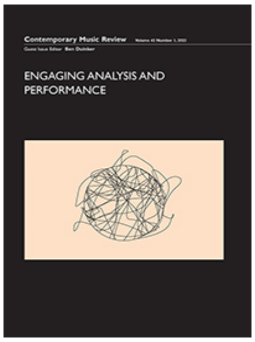

Contemporary Music Review

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/gcmr20

Navigating Technological Obsolescence: Analysis and Reconstruction of Stockhausen's *Mikrophonie I*

Timothy Roth

To cite this article: Timothy Roth (2023) Navigating Technological Obsolescence: Analysis and Reconstruction of Stockhausen's *Mikrophonie I*, Contemporary Music Review, 42:1, 61-81, DOI: 10.1080/07494467.2023.2225887

To link to this article: https://doi.org/10.1080/07494467.2023.2225887

Published online: 19 Jul 2023.

CONTEMPORARY MUSIC REVIEW
2023, VOL. 42, NO. 1, 61–81
https://doi.org/10.1080/07494467.2023.2225887

Navigating Technological Obsolescence: Analysis and Reconstruction of Stockhausen's *Mikrophonie I*

Timothy Roth

University of Toronto, Toronto, ON, Canada

This article outlines analytical methods for preparing and interpreting Karlheinz Stockhausen's sextet *Mikrophonie I* (1964) for tam-tam and electronics. Would-be performers of this work face significant accessibility issues: Stockhausen's recommended equipment—especially the electronic filter used to process the tam-tam's sound—is extremely rare. These issues often necessitate performers finding alternative solutions for equipment. *Mikrophonie I* is one of several works for live electronics that have become increasingly difficult to program, due to the obsolescence of the technology required to perform them. Performers often reconstruct the necessary electronics digitally, using software such as Max/MSP. Wetzel [(2006). "A Model for the Conservation of Interactive Electroacoustic Repertoire: Analysis, Reconstruction, and Performance in the Face of Technological Obsolescence." *Organised Sound* 11 (3): 273–284. https://doi.org/10.1017/S1355771806001555] describes a three-stage model for this reconstructive process that foregrounds the need for performer-led analysis. Using *Mikrophonie I* as a case study, I expand on Wetzel's model to navigate the reconstruction through two main analytical perspectives: the prioritisation of sound or *process*. These methods are then applied to my realisation process of *Mikrophonie I*. I describe the process of constructing a digital filter in Max/MSP based on a patch created by Christopher Burns [(2002). "Realizing Lucier and Stockhausen: Case Studies in the Performance Practice of Electroacoustic Music." *Journal of New Music Research* 31 (1): 59–68. https://doi.org/10.1076/jnmr.31.1.59.8104] and compare different interface options for using the filter in performance. Referring to previous recordings by the Stockhausen Ensemble (1965) and the percussion ensemble red fish blue fish (2014), I show how creative interpretations can help ensembles overcome the perceived shortcomings of their available tam-tam. Beyond the specifics of reconstructing the technology required for performing *Mikrophonie I*, this article underlines the indispensability of analysis for performers who specialise in works with obsolescent technology.

KEYWORDS
Live Electronic Music; Performance Practice; Stockhausen; Performance Research; Percussion

Introduction

For those who have fallen down the rabbit hole of performing works for live electronics, the realisation of an existing work requiring now-obsolete technology can be an intensive

CONTACT Timothy Roth tim.roth@mail.utoronto.ca

process. The sextet *Mikrophonie I* (1964), composed by Karlheinz Stockhausen (1928–2007), is no exception: despite the legacy of the composer, *Mikrophonie I* continues to face issues of accessibility and sustainability. This early work for live electronics requires performers to use microphones as active instruments to capture a wide variety of sounds generated from a single tam-tam. The sounds are transformed through the manipulation of microphone placement, electronic filters, and dissemination to four loudspeakers placed around the audience to create a diverse yet distinct sonic landscape. The model of filter that Stockhausen used when composing the work, the Maihak W49 Hörspielverzerrer, is next to impossible to acquire today without the assistance of the Stockhausen Foundation. Similarly, the 60-inch Paiste tam-tam called for in the score is much larger than the conventional orchestral tam-tam and is relatively rare to find, resulting in many performances on sub-standard instruments (Stockhausen and Kohl 1996, 96). For those that wish to perform this work without the support of the Stockhausen Foundation, suitable substitutions must be found or created.

Mikrophonie I is just one of many works of music for live electronics that have become difficult to perform due to obsolescent equipment; other notable works include *Solo* (1965–1966) by Stockhausen, Dialogue *de* l'Ombre *Double* (1985) by Pierre Boulez, and *Pluton* (1988) by Phillipe Manoury. Several problems exist in this repertoire:

(1) Works are not documented as thoroughly as is needed, and necessary electronic software/hardware can be difficult to preserve or distribute (Bernardini and Vidolin 2005; Lemouton et al. 2018).
(2) The materials and equipment become obsolete: electronic materials get lost or decay over time (Battier 2004) and software becomes incompatible with modern operating systems (Bonardi et al. 2008).
(3) Even if the equipment is accessible, it may be quite difficult to acquire because it is custom-made, out of production, or expensive to purchase (Bullock and Coccioli 2006)
(4) Performers without institutional backing and a team of technicians may lack the diverse skill sets required to approach many works in this repertoire. As described by Berweck (2012, 14):

> It is not possible to ascribe certain skills to such a *realizer*, since the requirements for each piece are different. To realize a composition like < by Alexander Grebtschenko, where ten small loudspeakers are slowly roasted by a current greater than they were constructed for, the performer of the piece must know how to solder. In the composition *on_radio* by Scott Hewitt the player must be able to program software. And in Alvin Lucier's *Music for Solo Performer* the player famously has to learn how to produce alpha waves.
>
> This situation is worsened for pieces where the original equipment no longer exists, and performers must search for methods to recreate obsolete software or hardware.

Several campaigns have been formed to remedy these issues, including the formation of the Cultural, Artistic and Scientific knowledge for Preservation, Access and Retrieval (CASPAR) Project organised by the European Union, the Integra Project at the Birmingham City University, and the Brahms database at IRCAM, as well as many articles documenting reconstructions of one or several pieces (e.g. Bosma 2017; Puckette 2001; Sluchin 2000). Nevertheless, the rate of technological evolution mandates constant re-evaluation of works for live electronics, both to investigate how new technology can be used to reimagine common methods for realisation and to ensure that the current technology needed has not yet lapsed into obsolescence. This is especially true for works such as *Mikrophonie I*. While scholars such as Burns (2002) have documented their process of preparing a modern realisation of this piece, including a description of the Max/MSP patch created for use with a MIDI controller to play the filter part, further work is needed to address the many problems performers face when taking on the challenge of its realisation.

Background

Composed as a sextet for tam-tam and electronics, *Mikrophonie I* was inspired by the minute sounds that can be made on a massive tam-tam when Stockhausen listened closely to its surface. The resulting composition divides six players into two groups, each with a tam-tam player, a 'microphonist', and a technologist. Each group of players and microphonists is positioned on either side of the tam-tam, with the technologists centred in the middle of the hall (see Figure 1).

The tam-tam player generates sounds; the microphonist amplifies that sound; then the technologist applies high and low-pass filters and distributes the sound between front and back speakers in the hall. Stockhausen was interested in the way that the performers worked together to create a cumulative sound (Stockhausen 1974, 9):

> In this way three mutually dependent, mutually interacting and simultaneously autonomous processes of sound-strutting are connected with each other, which were composed as synchronous or temporarily independent, homophonic or in up to six polyphonic layers.

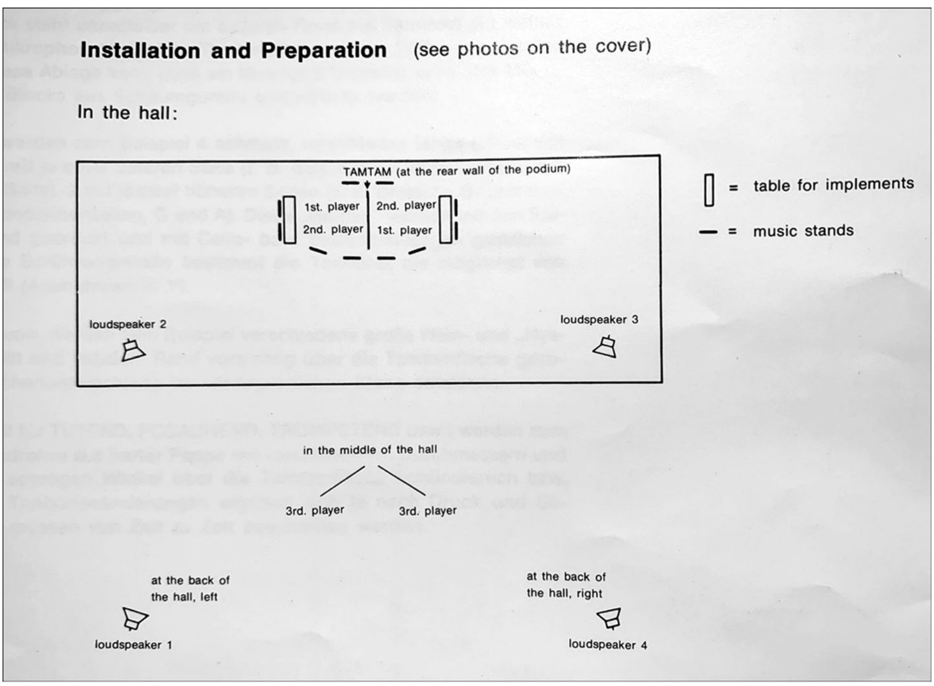

Figure 1. Installation diagram from score (Stockhausen 1974, 10). © Copyright 1974 by Universal Edition (London) Ltd., London.

The work is composed in 'moment-form', i.e. made up of self-contained groups of musical material that can be performed in any order (Kramer 1978). In the case of *Mikrophonie I,* the moments must be placed according to a connection scheme that accompanies the score. In each moment, Stockhausen identifies a number of 'sound characters' that, rather than being comprised of prescribed specific techniques and implements, are identified by their descriptive words (e.g., bursting, cackling, cheeping). The performers must choose implements and playing techniques that best fit the nature of the word and the notation in the score.

Stockhausen used custom notation systems for each player (Figure 2). In the microphonist part, line thickness determines the microphone's distance from the tam-tam and vertical height indicates the distance from the actual point of excitation. At the bottom of the page, Stockhausen describes the notation dictating the position of resonators that the microphonist uses at times. These consist of small open-ended containers of various sizes that the player holds above the microphone to manipulate timbre. Stockhausen devised a graphic system for the bandpass filter wherein the shaded areas correspond to the frequency area that is left open by the filter. The notation for the tam-tam player is the most detailed: the system is divided into high, middle and low registers depending on vertical height, and graphic figures indicate the nature of various articulations and sustained notes. The profound amount of detail in the notation necessitates equipment with a high level of precision, both when selecting implements for the tam-tam and when reconstructing the filters.

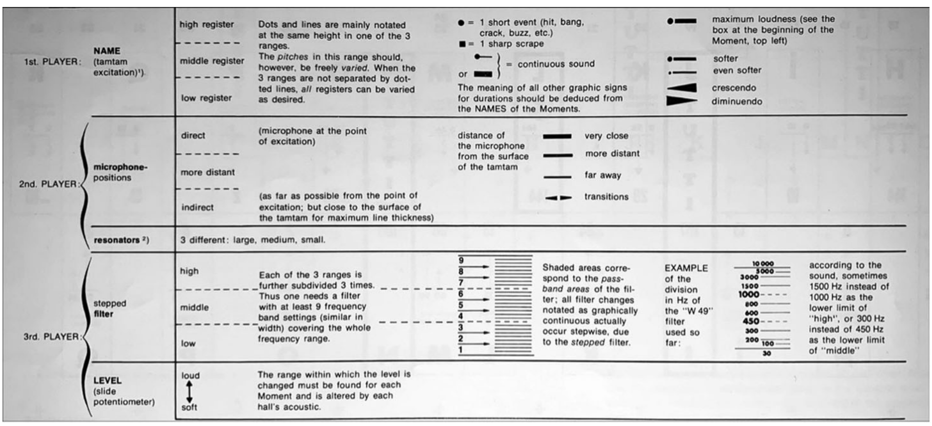

Figure 2. Diagram showing the notational system for *Mikrophonie I* (Stockhausen 1974, 14). © Copyright 1974 by Universal Edition (London) Ltd., London.

Reconstruction

When migrating and emulating electronics into new technology, the realiser is tasked with making pivotal decisions about how the work should be adapted that can have a lasting impact on the perception of the work. In some cases, the resultant work is refined in some way: Sluchin (2000) and Esler (2006) discuss the composer-approved improvements made for Stockhausen's work *Solo*, involving the reconstruction of the functions of several tape-delay machines in Max/MSP. A number of pieces, however, are more complicated to reconstruct using substitute materials. In the case of *Mikrophonie I*, Stockhausen was notably selective about both the filter and the tam-tam. In a 1972 lecture, the composer was lenient about interpretations of the work (Cott and Stockhausen 1973, 87):

> Someone said, must it be a tam-tam? I said no, I can imagine the score being used to examine an old Volkswagen musically, to go inside the old thing and bang it and scratch it and do all sorts of things to it, and play MIKROPHONIE I using the microphone. Play anything. Discover the micro-world of the acoustic vibrations, amplify it and transform it electronically. That's why I call it 'electronic live music' as opposed to electronic music which is produced in a studio.

By 1991, however, Stockhausen held a more rigid stance concerning the authenticity of the equipment. In a lecture about electroacoustic performance practice, he responded to a question concerning *Mikrophonie I* (Stockhausen and Kohl 1996, 97):

> It's extremely important to comprehend works, which were born to a particular historical moment, for their uniqueness. It just won't do to be continually discarding everything and making something different, but rather we should be preserving things and adding new ones. Anyway, it is my experience of music that every instrument, every item of equipment, every technique can produce something unique, which can be achieved in no other way. Since that is the case, then we can speak of an original technique, and thus deal with an original instrument. If it is imitable, then it is also not worth much.

Stockhausen also insisted that performances of *Mikrophonie I* use the Maihak W49 filter and stated 'if you try to substitute computerised filter simulations, the characteristic sound goes to hell' (Stockhausen and Kohl 1996, 97). He expressed his distaste for any tam-tams besides the few he had sanctioned, saying 'It all sounded wrong' (96).

Under these limitations, the piece is almost impossible to perform without the sanction of the Stockhausen Foundation. Christopher Burns (2002), in one of the first documented digital reconstructions of *Mikrophonie I,* opted for a 'pragmatic' approach, recreating the filter in Max/MSP and operating it with a MIDI controller. Regarding the tam-tam, the author concedes (Burns 2002, 64)

> From the beginning it was clear that our ensemble would not be able to offer a strict reproduction of the Brussels version; to begin with, we had no access to one of the small number of authorized 'Stockhausen Mikrophonie I' tam-tams created by Paiste. If we wanted to perform the piece, we would be obligated to use the smaller and more conventional instrument available to us. Deciding to go ahead, we had little choice but to make our own musical decisions about the work, in accordance with the score and our own intuitions.

Xenia Pestova, Mark Marshall, and Jacob Sudol came to a similar, more optimistic conclusion regarding Stockausen's *Mantra*, stating that 'the performance practice tradition of [Stockhausen's] works will have to change and expand beyond the control of the composer and his disciples in order to survive. Ultimately, creative decisions will have to be up to us' (Pestova, Marshall, and Sudol 2008, 4). But when the decisions are left to us, how does the contemporary performer best proceed with the realisation? Is there a way to transcend the singular dimension of pragmatism when performing works that face these issues?

Methods for Reconstruction

In order to answer these questions, it is necessary to expand on David Brooke Wetzel's model of analysis, reconstruction, and performance. The model is summarised in Wetzel (2006, 274):

> The first stage is an analysis of the required electronics which details the functions and effects of the interactive system in as 'machine-neutral' language as possible. The second stage is a reconstruction or emulation of the original system using current technology. The third stage is testing of this reconstruction through rehearsal and performance.

The analysis stage of this model involves 'a detailed documentation of the electronic processes and effects required for each work in a format that is independent of any specific device or system' (273) with the resulting document acting as a 'blueprint for reconstruction of the interactive system using available technology' (275). While this activity is undoubtedly crucial to the preservation and longevity of this repertoire, the results of analysis at this level do not inform the best method for proceeding when the documented electronic processes are not able to be directly implemented within the resource limit of a typical performing ensemble. Wetzel acknowledges this limitation in his dissertation, even citing *Mikrophonie I* as an example of a work that does not fit into the model (2004, 185–186):

> The first awkward situation for abstract analysis of electronic systems is encountered in when the original instrument is itself the exact and irreproducible embodiment of the composer's intentions. A case in point is given in Stockhausen's remarks regarding a new realization of *Mikrophonie I* … In such cases computer simulation may be the only option, but we are aware that something important is missing.

I believe that Wetzel's model can be modified in order to accommodate works that call for obsolete equipment that is difficult to reproduce. This involves a re-conceptualisation of the required analysis, which seems to play largely an archival role. A higher-level analysis must be undertaken to better describe the pertinent functions of the electronic processes, or in the words of Arbo (2018) 'an analysis of the properties that can be considered as constitutive of the work in the contexts of its production and of its reception' (306). With this in mind, I propose a refined version of Wetzel's model—documentation, analysis, reconstruction, and performance—wherein the activity previously described as analysis is renamed as the preliminary and still-crucial documentation stage. Figure 3 shows a diagram of the amended model, based upon the diagram from Wetzel (2006, 274).[1] Together, the two steps of documentation and analysis fulfil each of the necessary tasks of digital restoration proposed by Arbo (2018, 306):

(1) On a first level, a preservation concerns the (more general) properties which confer the status of a document on the entity: the aim is to safeguard the integrity of the original trace and media.
(2) On a second level, the focus is on what makes this document a (musical) work: the goal is to create the conditions of an effective activation of its aesthetic functioning.

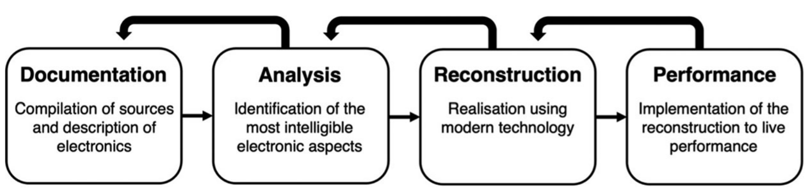

Figure 3. Expanded model for conservation of interactive electroacoustic repertoire based on a diagram from Wetzel (2006, 274).

These two tasks require distinct considerations: their separation into two consecutive steps allows for both to be addressed with a more transparent focus in series. The analysis stage acts as a crucial stepping stone for translating the compiled documentation into a reworked live electronic framework. This expanded model, while allowing for works such as *Mikrophonie I*, also opens up possibilities for more thoughtful and intentional realisations of works with live electronics.

Perhaps the most critical point within this model is deciding on—in the words of Arbo (2018)—the conditions that best create 'an effective activation of [the work's] aesthetic functioning' (306). Given that much of the original documentation for these works is directly from the composers themselves, it is often straightforward to make these decisions by using the available documentation to interpolate the composer's intentions for the work. However, there are several cases within the context of repertoire for live electronics where this approach falls short. There can be too little documentation to analyse; the obsolescence of technology can mandate significant adaptation from the documentation when a composer is no longer accessible to sanction these changes; or, as discussed earlier in the case of *Mikrophonie I*, the composer can outright condemn interpretations that use non-original equipment. For these cases, Guillaume Boutard's notion of intelligibility works well. Boutard (2016) introduces this concept when describing the goals and practices of the DiP-CoRE project, stating 'our intention is neither to understand a potential artist's intention at the level of the work, nor is it to deny the intention at the level of the activity, but to provide a framework for the transmission and the preservation of the intelligibility of the work' and shortly after 'we advocate to get rid of intentionality and look at intentional acts, within a process of negotiation of meaning as a purveyor of the intelligibility of the work' (760). The goal of analysis in this context, then, is to distil the aspects of the electronic processes that contribute the greatest level of intelligibility to a work. Focusing on the aspects of the work in this manner allows for a more comprehensive approach to performing works as they continue to age.

Sound and Process

Here I would like to explore two separate yet related criteria for intelligibility often present in works for live electronics: the prioritisation of *sound* or *process*. This idea is not novel: Boutard (2016, 760) and V2_Organization (2003, 6) describe the similar notion of 'process over product'.[2] While the distinction between sound and process is not necessarily relevant to the intelligibility of all works for live electronics, it is far-reaching enough to merit consideration when analysing live electronic works for reconstruction. The decision to prioritise one or the other can provide a concrete set of guidelines in situations where performers are asked to replicate the impossible. Here sound refers to the quality, diversity, and aesthetics of the sounds in performance, whereas process refers to the actual interaction that results in sound production during the work. Although the process is an aspect that could be completely opaque to both the audience and the performers, many electronic works from the twentieth century rely on its transparency. The work of composer Alvin Lucier is a good example: his work *Music for Solo Performer* (1965) calls for a performer to connect to a brainwave amplifier via electrodes placed on the head so that their brainwaves can activate percussion instruments placed around the audience. The knowledge that the performer's alpha waves are controlling the resulting sound makes for a fascinating experience where the audience can experience a performer's brain activity expressed through sound. Without awareness of this process, however, the performance experience is reduced to watching a person sitting silently on the stage while percussion instruments rattle around the room.

Radio Music

Another, more nuanced example of the prioritisation of sound vs. process in a reconstruction is found in John Cage's *Radio Music* (1956). In this work, and several others by Cage, performers 'play' the radio by changing the volume and frequencies across the AM band. Lindsay Vickery (2012) makes the point that the work faces challenges as AM radio stations have been declining in number: even if one adopted the original radios used for the performance, there may be soon be a time when a performance would yield only static (Vickery 2012, 8). Many performers have adopted a digital method involving creating a bank of pre-loaded 'radio stations' on the computer to cycle through for the performance. This indicates the prioritisation of sound over process: although the work will likely be performed on a MIDI controller instead of a radio, this gives the performers the opportunity to use vintage radio recordings in order to present a rendition that attempts to capture the sound of *Radio Music* around the time of its premiere. Vickery (2012) provides three solutions that seem to favour preserving the process of radio performance (8):

> The result of the ever-diminishing number of AM band radio stations is that *Radio Music* will be increasingly comprised of static rather than signal. There are several possible responses to this issue:
>
> 1. to embrace the realities of evolving technology and realise the work principally with the 'noise' of static;
> 2. to 'transpose' the work into a frequency band such as FM which is still relatively populated with Radio stations;
> 3. to 'narrowcast' internet radio stations in the vicinity of the performance.

Options one and two are certainly feasible now but are what Berweck (2012) calls 'intermediate solutions' (61) as radio stations may continue to dwindle in number. Vickery's third option, 'narrowcasting', involves transmitting radio signals in a short and specific area (such as a concert hall). This solution is by far the most sustainable but requires a much higher level of technological complexity to execute. All three of these options, as well as the radio-bank option discussed earlier, involve some sort of negotiation between generating characteristic sounds and conveying a transparent impression of process. These guidelines can be applied along with the performer's sense of intention for the work to create an intelligible interpretation for works with obsolescent electronics.

For *Mikrophonie I*, then, I applied these analytical concepts to approach both the reconstruction of the filter and the forming of sound characters on the tam-tam. Thankfully, there is ample documentation of the work from which one can analyse to distil the aspects of the electronics that are crucial to the intelligibility of the work. Based on the score, accompanying documentation, Stockhausen's recording of the work (Stockhausen 1965), and my own performance experience, I identify the salient aspects of the work to be:

(1) The curation of a diverse sound world through unique sound characters that are well-captured by the microphone and can realise the notation in the score.
(2) Performative and dynamic processing of these sounds in a way that is both sensitive to the performed sound characters and is able to realise the full potential of the notated technologist part in the score.

These assumptions have led me to prioritise sound over the process when choosing the sound characters played on the tam-tam. Regardless of whether the ensemble was or was not using a composer-approved tam-tam, it was more fruitful for my collaborators and myself to prioritise experimentation and development of unique characters than to adhere to Stockhausen's suggestions for sound. For my realisation of the electronics, I prioritised the process over the sound, particularly with respect to the interface of the filter. In the following sections, I draw on pre-existing documentation and my own analysis of *Mikrophonie I* to explore each of these aspects in further detail.

Maihak W49 Hörspielverzerrer

The Maihak W49 Hörspielverzerrer is a radioplay distorter consisting of 'two bandpass filters with variable bandwidth' (Stockhausen 1974, 10) (Figure 4). Williams (2012), in a thorough documentation and discussion of its use in *Mikrophonie I*, describes the Maihak W49 as 'designed for transforming sound in the context of radiophonic sound design, such as simulating distance, telephone conversations etc.' (80). He estimates that only approximately 120 units of this filter were ever produced (79).

One of the distinguishing features of the Maihak W49 is the presence of two knobs on the same fader track, each controlling the high or low end of the bandpass filter. Two W66c faders were bolted onto the Maihak W49 to act as volume control for the left hand while the right hand operates the bandpass filter (78). Notably, this was a stepped filter, consisting of eleven discrete frequency steps that the user could switch between: they were normally used in a 'set-and-forget' manner in the context of radiophonic sound design (57). Stockhausen's use of the filter as a dynamic instrument was, at the time, unusual (82):

> According to the legend printed above the faders the unit was not designed for people to move the faders around dynamically, so the resulting clicks and scrapes when doing so are not the signs of a poorly designed instrument, but are inescapable factors of the design of this particular device, and, critically, are factors of the repurposing of the instrument for electronic music performance—the realignment of the instrument with a music performance practice.

Stockhausen was notably fond of these sounds (Stockhausen and Kohl 1996, 97):

> The two metal levers of the filters scrape along on the carbon strips, and spray must now and then be used … Today, if you try to substitute computerized filter simulations, the characteristic sound goes to hell. The scraping and the skips between filter-levels is lost; but they actually belong to such a sound, when it is brightened up from below to above, or vice-versa.

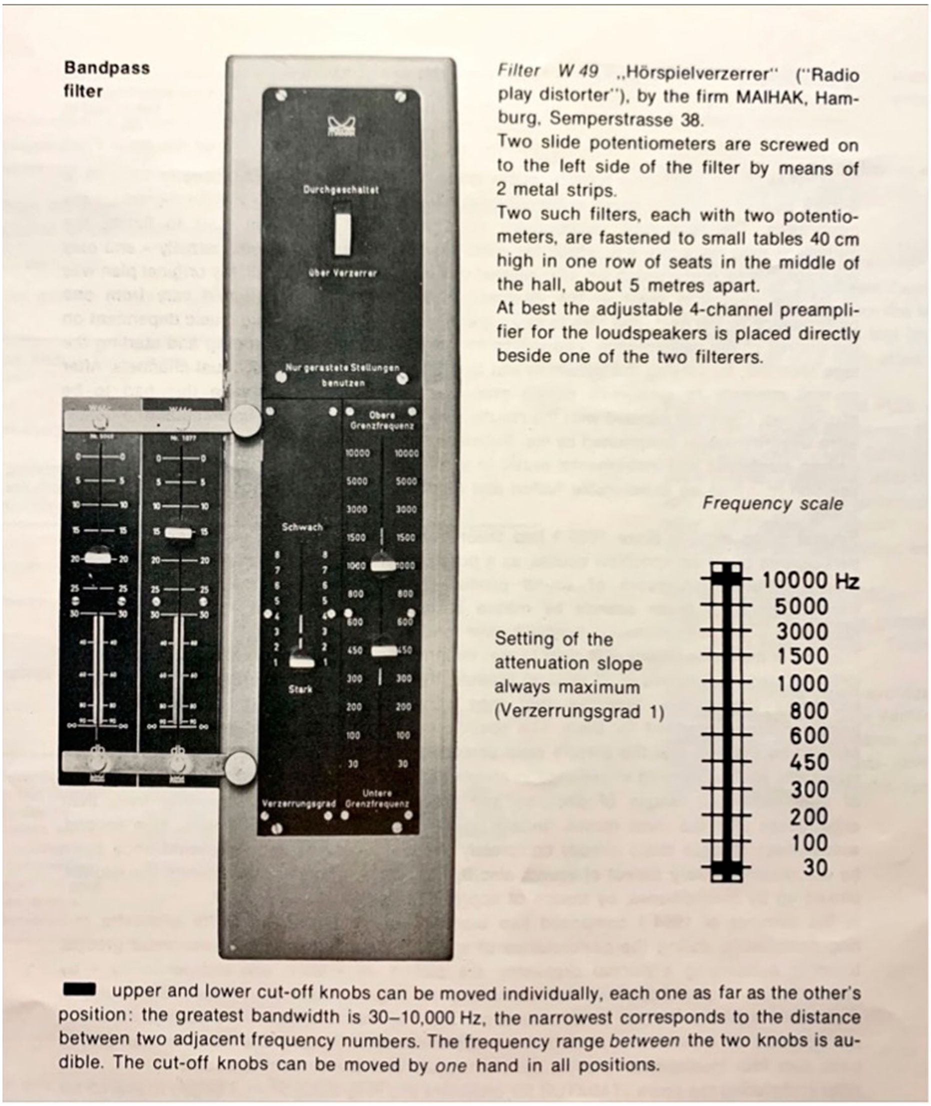

Figure 4. Diagram and explanation of the Maihak W49 from score (Stockhausen 1974, 10). © Copyright 1974 by Universal Edition (London) Ltd., London.

Thus, when reconstructing the electronics for *Mikrophonie I*, the salient features of the original electronics that merit inclusion in a reconstruction are (1) the dual knob fader, (2) the stepped frequency selection, and (3) the presence of incidental noise, i.e. extraneous scrapes and clicks that occur when moving between frequency steps.

Dual Knob Fader

The dual knob fader is an integral aspect of the filter part in *Mikrophonie I*. The parts for the technologists are notated so that both the top and bottom of the bandpass filter can be controlled with a single hand, allowing the other hand to control volume. Stockhausen quoted his colleague Thomas Kessler regarding this, who said ‘Even if the filter is created electronically with a computer, we should still construct them mechanically like they used to be, no matter what the electronics behind it are. It must still be the same for the hands’ (Stockhausen and Kohl 1996, 97). Certain moments, such as the technologist’s part for ‘Prellend Knatternd’ (Figure 5), require the dexterity afforded by the dual knob system. Here, the player must control both the top and bottom of the filter as shown in the top system while simultaneously following the volume changes shown in the bottom system. This excerpt is particularly challenging because it requires relatively fast switches between parallel and contrasting movements in the two filter knobs. Consider the circled area in Figure 5: the performer must first move the top and bottom knobs up together in a narrow band, then sweep only the bottom knob down and up, bring both back down together in parallel motion and then finally sweep the top knob back up to allow for all frequencies to pass. During this time, the volume fader ducks quickly in parallel with the opening of the filter, raising and lowering in contrast with the size of the open frequency band to keep the volume consistent. All of these gestures must take place in a relatively short time span: the circled gesture takes place over two beats. Having both the upper and lower frequency knobs on a single slider allows for one hand to perform this action ergonomically and with relative ease after some practice.

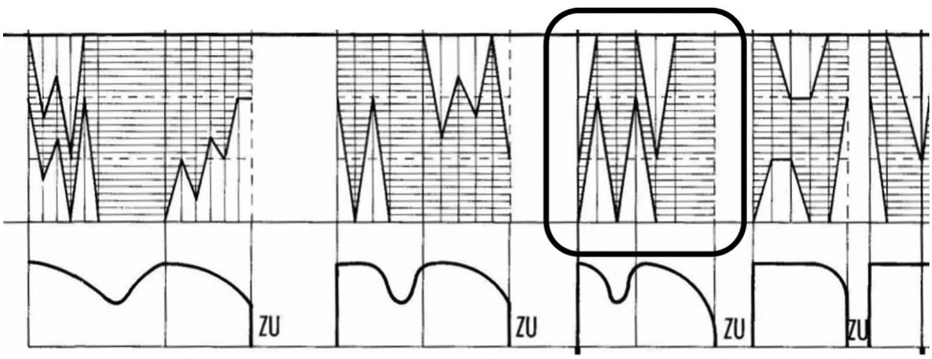

Figure 5. Filter and volume notation in the ‘Prellend Knatternd’ moment (Stockhausen 1974). © Copyright 1974 by Universal Edition (London) Ltd., London.

The dual knob feature of the Maihak W49 is relatively difficult to replicate, and very few, if any, faders have been manufactured in a similar manner since. Most performers today, as well as Burns (2002) in his reconstruction, choose to use two adjacent faders on a conventional MIDI controller. This can prove clumsy compared to the original filter because if the faders were to accidentally overlap then no sound would be produced. The original W49 filter never fully closes: because the filter is stepped, and the two filters cannot overlap, the frequency range can never be smaller than the range between two adjacent steps. Williams (2012) documents a solution designed by the anthos Ensemble, who created an analogue filter from scratch to imitate the Maihak W49. They use two adjacent filters to control the high- and low-frequency ranges, but added a metal spike to the side of the lower knob so that it can never pass the top knob (91). For my realisation, I wanted to create a solution that was more ergonomic for the technologists. After some testing, I designed and 3D-printed custom fader caps to use with a MIDI controller (in this case, the Behringer BCF2000) in order to create two matching ‘bars’ (Figure 6).

Figure 6. Picture of 3D-printed dual fader caps used on the Behringer BCF2000.

The bars are each secured to two fader caps that are designed to fit onto the MIDI controller. Thus, I use four faders for my recreation of the dual fader system: the first and the third fader for the top bar, and the second and the fourth faders for the bottom bar. The bars can be adjusted side-to-side so that both are in line with each other and are quite robust due to the double-cap system, allowing for the performer to make the quick and dramatic movements called for in the score of *Mikrophonie I*. The inner side of each bar is designed to be thick enough that, when used with the patch I designed in Max/MSP, one frequency band is always left open in the middle in a similar manner to the original filter even when completely closed.

Stepped Filter

One crucial aspect of the Maihak W49 is that the filter does not have a true fader as we understand it, but rather a linear fader-style switch (Williams 2012, 197). This mechanism was common in mid-twentieth-century filters but is rare today as the majority of manufacturers rely on continuous rotary knobs or slide filters. In his digital reconstruction of the filter, Burns (2002) incorporated this mechanism into his digital realisation to maintain the discrete motion between frequency steps of the original filter. One could consider keeping the filter continuous, as it would allow for the performer to more accurately realise some of the aleatoric shapes present in the notation for the filter part. In addition, performers using a MIDI controller with a Max patch in a similar method to

Burns (2002) will likely be using a continuous filter anyways, creating a disconnect between the movements of the interface and the stepped frequency output from the patch. However, there are certain moments in the score where the frequency steps are integral to interpreting Stockhausen's notation for the filter part. The area that denotes the filter spacing is divided into three sections, each with three subsections (see Figure 2) that divide and organise the range of the filter. At many areas in the work, the composer uses these subsections with such specification that the discrete frequency steps allows for cleaner execution of the material. One such example is in the 'Raschelnd (Rattelnd) Murmelnd' moment (Figure 7): along with helping define the scale of the jumps, the steps also provide a distinctive 'click' when moving, adding a rhythmic element that gives the filter more prominence in the resulting sound. Williams (2012), when describing a performance of *Mikrophonie I* with a continuous filter, noted 'The smooth frequency change and lack of steps robs the sound of aggressiveness and makes the piece sound more polite than the recordings made by the Stockhausen Ensemble' (91).

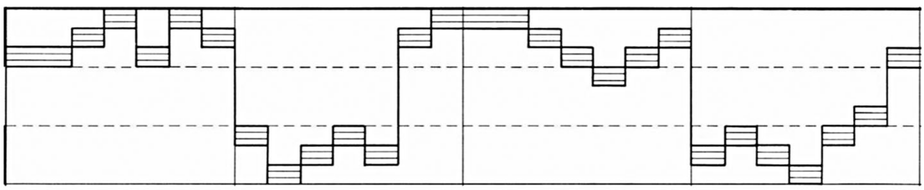

Figure 7. Excerpt of filter part in 'Raschelnd (Rattelnd) Murmelnd' moment (Stockhausen 1974). © Copyright 1974 by Universal Edition (London) Ltd., London.

For my realisation, I constructed a Max patch relatively similar to the patch described by Burns (2002) (Figure 8). Performers can connect a MIDI controller to drive the filters, which jump between the eleven frequency steps as described in the *Mikrophonie I* score (Stockhausen 1972, 14).[3] Users can also set the resonance of the top and bottom bandpass points to augment or diminish the presence of the filter in the resulting sound.

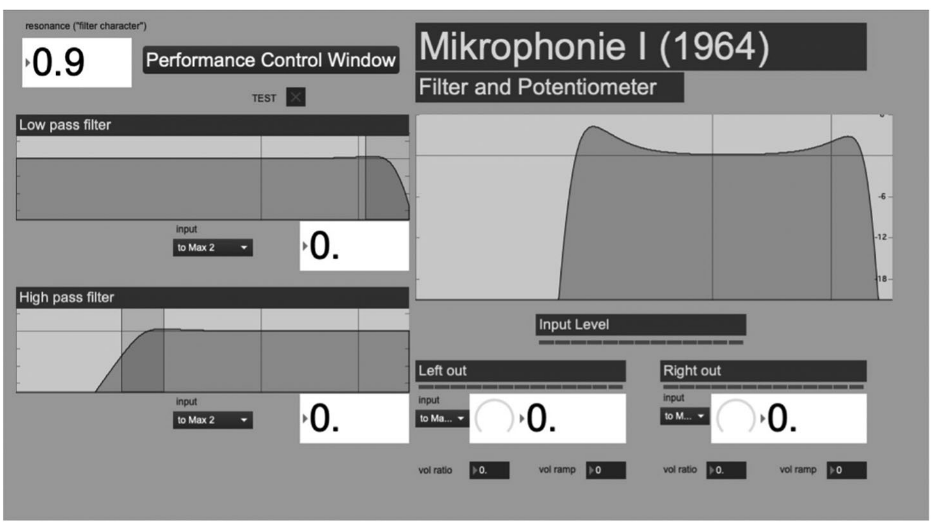

Figure 8 Picture of user interface from the author's *Mikrophonie I* Max patch.

Incidental Noise

Contrary to the above earlier quote by Stockhausen, the score for *Mikrophonie I* calls for 'click-free' filters (Stockhausen 1974, 10). Williams (2012) addresses the discrepancy between the two (84):

> There is a mismatch here, an inconsistency between the 'click-free' specification in the score and the 'scraping and skips' being regarded thirty-five years later as 'belonging' to the sound. The noises and imperfections have come to be regarded as signs of fidelity to the work in question. The imperfections are integral components of the original technique. It seems as though the listening practice inherent in performance practice has entrained the composer-performer to accept and incorporate the previously undesirable noises into the composition and identity of the piece itself. The importance of the noise element must be emphasised because there are many interpretations where this has been ignored and where the subsequent results have been adversely affected as a result.

This fundamental character of the filter described by Williams is where digital reconstructions fall short. Short of re-building the analogue components from scratch, there is no feasible possibility of incorporating these sounds into a new realisation of this work. But while the incidental noise certainly contributes to a more interesting sonic landscape, not all performers shared Stockhausen's enthusiasm for the Maihak W49 and the unique noises it produced. Williams (2012) details how Rolf Gehlhaar, a long-term member of the Stockhausen Ensemble, ' … recounts how they had to use contact cleaner to get rid of the frustrating clicks, and also how their fingers were painful and tired after a performance. He did not speak about the filter fondly' (83).

Until developments in technology and further innovation can remedy this in an accessible and sustainable manner, most performers must concede this quality in favour of a version of the filter that can at least function as a robust and dexterous instrument of expression.

Tam-tam

As the generative sound source, the choice of tam-tam has a large impact on an ensemble's performance of *Mikrophonie I*. The recommended tam-tam is an early version of the 60-inch Paiste Symphonic Gong that is still produced today: Stockhausen purchased the instrument in Frankfurt at the Music Trade fair to use in his composition *Momente* (1962) (Stockhausen and Kohl 1996, 96). Shortly after procuring the tam-tam that Stockhausen used for *Mikrophonie I*, Paiste began producing the tam-tams at a thicker width, reducing their sensitivity to smaller sounds such as those used in the work. Stockhausen lamented (96),

> These new tam-tams no longer respond to cardboard tubes and boxes, plastic dishes and lids, glasses, tea-caddies, suction-cups, egg-timer cases, massage vibrators, monochords, spaghetti-forks. It all sounded wrong. And once such a heavy tam-tam had been brought into vibration, it was scarcely possible to damp it.

He later worked with Paiste to produce a custom model of 'Mikrophonie' tam-tams (96). I have had the opportunity to perform this work with members of the Technology and Performance Integration Research (TaPIR) Lab using two different tam-tams: the Paiste Symphonic Gong Mikrophonie Gong owned by the University of California San

Diego, and a 36-inch with no known make or model owned by the University of Toronto. I also tested a few of Stockhausen's techniques on a modern Paiste 60-inch Gymphonic Gong, and Stockhausen is not wrong that many of the techniques that he crafted for the work are significantly less effective. One example of this is 'Pappohre' (cardboard tubes), a word that is not one of Stockhausen's sound characters but is called for several times throughout the score. In the score, Stockhausen describes a technique where 'cardboard buckets or postal dispatch tubes made of strong cardboard, of different diameters and lengths, are drawn continuously or jerkily over the tam-tam surface at an oblique angle' (Stockhausen 1974, 14). Stockhausen suggests that this technique may be used for the 'Tutend' (hooting), 'Posaunend' (tromboning), and 'Trompetend' (trumpeting) sounds, and indeed the Stockhausen ensemble can be seen using cardboard tubes when these sounds are called for in the 1966 video recording (Dhomme 1966). I was able to try this technique on the two separate tam-tams: a Paiste 60-inch Symphonic Gong made in 1998, which I measured to have a thickness of approximately 1.95 mm; and a Paiste 30-inch Symphonic Gong, which I measured to have a thickness of approximately 1.8 mm. From my experimentation with both tam-tams, the thickness of the 60-inch tam-tam significantly impedes the Pappohre technique: the heaviness of the tam-tam makes it more resistant to vibrations, making it difficult to create the sustained tones that Stockhausen asks for with the cardboard.

For situations like these, creative interpretation of the sound characters may be required. For example, the ensemble red fish blue fish, in a comedic display of craftiness, chose to make buzzing noises through different-size cones while facing the tam-tam for their 'Trompetend' and 'Tief Posaunend' sounds in the 'Rasselnd Ächzend Donnernd' moment (Stockhausen 2014). Alternatively, performers might even consider playing on the smaller tam-tam due to the relative ease in which the special techniques in the work can be performed in comparison to the larger tam-tam. Indeed, our ensemble perceived several advantages to a smaller tam-tam: the smaller diameter meant that it was much easier to dampen the tam-tam when called for in the score, and the extra space present between the tam-tam and the floor allowed for members to put their music directly in front of them while playing. But the smaller size did mean that the tam-tam swung a lot more, and during sections where both groups were playing the tam-tam sometimes became a moving target.

Our ensemble first performed on the 36-inch tam-tam and then brought the same implements when travelling to perform on the Mikrophonie tam-tam. On this instrument, we noticed a definite improvement in several aspects of the piece. The sheer size of the surface offered more opportunity to localise sounds for both players: the different groups could play on different spots on the tam-tam, interfering with each other less, and the microphonists had more area to play with distance when interpreting Stockhausen's microphone notation. One of the biggest differences was that the resonators used by the microphonist, which were picked up through the microphone but was barely audible by ear on the smaller tam-tam, were suddenly very loud and much easier to perceive. Although we used many of the same implements from our first performance, we did alter some implements to accommodate the new instrument. The stronger vibration of the tam-tam, for example, meant we were able to use heavier chains to rattle against the surface. Some sounds needed to be replaced simply because they did not activate on the Mikrophonie tam-tam in the same manner as the first tam-tam we had played. One example was a hand-held massager that a player would scrape against the surface to create an eerie, high-pitched noise that we used for the 'Jaulend' (howling) sound character: the effect worked with relative consistency on our 36-inch tam-tam but was next to impossible to perform on the Mikrophonie tam-tam. Cases such as this demonstrate that certain techniques may be unique to specific tam-tams. While it remains preferable to use the recommended tam-tam, it is worth considering that performers can attain a unique and dynamic interpretation through careful exploration of their available tam-tam.

Preparation and Rehearsal

One of the more time-consuming tasks for preparation of the work is the ordering of moments into a sequence that corresponds with Stockhausen's connection scheme, a task that Burns (2002) describes as 'daunting' (65):

> All the moments need to be fit into the provided skeleton; there is no tolerance built into the scheme for the near-inevitable 'moment that doesn't fit.' Even more demanding is the requirement that the moments be rehearsed without knowing how they fit together. The score is laden with musical recurrences and restatements, which can be difficult to make sense of without knowing the overall shape of the piece.

Like many performers of this work, Burns decided to instead perform the 'Brussels version' (Figure 9), the name for the original sequence developed by the Stockhausen ensemble and included with the score (65):

> This was a major time-saving step, but more importantly, it gave us a rich interpretive context in which to make, and in many cases revisit and remake, musical decisions at finer levels of detail. Adhering to Stockhausen's realization of form made it possible to think carefully and independently about the individual moments—where our solutions often diverged considerably from the composer's performing tradition.

The time-saving aspect is not insignificant. In order to develop a sequence, Stockhausen calls for each moment to be rehearsed individually, stating 'Only after all the players have together determined all the sound aspects of the individual Moments and have also rehearsed (initially without deciding on who should belong to which group), can they then judge which Moments are suitable for a particular connection' (12). Preparing the piece in this way requires performers to learn the entire piece instead of just their own music. Considering that the two groups alternate playing moments for the majority of the work, players would have to learn almost twice the amount of material in the process of preparing their own sequence. For this reason, and the others cited above by Burns, I decided not to prepare my own sequence for performance with the TaPIR Lab. Instead, I transcribed the sequence of another significant recording of the work given by the ensemble red fish blue fish, directed by percussionist Steven Schick (Stockhausen 2014).

Figure 10 shows a transcription of the connection scheme for the red fish blue fish version. The diagram in Figure 10 is structured similarly to the Brussels version connection scheme in Figure 9: the moments are placed in order and alternate between the two groups of players except for specified Tutti moments. The bottom system shows the approximate timings that each moment occurs in the recording released by the ensemble,

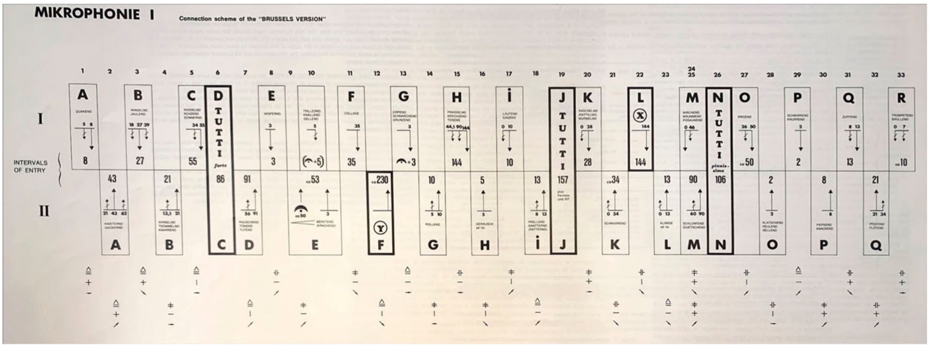

Figure 9. Connection scheme for 'Brussels Version' from score (Stockhausen 1974, 13). © Copyright 1974 by Universal Edition (London) Ltd., London.

red fish blue fish connection scheme

Overlap No.	91	43	10	3	?		8	21	2	3		34	13	5	8	5
I	A. Rauschend - Tönend - Tutend		B. Lautend Sagend		C. Trillernd knallend gellend	D. Tutti forte		E. Wirbelnd trommeld knarrend		F. Wispernd		G. Schnarrend		H. Gerausch		I. Schwirrend - Knurrend
II		A. Knisternd gackernd		B. Zirpend scharrend grunzend		C. Tutti forte	D. Trompetend - Brüllend		E. Klatschend heulend bellend		F. Y		G. Klange		H. Piepsend knackend	
timestamp	0:00	1:38	2:28	2:37	2:48	3:02	4:45	4:55	5:27	5:33	5:45	10:42	11:16	11:30	11:42	12:00

Overlap No.	N/A	N/A	60	8		19?	N/A	3		144	28	35	15?	10	21	
I		J. Tutti Pianissimo	K. Schlürfend - Quietschend		L. X		M. I Singend (II Streichtöne)	Quakend	N. Tutti 157	O. Prasselnd - Krächzend - Tosend		P. Collage		Q. Rollend		R. Prellend Knatternd
II	I. Rasselnd - Ächzend - Donnernd	J. Tutti Pianissimo		K. Zupfend		L. Wischend - Brummend - Posaunend		M. Berstend (Krachend)	N. Tutti 157		O. Raschelnd (Rattelnd) - Murmelnd		P. Winseld jaulend		Q. Pfeifend flotend	
timestamp	12:09	13:15	15:16	16:16	16:38	19:00	19:36	20:12	21:43	25:37	28:13	29:10	30:00	30:18	30:28	30:45

Figure 10. Connection scheme used by red fish blue fish, transcribed by author.

and the top system indicates the approximate measure numbers where the next overlapping moment should begin. The red fish blue fish sequence, being organised quite differently to the Brussels version, serves as an apt alternative for ensembles to use in future interpretations of the work. This transcription also serves as an additional resource for performers to study alongside Stockhausen's recording when preparing the work for performance.

Performance

Our initial rehearsals were in a relatively small rehearsal space, which made it extremely difficult to amplify the microphones without feedback. In order to proceed, we set up headphone monitors for both the filter and the microphone players. This turned out to be quite effective, as the microphone players were able to hear the effect of their own movements much more accurately than they normally would have: as noted by Bierstone (2019), '… not only are [the microphonists] transforming sound in ways that cannot always be anticipated, they also do not necessarily hear the result of their actions that get projected into the hall' (36–37). The headphone monitoring allows for players to contextualise their gestures within the larger sonic framework and to have input on how the microphone and the filter blend and interact. One example of a moment where this was particularly advantageous is at the very end of 'Y', shown in Figure 11. The 'Bellend' sounds played by the microphonist, along with the corresponding filter movements notated underneath, are circled in Figure 11. For each indication of the 'Bellend' sound, the filter quickly sweeps down and back up to create a combined gesture that accentuates and distorts the sound character. The timing is quite tricky to

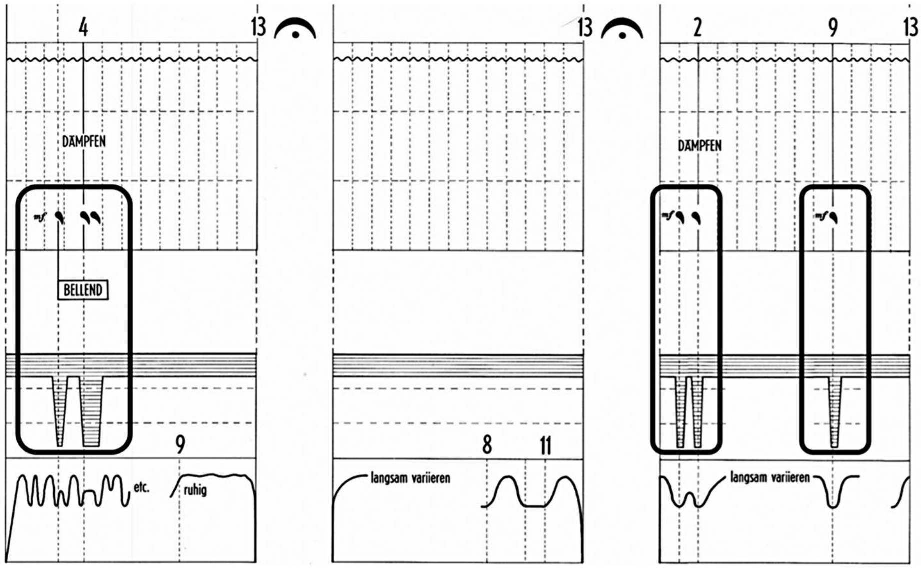

Figure 11. Excerpt from 'Y' moment from score (Stockhausen 1974). Bellend sounds are circled. © Copyright 1974 by Universal Edition (London) Ltd., London.

synchronise between the microphone and the filter player, but with headphone monitoring, the microphonist is able to more accurately coordinate their sounds with the filter sweeps. The increased interactivity between players afforded with this setup allows for a more transparent communication of process to the audience. Typically, the chain of sound production in the ensemble creates a one-way street wherein the microphonists react to the players and the technologists react to both. Headphone monitoring levels the playing field and helps cultivate a more typical chamber music environment where each player can listen and react to the other voices regardless of performance space, speaker positioning, and amplification level.

Conclusion

The realisation of *Mikrophonie I* that I have developed with the TaPIR Lab is an extension of Christopher Burns' 'pragmatic' approach (Burns 2002, 63). Beyond feasibility, however, I sought to reconstruct the filters in a manner that presents an accessible and sustainable solution for the work. If my aim were to realise the work in the most 'faithful' manner, I would build custom analogue filters from scratch that emulated the original Maihak W49 filter parameters, including the dual linear fader-style switch so that the interface would be the same. But how would this benefit future performers of this work? My own creation would quickly face the same issues of obsolescence as the Maihak W49. Instead, by hosting the Max patch and 3D-print plans that I have designed on the TaPIR Lab website I offer tools that can be implemented—and improved upon—by performers worldwide.[4] Although there are already modern solutions that allow for works such as *Mikrophonie I* to continue to be performed, it remains pertinent to continue to strive to surpass pragmatism when reconstructing works for live electronics. In the words of Bonardi et al. (2008):

> The worst situation for all these artistic works is the inability to reperform them (for various reasons) after their creation. Therefore, concerned institutions and composers are interested in sustainability. Paradoxically, this means preserving authenticity, while, at the same time, maintaining the possibilities for evolution.

Further analysis and creative use of technology can produce realisations that are similar in terms of accessibility but offer more refined interpretations of works for live electronics. The four-step model described in this article provides a method to help surpass the more challenging barriers to electronic performance created by inaccessible and obsolescent equipment. Similarly, the analysis of intelligibility—particularly through the notions of sound and process—acts as a directive for reconstructions that require significant reinterpretation of the original electronic framework. Through continued analysis and careful consideration, the reconstruction of electronic works can be regarded as an act of craftsmanship rather than one of compromise.

Notes

1. Notably, and in a similar manner to Wetzel's diagram, the direction of the arrows between each step is cyclical; the implementation of each progressive stage helps to further inform the ideas from the previous.
2. Composer Simon Emmerson noted something similar, asking 'what is "the original"? Is it the *sound* of the original or a *performance practice*?' (Emmerson 2006, 216)
3. There is a discrepancy between the 11 frequency steps seen on the majority of Maihak W49 units and pictured in the 1972 version of the score and Stockausen's own description of the filter having nine frequency steps (and the division of the filter notation into nine parts). Williams (2012) posits that this is either an error on the composer's part, an attempt to simplify the notation, or potential evidence that the filters at the WDR studios were customized in some way (81).
4. https://tapirlab.music.utoronto.ca/mikrophonie-i/.

Acknowledgements

I am grateful to members of the TaPIR lab for working to perform and record *Mikrophonie I*, and particularly grateful to Aiyun Huang for facilitating and supervising this project. Thanks are due to Örjan Sandred for his input on the Max patch. Finally, I would like to thank Eliot Britton, Ellen Lockhart, and Colette Simonot-Maiello for their valuable feedback on the early versions of this text.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Social Sciences and Humanities Research Council of Canada under Insight Grant #435-2020-0717.

Notes on Contributor

Timothy Roth is a percussionist, technologist and researcher based in Toronto, Canada. His research interests include the performance practice of music with live electronics, new musical instrument design, and popular music analysis. He is a research assistant in the Technology and Performance Integration Research (TaPIR) Lab and an active collaborator with the Music and Health Research Collaboratory (MaHRC) at the University of Toronto. Tim holds a Master's degree in Percussion Performance and a Master's in Music Technology and Digital Media, both from the University of Toronto.

ORCID

Timothy Roth http://orcid.org/0000-0003-1634-6834

References

Arbo, Alessandro. 2018. "From the Document to the Work: Ontological Reflections on the Preservation and Restoration of Musical Artefacts." *Journal of New Music Research* 47 (4): 300–308. https://doi.org/10.1080/09298215.2018.1486431

Battier, Marc. 2004. "Electroacoustic Music Studies and the Danger of Loss." *Organised Sound: An International Journal of Music Technology* 9 (1): 47–53. https://doi.org/10.1017/S135577180400007X.

Bernardini, Nicola, and Alvise Vidolin. 2005. "Sustainable Live Electro-Acoustic Music." In *Proceedings of the International Sound and Music Computing Conference*. Salerno: Sound and Music Computing Conference.

Berweck, Sebastian. 2012. "It Worked Yesterday: On (Re-)Performing Electroacoustic Music." PhD diss., University of Huddersfield.

Bierstone, Noam. 2019. "Integrating Performer-Controlled Electronics in a Post-Percussive Practice." DMA diss., McGill University.

Bonardi, Alain, Jérôme Barthélemy, Raffaele Ciavarella, and Guillaume Boutard. 2008. "First Steps in Research and Development About the Sustainability of Software Modules for Performing Arts." In *Proceedings of the Journées d'Informatique Musicale*, 105–110. Albi, France: Journées d'Informatique Musicale.

Bosma, Hannah. 2017. "Canonisation and Documentation of Interdisciplinary Electroacoustic Music, Exemplified by Three Cases from the Netherlands: Dick Raaijmakers, Michel Waisvisz and Huba de Graaff." *Organised Sound* 22 (2): 228–237. https://doi.org/10.1017/S1355771817000139

Boutard, Guillaume. 2016. "Co-Construction of Meaning, Creative Processes and Digital Curation: The Transmission of Music with Live Electronics." *Journal of Documentation* 72 (4): 755–80. https://doi.org/10.1108/JDOC-09-2015-0121

Bullock, Jamie, and Lamberto Coccioli. 2006. "Modernising Musical Works Involving Yamaha DX-Based Synthesis: A Case Study." *Organised Sound* 11 (3): 221–227. https://doi.org/10.1017/S1355771806001506

Burns, Christopher. 2002. "Realizing Lucier and Stockhausen: Case Studies in the Performance Practice of Electroacoustic Music." *Journal of New Music Research* 31 (1): 59–68. https://doi.org/10.1076/jnmr.31.1.59.8104

Dhomme, Sylvain, dir. 1966. *Mikrophonie I*. Kürten: Stockhausen-Verlag.

Cott, Jonathan, and Karlheinz Stockhausen. 1973. *Stockhausen: Conversations with the Composer*. New York: Simon and Schuster.

Emmerson, Simon. December 2006. "In What Form Can Live Electronic Music Live On?" *Organised Sound* 11 (3): 209–219. https://doi.org/10.1017/S1355771806001427

Esler, Robert. 2006. "Digital Autonomy in Electroacoustic Music Performance: Re-Forging Stockhausen." In *Proceedings of the 2006 International Computer Music Conference*. New Orleans, USA: International Computer Music Association.

Kramer, Jonathan D. 1978. "Moment Form in Twentieth Century Music." *The Musical Quarterly* 64 (2): 177–194. https://doi.org/10.1093/mq/LXIV.2.177

Lemouton, Serge, Alain Bonardi, Laurent Pottier, and Jacques Warnier. 2018. “On the Documentation of Electronic Music.” *Computer Music Journal* 42 (4): 41–58. https://doi.org/10.1162/comj_a_00486

Pestova, Xenia T., Mark T. Marshall, and Jacob Sudol. 2008. “Analogue to Digital: Authenticity vs. Sustainability in Stockhausen’s Mantra (1970).” In *Proceedings of the 2008 International Computer Music Conference*, 201–204. Belfast, UK: International Computer Music Association.

Puckette, M. 2001. “New Public-Domain Realizations of Standard Pieces for Instruments and Live Electronics.” In *Proceedings of the 2001 International Computer Music Conference*, 377–380. San Francisco, CA: International Computer Music Association.

Sluchin, Benny. 2000. “A Computer-Assisted Version of Stockhausen’s Solo for a Melody Instrument with Feedback.” *Computer Music Journal* 24 (2): 39–46. https://doi.org/10.1162/014892600559308

Stockhausen, Karlheinz. 1974. *Mikrophonie I: für Tamtam, 2 Mikrophone, 2 Filter und Regler, Nr. 15, 1964: 6 Spieler*. London: Universal Edition.

Stockhausen, Karlheinz. 1965. *Mikrophonie I/Mikrophonie II / Telemusik*. Karlheinz Stockhausen, Helmut Heissenbüttel, Aloys Kontarsky, Fred Alings, Johannes Fritsch, Harald Bojé, Jaap Spek. Stockhausen-Verlag Stockhausen 9, 1995, compact disc.

Stockhausen, Karlheinz. 2014. *Complete Early Percussion Works.* Steve Schick, James Avery, Red Fish Blue Fish. Recorded between May-October, 2008. San Diego, CA: Mode Records. DVD.

Stockhausen, Karlheinz, and Jerome Kohl. 1996. “Electroacoustic Performance Practice.” *Perspectives of New Music* 34 (1): 74–105. https://doi.org/10.2307/833486

V2_Organization. 2003. “Documentation and Capturing Methods for Unstable Media Arts.” Accessed August 14, 2022. http://v2.nl/files/2003/articles/1_2_capturing.pdf

Vickery, Lindsay. 2012. “Adapting John Cage’s Radio Music for a Digital Score Player.” In *Interactive: Australasian Computer Music Conference Proceedings*, 69–77. Brisbane, Australia: Griffith University, The Australasian Computer Music Association.

Wetzel, David Brooke. 2004. Analysis, Reconstruction, and Performance of Interactive Electroacoustic Music for Clarinet and Obsolete Technology: Selected Works by Musgrave, Pennycook, Kramer, and Lippe.” DMA diss., University of Arizona.

Wetzel, David Brooke. 2006. “A Model for the Conservation of Interactive Electroacoustic Repertoire: Analysis, Reconstruction, and Performance in the Face of Technological Obsolescence.” *Organised Sound* 11 (3): 273–284. https://doi.org/10.1017/S1355771806001555

Williams, Sean. 2012. “Electronic Music Instrument Practice and the Mechanisms of Influence Between Technical Design, Performance Practice and Composition.” PhD diss., University of Edinburgh.