Spectral Analysis and Comparison of Analog and Digital Recordings

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A Spectral Analysis and Comparison of Analog and Digital Recordings

by

Hannah Frosch

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A Spectral Analysis of Analog and Digital Recordings

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Abstract:

The music industry is constantly shifting and changing as new developments emerge. The biggest transition still discussed to this day is the shift from analog to digital. The digital world of media has opened many doors and created a simpler way of making and consuming media. However, the desire for a vintage/analog sound environment has grown increasingly popular over the years. The main research question I will be addressing in this thesis is: How do analog and digital recordings compare at a signal level? I will attempt to answer this research question through analyzing different audio signals. To do so, two separate recordings, one digital and one analog, will be obtained simultaneously through the same microphones. Those two recordings will be put through an analyzing program and compared. There is much research on both analog and digital, especially from the consumerism side of the industry. However, not much of that research attempts to discover and discuss the differences at a spectral or signal level. This research will offer a new way of looking at the comparison between analog and digital audio. By doing such research, I will be able to examine and make unique conclusions on the differences between the two.

Key Words: analog technology, digital technology, SpectraFoo, analysis, music industry, recording, audio
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Dedication

Mom, Dad, and Ashley

Thank you for pushing me to complete this project.

Your constant support has contributed to all of my accomplishments thus far.
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Introduction:

The music industry has been greatly transformed by technological advancements. Methods and practices for creating music are regularly shifting to keep up with the newest or trendiest forms of technology. There is a clear divide between digital and analog, but a majority of the time the two are used cohesively to achieve the desired outcome. Analog signals are represented by a continuous waveform, whereas digital audio is represented in a more structured form. This can be seen in the image (Figure 1) from Dave Gans’ (2015) article, Analog vs Digital Audio: An Overview.

The ability to use the two together provides an interesting dynamic of merging the old with the new. There is a possibility that an analog signal may be altered or affected by the use of digital technology, which is something that can be analyzed, using modern, digital tools.

Analog recording was originally introduced through the inventions of Thomas Edison’s phonograph and Emile Berliner’s gramophone in the late nineteenth century (Rumsey & McCormick, 2009, p. 168), thus beginning an ongoing competition to invent the best machine for capturing sound. Both had their positives and negatives, but the push to create the next best
product led to the introduction of more practical means of recording sound. For example, the creation of magnetic tape brought about many advancements such as multitrack recording in the audio field. To successfully record on magnetic tape, one must “convert an electrical audio signal into a magnetic form” (Rumsey & McCormick, 2009, p. 171). Due to the process of analog recording, some believe analog recording to be more “pure” when compared to the methods of capturing sound digitally. Analog technology has had a substantial growth in popularity over the past few years. For example, the resurgence of vinyl has created this desire to explore the technology of the past. Some authors argue that vinyl has given some antiquated technologies new life, stating:

“…the revival of vinyl as a format of choice for both young and old music enthusiasts in an era of digital streaming is intriguing as it represents a confounding retro-technology—an old and often displaced technology that regains a new lease of life to become part of nearly invisible everyday-life” (Sarpong, Dong, & Appiah p.109).

Technology that was once seen as antiquated or lacking innovation is now seen as trendy and desirable. When CDs hit the market, vinyl sales decreased by 33% and 15% in market share (Sarpong, Dong, & Appiah p. 112). Vinyl was quickly left behind as the CD grew in popularity and eventually became the norm. A similar trend can be seen in the modern music industry as CD sales decline giving way to another technological feat: online streaming and digital music. This presents a never-ending cycle of the new overtaking the old. However, vinyl has made a huge comeback despite that cycle and the rise in popularity of digital technology. In 2013, the industry saw a 101% increase in vinyl sales from the previous year (Sarping, Dong, & Appiah p. 112). This rapid increase in sales has led to the growth of analog technology. Many audiophiles and even just average consumers seek that authentic analog vibe that is just not present with
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digital technology. Vinyl records are definitely a huge factor in the newfound interest in analog technology.

As evidence above, the entertainment industry as a whole is influenced by constant shifts and trends in technology. To remain competitive, one must discover how to utilize these different trends. The reemergence of analog technology, especially in the music industry, is a very interesting trend. This shift has left many unanswered questions, dividing those who advocate for digital and those who want to preserve analog, with little research supporting or comparatively analyzing the opposing forms of technology. There is a clear divide between digital versus analog advocates. This thesis will examine both analog and digital recordings with the hopes of discovering more details about the relationship between the two.
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**Literature Review:**

The music industry has gone through many changes and progressions over time. The transition from analog to digital audio has forever changed the way music is created and even distributed. The ability to create commercial ready content independently has never been easier. According to John Watkins (2002), digital technology has opened so many different doors that were just not an option with analog technology (p. 1). Similarly, Ken C. Pohlmann (2011) states that “digital audio entails entirely new concepts and techniques, distinct from those employed in analog technology” (p. 16). Digital audio is able to keep up with the ever-changing music industry, making it the industry standard. With that being said, analog audio has had a recent growth in popularity, bringing it back to the forefront of the industry.

Digital audio can be described as a “series of numbers to represent analog voltages” (Winer, 2012, p. 233). A digital signal is a set of data that can be represented by actual numbers, which can be stored digitally and accessed later (p. 233). Simply put, digital audio can be seen as a set of numbers that can easily be modified. Also, digital audio is based on the binary number system. The binary number system is a unique system that was created by Gottfried Wilhelm von Leibnitz in 1679 (Pohlmann, 2011, p. 6). It allows information to be processed quickly and efficiently. Pohlmann (2011) explains that “from a machine standpoint, a binary system is ruthlessly efficient, and it is fast. Imagine how quickly we can turn a switch on and off; that speed represents the rate at which we can process information” (p. 6). Considering how quickly binary information can be processed, it is no surprise that it is used in digital systems. Digital audio is presented in many different formats. One of the main categories of digital audio compression formats is lossy. John Watkinson (2002) describes compression simply as “bit rate reduction and data reduction” (p. 157). Lossy compression attempts to reduce the amount of data
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without eliminating important parts. By using perceptive codes, lossy formats find the import
sounds that should not be eliminated or shrunk in attempts to be as close to the original sound as
possible (Kefauver & Patschke, 2007, p. 65). By eliminating parts of the signal, lossy
compression allows for the signal as whole to take up less storage space. According to Kefauver
and Patschke (2007), “subsequent compression/decompression generations of the recreated
signal will result in increased distortion and loss of fidelity, escalating with each generation” (p.
66-7). Every time the audio signal is reduced, and components are removed, the overall quality
of the signals is reduced. If used properly, lossy compression can save space without reducing
the quality too much.

A common example of a lossy format is MPEG. MPEG stands for Moving Pictures
Expert Group, which was formed in 1988 by the International Organization for Standardization
Different forms of MPEG are widely used and “established several standards for video and audio
and encoding in the late 1980s” (Kefauver & Patschke, 2007, p. 66). The most common and most
complex layer of MPEG is MPEG Layer III, more commonly known as MP3. According to
Pohlmann (2011), “[MP3’s] design is more complex than other layer codex. Its strength is
moderate fidelity even at low data rates” (p. 404). Another author describes MP3 as compressed
audio that enables transfer to a computer environment, and that MP3 files are compressed
substantially, while still maintaining an acceptable amount of quality (Gündüz, 2012, p. 203).
MP3 has contributed to the structural change in the industry to a more digital platform.

Another common type of digital audio compression is lossless compression, which
focuses more on quality. According to the authors of Fundamentals of Digital Audio, “there are
no quality-related issues in lossless compression…” (Kefauver & Patschke, 2007, p. 65). Some
of the examples of lossless formats are FLAC (Free Lossless Audio Codec), ALAC (Apple Lossless Audio Codec), WMAL (Windows Media Audio Lossless), and DST (Digital Stream Transfer) (Kefauver & Patschke, 2007, p. 65). Lossless compression works to compress data as much as possible without losing any of the viable information/data. In the Fundamentals of Multimedia, the authors state, “If the compression and decompression processes induce no information loss, the compression scheme is lossless” (Li, Drew, Liu, 2014, p. 186). As the name suggests, lossless compression results in no loss of information, thus, maintaining much of the quality. This does result in larger file sizes than that of lossy formats. One of the most common lossless formats is WAV. John Klepko (2005) explains that WAV was created by Microsoft and that it is “reasonable to assume that WAV format is the most common (non-compressed) audio file type used in production due to its native PC format that is also playable on audio software based either Mac or PC” (p. 38). WAV is compatible on different platforms, making it a commonly used format. As stated previously, a WAV file is uncompressed, so it loses very little information from the original. When comparing WAV to MP3, Jonathan Sterne (2006) states, “While it is true that at the level of formats, MP3 has less potential definition than.wav (which is the format used on a commercially pressed compact disc)…” (p. 343). The two formats are often compared, but both have unique qualities and are the best choice for different situations. Although digital audio’s lossless technology provides a near flawless result, it is not always perfect. The digital conversion process introduces issues such as noise, which is primarily a result quantization error or other digital phenomena. Quantization error can be described as the “the difference between the actual analog value at sample time and the selected interval value” (Pohlmann, 2011, p. 31). This error often results in distortion, thus ruining the quality of the audio (Pohlmann, 2011, p. 32). Advancements in digital technology have allowed for the ability
to monitor and correct these issues. The advancements in digital audio technology have provided new and efficient ways to record music, but it is important to understand that it has its flaws. Varying formats and digital technologies have also led to changes in the industry as a whole.

Since the implementation of digital audio, the whole business model for the industry completely changed. New strategies for marketing, selling, and consuming music/audio had to be developed to accommodate the change. Selling physical media was quickly becoming less and less necessary. Jerald Hughes and Karl Reiner Lang (2003) explain to readers that:

Now that music has entered the digital realm a new revolution is underway, one in which fundamental changes in nearly all aspects of the culture of modern music experience are being driven by the interaction between technological innovations and the social impacts of those innovations (p. 180).

Different innovations have led to shifts in the industry. For example, digital downloads and online streaming services have contributed to the creation of an instant gratification way of consuming. Media is so easily accessible that people often find themselves feeling frustrated if that instant access is hindered in some way. However, some have argued that digital technology has created a new sense of freedom for consumers, stating that:

Digitalization and MP3 technology revolutionized music consumption — a personal choice of music has become available at any time and in any place, without physical storage requirements such as shelves for records or racks for CDs. It is no longer necessary to purchase entire albums for only a few desired songs, but a consumer can freely choose how and when they listen to music (Cockrill, Sullivan, Norbury, 2011, p. 160).
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Digital technology has its own set of pros and cons, but it still remains the industry standard. Although digital technology seems to have taken over the industry, analog technology still manages to remain relevant.

Analog technology may be considered antiquated by some, but others swear by the authenticity and pureness it provides. One of the most commonly used forms of analog recording is tape-based recording. Tape recording grew in quality and popularity in the 1940s during WWII (Rumsey & McCormick, 2009, p. 169). However, it was not until the 1960s that the technology and techniques were available to produce commercial multitrack, stereo recordings (p. 170). When discussing analog recording, Francis Rumsey and Tim McCormick (2009) explain that “sound is recorded by converting continuous variations in sound pressure into continuous variations in electrical voltage, using a microphone” differing from a digital recording, which converts waveforms into numbers (p. 202-3). Many argue that analog technology allows for a more “pure” recording that is much closer to the original sound than digital recordings. Sterne (2006) states, “For many years now, critics have written of digital audio recording—in its myriad formats—as less ‘live’ or less ‘natural’ than analogue recording” (p. 338). Perhaps this is the reason for the rekindled interest in analog recording. Similar to analog, digital recordings have noise issues as well, although, not at the same level as analog technology, which is more susceptible to interference and different forms of distortion.

Due to the nature of analog technology, “[the replay system] is unable to tell the difference between wanted signals and unwanted signals. Unwanted signals might be distortions, noise and other forms of interference introduced by the recording process” (Rumsey & McCormick, 2009, p. 202). Although this may be the case, some find that the unwanted noise contributes to the charm and uniqueness of an analog recording. Any type of analog recording
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introduces unique artifacts to the overall sound and quality to the audio. One of those irregularities is called “wow.” Wow is a type of flaw in analog tape recording when “sound keeps rising and falling in pitch” (LeBel, 1956, p. 30). According to C. J. LeBel (1956), “wow is caused by irregularities in the speed at which the tape moves across the heads. If tape speed is absolutely constant (a condition which is very difficult to achieve there is no wow” (p. 31). Wow can lead to an unwanted, distorted sound on recordings. The same author even describes wow as being unbearable in some cases (p.30). Noise and distortion can affect an analog recording, so one must pay special attention to more details when recording on tape. Similarly to digital technology, analog has its very own set of strengths and flaws that must be considered when attempting to compare the two.

The introduction of digital technology has forever changed the music industry. The ability to instantly obtain audio is a privilege many take for granted. However, the authenticity and nostalgia of analog recordings are steadily regaining popularity. Ironically, some will use digital technology to achieve that analog sound rather than just employing the use of analog technology. When comparing the two forms of technology, it is easy to see that both have their own unique sets of strengths and weaknesses, which keeps the industry in a constant flux as to which method or process is “best”. Though the industry will never be able to completely remove “analog” technology from the recording process due to fundamental physics, it is a given that even the most “analog” recordings end up being converted to a digital format. This leads to questioning what differences exist, if any, between an analogically and digitally recorded signal. The supporting arguments presented in this review provide a basis for future research. While many discuss the basic differences between digital and analog, not much research was found on the analysis of the signals themselves or the impact digital technology has on analog signals.
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This study will attempt to compare the two technologies at the signal level, thus offering new evidence and conclusions on the relationship between digital and analog.
Method:

Through my research, I compared both analog and digital audio signals. These comparisons may serve as a guide to examine the differences between two recordings, which were obtained simultaneously, using the exact same microphones and preamps. With the exception of the recording device (and subsequent digitization of the analog signal), no differences existed in the signal path. Data was collected by recording audio—vocals and acoustic guitar—through a set of microphones. These microphones worked to record simultaneously to ensure that the two signals were the same. The recording session took place in a recording studio in College Hall at the University of Southern Mississippi. The studio is equipped with a Toft Audio ATB24 mixing board, which was utilized for the recordings. The TEAC 80-8 Reel-to-Reel Tape Recorder was used to capture the analog recording. The tape used was ATR 1/2” Master Tape. ATR Magnetics states that their master tape “provides for high-output, low-noise recording with an industry standard bias compatibility. Our advanced preparation and coating techniques produce a consistent, high quality product that meets the needs of professional recording studios and hi-fidelity enthusiast alike” (ATR Magnetics, n.d.). ATR is a front-runner in magnetic tape, so I was confident with the decision to use their 1/2” tape.

The studio is equipped with a vast selection of microphones that were utilized for the recording portion of my research project. The following microphones were used for the study: Neumann U87 (vocals), Rode NT5 (guitar), AKG 414 (guitar), and two Neumann KM 184s (room). The Neumann U87 was placed on a microphone stand with a pop filter at face level with the musician who was seated. The Rode NT5 was positioned close to the neck of the guitar. An AKG 414 was also used to capture guitar; however, this microphone was positioned close to the
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body of the guitar. Lastly, a matched pair of Neumann KM 184s were used as room mics to capture the ambiance of the room.

Following the simultaneous digital and analog recording, of which the analog signal was digitally captured using the record head output of the Teac, the song was mixed using all digitally recorded tracks and all analogically recorded and converted-to-digital tracks. The mixed analog and digital audio was run through an analyzing program. The program used to study the different signals is called SpectraFoo. For analyzing purposes, the analog signal was re-recorded from the tape to a digital format. To do so, both the left analog signal and left digital signal were imported into Pro Tools, a popular audio workstation. Thirty second samples from each were lined up and placed perfectly in time with one another. Once the samples were aligned properly, the digital signal was panned all the way to the left and the analog signal was panned all the way to the right. This served as a tool for differentiating the two signals, so they could be successfully compared when put through SpectraFoo. The same process was repeated for the right side audio. As a result, digital and analog left were compared and digital right and analog right were compared. SpectraFoo analyzes the audio signals, which allows for the examining of the data in waveforms and observe the how the two differ, if at all.
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Analysis:

To analyze the two audio samples, analyzing software called SpectraFoo was used. According to the manual obtained from its host website, Metric Halo (2011), SpectraFoo can be described as a “high–precision, low–latency, fully realtime audio visualization and analysis system” (p.11). SpectraFoo converts an audio signal into a visual representation of the signal. For this particular analysis, the spectragraph option was used. The spectragraph is an “ultra high resolution real-time two channel spectrum analyzer with snapshots, cursors and overlays” (Metric Halo, 2011, p. 18). The spectragraph takes the audio signal and presents it in a comparative waveform between two channels. In this study, two separate comparisons were made between the digital left and analog left, and the digital right and analog right mix channels respectively. The decision to use the final mix channels rather than the individual instrument channels was to ensure that the comparison accounted for waveform interaction between individual instrument channels as the final mix was constructed.

Figure 2 represents a comparison of digital and analog left-channel signals. The yellow waveform represents the digital signal and the blue waveform represents the analog signal. Since both signals were obtained simultaneously with no difference in signal flow (except for digitizing the analog signal for comparison), the signals should be similar, if not exact replicas of one another. However, that is not the case. The signals share broad similarities, but there are many discrepancies. For example, around the 800Hz mark, the analog signal is noticeably lower than the digital signal. The same can be concluded about the right side, which is displayed in Figure 3. In Figure 3, the pink line represents the digital signal and the green line represents the analog signal. Both graphs show a similar trend in which the differences grow greater and more frequent at higher frequencies. Starting at about 800Hz, the contrasts between the two signals
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become more prominent. This development is evident in both the left and right signals. The midrange frequencies from around 250Hz to 650Hz seem to be the most similar when looking at the comparison. It is also important to note the harshness of the peaks and valleys in the digital signal. When looking at the amplitude of the two signals, compared to the analog, the digital seems to produce a wider range of peaks and valleys. These differences could have a small sonic impact of the overall “sound” of the music, which may or may not be perceivable depending on the listener’s ability to listen critically. This may be a contributing factor as to why some prefer one to the other in terms of how it sounds.

Differences between the analog and digital signals are noticeable. Although these variances may not necessarily be noticeable to the untrained ear, they are clearly evident when examining the audio in a visual form as seen in Figures 2 and 3. The contrasts seen in the graphs are a result of the differences in the two technologies. Though exact causes remain unexplainable, the waveform data confirms that differences in recording technology (digital and analog) can impact the signal, and perhaps, the way we perceive and subsequently assess a musical recording.
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Figure 2: Graph from SpectraFoo analysis of the left audio signals

Figure 3: Graph from SpectraFoo analysis of the right audio signals
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**Conclusion:**

This project served as a means to compare two forms of audio recording technology. Analog and digital audio and means of recording can easily be compared. Digital technology has progressed and changed over the years to become a more efficient and timely way of capturing and reproducing sound. Analog methods have always been relevant across many industries, especially in the music industry. This study was primarily done for analyzing and comparison purposes. However, it also gave me the opportunity to work with technology that was new and challenging to me.

From the collected data, it was evident that both analog and digital recordings offer unique qualities. Although the recordings were obtained simultaneously, there were still discrepancies between the two waveforms. Multiple factors may be the cause for those differences seen in the spectragraph. In digital technology, sample rate, quantization error, jitter, and clock issues can result in data irregularities, which in turn, can result in noise or inaccurate waveforms. Given that the equipment used was of professional quality and an industry standard, the aforementioned issues were inherently minimized. In analog recordings, physical issues with the tape recorder such as worn heads and type of tape used can cause some irregularities as well. Also, tape tends to pick up more unwanted noise. This is a more plausible explanation for the differences between the recorded waveforms for this project. The differences seen in the analog signals are likely attributable to the medium itself and the use of analog equipment that wears down over time, even though both recordings were conducted simultaneously. When recording, it was interesting to feel the pressure of getting a good take as quickly as possible due to the limitations of the tape. The digital platform allows for an unlimited number of takes, but the analog tape physically runs out.
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The research presented in this project is not perfect due to equipment limitations, and there are improvements that could be made. As stated before, there is a chance worn equipment could have played a factor in the differences between the two signals. Perhaps newer equipment would produce more accurate readings, but you cannot buy “new” tape machines anymore – you can only accept the old technology as it is, with some improvements in the form of “modifications” or “new old stock.” Although digital and analog technology are often compared and looked at as two independent forms of technology, it is important to note that analog is inescapable in the recording process. The amount at which one chooses to embrace it will continue to be a personal choice.
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