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The Whys and Wherefores of Microphone Array Crosstalk in Multichannel Microphone Array Design

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ABSTRACT

Each aspect of crosstalk has a different and definable influence on a specific segment of the multichannel microphone array system - the difference in the effect of cross-talk between coincident (or near-coincident) and spaced multichannel array systems – the crosstalk introduced by microphones adjacent to a specific segment – the crosstalk introduced by microphones on the opposing sides of an array – the effect of crosstalk in the transitory and quasi-steady state regions of a natural signal – crosstalk reduction in the quasi steady state. Microphone arrays must therefore be designed to minimize this interference with the final sound image, be it front sound stage coverage or surround sound coverage. This paper also includes a description of the Twisted Quad compatible multichannel/stereo recording array system.

1.   INTRODUCTION

The word crosstalk in the reproduction of a multichannel recording can be applied to a number of different sources of interference between channels. Electrical crosstalk between channels has for a long time been so small as to be negligible. However inter-aural acoustic crosstalk is by no means negligible but can be considered as being part of our natural perception of the loudspeaker reproduction process and an integral part of the psychoacoustics of the standard loudspeaker listening configuration.

On the other hand the crosstalk produced by microphones adjacent and/or opposite to a specific segment of a microphone array, can have a considerable effect on our perception of that segment of the array. This type of crosstalk, called Microphone Array Crosstalk (MAC), cannot be considered as a single overall effect on the reproduction characteristics of a multichannel microphone array - the consequences of cross-talk introduced by each microphone outside a specific segment of an array must be considered in each stage of the multichannel microphone array design process.

Some of these sources of crosstalk are interdependent but it is worth highlighting them individually, even though the array design process for crosstalk rejection may per force influence more than one design parameter.

Three basic criteria must be ever present in the decisions that are made during the process of Multichannel Microphone Array Design (MMAD):

- The nature of the sound source.
- The use of spaced arrays as against coincident or near coincident arrays
- Specific design techniques in MMAD to reduce crosstalk impact

1.1. The Nature of the Sound Source

The effect of MAC is influenced considerably by the nature of the sound source. The relation of the transitory content of a sound source in relation to the quasi steady state or long decay tail of the sound of a musical instrument is in itself a major factor in the quality of reproduction in both stereo and multichannel sound recording. The excellent localization of percussive musical instruments is a typical illustration of this characteristic using our present microphone array sound recording techniques, whereas the opposite situation can easily be demonstrated with a recording of hand bells – bells have a particularly long decay tail. Particular attention must however be paid during the design stage of an array to reduce the so called "comb filtering effect" produced by MAC during the long decay tail of some musical instruments.

1.2. Coincident versus Spaced Microphone Array Systems

It is necessary, in the first stage of design, to separate the consequences of cross-talk in coincident (or near coincident) arrays, as against the effect of cross-talk in spaced multichannel arrays. Spaced microphone arrays have a major advantage over coincident systems in that the precedence effect[1] will considerably reduce the consequences of cross-talk in a spaced microphone array, whereas coincident or near coincident systems can only rely on cross-talk rejection due to the directivity patterns of the microphones. Microphone directivity crosstalk rejection is however somewhat problematic in the lower frequency range as the directivity patterns are rarely valid at low frequencies. But this is perhaps a theoretical debate, as no completely coincident first order microphone array can be designed with even a modicum of critical linking for surround sound recording.

On the other hand it is debateable if the microphone directivity rejection technique is really necessary in spaced arrays due to the fact that crosstalk rejection due to the precedence effect is predominant. In the spaced microphone array, this precedence effect advantage applies mainly to the cross-talk that might be introduced by microphones on the opposite side to a specific segment of an array. In Figure 1 due to the precedence effect the right-surround-microphone (Rs) will have little interaction with the left front segment developed by the left(L) and central(C) microphones.

The same can be said for each segment pair in relation to the respective microphone on the opposite side of the array:

> Right Front Segment w.r.t. the Ls microphone
> Left Lateral Segment w.r.t. the R microphone
> Right Lateral Segment w.r.t. the L microphone
> Back Segment w.r.t. the C microphone

More research needs to be done on the threshold values of crosstalk interference with respect to microphone array design – is there indeed a specific threshold, or is there in fact a progressively increasing interference from the opposite microphone to a segment? Blauert[1] indicates that the threshold lies somewhere between 630μs and 1ms i.e. a minimum of about 20cm between the segment microphones and the microphone on the opposite side of the array - distances normally encountered in MMAD being usually greater than this value. This would seem to confirm the importance of the precedence effect in spaced MMAD for crosstalk rejection.
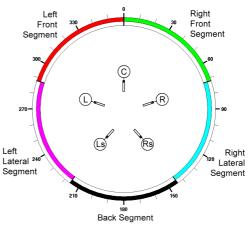

Figure 1 – Segment and Microphone Layout

1.3. Crosstalk due to Microphones in Adjacent Segments

In Figure 1 the microphones adjacent to the left-front-segment are the left-surround-microphone (Ls) and the right-front-microphone (R) and similarly for each segment and its respective adjacent microphones. The Ls and L microphones will cover an adjacent segment on the left of the left-front-segment, whereas the R and C microphones will cover an adjacent segment on the other side of the left front segment. Each specific segment will have potentially interference from each of the adjacent segments.

Adjacent microphones on each side of a specific coverage segment can produce three distinct situations:

- overlap between adjacent segment coverage
- criticallly linked segments
- 'underlap' or a coverage hole between segments

The three array configurations illustrated in Figures 2, 3 and 4 using small diaphragm hypocardioid microphones with a 10db back attenuation may be used for experimental verification of the reproduction of these coverage situations.
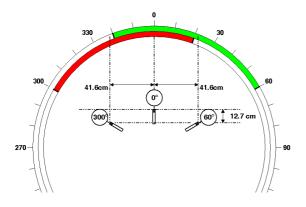
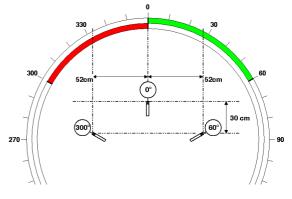Figure 2 – Overlap of Two Adjacent Segments

Figure 3 - Critical Linking
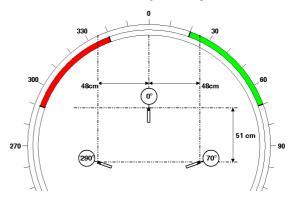between Two Adjacent Segments

Figure 4 – "Underlap" between
Two Adjacent Segments

1.3.1   Overlap

Overlap (Figure 2) can theoretically be described as coverage of the same part of the sound source by two separate but adjacent segments. This will NOT however produce a doubling of the vitual sound image simply because the listener's perception of this theoretical double information will in fact create a single virtual image - being our perception of the "sum" of the information from the two theoretical virtual images. The actual effect of overlap on the adjacent segments will be to produce "clustering" or "crushing" of the sound image around a single loudspeaker pole corresponding to the loudspeaker in the center of the overlap as shown in Figure 5.

This could also be considered as an asymmetrical increase in Angular Distortion of each of the adjacent segments within the overlap region.
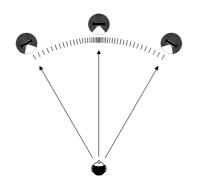
Figure 5 –Reproduction of Two Overlapping
Adjacent Segments

More research still needs to be done into the exact geometry of reproduction within this overlap region.

1.3.2.   Critical Linking

Critical Linking in a correctly designed array as shown in Figure 3 will eliminate completely any cross-talk between the adjacent segments. The two critically linked segments will reproduce as a perfectly smooth regular angular localisation from one segment to the other – the centre loudspeaker position being practically transparent as illustrated in Figure 6. In previous papers[2,3] the technique of Segment Steering using Microphone Position Offset or Electronic Offset to obtain Critical Linking was fully described.
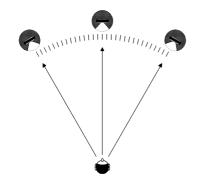

Figure 6 - Reproduction of Two Critically Linked
Adjacent Segments

1.2.2.   "Underlap"

Underlap is illustrated in Figure 4. This underlap or creation of a "coverage hole" does not mean that no

sound will be reproduced from sound sources within the underlap zone, but simply that the sound sources in this zone will be "condensed" onto the loudspeaker pole corresponding to the centre of the underlap in a left/right symmetrical array - being reproduced almost as a mono source as shown in Figure 7. This might also be considered as an extreme case of crushing onto the loudspeaker pole, however in this case no angular distortion of the adjacent segments is produced.

Figure 7 – Reproduction of Two "Underlapping"
Adjacent Segments

2.   CONCLUSION

Microphone Array Crosstalk can be reduced considerably by the use of spaced microphone arrays and optimum array design to produce critically linked segments, but the limiting factor to some extent will still be the nature of the sound source.
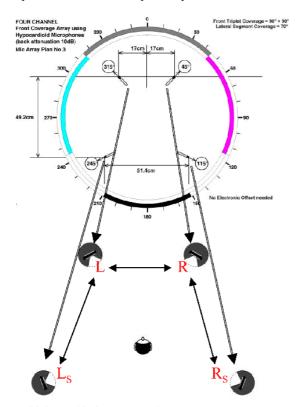
3.   REFERENCES

[1] 2001 «Spatial Hearing – The Psychophysics of Human Sound Localisation »
    by Jens Blauert - Sections 3.1.2. & 5.4
[2] 1999 - 107th AES Convention in New York - Preprint 4997 « Microphone Array Analysis for Multichannel Sound Recording »
    by Michael Williams and Guillaume Le Dû
[3] 2000 - 108th AES Convention in Paris - Preprint 5157 « Multichannel Microphone Array Design »
    by Michael Williams and Guillaume Le Dû
[4] 2004 - 117th AES Convention in San Francisco - Preprint 6230 « Multichannel Sound Recording using 3, 4 and 5 channel arrays for Front Sound Stage Coverage. using microphones with Omnidirectional, Hypocardioid, Cardioid or Supercardioid directivity » by Michael Williams

4. ANNEX - TWISTED QUAD RECORDING

Four and five channel arrays for front sound stage coverage were presented by the author in a paper[4] during the session on Multichannel Sound at the 117th AES Convention. A compatible multichannel/stereo microphone array recording process was also 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 8 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

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 9. 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.
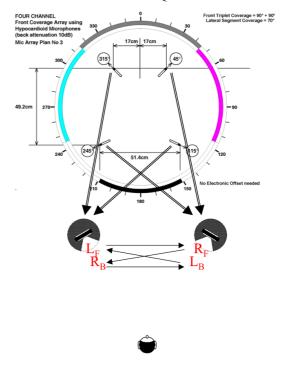

Figure 9 – A Twisted Quad Stereo Mixdown

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 10.

multichannel is just one such case.

Figure 8 – Normal Four Channel Recording Array and Reproduction Routing

Figure 10 – Stereo Reproduction Map

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.

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 the 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 Electronic Time Offset (ETO).

5. CONCLUSION

In multichannel reproduction the L, R, Rs and Ls are used to reproduce the corresponding microphones – the centre channel is usually either left vacant or possibly used for a central mono source. The front stereo pair can be used as the standard dual microphone stereo recording array. However if the right surround channel is mixed with the left front channel and the left surround is mixed with the right front channel a Twisted Quad recording array system is created.