5: Signal Extraction from Original Carriers

5.1 Introduction

5.1.1 The first, and most significant part of the digitisation process is the optimisation of signal retrieval from the original carriers. As a general principle, the originals should always be kept for possible future re-consultation. However, for two simple, practical reasons any transfer should attempt to extract the optimal signal from the original. Firstly, the original carrier may deteriorate, and future replay may not achieve the same quality, or may in fact become impossible, and secondly, signal extraction is such a time consuming effort that financial considerations call for an optimisation at the first attempt.

5.2 Reproduction of Historical and Obsolete Mechanical Formats

5.2.1 Introduction

5.2.1.1 The first audio recordings made were mechanical recordings, and this approach remained almost the only viable method for capturing sound until developments in electrical circuitry began to create a market for magnetic recordings during and after the 1930s. Mechanical recordings are recognised by the presence of a continuous groove in the surface of the carrier into which the signal is encoded. The encoding of monophonic audio is achieved either by modulating the bottom of the groove up and down with respect to the surface (vertical or hill-and-dale recordings), or from side to side (lateral recordings). All cylinder recording are vertical recordings, as are Edison Diamond Discs, some early shellacs and discs recorded by Pathé up until about 1927, when they began to record laterally cut discs. For a time, some radio transcription discs were also vertically cut recordings, primarily in the US. Lateral cut recordings are the more common form, and most coarse groove recordings (sometimes called 78s), transcription, and instantaneous discs are lateral, as are monophonic Long Play (LP) microgroove records. Microgroove discs are discussed separately in section 5.3 [1].

5.2.1.2 Mechanical sound recording formats are analogue, so called because groove wall is modulated in a continuous representation of the wave form of the original audio. Almost all of the mechanical recordings discussed are now obsolete,in that the industry which once created these artefacts no longer supports them.Early mechanical recordings were acoustic,as the sound waves acted directly on a lightweight diaphragm which drove the cutter directly into the recording surface. Later mechanical recordings were "electrical recordings" as they used a microphone and amplifier to drive an electrical cutting head. From 1925 onwards almost all recording studios began to make electrical recordings.

5.2.1.3 As the early mechanical recordings were all made when the industry was developing, there were few standards. Those that existed were poorly observed as the technology was constantly evolving, and many of the manufacturers would keep their latest techniques secret in order to gain a market

advantage. One legacy of this period is the immense degree of variation in most aspects of their work, not least in the size and shape of the recorded groove (see 5.2.4 [2]), recording speed (5.2.5 [3]) and equalisation required (5.2.6 [4]). Consequently, there is a need for those working with the recordings to have specific knowledge about the historical and technical circumstances under which these recording were created. For obscure or non standard recordings, it is advisable to seek advice from specialists, and even for the more common types of recording, caution should be exercised.

5.2.2 Selection of Best Copy

5.2.2.1 Mechanical recording may be either instantaneous or replicated. The former are mostly unique items, single recordings created of a particular

event. These include wax cylinders[1], lacquer (also known as acetate) discs and recordings created by office dictation machines (see 5.2.9 [5]). Replicated recordings, on the other hand, are pressed or moulded reproductions of an original master, and are almost always manufactured in multiples. Instantaneous recordings should be identified and treated separately and carefully.

5.2.2.2 Instantaneous cylinders may be distinguished by their waxy appearance and feel, and were generally made of a soft metallic soap. Their colour typically can vary from a light butterscotch to a dark chocolate brown, or very rarely, black. Replicated cylinders were made of a much harder metallic soap, or alternatively of a celluloid sleeve over a plaster core. These were manufactured in a variety of colours, though black and blue were the more common, and usually bear some content information embossed into a flattened end.

5.2.2.3 The first disc format capable of instant replay appeared around 1929. The discs were made of an uncoated soft metal (usually aluminium, possibly copper or zinc) into which a lateral groove was embossed rather than cut, and are easily distinguished from replicated shellac discs. Like the subsequent lacquer discs, the embossed metal format was designed to allow the discs to be replayed on standard gramophones of the time, and so recordings can be loosely categorised as coarse groove and 78 rpm, but the transfer engineer should expect some variation, not least in the groove profile.

5.2.2.4 Lacquer or acetate discs, introduced in 1934, are most frequently described as laminated, although that is not their method of manufacture, or as acetates, which is not the nature of their recording surface. They most commonly consist of a strong and stiff base (aluminium or glass, occasionally zinc) covered with a layer of cellulose nitrate lacquer, coloured dark to improve observation of the cutting process. Rarer are discs which have a cardboard base. The cutting properties are controlled by the addition of plasticisers (softening agents), such as castor oil or camphor.

5.2.2.5 Lacquer discs can appear similar to shellac or more typically vinyl, but they can be distinguished in several ways. The base material can often be seen between the outer lacquer layers, either within the centre hole or at the disc edge.Where the disc has a paper label the content information will often be typed or handwritten rather than printed. On discs without paper labels one or more additional off-centre drive holes may be seen near the centre hole. Though cellulose nitrate lacquer discs on metal or glass base are the most common instantaneous disc, in practice a great variety of other materials were used, such as cardboard as the base media, or gelatine as the recording surface, or as a homogenous recording disc.

5.2.2.6 Due to their inherent instability lacquer discs should be transferred with a high priority.

5.2.2.7 The selection of the best copy, in those circumstances where multiple copies on instantaneous discs exist, is usually a process of determining the most original intact copy of an item. In the case of mass produced mechanical recordings, where the existence of multiple copies is the normal situation, the following guide to selection of best copy applies.

5.2.2.8 Selection of the best copy of replicated mechanical media draws on knowledge of the production of the recording, and the ability to visually recognise wear and damage which would have an audible effect on the signal. The recording industry uses numbers and codes, generally located in the space between the run-out groove and the label in a disc recording, to identify the nature of the recording. This will help the technician determine which recordings are in fact identical, or alternate recordings of the same material.Visual signs of wear or damage are best seen in the way a recording reflects light. To best show the effect an incandescent light is a necessity, generally aimed at the recording from behind the technician's shoulder, so that they are looking down the beam of light. Fluorescent tubes, or energy saving compact fluorescent lights do not provide the necessary coherent light source to reveal wear and should not be used. A stereoscopic microscope is helpful in assessing groove shape and size, and in examining wear caused by previous replay, which helps selection of the correct replay stylus. A more objective approach involves using a stereo-microscope with a built-in reticule which enables more accurate selection of styli (Casey and Gordon 2007).

[1] The earliest commercial wax cylinders were replicated acoustically, one from another, and performers would often do multiple sessions to create batches of similar recordings. They should all be regarded as unique items.

5.2.3 Cleaning and Carrier Restoration

5.2.3.1 Grooved media may be adversely affected by past use, or through natural decomposition of the constituent materials, hastened to a greater or lesser degree by environmental storage conditions. Debris including dust and other airborne material can accumulate within the grooves, and fungal growth may be present where climatic conditions have allowed. This is particularly common with instantaneous cylinders. In addition, lacquer discs may experience exudation of the plasticisers from the lacquer itself. This typically has a white or gray mould-like appearance, but is distinguished by a greasy consistency. Mould, on the other hand, is typified by feathery or thread-like white or gray growth. Each of these conditions will compromise the ability of the replay stylus to follow the groove pattern accurately, and so appropriate cleaning of the carrier is necessary.

5.2.3.2 The most appropriate cleaning method will depend on the specific medium and its condition. In many cases a wet solution will produce the best results, but the choice of solution must be made carefully, and in certain cases it may be best to avoid the use of any liquids. Record cleaning solutions which do not disclose their chemical composition should not be used. All decisions about the use of solvents and other cleaning solutions should only be made by the archivist in consultation with the appropriate technical advice by qualified plastics conservators or chemists. It can however be stated that lacquer and shellac discs, and all types of cylinder, should never be exposed to alcohol, which may have an immediate corrosive effect. Shellac discs frequently contain absorbent fillers which can expand on sustained contact with moisture, and so should be dried immediately after cleaning with any wet solution. Any wet cleaning process should avoid contact with paper disc labels.

5.2.3.3 Castor oil has commonly been used as a plasticiser in the production of cellulose nitrate lacquer discs, which, as it exudes from the disc surface typically breaks down into palmitic and stearic acids. The loss of plasticiser causes the coating to shrink and consequently crack and peel away from the base. This is known as delamination. Several solutions have been employed successfully in removing the exuded acids (see in particular Paton et al 1977; Casey and Gordon 2007, p27).It has been observed however that after cleaning, lacquer discs may continue to degrade at an accelerated rate. It

is sensible therefore to create digital copies of the material held on cleaned lacquer discs as soon as possible after cleaning. It must again be stressed that the effect of all solvents should be tested before use. Some early lacquer discs have a gelatine rather than cellulose nitrate playing surface for example, which is soluble and would instantly suffer irreversible damage if treated with any liquid solution.

5.2.3.4 Certain other media may not be appropriate for wet cleaning, including shellac and lacquer discs which were manufactured with paper or card layers beneath the playing surface. Similarly, lacquer discs displaying cracking or peeling surfaces must be treated with great care, and instantaneous cylinders should be cleaned with a soft dry brush only, applied along the groove path. However, where mould spores are thought to be present, the utmost care should be taken to minimise cross contamination. Special care should be taken when cleaning moulds and spores as these may cause serious health problems. Operators are strongly advised to obtain professional advice before commencing work on such infected materials.

5.2.3.5 In cases where wet cleaning is deemed appropriate, it should be carried out with both the solution and carrier at room temperature, to avoid any damage to the carrier caused by thermal shock.

5.2.3.6 Often the most effective and efficient method of wet cleaning is to use a record cleaning machine employing a vacuum to remove the waste liquid from within the groove, such as those made by Keith Monks, Loricraft or Nitty Gritty.

5.2.3.7 Particularly dirty carriers, or those with stubborn marks such as dried-on paper deposits, may be more appropriately cleaned using an ultrasonic bath, into which the carrier (or portion of the carrier) is placed. The process works by vibrating a solution around the item, loosening dirt deposits.

5.2.3.8 In cases where it is not possible or appropriate to employ such equipment, hand washing may be carried out using an appropriate short bristled brush. Clean tap water may be used in the washing process, but should always be followed by a thorough rinse in demineralised water to remove any consequent contamination.

5.2.3.9 In addition to cleaning, some further form of restoration may be required. Shellac discs and cylinders of all types are brittle and liable to break if mishandled, and shellac will melt and warp at high temperatures. The exudation of plasticiser from lacquer discs causes the lacquer layer to contract upon a stable metal or glass base, creating stresses between the layers and resulting in cracking and peeling of the lacquer playing surface. Reconstruction of broken discs and cylinders is ideally done without resorting to glues or adhesives, as these inevitably form a barrier between the parts being joined which, however small, will be audible. Such processes are also generally irreversible, allowing for no second chances. The manufacturing processes used in replicating both shellac discs and cylinders will often result in a degree of internal stress in the carrier. If broken, the divergent stresses in the constituent pieces may cause them to contort somewhat. To minimise the effect of this, broken carriers should be reconstructed and transferred as soon as possible after the breakage occurs. The individual parts of broken carriers should be stored without touching. Storing them unsecured in their reconstructed form may encourage the finely detailed broken edges to rub together, causing further damage.

5.2.3.10 Shellac discs are usually best reconstructed on a turntable, upon a flat platter larger than the disc itself (another, disposable or non-archival disc is often ideal). The pieces are placed upon it in their correct positions and held in place around the centre spindle with re-usable pressure sensitive adhesive putty such as Blu-Tack, U-Tack, or similar around the outside of the disc.Where discs are thinner around the edge than in the middle, the putty may be used to raise the edges to the correct height. Take note of the direction through the groove that the stylus will travel: where the pieces cannot be perfectly vertically aligned, it is better for both the stylus and the resulting transfer that the stylus be obliged to drop down onto a lower fragment rather than be pushed up abruptly onto a higher one.

5.2.3.11 Cylinders which have suffered a neat break can often be reconstructed around the playback mandrel using 1/4 inch splicing tape as a form of bandage. More complex breakages will require specialist help.

5.2.3.12 Flakes from peeling lacquer disc surfaces may be temporarily fixed to allow the disc to be played, using tiny amounts of petroleum jelly between the flake and disc base. The long term effects of this procedure are likely to be deleterious, and it is used to attempt replay of discs which are judged to be unplayable by any other currently practicable means.

5.2.3.13 Where it is possible to play a warped or bent disc without flattening it, this should be the preferred option, as the risks associated with disc flattening described below will attest. The ability to play a warped disc can often improve when the rotational speed of the disc is reduced (see 5.2.5.4 [3]).

5.2.3.14 Shellac discs may be flattened in a laboratory (i.e., non-domestic) fan-assisted oven. The disc should be placed on a sheet of pre-heated toughened glass, and it is imperative that both disc and glass be clean, to prevent dirt fusing with the disc surface. There is a danger that in curing vertical warpage, some lateral warpage may occur. The disc should therefore not be heated any more than it has to be, and a temperature of around 42C is often sufficient (Copeland 2008 Appendix 1).

5.2.3.15 Flattening discs is a useful process because it can make unplayable discs playable. However, current research into the procedure of flattening discs with heat shows that it causes a measurable rise in subsonic frequencies, even in the low audible frequency range (Enke 2007). Though the research is not conclusive the point should be noted in determining whether to flatten a particular disc. The analysis of the affect of flattening was carried out on vinyl discs and whether it applies to shellac is yet to be determined, though the lower temperatures associated with treating shellac make it much less of a risk. Nonetheless, the possibility of such damage has to be weighed against enabling the playing of the disc.

5.2.3.16 Though it is strongly advised not to attempt to permanently flatten an instantaneous disc (and any attempt is likely to be unsuccessful and damage the disc surface), in some instances the warpage may be temporarily reduced by clamping or otherwise fixing the disc edges to the turntable. Great care must be taken, especially with lacquer discs whose surface may be damaged if placed under stress. Laminated flexible discs with a warp may have been rendered flat by placing the disc on the vacuum platter of a disc cutting lathe and carefully bringing the disc flat. All physical treatment should be undertaken with great care to avoid damage.

5.2.3.17 Some replicated discs have been produced with a non-centric spindle hole. It is preferable to play such discs on a turntable with a removable spindle or to raise the height of the disc above the spindle using, for example, waste discs and rubber interleave. In the latter case the height of the pickup arm should be raised at the supporting column by the same amount. It is possible to re-centre the hole using a reamer or drill, but such invasive approaches should be undertaken cautiously and never with unique or single copies. Altering the original artefact may well result in loss of secondary information.

5.2.4 Replay Equipment

5.2.4.1 Grooved recordings were made to be replayed with a stylus and pickup. Though optical technology has some special advantages which are discussed below (see section 5.2.4.14), and though advances in optical replay are bringing closer the likelihood of a practical system which does not require physical contact, currently the best and most cost effective approach to retrieving the audio content from such a recording is with the correct

stylus. For lateral recordings a set of styli with different radii in the range of 38 µm (1.5 mil^2), to 102 µm (4 mil), with an additional focus on 76 µm (3 mil) and 65 µm (2.6 mil) for early and late electrics respectively, is essential. The correct stylus for the particular groove will ensure best possible replay by fitting properly into the replay area, and avoiding worn or damaged sections of the groove wall. Records in good condition will reproduce with greater accuracy and reduced surface noise with elliptical tips; records in visually poor condition may be better suited to conical tips.Wear from previous use may well be to a particular region of the groove wall leaving some undamaged areas. Choosing an appropriate tip size and shape will allow these undamaged sections to be reproduced without including distortions caused by the damaged sections. A truncated stylus of either shape will better avoid any damaged areas in the bottom of the groove. Care should be taken in the replay of Pathé lateral discs as they typically have a larger groove width, and may require larger tip radii to avoid damage to the groove bottom.

5.2.4.2 Mono pickups are available, but it is more common to use stereo pickups as these allow separate capture of each groove wall. Moving coil pickups are often highly regarded because of their enhanced impulse response which aids in improving the separation of groove noise from audio signal. However, the range of various tip sizes for moving coil pickups is not as wide as that for moving magnet, are integral to the pickup, and those that can be ordered are around four time more expensive. Moving magnet pick ups are more common, more robust, lower cost, and generally more than adequate for the task.When replaying shellac discs a tracking force in the range of 30-50mN (3-5 grams) is often appropriate. It is recommended that a lesser tracking force be applied to lacquer discs. An advantage in using a stereo pickup is that this allows the two resultant channels to be stored

separately, enabling future selection or processing of the separate channels. For listening the two channels may be combined in phase for a lateral recording, and out of phase (with respect to the pickup) for a vertical recording.

5.2.4.3 Selection of a suitable stylus in vertical recordings is governed by different criteria to lateral recordings. Rather than choosing a stylus to sit in a particular space on the side of a groove wall, playback of cylinders and other vertical cut recordings requires that a stylus be chosen that is a best match for the bottom of the groove. This is critical with instantaneous cylinders, where even very light tracking forces will cause damage if the incorrect stylus is chosen. A spherical stylus is generally preferred especially if the surface is damaged, though an elliptical stylus may well avoid frequency dependent tracking error. Typical sizes are between 230 (9 mil) and 300 μm (11.8 mil) for standard cylinders (100 grooves/inch) and between 115 (4.5 mil) and 150 μm (5.9 mil) for 200 grooves/inch cylinders. Cylinders should be replayed with a stylus whose tip has a radius a little smaller than the bottom radius of the groove. A truncated stylus will damage the groove because tracking will take place at the edge rather than the tip, resulting in increased pressure to that part of the groove.

5.2.4.4 When it comes to making decisions about what equipment to acquire, knowledge of the content of a particular collection will be the primary guide to determining the type of equipment required. Different types of carriers will obviously require different types of replay equipment, but even within similar carriers some specialist needs may arise.

5.2.4.5 Generally, historical equipment should not be used, mainly because of its poor rumble performance and in the case of cylinder players, greatly increased tracking force compared with equivalent modern replay equipment. Some problematic cylinders may not be playable on this type of equipment as modern cylinder players normally track the grooves with auto- controlled feed retrieved from the motion of the needle.When using this set up it is virtually impossible to properly track locked grooves, or scratches nearly parallel to the groove. This problem can be solved by using a modern player with fixed feed, or a modified historical cylinder player.

5.2.4.6 Radio transcription discs commonly have a diameter of 16 inches. If such discs are held in a collection, it will be necessary to procure a turntable, arm and pickup for discs of this size. For standard discs up to 12 inch records generally a modern precision turntable, modified to allow varispeed in a wide range, is required.

5.2.4.7 Negative metal stampers manufactured for mass replication of discs can themselves be replayed if an appropriate bi-point or stirrup stylus is available. This type of stylus sits astride the ridge (which is a negative impression of a disc groove) and needs to be placed carefully so as to avoid falling between adjacent ridges. As the stamper holds an inverse spiral to the discs it was designed to replicate, it should revolve anticlockwise, that is, in the opposite direction to a replicated disc, in order to be played from start to finish. To do this correctly would require a fully reverse-mounted tone arm. Much simpler and just as effective would be to play the stamper from finish to start on a standard clockwise turntable, and reverse the resulting digital transfer, using any current high quality audio editing software.

5.2.4.8 Bi-point styli are now extremely difficult to obtain, and fall into two categories, namely low- and high-compliance. The former are designed to repair manufacturing defects in metal stampers and as such are not ideally suited to archival transfer work. The latter, employing a significantly lighter tracking force are designed for audible replay rather than physical modification of the stamper, and so can be considered more suitable.

5.2.4.9 Turntables and cylinder phonographs for archival transfer purposes need to be precision mechanical devices in order to produce the minimum transmission of spurious vibrations to the record surface, which acts as a receiving diaphragm for the pickup. Low frequency vibrations are called rumble, and these vibrations frequently have a considerable vertical component. To reduce rumble generated by external vibrations,the replay apparatus must be placed on a stable foundation that is not likely to transmit structural vibrations. The replay machine should have a speed accuracy of at least 0.1 per cent; wow and flutter (DIN 45 507 weighted) better than 0.01 per cent; and an unweighted rumble of better than 50 dB. The turntable will be either belt or direct drive; friction drive wheel machines are not recommended as suitable speed accuracy and low rumble is not possible with these devices.

5.2.4.10 Any power supply wiring and the electric motor must be shielded to prevent injection of electrical noises into the pickup circuit. If required, additional Mu-Metal plates may be used to shield the motor from the pickup. The connecting cable to the pre-amplifier must be within the specifications regarding the loading impedance for the pickup. The installation should follow best analogue practice and adequate grounding procedures must be adhered to in order to ensure noise is not added to the audio signal. All of the above suggestions and specifications should be quantified, by analysing the output from test discs (see 5.2.8 [6]).

5.2.4.11 Both turntables and cylinder phonographs should be capable of variable replay speed, with the possibility of half-speed replay being particularly desirable (see 5.2.5.4), and feature a speed readout to allow documentation, possibly as a signal suitable for automatic logging for metadata. The pickup arm must sit on a base that can be adjusted, not only as regards distance from the turntable centre, but also in elevation.

5.2.4.12 In order to evaluate and decide on the most appropriate equipment and settings, comparisons must be made between the different options. This is best achieved through simultaneous, or A/B comparison, and audio editing software should be chosen which allows multiple audio files to be compared simultaneously. Transferring portions of a recording with different parameters and aligning the different resulting audio files in the editor for listening purposes, allows repeated direct comparison and reduces the inherent subjectivity of the process to a minimum.

5.2.4.13 A decision will need to be made as to the application of an equalisation curve prior to digitisation (see 5.2.6 Replay Equalisation [4]).Where this is desirable, an appropriate preamplifier will be required, adjustable to recreate all necessary settings.

5.2.4.14 As an alternative to contact pickups the entire surface of a disc or a cylinder can be scanned or photographed at high resolution then converted to sound.Various projects have been developed up to a (quasi-) commercial level (ELP LaserTurntable; IRENE by Carl Haber,Vitaliy Fadeyev et al; VisualAudio by Ottar Johnsen, Stefano S. Cavaglieri, et al, Sound Archive Project, P. J. Boltryk, J.W.McBride, M. Hill, A. J. Nasce, Z. Zhao, and C. Maul). However, all of the techniques investigated so far present some limits (optical resolution, image processing, etc.), resulting in poor sound quality,

if compared to using standard mechanical devices. A typical application for optical retrieval technology is for records in very bad condition, where mechanical replay devices would fail, or where the recordings are so fragile that the replay process would cause unacceptable damage.

[2] 1 mil is .001" (1,000th of an inch)

5.2.5 Speed

5.2.5.1 Despite being referred to as "78s", it was very often the case that coarse groove shellac discs were not recorded at precisely 78rpm, and this is especially the case with recordings made prior to the mid-1920s. At different times certain recording companies would set different official speeds, and even these were varied by recording engineers, on occasion during recording sessions. There is insufficient space here to discuss specific settings, though they are covered elsewhere in detail (see for example Copeland 2008, Chapter 5).

5.2.5.2 It is imperative that the disc be replayed for transfer as close to the original recording speed as is possible, in order to recapture the sound event originally recorded as faithfully and objectively as possible. However, subjective decisions often have to be made, and to this end knowledge of the recorded content or context in which the recording was made can be useful. The chosen replay speed should be documented in accompanying metadata. This is particularly important where any doubt remains as to the actual recording speed.

5.2.5.3 Recording speeds of commercial replicated cylinders standardised at 160rpm around 1902, although prior to that Edison, at least, applied several short-lived speed standards (all lower than 160 rpm; see Copeland 2008, Chapter 5). Instantaneous cylinders, while often recorded around 160 rpm or so, have been found with recording speeds ranging from below 50 rpm to over 300 rpm. In the absence of a recorded reference pitch (as provided occasionally by some early recordists) these will need to be set by ear, and documented accordingly.

5.2.5.4 Replaying a disc or cylinder at reduced speed may improve the ability to accurately track damaged carriers. There are many ways that this can be attempted depending on the equipment available, but attention should always be paid to the effect this will have on the sample rate of the digital file when adjusted to compensate for the change, and an appropriate sample rate should be chosen accordingly. Half-speed replay may be the simplest to employ, as it can be coupled with a doubled sample rate to produce corrected-speed transfers with a minimum of distortion caused by sample rate conversion. It should be noted that reduced speed playback is just one of many techniques that may be used to solve tracking problems. It is useful to try other procedures first such as adjusting the anti-skate to counter-balance the direction that the stylus jumps from a skip or using more or less tracking force to keep the stylus in the grooves.

5.2.5.5 Although playback with reduced speed may deliver increased surface noise compared with original speed, it is also the case that the action of filtering equipment, digital or otherwise, may be more effective. Playing at reduced speed means that the high frequency signal is halved in frequency, while the rise time of the unwanted impulse noise caused by surface damage remains the same and can be more easily distinguished from each other. However, some sophisticated predictive filtering equipment may be less effective at non- original speeds. Low speed copies must be flat transfers, without applied equalisation which can be introduced later (see 5.2.6).

5.2.6 Replay equalisation

5.2.6.1 Equalisation became a possibility with the introduction of electrical recordings; it also became a necessity. Equalisation in recording is the

application of a frequency dependant boost or cut to the signal before it is recorded, and the inverse cut or boost on replay. This became a possibility with electrical recordings because the recording and replay systems now included electrical circuitry which enabled a process which could not have been applied in the acoustic recording process. It became a necessity because the way sound is represented on a disc would not allow the dynamic range or frequency response that the electrical technology enabled, to be recorded otherwise.

5.2.6.2 Sound can be recorded on a disc in two different ways;"constant velocity" or "constant amplitude". Constant velocity on a disc is when the transverse speed of the stylus remains constant regardless of the frequency. An ideal acoustic disc recording would display constant velocity characteristics throughout its recordable range. One of the implications of constant velocity is that the peak amplitude of the signal is inversely proportional to the frequency of that signal, which means that high frequencies are recorded with small amplitudes, and low frequencies are recorded with comparatively large amplitudes. The difference in amplitude can be very marked; across 8 octaves, for example, the ratio in amplitude between the lowest and highest frequency is 256:1. At low frequencies, constant velocity is unsuitable as the excursion of the groove becomes excessive, reducing the amount of available recording space, or causing cross over between tracks.

5.2.6.3 Constant amplitude, on the other hand, is when the amplitude remains constant regardless of the frequency. Constant amplitude, while most suitable for low frequencies, is unsuitable for higher frequencies as the transverse velocity of the recording or replay stylus could become so excessive as to cause distortion. To overcome the dilemma caused by both these approaches, disc manufacturers recorded electrical discs with more or less constant amplitude at the lower frequencies and constant velocity at the higher frequencies. The point of change between the two is described as the low frequency turnover (see table 5.2).

5.2.6.4 As the recording technology improved and increasingly higher frequencies could be captured, these higher frequencies resulted in correspondingly smaller amplitudes on the disc. A consequence of the very small amplitude of these high frequency components is that the ratio of the signal to the irregularity in the surface of the disc approaches equivalence. This would mean that the very high frequencies would be comparable in amplitude to the unwanted surface noise, otherwise known as a poor signal to noise ratio. To overcome this, the disc manufacturers began to boost the higher frequency signals so that these very high frequencies were often, though not always, constant amplitude recordings. The point at which the higher frequencies are switched from constant velocity to constant amplitude is called HF Roll-off Turnover (see table 5.2). The function of this higher frequency equalisation is improvement in the signal to noise ratio, and it is commonly termed pre-emphasis in recording and de-emphasis in replay.

5.2.6.5 The commonly used dynamic or magnetic pick-ups are velocity transducers, and their output can be directly fed into a standard preamplifier, if that is desired. Piezo-electrical and optical replay systems are amplitude transducers. In these cases a general 6dB/octave slope equalisation must be applied as the difference between a constant velocity and constant amplitude recording is 6dB per octave.

5.2.6.6 Acoustically recorded discs have no intentionally applied equalisation in recording (though engineers were known to adjust parts of the recording path). As a consequence of the recording process, the spectra of an acoustic disc would display resonant peaks in amplitude and related lows. Applying a standard equalisation to compensate for the acoustic recording process is not possible as resonances in the recording horn and the stylus diaphragm,

not to mention other mechanical damping effects, can vary between recordings, even recordings from the same session. In such cases the recordings should be replayed flat, i.e. without equalisation, and equalisation should be applied after the transfer has been made.

5.2.6.7 With electrical recordings it is necessary to decide whether to apply an equalisation curve on replay, or to transfer flat.Where the curve is accurately known equalisation may be applied either at the preamplifier prior to making the copy, or applied digitally after making a flat copy.Where doubt remains as to the correct equalisation curve, a flat transfer should be made. Subsequent digital versions may employ whichever curve seems most appropriate, so long as the process is fully documented, and the flat transfer retained as the archival master file.Whether or not equalisation is applied during the initial transfer, it is imperative that noise and distortion from the analogue signal chain (everything between the stylus and analogue- to-digital converter) is kept to an absolute minimum.

5.2.6.8 It is worth noting that a flat transfer will require around 20dB more headroom than one where an equalisation curve has been applied. However, as the potential dynamic range of a 24 bit digital to analogue convertor exceeds that of the original recording, the extra 20dB headroom can be accommodated.

5.2.6.9 Apart from the dynamic range limitations mentioned above, a drawback with transferring electrically recorded discs without de-emphasis is that stylus selection is primarily made through aural assessment of the effectiveness of each styli, and it is more difficult, though not impossible, to make reasonable assessment of the effect of different styli while listening to unequalised audio. An approach taken by some archives is to apply a standard, or house, curve to all recordings of a particular type in order to make stylus selection and other adjustments, and subsequently produce a simultaneous flat and equalised digital copy of the audio. As the exact equalisation is not always known, a flat[1] copy has the advantage of allowing future users to apply equalisation as required, and is the preferred approach.

5.2.6.10 There is some debate as to whether noise reduction tools for the removal of audible clicks, hiss etc are more effective when used before an equalisation curve is applied rather than afterwards. The answer very likely varies according to the specific choice of tool and the nature of the job to which it is applied, and in any event will be subject to change as tools continue to evolve. The most important point in this regard is that noise reduction equipment, even fully automated tools with no user-definable parameters, ultimately employs subjective and irreversible processes, and so should not be used in the creation of archival master files.

5.2.6.11 A complete record of all decisions made, including choice of equipment, stylus, arm, and equalisation curve (or its absence) must be recorded and maintained in metadata.

5.2.6.12 The main equalisation curves for replay are listed below.

Equalisation Chart for Electrically recorded coarse groove **LF Turnover[2]** **(78 rpm) Discs**

HF Roll-off **Turnover (-6 dB/octave, except where marked)**

Roll-off @ 10 kHz

Acoustics 0 0 dB

Brunswick 500 Hz (NAB) 0 dB

Capitol (1942) 400 Hz (AES) 2500 Hz -12 dB

Columbia (1925) 200 Hz (250) †5500 Hz (5200) -7 dB (-8.5)

Columbia (1938) 300 Hz (250) 1590 Hz -16 dB

Columbia (Eng.) 250 Hz 0 dB

Decca (1934) 400 Hz (AES) 2500 Hz -12 dB

Decca FFRR (1949) 250 Hz 3000 Hz* -5 dB

early 78s (mid-'30s) 500 Hz (NAB) 0 dB

EMI (1931) 250 Hz 0 dB

HMV (1931) 250 Hz 0 dB

London FFRR (1949) 250 Hz 3000 Hz* -5 dB

Mercury 400 Hz (AES) 2500 Hz -12 dB

MGM 500 Hz (RIAA) 2500 Hz -12 dB

Parlophone 500 Hz (NAB) 0 dB

Victor (1925) 200–500 Hz †5500 Hz (5200) -7 dB (-8.5)

Victor (1938–47) 500 Hz (NAB) †5500 Hz (5200) -7 dB (-8.5)

Victor (1947–52) 500 Hz (NAB) 2120 Hz -12 dB

Table 1 Section 5.2 Equalisation Chart for Electrically Recorded Coarse Groove (78 rpm) Discs[3].

* 3 dB/octave slope. N.B.A 6 dB/octave slope should not be used on these marked frequencies because though it may be adjusted to give the correct reading at 10kHz, rolloff would commence at the wrong frequency (6800 Hz) and be incorrect at all other frequencies.

† This only a recommended roll-off in order to achieve a more natural sound. The pronounced HF content is probably due to resonant peaks of the microphone and not due to the recording characteristic.

[1]Flat is generally taken to mean the unequalised output from a velocity type pickup

2 See Table 2, Section 5.3, footnote 5 for definitions of "Turnover" and "Rolloff". 3 Ref: Heinz O. Graumann: Schallplatten-Schneidkennlinien und ihre Entzerrung, (Gramophone Disc-Recording Characteristics and their Equalizations) Funkschau 1958/Heft 15/705-707. The table does not include every curve ever used, and other reputable sources vary slightly in their description of some of those listed. Research in this area is ongoing, and readers may wish to compare with other findings, such as Powell & Stehle 1993 or Copeland 2008, Chapter 6 etc.

5.2.7 Corrections for Errors Caused by Misaligned Recording Equipment

5.2.7.1 Any misalignment in the cutting stylus should ideally be replicated in the alignment of the replay stylus, in order to follow the cutter movement as closely as possible, and so capture as much information from the groove as accurately as possible. There are several ways in which a cutter may have been misaligned, most of which are difficult to identify, quantify and correct. However the most common misalignment is somewhat easier to identify and deal with. This occurs when a flat cutter has been mounted off its major axis, resulting in a recording which, when played with an on-axis elliptical stylus, reproduces a delay between channels. If the elliptical stylus cannot be rotated to match the cutter angle, (by appropriately mounting the pick up), replay using a conical stylus may ameliorate the problem to some extent, though with a possible compromise in high frequency response. Otherwise the delay may be fixed later in the digital domain, subsequent to the initial archival transfer.

5.2.8 Calibration Discs

5.2.8.1 Calibrating an audio system involves applying a defined input and measuring the corresponding output over a range of frequencies. A pre-amplifier/equaliser may be calibrated by supplying the input with a constant signal of variable frequency while loaded with the correct impedance, and the measurement consists in plotting (or data-logging) the output against frequency. Automatic apparatus exists for this. In use the input comes from a pickup cartridge, a transducer that converts a mechanical input to electrical output, and for this we need a mechanical calibrating signal.When mechanical recordings were commercially available test discs were produced for this purpose. The Audio Engineering Society (AES), via its Standardisation Committee, runs an ongoing and active project of developing and publishing a series of simple test discs, both for coarse groove work and for microgroove. The AES 78 rpm Calibration Disc Set: "Calibration Disc Set for 78 rpm Coarse-Groove Reproducers. AES Cat. No. AES -S001-064" is available from the AES website. http://www.aes.org/standards/data/x064-content.cfm [7]

5.2.8.2 If the calibration by means of a test disc has been performed with sufficient resolution, the plotted curve may be regarded as a plot of the transfer function of the pickup or the pickup-preamplifier¡equalizer combination. Apart from the fact that visual inspection of the curve will tell the operator of gross deficiencies, it may actually form the basis of a digital filter that may filter the digitised signal from the mechanical record, so that it becomes independent of the actual pickup (and preamplifier and equaliser) used. All it takes is to be certain that no adjustment has been changed between using the test disc and the mechanical record to be transferred (and ideally that the record materials for those two inputs behave the same way). (For further discussion see Brock-Nannestad 2000).

5.2.9 Office Dictation Systems

5.2.9.1 Sound recording technology has been marketed and used as a business tool virtually since its inception. Three broad categories of mechanical dictation formats can be defined, namely cylinders, discs and belts (see 5.4.15 for magnetic dictation formats).

5.2.9.2 Early cylinders and recording equipment sold for office use were generally the same as those used for other purposes, the resultant recordings being on standard 105 mm (4 1/8") length cylinders (see 5.2.4.3). However cylinder formats designed specifically for office use were made for many years by both Columbia (later Dictaphone) and Edison, both producing cylinders approximately 155 mm (6 1/8 inch) long with 160 and 150 grooves/inch respectively (Klinger 2002). Some later cylinder dictation machines recorded electrically rather than acoustically, but little if anything is known today about pre- emphasis applied.

5.2.9.3 Various grooved disc formats were launched, mostly after World War II, including the Edison Voicewriter and the Gray Audograph.While many such formats require specialist replay equipment, seven inch flexible Edison Voicewriter discs may be replayed on a standard turntable employing a US- type spindle adaptor and microgroove stylus. Recording speeds for these were generally below 33 1/3 rpm.

5.2.9.4 Beginning in the 1940s, several belt recording formats appeared. These were essentially flexible plastic cylinders, fitted over a twin drum assembly for recording and playback. Perhaps the best known of these is the Dictaphone Dictabelt. Their flexibility allowed them to be flattened for storage and delivery much like other office stationery, but this often resulted in their becoming permanently creased, creating challenges for the replay engineer. Carefully and gently raising the temperature of the belt and replay equipment has been known to be effective in this regard, though how appropriate this is will depend on, among other things, the particular plastic used in the belt. Specialist replay equipment will be required to replay belt formats.

5.2.10 Time Factor

5.2.10.1 A complex transfer may easily take 20 hours for 3 minutes of sound (a ratio of 400:1). An average transfer may take 45 minutes for 3 minutes of sound (a ratio of 15:1), which represents time spent on finding the correct settings for the equipment and choice of stylus, based on an analysis of the recording as it relates to others of its time and storage history. Some experienced archives suggest that, for the transfer of unbroken cylinders in average condition, two technical staff, (one expert and one assistant) can transfer 100 cylinders per week (a ratio of about 16:1). Obviously experience will improve both the ratio and the ability to estimate time required.

5.2.10.2 Digitisation can seem expensive and labour intensive, requiring a great deal of equipment, expertise and man-hours to transfer audio and create all necessary metadata. However this initial front-loading of effort and resources will be offset by the long-term benefits and savings of retaining a well-managed digital mass storage repository, greatly reducing future costs of access, duplication and migration. Note that a crucial factor here is the maintenance of the repository, discussed in detail in chapter 6 and elsewhere. The extraction of the optimum signal from the original carrier, as defined in this chapter, is a vital component of this strategy.

5.3 Reproduction of Microgroove LP Records

5.3.1 Introduction

5.3.1.1 Long Play (LP) microgroove[1] records first made their appearance around 1948, pressed in flexible vinyl[2] and hailed as 'unbreakable' in comparison to the preceding commercial records pressed from a rigid (and easily broken) shellac base.

5.3.1.2 By the time the vinyl disc was developed there was a greater industry agreement on standards. Grooves were cut at 300-400 to the inch as opposed to the 100 or so grooves per inch that was characteristic of the shellac pressings, and with a standard sized and shaped stylus on a cutting lathe that revolved at a speed of 33 1/3 rpm. 7" vinyl records, both singles and 'Extended Play' (EP), were made to be replayed at 45 rpm and in some cases 33 1/3 rpm. Larger diameter discs were on rare occasions produced for replay at 16 2/3 rpm for speech, where up to 60 mins could be recorded on one side. Equalisation characteristics still varied between companies, (see Table 2 Section 5.3 Equalisation Chart for Pre-1955 LP Records) however, many preamps catered for these variations. Eventually agreement was reached and the RIAA (Record Industry Association of America) curve became standardised throughout the industry.

5.3.1.3 Stereo records were commercially available from around 1958, and initially many records were produced in both mono and stereo versions. The groove walls are at right angles to each other and inclined by 45o to the vertical. The inner wall of the groove contains the left channel information, and the outer groove the right channel information recorded perpendicular to the respective groove wall. This has remained the standard, although at the time of its introduction a small number of stereo discs were made with a combination of lateral and vertical technology, an approach that was soon discontinued. Stereo pick-ups may be used to play mono records, but playing a stereo record with a mono pick-up will cause severe groove damage.

1 As some late generation coarse groove recording were pressed in vinyl the use of the term "microgroove" is preferred to using "vinyl" as a collective description.

2 "Vinyl" is a colloquial term for the material of the discs which basically consists of a polyvinyl chloride / polyvinyl acetate co-polymer (PVC/PVA)

5.3.2 Selection of Best Copy

5.3.2.1 As with historical mechanical and other obsolete formats (see Section 5.2.2 Selection of best copy [8]) selection is primarily made visually, for speed and to prevent wear. Staff should be well versed in the codes and identifiers used by the various record companies and usually placed just outside the label. This may reveal alternative or later takes, remasterings, or pressings. In selecting the best copies for digitisation, co-operation with other collections should be considered.

5.3.2.2 The working space must make parallel, oblique light available as overhead fluorescent lighting may obscure evidence of wear. The quality of light must be such that it is very clear what constitutes merely heavy modulation and what constitutes wear. If two copies only exist, and they display different wear characteristics, then retain both and transfer both.

5.3.3 Cleaning and Carrier Restoration