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Between air and electricity : microphones and loudspeakers as musical instruments

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Appendix 1 Technology of microphones and loudspeakers

I defined microphones and loudspeakers respectively as devices which turn sound waves (mostly in the form of air pressure waves) into something else and vice-versa (see chapter 1). This definition is based on Jonathan Sterne*'s analysis in *The Audible Past* (Sterne 2003) and is, in my opinion, valuable due to the fact that it does not rely upon any technical specifications, instead regarding microphones and loudspeakers as devices to undertake a certain process—whatever the technology they employ to do so. Another name for devices which convert one form of energy to another is "transducers". Microphones and loudspeakers can thus both be classified as transducers. Early sound reproduction technology—such as the phonograph, which did not yet use electricity—is included in this definition. This is contrary to many of the more technical definitions, since the use of electricity is often considered crucial to labelling a device as a microphone or loudspeaker. As I mentioned in chapters 1 and 2, electricity should be considered essential for the omnipresence of microphones and loudspeakers in music today, but this does not mean that there was no use of similar technologies before the use of electricity in sound reproduction technology.

Since electrically-powered microphones and loudspeakers are more complex than those which convert sound without the use of electricity, I will briefly explain the technology of the former in this appendix. I will not give an overview of all possible technologies, since that will surpass the scope of this appendix. Extensive elaborations on loudspeaker technology may be found in *Historical Perspectives and Technology Overview of Loudspeakers for Sound Reinforcement* (Eargle and Gander 2004), *Loudspeaker and Headphone Handbook* (Borwick 2000), *Loudspeaker Handbook* (Eargle 2003), and *Loudspeakers: For Music Recording and Reproduction* (Newell and Holland 2006). Microphone technology is discussed in detail in *Eargle's The Microphone Book: From Mono to Stereo to Surround - A Guide to Microphone Design and Application* (Rayburn 2011), and a more self-made approach focusing on live performances with musical instruments is explained in *Getting a Bigger Sound: Pickups and Microphones for Your Musical Instrument* (Hopkin 2002). The book *Electroacoustic Devices: Microphones and Loudspeakers* (Ballou 2009) focuses on both.

Although some knowledge about the technology of microphones and loudspeakers might be useful for artists working with them, I would like to underline that most of the works I discuss in my thesis focus on atypical uses of microphones and loudspeakers. Many artists do not consider how microphones and loudspeakers function exactly but rely mostly on their ears to judge their experiments. As the use of acoustic feedback in many of the examples exemplifies, artists are

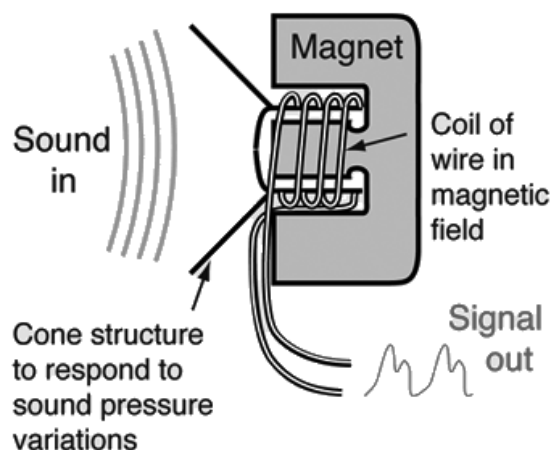
often interested in functions of these devices which have not been taken into consideration by their designer.

Microphones

Microphones are the devices that convert sound waves into "something else". I will consider two of the most common microphone technologies used to convert sound waves into an electrical signal: the dynamic microphone and the condenser microphone.

Dynamic microphone

As may be seen in the illustration, air pressure waves cause a membrane—commonly called a diaphragm—to vibrate. This membrane is attached to a small, movable induction coil, which in turn causes to vibrate. This coil is positioned in the magnetic field of a permanent magnet, and its movements to and from the permanent magnet produce a variable electric current through magnetic induction. The diaphragm, coil, and permanent magnet are hidden behind a windscreen in most microphones.

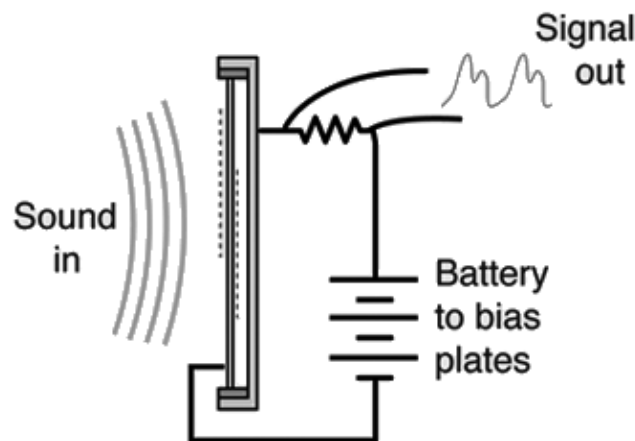


Dynamic microphone

Condenser microphone

As may be seen in the illustration, air pressure waves once more cause a diaphragm to vibrate so that the amount of space between this diaphragm and a stationary back plate constantly changes. Since diaphragm and plate are biased with a fixed charge, the changes in space between them will cause changes in the capacitance and therefore in the electrical signal. A battery or external power supply is needed to bias the plates. This power supply is usually at 48 Volts (although nowadays many microphones use only 12 Volts, or even 3 or 1.5 Volts) and is commonly called phantom power. Since the diaphragm of the condenser microphone is a very light diaphragm compared to the dynamic microphone diaphragm, the resulting signal is stronger, and condenser microphones tend to be more sensitive and responsive than dynamic ones. However, they are less suitable for handling loud sounds.

All microphones have specific directional characteristics. These so-called polar patterns, such as omnidirectional, cardioid, or shotgun patterns, describe the direction from which the microphone is picking up the most sound.



Condenser microphone.

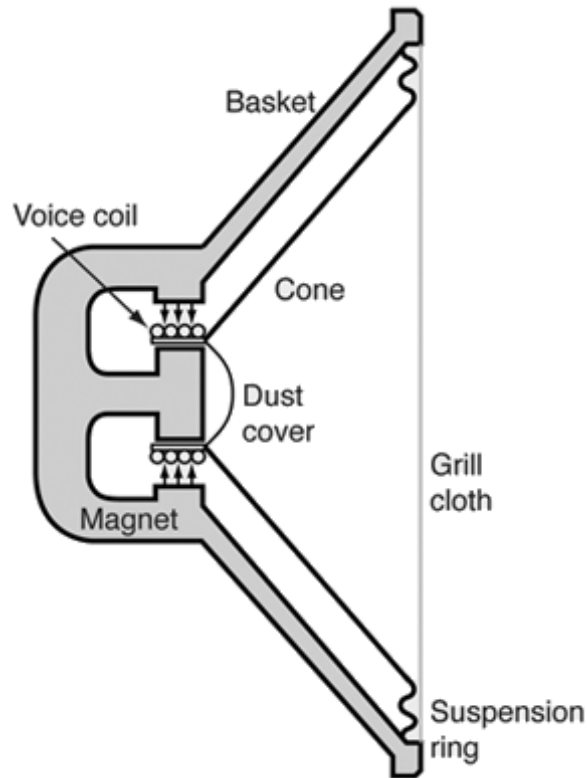
Loudspeakers

Loudspeakers are the devices which convert "something else" into sound waves. I will consider the technology of a loudspeaker that converts an electrical signal into sound waves, of which one of the most common is the moving coil technology. The groundbreaking implementation of this kind of loudspeaker, commonly known as a dynamic loudspeaker, was developed by Chester W. Rice and Edward W. Kellogg. The technology is comparable to that of the dynamic microphone, but in reverse, so that these loudspeakers are also used as microphones in certain applications.

As may be seen in the dynamic loudspeaker illustration, air pressure waves are produced by vibrations of a membrane commonly called the diaphragm, or cone. This membrane is put into vibration by the movement of a voice coil, which is attached to it and consists of a rolled-up copper wire. As soon as an electrical signal is applied to the coil, a magnetic field is generated around it to create what is known as a variable electromagnet, whose strength is proportional to the electric current in the voice coil. The voice coil is placed in a magnetic gap, formed by a permanent magnet. The interaction between the magnetic fields causes the voice coil to move back and forth, and the diaphragm moves along with the voice coil. When the voice coil is strongly attracted to the permanent magnet, the voice coil and the diaphragm move towards the inside of the loudspeaker; when the voice coil is repelled, they move outwards. The relationship between the electric supply and the diaphragm movements may be easily demonstrated by connecting a nine-volt battery to a loudspeaker, as explained by Nicolas Collins* (Collins 2009, 22), which will cause the diaphragm to move forwards or backwards depending on the connection of the battery poles.⁸⁹

Most of the single loudspeakers described above—commonly called a driver or a loudspeaker chassis—have a limited frequency range, such as subwoofers (for very low frequencies), woofers (for low frequencies), mid-range drivers (for middle-level frequencies), and tweeters (for very high frequencies). In many applications, several of these driver types are placed together in an enclosure, resulting in a loudspeaker with a special driver for each frequency range. The design of this enclosure is crucial to the sound of the loudspeaker system. Other loudspeakers are coaxial, which means that two different types of drivers are combined along one axis. This is common in, for example, automotive loudspeaker systems, since there is not much space for the installation of several drivers next to each other. In many loudspeaker systems, the drivers in the box are covered with a grill cloth; the drivers are thereby invisible. The term loudspeaker is used for a single driver as well as for a combination of these drivers in a single enclosure.

⁸⁹ John Bowers* implements these battery-generated signals in his *Victorian Synthesiser*, which I describe in Appendix 2.



Moving coil loudspeaker

Amplifier

Since the output signal of a microphone has a small range of amplitude, it must be amplified to bring the diaphragm of a loudspeaker into audible vibrations. This is commonly carried out through the use of an amplifier, which enlarges the microphone signal in as linear a way as possible, although some amplifiers are designed to focus on specific spectral characteristics of the sound. Several types of amplifier technology exist, giving rise to such devices as the vacuum tube amplifier and the transistor-based amplifier, the latter being more common today.

Piezoelectric microphones and loudspeakers

Since some of the works I discuss make use of piezoelectric technology, I will summarise this phenomenon. Piezoelectricity is the capacity of certain solid materials (such as crystal or ceramics, hence the alternate name, piezoceramic microphone) to react to mechanical pressure with changes in charge. These materials can pick up vibrations of solid materials—instead of air—and convert them into an electrical signal, or vice-versa. They are often used as contact microphones and sometimes as loudspeakers.

Appendix 2 Biographies

In this appendix, main professional function and birth date are given for all persons mentioned in the main text and marked with an asterisk. Besides these, I also mention several artists whose work with microphones and loudspeakers has been valuable for my research, but whom I did not describe in the main text. The choice of musicians and composers is highly conditioned by my own geographical circumstances, since I attempted to attend live performances of all the works I describe.

* **Ablinger, Peter** (born 1959) is a composer writing for conventional musical instruments and who creates electronic music and sound installations. In many of his works he focuses on varied aspects of so-called white noise.

Anderson, Laurie (born 1947) is a composer, performance artist and violinist. She is known for her experimental use of sound technology on stage, using different types of modified violins (for example, the tape bow violin) as well as for processing the sound of her voice (for example, the use of a vocoder in *O Superman* (1981)). For the piece *Small Voice*, she performs with a small loudspeaker in her mouth. By opening and closing her mouth, the resonance space for the loudspeaker changes and directly affects the sound.

www.laurieanderson.com

* **Ashley, Robert** (born 1930) is a composer. Mainly focusing on opera and multidisciplinary works, he is well-known for his television operas. He conceived the piece *The Wolfman* (1964) for amplified voice and tape using acoustic feedback as one of its principal sounds. The feedback is shaped here by the mouth of the performer, who holds his or her mouth as close as possible to the microphone. A tape is played through the loudspeakers at a high volume. By making very soft vocal sounds and raising the volume of the amplification, acoustic feedback occurs. By changing the shape of the cavity of the mouth with different tongue positions, the sound of the feedback is changed.

www.robertashley.org

* **Bayle, François** (born 1932) is a composer, principally of *musique concrète*. He was head of the Groupe de Recherches Musicales (GRM) from 1966 until 1997.

www.magison.org

Behrman, David (born 1937) is a composer whose compositions and installations concentrate

mainly on interactive real-time relationships with (imaginative) performers, sometimes involving the audience. In his piece *Wave Train* (1967) he makes use of acoustic feedback similar to that used in the Dieckmann-piano system. Electric guitar pick-ups are placed on the piano strings and amplified through loudspeakers. The sounds emitted by the loudspeakers cause the piano strings to vibrate again and in this way a feedback loop between piano strings and loudspeakers is established.

www.dbehrman.net

* **Bell, Alexander Graham** (1847–1922) was a scientist who undertook extensive research and patented several inventions in the area of telecommunications.

* **Boehmer, Konrad** (born 1941) is a composer and writer on music. He was the director of the Institute of Sonology in The Hague from 1994 until 2006.

www.kboehmer.nl

* **Boner, Charles Paul** (1900–1979) was a scientist working as a member of the Physics department of the University of Texas (1920–1970). He was specialised in acoustics and undertook research on acoustic feedback and sound systems.

Boulez, Pierre (born 1925) is a composer and conductor. He founded IRCAM (Institut de Recherche et Coordination Acoustique/Musique) in 1977. In his piece *Dialogue de l'ombre double* (1985) for clarinet, and live electronics, he uses a loudspeaker underneath a grand piano to add a coloured reverb to the sound of the clarinet. The grand piano is placed outside the concert hall. The sound of the clarinet radiates through this loudspeaker and brings the piano strings into vibration. These vibrations are picked up by a microphone, and diffused through the loudspeakers in the concert hall.

Bowers, John M. (currently active) is a musician, media artist and interaction designer, focusing on "home-brew" electronics, self-made instruments, and reconstructions of antique image and sound-making devices, alongside contemporary digital technology. His *Victorian Synthesiser* (2004) explores the technical possibilities of sound production in the second half of the nineteenth century. By connecting a battery to a loudspeaker, the loudspeaker diaphragm will make a "jump" forwards or backwards, depending on the polarity of the battery. To play his instrument, the *VS1*, as Bowers calls it, he places elements in between the loudspeaker and the battery connection. He uses a small metal plate and makes the connection between battery and loudspeaker by scratching this plate (connected to one pole of the battery) with a metal point (connected to one of the loudspeaker inputs). The irregular surface of the plate causes a much more complex on/off pattern of the battery current passing through the loudspeaker coil. This rapidly changing connection between loudspeaker and battery causes fast and irregular

diaphragm movements, which are perceptible as sound produced by the loudspeaker.
www.jmbowers.net

* **Cage, John** (1912–1992) was a composer. He is known for his very experimental approach towards music in general, using chance as a compositional method, focusing on everything that is audible and often collaborating in other disciplines, such as dance.

* **Chion, Michel** (born 1947) is a composer of *musique concrète* and a writer. His texts focus on the relation between the auditory and the visual.
www.michelchion.com

Cook, Perry (born 1955) is a computer music researcher. Together with Dan Trueman, he developed full-sphere and hemisphere loudspeakers from 1997 onwards. On full- or hemisphere bowls, commonly six (hemisphere) or twelve (full-sphere) loudspeakers are placed. The hemispheres are either mono or six-channel devices. These loudspeakers are often used in so-called laptop orchestras, since they can be placed close to the laptop player and diffuse their sound in all directions in a manner similar to conventional instruments.
www.cs.princeton.edu/~prc/

* **Collins, Nicolas** (born 1954) is a composer of electronic music. His installations and performances deal with uncommon uses of electronic equipment as well as with "misuse" of musical instruments.
www.nicolascollins.com

* **Comers, John J.** (year of birth and death unknown; active at the beginning of the twentieth century) was a scientist who principally focused on microphone technologies.

* **Craenen, Paul** (born 1972) is a composer and researcher, integrating choreographic and corporeal aspects in his compositions.
<http://users.telenet.be/paulcraenen/>

* **Davies, Hugh** (1943–2005) was a composer, musicologist, and inventor of experimental musical instruments. He has invented numerous new instruments and written many articles on electronic instruments.

* **De Forest, Lee** (1873–1961) was an inventor, most well-known for his invention of the Audion, the first triode vacuum tube. This electronic component was essential for the development of amplifiers of the electric signal used in sound reproduction technology.

* **Dieckmann, George F.** (year of birth and death unknown; active at the end of the nineteenth century) was a German scientist who emigrated to the United States, where he was among the first researchers on possible applications of electricity.

* **Di Scipio, Agostino** (born 1962) is a composer, sound artist and musicologist. His works focus principally on unconventional sound synthesis and processing methods.
<http://xoomer.virgilio.it/adiscipi/>

* **Driscoll, John** (currently active) is a composer and one of the founding members of the group *Composers Inside Electronics*. He uses instrumental applications of microphones and loudspeakers in many of his works. Continuing the *Focused Loudspeaker* research project from 1977, he developed rotating robotic loudspeaker instruments and used them, for example, in his work *Stall* (1981). He designed these loudspeakers to disperse the sound physically instead of using stereophonic technology, interacting with the space and revealing its acoustical characteristics, or as Driscoll formulates it: "to excite acoustical spaces in a musical manner" (Driscoll 2012, 1). In 2012 he began a new project on loudspeaker research and focused sounds, this time with Phil Edelstein, Doug Van Nort, Bob Bielecki, and Jonas Braasch.
www.cieweb.net/jdriscoll/

* **Edison, Thomas** (1847–1931) was an inventor who worked on the light bulb, the phonograph, and the motion picture camera.

* **Ellis, Alexander** (1814–1890) was a mathematician and a philologist. He translated *On the Sensations of Tone as a Physiological Basis for the Theory of Music* by Hermann von Helmholtz.

Ellison, Barbara (currently active) is a composer, visual and sound artist. In her work *The Drawing Room*, she explores the acoustic amplification of the act of drawing with the help of contact microphones as a means of creating an electronic sound environment.
www.barbaraellison.com

* **Eisenmann, Richard** (year of birth and death unknown; active at the end of the nineteenth century) was a Berlin based lawyer working at the physical institute of the Humboldt University in Berlin and a student of Hermann von Helmholtz.

Fullman, Ellen (born 1957) is a composer, instrument builder, and performer. In her performance *Soundwalker* (1980), she wears the *Metal Skirt Sound Sculpture* in which guitar strings are attached to the toes and heels of her shoes and to the edges of a metal skirt. The strings produce sound as a result of the leg movements in walking, and a contact microphone on the skirt amplifies the sound through a small portable amplifier and loudspeaker system, which

Fullman carries over her shoulder like a purse (Fullman 2012, 3).
www.ellenfullman.com

* **Goeyvaerts, Karel** (1923–1993) was a composer, known for his early implementation of total serialism in his compositions as well as experimenting with electronic sound generating possibilities.

Grisey, Gérard (1946–1998) was a composer. His *Prologue* (1976) for viola can involve optional electronics in which several instruments, such as piano, tam-tam and snare drum, are prepared with loudspeakers emitting the sound of the viola so that their instrumental resonance is triggered.

Graaff, Huba de (born 1959) is a composer and sound artist. Many of her works make use of different aspects of microphones and loudspeakers. In *Corenicken* (1991), three grids are suspended above the audience, bearing a total of 768 small piezo-ceramic elements used as loudspeakers. Two rotating loudspeakers are positioned on stage, their movements controlled by a computer. The performer wears the "Japon Fuzz," which is a tin dress with microphones, loudspeakers and other electronic parts attached. As she moves, the dress produces all kind of noise and feedback sounds. In *Hephaistos – a loudspeaker opera* (1997) loudspeakers are in the spotlights. This opera is staged using 40 different kinds of loudspeakers. The three singers each wear a loudspeaker head; there are five motorised loudspeakers and two rotating loudspeakers. Some loudspeakers are let down from the ceiling during the opera and several small loudspeakers are placed in the form of a peacock tail. In her opera *Lautsprecher Arnolt* (2004), one actor is on stage with many different, often moveable, loudspeakers, all developing different relationships with the actor and, in this way, becoming "characters" in the opera. De Graaff is interested in using loudspeakers in this way because they are thus turned into "quasi-sources" (Graaff 2013).
www.hubiware.nl

* **Haller, Hans Peter** (1929–2006) was a composer and specialist in electronic music. He was the head of the *Experimentalstudio der Heinrich-Strobel-Stiftung des Südwestfunks* from 1972–1989. During this time, Luigi Nono* collaborated with Haller for many of his compositions using live electronics.

Hartman, Hanna (born 1961) is a sound artist and composer. In many of her works she makes use of contact microphones to build new instruments. In her performance *The Washers* (2013), 33 metal rods are amplified with the help of three contact microphones. She is active in the ensemble *Les Femmes Savantes*.
www.hannahartman.de

* **Heiniger, Wolfgang** (born 1964) is a composer of live electronics and computer music, chamber music, and theatre music. In many of his works, interactive and scenic elements play an important role, often using sensor systems and electromechanical instruments.

www.schwebung.de

* **Helmholtz, Hermann von** (1821–1894) was a physician and physicist who worked on theories of vision, sensations of tone, electrodynamics, and thermodynamics.

* **Jeffery, Hilary** (currently active) is a trombone player and composer. He makes music in very different contexts, such as contemporary avant-garde, rock, techno, electronica, jazz, funk, pop, and improvised music.

www.hiljef.com

* **Kagel, Mauricio** (1931–2008) was a composer of instrumental music as well as radio pieces and movies. In many of his pieces he focused on the theatrical aspects of music.

Kaul, Matthias (born 1949) is a composer and percussionist. In his piece *Silence Is My Voice* (2005), a small loudspeaker is placed in the mouth of a singer. During the piece, sounds are radiated through the loudspeaker and may be modified by the singer by changing the position of his or her mouth.

www.matthiaskaul.de

Kessler, Thomas (born 1937) is a composer, mainly for instrumental music often combined with electronics. In *Voice Control* (1993/94), three percussionists control the sound processing executed by the computer with the help of their voice. The microphones are placed in different positions around the musicians and every microphone has a different function in the sound processing control. In *Utopia I* (2004) and *Utopia II* (2011) every single instrument of a symphony orchestra is connected to a personal live electronic set-up, containing, for example, a synthesiser, a laptop, and a control foot pedal. The sound resulting from this live electronic processing is diffused through a loudspeaker, which is placed next to the musician. The orchestral musicians are thus able to control the live electronic manipulations of their own sound.

www.kessler-thomas.com

* **Kinkeldey, Otto** (1878–1966) was a musicologist who focused his research on early keyboard music and Renaissance dance.

Lerman, Richard (born 1944) is a composer and sound artist who makes intensive use of piezo-

ceramic contact microphones in many of his works. *Travelon Gamelon* (1977) was the first live piece he developed with the help of contact microphone amplification. In this piece, the sound of bicycle spokes is picked up by attaching the contact microphone to the frame. The piece includes a detailed score for how the bicycles should be played.

www.west.asu.edu/rlerman/

Lilienstern, Genoël von (born 1979) is a composer. In the opera *Rigolator* (2008), he uses many different loudspeakers, often prepared with robotic objects. These objects can be brought into contact with the loudspeaker diaphragm by computer-controlled servo motors, and in this way, modify the vibrations produced by the diaphragm. Lilienstern also carries out experiments with flying loudspeakers.

* **Lockwood, Annea** (born 1939) is a composer and sound artist who makes performances, such as the *Piano Transplants* (1969–1982), using environmental sounds, and writes music for instruments using electronics and visual elements.

www.annealockwood.com

* **Lucier, Alvin** (born 1931) is a composer and sound artist. In his works he explores acoustic phenomena and auditory perception. He uses unusual set-ups, experimenting with technological devices in unorthodox contexts.

<http://alucier.web.wesleyan.edu/>

* **Maly, Valerian** (born 1959) is a performance and sound artist. He develops most of his works in collaboration with Klara Schilliger (1953). Their performances and installations are often site-specific interventions. He is a member of the *Ginger Ensemble*.

www.malyschilliger.ch

* **Merzbow** (artist name for Masami Akita) (born 1956) is a noise musician. Having worked with tape cassettes in his early career, he now mainly uses laptops to produce loud feedback and distortion noises.

www.merzbow.net

Maubrey, Benoit (born 1952) is a sound artist. He has developed many costumes with integrated electronic equipment and loudspeakers. The *Audio-Ballerinas* (1989) have loudspeakers in their tutus and are able to process sound in real-time, powered by solar panels. Sometimes they carry rakes with them, which are amplified by contact microphones. He has also equipped original steelworkers' uniforms (*Audio Steelworkers* (1986)), as well as clothes for street cleaners (*Audio Vacuum Cleaners* (1986)) containing loudspeakers, radiating steel working or vacuum cleaning sounds. In *Audio Geishas* (1997) kimonos are equipped with

samplers whose sounds are triggered by the dancers' movements in combination with light sensors. Sixteen loudspeakers are mounted on a large piece of polycarbonate with the form of a peacock tail worn by the performer in *Audio Peacock* (2003). The form of the peacock tail projects the sound in a highly directional way. More recently, Maubrey created an ensemble working with electro-acoustic feedback, called *Larsen Ensemble* (2011). They wear microphones, loudspeakers, guitar-effect systems with reverb, and delay effects on their backs,. They change feedback sounds by moving through space.

www.benoitmaubrey.com

* **Monahan, Gordon** (born 1956) is a composer and sound artist who often makes use of natural forces and the environment in his work. He also often uses very long piano strings (approximately 30 meters) that are brought into vibration by pulling vibrating electrical coils along the string, as in *Space Becomes The Instrument* (2009). In *New and Used Furniture Music* (2003), he uses piano strings again, and amplifies household objects with the help of contact microphones. Although, strictly speaking, not being part of my research, since it is an installation and does not even use microphones or loudspeakers, I would also like to mention *Music From Nowhere* (1990). Here, Monahan places several visually very different loudspeaker cabinets in the space. The loudspeakers themselves have been removed and replaced by acoustic sound-producing objects, such as water fountains, mechanical vibrators or motors. Visitors to this exhibition were usually convinced that what they were listening to recorded sound. The visual appearance of a loudspeaker is so strongly connected with a sound being reproduced in an "inaudible" way, that live sounds are identified as reproductions.

www.gordonmonahan.com

* **Neumann, Andrea** (born 1968) is a musician, playing principally inside the piano, and composer. She is active in experimental music, often working in collaborative projects, in the border areas between composition and improvisation. She is a member of the ensembles *Les Femmes Savantes* and *Phosphor*.

www.femmes-savantes.net/les-femmes-savantes/andrea-neumann

Nicolas, François (born 1947) is a composer who took part in the development of the Timée loudspeaker which consists of three cubes, on all sides of which a loudspeaker is mounted. This loudspeaker object has been designed according to the radiation properties of musical instruments; when used for sound diffusion, they are not placed around the audience but on a stage next to the acoustic instruments (Misdariis et al. 2001).

www.entretemps.asso.fr/Nicolas/

* **Nono, Luigi** (1924–1990) was a composer who worked with many forms of electro-acoustic

music. While his earlier works were composed for tape, from the 1980s on most of his pieces were scored for instruments and live electronic processing.

* **Oliveros, Pauline** (born 1932) is a composer and accordionist. Besides her activities in improvisation, experimental, and electronic music, she also developed the "Deep Listening" program.

www.paulineoliveros.us

Pasovsky, Yoav (born 1980) is a composer who often uses tactile transducers attached to musical instruments. Samples of the instrument as well as other kinds of samples are played while using the instrument itself as a membrane. His pieces *Pavane* (2012) and *Mimshak* (2012) are both composed with the use of this principle.

* **Pook, Lynn** (born 1975) is an artist who has made several works based on audio-tactile experiences.

www.lynnpook.de

* **Raaijmakers, Dick** (1930–2013) was a composer, sound artist, theatre maker, and writer. In many of his works, microphones and loudspeakers play an important role, often used in unusual ways. He has also written many texts on technology. The text in the catalogue of the exhibition *geluid < = > kijken* focuses particularly on loudspeakers (Raaijmakers 1971).

* **Radigue, Eliane** (born 1932) is a composer of electro-acoustic music, especially with the use of the ARP 2500 synthesiser. From 2001 on, she principally composes for acoustic instruments.

Raes, Godfried Willem (born 1952) is a composer, instrument inventor, and performer. He has developed many new musical instruments, focusing especially on musical automata. He sometimes uses loudspeakers in his musical robots, for example, for generating air pressure waves for a wind instrument (as in certain versions of his robot *Autosax*). In his second symphony, *Singing Bicycles* (1976), loudspeakers prepared with large tubes are attached to bicycles. These loudspeakers are driven by the dynamo of the bike, which delivers AC voltage. The pitch of the sound produced by the loudspeaker changes according to the speed of pedalling the bike. During the piece, all participants drive their bikes in a row, and the last biker has to ride past all the others to the head of the row. This change of speed due to passing all other bikers causes glissandi in the sound.

www.logosfoundation.org

* **Reese, Kirsten** (born 1968) is a composer and sound artist. She mainly works with electro-acoustic means and many of her works are site specific and often contain performative aspects.

www.kirstenreese.de

* **Riemann, Hugo** (1849–1919) was a music theorist. One of his most important works was the *Musik-Lexikon* (1882), an encyclopaedia of music.

Rodriguez, Ana Maria (currently active) is a composer, mainly writing music for instruments and live electronics. She often uses unconventional loudspeaker placements in her compositions, for example five loudspeakers in front of the audience in *Automatische Musik* or five loudspeakers along a 130 metre long bridge across which the audience walks in *One Way*. She is a member of *Les Femmes Savantes*.

www.femmes-savantes.net/les-femmes-savantes/ana-m-rodriquez

* **Rogalsky, Matt** (born 1966) is a composer, sound artist and musicologist. He has undertaken extensive research on David Tudor's *Rainforest*. In his own sound installations he often uses microphones and loudspeakers in unorthodox ways, for example by using microphones as loudspeakers in *Trio* (2012). He is currently a member of *Composers Inside Electronics*.
www.mattrogalsky.bandcamp.com

Schäfer, Sabine (born 1957) is a composer, sound and media artist. She developed the loudspeaker sculpture *Hörbild* (1995), which consists of 11 loudspeakers mounted on a transportable wall.

www.sabineschaefer.de

* **Schaeffer, Pierre** (1910–1995) was a composer and writer, who worked at the French radio. He developed the idea of *musique concrète* and composed several compositions in this genre, some in collaboration with Pierre Henry.

Scherchen, Hermann (1891–1966) was a conductor. He founded his own electroacoustic studio in the small Swiss village of Gravesano at his private house with financial aid from UNESCO: the Experimentalstudio Hermann Scherchen Gravesano, which existed from 1954 until 1966. His concept of recording was that it should sound as if the music were performed in the room in which it was played back, and not as if it were a recording from a performance elsewhere. Nowadays, in a recording, we hear the acoustic space in which the recording took place (Müller 2007). For Scherchen the loudspeakers should diffuse the sound in such a way that they trigger the acoustics of the space, which would imply that a recording is no longer a reproduction of a musical event that happened in another space and at another time. To achieve this effect, Scherchen invented a rotating loudspeaker ball, which he called *der aktive Lautsprecher* (not to be confused with what is called an active loudspeaker nowadays, referring to loudspeakers which do not need any external amplification). This was developed to distribute the sound in

such a way that each member of the public would sit inside the "sweet spot" or, actually, no sweet spot existed anymore. This loudspeaker was developed in 1959 and consisted of 32 speakers (215 mm diameter) placed on a 70 cm ball. The weight of the whole construction was 150 kilogram. This ball was placed on a stand and able to rotate in different directions (Loescher 1960, 5–6).

* **Scott, Leon** (1817-1879) was a bookseller and printer. He invented the phonograph in 1857.

* **Stanic, Lara** (born 1973) is a musician, performance and media artist. She develops her own stage performances, sound installations, radio works, and compositions for dance and theatre productions. She is a member of the *Ginger Ensemble*, which performs many works in which microphones and loudspeakers are approached as musical instruments.
www.larastanic.ch

* **Sterne, Jonathan** (currently active) is a scientist who has focused his research on the history and theory of sound in modernity.
www.sterneworks.org

* **Stockhausen, Karlheinz** (1928–2007) was a composer. Many of his compositions use live electronics. In his piece *Invasion-Explosion*, he makes use of loudspeakers attached to the back of a percussionist, as well as a percussionist who is walking around with loudspeakers in a snare drum.
www.stockhausen.org

* **Subotnick, Morton** (born 1933) is a composer of electronic music and co-founder of the San Francisco Tape Music Center.
www.mortonsubotnick.com

* **Tazelaar, Kees** (born 1962) is a composer of electro-acoustic music. Since 2006, he is head of the *Institute of Sonology* in The Hague.
www.keestazelaar.com

* **Tudor, David** (1926–1996) was a pianist, composer, and sound artist. He made extensive use of experimental electronics in his music and developed several works with microphones and loudspeakers as crucial sound shapers. His experiments with loudspeaker-microphone feedback, during his work at the Pepsi Pavilion in Osaka in 1970, resulted in the first version of his piece, *Microphone*. The sound system in the pavilion consisted of 37 loudspeakers and 32 inputs for microphones. These microphones could be routed to the loudspeakers in all kinds of different

ways, making it possible to create different movements of sound in space. Tudor decided not to have a sound input to the system but to use only acoustic feedback between the many loudspeakers and microphones. By using the several routings, this feedback would only occur for a short moment between one loudspeaker and one microphone. As soon as the input of a microphone moved to the next loudspeaker, the feedback stopped. Tudor describes the process as follows: "The modifying equipment gave me gating possibilities, since by simply pointing the microphones in space and then having the sound moving between the loudspeakers at certain speeds, the feedback would occur only for an instant. There were marvelous sounds made that reminded me of being on a lonely beach, listening to birds flying around in the air" (Miller 2009, 132).

www.davidthudor.org

* **Ulher, Birgit** (born 1961) is a trumpet player, mainly playing experimental music and free improvisation. One of the main themes in her work is exploring and extending the sounding possibilities of the trumpet.

www.birgit-ulher.de

* **Varèse, Edgard** (1883–1965) was a composer. He worked on the composition for the *Philips Pavilion* (designed by Le Corbusier and Iannis Xenakis) for the 1958 World Expo in Brussels in which 350 loudspeakers (of which, 25 were subwoofers) were mounted on the inner walls of the pavilion. Each track of a three-track tape could be routed to move along a so-called loudspeaker path. By isolating the walls with asbestos, a very dry acoustic response was achieved, resulting in a very clear perception of the position of whichever loudspeaker was sounding. Instead of a spatialisation of the sound, this is a positioning of the sound at a specific point in space. The pavilion was shaped like a cluster of nine hyperbolic paraboloids and the shape of the loudspeaker paths was along these irregular walls (Tazelaar 2013, 201–219).

* **Vermeulen, Roelof** (1895–1970) was an electrical engineer who worked at Philips. He has done extensive research on sound reproduction technology as well as electronic music.

* **Vidolin, Alvise** (born 1949) is a composer, often using electronic means. He has collaborated with Luigi Nono* during performances of Nono's compositions.

* **Wassermann, Ute** (born 1960) is a vocal soloist and composer. She often works with what she calls techniques for "masking" the voice with sounding objects, such as bird whistles, palate whistles or resonant objects. She is active as a free improviser and a member of *Les Femmes Savantes*.

www.femmes-savantes.net/les-femmes-savantes/ute-wassermann

Weissberg, Daniel (born 1954) is a composer who has developed multimedia projects, radio plays, electroacoustic music and musical theatre pieces besides composing instrumental compositions. In *Duo?* (1985), for clarinet and flute, many different music-theatrical situations occur during the piece and a loudspeaker becomes a third participant. In *A trois* (2003) for three electric guitars and live electronics, a layer of acoustic guitar sounds is intertwined with a layer of amplified guitar sounds. At the end of the piece, the musicians leave the stage and the distorted guitar sounds are amplified more and more. Every time a certain frequency reaches a certain volume, it is filtered out. This process of amplification and filtering goes on until even the hum of the pick-up is loud enough to be filtered out.

Weismann, Steffi (born 1967) is an audiovisual artist who explores the possible interactions between language, sound and new communication media. She is a member of the ensemble *Die Maulwerker*. In her work *LapStrap*, she wears a belt with audio equipment attached to it. She is able to control and diffuse all sound directly from this belt, since microphones, signal processor units, amplifiers, and loudspeakers are built into it. With a handheld microphone, Weismann walks around to pick up sounds of the environment and immediately processes them. *LapStrap* performances happen in a concert situation, with a sitting audience, as well as in an outdoor context.

www.steffiweismann.de

* **Wellmer, Anne** (born 1966) is a composer, performer, sound, and media artist. She creates performances, sound installations, live music for dance and theatre, radio art, music theatre pieces, network projects and improvisation with electronics. She is also active as a curator for sound art exhibitions and composition festivals.

www.nonlinear.demon.nl

Xenakis, Iannis (1922–2001) was a composer and engineer. In his piece *Persepolis* (1971) he used 59 loudspeakers all placed at different positions in the Persepolis ruins in Iran. An eight track tape was diffused on this system, each track on a different group of loudspeakers. He developed, together with Le Corbusier and Edgard Varèse, the *Philips Pavilion* at the 1958 World Expo (see Varèse for more information).

Yoshihide, Otomo (born 1959) is a composer and performer. He is active in many different musical styles, such as free improvisation, jazz, and experimental rock, and composes music for films and commercials. In his piece *Modulation With 2 Electric Guitars and 2 Amplifiers*, he uses two acoustic feedback loops which influence each other, and thus are in a constant state of change.

www.japanimprov.com/yotomo

* **Young, Thomas** (1773–1829) was a scientist who made important contributions to research on language, musical harmony, vision, light, and solid mechanics.

Zwaanenburg, Jos (born 1958) is a composer and flutist. For projects using conventional musical instruments in combination with live electronics, he has developed specific microphone techniques. Instead of using one microphone to pick up sound and using the sound as data for controlling sound processing, he gives each task to a separate microphone. As a result, a good quality microphone can be used to pick up the sound of the instrument whereas a contact microphone controls only the electronic processing.