A VERSATILE MULTI-CHANNEL SPL RECORDING SYSTEM FOR THE WORKPLACE

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1. INTRODUCTION

A versatile multi-channel system has been developed which will enable SPL's to be accurately monitored and recorded in places of employment, for the purpose of compliance with the new 'Noise at Work' regulations. Up to 20 locations of workplaces can be monitored with a fully loaded system. Each channel records four SPL's, two conforming to 'action levels 1 and 2' (85 and $90dBA_{SPL}$), the third is selectable whilst the forth indicates instrument overload (>115dBA). Metering is broadly in conformance with the British Standards' specification for personal sound exposure meters 1,2.

Both local and central real-time warning signals are available, so employees and managers alike can be aware if the SPL's are exceeding the relevant limits set down by recent legislation. Moment-by-moment SPL samples are stored in RAM, along with the date and time. The data can later be archived to disc, one year's data being storable on one disc. The information for any selected period can be subsequently expanded into hard-copy, should evidence be required at any later date.

The system has been principally designed to meet the requirements of recording studios, but is readily adopted to the needs of places of public entertainment, local authority monitoring of outdoor festivals, as well as most light industrial and commercial operations.

The repercussions of the new legislation.

The new Noise at Work regulations 4 state that "Where persons are in a noisy environment the noise should be measured in the working areas that they occupy, using a procedure which obviates or minimises the effects of reflections..."

Noise is taken to mean 'any audible sound'. For recording studios, the sound is predominantly music and portions and samples thereof, the qualities of which will usually be far more variable and spasmodic, than the noise produced by most industrial processes.

A VERSATILE MULTI-CHANNEL SPL RECORDING SYSTEM

The approach that has so far been advocated is one of assessing the noise level in a given environment and acting upon that one-off assessment in the provision of ear defenders, etc., to those employees or clients thereby affected. It is strongly emphasised in the Health & Safety executive's documentation that it is the responsibility of the managers of an establishment to ensure that such an assessment of SPL's is representative and current. Clearly this is impossible in the case of music program and the many and varied types of task and client that any commercial recording studio or theatre space is working with.

A one off measurement by a "competent person" is fully justified in a machine shop environment where the day to day or even month to month changes in noise level are likely to be due to machine wear and tear only. It would be a brave manager who could say the same about any performance or recording space under his (or her) control. It is thus proposed that the real time warnings to operators, coupled with the immediately available assessment of the previous day's or hour's noise exposure offered by the equipment under discussion is the only affordable recourse for the studio manager who seeks to comply with the requirements of the new legislation. It is also of note that long term records coupled with files of written warnings to employees would offer a strong defence against future actions for liability for hearing damage, by employees regretting their years of monitor system abuse in later life.

For the purposes of recording studios then, we interpret the new guidelines to require the SPLs in studios and adjoining control rooms to be 'data logged'.

The act also requires lamps or other indicators to inform all persons that they are exposed, including clients, employees and employers, of the onset of the two 'action' levels of 85dB and 90dB, beyond which they're advised to take protective measures.

Price defines a new approach.

Hitherto, equipment dedicated to data-logging SPLs has been very expensive, typically costing a minimum of several thousand pounds. Three reasons are immediately apparent:

First, because such equipment has generally been specified to meet the needs, both diverse and precise, of laboratories and acoustic consultants;

Second, because data-loggers have traditionally incorporated intricate machinery, namely X-Y plotters or thermal printers;

And third, there's a knock-on cost, as a result of the small numbers of units manufactured.

A VERSATILE MULTI-CHANNEL SPL RECORDING SYSTEM

Common sense suggests that the chances of recording studios installing data loggers voluntarily will be inversely proportional to the equipment cost. The approach taken has therefore been to minimise the required hardware to be purchased and to split the processes of data collection and its subsequent processing. The SPL monitoring instrument merely collects SPL data and stores it in RAM. When filled, the RAM can be downloaded via the ubiquitous Personal Computer onto floppy disc. The same (or any other) PC system can then be used for post-processing. In other words, to expand, arrange and then print or plot any part of the data, using software specially prepared by Harris, Grant Associates. Alternatively, the data can be arranged by downloading to any other data-gathering device (e.g. Psion or AMS data logger, amongst others), for remote, portable post-processing.

Our cost objectives could not be met without powerful data compression. A suitable data compression algorithm allows us to use a modest amount of RAM without having it 'fill up' too quickly. At the same time, the data compression employed must still provide a sufficient representation of noise dosage, enough to both satisfy the Health & Safety Executive, and allow the construction of a dependable record of noise exposures for any subsequent legal actions.

Data collection - the design requirements

Collecting the SPL data broadly requires an 'A' weighted SPL metering system, modified to sample the data in a consistent and justifiable manner. The integration needed to compute dose is conveniently relegated to the post-processing software. Instead, true rms data is stored, from which the personal daily noise dose **LEP, d** is readily computed.

The Health & Safety Executive's advisory literature cites that " A Type 2 grade" meter (a BS specification) will generally be sufficient unless the noise has a significant component above about 10kHz.." Although a 'significant component' is possible in a studio control room, it does not seem probable. The statistics of music spectra mitigate against sustained noise dosage in the 10kHz to 20kHz octave above which few if any loudspeaker systems are capable of sustaining any substantial acoustic power.

The BS Type 2 'general field' specification [2] requires a maximum overall accuracy of ±1.5dB for the 'A' weighted response. The specification is more stringent than it seems at first sight. For low cost manufacture, it has to be achieved every time without component selection or trimming, irrespective of worst case manufacturing tolerances, including the microphone's response. The weighted response then has to stay within tolerance over a moderate span of ambient temperatures, and a potentially wider span of relative humidity. Finally, it must not degrade for many years. The H&SE's advisory literature requires periodic calibration tests. When equipment is monitoring a statutory requirement, we envisage that any alignment, changes to PCBs or service exchanges would require considerable documentation to remain credible as an inviolable record of events. Besides, equipment calibration is inconvenient in a commercial recording studio, particularly when the equipment is auxiliary to the task of recording; it would require careful scheduling.

Beyond the 'A' weighted response, the consistency and stability of the remainder of the measurement circuitry, comprising true-rms conversion and digital logic is relatively cast-iron. By far the weakest point of any permanently installed sound measurement system is the microphone. The measurements won't mean much if the microphone is:

contaminated.
covered up.
replaced by another, alien microphone.

And there won't be any measurements at all if the microphone cable is broken, intermittent, wrongly connected or shorted.

Overall, it's evident that to be reliable and trustworthy, an SPL data-logging system has to monitor both the connections to the microphone, and the microphone itself. In effect, it has to be capable of continuously monitoring its' own calibration.

Self-monitoring of calibration could conceivably be achieved with a loudspeaker placed adjacent to the measuring mic. The loudspeaker would be periodically driven with a swept test tone, ideally daily. Although superficially attractive, there are several snags. First, the test could only be accomplished when the ambient SPL is well below the test level, typically when the premises is unoccupied. However, commercial recording studios commonly operate at random throughout the night and at weekends; there is no period guarantied to befit automatic calibration. The system might sound a buzzer to request 'Silence Please!' while it carried out a calibration, but this might be regarded as harassment by recording engineers, and the silence could all too easily be thwarted, making a nonsense of the process.

Second, the loudspeaker would have to be small enough not to upset the microphone's omnidirectional sensing. This wouldn't pose to much a problem with the 'A' weighted response, but there would be difficulties in gaining the bandwidth required for a 'C' weighted response from a miniature transducer for SPLs around 90dB. Equally, it would have to be reliable, while being subject to all the perils (such as dirt, dust, humidity and outright damage) that might afflict the very microphone that it's intended to check. Finally, the tone generation and the speaker's response would need to possess fundamentally better accuracy and stability than the microphone being measured.

A VERSATILE MULTI-CHANNEL SPL RECORDING SYSTEM

For 'cast iron' certainty, such a system would be not just expensive, but also clumsy, ideally requiring subsidiary monitoring to verify the accuracy of the calibration signal!

Our approach sidesteps the snags by utilising two microphones with individual weighting, equalisation and true rms circuitry. The rms output of the two microphones is continuously compared over the critical range of SPLs, and an 'out of calibration alert' is issued if the overall response differs by more than a fraction of 1dB. The validity of our approach is based on comprehensive monitoring or explicit errors - as outlined below. Provided explicit errors are separately monitored, it is highly unlikely that the individual microphones' acoustic receptivity and output voltage would degrade or deviate in such a way that both maintained an identical response. In other words, any excess dust, damage, excess humidity or other degrading factors would most likely affect the two microphones differently.

2. SYSTEM DESCRIPTION

Part 1 - The microphone assembly

Looking at the block schematic in figure 1, each channel employs two identical and adjacent electret capsules. Their positioning and the shape and size of the capsule's housing is designed to minimise deviations from the ideal omnidirectional response as well as differences in their individual response patterns.

For installation in recording studios, the microphones are enclosed in a cage, covered by reticulated foam to prevent the ingress of dust. In view of the generally clean atmosphere in recording facilities, the foam would need to be removed for periodic washing, typically every 6 to 12 months, depending on whether it's a 'no smoking' zone or not. For studios without washing machines, a set of spare covers would be supplied. We envisage that cleanliness of the filter and associated managerial awareness would be checked every two years or whenever a unit requires a calibration check.

The choice of microphone for a low cost measuring instrument is especially challenging, considering the retail cost of a precision microphone for acoustic measurements is of the same order as the entire budget. However, it is possible to purchase the capsules used in quite high specification microphones at a small fraction of the complete microphone's cost. The capsule that we eventually selected offered not just the flattest nominal response in the 'A' weighted range, but also the tightest tolerance on sensitivity and frequency response. The success of this approach is subsequently dependent on the design teams' expertise in the design of the microphone housing, with a view to maintaining the directivity pattern and frequency response within the BS specification.

Part 2 - Microphone supervision

The microphones' power and signal leads are monitored by window comparators. The limits are wide enough to allow for worst case component tolerances, variations with temperature and component drift, yet narrow enough to reject an 'alien' microphone, should one be connected. The window comparators will also detect broken or intermittent or shorted wiring. If any of these contingencies arise, a 'Microphone Error' is signalled to the CPU.

Part 3 - Preamplification

The signal from each microphone is passed to a precision preamplifier which amplifies the signal to a level suitable for rms conversion. The preamplifier is preceeded by RF filtration (as required by the BS specification2)), weighting and equalisation. Weighting is normally 'A', but the 'C' weighting and unweighted 'Lin' responses are also provided, to allow the instrument to be used for industrial monitoring purposes [1], as well as for recording SPLs in night clubs, e.g. where deep bass is upsetting neighboring premises. These settings have been subjected to the same, rigorous worst-case toleracing, drift and temperature analysis as the 'A' weighted equalisation.

The microphone capsule we have chosen has a substantially flat response from 60Hz up to 18kHz, but requires high-Q equalisation between 30 to 50Hz for accuracy when the 'C' and 'Lin' responses are selected. The 'Lin' response is useful in that it allows the accuracy of the equalisation together with the mic's intrinsic response to be verified independently of any weighting. The 'A', 'C' and 'Lin' settings are internal, so they cannot be changed after installation without breaking the seals. Furthermore, each setting is flagged to the CPU.

True rms conversion is carried out by a proprietry integrated circuit, specially designed for audio instrumentation. The rms output is a DC level. At this point, the Main and Reference signals for each channels' pair of microphones is routed to the signal comparison circuitry. The Main microphone's output is also conveyed to a series of four comparators whose thresholds are set to detect the four indicated levels. Two of the comparators, dedicated to detecting 85 and 90dBASPL, are individually factory trimmed to within 0.5dB accuracy, using a calibrated acoustic test signal. This compensates for the sum of the initial tolerances affecting system calibration. The threshold is furthermore biased towards the low side, to compensate for any small losses in sensitivity accumulating from the build-up of dust on the microphone cage's foam covering. The threshold levels of

[1] *The Health & Safety Executive's noise guide cites that the 'C' weighted response will be required in the future for peak SPL measurements of industrial machines in accordance with EEC directive 89/392/EEC.OJ No.L183/9-32.*

the two remaining comparators tested for nominal accuracy only; they are guarantied to lie within ±2dB of the target SPL by design.

For each channel, the 85 and 90dB comparators are connected to individual monostables, set to operate for (T+1) seconds, where T is the duration of the excess SPL. In turn, the monostables light a local LED. They can also switch any suitable external indicators, via an opto-coupler. Mains powered indicators can be controlled from an external contactor.

Finally, the four comparators' individual outputs are connected into the CPU and RAM.

'State-of-the-art' design techniques

The design and verification of the analogue electronics was carried out using an advanced PC-based analogue simulator that is faster and more powerful than SPICE and its immediate derivatives. Hitherto, SPICE-based simulators have been so tedious to set-up and use, as well as prone to human error and 'hanging' that the simulation of analogue circuitry by audio circuit designers has been restricted to the bare minimum, if used at all.

Using Monte-Carlo routines, we were able to rapidly simulate the worst case manufacturing tolerances and operating conditions, and compare the results against differing component tolerances, thereby avoiding the needless cost of any over-design (figure 2).

Analogue simulation was also used to explore and define the custom circuit topology needed to design the microphone's LF equalisation with the minimum of components. It had to provide a flat topped yet high Q peak at 35Hz, coupled to a rapid roll off below 1HZ, and minimal response deviation above 100Hz (figure 3).

3. CONCLUSIONS

We have produced an SPL data-logging instrument, the low hardware cost of which will make it affordable and accessible to the vast majority of recording studios, theatres, concert venues, nightclubs and related workplaces. In turn, it will enable them to meet the criterion of the new 'Noise at Work' act.

The instrument could also find applications in the broader field of SPL data gathering, including environmental noise surveys, particularly for researchers working on a tight budget while requiring many disparate areas to be logged simultaneously.

We plan to have a production model available by January 1991.

A VERSATILE MULTI-CHANNEL SPL RECORDING SYSTEM

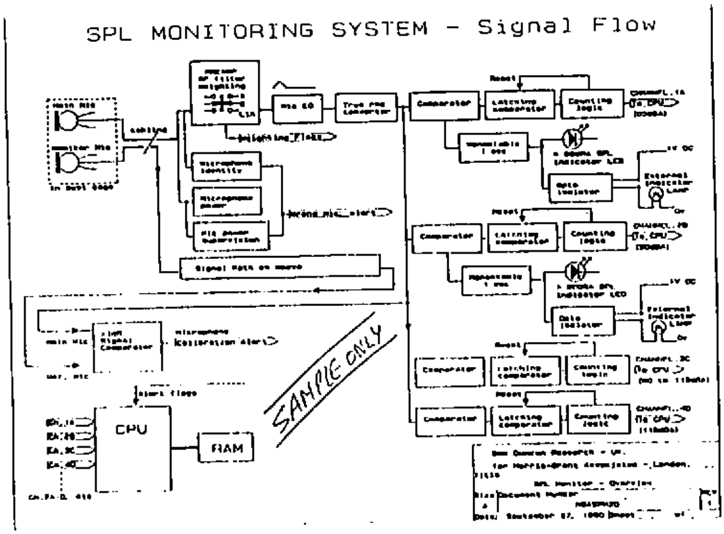

FIGURE 1.

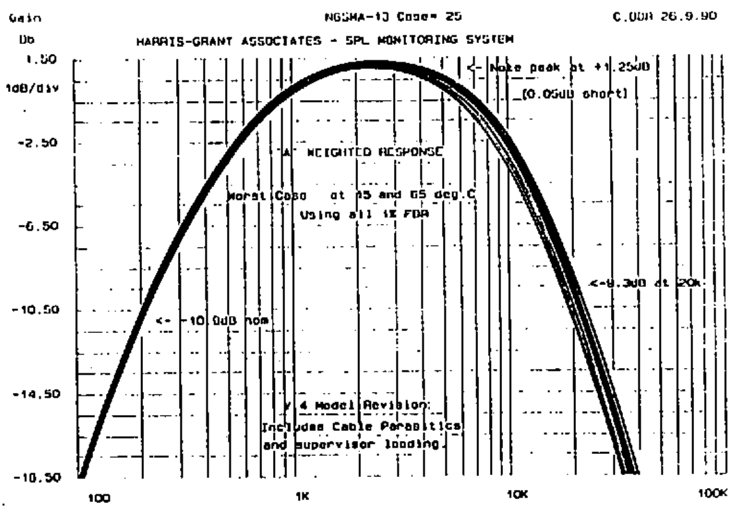

FIGURE 2.

A VERSATILE MULTI-CHANNEL SPL RECORDING SYSTEM

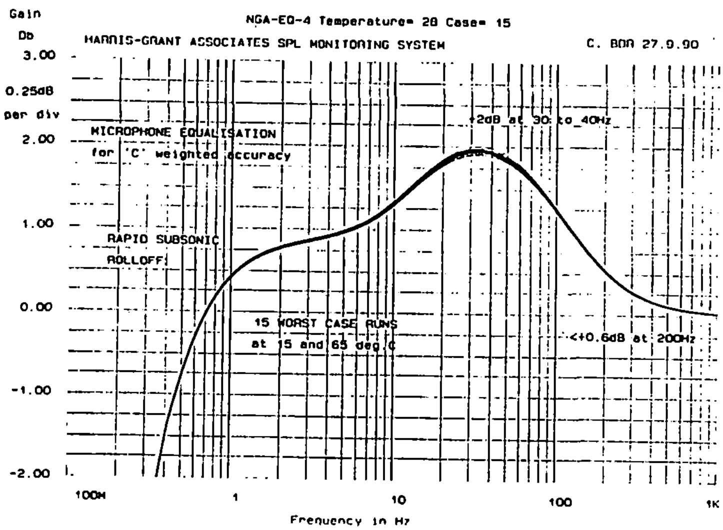

FIGURE 3.

4. REFERENCES

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5. ASSOCIATED REFERENCE MATERIAL

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