Between air and electricity : microphones and loudspeakers as musical instruments

Eck, C.H.Y. van

Citation

Eck, C. H. Y. van. (2013, December 17). *Between air and electricity : microphones and loudspeakers as musical instruments*. Retrieved from https://hdl.handle.net/1887/22868

Author: Eck, Cathy van
Title: Between air and electricity : microphones and loudspeakers as musical instruments
Issue Date: 2013-12-17

3 The sound of microphones and loudspeakers

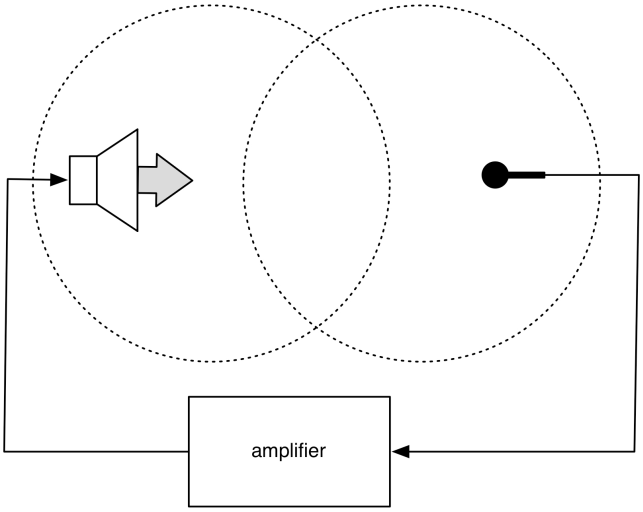
Transparent devices made audible

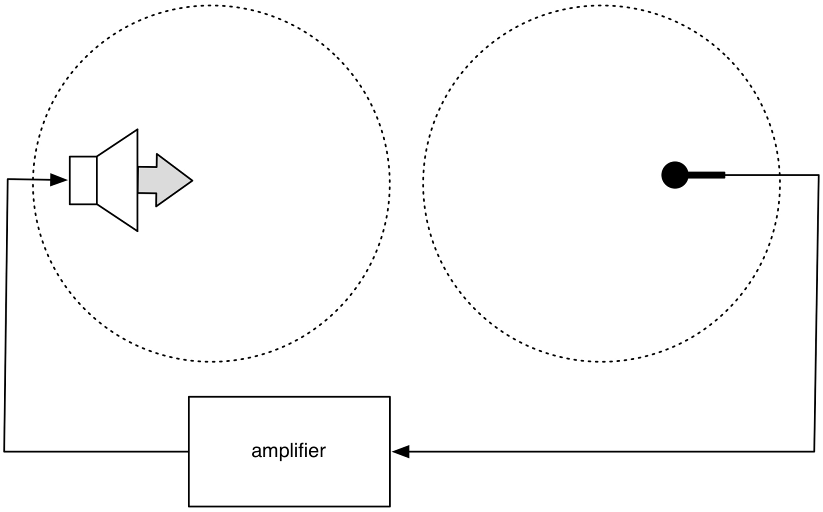
Microphones and loudspeakers are often perceived as transparent devices able to reproduce any sound. In other words, the devices themselves should not be "audible" to the perceiver. When listening to music through loudspeakers, the listener should have the impression of being immediately connected with the musical performance taking place, or which has taken place, in front of the microphone, as is the case with the *reproducing* and *supporting* approach; or the music only comes into existence upon leaving the loudspeaker, as with the *generating* approach. What happens when the music in front of the microphone and coming out of the loudspeaker is taken away, so that only the sounds found between microphone and loudspeaker remain, is what I search for in this chapter. I wish to discover what kind of sound can be produced by microphone and loudspeaker in themselves, with the least possible influence from sounds derived from conventional musical instruments or signal processing, for example. This investigation brings me back to the beginning of the nineteenth century, where I examine several ideas and devices which have played a role in the development of sound reproduction technology, as well as electric musical instruments developed during the nineteenth and the beginning of the twentieth century.

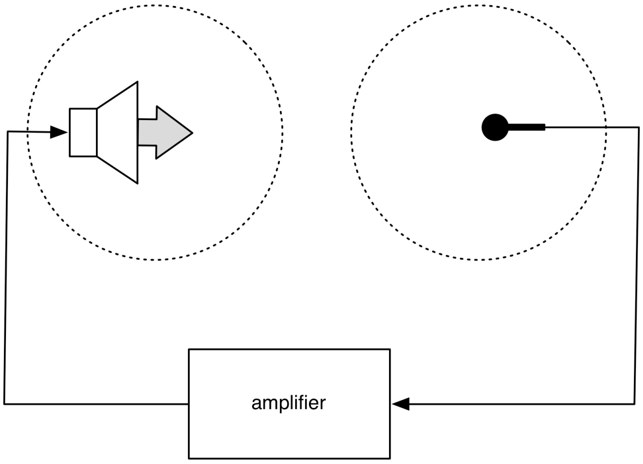
Acoustic feedback

The microphone is a silent device, not producing sound but picking up vibrations with its diaphragm. It is designed to respond to any mechanical vibrations, mostly transferred as air pressure waves, and as long as these sounds are within the limits of its capabilities to respond, the microphone is able to transduce them into an electrical signal.

The loudspeaker is a sounding device. It produces sound through the movements of its diaphragm, which are triggered by the electrical signal received by the loudspeaker. The loudspeaker itself has no way to verify if this electrical current is meant to be turned into sound or not. It merely moves its diaphragm analogue to the current, within the range of its material possibilities. Like the microphone, the loudspeaker diaphragm vibrates according to the limits of its frequency and amplitude range.







In a microphone and loudspeaker set-up as depicted at the top of the page, there will be acoustic feedback. This can be avoided by either increasing the distance between microphone and loudspeaker (the second scheme) or decreasing the volume of microphone and/ or loudspeaker (the scheme at the bottom of the page).

The loudspeaker needs an alternating electrical current to produce vibrations which form air pressure waves, perceived by humans as sound. It can use the electric current produced by a microphone. Since the electric current of a microphone is very small, this current must be increased by an amplifier for it to become functional for the loudspeaker.[38] At the same time, the microphone could pick up the air pressure waves emitted by this loudspeaker. The microphone output would be emitted by the loudspeaker again. If the sound is now softer than the first time, the sound will pretty soon disappear. But if the sound is emitted on a higher level that what is commonly called " acoustic feedback" is generated. The amplitude of the sound waves will become higher and higher, till the system will start to oscillate on one or several frequencies. Every element of a microphone and loudspeaker set-up has its own resonance frequencies. They will pick-up or diffuse the signal with slightly more amplitude at this frequency. Every time the signal is diffused and picked up again, the resonance frequencies get even more energy. For this reason, when the microphone and loudspeaker are placed close to each other, or high volumes are used, the resonance frequency will become louder and louder in the sound and thus cause acoustic feedback. The phenomenon takes place as soon as there is enough overlap contact between the sound waves diffused by a loudspeaker and picked up by a microphone. This contact is achieved when microphone and loudspeaker are placed (too) close to each other or through high enough amplification levels (see the three schemes on acoustic feedback).[39]

Unity of sound production with the use of microphones and loudspeakers

Konrad Boehmer* explains that the conjoined nature of sound-production and sound-diffusion is typical for musical instruments:

> The unity of sound-production and sound-diffusion which is so typical of instruments, was disrupted in favour of another scheme, namely that of sound recording and sound fixation. Here the diffusion became a separate act, in which the composition was no longer realised in sound but was already realised when made to sound (Boehmer 2004, 161).

---

[38] As I described in chapter 2 the invention of electric amplification has been very important for the mainstream use of microphones and loudspeakers in all kind of applications.

[39] This system does not only contain microphone, amplifier and loudspeaker, but of course all components in between those elements as well. An acoustic feedback system is also shaped by the distance between microphone and loudspeaker, the acoustics of the space, air humidity, as well as the cables used to transport the electric current from one component of the set-up to another.

I prefer to call sound-production sound-shaping due to the difference between the actual acoustical sound source—which is still the loudspeaker—and the semantical act of sound creation, the result of which is what is heard through the loudspeaker (see chapter 2 for a more in depth explanation of acts of sound creation). I use the word sound-emission instead of sound-diffusion, since sound diffusion is commonly defined in electroacoustic music as "the realtime (usually manual) control of the relative levels and spatial deployment during performance" (Harrison 1998, 117) and I include every way of emitting sound with the help of loudspeakers. Some of the construction elements of a musical instrument might be mainly designed for shaping the sound (like the strings of the violin) and others for amplifying the sound (like the body of the violin). The vibration of the strings cannot exist without them emitting any sound (the sound would be much softer if it would not be connected to the wooden body), and the wooden body cannot amplify the sound of the strings without shaping this sound according to its own characteristics. When a microphone and loudspeaker set-up produces acoustic feedback, it is behaving as a musical instrument in this unification of sound-shaping and sound-emission. No sound is coming from outside of the set-up, [40] as is normally the case when a microphone picks up a sound like a singing voice, and all sound radiated by the loudspeaker is shaped by the set-up of microphone, amplifier and loudspeaker as described at the beginning of this chapter. In music heard through loudspeakers, sound-shaping and sound-emission are divided into two different processes and should influence each other as little as possible, in contrast to how these processes are connected to each other in musical instruments. Influencing the diaphragm-movements of microphones and loudspeakers could be termed the sound-shaping process (sound-production, according to Boehmer). These movements shape the air pressure waves, perceived as sound, produced by the loudspeaker. This sound-shaping is mostly done in one of two ways: either a sound source (such as a musical instrument) generates air pressure waves which bring the microphone diaphragm into vibration (as is the case with the *reproducing* and *supporting* approach), or loudspeaker diaphragm is brought into vibration by an electrical signal which has been shaped by an electric circuit (this is typical for the *generating* approach). Often the resulting loudspeaker diaphragm movements are a combination of these two possibilities, as when a sound has been recorded and processed by a computer before it is sent to a loudspeaker. The resulting sound-emission (sound-diffusion, according to Boehmer) is performed by the actual diaphragm movements of the loudspeaker. The form of the air pressure waves produced by these diaphragm movements should be influenced as little as possible by the material and construction of the diaphragm. This is thus contrary to the situation when sound is produced by musical instruments (or in an acoustic feedback set-up!), since, in those cases, the material of the instrument is highly influential on the resulting sound.

---

[40] There is of course a small input excitation needed to bring the microphone diaphragm into vibration. This can be caused by a soft noise created by the amplifier or by some background noise in the room. Nonetheless the impression is that the sounds come into being "out of nowhere".

Acoustic feedback: an electro-acoustic oscillator

Robert Ashley* states that feedback is the only sound intrinsic to electronic music (Holmes 2008, 185). This implies that the sound produced by the combination of microphone, amplifier and loudspeaker—without any noticeable additional sound sources—is the fundamental sound of electronic music. Indeed, in acoustic feedback both sound-shaping and sound-emission are accomplished by the microphone, amplifier and loudspeaker set-up. It is probably for this reason that Ashley thinks of acoustic feedback as intrinsic to electronic music, in the same way as one could think of the sound of the violin as the intrinsic sound of the violin. When the violin is played, all parts of the violin together form a single sound system, interacting with each other to produce sound. The same is true for acoustic feedback: all parts of the microphone and loudspeaker set-up interact to produce the resulting sound. It is no longer possible to distinguish between the shaping and emitting of sound. Acoustic feedback is in fact the only sound which is entirely shaped as well as emitted through this system of loudspeaker and microphone.

There is a second reason, however, why acoustic feedback might be called the intrinsic sound of electronic music. Acoustic feedback may be described as follows: the output of the system (the sound emitted by the loudspeaker) is the input for the same system (the sound that brings the microphone diaphragm into vibration), and this input becomes again the output of the loudspeaker (which is obviously the reason this process was termed feedback). This enduring processing of the same signal, without any noticeable input from the outside, causes a signal shaped by the material participating in this process. The transportation of the signal is done either in the form of a fluctuating electrical signal (as long as the signal is between the microphone and the loudspeaker) or as a mechanical vibration (from the vibrating loudspeaker diaphragm causing air pressure waves which reach the microphone and bring its diaphragm into vibration). Depending on their material characteristics, as well as the characteristics of all the other parts of the system, the diaphragms will vibrate more easily at certain frequencies than at others. This is the so-called resonance frequency of the system.[41] The entire system of microphone, amplifier and loudspeaker vibrates at the frequency which is produced with the least resistance. The system oscillates at this frequency,, oscillating repetitively and regularly between its two extreme values.

In electronic music, oscillators are often used to generate an electronic signal. An oscillator is in that case a circuit which generates, like the acoustic feedback system, a repetitive signal, for instance in the form of a sine, a sawtooth or a square wave. For this reason acoustic feedback could be compared to an electronic oscillator. The sound of oscillators is often immediately

---

[41] In fact, most vibrating objects have resonance frequencies, at which they tend to vibrate much easier, than at other frequencies. A well-known example is the glass that breaks when brought into vibration at its resonance frequency and a more dangerous resonance frequency can be found in the vibrations of bridges, which can break when they are brought in their resonance frequency.

identified as a typical electronic sound, since regular oscillating vibrations (for example sine and square waves) are not found in mechanical vibrations. Oscillators are used in all kind of electronic warning signals, such as the beeps used for signalling the pushing of a knob (on phones, microwaves and in elevators). When electricity is the supplier of the energy needed to create the audio signal, as is the case with electronic oscillators and with acoustic feedback, there is no human movement involved, and it is therefore possible to keep the energy supply absolutely stable. Therefore the output signal of electronic oscillators will be regular, without any deviation. Acoustic feedback behaves largely like an electronic oscillator, although the process is slightly different. Although the electrical energy supply might be constant, feedback includes a mechanical aspect as well, namely what takes place from loudspeaker diaphragm to the point when microphone movement vibrations are transduced back to electricity again. For this reason, acoustic feedback is an electro-mechanical oscillator. As I will explore in more detail in the next two chapters, it is exactly this connection between the electronic processing and the laws of classical mechanics which can be very fruitful for all manners of exploration.

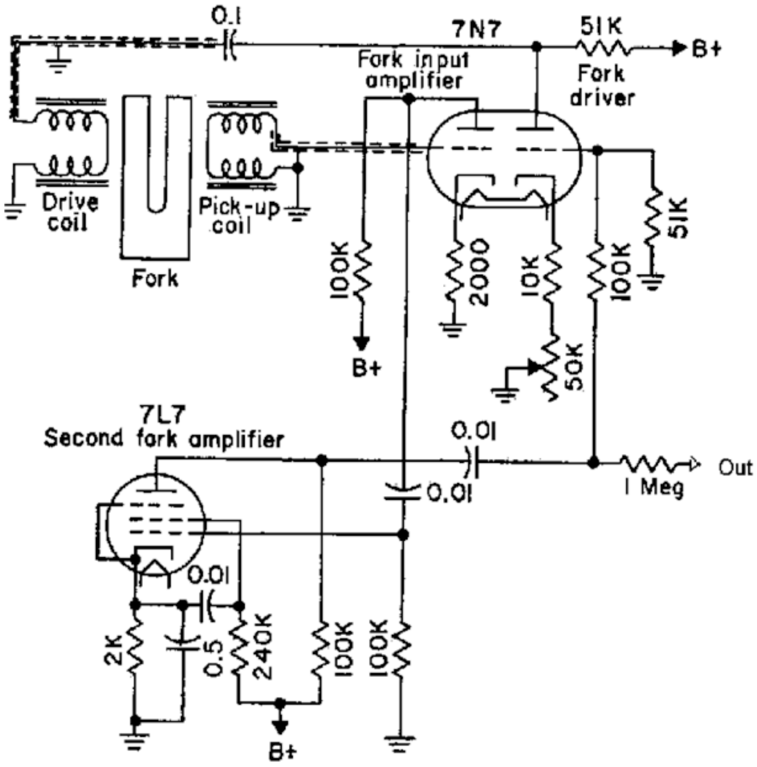
Some remarks on the history of acoustic feedback

As soon as sound reproduction technology was introduced at the end of the nineteenth century, the phenomenon of acoustic feedback came into being as well. This generative sound of the machines themselves was regarded as completely undesirable. A good example is the disturbance of telephone conversations at the beginning of the twentieth century by acoustic feedback. The telephone needed to be convincing to the public as a suitable new device for the transportation of music or conversations, and naturally any other sound was disturbing. Since a telephone microphone and loudspeaker are very close to each other (often both placed in the telephone horn), it was not easy to prevent the microphone from picking up sounds from the loudspeaker as well, instead of only the acoustic source (a voice, for example) that it was supposed to transport. Acoustic feedback could easily occur, and it was immediately identified as an annoying by-product which should be avoided. As can be read in patents at the beginning of the twentieth century, telephone conversations were indeed often disturbed by this so-called "howling" (Patent Gilchrest 1906).

Not surprisingly, scientific research on amplifying audio signals has concerned itself with avoiding feedback. Already as early as 1911, research on acoustic feedback was being performed by Søren Absalon Larsen, and the French term for acoustic feedback "effet Larsen" is named after him. Paul Boner* was one of the first to carry out extensive research on feedback, and in the 1960s proposed solutions for avoiding feedback, by, for example, introducing equalisation in public address systems (Boner and Boner 1966). With the use of equalisers, which reduce or increase certain frequencies in the audio signal, acoustic feedback could be avoided during concerts that use an amplification system, by searching for the resonance frequencies and filtering them out with the result that resonance on these frequencies would become impossible.

A tuning fork oscillator

Thinking of an acoustic feedback system as an oscillator capable of producing vibrations circulating through the system of microphone, amplifier and loudspeaker, is not only theoretically correct but has also been put into practice. An example is the tuning fork oscillator, a combination of a tuning fork and two small electromagnets, each placed close to one of the tuning fork prongs. Normally the sound of a struck tuning fork dies away fairly quickly owing to the resistance of its material. In this oscillator, the loss of energy is avoided by amplifying and feeding the vibrations of the tuning fork back into one of the prongs. One coil picks up the vibrations of one of the prongs of the fork, generating a current in the coil at the same frequency as these vibrations, which is then amplified and fed back into the other coil, causing it to vibrate.



The drive coil and the pick-up coil, each on one side of a prong, can be seen in the upper left of this scheme for the tuning fork oscillator.

Since both prongs are physically connected to each other, they will always vibrate with the same frequency and amplitude, but in opposite directions (Cary 1992, 339–340).[42]

At first sight, a tuning fork seems not at all related to microphones and loudspeakers. But, taking a closer look at the two small electromagnets and the prongs of the tuning fork, it might become clear that the prongs of this small metal object can be compared with the loudspeaker and microphone in an acoustic feedback set-up. The transduction of the vibrations of the diaphragms of many microphones and loudspeakers is often performed by electromagnets. The two small electromagnets close to the prongs function similarly to the electromagnetic coil construction in a dynamic microphone, or to the electromagnetic voice coil in a loudspeaker: one picks up the vibrations of the prong (this prong could therefore be seen as equivalent to a microphone diaphragm), and the other brings the second prong into vibration (and this prong thus becomes equivalent to the loudspeaker diaphragm).[43]

Contrary to the acoustic feedback described previously, here it is not air which transports the sound waves but the metal of the tuning fork. The fragile and light diaphragms of loudspeaker and microphone have solidified into rigid and solid bars of metal. The independence of loudspeaker and microphone becomes dissolved in the tuning fork, whose prongs are connected to each other. The tuning fork oscillator could be seen as an acoustic feedback set-up in which microphone and loudspeaker have lost their flexibility of vibrating on (theoretically) every possible frequency and are only able to respond to a single frequency. The resonance frequency of this system is determined by the frequency of the tuning fork. This oscillator demonstrates well that the element of a feedback system with has the strongest resonance for a certain frequency will cause the rest of the system also to vibrate at this frequency. Owing to the high resistance of the tuning fork to vibrate at any frequency other than its own resonance frequency, the frequency of the tuning fork becomes the resonance frequency of the whole system of tuning fork, coils and amplifier.[44]

---

[42] Cary uses this example for demonstrating positive feedback and how this phenomenon is used for producing an oscillator. As he mentions himself, these kinds of oscillators are rarely used anymore. Tuning fork oscillators were very suitable as low frequency oscillators and were used in all kinds of precision equipment, such as radio technology.

[43] See Appendix 1 for an explanation of microphone and loudspeaker technology.

[44] Whereas the coils could also easily contain a current with a different frequency, it is practically impossible to get a tuning fork to vibrate at another resonance frequency than its own.

Some remarks on the tuning fork

The tuning fork is connected in more ways than this to the development of microphones and loudspeakers. The tuning fork was an important scientific instrument to the nineteenth century acoustician. Invented in 1711 by the trumpeter John Shore, the tuning fork, with its quality of fixed pitch, was meant first and foremost as a practical help in tuning instruments.[45] The material properties of the tuning fork remain stable even under temperature changes, making it an extremely suitable device for delivering a reference pitch for tuning. Owing to its form, the two prongs vibrate 180° out of phase, causing the stem to move up and down in the motion of a sine wave. For this reason, the tuning fork produces that what is often called a "pure" tone, a tone, which is probably as close as one can get to a sine wave without using any electrical or electronic means. Only the attack produces other audible partials, but these fade out rapidly owing to the great resistance of the tuning fork against these frequencies.

Although the tuning fork was invented as an aid to tuning musical instruments, scientists discovered the usefulness of its characteristics (especially the periodic vibrations causing a pure tone, as described above) and started to make use of it for their research on sound. It became a crucial instrument in nineteenth century acoustical research, and several tuning fork experiments are closely related to the development of loudspeaker and microphone technology. Especially in musical applications, the relationship between microphones and loudspeakers in nineteenth century scientific experiments with early devices was often not unidirectional (as is the case in the *reproducing*, *supporting* and *generating* approach), with a signal flow moving only from microphone to loudspeaker. The connection in nineteenth-century devices and instruments is often more related to a feedback situation between microphone and loudspeaker. These devices often used the sound-shaping possibilities of the microphone and loudspeaker set-up, contrary to later developments, during the first third of the twentieth century with their high fidelity aesthetic and the corresponding demand for a "neutral" mediation of sound. In light of the above, acoustic feedback might form an interesting model for conceiving the relation between microphone and loudspeaker and particularly for considering these as together forming a single instrument. Through a closer consideration of their history of development and use, it becomes clear that they should no longer be regarded as only being "transparent" or "neutral" devices, but as devices which could have a strong content of their own. Although they can be transformed into transparent devices, transmitting sound from outside sources, my starting point will be the sound which is shaped entirely by them. In the remaining sections of this chapter, I explore some examples of inventions and experiments leading to loudspeaker and

---

[45] For a history of the tuning fork and its role in nineteenth century science, see *Die Geschichte Der Stimmgabel - Teil 1: Die Erfindung Der Stimmgabel, Ihr Weg in Der Musik Und Den Naturwissenschaften* (Feldmann 2008) and *From Scientific Instruments to Musical Instruments: The Tuning Fork, the Metronome, and the Siren* (Jackson 2012, 202–205).

microphone technology, starting at the beginning of the nineteenth century and ending around the time of the loudspeaker patent by Kellogs and Rice.

Nineteenth century research on sound

One of the tuning fork's first appearances in nineteenth-century science involves its use as a notation device for sound. Before taking a closer look at the tuning fork notation method, I give a brief perspective on the general development of acoustical science in the nineteenth century. One of the main endeavours of science in this period was to gain a more empirical knowledge of the world through the execution of experiments, and to objectify this knowledge by deriving it in ways which tried to be as independent as possible from individual perception (Rieger 2006, 9). Science itself became increasingly professionalised, developing stricter research methods and requirements. The experiments I discuss belong to the stream of research which attempted to objectify knowledge on sound and listening.[46]

One of the main problems with acoustical research is that sound is time-bound, consisting as it does of an alternation of low and high air pressure. For this reason it was impossible for nineteenth century scientists to make analytical observations on sound itself, since a longer period of time is needed to observe and analyse a phenomenon and sound could only be researched the moment it was heard. What scientists needed was an object which did not change over time and thus could be studied. Scientists began to look for ways to transform sound into researchable objects, to convert sound waves into forms more amenable to analysis. I examine some of the methods developed in the nineteenth century to notate sound. A second aim of acoustic research in the nineteenth century, investigated by controlling the different partials of a sound, was to understand the phenomenon of sound colour, in other words the spectral characteristics of a sound. This endeavour led ultimately to in electronic sound synthesis in the twentieth century.

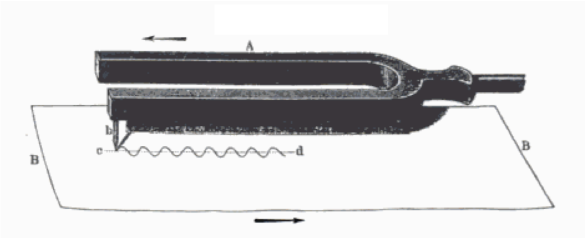
Thomas Young: visualising sound

At the beginning of the nineteenth century, Thomas Young* describes in his *A Course of Lectures* (1807) a machine by means of which sound may be directly notated, consisting of a cylinder, covered with paper or wax, which rotates at a certain speed. By connecting a pencil to a rapidly vibrating (and therefore sounding) object and placing the tip of this pencil in contact with paper

---

[46] The relationship between music and science in the nineteenth century is explored in-depth in *Harmonious Triads: Physicists, Musicians, and Instrument Makers in Nineteenth-Century Germany* (Jackson 2006).

on a rotating cylinder, the markings left by the pencil will notate and visualise the vibrations of the object (Young 1845, 288–289).[47] Young reports that up to 1000 vibrations per second may thus be measured (Young 1845, 146–147).[48] With this experiment, he was searching for a direct transcription of sound into a visual representation, a typical nineteenth century endeavour to objectify the perception of a specific phenomenon (in this case sound). The vibrations of the object, normally only perceivable as sound, were visualised by this method into a graphical result, becoming an object suitable for research instead of a vanishing sound. A tuning fork was, as might be expected, an interesting sound source to notate, with its simple and clear periodic vibration, very similar to a sine wave.[49] The experimental machine described and developed by Young was soon used by different scientists such as Wilhelm Weber, Wilhelm Wertheim and Jean-Marie Constant Duhamel to notate the vibrations of a tuning fork (Jackson 2012, 203).



The graphical method as depicted by Helmholtz.

---

[47] Of course, the vibrations of the sounding object have to be strong enough to bring the pencil into motion and, correspondingly, the pencil has to be light enough to transfer the vibrations of the sounding objects with the least possible distortion.

[48] This is a tone with a frequency of 1000 hertz (the term for vibrations per second).

[49] It might be the case, as is mentioned in several sources, that Thomas Young also used a tuning fork as a sounding object, however, I have not found a mention of this in his *Lectures*.

Hermann von Helmholtz: reversing the tuning fork notation

One of the most notable scientists in the nineteenth Century, performing a wide range of research on acoustics, was Hermann von Helmholtz*. What is remarkable in his research is the use of acoustic knowledge to clarify music. This was not only a new scientific approach in the nineteenth century, but also revolutionised music theory. His approach to music as a physical phenomenon and his aim of objectifying phenomena such as sound, the sense of hearing, and consonance brought about a rethinking of most of the axioms of music theory.[50]

Helmholtz was familiar with the method of notating the vibrations of a tuning fork, which he describes in much detail in his famous book on the immediate relationship and effect of acoustics on music theory: *On the Sensations of Tone as a Physiological Basis for the Theory of Music* (*Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* 1863). Helmholtz calls this tuning fork notation method a graphical method ("eine grafische Methode") and describes it as being used by mathematicians and physicists for facilitating the study of sound waves (Helmholtz 1865, 33).

More noteworthy, however, is his description of how one can visually create a moving, albeit limited, reproduction of the wave the tuning fork has notated:

> If the reader wishes to reproduce the motion of the vibrating point, he has only to cut a narrow vertical slit in a piece of paper, and place it over fig. 6 or fig. 7, so as to show a very small portion of the curve through the vertical slit, and draw the book slowly but uniformly under the slit, from right to left; the white or black point in the slit will then appear to move backwards and forwards in precisely the same manner as the original drawing point attached to the fork, only of course much more slowly (Helmholtz 1895, 21).[51]

Helmholtz thus not only visualises a static image of the movement of the prongs of the tuning fork, he also brings the graphical and immovable representation back into motion. By moving the

---

[50] The book *Helmholtz Musicus: Die Objektivierung der Musik im 19. Jahrhundert durch Helmholtz's Lehre von den Tonempfindungen* (Rieger 2006) gives an elaborated investigation into the influence of the work of Helmholtz on music theory.

[51] This quotation is from the translation by Alexander Ellis. The original German version by Helmholtz is: "Will der Leser die Bewegung des schwingenden Punktes sich reproduzieren, so schneide er sich in ein Blatt Papier einen senkrechten schmalen Schlitz, lege das Papier über Fig. 6 oder 7, so daß er durch den senkrechten Schlitz einen kleinen Teil der Kurve sieht, und ziehe nun das Buch unter dem Papier langsam fort, so wird der weiße oder schwarze Punkt in dem Schlitz gerade so hin- und hergehen, nur langsamer, als es ursprünglich die Gabel getan hat" (Helmholtz 1865, 35).

transcription of the vibration underneath a paper with a small slit, only one representation of location in time of the prong can be seen. Helmholtz foreshadows here, in a very abstract manner, the reproducibility of tuning fork vibrations. Exactly this idea, that sound is nothing more than reproduceable vibrations, becomes very important for several developments in sound technology during the succeeding decades. This is one of the first indications of the possibility of reversing the transformation of audible sound waves into a fixed form. It is clear, though, that Helmholtz was not interested in reproducing the sound itself, but in reproducing the movement of the object causing the sound.

Hermann von Helmholtz: Mittönen, a second tuning fork experiment

One of the subsequent experiments which Helmholtz describes in this book is the phenomenon of Mittönen (english: literally, to co-sound, translated as sympathetic resonance by Alexander Ellis* in his translation of *Die Lehre von den Tonempfindungen* (Helmholtz 1895, 40)). This word, uncommon in modern German usage, refers to the phenomenon of an object starting to vibrate in response to the vibrations made by another object, which is placed close to, but not touching, this object. An experiment for demonstrating this phenomenon was often performed using the favourite instrument of the nineteenth century acoustician: two tuning forks of the same frequency, placed close to each other, each mounted on its own resonant box (to amplify it). If one of the two tuning forks was struck and subsequently quickly dampened, the second tuning fork could be heard resonating owing to the sympathetic vibrations caused by air pressure waves from the struck tuning fork (Helmholtz 1865, 67–68).

This very common nineteenth century experiment proved that sound waves are transmitted through air. Objects capable of resonating at the frequencies of these sound waves will do so, if the sound waves are strong enough. This is, once again, an experiment in which the tuning fork is used as a kind of "pre-microphonic" object: not only is a tuning fork able to transform sound waves, as proven by the first experiment, it is also capable of responding to vibrations transported through the air. Scientists started to look for an object able to *co-sound* with as many frequencies as possible. This would be useful, as it would become possible to notate sounds without attaching a pencil directly to the sounding object. One of the disadvantages of the pencil was that it could only be attached to sounding objects with a very specific shape. It was impossible, for example, to notate the wave signal of the human voice or of most musical instruments. The solution was to use a thin membrane, able to vibrate at many different frequencies, instead of objects like tuning forks, with only one resonating frequency. All kinds of sounds transported by air pressure waves could be picked up by this membrane and notated, without any physical contact with the vibrating object.

An early example of using a membrane to pick up the vibrations of a sound source is the phonautograph (patented in 1857 by Leon Scott*), which uses two small, thin membranes, analogous to the tympanic membrane of the ear. Scott developed this machine by copying the physical properties of the human ear, and it was able to notate sound waves on smoked paper by means of a stylus attached to the membranes (Sterne 2003, 32–36). These notations were called phonautograms. Not surprisingly, one of the first sounds notated by Scott was actually the sound of a tuning fork, which, with its simple sound wave, was suitable for demonstrating the reliable functioning of the machine. This machine is a unidirectional, linear system: all manner of sounds can be notated with the phonautograph, but no part of it can be brought back into movement and heard again.[52]

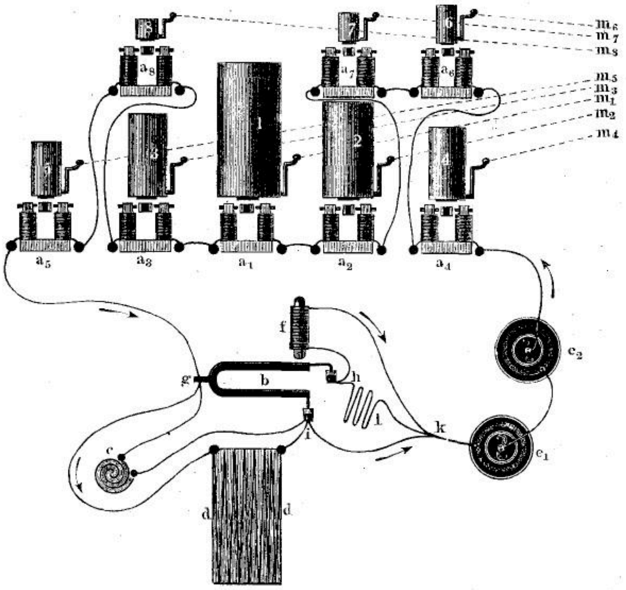
Hermann von Helmholtz: reproducing human vowels with tuning forks

Scott's phonautograph enabled a more objective study of sound by registering it as a static form outside of its perceptual immediacy in time. Helmholtz found a solution for the second aim of nineteenth century acoustic research, namely to analyse the different partials of a harmonic spectrum separately, by developing a device to research vowels as produced by human voices. Based on Fourier's theorem, which stated that every wave can be analysed as a sum of sine waves, he sought to reproduce human vowels by combining several partials, a process which would subsequently be called additive synthesis. Helmholtz described in *Die Lehre von den Tonempfindungen* a device using eight tuning forks of different pitch for the several partials of the spectrum,[53] kept in constant vibration with the aid of electromagnets. These function in nearly the same way as the tuning fork oscillator described above, except that instead of a feedback circuit keeping the oscillator in motion, all eight tuning fork oscillators are kept in motion by an intermittent current, provided by the largest tuning fork. Through the regular movements of the prongs of this large tuning fork, a connection to galvanic batteries is opened and closed, resulting in switching the current flow through the tuning forks on and off. Owing to this intermittent current, the electromagnets also become magnetised, attracting the tuning fork when the current flow is on and demagnetising when the current flow is off, allowing the prongs

---

[52] In 2008, a sonic reproduction of the air pressure waves as notated in these phonautograms was achieved by digitalising the notated wave forms (Giovannoni et al. 2008).

[53] In the Koenig Catalogue, the pitches are described as: ut2, ut3, sol3, ut4, mi4, sol4, ut5. One pitch is thus missing here, since Koenig describes eight tuning fork oscillators (Koenig 1865, 10).

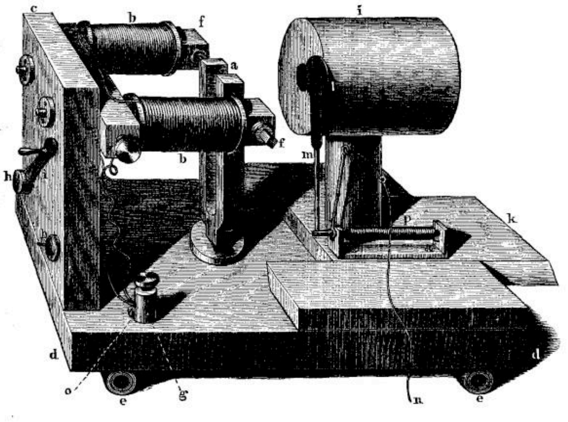


A schematic overview of the tuning fork device by Helmholtz.

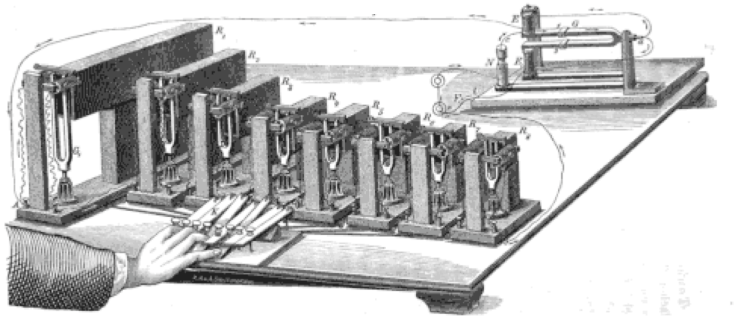
of the tuning forks to return to their original positions. Adjustable resonators in the form of cardboard tubes were used to make the sound of the tuning forks louder.[54]

---

[54] Description of the functioning of this tuning fork device in more detail: As soon as an electric current is moving through the electromagnets, they become magnetised and attract the prongs of one of the tuning forks. Both prongs move away from each other, towards the electromagnets. Once the current is taken away, the prongs move back again to their initial position. If the electric current is turned on and off in a frequency that forms a division of the frequency of the tuning fork itself, the tuning fork will start to vibrate at its own frequency. The turning on and off of the electric current in the electromagnets is called an intermittent current. Since all tuning fork harmonic frequencies are related to each other as partial tones (with relations such as 1:2:3:4:5), their harmonic frequencies can be divided by one fundamental frequency, which is the frequency of the largest tuning fork. This intermittent current is achieved in Helmholtz's device through the use of a tuning fork tuned to the fundamental frequency. The prongs *b* are connected to two small metal wires, which are dipped into mercury at *i*. Every time there is an electric current (delivered by galvanic batteries *e1* and *e2*) traveling through the mercury to the prongs of the tuning fork, the prongs will be attracted by the electromagnets. This will cause the wires on the prongs to be taken out of the mercury, thus breaking the electric circuit. Consequently there is no magnetic attraction, and the tuning fork returns to its initial state. This generates a current again, with a connection of the wires on the prongs to the mercury again. Since a tuning fork only vibrates at one frequency, the making and breaking of the electric circuit always occurs at the frequency of the tuning fork. In this way Helmholtz achieves a constant vibration of the tuning fork, which will keep the other eight tuning forks *a1* till *a8* vibrating as well. To make these eight tuning forks audible, he attached resonant tubes *m* that could be opened and closed. Normally tuning forks were attached to resonant boxes to make them audible, but since Helmholtz wanted to be able to hear them separately and in different combinations, he decided to attach adjustable resonators in the form of these tubes, their lengths adapted to the frequency of the tuning fork they were placed on.



One of the eight tuning forks used by Helmholtz in his device for reproducing human vowels.



Keys were used for opening the resonators of the different tuning forks.

This device combines the functions of sound-shaping and sound-emission. The vibrations are caused by the electromagnets, and the eight tuning forks and their connected cardboard tubes perform both functions. Similar to the prongs of the tuning fork used in an electromechanical oscillator, the prongs in this device could be seen as the predecessors of the diaphragm of a loudspeaker. If they were flattened out into light and thin membranes, able to resonate at several frequencies instead of just one, like the membrane in Scott's phonautograph, the tuning fork would function as a loudspeaker. As further examples in this chapter will show, such tuning fork applications during the nineteenth century can indeed be seen as evolving towards the applications of membranes performing similar functions.

The tympanic principle and the tuning fork principle

As I described in chapter 1, sound reproduction technology in general makes use of membranes to transduce sound waves into something else and back, a principle called "tympanic" by Jonathan Sterne. The tympanic principle is derived from the structure of the ear, which contains a membrane able to transmit all kinds of different sounds from the external world to our inner ear. As Sterne writes "[...] the functioning of the tympanic membrane (also known as the diaphragm or the eardrum) in the human ear was the model for the diaphragms in all subsequent sound-reproduction technologies. As a result, I call the mechanical principle behind transducers *tympanic*" (Sterne 2003, 22). This principle is the result of looking for a neutral transformation of sound into another medium, in which the visual representation of sound should be transferred directly from the vibrating object to the materials for notation, as Young demonstrated by attaching a stylus to the object. To represent visually the waveform of all sounds human beings hear, it would be simplest to attach a pencil to the membrane of the ear and transfer these vibrations directly to paper.[55] The tympanic principle—used, for example, by Scott in his phonautograph as mentioned above—is the result of a human-based model of sound perception. The object used for transmission in the tympanic principle, the membrane, should disappear, and no hint of it should be recognisable. We are not able to hear our own ear hearing, and the same should be the case for sound reproduction technology.

I would like to introduce the tuning fork principle, as a concept to set against Sterne's tympanic principle. This principle approaches the process from the opposite direction, since it reproduces only one frequency instead of many. Contrary to the tympanic principle, it is therefore not a generalisation for sound reproduction, but a specification. The tuning fork method arises from an abstract approach to sound and music, with the so-called pure tone, one sole frequency, named the sine wave, as its starting point.[56] This is seen as the source of all musical sound, since every sound wave can (theoretically) be constructed by adding multiple sine waves, each of a different frequency. According to this principle, the object used for transmission of sound (the tuning fork) is clearly connected with the sounds being produced, and the object is audible, in contrast to the membrane in the tympanic approach, which should not be "audible" at all. The difference between these approaches may be found in the semantic act of sound creation: the membrane in the tympanic principle transmits all kinds of acts of sound creation (except its

---

[55] Therefore, it might not come as a suprise that Alexander Graham Bell and Clarence Blake performed exactly this experiment. An extensive exploration of their work on the ear-phonautograph can be found in the book *The Audible Past* (Sterne 2003, 31–35).

[56] I must underline that the tuning fork itself does not produce a sine wave, but produces a wave that is as close to a sine wave as nineteenth century scientists could obtain.

"own" sound), whereas the tuning fork can only transmit one act of sound creation, namely its own sound.

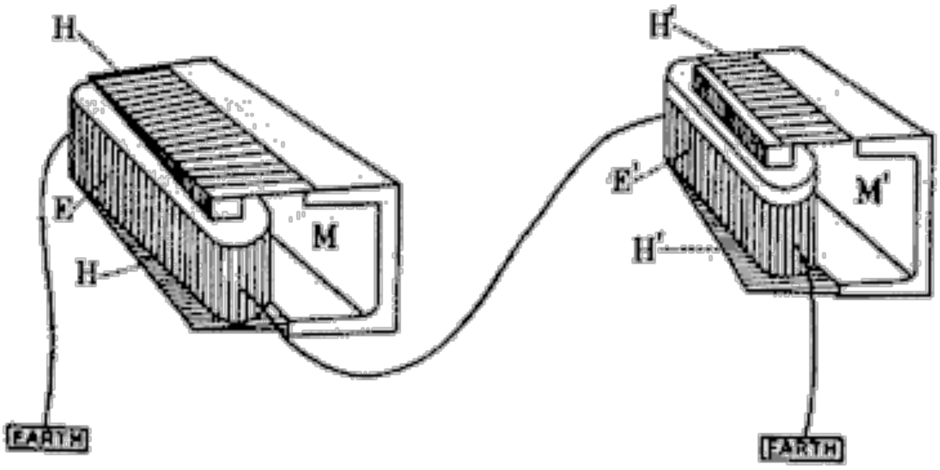
In my view, these two different principles complement one another, and both form the starting points of two different directions taken in sound technology, especially as concerns microphones and loudspeakers. This is the beginning of a division between one principle that focuses on a transparent reproduction of all possible sounds, using an imperceptible tool, and another which focuses on the converse, that is to say on producing a musical sound using a perceptible tool. When considering the development of sound reproduction technology during the nineteenth century, many of the new devices used tuning forks for either picking up frequencies (with the help of sympathetic resonance) or to emit frequencies (with the help of electromagnets). As I will demonstrate by means of the following examples, these tuning forks were gradually replaced at the end of the nineteenth century by membranes, which took over the function of picking up frequencies (microphones) and emitting them (loudspeakers).

Alexander Bell: using many metal rods to reproduce sound

The tuning fork device developed by Helmholtz was encountered in 1866 by Alexander Graham Bell. He misunderstood the description of this device, however, and thought it was possible to transmit spoken vowels to the tuning forks (Gorman 1994, no page numbers). For this reason Bell became convinced that it was possible to transmit not only vowels, but all manner of sounds, through a wire by means of electricity. He thus evidently confused sound synthesis with sound reproduction. It is because of this confusion and because of Bell's fascination for sympathetic resonance that he developed the idea of creating a new device for transmitting vocal sounds. By singing into the piano, while pressing down the sustaining pedal, Bell noticed that sound was produced due to the sympathetic resonance of the piano strings. The resonance of the piano strings is of course a very crude reproduction of the voice, but it gave Bell the idea that, if a piano contained more strings within one octave, it would be able to reproduce a sonic image of the sung sound (Bell 1878, 19). The strings of the piano could be compared with the eight tuning forks in Helmholtz's device, since every string is responsible for one partial of the spectrum.[57] By using many more than the eight tuning forks, employed by Helmholtz for reproducing vocal sounds, Bell expected to be able to reproduce sounds of higher quality and representational accuracy. Since using tuning forks would be expensive and impractical, Bell thought of using metal rods. He imagined such a device in 1874 and called it a *harp apparatus*. He describes the functioning of this apparatus as follows: "Utter a sound in the neighbourhood of the harp H, and

---

[57] A main difference between the piano and the device by Helmholtz is the many partials produced by a piano string as opposed to the single frequency tuning forks.



The harp apparatus consists of two identical devices, both containing a permanent magnet M. When a rod H of the left device is brought into motion by sound waves, the electromagnet E will cause an intermittent current which will be transmitted to the other electromagnet E'. The intermittent current should than bring the rods in vibration which have the same frequency (or a multiple of that frequency) as the intermittent current transmitted.

certain of the rods would be thrown into vibration with different amplitudes. At the other end of the circuit the corresponding rods of the other harp H' would vibrate with their proper relations of force, and the timbre of the sound would be reproduced" (Bell 1878, 19).

In my opinion this harp apparatus is a hybrid device between a musical instrument and a sound reproduction device. The sound (re)produced is no longer entirely shaped and emitted by the instrument itself, as would be the case with a conventional musical instrument. The tuning fork is still faintly present in the form of the rods, but all of them together perform the function of microphone (the first harp) and loudspeaker (the second harp). They are audibly functioning, transmitting a sound, yet the semantic act of sound creation is generated by something besides the rods themselves.[58] The border between the sound of the object itself and the sound of this object reproduced by another object is crossed with this apparatus, so that two different acts of sound production may simultaneously be heard, one of them being a strongly modified reproduction of the sound produced in front of one of the harps (a semantic act of sound production) and the other being the sound of the rods themselves (an act of sound production). The original sound is transformed by the sound identity of the rods themselves, and is therefore literally heard as a sounding through the rods. The harp apparatus was never developed by Bell and would probably not have functioned anyway,[59] but an impression of how a voice might be transmitted through a piano may be found in the piece *A Letter from Schoenberg* (1996) by Peter

---

[58] I have clarified, what I mean with the semantic act of sound creation in chapter 2.

[59] The harp apparatus would not have functioned, because an amplification between the "microphone" (the first harp H) and the "loudspeaker" (the second harp H") is missing. The electrical signal is therefore too small to bring the rods of harp H" in audible vibrations.

Ablinger*. For this piece, each of the different partials of the sound of a reading voice is assigned to one of the 88 keys of a piano by a computer. During the performance, the piano "reads" a letter by Arnold Schoenberg. When listening to the sound of this composition on the piano, what is heard is a complex and rapidly changing sound of many piano keys played together in groups or rapidly after each other. However, as soon as one reads the text while listening to the virtuoso piano music, the sound of the piano can be recognised as being a reproduction of the spoken text (see the video fragment of *A letter from Schoenberg*). This piece reveals the fragility of the border between perceiving abstract musical sounds, shaped and emitted by one and the same instrument (namely the piano), and sounds that are shaped by one object (in this case the human voice) and emitted by another (the piano). In this paradigm, the piano is situated between the *tuning fork principle* and the *tympanic principle*. The acts of sound creation within the piano result in two kinds of perception. First of all, they are connected to the piano, and the piano functions as a musical instrument. But, when reading the text while listening to the piano sounds, the resulting sound is recognised as referring to semantic acts of sound creation different from the sound of the piano itself, namely a human voice talking. The piano could thus be identified, according to the arguments made in chapter 2, as a sound reproduction device instead of a musical instrument.

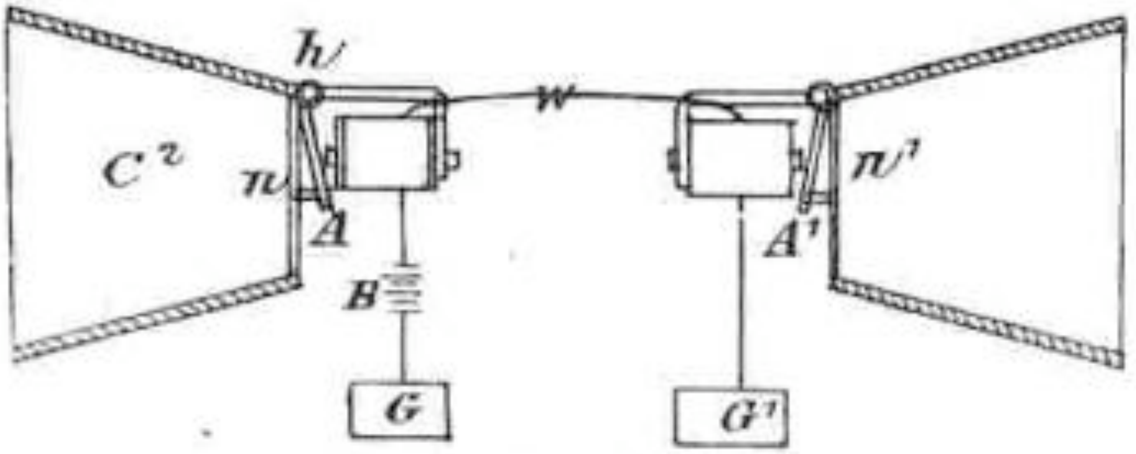
Alexander Bell: using symmetrical metal plates to reproduce sound

Bell himself began to search for a less complicated way of transmitting sounds, without the need for an endless amount of rods, inspired by the book *Wonders of Electricity* by Jean Baptiste Alexandre Baille, in which an acoustic telegraph is mentioned (Baille 1872, 140–143). What Baille describes could be called a flattened tuning fork, namely a steel plate. Bell exchanged the tuning forks in Helmholtz's device with such plates, and discovered that the combination of a metal plate and an electromagnet could reproduce not only a single pitch, but other partials of the spectrum too (Gorman 1994, no page numbers). With this discovery, Bell realised that a single plate was able to transmit a complex sound, containing several frequencies, eliminating the need for the many rods of the harp.

Bell's concept of transmitting sound evolved gradually from the tuning fork principle towards the tympanic principle. The many strings of the piano, the many tuning forks and rods of the harp, all resonating in response to a single frequency, are exchanged for a single membrane, able to vibrate, ideally, in response to all audible frequencies.[60] How this sound reproduction would

---

[60] Both the piano strings and the metal rods will be able to react also to frequencies that are related to their partials, since their spectrum contains more than a single frequency contrary to the spectrum of a tuning fork. The resonance will in general be the largest on the fundamental frequency and only the first two or three partials might resonate as well, so the number of resonance frequencies is still very limited compared to a membrane.



The device by Bell using single metal plates instead of many rods.

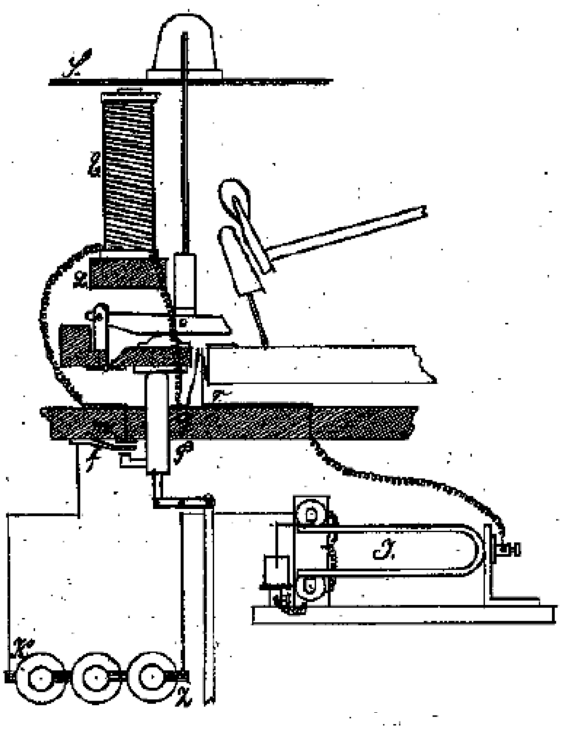
function is illustrated well by the picture above, once again a representation of a device which was never realised in this form. The elements for transmitting and receiving the sound waves of these two devices are designed by Bell to be exactly symmetrical. This reveals the paradigm of reproducing exactly the same sound as that which has been picked up. These symmetrical drawings seem to reinforce the following idea: if the receiver (later called microphone) vibrates in a certain way and the transmitter (later called loudspeaker) vibrates in exactly the same way, the sound is reproduced perfectly. The ideal microphone and loudspeakers for Bell vibrate in exact symmetry, in fact copying the movements of the prongs of a tuning fork, which also vibrate symmetrically in opposition. Looking at the construction of microphones and loudspeakers nowadays, it is clear that Bell's idea of symmetry was not the ideal technical implementation: modern microphones display a completely different construction than loudspeakers do, and tend to have, for example, much smaller diaphragms than loudspeakers. Picking up air pressure waves and emitting them are functions which require a different construction for optimal performance. Microphone diaphragms must vibrate in response to air pressure waves and should thus be very sensitive and light, reacting easily to every small fluctuation in the air pressure waves caused by sound sources in the space. Loudspeaker diaphragms, on the other hand, need to be able to produce air pressure waves, and their diaphragm should therefore react as minimally as possible to any other air pressure waves, emitted from other sound sources in the space. For this reason, early telephones as well as phonographs (see Thomas Edison's* phonograph patent (Edison 1878)) use two different diaphragms for the recording and the reproducing of sound. When using the "perfected" phonograph—as this device was called by Edison—which is known for recording and reproducing sound through the same horn, there are nonetheless two different diaphragms for these functions. That microphones and loudspeakers are mirrors of each other as suggested by Bell is demonstrated though by the frequent use of microphones as loudspeakers or loudspeakers as microphones in the less hi-fi-sound-oriented scene of experimental music. Nicolas Collins* describes some of these possibilities in the chapter "In/Out: Speaker as Microphone, Microphone as Speaker–The Symmetry of it All" (Collins 2009, 19–21). Obviously the reproduction qualities of these kinds of reversed technologies do not conform to the ideals demanded by the *reproducing* approach, but might be very fruitful for artistic explorations (see for example the performance by Lara Stanic, described in chapter 5).

Richard Eisenmann: an electric piano with tuning forks

The evolution from metal rods to metal plates is one of many stages in Bell's development of an early telephone.[61] The telephone is a tympanic device: the sound should be transmitted and not shaped by the device, since one wants to hear what the person at the other side of the line is saying. This sound reproduction technology was developed through the process of transforming the tuning fork principle into a tympanic one. The same process may be observed in the development of musical instruments which use electrical means for sound production, for example the electric piano between the 1880s and 1930s, beginning with the *elektrophonisches Klavier* invented by Richard Eisenmann*. His intention was to develop a new sound for grand pianos with the aid of electricity (Buß 1892, 92). The starting point this time is not scientific research, as was the case with the tuning fork experiments by Young and Helmholtz, but a musical instrument, namely the grand piano. The main element is a modified tuning fork current interrupter (see the tuning fork device by Helmholtz). Eisenmann used tuning forks and electromagnets to keep the strings of a piano sounding, or even to increase the sound level after the strings have been struck, which of course is impossible with an acoustical piano. In 1866 he patented an electromagnetic system for grand pianos and upright pianos which would prolong individual tones as well as generate sounds in imitation of other instruments (Eisenmann 1886). His patent description, as well as the various drawings, appear to describe nothing other than the Helmholtz tuning fork device; in this case, however, implementing a tuning fork-based current interrupter for every string of the piano which is intended to be kept in vibration.

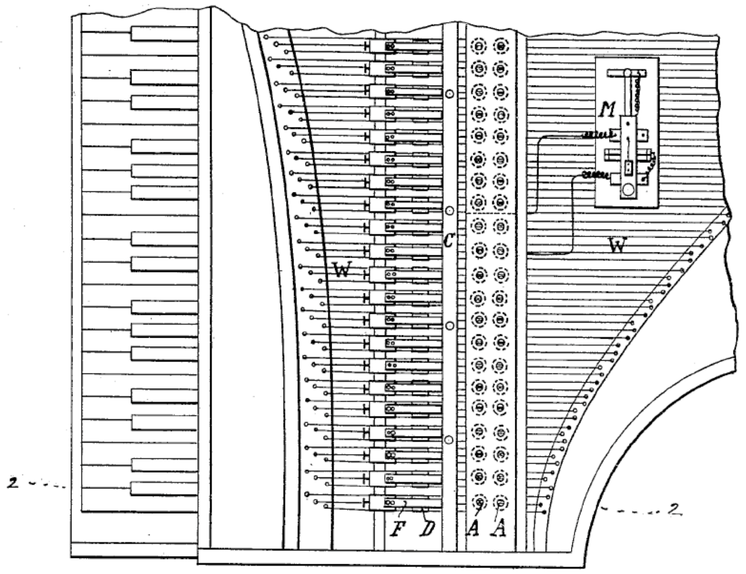
---

[61] The history of the invention of the telephone is actually much more complicated than the small steps I detail here and definitely should not be assigned to Bell alone. Names like Philipp Reis, Elisha Gray and Antonio Meucci should be mentioned, especially how the ideas about transporting sound "travelled" between these people and how patents and money played an important role as well. Since this is not part of my research and extensive literature on this subject has already been written, I will not write more about this. See for example the books *The Telephone and Its Several Inventors: a History* (Coe 1995), *The Telephone Patent Conspiracy of 1876: The Elisha Gray-Alexander Bell Controversy and Its Many Players* (Evenson 2000), chapter 3 of *Transforming Nature - Ethics, Invention and Discovery* (Gorman 1998).



As can be seen in this picture from the patent procured by Eisenmann, one of the prongs of the tuning fork has a wire connected to a small jar, probably filled with mercury, as in Helmholtz's original tuning fork interrupter.

This strong similarity to Helmholtz's tuning fork device is hardly astonishing since Eisenmann was working for Helmholtz at the institute for physics at the University of Berlin. Briefly, Eisenmann's piano works as follows: a tuning fork is placed next to a piano string with the same pitch. As soon as a key of the piano is struck, bringing the associated piano string into vibration by means of its attached hammer, the tuning fork will start to vibrate sympathetically along with the string. With the help of a tuning fork current interrupter, an intermittent current is produced, which is sent to an electromagnet placed close to the corresponding string. Instead of keeping the tuning fork in vibration, as in Helmholtz's device, the piano string is kept in vibration by the electromagnets. Eisenmann introduces a feedback loop here, since the tuning fork will resonate in sympathy with the piano string again, and in this way everything is kept in motion. By means of a pedal, the current may be disconnected, so that the piano string stops vibrating.



A picture from Eisenmann's second patent: The microphone *M*, picking up the sound of the strings *W*, controls the electric circuit, running through the electromagnets *A A*, which therefore attract the strings with the same undulations as with which the microphone moves. Each key of the piano closes the circuit of the electromagnet belonging to its string, so it is active when the key is pressed.

Although the actual sounding results of this electrophonic piano are reviewed very positively in a contemporary magazine, I doubt that this new technology functioned very well at the time.[62] Eisenmann soon patented a second version of the piano, this time using a microphone. Similar to Bell, he replaced the tuning fork, which was able to respond through sympathetic vibration to a single frequency, with a microphone which ideally can pick up all frequencies. His description of

---

[62] As it seems that only one electric circuit was used and the tuning fork interrupters were therefore all interrupting the same circuit, the result described above seems quite unrealistic. First of all, Helmholtz explains how difficult it is to mount the tuning fork at exactly the right height, so the wire enters and leaves the mercury with every vibration. Secondly, one must use a tuning fork with a low pitch, since the prongs need to make big movements. The prongs of a 120 Hz tuning fork oscillate several millimetres at the end and are therefore suitable for breaking and closing a current circuit through contact with mercury. Higher pitches would not be suitable for implementation in such a system, since the tuning forks would not be able to function as an interrupter. These features make it quite implausible that the piano was really able to sound as differentiated as mentioned above. It seems very unrealistic as well that every string had an electromagnet attached to it and a tuning fork at the same frequency. Most likely the system was implemented on some of the low strings of the piano.

what a microphone is able to do is very optimistic: "It is known that a microphone reproduces exactly all sounds which are produced in its neighborhood. It reproduces a whole opera, the voices of the singers and the sounds of each instrument" (Eisenmann 1893, 3). That the microphone did not solve all the problems for Eisenmann's electric piano is obvious, since the first commercially available electric piano was eventually developed only in the 1930s.

George Dieckmann: a piano string oscillator

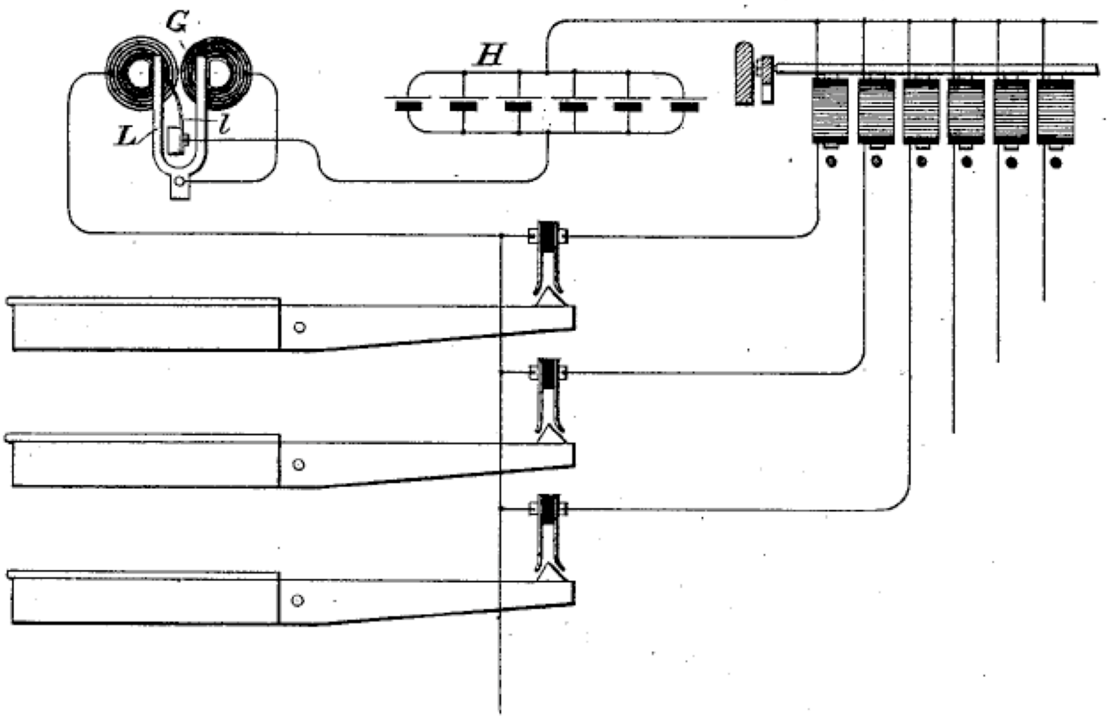
The quest for an electric piano continued, and the next example I explore was developed by George F. Dieckmann*, a German who had moved to New York. His system for keeping the strings of the piano in vibration is the closest to the tuning fork oscillator of all the systems I have discussed up to now. Dieckmann proposes here to cause the piano string to function as its own current interrupter. The vibrations of the piano string themselves open and close the connection to the current flow sent to the electromagnets. These electromagnets are placed close to the same string used for interrupting the current and keep this string in vibration, at the same frequency with which the string opens and closes the connection to the current flow (Dieckmann 1887, 3).[63]

There is no division here between sound-shaping and sound-emission, since the strings of the piano fulfil both functions, emitting sound similarly to the diaphragm of a loudspeaker while simultaneously functioning similarly to the diaphragm of a microphone by transducing the string vibration to the electromagnets.[64] There is no tympanic component, and the electrical component of the musical instrument is integrated into the instrument itself. No membrane is needed to pick up or generate air pressure waves, since the piano strings themselves pick up mechanical vibrations as well as generating them. Sound production in this electric piano thus works entirely according to the tuning fork principle, a technique which would soon become atypical in the production of musical sound with the help of electricity, as the next example will reveal.

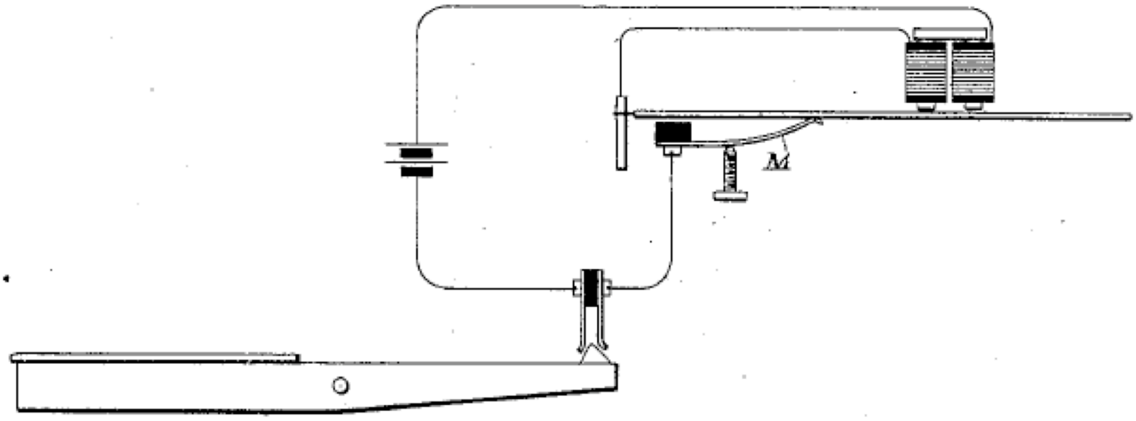
---

[63] Eisenmann shortly mentions the possibility of using a piano string as a current interrupter in his first patent, as well, but does not supply any further details (Eisenmann 1886, 1).

[64] Of course the resonant case of the piano influences the final sounding result as well, but this is not important for the feedback process.



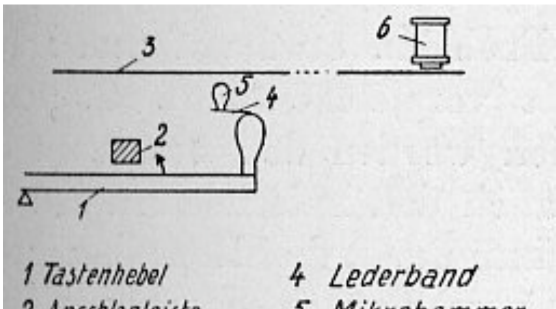
A scheme of the Dieckmann-system, showing the circuit-closing mechanisms on the keys, the general circuit breaker *G*, the tuning fork *L*, this time not with a jar of mercury but with a spring circuit breaker *l*, and the battery *H*.



The string serves as its own current interrupter in the Dieckmann-system.

Bechstein, Siemens and Nernst: a piano with a loudspeaker

Actually, one could say that in the Dieckmann-instrument the division between piano, on one hand, and microphone and loudspeaker, on the other, does not exist. It is one of the few instruments that could be called electric while functioning without the typical division for musical instruments using electricity between sound-shaping and sound-emission. The technology needed for this piano, which like the Eisenmann piano was never produced commercially, was also very fragile and difficult to install. The availability of better-quality loudspeakers in the 1920s was soon reflected in new developments involving electric pianos. A good example is the Bechstein-Siemens-Nernst-piano in 1931, better known under the name "Neo Bechstein". All three contributors to its development and name were experts on different terrains: the Bechstein company had experience in building excellent pianos since 1853, Siemens had patented one of the first loudspeakers in 1874, and Nernst was a professor at the same institute of physics at the University of Berlin where Helmholtz and Eisenmann had conducted their research.[65] The Neo Bechstein piano differs from the Eisenmann- and Dieckmann-instruments in being simply amplified rather than using a complicated feedback system. The strings are placed close to several electromagnets (one per five strings), which this time are used not to maintain the vibration of the strings, as in the Eisenmann- and Dieckmann-pianos, but as



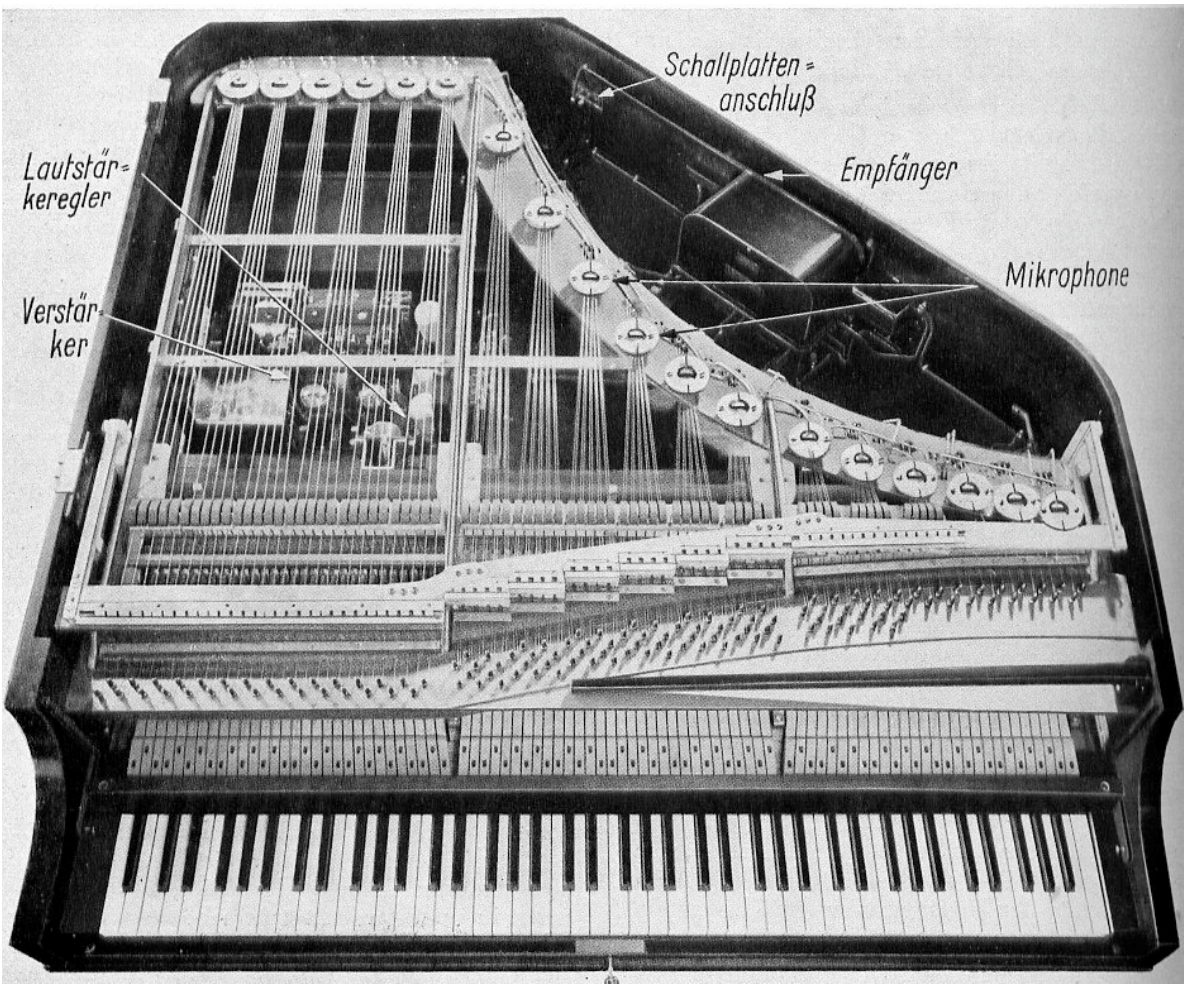
In the *Neo Bechstein* electromagnets (6) pick up the vibrations of the string (3) caused by hitting the piano key (1), which is connected to (4) a hammer (5).

---

[65] Although I did not find any evidential proof, probably the idea of the Neo Bechstein is still somehow related to the experiments by Eisenmann, performed forty years earlier at the same institution. The swell pedal, especially, which is present in both pianos to create crescendos after the attack, seems to reveal that it is a derivative of the same idea. The ideas of Helmholtz have been of great influence not only on the development of the electric piano, but as well on other electric musical instruments, such as the Telharmonium developed by Thaddeus Cahill in 1897 (Hagen 2010, 60).

microphones, converting the vibrations of the steel strings into electrical signals wich are transmitted to a large loudspeaker, whereas the acoustic (conventional) sound of the piano was made to be as soft as possible, using a special construction with very small hammers and without a soundboard.

Sound production by this instrument is based on the tympanic principle, and microphones and loudspeakers are integrated according to the *supporting* approach. The electromagnets pick up the vibrations of the strings, these are amplified by an amplifier, and a loudspeaker emits this sound. There is no longer a connection through sound waves between loudspeaker and microphone, creating an acoustic feedback circuit, and the mechanics of the piano are no longer



The core elements of the *Neo Bechstein*: an amplifier (*Verstärker*), a volume slider (*Lautstärkeregler*), a connection for a gramophone (*Schallplattenanschluß*), a radio (*Empfänger*) and electro-magnets (*Mikrophone*).

involved in a direct exchange with the electrical sound production, as was the case with the electric pianos previously discussed. The piano strings are nothing more than the suppliers of sound vibrations to a loudspeaker diaphragm, therefore shaping, but not emitting the sound, which should only be emitted by means of the loudspeaker. Contrary to the Eisenmann- and Dieckmann-pianos, there is thus a clear division between the musical instrument and the loudspeaker, which is treated as a device whose purpose is to make a certain sound audible,

The *Neo Bechstein* and its loudspeaker.

without revealing a characteristic sound of its own. As mentioned by Fritz Winckel, who collaborated on the development of the *Neo Bechstein*, the quality of loudspeakers needed to be good enough for them to function as a transparent sound emitter (Winckel 1931, 843).

The tympanic function of the loudspeaker used for the *Neo Bechstein* is underlined by the combination of the *supporting* and *reproducing* approach within this single instrument. Not only is the instrument amplified by the loudspeaker, but the *reproducing* approach is integrated into the instrument itself through the addition of a radio receiver as well as a connection to a record player to play records (Bechstein 1932, 19). One of the main reasons for these additions was, according to Bechstein, to bring the practice of music-making into the living room, as in the nineteenth century, when one was obliged to play a four-hand version of symphonies and operas in order to hear them at home. With this instrument, one could combine passively listening to music with actively playing the music itself, which, in his opinion, offered a deeper insight in the music. As he describes the use of this home entertainment system: "Now one can play for hours, day or night, without disturbing the neighbours: listening in between to the latest news, or allowing [the pianist, CvE] Lamond to play a sonata by Beethoven, and then immediately try to imitate him; each time the same sound is produced in the same way" (Bechstein 1932, 20).[66] This connection of musical instrument, radio and record player to the same device for sound emission, namely the loudspeaker, reveals that the latter is thought of not as contributing any characteristic sound of its own but as a device able to reproduce all kinds of sounds. As Bechstein claims in the citation mentioned above, the sound of the piano through the radio or the record player is the same sound as that of the piano: "each time the same sound is produced in the same way" (Bechstein 1932, 20). The sound caused by the vibrations of the piano strings is conceptualised in exactly the same way as the sound of a piano recording. All music-making in the home, whether a recording, a radio show or a piece played on the piano, sounds through one single sound-emission device: the loudspeaker.

Relating the tuning fork and tympanic principles to the four approaches

The developments described above constitute of course, only one of the possible focuses on the development of the first microphones and loudspeakers during the nineteenth century. I chose to focus on the role of the tuning fork—able to play only one single frequency—and microphones and loudspeakers, able to reproduce, ideally, every possible sound. Tuning forks, with their relatively heavy solid metal prongs, and microphones and loudspeakers with their thin and light

---

[66] My translation of: "Zoo kan men urenlang spelen op ieder moment van dag of nacht, zonder de buren te storen, intusschen gauw de laatste nieuwsberichten hooren, of zich door Lamond een sonate van Beethoven laten voorspelen, om dan meteen te probeeren, het hem na te doen: steeds ontstaat dezelfde klank op dezelfde wijze" (Bechstein 1932, 20).

diaphragms seem to fulfil completely different functions. As I demonstrated in this chapter, these two extremes came very close to each other in the nineteenth century, often being used to perform the same function in scientific devices or musical instruments. The tuning fork was often replaced by microphones and loudspeakers, used for picking up frequencies (the pianos of Eisenmann and Dieckmann) or for emitting frequencies (Helmholtz's tuning fork device). With the *Neo Bechstein*, a stage was reached in microphone and loudspeaker development in which microphones and loudspeakers functioned sufficiently well enough to be used for different approaches at the same time (*reproducing* and *supporting*).

The tuning fork principle also developed in another direction, and this resulted in the *generating* approach. Helmholtz tuning fork device for generating vowels could be seen as an early synthesiser. Pieces like Goeyvaerts' *Compositie Nummer 5 met zuivere tonen* [Dutch for *with pure tones*] as well as Stockhausen's *Studie II*, both using only sine waves for additive synthesis, could be seen as a direct descendents of the idea of developing sounds by adding the partials of a frequency spectrum. Since there is a clear division in these pieces between the device shaping the sound (sine wave generators) and that emitting the sound (loudspeakers), the *generating* approach could also be said to implement the tympanic principle for the emission of its sounds. The devices discussed in this chapter which used the tuning fork principle could therefore be regarded as predecessors of sine tone generators, as well as of microphones and loudspeakers.

Microphones and loudspeakers developed towards "neutral" and "inaudible" transducers of sound waves, and are therefore included in the tympanic principle. As I demonstrated at the beginning of this chapter, they are also able to function according to the tuning fork principle. This takes place during the phenomenon of producing acoustic feedback. I started this chapter with the idea of Ashley that feedback is the only sound intrinsic to electronic music (Holmes 2008, 185). At the end of this chapter, I must conclude, that much more variety in sound intrinsic to electronic music exists. Acoustic feedback seems to be an interesting starting point though for involving microphones and loudspeakers in the sound shaping process. In the next chapter, I take a look at what happens when artists use the microphone and loudspeaker according to the tuning fork principle and how composers, since 1950, started to apply this principle to *interact* (the fourth approach) with microphones and loudspeakers.