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SOUND SYSTEMS FOR LIFE SAFETY AND THE NEED FOR RISK ASSESSMENT

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1. INTRODUCTION

As a direct result of disasters which have cost lives, lessons have been learned and applied in the form of Standards. The Standards produced in relation to Life Safety systems are the most stringent ever produced, and yet they have to be sufficiently universal that they can provide guidance for all types of buildings. The latter has resulted in some sections being over prescriptive, yet other sections being woolly and open to mis-interpretation.

This paper describes further detail to the requirements of the various published Standards relating to sound systems used for emergency purposes, whether those be linked to fire detection and alarm systems or not, and whether the sound systems provide for automatic evacuation routines, or are for manual evacuation routines, or a combination of these.

This paper also identifies the areas where equipment and materials not available or proven at the time of the authoring of the Standards can be used, provided adequate safety measures are taken, in the design and installation of the system.

Since no two buildings are the same, the process of designing a sound system for emergency purposes must start with a risk assessment of the building concerned, related to its use and method of operation in real terms. The guiding principles for a design relate to that risk assessment.

2. GUIDING PRINCIPLES:

G1 Diversity:
When designing a system, the assessment of risk of failure must be analysed. All single points of failure must be minimised and preferably removed. The more diversity designed into a system, the more likely it is that a larger part of the system will operate when required, and to a higher standard. However, care should be taken to avoid unnecessary complication which might lead to unreliability or difficulty of maintenance.

G2 Intelligibility:
A system should be designed such that for an intelligible input there is an intelligible output. The coverage of the building with such an intelligible output must include all areas where people might need to escape from, including the escape routes, to safety. The risk of a person not hearing an intelligible message in an emergency must be assessed and compared to the likelihood of that space being occupied. e.g. a corridor or an office is a likely place to be occupied, but the ceiling of an atrium is not. What is usually the nub of the problem is areas which are either small, or rarely occupied, or both, e.g. store rooms electrical plant rooms, roof-top plant areas etc., where the assessment needs to be reasoned between pragmatism and percentage risk in a consistent manner.

G3 Proving that it still works:
A system should be monitored to so as to prove that for an acoustic input there can be an acoustic output when required. This monitoring must be automatic except for the loudspeaker itself which must be manually checked by testing the system on a regular basis. The monitoring must be continuous i.e. it is not acceptable to remove the monitoring at any time.

G4 Value engineering:
A system used to provide non-Voice Alarms services such as general paging or entertainment is far more likely to operate in Voice Alarm mode when required because it is "monitored" far more often in its non-Voice Alarm mode by staff and the Public. The only stipulation required is that Voice Alarm takes priority without compromise.

G5 Intuitive & easy operation, but safer due to reducing all areas of risk:
A system will not fulfil its role if the unfamiliar user cannot operate it easily and intuitively, nor will it fulfil its role if materials or equipment are chosen which do not address all the risks, not just those of fire, (e.g. vandalism, accidental damage etc.).

3. CONSIDERATIONS AND CROSS-REFERENCES:

The following codes have been used to provide logical indicators of subject matter:

- A Amplification
- C Cabling
- F Fault Monitoring
- G Guiding Principles
- L Loudspeakers
- M Microphone
- S Audio Signal Processing
- U Batteries or UPS
- X Control

In order to maintain a portrait format for this publication, the cross-references have been abbreviated as follows:

- GP Guiding Principle (as described above)
- B1 BS5839 part 1
- B4 BS5839 part 4
- B8 BS5839 part 8
- 69 BS EN 60849

		Consideration	GP	B1	B4	B8	69
M	1.	It should be noted that the Emergency Microphone forms a single point of failure unless it is duplicated and diversified. I.e. more than one area where emergency messages can be given.	G1			12.3	
M U	2.	If the microphone electronics is mounted locally, it could be phantom powered from the central equipment. In the case that it is locally powered (and there is no reason not to do so) then there needs to be a	G1	16			

			Consideration	GP	B1	B4	B8	69
			secondary power supply. This secondary power could take the form of a re-chargeable battery or a (small) UPS.					
M	X	3.	The integrity of the microphone used for emergency purposes must be continuously monitored. Whatever method of achieving this must provide a continuous system of monitoring through to the loudspeakers. E.g. if 20Hz is used to monitor the microphone, and 20kHz is used to monitor the remainder of the system, then the 20kHz must be injected into the audio signal before the 20Hz is filtered out. This implies that the 20Hz is detected prior to the filter and after the 20kHz is injected.	G3			7.2e	
M	X	4.	If the microphone electronics is mounted locally, then the status signal should be sent to the central fault monitoring system as well as the audio signal to the central equipment.	G3			7.2e	
X		5.	For larger buildings, and especially those used by the Public, there should be more than one place where an emergency microphone can be used on the basis that a fire or terrorism alert in the primary location may preclude the message being originated from that primary location.	G1			12.3	
X		6.	Zone selection panels for selecting zones for Voice Alarm messages should be ergonomically laid out, intuitive to use, and preferably topologically representative.	G2			17.3.2	5.2d
X		7.	Zone selection panels should also utilise topological touchscreens on larger systems, but it is important that these are duplicated and their connection cables diversely routed in order to avoid the risk of a single point of failure.	G1			12.3	
X	M	8.	In the case of large systems, and especially in complicated buildings to which the Public have access, the control panel may take the form of a touch-screen. This provides more relevant detail of a fault status than mere indicating lamps (e.g. critical or non-critical faults) provided that it is designed properly and takes into account the unique	G3			7.2i	

			Consideration	GP	B1	B4	B8	69
			requirements of the building. Where touchscreens are used, the secondary power is preferably given by means of a UPS, and the status of the touch-screen, the UPS and the microphone all need to be sent to the central fault monitoring system as well as the audio signal to the central equipment.					
X	C	9.	Where large sites require the control and amplification equipment to be distributed around the site (e.g. Stadia, shopping malls, educational establishment etc.) not only to reduce loudspeakers cable runs, but also to diversify the risk of a single site failure, the inter-connecting signal and data cable shall be selected for their ability to carry the relevant type of signal and routed in such a fashion to minimise the risk of being affected by fire or electromagnetic interference as well as being protected from fire and mechanical damage as far as possible by means of cable containment.	G1	17.1 17.15		7.2i	
S		10.	If any of the following functions are carried out by a digital signal processor, the risk of a failure constitutes a single point of failure, therefore the sources and outputs should be interleaved and routed via a pair of processors such that if one fails, only half the system is in failure mode: • 20kHz Injection and Mix • Routing of priority/emergency sources to outputs • Room Equalisation • Delay for the relative location of loudspeakers. • Detection of 20kHz on an emergency source.	G1				
S		11.	In the case of a multiple driver loudspeaker assembly using an active crossover, the speech range driver circuit must be monitored. If this uses a mixed tone (e.g. 20kHz) then the crossover must be arranged to have a suitable (High Q) notch band-pass at the appropriate frequency.	G3				
S		12.	If signal processing is carried out using discreet equipment which is totally analogue (or discreet units which have analogue	G1 G2			7.2f	

		Consideration	GP	B1	B4	B8	69
		inputs and outputs, yet process in the digital domain), care should be taken regarding warranties and overall reliability if it is proposed to modify these to provide secondary power directly from batteries. Similarly, the selection of such products should also take into account the risks associated with a single point of failure and the ability to successfully monitor the signal path in the event of dynamic level changes which affect the monitoring signal. e.g. automatic level control or active crossover monitoring by 20kHz tones.					
S	13.	The concept of allowing the emergency message – be it from a microphone or a message generator – to by-pass the signal processing in the event of a failure of that processor belies the importance of intelligibility. The solution should be to duplicate and diversify the signal path through two (or more) processors in an inter-leaved fashion.	G2				
S	14.	The concept of allowing the emergency message – be it from a microphone or a message generator – to by-pass the routing as an "all call" in the event of a failure of a processor may be satisfactory in smaller installations, or those installations which only use routing for non-VA purposes. However, where a building is to be evacuated in phases (e.g. hotels, multi-storey offices etc.) or buildings open to the Public (e.g. shopping malls, stadia, arenas, theatres etc.) which should be manually evacuated, the principle of an "all call" may actually cause personal damage or fatalities due to stampeding and clogging of exits by people who, having left a relatively safe area, mix with those from an endangered area. The solution should be to duplicate and diversify the signal path through two (or more) processors in an inter-leaved fashion.	G1				
S	15.	The use of digital signal processors (DSPs) for routing and signal processing is considered to be prudent for many VA designs. However, the processor must be able to operate in audio terms without direct connection to any other device which relies on the use of moving parts (e.g. a computer)	G5	6.9		6.8b	

			Consideration	GP	B1	B4	B8	69
			due to the higher risk of failure of the moving parts than the solid state parts.					
S		16.	Computers may be used to carry out non-critical activities such as programming of DSPs, detailed monitoring of status, remote control of non-VA applications etc., provided that the basic functions of VA audio, basic fault indication, and audible warning can be carried out independently.	G5	3.8.4.2 3.8.4.3			
S		17.	Computer-based systems may also be used for control of VA routing (e.g. touchscreens) provided that they are duplicated and diversified and monitored. I.e. there is more than one place to generate the emergency message.	G1	3.8.4.2			
A		18.	If any amplifier feeds more than one loudspeaker it constitutes a single point of failure, so that circuit should be split to two amplifiers which feed alternate, interleaved loudspeakers.	G1			8	4.1g
A	L	19.	If loudspeaker zone circuits are very large, then these should be broken down into smaller circuits fed by smaller amplifiers with the source distributed at line level, thus providing more diversity in the event of an amplifier failure. Alternatively a spare amplifier of the largest common denominator shall be provided (together with status monitoring) which shall be arranged to be automatically cut in circuit in the event of a failure of one of the amplifiers in the same rack (i.e. one spare per rack). The same degree of protection may be achieved by parallel banking amplifiers on constant voltage systems. Other means of minimising the risk attributable to amplifier failure may be appropriate.	G1			8	4.1g 4.1k
A		20.	Where dual or multiple channel amplifier units are served by common sections (such as power supplies or fuses) the output section shall provide sufficient short circuit protection so as not to affect the operation of the rest of the unit. The allocation of such amplifier channels shall be such that interleaved loudspeaker circuits are not fed from common sections, and thus avoid a single point of failure.	G1	9.12h			

		Consideration	GP	B1	B4	B8	69
A	21.	If an amplifier has the ability to be powered by more than one type of supply (e.g. mains and battery) the status of both the supply fuses must be monitored so as to ensure that when the alternative supply is used that it is able to operate correctly or flagged as a fault. If an amplifier has only one fuse (e.g. mains only) then no such monitoring is required since if it were to rupture this constitutes an equipment failure anyway.	G5			7.2i	
A	22.	Considering that the majority of circuit faults arise not from amplifier failure, but by line shorts (nails through loudspeaker cables re-configuration of the building causing loudspeakers to be removed and their cables shorted together) the use of standby amplifiers and parallel banking does not actually solve the problem. The diversity into more smaller load amplifiers is therefore preferred.	G3			8	4.1g
A	23.	Modern amplifiers are much more reliable than in the past and therefore the risk of an amplifier failure is much lower then other risk in the system. Nevertheless, if the hot standby amplifier arrangement is chosen, then this standby amplifier must also be monitored for its ability to work when put into circuit.	G3			7.2g	
A	24.	All amplifiers should be chosen for their ability to withstand short circuits (and open circuits) on their outputs (and inputs). Though modern amplifier designs generally have no problem in working with constant voltage transmission lines where the cabling can be highly capacitive, care should be taken to ensure that this actually the case when selecting amplifiers for this type of application.	G5				
A	25.	If a system is designed to use amplifiers which can operate directly from batteries as a secondary power source, care should be taken to allow for their ability to provide their rated output over the speech spectrum of 200Hz to 4kHz on the basis that some manufactures rate their product on the power output at 1kHz with only a little	G2				

			Consideration	GP	B1	B4	B8	69
			tolerance of frequency spectrum. The resultant effect is that the required intelligibility is not achievable due to a lack of signal to noise ratio in acoustic terms within the whole speech spectrum.					
A	L	26.	If a system is designed to use multiple loudspeakers on a low impedance circuit, these are likely to require being wired in series/parallel. In order to avoid the risk of a short circuit causing the loss of the whole loudspeaker circuit, the parallel connections should be made at the amplifier output terminals or as close as possible to this point. (N.B. This method of design is often superior to constant voltage since a short in one series line still allows other lines to operate, whereas a short on a constant voltage line usually results in a total loss of output). Monitoring of series/parallel circuits should preferably be carried out on each of the series lines by means of impedance monitoring.	G1				
A	L	27.	Systems employing series/parallel low impedance techniques should be designed to allow for the reduction in power due to cable resistance or use enables of sufficient gauge to minimise these losses.	G2			19.2c	
L		28.	Care should be taken when calculating the theoretical acoustic power output and response of loudspeakers since the manufacture's data is often measured using a signal connected to the low impedance terminals. The use of constant voltage (transformer) transmission lines can have a marked effect on the actual power delivered to the low impedance coil of the loudspeaker, and also other artefacts such as frequency response and harmonic distortion may effect the overall resultant acoustic signal.	G2				
L		29.	Connections to loudspeaker enclosures on a multiple loudspeaker circuit should be made by ceramic terminal blocks so as to avoid the risk of short circuits if fire attacks the loudspeaker itself.	G5			10.3	

		Consideration	GP	B1	B4	B8	69
L	30.	Connections to a single circuit loudspeaker enclosure may employ connectors of a construction suitable for the current capacity required which are not necessarily able to withstand attack by fire on the basis that a single circuit is a single point of failure. Such designs should allow for the area being covered to benefit from another such single circuit loudspeaker or equivalent in order to provide a similar level of duplicity protection as afforded by interleaved multiple loudspeaker circuits. The exception to this being small rooms (including lifts) where the occupancy level is low and/or the frequency of occupancy is low.	G5				
L	31.	A loudspeaker enclosure may need to be constructed of material such that it prevents the spread of fire where it otherwise pieces a fire compartment e.g. steel fire domes on ceiling loudspeakers where the ceiling void is a return air plenum.	G5			10.3	
L	32.	A loudspeaker enclosure should be constructed so as to minimise the risk of causing an explosion ignited by an electrical spark or heat emanating from its audio signal when used in a location here flammable air-borne material is likely.	G5			10.2g	
L	33.	A loudspeaker enclosure should be constructed from such material and in such a manner that it is less likely to fail to operate when required to do so due to vandalism. However this should not be to the detriment of its ability to provide an intelligible acoustic output.	G5			10.3	
L	34.	A loudspeaker enclosure need not be constructed of materials which are fire-proof unless the location requires it to withstand indirect fire or heat for a certain amount of time (the minimum time for evacuation) due to the fact that there are no other means of producing an alarm for that area (e.g. underground railway stations).	G5				
L	35.	A loudspeaker enclosure should be constructed of materials which do not melt or produce poisonous fumes when used in locations where this may directly affect people during an evacuation due to fire.	G5				

		Consideration	GP	B1	B4	B8	69
C	36.	Cables used to connect the loudspeakers to the amplifiers should be selected to be fit for the purpose following a risk assessment.	G1	17.1 17.3 17.6		19.2	
C	37.	Where loudspeaker cables are to be mounted within the reach of the Public, they should be able to withstand a reasonable degree of vandalism by means of mechanical protection e.g. steel wire armoured where persons may swing on them, e.g. in a football stadium.	G5	17.5.2			
C	38.	Where loudspeaker cables are routed through an area which is likely to be subject to fire e.g. offices, shops, entertainment lounges etc the cable should be able to withstand fire for at least 30 minutes or, in the case of stadia, places of entertainment etc., 3 hours as required by their licence to operate. (See BS7827)	G5	17.1 17.3 17.4.2 17.6		19.2 19.4	
C	39.	Where loudspeaker cables are routed through an area which is not likely to be subject to fire (or where the fire would have preceded the requirement to evacuate) e.g. the front of the stadium roof, or an open space alongside a building, these may require mechanical protection but would not be required to withstand fire.	G5	17.4.3		19.3	
C	40.	Where loudspeakers cables may be routed through areas which are commonly used to house temporary cabling by others (e.g. outside broadcast from buildings of entertainment) the loudspeaker cables should be mechanically protected and clearly labelled down their length so as to reduce the risk of being unintentionally cut in the process of removing the temporary cabling.	G5	17.5.2		19.3	
C	41.	Cables from microphones and control equipment sited remotely from the central equipment should be selected for their ability to carry the relevant type of signal and routed in such a fashion to minimise the risk of being affected by fire or electromagnetic interference as well as being protected from fire and mechanical damage as far as possible by means of cable containment.	G5	17.1		19.2b	

			Consideration	GP	B1	B4	B8	69
C		42.	Where fibre optic cables are used for signal and data distribution (far reasons including immunity to electro magnetic fields, high quality and high speed transmission over long distances etc.) the routes shall be at least duplicated and diverse and preferably of a true bi-directional ring characteristic, thus avoiding a single point of failure, especially if due to fire. The same applies to microphone and control over fibre optic cables.	G1	17.5			
C		43.	Where non fibre optic cables are used for signal and data or microphone and control signals, the principles of duplicate and diverse routes is recommended in order to avoid single point of failure risk.	G1	17.1			
C	M	44.	Consideration should be given to the type of cable connecting the Microphone & Zone Selection Panel to the central equipment. If digital systems are proposed for either audio or data or both, then fibre optic cabling may be preferable provided that the cabling is duplicated and diversely routed.	G1	17.1 17.15		19.2	
F		45.	Zone Selection panels or Engineering Control Panels providing indication of faults are not considered as "Control & Indicating Equipment" as described in BS5839-4. However, the fault monitoring system should give at least a common fault status (if not considerably more information) back to the Fire Detection Control & Indicating Equipment in order for the latter to give the information and controls required by BS5839-4.	G5	9.12g			
F		46.	Zone Selection panels must also indicate the status of the system, and if there is a failure, sufficient detail of that failure to indicate whether part of the system is still functioning, and if so, which part, so that the user can try to work around the problem.	G5		3.2.1b		5.3
F		47.	The status of the/each UPS should be returned to the fault indication locations.	G3		3.2.2b	7.2	5.3b
F		48.	Fault indication of a more detailed nature should be available in order to speed up the process of repair.	G3			7.2	5.3

		Consideration	GP	B1	B4	B8	69
F	49.	Fault indication (and preferably also interrogation) should be displayed using an intuitive medium such as a topological touchscreen on larger systems.	G3		4.4	17.3.4.3	5.3
F	50.	Fault indication should always be provided in the form of l.e.d. or other displays on the equipment in racks, so as to avoid any delay of repair works.	G3		3.2.1b	7.3.1b	
F	51.	For small systems where the control, fault indication signal processing and amplification is all in the same area (or even the same rack) audible warnings are required as specified.	G3		3.2.1a	7.3.1a	5.2
F	52.	For larger systems, and especially in distributed system, the audible fault warning should be at the rack recognising the fault, the central distribution rack, and at least one of the places where the emergency messages microphone and control panel is sited. i.e. when the system develops a fault a person is audibly alerted to that fact (even if the building is unoccupied at the time of that fault developing) at the earliest possible moment. Systems which auto dial a service company may prove to be an advantage but may not be a replacement for warnings on site.	G3		3.2.1a	7.3.1a	5.2
F	53.	For all but the very simplest and smallest systems, and especially for buildings occupied by the Public there should be an automatic log of faults with as much detail as possible. These logs should be over at least an 8 day period and stored in the form of a paper print-out as well as another storage medium whose duplication and erasure is available only to authorised people.	G3		3.9	7.4 c 2) I)	5.4 c 2) I)
U	54.	If uninterruptible power supplies (UPS) are used as the source of secondary power, the mains rated output cable should be routed as a ring mains to all equipment so as to avoid a single point of failure.	G1	17.5		18.6	
U	55.	The UPS should be arranged so as to bypass the inverters in the event of failure.	G5			18.6	

4. ELECTRO-ACOUSTICS AND INTELLIGIBILITY

There is no doubt that the attention to detail in terms of the systems design is often undermined by the lack of detail or knowledge of electro-acoustics, coupled with the intransigence of other members of the design or construction team to accept that the laws of physics cannot be bent.

The origins of the requirement for $65dB_A$ or 5dB above ambient noise in BS5839 Part 1 are apparently from studies commissioned by an insurance company in America before the 2nd world war. The sound pressure level parameter was intended for the design and application of bells and sounders. The ability of the human brain to differentiate between ambient noise and an unexpected sound has been shown to be such that the level of the unexpected sound can be well below the ambient noise and still be recognised by the brain. The same is not proven to be the case for voice alarms where the intelligibility of the alarm is also a fundamental requirement.

The design of voice alarm systems predominantly used as part of a fire detection and alarm system (which is the prime purpose of the various sections of BS5839) whereby this criterion of $65dB_A$ or 5dB above ambient noise is the sole arbiter has led to an under-specification of loudspeaker quantities or power. The pressure to provide a "compliant" system at a reasonable cost is also rife, but unfortunately this has also led to a "norm" where to design for the actual typical ambient noise is considered excessive.

The question of "what is compliant?" is often cited. Even without applying the requirements of BS7443 or BS EN 60849 to achieve a measured STI of 0.5, upon commissioning and demonstration to the Authorities, the building is rarely operational, and therefore is unrepresentative of the ambient noise which needs to be overcome by the system in the event of an emergency. This in turn has fuelled the trend towards under-specification at the design stage, based on falsely lower ambient noise levels.

More loudspeakers means more wiring and more amplifiers, which translates into greater and greater cost. But all the clever electronics and monitoring of fuses will not help when the alarm cannot be heard. The question therefore has to be raised "are the prescriptive elements of the Standards sacrificing the practical application of the woolly elements of the same Standards?".

There is also the question of the talker, the microphone, and the environment of these two. The average "emergency" microphone has relatively poor electro-acoustic properties and consideration needs to be given to the likelihood of plosives being distorted by mechanical as well as electrical means, thus reducing the intelligibility, as the message is being given. In terms of electronic processing, some basic equalisation and compression can be of considerable benefit to the signal, but too often it is not included or available by some manufacturing designers.

The environment surrounding the microphone is also critical. Not only should efforts be made to reduce the ambient noise, such as the talker being separated from other personnel - especially those using PMRs ("walkie talkies") - but also to be in an environment where there are no noisy machines - including the audible fault warning devices prescribed by BS5839 part 4 - and also to be in an environment which is not too reverberant.

It should not be over-looked that BS5839 part 8 specifically deals with automatic voice alarm systems, and that its guidance in terms of the live announcement is restricted.

A spell listening to the various flight announcements at an airport where the same system is being used by different talkers will demonstrate the need for designing out some of the curable problems. It will also prove the need for basic training and guidance notes. Such an exercise, combined with hearing the pre-flight safety announcements, will probably lead to the conclusion that well recorded messages would be better than monotonous live delivery.

Much can be done to improve the talker's competence by means of training. Too often, the talker is given training in all manner of other activities in relation to safety issues, yet not on the subject of making an announcement in a manner which can be understood by the listener. Who is to train? Who is to judge? There needs to be some established form of training so that the operator's staff can be trained and be certified to be to a minimum level of competency.

From the point of view of a designer or contractor, or construction team, there are enough problems in extracting the correct amount of money for the hardware, let alone meddle with training people to actually use what has been provided.

5. CONCLUSIONS

Each building is different - whether that be physically or operationally - and therefore the risk assessment has to be unique for each project. The ability to evacuate a building in the interests of life safety depends upon planning, design, system optimisation, avoidance of single points of failure, knowing when and where something is not working, being able to use the equipment easily and intuitively, and last but not least, training.

Application of the guidance of the current Standards should not be done without a specific and unique Risk Assessment for each project which covers all the point raised above, and augmented by attention to the likely operational parameters.

Revisions of the Standards should not only include the requirement of Risk Assessment, but should provide more guidance relating to operational issues as well as replacing the prescriptive aspects with technology tolerant guidance to reach the equivalent conclusion.