Tape Recording Hollywood: The Inaudibility of New Film Sound Technology

Eric Dienstfrey

Music, Sound, and the Moving Image, Volume 16, Issue 2, Winter 2022,
pp. 101-127 (Article)

Published by Liverpool University Press

16:2 Winter 2022 **MSMI**
https://doi.org/10.3828/msmi.2022.8

Tape Recording Hollywood
The Inaudibility of New Film Sound Technology

ERIC DIENSTFREY

Abstract
This article details the historical factors that shaped Hollywood's adoption of magnetic recording during the late 1940s and early 1950s. It draws upon economic theories of technological change, archival correspondence, technical records, analyses of postproduction workflows, and delineations of the structural constraints that limited how the film industry initially wired magnetic media into its production and postproduction stages. In so doing, I explain why the adoption of such a revolutionary recording technology did not initially usher in changes to the industry's modes of acoustical representation and why these changes instead took place several decades later.

Keywords: magnetic recording, film production, film postproduction, recording technology

An important yet often overlooked date in the history of sound technology is 16 May 1946, the day that US Army engineer John Mullin unveiled the Magnetophon K-4 to the San Francisco chapter of the Institute of Radio Engineers (Hammar, 1999). The machine was a reel-to-reel tape recorder, among the first ever made. It was designed by the German utility company Allgemeine Elektricitäts-Gesellschaft (AEG), and its magnetic tape was manufactured by the Badische Anilin- und Sodafabrik (BASF). At the time, BASF was owned by IG Farben, a chemical firm that financed the Nazi party and supplied the Zyklon B gas used in concentration camps (Middleton, 1945; Hayes, 2000). But these reported wartime activities seemed to matter little to the audience of radio engineers. Of greater significance were the Magnetophon's acoustics. Its recordings boasted eight-octave ranges and volumes as wide as eighty decibels (Power, 1946; Drenner, 1947). Most impressively, it was as small as a suitcase – the K stood for 'Koffer', a portable case (Hammar & Ososke, 1982). Despite the Magnetophon's lineage, those

Figure 1: Mullin (centre left) presents the Magnetophon to the Institute of Radio Engineers' San Francisco convention in 1946 (*High Fidelity/World Radio History*).

in attendance were by all accounts in awe of the German ingenuity (Leslie & Snyder, 2010).

Mullin treated his 1946 talk much like a declassification ceremony, though the device was far from a state secret. Several years prior, AEG had shipped an earlier model of the Magnetophon to General Electric's offices in New York in the hope of marketing the invention to American consumers (Engel, 1999). And months before the radio engineers convened, the US government distributed detailed pamphlets about the Magnetophon throughout the broadcasting industry (Anon, 1945a; Menard, 1946). By the time Mullin's presentation began, many leading manufacturers and radio engineers were already aware of AEG's and BASF's work.[1] The 1946 demonstration nevertheless ignited considerably more enthusiasm for tape-based media throughout North America due to Mullin's flair for pageantry. During his talk, he plugged the Magnetophon into a giant Western Electric loudspeaker, nicknamed 'The Tub', to showcase the machine's impressive decibel range. He also shared stories of his own heroism, tales he later published in *High Fidelity* and *Billboard* (Mullin, 1976a; Mullin, 1976b). It was he, Mullin proclaimed, who stood face to face with Nazis while rescuing the machine from a castle north of Frankfurt, and it was he who then smuggled the invention across the Atlantic. Such rhetoric bolstered the Magnetophon's historical significance and emboldened predictions that the device would revolutionise sound reproduction (see Figure 1).

In many ways, these predictions came true. Mullin's presentation intensified the radio engineers' interest in magnetic media and soon

[1] The magazine *Broadcasting*, for instance, published monthly columns about the Magnetophon beginning in the autumn of 1945. See Anon. (1945b), Anon. (1945c), and Drenner (1945).

facilitated American corporate investment as well. Ampex engineers who attended Mullin's talk began mass-producing derivative reel-to-reel recorders (Leslie & Snyder, 2010). Radio stations then installed the Ampex equipment to simplify the recording, editing, and re-playing of broadcasts, practices which would redefine the concept of liveness within the industry (Morton, 2004). Music producers similarly adopted the equipment to streamline multitrack techniques, which in turn transformed recording studios into spaces for overdubbing, looping, and other acoustical innovations (Schmidt-Horning, 2013; Skjerseth, 2022). The rapid adoption of tape media and tape-based experimentation also led to the publication of sound-centric magazines – such as *Audio*, *Audiocraft*, and *Tape Recording* – that regularly informed engineers and amateur hobbyists about the latest innovations in magnetic recording. In effect, the rise of postwar audiophile culture was indebted not only to turntables and hi-fi systems, but also to the reel-to-reel technologies that reshaped the sound industry's production practices and the aesthetic expectations of consumers.

Yet curiously, such changes did not occur within the motion picture industry, at least not at first. Though the major studios fully replaced their optical recording devices with portable tape recorders, multitrack mixers, and other magnetic recording equipment by 1952, the aesthetic transformations associated with these new technologies were delayed by several decades. As historian Jay Beck (2016) details, it was not until the 1970s that filmmakers consistently exploited the new medium's full production benefits, such as direct playback, non-destructive editing, and noise abatement. The densely layered sound designs that emerged from these experiments – as illustrated by *The Exorcist* (William Friedkin, 1973), *The Conversation* (Francis Ford Coppola, 1974), *Nashville*, (Robert Altman, 1975), *Star Wars* (George Lucas, 1977), and *The Black Stallion* (Carroll Ballard, 1979) – challenged the acoustical norms of the industry and ushered in entirely new sound practices. In contrast, the many uses of magnetic media throughout the 1950s were far more subtle, if not inaudible.

This initial hesitancy toward exploring the technology's full potential has yet to be explained. When scholars trace the history of the industry's sound techniques and workflows, their investigations typically prioritise periods of acoustical novelty, such as the optical era of the 1930s and 40s (Lastra, 2000; Jacobs, 2012; Hanson, 2017) and the Dolby era of the 1970s and 80s (Beck, 2016; Ament, 2021). The magnetic recording practices established between these two eras receive far less attention. Additionally, those who do examine Hollywood's magnetic technologies of the 1950s focus primarily on theatre systems like Cinerama, CinemaScope, and Todd-AO – flashy yet cumbersome formats installed only in select cinemas (Belton, 1992;

Malsky, 2015; Platte, 2015). The widespread adoption of tape-based media in all production and postproduction stages, in comparison, is regularly overlooked. Unlike other industries, Hollywood's transition to magnetic media is generally seen as a moment of aesthetic continuity, as well as a routine upgrade, and thus seemingly without much historical significance.

In the pages that follow, I account for this continuity and re-establish its importance for the history of media technology. Through an analysis of engineering discourse, oral histories, and economic theories of technological change, I argue that the film industry's transition to magnetic recording was governed by its structural dependence on optical media. Magnetic tape was cheap, materially efficient, and easy to use, but these advantages themselves were not enough to overcome institutional inertia that fostered the industry's resistance to technological change. By the late 1940s, Hollywood had established electrical standards and divisions of labour that were designed to support the production of optically recorded soundtracks; the costs of uprooting these systems greatly outweighed magnetic media's financial and aesthetic benefits. Engineers responded by designing magnetic equipment to be non-disruptive to the industry's modes of production. As a direct consequence of these efforts, the new medium's norms of use became indistinguishable from those developed for optical sound.

The seemingly unremarkable nature of Hollywood's transition to magnetic recording is therefore what makes it historically significant. It serves as a record for how the film industry constrains the aesthetic potentials of new equipment to render it compliant with economic demands. In contrast to film histories that define technological change as a mechanism that can bolster efficiency, product differentiation, and standards of quality, I show how studios also valued new media for their ability to fit within established practices and, more consequently, their propensity to codify existing aesthetic norms. This article investigates such phenomena by analysing magnetic recording's adoption in Hollywood. I chronicle the failures of early technological prototypes, after which I detail the industry's systematic transition to magnetic media beginning in the late 1940s. I conclude by showing how the medium's construction discouraged filmmakers from adopting new modes of acoustical representation, with specific attention to postproduction techniques before and after the arrival of magnetic tape.

The Optical Path

The economic factors that shaped the adoption of magnetic media originated in the late 1920s. At that time, Western Electric and RCA both introduced technologies that recorded sounds as narrow photographs, known as optical tracks. The innovations were welcome news to producers that had long hoped to add spoken dialogue to the cinema, but the formats were far from perfect. They were noisy, their frequency ranges were narrow, and the process of developing the sound photographs could take an entire day, thereby preventing filmmakers from immediately reviewing the quality of each take (Ralph & Matthews, 1938). But the two formats were also advantageous. Unlike sound-on-disk systems, photographic soundtracks were edited and spliced together with relative ease. And because they were stored on film, they could be housed on release prints, an affordance which enabled dialogue to play in synchrony with the picture. As a result, the industry officially standardised optical recording as its playback format in 1932 (Academy Research Council, 1932).

The technical limitations inherent to optical recording were soon addressed as well. According to historian Helen Hanson (2017), the 1930s saw studios create an economic infrastructure designed to improve the acoustical quality and cost efficiency of photographic soundtracks. This included a legal apparatus to support the licensing of patents, the development of ancillary equipment such as recording and mixing consoles to improve the technology's functionality, and new divisions of labour and management to streamline recording and photographic development. In so doing, studios would build an entire sub-economy centred around and dependent upon optical sound, industrial changes that all but guaranteed the format's long-term viability as Hollywood's preferred sound-recording technology.

Such historical developments typified phenomena that economists term 'path creation' and 'path dependence' (David, 1985; Arthur, 1989; Liebowitz & Margolis, 1990). Accordingly, when an institution adopts a new technology, it enacts a series of capital expenditures to accommodate the technology's implementation, investments that then weaken the institution's ability to adopt new technology in the future. Hollywood's transition to optical media specifically led to the formation of new engineering departments, legal offices, and workflows that ensured the format's norms of use would not disrupt pre-existing modes of representation, production, and distribution. The issue, however, was that this economic infrastructure also made it difficult for the industry to replace its optical systems with more cost-efficient and higher quality alternatives. The dissemination of entirely new technological processes and protocols would require the industry to reconstruct its economy to support the licensing, manufacturing, standardising, and servicing of the new systems, the costs of which would likely be exorbitant. Put another way, once studios adopted and disseminated optical recording, the risk–reward of any future technological change would need to overcome the sunk costs of the existing investment.

The industry's rejection of optical tape – a precursor to magnetic tape – illustrates such phenomena. Invented by James Miller in 1931, optical tape comprised a thin layer of opaque material that rested on a transparent plastic base (Miller, 1931). Like sound-on-disk recordings, engineers stored acoustical information onto the tape by way of vertical 'hill-and-dale' tracks. As the tape passed through the recording head, a sharp triangular stylus cut small vertical grooves into the opaque material, exposing the transparent plastic underneath in a manner that resembled RCA's variable-area soundtracks (Miller, 1935; Anon., 1937). In turn, optical tape recordings, with their elimination of photographic development processes, offered faster and cheaper means of recording film sound. Miller called the technology 'mechanographic' film, a portmanteau of 'mechanical' and 'photographic', though it was more commonly known as 'Millerfilm' (Anon., 1938) (see Figure 2).

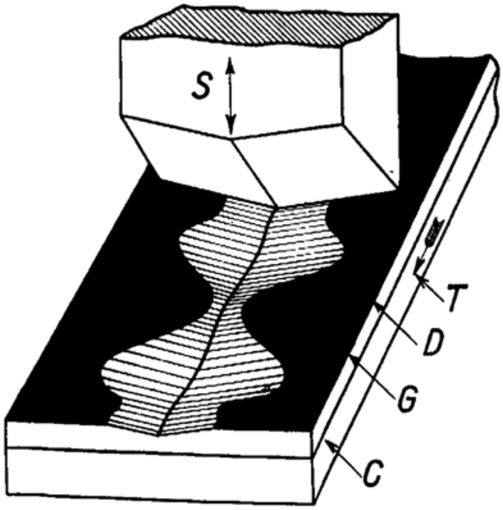


Figure 2: Miller's sharp, angular stylus would rock up and down and cut a variable-area track directly onto mechanographic media (*Journal of the Society of Motion Picture Engineers/ Media History Digital Library*).

Miller unveiled his innovation to the Society of Motion Picture Engineers (SMPE) in 1935. During the presentation, he noted that optical tape would not only save studios production and postproduction expenses, but its finer soundtrack edges would also minimise noise and nearly double the decibel range of motion pictures (Miller, 1935). He concluded by playing an orchestral recording made shortly before his presentation, one that demonstrated optical tape's impressive acoustical quality and immediate playback capability. The talk was warmly received by the society's members as well as by the press. *Variety* specifically reported that Miller's device was eye-opening to the four hundred technicians in attendance and predicted that Millerfilm's acoustical improvements to traditional recording methods would revolutionise the industry (Anon., 1935).

Despite this positive reception, though, studios declined to install optical tape on their production stages. The transition to the new process was presumed to require the gutting and rebuilding of the industry's technological infrastructure, the costs for which would exceed any short-term savings generated by the new equipment. Specifically, studios and theatres would have needed to invest in entirely new recording, re-recording, and playback machines that were optimised for Millerfilm's frequency characteristics. Manufacturers like Dupont and Eastman Kodak would also have needed to start mass-producing mechanographic film stock, an endeavour that would have likely necessitated the costly overhaul of their many manufacturing plants. Simply put, Hollywood was too economically dependent upon traditional photographic technology to adopt a potentially better recording system. Miller subsequently took his invention to Europe, where he successfully licensed it to the British Broadcasting Corporation and the Philips Company of the Netherlands, smaller institutions that saw little risk in experimenting with the new recording process (de Vries, 2005, pp.42–44; Street, 2006, pp.127–131).[2]

[2] After licensing the technology, Philips rebranded Millerfilm as 'Philimil' and the recording format as 'Philips-Miller' (Vermeulen, 1938).

As the rejection of Millerfilm demonstrates, studios had become locked into using older, if not inferior, technology. They had invested considerable resources into the adoption of photographic recording equipment, and therefore they had grown wary of replacing these sound systems with newer technologies, even when these technologies promised to improve quality and efficiency. Like in a game of poker, studios were 'pot committed' to optical media for the foreseeable future. Any potential upgrade to their sound systems would need to be perceived as financially and aesthetically advantageous, so much so that its benefits would need to outweigh the costs of a difficult technological transition. Otherwise, Hollywood was bound to reject it.

The Blattnerphone and the Telegraphone

Early magnetic recording technologies faced similar economic obstacles. Like Millerfilm, magnetic media offered immediate playback and eliminated the need for positive and negative film stock. Additionally, its recording method was touch-free, which enabled its soundtracks to be erased and its materials to be reused. As historian Mark Clark (1993) documents, the unique recording process was conceived in 1878, when New Jersey iron manufacturer Oberlin Smith paid a visit to Thomas Edison's laboratory in Menlo Park. Smith wished to hear Edison's latest invention: the phonograph. But instead of being amazed by the technology, Smith believed its recording methods were deeply flawed. Namely, he objected to the way the needle physically scratched the surface of each phonograph. For Smith, these scratches not only weakened the quality of the equipment, but they also added crackles and other noises to the soundtrack.

In response, Smith devised a scratchless method that converted signals into magnetic charges. Individual tracks of sound were to be coated with microscopic particles, such as iron filings, that had positive and negative polarities. And in place of a sharp stylus, a metal wire was to be coiled around a small magnet. When an electric signal travelled through the wire, the magnet would rock back and forth just above the magnetic filings, thereby converting the signal's pulses into a series of positive and negative charges on the surface of the soundtrack (Smith, 1888). The use of a magnet in place of a needle also allowed recordings to be erased and reused. If a technician disliked a recording, they could simply send a different electrical signal to the magnet, thereby re-orienting the polarity of the iron particles. Because of this touch-free and non-destructive design, magnetic recording had the potential to be immensely valuable to various industries, including Hollywood.

That said, for Smith's invention to work properly, the magnetic filings needed to rest on a medium that was strong enough to achieve a high-quality signal. Many early experiments in magnetic recording failed to find material that could meet these acoustical demands. One notorious example was a steel-based technology developed by German inventor Curt Stille (Lafferty, 1983). Initially dubbed 'System Stille', the technology stored sounds on a six millimetre-wide steel ribbon that held twenty minutes per spool at a recording speed of five feet per second. Stille licensed his technology to Ludwig Blattner, a German-born film producer who worked at Elstree Studios near London, England. Blattner rebranded Stille's device the 'Blattnerphone' and proceeded to promote it throughout the film industry. But his colleagues showed little interest in replacing their optical systems with Blattner's investment. By the early 1930s, the cash-strapped producer was reduced to demonstrating his device in cinemas between double features, recording filmgoers as they told jokes to each other and reproducing these jokes for the entire auditorium. These novelty acts were reportedly not lucrative enough to stave off bankruptcy, and in 1935 Blattner committed suicide.

In many ways the fate of the technology was sealed well before Blattner licensed it, for the costs of converting studios to steel ribbon outweighed the format's potential advantages. And though the Blattnerphone could record up to twenty minutes at a time, the machine needed to carry a mile of steel ribbon, a requirement that caused considerable strain on the backs of its operators. The weight of the spool also interfered with the speed of the motor, and this often distorted the recordings (Street, 2006). Of greater consequence was the fact that the steel ribbon used a charcoal-iron base that was only made in Sweden, a constraint that further limited the system's potential adoption (Lafferty, 1983). These shortcomings perhaps explain why Blattner himself did not use his technology when adding an orchestral score to release prints for *A Knight in London* (Lupu Pick, 1928). Instead, he recorded the music on a standard photographic soundtrack.

Film engineers found greater success with smaller and lighter magnetic media, as exemplified by another early recording technology: the 'Telegraphone'. Invented in 1898 by Danish engineer Valdemar Poulsen, the Telegraphone encoded magnetic signals onto a thin metallic wire (Poulsen, 1899; Poulsen, 1900). It also came with a microphone and a small speaker, much like phonograph-based dictation machines. To capitalise on the invention, Poulsen licensed it to American lawyer John Lindley in 1903. Lindley in turn founded the American Telegraphone Company (ATC) with the purpose of expanding the potential market for the new technology and manufacturing the device for commercial use (Clark & Nielsen, 1995). ATC's engineers enabled the steel wire to store up to thirty minutes of sound, and in the 1910s Lindley began promoting his device to businessmen and stenographers as a vast improvement upon standard dictation equipment.

ATC's marketing campaign initially benefited from the Telegraphone's prominence in popular culture. The serial melodrama *The Exploits of Elaine* (Louis J. Gasnier, George B. Seitz, Leopold Wharton, & Theodore Wharton, 1914), for instance, typecasts the Telegraphone as a *deus ex machina*. During its eleventh episode, a villain uses magnetic wire to record his scheme to murder the titular Elaine. Once the recording is discovered by a heroic scientist, the fiendish plot is revealed, and Elaine is rescued yet again from her premature demise (Anon., 1915; Coward, 1915).[3] Such product placement, though, was not enough for Lindley's corporate ambitions to materialise, and in 1919 he, like Blattner, declared bankruptcy (Clark & Nielsen, 1995).

[3] The original source novel by Arthur B. Reeve (1914) also featured the Telegraphone, alongside other new technologies including vocophones, cardiopulmonary resuscitators, and fingerprinting machines.

The Telegraphone nevertheless remained a relatively popular transcription technology in scientific research. During the 1920s, professors at the University of Southern California would employ the wire recording machine to study the characteristics of the human voice (Anon., 1929a). Specifically, they used it to legitimate proposed neologisms – such as 'plasmaphonic', 'diaprusophonic', and 'eudynoacousmophonic' – that describe the inner workings of human speech (Anon., 1928a). And to further promote their findings, they invited famous actresses like Norma Shearer and Anita Page to their laboratories, where the scientists could study their voices in detail and even help them diversify their speaking styles (Anon., 1928b; Anon., 1929b) (see Figure 3).

In the 1930s, studios would adopt wire technologies for similar purposes. After the transition to sound, the equipment was used to help silent-film actors learn to speak into newly installed microphones, many of which were noisy and limited to narrow frequency ranges. During the production of MGM's operetta *New Moon* (Jack Conway, 1930), for instance, the use of wire recordings allowed singers to ensure that their voices were in tune and blending properly (Anon., 1930). Soon after, studios began employing the equipment to spot-check non-musical performances. Warners, for example, used the technology on the set of Alfred Hitchcock's *Rope* (1948) to help

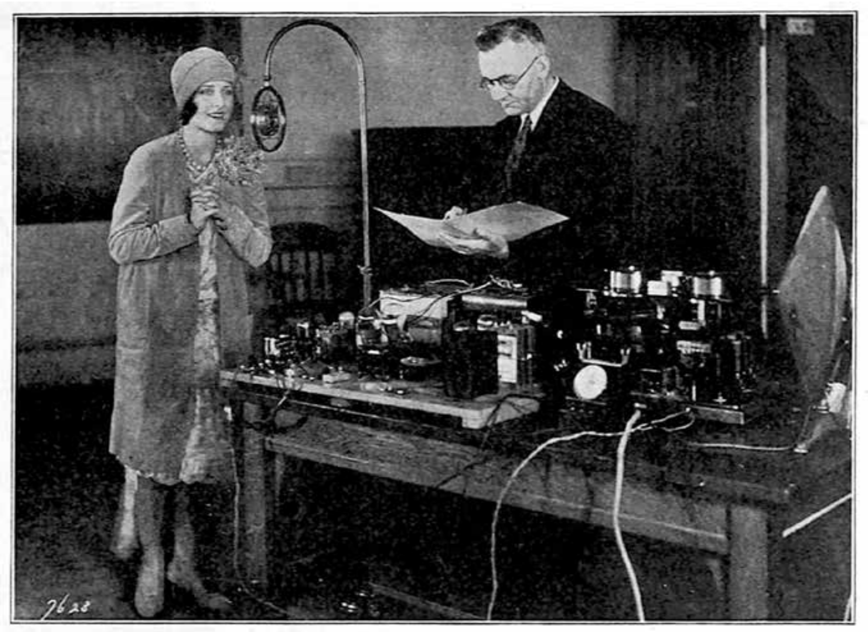


Figure 3: USC Speech Professor Ray Immel used the Telegraphone to record and study the voice of actress Norma Shearer in 1929 (*Exhibitors Herald-World/Media History Digital Library*).

its stars assess their emotionally charged deliveries after each ten-minute take (Mueller & Groves, 1949). Yet like Millerfilm, wire recording was never seen as a viable alternative to optical media. At best, filmmakers treated the new technology as a mirror for the voice, a tool to help actors quickly correct small mistakes in their dialects and emotional expressions.[4] The industry at the time did not envision that magnetic recording was capable of dramatically improving the sound quality of motion pictures, nor did it consider refining the technology for additional uses. In this regard, Hollywood's path dependence on optical sound limited studios to narrow understandings of magnetic recording's full potential.

[4] The comparisons between wire recordings and mirrors were promoted in Hollywood by Semi Begun (1937), an independent manufacturer of magnetic technologies, though the metaphor likely originated with Rudolph Mallina (1935), an engineer at Bell Telephone Laboratories who once used the phrase to describe the affordances of a steel-based recording system on display at The Franklin Institute science museum in Philadelphia.

Studios Adopt Magnetic Recording

These conceptual limitations nevertheless began to disappear, albeit slowly, by the end of the 1940s. During that time, Hollywood witnessed the combined profits of its ten largest studios shrink by more than 70 per cent (Balio, 1985). This dramatic loss of revenue was precipitated by a steady decline in film attendance, the rising price of 35mm film stock, and the ongoing strikes among below-the-line workers, many of which delayed shoots and increased production costs (Lafferty, 1981, pp.170–174; Schatz, 1997, pp.329–333). Further, the lower tax rates for businesses led those actors and directors who wished to avoid paying personal income taxes to form their own production companies (Staiger, 1983). And these newly formed companies created more competition among producers for on-screen talent, which in turn inflated actors' salaries and further diminished studio profits.

To address these conditions, studios began dramatically cutting their overhead costs. Personnel was downsized by nearly 50 per cent, from 24,000 to 13,000 employees by the mid-1950s (Balio, 1985, p.402). At the same time, studios looked to lower film budgets by trimming running times and even replacing expensive camera movements with simpler zoom shots (Lafferty, 1981, pp.174–177; Hall, 2018, pp.51–56). It was during this time that studios also reconsidered the economic benefits of magnetic recording. Of interest to industry executives was the technology's material efficiency, namely the ability for recordings to be erased and reused without the need for expensive photochemical processes. Moreover, ongoing innovations to magnetic media would address the many problems endemic to its equipment previously.[5] It was discovered, for instance, that the iron filings on the surface of the medium would continue to move after the recording process stopped, and this movement added distortion and noise to the signal (Barrett & Tweed, 1938; Westmijze, 1953). Engineers subsequently found that by adding an inaudible high-frequency tone – known as a bias – to each recording, they could prevent the iron filings from moving and could thereby widen the signal's frequency and decibel range (Gratian, 1949). Further, engineers developed a new type of recording material: magnetic tape (Thiele, 1988; Engel, 1988).[6] This flexible medium was lightweight and easy to edit and reuse, and thus was highly appealing to those looking to replace photographic equipment with more cost-efficient media.

The German-made Magnetophon served as the culmination of these innovations. Though not the first tape-based magnetic recorder ever developed, the suitcase-sized technology was the first to achieve considerable renown within the entertainment industry due to its professional design, its portability, and its reputation as 'Nazi war booty'. Following the Allied invasion, the US Department of Commerce disseminated technical pamphlets about the device to encourage American businesses to develop similar technologies that could be promoted and sold worldwide. The Magnetophon also benefited from a promotional campaign orchestrated by John Mullin, whose expertise, charisma, and business acumen later landed him a job as the head of engineering at Bing Crosby Enterprises (Hammar, 1999).

The advent of the Magnetophon ignited a postwar tape-recording boom throughout the entertainment industry. Alexander M. Poniatoff (the AMP in Ampex) and his colleague Harold Lindsay began researching consumer-grade magnetic recording equipment, such as the popular Model 200A tape recorder, which was directly informed by the design of the Magnetophon and which was adopted throughout music and

[5] For a more comprehensive breakdown of the many innovations to magnetic recording technologies during this time, see Malsky (2003).

[6] Incidentally, the development of paper tape was partially influenced by the success and popularity of the Philips-Miller recording system in Europe, for like tape, Millerfilm was a flexible, lightweight medium that enabled technicians to instantly review the recorded signal (Anon., 1934; de Vries, 2005, p.43).

broadcasting studios soon after its release (Hammar & Ososke, 1982; Leslie & Snyder, 2010). Other inventors, including Marvin Camras of the Armour Research Foundation and Semi Begun of the Brush Development Company, began developing similar equipment, and soon called upon companies like Shellmar, the maker of bread wrappers, and Minnesota Mining and Manufacturing (3M), the maker of Scotch tape, to begin mass-producing magnetically coated paper tape that could support the growing marketplace for new audio technology (Clark, 1992, p.213).

The Magnetophon's popularity also prompted the Research Council of the Academy of Motion Picture Arts and Sciences to convene at the SMPE convention in October 1946 to discuss whether it was feasible to replace photographic recording equipment with magnetic tape technology. The goal of the meeting, as outlined by Paramount engineer Loren Ryder, was for studios to better understand the current state of magnetic recording and for the emerging magnetic sound industry to learn more about the needs of filmmakers (Academy Research Council, 1947). The speakers at the meeting included Begun and Camras, as well as representatives from Magnecord and Indiana Steel (Begun, 1947; Tinkham & Boyers, 1947; Howell, 1947). All their presentations were met with scepticism. Some in attendance wondered if audiences would inadvertently hear magnetic splices, while others questioned if metallic sprockets demagnetised magnetic tracks (Camras, 1947).

The consensus among studio engineers was that magnetic equipment was not yet ready to be implemented on Hollywood's sound stages, as the current prototypes would disrupt the modes of production and distribution that were codified to support optical media. As a result, there needed to be technical requirements imposed on the technology. The consensus among the studio engineers in attendance was that all magnetic equipment needed to allow for lossless duplication, lossless reproduction for up to five hundred plays, perforations to maintain synchronisation with the picture, quick rewind times, three-second start-up times for motors, and the ability to record continuously for up to eleven minutes. All these demands would need to be met for the industry's four standard print sizes – 35mm, 17.5mm, 16mm, and 8mm – and, of greatest importance, the studios would need full ownership of the relevant patents to protect themselves from lawsuits. In a sense, studios called for manufacturers to design new media that could fit inside Hollywood's existing economic and technological infrastructure. The less distinguishable magnetic recording was from optical media, the less risky the investment.

RCA and Western Electric were the most prominent companies to follow the Research Council's guidelines when developing magnetic sound systems. They even worked to make installations of the new technology as simple as possible. First, the two manufacturers introduced small conversion kits that enabled studios to quickly update their photographic equipment with magnetic components. RCA's kits included new sound heads and other demagnetised parts that transformed its PR-23 optical recorder into a magnetic recorder (Masterson, 1948). Western Electric similarly provided studios with comparable conversion kits for its popular RA-1231 recording units (Frayne & Wolfe, 1949). The conversion kits were then followed by new lines of magnetic recorders, each designed for easy installation on film stages. RCA introduced its PM-62 two-channel recorder and PM-63 three-channel recorder (Lawton, 1951b; Singer & Ward, 1952; Singer & Ward, 1952). Western Electric likewise unveiled its Westrex 1035, a portable two-channel recording unit that was adaptable for both indoor and outdoor shoots (Lawton, 1951a).

Studios were quick to adopt the new equipment (Anon., 1949b). In 1948, Columbia wired its scoring stages with multitrack magnetic recording (Anon., 1949a). That same year, Warners collaborated with RCA to develop their own magnetic recorders, which the studio first exploited during King Vidor's production of *The Fountainhead* (1949) (Anon., 1948). Moreover, MGM and United Artists began using the Westrex 1035 recorder for films shot on location, such as Fred Zinnemann's *Teresa* (1951), which was filmed in Italy, and Jean Renoir's *The River* (1951), which was filmed in India (Pumphrey, 1950; Lawton, 1951a). For each film, the use of relatively lightweight sound equipment made it easier for mixers to work in smaller and more remote settings, minimising the costs associated with recording location dialogue. In response to this growing demand for magnetic equipment, Paramount's Loren Ryder acquired the West Coast rights for the small Swiss-made quarter-inch tape recorder known as the Perfectone (a forerunner of the Nagra). And in the early 1950s – through his side hustle, Ryder Sound – he began renting Perfectones to those hoping to produce films on the cheap, further disseminating the new equipment throughout the industry (Anon., 1959; LoBrutto, 1994; Yewdall, 2012, p.162) (see Figure 4).

Figure 4: Promotional material for the Perfectone demonstrated how the portable tape recorder was light enough for someone to wear it comfortably over their shoulder (*American Cinematographer/Media History Digital Library*).

An immediate benefit of magnetic technology was that it shortened production schedules. As location shoots became more common, so too did the need to prevent wind, aeroplanes, or car horns from interfering with production tracks. One solution was to delay filming until these noises quieted, but doing so meant forcing crews to work overtime. A cheaper option was to re-record any problematic dialogue during postproduction. Known as 'looping', the practice required actors to dub over their lines on a recording stage, typically while watching a loop of their onscreen performance (Lewin, 1951). Looping was not uncommon during the optical era, but it was difficult to administer as sound editors had to wait for recordings to be developed before determining if the line was in synchrony with the actor's lips.[7] With magnetic tape, the looped dialogue could be reviewed immediately, rendering the process cheaper, less laborious, and thus more practical. It was particularly beneficial to New York productions – such as *C-Man* (Joseph Lerner, 1949) and *The Sleeping City* (George Sherman, 1950) – where dialogue was routinely masked by the noise of city traffic (Lafferty, 1981, pp.193–197).[8] The new looping systems enabled the films' producers to fix any unintelligible lines 'in post'.

Furthermore, the new medium could dramatically reduce a film's budget, as Universal discovered when shooting *Iron Man* (Joseph Pevney, 1951) and *The Raging Tide* (George Sherman, 1951). The studio estimated that optical recording would have cost each picture $4,100 in print-related expenses – including an investment in 104,000 feet of negative stock, 29,000 feet of positive stock, and additional fees for photo development. With magnetic recording, the material costs dropped to $968 per picture, a 75 per cent reduction (Carey & Moran, 1952). Such savings meant that there was no longer a compelling reason for producers to delay the adoption of the new recording technology. By 1952, six years after the Magnetophon's premiere, every major studio in Hollywood had fully adopted magnetic recording on its production and postproduction stages (Groves, 1953).

Soundscapes of Continuity

Though studios worked to minimise the differences between magnetic and optical recording equipment, the new medium – particularly its wider acoustical ranges – encouraged several filmmakers to explore unconventional soundtrack designs. Lower noise levels on production recordings, for instance, meant that a greater number of sound effects could be combined in postproduction without dramatically amplifying soundtrack hiss. Such affordances were famously exploited during MGM's production of *Forbidden Planet* (Fred M. Wilcox, 1956). In place of a traditional

[7] For an in-depth example of how optical looping was often a difficult and time-consuming process, see the archived records of receipts and correspondence that chronicle the dubbing of post-synchronous dialogue during the postproduction of *Portrait of Jennie* (William Dieterle, 1948) – a film shot in New York City and looped in Los Angeles using optical media – in the David O. Selznick Papers (Box 3747, Folder 10), Harry Ransom Center, University of Texas at Austin.

[8] *C-Man* was notably re-recorded at Reeves Sound, a music studio in midtown Manhattan. Its owner, Hazard 'Buzz' Reeves, was an early manufacturer of magnetically coated film and later developed the seven-track magnetic stereo system used on select Cinerama releases (Reeves, 1953).

soundtrack consisting of library effects and orchestral cues, sound artists Bebe and Louis Barron recorded electrical beeps, buzzes, and tremolos onto magnetic tape. Then, using variable playback speeds, tape loops, and other methods of material manipulation, the Barrons combined these recordings to generate ornate and densely layered atmospheres to serve as the distant planet's uncanny soundscapes.[9]

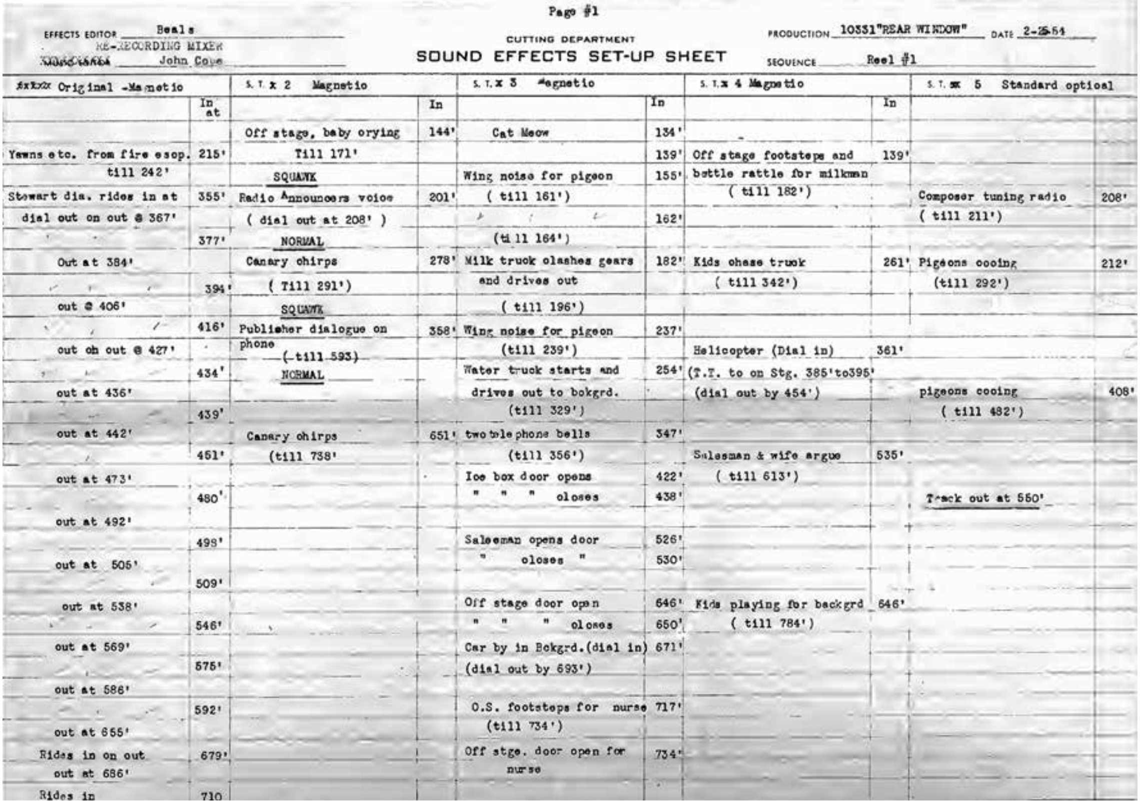
[9] For in-depth discussion of Bebe and Louis Barron's electronic tonalities for *Forbidden Planet*, see Leydon (2004), Wierzbicki (2005), and Platte (2015).

The wider acoustical ranges also meant that sound editors and mixers might not need to mask hisses, hums, and other surface noise with background music, as was common in the 1940s. Indeed, some magnetically recorded films soon did without orchestral music at key moments to let the soft rumblings of background effects accentuate suspenseful situations. Paramount's *Rear Window* (Alfred Hitchcock, 1954) is one such example. In contrast to most murder mysteries from prior decades, the film consists solely of diegetic sounds, such as the distant roars of Manhattan traffic or the faint conversations of neighbours. In turn, the soundtrack often becomes atypically quiet, especially as L.B. 'Jeff' Jefferies (James Stewart) watches and listens to the actions taking place through the windows of nearby apartments. When he first hears a woman's scream, for instance, there is notably no musical accompaniment, only the soft murmur of the outdoor soundscape. By exploiting the low noise floor of magnetic media, Paramount's sound editors enabled audiences to hear this event from Jeff's perspective and invited them to analyse the outdoor soundscape in search of an explanation for the mysterious shriek (see Figure 5).[10]

[10] Further analyses of *Rear Window*'s sound design can be found in Weis (1982), Neumeyer & Cox (1998), and Fawell (2000).

Such creative practices, however, were not the norm but the exception. Films like *Forbidden Planet* and *Rear Window* stand out in history because they deviate from the sound-editing conventions that defined the early decades of magnetic recording. Rather than experiment with the new medium, most filmmakers and technicians reinforced the modes of representation established during the 1930s and 40s. One reason for this stylistic continuity was the industry's adherence to optical-era distribution practices. Though the 1950s saw the introduction of several magnetic sound formats, including four-track and six-track stereo, most theatres passed on installing the technologies and instead kept offering only optical mono (Belton, 1992). In response, studios continued distributing their films on optical prints. Even the many stereo releases that roadshowed in first-run palaces throughout the 1950s and 60s were regularly downmixed for optical media so they could play in smaller venues once their roadshows ended (Dienstfrey, 2018, pp.415–427). And because optical prints were noisier and less detailed, the downmixing process could inadvertently mask or muffle the richer sound designs made possible by magnetic recording.

To address these matters, studios either tempered the use of wide-range effects or jettisoned them entirely for more conventional, optical-friendly



Page #1

EFFECTS EDITOR Beals
RE-RECORDING MIXER John Cope

CUTTING DEPARTMENT
SOUND EFFECTS SET-UP SHEET

PRODUCTION 10331"REAR WINDOW" DATE 2-25-54
SEQUENCE Reel #1

xxxx Original -Magnetic	In at	S.T. x 2 Magnetic	In	S.T. x 3 Magnetic	In	S.T. x 4 Magnetic	In	S.T. x 5 Standard optical	
		Off stage, baby crying	144'	Cat Meow	134'				
Yawns etc. from fire escp.	215'	Till 171'			139'	Off stage footsteps and	139'		
till 242'		SQUAWK		Wing noise for pigeon	155'	bottle rattle for milkman			
Stewart dia. rides in at	355'	Radio Announcers voice	201'	(till 161')		(till 182')		Composer tuning radio	208'
dial out on out @ 367'		(dial out at 208')			162'			(till 211')	
	377'	NORMAL		(till 164')					
Out at 384'		Canary chirps	278'	Milk truck clashes gears	182'	Kids chase truck	261'	Pigeons cooing	212'
	394'	(Till 291')		and drives out		(till 342')		(till 292')	
out @ 406'		SQUAWK		(till 196')					
	416'	Publisher dialogue on	358'	Wing noise for pigeon	237'				
out on out @ 427'		phone (till 593)		(till 239')		Helicopter (Dial in)	361'		
	434'	NORMAL		Water truck starts and	254'	(T.T. to on Stg. 385' to 395'			
out at 436'				drives out to bckgrd.		(dial out by 454')		pigeons cooing	408'
	439'			(till 329')				(till 482')	
out at 442'		Canary chirps	651'	two telephone bells	347'				
	451'	(till 738'		(till 356')		Salesman & wife argue	535'		
out at 473'				Ice box door opens	422'	(till 613')			
	480'			" " " closes	438'			Track out at 550'	
out at 492'									
	498'			Salesman opens door	526'				
out at 505'				" closes "	530'				
	509'								
out at 538'				Off stage door open	646'	Kids playing for backgrd	646'		
	546'			" " " closes	650'	(till 784')			
out at 569'				Car by in Bckgrd.(dial in)	671'				
	575'			(dial out by 693')					
out at 586'									
	592'			O.S. footsteps for nurse	717'				
out at 655'				(till 734')					
Rides in on out	679'			Off stge. door open for	734'				
out at 686'				nurse					
Rides in	710								

Figure 5: The cue sheet for the re-recording of *Rear Window* illustrates how a large quantity of magnetically recorded effects were layered together to create the detailed soundscape outside Jeff's apartment (*Film Music/Internet Archive*).

soundscapes. *Rear Window*, for instance, includes a handful of quiet and atmospheric sequences, yet it also features just as many scenes with source music (such as a phonograph playing in a nearby apartment) that conceals the noise made by optical media (Powell, 1954). *Forbidden Planet* is similar. Like other CinemaScope titles produced at MGM, the film initially saw a limited run in four-track magnetic stereo, but when it expanded to more theatres it played on optical prints (Dienstfrey, 2020, p.236). Knowing that the film needed to conform to both formats, MGM's sound team padded it with background effects to mask any hisses or hums generated by optical sound systems. In other words, though a film may have been shot and mixed on magnetic tracks, and at times even distributed to select theatres on magnetic prints, studios were still unlikely to exploit the new medium's full aesthetic possibilities during the 1950s and 60s. They instead designed their soundtracks to fit within the narrow acoustical ranges of the more common, yet inferior, optical technology.

At the same time, many of the editors and mixers who established magnetic sound's workflows had honed their craft during the optical era and appeared resistant to learning entirely new soundtrack techniques.

Some practitioners openly complained about the new medium, at times exaggerating its deficiencies. Todd-AO mixer Murray Spivack even argued that the use of magnetic recording on *Oklahoma!* (Fred Zinnemann, 1955) caused his assistant to drop dead. As Spivack recalled, his colleague was so used to erasing rejected orchestral takes that he accidentally erased the one good recording, '[s]o it took me another day to try and get a comparable take. And this fellow grieved about that so much, you know, and he had a weak heart […] And he died' (Spivack, 1995, p.116). Such anecdotes would only further temper excitement toward the new medium.

Another cause for concern was the opacity of the soundtracks. By the 1940s, technicians had grown accustomed to working with photographic recordings. The medium allowed editors to see the information on each track and to make splicing decisions quickly without running the track through a sound head. According to MGM sound editor Milo Lory,

> Any sound effects editor can look at an optical sound track, particularly the variable density type, and read it pretty accurately […] I've put lots of gunshots in, in the optical days, without even putting them in the moviola. I pick up the gunshot, and I can see the flash in there, and I know where it goes and put it in.
>
> (Lory, 1975, p.82)

This visibility led technicians to cut corners when building a scene: 'I've even seen people put a door slam in by taking a pencil and putting a bump on the sound track. It's crude, but it works' (Lory, 1975, p.81). In contrast, sounds on magnetic tracks were invisible to the human eye, which prevented editors from employing similar shortcuts. As historian David Morton notes, '[m]any editors in the early 1950s refused to work with [magnetic tape], complaining that unlike optical recordings, it was impossible to edit the film visually by looking at the undulations on the sound print' (Morton, 2004, p.126). These complaints – which call into question whether some editors listened to their library effects – were reportedly widespread among studio sound departments.

By the mid-1950s, though, most of their concerns had been resolved. Engineers developed equipment that drew pen lines alongside the magnetic tape, thus allowing technicians to continue editing films by sight as they had in the past (Ryder, 1950; Ryder, 1951).[11] At the same time, many technicians had become comfortable enough with the magnetic medium that they opted to make small tick marks on the film wherever a sound began. According to Warners engineer George Groves, 'because the editors got so used to playing mag track in a reproducing machine, with the fast forward and backward motion, […] you could easily spot a mark with a grease pencil where cuts should be made' (Groves, 1975, p.100).

[11] In addition to pen lines, C. Robert Fine – a former associate of James Miller and, later, the inventor of the Perspecta Sound theatre system – developed a means of cutting mechanographic tracks next to magnetic media in order for technicians to edit with variable-area versions of each recording (Fine, 1955).

Indeed, despite initial fears that the transition to magnetic recording would force editors to relearn their craft, technicians adopted editing methods that enabled their workflows to remain largely unaltered. Such practices ensured that magnetic recording brought about minimal changes to the ways films sounded.

The End of the Optical Path

The full cinematic potential of magnetic media was thus only achieved once the industry's structural dependence on optical-era workflows had dissolved. One catalyst for such changes involved changes to studio personnel. By the 1970s the many studio sound workers who had resisted magnetic recording in the 1950s – including Spivack, Groves, and Lory – had retired and were replaced with a new generation of practitioners who sought to simulate the tape-based experiments made famous throughout the music industry and who were more willing to develop techniques that explored magnetic recording's aesthetic affordances (Smith, 2015; Beck, 2016). Examples include Jim Webb's multitrack recording techniques in *Nashville* and *All the President's Men* (Alan J. Pakula, 1976), Walter Murch's use of tape manipulation in his sound effects for *THX-1138* (George Lucas, 1971) and *The Conversation*, and Buzz Knudson's deployment of wider decibel ranges when mixing *The Exorcist* and *Close Encounters of the Third Kind* (Steven Spielberg, 1977). In this regard, films of the 1970s sounded distinct from earlier releases because, unlike in the 1950s, there were fewer below-the-line workers seeking to preserve 1930s workflows.

This high turnover within the labour force also coincided with several technological upgrades that made it easier for workers to explore the acoustical capabilities of magnetic technology. That is, the mechanisms that were put in place to support optical recording, and that governed the implementation of newer workflows, were replaced by a more versatile infrastructure. The most consequential of these upgrades was the adoption of wide-range release prints. In the late 1960s, the International Organization of Standardization developed a new playback characteristic, nicknamed the 'X Curve', that dramatically expanded the frequency responses for all movie theatres and release prints (Vlahos, 1969; Rasmussen, 1976). Optical soundtracks could now boast playback ranges that were nearly as wide as magnetic recordings, thereby eliminating many of the constraints placed on editors and mixers in prior decades. The standard was possible thanks to the dissemination of compression-based noise reduction processors (Dolby, 1967) and third-octave equalisers – namely Altec's Acousta-Voicing system – which allowed technicians to minimise the attenuation of upper registers when reducing high-frequency hiss (Davis, 1968; Davis & Davis, 2008). Its use throughout the 1970s thus enabled editors and mixers to design quieter atmospheres and louder explosions without fear of their work sounding distorted or muffled when played on optical media.[12]

[12] The standard was used on select Dolby-encoded prints throughout the 1970s and was officially adopted by the film industry in 1978 (Allen, 1979; Dolby Laboratories, 1980).

The 1970s also saw the industry adopt a new metadata standard, nicknamed ‘time code’, that simplified and automated the editing and mixing of motion pictures. Time code used a high-frequency signal to create a unique binary number (a digital address) for every frame of film and every frame equivalent found in tape-based media (Alden, 1975). Though initially developed to improve the television industry’s methods of cutting and splicing videotapes, the advent of editing equipment that could generate and locate keyframes soon enabled motion picture sound workers to synchronise multiple sound-effect reels with greater precision (Dahlin, 1970). Postproduction sound teams – such as those overseen by Sam Shaw and Ben Burtt during the making of *Star Wars* and by Alan Splet and Ann Kroeber during the making of *The Black Stallion* – could now systematically pre-mix hundreds of tracks to create ornate and densely layered effects sequences – the kinds that Bebe and Louis Barron had designed for *Forbidden Planet* – and do so within the short timeframes typically allotted to postproduction sound work.

In other words, the conservative manner by which Hollywood constructed its magnetic recording equipment during the 1950s would slow down the adoption of new techniques and new modes of representation for roughly two decades. Such delays were intentional. Studios built the recording technology to be non-destructive to the industry’s economy. Similarly, its norms of use were developed to be indistinguishable from practices that were codified for optical media. In a sense, the industry’s dependence on an optical-era infrastructure discouraged sound workers from exploring magnetic technology’s full aesthetic potential. It was only after this infrastructure had dramatically weakened – a consequence of a new labour force, wider playback ranges for release prints, and the adoption of automated postproduction technologies – that the industry as a whole was willing to forgo its lingering dependence on pre-existing workflows. Whereas the technological needs of the industry in prior decades largely inhibited experimentation, the new sound economy created conditions that rewarded it. As a result, the era of aesthetic continuity that defined the adoption of magnetic recording in the 1950s and 60s would come to an end.

Conclusion

Within histories of cinema, there is considerable attention given to new technologies that revolutionise the way films look and sound. This privileging of aesthetic change, though, can minimise the economic importance of filmmaking innovations that initially fail to alter stylistic practices. The adoption of magnetic recording is one such example. Rather than transforming sound designs, it collectively reinforced the modes of acoustical representation established in prior decades. In turn, it illustrates the role that path dependence plays in the history of film technology. The standardisation of photographic sound equipment in the early 1930s led to the creation of an entire economy – including manufacturing practices, divisions of labour, and ancillary technologies – optimised to support the material and acoustical needs of optical media. And magnetic tape threatened to disrupt these practices. Its recording processes would have required an entirely new infrastructure, the costs of which would have potentially been exorbitant. As a result, the industry devitalised the technology. Engineers designed magnetic equipment to fit within Hollywood's pre-existing modes of production, while studios established techniques that maintained the industry's broader sound-design ideals. In other words, the invisibility of magnetic media in the 1950s and 60s was not a natural phenomenon. Studios deliberately rendered the technology indistinguishable from optical recording to minimise the economic disruptions typically precipitated by the adoption of new media.

Acknowledgements

Thanks to Jim Buhler, Katie Quanz, Jeff Smith, Kyle Stevens, and the journal's two peer reviewers for providing feedback on earlier drafts of this article.

◆ ◆ ◆ ◆ ◆

References

Academy Research Council (1932) *Technical Bulletin: Adoption of Uniform Aperture Specifications*. Los Angeles: Academy of Motion Picture Arts & Science.

Academy Research Council (1947) 'Research Council Basic Sound Committee: Discussion of Magnetic Recording', *Journal of the Society of Motion Picture Engineers*, 48 (1), pp.50–56.

Alden, Alex E. (1975) 'American National Standard', *Journal of the SMPTE*, 84 (7), pp.562–563.

Allen, Ioan (1979) 'Committee on Audio Recording and Reproduction Technology', *SMPTE Journal*, 88 (1), p.68.

Ament, Vanessa Theme (2021) *Divergent Tracks: How Three Film Communities Revolutionized Digital Film Sound*. New York: Bloomsbury.

Anon. (1915) 'Remarkable Machines Shown', *Motography*, 6 March, p.356.

Anon. (1928a) '"Talkies" Give Birth to Many New Words to Describe Actor's Voice', *Exhibitors Herald and Moving Picture World*, 4 August, p.32.

Anon. (1928b) '"Voice Dissector" Shows Faults That May Be Corrected', *Motion Picture News*, 9 June, p.1954B.

Anon. (1929a) '700 Educators Cooperate with Industry in Training Voice for Audiens', *Exhibitors Herald-World*, 5 January, p.64.

Anon. (1929b) 'Here's Principle of Telegraphone at Sound School', *Exhibitors Herald-World*, 5 January, p.43.

Anon. (1930) 'Wire Recording for Playbacks at M-G-M', *Variety*, 27 August, p.31.

Anon. (1934) 'Dutch Electric Firm, Said to Be Biggest in the World, Invading World's Talker Equipment Field', *Variety*, 24 July, p.5.

Anon. (1935) '"Push–Pull" Recording Challenges Hill-and-Dale at SMPE Convention', *Variety*, 29 May, p.29.

Anon. (1937) 'The Philips-Miller Recording System', *Communication and Broadcast Engineering*, 4 (5), pp.11–12, 27.

Anon. (1938) 'Sound on Film up Again', *Billboard*, 23 July, p.5.

Anon. (1945a) 'Closed Circuit', *Broadcasting*, 26 November, p.4.

Anon. (1945b) 'German's Tape Recorder, Magnetophon, is Termed Superior to Other Methods', *Broadcasting*, 3 September, p.24.

Anon. (1945c) 'Magnetophon Now Being Tested in U.S.', *Broadcasting*, 29 October, p.92.

Anon. (1948) 'New Magnetic Recorder Developed at Warners', *Variety*, 25 August, p.23.

Anon. (1949a) 'Columbia Submits Plans for New Recording Device', *Box Office*, 22 October, p.54.

Anon. (1949b) 'Right off the Reel', *Business Screen*, 10 August, pp.6, 44–45.

Anon. (1959) 'Product Report on the Perfectone Tape Recorder', *American Cinematographer*, 40 (9), pp.492, 494, 496.

Arthur, Brian W. (1989) 'Competing Technologies, Increasing Returns, and Lock-In by Historical Events', *The Economic Journal*, 99 (394), pp.116–131.

Balio, Tino (1985) 'Retrenchment, Reappraisal, and Reorganization, 1948–'. In: Balio, Tino (ed.). *The American Film Industry: Revised Edition*. Madison: University of Wisconsin Press, pp.401–447.

Barrett, A.E. & Tweed, C.J.F. (1938) 'Some Aspects of Magnetic Recording and its Application to Broadcasting', *Journal of the Institution of Electrical Engineers*, 82 (495), pp.265–285.

Beck, Jay (2016) *Designing Sound: Audiovisual Aesthetics in 1970s American Cinema*. Piscataway, NJ: Rutgers University Press.

Begun, S.J. (1937) 'Magnetic Recording-Reproducing Machine for Objective Speech Study', *Journal of the Society of Motion Picture Engineers*, 29 (2), pp.216–218.

Begun, S.J. (1947) 'Recent Development in the Field of Magnetic Recording', *Journal of the Society of Motion Picture Engineers*, 48 (1), pp.1–13.

Belton, John (1992) '1950s Magnetic Sound: The Frozen Revolution'. In: Altman, Rick (ed.). *Sound Theory, Sound Practice*. New York: Routledge, pp.154–167.

Camras, Marvin (1947) 'Magnetic Sound for Motion Pictures', *Journal of the Society of Motion Picture Engineers*, 48 (1), pp.14–28.

Carey, Leslie I. & Moran, Frank (1952) 'Push-Pull Direct-Positive Recording – An Auxiliary to Magnetic Recording', *Journal of the Society of Motion Picture Engineers*, 58 (1), pp.67–70.

Clark, Mark (1992) *The Magnetic Recording Industry, 1878–1960: An International Study in Business and Technological History*. PhD thesis. University of Delaware.

Clark, Mark (1993) 'Suppressing Innovation: Bell Laboratories and Magnetic Recording', *Technology and Culture*, 34 (2), pp.516–538.

Clark, Mark & Nielsen, Henry (1995) 'Crossed Wires and Missing Connections: Valdemar Poulsen, The American Telegraphone Company, and the Failure to Commercialize Magnetic Recording', *Business History Review*, 69 (1), pp.1–41.

Coward, Neil G. (1915) 'Kennedy Faces Clutching Hand at Last', *Motography*, 20 March, pp.447–448.

Dahlin, Ellis K. (1970) 'Standardization for Time and Control Code for Video Tape and Audio Recorders', *Journal of the SMPTE*, 79 (12), pp.1086–1088.

David, Paul A. (1985) 'Clio and the Economics of QWERTY', *The American Economic Review*, 75 (2), pp.332–337.

Davis, Don (1968) 'Altec Acousta-Voicing', *Audio*, 52 (11), pp.21–22, 24–25.

Davis, Don & Davis, Carolyn (2008) 'Audio and Acoustic DNA – Do You Know Your Audio and Acoustic Ancestors?'. In: Ballou, Glen M. (ed.). *Handbook for Sound Engineers*, 4th edition. Burlington, MA: Focal Press, pp.3–20.

de Vries, Marc J. (2005) *80 Years of Research at the Philips Natuurkundig Laboratorium (1914–1994)*. Amsterdam: Pallas Publications.

Dienstfrey, Eric S. (2018) *The Stereo Impulse: High-Fidelity Cinema and the Making of Modern Surround Sound Aesthetics*. PhD thesis. University of Wisconsin–Madison.

Dienstfrey, Eric (2020) 'Monocentrism, or Soundtracks in Space: Rediscovering *Forbidden Planet*'s Multi-Speaker Release'. In: Buhler, James & Lewis, Hannah (eds). *Voicing the Cinema: Film Music and the Integrated Soundtrack*. Urbana: University of Illinois Press, pp.229–244.

Dolby, Ray M. (1967) 'An Audio Noise Reduction System', *Journal of the Audio Engineering Society*, 15 (4), pp.383–388.

Dolby Laboratories (1980) *Background Information on Film Sound*. London and San Francisco: Dolby Laboratories, Inc.

Drenner, Don V.R. (1945) 'Engineer Finds Magnetophon Superior', *Broadcasting*, 19 November, pp.36, 84.

Drenner, Don V.R. (1947) 'The Magnetophon', *Audio Engineering*, 31 (9), pp.7–11, 35.

Engel, Friedrich K. (1988) 'Magnetic Tape: From the Early Days to the Present', *Journal of the Audio Engineering Society*, 36 (7/8), pp.606–616.

Engel, Friedrich K. (1999) 'The Introduction of the Magnetophon'. In: Daniel, Eric D., Mee, C. Denis, & Clark, Mark H. (eds). *Magnetic Recording: The First 100 Years*. New York: Institute of Electrical and Electronics Engineers, pp.47–71.

Fawell, John (2000) 'The Sound of Loneliness: *Rear Window*'s Soundtrack', *Studies in the Humanities*, 27 (1), pp.62–74.

Fine, C.R. (1955) 'Apparatus for Use in Producing Sound Motion Picture Films'. US Patent no. 3,005,058.

Frayne, John G. & Wolfe, Halley (1949) 'Magnetic Recording in Motion Picture Techniques', *Journal of the Society of Motion Picture Engineers*, 53 (3), pp.217–235.

Gratian, J.W. (1949) 'Noise in Magnetic Recording Systems as Influenced by the Characteristics of Bias and Erase Signals', *Journal of the Acoustical Society of America*, 21 (74), pp.74–81.

Groves, George (1953) 'Progress Committee Report', *Journal of the Society of Motion Picture Engineers*, 60 (5), pp.535–552.

Groves, George (1975) 'Interview with Irene Atkins'. In: *American Film Institute/Louis B. Mayer Oral History Collection*. Glen Rock, NJ: Microfilming Corporation of America.

Hall, Nick (2018) *The Zoom: Drama at the Touch of a Lever.* Piscataway, NJ: Rutgers University Press.

Hammar, Peter (1999) 'In Memoriam', *Journal of the Audio Engineering Society*, 47 (9), pp.776–777.

Hammar, Peter & Ososke, Don (1982) 'The Birth of the German Magnetophon Tape Recorder 1928–1945', *db Magazine*, 16 (3), pp.47–52.

Hanson, Helen (2017) *Hollywood Soundscapes: Film Sound Style, Craft and Production in the Classical Era*. London: BFI.

Hayes, Peter (2000) *Industry and Ideology: IG Farben in the Nazi Era*, 2nd edition. Cambridge: Cambridge University Press.

Howell, H.A. (1947) 'Magnetic Sound Recording on Coated Paper Tape', *Journal of the Society of Motion Picture Engineers*, 48 (1), pp.36–49.

Jacobs, Lea (2012) 'The Innovation of Re-Recording in the Hollywood Studios', *Film History*, 24 (1), pp.5–34.

Lafferty, William (1981) *The Early Development of Magnetic Sound Recording in Broadcasting and Motion Pictures, 1928–1950*. PhD thesis. Northwestern University.

Lafferty, William (1983) 'The Blattnerphone: An Early Attempt to Introduce Magnetic Recording into the Film Industry', *Cinema Journal*, 22 (4), pp.18–37.

Lastra, James (2000) *Sound Technology and the American Cinema: Perception, Representation, Modernity*. New York: Columbia University Press.

Lawton, Ralph (1951a) 'The Westrex Magnetic Film Recording Systems', *American Cinematographer*, 32 (5), pp.182, 200.

Lawton, Ralph (1951b) 'The RCA Magnetic Recording System', *American Cinematographer*, 32 (8), pp.310, 322–323.

Leslie, John & Snyder, Ross (2010) 'History of the Early Days of Ampex Corporation', *AES Historical Committee*, 17 December, pp.1–14.

Lewin, George (1951) 'Special Techniques in Magnetic Recording for Motion Picture Production', *Journal of the Society of Motion Picture Engineers*, 56 (6), pp.653–663.

Leydon, Rebecca (2004) '*Forbidden Planet*: Effects and Affects in the Electro Avant-Garde'. In: Hayward, Philip (ed.). *Off the Planet: Music, Sounds and Science Fiction Cinema*. Eastleigh: John Libbey, pp.61–76.

Liebowitz, S.J. & Margolis, Stephen E. (1990) 'The Fable of the Keys', *The Journal of Law & Economics*, 33 (1), pp.1–25.

LoBrutto, Vincent (1994) 'Arthur Piantadosi'. In: LoBrutto, Vincent (ed.). *Sound-On-Film: Interviews with Creators of Film Sound*. Westport, CT: Praeger, pp.11–20.

Lory, Milo (1975) 'Interview with Irene Atkins'. In: *American Film Institute/Louis B. Mayer Oral History Collection*. Glen Rock, NJ: Microfilming Corporation of America.

Mallina, R.F. (1935) 'A Mirror for the Voice', *Bell Laboratories Record*, 8 (7), pp.200–202.

Malsky, Matthew (2003) 'Stretched from Manhattan's Back Alley to MOMA: A Social History of Magnetic Tape and Recording'. In: Lysloff, René T.A. & Gay, Leslie C. (eds). *Music and Technoculture*. Middleton, CT: Wesleyan University Press, pp.233–263.

Malsky, Matthew (2015) 'The Grandeur(s) of CinemaScope: Early Experiments in Cinematic Stereophony'. In: Théberge, Paul, Devine, Kyle, & Everrett, Tom (eds). *Living Stereo: Histories and Cultures of Multichannel Sound*. New York: Bloomsbury, pp.207–225.

Masterson, Earl (1948) '35-mm Magnetic Recording System', *Journal of the Society of Motion Picture Engineers*, 51 (5), pp.481–488.

Menard, James Z. (1946) *High Frequency Magnetophon Magnetic Sound Recorders*. Office of Military Government for Germany (US), Field Information Agency Technical: Final Report no. 705.

Middleton, Drew (1945) 'U.S. Seized Farben Plants to Bar Reich Arms Output', *New York Times*, 6 July, p.1.

Miller, J.A. (1931) 'Sound Record and Method of and Apparatus for Making It', US Patent no. 1,919,116.

Miller, J.A. (1935) 'Mechanographic Recording for Motion Picture Sound-Tracks', *Journal of the Society of Motion Picture Engineers*, 25 (1), pp.50–64.

Morton, David (2004) *Sound Recording: The Life Story of a Technology*. Baltimore: Johns Hopkins University Press.

Mueller, William A. & Groves, George R. (1949) 'Magnetic Recording in the Motion Picture Studio', *Journal of the Society of Motion Picture Engineers*, 52 (6), pp.605–612.

Mullin, John T. (1976a) 'The Birth of Tape', *Billboard*, 4 July, pp.MR-12, MR-38, MR-46.

Mullin, John T. (1976b) 'Creating the Craft of Tape Recording', *High Fidelity*, 26 (4), pp.62–67.

Neumeyer, David & Cox, Helen (1998) 'The Musical Function of Sound in Three Films by Alfred Hitchcock', *Indiana Theory Review*, 19 (1/2), pp.13–33.

Platte, Nathan (2015) 'Postwar Hollywood, 1947–1967'. In: Kalinak, Kathryn (ed.). *Sound: Dialogue, Music, and Effects*. Piscataway, NJ: Rutgers University Press, pp.59–82.

Poulsen, Valdemar (1899) 'Method of Recording and Reproducing Sounds or Signals', US Patent no. 661,619.

Poulsen, Valdemar (1900) 'The Telegraphone: A Magnetic Speech Recorder', *Electrician*, 10 November, pp.208–210.

Powell, Mary (1954) 'Rear Window', *Film Music*, 14 (1), pp.20–21.

Power, R.A. (1946) 'The German Magnetophon', *Wireless World*, 53 (6), pp.195–198.

Pumphrey, Melvina (1950) 'Cameras Finally Role on "The River" in India', *New York Times*, 26 February, p.X5.

Ralph, C.M. & Matthews, J.G. (1938) 'New Ideas in Mobile Sound Recording Equipment', *Journal of the Society of Motion Picture Engineers*, 30 (5), pp.577–586.

Rasmussen, Erik (1976) 'Acoustic Response Measurements and Standards for Motion-Picture Theaters', *SMPTE Journal*, 84 (3), pp.164–169.

Reeve, Arthur B. (1914) *The Exploits of Elaine*. New York: Harper & Brothers Publishing.

Reeves, Hazard E. (1953) 'Adding the Sound to Cinerama'. In: Quigley, Jr., Martin (ed.). *New Screen Techniques*. New York: Quigley Publishing Company, pp.127–131.

Ryder, Loren L. (1950) 'Motion Picture Studio Use of Magnetic Recording', *Journal of the Society of Motion Picture Engineers*, 55 (6), pp.605–612.

Ryder, Loren L. (1951) 'Editing Magnetic Sound', *American Cinematographer*, 32 (4), pp.137, 156–158.

Schatz, Thomas (1997) *Boom and Bust: American Cinema in the 1940s*. Berkeley: University of California Press.

Schmidt-Horning, Susan (2013) *Chasing Sound: Technology, Culture and the Art of Studio Recording from Edison to the LP*. Baltimore: Johns Hopkins University Press.

Singer, Kurt & Pettus, J.L. (1952) 'A Building-Block Approach to Magnetic Equipment Design', *Journal of the Society of Motion Picture Engineers*, 59 (5), pp.319–334.

Singer, Kurt & Ward, H. Connell (1952) 'A Technical Solution of Magnetic Recording Cost Reduction', *Journal of the Society of Motion Picture Engineers*, 58 (4), pp.329–340.

Skjerseth, Amy E. (2022) *Music's Visual Waves: Popular Music Technology and Audiovisual Aesthetics*. PhD thesis. University of Chicago.

Smith, Jeff (2015) 'The Auteur Renaissance, 1968–1980'. In: Kalinak, Kathryn (ed.). *Sound: Dialogue, Music, and Effects*. Piscataway, NJ: Rutgers University Press, pp.83–106.

Smith, Oberlin (1888) 'Some Possible Forms of Phonograph', *Electrical World*, 8 September, pp.116–117.

Spivack, Murray (1995) *An Oral History with Murray Spivack*, interview by Charles Degelman. Academy Oral History Program, Margaret Herrick Library, AMPAS.

Staiger, Janet (1983) 'Individualism versus Collectivism: The Shift to Independent Production in the US Film Industry', *Screen*, 24 (4/5), pp.68–79.

Street, Seán (2006) *Crossing the Ether: Pre-War Public Service Radio and Commercial Competition in the UK*. Eastleigh: John Libbey Publishing.

Thiele, Heinz H.K. (1988) 'Magnetic Sound Recording in Europe up to 1945', *Journal of the Audio Engineering Society*, 36 (5), pp.396–408.

Tinkham, R.J. & Boyers, J.S. (1947) 'A Magnetic Sound Recorder of Advanced Design', *Journal of the Society of Motion Picture Engineers*, 48 (1), pp.29–35.

Vermeulen, R. (1938) 'The Philips-Miller Method of Recording Sound', *Journal of the Society of Motion Picture Engineers*, 30 (6), pp.680–693.

Vlahos, Petro (1969) 'An Acoustic Response Standard', *Journal of the SMPTE*, 78 (12), pp.1043–1045.

Weis, Elizabeth (1982) *The Silent Scream: Alfred Hitchcock's Sound Track*. Rutherford, NJ: Fairleigh Dickinson University Press, pp.107–124.

Westmijze, W.K. (1953) 'Studies on Magnetic Recording: III. The Recording Process', *Philips Research Reports*, 8 (4), pp.245–269.

Wierzbicki, James (2005) *Louis and Bebe Barron's* Forbidden Planet*: A Film Score Guide*. Lanham, MD: Scarecrow Press.

Yewdall, David Lewis (2012) *The Practical Art of Motion Picture Sound*, 4th edition. Waltham, MA: Focal Press.

Media Cited

All the President's Men, Alan J. Pakula, USA, 1976.

The Black Stallion, Carroll Ballard, USA, 1979.

Close Encounters of the Third Kind, Steven Spielberg, USA, 1977.

C-Man, Joseph Lerner, USA, 1949.

The Conversation, Francis Ford Coppola, USA, 1974.

The Exorcist, William Friedkin, USA, 1973.

The Exploits of Elaine, Louis J. Gasnier, George B. Seitz, Leopold Wharton, & Theodore Wharton, USA, 1914.

Forbidden Planet, Fred M. Wilcox, USA, 1956.

The Fountainhead, King Vidor, USA, 1949.

Iron Man, Joseph Pevney, USA, 1951.

A Knight in London, Lupu Pick, Germany/UK, 1928.

Nashville, Robert Altman, USA, 1975.

New Moon, Jack Conway, USA, 1930.

Oklahoma!, Fred Zinnemann, USA, 1955.

Portrait of Jennie, William Dieterle, USA, 1948.

The Raging Tide, George Sherman, USA, 1951.

Rear Window, Alfred Hitchcock, USA, 1954.

The River, Jean Renoir, France/India/USA, 1951.

Rope, Alfred Hitchcock, USA, 1948.

The Sleeping City, George Sherman, USA, 1950.

Star Wars, George Lucas, USA, 1977.

Teresa, Fred Zinnemann, USA, 1951.

THX-1138, George Lucas, USA, 1971.