Sound Level Meters – The Past, Present and Future

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Before the turn of the millennium, sound level metering equipment was still predominantly analogue but over the last 20 years developments in digital electronics have revolutionised the design and use of SLMs. In a 1992 Euronoise paper, when handheld devices were just beginning to embrace digital functionality for a few controls, storage or perhaps displays, the question was raised, "Where will it stop?" Clearly, cessation of any such developments is about as far from the case as it could be; device capability has grown to the point where not only have the number of measured acoustical parameters increased, but predominantly statistical computations and frequency and time weightings are all carried out in the digital domain. Component miniaturisation has evolved handheld units that are capable of more than rack-mounted machines could deliver 25 years ago. Interestingly, the initial-stage electro-acoustic analogue transduction technologies have not seen such dramatic changes; even now, although it may appear that we stand at the doorway of the next major leap forward with MEMS transducers and digitally-stored and interfaced data with TEDS microphones, there are still many challenges to be yet faced before such technologies can be embraced and incorporated. Nevertheless, not all changes have been improvements; battery life for one has taken a backward turn from earlier devices. This paper describes the development of the sound level meter over a period that fairly well equates with the IoA's own timeline, and also discusses the current challenges that we face now in driving further developments and possible challenges in the future."

1 Introduction

In 1992, Wallis[1] presented a review of the current developments in acoustics instrumentation. Certainly, at that stage, there was a revolution underway; the ever increasing prevalence of digital computer systems had reached the acoustic world. Mobile phones were available & although they did not become mainstream devices until the latter end of the decade, the same digital electronics technology was available to designers of electronic equipment. Prior to this, Sound Level Metering (SLM) devices were predominantly analogue, with some taking on digital electronics for matters which were somewhat irrelevant to the actual electro-acoustical aspects of the device, such as displays or data storage. Many manufacturers were looking ahead, quite rightly foreseeing a dramatic change in the world of noise metering equipment. The development of technologies in electroacoustic transduction is also addressed, with consideration of the implications of emerging new technologies upon SLMs. Additionally, with modern personal telecommunications equipment putting powerful, programmable and multi-sensor-equipped computing devices in the hands of the general public appears to present an alternative to dedicated equipment; whether this is a likely pathway for the industry to take is herein discussed.

2 A brief history of noise

Our understanding of sound has developed greatly since the emergence of our abilities in audio recording and manipulation, the vast majority of which can be attributed to only the last century.

Historically, the origins of our understanding of sound begins with Pythagoras; within his teachings, spurned from his observations of the acoustics of blacksmiths hammers, were conveyed the concept of harmonics and the chromatic series that makes up the musical scale. Aristotle can be attributed to the development of the modern concept of sound propagation, albeit with the inclusion of few incorrect assumptions regarding differing wave speed with frequency. Very early accounts suggest Pliny the Elder made some attempts to compare the noise of various cities, obviously having little other than his own ears to make the judgements.

From the Roman period and beyond, acoustics remained very much an art form. Vitruvius, whom was primarily an architect, is reported to have held an expertise in the design of spaces with the purpose of controlling the acoustics therein. As conveyed by Rossing (2007)[2], he is quoted "*We must choose a site in which the voice may fall smoothly, and not be returned by reflection so as to convey an indistinct meaning to the ear"*; such writings demonstrate a quite exceptional understanding of the propagation of sound, and the effects of reverberation times and paths upon perception and intelligibility.

Scientific investigation regarding sound has not been the most dominant of subjects before the 20th century. While Newton proposed an analytical determination of the speed of sound in *Principia,* Gassendi is attributed to have made the first attempts the measure the speed of sound earlier in 1635. Savart established frequency measurement in the 1830s using his own version of a spinning wheel, developed from Hooke's earlier version. In the 19th century, Helmholtz; still synonymous to this day for his theory on resonators, published his work "*On the Sensations of Tone",* and then Bell and other contemporaries certainly paved the way in electro-acoustics with the development of telephony. Strutt[3] [Lord Rayleigh] could be attributed as being one of the founders of theoretical acoustics, even though the discipline still had not been given that name, developing the first issue of *"The Theory of Sound"* in the late 19th century.

2.1 Sound as noise

Beyond the physics of particle motions and interaction that governs the world of sound, human perception of it is regarded in different manners; to coin the well-known vernacular; "one man's music is another's noise." The human perception of sound as noise incorporates some level of subjective opinion, driven by social, age, physical and/or mental health differences, all of which is of high interest at the time of writing and the subject of much research to determine standardised metrics by which annoyance can be generalised and measured.

Noise control goes back much further than might be envisaged; Ross[4] reports upon the use of a curfew bell in medieval times that signified the cessation of blacksmiths and other noise-producing operations at around 8:00-9:00p.m. Pepys makes numerous commentaries on noise throughout his diaries and Dekker (1606)[5] remarks in his work *"The Seven Deadly Sins of London"* upon the 'clamour' of noises in the streets of London. To have suggested a requirement for noise control in Victorian factories would have (excusing the pun, but possibly quite literally) fallen on deaf ears; it was the culture to expect that such institutions were inherently noisy & any consequent health issues arising from this environment were far from priority concern, if known at all.

2.2 First steps to survey noise levels

Noise surveying developed greatly in the 1920's, simultaneously across the continents with evidence of similar advances in New York and, as described by Fouvry (1996)[6] in Melbourne, Australia. This period was known as the *Roaring Twenties,* and with good reason, for there is much documentation to be found regarding the deafening noise levels in the crowded, tram-laden concrete streets of New York City; also bustling with loud clubs and even rooftop dance floors of the jazz-era; all consequently leading to a large number of noise complaints. In New York, the Noise Abatement Commission was established in 1928, a division of which was the Committee on Noise Measurement and Survey, whom set about to realise the definitions of measured parameters and procedures that should form part of a standard noise survey. It is important to consider that, at this stage, even the most basic aspects of such surveys; even the units of sound pressure, had not been determined. Ultimately, the first recorded survey of noise was conveyed in the 1930s report *City Noise.*

2.3 Sound measurement & early instrumentation

It is a good starting point to consider what is required in the measurement of sound. Sound is a pressure oscillation about the ambient level; waves of rarefaction and compression of the air & if one were able to temporally resolve the motion of vibrating objects causing these pressure fluctuations, objects would be seen to oscillate back and forth across an equilibrium position. Raleigh's experimentations describe the use of stroboscopic sampling of vibrations; *"Observations upon the* *swellings and contractions of a regularly resolving jet may be made stroboscopically, one view corresponding to each complete period of the vibrator; or photographs may be taken by the instantaneous illumination furnished by a powerful electric spark".*[7] In this example, the peak amplitude of oscillation is being sampled & when 'freezing' of the motion is achieved via a stroboscope, the oscillating frequency determined. If we were to analyse an electrical signal of such oscillation, it would fluctuate between positive and negative voltage. Clearly, taking an average of this would result in zero, thus, in order to determine a *level* one must first rectify the signal. Prior to the development of semi-conductors, this was not the easiest of procedures.

Methods of measurement had been presented earlier; Pierce (1908)[8] describes an apparatus that used a thin sheet of Molybdenite as a rectifier in a basic circuit with an adjustable condenser, transformer and galvanometer. It is interesting that this material is even now being investigated for its remarkable semiconductor properties; as reported by Dume[9], over a century after Pierce described his apparatus, the first transistor using Molybdenite was produced in 2011 with a light-emitting device created only last year.

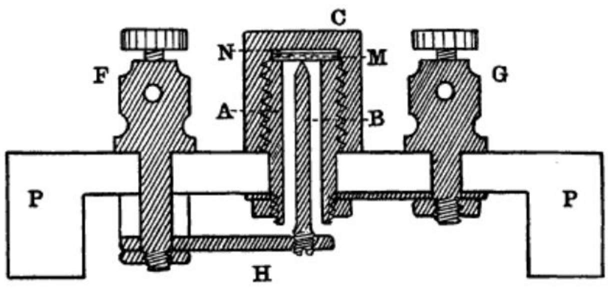

FIGURE 1. — Rectifier.

Figure 1: Early rectifier made by Pierce using Molybdenite[10]

As mentioned, the 1920s-1930s were the revolutionary period in the development of noise surveying, policy and metering equipment. At this time, scientific discovery in electrical and electronic devices was progressing rapidly, providing a range of approaches in which sound levels could be determined. Portability was rather lacking; most equipment required its own transport, although a very early portable device can be seen in Figure 2. The earliest methods of sound level measurement were often of a comparative rather than absolute approach; Lemon (1925)[11] used an approach with a pre-calibrated buzzer, which was increased in amplitude until the noise just masked that of the measured source.

Figure 2: STC (Standard Telephone and Cables Limited, previously Western Electric Co. Ltd.) Sound Level Meter from 1934[12]

2.4 First standard for sound level meters

Not long following the beginnings of the Acoustical Society of America, a sectional committee chaired by Knudsen was appointed and set to work developing, and ultimately publishing, the first standard for noise meters; S24.3-1936[13]. This incorporated the recent loudness weightings, then only just having been developed by Fletcher (1933)[14]. Despite considerable research since, such as that by McMinn (2013)[15], other than slight modification in the 1944 revision of Z24.3, the A-weightings have gone unaltered even within the latest sound level meter standards such as IEC61672-1:2013[16] or the ISO 226 standard for normal equal loudness contours. Also defined within Z24.3-1936 was the parameter and unit by which to measure sound, this being the sound level, modified by A or B weightings for moderate and high levels respectively, measured in decibels relative to the reference value of 20µPa for the low limit of human hearing.

Although most attention was given to, and many advances driven by World War II, the latter half of the 1940s saw further large-scale noise surveying in Chicago. Instrumentation was bespoke and far from portable; Marsh (2012)[17] describes the equipment as *"installed in the back of a station wagon with access provided across the lowered tailgate. The instruments were big, heavy and required large batteries to provide the electrical power."* The device nevertheless was quite capable, having an octave-band filter set and using a magnetic *wire* recorder; the predecessor to the magnetic tape recorder, first developed by Valdimar Poulsen in 1899. Rather than an on-site comparative measurement, as with the aforementioned method adopted by Lemon, the recordings were then taken back to a laboratory for analysis; whether an appreciation was held of the decay of levels over time upon such recording mediums is unknown.

3 SLMs in the early days of computing

From the middle of the 20th century onward, it is of interest to consider the progress made in computing in general in conjunction with the progress of sound level metering technology, as many parallels can be made. Thermionic valves were, although not commonplace, available even at the earliest stages of the developments of noise metering equipment. However these required significant power & battery technologies did not present many easily-portable options.

The Computing world saw the creation ENIAC (Electronic Numerical Integrator And Computer); a general purpose electronic computer, developed for the USA Ballistic Research Laboratory. Understandably, this 'computer' was an institution in itself; according to Farrington (1996)[18] weighing 30 tons, with 19000 tubes & consuming 175kW of power when in use.

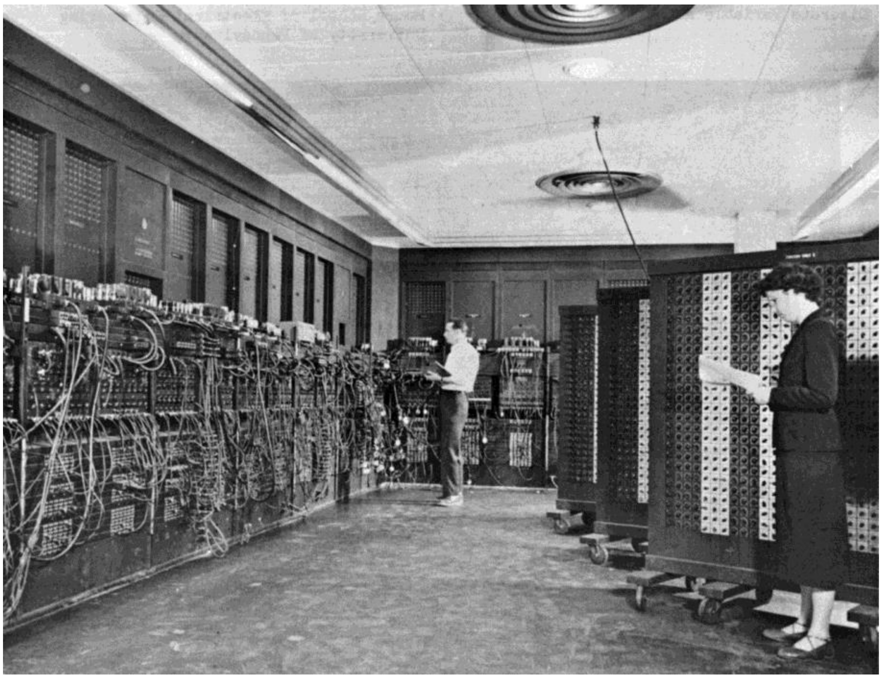

Figure 3: The programming area of ENIAC in building 328 of the US Ballistic Research Lab.[19]

Remarkably, the successor to the ENIAC was the EDVAC (Electronic Discrete Variable Automatic Computer), which used mercury acoustic delay lines; twin, 64-line, 8-word/line as memory units. Was this the first combination of computers and acoustics?! In this era, the first commercial SLMs were produced by companies such as General Radio and Rion, all operating using valves.

3.1 The semiconductor revolution

Electronics development was accelerated through World War II, along with a multitude of other technological development. 1948 saw the invention of the transistor & the beginning of the digital age. Surprisingly, the benefit of incorporation of these devices into a sound level meter was not brought about until the late 1950s. Even later in 1966, Dawe instruments were still marketing their devices as ‘Fully Transistorised’[20]. Comparatively, GEC (UK) had completely removed valves from their computer well before the end of the 1950s. Regardless, as the end of the 1960s approached, the majority of SLMs incorporated transistor-based circuitry, and the huge power and thus weight saving benfits led toward a truly portable SLM.

3.2 Early combinations of SLMs with emerging computer systems

The 1970s saw significant development and scope of use of computers, but were far too large to be considered for field use. The 1980s saw the development of the Apple 2 and the Acorn BBC in the UK. Desktop computers now provided the user the ability to program in BASIC & thus perform statistical analysis upon data; previously requiring extensive external hardware or even mechanical analysers. 1984 saw the use of a BBC Micro system to measure and predict the Leq at a Status Quo concert, informing the mixing desk operator of the levels that could be used over the next 15 minute period in order to stay within the GLC guidelines for level. The 1990s saw various developments; in the late 90s, personal computing had really turned personal, with laptop devices providing totally portable solutions. With systems such as the 01dB ARIA, multi-frequency analysis was possible within a single laptop-orientated system.

Beyond this period, other than for extended data analysis & generation of reports, it could be viewed that computers and sound metering equipment parted ways again, for devices became so capable that the outbox processing provided by interfacing a personal computer could now be packed into the case of a handheld device.

4 Developments in standards & the emergence and development of the commercial market

Since the first commercial units, the design and function of SLMs has been driven by the requirement to meet standards. Throughout the 1960s there were four main players in the sound level meter market; firstly the market-dominating Brüel & Kjær, followed by General Radio, RFT and Dawe. However, a noise standard, released in the USA under the Walsh-Healey act in 1969 changed the face of the SLM market. The regulation outlined a maximum permissible noise dose of 90dB for eight hours, with a somewhat-unexplained 5dB doubling; the tradition of which still complicates the international market

4.1 Standard IEC 123: Implications upon the SLM front-end

By the earlier standards, the detector/rectifier were mean or averaging rectification designs. However, with the publication of IEC 123 in 1961, designers realised a r.m.s. rectifier was required for acoustic measurement. At the time, this was far from straightforward & two approaches resulted; one which was effectively a cheat, producing an output which met the specifications of the test without actually measuring r.m.s., and another that was so power hungry that it could never be developed within a portable unit. The former of these approaches was a very simple two-diode circuit, as displayed in Figure 4, followed by the actual r.m.s. detector, clearly of far higher complexity. In the 1970s, this circuitry was put into a single chip by Gilbert at Analogue Devices.

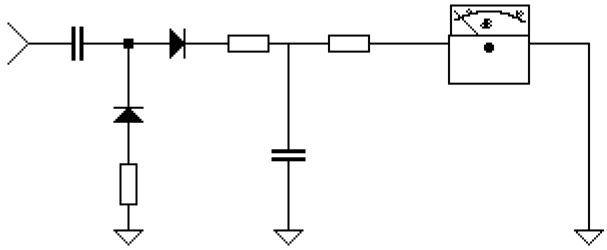

Figure 4: Two-diode circuit by Wallis

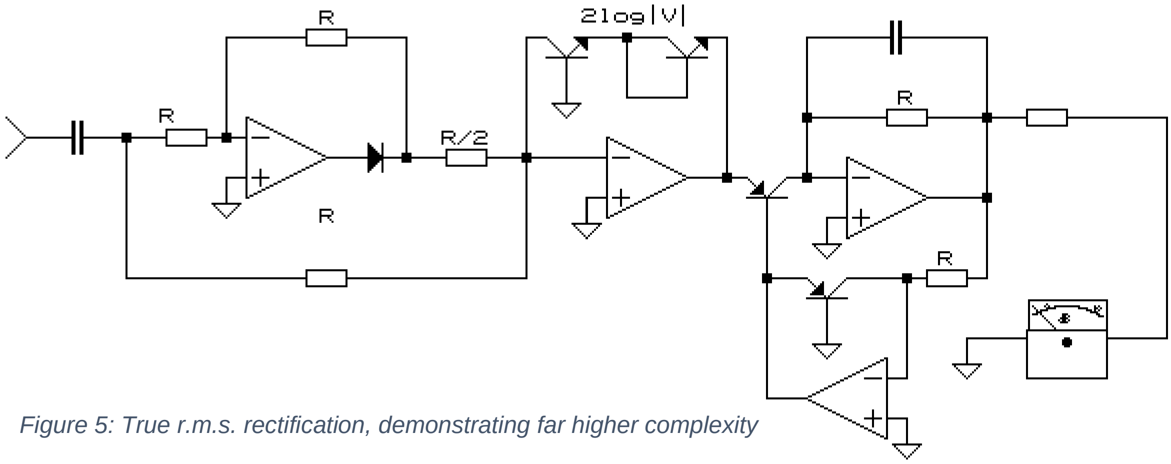

Figure 5: True r.m.s. rectification, demonstrating far higher complexity

This approach provided the significant leap forward in that the scales on meters could now be linear in decibels; additionally, the dynamic range expanded greatly; up to around 50dB instead of the 15-20dB of earlier devices. The problematic switching between short ranges of earlier devices in rapidly-changing acoustic environments was far reduced, but at the expense of increased temperature drift and, of course, a much higher cost. 1974 saw the first production model of this form by General Radio.

4.2 Inner workings of integrating meters

Sound level meters always had the design goal of being able to measure Leq (or rather LAeq); this metric is a measure of the actual acoustic energy. Previous units had been available in the 1970s; the Computer Engineering Ltd. (now Lucas-CEL) 112 noise integrator was released in 1972 and shortly afterward the 122 noise dosimeter in 1974, followed by a true Leq CEL-175 in 1977. Dosimeters from Quest and DuPont in the USA arrived before this, but by the specification of the 5dB doubling rate that they were required to meet, these were not true energy integrators. B&K's 2218 is probably the best claim to the first true Leq meter. For a meter to properly measure Leq requires 120dB acquisition range; still only just possible now & difficult within the first-stage operational amplifiers before sampling of the signal.

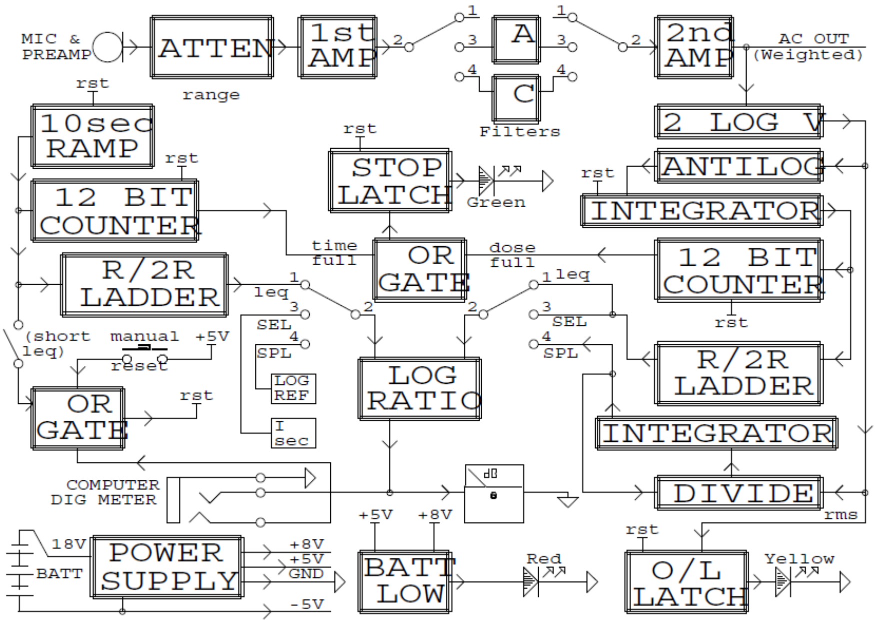

Figure 6: Block diagram of the Cirrus Research 222 Integrating SLM

The block diagram of the Cirrus 222, shown above in Figure 6 is a good indication of the level of complexity of the analogue circuitry; although some aspects used the CMOS 4000-series from matters such as the 12-bit counter & could be considered ‘digital’, there was no microcontroller nor programmed aspect of the device functionality. While various other methods were employed by the other manufacturers in realising the same goal, all for which the same can be said, for a energy-integrating Leq meter to have been developed entirely using analogue circuitry is a triumph; one could argue, even ‘cleverer’ than their modern digital counterparts.

4.3 Difficulties in the digital transition

Boiled down to the simplest form, a SLM is an acoustic transducer, fed through an amplifier (or impedance matching network) producing a voltage which is connected to some form of metering. The immediate impression would be that bolting a digital voltmeter in place of the old analogue VU meter would produce a digital sound level meter, although the reality was far more complex.

Some of the first attempts at digital meters reported rapidly-changing values; a steady-signal within a lab was easy to resolve, but with real-world fluctuations of the audio signal, the displays were not particularly easy to make readings from. The ability to make a fair judgement of Lmin and Lmax; straightforward of course with an analogue needle, was lost with a digital display. Additionally, the amplifiers, filtering and weighting networks had not been designed for such a large dynamic range. Auto-ranging circuits were developed by companies such as General Radio, but this led to issues with the device not switching fast enough to cope with rapidly changing sound pressure levels.

4.4 Capabilities at the turn of the millennium: hardware developments

Microprocessors were now commonplace throughout the world of electronics, and SLM designs followed accordingly. Most devices had or were moving toward fully addressed LCD displays, which opened up the possibilities of displaying far more information; charts could now be presented on-screen without the need for external processing of the data. Analogue to Digital Converters were becoming available with sufficiently high bit depths and linearity to be used for measurement purposes.

4.5 The modern era; direct AD sampling of the voltage

Early designs incorporating microprocessors used such devices for matters of control of displays; as can be seen in the block diagram of a SLM from the turn of the century in Figure 7. Much of the earlier-used analogue circuitry for the pre-conditioning and weighting of the signal found in purely analogue designs, as described earlier, is still present. This is caused by the limitations of ADCs at the time; without the prior use of a logarithmic amplifier, the dynamic range of low-bit-depth ADCs would have been entirely insufficient.

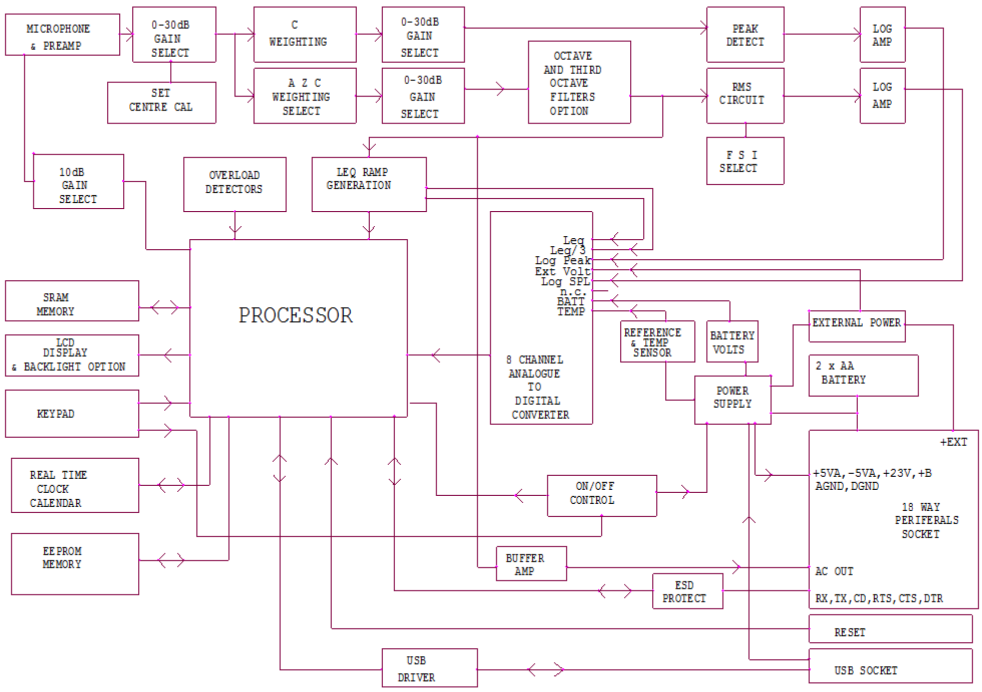

Figure 7: SLM block diagram architecture of an early 2000's device

Most manufacturers have now adopted an architecture that directly samples the voltage straight from the pre-amplifier. All aspects of signal conditioning or weighting filters and, more importantly, calculations upon the signal to derive *any* acoustic parameter are simply carried out by algorithms within the firmware, with no additional hardware complexity. While two ranges are seen, sampled independently and auto-ranged within the firmware (now with the speed of processing high enough to avoid issues with rapidly-changing sound levels) the currently-available device capabilities are only slightly hindering further simplification and total, full-dynamic-range direct microphone-to-ADC sampling.

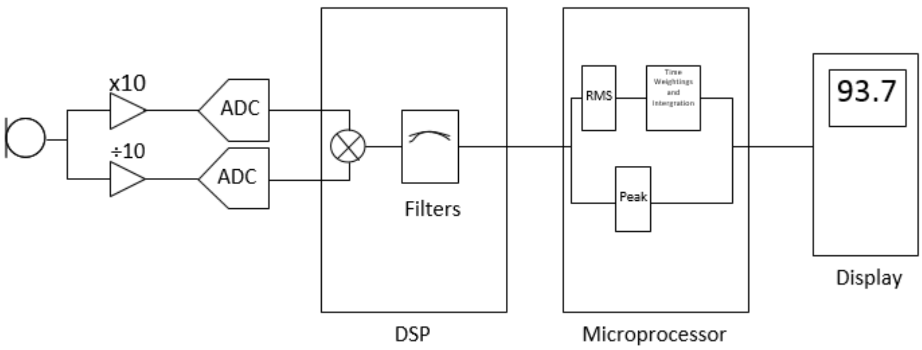

Figure 8: Block diagram of the Cirrus Research 'Optimus'

5 Microphones: Types and advances

5.1 Early devices

Davis (2007)[21] suggests that the term microphone originates from Sir Wheatstone, describing stethoscope-like devices, although there are many reports[22,23] of the word first appearing in a dictionary in 1683 to describe purely acoustical devices such as 'ear trumpets'. The concept of a microphone as a *transducer* was developed much later by Bell with the invention of the telephone. Although the original invention of 1876 was of which was a 'liquid transmitter', based upon changes in resistivity, the eventual microphone transduction method employed in his telephone was an electro-dynamic device.

Almost ubiquitously, every design of microphone/method of transduction developed before the new millennium incorporated a membrane to convert the sound pressure wave into mechanical movement; even the apparent exception by Davis' suggestion that the flame microphone of Blondell & Chambers (1902/1910) did not is not clear, as it appears according to Paquette (2001)[24] that the pressure of the gas supplying the flame was controlled by a diaphragm-operated valve.

During the development of SLMs right at the start in the earlier half of the 20th century, the carbon microphone was prevalent. These devices operate on the principle of a diaphragm applying pressure to carbon granules, which change in resistance; thus, with a steady voltage applied to one plate, a varying voltage proportional to the sound pressure is produced at the other plate.

When SLMs were released commercially in the 1950s, piezo-electric microphones were more prominent; the General Radio 1551-A having a Rochelle salt (potassium sodium tartrate) based device; the Shure 98-98. By the description and data reported by Medill (1953)[25], this device has a performance that was not too far from meeting the same class-1 specifications we have today within BS-EN-61094-4. Such devices have a membrane, again for the purpose of transforming acoustic pressure into mechanical movement, but by the action of some force-multiplying leverage, a piezoelectric crystal is made to bend, generating a voltage. Although Rochelle salt would not be the material of choice; it is particularly susceptible to failure in high humidity, there is no theoretical reason why a low cost piezo-electric device should not meet class-1. In the 1970s, many companies attempted to develop a piezo-electric microphone, but the size of the market and complexity of the work at the time led to many giving up the work.

5.2 Non- and Pre-polarised Condenser microphones

The sound level metering market has been overwhelmingly dominated by condenser microphones. Even though we are nearing one-hundred years since its invention by Wente in 1921, the performance provided by this device has been unsurpassed in all aspects simultaneously. Earlier versions of the device carried the issue of arcing of the polarising voltage, making environmental measurement particularly difficult; many acousticians experienced in the use of non-polarised condenser mic's will likely convey the practice of carrying three microphones, two kept in one's pocket ready to replace the capsule of rapidly-decreasing performance fitted to the meter.

The real breakthrough with condenser microphones was made with the introduction of an electret layer carrying a permanent charge & thus doing away with the requirement of a polarisation voltage. While it is possible to use a polymer electret as the membrane; the design approach for many low-cost electret capsules, the material is not rigid enough to reach a sufficiently high first-order resonance and thus a flat response below this, as required by the class-1 specifications of EN-61094-4:1996[26]. The next step in the evolution of the electret condenser microphone (ECM) was to place a very thin layer of electret material; usually a fluoropolymer such as PTFE or FEP; directly upon the backplate. This then allows a metal foil to be used as the membrane, and thus the performance greatly improves. Much of the development of the ECM can be apportioned to Sessler & West who filed a patent for the device in 1962[27]. However, the dimensions and tolerances of the components requires precision of a few microns; the gap between the backplate and membrane is of the order of twenty microns and thus susceptible to any dirt in the assembly process preventing unimpeded motion of the diaphragm. The assembly of ECMs thus was, and still is, at the limits of what is achievable by 'macro-engineering'; that is, engineering by regular machining and manual assembly methods. Consequentially, ECMs have always been expensive to produce. However, advancements in alternative manufacturing technologies have realised other methodologies that can produce a device of comparable performance which, although still possibly in 'teething stages', would appear to be the next stage in class-1 microphone production.

5.3 MEMS microphones – a new chapter in transducers?

The vast majority of microphones now fitted to electronic devices such as mobile phones are Micro-Electro-Mechanical-System (MEMS) types. This technology arose from the realisation that the fabrication methods used to fabricate silicon semiconductor chips could be used to produce mechanical systems of dimensional orders of magnitude of micrometres, even tens of nanometres. The actual design of a MEMS microphone is fundamentally a condenser type, but with the diaphragm and supporting features all 'machined' in-situ from the silicon. There are other quite radically different approaches; Microflown Technologies produce a device by MEMS fabrication methods that directly measures particle velocity by means of heat transfer between two extremely small filaments. In MEMS device fabrication, the manufacture process becomes far more difficult. Silicon chips are little affected by dirt entering the manufacture process; quite conversely for MEMS, which are affected in much the same way as an ECM is during manufacture. While this does decrease the yield (which is generally low already within chip manufacturing) and increase the cost, the actual price increase relative to regular silicon chips still does not come close to the cost of producing ECMs. Due to the size of the devices, the noise floor relative to the signal generated is one of the major prohibitive factors in a MEMS microphone being suitable for a measurement microphone. Although the package is quite robust, with all the delicate assemblies housed within the chip, other factors such as susceptibility to electrostatic discharge, not affecting ECMs, also become a concern with MEMS, as discussed by Fonseca and Sequera (2011)[28], within which it is suggested that humidity is also a major concern for the performance and operating life of MEMS devices.

One other argument prohibiting the immediate incorporation of MEMS is the aspect of calibration of the devices. Strictly, this is not the most difficult of issues to resolve; one only need to develop a method of mounting the microphone within a controlled acoustic environment, be that free-, pressure- or diffuse-field. Here, matters of tradition, and of course the reality of passing equipment re-design cost onto the customer makes it more difficult to introduce a new microphone type. Approaches made by some manufacturers, such as Svantec with their SV 104 dosimeter, have used a regular ½" housing to mount much smaller MEMS sensors, which allows fitment of a regular calibrator. While this resolves the calibration issue, it rather spoils one of the major benefits of MEMS; the smaller devices present the potential for less disturbance of the acoustic free-field; of course, for a dosimeter, the field is disturbed far more by the form of the whole device and the placement on the body, allowed for by the less-stringent specifications for dosimeters compared to SLMs. By their size however, MEMS microphones have opened up new possibilities in sound monitoring; particularly in MIRE (Microphone In Real Ear), where even more accurate monitoring of true personal noise dose can be attained.

5.4 The end of the membrane?

Mentioned earlier, the premise that every microphone design has in some manner incorporated a membrane is now beginning to be disproven. Of even more recent development, entirely new methods of the measurement of sound are emerging, which are quite radically different. Using the principle that the refractive index of air changes with pressure, laser light can be used to determine the sound pressure at a point in space. Techniques have been around since the later 1990s, the work of Caron *et. al.* goes back to 1998[29], and earlier in related work; the methodologies within this work detect and generate a signal from the acousto-optic interaction. More recently, research at the National Physics Laboratory, UK, has used more developed techniques to derive a method of absolute measurement, using a method of Gated Photon Correlation Spectroscopy, by which the absolute particle velocity is measured directly. The question of whether this exceptional work could ever be brought away from the laboratory and implemented in a portable device is possibly not answerable at the moment, but the fundamental changes it would make to sound measurements are ground-breaking; essentially, pressure-to-free-field corrections and disruption of the acoustic field by the measurement device could be a thing of the past.

6 Future challenges currently restricting SLM's.

As mentioned, the advances in digital processing technology have allowed designers to directly sample the voltage straight from the pre-amplifier. The capability of an Analogue to Digital Converter (ADC) to do this for the full dynamic range required for SLMs is only of very recent development. 24-bit audio has been around since the turn of the millennium, but many implications of a 24-bit depth ADC did not actually provide a full 24 bit resolution to the audio signal. Even at the time of the design of the Optimus at Cirrus Research around 2010, many 24-bit ADC chips that were investigated really had only 21 bits; the end three least significant bits always remained unchanged. At the time of writing however, chips are coming onto the market that advertise a true 32-bit resolution[30]. Storage on portable devices is also still a limitation, despite the ever-increasing capacity of digital storage media, the simultaneously-increasing bit depth causes something of a balancing act against progress.

Aside from the above matters, there is a current development in the industry that would appear to question the fundamental principle of the sound level meter as an exclusive device...

6.1 A move away from dedicated devices?

Luquet and Razwadowski foretold a possible path down which future metering devices may go in the 1988[31] Internoise conference; *"The exponential expansion of computer technology means that programmable and evolutive systems supersede fixed electronic equipment."* Handheld mobile phone devices are becoming more and more capable in processing power & storage, and come with attached peripheral sensors covering almost ever physical metric that one may desire, and interfaces for a multitude of multimedia protocols. It is fair to say that devices, once fantastical objects in science fiction movies, are now a reality & moreover provide the flexibility in being programmable to carry out near any task that one might wish. Thus, of very current interest is the development of low-cost software 'apps', running on mobile communications devices that perform metering of the sound level from the microphone. This is understandable; such devices incorporate very similar architectures and all the required devices; microphone, ADC, processing & display, are in some form present to provide all the functions implicit in a SLM.

The concept is fraught with problems, not only because many components within the devices simply are not up to the specification; the microphone in particular with cheaper devices, but because the devices are designed with other purposes in mind than precise measurement. Smartphone devices are designed to be exactly that; a feature-packed, multi-media mobile communications device, which must exhibit low power consumption and importantly low bandwidth consumption. Significant filtering of the audio signal chain thus takes place as well as very complex signal coding algorithms which on many devices cannot be deactivated. This issue is addressed by Faber (2012)[32] whereby Apple devices with iOS firmware prior to version 6 have filtering on the input to improve the performance against wind and 'pop' noise from aspirated plosives in the spoken voice. However, by careful consideration of each of these factors, and with the possible potential for the high-end of MEMS devices being capable of meeting the standard, it is possible to correct for such effects.

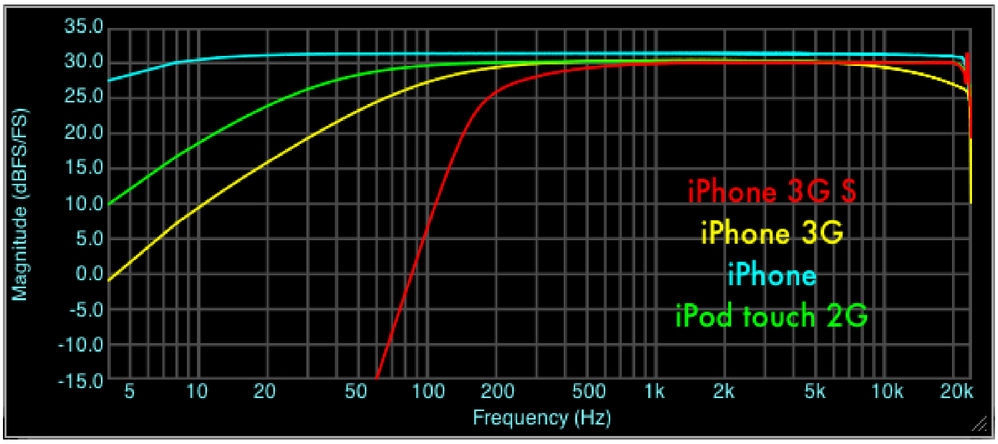

Figure 9: Input frequency response of various iPhones, displaying filtering on some devices wholly inappropriate for noise measurement[33]

To counter this argument, two major factors will always remain; calibration and standardisation. It is debateable that, with the frequency response of microphones now fitted to mobile phones being good enough to meet IEC standards, it is still not possible to perform a calibration without access to controlled acoustic environment such as a reverberation chamber. This matter can be resolved; most devices allow the attachment of standard-dimension microphone capsules such that a standards-meeting calibrator can be used to adjust the device prior to measurement. Clearly, this imparts significant additional cost; in fact, probably adding the most expensive individual component of the whole SLM system.

The latter issue is much more difficult to resolve; at least, without significant collaboration between the manufacturers of the smartphone devices and the software designers. By an app designer restricting their software to few or better one device, a standard hardware architecture may appear to be assumed. However, with devices often being made in multiple factories, it is not guaranteed that a given model of smartphone would have the same hardware as the next. Even then, to acquire PTB approval every designer of a sound level meter app would have to seek re-approval with every update to the smartphone firmware. Considering the few-dollars-a-licence revenues likely to be gained from the development of a SLM app, this is far from lucrative.

7 Conclusions

SLMs have come a long way from the earliest days of comparative level monitoring, in-line with just over a century of development of electro-acoustics and digital computing technologies, leading to highly-accurate absolute measurement of metrics far beyond the simple sound pressure level. Standards have developed over the years & sometimes driven designs in unintended ways; devices sometimes being developed with the focus more upon meeting the standard than producing a device that functions in the 'acoustically correct' manner. We have seen devices evolve dramatically from the single-metric devices at the dawn of noise surveying, to powerful, multi-functional analysis tools. Although two decades ago, complete integration of the SLM and PC appeared the way forward, the computing power of handheld devices is so great now that they could soon even eliminate the need for any involvement of a PC. Developments in transduction technologies may appear to present potential alternative methods for the initial acquisition of the acoustical signal, but to date, no device has entirely surpassed the electret condenser capsule. The emergence of cheaper alternatives presented by software running on generalised 'smartphone' devices could, on the face of the matter, appear to be a potential replacement for the dedicated SLM. However, implications of standards approval, requiring testing far beyond the budgetary constraints of any app developer for such software would appear to cause progress along this avenue to be prohibitive.

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