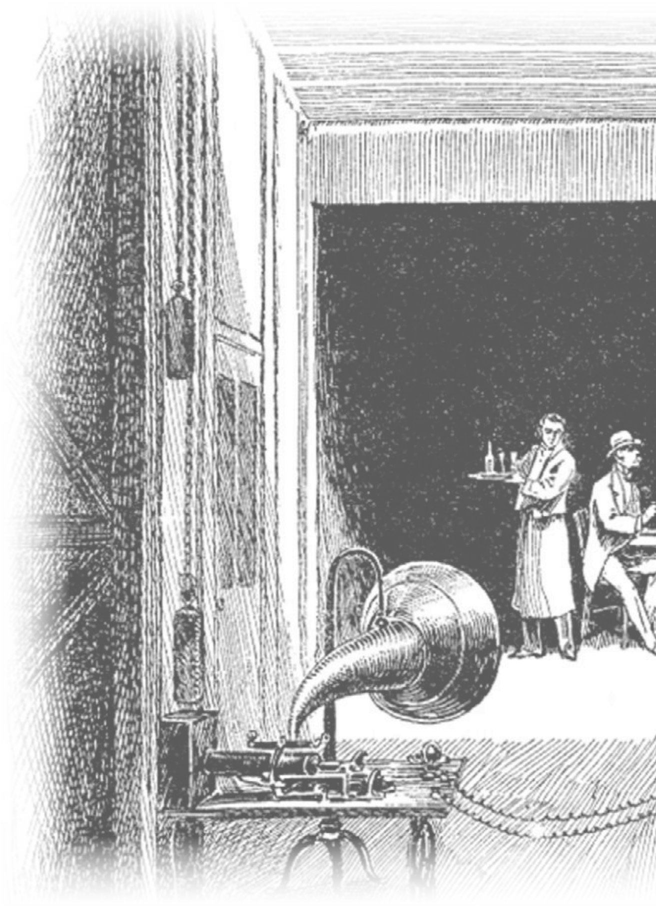

How Pictures Learned to Talk

Films were never really silent

By **Peter Beil** (Germany)

Now that sound effects in film theaters nearly lift us out of our seats and even the softest whisper is audible in the back row thanks to modern audio technology, it's worth looking back at the origins of sound in films.

In the early days of film theaters, piano players, organists (**Figure 1**) or even complete orchestras provided musical accompaniment for films. However, that always depended on the interpretation of the musicians, and it was rarely synchronized with the picture on the screen.
In 1893 William Dickson (hired as Chief Engineer by T.A. Edison) combined phonograph technology with kinetograph technology to create the Kinetoscope (**Figure 2**), which was exhibited at the Chicago World Fair. Unfortunately, it only worked with short film strips or film loops.

Scratchy but more or less synchronized: sound on disc

The next logical step was to combine the film projector (already technically improved) with a phonograph. The French company Gaumont patented this technique in 1901. The earliest known instance of music synchronized to a motion picture was in 1908 when Camille Saint-Saens composed music specifically for the film *L'Assassinat du Duc de Guise*, which came with a phonograph record. This technique only became truly established in 1924 when Warner Bros. Entertainment launched a commercial version under the name Vitaphone (**Figure 3**). The phonograph records used in that system had a diameter of 17 inches (about 43 cm) and spun at 33⅓ rpm, providing enough capacity for the 1000 ft (300 m) roll length common at that time. The film roll and the record

Figure 1. The Wurlitzer theater organ.

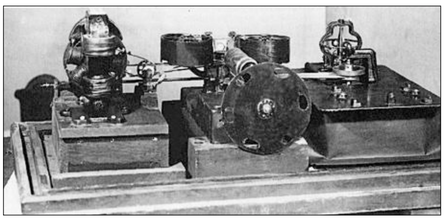

Figure 2. Dickinson's Kinetoscope.

Figure 3a. The Vitaphone projector.

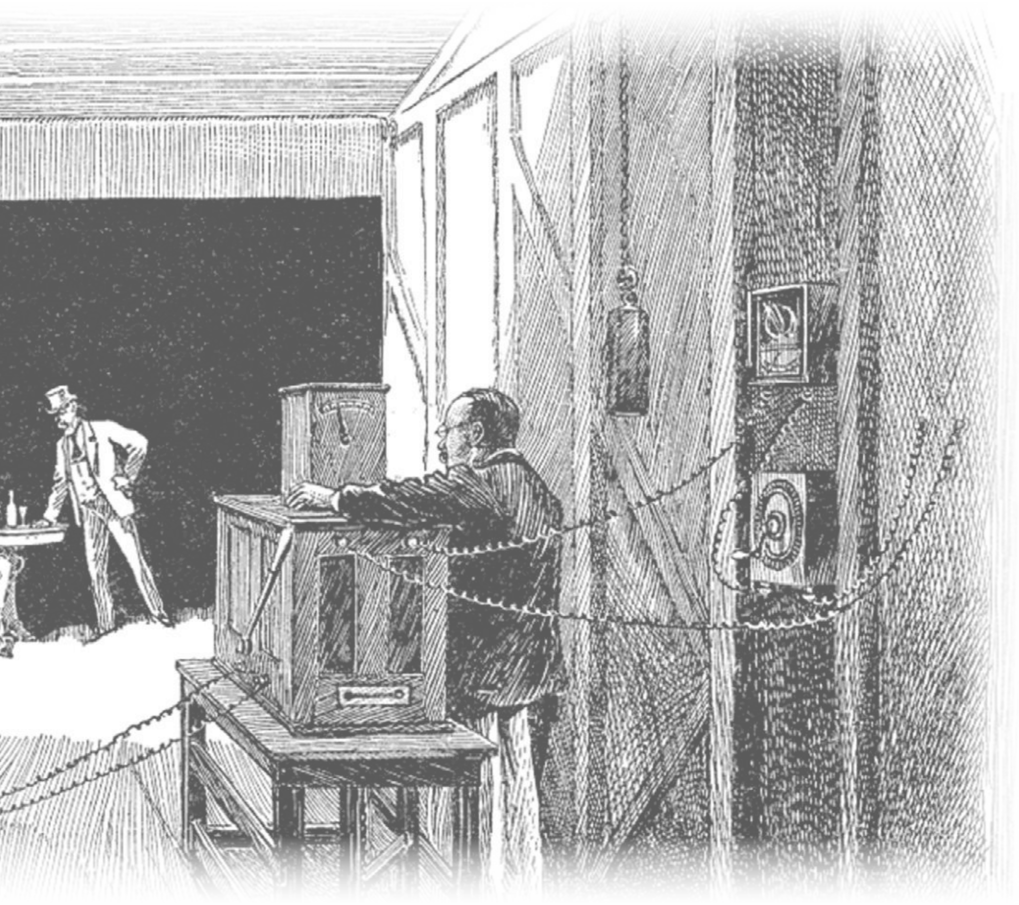

Figure 4. The premiere of *The Jazz Singer*.

Figure 5. Silent film (left) and sound film (right).

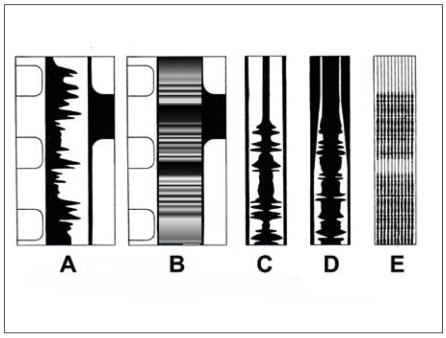

Figure 6. The six optical sound track methods. A: Unilateral variable area; B: Variable density; D: Bilateral variable area; D: Eurocord; E: Multi variable area

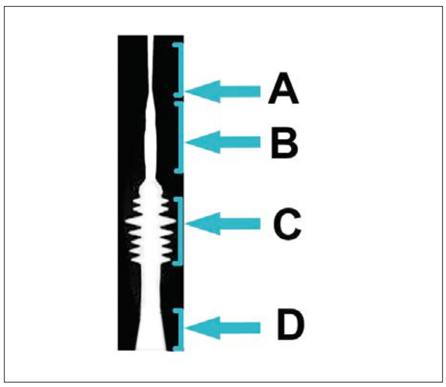

Figure 7. Track width definition. A: Soft sound; D: Loud sound; B: Bass tone; C: Treble tone

both had start marks for synchronization by the projectionist. The record was played from the inside to the outside, just like modern CDs. The best known film using this technique was *The Jazz Singer*, which premiered in 1927 and made Al Jolson world famous (**Figure 4**).

Sound from light

For many decades, the most commonly used sound technique worldwide was sound on film using an optical sound track. This was the first method that allowed the sound and picture to be combined and synchronized on a single medium. Several people were instrumental in the development of optical sound on film technology in the 1920s. The pioneers of this technology were the Polish engineer Józef Tykocinski-Tycociner, the German engineers Hans Vogt, Joseph Massolle and Benedikt Engl, and the Swedish inventor Sven Berglund. When the US inventor Lee de Forest also applied for a patent, that touched off a patent war lasting many years, which was only settled in 1930 by the so-called “sound film treaty”. That resulted in a uniform system worldwide.

At last: lip sync with optical sound on film

The optical sound track width was specified at 2.2 mm (about 0.09 in), and the width of the image area between the perforations was reduced to make room for the sound track on the film (**Figure 5**). There are two fundamentally different methods: variable density with modulation by variable light intensity with constant track width (**Figure 6b**), and variable area with modulation by variable track width (**Figure 6a/6c**). A variant on variable area called “multi variable area” **(Figure 6e**) was less popular. Because sound reproduction quality with variable density is largely dependent on correct photographic processing of the negative and the prints, the bilateral variable area method was most often used because it was easier to make good prints. Unfortunately, in the early days the fine tips of the profile were often blurred by overdevelopment, causing loss of treble tones. The Eurocord method, in which the clear area is dynamically masked by a black shutter (**Figure 6d**), was developed several years later to reduce noise from the clear area. This had to

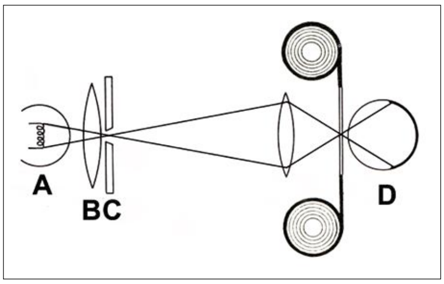

Figure 8. Basic structure of an optical sound track reader. A: Sound lamp; B: Condenser lens; C: Slit, D: Photocell.

Optical illusion

Motion picture reproduction is based on the latency of human vision. individual static images (frames) are projected in rapid succession. In a film projector this is done by a Geneva drive mechanism (**Figure 15**). The drive wheel A rotates continuously, and the pin D advances the driven wheel one step at a time. The cam C locks the driven wheel when it is not moving. As a result, the image is stationary 24 times a second, after which the image area is covered by a shutter. During this time the film is moved to the next frame, and then the next frame is projected. To keep the resulting flicker effect as small as possible, films are projected at a standardized rate of 24 frames per second.

Figure 9. Exciter lamp.

Figure 10. Photocell.

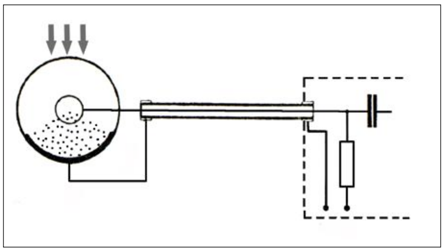

Figure 11. Basic photocell circuit.

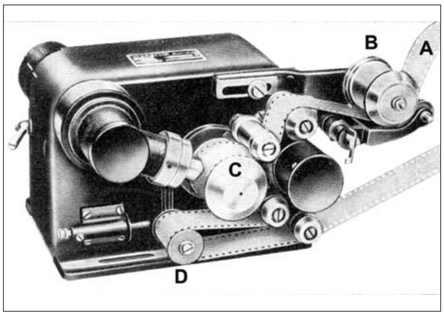

Figure 12. Eurocord optical sound track reader A: Film loop; B: Brake roll; C: Flywheel; D: Tension roll.

follow the profile at a uniform distance to avoid being interpreted as a sound signal on reproduction.

Reading light signals

The optical sound track, standardized worldwide, is read using a narrow slit with a width of 0.018 mm (0.7 mil). A narrow track width corresponds to a soft sound (**Figure 7a**), and a wide track width corresponds to a loud sound (**Figure 7d**). Slow changes in the track width generate low audio frequencies (**Figure 7b**), while fast changes generate high frequencies (**Figure 7c**). With a frame rate of 24 fps, the film travels at a rate of 456 mm per second. With the standardized slit width of 0.018 mm, the theoretical sampling rate is 456 ÷ 0.018 = 25,361 half-cycles per second, or about 12.5 kHz. Under ideal conditions the signal to noise ratio is 40 dB. These figures may appear rather meagre by modern standards, but in combination with the usual theater loudspeakers at that time with enormous wooden baffles, horn structures and tube amplifiers (with corresponding harmonic distortion), the sound was considered highly satisfactory.

The technology

Sound reproduction is based on a clever combination of optics, electronics and mechanics (**Figure 8**). Light from the exciter lamp (A) is focused by a condenser lens (B) onto the previously mentioned slit (C), which must be perfectly perpendicular to the sound track to avoid non-linear distortion. A lens projects the resulting narrow light beam precisely onto the optical sound track. The light emerging from the other side of the film strikes a photocell (D), which converts the light signal into an electrical signal. That signal is then converted into audible sound by a suitable loudspeaker.

The exciter lamp (**Figure 9**) is a special type with an especially stable filament. That is necessary because large theater projectors always vibrate, and a vibrating filament would color the sound signal by adding its own modulation. The lamp must also be operated from a DC voltage to avoid AC line hum. The lamp socket is notched to allow the lamp to be exchanged very quickly in the event of lamp failure.

The photocell (**Figure 10**) operates on the same principle as a vacuum tube and has a reddish-brown varnish coating to protect it against stray light. The ring-shaped anode (positive terminal) is a characteristic feature. The cathode (negative terminal) is the light-sensitive layer behind the anode. When light strikes the cathode, it releases electrons which travel to the anode. The resulting current flows through the input resistor of the amplifier to produce an AC signal (**Figure 11**). The photocell is connected to the amplifier through a low-capacitance cable to avoid loss of high frequencies. Naturally, photocell design evolved over the course of time, and later they were replaced by photodiodes.

From sound to light

The same basic principle is used to produce the optical sound track on film. For a variable density sound track, the brightness of the light source is modulated by the audio signal. For a variable area sound track, one or two leaf shutters in front of the slit are driven by the amplitude of the audio signal to modulate the track width. The track is exposed on especially high contrast film stock to produce an essentially black-and-white image with no gray tones.

On a sound film the optical sound track is 20 frames ahead of the picture. If the sound track were sampled in the film gate, the result would be a loud

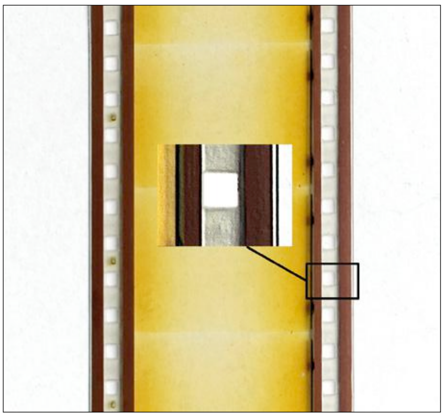

Figure 13. Sound film with four-channel magnetic track.

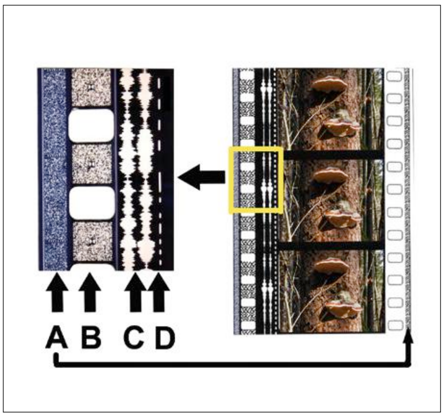

Figure 14. Layout of modern optical sound tracks. A: Sony SDDS; B: Dolby SR; C: Dolby Stereo; D: Time code for DTS.

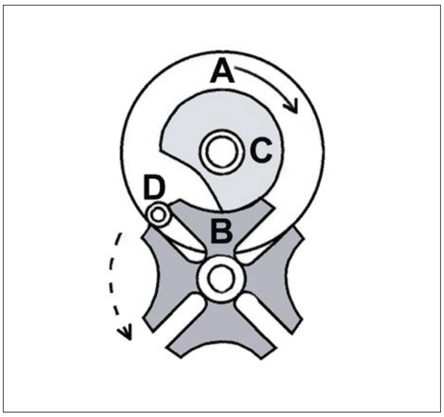

Figure 15. Geneva drive mechanism. A: Drive wheel; B: Driven wheel on transport shaft; C: Locking cam for stationary phase; D: Drive pin.

knocking sound. The film is transported with intermittent motion (see inset). This jerky motion must be smoothed out for sound track scanning. This is done by the sound reader (**Figure 12**) with a film loop (A) and a friction brake roll (B), followed by a flywheel (C) and a spring-loaded tension roll (D) which smooth out any remaining irregularities.

Sound gets colorful

The advent of color films created some new problems. Before that time, nobody worried about the color sensitivity of photocells. However, complicated copying methods were necessary to obtain black-and-white sound tracks with enough contrast on color film. The cyan sound track was developed to simplify this process, but it had to be scanned with red laser light. Because conversion of cinema equipment lagged behind, a magenta sound track which worked equally well with white and red light was introduce for the transition period.

The magnetic sound intermezzo

Magnetic audio recording made its way into sound on film technology in the early 1950s. For this, four magnetic sound tracks were placed on the 35 mm film for the left, middle, right and effects channels (**Figure 13**). To reduce background noise from the latter channel, it was only switched on by a gate filter for specific sound events. Since 35 mm film actually did not have room for more sound tracks, the perforations were made a bit narrower to allow the film edges to also be used.

For space reasons, the magnetic sound track playback device was placed above the film gate, displacing the sound backward by 28 frames.

In addition, the projector had to be demagnetized at regular intervals, the sprocket rolls had to be changed due to the smaller perforation dimensions, and the film reels had to be replaced by plastic reels. The magnetic head was also subject to fairly high wear. Due to the complicated handling and high cost of converting the theaters, four-channel magnetic sound track technology quickly vanished into oblivion.

The comeback of optical sound on film

Optical sound on film had been stuck at the same technological level for about 50 years when Dolby took the system under its wing. Dolby A, launched in 1976, significantly improved sound quality and allowed two sound tracks for left and right channels to be placed on film. Differential readout additionally allowed these tracks to contain a middle channel and an effects channel in the Dolby Stereo system (**Figure 14c**).

Progress in digitalization lead to the launch of Dolby Stereo SR (Special Recording) in the early 1990s, which enabled surround sound systems with a subwoofer such as 5.1 or 7.1. Due to space constraints, this sound data was placed between the perforations (**Figure 14b**). Because digital technology is sensitive to irregularities and dirt on the sound track, Sony launched their own system (SDDS) in 1994 with eight channels and redundant sound tracks on the left and right edges (**Figure 14a**).

The Digital Theater Sound (DTS) system should also be mentioned. In this system the sound is on as many as three separate CD-ROMs, which are coupled to the film by a time code track (**Figure 14**). That works even if the film tears or there is no picture. DTS is also a multichannel surround sound system.

Mechanical projectors have now been supplanted by digital technology, with optical film virtually limited to special art house theaters. The latest craze in film sound technology is Dolby Almos, which uses ceiling-mounted loudspeakers to create a new total surround sound experience. Who knows what will come next? ⏮

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