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The recording angle – based on localisation curves

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ABSTRACT

The useful pick-up sector of a stereophonic microphone is indicated by the recording angle. It is based on phantom source shift data due to resulting inter-channel level and/or time differences. However, in related literature the recording angles of known microphones such as XY, Blumlein, AB, ORTF, OCT, etc. are differing because they are determined from different interpretations of these data. It is proposed to rest on the so-called localisation curve, which describes the directional translation of sound sources within the loudspeaker basis and corresponds with directional balancing results in practical recording situations. The newly defined "Recording Angle_75%" is proposed to be the suitable key value in the Tonmeisters' practice.

1. INTRODUCTION

It is a basic purpose of stereophonic microphones to pick up the directional information of the sound scene in order to achieve a corresponding perception of directional distribution and dimensions of sound sources during loudspeaker reproduction. Stereophonic microphones are particularly useful in cases where the number of sound sources is large, or where the sound source dimensions should be reproduced in proportion with the stage. For example, it is necessary to use a stereophonic pick up for the piano in order to avoid spot-wise imaging, rather, to achieve an adequate directional distribution of the sound source elements forming the shape of the piano close to reality. Not least for natural recording well-balanced directional imaging is desirable.

As is generally known the directional translation characteristics of stereophonic microphones are based on two fundamentally different effects:

- The psycho-acoustical effect of phantom source shift between adjacent loudspeakers due to inter-channel signal differences in terms of level and time.
- The physical generation of the interchannel signal differences due to the arrangement and directivity characteristics of the applied microphone capsules.

Both effects result in the so called localisation curve, showing the phantom source shift as a function of the input source angle Ω. This curve describes the directional translation characteristics of a stereophonic microphone. Its shape has the essential impact on the directional distribution of phantom sound sources within the loudspeaker basis.

How can we consider the localisation curve in practical recording situations? It will be shown below that the well-known recording angle does not provide reliable guidance for balanced and proper directional distribution of sound source elements on the stage. We propose to use a so called "Recording Angle_75%", which characterises the relevant part of the localisation curve correctly and therefore could describe the directional properties of a stereo microphone setup more sufficiently.

2. PHANTOM SOURCE SHIFT

Lateral displacements of the phantom sound source due to interchannel level differences ΔL and time differences Δt have been measured by many authors. Typical phantom sound source shift transfer curves $A_{\Delta L} = f(\Delta L)$ and $A_{\Delta t} = f(\Delta t)$ are plotted in Figures 1 and 2.

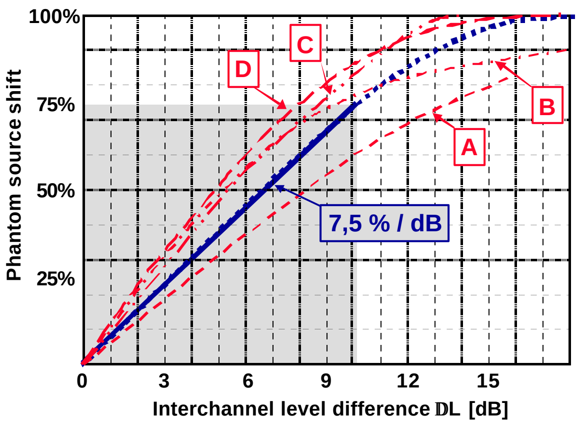

Fig. 1: Relative phantom sound source shift $A_{\Delta L} = f(\Delta L)$ (dotted thick curve after Wittek [1]) and center shift factor $Z_{\Delta L} = 7{,}5\ \% / \mathrm{dB}$ (thick line)
Curve A: After Leakey [2]
Curve B: After Mertens [3]
Curve C: After Brittain and Leakey [4]
Curve D: After Simonson [5]

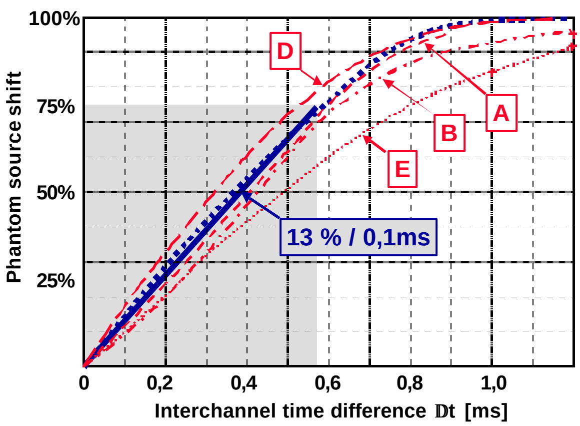

Fig. 2: Relative phantom sound source shift $A_{\Delta t} = f(\Delta t)$ (dotted thick curve after Wittek [6]) and center shift factor $Z_{\Delta t} = 13\ \% / 0{,}1\ \mathrm{ms}$ (thick line)
Curve A: After Leakey [2]
Curve B: After Mertens [3]
Curve D: After Simonson [5]
Curve E: After Sengpiel [6]

The following characteristics should be noted:

1. The phantom source shift is given in %. It has a constant relation in the loudspeaker basis and is independent of the listening angle, e.g. 30° or 60° [7].
2. The phantom sound source shift transfer curves depend on the characteristic of the audio signal. This explains significant discrepancies of measuring results from different laboratories (see curves A … E).
3. Particularly in the shift region > 75 % close to the loudspeakers the discrepancies are remarkable. The 100% shifting point (maximum value of level and time difference) is not exact.
4. Our calculations of localisation curves are based on the dotted thick sound source shift curves $A_{\Delta L} = f(\Delta L)$ and $A_{\Delta t} = f(\Delta t)$ (after Wittek [6])
5. The shape of both sound source shift curves shows a linear area in the center region A = 0% … 75 %
6. In this center region shift factors can be applied of approximately $Z_{\Delta L} = 7{,}5\ \% / \mathrm{dB}$ and $Z_{\Delta t} = 13\ \% / 0{,}1\ \mathrm{ms}$.
7. For small interchannel differences we can postulate an equivalence factor of about 0,06 ms/dB. - 1 dB level difference induces the same shift as 0.06 ms time difference.
8. Interchannel time differences > 0.6 ms may cause quality impairments with respect to sound colour and localization focus.

It has been shown in former papers [7], [8] that in cases where a combination of level and time difference is effective the phantom sound source shift in the center region can easily be calculated. If the phantom sound source is shifted due to ΔL and additionally due to Δt (same direction) the resulting shift is approximately the sum of both single shifts. It is

$$\mathbf{A\ (\Delta L, \Delta t) = A\ (\Delta L) + A\ (\Delta t)}$$

For example, the direction of a sound source picked up with an ORTF microphone is Ω = 30°. This microphone configuration implies interchannel differences of ΔL = 5 dB and Δt = 0.25 ms, resulting in $A_{\Delta L} = 37{,}5\ \%$ and additionally $A_{\Delta t} = 32{,}5\ \%$. The sum of both is A = 70%. If a standard two channel loudspeaker arrangement (listening angle 60°) is applied, A = 70%. corresponds with a shift angle of 21°. The ORTF microphone transfers the input source angle Ω.= 30° into the perceived angle of 21° during two channel stereo loudspeaker reproduction. If however we would use the two channels C and L or C and R of the standard surround loudspeaker arrangement (listening angle 30°), the phantom sound source would be perceived accordingly at 10,5°.

3. LOCALISATION CURVES

The localisation curve originates when the physical transformation of the microphone setup and the psychoacoustical transformation depicted in the ladder chapter are linked. A signal arriving at an input angle Ω is transferred into interchannel signal differences and these are then transferred into the related phantom source shifts (see chapter 2). Figure 3 illustrates this transfer chain:

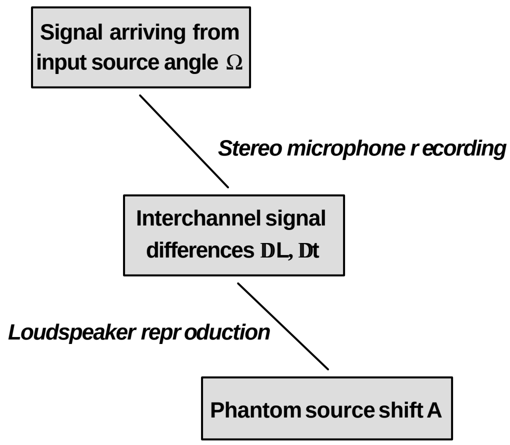

Fig. 3: Directional transfer chain

That means the directional transfer function determines the phantom source shift depending on the input source angle. In a mathematical form that is:

$$A_x = f_x(\Omega);$$

with Ω as the input source angle and A as the related phantom source shift in percent.

The **localisation curve** is the graph of the directional transfer function of a microphone configuration.

In Fig. 4 this relationship it is illustrated for the ORTF-Microphone. Ω is plotted in a range of [-90° , 90°] that means that sound incidents arriving from the front direction are considered. A is plotted as the percentage phantom source shift. In a standard stereo configuration +/- 100% corresponds to +/- 30°.

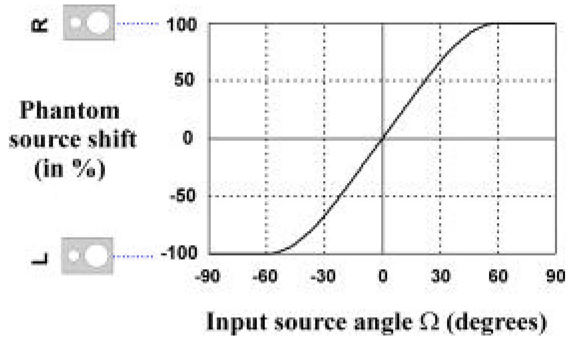

Fig. 4: Localisation curve of the ORTF-microphone (cardioids, 17cm, +/-55°)

The localisation curve is the characteristic representation of the stereophonic microphone configuration. It provides information on two relevant imaging properties. These are:

- The pick-up sector which results in a directional distribution of sources within the loudspeaker basis. (**recording angle**)
- The directional balance of sources in the loudspeaker base, resulting from the shape of the localization curve. This may be called "**directional translation**"

4. THE RECORDING ANGLE

In the literature and in Tonmeister´s common practice the recording angle plays an important role. It is the usual key value used to design the appropriate microphone configuration. The microphone directional imaging is supposed to be optimum when its recording angle matches with the angular range of the sound sources in the recording room. The Tonmeister has to trust in the given value when trying to use a special configuration. However, these values in the literature differ quite a lot, as the following table shows:

Setup	HUGONNET	SENGPIEL	WILLIAMS	WITTEK
ab *omnis, 50 cm*	**130°**	**180°**	**100°**	**74°**
AB *omnis, 100 cm*	**-**	**62°**	**-**	**36°**
ORTF *cardioids, +/- 55°, 17 cm*	**90°**	**96°**	**100°**	**102°**

Table 1: Recording angles of three 2-channel stereo microphones, as found in literature, see [9], [6], [10], [1], [11]

The deviations are caused by two effects:

- The 100% shifting points (maximum value of level and time differences) are not exact, they depend mainly on the audio signal (see Figures 1 and 2, curves A…E)
- There is no general rule on how to interpret the phantom sound source shift curves close to A = 100%. Where is the end of the useful part of the transfer curve?

On top of that, even if the Tonmeister has somehow got the correct recording angle, a new problem arises: The Tonmeister has to trust the directional balancing provided by a microphone with the recording angle as the only given characteristic.

However, also the shape of the localization curve has a significant impact on the directional balancing result. Figure 5 shows localisation curves of 4 different microphone configurations having the same recording angle:

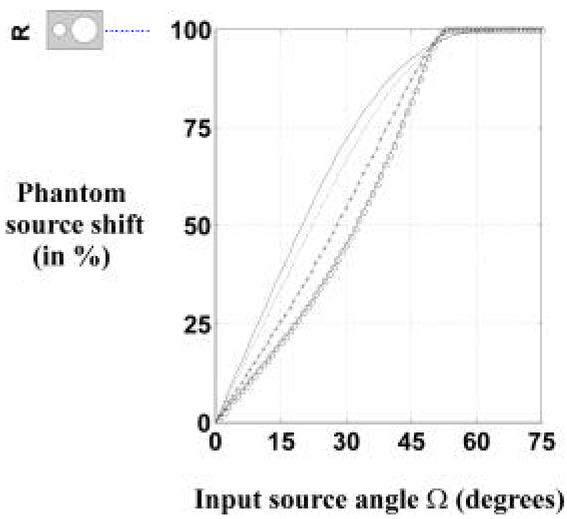

Fig. 5:
Localisation curves (plotted only for positive input angles) of 4 different microphone configurations, recording angle = const. = ca. 100°

Solid : ab, omnis, 39.5 cm
Dashed ORTF, cardioids, 17 cm, +/- 55°
+ + + XY, Supercardioids, coincident, +/- 54°
° ° ° quasi-Blumlein, fig. of eights, coincident, +/- 30.5°

According to the localisation curves the phantom source image of a recording will look clearly different. Figure 6 shows the resulting directional imaging of two instruments recorded by these four microphones (still having the same recording angle!) :

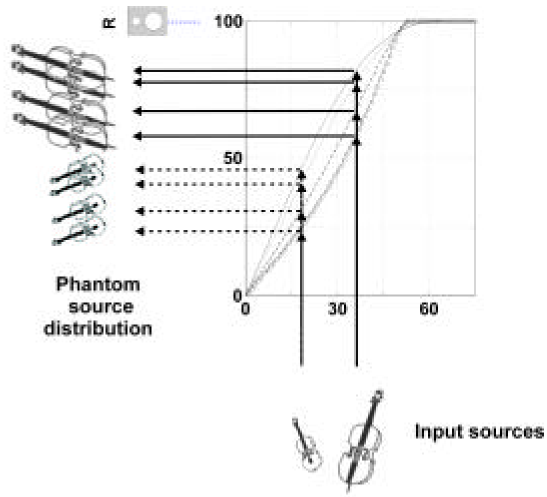

Fig. 6: Resulting localisation of two instruments using different microphone configurations with the same ***recording angle***: according to Fig. 5

The reason for these enormous deviations is found in the physics of the microphone's translation (input angle → signal differences). In particular, the two shapes of the transfer functions

DL = f (W)

Dt = f (W)

are different. For example, in the case of ab-configurations the shape of $\Delta t = f(\Omega)$ is effective (see Fig. 5 left curve), and in the case of coincidence configurations the shape of $\Delta L = f(\Omega)$ is effective (see Fig. 5 right curve). This can be studied more detailed by means of the Image Assistant (see Chapter 6).

The shortcomings of the recording angle cause confusion and may decrease the usefulness of this key value. However, when looking again at the localisation curve – the most detailed information about the directional behaviour of a microphone configuration – it can clearly be seen that deviations on both the psychoacoustic and the physical side are present in particular in the outer area of the curve where the phantom sound source approaches one of the loudspeakers:

This area is far from being the most important imaging area in a stereo recording. So why has it such a big influence when defining the recording angle? This influence is eliminated when going to a different approach:

In Figure 7, the configurations of Figure 6 are varied to show that in the most important imaging area (say between –75% and +75%) the different microphone setups do not differ very much any more. Now, they were designed to match not in the outer area but in the very much more important inner area of phantom source imaging. The point of intersection is defined at A = 75 %.

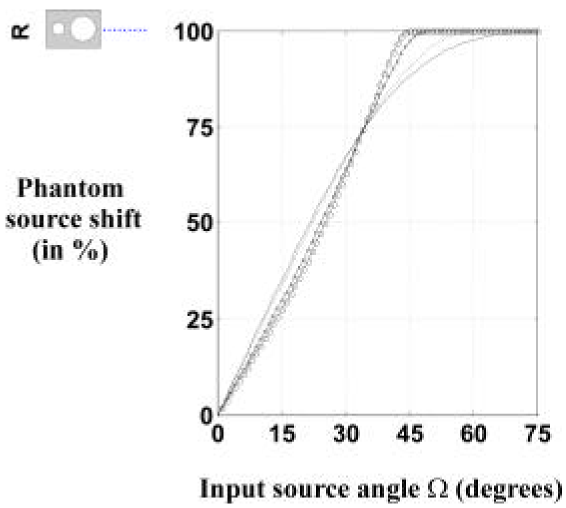

Fig. 7:
Localisation curves (plotted only for positive input angles) of 4 different microphone configurations, recording angle_75% = const. = ca. 70°

Solid :	ab, omnis, 36.5 cm
Dashed	ORTF, cardioids, 17 cm, +/- 55°
+ + +	XY, Supercardioids, coincident, +/- 60°
° ° °	quasi-Blumlein, fig. of eights, coincident, +/- 38.5°

The result is a surprisingly good matching of the different curves, that means they in fact have a very similar imaging behavior. Figure 8 shows again the example "string quartet", now the resulting imaging of the new, localisa-tion-matched configurations is plotted.

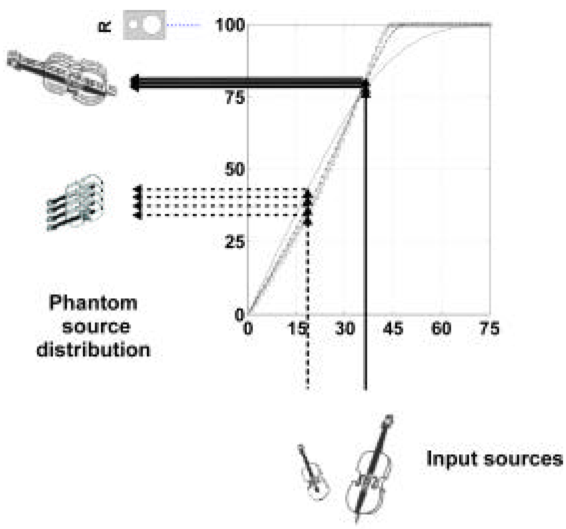

Fig. 6: Resulting localisation of two instruments using different microphone configurations with the same ***Recording Angle_75%***: according to Fig. 7 (compare with Fig. 6 !)

This result even stays similar when calculating the curves according to a different psychoacoustic basis, mainly the intersection points for 100% phantom source shift change when different experimental data is applied.

5. THE RECORDING ANGLE_75%

This leads to the definition of a new, representative (it represents the localisation curve optimal) characteristic of a microphone configuration:

Recording Angle_75%.

The Recording Angle_75% is the angular range of input source directions that leads to corresponding phantom source shifts in the range +/- 75%.

Experience has shown that the 75%-range of phantom source shifts is Tonmeister´s most important creative area. The Recording Angle_75% is the key value needed for directional balancing with a stereo microphone. It avoids confusion or room for different interpretations.

Using any 2-channel-stereo microphone the assumption of linear imaging within an area of +/- 75% phantom source shift can be made. Table 2 shows the Recording Angle_75% of some popular 2-channel stereo microphones:

Name	Setup	Recording Angle_75%
XY	Cardioids, +/- 45°, 0 cm	142 °
ab	Omnis, 40 cm	60 °
AB	Omnis, 100 cm	24 °
ORTF	Cardioids, +/- 55°, 17 cm	68 °
Blumlein	Figures of eight, +/- 45°	58 °

Table 2: Recording Angle_75% of some popular 2-channel stereo microphones

Using 3-channel microphones the shape of the localisation curve gets more complex because now the linearity of the curve is dependent on the design of the microphone configuration. In [1], [12] [13] it has been shown which prerequisites a 3-channel-setup has to fulfill to avoid non-linearity and impairments on sound colour and focus. However, the newly defined recording angle is a useful key value regarding these setups, too. It avoids present confu-sion about the recording angle.

Table 3 shows the Recording Angle_75% of some 3-channel stereo microphones:

Name	Setup	Recording Angle_75%
OCT 70	L,R: supercardioids, +/- 90°, 70 cm C: cardioid, front offset 8 cm	80 °
OCT 50	L,R: supercardioids, +/- 90°, 50 cm C: cardioid, front offset 8 cm	96 °
INA 3	L,R: cardioids, +/- 60°, 92 cm C: cardioid, front offset 26 cm	86 °
INA 5	L,R: cardioids, +/- 90°, 35 cm C: cardioid, front offset 17.5 cm	128 °

Table 3: Recording Angle_75% of some 3-channel stereo microphones. See [13] and [14] for configurations details

Filling the sound stage

Generally the Tonmeister wishes to make use of the whole phantom source area. Therefore the localisation curve should have an intersection point with the 100%-line at any input angle. The use of the Recording Angle_75% would make no sense if this prerequisite is not fulfilled. Imaging will then not be linear within the 75%-marks. Examples of microphone setups not matching this prerequisite are: too closely spaced omnis (25 cm), coincident cardioids with too narrow angle of axis (35°).

This prerequisite is (at least for many Tonmeisters) valid also when the listener is moving in a defined degree. Now, stability cues of the microphone design will play a role.

The following Figure 9 illustrates the way in which the characteristic "Recording Angle_75%" is used in practice. When deciding which section of the sound sources, e.g. of an orchestra, will be *linearly* represented within the +/-75% phantom source shift region between the loudspeakers, the Tonmeister is defining the Recording Angle_75% for the current situation:

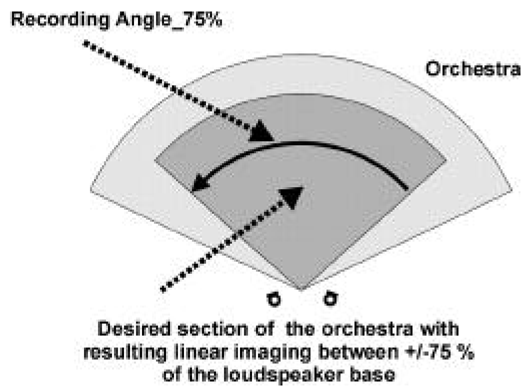

Figure 9: Finding the Recording Angle_75% for an orchestra recording

It has been shown that the Recording Angle_75% can be a useful, in most cases sufficient description of the directional imaging of a stereo microphone. However, details of the imaging can only be seen from the localisation curve, especially in cases where the design of three-channel stereo microphones is intended. The next chapter will introduce a quick and easy way to view the localisation curve of arbitrary 2 or 3-channel-microphone setups.

6. THE "IMAGE ASSISTANT": GRAPHICAL REPRESENTATION OF LOCALISATION CURVES

The "Image Assistant v2" is an online JAVA tool (on www.hauptmikrofon.de, [11]) to calculate the localisation curves of arbitrary stereo microphone setups. It is based on the theoretically and experimentally derived data of chapter 2. As this tool was described in [12] only a short summary shall be given here.

The input data are:
- stereo microphone setup, see Fig. 10
- optional: electronical manipulations
- loudspeaker configuration
- listening position

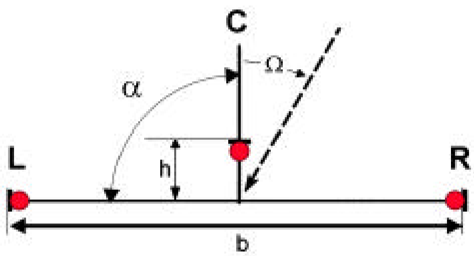

Fig. 10: "Image Assistant": Input parameters of a L-(C)-R stereo setup Ω is one sound incident angle

The output is:
- the localisation curve plus Recording Angle_75%
- the actual loudspeaker signal differences at the listening position
- the directional distortion of non-sweet-spot listening

Details about the design and the operation of the Applet can be found in [11].
Additional experiments were performed to study the localisation of phantom sources derived from contradicting signal differences. These data are included in the calculations of the "Image Assistant v2.0" and important to have knowledge about the directional distortion of non-sweet-spot listening. The results are published in [15].

Using this tool it is an easy thing for everybody to design microphone setups that have suitable properties for a specific purpose. It is possible to study the advantages and disadvantages of each setup and also to learn about microphone imaging in a practical way.

7. CONCLUSION

Problems of finding a suitable stereo microphone configuration in practice have been shown. The disadvantages of trusting the “Recording Angle” as the only localisation-describing key value are demonstrated. With the localisation curve and the newly defined characteristic “Recording Angle_75%” the directional properties of a stereo microphone setup are described sufficiently. In particular, the “Recording Angle_75%” provides a concentrated and therefore useful way of describing the setup’s localisation behaviour. Regarding the Tonmeister’s intention of creating a balanced and proper directional distribution of phantom sources within the loudspeaker base(-s), this key value is a suitable information to support his decisions.

The Recording Angle_75% is derived from the localisation curve which is the correct and detailed description of a microphone setup’s directional transfer function. It is defined as that pick up sector which is perceived in the central area +/- 75% of the loudspeaker base (the complete area is +/- 100%). Within this sector a linear directional translation is ensured and spatial distortions are avoided.

A useful tool to calculate these localisation curves and the Recording Angle_75% as well as to illustrate the microphone’s properties is the “Image Assistant”. An online JAVA Applet that can be used on www.hauptmikrofon.de [11].

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