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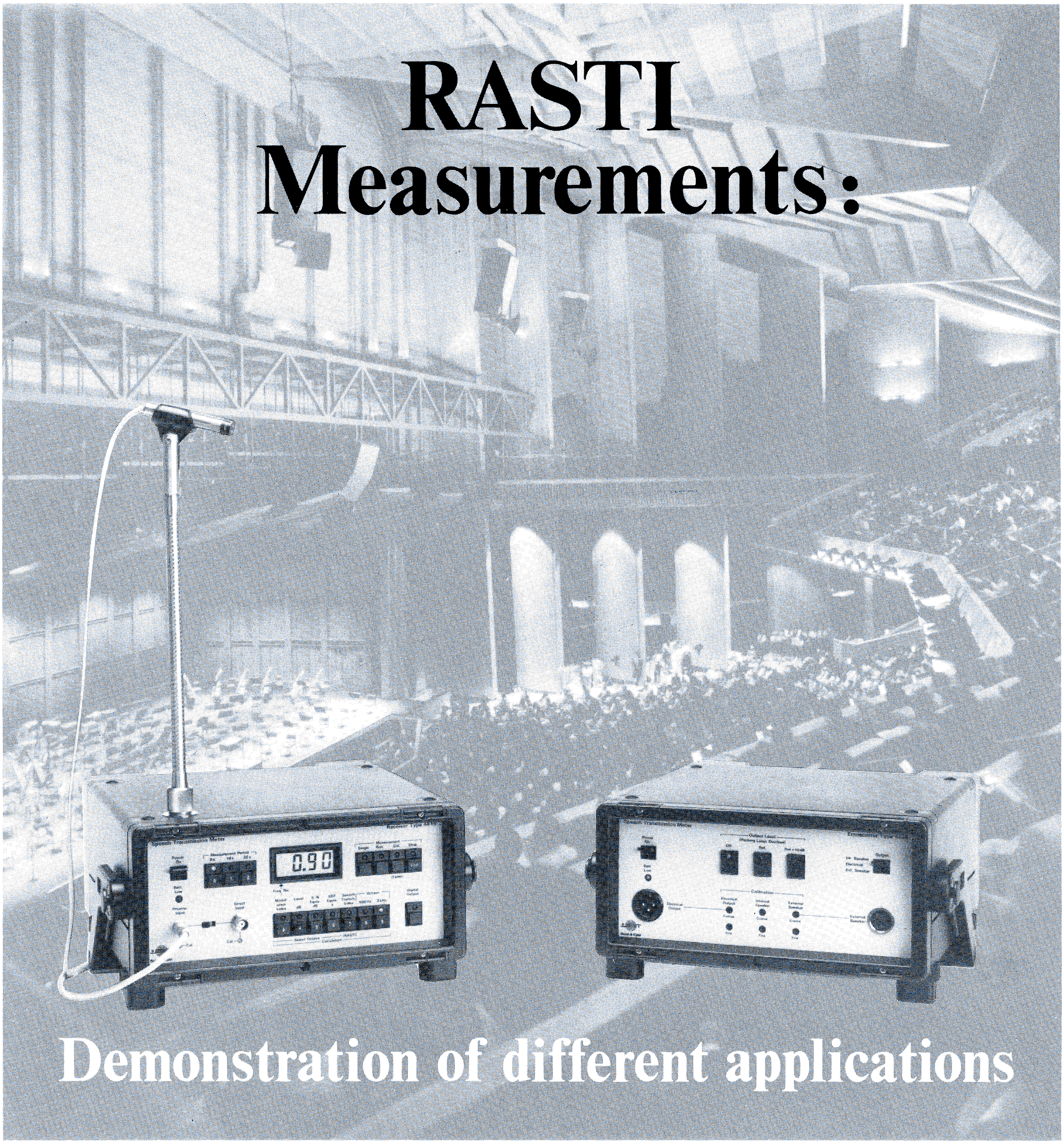
RASTI Measurements:



Demonstration of different applications

Brüel & Kjær

RASTI measurements: Demonstration of different applications

by *Thomas R. Horrall,* BBN, Cambridge, M.A.
Torben Jacobsen, Brüel & Kjær, Denmark

Introduction

Speech intelligibility in theatres, lecture rooms, churches, airplanes, etc. is an important consideration, which is why its evaluation is often required. Subjective methods can be used for this evaluation, in which people assess the intelligibility at different places in the room. This method is rather time consuming and the deviation of the results is rather high. For these reasons objective methods have been developed. RASTI, which stands for Rapid Speech Transmission Index, is a new standardized method.

The aim of this application note is to describe and demonstrate special uses of the RASTI method. The work was performed in cooperation between Brüel & Kjær and Bolt, Beranek and Newman, Cambridge. The instrumentation used was the Speech Transmission Meter, Transmitter Type 4225 and Receiver Type 4419.

The RASTI method and the foundation for it is briefly mentioned below and described in detail in references [1 – 5] and is being standardized by IEC [6]. For another use of the RASTI method see [7].

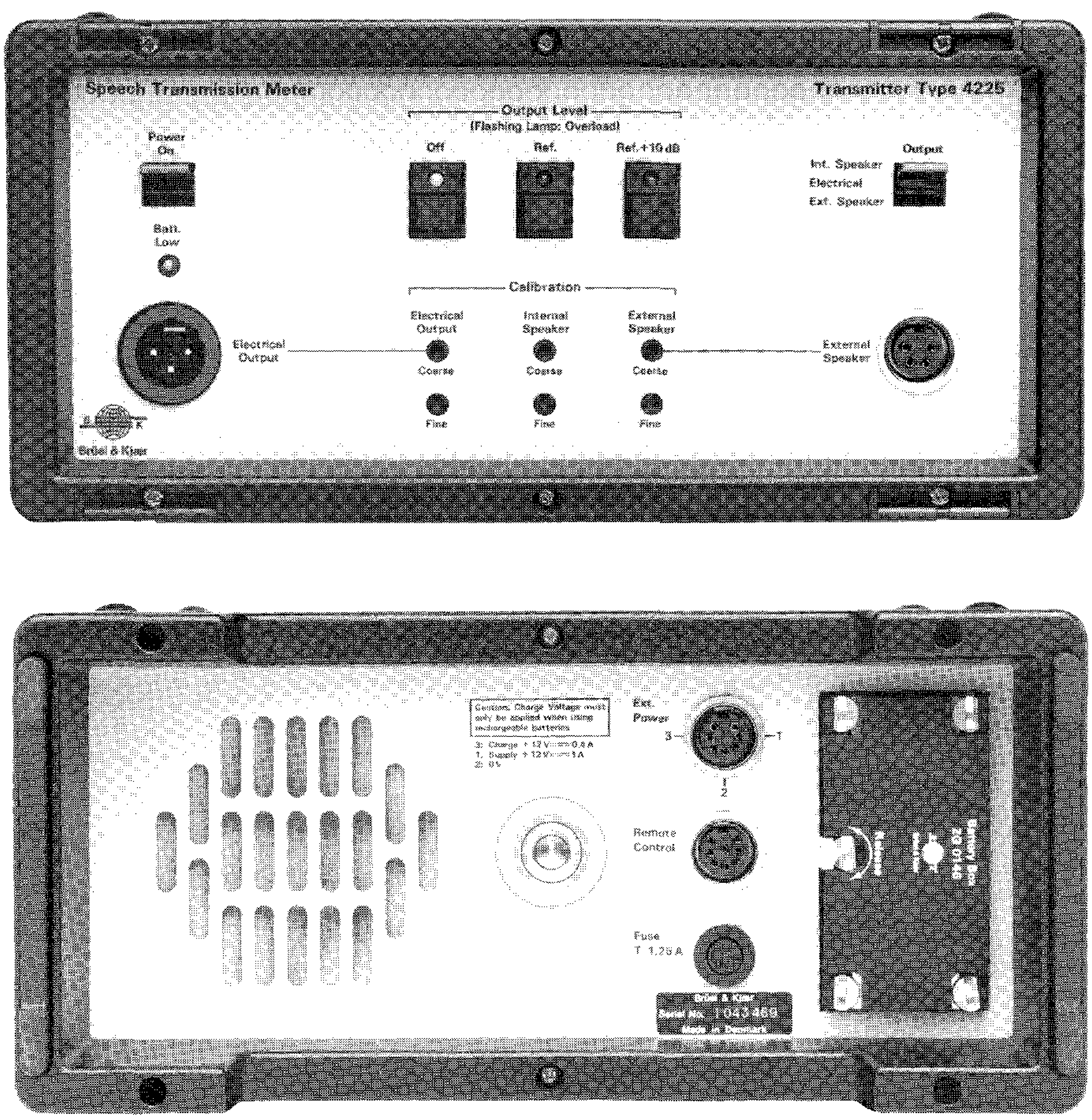


Fig. 1. Front and rear panels of the Speech Transmission Meter, Transmitter Type 4225. The Ref. Output level is according to the IEC standard and is equivalent to a speech level of 60 dB(A) (L_{eq}) at 1 m from the speaker. Three different output facilities exist: a built-in loudspeaker, an output for external speaker and an electrical output. The box together with the built-in loudspeaker have approximately the same directivity as that of a human being.

The RASTI Method

The basis for the RASTI method is a measurement of the modulation transfer function between the transmitter (the speaker) and the receiver (the listener). Conversion of the modulation transfer function to a speech

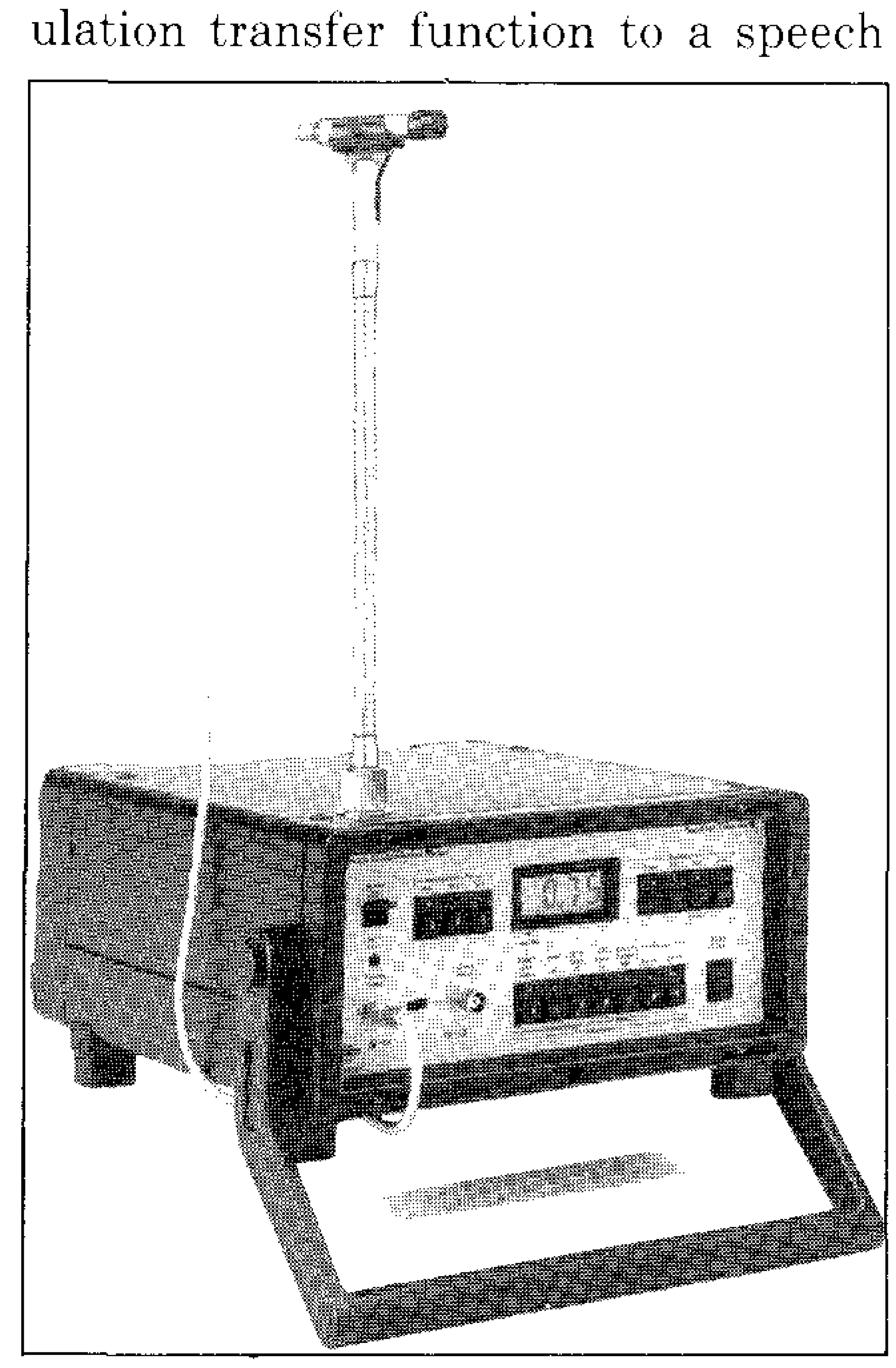


Fig. 2. The Speech Transmission Meter, Receiver Type 4419. The signal is measured with the microphone, but also direct electrical input is possible. The measurement time can be 8, 16 or 32 seconds. After the measurement the RASTI value is displayed. Other results can be called to the display by means of the appropriate pushkeys or read out by means of the serial interface.

intelligibility rating was developed by the Institute for Perception, TNO, the Netherlands. This rating is called the Speech Transmission Index, STI.

The disadvantage of the full STI method is that it demands 98 measurements, and therefore a quicker method – the RASTI method – has been developed and is now being standardized. By means of the RASTI method it is possible to evaluate the intelligibility in one listening position in 8 seconds.

During a measurement the transmitter (see Fig. 1) is placed at the speaker's position and sends out a test signal which contains information about the speech spectrum, fluctuations in speech, and speech level. The Receiver (see Fig. 2) is placed at the listener's position and by means of a discrete Fourier Transform the modulation transfer function is measured and from this the RASTI value is calculated. The result appears in the Receiver display and can be printed out on a printer. Besides the RASTI value, other information of diagnostic value is provided. This facility ensures that the RASTI instruments also can be used as a diagnostic tool.

Sound Masking System in Open-plan Offices

Studies of office workers' satisfaction over the last 20 years have demonstrated the importance of obtaining an adequately low level of speech intelligibility between adjacent offices. Most workers are distracted and find it difficult to concentrate if they can understand unwanted and intruding conversations.

Speech intelligibility depends primarily on the ratio of sound levels of speech to background noise and reverberation experienced by a listener. However, good open-plan office construction assures very low reverberation so that only the speech to noise ratio is important. Good office construction also reduces speech sound transmitted from one office to another so that a comfortable level of background noise will assure that the intelligibility is no higher than about 0,20 as measured by the articulation index (AI), ANSI standard S.3-2.

Open-plan offices are extremely popular in the USA. Quality offices of this type are normally provided with extensive acoustical treatment of ceilings and partial-height dividing partitions in order to reduce transmitted speech sound. However, the background noise from conventional sources, such as the building ventilating system, is normally insufficient to assure low enough intelligibility. As a result, electronically generated and frequency contoured sound provided by a sound masking system has become a part of most high quality open-plan office installations.

The ideal adjustment of a sound masking system is that which has both a spectrum shape and sound level yielding the lowest perceived loudness, and which simultaneously provides the 0,20 AI or other intelligibility goal. Achieving the lowest possible background noise level is a critical part of assuring that the masking system is subjectively unobtrusive, and accepted as part of the normal environment by the office worker.

A standard sound level meter with A-weighted scale can be used to indicate the perceived loudness of background noise, but cannot indicate intelligibility directly. As a result, various objective and subjective test methods have been developed to estimate inter-office intelligibility. These methods typically require a skilled test operator, are time consuming, and suffer from limited repeatability and reliability. Clearly, an instrument capable of making rapid and reliable measurements correlated directly with intelligibility would be a valuable tool. To evaluate the RASTI method for determining intelligibility, in situ measurements were made in open-plan offices of BBN Laboratories which are equipped with a calibrated and adjustable sound masking system.

The RASTI transmitter was located in one office (PIRN) and positioned corresponding to mouth height for a seated speaker (see Fig. 3). The RASTI receiver was located in the adjacent office (HIRTLE) and similarly positioned corresponding to ear height for a seated listener. The height of the partition dividing the two offices was 62″ = 1,57 m, and all ceiling and partition surfaces were well treated with sound absorbing materials. The end walls of both offices were acoustically hard.

Separate sets of RASTI measurements were made for the transmitter directed toward the receiver, for two source levels corresponding to normal speech and raised voice, and for three adjustments of background sound level.

The background sound level was measured in octave bands with a precision sound level meter/filter set, and was also confirmed in two bands with the RASTI receiver, see Table 1.

The octave band sound isolation between offices had been measured earlier for the same transmitter and re-

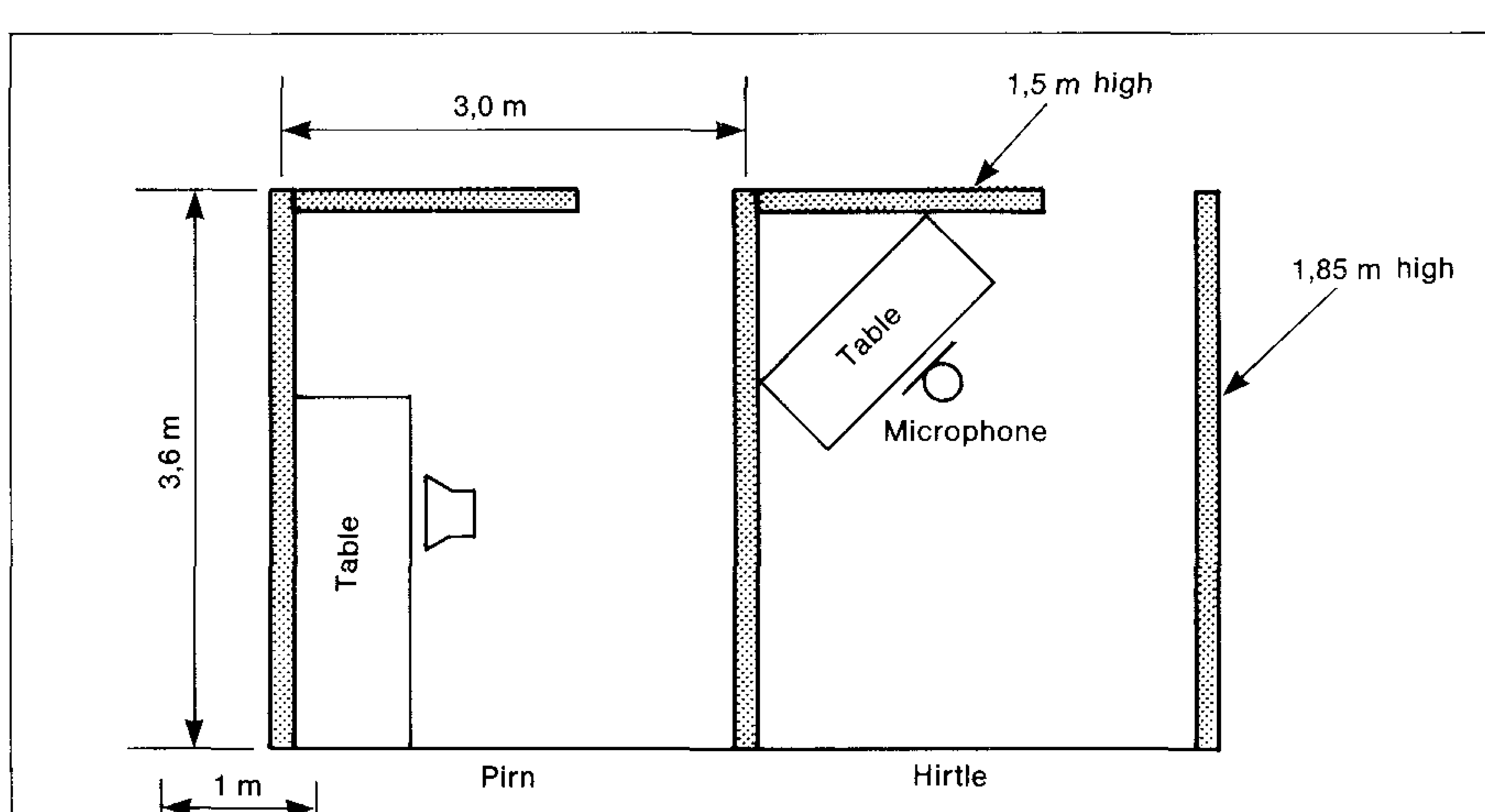


Fig. 3. A plan of the open-plan office

ceiver positions, using broadband random noise played through a small loudspeaker with directivity approximating that of the human voice and with a precision sound level meter/filter set. These measurements allowed direct calculation of the AI, using a BBN computer program (OPLAN), for comparison with those derived from RASTI measurements. Translation from RASTI value to AI is according to the method described in Acustica, Vol. 46, 1980, p.60. For pure noise interference (no reverberation), the RASTI is 0,1 greater than the AI: this condition is obtained in a well-treated open-plan office. The BBN computer program was provided with data for the two source levels (60 dB(A) = IEC standard level and 70 dB(A) = IEC standard level + 10 dB) corresponding to normal and raised-voice speech at 1 meter from a speaker. These levels are used by the RASTI transmitter, so that results should be directly comparable. The results are shown in Table 2.

Results					
Octave band frequency	250	500	1000	2000	4000 Hz
Background Noise					
1. BBN normal space average design level	48	46	43	39	32 dB
2. Measured at normal masking level + 3 dB, SLM at HIRTLE	51	49	46	44	36 dB
3. Measured at normal level + 3 dB, RASTI receiver HIRTLE	– –	49,0 49,1	– –	43,7 44,3	– –
4. Normal level from 2 (after return to normal setting), SLM at HIRTLE	48	46	43	41	33 dB
5. Normal level, RASTI receiver at HIRTLE	– –	45,4 45,8	– –	40,3 41,1	– –
6. –3 dB masking level, RASTI receiver at HIRTLE	–	43,5	–	38,2	–
7. Masking system off (ventilating system only)	–	35,9	–	24,4	–

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Table 1. Background noise measurements in the open-plan office

Agreement is excellent for the case tested with masking level adjusted for 3 dB above normal ambient and for a transmitter source of IEC standard level. Other agreement is good, with maximum differences of 0,11. The difference may be due to a slightly different frequency dependence in the sound isolation between offices than assumed by the RASTI method.

For typical open-plan office construction, the AI increases by approximately 0,1 for each decrease of background level of 3 dB. Hence, a maximum error of 0,1 in either AI or RASTI translates directly to a maximum error in background level setting of about 3 dB from optimum. This difference is also normally considered to be barely perceptible, so that even the maximum error would not be serious. It is also apparent that the RASTI consistently estimates the intelligibility to be slightly higher than the OPLAN program, at least for the range of conditions tested. Thus a RASTI-value of 0,3 or less will indicate good privacy conditions. However, values slightly above this may also be acceptable.

	Transmitter Source Level = 60 dB(A)			**Transmitter Source Level = 70 dB(A)**		
	RASTI	**AI from RASTI**	**AI from Oplan**	**RASTI**	**AI from RASTI**	**AI from Oplan**
1. Masking level = Normal + 3 dB, Sound source facing receiver	0,20	0,10	0,08	0,49	0,39	0,30
2. Masking Level = Normal Sound source facing receiver	0,29	0,19	0,12	0,61	0,51	0,40
3. Masking Level = Normal –3 dB	0,38	0,28	0,17	0,65	0,55	0,50
4. Masking off	0,63	0,53	–	0,76	0,66	–

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Table 2. Results from the open-plan office

RASTI Measurements in the Newman Auditorium

The Newman Auditorium at BBN Laboratories is a medium size (174 seats) auditorium used for lectures, film presentations and occasional musical presentations. No speech amplification is used, but intelligibility is generally considered to be excellent. The background noise level is controlled to less than NC–25, and the mid-frequency reverberation time is about 0, 8 seconds. The rear wall is acoustically absorbent to prevent echoes.

The transmitter was located on the platform stage and oriented towards the audience seating. The transmitter level was IEC standard level. RASTI values were measured at 7 seats at representative locations throughout the auditorium. Fig. 4 illustrates the measured values, all of which are characterized as "good" or "excellent" according to the IEC standard.

measurements were made and the RASTI results were 0,45, 0,47 and 0,47, indicating "fair" intelligibility.

The results show that it is possible to make RASTI measurements in a factory in spite of high background noise. Furthermore, the results in this case show that it is possible (but difficult) for the operators to communicate, but only if they stand close to each other and speak loudly.

It can be concluded that the telephone in the factory hall is not of much use, but the telephone in the office can be used although it is still necessary to speak loudly.

In other connections, PA systems have been evaluated in power plants with background noise levels of 90–100 dB(A) and where the reverberation time has a large influence. In these applications the RASTI method has also been shown to be valuable.

Concert/Drama Hall with Adjustable Reverberation Time

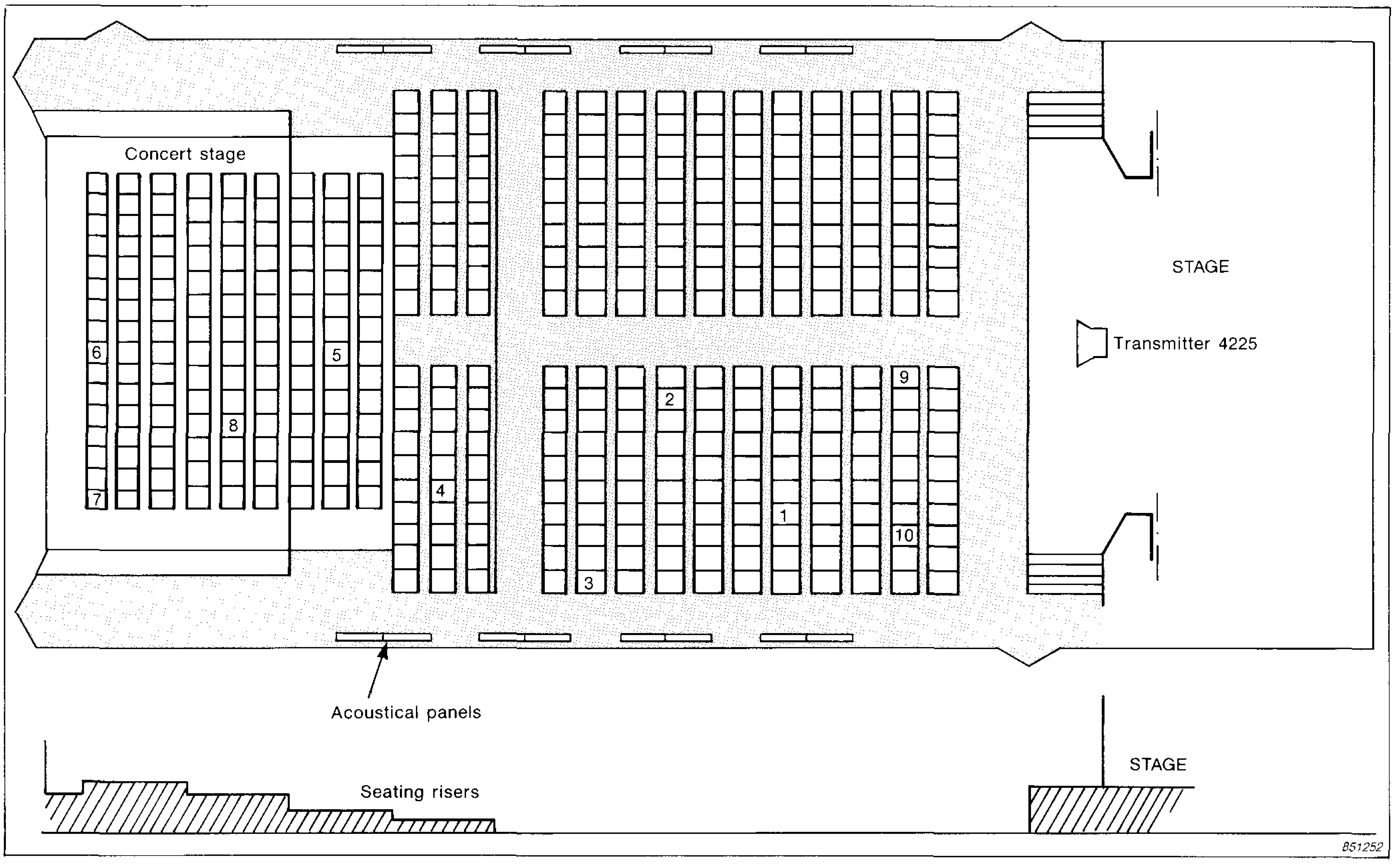

Fig. 5. The seating plan for the concert/drama hall

51 Walden Street is a small auditorium used both as a concert hall and a drama theatre by community performing arts groups in Concord, Massachusetts. It has acoustical panels along the side wall which can be adjusted for sound absorption to lower the reverberation time for theatrical use, or adjusted for sound reflection to increase the reverberation time and early lateral energy fraction for musical performances. Opposite ends of the hall are used as the stage for musical and drama presentations. No sound amplification is used for either type of performance.

	RASTI Values at Seating Location Number									
	1	2	3	4	5	6	7	8	9	10
Side Wall Panels Soft, Ceiling Panels Hard Side Down	0,57	0,58	0,54	0,51	0,54	0,56	0,55	0,55	0,59	0,57
Side Wall Panels Hard, Ceiling Panels Hard Side Down	0,54	0,51	0,51	0,49	0,48	0,57	0,54	0,51	0,57	0,53
Side Wall Panels Hard, Ceiling Panels Soft Side Down	–	–	–	–	0,50	0,51	0,54	0,53	–	–

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Table 3. Results from the different positions shown in Fig.5 when the hall is used as theatre

In addition to the side-wall acoustical panels, there are panels above the music stage which are acoustically absorbing on one side and reflecting on the other: these can be inverted with the absorbing side down for loud musical groups such as brass bands, or the reflecting side down for symphony or small musical ensembles. With the reflecting side down, cross-stage communication (ensemble) should be enhanced (RASTI value increased) so that, for instance, the string-bass players can better hear the violin sound and vice versa. Using these panels with the reflecting side down may also provide ceiling reflections to audience seated on the music stage for drama productions at the opposite end of the hall. These reflections could be particularly useful since these seats are furthest removed from the drama stage.

RASTI measurements were undertaken to assess the effect of different panel adjustments. The first set of measurements was taken for the hall used in the theatrical configuration. (See Fig. 5.) The RASTI transmitter was located on stage with the level set to IEC + 10 dB to simulate a trained actor voice level. The results at different seating locations are found in Table 3.

Because the hall is quite reverberant when unoccupied (as measured), the RASTI values do not vary widely at different locations. However, measurements do indicate that intelligibility is enhanced with absorbing side walls. In addition, location No.6 at the center rear of the hall provides slightly improved hearing conditions with the overhead panels reflecting side down. These results correspond with the experience of the users.

The second set of measurements was taken to assess cross-stage communication for musical performance. For these measurements the RASTI transmitter and receiver were set up on opposite sides of the musical stage and music stands were interposed between them to block the direct line of sight to simulate the barrier effect of musicians and instruments in the middle of the stage.

An important aspect of conditions for a good ensemble is the ratio of "wanted" (distant instrument) sound to local instrument sound. In order to determine what level of local sound could be generated while maintaining an acceptable remote/local ratio, a variable level broadband random noise generator/amplifier/loudspeaker unit was placed near the RASTI receiver.

The RASTI value was then measured as a function of the local sound level as well as with the overhead panels adjusted for cross-stage sound reflection or absorption. The local sound level was measured with an SLM and the RASTI receiver, and in one case the local sound level was simulated by programming the receiver for a particular background noise level. The measured results are shown in Table 4.

The results indicate a substantial improvement in cross-stage communication when the local sound level was adjusted for 60 dB(A) and the overhead panels were adjusted for sound reflection from one side of the stage to the other. For the same local sound condition, but with the panels absorbing, the RASTI decreased by more than 0,1. Although 60 dB(A) is much lower than a typical orchestral sound level, the ratio of sound from the RASTI transmitter to the local noise source may be more typical. In any case, this result corroborates reports from musicians who have played with the panels set both ways. Comparison of results with similar measurements in other halls could be most useful in determining relative stage ensemble conditions.

A second possible use of RASTI in music halls could be as a measure of clarity for various sections of the audience. Either too much clarity (high RASTI values) or too little is probably undesirable. Through measurements in a variety of halls, it should be possible to establish a range of RASTI values generally considered to represent good hearing conditions.

Local Sound Level			Ceiling Panels all absorbing		1st row reflecting	1st & 2nd row reflecting
dBA	500 Hz dB/oct.	2000 Hz dB/oct.	RASTI value Measurement 1st	2nd	RASTI value	RASTI value
40			0,54	0,59	0,56	0,56
50			0,47	0,53	0,52	0,53
60	51	55	0,29	0,34	0,39	0,41
65			0,23	0,23	0,26	0,24
70			0,10	0,15	0,13	0,13
Noise floor of 4419 used instead of background noise:						
60	51	55	0,32			

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Table 4. Results from the measurements on the concert stage

Evaluation of sound reinforcement systems for a performing arts center

The Filene Center at Wolf Trap Farm Park is a large outdoor/indoor music and theater facility near Washington, D.C. Recently rebuilt after a disastrous fire, the facility is used for both popular and classical music performances of all types. Opera is also presented. BBN Laboratories were the acoustical and sound system consultants for the reconstruction.

The main building provides for about 3,500 seats on a main floor and a single large balcony. The side walls consist of alternating sound reflecting panels and openings to outdoors. There is an enclosing roof, and the rear of the main floor and balcony is completely open to a sloped lawn so as to provide visual and acoustical communication to the outdoor audience seated there. The lawn may accommodate upwards of 2,500 audience members.

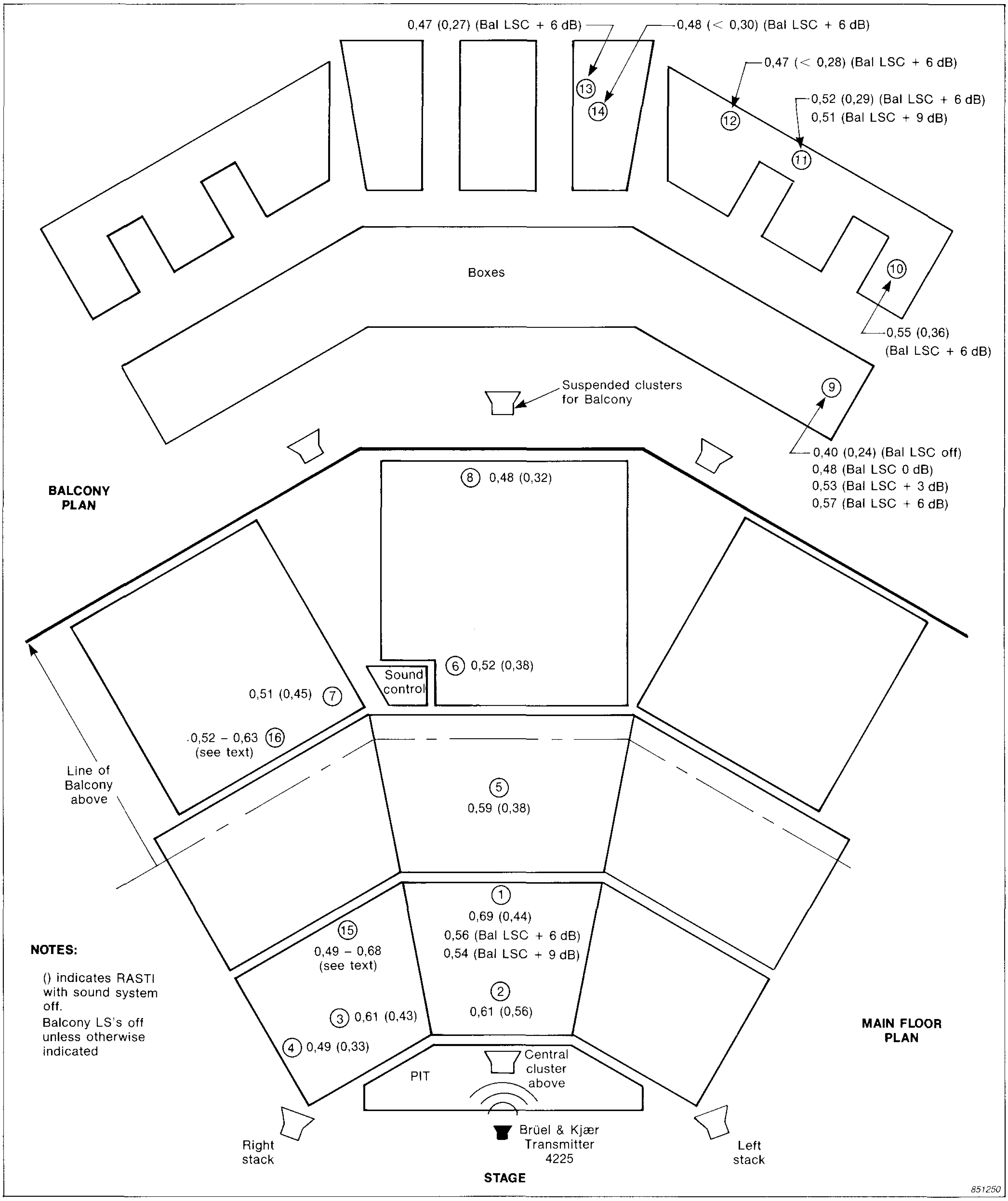

Fig. 6. Plan of the performing arts center

Sound amplification systems for the facility include a large 3-way loudspeaker cluster above the proscenium on the hall center-line to serve the forward part of the main floor audience which is not covered by the balcony overhang. A separate under-balcony system of distributed ceiling-mounted loudspeakers serves the audience seated there, most of which does not have a line of sight to the loudspeaker cluster. In addition, three identical suspended loudspeaker clusters are provided for each of the three sections of the balcony (center and each side). The under-balcony and balcony loudspeaker signals are delayed electronically so as to synchronize with sound from the main center cluster. Two large "side stack" loudspeaker clusters are built-in, one on each of the proscenium openings. A separate multi-cluster loudspeaker system is provided for coverage of those seated on the lawn outdoors.

The sound systems are used for virtually all popular music presentations. For classical music, the indoor sound systems are normally used only for reinforcing instrumental or vocal soloists, but not for ensemble or orchestral reinforcement.

The transmitter was placed stage center and oriented directly toward the audience for acoustical measurements. The source level used was IEC + 10 dB since it is more representative of voice level from a trained singer. For measurements on the reinforcement system, a microphone was placed about 0,3 m in front of the 4225 loudspeaker. Certain measurements were made with the sound system driven directly by the 4225 electrical output.

Noise at Receiver Loc. 1 500 Hz OB / 2000 Hz OB	RASTI Value
76,1 / 64,7	0,09
73,1 / 61,7	0,19
70,1 / 58,7	0,27
67,1 / 55,7	0,36
64,1 / 52,7	0,42
61,1 / 49,7	0,46
58,1 / 46,7	0,49

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Table 5. RASTI values in location 1, for different background noise

Loudspeakers Operating	RASTI at pos. 15 Forward, Near Right LS Stack	RASTI at pos. 16 Center of Main Floor, Right Side
Center & Balcony Clusters	0,49	0,55
Both stacks, Center & Balcony Clusters	0,53	0,52
Both Stacks Alone	0,61	0,58
Right Stack only	0,68	0,63

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Table 6. Results with different loudspeakers

The receiver's microphone was placed on a tripod so that the microphone corresponded to ear-height for a seated listener. RASTI measurements were made at representative seat locations throughout the main floor and balcony. No measurements were made outdoors.

Measurements were made at most locations both with and without use of the sound amplification system since the hall may be used in corresponding ways. Separate RASTI measurements were also made with different level adjustments of the three delayed clusters relative to the main cluster.

Fig. 6 illustrates the results of the measurements.

The results indicate that intelligibility is rather low at most seats when no amplification is used, as expected. Only in the center of the room near the stage is it possible to understand unamplified speech.

Finally, a set of RASTI measurements were made at a seat (position 1) near the center of the main floor when an orchestra was simulated by playing different levels of random noise through monitor loudspeakers on stage, but with the 4225 transmitter electrical output connected directly to the sound system input. The purpose of this particular test was to illustrate the masking effect on intelligibility in the hall of reverberant sound caused by operation of artists' stage monitor loudspeakers.

The RASTI values and background noise levels as measured by the 4419 receiver at position 1 on the main floor with 3 dB steps in noise from the stage monitor loudspeakers are shown in Table 5.

RASTI values were also measured on the main floor with various combinations of loudspeakers on and off; see Table 6.

Some care must be taken in interpreting the results. When the amplification system is in use the intelligibility depends largely on reverberation characteristics rather than background noise. The main building has reverberation characteristics like a fully enclosed hall, but because it is open to the outdoors, use of upholstered seats is not practical for stabilization of reverberation time with varying audience size. This results in RASTI measurements in the unoccupied hall which are substantially lower than would be expected for the more usual fully occupied and less reverberant hall. Nevertheless, comparison of the RASTI values at different seats serves as a very useful guide in determining areas of potential problems. Indeed, there have been reports of inadequate intelligibility during some performances in areas with low measured RASTI values. Work is under way to improve the coverage of the sound system in these areas.

It is also apparent that inappropriate signal balance among the various loudspeakers can badly deteriorate intelligibility in certain seating areas. For instance, operating the balcony loudspeakers at higher levels (+ 6 and + 9 dB) slightly improves the RASTI values at balcony areas 9 and 11, but deteriorates the results on the forward part of the main floor – area 1 – as the late sound energy from the balcony loudspeakers returns to the front of the hall.

There are many ways in which a complex sound reinforcement system may be operated which affect the intelligibility achieved. The RASTI method allows practical objective analysis of these operating methods, as well as comparison with portable systems which may be brought in by visiting artists, or even comparison with systems serving other similar spaces.

Conclusions

Both for the measurements described in this application note and for measurements in very large buildings (e.g. St. Paul's Cathedral, see [7]) the RASTI method has proven itself to be a very quick and useful method for evaluating speech intelligibility. In many circumstances it is the only existing method which can be used for an objective evaluation of intelligibility.

In future it is expected that the RASTI method will become incorporated in standards for assessing speech intelligibility in a range of applications, including the evaluation and classification of emergency systems.

Acknowledgements

We want to thank all Companies and people involved in the measurements mentioned above.

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Brüel & Kjær
DK-2850 NÆRUM, DENMARK
Telephone: + 45 2 80 05 00
TELEX: 37316 bruka dk

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