

# Directivity measurement of a singer

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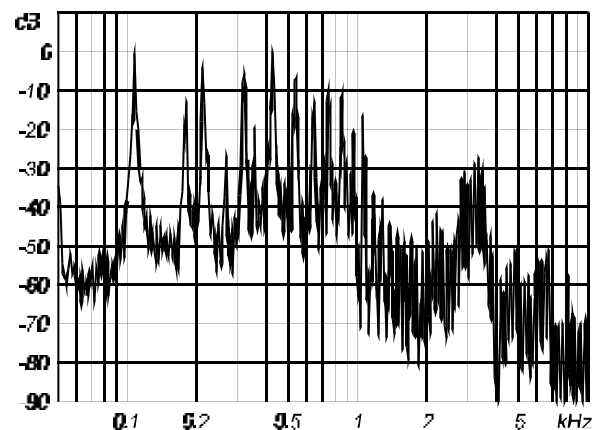
## 1 Introduction

For accurate room acoustical simulations, it is necessary to have a good knowledge of the radiation properties of the sound sources. Within a larger project [Je, JeKo], the radiation properties of a singer have been investigated and an artificial singer has been constructed to accurately reproduce the human voice. A new measurement method has been applied, because the non-stationary character of the voice does not allow for measurements with one scanning microphone as used in the measurements of e.g. loudspeakers.

## 2 Properties of the human voice

For the calculation of the directivity, a stationary, broadband signal is quite helpful. Unfortunately, the human voice varies quite strongly in both, amplitude and frequency distribution during pronunciation of e.g. a vowel. Additionally, the harmonic nature of the singing voice yields a rather discrete distribution of the sound energy.

The Fourier transform of a voice sample (picture to the right) shows the spectrum of the sung vowel "o". The energy is concentrated in the peaks from approx. 100 Hz up to about 5 kHz. The gaps between the peaks make it impossible to derive a directivity at these frequencies.

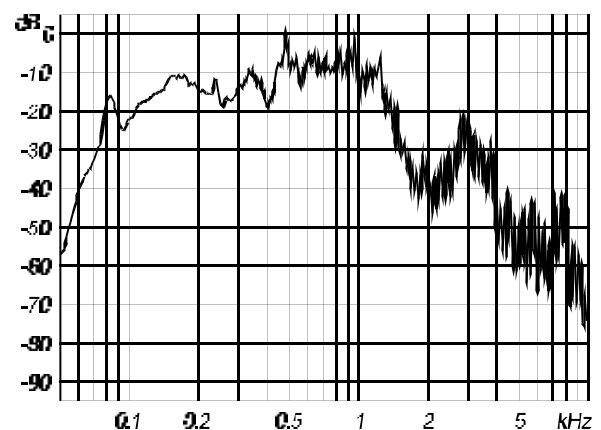


## 3 Measurement principle

A solution to this problem is to have the singer sing a glissando - i.e. a vowel with increasing pitch. The Fourier transform of this signal will contain energy from the lowest to the highest harmonics.

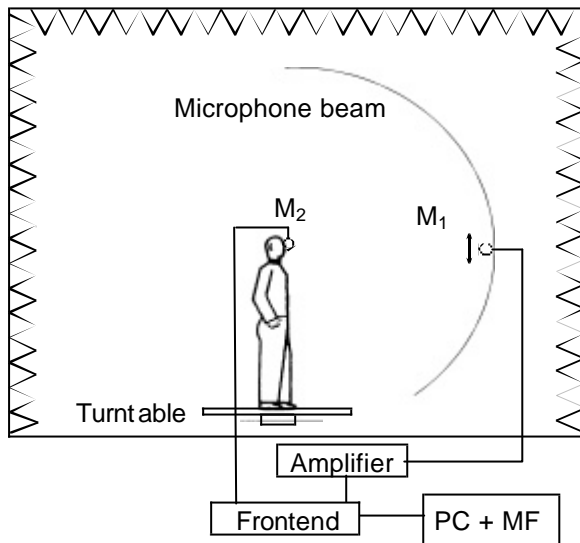
To the right, the spectrum of the swept vowel "o" is shown, sung from a bass singer from the lowest possible pitch throughout one octave.

The level fluctuations of the singing voice can be compensated with a reference signal from a second microphone as described in the measurement set-up.



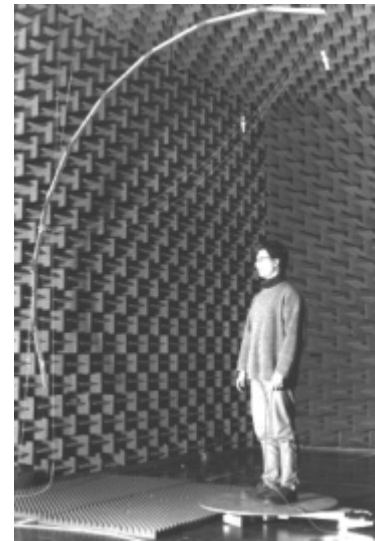
## 4 Measurement set-up

For the measurement procedure, the singer stands on a turntable (see pictures below).



To the left, the measurement set-up is sketched. The signal processing is performed within the computer-based software “Monkey Forest” (MF).

On the right, a photo from the measurement of a singer’s directivity is shown.



The reference microphone ( $M_2$ ) is taped to his or her nose and records the sound pressure near the mouth. The other microphone ( $M_1$ ) records the sound pressure at fixed distance from the singer’s mouth. The energy ratio of the spectra

$$S_{rel}(f) = \frac{S_{M_1}(f)}{S_{M_2}(f)}$$

does not depend on amplitude fluctuations of the source signal, provided that the signals contain enough energy.

The ratio can be normalised to an average sound pressure level at  $M_1$  which can be moved along a beam that accommodates directivity measurements from  $-40^\circ$  to  $+90^\circ$  elevation.

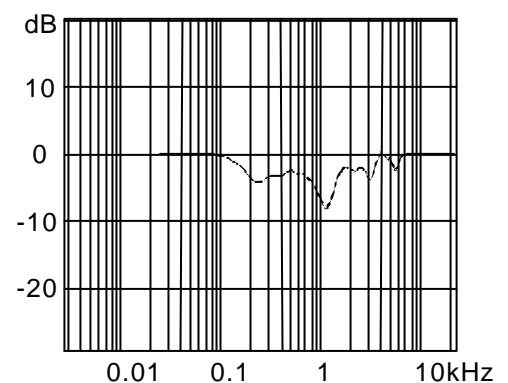
## 5 Compensation for the microphone position

Due to the microphone’s close position to the mouth and the head, an equalisation of the stationary spectrum recorded by  $M_2$  has to be performed. For this purpose, the artificial singer (described in the lower left part) was equipped with the nose microphone and was fed a “pre-whitened” signal that yielded a flat spectrum at a two meter distance.



On the left, the set-up for the measurement of the compensation spectrum is shown.

To the right, the spectrum of the signal from the nose microphone recording is plotted. The correction for the level loss was applied during internal processing of the signals, within the measurement program.



## 6 The artificial singer

The purpose of constructing an artificial singer is to achieve natural reproduction of the human voice with regard to both the frequency behaviour and the radiation properties. Preliminary investigations on a simple cylinder-shaped artificial speaker revealed insufficient sound power due to the limitations of the small loudspeaker as well as a radiation characteristic that lacks the details of a real singer's directivity. In close cooperation with the workshops at ITA, a human-like artificial singer was constructed that meets the requirements for the reproduction of a loud human voice.



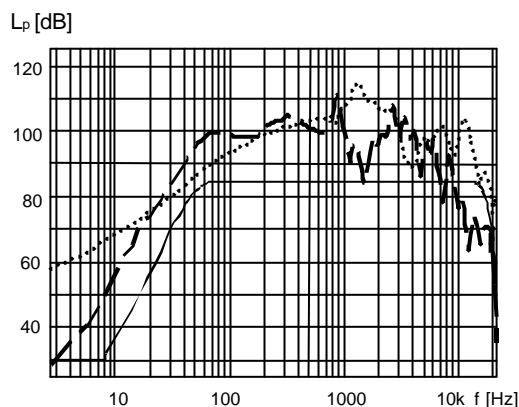
### Technical properties

- shape equals the ITA dummy head  $\Rightarrow$  natural diffraction
- one midrange loudspeaker (TPC 80 RW/4h) for the radiation through the mouth with
- guided airflow from loudspeaker to mouth to avoid standing waves
- two low-range speakers (Fane Studio 5M) with as a 4th-order symmetric bandpass system for the bass-voice reproduction
- opening of the bass reflex tube in the neck
- transition frequency between midrange and bass system: 150 Hz
- equalisation of the frequency response for both channels separately with the digital controller HUGO® [JK]

To the left, the interior of the artificial singer is shown. The two bass speakers can be seen, as well as the bass reflex tube. The head is formed from a gypsum form and consists of polyester. The upper part of the torso is made of seven handcrafted pieces of wood.

The plot to the right indicates the frequency responses of the installed midrange (red) and the bass loudspeaker (green) as well as the curve for the equalised singer (blue). The high and constant level that can be achieved with the equalised system extends 80 dB from below 70 Hz and allows reproduction of soprano to bass singing voices.

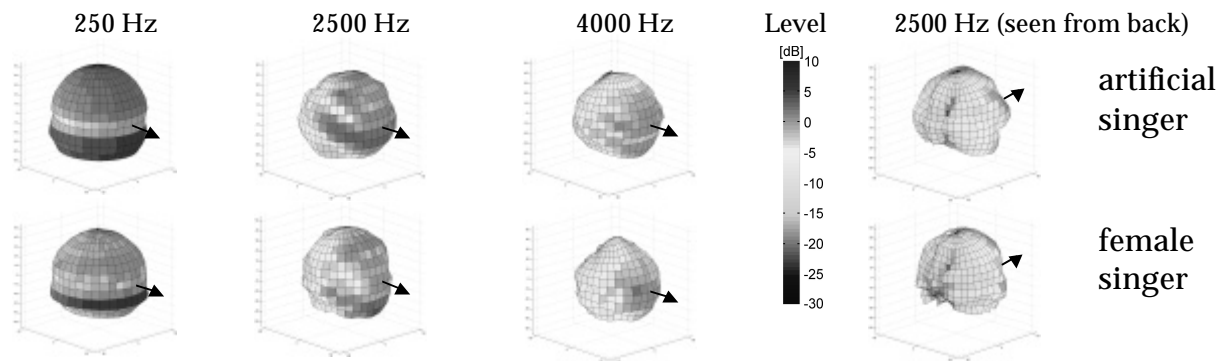
Subjective listening tests confirmed the realism of (1) the head's voice and (2) using measured impulse responses of the voice in choir auralisations [JeKo].



## 7 Directivity plots

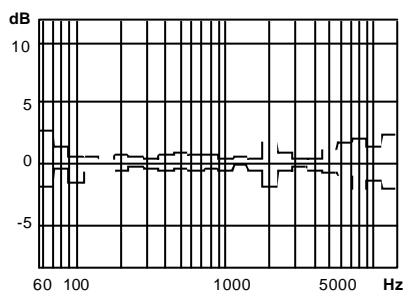
The directivity plots presented below depict the radiation properties of a female singer, compared to the radiation of the artificial singer. The ratio of the signals has been corrected for the microphone position and averaged in one third-octave bands. The levels are normalised to the value of the 0° elevation and 0° azimuth (arrow). The pictures on

the left show the directivity seen from the right front of the artificial singer (upper row) and of a female singer (lower row). They are in good agreement with former measurements [MeMa].

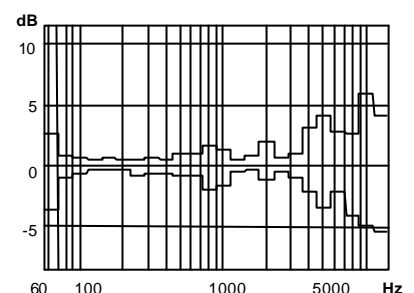


## 8 Uncertainty of the measurements

One source of measurement errors is the repeatability due to changing distance from the singer's position to the microphone  $M_i$ . The following graphs indicate the measurement error. The maximum error out of 10 measurements is plotted vs. frequency.



The graphs indicate the error for 0° azimuth (left figure), and for 180° azimuth (right figure). The cause of the increasing error is the insufficient energy content of the voice at high frequencies.



## 9 Conclusions

The method presented above allows for accurate and reproducible measurements of the directivity of non-stationary sound sources. Thanks to the simple measurement procedure, the radiation characteristics of different singers can be studied in detail. The results obtained so far indicate a good agreement between directivity measurements on human singers and the artificial singer and reveal interesting interference patterns that have not been measured before. This method could also be applied to directivity measurements of musical instruments.

## 10 Literature

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