Multichannel Microphone Array Design

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Abstract :

The design of a microphone array for multichannel sound recording involves the manipulation of many interrelated parameters : Segment Coverage, Electronic Time and Intensity Offset, Microphone Position Offset. This paper discusses the options available to the sound engineer in the choice of segment coverage by the Front Triplet and Back Pair, and how Critical Linking can be obtained in relation to the Lateral Segments. A basic design procedure is illustrated that will enable the sound recording engineer to design the microphone array needed for a specific reproduction configuration.

Introduction

The basic parameters of a Multichannel Microphone Array were presented at the 107th AES Convention in New York in a paper (2) entitled Microphone Array Analysis for Multichannel Sound Recording (preprint 4997). Parameters such as Segment Coverage, Electronic Time and Intensity Offset, Microphone Position Offset were defined, and their influence on the design of a microphone array was discussed. However the design of a specific microphone array to meet the needs of a particular sound recording environment was beyond the scope of this first paper. This present paper tries to meet to some extent the needs of an individual sound engineer to be able to design a microphone array taking into account the particular musical and acoustic environment for a specific recording.

Each stage in the design procedure is discussed :

- ***Front Triplet Coverage*** - The reproduction of this front sound stage is probably the most important stage in the design of a specific Multichannel Microphone Array (MMA) design. In general the direct sound from most sound sources encountered will be covered by this front triplet, however the configuration of the three microphones will also condition considerably the difficulties encountered in obtaining critical linking with the lateral and back segments.

- ***Back Pair Coverage*** – This is usually dependant on the musical sound source configuration. Is the sound source completely surrounding the microphone array or is the disposition more traditional? In the second case however, the coverage should be chosen in relation to the particular acoustic environment, the artistic choice of the sound engineer will also influence the type of envelopment that he considers necessary in the back reproduction segment.

- ***Lateral Segment Coverage*** is now a "fait accompli" - but we need all our skill in the use of different types of offset to obtain the desired Critical Linking with the other segments. The lateral segments also play an important role if the sound engineer is looking for wider sound stage reproduction than the tradition 60° frontal cone. This is a largely unexplored characteristic of multichannel systems, and needs careful experimentation before we can fully exploit it's potentialities.

Sound Perspective and the Use of Multichannel Sound Recording Systems

In the great majority of sound source situations, that we are usually called upon to record, the sound source occupies a limited sound stage in front of us, while the surrounding sound field is made up mostly of early reflections and reverberation. Although we are obviously interested in reproducing the total surround sound field as realistically as possible, due to the basic limitations of any microphone recording system in the reproduction of sound perspective, we must give priority to the reproduction of the main sound stage.

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 in order to obtain satisfactory reproduction of the sound perspective compared with perception by normal hearing of the actual sound source. The perception of distance is mainly a function of the ratio of direct to reverberant sound and therefore directly influenced by the directivity of the microphones used in the system (although some other factors may influence our perception of sound perspective). The realistic reproduction of early reflections and surrounding reverberation in a multichannel system does modify to some extent our perception of this direct to reverberant sound ratio with respect to monophonic or stereophonic reproduction. But as always the exact ratio is ultimately up to the appreciation of the sound recording engineer.

We must therefore choose the position of the microphone system so that it creates the most satisfactory impression of sound perspective. There are no absolute rules to obtaining a realistic impression of perspective - this first step in the positioning of the microphone system cannot therefore be based on simple acoustic or psychoacoustic data – it is part of the « art » of sound recording. The angle occupied by the sound source as "seen" by the microphone system will generally be much wider than the eventual angle of reproduction. This process has long been understood in the context of stereophonic sound recording, and it must be taken into account in a similar way when designing a microphone array recording system for multichannel reproduction. In this situation it means that each sound reproduction segment covered by a pair of loudspeakers will **not** reproduce exactly the same corresponding angle of the original sound field.

The advantage of multichannel surround sound reproduction 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 absolute limits to the main sound stage and be little better than the traditional stereophonic reproduction. However the front perception zone of reproduction 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.

A multichannel surround sound reproduction system is also capable of reproducing realistically the multitude of early reflections and the surrounding reverberation, which are mainly responsible for the feeling of « space » in a good recording. So great care must be taken in the positioning of the sound source and the microphone array, in relation to the acoustic environment, to exploit this effect to a maximum.

The approach is obviously different in the the case of a completely surrounding sound source, either where one needs to record the natural sound environment of, say, a forest, or in the case of a certain number of musical works written specifically with a view to creating a surround sound environment. The microphone system is then, by definition, placed in the middle of the surrounding sound source. In this type of situation the smooth reproduction of the sound field means that each sound reproduction segment covered by a pair of loudspeakers must correspond exactly to the same segment of the original sound field. But the realistic reproduction of sound perspective depends entirely on our ability to place each sound source at the required distance from the microphone system. This means unfortunately that we must accept as inevitable the distortion of perspective in the recording of the natural outdoor sound environments – fortunately the perception of the exact distance of this type of sound source is rarely critical.

Front Triplet Design

The choice of the Front Triplet Coverage Angle is determined basically by the position of the microphone system, and the angular width of the sound source as "seen" by the microphone array – much the same as with a two channel stereophonic microphone array. However we have a degree more liberty in the choice of the coverage angle than was the case in stereo. The coverage angle can either be **within** the angle occupied by the sound source, in which case it is the lateral segments that will reproduce the extremities of the sound source, or as with stereo, the coverage angle can be **greater** than the angle covered by the sound source - the reproduction of the direct sound from the source then being within the two front segments.

The limit case in which the coverage angle is equal to the sound source angle is of course also possible but does not suffer from that claustrophobic impression often given in stereophonic recordings when not enough attention has been paid to producing a certain quantity of « side-room ». Side-room can be considered as the "space" left in between the extremities of the reproded main sound stage and the limits to the possible stereophonic image created by the position of the loudspeakers. This is very similar to the headroom that is necessary for good balance in a picture.

The abrupt limit to the sound field of stereophonic reproduction is not perceived in a multichannel reproduction system due to the continuation of sound field reproduction, obtained on condition that the lateral segments are Critically Linked to the Front Triplet Coverage. The « side-room » in a multichannel system is no longer necessary as we have all the room that we need !

We have therefore three choices possible for the the Front Coverage Angle :

a) **Front Coverage Angle > Angle of the Sound Source** – in which case the sound source will be reproduced within the sound stage generated by the front three loudspeakers
b) **Front Coverage Angle = Angle of the Sound Source** – in this case the sound source will fill the whole of the front sound stage
c) **Front Coverage Angle < Angle of the Sound Source** – in this case we will need the lateral segments to continue the reproduction of the sound source in the left and right lateral segments, generated by the left front & left back loudspeakers, and right front & right back loudspeakers respectively.

Once we have determined which choice to make for the Front Coverage Angle and knowing the position of the microphone system we will be able to consider the actual combinations of distance and angle between the microphones that we need to adopt.

We will consider two specific examples of Coverage Angle.
Table 1 : where the Front Triplet has a total **Coverage Angle of 120°.** This means that both the Left Front Pair and the Right Front Pair must cover an angle of 60° each
Table 2 : where the Front Triplet has a total **Coverage Angle of 110°.** This means that both the Left Front Pair and the Right Front Pair must cover an angle of 50° each.

Table 1

It would seem to be a good design precaution in this first stage to choose a system where the angle between the microphones is as near as possible equal to the Coverage Angle of each segment. From Table 1 (Front Triplet Coverage Angle of 120°) we can see that there is only one combination that satisfies this condition :

Column 1 - 2nd Set - **60° / 53 cm** – offset 0°

i.e. 60° angle between the axes of directivity of the microphones and 53 cms distance between the centre of the diaphagm of each of the microphones. With this system we will not need any offset as the coverage angle is the same as the angle between the microphones. However in order to show the various solutions to Critical Linking that are possible where Offset is necessary, we will also consider two other possibilities where the angle between the microphones is both greater than, and, less than the Coverage Angle. The following two combinations will be considered :
One where the angle between the microphones is less than the Coverage Angle

Column 1 - 1st Set - **50° / 56cms** - Offset +5°

The other where the Angle between the Microphones is greater than the Coverage Angle

Column 1 - 3rd Set - **70° / 50.5 cms** – Offset -5°

Table 2

In the calculation of Table 2 (Front Triplet Coverage Angle of 110°), although it was possible to find a combination of Distance/Angle so that the angle between the microphones was equal to the desired Coverage Angle (55° / 60 cms), once Critical Linking in the centre of the Front Triplet was produced with Microphone Position Time Offset, it was found impossible to obtain Critical Linking with the remaining segments (the lateral and back segments). The same situation was found to be the case for other combinations of distance and angle between the microphones such as : 65° / 57.5 cms and 80° / 63.5 cms. Here the Coverage angle is certainly 110°; but no satisfactory solutions for Critical Linking were found. This problem is due simply to the fact that the Intensity/ Time Difference function is far from being linear, and that in this type of situation, no intersection is obtained between the psychoacoustic limits and the physical characteristics of the systems considered. This can be seen clearly in the paper presented at the 107th AES Convention (2) and also in a previous paper on stereo systems presented in 1987 (1).

However a few solutions were obtained for the following combination : **75° / 55 cms**

This illustrates clearly that not all combinations of distance and angle for the front and back coverage find satisfactory solutions for critical linking with the lateral segments. In many cases Critical Linking of the Lateral Segments depends on the type of offset that is considered acceptable. If only Time Offset is considered acceptable, then the number of solutions is relatively limited, however if some intensity difference offset is possible between the front and back microphone systems then there are considerably more possibilities. But for the time being we will limit the number of examples chosen to only those shown in Table 1 & 2 and only the effects of Electronic Time Offset will be considered.

In both Table 1 & 2, the second column gives the amount of Offset necessary to obtain Critical Linking in the centre of the Front Triplet. Microphone Position Time Offset (MPTO) is the most practical solution to Critical Linking, but Electronic Time Offset (ETO) is also a satisfactory solution. Electronic Intensity Offset (EIO) obviously influences the energy distribution function in the the reproduction of the front sound stage, but in the opinion of many sound engineers this can in certain circumstances be used to produce good results. It is obviously a factor that must be chosen according to each particular recording situation. Also it must not be forgotten that we can also use combinations of two or three different types of offset if desired.

Back Pair Design

In this case we simply have a back facing stereo pair, where the coverage angle can be determined from the standard Stereophonic Recording Angle Diagrams (1). We have chosen for the sake of illustration a Coverage Angle of 100° giving rise to a whole range of combinations of distance and angle, a few of which have been shown in column 3 of each table :

0° / 50 cms ; 10° / 44 cms ; 20° / 39.5 cms ;
30° / 36 cms ; 40° / 33 cms ; 50° / 30.5 cms

Lateral Segment Design

Columns 3 & 4 in each table show both the distance needed between the Front Triplet and Back Pair to obtain the necessary Coverage Angle for the Side Segments, and the Electronic Offset needed to obtain Critical Linking with the Front and Back Segments. The distance between the Front Triplet Microphone System and the Back Pair must be chosen so that the Lateral Coverage Angle corresponds to the remaining Coverage Angle for the lateral segements.

However the distance and angle between the microphones forming the Back Pair obviously introduce a certain quantity of Microphone Postition Offset (MPTO) between the Front Microphone System and the Back Pair. The Offset applied to the Lateral Pairs must both compensate this Microphone Position Offset and introduce additional Offset to obtain Critical Linking of the Lateral Segments with the Coverage of the front and back microphone systems. It is interesting to note that although the distance between the front and back microphone systems varies somewhat, there is a remarkable consistancy in the amount of offset that is needed to obtain critical linking of the lateral segments for each of the back pair configurations considered.

For the sake of illustration we have chosen to apply only Electronic Time Offset to obtain Critical Linking. However Electronic **Intensity** Offset can also be used if we wish to vary the energy distribution between the front and the back of the system – either to increase reverberation and early reflections or to attenuate them. Again this is an operational adjustment which must be used in accordance with each particular recording environment.

Conclusion - Total Design Flexibility

If the sound recording engineer feels that he has a clear understanding of the different types of offset and their influence on the position of the coverage angle of each segment, he should not hesitate to experiment with different types and values of offset when other system configurations are needed, using as a starting point the systems described in this paper.

Although at the beginning of this research into Multichannel Microphone Array Design it was hoped to produce a series of diagrams and tables to assist the sound engineer in designing his own microphone array to suit any recording environment, it has proved much too long and combersome to present all these diagrams and thereby link ail the interacting parameters into a complet graphical design procedure. The authors have therefore decided that the best solution is to develope some specific design software.

The first development version of this software has been used to produce figures 2 to 22 for this paper and will also be used during it's presentation. It is hoped that this software will be available to the public soon after presentation of this paper. A simplified algorithm of this software is shown in Figure 1.

References :

(1) 1987 ; 82nd AES Convention in London – Preprint 2466 (H6) - Unified Theory of Microphone Systems for Stereophonic Sound Recording » by Michael Williams

(2) 1999 : 107th AES Convention in New York :
Preprint 4997 - Microphone Array Analysis for Multichannel Sound Recording by Michael Williams and Guillaume Le Dû

Table 1
** - All coordinates are measured relative to the centre microphone position*

FRONT TRIPLET Coverage 120° [60° (L) & 60° (R)]		BACK PAIR Coverage 100° [50° (L) & 50° (R)]	SIDE PAIR Coverage 70° [70° (L) & 70° (R)]	
Angle and Distance	Offset **MPTO**	Angle / Distance	"Y"coords Back Pair	ETO
50° and 56 cms	**Offset +5°** MPTO +7°	0° / 50 cms (figure 2)	54.5 cms	0.78 mS
		10° / 44 cms (figure 3)	55.5 cms	0.80 mS
		20° / 39.5 cms (figure 4)	56.0 cms	0.80 mS
		30° / 36 cms (figure 5)	57.0 cms	0.80 mS
		40° / 33 cms (figure 6)	58.5 cms	0.80 mS
		50° / 30.5 cms (figure 7)	59.5 cms	0.80 mS
60° and 53 cms	**Offset 0°**	0° / 50 cms (figure 8)	55.0 cms	0.80 mS
		10° / 44 cms (figure 9)	55.0 cms	0.80 mS
		20° / 39.5 cms (figure 10)	56.0 cms	0.81 mS
		30° / 36 cms (figure 11)	56.5 cms	0.81 mS
		40° / 33 cms (figure 12)	57.5 cms	0.81 mS
		50° / 30.5 cms (figure 13)	59.0 cms	0.80 mS
70° and 50.5 cms	**Offset -5°** MPTO -7°	0° / 50 cms (figure 14)	55.0 cms	0.80 mS
		10° / 44 cms (figure 15)	55.5 cms	0.81 mS
		20° / 39.5 cms (figure 16)	56.0 cms	0.81 mS
		30° / 36 cms (figure 17)	57.5 cms	0.82 mS
		40° / 33 cms (figure 18)	58.0 cms	0.81 mS
		50° / 30.5 cms (figure 19)	59.0 cms	0.80 mS

Table 2

FRONT TRIPLET Coverage 110° [50° (L) & 50° (R)]		BACK PAIR Coverage 100° [50° (L) & 50° (R)]	SIDE PAIR Coverage 75° [75° (L) & 75° (R)]	
Angle (b) and Distance (d)	Offset MPTO	Angle (b) and Distance (d)	"Y"coords of Back Pair	ETO
75° and 55 cms	**Offset -10°** MPTO -13°	0° / 50 cms (figure 20)	53.0 cms	1.01 mS
		10° / 44 cms (figure 21)	53.0 cms	1.01 mS
		20° / 39.5 cms (figure 22)	54.0 cms	1.02 mS
		30° / 36 cms	No Solutions	
		40° / 33 cms		
		50° / 30.5 cms		

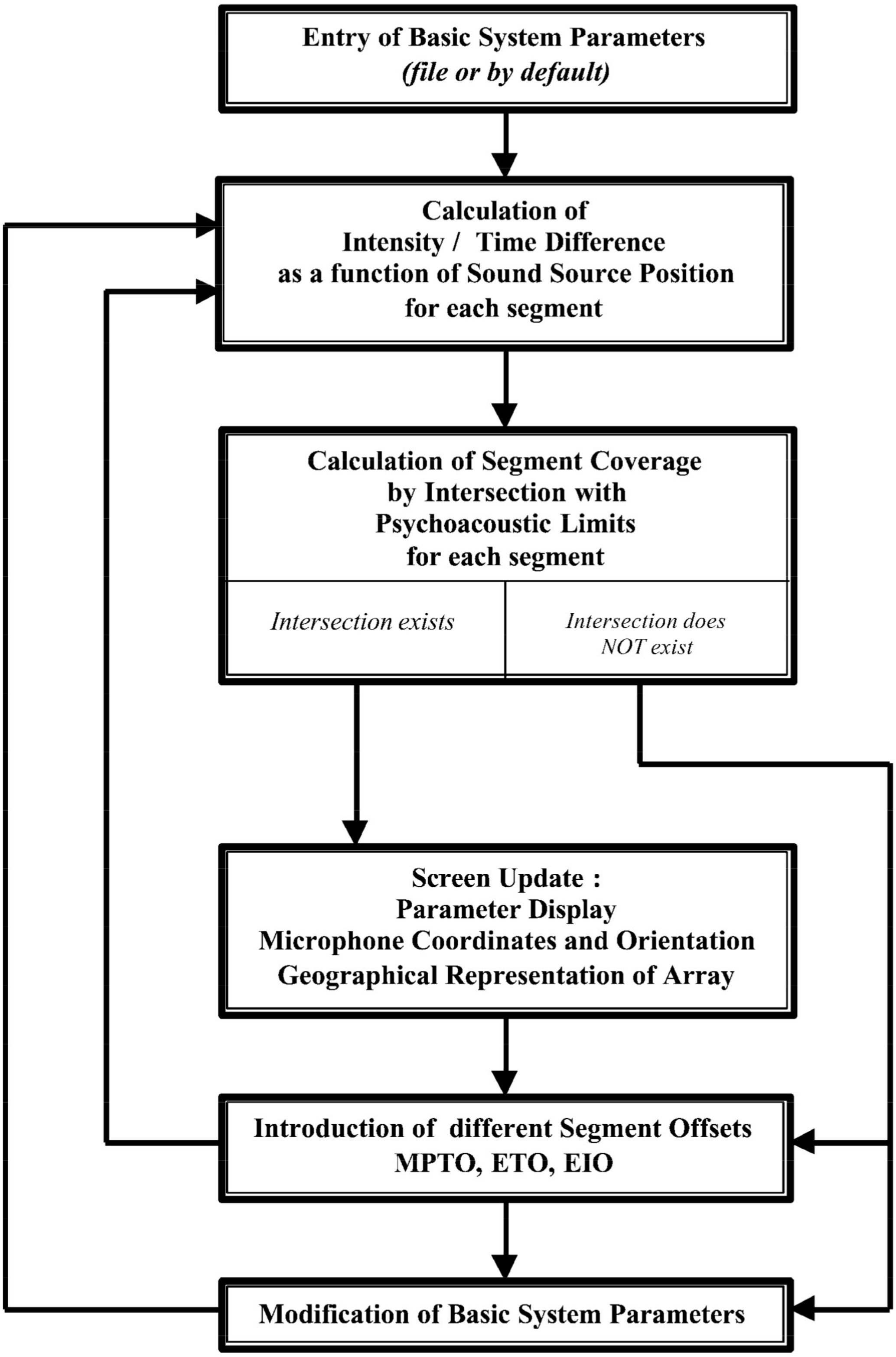


Figure 1 : Simplified Algorithm of the Multichannel Microphone Array Design Software

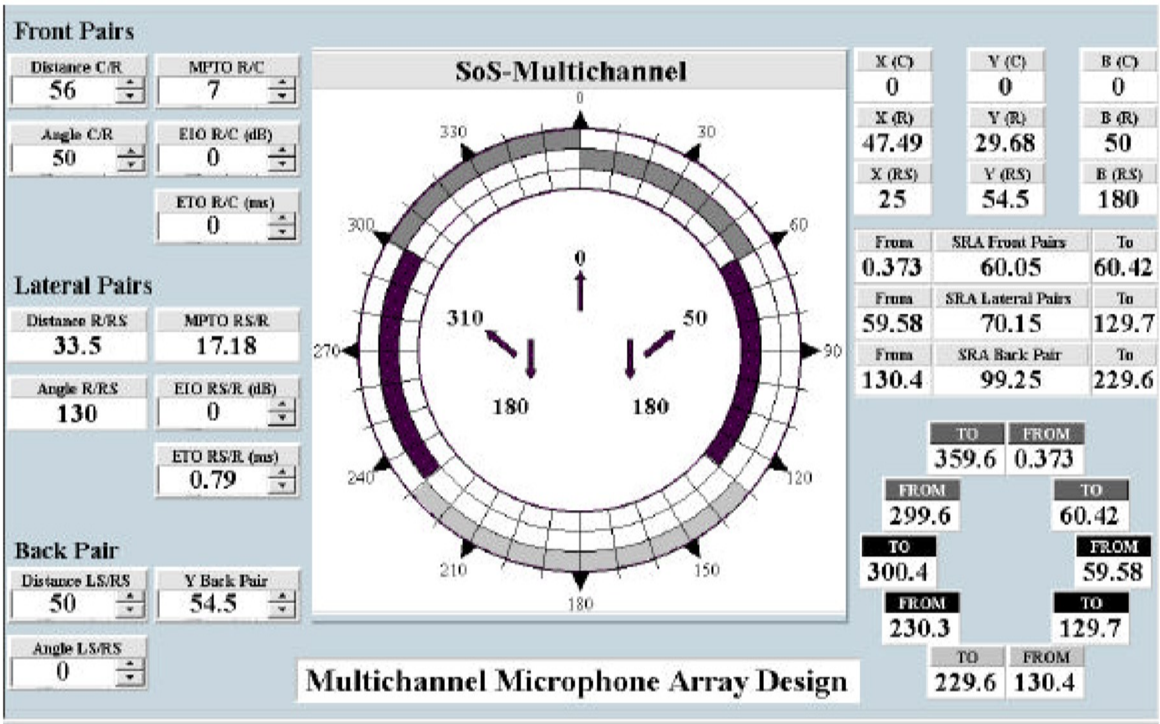
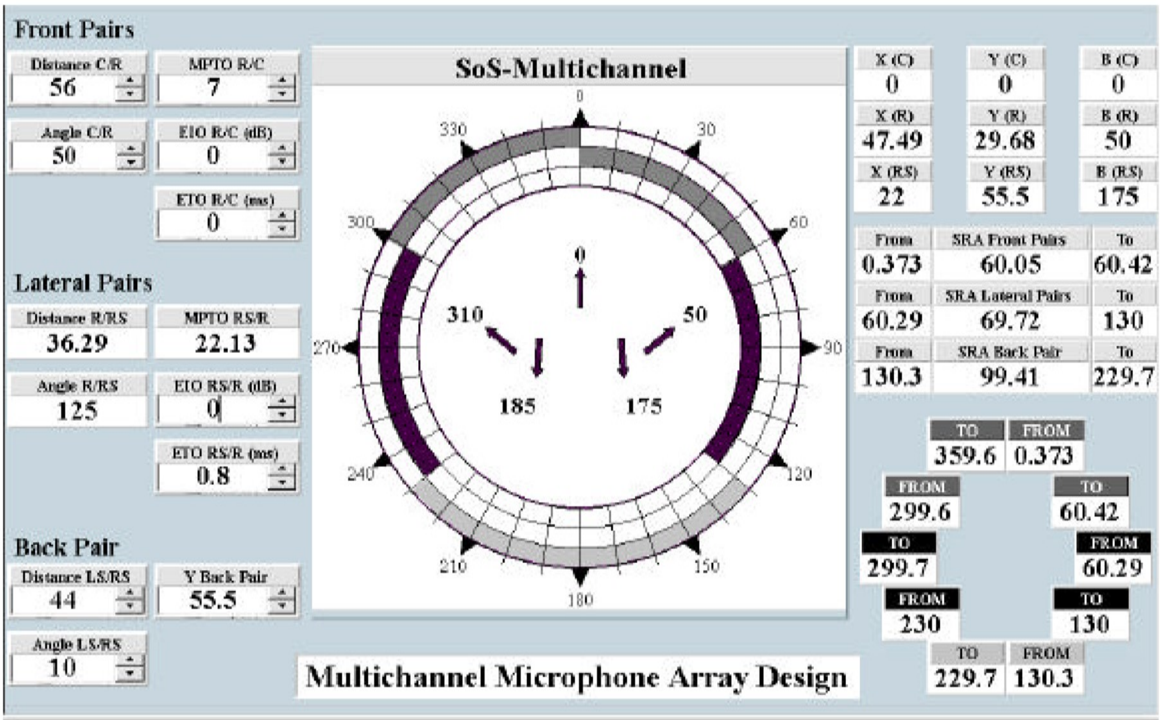


Figure 2



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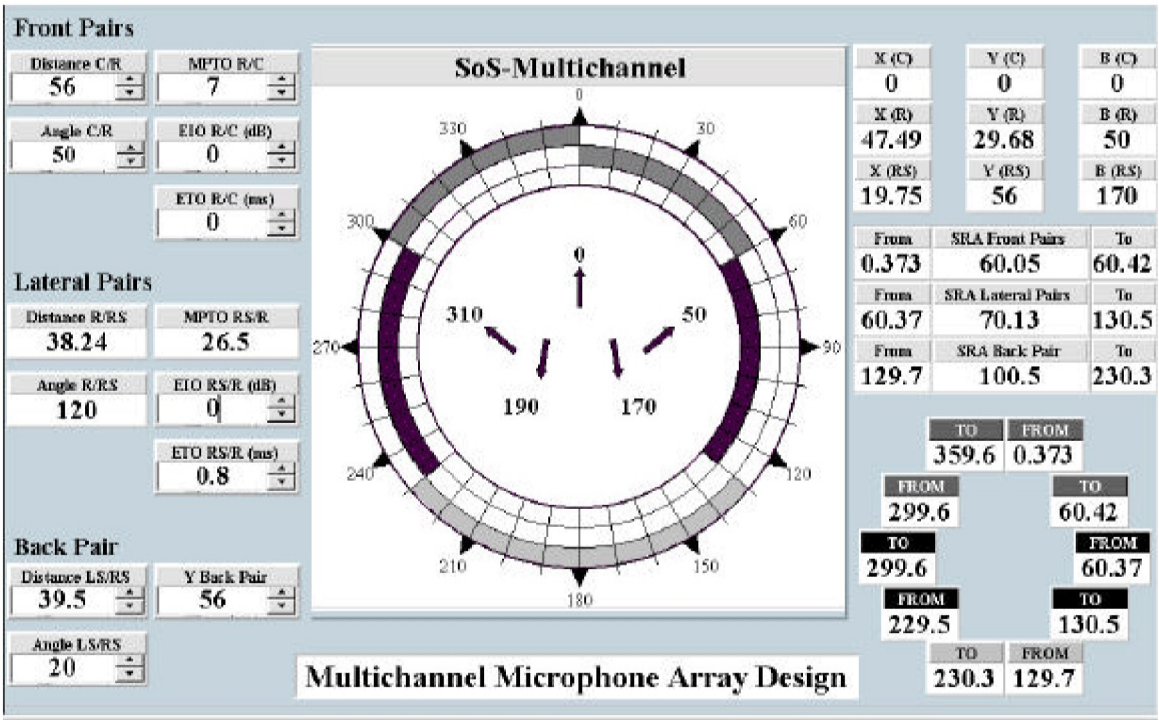

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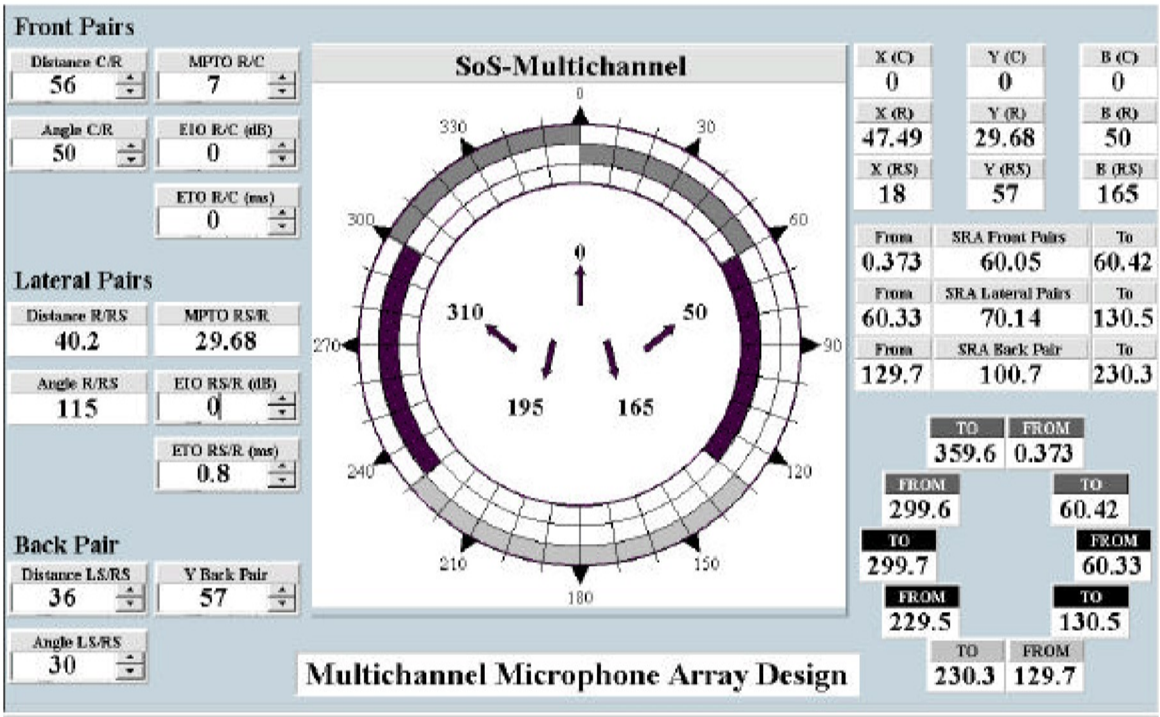

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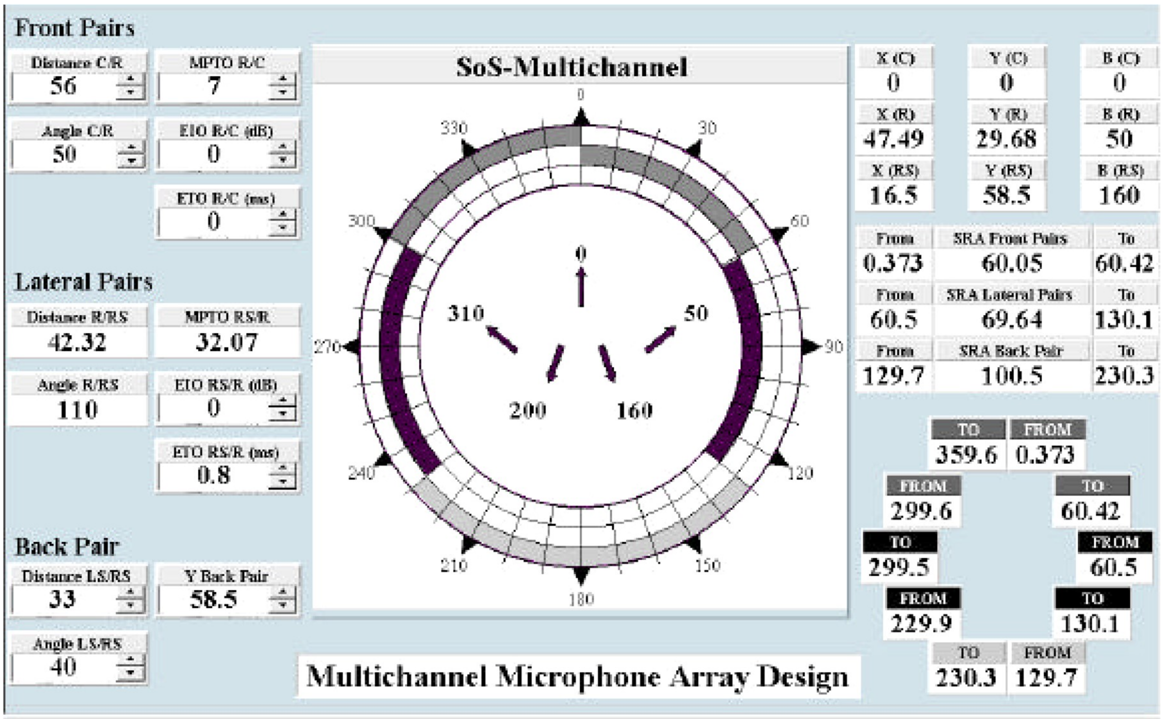

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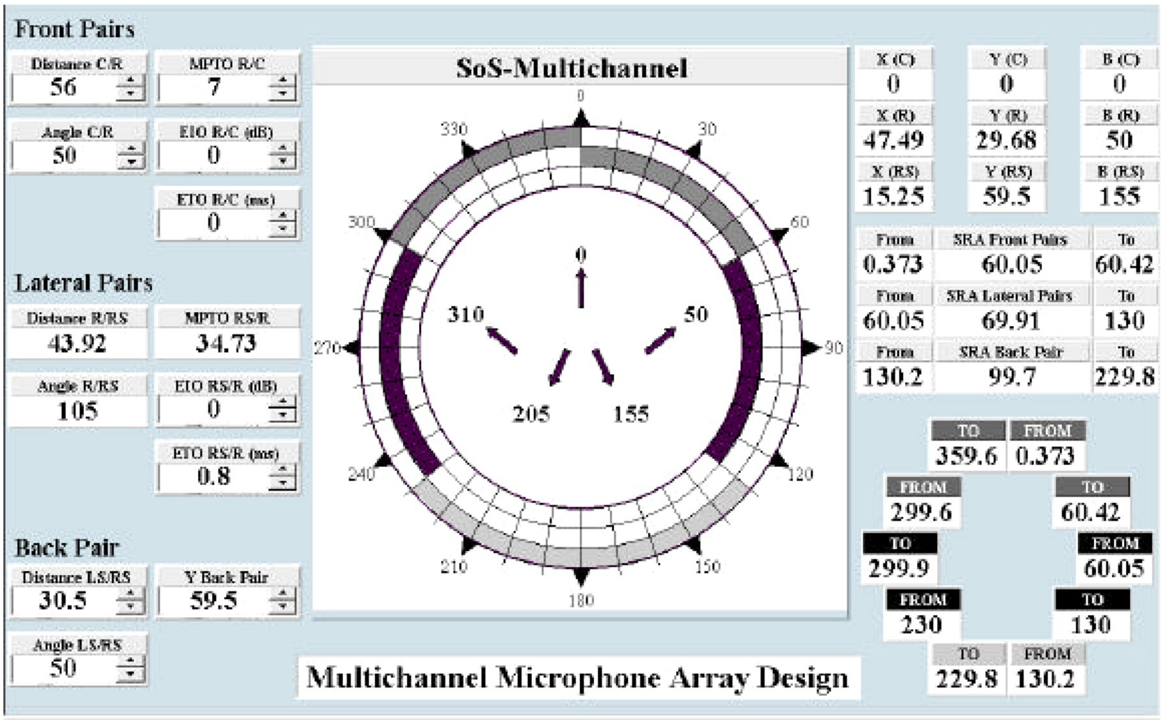


Figure 7

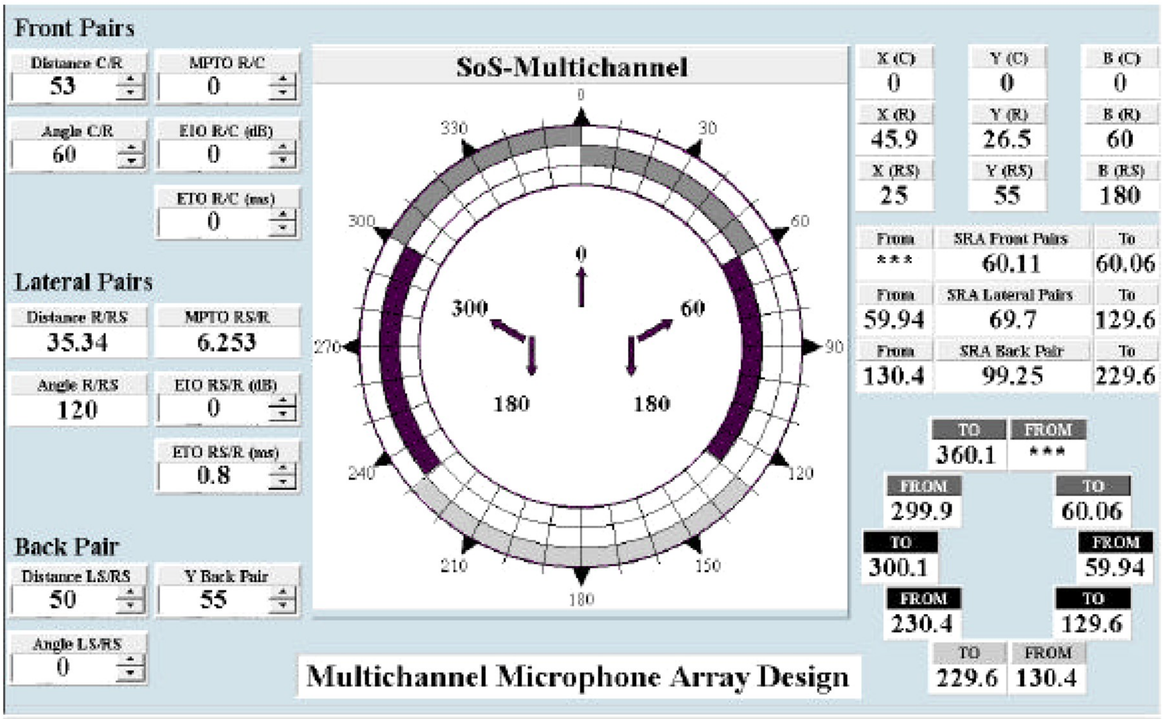


Figure 8

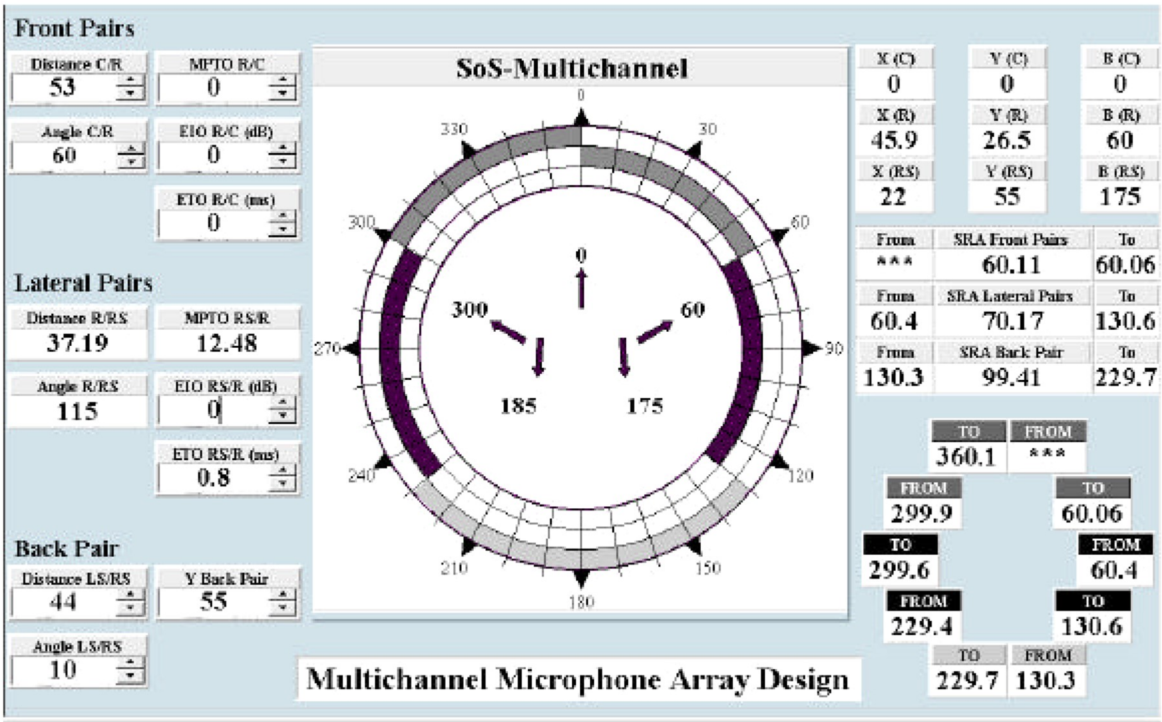


Figure 9

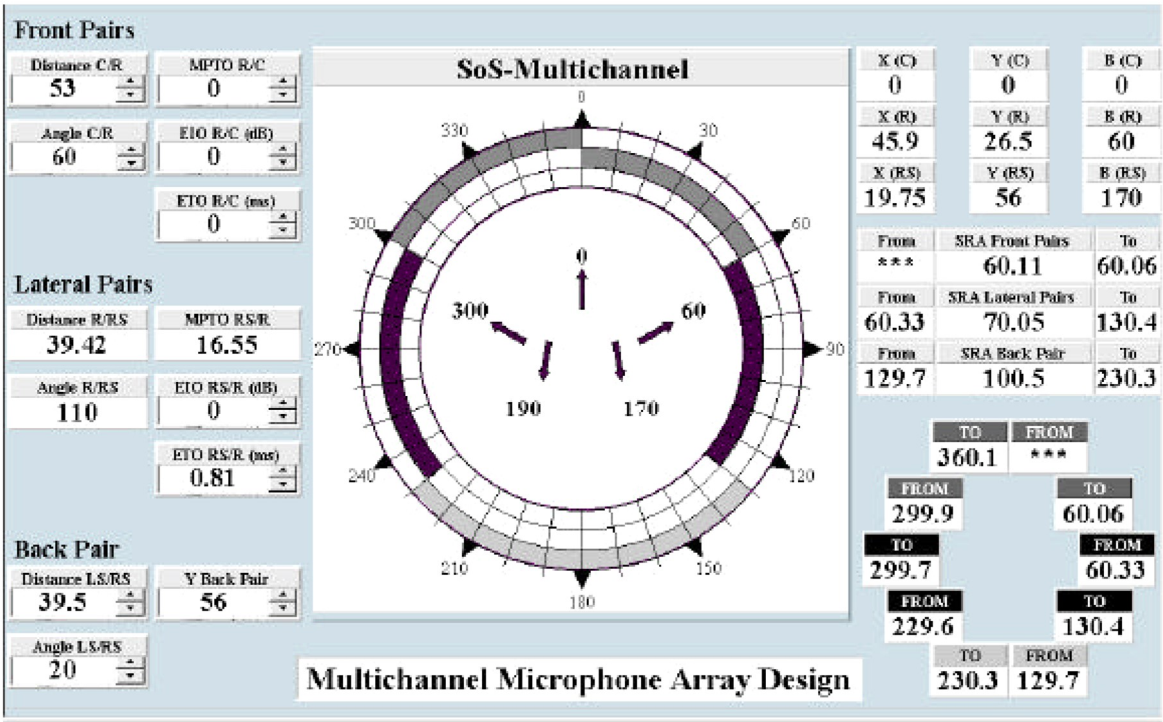


Figure 10

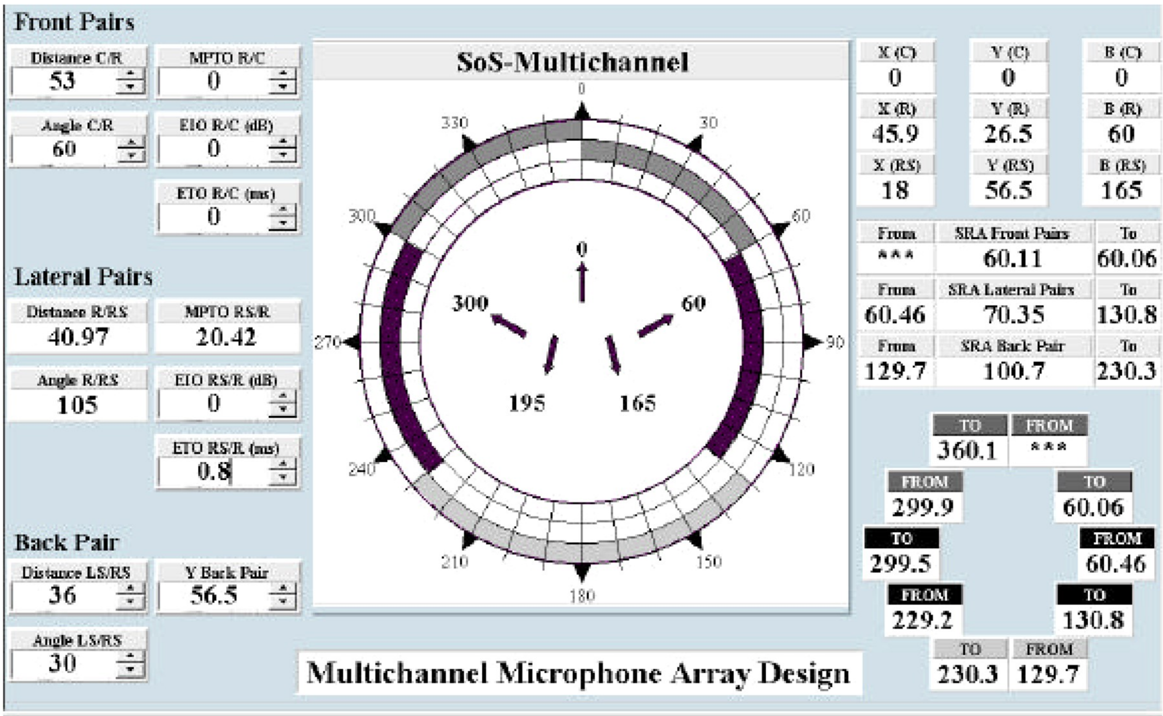
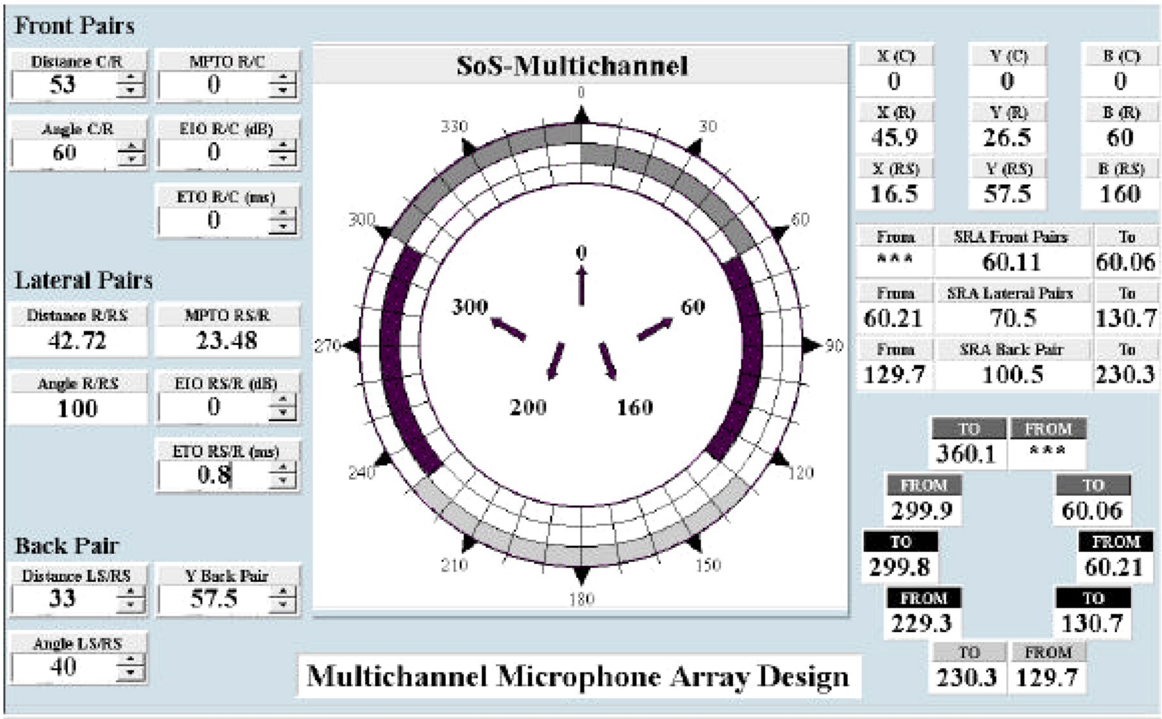


Figure 11



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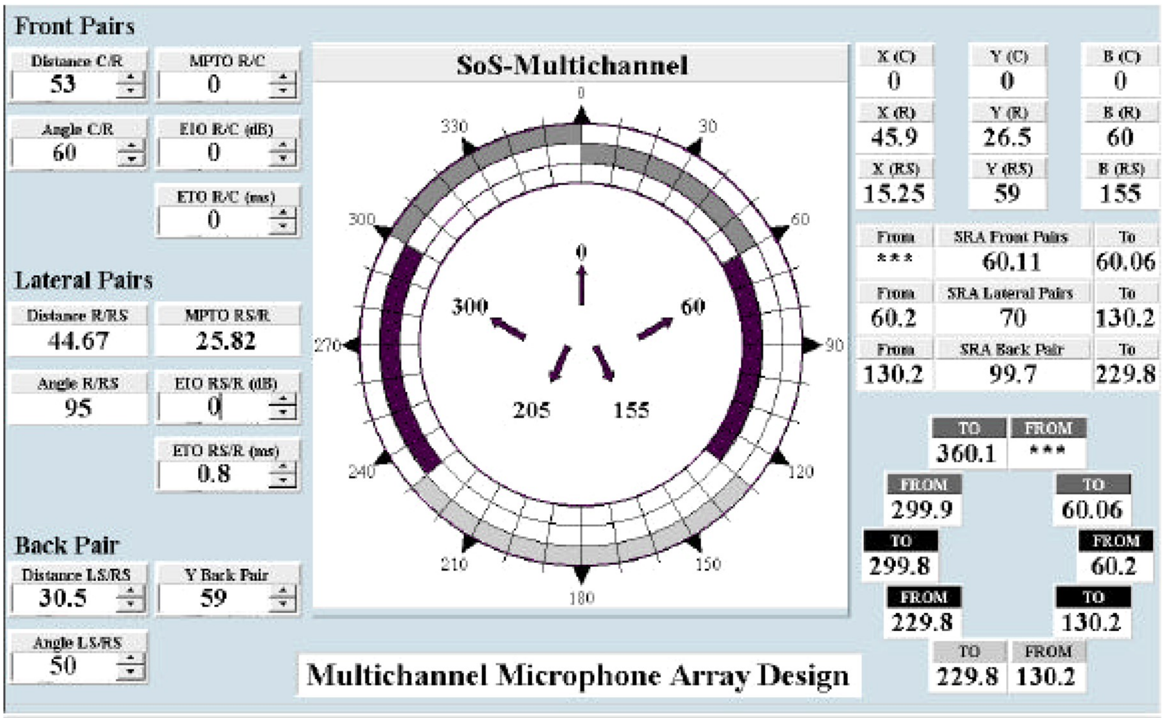

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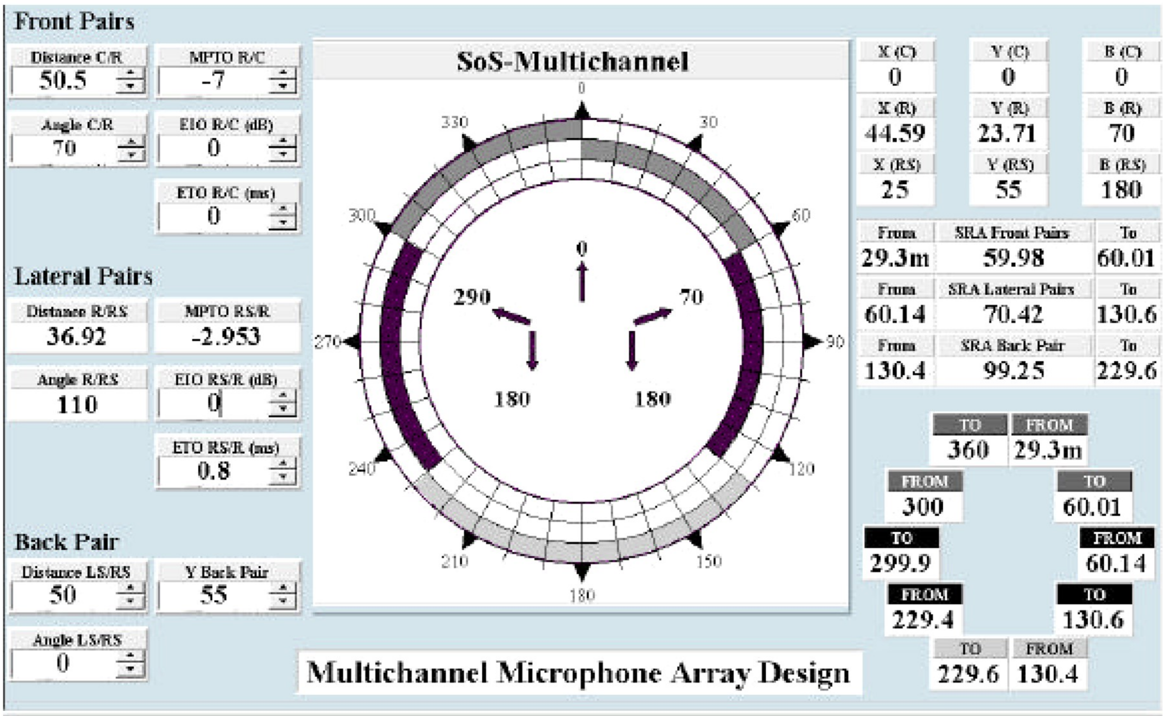
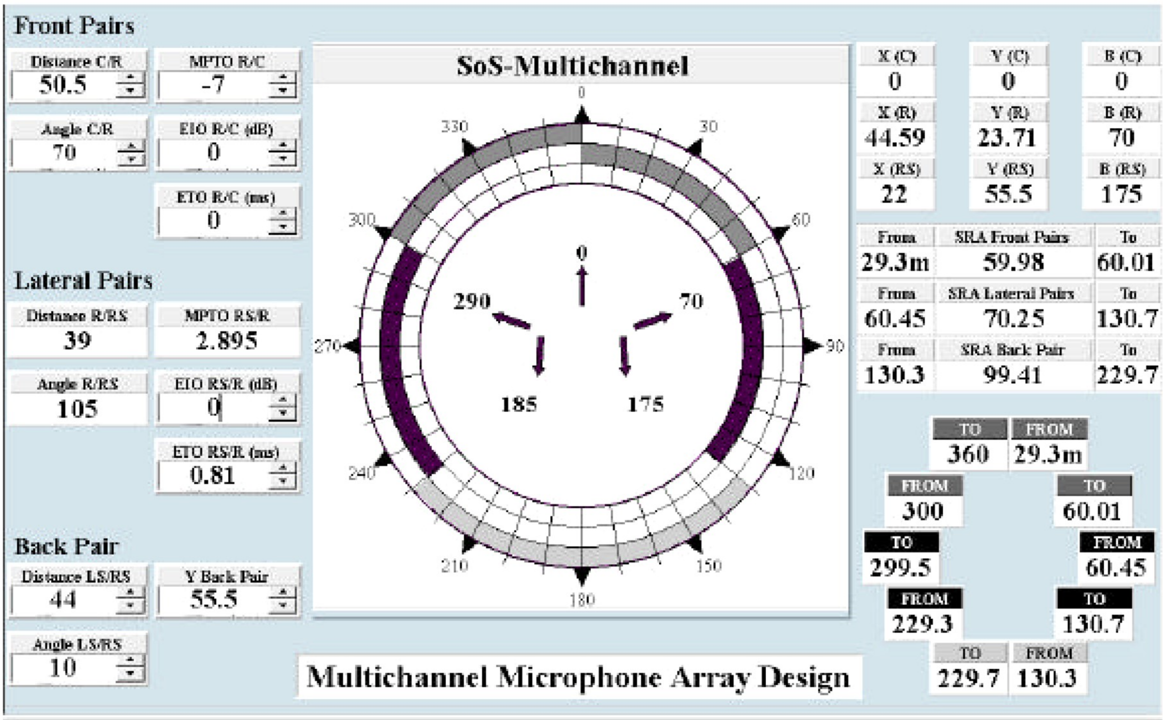


Figure 14



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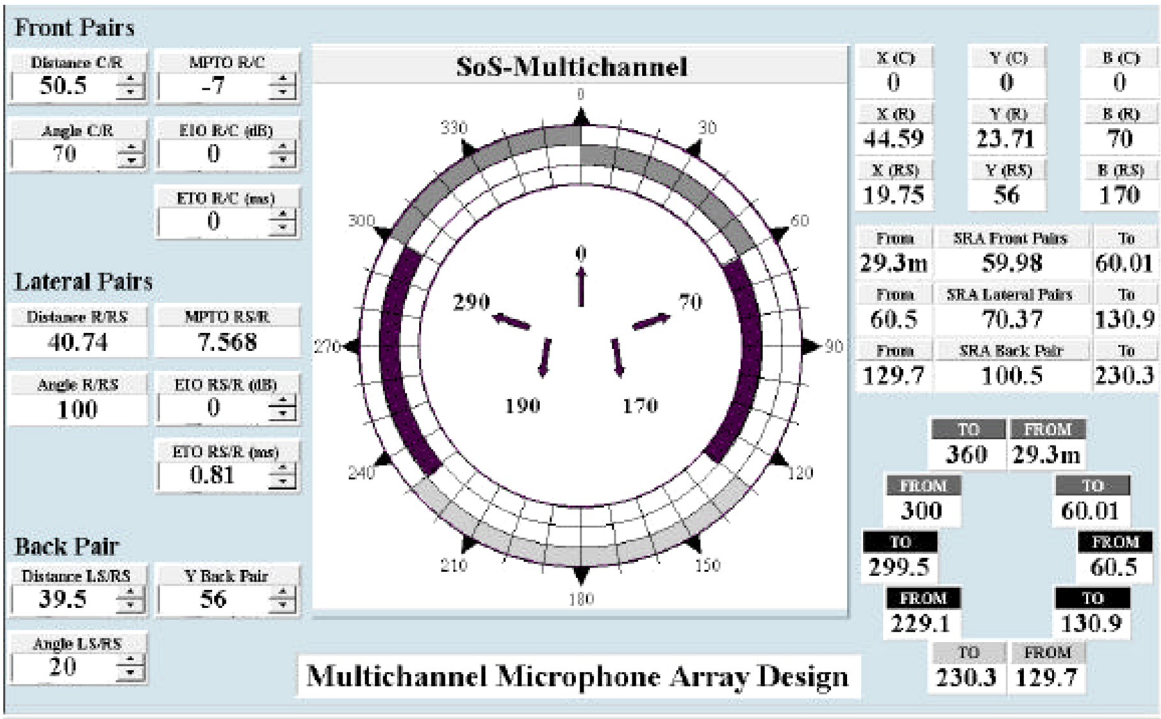
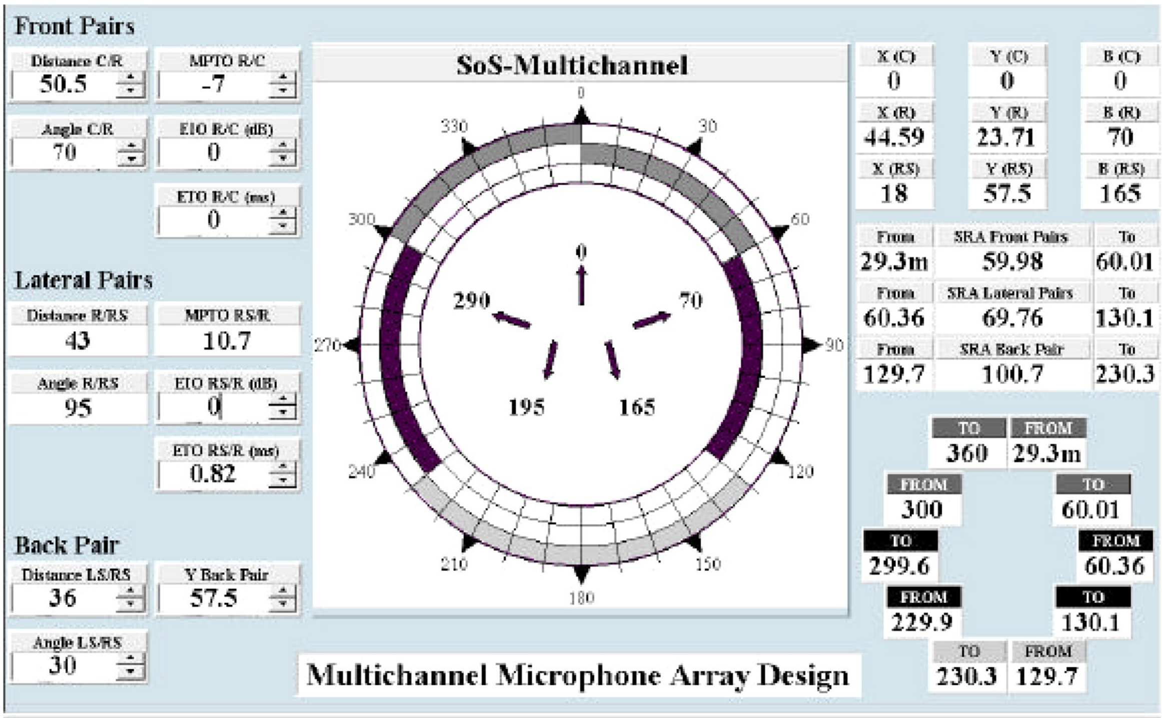


Figure 16



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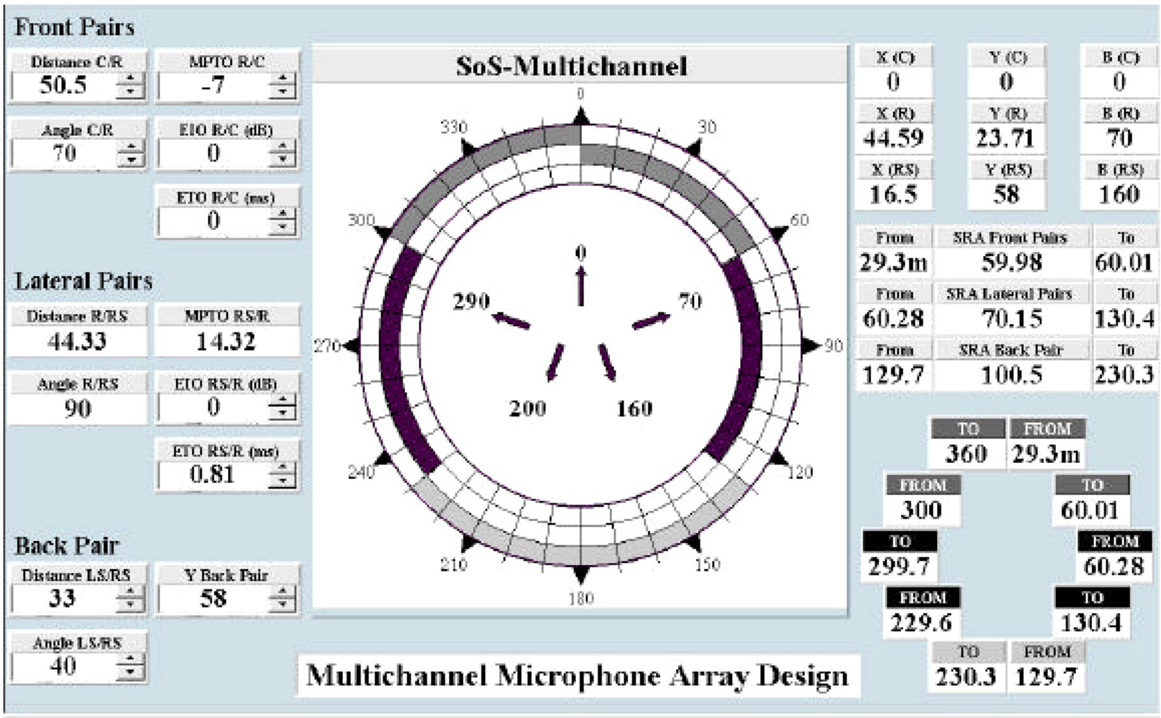
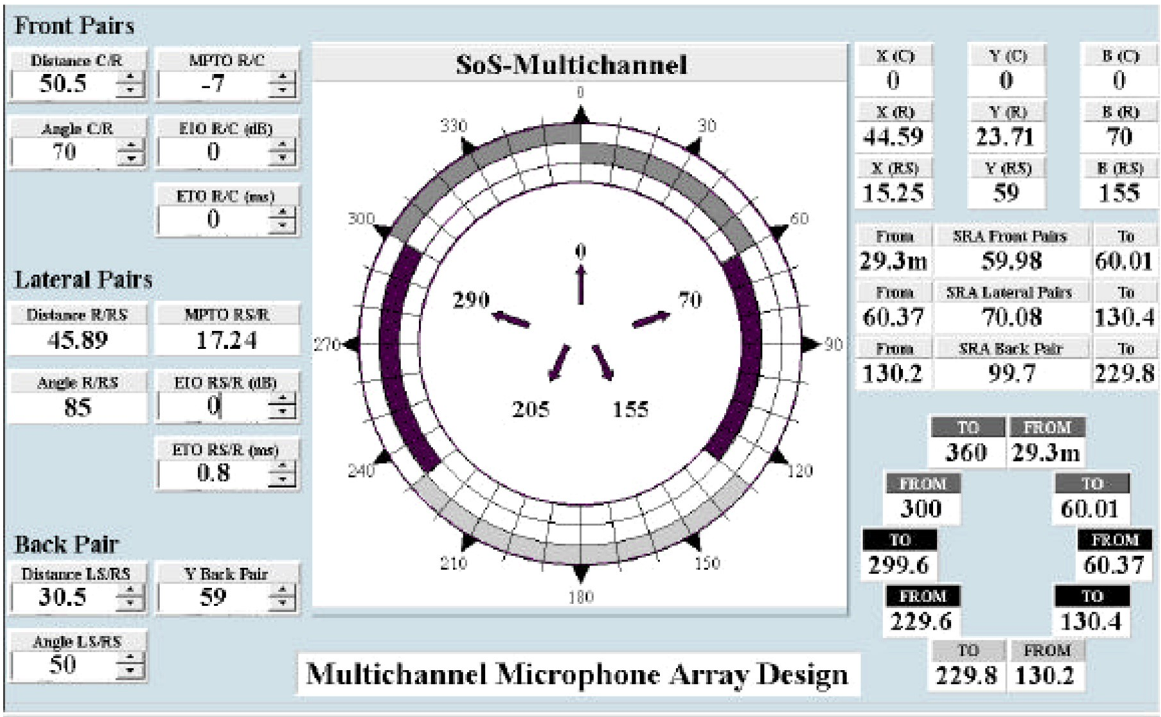


Figue 18



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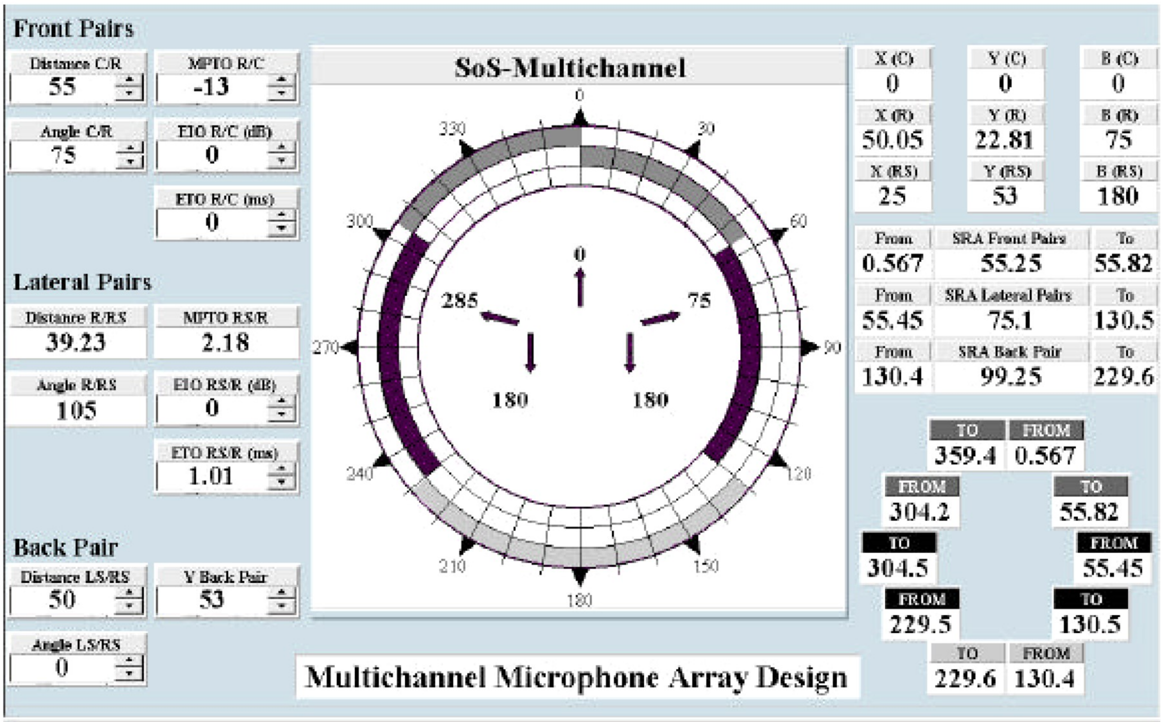

Figure 20

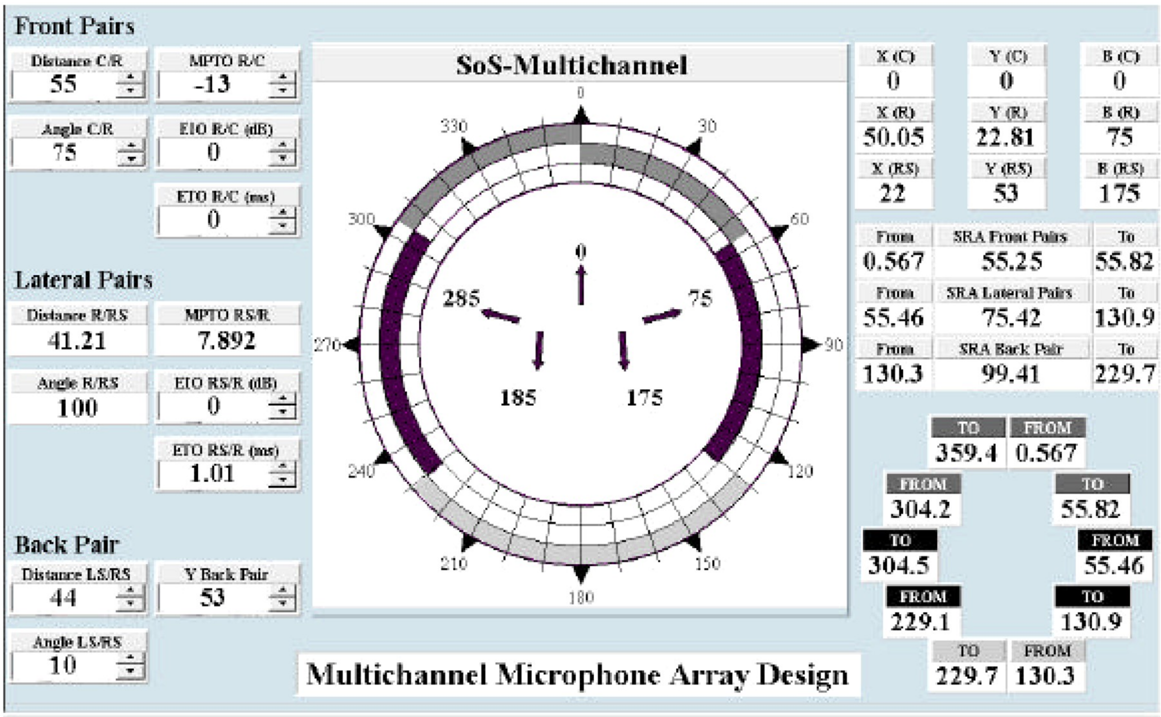

Figure 21

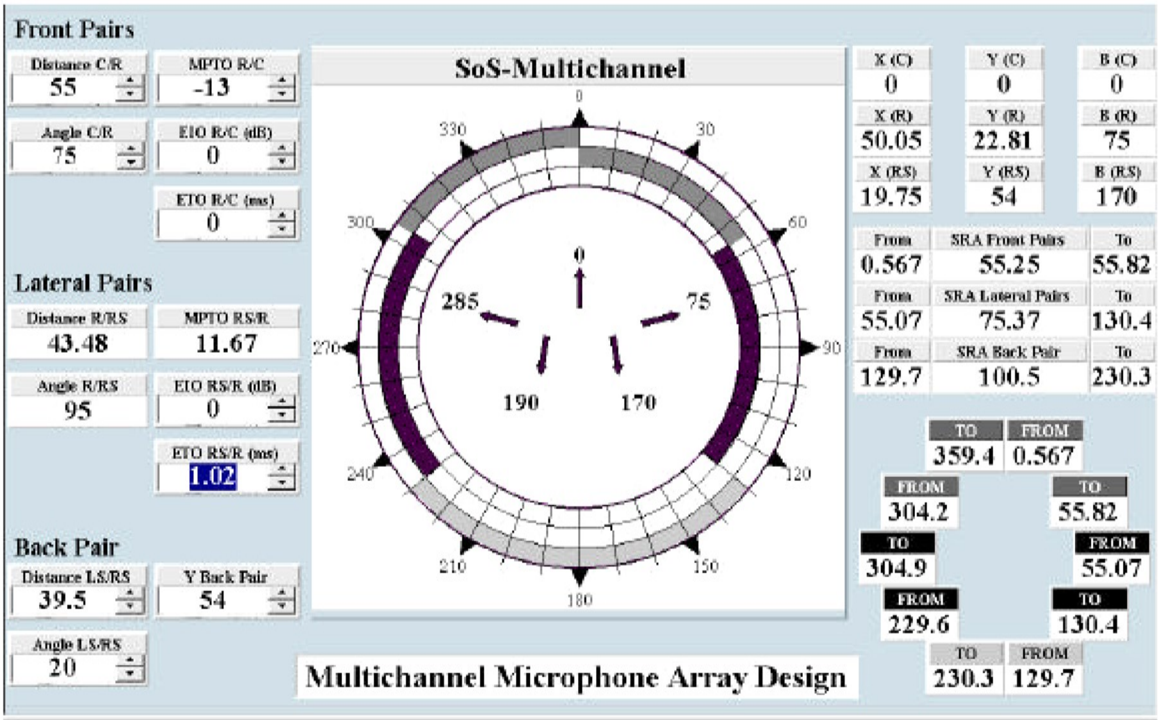
Front Pairs
Distance C/R
55
MPTO R/C
-13
Angle C/R
75
EIO R/C (dB)
0
ETO R/C (ms)
0
Lateral Pairs
Distance R/RS
43.48
MPTO RS/R
11.67
Angle R/RS
95
EIO RS/R (dB)
0
ETO RS/R (ms)
1.02
Back Pair
Distance LS/RS
39.5
Y Back Pair
54
Angle LS/RS
20
SoS-Multichannel
0
30
60
90
120
150
180
210
240
270
300
330
0
75
170
190
285
X (C)
0
Y (C)
0
B (C)
0
X (R)
50.05
Y (R)
22.81
B (R)
75
X (RS)
19.75
Y (RS)
54
B (RS)
170
From
0.567
SRA Front Pairs
55.25
To
55.82
From
55.07
SRA Lateral Pairs
75.37
To
130.4
From
129.7
SRA Back Pair
100.5
To
230.3
TO
359.4
FROM
0.567
FROM
304.2
TO
55.82
TO
304.9
FROM
55.07
FROM
229.6
TO
130.4
TO
230.3
FROM
129.7
Multichannel Microphone Array Design

Figure 22