# IMPROVING THE LOW FREQUENCY DIRECTIVITY OF LINE-ARRAY MICROPHONES

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## PREAMBLE

The directivity of line-array microphones is limited by their maximum dimensions. Physically, the ratio of the wavelength to the dimensions determines the lowest frequency where the array is effective. Microphone lines that are several metres long can handle low frequencies with the same directivity as they do the mid-range frequencies, but in practice this is unwieldy. A line-array microphone as a spot microphone can be very effective, especially if the bass response is improved to reject the off-axis sound. In this paper, we present a method wereby a line-array microphone of only 30cm in length can have the same directivity at 100Hz (9dB) as it has at 1kHz. This is achieved by adding an additional capsule behind the main array (at approximately 24cm distance) whose signal is added to the main array. The overall arrangement is structured and operates purely in the analogue domain, so latency is avoided.

## 1 INTRODUCTION

Microphone arrays and line-array microphones have been used successfully in many applications. In particular, the line-array microphone (eg: KEM 970) provides as an indespensible tool in acoustic conditions where good rejection above and below the plane of the microphone is required. However, with all the microphone arrays produced so far, good directivity at low frequencies can only be achieved with large dimensions. Unfortunately the unwieldy size of such microphones limits their practical use. So - is it possible to improve directivity at low frequencies while maintaining practical dimensions?

## 2 APPLICATIONS OF THE LINE-ARRAY MICROPHONE

In order to separate the wanted sound from the unwanted, a pronounced directional characteristic is needed. In many cases, the standard microphone patterns: cardioid, hyper-cardioid, figure eight, etc., are not really suitable as they pick up as much in the vertical plane as they do in the horizontal plane. Line-array microphones have a non-rotationally symmetrical directivity characteristic (Fig. 1), which can be very advantageous in such cases. In the horizontal plane line-array microphones have a cardioid polar pattern. In the vertical plane they have a narrow acceptance angle for better rejection of off-axis sound. For several years, a line-array microphone called "KEM" (Cardioid Plane Microphone – in German: "Kardioid-Ebenen-Mikrofon") has been used successfully.

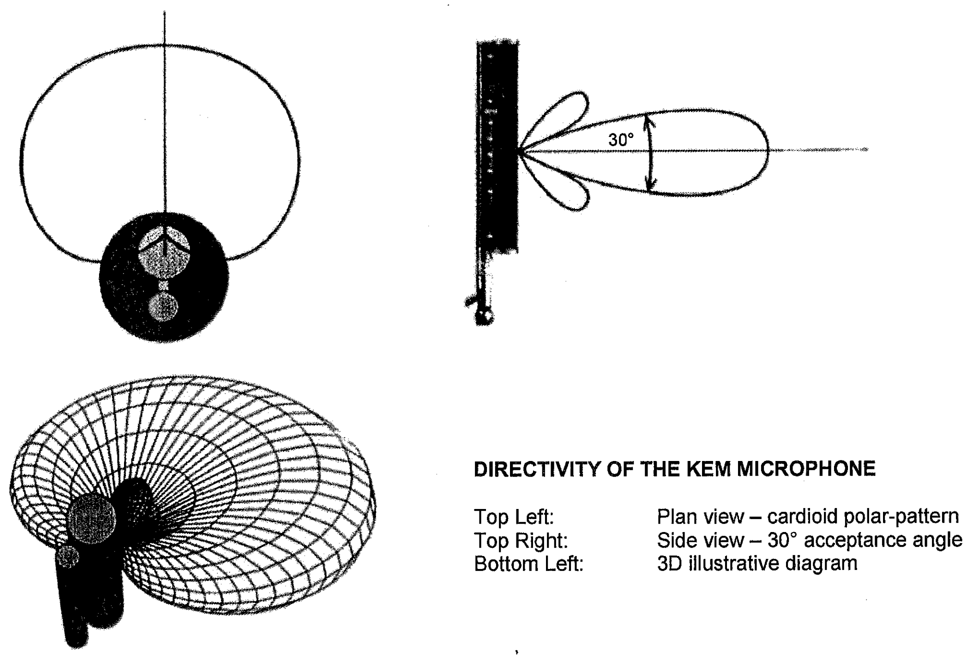



*Figure 1: The non-rotationally symmetrical directivity of a line-array microphone (KEM)*

## 2.1 KEM at the lectern

As a speaker's microphone at a lectern, the KEM has proven itself over many years; for example there is a pair in the plenary assembly hall of the German Bundestag (Fig. 2). Here they supply the sound for parliamentry television broadcasts as well as for the public address system in the chamber. The orators have freedom of movement in the horizontal plane, without the fear of sound fluctuations in level or tone. In the vertical plane, annoying reflections from the room and possible feedback from the PA system can effectively be suppressed. The microphones are such an iconic component of the Chamber, that you can even see them included in a newspaper cartoon (Fig. 3).

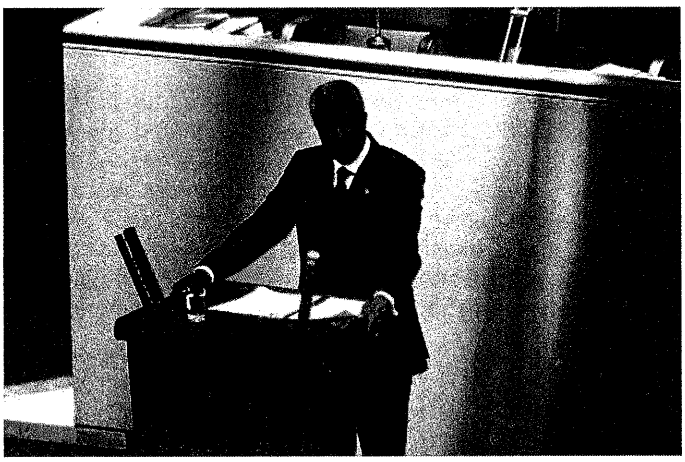


*Figure 2: UN Secretary General Kofi Annan speaking to the German Bundestag in February 2002*

*Figure 3: Detail of a cartoon in the Süddeutsche Zeitung, 7/8 October 2000*

## 2.2 KEM used in video conferencing

In high-quality video conferencing systems, all the conference participants can be picked up by a single line-array microphone. All the delegates round the table are equally covered, even those at the extreme ends. Speech intelligibility is excellent because the unwanted reflections in the vertical plane (ie: from the table and ceiling) are rejected. Overall, a very natural dialogue is achieved; with the added advantage that, because individual microphones are not needed, the delegates forget the microphone is there and just converse naturally.

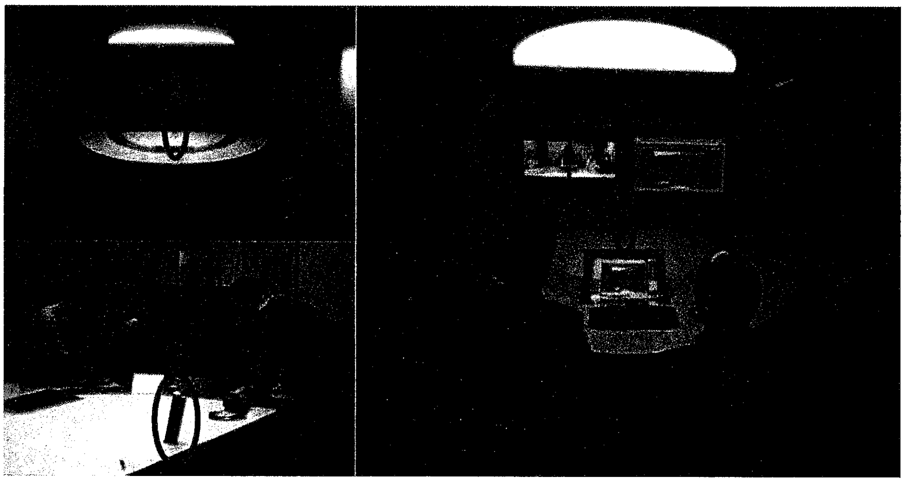


*Figure 4: A KEM (ringed in the picture) positioned centrally in front of the video screen covers everyone sitting at the table – so all participants of the video conference are picked up with a single microphone and converse naturally as they are not hampered by individual delegate mics.*

## 2.3 KEM as a recording microphone for television productions

As a theatre microphone, the KEM line-array microphone can be used to pick up the action on stage. For example, in a classical gala on ZDF in Germany, line-array microphones were placed along the edge of the stage, so as to pick up the singing of the many performers who freely moved while singing (Fig. 5). The directivity of the line-array means that floor noises and reflections are rejected by the microphone.

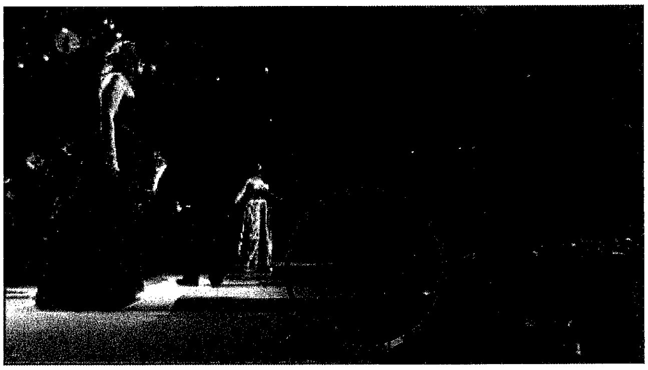


*Figure 5: KEM line-array microphone as a recording microphone on the edge of the stage at a gala classical performance*

## 2.4 KEM as a spot microphone for the choir in classical music productions

The use of the line-array microphone as a spot microphone for the choir in classical music productions was described at the Tonmeistertagung in 2000 [1]. Here again, the directional characteristics of the line-array microphone can be used very profitably, the choir is homogeneous and wide and can be covered in its entirety by the line-array microphone. Crosstalk from the orchestra is avoided by the narrow acceptance angle in the vertical plane (Fig. 6). This application of the microphone line is becoming a firm favourite in recording practice. For instance, the Leipzig Gewandhaus concert recordings by the choir of the MDR are supported by suspended KEM line-arrray microphone (Fig. 7).

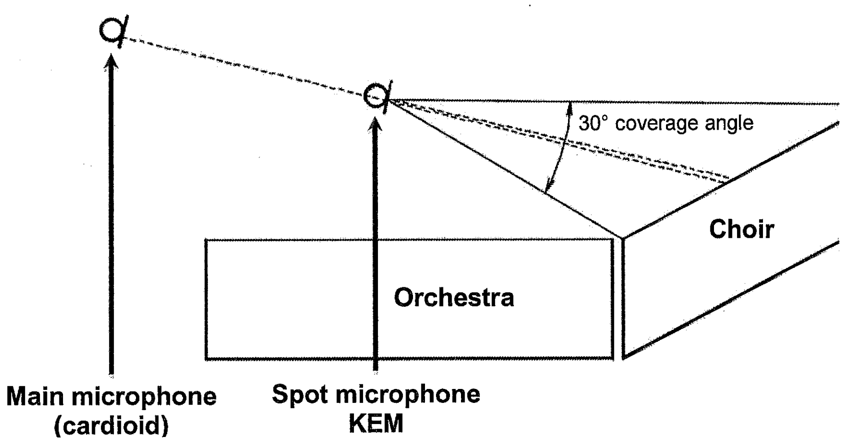



*Figure 6: The small acceptance angle of the line-array microphone in the vertical axis avoids crosstalk from the orchestral sound to the choir spot microphones*

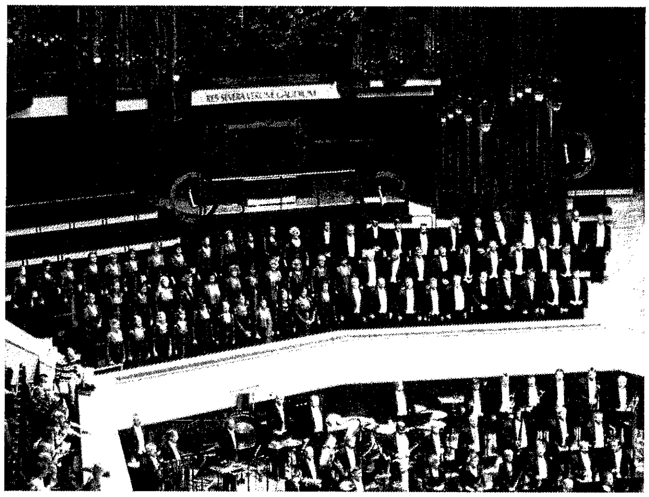


*Figure 7: Three KEM line-array microphones suspended in front of the choir in the Leipzig Gewandhaus separate the choir from the orchestra*

# 3 IMPROVING THE LOW FREQUENCY DIRECTIVITY

At the lectern, in video conferencing and use in other areas where a good and clear voice transmission is required, the KEM 970 has proved itself over and over again. However, for use in music production an improvement in the efficiency of the microphone array down to low frequencies (100Hz) to the same level as at mid-range frequencies would be desirable. A method has now been developed with which the low-frequency directivity of the microphone could be greatly improved; also, care was taken to ensure that the process operates latency-free and the overall size of the arrangement stays withing the boundaries of ease-of-use, with dimensions that are practical and not too large.

## 3.1 Required line length

With microphone arrays and microphone lines the max. dimension of the arrangement limits the directivity at low frequencies. The relationship between maximum dimensions and wavelength is crucial. An example to clarify this: So that a line-array microphone achieves the directional characteristic shown in *Figure 8* at 630Hz, a line length of at least 28cm is needed. To have the same directivity at 100Hz, a length of more than 170cm is required. Such dimensions are unwieldy in practical use. So, it is apparent that a better vertical directivity at low frequencies by increasing the length of the microphone line is indeed possible, but it would be highly impractical in most applications.

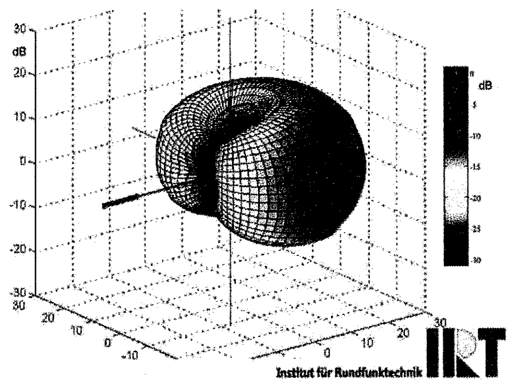



*Figure 8: Directivity of a line-array microphone with a length of 28cm, at a frequency of 630Hz (equivalent to a length of 170cm at 100Hz)*

## 3.2 Offset Capsule – A Triangular Arrangement

Another solution had to be be found. *Figure 9* shows the principle.

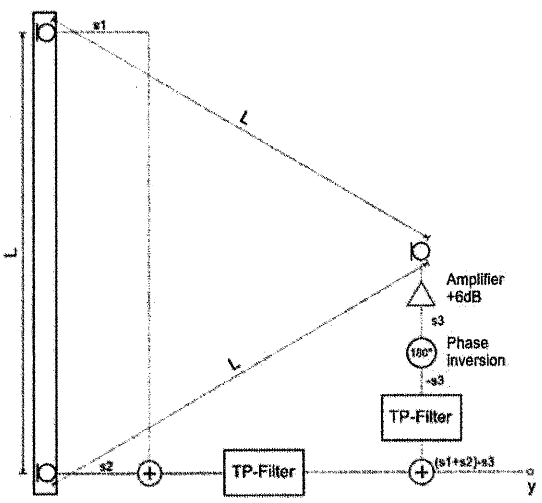



*Figure 9: The principle of the triangular arrangement with offset capsule. The signal of the two outermost capsules of a line-array with a length of 28cm is added to the signal of an additional microphone capsule (cardioid) to form the output signal.*

The two outermost microphones of the KEM 970 have a distance between them of 28cm. This line distance determines the lowest practical frequency. These two capsules are added to a third capsule to make a triangular arrangement. The signal from the third capsule is amplified, inverted and summed with a suitable low-pass filter with the filtered output signal of the two outermost capsules. The overall arrangement is structured and operates purely in the analogue domain with zero latency.

## 3.3 The achieved directivity

*Figure 10* shows the results of the method described, the directivity of the array shows the same value at 100Hz (9 dB) as it does at 1kHz.

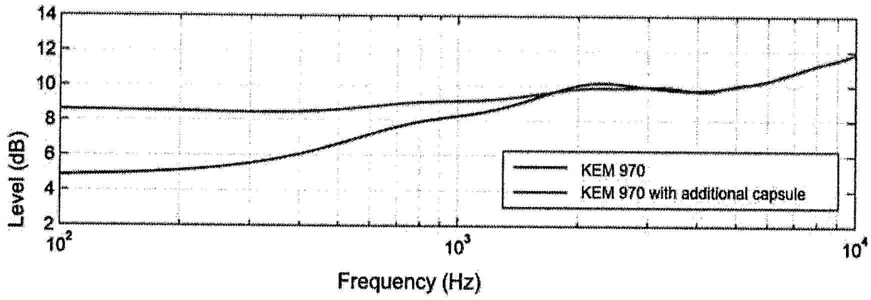



*Figure 10: Use of the offset capsule, the array directivity at 100Hz is raised to the same value as it has at 1kHz (Directivity = Free field [on the main axis] - Diffuse field transfer measurement)*

The results of the vertical and horizontal directivity versus frequency is shown in *Figures 11* and *12*. The transitions between the colours indicate the isobars, ie the areas of equal sound pressure in dB relative to the main axis (0dB). In the figures the behavior of the standard KEM 970 line-array microphone is compared with the (KEM 975) microphone with the offset capsule. It is easy to see how the acceptance angle of the microphone array at low frequencies is much narrower with the offset capsule. The principle of the offset capsule also has increased directivity in the horizontal plane (Fig. 12). The combination of both levels gives the balanced development of the directivity measurement shown in *Figure 10* (*Figures 11* and *12* show simulated results. The representations were examined and confirmed by actual measurements.)

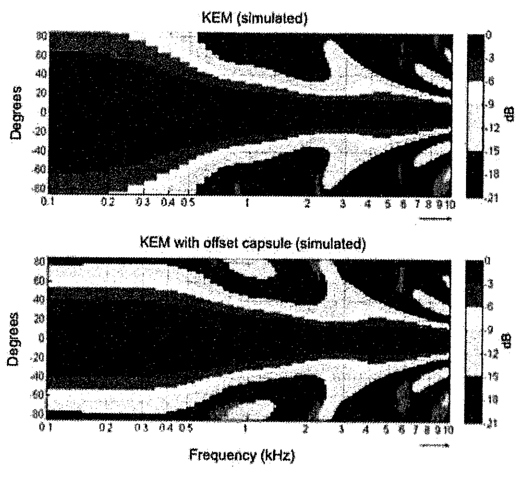



*Figure 11: Vertical directivity of KEM (top) and KEM with offset capsule (below) for frequencies from 100Hz to 10kHz*

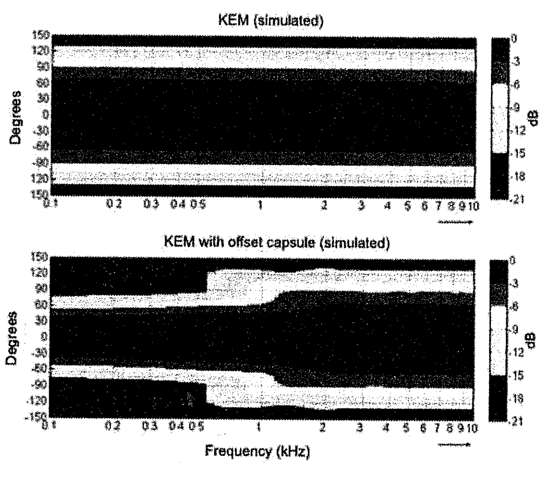



*Figure 12: Horizontal directivity of KEM (top) and KEM with offset capsule (below) for frequencies from 100Hz to 10kHz*

In *Figures 13* and *14,* the improved directivity of the offset capsule is shown in the vertical and horizontal polar diagrams – measured at 400 Hz.

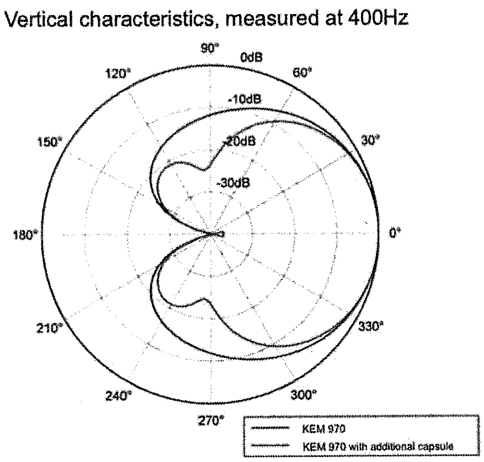



*Figure 13: Vertical polar plot at 400 Hz; KEM without and with offset capsule*

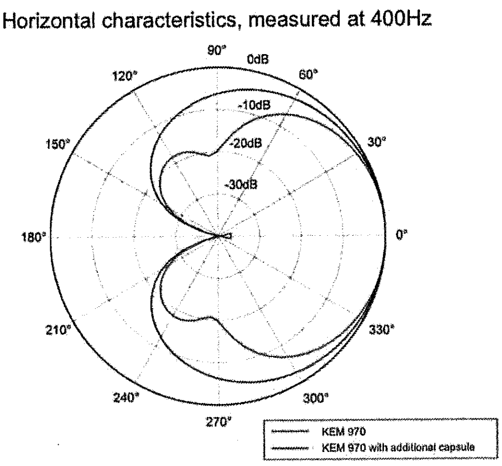



*Figure 14: Horizontal polar plot at 400 Hz; KEM without and with offset capsule*

## 3.4 How does such an arrangement work?

As seen in *Figure 15*, the patented research resulted in a practical product. The KEM 975 from Microtech Gefell is the successor of the KEM 970 and has the offset capsule as an option. The additional capsule can easily be mounted or removed as required. There is no additional cabling and no manual switching of the capsule.

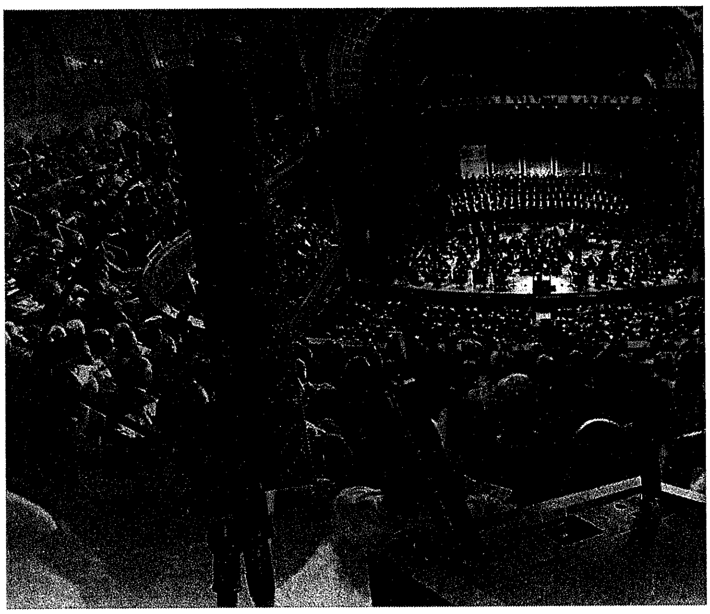


*Figure 15: The Microtech Gefell KEM 975 showing the optional offset capsule*

In music recording situations the offset capsule would be used to achieve the directivity at bass frequencies. When used on a lectern (for example) where bass is limited or non-existant, the KEM 975 would be used without the offset capsule. An added advantage with the KEM 975 is that the microphone noise floor is lower when compared to the old KEM 970 making it more suitable to music recording than the old model.

# 4 CLIPS

Two prototypes of the assembly "KEM offset capsule" were used, in November 2011, at a recording session of Handel's "Messiah" in the church of St. Sebastian in Munich – they were being tested as spot microphones for a choir. The two assemblies were installed above the orchestra in front of the choir (Fig. 16). The crosstalk from the orchestral sound (low strings, chamber organ and timpani) was significantly reduced by the use of the KEM as a choir-spot microphone.

*Figure 16: Two prototypes of the arrangement were used to record the choir*

The audio samples are available on the IRT website [2] and can be switched and compared. Playback of the examples is possible with any current browser. During playback, you can switch back and forth between versions: KEM with offset capsule, KEM without offset capsule, the cardioid offset capsule on its own and the overall mix. The separation of the desired (choir) and undesired orchestra (timpani, strings, organ) by the method described at low frequencies is chearly audible.

The sound samples have also been embedded in MP3 format on a PowerPoint slide (Fig. 17) that can be downloaded from the Sound-Link website (see links under *Figure 17*).

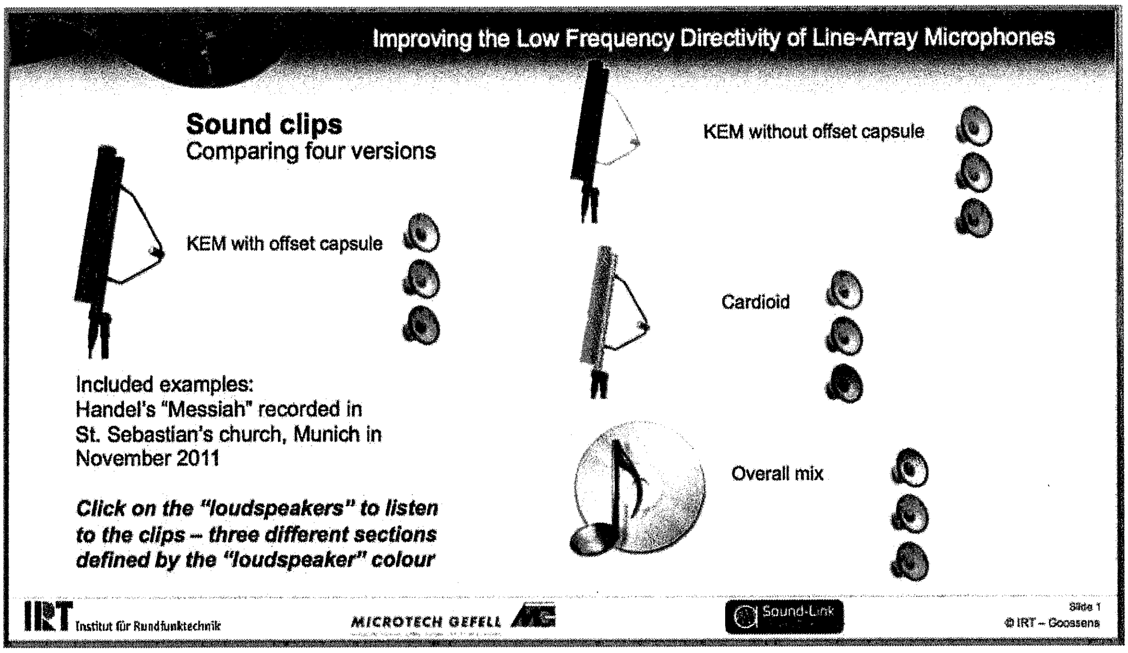



*Figure 17: This diagram shows the PowerPoint slide with imbedded sound samples. The Clips can be compared back and forth with each other. There are three different music samples (indicated by the different coloured loudspeakers) which can be compared with each other. Open the PowerPoint and click on the relevent loudspeaker and then click on "play".*

*The PowerPoint can be downloaded from: http://tinyurl.com/KEMsoundfiles or http://www.sound-link.co.uk/media/KEM 975 - MP3 sound files.pptx*

# 5 SUMMARY

This research shows that a line-array microphone (KEM) of only 28cm in length can have a directivity at 100Hz to the same value as it has at 1kHz (9dB) when an additional capsule is attached to the main axis about 24cm to the rear of the main array and included in the formation of the main output signal. The overall arrangement is structured and operates purely in the analogue domain, so latency is avoided. When used as a choir microphone it supports the separation of the desired (choir) from the undesired (orchestra) with improved directivity at low frequencies, with the added advantage of lower self-noise in the new design.

# 6 THE FUTURE

This described and patented method can be applied not only to line-array microphones but also to microphone arrays. First attempts are promising much. So arrays can also be conceived with good directivity at low frequencies that would not otherwise have been practical because of their size.

# 7 ACKNOWLEDGEMENTS

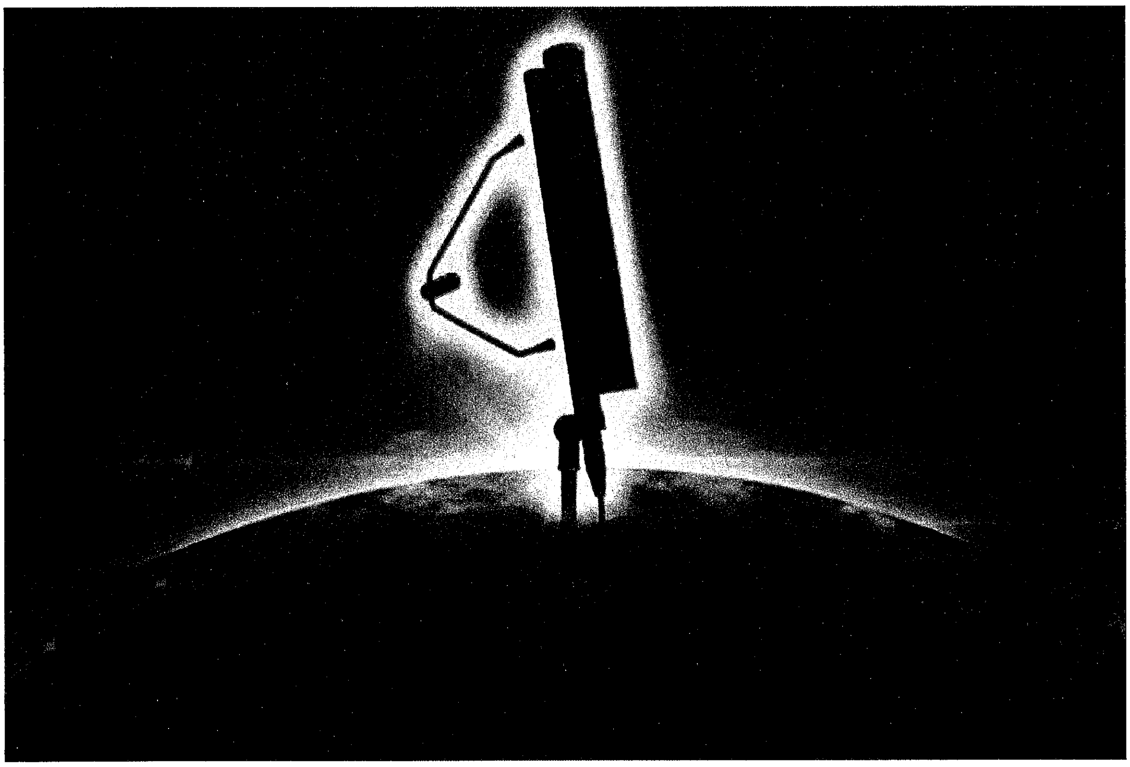
Thanks to Michael Weitnauer for the creation of the audio player used on the website. Also, thanks to Corbinian Augustin and Sarah Shoemaker for their valuable contributions.

Dipl.-Ing. Sebastian Goossens (IRT, Munich) did the original research and wrote the German version of this paper, which was originally presented at the Tonmeistertagung in Germany.

This English translation was done via an on-line translation app and then re-written in real English by John Willett of Sound-Link ProAudio for the presentation of this paper in English.

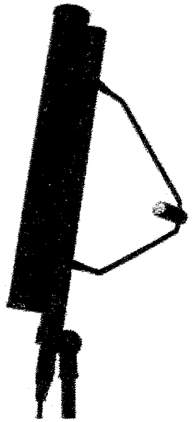

# 8 REFERENCES


1. Goossens, S.: "The KEM microphone in a musical production" 21 Tonmeistertagung, 2000, Proceedings (ISBN 3-598-20362-4), 745-753
2. http://www.irt.de/de/themengebiete/akustik/messungen-und-entwicklungen.html

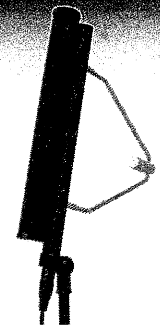



## Sound clips

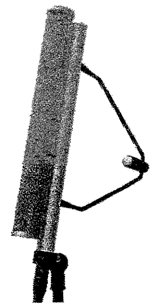
Comparing four versions



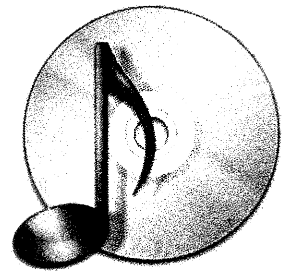
KEM with offset capsule



KEM without offset capsule



Cardioid



Overall mix

Included examples:
Handel's "Messiah" recorded in St. Sebastian's church, Munich in November 2011

***Click on the "loudspeakers" to listen to the clips – three different sections defined by the "loudspeaker" colour***

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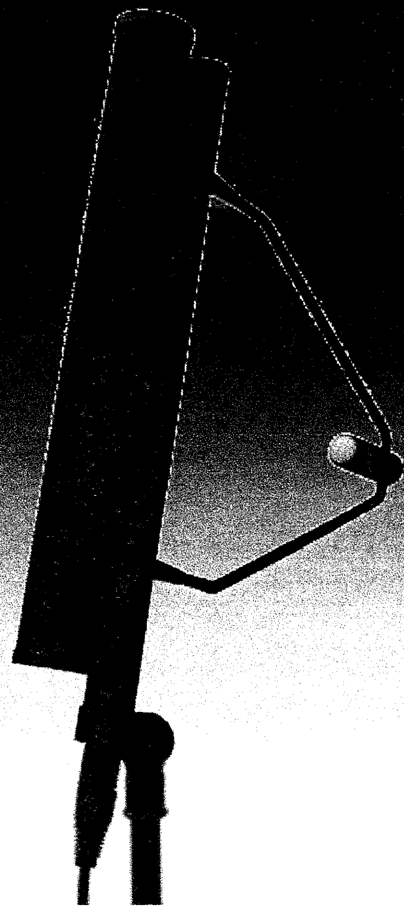
Thank you for listening

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