PHOTOSENSITIVE TECHNOLOGY IN FILM AND SONIC ARTS

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Abstract

Photosensitive elements have played an essential role in the fields of film-phonography, animation, electronic music, and installation art. Their history in Film begins in the 1920s and develops quickly into a web of experimentation and research into techniques for recording, manipulating, and generating audio signals. Film-makers, composers, engineers, and other artists from Russia, Germany, Canada, England, and the United States had important roles in pushing the qualities of photosensitive components into new artistic areas. This thesis discusses these achievements, their respective aesthetics, and current projects that incorporate photosensitivity.

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1 Introduction

Because of the written score, music can exist as a system where visual data is translated into sonic material. As distant as they might get from traditional musical notation scores create systems where shapes and colors are interpreted and expressed as sonic results. It becomes a system where information from one medium generates energy in another. As electronic applications for sound were developed, the process of creating sonic energy with new unorthodox media was explored in a few different ways. One of these ways came through the application of photosensitive technology in electronic sound systems.

Photosensitive electronic components change their properties in the presence of light. Some are used to impede the flow of current in circuits – photoresistors – while others are used to modulate or generate current – phototransistors. In sound, these components can generate or modulate audio signals that are analogs of their reactions to light – a process that was implemented for optically recording and reproducing sounds in synchrony with film. This process (film-phonograph; optical sound; sound-on-film) was an efficient technology as it did not require external synchronization devices. Earlier systems required complicated arrangements of motors and phonograph-disc players to synchronize film and sound. It was also effortless to operate as the soundtrack was printed onto the film and amplification systems were built into projectors. From the 1920s it became a standard for the film industry through the century.

As optical sound became more popular, so did experiments with the medium. The process results in a visible marking on a strip of film and to a number of artists and engineers it meant that the soundtrack did not always have to consist of recorded sounds. From the 1920s through the 1960s a number of experiments in film-phonography yielded developments in sound synthesis and control. They inspired works and research that explored the aesthetic potential of exploiting the photosensitive features of the optical soundtrack leading to several branches of abstract film-phonography. Today photosensitive components are being combined with digital technologies for new musical systems in performance and installation contexts. This thesis presents a few historical and current projects that incorporate photosensitive elements for the generation or control of sound.

2 Early Film-Phonography

Silent films provided opportunities for composers to use visual materials to guide their music. Solo pianists, chamber ensembles, orchestras, and phonographic recordings often provided musical accompaniment for silent-films. It wasn’t until the early 1900s that engineers and film-makers began to explore the possibilities of creating mechanisms that fixed a soundtrack to a feature film. As complicated as the idea was, however, the time period saw a boom in technologies that aimed at synchronizing film with sound.

Léon Gaumont’s Chronophone Model C from 1908 attempted to solve this issue with a sophisticated and intricate sound-on-disc system. It included an interface for manually synchronizing separate driving mechanisms for film and sound tracks as well as a double phonograph player which allowed multiple-disc soundtracks to be played (Bedding, 1908). Warner Bros.’ Vitaphone technique from 1926 implemented a similar sound-on-disc system that produced feature films using a single motor for the entire process – recording and screening (Wilkison, 1996). The issue with these systems is that they depended too much on the precision of mechanical motors and their operators. Multiple-disc systems required accurate timing for splitting the soundtrack onto consecutive records. Machine operators had to know when and how to synchronize the separate discs at the appropriate time. Miscalculations or errors in the film and soundtracks for single-motor systems during the recording or screening process jeopardize the entire product.

One solution to sound-film synchronization was to encode sonic material directly onto film using photosensitive processes. Because both tracks end up on the same medium, synchronizing and editing films with their corresponding soundtracks proved to be a more efficient process than previous sound-on-disc systems. Another efficient aspect of recording sound onto film was that its photosensitive emulsion provided a familiar way of recording material onto the medium. Film-phonography thus became a popular method for producing soundtracks for sound-films.

Aesthetically, synchronized sound-films were met with mixed critical reception. These technological achievements signified an end for part of a language of visual techniques that symbolized and recompensed sonic events in film. The prominence of the silent-film would begin to diminish as more studios shifted towards producing sound-films. Many saw the sound-film as a greater technological achievement than an artistic one. The sound-film offered a "unique perceptual experience" while revealing certain qualities of sounds (particularly voices) that had not been heard before (O'Brien, 2005, p.4). Previous juxtapositions of film and sound conveyed narrative elements visually while sound served as a device used for supplementation. The film alone provided all of the information necessary to communicate the message. With the advent of better sound-film technologies sound was used to convey just as much information as the screened images, bringing about new practices and artistry in Foley recording and sound-effect creation.

2.1 The Optical Sound System

Optical sound is based on a simple idea – measuring fluctuations of light over time. On one end of the mechanism a light shines through the soundtrack markings on a strip of film (figure 2.1 shows four blank film frames with markings on the soundtrack portion of the film). At the other end a photosensitive component measures the amount of

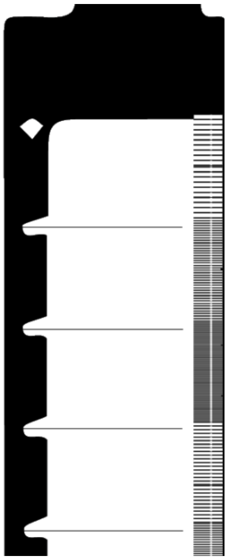

Figure 2.1: blank frames with marked soundtrack.

light that makes it through the film. As the strip moves through the feed-mechanism of the projector, the varying opacities and shapes of the markings on the soundtrack create changes in the measurements taken by the photosensitive component. The changes in light are transduced into electric signals that are amplified and sent to a speaker.

A simple analog to sound-on-film is a vinyl record. The grooves on a record directly resemble the types of markings exhibited on a traditional optical soundtrack for a feature-film. The cartridge from a record player transduces the moving grooves on the record into a signal similar to that which results from the photosensitive process of optical sound. These two processes also share similarities in their recording methods. A stylus engraves grooves onto a disc by sensing fluctuations in air pressure or electricity. In the optical system, a focused beam of light creates markings in the film's emulsion whose size or opacity corresponds to the sounds being recorded.

Eventually, alternatives for traditional sound-on-film techniques were sought, as the fidelity of the photosensitive process was questionable. Robert Warren, a film applications engineer for Dolby Laboratories, Inc. compares the optical track to a bucket of water:

> It only holds so much. If you put in another drop when you have the bucket full, that drop runs out over the top. It has to go somewhere, but it does not end up on your film sound track. So the problem of getting volume levels on optical soundtracks is a constant nonforgiving piece of the puzzle. On the other end of the spectrum, when it gets quieter and quieter, you eventually get down to the noise floor the optical medium has, so you have nothing but hiss. So in your sound design you have to fit all of your dialogue, effects, and music between the noise floor of the medium and full bucket of water. (LoBrutto, 1994: 131)

Even though the medium can be difficult to work with for traditional feature film soundtracks, it is an effective, durable, and inexpensive medium for film-sound synchronization (LoBrutto, 135).

The early years of optical sound saw many developments that pushed traditional cinema into a new technological era. Aside from the traditional audience, abstract artists also enjoyed a technological enlightenment with photosensitive systems. The optical system was recreated and manipulated in similar ways in different parts of the world. Optical sound systems proved fruitful for the film industry, but they also flourished in the fields of sound synthesis, animation, and abstract film. The photosensitive qualities of optical sound systems and the way individuals interacted with them created bridges for audiovisual art in ways that had not been explored before.

3 Abstract Film-Phonography

It is possible to create specific timbres and textures by controlling exactly what goes onto the soundtrack portion of a strip of film. Horizontal patterns of markings will result in different timbres. Vertical repetitions of these markings will yield a tone. These two details were explored by artists from Germany, Russia, Scotland, England, and the United States of America influencing future generations of optical research in sound synthesis and analysis. This section introduces four ideas for abstract film-phonography including ornament sound, paper sound, hand-drawn sound, and printed sound.

3.1 Fischinger and Pfenninger

Oskar Fischinger's experiments with optical soundtracks introduce the idea of sound "ornaments" (some of which are shown in Figure 3.1). By organizing different shapes into patterns, Fischinger decorated the optical soundtrack keeping a focus on the visual aspect of optical sound production. The early explorers of optical sound synthesis shared a "sudden realization of an entirely synthetic, virtual environment of musical space." The "indexical relationship" between the images on the soundtrack and the produced sounds were "clearly demonstrated and easily understood." (Brown, 2012, 87) Fischinger approached the subject with exactly those realizations and a great amount of prospect:

> A number of experiments that I [Fischinger] have just made confirm the unprecedented range and significance of this method [ornament sound]. The soundtrack on present-day films is only 3 millimeters wide, but the artist of the

Figure 3.1: sound ornaments created by Oskar Fischinger (Brown, 2012, p. 88).

> future will naturally require the full width of the film-strip just for his musical composition. . . In reference to the general physical properties of drawn sounds, we can note that flat and shallow figures produce soft or distant-sounding tones, while moderate triangulation[s] give an ordinary volume, and sharply-pointed shapes with deep troughs create the loudest volume. . . The new methods introduced here offer new, fruitful stimulation that should be provocative to the whole musical world. (Fischinger, 1932)

Fischinger was interested in the possibility of "pure artistic creation." His exploration of optical sound synthesis overlooked the technology and was focused on the new-found control of sonic materials through a visual process. Rudolph Pfenninger, a Swiss engineer, approached optical sound synthesis from a different perspective.

Pfenninger, who was working in Munich at the time, was interested in the re-production of specific sounds. The graphics that Pfenninger tested were "*not* ornaments but . . . semiotic entities that can be combined to produce sounds in a linguistic – which is to say, thoroughly technical and rule-governed – manner”. Synthesis and sonic results were the focus of his research which served to “liberate composition from the constraints of both the extant musical instrumentarium and reigning notational conventions.” He sought to reconstruct specific sounds with organizations of different patterns (Levin, p. 58).

3.2 Avraamov and Sholpo

One of several parallels between German and Russian developments in abstract film-phonography is in the concept of sound ornaments. As Fischinger and Pfenninger were well into their experiments with optical sound in the early 1930s, a film released in 1929 in Russia introduced the idea of the sound ornament to the public (Smirnov, 2013, p. 175). What followed was a movement of thought and technological achievements that inspired optical sound synthesis research in Russia.

Arseny Avraamov was a composer based in Moscow. His ideas sparked movements in music that introduced sounds from everyday industrial life and common noises to the musical spectrum. Between 1929 and 1930, Avraamov began to experiment with optical sound ornaments (shown in Figure 3.2) trying to find harmonies in the microtonal music that had resulted from art movements following the October Revolution. Avraamov’s ornaments are similar to the images that Fischinger was creating during the same time, but it is unknown whether there was any communication between the two. Both explore repetitive patterns along with layers of shapes of different dimensions, showing an understanding of how the optical soundtrack functioned in

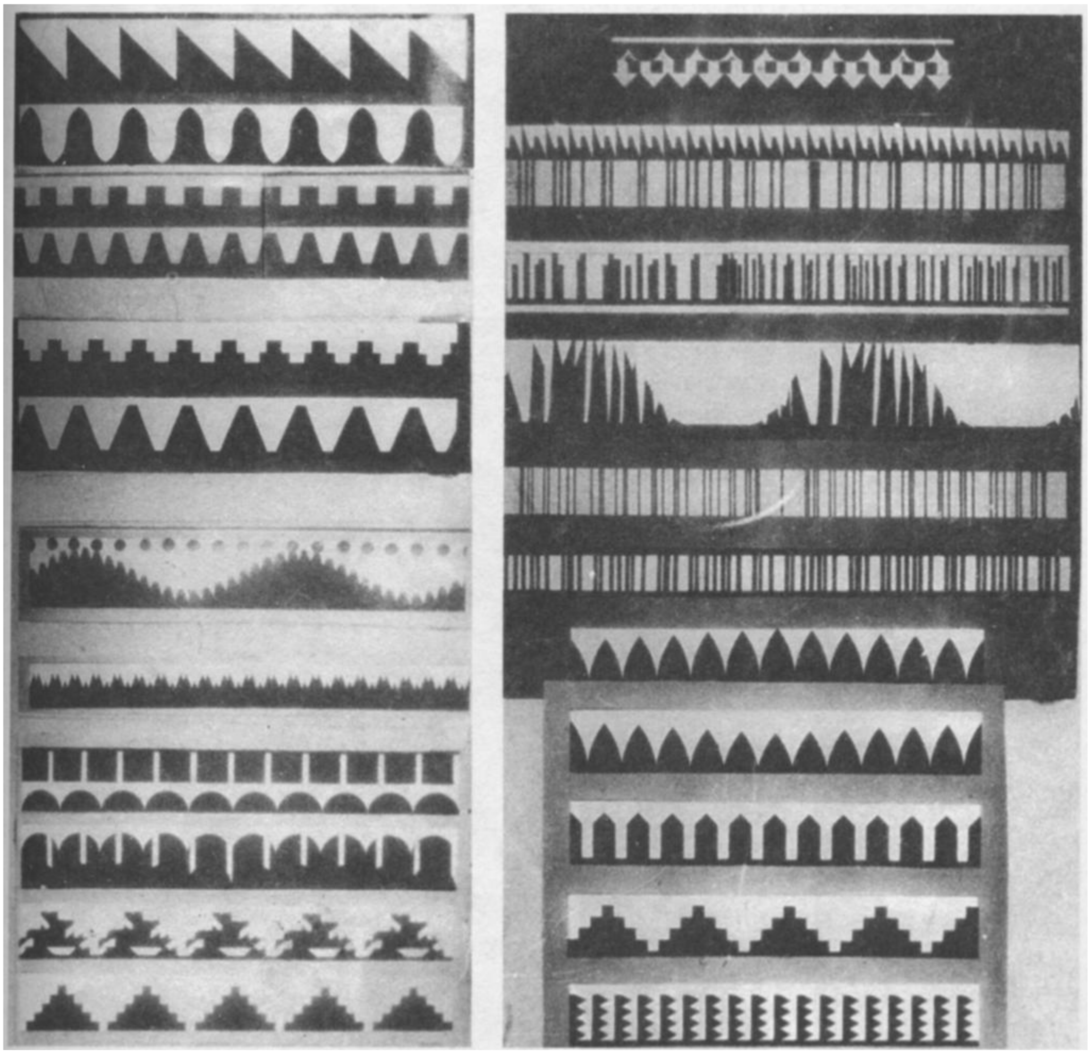

Figure 3.2: sound ornaments created by Arseny Avraamov in Moscow (Smirnov, 2013, p. 179).

relation to moving images. Avraamov was also instrumental in starting groups and laboratories that explored the potential of the optical soundtrack as a musical instrument and as a tool for sound analysis. “From 1930-34 over 2,000 metres of ornamental sound tracks were produced by Avraamov’s Multzvuk Group and Syntonfilm, including the experimental films *Ornamental Animation, Marusia otravilas, Chinese Tune, Organ Chords, Untertonikum, Prelude, Piluet, Staccato Studies, Dancing Etude* and *Flute Study*” (Smirnov, 2013, pp. 177 – 182).

Also exploring optical sound in Russia in the 1930s was engineer Evgeny Sholpo, whose laboratory was based in Leningrad. Sholpo's work concerned a different type of optical sound synthesis: paper sound via the Variophone – a system invented by Sholpo for synthesizing sounds and recording them onto film. The Variophone was developed as an instrument for composers and is described as a "mechanism for the transformation and addition of harmonious fluctuations with different amplitudes" (Smirnov, 2013, p. 195). The instrument called for composers to cut sections out of optical discs (examples shown in Figure 3.3) that would be placed on a motor. The motor rotates the discs at rates specified by the composer as a light shines through cut-out sections on the discs. The patterns of light-fluctuations produce tones that are variable in pitch and amplitude and can be recorded in real-time onto film.

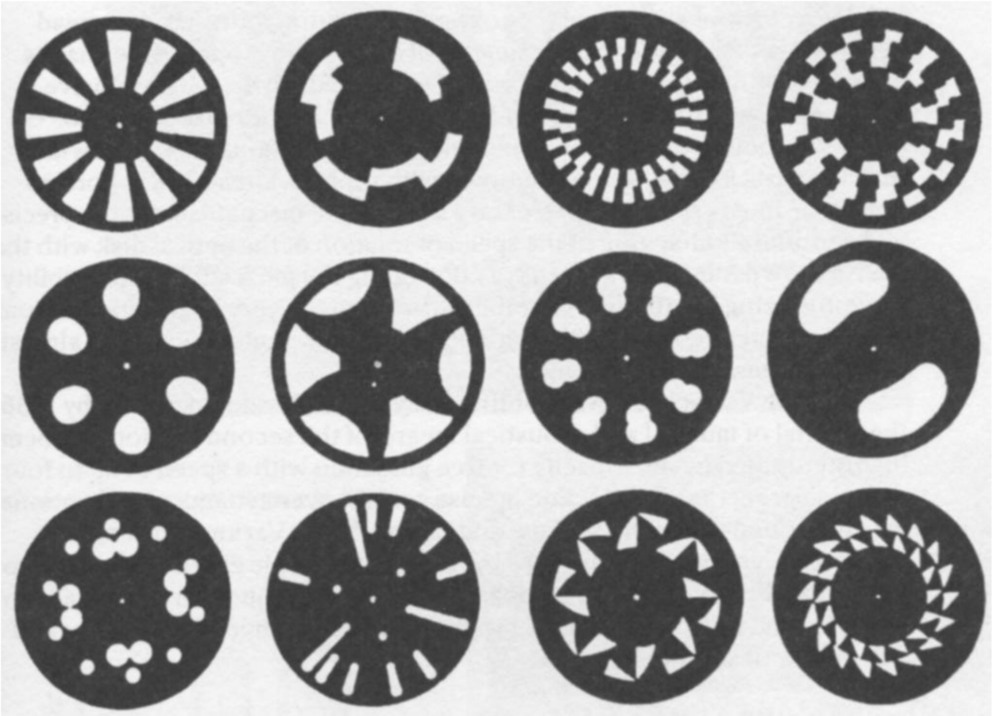

Figure 3.3: examples of optical discs used in the Variophone (Smirnov, 2013, p. 195).

Although he suffered a few hardships – including location changes, funding issues, and missiles exploding near his laboratory – Sholpo was able to build a few versions of the Variophone, demonstrating and implementing the paper-sound method. Its sound was similar to the electronic music of the 60s, but more expressive as Sholpo had developed ways of implementing subtle rhythmic changes and dynamic shifts (Smirnov, 2013, p. 191-195).

Unfortunately, like many other electronic music developments in Russia during the 1930s, optical sound achievements were met with eventual termination or turmoil. Avraamov's archive of sound ornaments was burned to make rockets and smoke screens. The most functional version of Sholpo's Variophone was destroyed by a nearby explosion. Sources of federal funding for these experiments were cut when experiments in synthesis and microtonality resulted in sounds that were vilified by popular opinions of music – an uncanny parallel to the fate of experimental arts in Germany during the late 1930s and 1940s.

3.3 McLaren and Sherwin

In 1940, a Scottish-born animator named Norman McLaren released the animation *Dots*. The work features abstract animations and a hand-drawn soundtrack. He "achieved a level of sophistication using this technique [hand-drawn sound]. The musical range is over several octaves and integrates perfectly with the moving blue and white dots that bounce across the bright red background" (Wilson, 2006). Because the soundtrack is hand-drawn, McLaren has the opportunity to create audiovisual relationships that are difficult to achieve via standard recording processes. He can articulate any image or

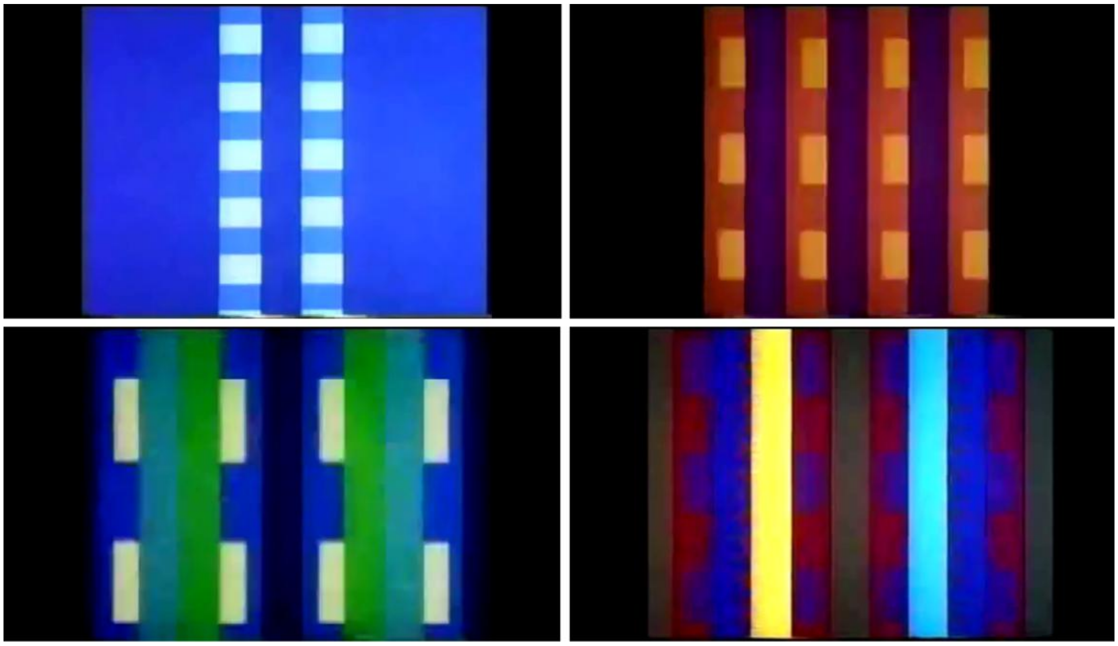

Figure 3.4: stills from Norman McLaren's *Synchromie* (1971). Courtesy, National Film Board, Ontario, Canada (McLaren, 1971).

action with any type of sound that he wishes to draw onto the soundtrack. 1952's *Neighbours* features another hand-drawn soundtrack, this time set to a pixilated (stop-motion with live actors) animation instead of abstract imagery. McLaren explored and revealed the optical soundtrack's potential as a tool for audiovisual art. His experiments were directly related to the production of musical sequences, demonstrating some of the basic components of music – pitch, harmony, duration, rhythm and timbre. A perfect example of this is his 1971 animation *Synchromie*. In this piece, the hand-drawn soundtrack – musical sequences of rectangular waveforms – informs the visual content – colored sequences of the drawn soundtrack (shown in Figure 3.4).

Creating audiovisual associations with optical soundtrack is as simple as using synthesized soundtracks for visual frames (as in *Synchromie*) or using visual frames to construct the soundtrack. Guy Sherwin explored the latter with the 1977 piece *Musical Stairs* (Figure 3.5 shows a clip of a strip of film from the piece). Here, Sherwin takes a simple staircase and uses abstract film-phonography to attribute musical qualities to the piece.

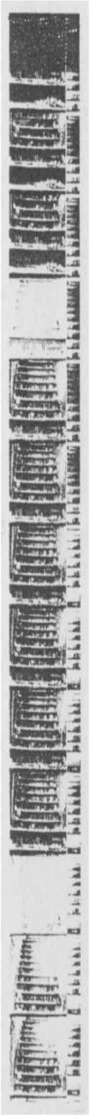

Figure 3.6: a segment from Guy Sherwin's *Musical Stairs* (1977) (Sherwin, 2011, p. 51).

> The stairs were filmed from a fixed position. By tilting the camera up and down, I made an approximate musical scale in eleven tones – the more stairs included in the frame the higher the pitch. Varying the exposure alters the volume – the darker the image the louder the sound. (Sherwin, 2007, pp. 50-51)

The visual images and sound source are generated by the same material and contribute to the creation of a clearly communicated audiovisual language. All of the material for this piece comes from the same source.

3.4 Beebe and Rowley

Two recent pieces that contribute unique approaches to abstract film-phonography are *TB TX DANCE* (2006) by Roger Beebe and *Optical Sound Film No. 2* (2013) by Benjamin Rowley. Both of these pieces are similar in that their soundtracks are made from the visual images of the piece, but different in structure.

TB TX DANCE is made up of 1-second segments of different laser-printed patterns and animations. The 1-second segments exploit a very important standard for optical sound playback – the amount of time that it takes for a frame to travel from the lens to the optical sound component is about 1 second. In *TB TX DANCE* Beebe prints the images so that the part of the image makes it onto the soundtrack. The part of the soundtrack that is printed onto a certain frame will be heard 1 second after that frame is projected. Using two projectors, he shows the positive and negative prints of every image (two examples shown in figure 3.7a). Some of the images contain bigger shapes and thus produce lower rhythmic tones. Other images have patterns of small dots, producing noisier tones with higher spectral content. Blank frames create a surprising effect during the piece. Because of the 1-second offset between the visual frames and the soundtrack, there are times when the blank frames are met with the sounds of previous frames, creating positive and negative synchronization effects – positive meaning that a point of synchronization is created by presenting material in both the sonic and visual components

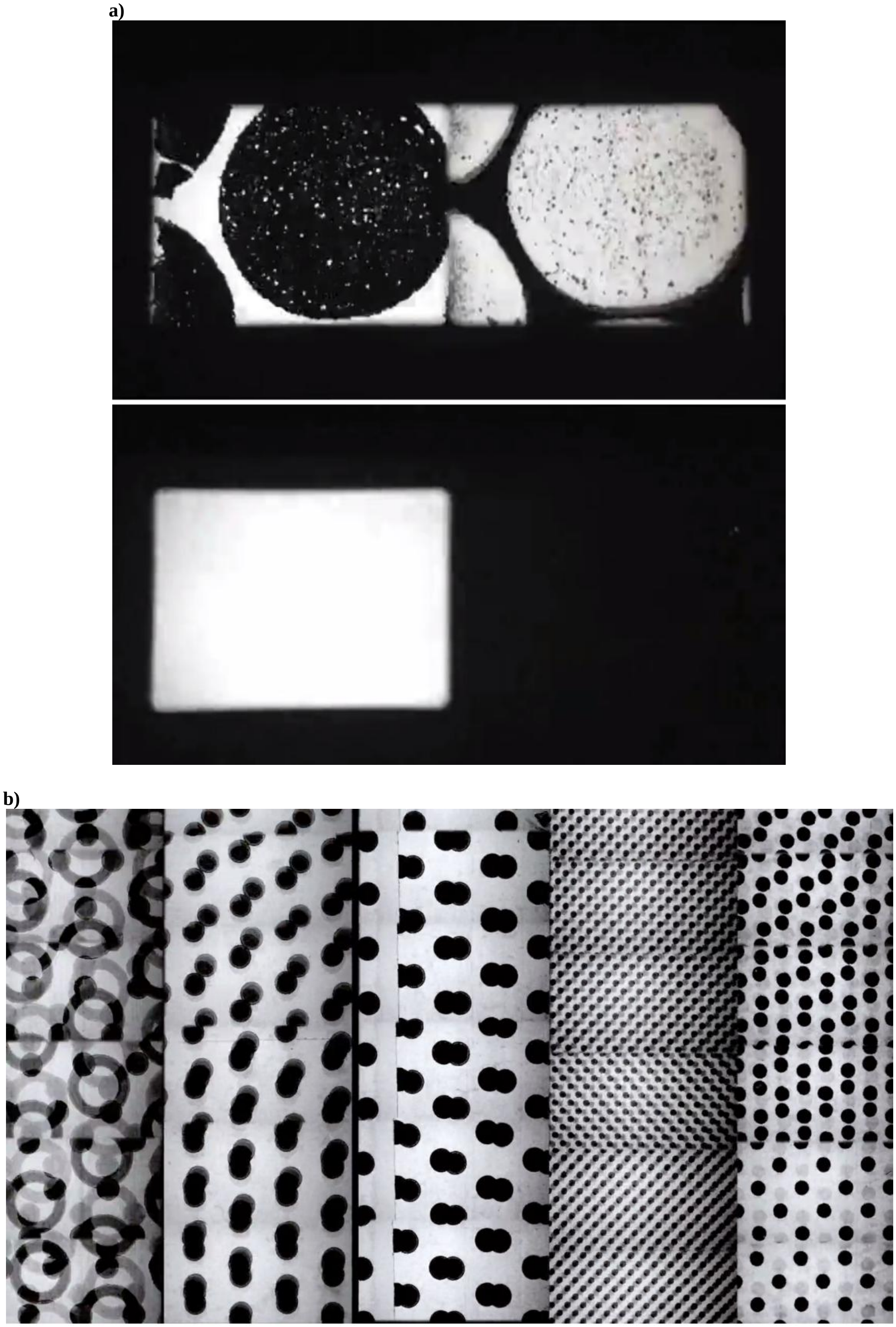

Figure 3.7: a) two stills from Roger Beebe's *TB TX DANCE* (2006); b) one still from Benjamin Rowley's *Optical Sound Film No. 2* (2013)

of the piece, and negative meaning that synchronizations are created by removing material or presenting blank materials.

Points of synchronization “naturally signify in relation to the content of the scene and the film’s overall dynamics. They give the audiovisual flow its phrasing, just as chords or cadences, which are also vertical meetings of elements, can give phrasing to a sequence of music” (Chion & Gorbman, 1994, p. 59). These points attract attention and have the ability to establish audiovisual rhythms and anticipations. In *TB TX DANCE*, Beebe achieves this by using the 1-second audio-visual offset to his advantage.

Rowley’s *Optical Sound Film No. 2* (shown in Figure 3.7b) uses a similar process of printing patterns onto film that make it onto the soundtrack portion. Multiple sound and film tracks attribute a harmonic quality different from Beebe’s *TB TX DANCE*. The final image is divided into 5 segments, each with its own flowing pattern and soundtrack. Rowley creates audiovisual harmonies and dissonances by introducing similar or contrasting patterns on the separate tracks. By shrinking or enlarging the same pattern, he creates simple relationships that attribute musical qualities to the final film.

These two pieces tackle a major aesthetic issue with film-phonography: synchronization. These pieces do not require rigorous synchronization of distinct sounds with certain visuals. Both let the mechanics of the projectors work to their advantage, articulating the aesthetic possibilities of projectors in their most natural state. They create systems whereby the projector becomes an interpreter that carries out a piece despite any limitations it might have.

3.5 *check* (Dominguez, 2013)

check is a fixed-media piece for xerographed film completed in July 2013 at Dartmouth College. Inspired by abstract film-phonography experiments, it explores the sonic potential of juxtaposing two geometric patterns with black and white frames. *check* was created by xerographing collages of printed patterns onto strips of clear 16mm film – a process that was chosen after a few experiments. The result is a three and a half minute film, where xerographed collages are animated and directly translated into an audio signal by a 16mm projector.

3.5.1 Early test-loops

Upon learning about the xerographed sound technique, it was necessary to learn how to implement the process efficiently and effectively. The chosen technique involved making templates in an image editing program that would serve to xerograph precise images onto strips of film. Strips were spliced into loops to be recorded and analyzed. One of these early templates is shown in figure 3.8.

3.5.2 Preparation of materials

The patterns chosen for “check” were picked on an intuitive basis. Because the sounds from these patterns had not been heard during the composition phase, it created an interesting situation – one where a composer can see the activator of an instrument, but has yet to experience the outcome of this interaction. It’s as if a composer writing for cello knows how the bow functions and where the hand is placed on the fingerboard, but has never heard the sound of a cello before. After careful inspection of over 80 pages of

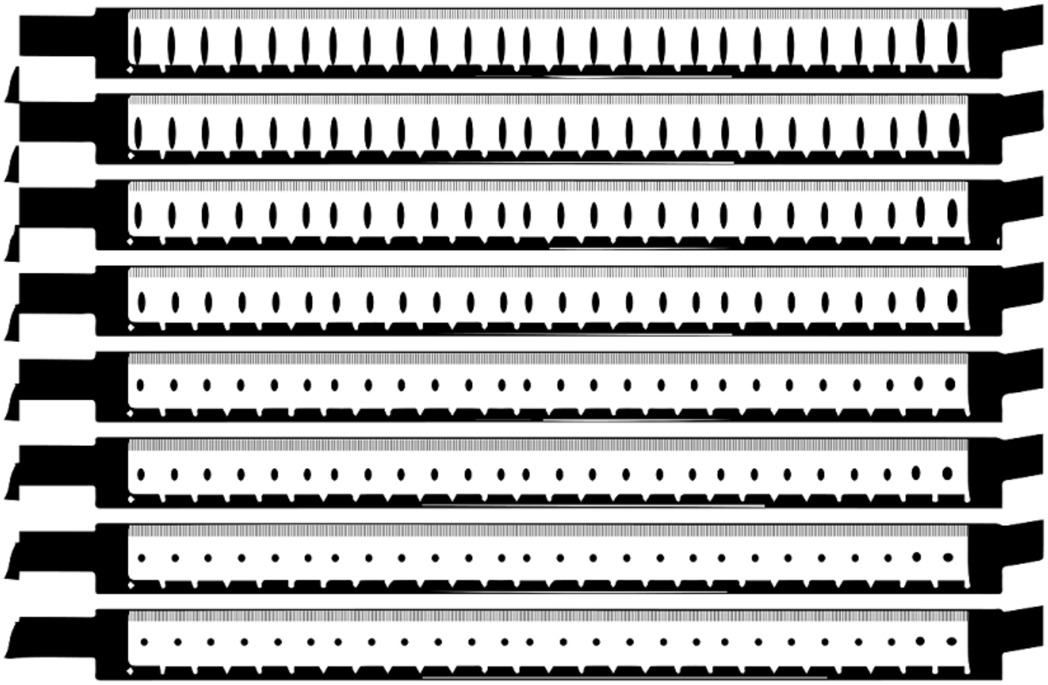

Figure 3.8: test-template for xerographed-sound synthesis.

patterns (from Jean Larcher's "Optical and Geometrical Allover Patterns" published by Dover Books), 2 patterns and their negatives were picked.

12 collages were made incorporating 2 patterns and black and patterned backgrounds. Composed of stripes of patterns and solid black and white, each collage slices the background into sections of solid or patterned frames. Strips of clear film were then attached to sheets of paper. Each strip was about 25 frames long, which, when running at 24 frames per second, makes 1.04 seconds. In total, there were 202 strips of film attached to 12 sheets of paper. The collages were copied onto the film-sheets and each strip was spliced to the next one. The final step was to create titles for the beginning and end of the piece, which were made from a simple pattern of the pieces name.

3.5.3 Structure of *check*

Since the xerographing process resulted in sheets of 15-17 strips of film that last 1 second each, planning the piece was similar to working on an audio track in a digital audio workstation. The time-frame for the piece was about three minutes, leading to the calculation that 12 collages could be made to fit all of the film needed to fulfill the proposed duration. Figure 3.9 shows all of the collages that were made for *check*.

Each collage works similarly and has a direct effect on not only the visual, but also the sonic qualities of the piece. A landscape-oriented sheet of paper is attributed two things: a background pattern and a collection of strips of a contrasting pattern. The pattern-strips are attached horizontally across the sheet and the film-strips are oriented vertically with their order reading from left to right. Starting with solid portions of black and white, the series of collages progresses from solid blocks into patterns and their negatives and finishes with solids.

The steady pulse in the piece is attributed to the spliced area of the film strips. Solids attribute a strobe-like effect to the visuals and a thick, full-spectrum pulse to the audio. Patterns, on the other hand, had unique qualities. One pattern consists of different sizes of triangles, attributing a pulsating quality to the displayed visuals and a frequency-modulated saw-wave to the audio. The other pattern is a gradient of small dots that creates a slowly moving block of points accompanied by a soft drone. Even the titles produced their own sound attributed to the font style, typeface, and size.

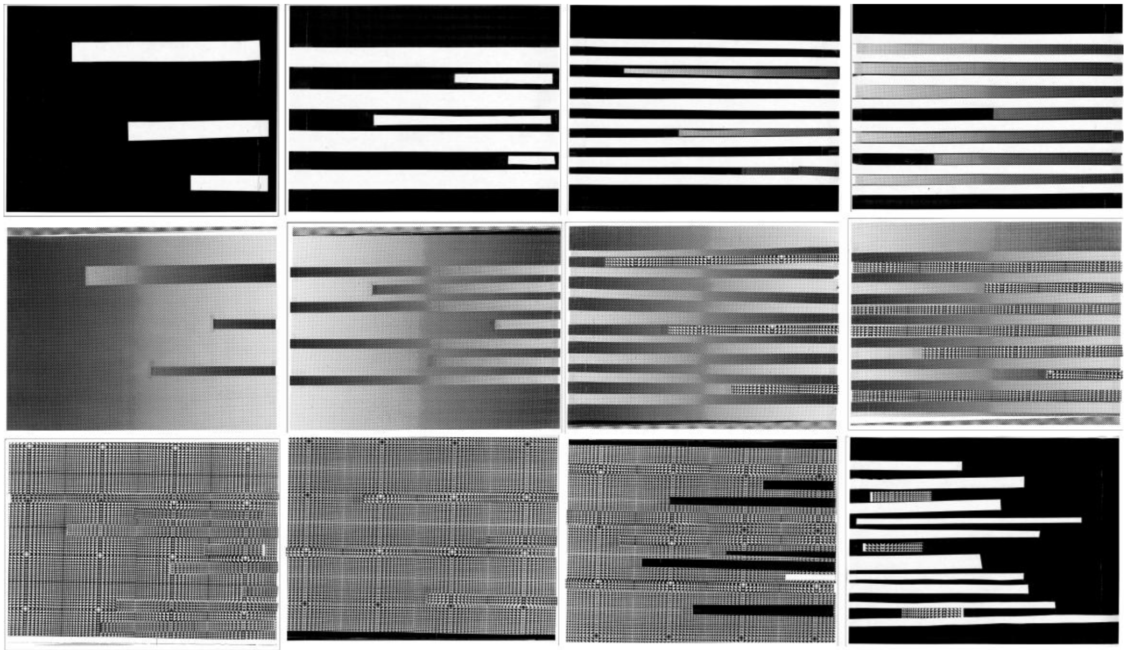

Figure 3.9: the collages for *check* arranged in order from top-left to bottom-right.

3.6 Results in Film-Phonography

check is a piece that resulted in a slightly blind exploration of compositional materials. Without the real-time playback functions of DAWs and real-time programming languages, composers have to think differently about how they use the compositional resources they have. It becomes similar to composing music with the performer in front of you. Prints can be made onto film and played in loops or segments, just as a performer can play parts of the music that you've written. But, it isn't until the entire piece is complete that the composer gets a chance to listen and reflect on the music. By intentionally marking the film that passes through the optical sound system of a projector a composer is given the opportunity to create a directly related audiovisual language. Film-phonography therefore opens an array of potential ways to create new sounds. Ornament sound takes a composer on a path focused on the visual properties of the soundtrack. Paper sound pushes interests towards the orchestration of interesting timbres.

Hand-drawn sound gives the composer an opportunity to activate the intuition behind a tactile technique for sound production. Alternative modes of printing onto film yield interesting timbres as different printing technologies make markings in different ways. The optical soundtrack has opened the door for artists and engineers from different backgrounds to conduct sound-synthesis research in a variety of ways.

4 Early Systems for Optical Sound Synthesis and Control

Sholpo's Variophone was one of the earlier machines dedicated to the production of sounds with photosensitive components. The system yielded promising musical results with its paper-disc method for sound-synthesis. It allowed composers to record musical notes onto film in a very accurate but foundational way. In the years surrounding developments of the Variophone, photosensitive components were implemented in other systems that control spatialization and sound synthesis on a larger scale. This section discusses three devices for synthesis and control of sound with photosensitive elements: 1) N.M. Molodsov's 1934 patent for the spatialization of sounds with optical sound technology; 2) Evgeny Murzin's ANS Synthesizer built between 1938 and 1958; and 3) Daphne Oram's "Oramics" machine built between the 1950s through 1970.

4.1 S(urr)ound-on-Film

Up to the early 1930s, photosensitive systems had been used mainly for synthesizing sound or sound recording. One of the earliest concepts for breaking out of the synthesis aspect was patented by N.M. Molodsov in 1934. He filed a certificate for a "device for sound on film reproduction, intended to create the illusion of spatial movement of sounding objects by reproducing sound by means of sound film" (Smirnov, 2013, p. 143). Molodsov created a system where the amplitude of four speakers was controlled independently by four photosensitive components (Figure 4.1 shows a diagram for this system). The photosensitive components would read markings on film similar to

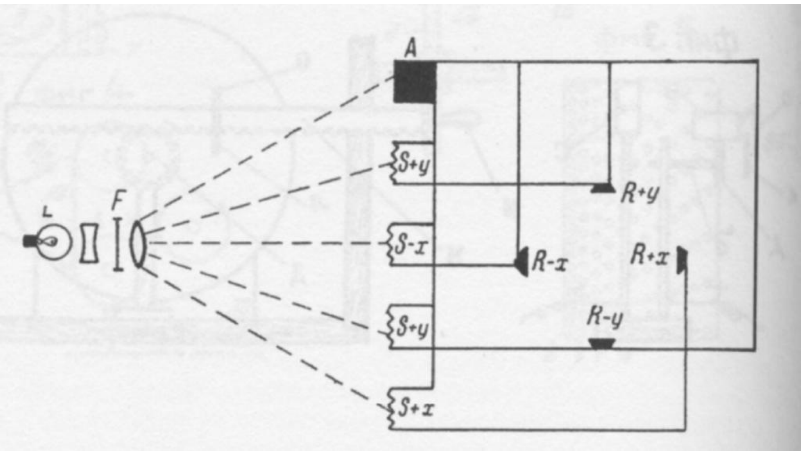

Figure 4.1: N.M. Molodsov's diagram for optical surround-sound control (Smirnov, 2013, p. 146).

the previously mentioned optical sound systems. This system is perhaps the earliest optical sound technique implemented to control the spatialization of a sound source.

4.2 Murzin's ANS Synthesizer

During the years surrounding the development of the Variophone, another Russian engineer was working on a machine for optical sound synthesis. Evgeny Murzin is most notable for his work on the ANS Synthesizer. The ANS is named after composer Alexander Nikolayevich Scriabin and is based on the idea of "synthesizing a sound from an artificially drawn sound wave." Murzin began to develop the ANS synthesizer in 1938, but the instrument was not completely developed until 1958. In an article on the ANS, engineer and composer for the ANS Stanislav Kreichi describes one of the main parts of the instrument as consisting a "photo-optic generator…designed in the form of a rotating glass disk . . . with 144 optic phonograms of pure tones, or sound tracks. A unit of five similar disks with different rotating speeds produces 720 pure tones." (Kreichi, 1995, p. 59) The ANS is almost a continuation of the research that Sholpo was doing with the Variophone. Both of these instruments were meant for musical composition and implemented a spinning disc system. Their main difference is that with the Variophone, a composer uses one disc to produce one tone. The ANS implements a system of four discs, each containing 144 possible sine waves that were activated when light passed through the disc. Kreichi continues by describing the process of composition for the ANS:

> To select the needed tones, a coding field (the 'score') was designed in the form of a glass plate covered with an opaque, nondrying black mastic. The score moves past a reading device made up of a narrow aperture with a number of photoelectric cells and amplifiers. Scraping off a part of the mastic at a specific point on the plate makes it possible for the light from the corresponding optic phonogram to penetrate into the reading device and be transformed into a sound. (Kreichi, 1995, p. 59)

The ANS saw success through the 1960s in Moscow among groups of composers and in the early film scores of Andrey Tarkovsky. It would be the last significant development in Music Technology in the U.S.S.R. (Smirnov, 2013, p. 231)

4.3 Oram's "Oramics"

The world saw a decline in photosensitive systems for sound synthesis due to the mass production of analog tape after World War II. This, however, didn't stop Daphne Oram from realizing a synthesizer that would refer back to the optical sound developments of the 1930s.

In the late 1950s, Daphne Oram was working on prototypical schematics for her photosensitive compositional workstation 'Oramics.' This project took over a decade to come into fruition and was finished in 1970. The Oramics machine implemented a multi-track system that accepts hand-drawn waveforms that determine different qualities of sounds. The waveforms are drawn onto strips of film that are read across photosensitive scanners devised by Graham Wrench, one of the main engineers in Oram's group. The signals from these scanners are sent to different equipment modules that determine the variables associated with the qualities of the produced sounds. (Manning, 2012)

Regarding the multi-track interface, Peter Manning states that "the control system accommodates ten film strips, divided into two groups of five. Four of the tracks in the lowest group…provide the amplitude envelopes for the individual waveform scanners. The fifth is used to control the amount of enhancement to be applied to the resulting timbre using feedback from a reverberation unit." The other five tracks of the control system were used to determine the desired pitch via a digital coding system that utilized photocells to measure patterns that resemble the neumes of ancient forms of musical notation. Regarding the multi-track digital system, Manning states that "one group of tracks (the lowest) specifies the required value in 1000-Hertz steps, the second the value within that step to the nearest 100 Hertz, the third to the nearest 10 Hertz, and the fourth to the nearest Hertz." Oramics was not the simplest machine to operate, but it provided yet another novel way of creating and thinking about music while using photosensitive processes. (Manning, 2012)

5 Current Projects in Photosensitivity

The previous section presented three historical systems that take photosensitive elements out of the context of film-making and into the world of sonic composition. This section presents four recent projects that implement photosensitive systems for the production or control of sound.

5.1 Mathy's *Light Frequency Fingertips*

Robert Mathy's *Light Frequency Fingertips* (2009) is an example of one piece that uses the analog properties of optical sound circuits in a performance context. He made customized bicycle tubes that fit four of his fingers. Each tube has a cap that contains a phototransistor, allowing the performer to create optical signals by moving her/his fingers around light-emitting devices. A typical performance includes the use of a touch-screen device. Mathy states that "any subtle movement of the fingertips creates a slightly audible change in sound. Fading and mixing is also done by moving the fingers." (Mathy, 2009) The end result is a polyphonic, light-dependent synthesizer whose frequencies change according to the position of fingers around light sources.

5.2 Varchausky's *La Biblioteca Siega*

Another example of photosensitive components in artistic performances is the live portion of Nicolás Varchausky's *La Biblioteca Siega* (2011). In this piece, members of an orchestra of blind musicians play custom-built instruments that read fluctuations in light. Varchausky's process parallels the Variophone and ANS Synthesizer by using perforated discs. On one of these instruments, a light is shone on a disc that contains patterns of perforations. The performers rotate the discs with hand-crank systems and photosensitive components read the fluctuations. The analog signals created by the photosensitive components are digitized and interpreted in Supercollider software. (Varchausky, 2013) Another one of the instruments is composed of a bar of light covered with a patterned baffle used to shape the light. The performers then drag photosensitive elements that communicate luminous fluctuations to the computer. The process of digitization results in a performance that takes the analog features of photosensitive components and augments them so that they reach new potential by controlling digital sound processes.

5.3 *p1x3L8Ed* (Dominguez, 2012)

p1x3L8Ed is a multimedia installation that uses generated visual projections to shine grids of color onto three wall-mounted square-wave synthesizers. It was premiered at the Sound/Unsound installation show on November 14th, 2012.

5.3.1 Exploring photosensitive synthesizers

The idea for *p1x3L8Ed* came about when implementing the Hex Schmitt Trigger square-wave oscillator example from chapter 18 of Nicolas Collins' "Handmade Electronic Music" (2006). The example results in a simple square-wave oscillator. It is possible to adjust the frequency of this oscillator by applying different amounts of resistance in the circuit. One example is of the circuit with a photoresistor that controls frequency (a schematic from Collins' book is shown in figure 5.1).

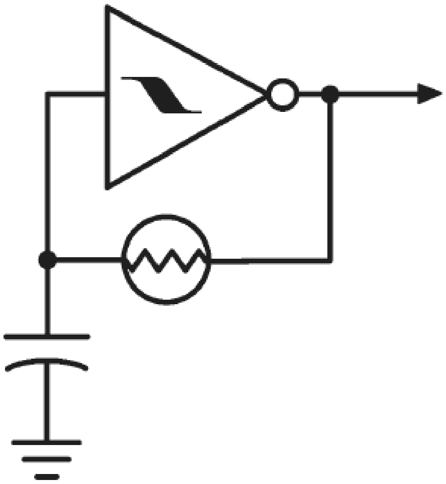

Figure 5.1: schematic for Hex Schmitt Trigger synthesizer with a photoresistor controlling frequency (Collins, 2006, p. 116).

When done multiple times, this photosensitive circuit yields a polyphonic square-wave synthesizer whose frequencies are controlled by light. These tests would become the main component for *p1x3L8Ed.*

5.3.2 Structure of the piece

The piece has three components: 1) 3 photosensitive synthesizer circuit-boards containing 9 oscillators each, 2) 3 wooden boxes with transparent façades, and 3) video projections. The synthesizers are housed in the wooden boxes and hung on a wall. Each box has a transparent façade allowing light to shine onto the circuits. The 9 photosensitive elements from each circuit are arranged in a 3 x 3 grid on the transparent façade of each box. A projector then shines grids of color onto each box (this can be seen in figure 5.2).

5.3.3 Audiovisual results

The audio content for *p1x3L8Ed* consists only of square-wave oscillators.

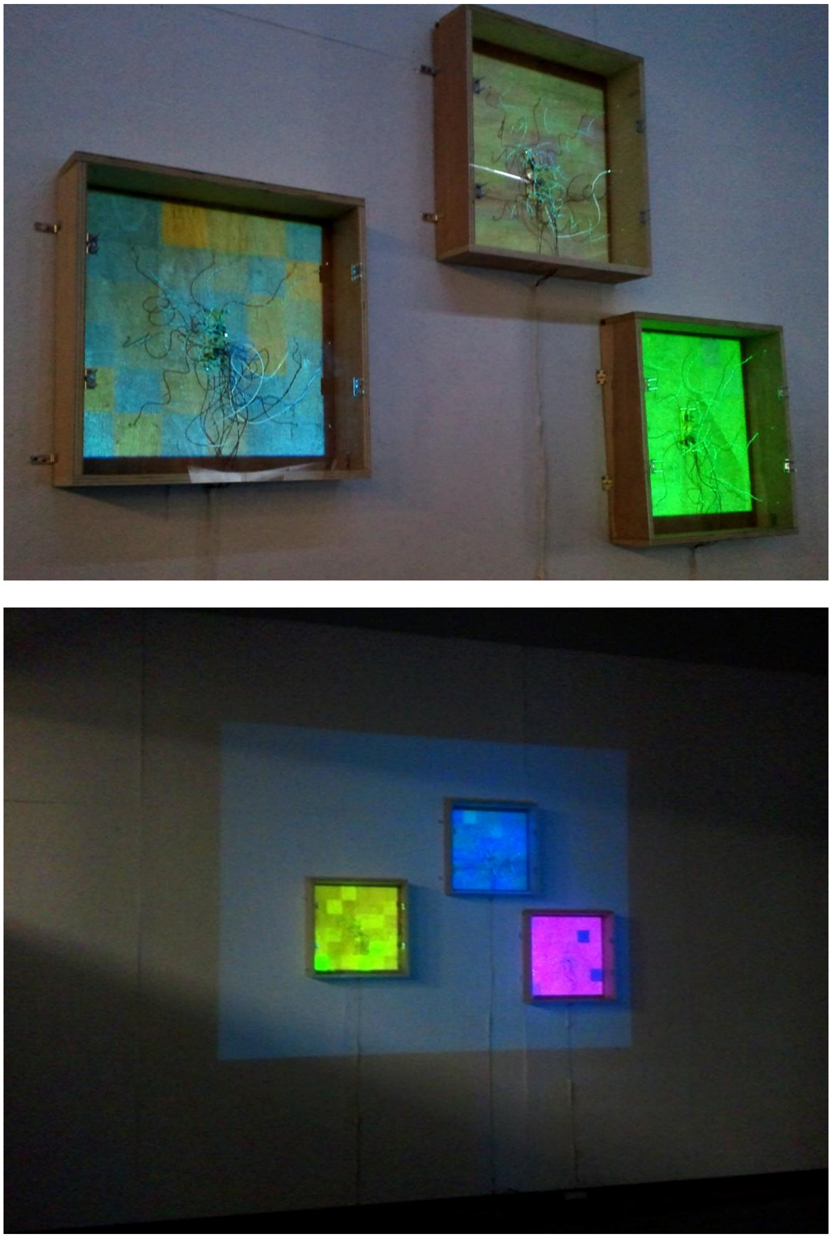

Figure 5.2: ***p1x3L8Ed*** **(Dominguez, 2012)**

Visually, the piece uses ever-shifting grids of light that create flowing textures of pixelated colors. The cells in each grid share hue properties so that each cell is similar but different from the next. Cells flow through the color spectrum in slow and fast behaviors causing the frequencies of the oscillators to shift in different ways. The projections are generated in Max/MSP/Jitter and run indefinitely. For amplification, each box has an audio-jack that connects to a mixer and a pair of speakers. The final audiovisual result is a dense texture of square waves whose frequencies are linked to the rate of color-change in the projected grids.

5.4 The 16-CdS and *photosinebank* (Dominguez, 2013)

The 16-CdS (shown in figure 5.3) is a surface controller that allows the user to manipulate 16 digital signals via a grid of 16 photoresistors that are connected to an Arduino microcontroller. Casting shadows or shining light on the controller presents the opportunity for a performer to make use of ambient or synthetic light-sources during a performance. The first version was completed during the fall of 2013 with the help of Ezra Teboul.

photosinebank is an improvised piece for laptop running Max/MSP using the 16-CdS surface controller. The 16-CdS controls the amplitudes of 16 oscillator banks – each generating 10 sine waves. Driven by the improvised decisions of the performer, the performance slowly progresses as clusters of sine waves surge in and out of the encompassing sound-world. These undulations are attributed to the frequency-interval between consecutive oscillator banks. Signals from the oscillators are run through a system of feedback-delays, causing the tonal masses to clash and eventually blend into each other. Parameters for fundamental frequencies, frequency interval, and amplitude are controlled by the performer, but only the amplitudes are controlled by the 16-CdS. The piece was premiered at the Audiotheque in Miami, FL as part of their “Year-End Fest” on December 26th, 2013.

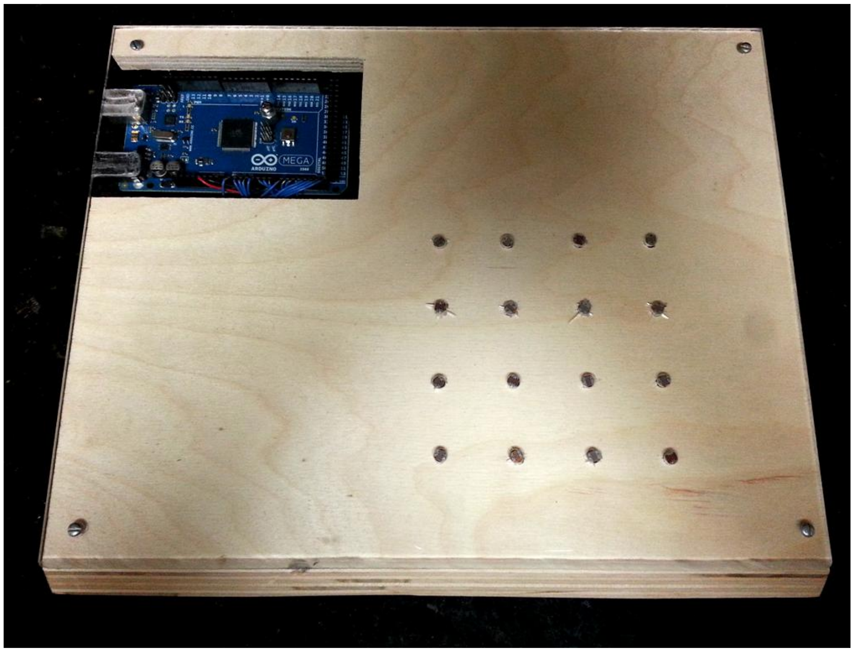

Figure 5.3: the 16-CdS surface controller.

5.4.1 Sound synthesis in *photosinebank*

photosinebank is composed solely of sine waves generated by 16 oscillator banks that are organized into four groups. Three layers of data processing determine the frequencies that are emitted during the performance – the first one being the global fundamental frequency of the current section in the performance. Once the fundamental is chosen by the performer, this number gets multiplied and assigned to each group. Starting with the first group, their initial multipliers are 1, 1.498, 2, and 2.996. These multipliers are equal to the ratios corresponding to the tonic, perfect fifth, octave, and perfect twelfth intervals on the 12-Tone Equal Temperament (12-TET) system for tuning.

The next layer of data processing happens within each group. Since each group contains four oscillator banks, four numbers for each group were chosen to multiply the frequency value from the first layer and assign fundamental frequencies to the individual oscillator banks. The first group's multipliers are 1, 1.497, 2, and 2.996 – the same ratios that are used to multiply the global fundamental frequency. The second, third, and fourth groups multiply their fundamentals by 1, 1.497, 1.781, and 2. The ratio between these numbers and the fundamental is equal to the tonic, perfect fifth, minor seventh, and octave intervals on the 12-TET system. At this point, it can be said that each group represents a different chord made up of intervals above the global fundamental frequency.

The final layer of data processing happens within the individual oscillator banks. Each bank contains ten oscillators, totaling to 160 oscillators for the entire program. A mechanism takes the oscillator bank's assigned fundamental and increments it by a user-defined amount (this is the second user-defined parameter in the piece), determining consecutive frequencies for each oscillator. A layer of synthetic reverb is added to the sum of all of the signals from the oscillators, resulting in the final output.

The final sonic result is a cluster of sine waves, all stemming from the global fundamental frequency. Some frequencies are repeated and others are only cents off from each other causing slow undulations and interference patterns. The user-defined increment in the third layer of data processing has the potential of creating extremely slow swells in amplitudes of consonant waves, or aperiodicities within frequency values that attribute a fluttering texture to the overall sound mass. These are all qualities that occur when the 16-CdS is at rest.

5.4.2 Sound control

Within Max/MSP, the performer has the ability to manipulate the global fundamental frequency, the frequency increment, and the qualities of the reverb that is applied to the final signal. All of these factors are separate from the function of the 16-CdS controller.

As previously stated, the global fundamental frequency controls the frequencies emitted by all of the oscillators in the performance. Changes to this parameter have the potential of drastically shifting the tonality of the piece. However, when combined with particular settings for frequency increments and reverb, a change in the global fundamental can cause a shift that happens slowly. Masses of sine-waves first clash with each other but eventually reach a stable condition. The frequency increment has much to do with this, as increments of a few cents will cause the phases of individual oscillators to interfere with each other slowly while increments of a few hertz will create strong dissonances between consecutive oscillators. Concerning the reverberation effects, the user chooses a starting point and increment for the delay-lines (this is the same function that determines consecutive frequencies within oscillator banks) and a percentage that determines how much of the delayed signal gets fed back into itself. The reverb is simply delaying and playing back sine waves on top of each other. For a performance of *photosinebank*, proper settings of the reverb cause tone-clusters to continue sounding for over fifteen seconds when the oscillators' amplitudes are all set to 0 dB.

5.4.3 Programming for the 16-CdS

As mentioned in previous chapters, the 16-CdS's control data comes only from a 4x4 grid of 16 photoresistors that give lower values in darkness and higher values in lightness. *photosinebank*'s overall design came about when thinking about musical applications for the controller. A simple idea was to have 16 oscillator banks controlled by the light reaching each photoresistor. Furthermore, the grid has a 4x4-square layout, bringing up the idea of organizing the oscillator banks into groups of four, bound by some sort of relationship (their frequencies in this case).

Starting on the upper-left corner of the grid, the first photoresistor is mapped to the fundamental oscillator bank of the first group. The next resistor to the right is mapped to the successive bank in that group. This process continues with the two photoresistors directly under the previous two, forming a quadrant of 4 resistors that are mapped to the first group of oscillator banks. The quadrant in the upper-right corner of the grid is mapped to the next group of banks, continuing with the bottom-left and finally the bottom-right quadrants. A simple connection between the amount of light reaching each photoresistor and the amplitude of each corresponding oscillator bank was implemented, where greater intensities of light correspond to louder amplitudes and vice-versa. Each quadrant on the grid therefore controls the amplitude of each group of oscillator banks and – because of how frequencies are calculated for the groups – the spectral content of the current point in the performance.

5.4.4 A typical performance of *photosinebank*

photosinebank is naturally a slow piece. There is no strict score for this piece, although the patch functions in a very specific way. In a sense, it becomes a musical instrument just like any other. Instead of having factors such as pitch range, activation energy, and volume as constraints, it deals with frequency distribution, ambient light, and spectromorphological progression. A performer will achieve either trembling aperiodicities or undulating harmonies exposed by the physical allocation of light onto the surface controller. Having this in mind, the performer can choose to prepare, or simply improvise, a progression of frequencies and gestures that guide the piece.

5.4.5 Relative gestures and techniques for *photosinebank* and the 16-CdS

Since the performance involves use of a laptop and the 16-CdS, the performer will have to make sure that both of these items are accessible by both hands. The laptop portion of the performance only requires the performer to change 3 numbers at will. It does not require full attention at all times, leaving room to manipulate the 16-CdS with both hands throughout different moments in the performance. Also important is the calibration of the controller within sources of ambient light in the room. Maximum amplitudes should be exhibited when the performer is at rest and the grid of photoresistors is at its highest amount of exposure to ambient light.

With enough time, the performer can learn to execute different gestures with the controller. One possible gesture is to cover a portion of the grid for enough time to eliminate the corresponding frequencies from the spectrum, and then quickly allow light to reach the grid, causing the missing frequencies to swell back in. Another technique is to block the entire grid at the same that the global fundamental is changed, allowing the performer to bring in newly assigned frequencies at will.

A more explorative process that can be investigated is to find the resonant frequencies of the performance space and use them for the performance. This can be done by generating a sine-wave sweep and tracking frequencies that create louder resonances in the room. Amplifying the output signal of a microphone to the point where some of the signal makes back into the input (feedback) will also expose resonant nodes in the space that can be tracked and remembered.

5.4.6 Results with *photosinebank* and the 16-CdS

photosinebank is a piece where listening shares a creative space with shadow production. Natural behaviors exhibited by the program during static points in activity allow the performer to analyze the current sonic situation and make decisions regarding the course of the piece. These decisions result in physical movements which lead to changes in sonic spectra. Physical movements produce fluctuations in the light-intensity readings of the controller. A simple wave of the hand results in an even undulation, and an intricate hand-shape placed on the controller eliminates a specific portion of the overall sonic output. Here, manipulation of ambient light becomes what the stick is to the drum, but in the opposite sense – where the drum is always sounding and the incorporation of physical energy results in deactivation.

6 Conclusion

The photosensitive qualities of film-phonography created bridges between a wide set of art forms. Artists who normally worked with visual media used their skill-set for musical compositions. Visual artists were able to apply their skills and intuition to the world of sound synthesis. The roll of film became a musical score with the achievements of Sholpo and Oram. Avraamov and Fischinger sought to find the sonic qualities of ornamental patterns. The animations and films of McLaren and Sherwin revealed the potential of approaching their work in a musical way. The projector itself turned into a musical instrument with the works of Beebe and Rowley. Varchausky and Mathy's projects demonstrate the sonic potential of manipulating visual components in a performance context. The byproducts of experiments with photosensitive technologies of the 1920s yielded a world of sound that had not yet been accessed. The years that followed saw experimentation and innovation that pushed photosensitive components into new sonic territories. An electronic process that measures visual information was driven to create and manipulate sonic output.

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