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TECHNICAL INNOVATIONS IN THE FIELD OF ELECTRONIC MODIFICATION OF ACOUSTIC SPACES

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1. SUMMARY

This paper sets out a case for the reconsideration of electro-acoustics as a way of tuning a hall for a particular concert, or a theatre for a lyric performance or a concert performance.

The paper discusses the way such systems work, the range of possibilities for application and practical experience of one such system, the System for Improved Acoustic Performance (SIAP), in new and existing theatres. The application of these systems for large scale opera productions in big "arena" type halls in place of conventional public address systems is also discussed.

2. HISTORY

The unsuitability of theatres as concert halls is well known. The acoustic requirements for speech and orchestral music are very divergent and not just in their reverberation time. Yet many halls have to be "multi-purpose", inevitably with meagre or no success, though one sees many examples of courageous attempts at achieving the almost impossible.

If one chooses to build a proper concert hall the specific volume (m^3/person) must be about twice that for a hall meant for speech. To adjust the acoustics to other purposes like drama and opera, elaborate installations like movable ceilings, adjustable reflectors, retractable banner curtains and so forth are necessary. Tackling the problem in this way is expensive and has huge consequences for the architecture. Conversion from one mode to another is often time-consuming and therefore expensive, and is also an impractical solution for everyday theatre work patterns.

Furthermore physical adjustment solutions are not realistic for the many existing theatres, and the existing and multipurpose venues yet to be built. In addition there are many auditoria which have proved to be acoustically dissappointing or which now serve a different purpose than that for which they were originally designed.

As acousticians and theatre consultants we have been confronted again and again during the course of the years with auditoria clearly needing a considerable acoustic improvement or in which variable acoustics were desired and with no possibility of solving the problems by architectural or mechanical means.

Some fifteen years ago, the basic concept arose of an electronic system for variable acoustics, which did not use acoustic feedback (with its inherent instability) for increasing the reverberation time. This concept developed into a specification which looked to achieve the acoustic improvement not by over-riding but by taking the existing acoustic character of the particular auditorium into account.

By 1987/1988 microprocessor technology, especially in the field of digital signal processing, had progressed enough to put the idea into practice. After a first stage of experimenting, the system was tested extensively in a number of theatres. In these tests not only the system's acoustic performance but also its practical usefulness in theatres was investigated.

3. STARTING POINTS FOR THE DEVELOPMENT OF AN ELECTRO-ACOUSTIC SYSTEM

Each auditorium has its own unique acoustic characteristics. These can be expressed by a number of well established parameters like reverberation time (RT), early decay time (EDT), speech intelligibility (STI, RASTI), clarity, lateral efficiency, centre time etc. Modern measurement systems such as TEF (time delay spectrometry) and MLSSA (maximum length sequence system analyzer) are not only capable of measuring these parameters accurately but also provide the facility to analyse the reflection patterns, energy-time-curves etc. in detail.

From the beginning of the development of the system it has been clear that, in almost all cases, it is not possible to put the complete desired electronically generated acoustics over the existing natural acoustics: the natural early reflections, which play an important role in the acoustic character of each individual auditorium, are too pronounced to make such an approach successful. If this approach is to be used then large quantities of absorbing surfaces have to be added to the auditorium. Furthermore for an average municipal theatre a volume of about 3500 m^3 and an RT of about 1 second are typical, resulting in a sound level in the reverberant field which makes a further significant level increase undesirable because:

- A steady-state-level rise easily becomes unnatural and gives the impression of amplification; the human ear appears to be quite sensitive to this effect
- The loudness of a symphony orchestra or a brass band would become excessive.

Kleiner et al[1] proved (put simply) that for masking or dominating the natural acoustic by an artificially generated acoustic, the artificial acoustic needs to be 6 to 10 dB louder than the natural one. This was confirmed in the experimental stage of the new system in theatres. Besides, why would it be desirable to neglect the existing natural acoustics of an auditorium? It is these very acoustics which give each hall its unique character.

Large concert halls for symphony orchestras will still have to be built since copying the acoustics of famous halls like the Amsterdam Concertgebouw or the Vienna Musikverein in a theatre will, at the very least, result in the problem that the acoustic and visual perceptions are very different, giving the audience and performers the feeling that something is wrong; we call this effect "dissociation".

The acoustic enhancement system which was developed in these experiments has been given the name "System for Improved Acoustic Performance", abbreviated by its acronym SIAP. As the name indicates the system's purpose is to improve the acoustic performance of the auditorium, taking the acoustic character of that auditorium into account. The system is not just a reverberation system, which means that it is not solely intended to increase the reverberation time. It is an electro-acoustic enhancement system capable of influencing all the relevant acoustic characteristics of a hall.

The total of the direct sound, the energy ratios of early to late and of lateral to total of early reflections, the reverberation time and reverberation level are important factors which together define the acoustics of a room. The early reflections are usually only a little weaker than the direct sound and comparatively small in number. With increasing delay times the number of reflections also increases and their individual loudness decreases. The beginning of the reverberation "tail" in auditoria of average size is about 200 to 300 ms after the arrival of the direct sound. The sound quality and naturalness of artificial reverberation are mainly achieved by the reflection density, and the extent to which the reverberant sound reaches the listener's ears from all directions with equal loudness and without the position of the loudspeakers becoming apparent. It will be clear that these concepts, now generally accepted in the field of room acoustics, must be the starting point in the development of an electro- acoustic system.

4. THE WORKING REQUIREMENTS OF A SYSTEM

A system that is applicable in theatre practice has in our opinion to meet certain demands of which at least the following have to be mentioned.

Microphones and loudspeakers must have permanent and fixed positions; if microphones and/or loudspeakers have to be installed before each performance or concert and taken out afterwards, then it must be expected that the system will not be used as regularly as is acoustically necessary and it also makes defects more likely.

4.1 Microphone Location

In a fly tower, that is to say behind the scenes, microphones are not easily used, for:

- They obstruct the use of stage machinery, lighting and scenery;
- The system would transmit unwanted stage noises into the auditorium, for example fans in spotlights, stage machinery, changing of scenery etc.

In the vicinity of the house curtain, microphones are difficult to use (on either side of the proscenium opening):

- Because of noise caused by the runners in the curtain rails during movement of the curtain as well as noise from the resulting air movement around the microphones;
- Because of (often variable) shielding of the back stage playing area by the borders and (if present) the movable lighting bridge directly behind the stage opening which may also be used to adjust the opening height, usually between 5 and 9 m above the stage floor in typical proscenium theatres
- Microphones cannot be positioned in the "lightlines" of the auditorium lighting bridges or slots.

For psychological reasons the microphones have to be positioned in such a way as to be as near invisible as possible.

4.2 Microphone Performance

For the acoustic performance of the system the following criteria are essential with respect to the microphone positions and configuration:

- The whole playing area including the orchestra pit has to be covered very evenly; this is of course of vital importance for the balance of singers and orchestra in a lyric theatre performance
- The microphone-to-source distance must be short enough for the system to be able to reproduce the desired early reflections; however distances of up to 10 m are usually no problem since the distance between the microphone and the loudspeaker plays no role; this presents an advantage over natural acoustics
- The applause of the audience has also to be picked up in order to achieve that this sounds with the same acoustics as the sound coming from the stage; an applause with 1 second RT sounds as a meagre success if the music that just decayed had a more reverberant character.

Usually in the design of a SIAP-system the microphone positions are chosen above the front edge of the forestage or orchestra pit on the long axis of the hall. The microphones are incorporated in a compact cluster (about 120 cms. long) consisting of one or two rows of a small number of microphones (typically 3 to 4) and are located above the lightlines from the lighting galleries in the auditorium and above the sightlines of the audience. Usually supercardioid microphones are used having a polar pattern which is frequency-independent in the range from at least 100 - 10,000 Hz; this prevents colouration, especially of moving sound sources which is of great importance in the lyric theatre (opera, musical etc.). Not only the direct sound, but also the early reflected sound is picked up by the microphone cluster as well as some reverberation, but however, no strong late reflections. The advantages of this are:

- Less dependence on the directionality and positions of sound sources
- Greater reflection density in the reverberation tail, thereby improving the important naturalness of the sound.

4.3 Loudspeakers

Loudspeaker positions are designed such that, in combination with the software programmed in the SIAP processor the desired parameter values like frontal to lateral and early to late energy ratios are achieved. To make sure that in each position in the audience area as well as on stage the reverberation is heard as coming from all directions with equal loudness, it is necessary that in each position the sound that is heard is coming from all, or nearly all of the loudspeakers.

In the SIAP system this is achieved by using hemispherically radiating high quality loudspeaker systems, which must be chosen for the absence of a sound "character" of their own, because of the requirement for extreme naturalness of the final acoustic.
The hemispherical polar pattern of the speakers which is also quite frequency-independent, prevents localization of the individual speakers by the listeners.

4.4 Acoustic feedback

As is generally known in the field of acoustic enhancement systems, the allowable gain of a single channel microphone- amplifier- loudspeaker configuration is -17 to -20 dB to prevent instability (oscillation or "howl round") and colouration (frequency selective decay or "ringing").[2,3] The consequence is, that with single-channel systems, even if very directional microphones and loudspeakers are used, the sound level of the artificial reverberation has to be set at such a low value that the Early Decay Time, the "running reverberation" which is so important for music, cannot be increased. Only the "terminal reverberation" will then be audible as a low level reverberation tail. In the SIAP system acoustic feedback is reduced by a combination of a number of measures, of which the most important are:

- Microphones with a frequency independent supercardioid polar pattern, thereby reducing the pick-up of reverberation and late reflections
- Equalization of each microphone to loudspeaker transfer function in 1/3 octave bands
- Division of the system in a number of subsystems (boards) each comprising one or more uncorrellated channels
- Elimination of a residue of colouration by means of a modest and sophisticated time-variation of the reflections in the individual channels, if necessary.

5. SIAP SYSTEM DESIGN

The number of processor boards and channels required is calculated during the design process of each individual system. For example, in the auditorium of Shatin Town Hall in Hong Kong the system comprises 4 dual channel processor boards and a total of 32 output channels. Figure 1 shows a block diagram of the system. Each board is fed with the signal of the microphones which are mounted in a central cluster of 4, suspended from the ceiling at a height of approximately 10 m above the front edge of the forestage/orchestra pit. There are 68 loudspeakers. Figure 2 shows the plan and section of the auditorium of Shatin Town Hall. Without noticeable colouration a steady-state-level rise of 10 dB reverberation level could be obtained. This is more than needed because of the maximum tolerable loudness of a full symphony orchestra.

In our experience, and confirmed by others, an extensive time-variation can offer an extra system gain of 8 to 10 dB over non time-variant systems.[4] The disadvantage of this technique is, however, that it is no longer possible to provide the characteristic acoustic of the hall as the combined result of the auditorium and the system, since there are no longer typical reflection patterns generated by the processor. The system would then be functioning only as an ordinary reverberation system instead of being an acoustic enhancement system. However a careful system design comprising a number of independently programmable channels and the application of sophisticated time variance prevent this drawback.

5.1 The processor

The composition of processorboards forms the SIAP processor, which is fully digital (equalization included). These processorboards are built into a small number of racks and have a central operating system and a control panel to switch all boards to the same settings simultaneously. By means of a simple push-button device the operator selects the desired setting for each type of performance. Usually 6 to 9 settings are sufficient to cover the range of desired acoustics for drama to symphonic and choral concerts.

The dynamic range of the SIAP processor is better than 95 dB, i.e. greater than the dynamic range of a 120 piece symphony orchestra. Starting from a tolerable electronically generated background noise level by the system of 20 to 25 dB(A) in the auditorium (NR 15 to 20), the system can produce sound levels of 115 to 120 dB(A) in the reverberant field without distortion since plenty of amplifier power is made available in each system. Limiters, compressors etc. are therefore superfluous. Furthermore these would affect the natural dynamics in music and thereby degrade the system.
The acoustic parameters programmed in the processor for each individual channel are amongst others:

- Reverberation time dependent of frequency
- Reverberation level
- Time delay, level and frequency response of the (early) reflections; in this way the "attack" of the hall as well as a "sustain" or "plateau" of early reflections in the first 200 to 300 ms can be generated followed by the reverberation tail; this is considered by some acousticians as being a typical characteristic of a shoebox shaped concert hall
- Reflection density in the reverberation tail
- Time-variation if relevant.

Figures 3 to 5 show the output of a SIAP processor on the bench with no natural acoustic input. The figures illustrate the potential subtlety of the SIAP processor in making available to the acoustician the ability to profile each of these parameters.

5.2 Programming

The SIAP system is unique in that the approach is to modify the natural acoustics by providing the missing reflections from each surface (or lack of surface) in the auditorium in question that are considered necessary for achieving the desired acoustics.

The existing acoustics are carefully analyzed for this process, for example by means of the impulse response measurements. Measurements may be made with directional microphones to obtain "geographically specific" information. For theatres not yet built computer simulation using modern ray-tracing techniques and measurements in small models can be used. The system adds sound energy in the appropriate geographical position to adjust early reflected energy as well as reverberation that would be expected were the natural acoustics to be good for the purpose

The SIAP models the actual auditorium and corrects its deficiencies accurately, taking into account the important relationship between the visual and acoustic perceptions. As mentioned before too great a difference will cause the listener to develop a feeling of "dissociation". Especially an auditorium sounding (considerably) wider or higher than it really is should be avoided.

Acoustic shortcomings like echos, flutterechos or excessive reverberation can of course not be eliminated by electro-acoustic systems. However they can be made less disturbing: if not easily removed by absorption or diffusion, an echo can be "surrounded" with adjacent reflections making it less discretely audible. "Filling in" of reflections in the gaps of a flutterecho appears to work in practice.

Adding early reflections allows one to make a reverberation tail sound less reverberant by improving the early to late energy ratio (Clarity). It is also possible to greatly reduce clarity without the need of a long reverberation time. Experiments at the Casino Theatre ('s-Hertogenbosch, Holland) illustrate this, for example on a position in the centre stalls:

System off:	C_{80} = +6,9 dB,	RT = 1.2 secs,	EDT = 0.7 secs
System on:	C_{80} = -1.4 dB,	RT = 1.8 secs,	EDT = 2.1 secs

6. COMPARISON OF SOME ESTABLISHED SYSTEMS

The principle of SIAP contrasts with other systems which over the years have used different approaches. Assisted Resonance (AIRO) and Multiple Channel Reverberation, the MCR system (Philips), generate reverberation by means of acoustic feedback (recirculation of the input sound reproduced by the loudspeakers back to the microphones) and have to operate close to oscillation ("howl-round"). They are therefore prone to colouration caused by frequency-selective decay and comb-filter effects. Such systems do not generate early reflections and are not (yet) capable of influencing a number of important acoustic parameters independently.

ACS and other systems have been and are still being tried to create an "acoustic holograph" (analogous to visual holography) through reconstructing wave fronts by means of loudspeaker arrays.[5] These can only work satisfactorily in dry natural acoustics because the synthetic acoustics need to be dominant, i.e. 6 to 10 dB louder than the natural acoustic. In such a system, for example, a shoebox type concert hall is electronically modelled around a fan shaped theatre with very dry natural acoustics. According to oral reports as well as our own experience, existing systems applying acoustic holography (as is to be expected with loudspeaker arrays) show that the interference between the individual loudspeakers limits the range of a more or less successful wave-front-reconstruction to a bandwith of about one or two octaves.

A more recent system is the Lexicon Acoustic Reinforement and enhancement System (LARES) marketed by Lexicon Inc., USA. This system usually employs one or two Lexicon standard off-the-shelf digital reverberation processors, which by means of optionally available completely time-variant signal processing can achieve an effective system gain without instability. However, since no specific reflection patterns are generated, this system is not intended to take the natural acoustic into account. It is therefore a system suitable for non-critical venues. LARES tends to be a solution which is available to most theatres using their existing digital delay equipment, were they to spend a little effort on the layout of loudspeakers.

Since SIAP provides the reflections missing in the natural acoustics of the particular auditorium, the total result is a natural sounding acoustic without making it noticeable that an electro-acoustic enhancement system is doing a (major) part of the job. It should be noted that this is very different from a simple collection of digital delays and reverberation units for it contains geographically specific source information and output responses. Each processor performs the function which could otherwise only be attempted by enormous amounts of delay and reverberation equipment, even if suitably speedy adjustment of pre-programmed settings could be arranged for the multitude of items required.

As far as we know SIAP is the only system which feeds early reflections as well as reverberation and other specific information to each individual loudspeaker. Contrary to other systems (ERES + RODS, or ACS) there are no separate "early reflection speakers" and "reverberation" speakers. Furthermore for this purpose SIAP processing uses 100% digital processors (some other systems for instance use analogue delays of the so called "bucket-brigade" type). Apart from the very powerful character of the processor, digital processing has important advantages:

- Full audio bandwidth 20 - 20,000 Hz
- Dynamic range better than 95 dB (not attainable with analogue delays); this makes limiters, compressors etc. superfluous since the dynamic range exceeds that of symphonic music, brass bands etc.
- Minimal distortion
- Large programming possibilities.

6.1 Use of the latest processors in practice

Practical experience has now been gained on a range of applications:

- Variable acoustics to make an auditorium suitable as a drama theatre, a lyric theater and a concert hall
- Speech reinforcement (public address)
- Constructing the necessary acoustics for large scale opera productions in large halls like sports halls, arenas etc.

6.2 Variable acoustics and improvement of acoustics

Since their introduction in 1989 SIAP systems have been installed in a number of existing theatres and as well as in new theatres where it could be incorporated in the architectural design, namely:

Name	Place	Country	Seating capacity	Year of inauguration
Alfred Beck Theatre	Hillingdon	UK	600	1989
Alban Arena	St. Albans	UK	850	1990
Cliff's Pavilion Theatre	Southend-on-Sea	UK	1600	1992
Cultural Centre	Aalter	Belgium	500	1994
Cultural Centre	Ninove	Belgium	600	1994
Royal Dutch Theatre	Antwerp	Belgium	2100	1994
Shatin Town Hall	New Territories	Hong Kong	1400	1994
Casino Theatre, main auditorium	's-Hertogenbosch	Netherlands	862	1989
Casino Theatre, small auditorium	's-Hertogenbosch	Netherlands	240-400	1990
Purmaryn Theatre	Purmerend	Netherlands	550	1990
University for Technology main hall of Auditorium	Eindhoven	Netherlands	2000	1991
Municipal Theatre Concordia	Breda	Netherlands	800	1992
Chassé Theatre	Breda	Netherlands	1320	1994
Municipal Theatre De Lievekamp	Oss	Netherlands	619	1992
Cultural and Conference Centre De Reehorst	Ede	Netherlands	620	1992
Sportshall De Maaspoort[1)]	's-Hertogenbosch	Netherlands	2800	1990
Sportshalls South[1)]	Amsterdam	Netherlands	3800	1991

1): Temporary installation for the large-scale Aïda opera production in August/September

A number of systems are planned in various countries until 1996

All these systems have at least 6 to 8 pre-programmed settings like the Casino Theatre main auditorium system where the following settings proved to be preferred after a number of rehearsals and concerts.

Table A: Typical SIAP system settings

Setting	Purpose	Reverberation Time (seconds)	Early Decay Time (seconds)
0 (off)	Film, Popconcert	1.2	0.7
1	Speech, drama	1.2	1.1
2	Chamber music, Musical, Operetta	1.3	1.2
3	Opera, ballet	1.5	1.4
4	Classical and Modern symphonic music	1.7	1.6
5	Average symphonic music	2.0	2.0
6	Late romantic symphonic music	2.2	2.3
7	Choir, without orchestra	3.0	3.0
8	Cathedral setting for demonstration purposes and effects	10.0	10.0

Figure 6 shows reverberation curves for the auditorium of Shatin Town Hall, Hong Kong.

Setting 1 does not increase RT, it only adds early reflections for better speech intelligibility in the audience area and for improved foldback for the actors on stage. Setting 5 is the most popular setting for symphonic concerts. The home orchestra as well as guest orchestras like the Royal Concertgebouw Orchestra in total give about 40 concerts in this theatre each season. Musicians, soloists (including José Carreras), conductors as well as radio and recording engineers without exception are very enthusiastic about the achievements of the SIAP system and especially note the considerable effect it has whilst maintaining a completely natural sound. Figures 7 and 8 show in graph form the subtlety of these changes whilst the following table gives illustrations of the achievements.

Table B: Casino Theatre, comparison of some settings

Acoustic parameter	SIAP OFF	SIAP setting A	SIAP setting B
Reverberation Time T_{60}	1.2 secs	1.6 secs	1.8 secs
Early Decay Time EDT	0.7 secs	1.7 secs	2.1 secs
Clarity C_{50}	0.0 dB	-4.1 dB	-5.7 dB
Clarity C_{80}	6.9 dB	1.6 dB	-1.4 dB
Centre Time T_1	51 ms	132 ms	161 ms
Direct/Reverb-ratio	-1.8 dB	-8.3 dB	-12.1 dB

7. ORCHESTRA SHELLS

Except the Casino Theatre and Shatin Town Hall, the theatres mentioned do not have a reflecting stage environment such as an orchestra shell. The SIAP stage system comprising a separate stage processor, amplifiers and loudspeakers provide for this by generating appropriate reflection patterns and reverberation and, if desired, an increase of the sound level. This doesn't mean however that orchestra shells or other reflective means are completely superfluous. The effects of a reflective stage environment are:

- The sound of the instruments reaches the microphones with a correct natural balance.
- The sound of very directional instruments, such as horns which have their bells projecting backwards, reaches the microphones and is not absorbed by any stage curtains.

In our experience a reflecting stage environment, for example a full size orchestra shell, is not needed with the SIAP system. However reflecting surfaces like a stage rear wall or a simple (incomplete) orchestra shell are recommended although not absolutely necessary.

8. PUBLIC ADDRESS

When using SIAP as a public address system for speech reinforcement through close-miking, the system offers a particular advantage for "difficult" spaces. The powerful processor makes it possible to provide each individual loudspeaker system with its own appropriately delayed signal. Furthermore the achievable system gain is considerably higher than with conventional P.A. systems.
In the central hall of the Auditorium of Eindhoven University for Technology, The Netherlands, these characteristics of the system were necessary to design a successful P.A. system to replace the old unsatisfactory system.

The hall is of square shape (40 x 40 x 9 m^3), and accommodates an audience of over 2000 on the flat main floor and in a gallery. The SIAP system installed in 1991 comprises a central cluster of high quality column loudspeakers above the end stage, a supporting cluster in the centre of the hall and 28 speakers built into the ceiling and the gallery overhangs for even coverage of the audience and for reproduction of background music. In the unoccupied hall (RT = 2.0 s) RASTI measurements by the client exceed 0.65 in almost all seating positions and are better than 0.60 everywhere in the hall. For comparison: without the system the values are between 0.30 and 0.50. The system gain in the speech frequency range was measured to be between 30 and 32 dB resulting in a still excellent speech intelligibility with capacity audience of over 2000 noisy students, even in the most difficult areas of this space.

9. TEMPORARY INSTALLATIONS FOR LARGE SCALE OPERA PRODUCTIONS

In August 1990 Sportshall De Maaspoort at 's-Hertogenbosch was temporarily converted into a venue for an ambitious opera production (Verdi's Aida). The hall seated an audience of 2800 surrounding a sand covered playing area measuring 30 x 18 m^2. The orchestra platform was in a corner of the hall. Measurements during the planning of the production showed that with an audience the reverberation time would drop below 1 sec and that there would be a serious lack of early and especially lateral reflections. Furthermore the directionality of the human voice would cause various problems with this audience and stage lay-out.

In the system design the hall was divided into a number of sections each having their own loudspeakers for frontal, lateral and overhead reverberant sound. The microphones were concentrated in 3 clusters about 8 m high above the playing area and the orchestra, of course out of the lightbeams of the spotlights.

Application of an acoustic enhancement system for such a production is a rather different approach from the P.A. systems which have been used until now. These normally work with great numbers of radio microphones and an elaborate mixing console with operators, and they provide only amplification, often with some reverberation effect, but no real acoustic enhancement. The effect is that of a studio production in sound, with the engineer more dominant than the conductor, whilst from the performer's viewpoint there are difficulties in relating to the orchestra and to the chorus who must generally be remote (grouped around microphones rather than grouped dramatically) to avoid impossible mixing difficulties.

Because of the acoustic success of the Aida the SIAP-system was also selected for an Aida production at the Sportshall South in Amsterdam in August/September 1991. Although it was a repeat of the successful 's-Hertogenbosch production, the scale was somewhat larger:

- Cubic volume: 40,000 m^3 (hall measures 75 x 55 m^2).
- Playing area (central stage): 40 x 20 m^2 (sand covered).
- Seating capacity: 4000.

According to measurements the natural acoustics for opera appeared to be even worse than at the Maaspoort Hall, especially because of the complete absence of surfaces that could provide early reflections and the curved roof causing focussing effects. This was a particular disadvantage, since the seating area surrounding the stage means that a singer continuously has his back to about 75% of the audience.

Here also an extensive system was installed comprising 60 microphones divided over 5 clusters 8.5 m above the stage and orchestra and 128 loudspeakers flown from the rigging and divided over a number of sections as described before. Apart from the desired RT, reflection patterns etc., the system also featured correct localization of the sound sources (singers, choir, orchestra, brass group) and compensation for the directionality of the singers' voices in a natural way. The latter means that:

- Singers are heard well, no matter in which position they are projecting their voices
- The sound level and spectrum of a singer changes when he or she is turning away, but not as much as in natural acoustics.

Because of the large volume of the hall, a certain amplification was considered desirable. The system gain, reflections as well as reverberation, was set at 5 dB above the natural reverberation level of the hall. RT was set at 1.8 seconds as a result of experiments during rehearsals established in collaboration with conductor, singers and stage manager. Even the very loud fireworks at the end of Act II (Triumphal March; approx. 106 dB(A) on the system microphones) did not overload the system and showed a safety margin of some 10 dB. So, if enough power is available in the amplifiers, in this case a little over 12 kW peak power, limiters are indeed superfluous.

10. CONCLUSION

From the experiences gained up to now with the SIAP systems we conclude that:

- The system offers variable acoustics that are applicable in practice.
- The sound quality is very natural, which together with the way the processor is programmed, makes it very difficult to percieve that an electro-acoustic system is doing the job.
- Large systems are applicable in practice for large scale opera and musical producions as an alternative to, or in combination with, P.A. systems.

A SIAP-system can offer individually or combined in one installation:

1. Acoustic enhancement
2. Speech reinforcement
3. Reproduction of effects (e.g. Dolby film sound);

(2 and 3 can be provided at small extra cost when added to a SIAP electro-acoustic enhancement system).

SIAP is patented in the United States of America (1992) and patents are pending in a number of other countries all over the world. When European patents are granted greater technical information will be released on the details of the system.

11. THE POTENTIAL FUTURE

From direct experience gained to date with this latest generation of electro-acoustics it is clear that we are entering a period when it is possible to subtly and delicately enhance the acoustics of auditoria with stability and with a dynamic range sufficient to meet any foreseeable natural musical or lyric performance. It is thus time to reappraise the commonly held prejudice against electro-acoustics, derived no doubt from the poor performance of past systems.

A concert piano is tuned for each performance specifically to suit the playing style of different pianists yet we appear to prefer that pianist to perform in a concert hall which must also accommodate a chamber group or a full orchestra with no change in its acoustic, despite the indisputable desirability of different acoustic environments for these different musical forces. Similarly we expect an opera house to play Mozart and Wagner in the same acoustic.

Whilst mechanical variation of acoustics have been used for some years they have rarely proved subtle enough or practical for daily change. The means appear now to be available for acousticians to design not only the acoustics that they wish for one role of the auditorium but also to design and obtain specific acoustic characteristics for other roles for the same house. This new freedom will be welcome not only to the acoustician and to his client, who will often save money by building a smaller volume building, but also to the audience which is increasingly used to hearing different types of music in different selected acoustic environments on CD's and high quality tape recordings. By improving the acoustic for each performance at live performances we can attract a larger audience from the increasingly demanding music going public.

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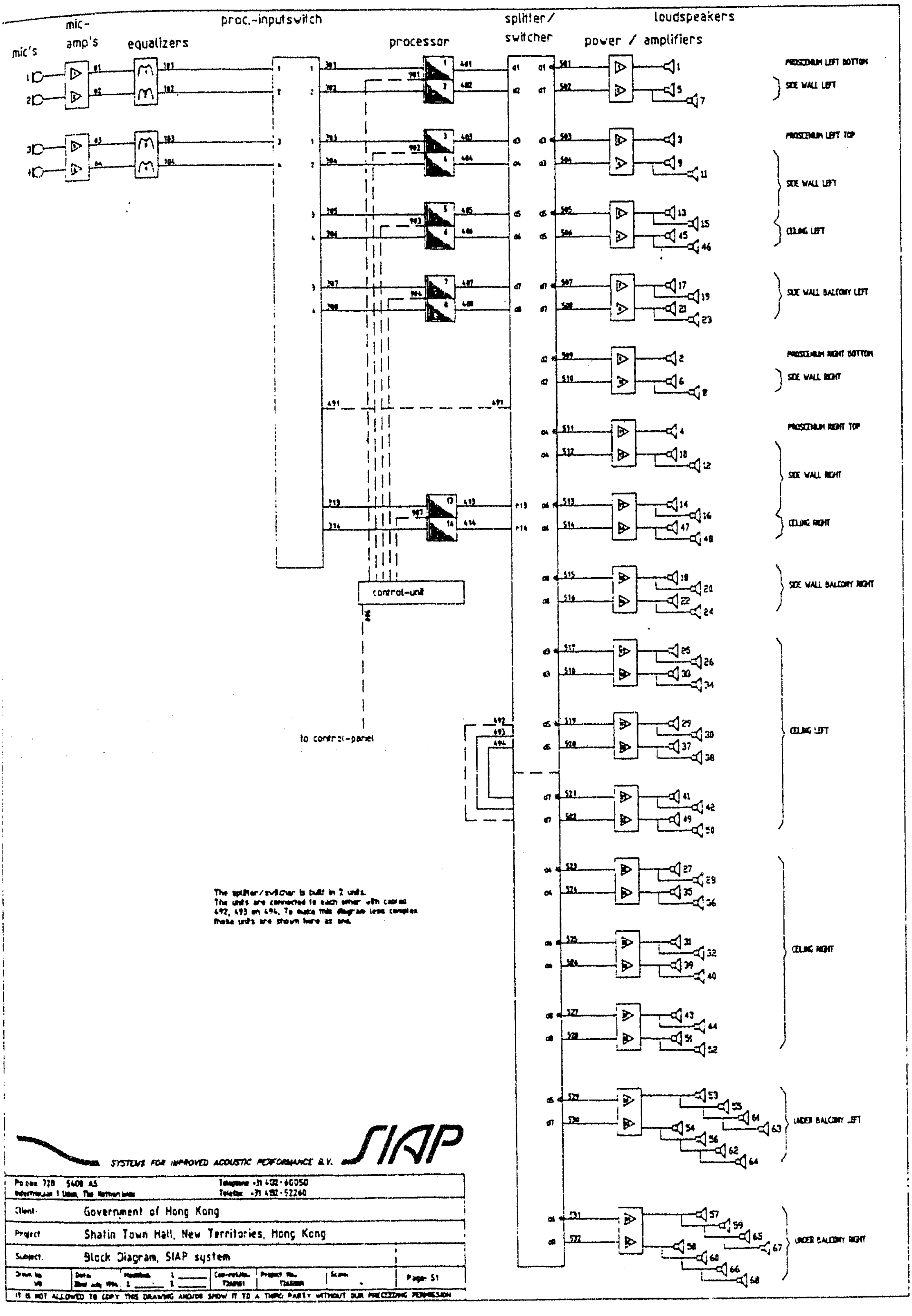


Figure 1. Block diagram of the SIAP system

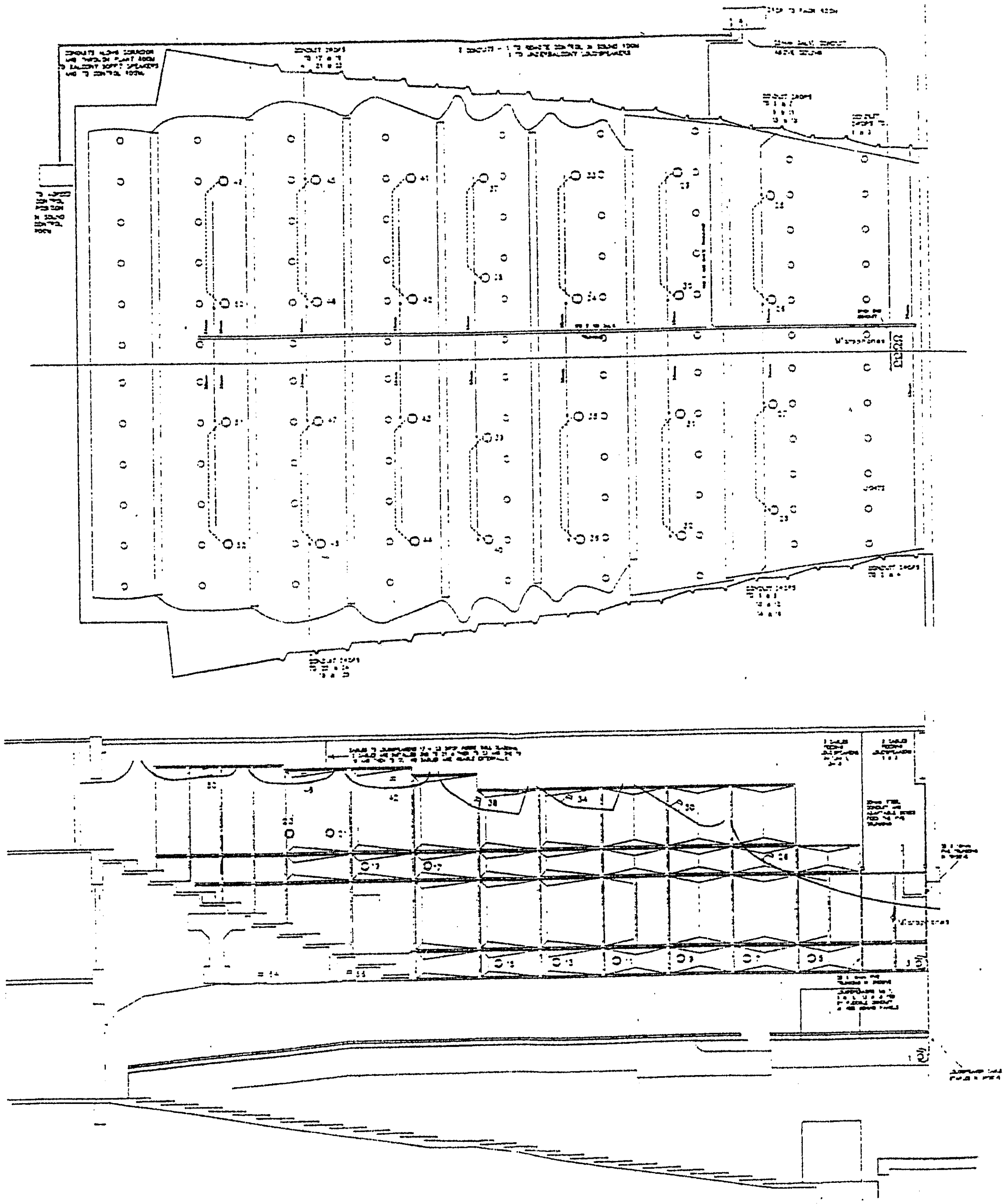


Figure 2. Reflected ceiling plan and section of the auditorium of Shatin Town Hall, Hong Kong

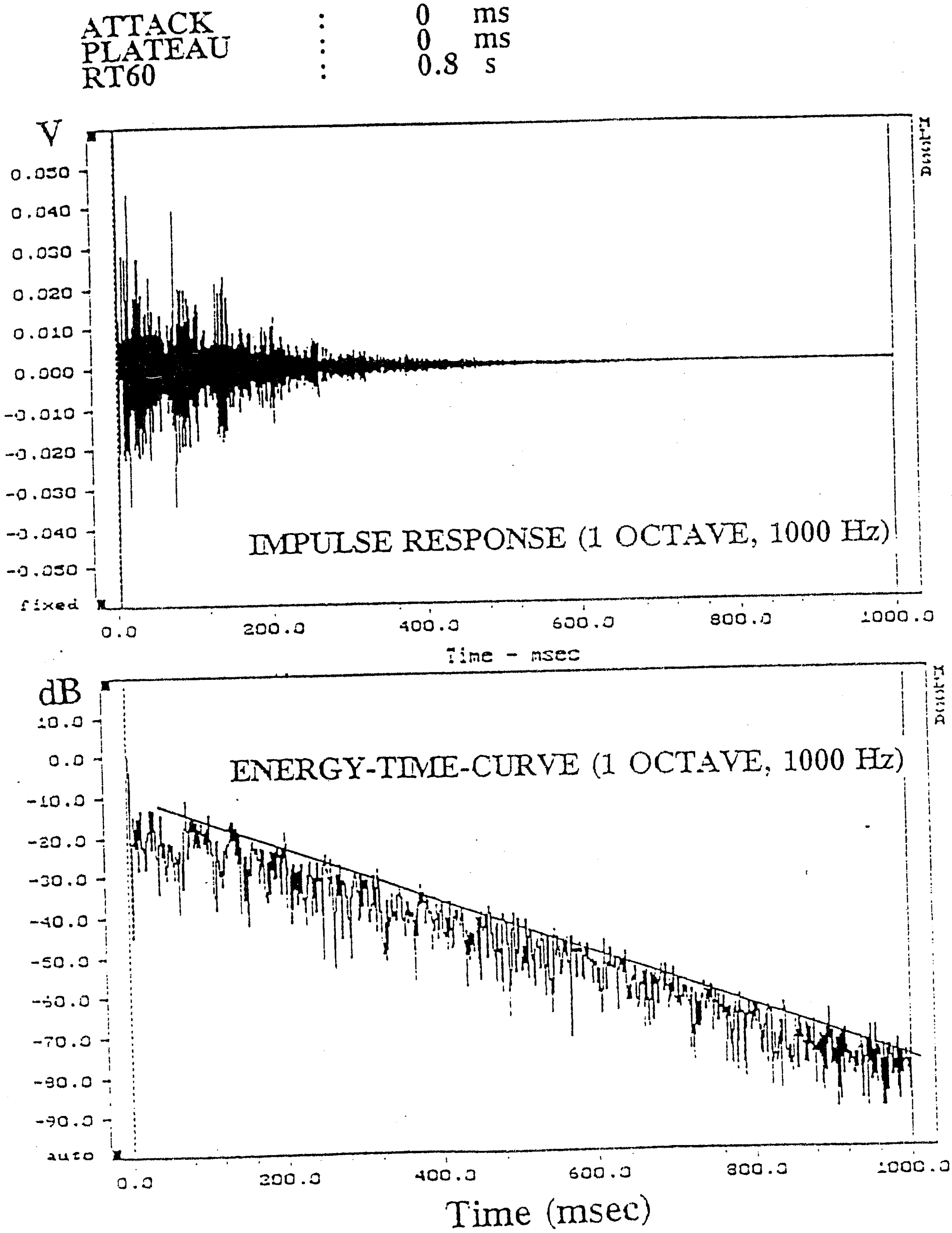


Figure 3. Output of a SIAP processor showing particular acoustic parameters

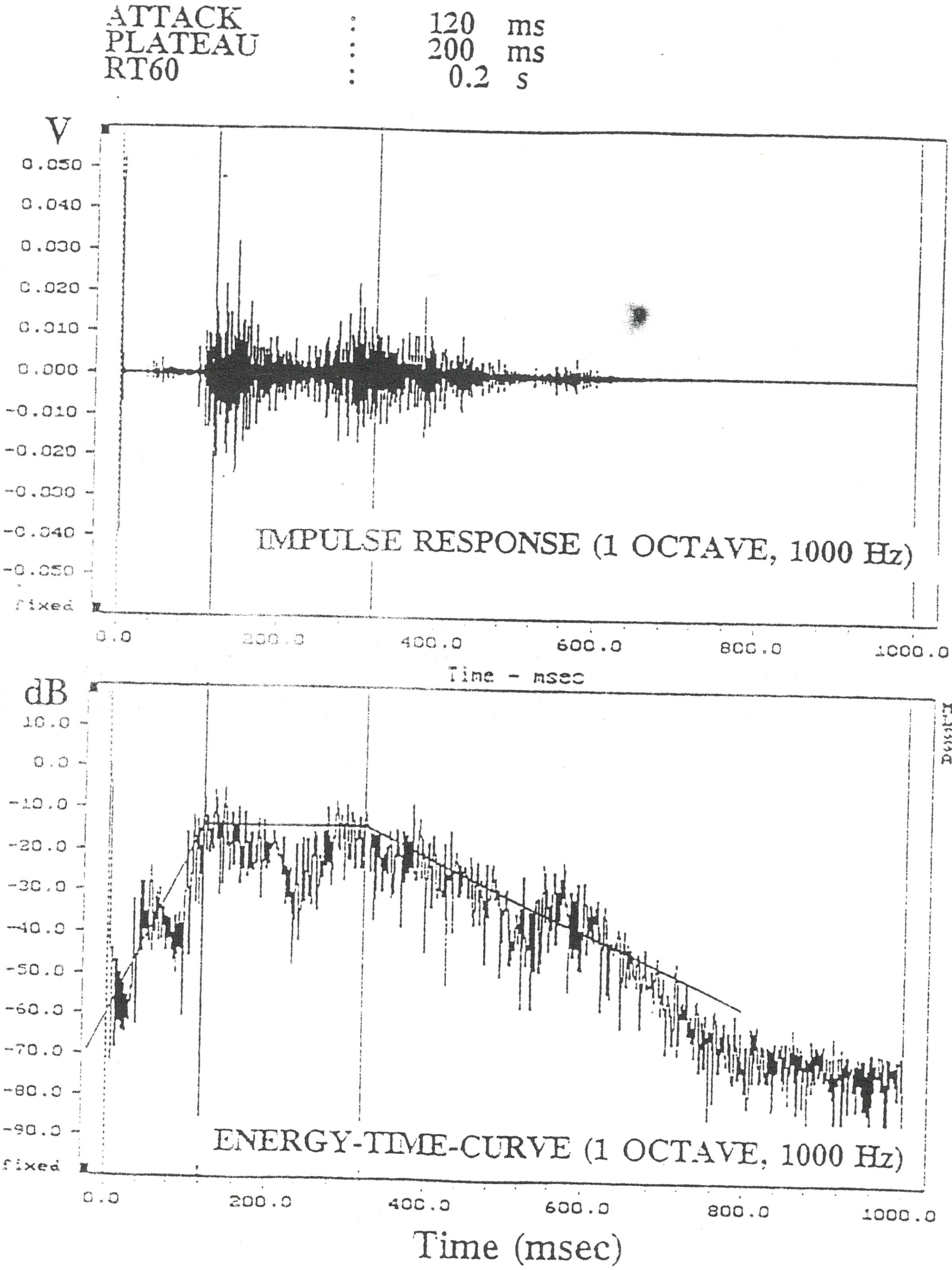


Figure 4. Output of a SIAP processor showing particular acoustic parameters

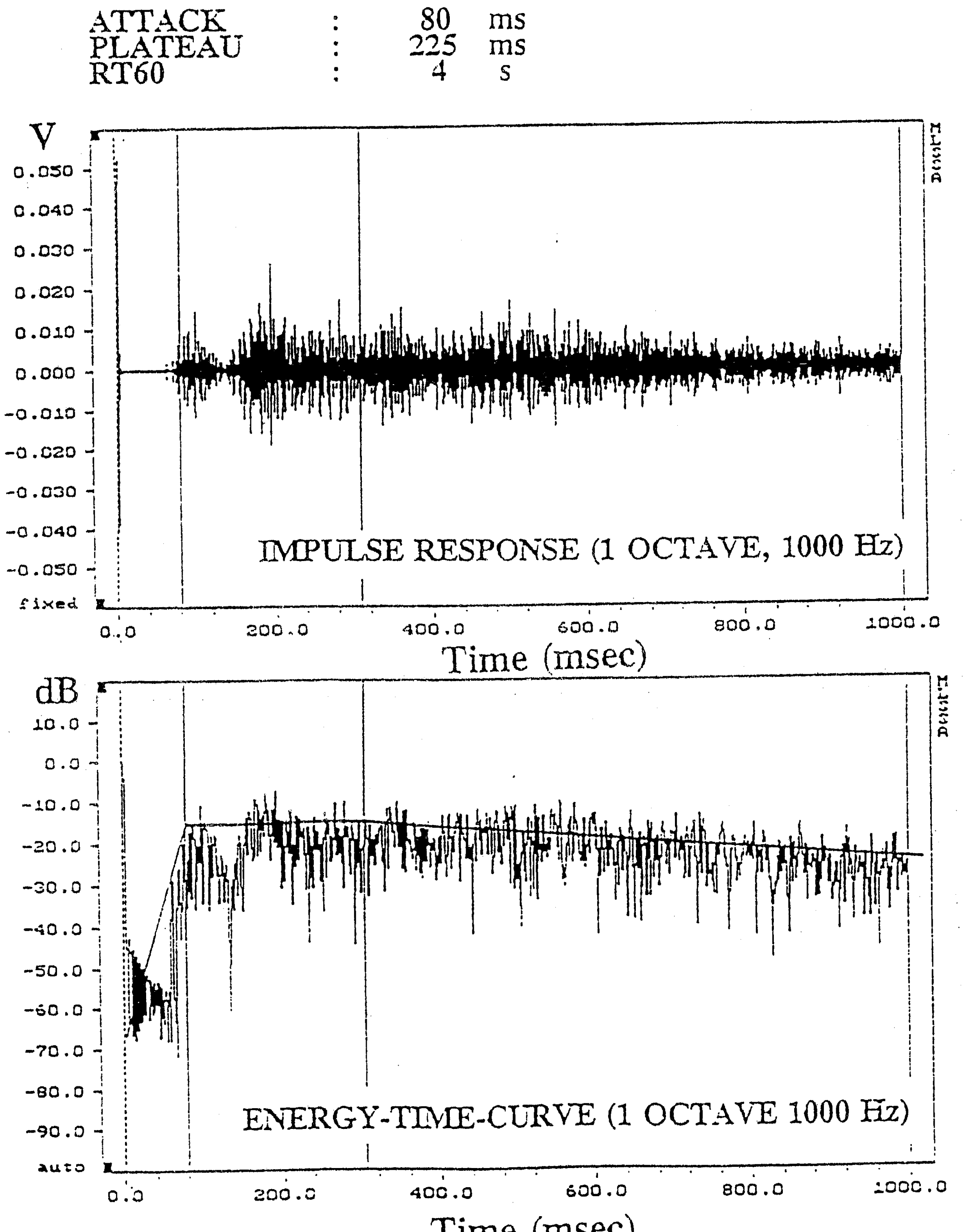
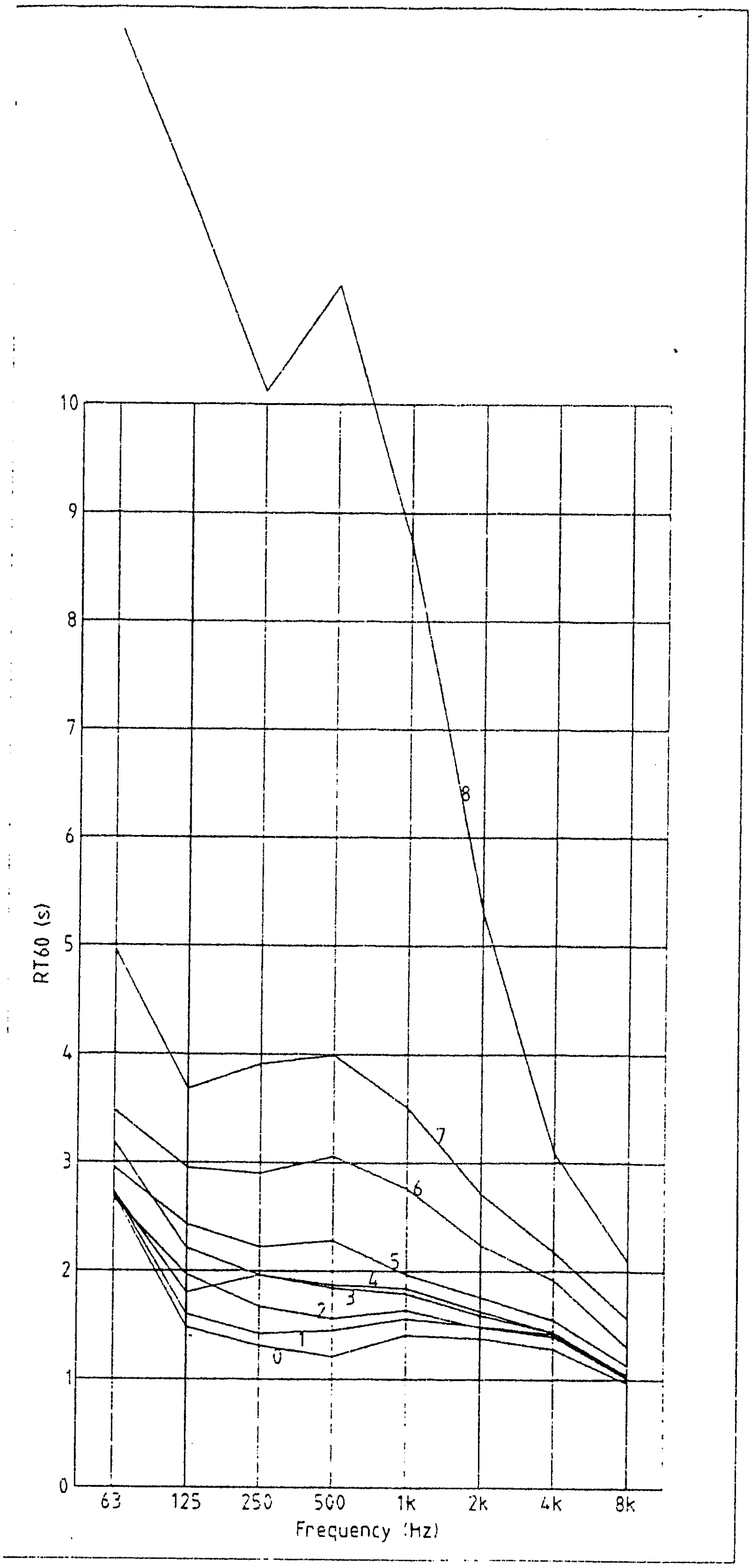


Figure 5. Output of a SIAP processor showing particular acoustic parameters



Shatin Town Hall
Hong Kong

8 - SIAP 8
Cathedral, special effects
7 - SIAP 7
Choir without orchestra
6 - SIAP 6
Choir with orchestra
5 - SIAP 5
Late romantic symphonic music
4 - SIAP 4
Average symphonic music
3 - SIAP 3
Classical symphonic music
2 - SIAP 2
Opera, chamber music, folk music
1 - SIAP 1
Speech
0 - SIAP off

Figure 6. Reverberation curves for the acoustic of the Shatin Town Hall at different SIAP settings

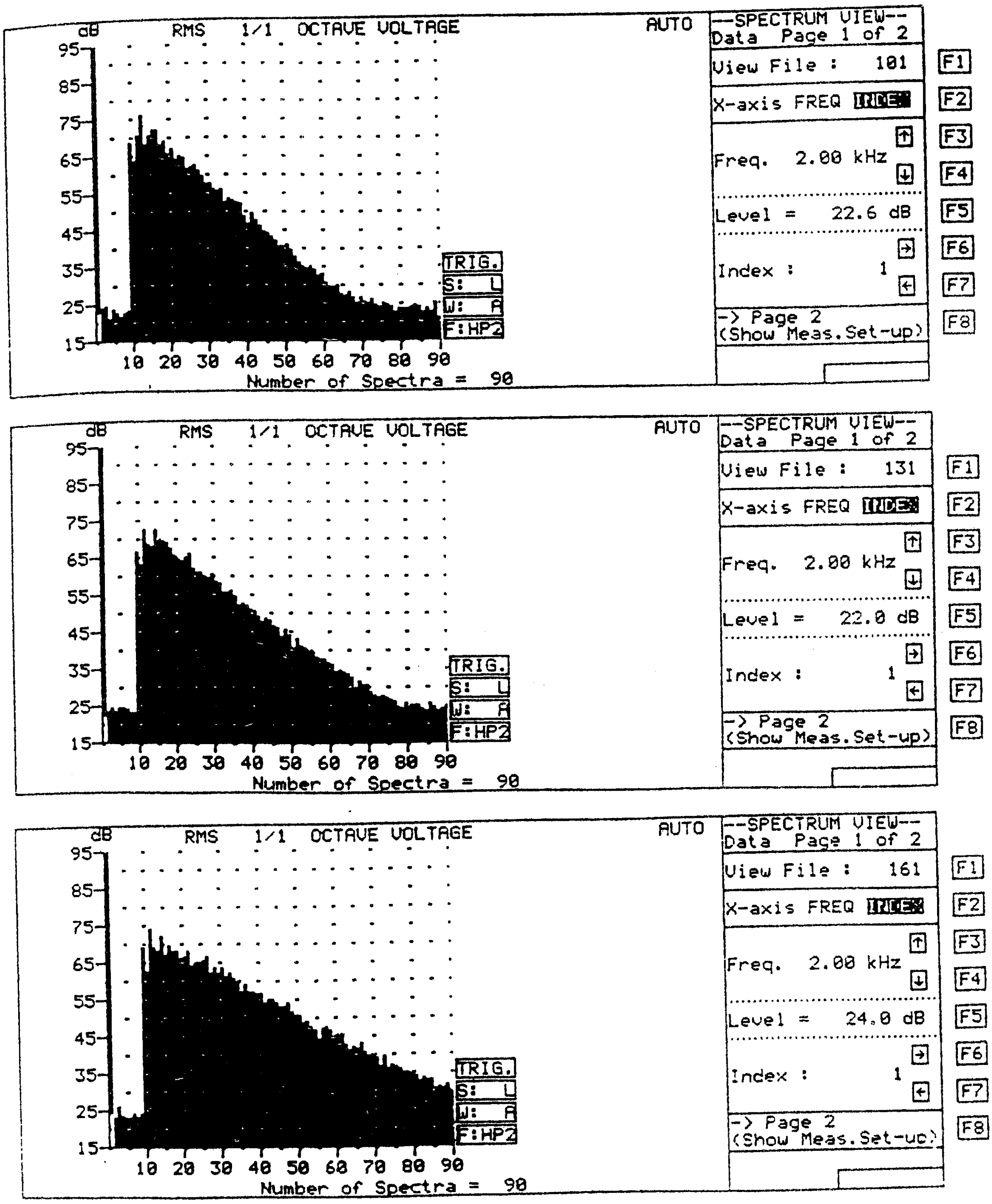
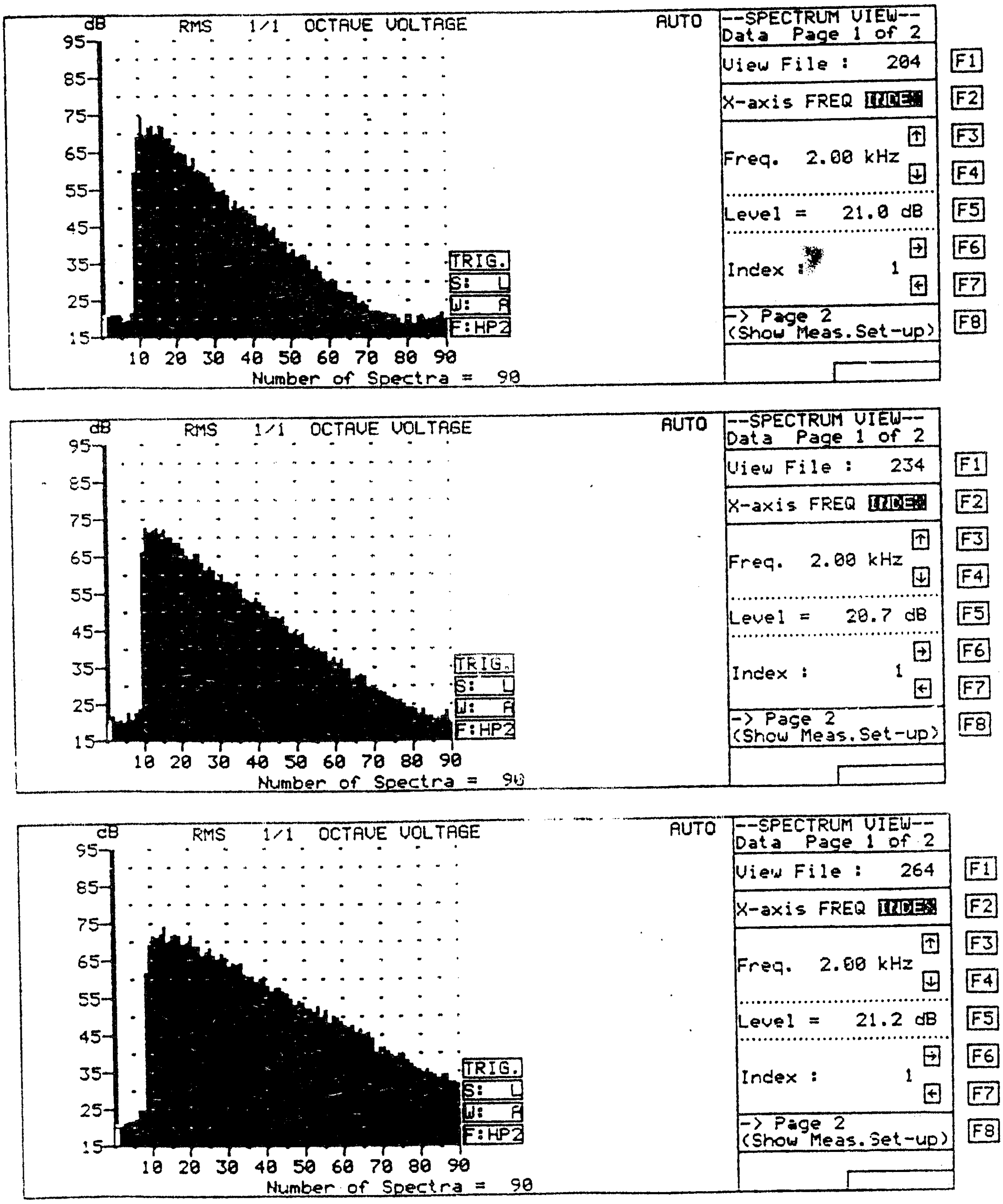


Figure 7. Decay curves Shatin Town Hall stalls position 2 KHz octave band



SIAP Off

SIAP setting 3

SIAP setting 6

Figure 8. Decay curves Shatin Town Hall under balcony position 2 kHz octave band