extensively for television, but in the cinema industry its use is confined mainly to the processing of special effects. It may well be that as processor speeds increase and the capital costs of film reduce, digital imaging technologies will become more cost effective overall than film. But even that cautious speculation also assumes that film technology will cease to improve (whereas in fact new generations of film stock have consistently outperformed their video and digital imaging equivalents in image quality, versatility, compatibility and longevity), and that sectors of the industry which currently operate on low capital equipment and high media costs (most notably cinema exhibition) will be able to find substantial additional funding to finance the conversion. It is likely, therefore, that film will continue to play a key role in the development and use of moving image technologies well into the twenty-first century.

chapter two | cinematography and film formats

Cinematography

'You know what wouldn't be bad? Ghosts. They come through the screen, fly over the heads of the audience ... ghosts that drip blood. I can see it all now: Bloodoscope ... Bleedorama!' – John Goodman in *Matinee* (1993, dir. Joe Dante)

Chapter one examined how the physical and chemical properties of the world's earliest and longest-lived moving image medium – photographic film – shaped the growth of an industry and culture which evolved around it. This chapter will expand on that overview to explore two specific areas of technology which are needed to produce moving image content on film. Cinematography, which can broadly be defined as the technology needed to expose photographic images (or 'frames') onto film which are intended to be reproduced as a moving image sequence, consists primarily of the cameras themselves and the peripheral technologies designed to facilitate their use (such as studio lighting). Film formats relate to the practice of standardisation, one which has proved to be a crucially important reason why film became the longest lived and most successful moving image medium. When Henry Ford famously declared that he would supply the Model 'T' 'in any colour, as long as it's black', he was pointing out that the private car could only be successful as a mass-produced consumer product if the cost of producing it was kept as low as possible relative to the disposable income of Ford's intended customers. The only way to achieve that was to develop a single design which could be manufactured many times over on a production line.

By the same logic, when a chief projectionist I once worked for expressed his complete disinterest in any of the cultural or artistic issues related to the films he was showing by declaring that 'as far as I'm concerned, it's this wide [holding up his right thumb and forefinger roughly 35 millimetres apart] and it goes through a projector', he unwittingly identified the key aspect of film technology which has made it so successful. The film he was referring to is 35 millimetres wide, has four evenly-spaced perforations alongside each frame and the dimensions and position

of the frame and soundtrack(s) on the topography of the film's surface are defined according to published and universally accepted standards. That ensures that it will not only go through his projector, but almost *any* projector, anywhere in the world. But this has not always been the case. The film that we use today only became 'this wide' as a result of aggressive marketing, trade wars, political issues and other factors which had a greater influence on the history of media economics than many would readily admit.

When you consider that most sectors of the global film and television industries in general, and Hollywood in particular, depend for their economic survival on being able to sell their products in international markets, it becomes obvious that standardisation is not an obscure technical detail, but one of many instances in which technological issues have greatly influenced the historical development of moving image industry, economics and culture. Furthermore, they continue to do so.

This chapter, therefore, will address the historical development of two crucial areas of technology allied to film, but which in the main have evolved separately from the properties of the film base and emulsion itself, hence their omission from chapter one. It will offer a historical overview of the technology used for initially recording the moving image and for standardising the means of its distribution and exhibition, and suggest ways in which these processes of evolution impacted on the wider histories of moving image history and culture.

The moving image film camera

The film camera is essentially the combination of mechanical and optical techno-logies needed to expose still photographs, or 'frames' onto film in rapid succession in order that, after processing and printing, they can be reproduced as a moving image sequence. Professional motion picture cameras generally record the picture only, though more modern ones will include an electronic or mechanical system for interlocking the film movement with an external sound recording device. The camera, essentially, consists of five key components:

- THE FILM TRANSPORT MECHANISM, which contains two lightproof containers, or 'magazines' to house the unexposed film stock and to wind it up after exposure, plus the rollers and driven sprockets needed to feed the film through the gate.
- THE GATE, a metal plate containing an opening which corresponds to the dimensions of the exposed frame, against which the film is held stationary during exposure.
- THE INTERMITTENT MECHANISM, which advances the film through the gate between exposures. This usually consists of one or more pins which engage the perforations in the film stock, pull a predetermined length of film through the gate, retract and then return to the starting position.
- THE SHUTTER, usually a concentric metal disc with one or more protruding blades. The movement of the shutter is mechanically interlocked to that of the intermittent mechanism to ensure that a shutter blade is blocking the flow of light while the film is in motion.

- THE LENS, which consists of one or more ground and polished glass elements mounted in a cylindrical barrel. These refract, or alter the shape of, the light which passes through them in order to form the image to which emulsion of the film is exposed.

In the 110 years between the earliest known patent for a moving image camera using roll film (granted to William Friese-Greene and Mortimer Evans on 25 February 1890[1]) and the turn of the twenty-first century, all five of these components have undergone a continuous process of evolution and redesign. Raw materials, developments in manufacturing processes (especially for lenses) and the introduction of electronic and computer technology to control the mechanisms have also played a part in making the film camera of 2005 a vastly superior instrument to the ones used a century earlier. But, in a striking demonstration of the relative success of format standardisation, it would be possible to expose today's film stock in an 1890s camera and still produce a recognisable moving image.

Early camera technology

Although Friese-Greene's and Evans' patent was granted in 1890, there is no evidence that they ever got their camera to work. In general terms, there was a three to five year gap between the initial marketing of cellulose nitrate film by Kodak in 1889 and the beginnings of cinematography as we know it today. Whilst the inventors of the late nineteenth century realised that, in theory, film was the medium needed to record moving images, progress on the technology needed to make (and reproduce) the recording was slow. The engineers and scientists who had built either paper-roll cameras or glass-plate cameras with multiple lenses quickly realised that neither system was immediately adaptable to film. Possibly the earliest camera to be used in a systematic production schedule was Edison's Kinetograph, which was initially used to shoot films for showing in Kinetoscopes before the emergence of viable film projectors in 1895. It was large, heavy, could only be used in a fixed position and was driven by an electric motor. The intermittent mechanism was similar to that of a Maltese Cross design, which, ironically, would later become the standard form of intermittent mechanism used in most 35mm cinema projectors to this day (the different types of intermittent mechanism are covered in detail in chapter five).[2]

The other main camera design to emerge during the 1890s was the Lumière *Cinématographe*, in which a claw, mounted adjacent to the gate, was driven by two cams in order to produce the intermittent motion needed. The *Cinématographe* was in fact a camera, printer and projector in one unit, the change of function being accomplished by the addition of a light source and minor adjustments to the mechanism. Within the next two decades Maltese Cross mechanisms would become the intermittent unit of choice for projection, whilst claw mechanisms would become the standard for cameras, primarily because the latter produced a more accurate film movement but was less able to withstand the intense heat produced by the light sources used in cinema projection. Describing a Maltese Cross camera mechanism developed by the British pioneer R. W. Paul in 1898, Barry Salt observes that

'although it had the advantage of reversibility, it also had the disadvantage of poor registration, at least when compared to the Lumière mechanism'.[3] Throughout the late 1890s camera design and manufacture was essentially a small-scale cottage industry, with individual models being hand-built in small quantities for specific purposes. In the 1900s and 1910s their constituent technologies began to standardise, with the result that a small number of designs started to be mass-produced. Their features, capabilities and limitations would, when combined with the characteristics of the film exposed in them, prove a major influence on studio and location production technique throughout the silent period and beyond. Until the introduction of synchronised sound in the late 1920s, almost all cameras were driven by hand-cranking, with a handle that was directly linked by a system of gears to the sprockets, intermittent mechanism and take-up spindle. The only exceptions were cameras designed for amateur cinematography and some smaller models intended for newsreel use, which were driven by a clockwork motor that would enable takes lasting between ten and twenty seconds. Electric motors were virtually unheard of in cameras during this period because they were large, very heavy and required an external power supply. One of the few exceptions was the electrically-driven Edison Kinetograph, which restricted its use to the 'Black Maria' studio developed by Dickson and which was unable to be operated in remote locations.

By the mid-1910s, industry standards had been established for different categories of camera. The 'one-sprocket topical [newsreel] camera', for example:

> ... will usually have a first-class lens and should be capable of doing ordinary work, but will probably have a shutter with fixed aperture and will lack the inside focusing tube, film measurer and such-line accessories.[4]

This generation of camera, specifically designed for portability, was limited to a magazine capacity of 100 feet (just under 1¾ minutes continuous shooting at 16fps). The more advanced cameras designed for studio use during this period featured interchangeable lenses of different focal lengths, a larger magazine capacity (the largest capacities in general use were 400 feet – just over 8 minutes – rising to 1,000 feet – just under 17 minutes – by the late 1910s), a viewfinder and a footage counter. These models were not easily portable, however, and could only be used when mounted on a tripod. Among the models developed during the early period was the Pathé studio camera of 1903, which contained a claw-based intermittent mechanism similar to that of the Lumière *Cinématographe*, but which incorporated an idea patented by Woodville Latham in 1895: a loop of film between the continuously rotating sprockets and intermittent claw, in order to absorb the inertial shock of the film being pulled from and to the larger (and thus heavier) rolls of film needed for longer sequences of exposures, or 'takes'.[5] In 1905 the design was modified to incorporate external film magazines with a 400-foot capacity.[6] Another widely used camera was developed by James Williamson in Britain and manufactured from 1904. The magazines were enclosed, had a refined intermittent mechanism and featured a more accurate pull-down motion than its predecessors. In 1908 the French Debrie Parvo camera set the precedent for a series of small, portable designs intended specifically for newsreel and location use. Both 400-foot magazines and the mechanism were all built into a small box of around 21cm³, and other features included an adjustable shutter speed and a viewfinder which could be used during a shot. The Parvo could easily be operated while hand-held (i.e. without the need for any external support device, such as a tripod) in good lighting conditions.

Camera design and the rise of the studio system

The move towards standardised, mass-manufactured camera designs for studio use became firmly established in 1912 with the launch of the Bell and Howell model 2709 studio camera. This introduced a number of technical innovations which ensured that the 2709 would remain *the* standard studio camera used by Hollywood until the arrival of sound, almost two decades later. It also set an important industrial precedent, which was that of an external equipment manufacturing firm, with no direct financial links to the business of film production or exhibition, being responsible for introducing a key technical advance. This pattern – of equipment design and manufacture companies, separate from studios, distributors and cinemas, anticipating the film industry's needs and then developing technologies to meet them – would become the dominant means by which the global film industry adopted new technologies. Combined with technical and economic conflicts involved in the process of standardisation (covered in greater depth below), this pattern would establish the industrial/institutional model of technological development which held sway virtually throughout the twentieth century.

The idea of film technology being developed through a service industry distinct from the business of producing and exhibiting the creative content of the films themselves was the driving force behind the establishment of Bell and Howell in 1907. Of its founders, Donald J. Bell began working as a projectionist in Chicago in 1896. He soon recognised the difficulties and inefficiencies of operating and maintaining a large number of different projector designs, most of them the product of cottage industry design and manufactured in small quantities. Albert S. Howell was a recently-qualified mechanical engineer to whom Bell was introduced at the machine tool works where the latter was employed, and which fabricated spare projector parts individually and to order for Bell. The first mass-produced equipment marketed by Bell and Howell was a film perforating device in 1909; this rapidly became the industry standard, so much so that 'BH' shape perforations are still in common use for negative stock today. The 2709 camera, first sold in 1912, firmly established Bell and Howell on two counts: firstly, the camera introduced some technical features which marked a radical departure from any other 35mm studio camera commonly available at the time, and secondly it was manufactured on a production line basis, which increased efficiency and reduced operating costs through the economies of scale which apply to mass-production. Spare parts were readily available, and technical support was provided to studios in the form of service packages. The 2709 had a 1,000-foot magazine capacity, thus making it suitable for the longer takes needed by

increasingly elaborate studio sequences. The gate mechanism and pin registration system on the 2709 incorporated two features which were novel for their time but which are a standard feature on virtually all 35mm cameras now. The first was the use of a pin registration system, in which a pressure plate, mechanically linked to the intermittent movement, held the film in place on fixed pins engaging the perforations during exposure, and then pulled it back to engage the intermittent claw to advance the next frame. When combined with an automatic perforator which ensured almost perfect accuracy in the spacing of the perforations in the raw film stock, this mechanism offered vastly improved vertical stability in the projected picture. The second was its all-metal body: as H. Mario Raimondo Souto notes, camera bodies before around 1920 were almost exclusively wooden, which required extensive maintenance and which were prone to light leakages.[7] Other features which had previously been available on a limited scale but not in a mass-produced piece of standard equipment included a variable shutter angle which could be adjusted during a shot (thus making it possible to produce fades in the camera and eliminating the need to introduce them in printing) and a rotating lens turret which enabled quick and simple changes to a lens of a different focal distance.

It is estimated that around 1,500 model 2709s were manufactured in total; not much in the context of today's consumer electronics, but a huge quantity for a specialised piece of industrial machinery.[8] Despite the initially high capital outlay of around $2,000 for the camera itself,[9] studios quickly realised that the economies of scale on which it was produced enabled highly cost-effective operation in a production environment. Production continued until 1958, and a small number of 2709s remained in use as rostrum cameras for animation until the mid-1990s, when digital mastering technology superseded this remaining niche in the market. There are very few other industries in which a standard piece of equipment remains in regular use for almost nine decades, and therefore the 2709's longevity is a powerful example of the relative mechanical simplicity of film-based moving image technology.

Although the 2709 was used for specialist processes over many years, its heyday as a mainstream studio camera was during the 1910s and 1920s. The conversion to sound in 1926–30 effectively rendered it obsolete for this purpose for two key reasons. Firstly and most importantly, the predominant studio practice during the silent period was to operate motors by hand cranking. Although an electirc motor was available for the 2709, the power supply needed made it more difficult to use the camera on location in this configuration, and further added to the noise it made (of which more below). Motor-driven cameras were essential for filming with synchronised sound, as accurate reproduction of the recording depended on a consistently accurate film transport speed, which was then matched in projection. Consistency of shooting speed was not considered a major issue during the silent period – indeed, variations were often deliberately introduced as an artistic effect. The 2709, like most other cameras built during this period, followed the convention of one complete revolution of the cranking handle passing eight frames (half a foot) of film through its mechanism. Steady cranking at two revolutions every second, therefore, would equal a shooting speed of 16 frames – or one foot – per second, which

was considered the *de facto* norm until changes in projection technology during the 1920s precipitated a gradual increase (see chapter five for more on the differences in shooting and projection speeds). The second reason was the price to be paid for the 2709's extraordinarily precise pin-registration system compared with other cameras of its day: the mechanism was inherently very noisy, and would easily be audible on any sound recording made in close proximity to it. In the early days of sound some 2709s were fitted with electric motors and enclosed in a soundproof booth. This all but ruled out any form of camera movement (i.e. panning or tracking) during a shot, and it was clear that for use with synchronised sound, a fundamentally new design would be needed.

During World War One the nascent American film industry gradually relocated from the East Coast to the West Coast of the United States, driven by greater flexibility, cheaper land costs and the higher levels of light needed to shoot on location using the slow film stocks of the day. By the mid-1920s production activity had become largely concentrated in a hitherto obscure suburb of Los Angeles known as Hollywood, and had eclipsed that of war-battered France as the world's largest (in terms of monetary turnover) film industry. It was hardly surprising, therefore, that the more significant advances in camera technology during this period took place in the United States. These were provided chiefly by the Mitchell company, which sold its first camera in 1920. In its early versions, the functionality of the Mitchell mechanism did not vary significantly from that of the Bell and Howell. The main difference was a more accurate and easier to use viewfinder (but which as with all cameras before the advent of reflex viewfinders, could not be used during an actual shot). The intermittent mechanism used two simultaneously moving claws and cams, whilst a third cam operated a pressure plate which held the film in place during exposure. This was not quite as accurate as the pin-registration system used in the Bell and Howell, but the mechanism was a lot quieter and required less power to drive it (which meant that it could be adapted to be driven by an electric motor far more easily). The design was steadily refined throughout the 1920s, with a pin-registration system being added in 1928. This was a lot quieter. Another advantage of the Mitchell was that the shape of the camera body could more easily be encased in an outer shell, or 'blimp', which deadened the motor noise almost entirely for sound shooting, whereas the Bell and Howell was so noisy it had to be operated within a booth.

The Mitchell model BNC, introduced in 1934, was so quiet as to be almost undetectable by the studio microphones in routine use, and its introduction effectively rendered the Bell and Howell obsolete except for silent shooting (e.g. by second units on location) and specialist applications, most notably as a rostrum camera for stop-motion animation, for which the unsurpassed accuracy of its film registration system was used to great advantage. For studio use, the BNC enjoyed almost exclusive market domination until the mid-1960s. Mitchell also produced the first camera mechanism to be adapted for use with a widescreen format, when a 70mm version was developed for the short-lived Fox Grandeur process in 1929–30.

The only other significant studio camera design to emerge between the wars was the Technicolor beam-splitting camera, designed and produced by the Techni-

color corporation for use in their three-strip colour cinematography process. As the camera was an integral part of that process and was not used for routine cinematography, its design and operation will be considered along with the other components of Technicolor in chapter three.

Camera design for actuality and documentary filming

Studio-shot features were not the only purpose for which moving images were originated on film, however, and a number of smaller, more portable models emerged during the 1920s. These were intended primarily for news and documentary filming, and incorporated some of the advances of their larger cousins. Three examples in particular are worth noting. The British Newman-Sinclair company had been around since the 1900s, and the wooden-bodied Newman-Sinclair Standard, first marketed in 1910, quickly became established as a favourite among news and actuality cameramen in the UK and Europe. The relatively large body size, simple claw-and-cam pulldown and fully enclosed magazines made for durability and easy maintenance, and among the Standard's notable users were Herbert Ponting and Frank Hurley, the cameramen who accompanied Captain Scott and Ernest Shackleton to the Antarctic respectively. In 1928 Newman-Sinclair produced the 'Autokine', which was used extensively among documentary filmmakers (mainly in Britain and Europe) for several decades. Oblong-shaped and roughly the same size as a Debrie Parvo, the Autokine featured a rugged, durable design, a pin-registration system, easily interchangeable lenses and – crucially – a double-springed clockwork motor which was capable of running the entire 200-foot magazine capacity in one take (Newman-Sinclair had experimented with electric motors in an earlier model of 1922 but found them to be too heavy, with insufficient battery capacity to film for any significant length of time). Without the need to hand-crank the mechanism, the Autokine was the first mainstream, professional 35mm camera which could reliably be hand-held. Probably the most extensive users of Newman-Sinclair Autokines were the British 'Documentary Movement' of the 1930s and 1940s, who valued their portability, versatility and ease of use in unorthodox locations. Well-known films shot (largely or entirely) with Autokines included *Man of Aran* (1934, dir. Robert Flaherty), *North Sea* (1938, dir. Harry Watt) and *Land of Promise* (1946, dir. Paul Rotha). As documentaries in those days hardly ever used synchronised sound (the soundtracks usually consisted of a post-synched commentary, effects and music), the noisy clockwork mechanism was not a problem.

Another camera designed for specialist actuality filming was the model developed by the American explorer and museum curator Carl Akeley in 1918. It was drum-shaped, with a cylindrical shutter occupying the entire surface of the inner chamber. A gyroscopic tripod head and a viewfinder assembly with an adjustable angle allowed easy use on rough terrain and in difficult locations, whilst the distribution of weight within the camera body and a twin viewfinder lens enabled a new generation of long and heavy telephoto lenses to be used with comparative ease. Akeleys were initially used by the military and by actuality cameramen, most famously by Robert Flaherty in his documentary about Eskimo life, *Nanook of the North* (1921). But their unsurpassed versatility eventually led to their purchase by the Hollywood studios. From the mid-1920s onwards, Akeleys were increasingly used alongside 2709s for location work, so much so that the term 'Akeley shot' was used within the industry to describe a technically complex panning shot photographed in difficult or dangerous circumstances.[10] Akeley cameras were instrumental in the development of the action/adventure genre during the 1920s, being used on for the moving shots in spectacular epics such as *Ben Hur* (1925, dir. Fred Niblo) and *Wings* (1927, dir. William A. Wellman), as well as the stunt work for slapstick stars including Buster Keaton and Harold Lloyd. Aware of the niche market for small, portable 35mm camera mechanisms Bell and Howell launched its own, the Eyemo, in 1926. This design substituted the pin-registration system with a simple cam movement, thus reducing weight, and was able to be loaded and unloaded in daylight (essential, given that its film capacity was only 100 feet).

The other major technological advance in camera design to emerge before World War Two was the reflex viewfinder. Nowadays it is taken for granted that any camera – still or moving image, film, video or digital – will incorporate a means by which the photographer can accurately determine the composition of the image s/he is recording. Today these generally take one of two forms. The *rangefinder* system consists of an entirely separate optical system which is positioned close to the lens which actually receives the exposure to be recorded. While this is reasonably simple and cheap to produce, one serious drawback is the problem of parallax errors. This refers to the slight difference in composition caused by the distance between the optical centre of the viewfinder and that of the taking lens. This needs to be corrected – which is usually done by skewing the angle of the viewfinder lens slightly – in order for the former to give a reasonably accurate view of what the latter will record. However, slight errors can still be introduced, especially when filming very close subjects: the closer the subject is to the camera, the more greatly amplified the difference in angle between the rangefinder and taking lens will be.

The *reflex* viewfinder solves this problem by introducing a system of mirrors which enables light from the taking lens to be directed into a viewfinder as well as onto the film. The core of the system is a 'shutter mirror' which blocks the light path from lens to film while directing light into the viewfinder. During exposure this mirror is raised, obscuring the viewfinder and permitting exposure. Anyone who has a single-lens reflex still camera can see this working simply by removing the lens (having first ensured that no film is loaded), setting the shutter speed to 'B' and pressing the shutter. The mirror facing the lens will rotate upwards through 90°, enabling the operator to see directly into the film chamber. In a moving image film camera, the length of each exposure relative to the time taken for film movement is such that the repeated movements of the mirror will appear as a flicker through the viewfinder, but the operator is able to maintain accurate composition throughout a shot. Not only does this eliminate parallax errors, but it has the added advantage of enabling the photographer to see whether or not the subject is in focus.

Reflex viewfinders were not available in moving image cameras at all before 1937 (though their use in 35mm still cameras dates back to the late 1920s), and the viewfinding systems available varied from nothing at all to rangefinders which were initially of limited accuracy. Studio techniques evolved to deal with this issue: the distance between camera and subject would be measured, to ensure that focus was set accurately (hence the job title 'focus puller'), and by comparing the focal distance of the lens in use with the optical centre of the shot it was possible to determine, with reasonable accuracy, the outer limits of the frame. This procedure was not easy, especially with shots that involved camera movement, and therefore the development of more accurate viewfinding systems during the 1920s and 1930s had a significant impact on the composition and style of shots produced throughout the industry, from highly formal studio features to newsreel filming at sports events.

The first mass-produced 35mm camera to incorporate a reflex viewfinder originated in Germany in the mid-1930s. The firm of Arnold & Richter (Arri) was established in Munich in 1917, and produced its first moving image camera, the Kinarri, in 1925. August Arnold's Arriflex, launched at the Leipzig Fair in 1937, revolutionised the German film industry with its reflex viewfinder and an entirely new claw-and-cam mechanism which produced accuracy of registration approaching that of the Bell and Howell but without the need for a pin-registration system. In it, the claw assembly is moved by a triangular cam driven by a rotating shaft. This arrangement produces a very short period immediately before and after each exposure during which the claw remains fully inserted through the film perforations but entirely stationary, thus absorbing all vibrations produced by the film movement, a function which, in the 2709 and the Mitchell, is accomplished by pin registration. Arriflexes were used extensively by the Nazis both for location and studio work (such as filming on battlefields), and were greatly envied by Allied cameramen during World War Two because of these mechanical innovations. It was the first 35mm camera which offered a level of functionality approaching that of a full-scale studio camera, but which could also be described as truly portable. After the war Arriflexes found their way west, but initially only to a limited extent: Flaherty (again) used one to film *Louisiana Story* (1947, dir. Robert Flaherty), while the Warner Bros. cinematographer Sid Hickox put the reflex viewfinder to striking use in the half-hour opening sequence of the Humphrey Bogart thriller *Dark Passage* (1947, dir. Delmer Daves), which is shot subjectively, i.e. entirely from the hero's point of view. In spite of the obvious operational advantages of the Arriflex, the reflex viewfinder was not incorporated into a standard Hollywood studio camera until the Mitchell BNCR was produced in 1967.

The post-war evolution of 16mm cameras

From the 1950s to the 1980s the development of film camera technology was largely influenced by three factors: the desire to reduce the cost and increase the efficiency of studio practices, the introduction of widescreen and wide film formats and the growing use of film, and in particular 16mm film, as an origination medium for television.

No significant new 35mm camera mechanisms appeared during the 1950s. The evolution of 16mm from the system launched by Eastman Kodak specifically as an amateur format in 1923 to its growing professional use in film and television after the war will discussed more extensively under the heading of film formats below. It is noted here because developments in 16mm cameras during the late 1940s and 1950s made this transition possible and provided the technological basis for the expansion of 16mm into specialist cinema applications and television. A 16mm version of the Arriflex, the 16ST, appeared on the market from the early 1950s, incorporating a slightly modified mechanism from the 35mm version. Most notable was the use of pin registration, which, given that the much smaller size of the 16mm frame would serve to magnify any unsteadiness in registration many times more than with 35mm, was considered essential.

Other 16mm reflex models quickly appeared from manufacturers including Paillard Bolex in France and Canon in Japan, while the Bell and Howell Filmo – the 16mm ancestor of the Eyemo which had been manufactured since 1923 – enjoyed increased sales. Production continued until 1979, a longer run even than the 2709. By the late 1950s these cameras accounted for virtually all television output which was not broadcast live. In the 1960s these 16mm designs began to incorporate the means of synchronisation to an external magnetic sound recording device, such as the Arriflex BL, launched in 1965 and the last major 16mm professional camera mechanism, the Aaton, introduced in the mid-1970s. 16mm was also adopted enthusiastically by a new generation of documentary makers, notably the 'Free Cinema' group in Britain and the 'Direct Cinema' group in the US. Directors such as Lindsay Anderson, Peter Watkins, D. A. Pennebaker and Frederick Wiseman used the unprecedented portability of the new cameras together with related technologies such as faster film stock and magnetic tape sound recording to create a genre of actuality filming which simply would not have been possible with 35mm. It has been argued that this is the direct ancestor of today's 'fly on the wall' television documentaries. By the 1980s 16mm was effectively finished as a widely used origination medium, as its principle market in television news and documentary filming was being superseded by the ever more portable and reliable broadcast video technologies. As Brian Winston notes, 'the 16mm synch rig's heyday was to be a brief two decades',[11] from the late 1950s to the late 1970s, and during this period the

Fig. 2.1 The Arriflex 16MQ camera in use for actuality filming, circa 1960s. 16mm with magnetic sound recording was used extensively in the 1960s and 1970s before its replacement by videotape for television news and documentary production. Photo courtesy of BFI Stills, Posters and Designs.

Fig. 2.2 Two photographs taken with a zoom lens on a modern 35mm still camera. The top picture was taken at the widest setting, the bottom one at the closest. Without a zoom lens, the second picture could only have been taken either by physically moving the camera closer to the building, or by replacing the lens with one of greater focal length.

most significant developments in camera design were driven by the growth of this format. As with Flaherty's use of an Akeley in the Arctic, the evolution of 16mm cameras marks a powerful example of an industry and culture being directly inspired by the possibilities offered by a particular technology.

One constituent technology which was key to the growth of the 16mm camera was the so-called 'zoom' lens. These lenses, which enable the operator to variably enlarge or reduce the focal distance (and thus the area of coverage) of the lens are today (like viewfinders) provided as a standard feature on virtually every still, moving image, digital and video camera sold, except those for highly specialist professional applications. It is now almost impossible to enter a consumer electronics shop and buy any sort of camera without one. Before the mid-1950s, however, the only lenses commonly available were of a fixed focal distance.

In its simplest form, a photographic lens consists of a single piece of ground and polished glass, the curved surface of which 'refracts', or directs the angle of light passing through it to converge on a determined point (such as the film surface) behind it. The distance between the lens element and the surface on which the light is intended to converge determines the *focal length*, which is the physical area covered by the lens as illustrated here. In reality, single-element fixed lenses are no longer used at all except in disposable still cameras, with most designs incorporating additional, movable elements enabling the lens to be 'focused', i.e. the physical distance between the lens and the subject being photographed to be set. In a film camera, this setting, together with the film speed, level of ambient light, length of exposure and lens aperture (the size of the hole through which the final lens element directs light onto the film surface) are all variables which determine the depth of field in a shot, which is the proportion of the image behind and in front of the subject which is also in focus.

A 'prime' lens – one with a fixed focal length – does not enable the area it covers to be altered, except by physically moving the camera to which it is attached. For this reason lens turrets became a widespread feature on 35mm moving image cameras from the 1910s onwards. They were first introduced on the Bell and Howell 2709 and proved ideally suited for studio use. For example, the use of a lens turret would enable a cinematographer to film a medium long shot immediately followed by a medium close-up without having to move the camera and without the director or performers having to reconfigure the scene on stage. For location and actuality filming, however, the restrictions imposed by prime lenses were far more of an issue. While newsreel cameramen in the 1920s and 1930s were extremely skilful in selecting and unobtrusively changing between lenses in filming events such as football matches and parades, the introduction of a lens which permitted its focal distance to be infinitely varied during a shot was obviously far more preferable. The first zoom lenses appeared in 1925.[12] One of the earliest to be marketed for 35mm use was made by the Leicester-based Taylor-Hobson company, which had become one of the world's leading producer of lenses for cinematography and projection. The 'Varo', launched in 1932, had a variable focal length from 40mm to 120mm but there were two major drawbacks: it absorbed so much light that its use was difficult, even under intense studio lighting, and the focus setting could only be adjusted by taking the unit apart, thus further limiting the sort of zoom shot which was practically achievable. Furthermore the lens alone was almost as big and heavy as a 35mm studio camera.[13] Similar models appeared in Europe and the United States during the 1930s and early 1940s, all of which had similar drawbacks and were not used on any significant scale.

A modern zoom lens enables its focal distance to be adjusted by effectively incorporating two lens systems into a single unit. The distance from the zooming lens to the prime can be moved, while a mechanical system automatically adjusts the focus of the prime as this is happening. This, of course, requires the light to travel through a much higher number of glass surfaces, which has two implications: firstly, that a zoom lens absorbs more light, and secondly that a greater level of distortion is introduced into the recorded image. For these reasons zoom lenses were not (and still are not) used extensively in 35mm studio work; in a controlled environment such as a film studio the shooting requirements of a fixed prime can easily be met and they generally deliver a much higher image quality. Zoom lenses made their biggest impact in the 16mm market, where the versatility of a variable focal length for news, documentary and location shooting had a major impact. Interestingly the first 16mm zoom lenses which resembled the ones used today in operation (i.e. the zoom could be adjusted without the need to refocus) to sell in significant numbers both came from French companies: the Pan-Cinor, made by Berthiot, was a 16mm lens with a 17.5mm to 70mm zoom in 1956, while Angénieux launched a similar model two years later. By the early 1970s later variants of the Arri BL were being packaged with a more advanced 12mm–120mm Angénieux (first produced in 1963), a combination which, for news and documentary filming 'became ubiquitous'.[14]

Studio cameras after the 1960s: Widescreen and special formats

As has been stated above, there was no significant development in conventional 35mm studio camera design during the 1950s. Hollywood continued to use Mitchell BNCs and, to a lesser extent, 2709s and Arriflexes, the latter of which was used extensively in European studios. The Soviets and Chinese developed what were effectively clones of a number of Western cameras, most notably the Mitchell NC. Developments in studio camera technology which did take place in the post-war period can be placed into two categories: the emergence of camera mechanisms and lenses for use in widescreen and wide film systems, and the introduction of precision electronics and microprocessors to control and synchronise a camera's operation from the 1980s onwards.

Of all the widescreen and special format systems which emerged during the 1950s (which will be considered in greater depth below under the heading of film formats), the two which stuck required little or no modification to existing camera mechanisms. These were CinemaScope (and its numerous offshoots and variants), which optically compressed, or 'squeezed' a wide image into the conventional 35mm frame, and the Todd-AO system (and again, a great many variants thereof) which used film stock 65mm wide and with a slightly taller frame area to produce a much larger, uncompressed image. Stereoscopic film, or 3D, enjoyed a brief period of popularity during the early to mid-1950s. In order to photograph an approximation of the three dimensions as seen by the human eye, a pair of electrically interlocked cameras (usually Mitchell NCs) were mounted in a large casing which both positioned them for parallax and blimped them for sound. This assembly weighed almost as much as a small car and made any form of camera movement practically impossible. The resulting two 'left eye' and 'right eye' film strips would be shown by two projectors running in synchronisation onto the same screen. The viewer wore a pair of polarised glasses, which would enable the viewer's brain to 'translate' the two projected images into

Fig. 2.3 An anamorphic image as it would appear on the film (left) and in projection (right).

the impression of a three-dimensional image. Interestingly this technique has been revived in the 1990s with the addition of 3D to the large-format IMAX process, in which a pair of wide-format 65mm Arri cameras are used. The CinemaScope process used existing studio camera mechanisms without any significant modification, while the first generation of 65mm cameras were the same adapted Mitchell NCs which were briefly used in the Fox Grandeur process at the end of the 1920s (see below). From the point of view of cinematography, the key widescreen developments during the 1950s and 1960s were essentially in the lenses.

The essential technology in CinemaScope is the *anamorphic* lens, which through a system of barrel-shaped or prismatic elements compresses the image along its horizontal plane during exposure. In projection, the process operates in reverse and the picture is expanded. The earliest generation of anamorphic lenses, produced by Bausch and Lomb, could only be used in conjunction with 50mm primes. The two had to be focused separately, thus inhibiting camera movement. Henry Koster, who directed the first CinemaScope feature *The Robe* (1953), recalled that blocking and acting on set had to be configured as for a stage play, simply because of the need for a static camera and the fixed focal length of its lens. As the 1950s and 1960s

progressed, lenses for widescreen cinematography became more versatile, could accommodate larger apertures and were produced in a wide range of focal lengths.

The Panavision company, founded by Robert Gottschalk in 1954, grew through the following decade and a half to become, along with Arri, the market leaders in 35mm studio camera technology. Panavision originally produced an alternative range of anamorphic lenses to the Bausch and Lomb anamorphs produced according to Henri Chrétien's original designs from the 1920s. The prime lens and anamorph could be combined into a single unit, making focusing easier and enabling quick and straightforward changes between lenses of different focal distances: by 1963 the lenses available ranged from 25mm to 360mm.[15] Panavision also introduced a new system for marketing its technology. As with the introduction by Bell and Howell of mass-produced, standard equipment design in the 1910s, this development would, by the end of the century, have been adopted in many different areas of the industry. Panavision only rented cameras and lenses to studios; it did not sell them outright.

There is one significant precedent for this, which was the three-strip Technicolor system in the 1930s and 1940s. A studio could not buy a Technicolor camera or film stock, and neither could the processing and printing be done at a lab of its choice. Instead, a producer had to enter into an all-inclusive contract with Technicolor. Its provisions covered the number of cameras available, where they could be used, the involvement of Technicolor personnel on set, the arrangements for laboratory work and the number of release prints of the finished film which the distributor undertook to purchase. Given the exclusivity and integrated nature of the process as a whole (the cameras by themselves were useless without access to the patented negative stock and laboratory techniques) together with the relatively small number of Technicolor films produced, this business model failed to make much impact on the industry as a whole; and in any case it was smashed in the early 1950s when single-strip tripack colour film, which could be used in any camera whatsoever, became available (see chapter three).

Panavision adopted a variant of this approach in which cameras and lenses were 'dry hired' to studios. Unlike Bell and Howell, which supported its equipment through sales of spare parts and maintenance contracts, Panavision cameras were supplied on a hire basis only. But unlike with Technicolor, no conditions were placed on how they could be used. This was accepted by studios because the inherent image quality produced by the Panavision lenses was far superior to anything the studios' own research departments or third-party suppliers were able to produce. Panavision's cameras were not fundamentally new designs, being based on Mitchell BNC mechanisms which the company acquired second-hand during the late 1950s and early 1960s, to which were fitted reflex viewfinders and more effective soundproof blimps. The Panaflex camera, first introduced in 1963, was basically a hybrid of Arriflex optics and Mitchell mechanism. These designs were further refined through the 1970s and 1980s. The last fundamentally new design from Arri, the 535, incorporated computer technology to synchronise film to shutter movement and can also record data on the edge of the film needed to assist in cutting the negative and

synchronising sound. A 65mm/70mm version, the 765, was also launched in 1989. Its first use on a widely-distributed feature film was to shoot *Little Buddha* (1993, dir. Bernardo Bertolucci), although the subsequent decline in the use of 65/70mm has prevented the 765 from entering mainstream production use. Arris, together with updated and modified Panaflexes, were the cameras used for the majority of 35mm filming at the end of the twentieth century.

This was the situation at the end of the 1990s, and it could well be that the two mechanisms which dominate 35mm studio cinematography – basically updated and heavily modified versions of the 1934 Mitchell BNC and the 1937 Arriflex – represent the final stage in the development of film camera fundamentals before the industry 'goes digital'. Not that this needs to happen soon: as we have seen, the most successful camera mechanisms have useful lifetimes measuring tens of decades, while the medium onto which they record – 35mm film – has been in constant use since the 1890s and continues to be used today.

The evolution and development of film camera technology has both shaped and been shaped by the industry and culture which has used it and its relationship with the other forms of technology needed to get an image from a studio set (or location) to a cinema or television screen. A number of economic models for the development and production of cameras and lenses have been seen. The earliest models were individually fabricated, usually by filmmakers themselves. Towards the end of the 1890s cameras began to be manufactured on a sale basis, though still in very small quantities. As the film industry rapidly expanded during the 1900s and 1910s the operation, performance and maintenance requirements expected of this technology made it apparent that mass-production would soon follow as the dominant economic model.

There then followed the 'Model T' approach of Bell and Howell in the 1910s and 1920s following their launch of the 2709. The 1920s and 1930s saw new cameras emerge, designed for specific uses and by more specialist sectors of what was rapidly becoming a large-scale global industry. These ranged from the Mitchell BNC and the Arriflex, which were intended primarily for studio use, to the Akeley and the Newman-Sinclair, designed for newsreel and actuality filming. The second half of the century saw the adaptation of pre-existing hardware to new formats (such as CinemaScope) and finally the marketing of integrated camera and lens packages by Panavision which, for studio use, established the supply of camera equipment very much as a service industry. The needs of the controlled production environment in a studio and those of documentary and news filming were addressed through separate forms of camera mechanism, and it was the growth of the latter which drove 16mm in the 1960s and 1970s. That such a relatively small number of mechanisms have accounted for the entire world's film production for over a century (extending the Model T analogy, imagine if only 10 designs of motor vehicle had accounted for 90 per cent of the world's road transport over a similar period) was made possible by a form of technology which did not in itself produce any hardware, but which rather have determined the way hardware has been designed and manufactured – film format standardisation.

Film Formats

'My fondest hope for the industry – standardisation.' – Donald J. Bell[16]

This is hardly a surprising comment, given that during the two decades before Bell made it, his company had risen to become one of the largest suppliers (probably second only to Eastman Kodak, which by the same token also had a vested interest in promoting standardisation) of moving image technology to the Western world on the back of that very strategy. If 100 per cent of the world's film studios use 35mm cameras, then a single mass-produced model could potentially take 100 per cent of the market share. If 30 per cent of those studios shoot on a different gauge, however, then the maximum potential number of sales is instantly reduced. There is a further need for technological standardisation within the industry, which relates to the comment by the projectionist at the start of his chapter, namely that film is 'this wide and goes through a projector'. Since the 1910s the world's dominant film industry – Hollywood – has depended for its success on being able to market its output globally, and not just in its country of origin (although the comparatively huge US domestic market gives Hollywood an inherent economic advantage compared to smaller countries).

Shortly after the conversion to sound the producer Samuel Goldwyn famously remarked that 'if the US spoke Spanish, Britain might still have a film industry'. He was of course referring to another type of standardisation: the spoken word. During the 1920s Hollywood was able to aggressively expand its overseas sales because American silent films could be made intelligible to non-English speakers by simply translating the intertitles, a process which cost virtually nothing in comparison with the overall production budget of a feature film. During the early years of sound, the technologies needed to achieve the same result, i.e. subtitling and dubbing, were difficult, limited, expensive and did not work very well. As a result Hollywood's international sales slumped, and about the only overseas market which did not fall victim to this was the UK. This was for the simple reason that as the two countries speak the same language (or at least, versions of it which are largely comprehensible to native speakers of the other), Hollywood talkies could continue to be marketed in Britain without any additional costs.

Even Hollywood's economic might could not standardise the English language to the extent that translated films are no longer necessary (so much so that British films featuring strong regional accents or dialects are routinely subtitled for release in the United States). But the principle articulated by Goldwyn applies to virtually every form of moving image technology, and indeed the fundamental principles of many other forms of technology are often dictated by pre-existing standards. For example, as we shall see in chapter three, the form of colour film which eventually dominated the industry throughout the second half of the twentieth century did so largely because it was 'backwards compatible', i.e. it could be used in pre-existing cameras and projectors. This was despite some major drawbacks compared to other colour systems which had been successfully used in the past. Standardisation was

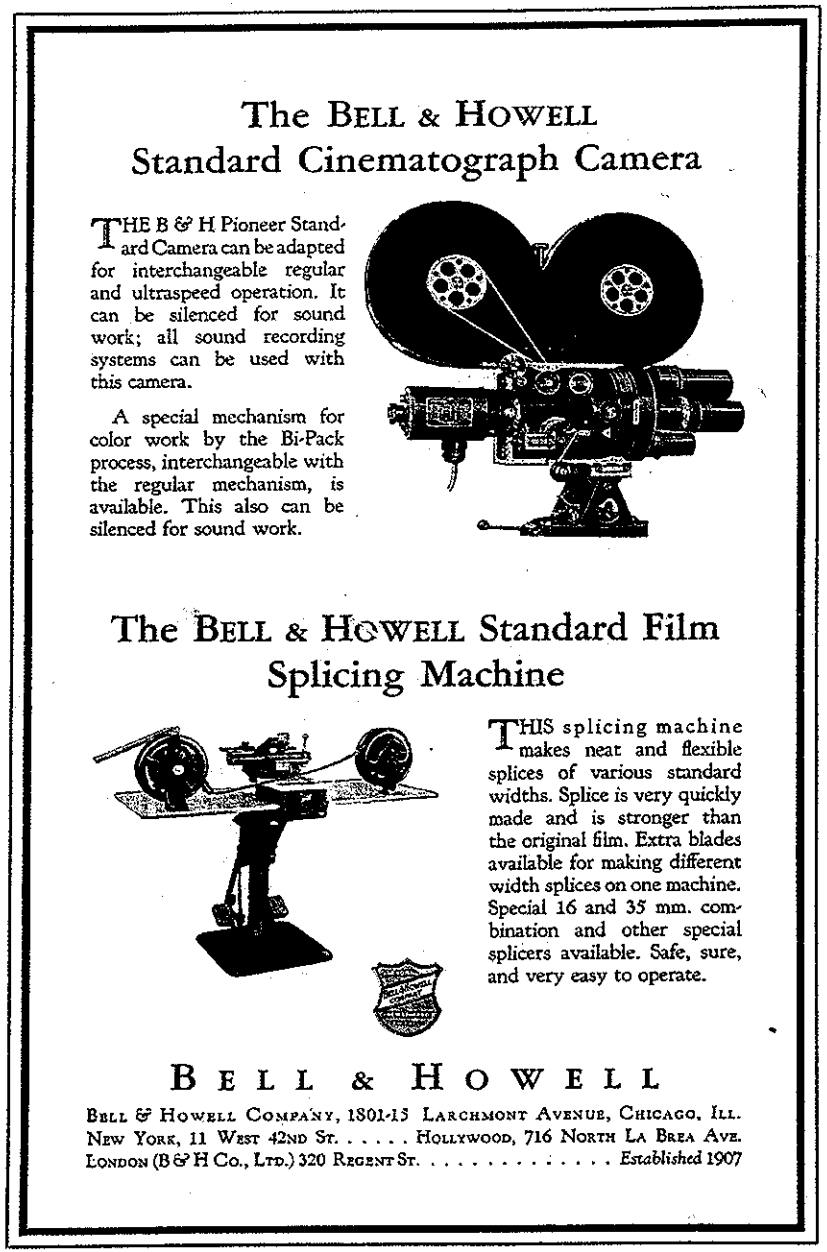


Fig. 2.4 Advertisement for the Bell and Howell 2709 camera and standard perforating machine, stressing the economic benefits of standardised equipment (author's collection).

vital to television being able to work at all, as the mass-produced receivers in people's homes had to all be able to decode and display the same transmitted signal. The history of television (and of electronic imaging in general) is of products deliberately being designed to work in conjunction with some technologies but be incompatible with others in order to serve the manufacturer's economic interests. This was a coming together of technological innovation and business practices which had its origins right at the very beginning, in the early 1890s: the standardisation of film formats.

Establishment and use of the initial standards

To begin, let us consider the parameters which are understood to be defined by the term 'film format':

- Width of the film.
- Orientation (which way round the base and emulsion side of the film is positioned for correct use in a camera, printer or projector).
- Dimensions, shape and position of perforations on the film surface.
- Dimensions, position and orientation (i.e. whether vertical or horizontal) of each photographic image, or 'frame'.
- The characteristics of each frame which determine how it must be viewed or reproduced, e.g. its aspect ratio (proportion of width to height) or whether the image is anamorphic or stereoscopic.
- The 'pull-down', i.e. the length of film which needs to be advanced by a camera's or projector's intermittent movement in order to position consecutive frames accurately in the gate. This is normally expressed in numbers of perforations, because film is moved intermittently by means of sprocket teeth which physically 'pull' the film by its perforations.
- The film transport speed, expressed in the number of frames per second which are exposed and projected in order to accurately reproduce the impression of movement as recorded.
- Dimensions, position and type (e.g. optical, magnetic or digital) of any soundtrack recorded on the film (this will be considered further in chapter four).

All of these variables must be the same throughout the production, duplication and exhibition processes in order for film to be able to reproduce the impression of a photographic moving image in the same way it was recorded: a film shot at 18fps will appear too fast if it is projected at 24, and a film shot with an anamorphic lens will appear compressed if projected through a spherical one (as in the 'squeezed' image in fig. 2.3). The process of standardisation, therefore, ensures that equipment manufacturers and users, producers, distributors and exhibitors are all singing from the same hymn sheet in the way they handle film-based technology in the various stages of its progress from studio to cinema.

The process from which emerged the first amd most widespread standardised film format began when Edison's assistant W.K.L Dickson placed an order for celluloid (nitrate) roll film from Eastman Kodak in August 1889. By 1982, when the Kinetograph camera and Kinetoscope viewing device (see chapter 5 for more on

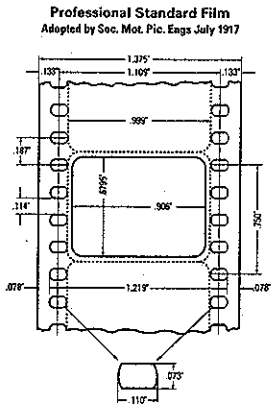


Fig. 2.5 The film format specification for 35mm 'professional standard' as determined by Edison in 1889 and subsequently adopted by the newly-formed SMPE (above), and an example of release print in that format.

the latter) went on market, the basic format was there. With slight refinements and modifications, it is still in use today. It was 35mm wide, 'pulled down' a length of four perforations to advance each frame and had an aspect ratio of approximately 1:1.33 (vertical:horizontal). These choices were, according to John Belton, 'determined by a complex interplay of technological, economic and ideological factors',[17] but essentially they derive from two factors. Firstly the width and density of the film base needed could be manufactured using production lines designed for existing still photography stocks with only minor modifications, and its size and weight when handled in the lengths needed for moving image use were considered acceptable. Secondly, the ratio of 1:1.33 conformed to Dickson's aesthetic ideas of shot composition, again in still photography (of which he was a keen amateur practitioner). Paul Spehr has argued that this position oversimplifies the process of research and development which led to the initial standardisation of 35mm, suggesting instead that it was arrived at because of the mechanical requirements of early Dickson mechanisms, the limitations of the film casting plant in use at the time and the desire to avoid the use of technologies covered by existing patents.[18]

These two decisions set an extremely far-reaching precedent. Because the world's largest manufacturer of film was producing 35mm on an industrial scale, equipment manufacturers throughout the world followed suit and made cameras, printers and projectors which used it. By the mid-1900s the almost universal use of 35mm had made possible an international trade in film equipment, as European manufacturers increasingly sought to market their products in North America. The result was a sustained patent war which lasted for over a decade, with various parties trying to restrict or deregulate the rights to commercially exploit specific aspects of the technology in various different countries. Chief among them was the 35mm standard. Transatlantic imports of film – both raw stock and completed productions – from the UK and France (principally from the French Pathé and Lumière companies) had worried Edison and the main American film producers for some time, with the result that a consortium consisting of Edison, Eastman and a number of smaller players (notably the American Mutoscope and Biograph Company) formed the Motion Picture Patents Company (MPPC) with an alliance of producers at a meeting on 18 December 1908. This was in effect a 'closed shop' which used Edison's patent rights over the basic camera and projection technology to ensure that only Eastman Kodak film stock could be used in conjunction with it. Kodak undertook only to supply stock to members of the company, who paid a levy to the

MPPC for every foot they purchased. Only one non-American company, Pathé, was invited to join. It is believed that this was either an attempt by Edison and Eastman to 'divide and rule' the European market[19] or a reflection of the fact that Pathé was the only non-American company capable of supplying sufficient quantities of film to the US market to represent serious competition.

The MPPC eventually fell apart through a combination of legal action and market forces. Those smaller elements of the American film industry which were not a part of it produced or bought camera and projection technology which circumvented Edison's patents and used it in conjunction with imported stock. This undermined the MPPC's monopoly, as the technology regulated by its patents gradually lost market share to an emerging sector of competitors. A series of lawsuits culminating in a Supreme Court decision in 1917 effectively settled the issue: the practice of compulsorily tying the use of Eastman Kodak film to specific cameras and projectors was ruled to be a violation of antitrust legislation. Jeanne Thomas Allen suggests that 'the Edison/MPPC phase in the industrial development of film marks a transitional step from the entrepreneurial competition of the early years to consolidation and conservatism'.[20] It is important to bear in mind that the underlying basis for this development taking place was the existence of a *de facto,* almost universal film format: 35mm, 1:1.33, four-perf pulldown.

If Eastman's film had not been technically compatible with non-Edison equipment, there would have been no need to establish the MPPC in the first place, and even if it had existed there could have been no serious allegation that its activities were monopolistic, because producers would have been free to obtain film and equipment 'packages' from other sources. A more recent analogy would be the Apple computer company's policy of marketing computer hardware and the Mac OS operating system as a combined package. As no other operating system will run on Apple computers and Mac OS cannot be used on any non-Apple computers, it can hardly be considered a restrictive practice for the two to be sold together, because one is useless without the other. But if Microsoft were to form an alliance with a PC hardware manufacturer and then refused to allow its Windows operating system to be used with any other computers, that would be a completely different matter. Windows is compatible with personal computers produced by a wide range of manufacturers, and also on machines assembled by consumers from individually purchased components. Any systematic attempt to restrict this would thus be monopolistic, since, as with 35mm film, the technical standards implemented within the products allow for greater compatibility.

Although the MPPC did not last very long, the film format it unsuccessfully tried to control was rapidly becoming established as the industry standard. During the late 1900s automated perforating technology gradually standardised the size and pitch of 35mm perforations (see chapter one), and an international conference of film producers in Paris in 1909 adopted 35mm as the professional standard.[21] In July 1916 the Society of Motion Picture Engineers (SMPE, from 1950 the Society of Motion Picture *and Television* Engineers) was formed in New York, which by virtue of the American film industry's economic dominance would become the world's

most prominent standard-setting body throughout the century. Its objectives were 'advancement in the theory and practice of motion picture engineering and the allied arts and sciences, *the standardisation of the mechanisms and practices employed therein* and the dissemination of scientific knowledge by publication.'[22] One of the first standards it set is the one reproduced in fig. 2.5, which enshrined 35mm as the 'professional standard film'.[23]

Film formats and the conversion to sound

The conversion process itself will be considered in detail in chapter four. This process, which in the West happened approximately between 1926 (the first commercial screenings of a feature film synchronised to a recorded soundtrack) and 1932 (the last cinemas without sound equipment either getting it or going out of business), had two significant impacts: the issue of formats and standardisation, which will be discussed here. The two main standardisation variables were the film transport speed and aspect ratio. The former had never been effectively standardised while the 'professional standard' of the latter was incompatible with the new sound technology and had to be changed.

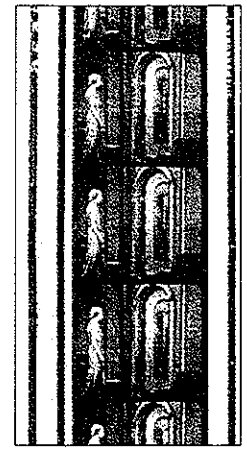
As has been mentioned in the context of cameras, the speed of film through a mechanism is expressed in the number of individual images, or frames, exposed or projected per second (the acronym 'fps', which for some reason is usually given in lower case).[24] The majority of hand-cranked cameras followed a convention established by Lumière Cinématographe whereby one turn of the handle exposed eight frames. This was far too slow to give the illusion of continuous movement in projection, and therefore Lumière took to cranking at two turns, or sixteen frames, per second. This was also a convenient measurement because 16 frames are equal to exactly one linear foot of 35mm four-perf. With a three-blade shutter installed in the projector this was enough for the movement on-screen to appear seamless. Lower speeds resulted in visibly disjointed or jerky movement. Higher speeds give a more accurate rendition of movement, because less 'unrecorded' or 'lost' time elapses between one frame being exposed in the camera and the next. But higher speeds consume a greater amount of film stock and were generally considered unnecessary.

There was no standard shooting and projection speed during the silent period and no attempt was made to ensure that the two were identical in the case of individual films. Given that both cameras and projectors were generally hand-cranked in those days it would have been technically impossible to determine and enforce one anyway. Before the rise of the studio system after World War One, individual cinematographers would evolve characteristic shooting speeds and cinemas would usually determine the projection speed of a film in order to fit an allocated time slot for its screening.[25] During the 1920s, studios would advise cinemas of the speed they wished a film to be shown at, which often bore little relationship to the shooting speed. For example, comic effect could be heightened or action sequences made more spectacular by projecting a film at a slightly higher speed than it was shot at.

The result of the existing technology and industry practices of the late 1920s was that speed remained one variable not to have been fixed by the process of industrial development which led to the 35mm 'professional standard' of 1917. These industry practices notwithstanding, another major reason for this is that individual viewers tend not to be particularly sensitive to slight variations in the rendition speed of a moving image. As an SMPE member noted in 1927, 'the plain truth of the matter is that except for certain key actions, such as walking, eating and dancing, the projection speed can vary over wide limits without apparent falsity'.[26]

This was certainly not the case with an audio recording. The technological principles involved will be covered in greater detail in chapter four, though for the purposes of this discussion it is important to note that all analogue sound processes (i.e. all sound recording technology until the 1980s) depended on consistency and accuracy of the speed at which the recording medium is transported in both the recording and reproducing devices. Any variation will not only introduce differences in speed, but also in the frequency (pitch) of the sound being reproduced. Thus even a slight inconsistency of speed will sound obviously 'wrong', unlike its moving image counterpart which, thanks to the human brain, has a built-in margin for error. When moving images and sound began to be recorded and reproduced synchronously, therefore, there was, for the first time, a need for a standardised and consistent film transport speed to be implemented throughout all sectors of the film industry.

After a period of experimentation, the two competing sound systems which were launched both used a standard speed of 24fps, or 90 feet per minute. According to an engineer who worked on the Western Electric technology, the figure was arrived at as a 'reasonable compromise', in the middle of the range of projection speeds commonly used by exhibitors.[27] It is certainly true that the decision was largely exhibition-led. Cinema projection speeds gradually increased throughout the 1920s with the effect that by 1925, a Hollywood director remarked that 'as a matter of fact, most theatres show pictures at a speed of 85–90 feet per minute [22.6–24fps]', while the head of a cinema chain in Indiana also remarked that 24fps had become a *de facto* standard for projection.[28] The reasons for this will be covered in chapter five, but in relation to sound it would seem that the engineers involved in determining the sound speed decided to formalise what had become a standard by default rather than attempt to enforce a new one. The implementation of this standard required all cameras and projectors to be powered by electric motors, as neither



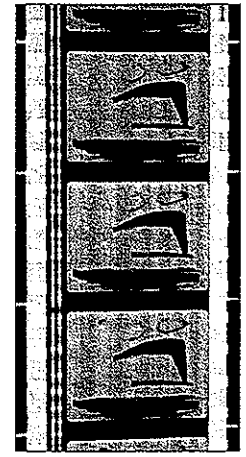


Fig. 2.6 The 'early sound' aspect ratio (above) and the 'Academy' ratio of 1932 (below). The frames above have been photographed with a 'full gate' silent camera and the optical soundtrack printed afterwards, which crops the image – note that the rounded corners of the camera aperture are visible on the right but not the left of the film reproduced above. The Academy ratio introduced a black bar ('matte') between each frame in order to restore the on-screen proportions of the old silent ratio.

clockwork nor hand-cranking could achieve the consistency of speed needed for sound reproduction.

The other format change required by the conversion to sound was to the 'standard professional' frame dimensions. The 1917 specification defined a frame which occupied the entire width of the film between the two rows of perforations, with a very small black matte of .071" separating each frame. This standard remained in use with the Warner Bros.' Vitaphone sound system, in which a film camera was mechanically synchronised to a disc (gramophone record) cutter, and the projector to a turntable. Thus the soundtrack did not affect the topography of the film in anyway, apart from requiring a constant speed of 24fps. The Fox Movietone, RCA Photophone and Western Electric systems, however, recorded optical sound: that is, the analogue waveform produced by the microphone was recorded photographically onto the film. The first sound films were either photographed as 'single system' negatives (meaning that both picture and sound were recorded simultaneously in the same camera and onto the same negative stock) using specially designed cameras, or on separate strips, using largely unmodified 2709 and Mitchell NC cameras for the picture, with the recording being made on a separate sound camera and synchronised during the editing process by means of a clapperboard.[29] For projection, both the picture and sound recordings had to be combined onto a single strip of film, with the result that the soundtrack obliterated a vertical strip of picture on the left of the frame (see fig. 2.6, upper illustration). The aspect ratio of the visible area of the frame remaining is thus changed considerably from the 1917 'professional standard', to a ratio of approximately 1:1.15.

This created problems both in production and in exhibition. In cinemas, projectionists discovered that either the optical soundtrack would be visible on the screen or the picture was too small to fit it. They soon started producing aperture plates (a piece of metal mounted between the light source of a projector and the film, with a hole corresponding to the dimensions of the printed frame) which masked off the soundtrack and a strip at the top and bottom of each frame, together with lenses which magnified the remaining picture area slightly more so that it fitted onto their existing screens. This practice was not approved of by the studios. Cinematographers found that if a sound film produced for disc release were subsequently printed with optical sound-on-film, an area along the left of the picture would be lost. And any sound-on-film in which shots were composed for the square ratio would risk actors' heads being cropped in projection. King Vidor, while filming *Hallelujah!* on location in 1928, was forced to cable his producer over the issue, asking him to 'please let me know if you are contemplating changing method of synchronising releases from records to Movietone so I can allow space outside of frame'.[30]

Possibly because tens of thousands of cinemas already existed with their stages and screens built for the 1:1.33 silent ratio, the early sound aperture did not last. One of the few people to defend it was Sergei Eisenstein, who preferred its aesthetic qualities,[31] but his was a lone voice: the industry consensus was that Dickson's ratio of 1:1.33 should be somehow restored. This was achieved by defining new frame dimensions which did not occupy the area in which the soundtrack was positioned

and increasing the height of the black matte between each frame to the point at which the silent ratio was restored, albeit into a smaller frame size. Improvements in emulsion density in the previous three decades meant that there was no significant loss in the definition of a projected picture using the newer, smaller frame. This ratio was adopted by the Academy of Motion Picture Arts and Sciences in 1932 (hence it became known as the Academy ratio), with the SMPE implementing the standard specifications shortly afterwards.[32]

Widescreen film formats

The Academy ratio remained the predominant format for cinema exhibition for a further two decades, until the mid-1950s. In other areas of moving image technology it remains the standard, most importantly television (although the introduction of DVD and digital TV broadcasting in the very last years of the twentieth century began to stimulate sales of widescreen television receivers), but also in amateur film and, much later, the display monitors for personal computers. There are a number of factors why widescreen became established when it did, in the early 1950s. The emergence of television and the need for theatrical cinema exhibition to find a technological means of product differentiation from its new competitor (i.e. a selling point which television could not offer) is often cited as a reason, as are post-war demographic changes which adversely affected traditional cinema audiences.[33]

One question which is worth addressing is why several large-screen and widescreen systems were developed, used on an experimental basis and then abandoned during roughly the same period as the conversion to sound. One notable silent precursor was Magnascope, which used standard 35mm film and what was in effect a zoom lens on the projector.[34] During certain key sequences in a film the projectionist 'zoomed out' the lens (i.e. increased its focal distance) and opened motorised masking curtains around the screen, thus increasing the size of the projected image. Two notable productions which used this device were *Chang* (1927, dir. Merian C. Cooper & Ernest B. Schoedsack), a wildlife documentary in which shots of a stampeding herd of elephants were 'Magnascoped', and *Wings* (1928, dir. William Wellman), a World War One fighter-pilot melodrama in which the Magnascope lens was zoomed to project the aerial sequences, which were shot using Akeleys carried in the planes themselves. Another similar process which temporarily increased the screen size and/or ratio for dramatic effect was the French Polyvision system, which in anticipation of Cinerama 25 years later used three interlocked 35mm cameras and projectors to produce the image. The only significant feature film which used the system was *Napoléon* (1927, dir. Abel Gance), which even then was only shown in widescreen in a handful of venues.

In the following years attempts were made to introduce widescreen systems which were based on wide film gauges (i.e. film which was physically wider than 35mm). All stuck to the four-perf pulldown of standard 35mm, presumably so that the intermittent movements of existing cameras and projectors could be incorporated into the new equipment, although John Belton argues that the cinema architecture

at the time precluded the use of frames higher than four perforations.[35] Paramount introduced Magnafilm, which was 56mm wide with an aspect ratio of approximately 1:2.0; Warner Bros.' 'Vitascope' used 65mm film with a similar ratio, and the RKO 'Natural Vision' format used 63.5mm film with a ratio of 1:1.85 (the same ratio as the most commonly used 35mm widescreen format today). All were used for a small number of features shown only in specially equipped city-centre venues in roughly the period between late 1929 and early 1931, before promptly disappearing without trace for a generation.

One widescreen format introduced during the 1920s is of particular interest, since its underlying mechanical technology was recycled into one of the more successful systems of the 1950s, and indeed was still in limited use at the time of writing. Used briefly between the first public screening on 29 September 1929 and the summer of 1930, Fox Grandeur used 70mm film in a process which had much in common with the 70mm Todd-AO format of the 1950s. The cameras were Mitchell NC mechanisms adapted for 70mm use and the projectors were based on existing Simplex machines, with the 70mm gate and film path components being supplied by Mitchell. Grandeur differed from the following generation of 70mm technology in that the pulldown was four-perf, the film speed was 20fps and the sound was optical. A number of shorts (including several releases of the Fox Movietone newsreel) and two features were shot in 70mm Grandeur: the musical revue *Happy Days* (1930, dir. Benjamin Stoloff) in which Marjorie White plays a showboat singer who makes it big on the New York stage, and *The Big Trail* (1930, dir. Raoul Walsh), a western charting the tribulations of an Oregon wagon train which was notable only for its use of widescreen and a hitherto unknown lead actor called John Wayne.[36] Both films were shot simultaneously using the 70mm Grandeur and standard Mitchell NC 35mm cameras.

But in the end, the first generation of widescreen technology disappeared almost as soon as it arrived. One possible reason for this could be the economic strategies of the studios for promoting its use. The 1929/30 introduction of widescreen was an attempt by the studios to link it technologically and institutionally to sound: the thinking was that while the industry was absorbing the huge capital outlay needed to convert to sound (e.g. the equipment needed in hundreds of thousands of cinemas across the world), widescreen could be introduced at the same time for comparatively little extra. The two were deliberately marketed as a package, as this quote from a Fox press release shows:

> The development of the Grandeur system has been an inevitable result of the revolution which Fox Movietone bought to the motion picture business. The new type of motion picture entertainment which came with sound demanded equal improvement in visual reproduction; Grandeur pictures do for vision what Movietone does for sound.[37]

The rest of the industry did not agree, and widescreen was effectively shelved for the next two decades. Another factor which mitigated against the introduction of widescreen in 1929/30 was again economic rather than technological: the Wall Street crash of 1929. Its timing could not have been better for sound and could not have been worse for widescreen. In the months leading up to their peak on 3 September 1929 US share prices rose by several hundred per cent, so much so that 'neither the World Series nor talking pictures could compete in fascination with the Stock Exchange ticker as it tapped out dreams – and realisations – of avarice'.[38] On 23 October – less than a month after the Grandeur premiere of *Happy Days* in New York – they crashed, marking the start of a recession which was to last until the middle of 1932. Compared to other US service industries Hollywood survived largely unscathed, but the new economic climate served to inhibit investment in technological research and development along with virtually everything else which was not essential to the core business of film production and exhibition. It could well be that if the Wall Street Crash had happened a year later, widescreen would have become an established technology by the mid-1930s. As it happened, the next significant technological change introduced by the American film industry – three-strip Technicolor – began to appear in the late 1930s, by which time the US economy was firmly on the way to recovery.

In this context sound just got in under the wire. By the autumn of 1929 Hollywood had committed to producing 'talkies', a large proportion of cinemas throughout the Western world had already installed the reproduction equipment and the rest were compelled to doing so whether they wanted to or not. Too much money had been spent and too many boats had been burnt for the industry to back out. Widescreen, however, was still in the research and development stage with the early experimental shows in first-run city centre cinemas taking place during the autumn and winter of 1929 at the moment of, or just after the crash. Sound had already passed the point of no return. This huge investment in technology had been made largely on the back of speculative investment by bankers, who now had no choice but to wait until it started delivering revenue. The crash ensured that however hard the studios tried to link the technologies of sound and widescreen, the money just was not available to enable an industry-wide roll out of the latter. But a further explanation for the failure of the 1929/30 widescreen experiment can be found in an issue that has recurred throughout this chapter: standardisation. This happened very quickly with sound: sound-on-disc was obsolete by the early 1930s and although various competing systems emerged for optically recording sound-on-film (which will be discussed further in chapter four), they were all reproducible using the same equipment in the cinema. This was not the case with the 1929/30 widescreen cinema processes: they used film gauges of differing widths, each requiring a totally different set of cameras and projectors, i.e. they violated the 35mm standard. Furthermore, other aspects of the format definitions (such as the speed and aspect ratio) were not standardised, thus adding to the cost and complexity of their use. Of these systems a contemporary technical manual remarked that 'just as there was no standard of film size, no rate of fps was established and the taking rate varied from 8 to 60 among the different systems, each of which was distinguished by some fantastic and polysyllabic name'.[39] Hollywood producers called for a widescreen standard to be established, but none ever was.[40]

The 1950s and widespread widescreen

Widescreen film formats returned – this time for good – in the early 1950s. An indication of the reasons why can be found in the opening scenes from *This is Cinerama* (1952, dir. Mike Todd *et al.*). This film, the very first of the new generation of widescreen productions, begins with a black-and-white, Academy ratio prologue in which the broadcaster and newsreel commentator Lowell Thomas presents a brief history of 'moving' images from Neanderthal cave paintings to the post-war growth of television. He emphasises the small, black-and-white images produced by the latter immediately before we see the curtains open out to reveal the full screen and thence the first wide, colour images.

Television has been blamed for many of the industrial, cultural and technological changes to film and cinema during the second half of the twentieth century, and it is certainly true that the 1950s saw the most intensive growth in the market saturation of this medium. But it would be oversimplifying the issue to say that widescreen technology was dusted off and put into full-scale use at the moment it was simply as a weapon with which the film industry could take on television. Wider forces for change and wider processes of change began to emerge during this period, of which this technology was an important factor but not the only one. Another example to sit alongside Lowell Thomas and television is a 1958 manual entitled *How to Make Good Home Movies*. The case-studies it explores include a country fair, a mother bathing her baby, 'Laura's Seventh Birthday' and 'Going to the Zoo'.[41] The many and various leisure activities cited in the book do not include going to the cinema. In Patricia Zimmerman's words, moving images had become 'a commodity for use within nuclear families' as distinct from a form of entertainment consumed in a communal setting.[42] The immediate post-war period saw a large proportion of the male population being released from the armed forces and starting families. This in turn led to a large expansion in house-building and the creation of new, suburban communities which were an appreciable distance from the town and city centres where cinemas tended to be located. Furthermore, a significant proportion of the cinemas in the UK and Europe had been damaged or destroyed by bombing. In the US a court decision in 1948 (the so-called 'Paramount case') found that the dominant Hollywood studios were operating monopolistic practices and ordered them to sell many of the cinemas they owned. A significant number closed as a result, and not only those which were studio-owned or controlled: independent theatre operators were also affected by these fundamental changes in the economic and regulatory framework of the exhibition sector. Film historians have characterised the late 1940s and early 1950s as marking the end of the 'Classical Hollywood' period, or in economic terms the dominance of the Hollywood 'system' in which studios, distribution infrastructure and cinemas were all owned and operated by the same companies. The film industry's core market was under threat from a number of economic, cultural and demographic changes; as with sound and the Great Depression, technology – this time in the form of a significant upgrade to the picture and sound technology – was the weapon Hollywood used to fight back on all these fronts.

Cinerama

Essentially, four significant widescreen systems came on the market during the early to mid-1950s. The first, Cinerama, was the invention of Fred Waller, a Hollywood research scientist between the wars, and Mike Todd, a Broadway theatrical producer. The process consisted of a cinema auditorium fitted with a deeply-curved screen intended to approximate the human field of vision, lit by three synchronised projectors positioned at reciprocating angles in boxes at the rear of the auditorium. Cinerama images were shot using three interlocked camera mechanisms mounted on a frame, using standard 35mm film stock but with a non-standard pulldown of six perforations, giving each image, or 'panel', an almost square ratio, and a non-standard speed of 26fps. There was no sound-on-film, with the six-channel magnetic soundtrack being reproduced from a separate device (known as a 'follower') which was electronically synchronised to the projectors. The first public screening of *This is Cinerama* took place in New York on 30 September 1952.

Cinerama followed the familiar pattern established by Vitaphone for sound and three-strip Technicolor in the case of colour: it established a market for widescreen and proved that the principle was an economically viable one, but the process itself was technically flawed and was soon pushed out by other systems which resolved the problems that quickly emerged. Cinerama camera assemblies were large, cumbersome, had a limited range of lenses and were very restrictive to use, especially in shooting fictional feature films in the way that Hollywood directors were used to. Cinerama required a specially designed auditorium which necessitated totally gutting and rebuilding an existing cinema to accommodate the projectors and screen. Cinerama exhibition was very labour intensive, needing as many as 17 projectionists to operate each screening. The joins between each panel were clearly visible, despite modifications to the projector apertures to try and lessen their impact. And the technology itself was just not very reliable. Four film elements running in separate mechanisms had to remain in constant synchronisation, and any show could be abruptly halted either by an equipment failure or a film break (and early triacetate film stock tended to break quite often). This happened so frequently that a number of short 'breakdown films' were produced. These featured Lowell Thomas explaining the intricacies of the technology and the various ways in which it could go wrong while the projectionists tried to resynchronise and restart the Cinerama projectors.

The other precedent set by Cinerama was to subtly change the exhibition context to meet the needs of widescreen technology. During the 'classical' period a key reason for Hollywood's economic success was that format standardisation and duplication technology allowed a single film to be copied many hundreds or even thousands of times at a relatively insignificant cost (insignificant in comparison with the production costs of a feature) and distributed all over the world. The studios were thus able to apply the 'pile 'em high and sell 'em cheap' principle, because the potential customer base was so large that even lavishly produced star vehicles could be 'sold' to consumers in the cinema at a very low unit cost. This was just not possible

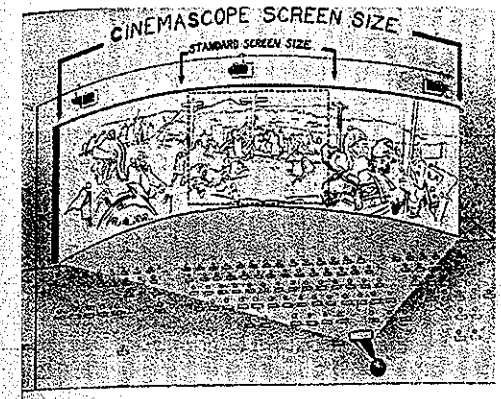
with Cinerama, given its technical and architectural demands. So Todd and Waller adopted the so-called 'road show' practice, in which a single film would be shown in a prestige city-centre venue for months at a time and then move on, rather than for two or three days at hundreds of venues across a country. Seats had to be booked in advance and the price was similar to that of a Broadway musical (i.e. many times more than a visit to a suburban fleapit). While this was essentially a practice borrowed from legitimate theatre, 'road-shows' had been used to a deliberately limited extent by Hollywood to market prestigious or highly-budgeted films from the teens onwards. Its significance in this instance was in showcasing form (i.e. the technology) over content.

Hollywood and 3D

In the end only seven films were produced using the three-projector Cinerama system, most of them travelogues and documentaries,[43] and less than thirty compatible auditoria were ever built.[44] Nevertheless, Hollywood took note of Cinerama's short-term economic success and looked for ways of capitalising on the public enthusiasm for new moving image technologies while also meeting the requirements of mass-distribution. Their first attempt did not last very long. Immediately before one of the major studios took on widescreen, independent producer and former radio impresario Arch Oboler produced and directed *Bwana Devil,* first shown in Los Angeles on 26 November 1952. Though unremarkable in terms of content – a cheap and nasty low-budget horror film in which a pride of man-eating lions pick off unsuspecting railway passengers – in form it marked the beginning of Hollywood's technological fight back. While Todd and Waller had changed the shape of the screen, Oboler tried to change the shape of the picture itself – with an image that appeared to be three-dimensional.

The technical processes he used were not new,[45] though Oboler's exploitation of them marked the first (and last) systematic attempt to mass-market 3D. This format uses the Cinerama method of multiple camera mechanisms physically positioned in relation to each other and electrically synchronised: in this case two cameras are mounted with their lenses roughly the same distance apart as human eyes, in order to expose a 'left eye' and 'right eye' image. The resulting films are then projected simultaneously through polarising filters while viewers wear spectacles which enable the human brain to perceive the two images as originating separately through their left and right eyes, thus reproducing the illusion of a three-dimensional image. Oboler's 3D system did not vary the standard aspect ratio or film format, which remained the 35mm four-perf Academy ratio. Therefore no architectural modifications to cinemas were needed and standard cameras and projectors could be used (thus reducing production and exhibition costs), though two of each were required.[46]

For a very short period during 1953 and 1954 two Hollywood studios attempted to introduce 3D as an alternative to Cinerama. Unlike Oboler's B-movie 'lion in your lap' Warner Bros. and MGM briefly attempted to produce first-run features in the format, for example the musical *Kiss Me Kate* (1953, dir. George Sidney) and the sus-



CinemaScope, with its revolutionary new lenses, achieves the illusion of depth without use of glasses. Its life-like, panoramic scope, plus stereophonic sound effect provided by strategically placed speakers permitting sound to originate from the part of the screen where the action takes place, combine to make the audience experience complete engulfment and participation in the action. Dotted lines show size of conventional screen as compared to new concave, all-purpose CinemaScope screen.

TWENTIETH Century-Fox's revolutionary CinemaScope has successfully passed a long series of exacting tests and has proved itself one of the greatest technological advancements since motion pictures found their voice 20 odd years ago.

Following President Spyros P. Skouras' and Production Chief Darryl F. Zanuck's momentous decision to go all out for the life-like curved screen process with stereophonic sound, the studio also announced that directors, cameramen and technicians had moved with speed, confidence and efficiency to make CinemaScope pictures available to cinemas this autumn.

After the audience-participation medium had been subjected to experiments to master the improved technique which it makes possible, it was put to work on the studio's biggest production for years, the $5,000,000 "The Robe," a Technicolor film of Lloyd C. Douglas' best-seller. At the same time several other films were scheduled for CinemaScope treatment while samplings of every conceivable action and locale were photographed to demonstrate the advantages of the new medium for every type of film — action, drama, musical or comedy.

Simple and inexpensive and not requiring glasses for viewers, CinemaScope achieves with one camera and one projector the

Fig. 2.7 Publicity brochure for CinemaScope produced by TCF for the British launch of the format in 1954 (author's collection).

pense thriller *Dial M for Murder* (1954, dir. Alfred Hitchcock). But within a short time the compatibility issues and technical shortcomings of 3D proved to be its undoing. As with Cinerama there was a lot to go wrong in the cinema (for example, a film break would halt the show), additional projectors were needed and the audience had to wear uncomfortable glasses for the system to work. Following Oboler's precedent 3D continued to be used in the occasional horror film for several decades afterwards, e.g. *Jaws 3D* (1983, dir. Joe Alves), the closing reel of *Freddy's Dead: The Final Nightmare* (1991, dir. Rachel Talalay), and more recently as an add-on to the IMAX special format process. But as a mainstream film format it never gained a foothold.

CinemaScope

During the brief 3D interlude of spring–summer 1953, Twentieth Century Fox (TCF) were working on an alternative widescreen system, to be known as CinemaScope. While production practices changed and a certain amount of auditorium rebuilding still had to be done (i.e. to accommodate the wider screen), this was not anything like as extensive or expensive as for Cinerama, because CinemaScope was able to produce a wide image using existing cameras and projectors with only minor modifications. CinemaScope used standard 35mm, four-perf film with frame dimensions of 18.16mm by 23.16mm, giving an aspect ratio of approximately 1:2.55, and four stripes of magnetic oxide (one on each side of either row of perforations) to carry the stereo soundtrack. Smaller perforations, known as 'Fox holes' were used to maximise the available surface area, and the picture was horizontally compressed using anamorphic lenses on the camera and projector. TCF originally licensed the lens design from the French scientist Henri Chrétien, whose 'Hypergonar' lenses were used in France during the brief widescreen boom of the late 1920s. A succession of American companies – initially Bausch and Lomb, and later Panavision – subsequently developed anamorphic lens technology to improve the speed, focal distance and optical characteristics, and within a few years it had become a core part of American film production, later becoming established in Europe and across the world. On 16 September 1953 the first CinemaScope feature, *The Robe*, opened in New York, almost exactly a year after Cinerama had done likewise.[47]

Of the widescreen systems introduced during the 1950s, CinemaScope was by far the most successful, if measured by the criterion of market saturation. This is because its inventors had followed the principle which had characterised all the key developments in moving image technology up to that point: it maximised the on-screen effect, minimised the investment needed in technology and infrastructure and was entirely backwards compatible. CinemaScope consisted of equipment which was added to existing cameras and projectors and which did not affect their ability to shoot or show any of the pre-existing 35mm formats. Interestingly, the one aspect of CinemaScope to be rejected by the industry was TCF's attempt to package the process with stereo sound. Just as a generation earlier Fox had tried unsuccessfully to sell Grandeur as an integrated package with Movietone, on this occasion there was sustained resistance from smaller, independent exhibitors to being compelled to buy

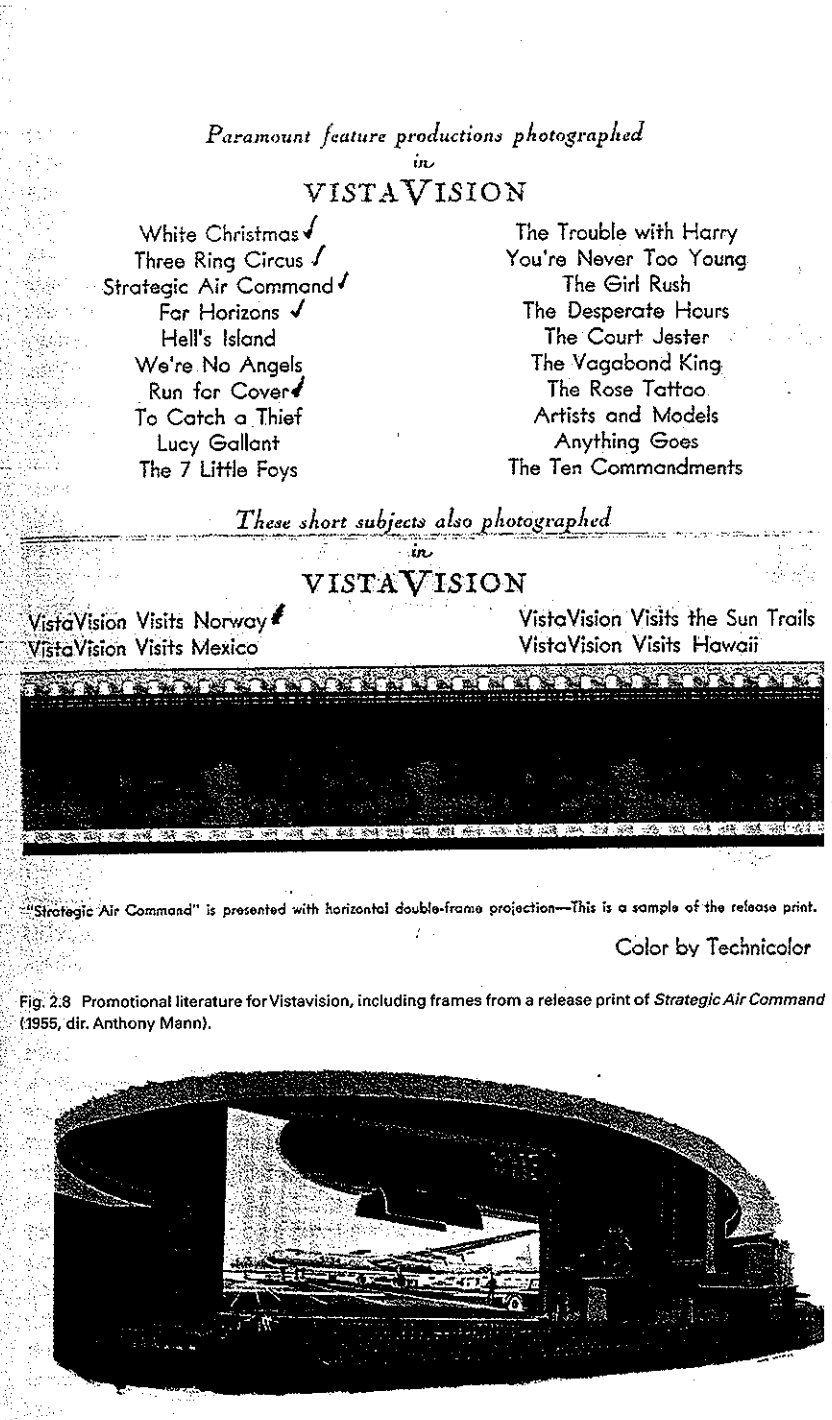


Fig. 2.8 Promotional literature for Vistavision, including frames from a release print of *Strategic Air Command* (1955, dir. Anthony Mann).

both CinemaScope and magnetic stereo at once. In 1956 TCF followed the lead of other studios (most notably Warner Bros.) which had started producing anamorphic prints with mono optical sound and announced that it would do likewise. In the new variant, the width of a frame was reduced to the 'scope' ratio we have today of 1:2.35 in order to accommodate standard perforations. Fox holes had proven susceptible to tearing and straining in repeated projection, and had significantly shortened the useful life of each print, although four-track mag prints continued to be produced on a limited scale until the late 1970s. The MPPC episode in 1909–17 had shown that attempts to make the purchase of one technology (film stock) conditional on another (cameras and projectors from approved manufacturers) in a way which defied market forces would not work. Hollywood found this out again a decade later when they tried to introduce widescreen on the back of sound, and a third time when TCF tried to introduce stereophonic sound as an integrated package with CinemaScope.

VistaVision

The following spring, on 27 April 1954, Paramount unveiled the Bing Crosby musical *White Christmas* (1953, dir. Michael Curtiz) at New York's Radio City Music Hall, and with it yet another widescreen system intended to make technology succeed where predicable genre cinema was rapidly failing. VistaVision also used 35mm film, but instead positioned the wide frame horizontally. With frame dimensions of 24mm x 36mm (the same size as the frame exposed in a 35mm still camera), this offered a vastly higher definition image to CinemaScope, without introducing the slight distortion caused by even the highest quality anamorphic lenses. As with CinemaScope, only one camera and projector was needed, but unlike with CinemaScope, these could not be used with any other format.

VistaVision lasted as long as it did – until *One Eyed Jacks* (1961, dir. Marlon Brando) as a primary production format – largely because VistaVision originals could be optically printed onto standard 35mm (spherical or anamorphic) with the release prints retaining a significant increase in picture quality when compared to films originated in a lower resolution format, hence the slogan 'Motion Picture High Fidelity'. With a native aspect ratio of approximately 1:1.5 VistaVision did not claim to offer a wider image than any of its competitors but did produce a sharper and denser picture, even after printing to a different format for exhibition. The only other studio to use VistaVision was the Rank Organisation in the UK, which licensed it from Paramount in 1955. According to Geoffrey Macnab this was purely and simply to combat the spread of television,[48] and support for that argument can be found in one of Rank's first VistaVision productions, possibly one of the most atypical examples of a big-budget widescreen premiere. In *Simon and Laura* (1955, dir. Muriel Box), the ostensibly happy couple of a television soap opera are in real life on the verge of divorce, and finding it increasingly difficult to separate their idyllic fictional relationship on the small screen with their mutual hatred of each other on the larger VistaVision one. To warn of the perils of live broadcasting, the film's *dénouement* shows the transmission of the series' Christmas special episode, in which the two stars conduct an unscripted, spontaneous and almighty row as the producer looks on in helpless horror, contemplating imminent unemployment. Referring to Paramount's somewhat more saccharine subject matter, one critic suggested that the film be more appropriately titled *Black and White Christmas*.

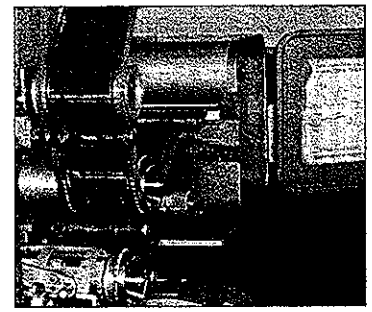


Fig. 2.9 Todd-AO 70mm film threaded in the magnetic sound pickup of a modern projector (picture courtesy of City Screen, York).

One of the main casualties of VistaVision was the Rank-owned Kalee company, which by the mid-1950s was one of the world's largest producers of cinema projectors. With Rank's decision to adopt VistaVision Kalee invested heavily in the research and development for a VistaVision machine, which reached the prototype stage just as Paramount was abandoning the format. VistaVision had never been used for exhibition on any significant scale in the US, and projectors had never been mass-produced. Rank discovered that the vast majority of cinema projection rooms simply did not have the physical space to accommodate two sets of projectors (the VistaVision machines could not show standard 35mm as well), and in the end only four were built, two of which were used briefly in Rank's flagship cinema, the Odeon Leicester Square, for premiere runs of Rank and Paramount VistaVision productions. It is thought that this failed investment was a major reason for Kalee's subsequent closure, and thereafter Rank cinemas imported their projectors from the Italian firm of Cinemeccanica. VistaVision continued to be used on a very limited scale for back-projection plates in studios until superseded by digital technology in the late 1990s.

Todd-AO and 70mm

The last of the 1950s widescreen formats was conceived as a modification of Cinerama which offered similar picture and sound characteristics but which could be delivered using much cheaper and more reliable technology. It was also the final system to appear, the first screening of *Oklahoma!* (1955, dir. Fred Zinneman) taking place on 10 October 1955. The core technology was essentially a resurrection of Fox Grandeur, consisting of a 65mm camera negative and 70mm print stock, the additional width being to accommodate four stripes of magnetic oxide which held six separate channels of soundtrack. The differences were that the pulldown was increased to five perforations and the film transport speed was initially 30fps. As with Cinerama, Todd-AO was projected onto a curved screen (with a horizontal angle of 128°), using optically compensated lenses to produce the curve from a single strip of film.

This format was the product of Mike Todd, who had left Cinerama in 1952 to work on a more technically viable alternative, and Brian O'Brien of the American Optical ('AO') company, who was primarily responsible for the lens technology. CinemaScope and the Todd-AO 70mm format are the two 1950s widescreen systems which still survive in some form today, because as with CinemaScope, the Todd-AO

projector was compatible with the pre-existing standard. By replacing a few components it could also be used to show 35mm (unlike the Grandeur projector of 1929). In the end only two films were produced in the original curved-screen, 30fps version of Todd-AO: *Oklahoma!* and *Around the World in Eighty Days* (1956, dir. Michael An-

Fig. 2.10 When it proved impossible to market VistaVision horizontal projectors for cinema exhibition, Paramount promoted it as an origination medium which would yield higher quality release prints for conventional 35mm, non-anamorphic widescreen release (author's collection).

derson). Subsequent variations to the format enhanced its backwards-compatibility. The film speed was reduced to 24fps, thus enabling productions to be more easily released on 35mm anamorphic prints, while the 'bug eye' lenses were replaced with spherical ones so that 70mm could be shown on a flat screen (in 1962 the director David Lean demanded that the curved screen at a London West End cinema be replaced with a flat one lest it distort the mirage sequences in *Lawrence of Arabia*). Furthermore Cinerama abandoned their three-strip process in 1963 and replaced it with a system based on 70mm film with anamorphic compression. 70mm production declined throughout the 1960s and 1970s, while optically-enlarged prints from 35mm originals (using wet-gate printer technology developed by Panavision) were made on a regular basis, primarily to utilise its six-channel sound capability. Before the launch of digital sound-on-film in 1992 there was no other way of presenting six-channel stereo besides 70mm, hence the reason blow-ups were made on a regular basis, even if in most cases the increase in picture quality was marginal.

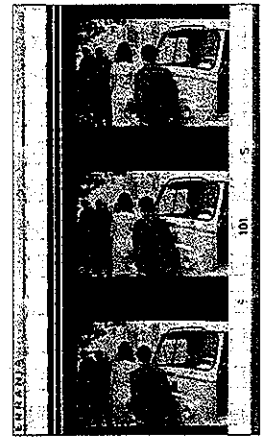
So, of the four key widescreen technologies launched during the 1950s, one (Cinerama) lasted only a decade before effectively disappearing without trace, another (VistaVision) lasted only a short time as a production and exhibition format but remains in limited use for special-effects production and special venue exhibition, a third (70mm) retains a niche market for high-quality imaging, while 35mm anamorphic formats (i.e. CinemaScope and its derivatives) remain a standard format for which virtually every cinema is equipped and which accounts for a third to a half of feature films produced in the Western world today. It is interesting to note that the two

formats which survived are those which sought to modify and improve on existing norms rather than abandon them altogether, which is yet another example of standardisation as the moderating influence between the aspirations of the technologists and the economic realities of the film industry. And in the absence of a dedicated widescreen format, producers have since the 1950s been extending the technique used to create the Academy ratio of placing a black matte between each frame on standard 35mm in order to produce wider ratios but keep the four-perf pulldown. Following the initial success of CinemaScope, Paramount began to use a 1:1.66 matte on standard 35mm for reduction prints of its VistaVision features; other studios settled on 1:1.75 and 1:1.85.

Thereafter format confusion reigned. In the absence of any firm standard for 35mm spherical widescreen most cinemas equipped themselves for one or other of the ratios in use, the decision being made more on the basis of architectural conditions inside the auditorium and the cost of lenses than with any regard to the ratio in which films were intended to be shown. By the late 1970s Hollywood had more or less settled on a 'flat' widescreen ratio of 1:1.85, which was also adopted in the Far East, while Europe and Asia tended to use 1:1.66. This remains the case today, although 1:1.66 is increasingly falling out of use (even in France, where 1:1.66 had become firmly established as the ratio of choice among the *Nouvelle Vague* directors such as Jean-Luc Godard and Claude Chabrol), as 1:1.85 more closely approximates the proportions of the 16:9 widescreen television screen.

By the end of the twentieth century 1:1.85 had effectively replaced Academy as the standard 'flat' ratio for cinema exhibition, although unlike with Academy, no universally accepted standard exists which says so. Even by the late 1990s a projectionist with a choice of widescreen lenses available would usually have to determine which one to use by holding a section of print against a light source and making a guess based on the apparent composition of the frame. The British cinematographer Walter Lassally observed that this state of affairs has led to a policy of 'shoot to protect' among production designers and cameramen, in which the frame area between the 1:1.85 boundaries and the edge of the Academy matte is kept clear of any action (for display on a TV screen or in case this entire area is masked in projection) but included in the frame composition (lest the film be projected with an Academy mask), as in the lower example in fig. 2.11.[49]

The aspect ratios in use in 2005, therefore, have their origins in a spate of research and development undertaken by the Hol-



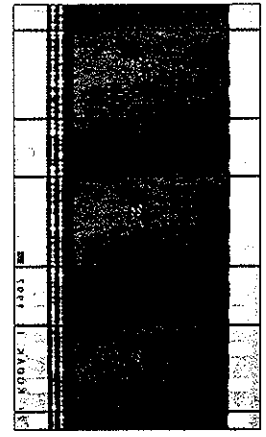


Fig. 2.11 Widescreen pictures from standard film. Originally devised by Paramount as a means of showing VistaVision without the need for a dedicated projector, this format is now used to release virtually all theatrical features which are not shot anamorphically. The film above is 'hard matted' to a ratio of 1:1.66; below is film (which also has a stereo optical soundtrack) shot in a camera with an Academy mask, but intended to be projected with a lens and aperture plate which magnifies the area of the frame between the black lines to give a ratio of 1:1.85.

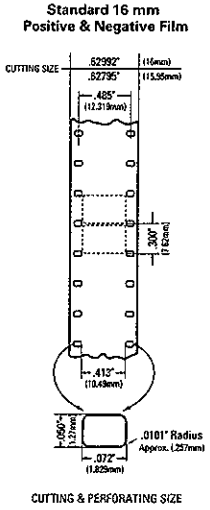


Fig. 2.12 SMPE specification for 16mm film.

lywood studios during the late 1920s. This did not initially lead to industry-wide implementation, largely because the formats which resulted were not in any way compatible with pre-existing 35mm production and exhibition technology and because the prevailing economic conditions impeded their introduction. Hollywood tried again in the 1950s, and of the spate of formats developed this time two eventually stuck: CinemaScope because it offered a substantially wider image simply by attaching a new lens to existing equipment and 70mm because the projectors could also show standard 35mm. Furthermore the economic conditions this time were such that significant changes to the technology used in moving image production and exhibition were likely to address a problem rather than cause one.

Sub-35mm film formats

'In 1918 I proposed at a meeting of the SMPE held at Rochester, NY, the creation of a new and separate standard for motion pictures used *outside* the theatre, or on what is usually called the non-theatrical field.'[50]

It is easy to see what prompted this remark, made by Albert F. Victor of the Victor Animatograph Corporation at a lecture in 1944. Between 1898 and the launch of the first mass-marketed sub-35mm gauge – the Cine-Kodak 16mm system in 1923 – at least 41 camera and projector systems were designed for amateur use, 30 of which used nitrate![51] During the early years of the twentieth century, amateur cinematography was clearly not a hobby for the faint-hearted. Although there were efforts to promote equipment aimed specifically for the 'home movie' sector, the reality was that non-professional filmmaking before 1923 was sporadic and limited, and most film not intended for revenue-earning exhibition was shot by people with some connection to the film industry (which gave them access to equipment and film stock) and on 35mm.

Between the appearance of the first acetate stocks in 1909 and the 16mm gauge in 1923 the use of sub-35mm gauges for cameras and projectors intended for non-professional users was attempted by several manufacturers, without commercial success. As early as 1898, in fact, the British pioneer Birt Acres had laterally split 35mm film in two, producing a 17.5mm strip for use in his 'Birtac' camera. The two major drawbacks with this and all the other pre-1909 systems were that the stock was nitrate and that reversal film was not available for moving image use at this stage (the technique was first developed in 1899 – see chapter one), meaning that amateur cinematographers had to go to the trouble and expense of shooting a negative and then having a print made. The first gauge intended purely for amateur use which took advantage of Eastman's earliest acetate base was sold by Pathé Frères in Paris from 1912.[52] Again using a negative-positive system, the Pathéscope system featured a film gauge of 28mm. Pathéscope camera negatives (and, in the case

of commercial titles sold for home exhibition on the format, printing intermediates) were nitrate in order to take advantage of its durability, but projection prints were acetate to minimise the risk of fire. Nitrate elements had four perforations on both sides of each frame. Acetate elements, however, had four perforations per frame on one side, which were engaged by the transport sprockets in the camera and projector mechanisms, but only one on the other. This was adjacent the frame line and was engaged by the projector's intermittent movement. This asymmetrical arrangement of perforations on the print stock ensured that it was physically impossible to thread nitrate stock in a Pathéscope projector (and thus ignite it) and equally impossible to thread prints the wrong way round, thus making life easier for the non-professional operators. It was this system – only with acetate negatives as well – which Albert F. Victor called for the SMPE to standardise along with 'professional standard' 35mm in 1918, and which it duly did.

Meanwhile Eastman Kodak had been working during the 1910s on adapting the chemistry of reversal processing to an emulsion for moving image use. By the end of the decade the company believed that the combination of an acetate base and reversal processing (i.e. the customer got a projection positive straight out of the camera) had made amateur film ready for the mass-market. Safety was a big selling point, and George Eastman did not believe that the compromise offered by the Pathéscope system was sufficient in the hands of untrained amateurs. In June 1923 Eastman Kodak launched the Cine-Kodak system ('system' meaning a package of camera, projector, sale and processing of film stock), using a gauge of 16mm with a single perforation on either side of each frame. Eastman was reflecting widely held concerns about the use of nitrate in private homes, as this quote from a 1929 manual on home cinematography demonstrates:

Fig. 2.13 The 9.5mm Pathéscope system was originally marketed in 1923 as a way of viewing commercially produced films at home, but after Eastman Kodak launched their 16mm format the same year, cameras were soon made available.

> It [safety film] renders the home projection of films safer than much that ordinarily goes on in the home – cigarette smoking, for instance – and incidentally, disposes of any questions that conceivably might, and not improbably would, arise in relation to tenancy and fire insurance where an accumulation of films was known to exist or frequent exhibitions took place.[53]

As with the 28mm Pathéscope perforation arrangements, the choice of 16mm was made deliberately on health and safety grounds. 16mm *could not* be produced by slitting 35mm in half, and as 35mm was the only film gauge for which nitrate stock was routinely manufactured, there was no danger – as there could be with 17.5mm

– of 16mm nitrate ever getting into circulation, either by accident or design. Eastman made it a selling point that 16mm was and would always be a safety-only gauge. When 16mm entered systematic professional use during World War Two this became a contentious issue, as we shall see below. The width of 16mm was determined by calculating the dimensions of a frame needed to produce a six-foot by nine-foot image in projection (deemed to be the largest image a tungsten-lit projector would ever be capable of) and adding space for perforations.[54]

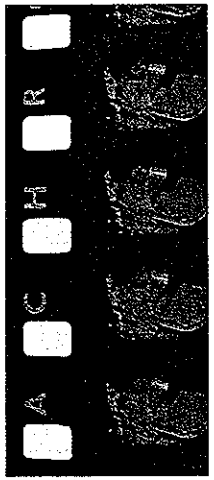
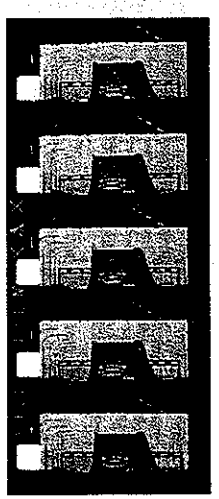


Fig. 2.14 Standard 8mm (1932, above) and super 8 (1965, below) film gauges.



Within a few years 16mm dominated and had substantially enlarged the market for amateur cinematography, with cameras and projectors also being manufactured and sold by Bell and Howell and Victor Animatograph. In the autumn of 1922 Pathé abandoned 28mm and produced an alternative, much cheaper gauge: 9.5mm. Uniquely, the perforations were not situated along the edges of the film stock but in the centre on the frame line. Initially the format was used only as a home entertainment medium, for viewing reduction prints of theatrical features and shorts on home projectors, but the following year Pathé introduced the first 9.5mm camera. This format achieved a significant proportion of the market share in Europe, where cameras and film stock continued to be sold until the early 1960s, but was never used on a significant scale in the US. 9.5mm enthusiasts pointed out that the frame dimensions (and thus the picture quality) was almost as large as 16mm, but the cost of stock and processing was around half that of the Kodak system. To reduce costs even further, Pathé developed a reversal system which enabled home processing kits for 9.5mm to be used, but the temperature control and timing requirements of reversal development proved to be too precise for most amateurs to achieve. By the mid-1920s virtually all processing was being handled by the company's own laboratories.

The next significant sub-35mm format to enter the marketplace was 8mm, in 1932. 'Latest Eastman Achievement Cuts Cost of Movie Making Nearly Two Thirds' declared a Kodak advertisement from July of that year.[55] The principle on which this format had been created showed that the deliberate incompatibility in the 35mm to 16mm reduction process was an exception (implemented for health and safety reasons) which broke a rule that was now being observed again: reduce research and development costs as much as possible by recycling as many characteristics as possible in an existing format in creating a new one. 8mm film did not even slit 16mm down the middle to start with. The raw film stock supplied for use in the camera was standard 16mm only with additional perforations added.

The first 8mm film was supplied in lengths of 25 feet of specially perforated (but otherwise standard) 16mm reversal stock. It was exposed in two passes, then slit and joined at the lab after processing. Some later camera designs (most notably models from Bell and Howell) were made to take pre-split raw stock, which had the advantage of a greater footage capacity and a wider range of laboratories which could handle the new stock.

A further refinement of the 8mm system was the 'Super 8' format, launched by Kodak in June 1965. This essentially reduced the size and increased the pitch of each perforation by almost half and used the extra space to increase the frame dimensions, thus increasing the image definition available in projection and making space for an optical or magnetic soundtrack. As with 9.5mm, the original purpose of Super 8 was as much a pre-VCR format for viewing 'pre-recorded' (i.e. reduction prints made from 16mm internegatives) material in the home as an amateur-filmmaking medium. Standard 8 had proven a very resilient gauge for amateur use, mainly because the large and closely-spaced perforations could withstand a certain amount of mishandling. But the format could only carry a very low quality magnetic soundtrack (during the 1950s and 1960s a number of devices were marketed to synchronise 8mm projectors with early consumer tape recorders, though none was easy to use or particularly reliable)[56] and therefore the designers of the new 8mm variant were trying to adapt the gauge in order both to increase the picture quality and accommodate a soundtrack. Initial problems caused by the smaller perforations tending to strain and tear in projection were largely overcome when in 1967 Fuji marketed a variation of the system known as Single 8, which used polyester stock as distinct from triacetate. This marked the first widespread use of polyester film base, and was followed subsequently by its use in 16mm prints for airline use in the 1970s and eventually 35mm cinema release prints in the early 1990s. Super 8 was the last film format marketed for amateur use before consumer moving image technology started to become video-based in the late 1970s.

Fig. 2.15 16mm with optical soundtrack

From the late 1930s 16mm started to be used in a wider range of applications than simply for home movie making. In 1932 Bell and Howell launched the Filmosound projector, which enabled optical sound to be added to 16mm. Research during the 1920s had established that, unlike 35mm, 16mm film did not need to be perforated on both sides in order to produce an acceptable level of horizontal stability in camera and projector gates. The unperforated side could be used as a guided edge which, as long as it maintained physical contact with the gate assembly, could accommodate a soundtrack.

Thereafter 16mm started to be used for moving image applications other than home-movie making, but which for a number of reasons could not be accommodated by mainstream cinema exhibition. These included educational films for schools, promotional and training films produced by industry and government information and propaganda films. As 16mm was an exclusively safety format none of the health and safety restrictions associated with nitrate applied to 16mm. Films could therefore be shown in venues other than licensed and regulated cinemas, including schools, factories, church halls, community centres and political organisations. From the 1930s onwards 16mm was also used by groups of enthusiasts known as film societies to

show reduction prints of commercially produced features; this often included films which had been banned from 35mm theatrical release for political reasons, and the increasingly professional role of the format attracted increasing opposition both from the mainstream film industry and governments around the world. As we have seen in chapter one, it has been argued that the reason why nitrate remained in use as long as it did was a deliberately maintained restrictive practice.

The use of 16mm was given a further boost during World War Two. The need to transport release prints and equipment for showing to troops in remote locations and for raw camera stock to be used in news reporting made a format which was smaller, lighter and a lot less dangerous than 35mm very attractive. Even with the slightly improved mechanical tolerances of acetate propionate, cameramen frequently found that the stock would jam and tear, as this writer commented:

> ... but the 16mm medium is no longer confined to amateur use, and has not been for a long time. Being used by professionals for professional purposes in a professional manner, professionals have long been hampered by the shortcomings of this slow-burning base ... There is only one solution to this problem, and that is the use of nitrate.[57]

16mm nitrate was never manufactured in the West, although it is believed to have been used extensively in the USSR and China as late as the 1960s.[58] Although there are a number of powerful factors to undermine the argument that 35mm nitrate was maintained as an industry standard in order to prevent the use of 16mm from expanding, such an argument does point to the increasingly complex issues which emerged as 16mm became the first (and, as it turned out, the only) sub-35mm format to be used on any significant scale professionally.

The introduction of cellulose triacetate safety film from 1948 onwards removed any remaining issues of durability and tensile strength, and with them the last barrier preventing the 16mm format from entering widespread industrial use. During the immediate post-war period to the mid-1980s, the most extensive use of 16mm was as the *de facto* recording and reproduction medium for television. The relationship between television and film will be considered in greater depth in chapter six, though for the purposes of this discussion it should be noted that video recording technology did not exist at all before 1956. The earliest videotape recorders were about the size and weight of a small car and almost required a PhD in electronics to operate. Video technology could not be considered portable in any meaningful sense until the advent of 'ENG' (electronic news gathering) equipment in the late 1970s, and therefore film – specifically 16mm film – was an important part of television technology during the three decades between the introduction of mass-broadcasting and this role being superseded by videotape. Meanwhile, the introduction in 1955 by Kodak of two high-speed, low-grain 16mm black-and-white reversal stocks (types 7276 and 7278) enhanced the suitability of 16mm for this application.

The format's versatility was further extended by the introduction of the Super 16 format in 1971, in which the frame area is extended to cover the strip of film normally occupied by the soundtrack (the sound is recorded and synchronised from separate magnetic tape). This produces an aspect ratio of approximately 1:1.75 (known as '16:9' in the television industry) without any loss of definition relative to standard 16mm. Super 16 was initially used by feature filmmakers on a limited budget or who needed smaller and more portable cameras than is possible with 35mm, for subsequent enlargement to 35mm intermediates and release prints. It also started to be used by television following the introduction of HDTV and subsequent widescreen television in the 1990s. By 2000 16mm was almost obsolete, and was only used on any significant scale for archival preservation. In the early 1990s, portable video projectors became available at similar prices to the 16mm machines of a decade earlier, and rapidly superseded 16mm for non-theatrical exhibition. In cinemas, the growth of multiplex exhibition in the 1980s (more on that in chapter five) increased the demand for 35mm release prints, causing labs to equip themselves for 35mm mass production. 16mm release printing remained a labour-intensive, manual operation, so much so that by the early 1990s a typical 16mm release print of a mainstream studio feature actually cost more to produce than its 35mm equivalent. Therefore the film societies and part-time venues re-equipped for 35mm. Increasingly high-definition videotape formats, which could withstand copying through multiple generations (essential for editing) without any visible loss of image quality in transmission, largely superseded 16mm for television production. By 2000, the only remaining uses of 16mm and Super 16 as a production medium were for low-budget theatrical features and prestigious, high-budget television drama and nature documentary filming, applications for which even the image quality of modern digital videotape was not considered sufficient, and by students.

Large film formats

This topic has been covered to a certain extent in the section on widescreen above, in that Cinerama, VistaVision and 70mm were all technologies developed to produce a larger (in terms of absolute size as distinct from aspect ratio) image than could be obtained from a single strip of 35mm. However, I have counted them among conventional cinema processes because they were first and foremost new technologies for making conventionally acted, directed and produced narrative feature films for showing in cinemas. In the event Cinerama failed because the auditoria had, in effect, to be specially built. There is another group of large film formats which were not primarily designed for conventional cinema auditoria, but specifically for special entertainment venues such as fairgrounds, theme parks, museums and major exhibitions.

The first and longest lasting was Imax, first demonstrated at an international trade fair in Japan in 1970.[59] Developed by the filmmakers Graeme Ferguson and Roman Kroitor and the engineer Robert Kerr, it was in principle a 70mm variant of VistaVision: 70mm film with the same perforation size and pitch as Todd-AO but which moved horizontally, each frame occupying the length of 15 perforations. This frame was so large (three times as big as normal 70mm) that it was possible to project it onto a screen 24 metres tall – the equivalent height of an eight storey building. While the initial generation of Wilcam-Imax cameras used the pin-registered cam-and-claw

mechanism similar to that of the 1970s generation of Panaflexes, a conventional, mechanical intermittent mechanism was found to be impossible in projection because of the speed of film transport and the intense heat produced by a lamp needed to illuminate a screen that big. Instead, the projectors used the so-called 'rolling loop' method in which both film and picture gate rotate in synchronisation. Other variants of Imax soon followed, including Omnimax (curved screen) in 1973, Imax-3D in 1986, which simply applied the same technique used for *Bwana Devil* and the 1950s generation of 3D films (two synchronised projectors with the viewer wearing polarised glasses) to Imax, and Imax-HD in 1992, which enabled viewers to sit closer to the screen without experiencing visual distortion.

The output of Imax films has until very recently been confined to the genres of documentary, travelogue and music video. Notable public successes have included *The Dream is Alive* (1985, dir. Graeme Ferguson), about the US space programme, a music film *At the Max* (1991, dir. Noel Archambault *et al.*) featuring the Rolling Stones and *Fires of Kuwait* (1992, dir. David Douglas), dealing with the reconstruction in the Middle East following the 1991 Gulf War, which won the best documentary Academy Award. One key limitation of the system was that until the late 1990s the capacity of an Imax projector limited a film's running time to approximately 45 minutes (though *At the Max*, running 89 minutes, was shown in two halves with an interval). This was eventually overcome and the 82-minute animated feature *Fantasia 2000* (2000, dir. Hendel Butoy *et al.*) was shown in the small number of converted Imax cinemas which could accommodate the larger reels, as well as being released conventionally on 35mm. Unlike any other special format/special building system, Imax has survived successfully for over three decades because it only ever aimed for a niche market. Unlike Cinerama, the system's promoters never tried to persuade every suburban multiplex to equip themselves with the format, instead opening small numbers of purpose-designed venues in prestigious city-centre locations. From 2002 digital film processing technology has been used to produce Imax enlargements of feature films originally shot in conventional formats: at the time of writing *Apollo 13* (1995, dir. Ron Howard), *Star Wars: Episode 2 – Attack of the Clones* (2002, dir. George Lucas) and *The Matrix Reloaded* (2003, dir. Andy & Larry Wachowski) have been given a limited roadshow release in this format. However, and despite the ability to convert ordinary films into this large-screen format, Robert Carr and R.M. Haynes correctly point out that, 'regardless of the extremely high definition or clarity of Imax, it will never be a general film process due to its logistical and financial implications'.[61] The UK market vindicated this prediction in January 2004, when one of the country's nine IMAX screens was forced to close due to falling revenue. 'For the purists it will remain unbeatable', commented the commercial director of another venue, 'but that doesn't point to a growth market, which is a worry.'[61]

Other special large film formats which have been used since the 1970s include Showscan, which used conventional 70mm film only running at a speed of 60fps in order to heighten the clarity of movement and totally eliminate visible flicker, and a number of hybrid 70mm systems with a vertical, 8-perforation pulldown for showing reduction prints of Imax originals in venues such as fairgrounds and theme parks.

Conclusion

The decision which marked the start of film being used in a systematic way to originate, duplicate and display moving images was the definition of a format and a standard. Before the early 1890s the *principles* of film-based moving image technology – a flexible, transparent base, coated with a photosensitive emulsion which was exposed and projected intermittently between movements of a fixed distance – had been established. But in order for them to work efficiently and economically in practice the variables inherent in these principles had to be fixed. How wide would the film be, what were the dimensions of each frame, what length of film would be pulled down by each movement and how many times per second would these movements take place? Unless those variables are the same in both the camera and projector, the illusion of a moving image cannot be reproduced effectively.

In the early 1890s, therefore, W. K. L. Dickson determined a standard which he and his employers hoped would be adopted throughout the nascent industry, not least because the latter owned the patent rights. It was the same logic that would later motivate Donald J. Bell's 'fondest hope' for equipment standardisation. Standard 35mm proved to be ideally suited for conventional cinematography and auditorium projection, so much so that (with a few minor variations), this format is still being used for this purpose in 2005. But as the range of applications for film expanded to encompass systems designed specifically for amateur use, widescreen, film as an recording medium for television and film for special venues, new formats were evolved to address these purposes. They stood or fell on their compatibility with (and in the case of 16mm, its deliberate incompatibility with) pre-existing formats and the ways in which the technologies were commercially exploited. The MPPC episode and TCF's attempt to sell CinemaScope and stereo sound as a package demonstrated (as would the Betamax consumer video format in the 1970s) that an increasingly sectorised industry would not put up with the use of one form of technology being made artificially contingent on another. Formats which were designed and marketed in a way which were most compatible with existing technologies introduced the smallest additional cost element possible and functioned in an essentially open marketplace. Therefore the Academy ratio, Super 8, CinemaScope and 5-perf 70mm all survived, while 3D, the 1920s widescreen systems, 9.5mm, Cinerama and VistaVision were only used for a short time and on a limited scale, and were never really commercially viable. About the only significant exception to this rule is the triumph of 16mm over 17.5mm, and this was artificially engineered for a specific political reason: the danger of allowing nitrate film to be used in an unregulated environment. A convincing demonstration of this phenomenon can be found in the growing importance of standard-setting bodies, most importantly the SMPE/SMPTE, and to a lesser extent the ISO and DIN.

The next two chapters will consider how two additional technologies – colour and sound – were developed and adapted for compatibility with established film and equipment formats in order to meet the demands of the commercial climates in which they emerged.