The Evolution of Sound Recording, Homemade Piezo Contact Microphones, and Electro-Acoustic Composition

Towards partial completion of a
M.Sc. in Sound Engineering and Audio Production
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School of Creative Technologies

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2024–2025

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Abstract

This paper, split into two parts, first explores the evolution of recording technology and its historical development while dissecting inner mechanisms of popular technology of certain eras, leading into its impact on contemporary studio practices. The history of sound recording is typically divided into four key eras: the Acoustic Era (1877–c.1920), the Electrical Era (c.1920–1945), the Magnetic Era (1945–1975), and the Digital Era (1975–present). The first section of the paper discusses the importance and construction of the inventions of the phonautograph and phonograph, marking the first attempts at sound reproduction. The Electrical Era saw significant advancements, including the invention of microphones and improved recording technologies, transitioning to a more electric-based system of transduction. The Magnetic Era brought the development of tape recording, multitrack recording, and enhanced microphones, changing the studio environment and musical creativity. The Digital Era introduced Digital Audio Workstations (DAWs), offering new possibilities for sound creation and editing, making professional-quality music production accessible to individuals.

The second part of the paper delves into the creation of homemade piezoelectric contact microphones, emphasizing their ability to capture acoustic vibrations in an attainable way. Finally, this paper discusses the process of creating the original composition written with the piezoelectric contact microphone and its mixing process in Dolby Atmos; this second half of this paper focuses on the practical aspect of contact microphone creation and revamping for sub bass woofer sounds. To conclude, the intersection of technology and creativity in sound design continues to transform media production, allowing for the exploration of new sonic territories,

and while impossible to predict with unwavering certainty, it is likely that this next era of sound recording is likely to be heavily impacted or hybrid-led by Artificial Intelligence in some form.

PART I
Setting the Stage: Amplification in Live Theatre as a Precursor to Sound Recording

Before getting into sound recording and reproduction, it is important to clarify its very early roots lie in the concerns of sound amplification, or the study of sound itself; this ancient area of study fascinated scholars across many different cultures and throughout centuries. Ancient Greeks are especially well known for their contributions to this area, with records as early as circa sixth century B.C.E. of Pythagoras' illustrations studying the vibrational plucking of strings. Ancient Greeks were also renowned for their deep understanding of acoustics in their construction of theatres, building their amphitheaters specifically for reflection and absorption for audience cognition, boosting the reception of sound using acoustic amplification techniques.[1] These techniques included specific arrangements of vases tuned to resonate with different notes of the Greek scales, and were strategically placed to enhance sound quality and reception (Montgomery, 1959).

Acoustic amplification was historically made up of both live foley artists and the construction of the theatre itself. During the Roman Empire, Heron of Alexandria invented an acoustic thunder machine using brass balls that would drop onto dried hides arranged like a kettledrum, along with developing a wind machine with fabric draped over a rotating wheel to mimic storm sounds during performances (Theatrical Sound Designers and Composers Association). This invention used the reverberation of small canals built into the theatre to simulate thunder during performances–a literal amplification of the narrative. As theatre traditions progressed all around the world, so did the accompanying art of live foley during these

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[1] The Greeks were masters at acoustic engineering, designing stage design, seating arrangement, resonance, and material considerations with the intention of naturally amplifying every auditory aspect up towards the audience.

performances, along with the invention of specific devices meant to portray specific sounds.[2] This is an early example of the idea that sound could be "reproduced," or replicated–not by a recording, but by mimicking certain noises in association with a narrative–that is an early example of the practice of foley. Fast forward to the early modern period, and we see sound is still a common fascination shared by many physicists and scientists. Phenomena such as the Principle of Resonance, (which Galileo called sympathetic vibration) the mathematical description of vibrating strings, (Mersenne's Laws) and a general influx of theories of waves phenomenon, including light and electromagnetism, continued to lay the foundation for the eventual discovery of the transcribing of sound waves, of then which led to the eventual development of sound reproduction technology (Morton, 2004).

The Four Eras of Sound Recording and Reproduction

The Acoustic Era (1877–c.1920)

With the Industrial Revolution begins the conception of inventions that have eventually led us into our current digital age. The first era of recorded sound, referred to as the Acoustic Era, began in 1877, though the start of recorded sound design can be attributed to the invention of the Phonautograph (1857) twenty years earlier by Frenchman Édouard-Léon Scott de Martinville. The device was intended to do for the ear what the camera did for the eye; it was a stenograph that transcribed amplitude envelopes and waveforms of speech in order to determine the frequency of a given musical pitch (Sir Ernest T. Fisk, 1948). In fact, it was not believed before the 1870s that the transcribed recordings (called phonautograms, hence the name) contained enough information about the waveforms that they could, in theory, actually recreate

[2] There are several examples of these "sound machines" or percussive instruments throughout different time periods and cultures used as foley. A significant one is the Wind Machine, also named the Aeliophone, which is a friction idiophone used for orchestral compositions and musical theater productions starting in the 17th century. These are examples of sound reproduction, a precursor to the idea of recording centuries later.

the sounds. Though this device wasn't invented with the intention of reproducing sound, it provided a vital first step into the creation of the audio recording field and opened a world of possibility.

With the invention of the first mechanical phonograph cylinder in 1877 by Thomas Edison, (the first practical sound recording and reproduction device) the opportunity of reproducing recorded sound began its journey into reality, even though the phonograph was, at the conception of its invention, "doomed to a period of silence…remain[ing] a toy and nothing more," for years (Scientific American, 1896). This phonograph made a mechanical record of sound, which featured a spiral groove on a flat disc; Edison later focused on a brass cylindrical design covered with tin foil, which was indented by a stylus attached to a vibrating diaphragm (Sir Ernest T. Fisk,1948). Though this did reproduce sound, and it was incredibly revolutionary, it was of poor quality.[3] Despite this limited sound, the phonograph still made its way into theatrical sound design, appearing in shows such as *Uncle Josh's Troubles in a Hotel* (1898) and *Chimmie and Maggie in Nickel Land* (1907) as a form of source music or sound, which can now be defined as Diegesis.[4] Though the phonograph was successfully incorporated, the poor quality of the recorded sounds was taken into consideration–the phonograph was also difficult to operate, and it took a high level of skill to successfully manage it. Circa 1930, the "scratchiness" of the recording was replaced with live foley crews, as a clearer, consistently loud sound was preferred to the difficulty of consistent reproduction with the emerging technology (TSDCA).

In 1885 came the invention of the Graphophone by Alexander Graham Bell, which included improvements upon Edison's phonograph by using a specific type of a sharp

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[3] The phonograph provided a service which had been unimaginable before 1877, and coincided with many modern inventions which were rapidly changing peoples' lives–the telephone, electric light, street car, the camera, the safety razor, etc.

[4] Diegetic music, or Source Music, is music in a narrative that is part of the fictional setting and so, presumably, is heard by the characters as well as the audience.

flat-fronted recording stylus to cut the record. Inspired by the preceding technology of both Bell and Edison, Emile Berliner developed the Gramophone in 1887, the most accurate mechanical reproduction of sound yet, and the device that became the most popular and well known by far. Berliner used a disc instead of a cylinder and a groove cut from side to side, (a lateral cut instead of Edison's vertical "hill and dale" cut) and the cylinder fell out of use, rapidly replaced by record disks.[5] It's worth noting that the gramophone was aimed for home entertainment, and was not capable of recording, nor was it intended to.

These early recordings were of low fidelity[6] and volume and captured only a narrow segment of the audible sound spectrum — typically only from around 250 Hz up to about 2,500 Hz — so musicians and engineers were forced to adapt to these sonic limitations. This led to a preference for naturally louder instruments (trumpets, trombones) and lower-register brass instruments (tuba, euphonium). The advent and adoption of electrical disc recording and radio in the early 1920s stimulated the development of better quality carbon microphones, which eventually led to the invention of the first compressor microphone due to its unstable nature.

The first world war also affected the rise in acoustic advancement, and discoveries made in the late 19th century aimed at advancing telephone technology proved invaluable to the war efforts. Scientists used the carbon microphone as a receiver in the context of ultrasonic wave detection, using a regular carbon microphone to receive the ultrasonic waves produced by their electrostatic transducer, which was designed to emit these waves. Once again, it was noted that the unstable nature of carbon provided poor and irregular results.[7] To counteract this, physicists

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[5] Morton, David L. Jr., 2004. Sound Recording: The Life Story of a Technology, pp. 18–20. Baltimore: Greenwood Press.
[6] Distorted audio with noticeable imperfections and skips; low audio quality.
[7] Unstable is perhaps a misnomer here. Carbon atoms are neutral, so when they are compressed, they produce very little energy–there are no opposing charges to move around—meaning less electrical current is produced to carry a signal. This is part of the reason why carbon microphones had such a weak signal and why alternatives were quickly sought, especially in crystals that contain polar bonds (i.e. quartz).

Ernest Rutherford and Paul Langevin used piezoelectric crystal plates to attempt to convert sound waves into electric waves. This was far from sonar, but is was used for underwater signalling,[8] and today, piezoelectric foils in contact microphones[9] use specialised ceramics with good results, a feat which owes its advancement to Rutherford's piezoelectric research.[10] As the field of acoustics grew, its impact on musicians and their audiences cannot be understated.

The Electrical Era (c.1920–1945)

The movement from the Acoustic Era to the Electrical Era can be considered a period of translation, as the thinking of solving the equation of recorded sound changed from mechanical writings to electric circuit diagrams–electric oscillations stenographed in the gramophone were translated into mathematical equations. Acoustic variables such as force, speed, displacement, mass, and elasticity were replaced by electric variables such as tension, current, charge, self-induction, and capacity. By the 1930s, these electric diagrams and systems had become mathematically identical representations of the acoustic systems, even in the case of representations of nonelectric systems; the new language of electro-acoustics had been born.[11]

The early days of the microphone stretch back to various inventors and rudimentary transmission from the Acoustic Era, particularly the invention of the telephone. The transduction[12] used in the first telephone consisted of generating electrical waves in a circuit by

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[8] Sending and receiving messages in water.

[9] A piezo disk essentially behaves as a capacitor that generates a voltage when exposed to vibration. Many musicians make their own piezo contact microphones today, as the disks are quite cheap (they are constructed out of crystals, usually or Rochelle salt, though not always). They are found in small electronics, such as lighters, watches, and even musical greeting cards. As opposed to carbon atoms, the molecular structure of quartz contains silicon and oxygen; (silicon dioxide) the former is more negatively charged and the latter more positively charged; they also contain a lack of atomic symmetry. This means that when compressed, the negative and positive charges shift in opposite directions, creating an electrical charge that can carry, or “translate” these acoustic waves into electrical signals.

[10] It’s important to note that Rutherford’s research was based on the brothers Curie’s work (c. 1880s) on using piezoelectric methods to measure electric charge and pressure.

[11] Wittje, R., 2013. The Electrical Imagination: Sound Analogies, Equivalent Circuits, and the Rise of Electroacoustics 1863–1939. Osiris [online], 28(1), pp.40–63.

[12] The conversion of acoustic sound waves in the air to electromagnetic waves, or pulses of electrical current.

using spoken air waves (using a sensitive mechanical device, like copper wires and liquid, conductive materials all connected together) to change the flow of electrons in a circuit. The second way to convert sound waves into electric waves was to generate a new current through electromagnetic transduction. These two transductions of sounds were the basis for the first microphone, and though this consisted of plenty of electrical static and noise, once the principle was established, scientists were quick to improve this technology (Morton, 2004).

Using this idea of transduction, the first microphone designs included "sound transmitters," with metallic strips resting on a membrane with a metal point contact to complete an electrical circuit, which eventually culminated in Edison refining the carbon granule microphone, resulting in the carbon-button transmitter in 1886.[13] However, the inherent instability problems of carbon granules provoked the search for better alternatives, and after decades of research, the first capacitor[14] microphone was developed. It wasn't until the early 1920s that precision stretched-diaphragm condenser microphones started to be manufactured, aided by the advent of electrical disk recording.[15] Thus, the carbon microphone became the precursor to the modern day condenser microphone.[16]

In 1928, Georg Neumann and Company introduced to the consumers market their condenser microphone, the bottle-shaped CMV3. In 1932, Shure released its first condenser microphone, the Model 42, and a mere two years later, Shure released an impressive eight

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[13] Early contributors of the microphone are German physicist Johann Philipp Reis (1834–1874), An American inventor Elisha Gray (1835–1901), David Edward Hughes (1831–1900), Thomas Edison, and Alexander Graham Bell. These inventors built models around the same time, refining diagrams and transmitters.

[14] Capacitor mics (Bell laboratories, 1917) were originally intended for use as a laboratory sound intensity measurement tool, though the technology was adopted for commercial condenser mics within the decade.

[15] Wittje, R., 2013. The Electrical Imagination: Sound Analogies, Equivalent Circuits, and the Rise of Electroacoustics 1863–1939. Osiris [online], 28(1), pp.40–63.

[16] A condenser microphone contains a large or small diaphragm (a thin membrane parallel to a metal plate) inside its capsule. When audio waves hit the diaphragm, it vibrates and produces a charge in the metal plate, which is then converted to an audio signal. As this signal isn't as strong as the output needed for further processing, the condenser microphone needs an in-board preamplifier to boost the signal.

models of condenser mics. A year later, they added three more.[17] Type A ribbon microphones were introduced in 1935, quickly becoming the BBC's radio microphone of choice, preferred over condenser microphones since they were not as susceptible to moisture. These ribbon microphones are still widely preferred today for ensemble recording as they are bi-directional, and as their inner capsule contains a metallic ribbon plate surrounded by opposite magnets, the sound it produces is characteristically warm and smooth (their natural high frequency roll-off naturally cuts out harsh tones).

While microphones were adept at capturing sound, there was still the matter of audio recording and reproduction. Starting around the beginning of the electric era, transcription disks were used to record the sound waves. These were extremely delicate commodities made of substrate and laminate; the former, which was the base, was coated with the laminate in which the audio grooves were cut with a stylus. One of the many issues with this technology was the laminate. It needed to be soft enough to etch into, and this same quality made it extremely fragile; each reproduction of the disk deteriorated the recording and created audible wear and tear. Combine this with the high cost of manufacturing, extensive care and cleaning upkeep, and the lack of editing capabilities, and the need for a better recording technology became immediately evident. This part of the current technology was still operating with the mechanical principles of the acoustic era, and even though acoustic signals were being converted into electric via microphones, the disks and styluses were a strong link to earlier acoustic technology that restricted editing or retakes.

This period was a time of rapid, simultaneous invention, a continuation of the rising culture of industries of the industrial revolution combined with the immense pressure of the

[17] The History of Condenser Microphones and Artifacts from the Shure Archives, 2021. [online]. Available at: https://www.shure.com/en-US/insights/the-history-of-condenser-microphones-and-artifacts-from-the-shure-archives. [Accessed 4 February 2025].

second World War. This intense consolidation of factors led to a push for a rapid rise in technological understanding, not only in the acoustics field, but everywhere.

The Magnetic Era (1945–1975)

These acoustic innovations and realities of the second World War had a huge impact on musicians and the studio as a workplace, and this impact changed the audio engineering and recording strategies of artists. Up until the 1940s, studio sessions were recorded in a few hours, and could easily yield a couple of songs with multi-microphone setups. These microphone setups weren't always optimal and true to the live experience; the Onyx sessions with the Parker Quintet is a famous example of the live audio engineering structures of the time.[18] Performances were structured more or less the same as they were live, with microphones set up around instruments and transcription disk recorder used. Great importance was placed on the musicality of the musicians as one shot takes were the studio standard due to the un-reusability of the expensive disks. With the invention of technologies such as tape recording, professional magnetic tape recorders, improved microphones, and multitrack recording, the recording studio changed from a functional worksite (where performances were recorded on the spot) to a collaborative workplace. This monumental technology not only changed studio culture, but invented entire genres and creative practices–the musical creative process now involved entire teams. Armed with this developing technology, engineers began to look at recording with a different end goal; faithfully reproducing a studio performance was not the end all be all anymore, instead, the idea that technology could create and distinguish distinctive artist sounds was born (Horning, 2000).

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[18] In 1948, Dean Benedetti, under the direction and instruction of the studio's management, was forced by executive management to set up his microphone right next to the drum kit, completely drowning out the rest of the live performance. This is an example of the developing studio practices of the time.

Perhaps the most key technological advance of this time was the magnetic tape recorder. The concept of sound waves traveling along wire was well established in the acoustic era, but due to the inefficiency of the surrounding technology (microphone and recording limitations) the concept wasn't yet usable in the recording studio. At its core, tape recording uses electromagnetic conduction[19] to convert an electrical audio signal into magnetism, which is used to realign the actual magnetic particles on a reel of recording tape. This creates a magnetic representation of the audio waveform–essentially a waveform transcription (electrical version of the mechanical phonautograph).[20] When recording, an audio signal (voltage) is sent to the record head, which is a temporary magnet (one for each track) which is then converted into lines of magnetic force on the tape which is being pulled past. During playback, the reverse is done, meaning the magnetic signal on the tape is then converted back to an electrical waveform, which is then sent to an audio interface for processing. The actual recording is the tape with the realigned magnetic particles that are permanently altered, and the degree to how well these new alignments retain their state depends on the strength of the voltage used. If the signal is too strong, it will over saturate,[21] and the tape will clip and distort. If the signal is too weak, signals may fail to magnetize clearly, resulting in affected waveforms that create harmonic distortion–yet another reason sound engineers became so vital. Controlling tape speed was also a vital aspect of the process, measured in IPS, or inches per second. For professional recording, most analog users settle at 15 IPS or 30 IPS. 30 IPS provides better high frequency response and audible dropout, but is more expensive due to needing more tape for the same tracks, as well as needing more

[19] Magnets and electricity are easily linked. Electromagnetism occurs when a conductor (like iron, for example) is placed in a changing magnetic field, which causes an electrical signal, or voltage, to flow along the conductor. This technology is used in speakers and microphones.

[20] Multitrack tape recorders do this independently for every track, which is part of the reason the early days of tape recording were so expensive (on top of each etch into the tape by electrical signals being permanent).

[21] Though this is technically an overload of signal, it can be left in to create that warm characteristic associated with analog, and the harmonic distortion from low signals similarly creates that nostalgic sound.

robust machinery to handle the speed reliability without dropouts. 15 IPS offers slightly better low-end response with a more manageable price tag. In continuation, and as with most analog formats, while the actual recording process was linear, the signal response on tape is not (in terms of frequency response). This is because correct playback requires equalization, as lower level signals are non-linear,[22] and too much saturation can cause new harmonic distortion.

By the end of the 1960s, these new studio practices had borne an expectation of sound associated with the artists publishing their music; techniques used to create uniquely identifiable sounds owed their existence to the studio as a creative, musical tool. The quality of recorded work had now exceeded live performances to such an extent that listeners were actually more likely to judge the live performance based on how closely it resembled the record, rather than the other way around (Horning, 2000).

While the magnetic tape was one of the most important inventions of the magnetic era (hence the name) it was not the only one. The 33/3 rpm long-playing (LP) microgroove album,[23] multi channel stereo-recording, improved microphones and a better understanding of room acoustics, as well as the introduction of more specialized roles, revolutionized the industry, and multi-track recording,[24] born of the magnetic tape, laid the framework for the construction of the Digital Audio Workstation.

The Digital Era (1975–present)

With the advent of the computer eventually came Digital Audio Workstations, or recording, editing, and mixing software that enables at home recording. With microphones,

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[22] Saturation occurs with stronger signals, which can be avoided by keeping sound levels from exceeding the saturation point (when audio is forced beyond the receiving equipment's capacity to handle the signal).
[23] The first microgroove LP record was released by Columbia Records in 1948, spinning at 33 1/3 revolutions per minute and holding about 23 minutes each side. This 12-inch LP quickly became the standard format for commercial recordings, laying the framework for the album.
[24] Developed circa 1950 with the magnetic tape recorder, this method involves recording parts separately with the intention of combining them later to create an entire song. This is done digitally today.

interfaces, cables, midi keyboards, and almost anything found in a professional studio more commercially available than ever before, the everyday person now has the ability to make reasonable quality music, and depending on their skill and musicianship, professional quality pieces. Computers have become studios in a box, and the individual can now professionally create their own work at home, and digital over analog has become the practical norm.

There are endless routes and diversions when discussing the digital medium and its construction from actual hardware to data processing; for the purposes of this paper, the subject matter will focus on a brief overview of computer audio processing, not the construction of computers, their background, or their complex circuitry.

Digital has been considered the opposite of tape for many reasons, one of them being that while tape recording is a linear medium, (in terms of the recording process itself, as the process requires the tape to by physically wound to the desired section) a computer's hard drive can access its stored data in milliseconds. This process, defined as direct and non-linear access, made tape editing (as a necessity) obsolete. The analog recording process is inherently two dimensional[25] in terms of its electrical waveforms, making any waveform valid–if one variable is not constant, say, the speed of the tape recorder, then this waveform is read as valid, indistinguishable from another (like a voltage error). Analog cannot detect these differences in signals, which means that by its very nature degredations cannot be separated from the tape, another characteristic of its sound – analog signal will always change over time.

Digital does not have these limitations, as the computer reads these signals as pure, unaltered, coded, numerical data – a matter of translation, an alternative way of reading the waveform, (which can be done in numerous ways) all of which essentially describes the

[25] This two dimensionality comes from the representation of the components of an electrical waveform used in analog production. The voltage in the signal changes with respect to time, so at whatever point you stop an analog recording, you can calculate the value of the recorded signal (linear recording process with an infinite resolution).

waveform numerically. Perhaps the most common format of this translation is the Analogue to Digital (A/D) converter found in interfaces and electronic devices in which the analog signal is translated into the binary[26] digital values of "0" and "1." By this process, the converter has given the variables in analog (voltage, time, currents, etc.) countable digital values, which are then quantized and coded. This binary system is, contrary to what may be a first look, very robust technical information–it leaves nothing up to interpretation, and they leave no room for distortion or deterioration of signals of the waveform. It either is or isn't. Related to this is slicing, or setting thresholds half-way between ideal levels for certain voltages. Any voltage above the threshold is a 1, and any below is a 0; this process rejects significant amounts of unwanted noise added to the signal.

The advantages of using a digital medium are limitless, and in its most practical format, a computer's robust processor and Random Access Memory (RAM) give us access to multitasking, an unsung hero of digital music production. The actual reproduction quality of a digital audio system is also the most independent of the medium we can use, depending only on the quality of materials used in the signal conversion process. This acoustic to electric to digital conversion allows infinite opportunities which are simply not possible with analog systems.

This isn't to say that analog technology isn't used today; that is far from the truth, though the process of solely, independently using analog technology and methods is incredibly rare. Analog mixers are very popular in studios, as are digital and hybrid mixers, and analog synthesizers,[27] the earliest form of synthesizers, are still frequently used. The difference is these

[26] In an arithmetic sense, the binary system is the simplest numbering scheme possible, 1 and 0. Binary thought is representative of either true or false statements.

[27] Analog synthesizers use analog circuits to generate electronic sound, offering a practical approach to musicians and composers. Certain vintage analog synthesizers also offer unique, irreplaceable characteristics, such as distortion, noise, natural and unpredictable variation, and drifting tuning; this usually creates warmth and a harmonic complexity that arises from a sort of improvised experience. Several plugins today mimic these sounds.

analog signals are almost always used with an end goal of conversion into a digital format (DAW) for editing, comping, online distribution and consumption.

While digital synthesizers emerged as a more stable, powerful, and cost-effective alternative, they didn't have the same level of waveform variation and warmth in tone. The use of analog synths in modern music production is largely dependent on your personal preference and the sound characteristics you're after.

It would be nearly impossible to list every single reason digital recording, in combination with the internet, has completely changed the playing field, and could easily be its own research topic. From music distribution services, to cheaper equipment, to access to the worlds' music library, the current musical landscape has been shaped by the endless opportunity evolving technology provides.

PART II

The PiezoElectric Contact Microphone

As a continuation of fascination in the field of recording and reproduction, I set out to create my own contact piezoelectric pickup microphone as a means to recreate, for my own compositional purposes and exploration, what early acoustic scientists long discovered through their work and experiments.

The disk itself came pre-made for under six dollars online; I ordered a 27 mm, 0.3 mm thick piezoelectric disk made of brass and ceramic. Its small and lightweight composition has a resonant frequency of 3.0~5.0+/- 0.5 KHz, with an impedance[28] of 300 ohms. I brought the disk

[28] Electrical impedance is described as the measure of total opposition that a circuit (or part of a circuit) presents to an electric current; impedance includes both resistance and reactance. Ohms are the unit of measurement assigned to impedance.

to the tech room here at Confetti London to solder the disk onto an XLR cable, which was made in the tech room specifically to attach to the contact microphone.[29]

To start, the XLR cable was cut to reveal the three inner conductor wires inside the rubber sheath (copper, red, and blue, figure a.). The paper insulation was removed and about a quarter inch of green sheath was added to the grounding wire as extra insulation; the conductor wires were then tinned at the tip to solder into the connector cups (figure b.). The cups are then assembled into the male connector.

At the other end of the cable, a similar process was repeated; about a quarter inch of rubber sheath was removed to reveal the three conductor wires, two of which (blue and copper) were twirled together inside the green insulation sheath. The red, or positive wire, was soldered onto the center of the ceramic plate (positive connection) and the blue and copper inside the green sheath were soldered onto the edge of the plate (negative charge).

The piezoelectric contact microphone is now live, (figure e.) and can be used for a variety of purposes with high levels of sensitivity when in physical contact with objects; creativity is limitless with the possibilities of turning almost anything into an instrument. With the proper tools, this process could be completed in as little as twenty minutes.

To use the disk, it can be plugged into an interface and set up in DAW configurations as a normal microphone. The material of the disk is naturally incredibly sensitive, and picks up the sound of anything it is attached to. By turning up the gain on the interface, you can establish how delicate the pickup of the disk will be; for capturing contact sounds, such as acoustic instruments or random noise, you can place regular tape on top of the disk to keep it in place, as the movement of the disk is also captured alongside the vibrations of the object it is on.

[29] Special thanks to Andy Jones at Confetti London who soldered the contact microphone and for his scientific explanations, as well as for allowing me to photograph the process. With the disk, you can turn almost anything into an instrument!

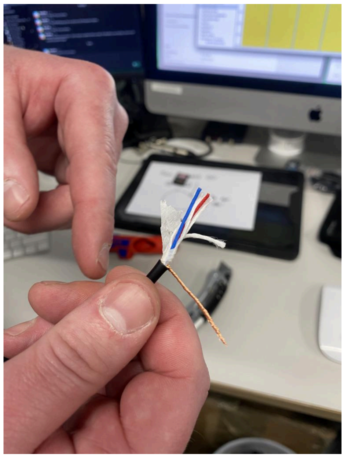

Figure a. The XLR cable has its rubber outer sheath cut to reveal the grounding cable (copper) and red and blue wires.

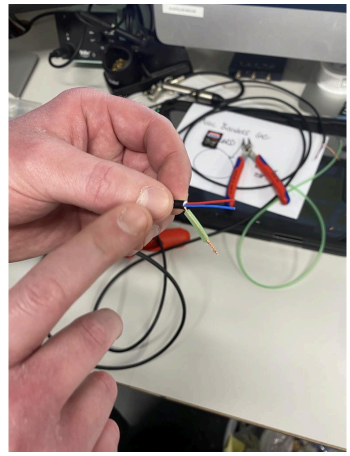

Figure b. The grounding cable is wrapped with insulation.

Figure c. The three conductor wires (already tinned with solder) are connected into the connector cups.

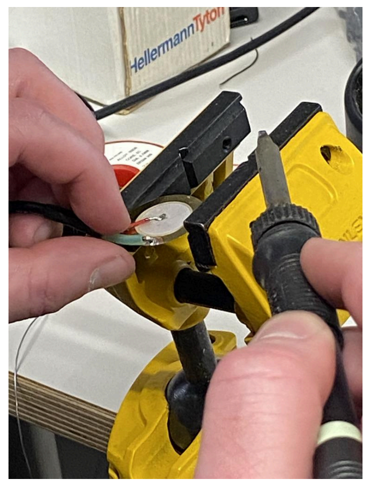

Figure d. The other end of the XLR cable is cut to reveal the conductor wires (not pictured). The red, or positive conductor wire, is soldered onto the positive ceramic plate close to center. The grounding and blue cable are twined together into a green insulation sheath and soldered to the outer ridge (negative).

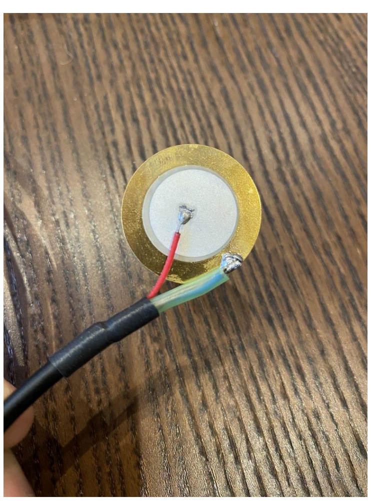

Figure e. The finished contact piezoelectric microphone.

The Electro-Acoustic Composition: A Description and Narrative Explanation

As a continuation of interest in the field of electronics and music composition, this project naturally evolved into a creative endeavor using the contact microphone and Ableton. By plugging the piezoelectric microphone into an interface, I was able to capture normal sounds of the surrounding room and modify them using plugins and audio effects to the aim of changing their recognizability completely. During this process, I found that the contact microphone worked superbly well when in direct, physical contact with practically any object; where it did falter was in its sensitivity to spoken sound, as without the physical contact the ceramic plate did not vibrate sufficiently to record as cleanly a sound as when it functions as a pickup (though it is completely able to record sound without contact, it is received weakly and to compensate the gain must be turned up significantly, which then in turn amplifies contact noise). Examples of recorded subjects in this piece are the rolling sounds of the studio chair, the clicking of the computer keyboard, dinging of my metal water bottle, a bit of vocals, lighting a match, pouring coffee, and playing the guitar. When used as a pickup microphone, it's able to produce a good, characteristic sound on an acoustic guitar (though slightly buzzed) as long as the device is taped directly to the surface of the guitar body. It's important to note that this microphone has significant latency, though that could perhaps be shortened with higher quality interfaces. When creating ambient sounds it's not noticeable, but during melodic elements and looping the latency becomes an issue to work around.

The piece itself is constructed in two parts, an A section and a B section, and it describes, overall, a rogue robot cowgirl from Earth built to be the first to survive long-term on a far off newly discovered planet in an unfamiliar solar system: the beginnings of extended planetary space exploration – The Wild West of Space. Here, our main character, the robot cowgirl, is traveling through space when something goes wrong on the aircraft carrier, and she becomes aware she will not be able to survive as planned. As her last act, (one of deep humanity) she picks up the guitar she insisted on bringing (robots do have musical inclinations in this universe, and perhaps in ours as well) and plays one last time as she looks out upon the planet she won't make it to. This melody, her guitar, voice, and continuation of random spacecraft nosies, narrates her final goodbye – perhaps in another follow up piece will come the happy (happier) ending.

The A section is mostly composed of errant sound design noises, meant to invoke a feeling of great space and zero gravity, a sort of randomness that only occurs with a sense of infinite aerial capacity – the auditory landscape is meant to define images of erratic metals clanging on each other inside a spacecraft as it makes its way through space. It must be noted that if this were a true non-gravity situation interpreted by a human astronaut, then the objects would make no sound discernible to the human ear without technological translation, as sound travels by vibrating molecules in air and cannot travel without a medium. So, for the purposes of this piece, a bit of imagination must be employed; the robot is able to "hear" these sporadic, clanging sounds in the air carrier by way of built in sonification processing, or reproducibility. Since space is full of waves that *can* travel without a medium (radio waves, plasma waves, magnetic waves, gravitational waves, shock waves, etc.) scientists have built devices that can record and process this information, and for the purposes of this imaginative narrative, our main character robot has a sort of a built in auditory processing device for sound translation purposes. Perhaps it can be referred to as a Robot Phonautograph?

The distortion is meant to create an uneasy feeling of disorientation and lack of clear footing – the sort of natural nervousness sprung from humanity being completely dependent on perfect technology to be able to survive the inherent dangers of the space exploration frontier.

The B section begins at the establishment of the melodic guitar line that is based around a D minor pentatonic scale (D, F, G, A, C, missing the ii° and the VI), though sections of this melody are heavily foreshadowed in the A section; the phrase is a question, and leading into the guitar melody we get the sense of an answer by starting on the “tonic” center, or D. The guitar is purposefully a bit off kilter and imperfect, and has been dressed up with plugins to “stratify” the acoustic guitar sound into something with more bite and edge – something to better illustrate the early robot end. This B section combines earlier sounds we heard with her final melodic goodbye, phrasing that remains primarily in the D minor pentatonic scale.

With our robot heroine singing her final song, I open the discussion to predictions of the future of music in our ever changing landscape, one that could, one day, be as changed as a different planet entirely. Though there might not be a happy ending in this piece, for future musical endeavors written in this universe I would look to create a positive and hopeful resolution at the end of the entire narrative, as hope is a vital (and perhaps the most important) ingredient for any pioneers on any new frontier.

Revamping to Create a Subwoofer Bass

In order to create a subwoofer bass sound out of the recordings, I firstly took the original sound (the sound of a chair rolling around on wooden studio floors) and sampled and stretched it; I used free plugins to create reverb and distortion (Ableton stock, Valhalla, and Airwindows) while also transcribing the noise downwards. Once this was done, I soloed the sound and recorded under it to resample it, distorting it even further to add odd, unpredictable complexities and clicks, a digital version of analog tape splicing and cutting.

To begin the revamp process, we began by patching the live room (Confetti x207) to the studio next door (x210), in which we placed two 414 condenser microphones – one to capture the room sound, the other in front of a bass amp (figures e and f).[30] This is the only point during the construction of this piece where a microphone other than the piezoelectric disk was used (it would not have been possible to revamp the bass sound with only one piezoelectric microphone, so we opted to use condenser microphones as a matter of practicality). A snare from a drum kit was placed next to the bass amp to add interesting texture via errant rattling, another sound which could be further resampled for textural purposes. We used a reamp box to expand the signal from the disk, and then added a third microphone directly in front of the bass amp; the signal was patched back into the live room to adjust as necessary, and we used Pro Tools to record and later export the stems. Once the signal flow was steady and established, we were able to adjust the pitches of the drawn out sub sound (via the built in laptop midi keyboard) to add more dimension and texture, creating an entirely new and unique sub bass sound. Excitingly, the process of revamping offers unlimited potential in the creation of new sounds, aural modifications, and resampling, and can be a completely unique way to create randomized textures and colors for a piece. The idea for this sound was to create an unsettling low frequency sub bass that operated at a level that was easily felt, not just heard, while listening to the piece – an unsettling echo fit for deep space, information that can be physically processed, but perhaps not in such a typical auditory fashion.

Mixing in Dolby Atmos

Once the piece was mixed in Ableton, I was able to mix the song in the Live Room specifically using Dolby Atmos, which is a surround sound technology that adds height channels that are interpreted as three-dimensional objects with neither horizontal nor vertical limitations. In this specific context, a 9.1.4, there were nine speakers at standing height around the room, one

[30] Special thank you to Olly Shelton at Confetti London for helping me figure out how to resample and revamp these samples!

Figure e. The two microphones in front of the bass amp, along with the reamp box and snare drum.

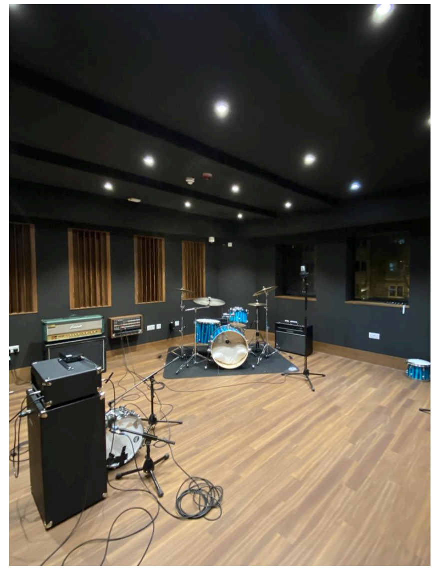

Figure f. The room overall set up, along with the room capture microphone.

sub bass woofer, and four speakers on the ceiling. Essentially, it creates an extremely heightened sensation of the components of a piece of sound, effectively placing the listener more into the music than ever before. Since this is an electro-acoustic, and essentially narrative piece, the final mix and master in Dolby Atmos seemed not only appropriate, but a special way to communicate the narrative of the piece.

The process of mixing in Dolby Atmos began after the final mix had been done and each track was mixed to taste. Once that was done, stems were imported into Pro Tools and set up for Atmos. I separated first the background design sounds and clangs from bass and melodic phrases, putting the bass first into the subwoofer (where it stayed during the entire piece). After reorganizing the tracks into groups and relabeling, I was able to think about where to "throw" each sound and when. To start, I ensured all the correct settings were in place inside of Pro Tools (Playback engine on Dante Virtual SoundCard instead of HDX, making sure interleaved is on, I/O setup set to 9.1.4 stereo out 15-16, etc.) and then was able to click the small fader button next on the output to record which speaker I wanted to send each sound to and when (after making sure touch, and not read, was on under the track name). I redid each sound until I was satisfied with which speaker played each sound when, and then made sure to save as I went along. To create reverb, I created a separate track with different folders underneath it (height, right, and left) and routed the sends of the specific channels that needed more reverb to that output.

While mixing, I was able to create more depth and space in the piece by adding more reverb, limiters in a couple of weak spots, and automation within each track (figure g and h). This process of mixing was incredibly rewarding, and although it was repetitive, I found it made a significant difference in my own perception. Mixing in Dolby Atmos is a very worthwhile endeavor that's worth the steep learning curve, and would encourage anyone with access to any Atmos facilities to take full advantage.

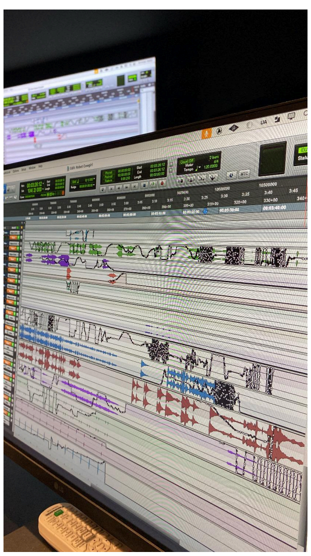

Figure g. Automation in touch mode in Pro Tools; this figure shows to which speaker and when each sound in each track is moving.

Figure h. Movement in Atmos, as well as varying size changes of different height channels.

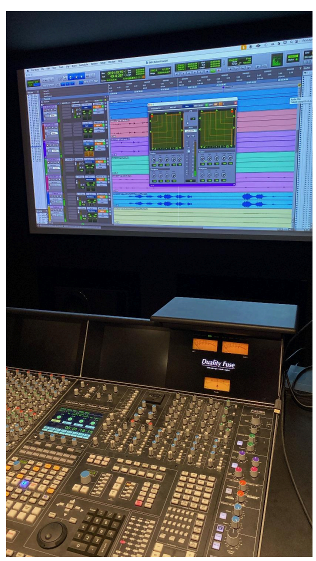

Figure l. This controller shows the headphones option, recently programmed to enable binaural mixing during the same Atmos session to export different mixes: ADM, binaural, and stereo.

As part of the mixing process, I also created a binaural mix by choosing whether to send certain sounds Near, Mid, or Far away. I also created a stereo mix; both files were easily created in the bounce files section of Pro Tools when it was time to export the mixes.

A Brief Prediction on the Next Era via Composition: (Present – Future?)

The concern, or potential excitement, about artificial intelligence in the creative space is not a new one, though the specificities of today's technological engineering were not spelled out or predicted to the precise letter. In fact, as far back as 1952 we can see artists and engineers concerned about the impact of emerging technology on the originality of the artistic process:

> *"In 1952, Newsweek magazine profiled the work of Columbia and Victor recording engineers. The 'Men Behind the Microphones' whose 'engineering cleverness', along with the technological revolution of the previous five years had introduced a 'new medium' in which both the listener and the recording engineer gained more control over the music, had vastly improved the sound of records (Anonymous, 1952). According to the article, some of the 'tricks' of the trade included: careful placement of microphones, considered in some large recording companies to be proprietary information; the use of controlled reverberation by means of parabolic reflectors, stairwells, and other chambers; the technique of boosting high frequencies, a form of deliberate distortion of the sound in order to mask the needle hiss that becomes audible at high frequencies; and cutting and splicing taped performances to achieve a 'composite' performance. The article ended with a prescient observation that the recording engineer 'could take over the recording industry and dispense entirely with the musician .... But today's crop of record engineers ... are far too appreciative of the human beauty of music to betray art to a robot' (Anonymous,*

1952: 59)."

(Horning, 2004).

Of course, this is not identical to the presence of artificial intelligence today, and it seems likely to be a part of the human condition to be wary of new technological developments (hesitation during the millennium at the dawn of the internet, cell phones, etc.). While the concern for artist integrity amongst advancing technology isn't a new one, never before have we experienced such direct and specific concern for the integrity of the process of creation as we have today – stolen artwork, fakes, poorly constructed images and pictures so perfectly articulated they seem to be irrefutably real. With AI producing songs in seconds, this shifting musical landscape (which has always been a part of the human narrative) has shifted the focus from quality to quantity and from human to computer. Along with the creation of songs, there are AI mixing and mastering services, yet more competition for the studio engineer (or competitive edge, depending on the perspective).

Though neither this paper or musical piece explore AI, what it is meant to discuss is the idea of a guess at the jagged musical frontier by painting an extreme example of a robot cowgirl in deep space. With the tradition of the periodization of history (though we understand things are not necessarily always linear) it is of human nature to speculate what might come next, especially during a time of high invention and ever-evolving digital instruments. This piece is my best prediction, and thereby musical interpretation, of what the jagged AI frontier[31] could look like in a musical context: the intersection of AI, robots, and humanity in space told through a musical narrative. As AI capabilities overlap and merge more with those of humans, the integration of human work with AI poses new fundamental challenges and opportunities, in

[31] This idea comes from an experimental study dissecting the effects of AI on worker quality and productivity and the intersection and collaboration of human and AI relationships.

particular in knowledge-intensive domains (Dell'Acqua et al., 2023). It seems AI can certainly be used to streamline repetitive or tedious processes, a capability which can certainly aid the artist with their time management, as well as serve as a drawing board or quick aid; it can also produce artwork (its quality is up for debate and requires another paper entirely) that makes the artists' work less immediately relevant, depending on whom you ask and what is it used for. While the overall effects of artificial intelligence in music creation software have yet to play out in their entirety, (as they are still mostly at their inception, and even the term AI didn't really rise in popularity until about 2023) there are limitless possibilities and avenues for both concern and optimism. Only time (and musicians) will tell.

Conclusion

Overall, the life story of sound recording technology reflects a dynamic interplay between technological advancements and the creative practices of its users and teams. This has led to infinitely complex and profound changes in the music industry, cultural production, and the division of labor in a studio and created a specific creative culture completely unique to music studios. While predicting the future is impossible, it's a rational guess to assume the next big technological wave both inside and outside of the music studio will involve artificial intelligence.

As we are still in the "Wild West," of the AI era it is possible we will have to be, from several different contexts, mindful stewards of our own technological development, (as has always been the case) though AI is not the only route of new recording technology or production. This new frontier will have to be explored and developed, one range at a time, by creatives and cowgirls.

Works Cited

Analog-to-Digital Converters (ADC) - Basics, 2019. [YouTube]. iMooX at. 10 November. Available at: https://www.youtube.com/watch?v=0y8AD8maAHo. [Accessed 21 of February 2025].

Audio Concepts 107: Analog Tape Recording - 3. Physics of Tape, 2019. [YouTube]. macProVideoDotCom. 19 June. Available at: https://www.youtube.com/watch?v=5W8NCLM6s88. [Accessed 20 of February 2025].

Audio Saturation: What it is & How it can Improve Your Mix. *emastered.com* [online]. Available at: https://emastered.com/blog/audio-saturation. [Accessed 10 February 2025].
Fitzwater, Aleah, 2024. The History of the DAW - How Music Production Went Digital. *Soundtrap* [online]. Available at: https://www.soundtrap.com/content/blog/the-history-of-the-daw. [Accessed 14 February 2025].

Dell'Acqua, Fabrizio, et al., 2023. Navigating the jagged technological frontier: Field experimental evidence of the effects of AI on knowledge worker productivity and quality. *SSRN Electronic Journal* [online], DOI: https://doi.org/10.2139/ssrn.4573321. [Accessed 20 March 2025].

Electric Transcription Disks. *The Audio Archive* [online blog]. Available at: https://www.theaudioarchive.com/TAA_Resources_Disc_Transcription.htm. [Accessed 12 of February 2025].

Elson, Arthur, 1921. Architectural Acoustics. *The Musical Quarterly* [online], 7(4), pp.469–482. DOI:https://doi.org/10.2307/738182. [Accessed 10 January 2025]

Fisk, E.T., 1948. The Development of Sound Recording and Reproduction. *Journal of the Royal Society of Arts* [online], 96 (4760), pp.105–120. DOI:https://doi.org/10.2307/41363534. [Accessed 12 February 2025].

Godfried-Willem Raes. *Piezo disk contact microphones: problems and solutions* [online]. Available at: https://www.logosfoundation.org/g_texts/Orfeus/preamps/piezo_disks.pdf [Accessed 5 February 2025].

Hareendran, T.K., 2020. Piezo Ceramic Discs – Some Practical Thoughts. *Codfrey* [online blog]. Available at: https://www.codrey.com/electronics/piezo-ceramic-discs-practical-thoughts/. [Accessed 5 February 2025].

History of Sound in Theatre, 2014. *Theatrical Sound Designers and Composers Association,* [online]. Available at: https://tsdca.org/history/. [Accessed 20 January 2025].

Homemade Piezo Mic, 2017. [YouTube]. 12 June. Available at: https://www.youtube.com/watch?v=3jduFLhjft0. [Accessed 10 of February 2025].

Horning, Susan S., 2004. Engineering the Performance: Recording Engineers, Tacit Knowledge and the Art of Controlling Sound. *Social Studies of Science* [online] 34(5), pp.703–731. DOI:https://doi.org/10.2307/4144358.

Jackson, George, 2023. What is Electromagnetic Conduction? *Physics Netowork* [online blog], 17 May. Available at: https://physics-network.org/what-is-electromagnetic-conduction/. [Accessed 12 of February 2025].

Jenkins, Amanda, 2019. Inside the Archival Box: The First Long-Playing Disc. *Library of Congress Blogs: Now See Hear! National Audio-Visual Conservation Center* [online blog], April 13, 2019. Available at: https://blogs.loc.gov/now-see-hear/2019/04/inside-the-archival-box-the-first-long-playing-disc/. [Accessed 25 of February 2025].

Mellor, David, 2006. The principle of operation of a capacitor (condenser) microphone. *Adventures in Audio with Audio Masterclass* [online blog]. Available at: https://www.audiomasterclass.com/blog/the-principle-of-operation-of-a-capacitor-condenser-microphone. [Accessed 13 February 2025].

Millard, Andre, 2005. *America on Record: A History of Recorded Sound.* Second Edition. New York: Cambridge University Press.

Montgomery, 1959. Amplification and High Fidelity in the Greek Theater. *The Classical Journal* [online], 54(6), pp.242–245. DOI:https://doi.org/10.2307/3294133. [Accessed 10 January 2025]

Morton, David L. Jr., 2004. *Sound Recording: The Life Story of a Technology.* Baltimore: Greenwood Press.

Piezoelectricity - why hitting crystals makes electricity, 2016. [YouTube]. Steve Mould. 16 May. Available at: https://www.youtube.com/watch?v=wcJXA8IqYl8&t=470s. [Accessed 18 of February 2025].

Pretto N., Fantozzi, C., Micheloni, E., Burini, V. and Canazza, S., 2018. Computing Methodologies Supporting the Preservation of Electroacoustic Music from Analog Magnetic

Tape. *Computer Music Journal* [online], 42(4), pp.59–74. DOI: https://doi.org/10.2307/26777148. [Accessed 2 February 2025].

Remnick, David, 2024 . *Holding the Note: Profiles in Popular Music.* New York: Penguin Random House Vintage.

Robjohns, H., 2006. *A brief history of microphones* [online pdf]. [Accessed 9 February 2025].

Schock, B., 2024. The 3 microphone types compared in different use cases. *Higher Hz.* [online] Available at: https://higherhz.com/microphone-types-comparison/ [Accessed 4 February 2025].

Scrivens, Andrew, 2023. The Role of Analog Gear in Modern Music Production. *Andrew Scrivens Music Gear, Live, Studio and Lessons* [online]. Available at: https://andrewscrivens.com/analog-music-production. [Accessed 14 February 2025].

The Difference Between Large-Diaphragm and Small-Diaphragm Condenser Microphones, 2022. *Rode* [online]. Available at: https://rode.com/en/about/news-info/the-difference-between-large-diaphragm-and-small-diaphragm-condenser-microphones. [Accessed 4 February 2025].

The Evolution of Music Production Recording in Studio Over the Years, 2024. *Finchley Production Studio* [online]. Available at: https://www.finchley.co.uk/finchley-learning/the-evolution-of-music-production-recording-in-studio-over-the-years. [Accessed 4 February 2025].

The History of Condenser Microphones and Artifacts from the Shure Archives, 2021. [online] Available at: https://www.shure.com/en-US/insights/the-history-of-condenser-microphones-and-artifacts-from-the-shure-archives. [Accessed 4 February 2025].

The Phonograph, 1896. *Scientific American* [online], 75(4), pp.65–66. DOI: https://doi.org/10.2307/26119791 [Accessed 12 February 2025].

Turn Nearly Anything Into an Instrument, 2017. *Instructables* [online]. Available at: https://www.instructables.com/Turn-Nearly-Anything-Into-an-Instrument/ [Accessed 3 Mar. 2025]. [Accessed 4 February 2025].

Watkinson, John, 2002. *An Introduction to Digital Audio.* Second Edition. Massachusetts: Focal Press.

What Does Computer Memory (RAM) Do?, 2022. *Crucial.com* [online] Available at: https://www.crucial.com/articles/about-memory/support-what-does-computer-memory-do. [Accessed 20 February 2025].

What Is Dolby Atmos?, 2022. [YouTube]. Sweetwater. 2 January. Available at: https://www.youtube.com/watch?v=gQvqGO814IE. [Accessed 28 of February 2025].

Wind Machine / Aeliophone, 2013. [YouTube]. theatrecrafts. 8 February. Available at: https://www.youtube.com/watch?v=pmYoAmFcD3o. [Accessed 9 January 2025].

Wittje, R., 2013. The Electrical Imagination: Sound Analogies, Equivalent Circuits, and the Rise of Electroacoustics 1863–1939. *Osiris* [online], 28(1), pp.40–63. DOI:https://doi.org/10.1086/671362. [Accessed 13 February 2025].

Zach Poff, 2024. Building A Simple Durable Contact Microphone. *Zachpoff.com* [online]. Available at: https://zachpoff.com/resources/building-contact-mics/. [Accessed 4 February 2025].