The Contact Microphone: a cultural object

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Introduction

A contact microphone is a microphone that senses audio vibrations through physical contact with a solid surface or immersion in liquid, and converts them into an electric signal. It is an old, often inexpensive technology that has stimulated the creativity of several generations of musicians and sound-artists, precisely because of its peculiar property of activating a different way of listening. Contact microphones have been widely used to turn everyday objects into "musical instruments," as an alternative to synthesis. Sonic exploration of the acoustic characteristics of different objects uncovered new ways to conceive sound material while revealing a different perception of the materiality of sounds. A contact microphone can be intended as a cultural object if one takes into account the connections and relationships arose between musicians and composers who have used this technology, even when their purposes and aesthetics differ.

Brief historical overview

The history of the contact microphone is related to the history of piezoelectricity, since most contact mikes have been made with piezoelectric materials.[1] Piezoelectricity was discovered in 1880 by the Curie brothers, who observed changes in the surface charges of different crystals—tourmaline, quartz, topaz, cane sugar and Rochelle salt—when subjected to mechanical strain. They named the phenomenon "piezoelectricity" (from the Greek word πιέζειν piezein = press, squeeze). The inverse piezoelectric effect—mechanical strain resulting from the injection of an electrical signal—was discovered soon after. The first practical applications of piezoelectric principles appeared during World War I, most famously sonar, based on research by the French physicist Paul Langevin (previously a doctoral student of Pierre Curie) and the British/Canadian Robert William Boyle. An electric pulse was sent to a piezoelectric crystal, which produced high-frequency mechanical vibrations that were transmitted through the water. Upon encountering an object, these signals reflected back. A second piezoelectric sensor detected this reflected energy and converted it back into an electrical signal. The distance from the ultrasonic source and the reflecting object was determined by the elapsed time between transmission and reception. This technology was of strategic importance in both world wars. Years later musicians and sound-artists began using underwater microphones (hydrophones) with far more peaceful intentions.

The trickle-down of sonar technology stimulated the development of many other kinds of piezoelectric devices. After World War I, more familiar piezoelectric applications – such as microphones, phonograph pick-ups and signal filters – were invented and put into practice. During World War II, researchers in the United States, Japan and the Soviet Union replaced naturally-occurring crystals with ferroelectrics – new discovered artificial materials that exhibited stronger piezoelectric properties; these were incorporated into more powerful sonars, ceramic phonograph cartridges, piezo ignition systems, the sonobuoy (sensitive hydrophone listening and transmitting buoys for monitoring ocean vessel movement), miniature sensitive microphones, and ceramic audio tone transducers.

After World War II, Japan dominated the international market for piezo materials, manufacturing several types of piezoceramic signal filters that addressed needs arising in television, radio and communications equipment, as well as piezoceramic igniters for natural gas/butane appliances. The market for piezoelectric applications continued to grow, with the emergence of audio buzzers (such as those in appliances and smoke alarms) and ultrasonic transducers (used in motion detecting intrusion alarms and early television remote controls). More recently, piezoelectric technology has been applied in the automotive domain (wheel balancing, seatbelt buzzers, tread wear indicators, keyless door entry, and airbag sensors); computers (microactuators for hard disks, piezoelectric transformers); a wide range of other commercial and consumer devices (inkjet printing heads, strain gauges, ultrasonic welders, smoke detectors); and medical, biomedical and bioengineering applications, including insulin pumps, ultrasound imaging and therapeutics, piezoelectric and biomedical implants with associated energy harvesting.

Musical applications

Piezoelectric innovations played an important role in the development of electronic music, especially in the experimental scene from the late 1950s onward. One of the main reasons can be found in the possibilities unfolded by amplification, as Michael Nyman observes:

> Amplification may reveal a previously unheard, unsuspected range of sounds, drawn out of the hitherto mute or near-mute instrument of whatever nature, bringing about both quantitative and qualitative changes in the materials amplified.[2]

As Nyman suggests, an amplified sound — a sound transduced from the acoustical to the electronic domain — is perceived differently not only because quiet sounds can be made very loud, but more significantly because the proximity of a microphone captures features of the sound source that were previously unheard. This shift in perception is even stronger when the microphone is a contact mike. Vibrations picked up directly from a surface sound different from the same vibrations after they travel through the air. The resonant material acts as a filter, and the contact microphone picks up the object's "inner sound," like a heartbeat heard through a stethoscope. Through piezoelectricity, composers and musicians started to grasp the full potential of amplification as a creative tool.

Cartridge Music – John Cage

John Cage was one of the key figures in the musical application of contact mikes and extreme amplification, as exemplified in his *Cartridge Music* (1960). In this early piece of live electronic music, all sounds are produced through the amplification of very small sounds, primarily using piezo-ceramic phono-cartridges from record players. Performers replace the cartridge needles with different materials—twigs, pipe cleaners, springs—and manipulate the objects by scraping, plucking, etc., to elicit different sounds, which are amplified and sent to the speakers.[3] The phono-cartridges act as contact microphones used to extract new sounds from familiar objects. *Cartridge Music* embodies several concerns that, over the following years, would become axiomatic in much experimental electronic music. One, already noted, is the role of amplification in the production and discovery of new sounds. The sound production, moreover, is strongly connected with gestures performed on everyday objects instead of traditional instruments. Finally, *Cartridge Music* is representative of a certain DIY approach to electronic systems—in 1960 few could afford oscillators and tape recorders, but everyone seemed to own a record player that could be "hacked" to play this piece. These concerns were present in Cage's research before *Cartridge Music.* As

Nyman points out, “Cage's *Cartridge Music* had its roots in his pre-war *Imaginary Landscape No.1* (1939) which introduced a number of proto-electronic instruments, and, more relevantly perhaps, in the category of 'amplified small sounds' of *William Mix* (1952).”[4] Indeed, Cage had experimented with amplification before *Cartridge Music.*[5] He had also previously imported non-musical objects into the concert hall: *Water Music* (1952) uses whistles and radios, while *Living Room Music* (1940) invites musicians to use “any household objects or architectural elements” as instruments.[6] But with *Cartridge Music* especially, Cage pointed out a different way of conceiving electronic music, bypassing the equipment of the electronic studios, and inventing and adapting portable electronic devices for improvising or performing indeterminate music.[7] *Cartridge Music* exerted a profound influence on the younger generation of composers who started making electronic experimental music in the 1960s and ‘70s.

David Tudor and Composers Inside Electronics

With regard to the development of live electronic music David Tudor was truly a pioneer: after a pivotal role as a virtuoso pianist in the development of the post-war musical avant-garde, Tudor became one of the first live electronic performers, with a very personal approach to electronic technology, strongly influenced by his collaboration with Cage[8]. After assisting in the development and performances of *Cartridge Music,* Tudor continued to experiment with similar setups in other pieces by Cage, such as *Music for Amplified Toy Pianos* (1960) and *Variations II* (1961).[9] For each of these pieces, Tudor used a set of phono cartridges to amplify the piano sounds. He gradually acquired enough knowledge and confidence to design his own electronic circuits for use in conjunction with the cartridges, and came into his own as a composer (as distinct from a performer) of electronic music.

A few years later another group of musicians – Composers Inside Electronics – expanded Tudor’s "hands-on" way of working with electronic means[10]. The group came together on the occasion of a workshop that Tudor gave in 1973 around his composition *Rainforest* in the “New Music in New Hampshire” conference in Chocorua, NH. (David Behrman, Gordon Mumma, Frederic Rzewski and several others also gave workshops at the conference). John Driscoll, Paul De Marinis, Phil Edelstein, Linda Fisher, Ralph Jones, Martin Kalve and Bill Viola were among those who attended Tudor's workshop. As Driscoll remembers:

> David was holding a workshop on the idea of *Rainforest* and processing signals through an acoustical transformation. So he introduced us to this idea of taking a sculptural object and putting a transducer on it, holding directly to it, and vibrating that material, then a contact microphone on the object to re-amplify the signal that was in the material. It's very common now, but at that time it was not. And the idea was to discover the signals that the object like to resonate with.[11]

Rainforest was originally conceived for choreography by Merce Cunningham in 1968, and by 1973 the piece had already been performed in several different versions. Driscoll recounts that during the workshop the piece took a slightly different form—using bigger objects such as a wagon wheel, a wine barrel, bed springs, etc.[12] The objects had to be suspended in order to resonate freely, so they were hung from the beams of a barn, creating an environment of sounding sculptures through which the audience could walk. At the end of the workshop, the piece was performed, and several of the participants asked Tudor if he would be willing to continue the project.[13] The Chocorua version, later titled *Rainforest IV*, was subsequently performed over 125 times, in more than 45 cities.[14] The group was officially dubbed “Composers Inside Electronics” in 1976, when Tudor was invited to the Festival d’Automne in Paris. He wanted the musicians from the Chocorua workshop to assist

him on *Rainforest*, and in the course of the festival they also performed Cage's *Cartridge Music* and works by Takehisa Kosugi, as well as pieces by various members of the ensemble. The name was chosen to represent Tudor's ideas, around which the group was shaped:

> David thought most music focuses on the idea that you have a musical concept and then you find the instruments to realize it, and he believed in the reverse of that: when you start with an instrument, you explore it and that suggests the music that you make. So, that was the reason behind the name "Composers Inside Electronics": the ideas start inside the electronics and then became musical, the instrument suggests the music. When he was building his electronics, it was never the "normal" use of the electronics: he was making this no-input mixing, and for him, this was just a new concept to generate sounds. In the early '60s, nobody had computers, nobody had access to the labs of electronics, nobody had synthesizers, and David sort of explored that world trying to use the electronics to make the music he was interested in.[15]

In the beginning, crystal phonograph cartridges were used as contact mics in *Rainforest*'s realizations. Tudor was familiar with them from his work on *Cartridge Music*. Driscoll remembers the Astatic 12u (figure 1), whose the needle was inserted in a hole in such a ways that it could be replaced by a piece of steel wire, creating a less fragile contact point. Later, when this type of cartridge became hard to find, the group started experimenting with other kinds of contact-mics, such as throat-microphones and bone transducers (put against the jaw to conduct sound via bone to the inner ear)—often used by people with hearing. The group's collection also included disk cutterheads (devices for cutting records, here used in reverse as microphones) and microphones used for listening to the heartbeat of a foetus (figure 2). Using so many different types of device created challenges, Driscoll recalls. "Each kind of microphone needed a specific pre-amplifier, with a specific circuit. When piezo disks became available, they were used as well, though they usually have a peaked resonant frequency, whereas the cartridges were have a gentler curve and when you put a reverse curve in your pre-amplifier you could bring out a lot of the bass."[16]

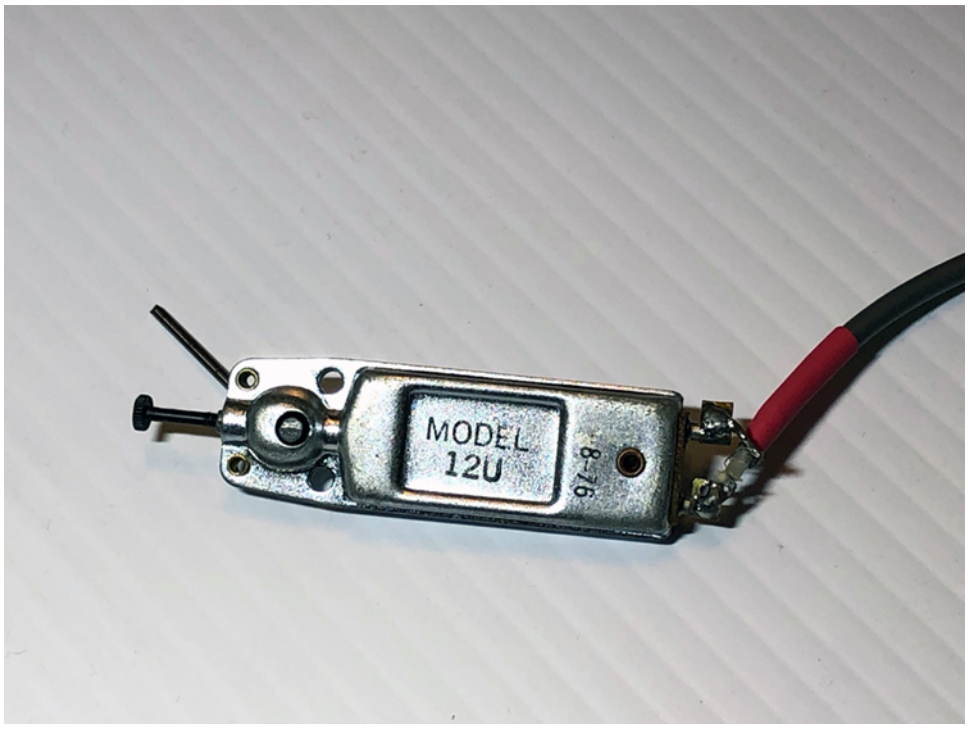

Figure 1: Astatic12u, phono cartridge. Photo © John Driscoll, used by permission.

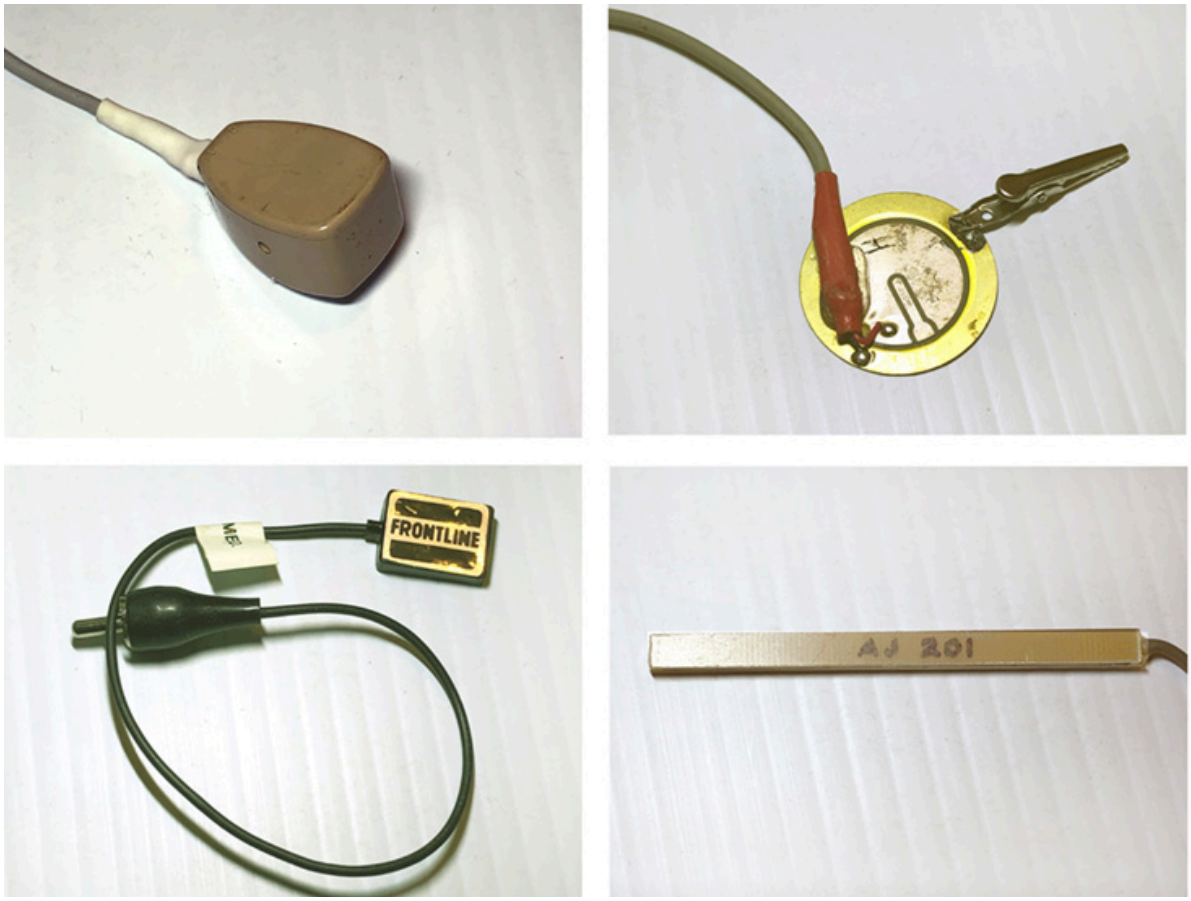

Figure 2: Different contact microphones from the collection of John Driscoll. Clockwise from top left: small throat mike; piezo piano pickup; homemade piezo pickup; Frontline pickup. Photos © John Driscoll, used by permission.

Richard Lerman

Richard Lerman contributed significantly to the research on the musical use of contact microphones. He began experimenting with different kinds of contact microphones in the mid-1960s, using them to record sounds made by "wind harps, plants, boat anchor ropes, rocks, cactus thorns, heat expansion in metal, spider webs (with limited success). He attached them to many kinds of self-built and traditional musical instruments, and even used them as loudspeaker drivers to induce sound into metal and glass sculpture."[17] Lerman was studying at Brandeis University in Waltham, Massachusetts, when Alvin Lucier was running the electronic studio there (with Anthony Gnazzo). When Lucier left Brandeis for Wesleyan University, Lerman — "vastly unprepared but really curious" became the technical director of the studio by default.[18] According to Lerman, during that period John Cage and David Tudor were often around, as well as Gordon Mumma, from whom he learned to solder. Lerman remembers Tudor telling him, "Richard, if you want to do electronic music, you have to learn some electronics." Taking the words seriously, Lerman was "early in the game" using piezo disks both as microphones and loudspeakers (or, as he puts it, "soft speakers"). The first versions of his piece *Travelon Gamelon* (1977) used "phono cartridges between fender washers, housed in the plastic box that [the cartridges] were packaged in."[19] Suggesting the percussive, metallic timbre of a gamelan orchestra, the sounds in *Travelon Gamelon* were produced by the rhythmic movements of bicycles captured by contact mics. The cartridges were fragile, and even in protective plastic housings, they often broke. So Lerman started experimenting with piezo materials:

> I was researching a lot of different sources about phono cartridges and discovered that ceramic cartridges (EV 81T's) were piezo devices and were usually made from something like barium titanate. Seeing the word "piezo" with "disks," maybe from a company in Massachusetts called Meshna Electronics, I started buying up different kinds of disks. These were much easier to work with than with the phono carts. So I began using the piezos probably in '78 / '79 or so. They were much more rugged once I figured out the best way to solder them. I began in earnest to work with the disks and to construct preamps for them using various op-amps that were around.[20]

Materials for such DIY projects were available from electronic surplus dealers, as well as from hobby retailers such as Radio Shack, and manufacturers such as Electro-Voice, Kent, Astatic, and Barcus Berry (figure 3).

Figure 3: Contact microphone 805-ElectroVoice, pictured in a 1957 Electro-Voice catalog 1957). In the catalogue the microphone is described as "Contact—For guitar, banjo, any vibrating-string instrument. Hi-Z. Sealed crystal. Chromium finish. 15-foot cable. List Price ...$20.00".

At the same time, European avant-garde composers were developing electronic works, mostly recorded onto tape in radio studios,such as WDR (Köln, Germany), ORTF (Paris, France), Studio di Fonologia (Milano, Italy), and BBC Studio (London, UK).[21]

Mikrophonie I – Karlheinz Stockhausen

Karlheinz Stockhausen explored live electronic processing in his pivotal work, *Mikrophonie I* (1964).[22] The only sound source is a large tam-tam gong that is excited with objects of different materials—glass, cardboard, metal, wood, rubber and plastic. The performed actions are amplified with a strongly directional microphone and then processed in real-time. The six performers are divided into three groups: the first two play the tam-tam, the second two manipulate the

microphone, while the third pair modulate the microphone's sound with a filter and a potentiometer. The distance and location of the microphone affect the clarity and the timbre of the sound, in much the same way physical location affects the sound heard through a contact mike. With the help of Jaap Spek, the technician at Cologne's WDR radio, Stockhausen had started using contact microphones (figure 4) to amplify the metal and string sounds in many of his pieces, including *Mixtur* (1964), *Prozession* (1967), and *Kurzwellen* (1968).[23] The latter two were performed several times by the composer and violist Johannes Fritsch, who was part of the Stockhausen Ensemble (1964-1970), together with Rolf Gehlhaar. Fritsch and Gehlhaar continued to experiment with contact mics after they left Stockhausen's group and formed the Feedback Studio (active between 1971 and 2001). Gehlhaar remembers Fritsch using a piezoelectric contact microphone manufactured by Schaller for Fritsch's piece *Partita* (1966) for amplified viola and tape delay:[24]

> Normally, when he played, he had the microphone attached either to the bridge [of the viola] or to the soundboard very close to the bridge. The position varied with what quality of sound he wanted to produce —on the bridge, brighter, sharper sound; on the soundboard, slightly more muffled, rounder sound. . . The Schaller contact microphone was very useful for installations and theatrical applications, where, for example one could be attached to the clinking chains that an actor was wearing as a part of his costume . . . In the Feedback Studio we experimented a lot with the contact microphone and various instruments as well as surfaces in our installations of the early 70s, where we would turn whole rooms and all the objects with them into musical installations. For this purpose I often found the contact microphone too sensitive or difficult to employ. I began to research other ways of amplifying objects, for example by hanging them on steel strings passing over an electromagnetic guitar pickup. This produces very interesting sounds. Another technique I developed for installations was to employ piezoelectric emitters as microphones by placing small weights on them, one edge on the piezo, the other on the object to be amplified. This works very well.[25]

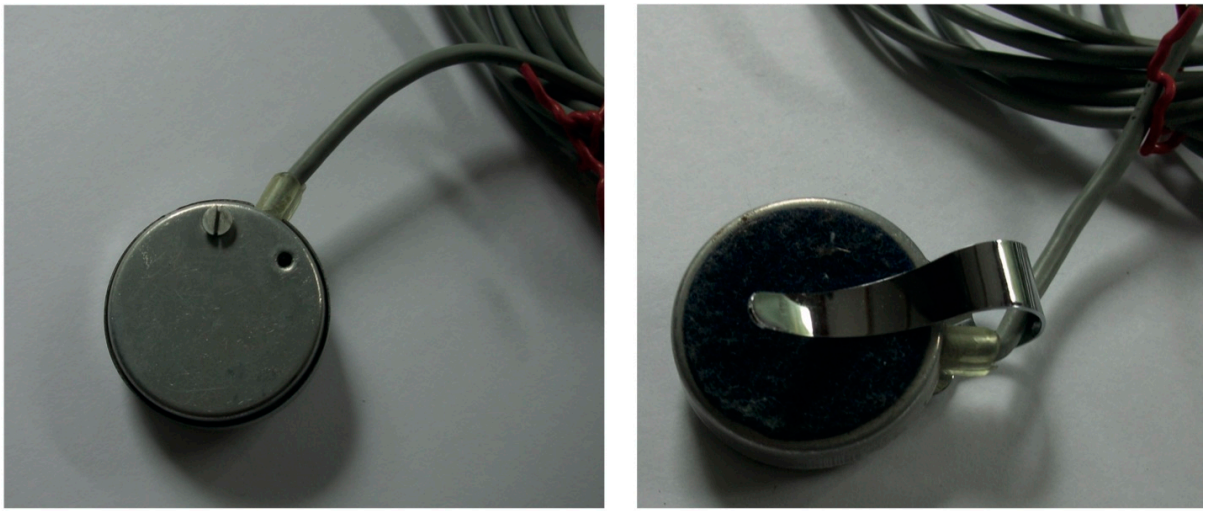

Figure 4: Contact microphone used by Stockhausen Ensemble. Photo © Sean Williams, used by permission.

Hugh Davies

Hugh Davies (1943- 2005), a British composer and early advocate of live electronics, invented more than 130 concert instruments, sound sculptures and site-specific installations, many of which made use of contact microphones of various types. He was strongly influenced by his experiences as Stockhausen's assistant between 1964 and 1966, including his participation in the first performances of *Mikrophonie I* under Stockhausen's direction.[26] The role of amplification and everyday objects in this piece had a profound effect on Davies, marking the point from which he

abandoned tape music to concentrate on live electronic music. When he returned to the UK in 1967 he began building his own instruments, recycling everyday objects, applying contact microphones, and foregrounding sounds that were not usually part of the musical realm.[27] In these projects, Stockhausen's influence was balanced by that of Cage and Tudor, especially in regards to the low-fidelity aesthetics and DIY ethos employed in realizing his instruments, as well as the freedom to combine more diverse sound sources.[28] In 1968 Davies created *Shozyg I* (figure 5), which consists of a book whose pages had been hollowed out to make space for objects mounted inside its back cover. The objects—a ball bearing, three fretsaw blades of different lengths and two different springs—were grouped in two areas, each group amplified by a piezoelectric pickup, chosen according to its filtering characteristics. The objects were played using fingers, fingernails, screwdrivers, needle files, toothbrushes, small electric motors, etc.[29]

Figure 5: *Shozyg I* (1968), self-built electro-acoustic musical instrument by Hugh Davies. © Science Museum/Science & Society Picture Library, used by permission.

Between 1968 and 1975 Davies was a member of Gentle Fire.[30] Beside performing compositions by living composers such as Stockhausen, Ashley, Cage, Cardew, Feldman, Wolff, etc., Gentle Fire performed collective pieces composed by the group between 1970 and 1973, which further explored live processing of sound as well as invented instrumentation. In *Group Composition III* and *IV* the ensemble shared a single instrument invented by Michael Robinson, the gHong, which was made up of three metal oven racks and a wooden crossbar on the fourth side from which four large springs were suspended.[31] Each side of the gHong was connected to two contact microphones: one of high-quality, such as a stethoscope or transducer, the other a contact microphone with a reduced frequency response. By varying the balance for each pair of microphones on a mixer it was possible to obtain substantial filtering effects, so the use of microphones was crucial in the playing of the gHong.[32]

***The Artaudofoon* – Peter Schat**

The idea of amplifying metal sounds with contact microphones was also applied by the Dutch composer Peter Schat (1935-2003). Early in his carrier, with the help of sculptor Frans De Boer-Lichtvelt and technician Jo Scherpenisse, he designed an instrument called the *Artaudofoon*. In the '60s Schat was part of a group of politically engaged young composers that included Misha Mengelberg, Louis Andriessen, Dick Raaymakers, Jan van Vlijmen, Reinbert de Leeuw and Konrad Boehmer, who founded the Studio voor Elektro-Instrumentale Muziek (STEIM).[33] Nico Bes, who began working at STEIM in 1971, recalls one of his first experiences with contact microphones was the *Artaudofoon*.[34] Inspired by Antonin Artaud's Theatre of Cruelty, it consisted of five metal sculptures whose sound was amplified by contact microphones attached to them. According to Schepernisse, Schat used the throat-microphones used by helicopter-pilots.[35] The exact origin of this huge instrument is unclear. According to Schat's biographer, Bas van Putten, the idea first arose in 1965 while working on his opera *Labyrinth,* when he thought of building a huge electro-acoustic percussion instrument, equipped with many "contact microphones, a filter, a modulator, an amplifier and a set of loudspeakers."[36] In September 1966 Schat tried to get funding from Philips because of technical problems and the high cost of electronic parts, and he received a commission that year from the Rotterdam Art Foundation for a theatrical work, *Electrocution,* which would use the *Artaudofoon* as a percussive instrument, but the work was never written. Van Putten, however, mentions the 1966 movie by Frans Weisz, *The Gangster Girl (Het Gangstermeisje)*, which includes a concert scene filmed in the Kleine Zaal of the Concertgebouw and featuring a composition played by the *Artaudfoon* and three double basses (figure 6). [37, 38]

Figure 6: *Artaudofoon,*Peter Schat standing in the middle. Presentation of the new percussion instrument in the Concertgebouw in Amsterdam, 1966.This picture appears with this caption in the online *Memory of the Netherlands Database*, with the date of 14 March 1966. A similar picture was published in the *San Francisco Examiner* on 17 July1966, mentioning the *Artaudofoon* as the percussion instrument "unveiled last week," but without specifying the occasion in which the picture was taken. It remains unclear whether the picture was taken during the shooting of the movie - since the location seems to correspond – or during another occasion.

It is possible that the bit of music played in the movie was an improvisation or an open-form composition, such as the one published in 1967 by Donemus. The latter, titled *First Essay on Electrocution*, for violin, guitar and metal percussion instruments (three players), seems to have been a work in progress, as can be deduced from Schat's request to settle the fee, unusually written in the score, right before the technical notes.[39] In the technical notes Schat wrote: "it is the best to use the *Artaudofoon* for the performance […] it is, however, also possible to use cymbals and other metal percussion instruments, the sound of which is scanned with contact microphones," suggesting that he was becoming aware of the difficulties in using the *Artaudofoon*. Indeed, the project was soon abandoned and the *Artaudofoon* forgotten.[40] One instrument is still archived at STEIM (figure 7).

Figure 7: One part of the *Artaudofoon* archived at Steim. Photos © Nico Bes, used by permission.

Conclusions

The diverse experiences described are united by a shared interest in the possibilities of amplification and of new ways of experiencing sound through the use of contact microphones. The 1960s, ‘70s and '80s were a time of lively circulation of ideas. Long before the Internet made this kind of sharing effortless, international festivals and concerts offered occasions for musicians to meet and share each other's work and technical research. American composers travelled throughout Europe, bringing new ideas from the New World. Cage and Tudor were among the earliest, and had a profound effect. Tudor in particular acted as a bridge between American and European communities. Beginning in the 1950s, he premiered works by composers including Stockhausen, Maderna and Boulez, building strong connections with the European avant-garde.[41] At the same time, he often toured with Cage, introducing new music from other American composers as well. It is worth noting, that the premiere of *Cartridge Music* took place in Germany (with Stockhausen present in the audience) at Mary Bauermeister's Cologne atelier, on 6 October 1960.[42]

In the following years, a younger generation of American composers participated in festivals and concerts in Europe, contributing to the development of an international community. Richard Lerman recalls that his first trip to Europe was in 1979 for the Muzicki Biennale Zagreb, where he performed *Travelon Gamelon*. At the 1981 Spiel und Klangstrasse festival in Essen, Germany, run by percussionist Michael Jüllich, he met Godfried-Willem Raes.[43] A Belgian artist who worked extensively with piezoelectricity, Raes had been running Logos, a venue for experimental music in Ghent, since 1968.[44] Lerman had his first performance there in September 1981. [45] Hugh Davies also had contact with Raes, who purchased a *Springboard* from Davies' collection of self-built instruments in 1974 (figure 8).

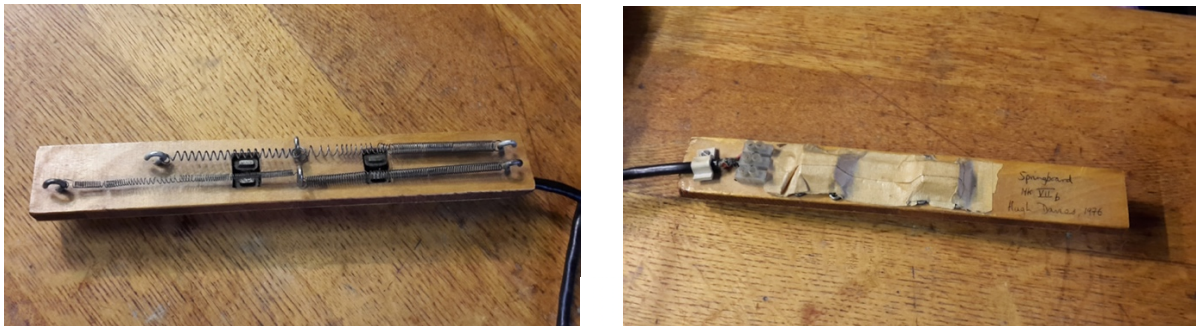

Figure 8: Springboard by Hugh Davies, owned by Godfried-Willem Raes. Photo taken at Logos Foundation by the author (20/03/19).

In such an interconnected community, the exploration of new possibilities of amplification contributed to new attitudes and practices of music making. As John Driscoll noted, Tudor's idea of inverting the role of the instrument in the process of music creation had a profound influence on the development of experimental music. The instrument was no longer the means to realize a musical idea, but became itself the starting point of a whole creative process. The possibility of amplifying the previously inaudible encouraged new perspectives, contributing to more creative approaches in the development of DIY practices and collaborative works. Because of its relevance to this process, a technological artifact—the contact microphone—became a cultural artifact, contributing to the cross-pollination between different artistic disciplines. In this context the gradual shift of David Tudor from his role as the representative pianist of the avant-garde, to that of creator and

ambassador for a personal, exploratory way of dealing with electronics, exemplifies the path of a musical movement—enriched by experimentalism, through personalities such as Hugh Davies and Richard Lerman, and the collective activities of groups such as Gentle Fire, Feedback Studio and Composers Inside Electronics.

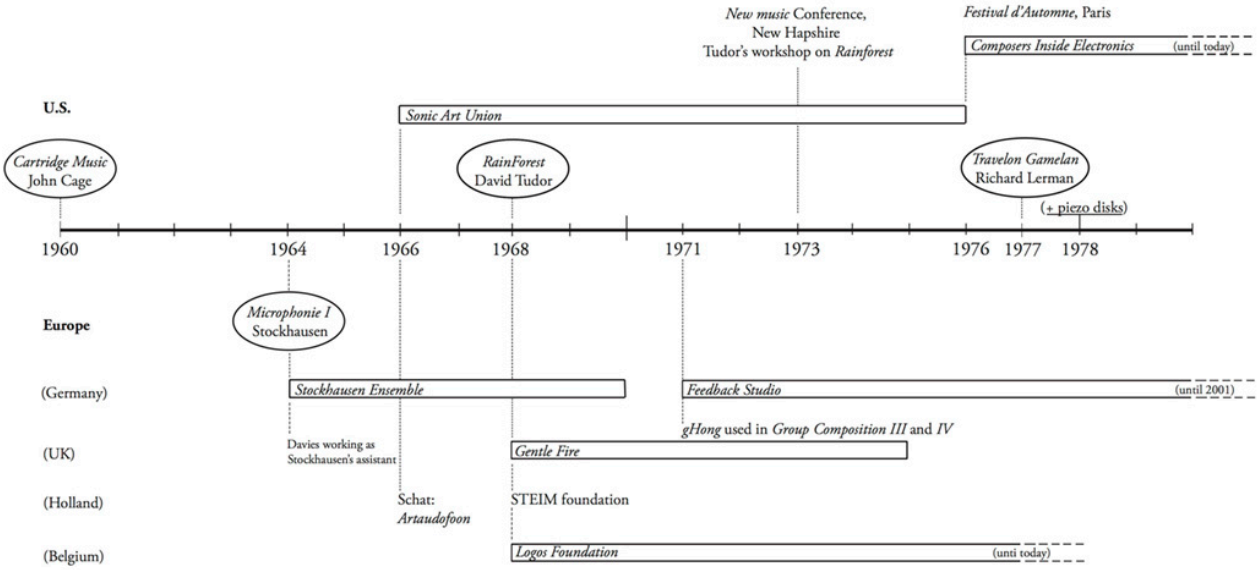

Figure 9: Timeline of the contact microphone.

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[1] Other contact microphones are electromagnetic, employing the same principle of a guitar pickup with the difference that electromagnetic contact microphones include a metal diaphragm to transduce any physical vibration into a distortion of the electromagnetic field, while the guitar pickup is merely a coil detecting the field distortions induced by the vibrating ferric material of the string.

[2] Nyman, Michael (1999). *Experimental Music: Cage and Beyond*, Cambridge : Cambridge University Press, p.92.

[3] *Cartridge Music* has an open form. The score consists of a number of transparent sheets, and the patterns drawn on them provide only the means to determine a time structure. Each performer has to superimpose the transparencies and work out the time structure by observing the ways in which the drawn lines and patterns on the sheets intersect. The choice of objects and means of manipulation are left entirely to the musicians. See sidebar "John Cage – The Father of Invention" in chapter 7.

[4] Nyman (1999), op. cit., p.90.

[5] See also *Imaginary Landscape No. 2* (1942) in which both instruments and electronic devices are amplified through contact microphones.

[6] In the performance notes Cage offers examples of objects that might be employed: "1st player — magazines, newspaper or cardboard; 2nd player — table or wooden furniture; 3rd player — largish books; 4th player — floor, wall, door or wooden frame of window" (Cage, John (1940) *Living Room Music*, Peters Edition).

[7] See Nyman (1999), op. cit., p.89.

[8] See sidebar "David Tudor and *Rainforest*" in chapter 8, and You Nakai's and Michael Johnsen's

essay on the website.
9

See: Iddon, Martin (2015). *John Cage and David Tudor, Correspondence on interpretation and performance*, Cambridge University Press, pp.187-186.
10

See sidebar “Composing Inside Electronics” in chapter 15.
11

Skype interview with John Driscoll, 25 March 2019.
12

As Driscoll explains, in the early iterations of the piece, Tudor used small objects on a table top, and specific homemade electronics with feedback oscillators. “The acoustic output of those small objects was not very loud, but the signal that was sent to the loudspeakers was quite loud” so listeners were hearing through the loudspeaker system, rather than hearing the object itself. (Driscoll, Skype conversation – 25/03/2019).
13

“Bill Viola made an arrangement in Syracuse with the Everson Museum, and Ralph Jones found an opportunity in Buffalo”. Ibid.
14

Ibid.
15

Skype interview with John Driscoll (25 March 2019).
16

Ibid.
17

In *A Guide for working with Piezo Electric Disks to introduce Children to Issues of Acoustic Ecology and Sonic Creativity* <http://www.public.asu.edu/~rlerman/PDF%20Files/Children%20&%20Piezo%20disks.pdf > accessed 15 April 2019.
18

Email from Richard Lerman (26 September 2018)
19

Ibid.
20

Ibid.
21

In France in the 1940s, Pierre Schaffer had already started the Groupe de Recherches Musicales at the Radio Diffusion Télévision Française (RTF), where he been working almost ten years. A few years later, Karlheinz Stockhausen was working in the WDR studio in Cologne, and Luciano Berio at the Studio di Fonologia in Milano, etc. Cage worked at Studio di Fonologia in Milan from November 1958 until March 1959, and composed *Fontana Mix* (1958) there.
22

Mikrophonie I was premiered on 9 December 1964 in Brussels. The piece resulted from Stockhausen's experiments in the summer of 1964 on the large tam tam that he had previously bought for *Momente*.
23

These contact mics might have come from the WDR Studio, as did most of the equipment Stockhausen used.
24

Schaller contact microphones are still produced today. The most popular model is the Schaller Oyster S/P <https://www.thomann.de/gb/schaller_oyster_723.htm > accessed 13 May 2019.
25

Email from Rolf Gehlhaar 28 April 2019.

26

The collaboration started because Davies was writing about Stockhausen. The book was never published, but Davies maintained a working relationship with Stockhausen lasting several years. He continued to correct Stockhausen's scores and perform his works in the UK.He may also have been aware of Fritsch and Gehlhaar's experiments with contact mics, as they were in Stockhausen's ensemble at this time

27

After Cologne, Davies moved to Paris and then New York, working on compiling the *Répertoire international des musiques électroacoustiques* (*International Electronic Music Catalog)* (RIME), published in 1968. Back in the UK he founded the electronic music studio at Goldsmiths College, which he directed until 1986. In 1982, Davies set up a small studio at Oxford University, helped by Daphne Oram, one of his mentors as a student. [For further info see also Palermo 2015, op.cit.]

28

Davies recalled a remarkable concert in London by Cage, Tudor and Mumma in November 1966 during a visit by the Merce Cunningham Dance Company. They may have performed *Music for Amplified Toy Pianos* (1960). [See Davies, 2001].About Davies' own materials, Fiorenzo Palermo remembers: "The first magnetic pick up he used was around 1969 and came from ex-RAF microphones, which he claimed had been used in Spitfires during the Second World War. Subsequently, when the supply of these diminished (he got them from stores in Denmark Street in London), he turned to old telephone handset earpieces or headphones used by the military or by telephone operators. I don't think Hugh built his own microphones, but rather salvaged and repurposed them. Nonetheless, I have found in my research that in the occasion of a performance of *Sternklang* by Stockhausen in Bonn in 1980 Hugh played an A clarinet with a self-made contact mike and pre-amplifier." Email from Fiorenzo Palermo (25 May 2019).

29

For a more detailed description and pictures see Palermo 2015, op.cit. Palermo specifies that Davies had begun using piezoelectric microphones "at least since the establishment of the Goldsmiths Electronic Music studio in 1967, which had two piezos in its initial equipment, and he used these to amplify all kinds of objects (combs, broken light bulbs, springs), recording "Galactic Interfaces" as a result." Email from Fiorenzo Palermo (25 May 2019). In other works Davies used magnetic pickups: *Concert Aeolian Harp* was built from egg slicers "by mounting the fine fretsaw blades on an aluminium frame, which would have then been fixed to a stand. The blades were arranged in parallel and microphones placed at the extremity of the aluminium frame that ran perpendicular to the blades. To play the *Concert Aeolian Harp*, the performer blew on the fretsaw blades, producing a quality of sound similar to an Aeolian harp. [Palermo 2015, op.cit., pp.191-192].

30

The other members were Richard Bernas, Patrick Harrex, Graham Hearn, Stuart Jones, Richard Orton and Michael Robinson. The name Gentle Fire arose from consultating the I Ching about the path they should take: "hexagram No. 37, the Family, came up'the two trigrams of which are Sun and Li, meaning Gentle Wind and Clinging Fire respectively—indicating clearly to the group that they should continue these activities and supplying the name Gentle Fire" (Davies 2001, op.cit. p.54).

31

In *Group Composition III* the *gHong* was the only sound source, while in *Group Composition IV* each member chose another additional instrument to play.

32

According to Palermo [Palermo, op.cit., pp.138/140] the *gHong* was originally meant to satisfy the score instructions of Christian Wolff, the score instructions read: 'Construct an instrument, or find something, or use an instrument as part of a construction which can make 5 different pitches, or 11 or 3 different pitches; 6 different qualities of sound (they can be made to depend on the manner of performance), or 2; and which can sustain sounds at least somewhat before they begin to fade', and the different microphones placed on the instruments allowed for an extension of the sounds

produced.
[33]

See Otto, Andreas (2008). *Die Entwicklung elektronischer Musikinstrumente am Steim (Studio für elektro-instrumentale Musik) im Amsterdam seit 1969*. (MagisterArbeit), pp.14-15. <https://docplayer.org/2117578-Die-entwicklung-elektronischer-musikinstrumente-am-steim-studio-fuer-elektro-instrumentale-musik-in-amsterdam-seit-1969.html > accessed 18 April 2019.
[34]

Email from Nico Bes, 5 February 2019.
[35]

Email from Jo Schepernisse, 9 April 2019.
[36]

See Bas van Putten (2015). A*lles moest anders. Biografie van Peter Schat*, Amsterdam: Uitgeverij De Arbeiderspers, 2015, p.381. *Labyrinth* was premiered at the Holland Festival 1966, conducted by Bruno Maderna, then guest director of the Concertgebouw
[37]

According to van Putten, Schat played two roles in the movie: “the Stranger," who falls in love with the title character, and the conductor of his own music for *Artaudofoon* (see Van Putten 2015, op. cit., pp.386-389).
[38]

Fig.7 was found in the online *Memory of the Netherlands Database*, with a date of 14 March 1966. It is possible that the picture was taken during the shooting of the movie, since the location appears correct. The caption of a similar photograph published in the *San Francisco Examiner* on 17 July1966 mentions the *Artaudofoon* as the percussion instrument “unveiled last week,” but does not specify the occasion in which the picture was taken.
[39]

“Here is the composition written as result of your commission. I hope that you will in the near future pay the second half of my fee, namely 750 guilders, into my transfer account (No. 122,747) Thank you very much.” (In Schat, Peter (1967) *First Essay on Electrocution,* for violin, guitar and metal percussion instruments (3 players). Donemus [score]).
[40]

Idem.
[41]

Tudor premiered, for example, Stockhausen's *Klavierstück XI*, in New York on 22 April 1957,(to the disappointment of Wolfgang Steinecke, who had agreed to a world premiere in Darmstadt a few months later), and Bruno Maderna's *Piano Concerto* on 2 September 1959 with the Heissischer Rundfunk symphonic orchestra. See: Iddon (2013), pp.181-183.
[42]

See Iddon (2015), p. 166. The performers included Nam June Paik, Hans G. Helm, Benjamin Patterson, William Pearson, Kurt Schwertsik, Cornelius Cardew, alongside Cage and Tudor.
[43]

Email from Richard Lerman (12 May 2019).
[44]

Raes focused on piezoelectric elements in systems using ultrasonic motion detectors, but he also made works using piezoelectric microphones to amplify objects. In *Holosound*, from the early 1980s, piezoelectric elements were used to build an ultrasound system of gestural sensors, and also in the sound-producing component: the ultrasound demodulated trigger objects such as springs and chimes attached to piezoelectric microphones, so that the movements of the objects could be amplified, producing sound.
[45]

<http://users.telenet.be/stichtinglogos/concerts/concerts1981.html> and <http://users.telenet.be/stichtinglogos/concerts/concerts1968.html> accessed 24 June 2019.last access 24 June 2019.