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# The Sound-Characteristic of the Vienna Philharmonic Orchestra Investigated with Digital Measuring Methods

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# THE SOUND-CHARACTERISTIC OF THE VIENNA PHILHARM( )IC ORCHESTRA INVESTIGATED WITH DIGITAL MEASURING METHODS

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## SUMMARY

*Some of the outstanding orchestras of the world are said to have a special "Sound". Various explanations of this phenomenon can be heard, for example: the local tradition of playing-technique, special instruments, etc., but up to now no scientific investigations were made in this field. This paper describes the application of special measuring methods (illustrated by means of investigations on "french-horns") to answer the question: Is there any significant difference in sound characteristics between the Vienna Philharmonic and other outstanding orchestras (for instance the New York Philharmonic), and if, what causes this difference? With "BIAS", a digital method for measuring the acoustical behaviour of brass instruments, the influence of the instrument on the steady state and transients parts of the orchestral sound is determined. After that, the interaction player-instrument is examined to evaluate the influence of the player. 3-D plots of transient parts of the sound illustrate the differencies. Various sound examples are given to prove the accuracy of the applied methods.*

## 0. INTRODUCTION

Sound differences of orchestral interpretation have been known throughout the history of instrumental music. In spite of the relatively uniform notation of the scores used, the way in which orchestral music was played in the various musical capitals of Europe differed considerably. This is hardly surprising since the interpretation was done on different regional instruments and was subject to the given tradition of musical practice, the intellectual climate and the social setup in the largely closed cultural environments of that time. The opportunity for direct but subjective comparisons was given only to widely traveled musicians and performers as well as to a small elite audience.

With the use of mass media in the 20$^{th}$ century the situation changed radically: International standards for orchestral sound have developed since. In an "International Concert" it is only a few orchestras which can easily recognized (for instance some French and Eastern orchestras by the vibratos of the wood and brass wind instruments). The socalled "Viennese Sound" is a somewhat more complex phenomenon. Besides a special tradition of musical education and practice, it also involves the use of particular wind instruments. The "Vienna F-Horn" and the "Vienna Oboe" are used only by orchestras of the Viennese tradition. They, in addition, prefer trumpets and trombones with a narrow scale.

Considering modern recording techniques and the use of CDs as well as the fact that a lot of money is spent by people consuming music produced by orchestras, the fact of a "Particular Orchestral Sound" as an argument for selling ones recordings gets interesting for music managers. Since there is no essential difference in playing-quality between the top orchestras of the world, the question of particular Sound Quality of an orchstra gets more and more important.

As many crit conductors and important persons of the international music scene affirm the existence of a typical sound of the orchestras of the Viennese tradition, it is of interest, therefore, to examine this question with objective measuring methods and, in particular, the way in which the personality of the musicians and the particular instruments used contribute to this phenomenon.

The judgement of orchestral sound quality (including spectral information and especially the onset and transient behaviour of the instruments) is strongly connected with a special and very complex sort of "acoustic pattern recognition". Because it is -up to now- impossible to perform this pattern recognition by computer like the ear and brain of human beings does it during the reception of music, we chose the method described below.

## 1. METHOD

* At first the acoustical behaviour of the musical instruments used by the Vienna Philharmonic is measured and compared with the instruments used by other top orchestras. Different measurement arrangements for strings, woodwinds and brass wind instruments are used.

* The second step is to excite the instruments with an artificial playing device [1] in an anechoic chamber. Sound produced in this way is used for comparison with the sound produced on the same instruments by real players in the same room and under the same conditions. The results of such comparisons allow the calculation of the influence of the player on the sound.

* After the investigation of the instrument alone and the combination instrument-player, statements on the differences of sound quality, intended by the musician (stylistic ideas) and caused by the instrument (spectral envelope, harmonic structure, onset behaviour etc.) can be made.

* Finally after the measurements of the peculiarities of sound and interpretation of individual orchestra musicians and their instruments, the last step is to relate these data to the sound of the whole orchestra. In order to determine the contribution of these data to the sound quality of the whole orchestra, recordings of concerts of the Vienna Philharmonic, New York Philharmonic, Cleveland Orchestra, Orchestra National de France, London Symphony Orchestra, etc. during a period of three years (Großer Saal des Wiener Musikvereins, Wiener Konzerthaussaal) were made.

It can be easily seen, that the volume of this project is too extensive to be discussed here in detail. Therefore in this paper the applied methods and some results will be explained by means of our investigations on the contribution of the Viennese F-Horn to the particular sound quality of the Vienna Philharmonic Orchestra.

## 2. THE VIENNESE F-HORN. PRINCIPLES OF CONSTRUCTIC

Only in Vienna a special type of french horns is used, the Wiener F-Horn, whilst worldwide the musicians play on "Double Horns" and a few on "Triple Horns". From the point of an engineer, such an instrument is a tube with oscillating air (including a regime of standing waves) inside (Fig. 1 ). The musician can play tones only at frequencies which support the existence of standing waves inside the tube. The position of these socalled resonance frequencies (musicians know them as "natural tones") depends on the length and cross section of the tube (Fig. 2 ). Therefore the acoustic behaviour of a horn is mainly determined by these parameters.

Fig. 3 shows the differences in construction between the two types of horns (a schematic picture of the Viennese type on the left side, the double horn on the right). For both types of instruments the tube (length about 3.6 meters) consists of a short conical part (about 20-30 cm) at the beginning of the instrument which leads from the mouthpiece to the cylindrical section (including the valve mechanism which provides the player with the full chromatic scale over the playing range) with a length of about 1.5 - 1.8 m. Finally a conical part is added, which leads to the bell (with a somewhat exponential flare) of the instrument. The peculiarity of the detachable "crook" (the first 1.2 meters of the instrument) in the case of the Viennese horntype has no acoustic influence on the radiated sound or playing technique (but some advantages for practical use: in former times the musicians took a short conical tube instead of the crook and changed the tune of the instrument from "F" to "b").

## 3. THE LENGTH OF THE TUBE AND ACOUSTICAL CONSEQUENCES.

The length of the vibrating air column of a french horn is about 3.6 meters. A double horn player can choose (with the help of an additional valve called "thumbvalve") between the above mentioned tube and a shorter one with a length of about 2.7 meters. In the case of a triple horn the player is provided with three tubes (3.6 m, 2.7 m, and 1.8 m, which correspondend to a tuning in "F", "b" and "high f"). In contrast to the Viennese hornplayer who works over the whole playing range with the 3.6 m air column, the double and triple horn players uses the shorter air columns for the middle and high register .

### 3.1. Energy requirement and onset behaviour.

Considering the fact that a longer air column means more mass and the musician has to provide the vibrating air column with energy ( = air pulses), it is clear, that the double horn requires less energy for producing the same standing wave amplitudes during the onset process than the Viennese type of horn (Fig. 4 ). This effect is important only for the beginning of the tone, because at the moment the regime of the standing waves is settled, the player has to compensate only the energy losses caused by friction and sound radiation. Therefore this effect gets importance only for playing many "staccato notes". As the shape and the duration of the beginning of musical tones is strongly related to the musical context and has to be seen in relation to the metrum (for "Presto" about 40 ms, "Adagio" up to 120 ms [ 2 ]), the musician is forced to compensate the acoustic behaviour of his instrument.

**3.2. Influence of t length and cross section on spectra of radiated sound.**

In addition to the mentioned influence of tube length on playing technique for staccato notes (concerning the onset behaviour), the increased energy requirement of the longer tube influences the spectrum of the produced sound too. In addition to this, the diameter of the cylindrical section of the Viennese type of horn is about 10.7-10.8 mm, whilst the diameter of double horns varies between 11 and 13 mm. The reduced diameter of the Viennese horn causes a higher energy loss (at the walls) and therefore requires a higher energy input for the same amplitude than a double horn with its larger cross section.

How does the player manage an increase of energy input? The lip-action of the player is similar to the function of a valve [ 3 ] which provides the instrument with air pulses by opening and closing. Opening and closing 440 times per second means, that the musician plays an a=440 Hz. As the playing frequency must not change and the displacement of the lips is limited, a higher input only can be managed by shortening the phase of opening and closing. If we look at the quantity of air passing the lip-valve during one cycle, we can see that the shape becomes similar to a rectangular wave form (Fig. 5 ). Fourier Analysis of such a soundwave showe an increase of the higher partials which means, that in principle a tone produced on a Viennese F-Horn compared with a tone played on a double horn sounds brighter.

This effect do not occure if the horns are blown with an artificial blowing device which means, that the different sound quality is caused only by the interaction between the player and the instrument.

**3.3. Differences in sound spectra.**

If we look at tones (with the same frequency) played by various musicians with the same instrument and under the same conditions, we must accept that the spectra differ extremly concerning the number and amplitude of the harmonics, even if we compare only tones with equal sound pressure level (Fig. 6 ). That phenomenon is quite clear if one remembers that the radiated sound depends on the transfer function of the instrument and (primarily) on the input spectrum of the musician. In order to evaluate the difference in sound spectra between Viennese and other horntypes without the individual influence of the player, the use of various Formant Theories [ 4 ] for explaination must fail. On the contrary the method of linear regression seems to be useful [ 5 ].

Fig. 7 represents the results of 200 compared spectra for three tones and a dynamic level of mezzoforte. The data were obtained from "crescendos", played in the anechoic chamber. Linear regression was calculated only for sounds with equal sound pressure levels. The diagram of Fig. 7 shows that sound character of the Viennese F-Horn is represented by a particular richness of higher partials. The difference increases with increasing (musical) dynamic and frequency. This means that the impression of "fortissimo" starts on Viennese horns at a lower sound pressure level than on double or triple horns with their shorter tubes. Beside this, the Viennese horn player is provided by his instrument with a larger dynamic range.

### 3.4. Tube length and spectral dynamics.

Taking in account that, within the same range of radiated sound pressure level, the Viennese horn provides the player with a larger variety of "sound colors", it is easier for the musician to change the sound color playing a Viennese horn (without changing the loudness) than playing on a double horn. This enables the player to produce a sound which comes close to his intention and to the character of the interpreted music. Using the shorter tubes of the double and triple horns reduces the dynamic range and causes a more uniform sound color.

The diagrams of Fig. 8 give an impression of the differences between the spectral dynamic range of the Viennese Horn and the three tubes of an triple horn. Even at the same tube length (the two diagrams on the left) the Viennese type has a larger range of variation caused by the smaller cross section. The data were obtained from crescendos (84-97 dB) played in the anechoic chamber of our Institute. The curves of the various harmonics are related to the increase of the intensity of the tone by 1 dB.

### 3.5. Acoustical behaviour - tested with BIAS.

It is well known that the measurement of the input impedance of brass wind instruments gives good information on the quality of these instruments. Fig. 9 shows such curves ( impedance versus frequency) for the three lengths of tubes. The measurement was done with BIAS (Brass Instrument Analysing System). This computer aided measurement system was developed by Th. Ossmann, H. Pichler and the author for evaluating the quality of brass instruments. Detailed informations are given in a paper presented at the 87$^{th}$ Convention of the AES in New York [ 6 ] and [ 7 ]. A block diagram of the measurement arrangement shows Fig. 10.

A comparison of the three input impedance curves of Fig. 9 shows exactly the characteristic behaviour of the three tubes. Note that with equal excitation energy the shortest tube (high f-horn) produces the highest impedance peaks. This represents exactly the the situation of energy distribution inside the tube (in the plane of the lips inside the mouthpiece). Another important effect of the different tube length on playing technique can be obtained from these impedance pattern: The distance between the various peaks at the frequency axis is -depending on the length of the tube- quite different.

### 3.6. Tube length and clean attack.

At first, the impedance peaks of the shorter tubes are significant higher. This means an easier attack for the player. Second, the distance between two peaks is shorter in the case of the longer tube. This means, that the Viennese player has to tune his lips more exactly to avoid the excitation of the instrument with a non desired frequency which has its impedance peak in the neighbourhood of the desired frequency ("horn-crack"). Generally, the chance to "get" the desired frequency is in the case of the shorter tubes better than in the case of the 3.6 m tube of the F-Horn.

## 4. VALVE SYSTE[illegible] AND THE MICROSTRUCTURE OF TONE TRANSITIONS.

All brass instruments are provided with valves which extend the tube in length inserting an additional air column in the cylindrical section. The "first" valve lowers all impedance peaks of the tube by two semitones, the "second" by one semitone and the "third" by three semitones. This is necessary to get the full chromatic range between the natural tones (resonance frequencies of the fixed tube). All types of horns (with the exception of some "French" horns which use sometimes piston valves) are provided with rotary valves. In contrary the Viennese F-Horn is provided with the "Vienna Valve", a sort of double piston valve.

It is interesting that every (professional) musician can tell you at once and without having seen the player with his instrument, if a certain slur is played with rotary or piston valves, but he never can explain which is the characteristic difference in sound. The answer you get is always: " It sounds like a piston valve, or it sounds like a rotary valve".

### 4.1. Rotary valve and Vienna valve. Differences in design and function.

The principle differences in design and function shows the upper part of Fig. 11. If the musician plays two tones "legato" he depresses the valve. At the same time he changes (increases or decreases) the tension of his lips to tune the vibration frequency of his lips according to the new frequency. During that action (where only the starting point and the end of both, pressing the valve and tuning the tension of the lips must be synchronized) there exists always one point at which the mechanical device inside the valve has a position in the middle between depressed and non depressed ("half depressed", lower part of Fig.11). It is of interest that in this position the Vienna valve offers the vibrating air two paths (and only two paths) whilst the rotary valve opens at least four and more paths. Because of the effect of superposition this causes mostly a "break down" of the standing wave system inside the tube for a short time duration.

In order to investigate these phenomenons caused by different valve systems we used BIAS again, but instead of a sinus sweep for excitation we took several fixed frequencies between the frequency of the starting tone and the frequency of the destination tone and moved the valve slowly with the help of an electrical motor. Fig. 12 shows the results of this measurement for the Vienna valve and the rotary valve in the case of a semitone-slur. These diagrams represent the impedance (air pressure) situation in the mouthpiece for the lips of the player during that slur. It can be easily seen that the low impedance valley at the rotary valve graph is responsible for the above mentioned "break down" of the standing wave system which can be heard by the listener as a short noisy effect. In contrary to this the situation at the Vienna valve graph: the impedance ridges at every time during the slur enable the player to let the two tones flow one into another.

It is not enough place here to discuss the consequences for playing technique, because this field is very complex and depends strongly on the used type of instrument and the played frequencies. For trumpets, to give an example [Fig. 13 ], the situation is sometimes quite the opposite [ 8 ], [ 9 ].

## 4.2. Graphic representation of the radiated sound events during to  ransitions.

The duration of such typical noise bands occuring at legato playing is about 20-60 ms. This requires a hard/software system which allows a three dimensional plotting of the analyzed sound events (frequency - amplitude - time). In addition to this the analysis of extreme short parts must be possible. For this purpose we use the Sound Tools - an integrated workstation for acoustic, speech, music and signal processing, developed at the Austrian Academy of Science [ 10 ]. Fig. 14 shows the differences in sound for an interval of a sext played with a Viennes and a double horn.

## 5. DISCUSSION

It was shown by the example of the "horn" that there are differences in the acoustical behaviour between instruments used in Viennese Orchestras and worldwide used instruments. As the interaction of the player and the instrument represents (in the physical sense) a circuit in which one part influences the action of the other, the produced sound can be seen as the complex sum of the intention of the musician and the acoustical behaviour of the instrument. For the Viennese F-horn it means:

* Generally a "brighter" sound for the stady state phase of tones
* A larger range of dynamic level (supported by the impression of fortissimo at lower levels)
* Better support for changing the sound color
* Better support for playing slow and lyric passages of music (valve system)
* Less support for playing quick and more technical (in the musical sense!) passages
* Requires higher concentration tuning the tension of the lips due to the desired frequency
* Requires more energy for staccato notes and the settling up phase.

## 6. VERIFICATION WITH ORCHESTRAL SOUNDS.

As the horns are a part of the orchestra, the sound of the whole orchestra must contain the above mentioned particularities (in the steady state and transient parts). Sound examples can demonstrate this very good. Many problems arise, if one tries to show the difference by computer. The method of linear regression only works if the orchestral sound is dominated by the horns (i.e. "fortissimo" passages at symphonies of Bruckner, Mahler, etc. or solo-concertos). Typical differences of the k-values are about 0 - 0.45, but these values do not represent the impression of the audition really. Some success we had using Sound Tools performing a cepstrum with various coefficients. Fig. 15 gives an example for that method.

## 7. CONCLUSION

It was demonstrated that using modern techniques of data acquisition and analysis, it is possible now to verify the existence of differences in the sound of top orchestras and to point out the background with physical methods.

## 8. ACKNOWLEDGEMENT

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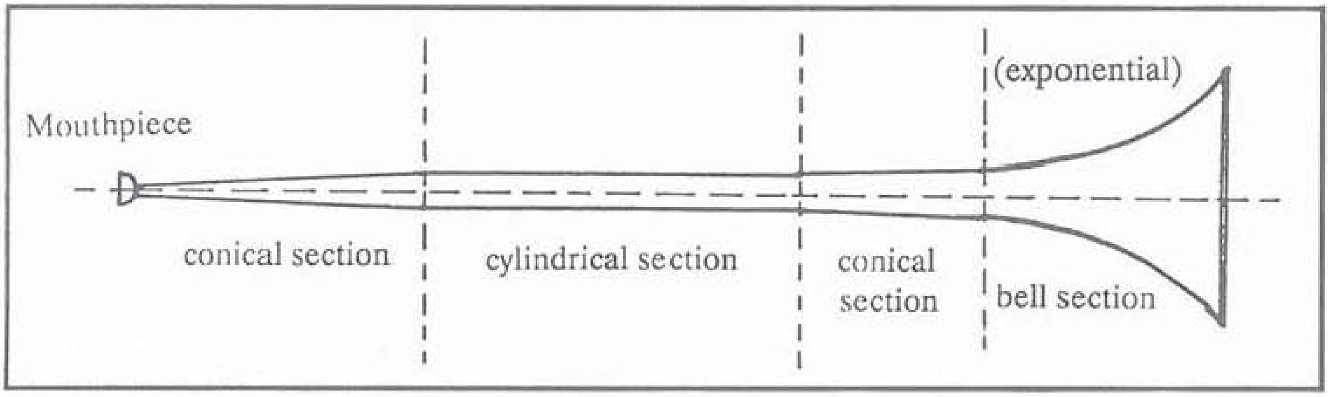



Fig.1: Simplified schema of a brass wind instrument.

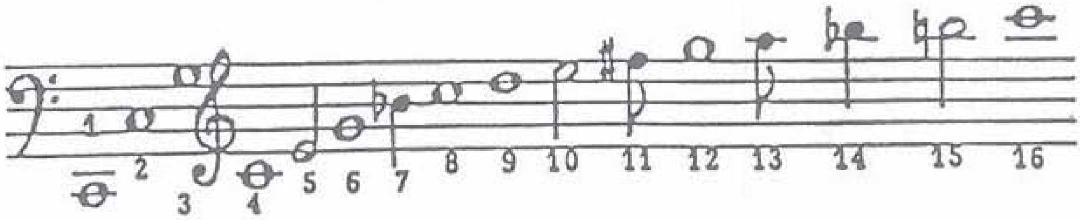



Fig.2: The first 16 natural tones (resonance frequencies) of a brass instrument. The value of the written note indicates the factor of correspondence between the resonance frequency and the musical note.

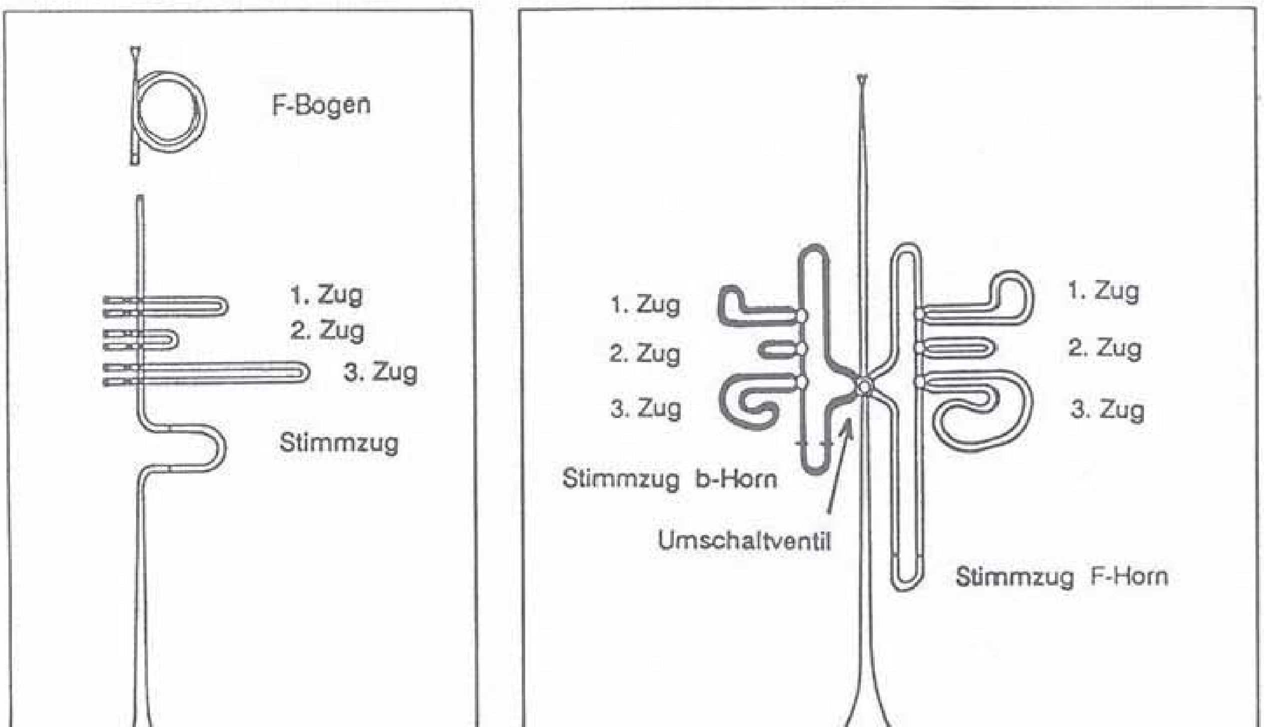



Fig.3: Schematic representation of the differences in construction between a Viennese F-Horn (left side) and a Double Horn (right side).

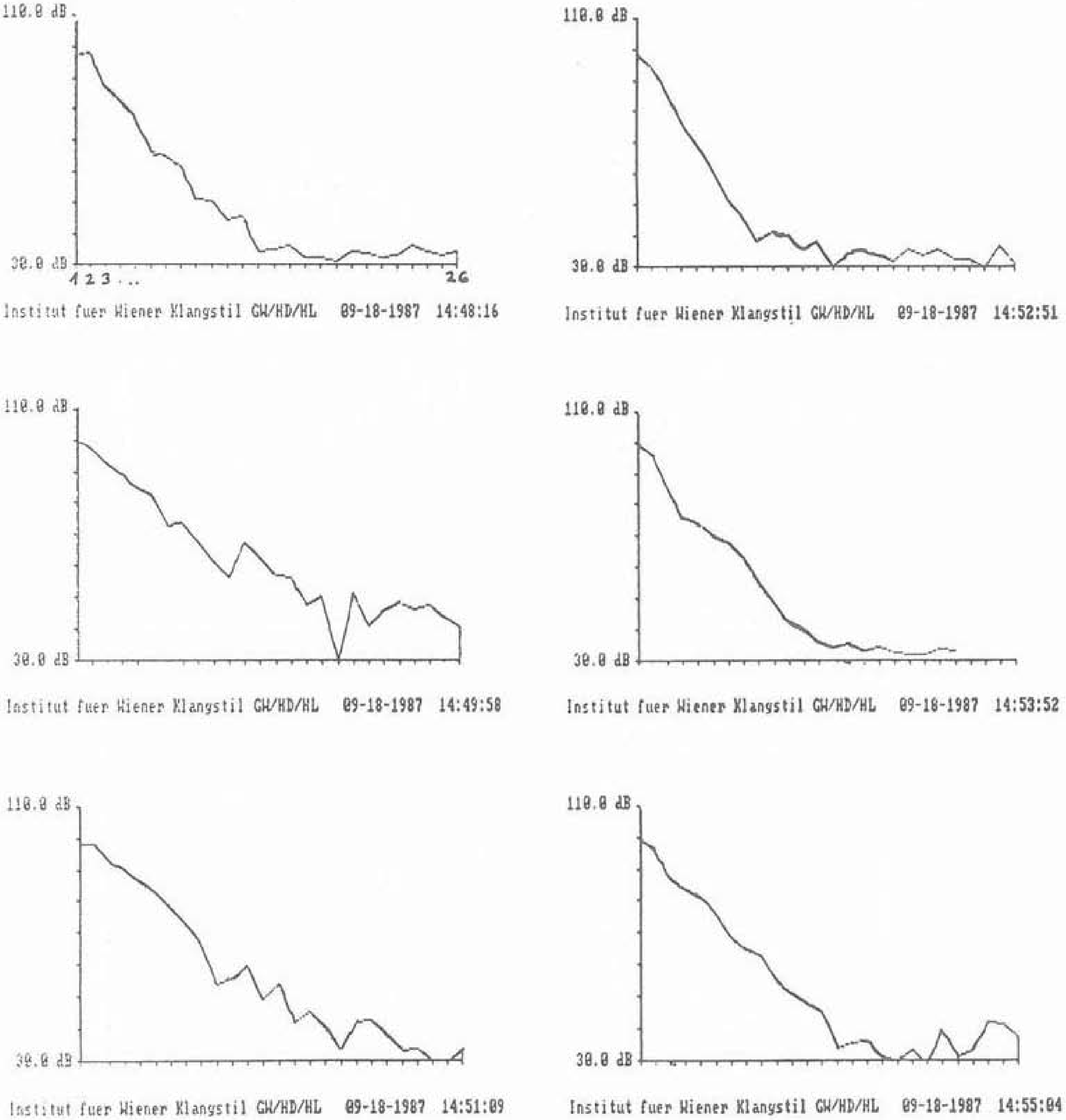



Fig.6: Six different players on the same instrument under the same conditions playing a f=350 Hz with "mezzoforte". Horizontal axis: Number of the harmonics.

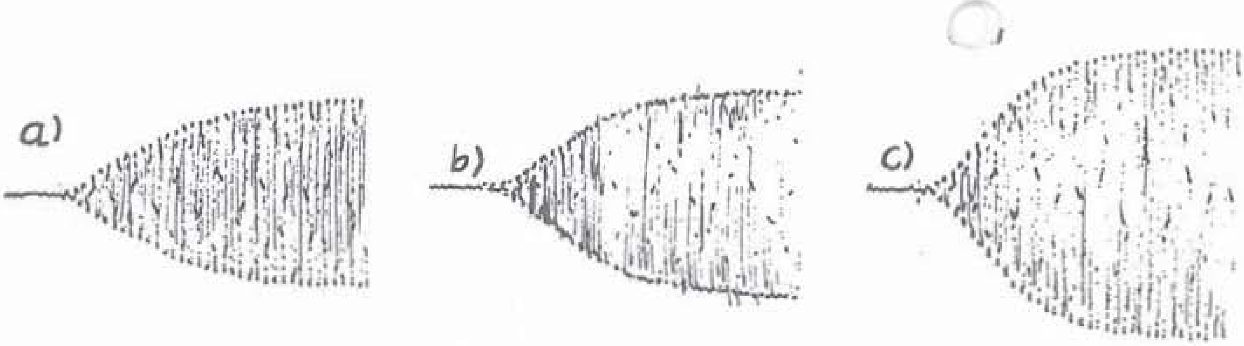



Fig.4: Time function of the standing wave system inside the tube (in the mouthpiece in the plane of the lips) for the beginning of the tone **f**= 350 Hz and three different tube lengths (a=3,6 m, b=2,7 m, c=1,8 m) which correspondend with the F-Horn, b-Horn and high f-Horn.

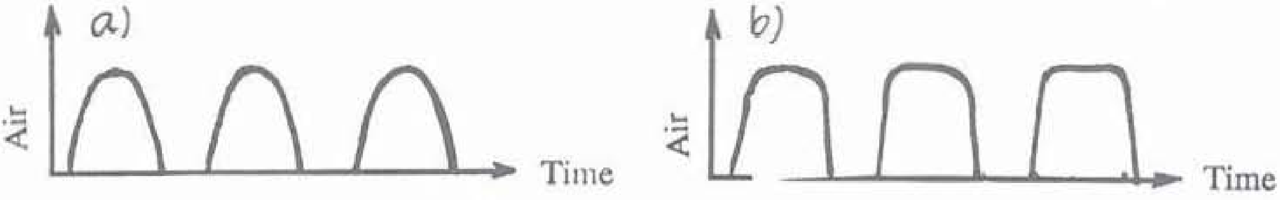



Fig.5: Quantity of air passing through the "lip valve" of the player versus time (a = normal input, b = increased input).

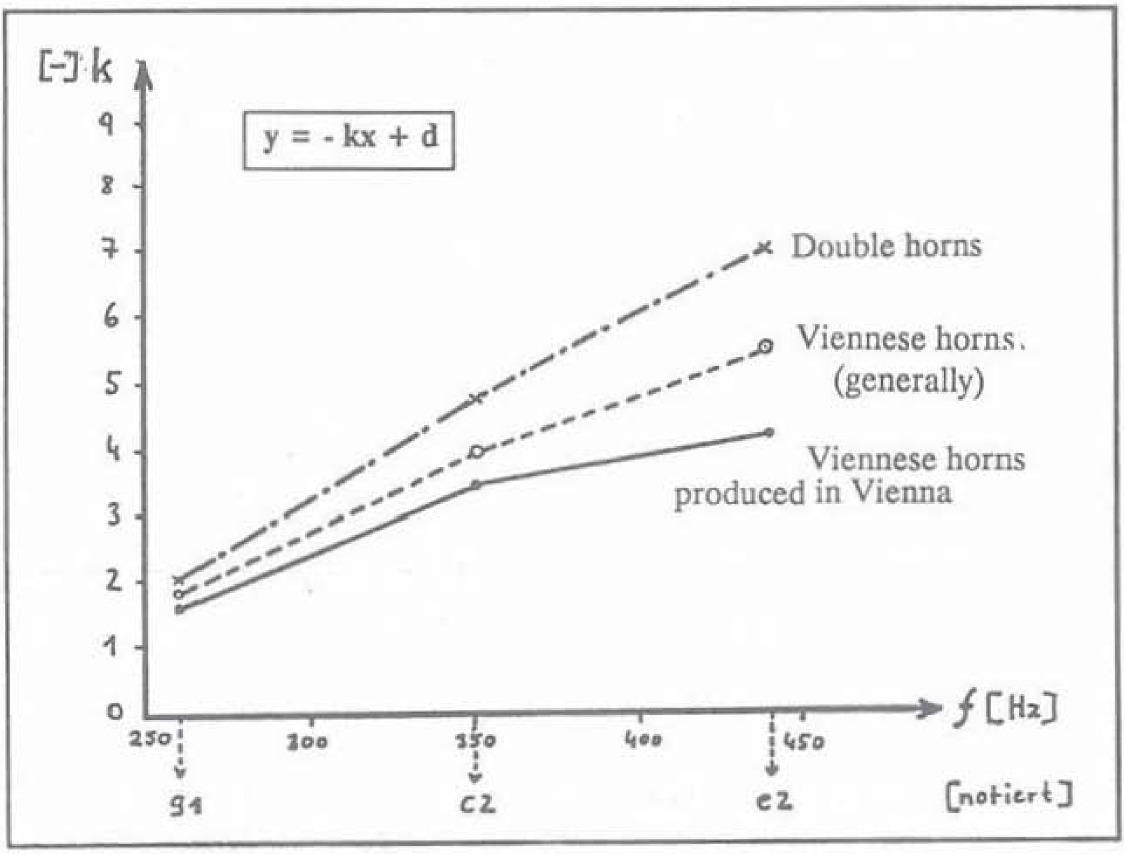



Fig.7: Differences in spectra of the steady state part of the tones between the Viennese model and double horns. Typical values of difference between 0.5**k** (lower register) and 3**k** (high register).

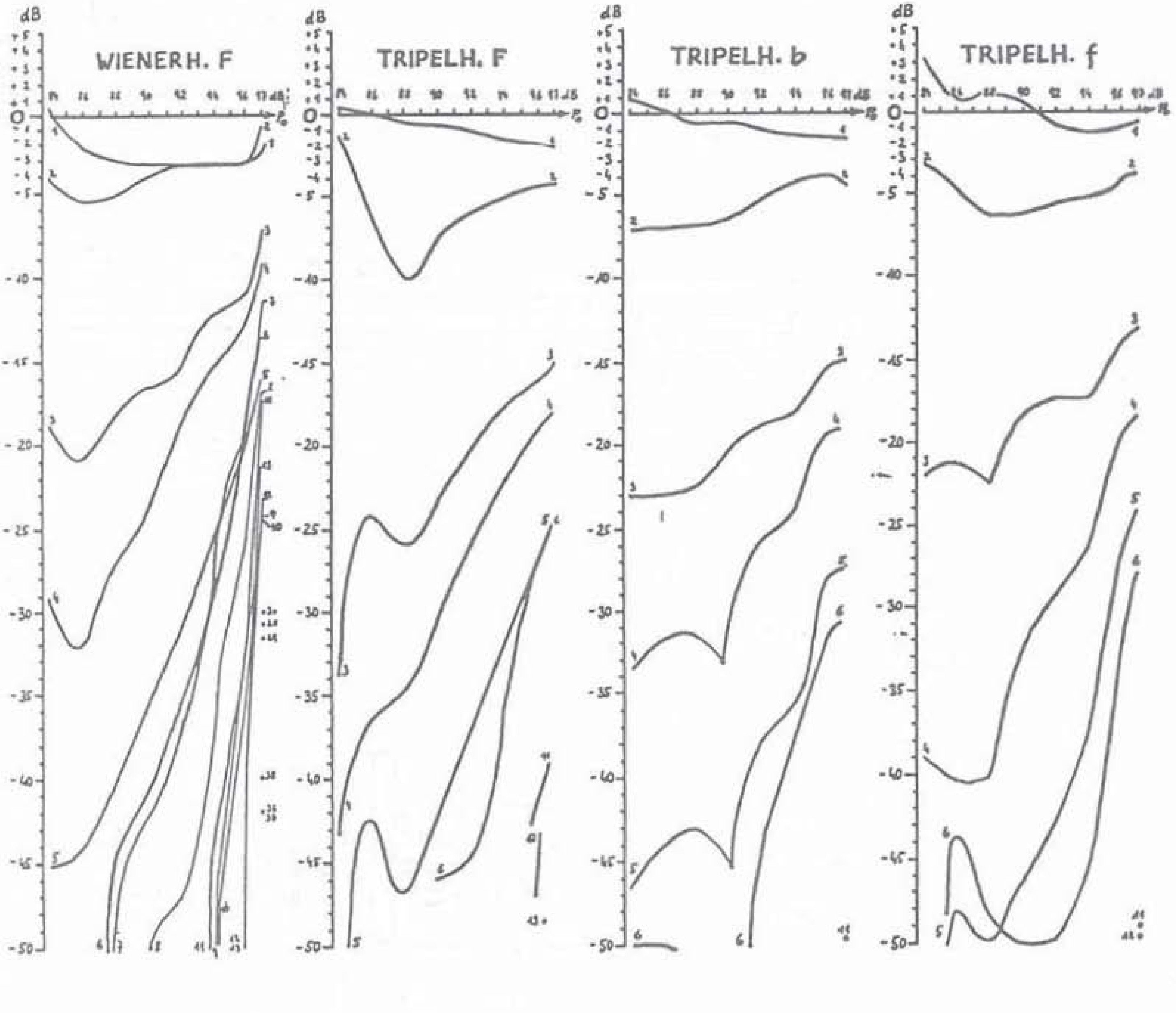



Fig.8: Spectral dynamic. Development of the harmonics during a crescendo. Amplitudes of the partials related to the increase of the sound pressure level with 1 dB.

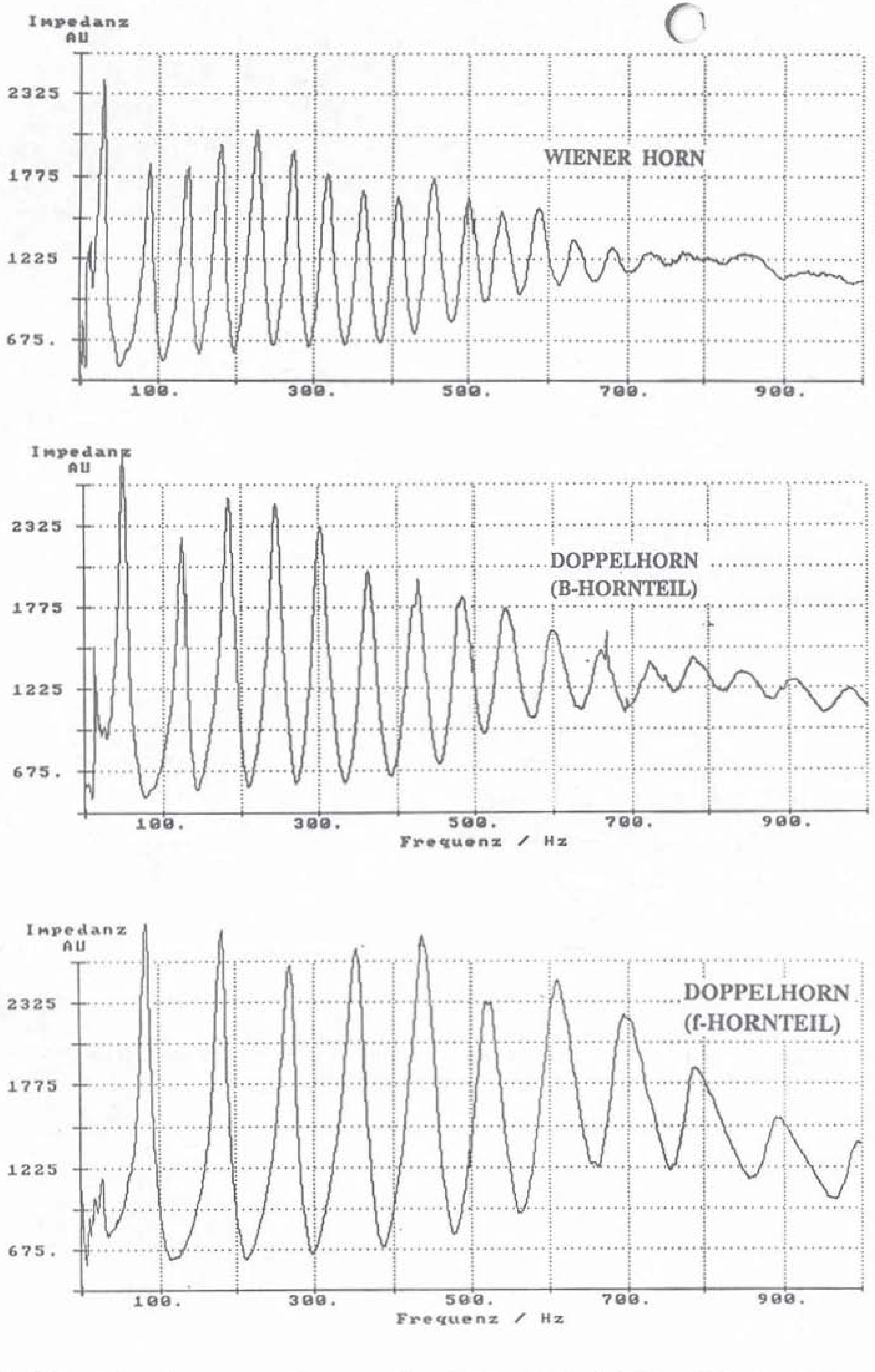
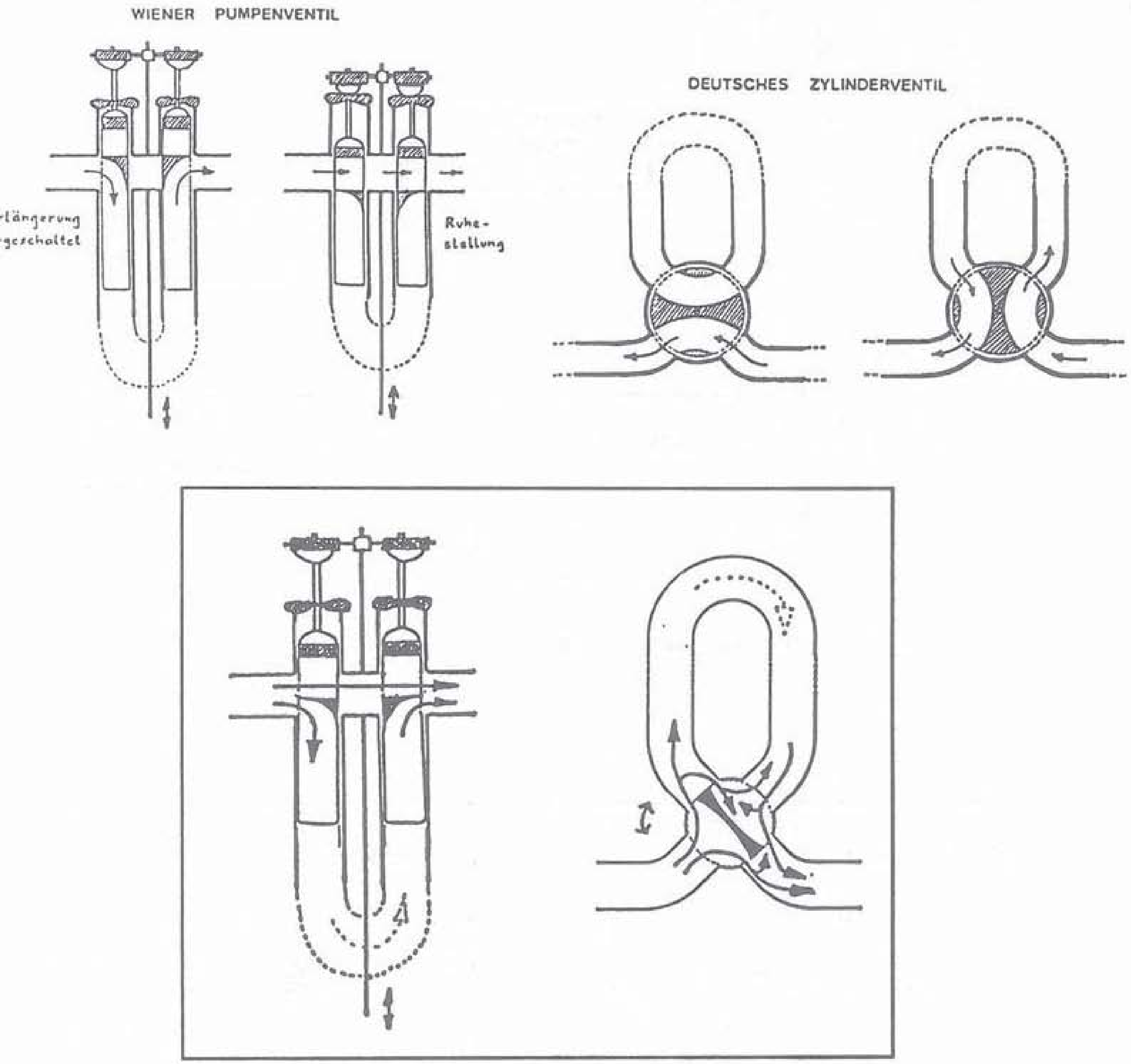



Fig.9: Input impedance versus frequency for a F-Horn (3,6 m), b-Horn (2,7 m) and high f-Horn (1,8 m).




ig.11: Schematic representation of the different construction of the Vienna Valve and the Rotary Valve (upper part). Difference in function (lower part).

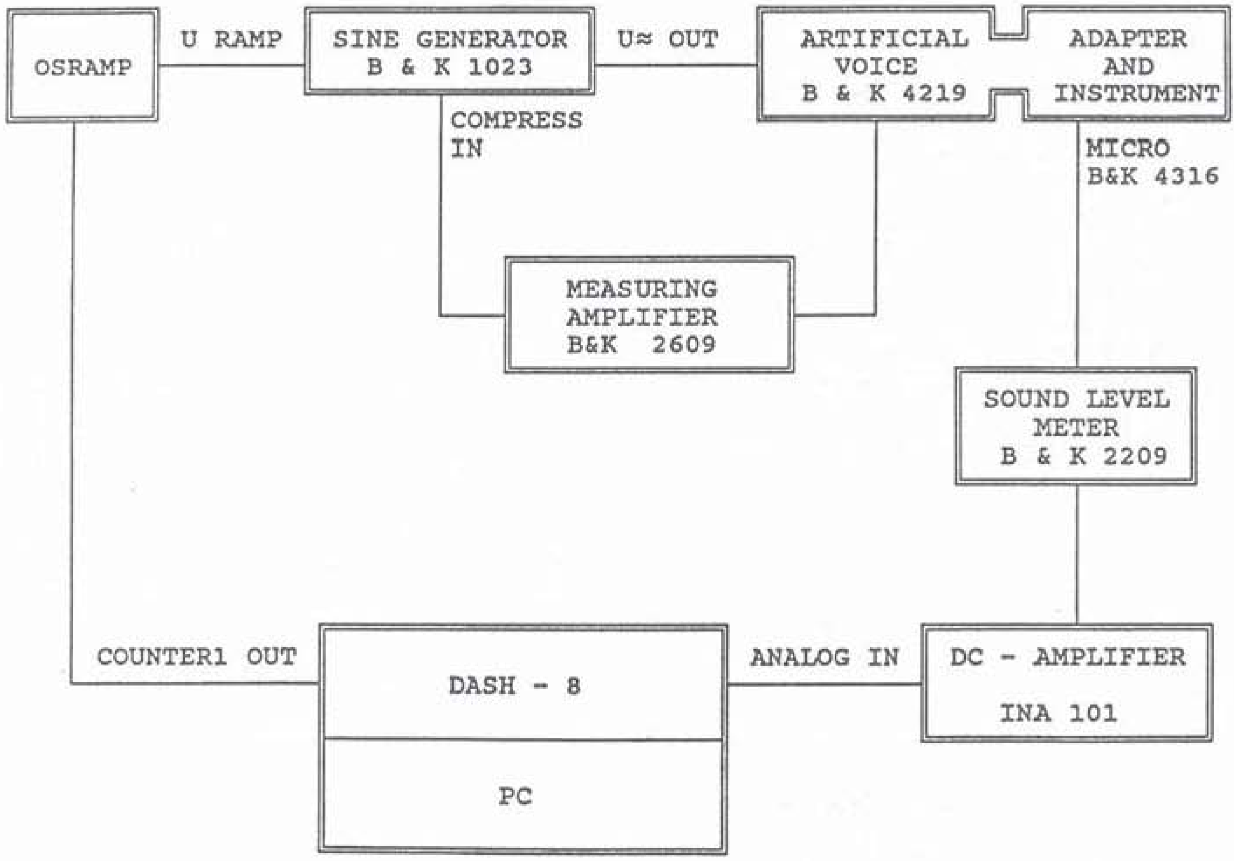



Fig.10: Block diagram of the measurement arrangement of BIAS.

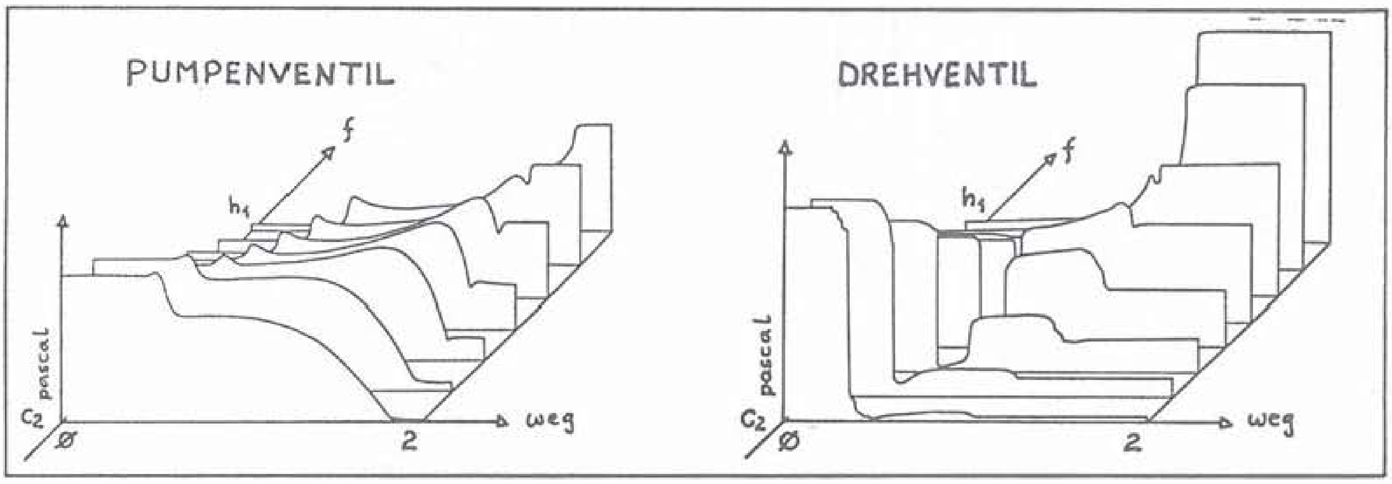



Fig.12: Impedance pattern for a slur of a semitone for all positions of the valve and various frequencies between the start and destination frequency. Left side: Vienna Valve, right side: Rotary Valve.

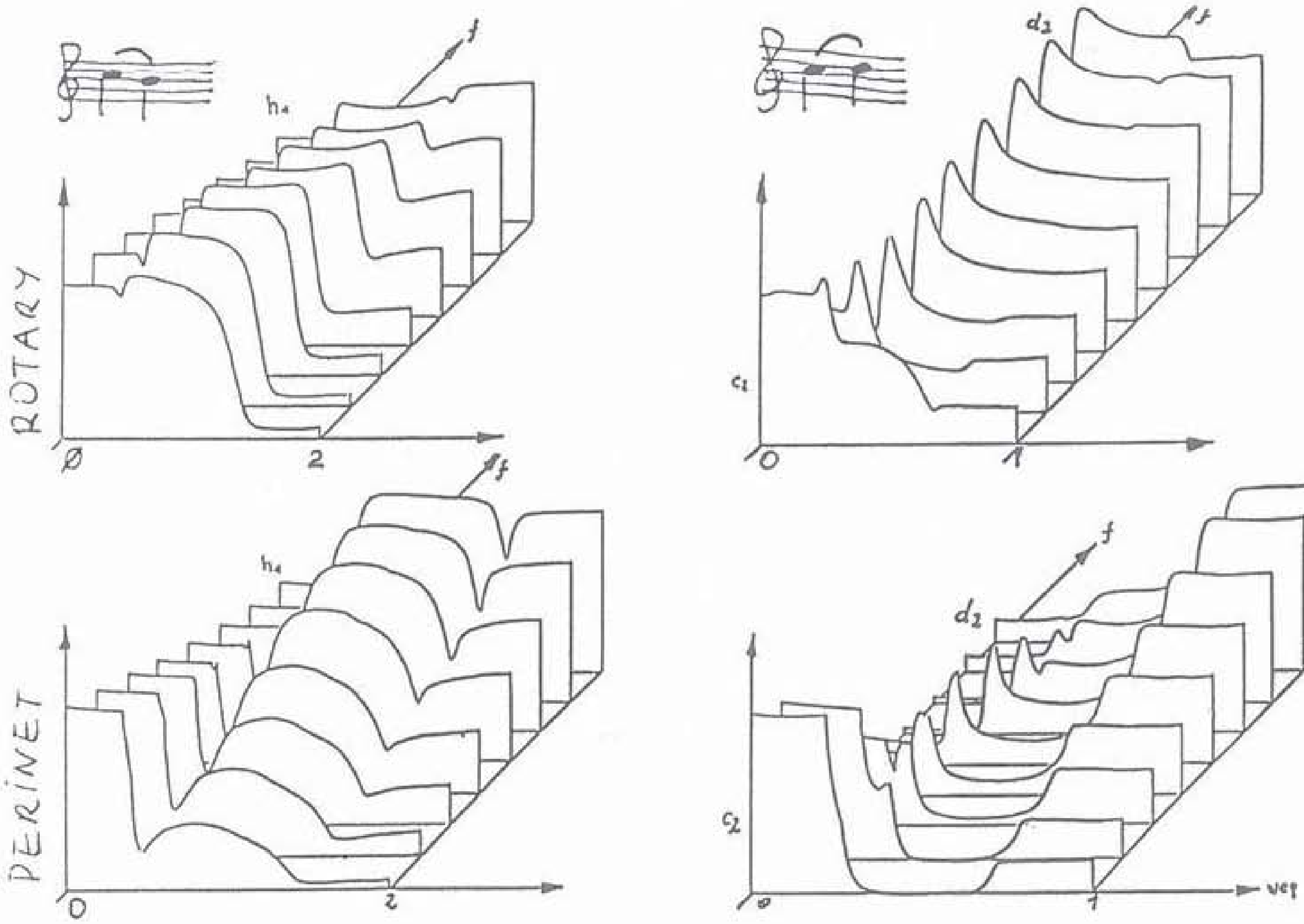



Fig.13: Impedance pattern for a semitone and two-semitone intervals on trumpets.
Upper curves: Rotary valve, lower curves: Perinet valve.

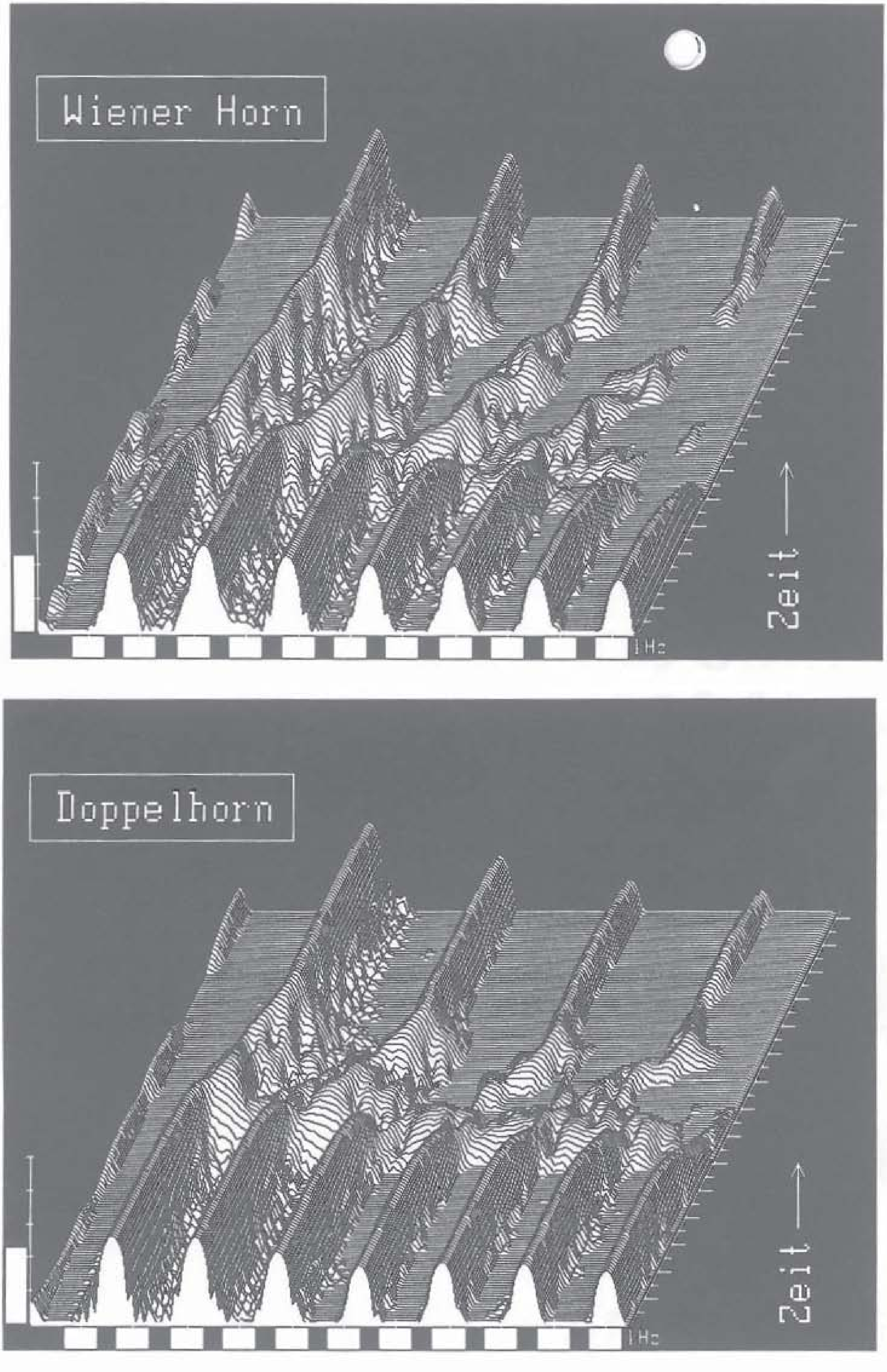



Fig.14: Three dimensional representation of the difference in radiated sound caused by different valve systems.

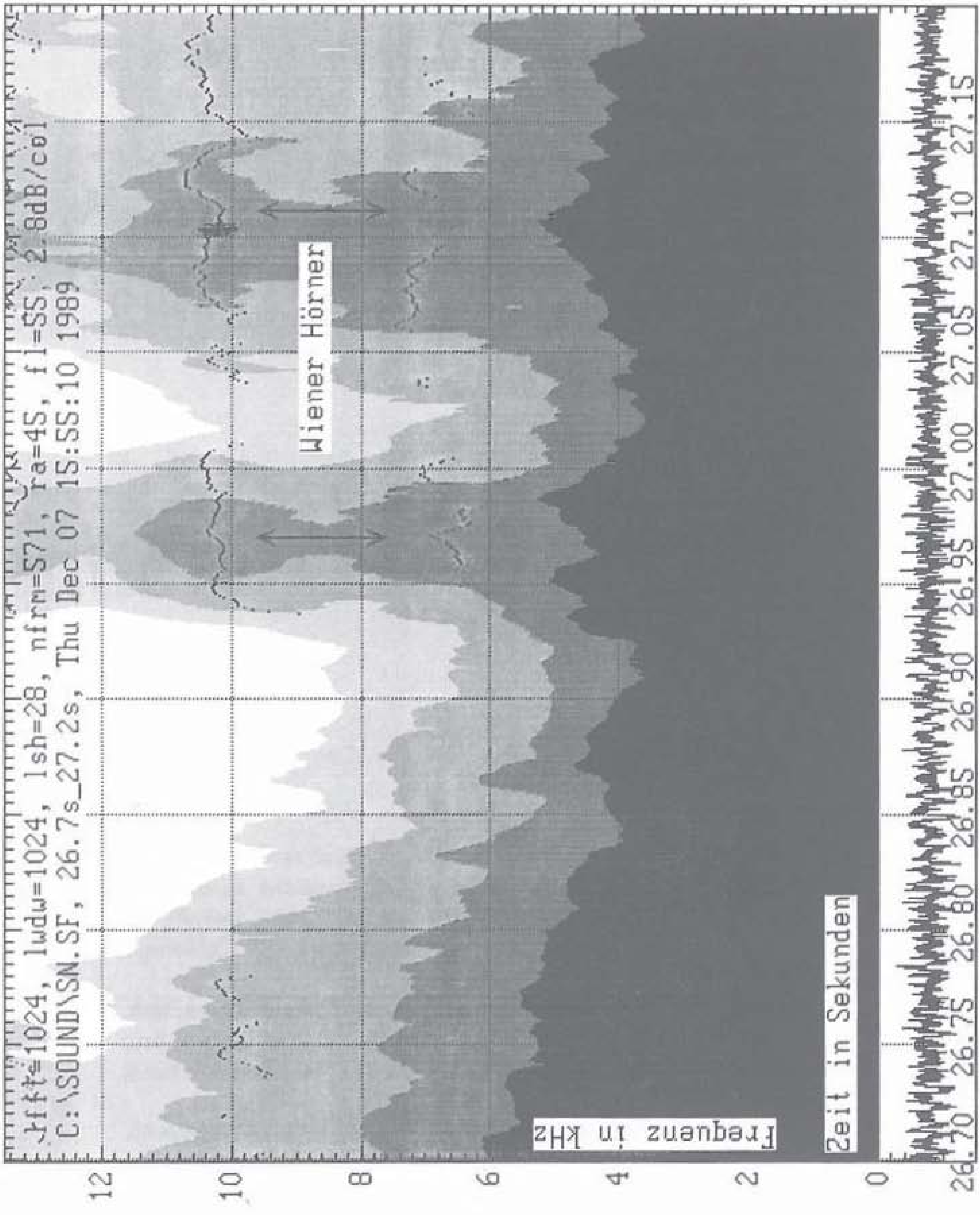



Fig. 15: With cepstrum analysis visualized peculiarities of sound of the Vienna Philharmonic Orchestra caused by a special type of horns.