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# XY AND MS MICROPHONE TECHNIQUES IN COMPARISON

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## 0. ABSTRACT

XY and MS microphone techniques can be considered theoretically equivalent, ie: both signal formats can be transformed into each other, assuming ideal microphone characteristics. In practice, however, specific differences may arise between the two systems. The theoretical relationships will be derived with regard to first order directional microphones, and the individual properties of both techniques will be described in detail. Furthermore, it will be shown that the MS technique is less prone to the imperfections of real microphones than the XY technique.

## 1. INTRODUCTION

Both XY and MS techniques use coincident microphones, ie: two microphones are mounted closely together to prevent time delay effects almost totally. At ideal conditions pure intensity stereo signals result which can be summed to mono without comb-filter effects. The unrestricted mono compatibility is a significant feature of coincident stereo techniques.

The XY technique uses two identical directional microphones. In relation to the recording axis, they are arranged at equal and opposite offset angles. The leftward pointing X microphone supplies the L signal directly, and the rightward pointing Y microphone the R signal. The stereophonic properties depend on the directional characteristics of the microphones and the offset angle.

The MS technique uses a rectangularly mounted pair of microphones. The M microphone is aimed at the centre of the performance area and may feature any kind of directivity, including the omnidirectional characteristic. This microphone supplies the monophonic signal directly. The S microphone is always a pure pressure-gradient receiver with a bi-directional (figure-of-eight) characteristic, the positive side of which points to the left (90 degrees offset angle).
The M and S signals must be converted to L and R signals by means of a sum-and-difference matrix (L=M+S, R=M-S). The stereophonic properties depend on the directional characteristic of the M microphone and the relative S level applied.

## 2. XY-MS EQUIVALENCE

Standard microphones exhibit directional characteristics of the first order which can be generally considered a superimposition of omnidirectional and bi-directional characteristics with differing amounts. The extremes of pure omnidirectional and bi-directional characteristics are performed by pure pressure and pressure-gradient receivers, respectively, while all other directional characteristics arise if the microphones respond partly to the pressure and partly to the pressure-gradient of the sound field.

Fig.1 shows the most widely used directional characteristics and the associated omnidirectional and bi-directional components:-

a) omnidirectional
b) wide-angle cardioid (1/3 bi-directional, 2/3 omnidirectional)
c) cardioid (1/2 each)
d) super-cardioid (2/3 bi-directional, 1/3 omnidirectional)
e) bi-directional

The super-cardioid and the bi-directional patterns show a back lobe with reversed signal polarity. Super-cardioid and wide-angle cardioid provide a backward attenuation of 9.5 dB.

Based on the superimposition principle, Fig.2 presents a graphical derivation of the XY-MS conversion. By way of example Fig.2a shows an XY system with two cardioid microphones. The cardioid characteristics can be substituted by the associated omnidirectional and bi-directional components as shown in Fig.2b. Thus identical omnidirectional components result besides bi-directional components of equal amount which are oriented in the X and Y directions. The bi-directional components may be split down further into components oriented forwards and sideways as shown in Fig.2c. The forward oriented components are identical, while the lateral components are equal-sized but opposed. These lateral components represent the actual difference between the X and Y signals. They are responsible for the stereo effect and form the S or side signal. The remaining signal components are common to both, X and Y signals and form the M or mono signal.
Fig.2d shows the resulting directional patterns of the M and S signals. Evidently, the M and S signals can be derived directly from the XY signals by a sum-and-difference formation. As this signal transformation is also reversable, a basic equivalence of the XY and the MS techniques for first order directional microphones results.

The diagrams shown in Fig.3 permit the graphical determination of the equivalent MS parameters. The M directivity can be evaluated from the upper graph, and the associated relative S level from the lower graph.
For example, an XY system with two cardioids at offset angles of 60 degrees (120 degrees included angle) is equivalent to an MS system with a wide-angle cardioid. The level of the S microphone has to be reduced by 4.8 dB relative to the M microphone. If the sensitivities of the M and S microphones are different, a suitable correction has to be applied. Of course, the diagram can also be used in the opposite manner to evaluate the XY parameters for a given

MS arrangement.

Generally, the resulting mono directivity is wider than the directivities of the X and Y microphones. This is due to the loss of the bi-directional S component in the formation of the mono signal. The widening of the mono directivity is virtually negligible for small offset angles up to 45 degrees but becomes rather significant at larger offset angles. At 90 degrees offset angle (back-to-back configuration) the resulting mono directivity is omnidirectional in any case.

In principle, a continuous variety of directional microphones is necessary to set up all kinds of equivalent XY and MS configurations. In practice, however, the possibilities in both systems are limited, as normally only microphones with few fixed directional characteristics are available. Therefore, the properties of XY and MS systems will now be discussed based on a selection of directional characteristics according to Fig.1.

## 3. XY AND MS CONFIGURATIONS WITH STANDARD DIRECTIVITIES

One fundamental property specific to a microphone system is the recording angle which defines the angle between the centre axis (symmetry axis of the system) and the direction where the level differences between the L and R signals are at a maximum. The recording angle defines the angular range of sound incidence where regular stereophonic reproduction is obtained. In most cases there is another opening for rearward sound reception besides the recording angle for frontal sound pick-up.

Another important aspect concerns the relationship between the sound incidence angle and the stereophonic reproduction angle. As both, XY and MS recording techniques supply pure intensity cues, a relationship published by H. Mertens [1] can be applied which relates the reproduction angle to a level difference of the L and R signals for the standard listening configuration based on an equilateral triangle (Fig.4). This relationship is shown in Fig.5 and is valid at frequencies between 330 and 7800 Hz within +/- 3 degrees. The level difference is plotted at the horizontal axis and the reproduction angle can be read from the vertical scale. 0 degree reproduction angle means localisation at the centre of the stereo base, and 30 degrees means localisation at one of the loudspeakers.

The following figures show the stereophonic properties of various XY and MS configurations. The recording angles and the different recording areas are illustrated in the upper graphs. The vertical scales represent the offset angles of the XY configurations or the relative S level of the MS configurations, respectively. The sound incidence angle is plotted at the horizontal axis where the recording angle can also be evaluated.
The lower graphs show the related stereophonic imaging performance. Again, the sound incidence angle is plotted at the horizontal axis. The reproduction angle can be read from the vertical scale. The curves represent different

XY offset angles or S levels, respectively.

### 3.1 XY CONFIGURATIONS

Fig.6 shows the XY properties of WIDE-ANGLE CARDIOIDS. The lower graph illustrates that the stereo image does not cover the full base width but is rather limited to some 20 degrees at best. The recording angle can be altered between 90 and 120 degrees. In-phase reproduction with correct side direction is maintained for all angles of sound incidence. The downward bend of the curves indicates that the stereo image is affected by geometric compression effects.

Fig.7 shows the XY properties of CARDIOIDS. The recording angle can be altered between 90 and 180 degrees. Again, in-phase reproduction at the correct side is maintained for all directions of sound incidence. As all reproduction curves touch the upper edge of the graph, full stereo width is available at all offset angles.
The individual curvatures indicate deviations from the ideal geometrical reproduction performance which would be represented by a straight line. Downward bends indicate image compression at the base edges, whereas upward bends indicate expansion. The lower graph shows that compression effects occur at frontal sound pick-up for offset angles above 30 degrees, whereas expansion occurs at smaller offset angles. Best reproduction linearity is performed at offset angles around 30 degrees.
The reproduction of sound from the rear is always affected by angular compression. Extreme compression effects occur where the curves touch the upper edge of the graph. The reproduction is then clustered at one of the loudspeakers.

Fig.8 shows that XY configurations are more complex with SUPER-CARDIOIDS due to their additional back lobe. The recording angle for frontal sound incidence is represented by the left-hand line in the upper graph. It can be altered between 30 and 120 degrees.
Sound from the rear is reproduced in-phase but side-inverted for offset angles below 60 degrees, and without side-inversion for offset angles above 60 degrees. At precisely 60 degrees offset angle there is no in-phase reproduction for rearward sound incidence.
In all other conditions the L and R signals are out of phase. This arises from the fact that the microphones receive the sound at opposite lobes of the directional patterns which supply opposite signal phases. The same effects occur also if bi-directional microphones are used. These out-of-phase signals introduce a sort of "spatial phasiness" with ambiophonic effects and prevent concrete stereo localisation. Out-of-phase reproduction of ambient sound certainly is a more-or-less unconsious ingredient of many sound recordings. The dashed curve shown in the upper graph indicates the angles of sound incidence where the L and R signals are equal but out of phase (L=R). Reproduction of sound from these directions is extremely blurred and creates strong spatial phasiness.

The reproduction curves shown in the lower graph are steeper compared to cardioids. Again, best reproduction linearity is maintained at offset angles around 30 degrees. The dashed curves indicate that rear sound is reproduced side-inverted. As the microphone signals are out-of-phase for sound incidence around 120 degrees which prevents concrete stereo localisation, these areas cannot be represented by curves.

Fig.9 shows that BI-DIRECTIONAL microphones perform symmetrical stereophonic properties for opposite directions of sound incidence, but side-inverted imaging of rear sound. Out-of-phase areas exist at lateral sound incidence. The recording angle for front and rear sound pick-up can be altered between 0 and 90 degrees. The reproduction curves are even steeper than with super-cardioids. Geometric distortion is least at offset angles around 30 degrees. At 90 degrees incidence angle the L and R signals are equal but out-of-phase.

3.2 MS CONFIGURATIONS

Fig.10 represents the MS properties of OMNIDIRECTIONAL microphones for various relative S levels (assuming identical sensitivities of the M and S microphones). The curves are symmetrical with respect to frontal and rearward sound incidence.
In-phase reproduction at the correct side is performed at all directions of sound incidence for S levels below 0 dB. The recording angle is then a constant 90 degrees. At S levels above 0 dB lateral sound is reproduces out-of -phase, and the in-phase pick-up areas are significantly restricted. For example, the recording angle decreases from 90 degrees at 0 dB to 45 degrees at +3 dB S level.

WIDE-ANGLE CARDIOIDS (Fig.11) show properties similar to omnidirectional microphones, but the recording angle is increased to 120 degrees at S levels below -4.8 dB. The reproduction curves show that angular linearity is slightly improved, compared to omnidirectional microphones.

The recording angle of MS systems with CARDIOIDS (Fig.12) can be altered between approximately 0 and 180 degrees. Angular linearity is excellent at S levels around -12 dB, but also satisfactory at higher S levels. Thus the recording angle can be varied widely by means of the S level without causing significant geometric distortion. It is remarkable that there is no in-phase opening for sound from the rear. Sound from directions beyond the recording angle is always reproduced out-of-phase.

SUPER-CARDIOIDS (Fig.13) show less complex features in MS than in XY configurations. The recording angle for frontal sound perception can be altered between approximately 0 and 120 degrees. Best imaging linearity is achieved at S levels around -8 dB.
There is an additional rear opening beyond 120 degrees with side-inverted reproduction. Out-of-phase reproduction occurs at the gap around 120 degrees. At exactly 120 degrees the L and R signals are equal but out-of-phase.

MS with crossed BI-DIRECTIONAL microphone (Fig.14) was introduced by Alan Blumlein in the early 1930's. The associated properties are closely related to the XY configurations with bi-directional microphones. The best geometrical linearity is achieved at -6 dB S level. The sound reception from the front and rear hemispheres is symmetrical but side-inverted, and out-of-phase areas exist at lateral sound incidence.

## 4. COMPARISON OF XY AND MS TECHNIQUES

### 4.1 THEORETICAL CONSIDERATIONS

Fig.15 shows graphical superimpositions of XY and MS reproduction characteristics which have been selected to form bunches of curves with equal initial slopes. The upper graph presents the properties of XY configurations. The curves are marked by the directivity and the offset angle (W = wide-angle cardioid, c = cardioid, S = super-cardioid, B = Bi-directional). The lower graph presents the properties of MS configurations. The steepest curve in each bunch represents the bi-directional M microphone, whereas the strongest curvature represents the omnidirectional M microphone.

A comparison of both graphs leads to the following results:-

A. All types of directivity can be used in MS systems, including the omnidirectional characteristic, whereas the latter cannot be used in XY systems.

B. In MS systems, any slope is possible with any type of directivity, whereas in XY systems the choice is severely restricted if reproduction curves with larger slopes are desired.

C. The recording angle of MS systems can be varied to a greater extent if directivity types with a low bi-directional component are used. If, for example, wide-angle cardioids are used, the recording angle of an MS system can be altered between approximately 0 and 120 degrees, whereas the recording angle of an XY system can only be altered between 90 and 120 degrees.

These facts suggest that the MS technique is more versatile than the XY technique.

### 4.2 PRACTICAL CONSIDERATIONS

Real microphones are not perfect. Their directional characteristics show more-or-less significant deviations from ideal properties at increasing sound incidence angles and high frequencies.

The next figures show the directional properties of some widely used studio condenser microphones. The frequency response curves have been recorded at sound incidence angles between 0 and 90 degrees in steps of 15 degrees, thus covering the entire front hemisphere.

Fig.16 shows the directional properties of large multi-pattern microphones which have been switched to cardioid characteristics as the most frequently used directivity. Although the microphones have been produced by different manufacturers they are quite similar in performance.
It can be seen that the rated characteristic is featured only at medium frequencies (rated attenuation 6 dB at 90 degrees). At low frequencies a transition to a characteristic similar to the wide-angle cardioid occurs. This is typical for microphones incorporating double-diaphragm transducers. This effect becomes even more clearly detectable at rearward sound incidence not considered in the graphs.
Another common feature is the concentration of the frequency response curves in the upper frequency range and the attached expansion which indicates adjacent widening and contraction of the directivity characteristics.

Fig.17 shows the directional properties of cylindrical studio condenser microphones with diameters of around 2 cm and cardioid characteristics. Here too, the frequency response curves show similar compressions and dilatations in the upper frequency range.
The acoustic design of the microphone front-end and the rear matching to the sound-field contribute to these effects. Most frequently, the transducer is shifted back into the microphone housing. This is particularly unfavourable as a space in front of the diaphragm is created, leading to resonance effects which emphasize on-axis sound and affect off-axis sound, thus increasing the directivity at high frequencies and creating tonal colourations of the off-axis sound.

By contrast, Fig.18 shows the directional properties of a microphone in which the transducer front is flush with the microphone housing. A gauze cap which is permeable to frontal and lateral sound provides mechanical protection for the transducer. In addition, due to the rearward acoustic matching to the sound-field, the directional properties change as little as possible at high frequencies. The slope of the frequency response at lateral sound incidence does not exceed 6 dB/octave and no annoying peaks occur in the transition range.

However, diligently designed bi-directional microphones show even less deviations from ideal directivity performance, especially if they incorporate symmetrical transducers. Fig.19 presents the directional properties of such a microphone. It is evident that neutral pick-up is guaranteed for all directions of sound incidence.

Taking the directional properties of real microphones into consideration, it becomes clear that the MS technique provides a higher recording fidelity than the XY technique. There are at least two reasons for this:-

A. The microphones in an XY system are operated mainly at off-axis conditions, especially at larger offset angles. Thus, the influence of directivity imperfections is more serious than with MS systems, where the M microphone is aimed at the centre of the performance. This is illustrated by Fig.20. As can be seen, the maximum sound incidence angle for the M microphone is only half that of the X and Y microphones, although the covered performance area is the same for all microphones. However, this area is symmetrically picked up by the M microphone, but unsymmetrically by the X and Y microphones. Therefore, the MS system can supply the more accurate monophonic (M) signal in comparison with the XY system.

B. The MS system picks up the S signal with a bi-directional microphone. As already mentioned, the directivity performance of this type of microphone can be designed with a high degree of perfection. Thus, errors in the S signal can be kept particularly small for all directions of sound incidence. Therefore, the MS system can supply a highly accurate side (S) signal.

As the M and S signals are more accurately captured by the MS technique than by the XY technique, it is evident that the L and R signals are more accurately generated by the MS technique than by the XY technique.

Besides these fundamental advantages, there are some additional benefits of the MS technique which are worthwhile being mentioned:-

A comparison of the XY and MS properties show that the MS technique is the more universal one, as all directional characteristics, including the omnidirectional characteristic, can be used.

Furthermore, as omnidirectional microphones and wide-angle cardioids commonly show extended low frequency responses, the MS technoque can also serve with an improved low frequency response.

In addition, the MS technique is easier to manipulate, as the recording angle can be controlled electronically simply by moving a fader; whereas the XY technique requires mechanical adjustment. Using the MS technique, the recording angle can be altered in the course of monitoring, and can thus be judged instantaneously.

Another advantage of the MS technique results from the fact that the mono directivity does not depend on the amount of S signal applied to create the stereophonic effect. Thus, if recordings are made in the MS format a predictable mono signal is always captured. In addition, the stereophonic image can be simply influenced by modifying the S level without changing the mono signal. This can even be done during post-production.

## 5. CONCLUSIONS

Although the XY and MS techniques can be considered theoretically equivalent they each show specific properties which result for mainly two reasons:-

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A. As standard microphones provide only a limited number of directivity types, both systems supply different characteristics in practical use.

B. As the microphones are dissimilarly exposed to the sound-field in the two techniques, the imperfections of real microphones cause differing results. It has been shown that the MS technique is less prone to these flaws.

The latter fact suggests that the MS technique ultimately causes fewer errors than the XY technique, and thus performs with higher recording fidelity, as a matter of course.

One condition, however, should be met if the advantages of the MS technique are to be fully exploited:-

The frequency responses of the M and S microphones should largely match and be as smooth as possible. In the past, this could not be taken for granted as each directivity type was associated with peculiarities of the frequency response. More recently, however, microphones with almost neutral and standardized characteristics have become available, so that it has become possible to create ideal conditions for a problem-free implementation of the MS microphone technique.

## 6. REFERENCES

[1] M. Dickreiter: Handbuch der Tonstudiotechnik, 1982, p.81.

## 7. DIAGRAMS

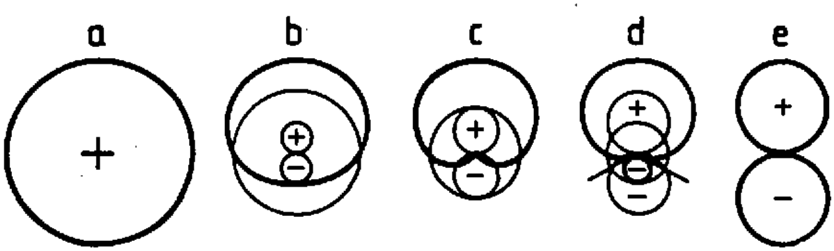



Fig.1 First order directional characteristics

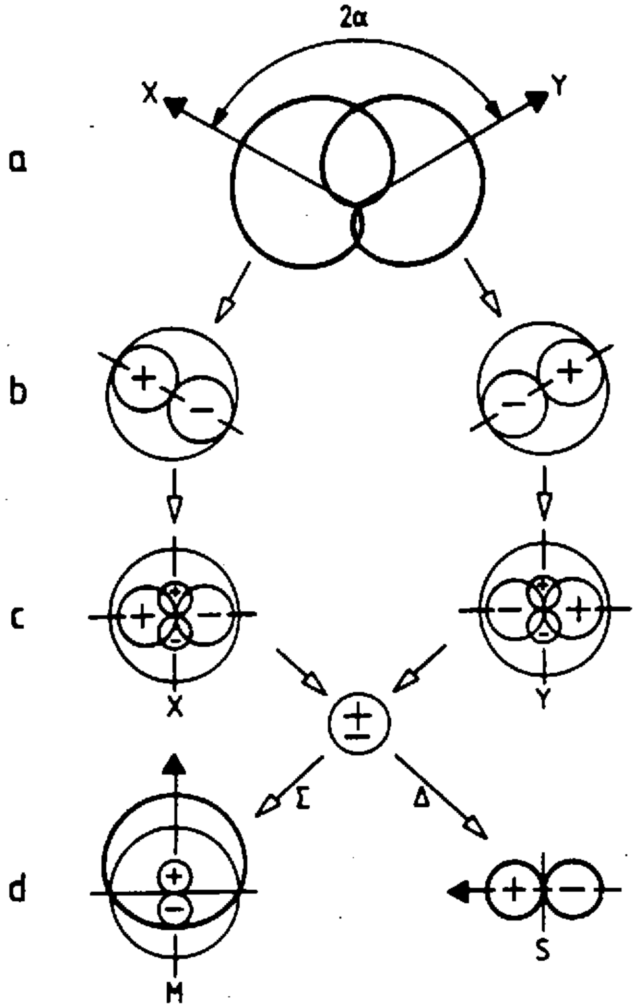
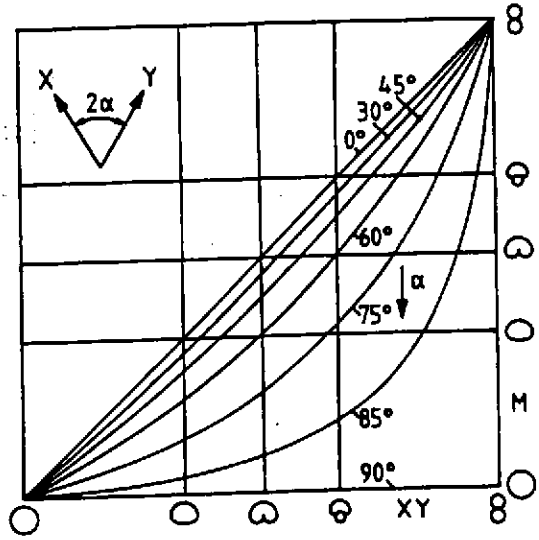



Fig.2 XY-MS equivalence



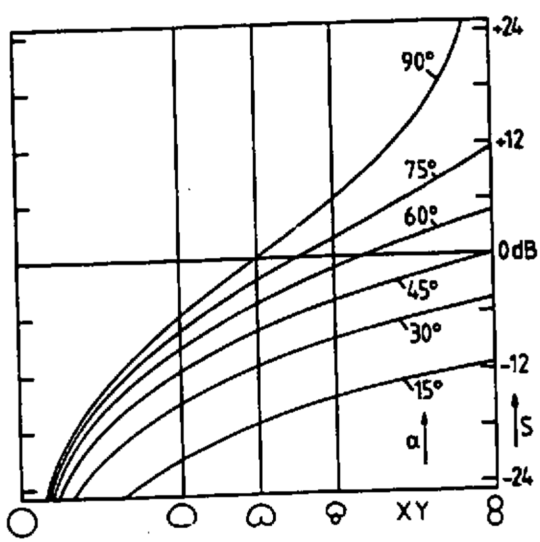




Fig.3 Equivalent XY-MS parameters

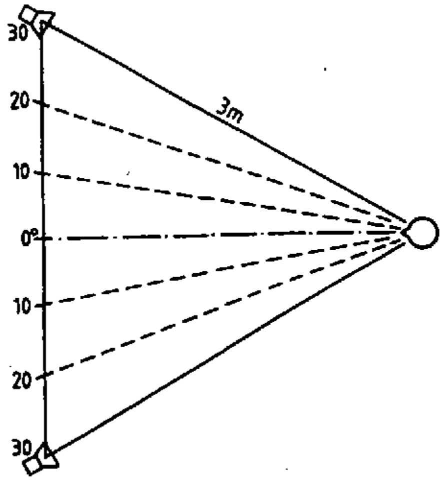



Fig.4 Standard listening configuration

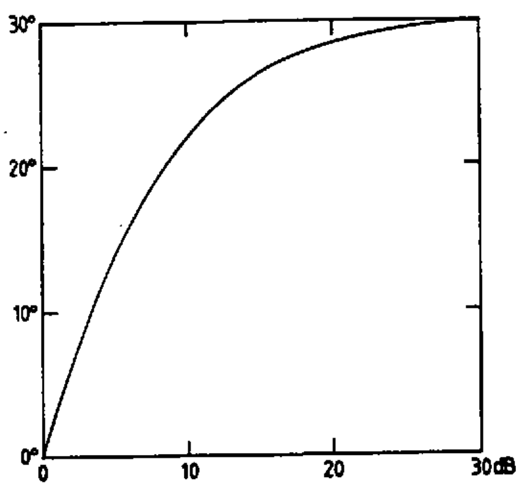



Fig.5 Stereophonic localisation

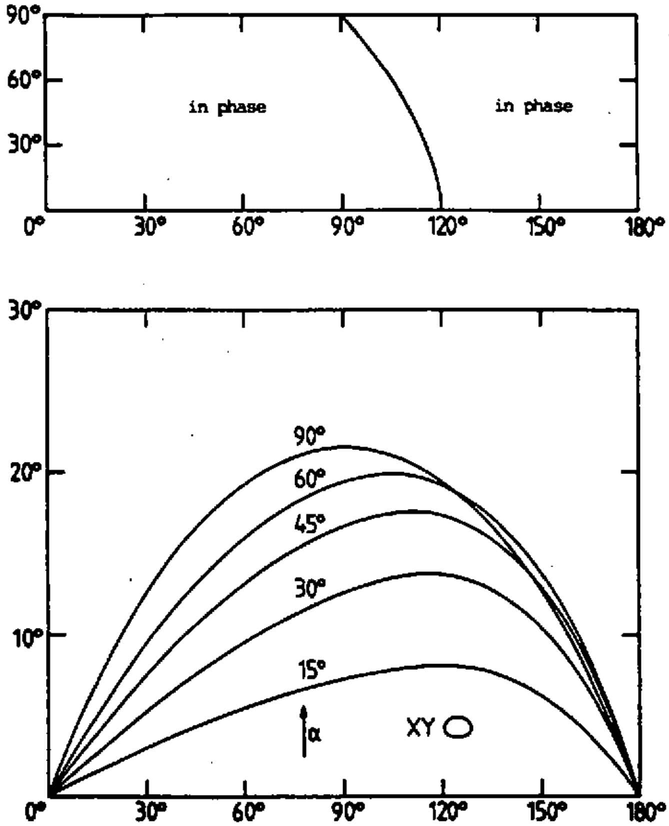



Fig.6 XY properties of wide-angle cardioids

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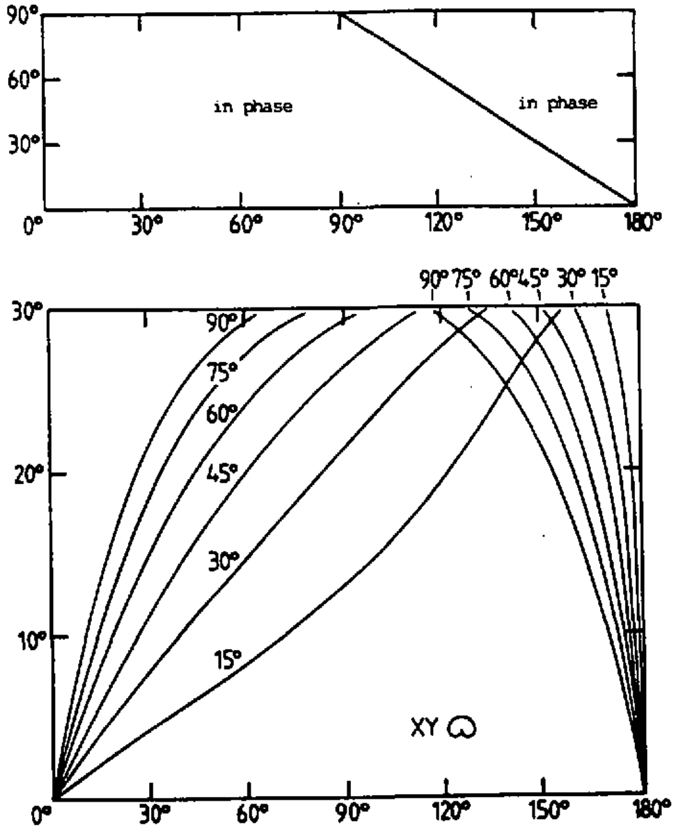


Fig.7 XY properties of cardioids

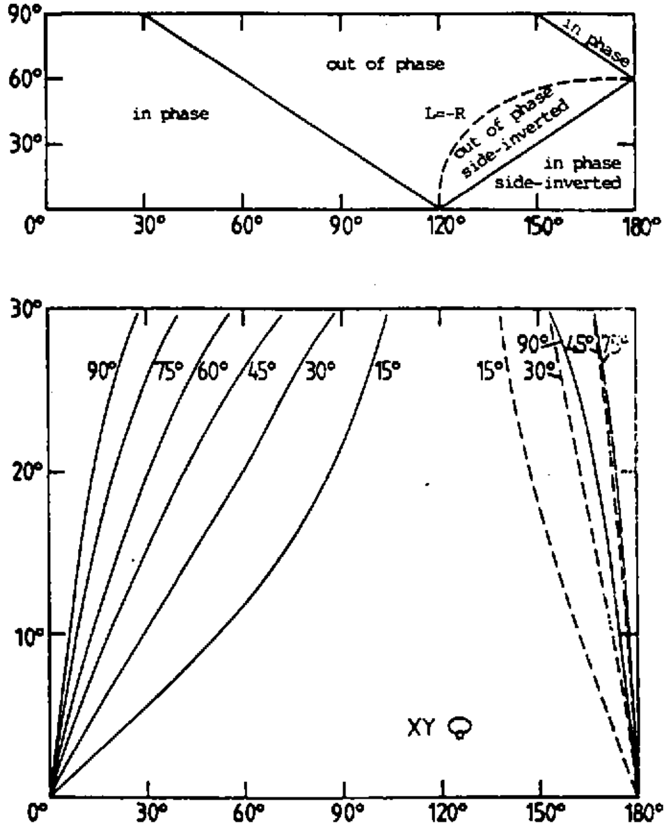


Fig.8 XY properties of super-cardioids

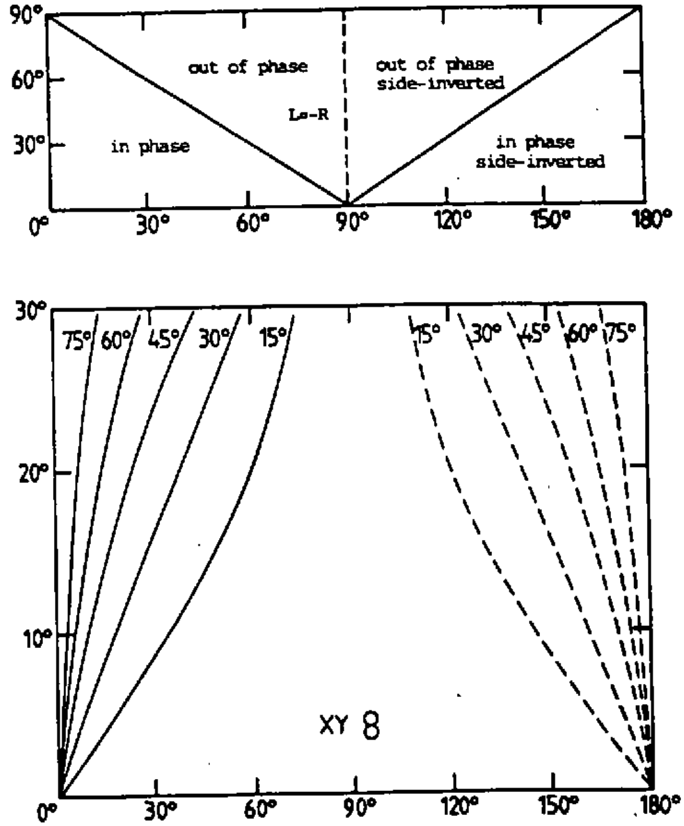


Fig.9 XY properties of bi-directional microphones

 

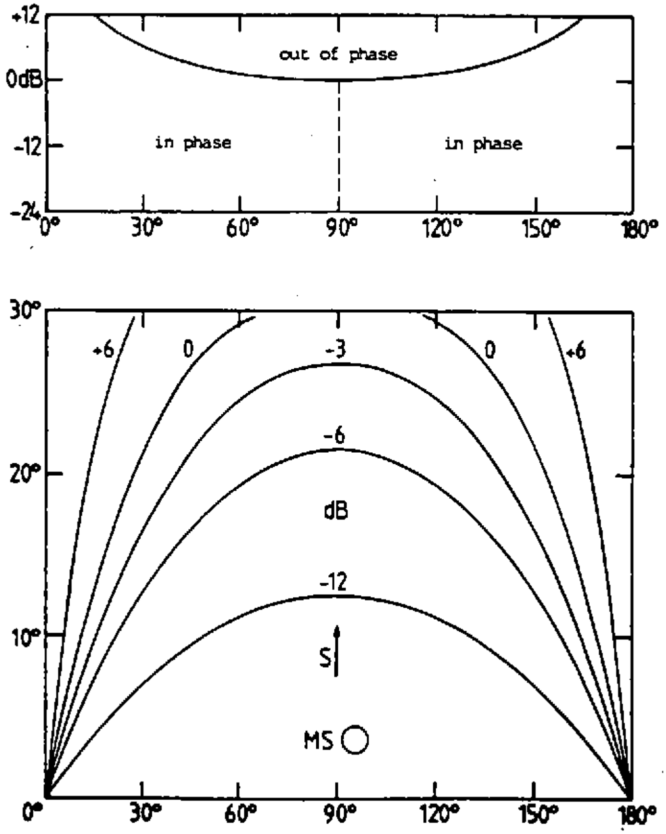


Fig.10 MS properties of omnidirectional microphones

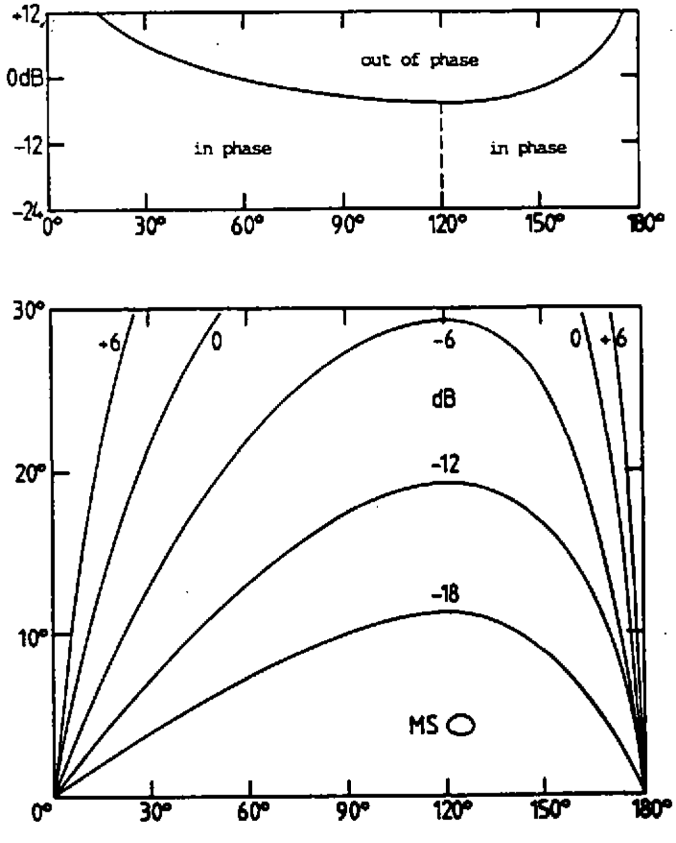


Fig.11 MS properties of wide-angle cardioids

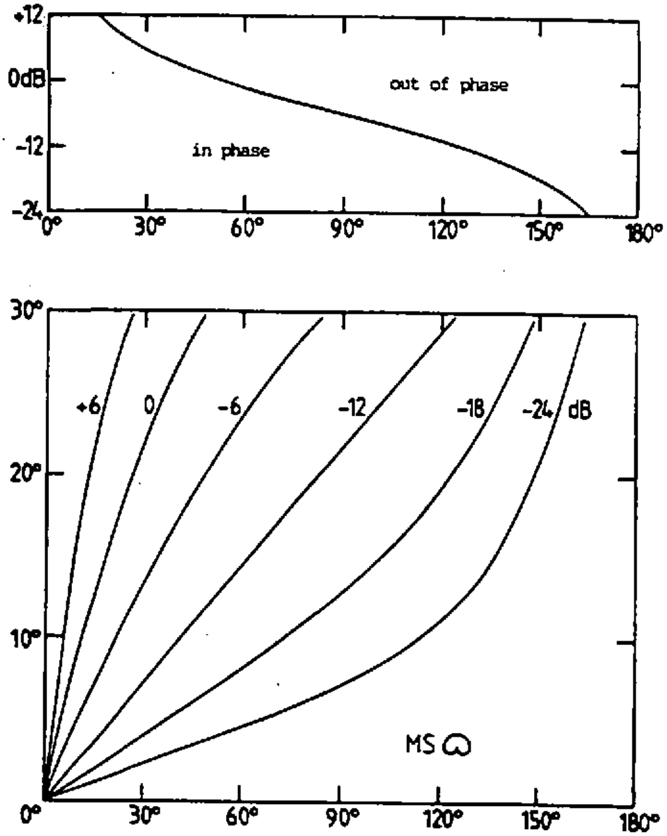


Fig.12 MS properties of cardioids

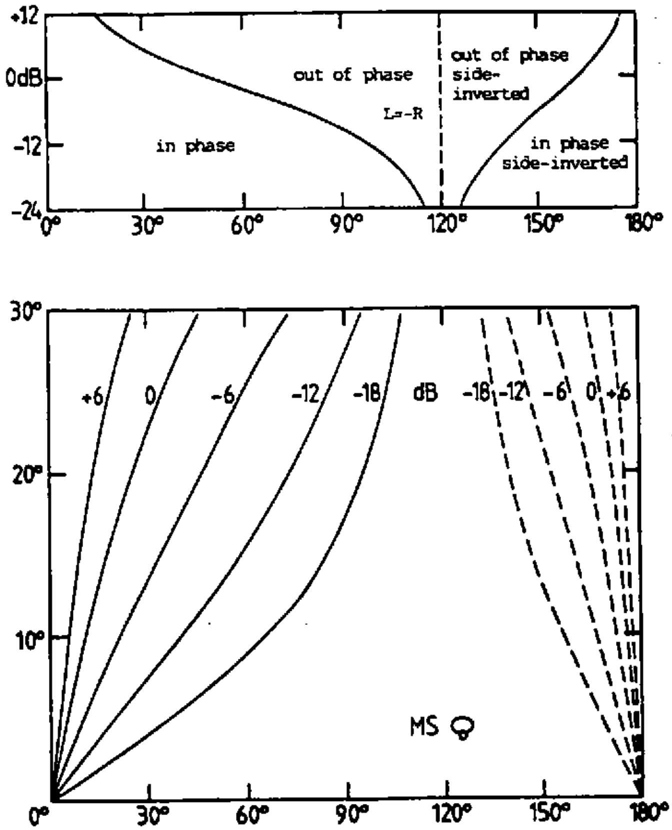


Fig.13 MS properties of super-cardioids

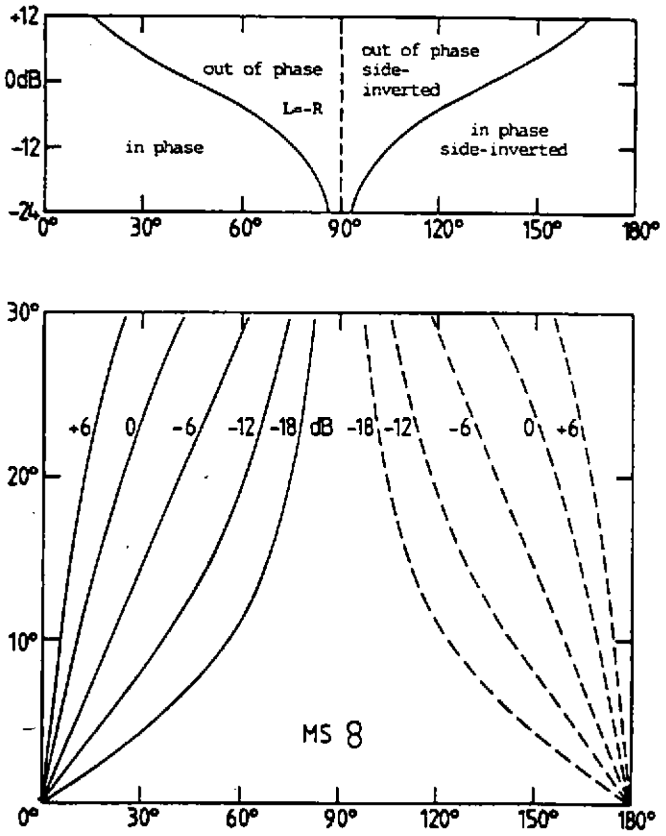


Fig.14 MS properties of bi-directional microphones

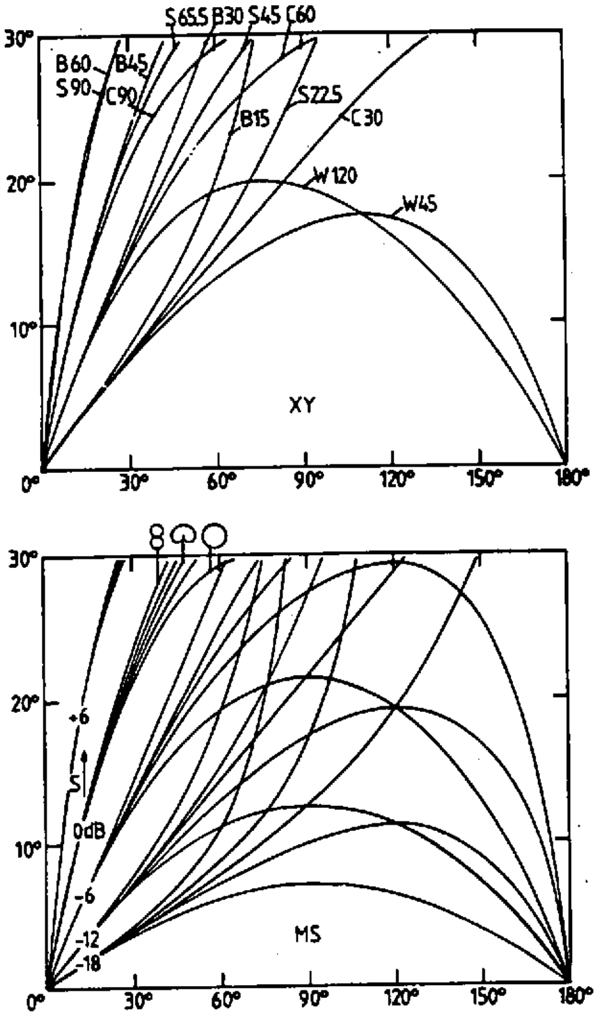


Fig.15 Superimposition of XY and MS localisation properties

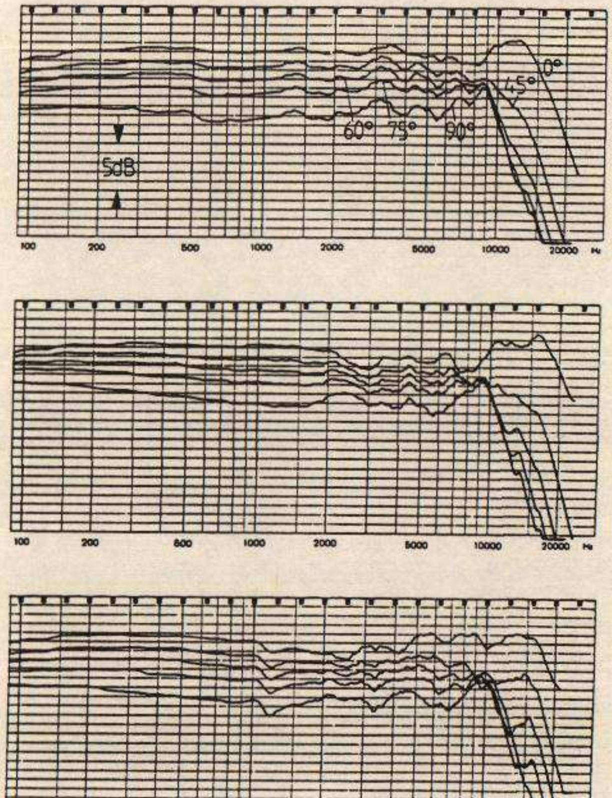


Fig.16 Directional properties of large multi-pattern studio condenser microphones

(switched to cardioid characteristic)

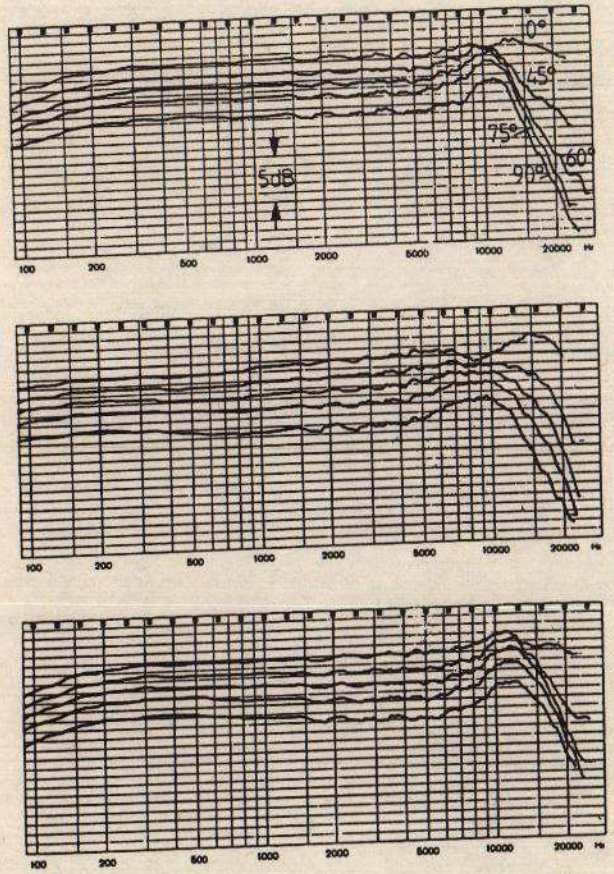


Fig.17 Directional properties of cylindrical studio condenser microphones (cardioids)

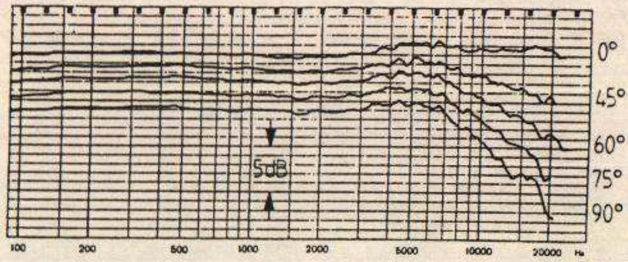


Fig.18 Directional properties of the Sennheiser MKH 40 (cardioid)

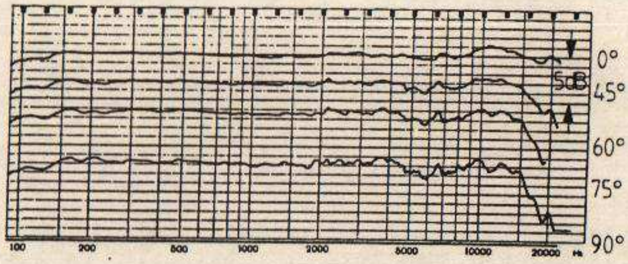


Fig.19 Directional properties of the Sennheiser MKH 30 (bi-directional)

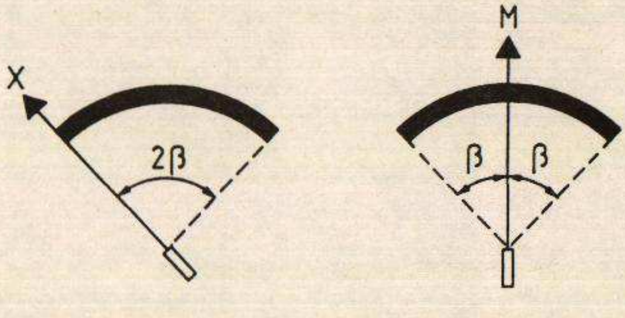


Fig.20 Exposure of X and M microphones to sound