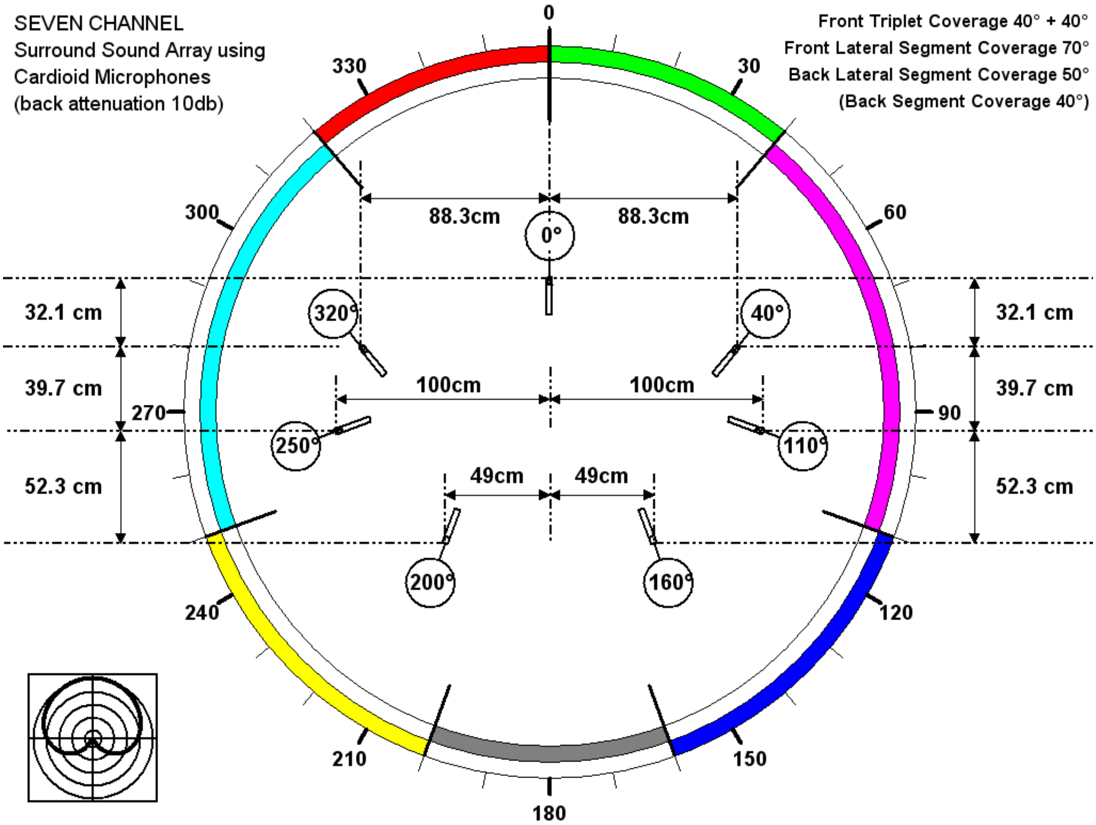

FIGURE 14 - CARDIOID 7.0 SURROUND SOUND ARRAY

2.3 Designing for Interformat Compatible Arrays

This paper should be read in conjunction with the paper on MAGIC Arrays presented at the 122nd AES Convention in Vienna[3]. Many different 5.0 multichannel designs were presented in this Vienna paper for different Front Coverage Angles and different 1st order directivity patterns.

The obvious illustration for a MAGIC Array for 8.0 multichannel design for Cardioid microphones is to use as a starting point the 5.0 compatible array design shown in Figure 15 with a Front Coverage of +/- 45°. The front coverage segments can be either treated as a stereo pair with the Left or Right microphone forming the pair, or considered as a triplet using the Centre, Left and Right microphones - the total coverage is equivalent.

If we apply the same technique to each of the four quadrants (front, left lateral, right lateral and back segment) then we obtain very simply an 8.0 multichannel array as shown in Figure 16 (this diagram is not to scale). All outer microphones are 174cm from the centre quad array, and all outer microphones are delayed by about 4mS with respect to the centre quad array.

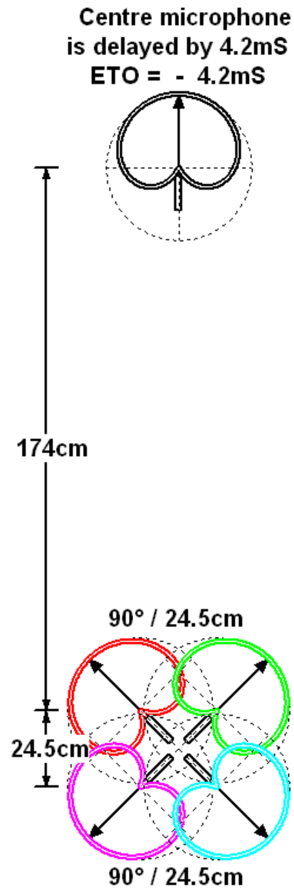

FIGURE 15 - CARDIOID 5.0 MAGIC ARRAY +/- 45° FRONT COVERAGE

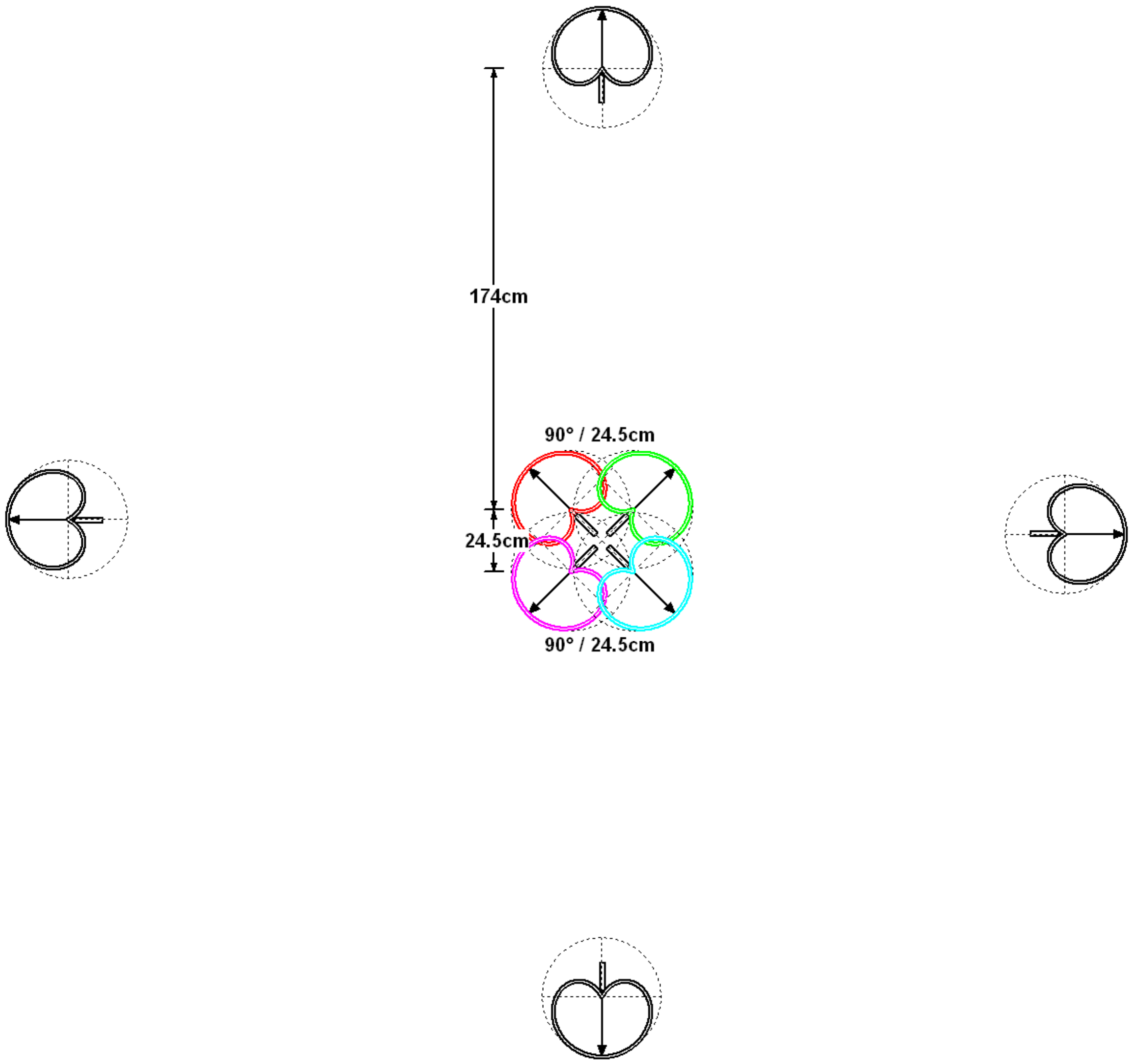

FIGURE 16 - AN 8.0 MULTICHANNEL CARDIOID MAGIC ARRAY

To adapt this eight channel array for compatibility with any lower order channel system, it is just a question of selecting the appropriate microphones for the specific channel configuration that is required, without any other alterations to the configurations. For a 7.0 channel system all that is necessary is to mute the back facing microphone. For a 6.0 channel system one would mute the Left Median and Right Median microphones. For a 5.0 channel system it only necessary to use the C, L, R, Ls and Rs microphones. A 4.0 channel system needs only the L, R, Ls and Rs microphones. Whereas a 3.0 channel system would use only the C, L, R microphones, and if required, Twisted Quad mixing could be added by folding in the Ls and Rs microphones to the R and L microphones. A stereo system will, of course, use just the primary L and R microphones with or without the addition of Twisted Quad mixing of the Ls and Rs microphones.

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.

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 with only the left/right directionality being inverted to right/left.

In everyday practical multichannel sound recording it is often necessary to be able to change the coverage angle of the front segments to increase or decrease their angular coverage. The following example of an experimental eight channel compatible hypocardioïd array is designed so as to have two different sets of coverage angles

- one set of 40° + 40° coverage at the front and back,

- the other set of 50° + 50° coverage on the sides.

If necessary the array may simply be turned through 90° to present a wider coverage angle to the frontal sound sources. Critical Linking is obtained with both ETO (Electronic Time Offset) of about 4mS and ELO (Electronic Level Offset - formerly called Electronic Intensity Offset) of about 2db applied to all the 'satellite' microphones with respect to the quad centre microphones. It may be necessary to alter these offset values for operational reasons to take into account the spacing of satellite microphones relative to the distance between the main microphone array system and the sound sources.

The centre 'quad' (L, R, Ls and Rs) has the following configuration:

L & R - 36cm / 100° with- 80° Coverage
Ls & Rs - 36cm / 100° with 80° Coverage
L & Ls - 31cm / 80° with 100° Coverage
R & Rs - 31cm / 80° with 100° Coverage

whilst the intermediary Centre microphone (C) is placed at 140cm from L & R pair - the Back (B) microphone is also at 140cm from the Ls & Rs microphone pair - the Left Medial (Lm) and Right Medial (Rm) microphones are placed at 100cm from the L & Ls and R & Rs pairs in the centre quad setup, as shown in Figure 17.

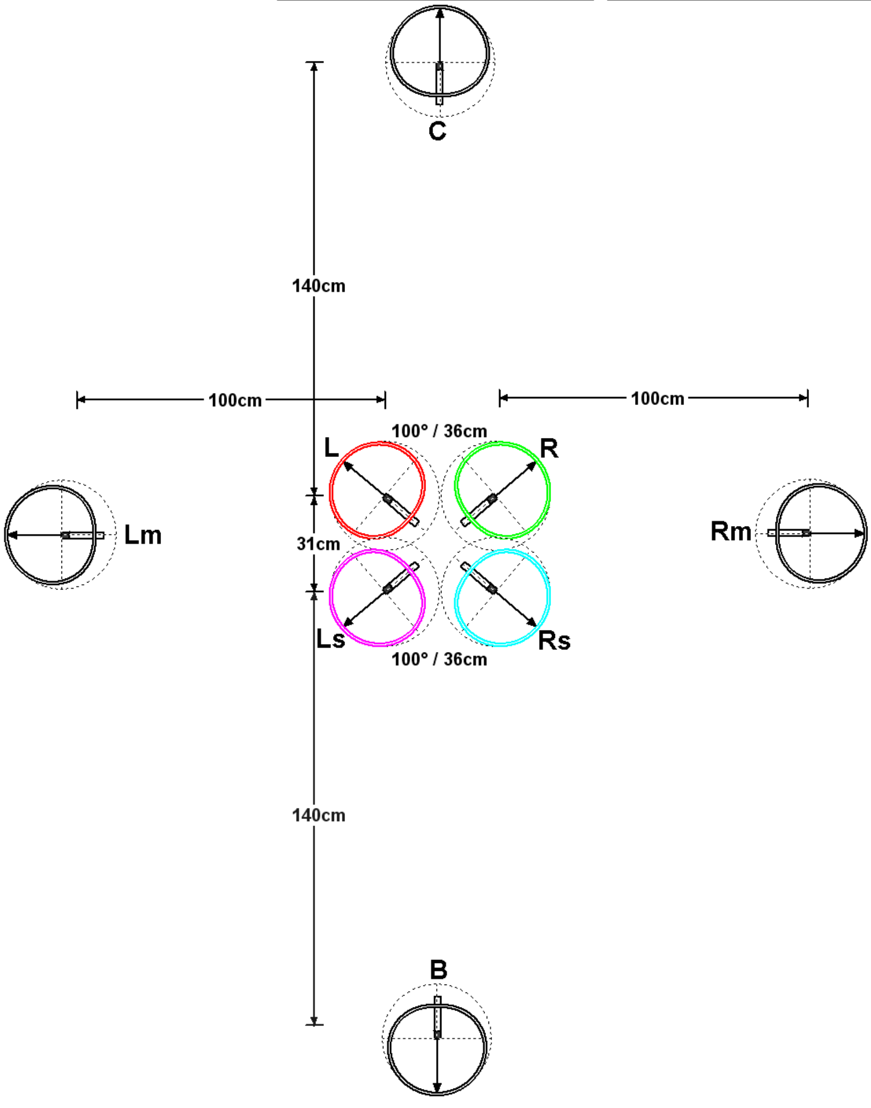

FIGURE 17 - EXPERIMENTAL 8.0 HYPOCARDIOID ASYMMETRICAL ARRAY

Acknowledgements
I would especially like to thank Umberto Nicolao for organising, at such very short notice, a special recording session in February 2008 in St Peter's Cathedral in Schio, Italy, and for contacting the musicians and singers who participated in this impromptu recording session. And of course many thanks to the musicians and singers who took part: Organist Simone Gheller, the 'Associazione Musicale Coenobium Vocale' (Gregorian Chant), the 'Schola Cantorum S.Cecilia in Schio. Dir. Luciana Silvestri', the Indian Classical Music Group 'Lila' from Verona and 'Piccoli cantori di Poleo. Director: Sabina Sacchetto'. and to Mons. A.Tessarollo for permission to use the Cathedral for the recordings and again at such short notice.

These recordings will probably be available in 5.0 DVD Audio format. Please contact:
mike@soundsscot.com

References
(1) 1991 - 91st AES Convention in New York, Preprint 3157 « Microphone Arrays for Natural Multiphony » by Michael Williams
(2) 2004 : 117th AES Convention in San Francisco : Preprint 6230 «Multichannel Sound Recording using 3,4 and 5 channel arrays for Front Sound Stage Coverage » by Michael Williams
(3) 2007 : 122nd AES Convention in Vienna - Preprint 7057 «MAGIC Arrays – Multichannel Microphone Array Design applied to Microphone Arrays Generating Interformat Compatibility» by Michael Williams