The Complete Restoration of a Wurlitzer Model 206 Electric Piano

By

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Dedication

This project is dedicated to my brother, Drew. Throughout my life, no one has had as great an influence as he, and I would not be where I am without him. He has encouraged and supported me selflessly throughout my journeys, both in audio and analog electronics. His love for music, recording, audio equipment and creation has been infectious and has kept me from feeling isolated in my interests. Whether I needed someone to vent to, ask advice of, or share my successes with, he was there every time. I am incredibly grateful for his help and support in this project, and I am glad to have him as a brother and a friend.

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I would like to acknowledge my family for giving me the support and encouragement I needed in this project. They are always there for me, especially when I am stressed. I thank Alton Dellinger for being an excellent advisor and mentor to me. Although I have only been working with electronics for a little over a year, I have gotten further than I ever would have without his experience and wisdom guiding me. I would also like to thank Dale Brown for assisting me with resources to help me complete this project. Finally, I would like to acknowledge Laura Clippard for answering the inevitable flurry of questions that I have every couple of months about anything relating to the honors college, and for being kind and patient with me.

Abstract

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In this thesis, I outline how I fully restored a vintage Wurlitzer electric piano. I restored the piano physically, electrically, and mechanically. My goal in this restoration was not only to make the piano sound good, but to make it feel and look good as well. In order to evaluate my work, I featured the Wurlitzer in a recording, bringing the project to life in a way that honors its history. I also pitted it against two other Wurlitzers that had been restored in the past. Following the completion of this thesis, the Wurlitzer electric piano that I restored will be installed in one of MTSU's recording studios. I completed this project not only to further my knowledge of an amazing instrument, but also to give others the opportunity to be influenced by it as I have.

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Introduction

The Rudolph Wurlitzer Company was started in 1853 in Cincinnati, Ohio. The company began by manufacturing organs, and gradually moved on to a number of different instruments, most notably the piano. Wurlitzer started off by only creating their own pianos, and specialized in entry level upright and grand models. In 1919, the Wurlitzer company acquired the Mellville Clark piano company in DeKalb, Illinois. Wurlitzer used this location to manufacture many pianos throughout the years, and they continued innovating and improving on their acoustic piano designs (Beentjes, 2020). In 1954, the first Wurlitzer Electric Piano was designed and manufactured by Benjamin Meissner, who had previously patented a stringed electric piano in 1940. Meissner was working for the Wurlitzer Company when he developed and demonstrated this first Wurlitzer Electric Piano, the Model 100 (Duncan, 2021). The first iterations of the Wurlitzer electric pianos all had tube amplifiers and were made of mostly wood **(See App. B, 1)**.

Gradually, the designs improved and grew easier and cheaper to manufacture, and the company moved to all solid-state amplifiers. The Wurlitzer 206, which is the subject of this thesis, comes from the second-to-last line of the Wurlitzer electric pianos, predating the 200a series. The last Wurlitzer electric pianos were manufactured in 1983. The Wurlitzer Electric Piano was developed as a practice instrument, and advertisements boast the piano’s ability to be played without any ruckus or annoying bad notes **(See App. B, 2)**. Many pianos were bought for this very reason, and they populated homes around the country. For gigging musicians, however, the Wurlitzer offered not only a unique tone and characteristic sound, but it offered *portability.* This allowed pianists to bring their instrument to any gig with much more ease than before. With this advantage, The Wurlitzer gradually became prominent in genres of music from jazz to pop. Artists such as Ray Charles, The Cannonball Adderley Quintet, Aretha Franklin, Marvin Gaye, Donny Hathaway, and Bill Withers featured Wurlitzer on songs from the 50s onward **(See App. B, 3)**. The Wurlitzer has become a recording studio staple, and has consistently been a sound in various genres since its creation (Allen, 2022).

Within the first month of working for the audio maintenance shop for the Recording Industry program at MTSU, I visited one of our storage facilities located in an off-campus building. Within this facility, the maintenance department kept older digital tape machines, acoustic paneling, many feet of unused multi-channel audio cables, older rack-mounted hardware equipment, and to my surprise… two Wurlitzer 206 electric pianos. Both pianos were in a state of disrepair, one being significantly worse than the other. I was immediately intrigued and inspired. I had played Wurlitzers before, and to me, they are one of the most enchanting instruments to play and use for writing music.

Although I did not have the skill and knowledge to complete a full restoration at the time, I knew then that it was something that I had to do. I consulted with Dale Brown, who had experience with Wurlitzers, and he knew some about the history of these 206s. He allowed me to take the less damaged Wurlitzer and start repairing and restoring it. I was allowed to take parts from the other, more decrepit Wurlitzer, and to order some of the required components through the maintenance department. Thus began my year-long journey in learning the minute details about this Wurlitzer, and growing in my knowledge of electronics, mechanics, music, and patience.

Approach and methods

To fully restore this Wurli 206, I employed the use of many different skill sets, some of which I had to develop as the project progressed. The restoration needed to be tackled from several angles including physical and aesthetic improvements, electrical improvements, mechanical improvements, and musical improvements. I approached this project with the knowledge I have attained from my time in school as an audio production major, and as an electronics minor. I drew from experience in my jobs as a studio maintenance technician and as an assistant microphone repair technician. The knowledge that I brought to this project helped me to a limited degree. What pushed me further was the research, experimentation, and critical thinking that I did along the way.

My approach to this project was half academic and half creative. As I have learned through my time working with electronics, intuition and experience are implemented more often than theory. For example, while it is important to understand how the atomic physics of a semiconductor allow electric current to flow under certain conditions, this is irrelevant when trying to tell if the distortion you are hearing is coming from the signal transistors or from the power transistors. Intuition and experience will tell you that the power transistors are handling higher voltages, wattages, and therefore more heat. This makes these more likely to fail. I thought it was important to classify this thesis as a creative project; I hold the belief that audio and music are inherently interconnected, and should hold an equal amount of science and creativity when paired together.

Physical restorations

The physical state in which I discovered the Wurlitzer was rough. As I found it, the piano was missing its main faceplate and both knobs. The tolex wrap surrounding the body was grimy and discolored, and the keys were also covered in several layers of oil and dirt. Additionally, there were many places on the lower cabinet in which the tolex was peeling **(See App. B, 4 and 4.1)**. Before I did anything to the piano, I needed to thoroughly clean the unit. Upon the initial disassembly, I found years' worth of dirt, dust, paper scraps, and old gum wrappers under the keys **(See App. B, 5)**. I cleaned every key with soap and water, and I cleared out the paper scraps that were lodged in the key bushing felts. The next step was to vacuum all the keybed, around the action, behind the main rain, and in the lower cabinet.

In order to clean the Tolex, I needed to do some research, as I had little to no success with conventional soft cleaners such as windex and dish soap. After a few minutes of scouring forums, I was able to find a video from a man who specializes in cleaning old guitar cabinets that are wrapped with tolex. He suggested using a combination of car convertible top cleaner, and a soft bristle brush. I was able to pick up these items at the store for less than $20, and the results were much better than my previous attempts **(See App. B, 6)**.

Once I cleaned the tolex as well as I could, I focused on trying to clean up the edges and eliminate the peeling. I was able to find more resources online that gave me ideas on how to glue the edges down in a way that would stay. Before I was able to use any of these methods, I had to remove the rubber edge surrounding the cubby cutouts on the cabinet's front panel. Once this was completed, I used a combination of wood glue and painter's tape to adhere the loose tolex. The painters tape supplied enough pressure and tension to keep the edges down as the wood glue dried **(See App. B, 7).** After the glue had enough time to set (approximately 24 hours) I was able to reattach the rubber edging back to the front panel. I reattached it in the same way in which it was originally assembled, using a staple gun. To hold it in place as I was stapling, I used zip-ties and more painter's tape. The restored front panel was ready for reassembly.

There was a small hole near the bottom of the rear panel where the previous AC cord had been installed. Because I planned on changing the design and integration of the AC input, I wanted to make this hole less obvious. I decided to create a small wooden plug to fill it, and I glued down the surrounding Tolex. To ensure that this glue would hold, I used the same method from gluing the front panel Tolex. This was a small detail, but I wanted this Wurlitzer to look clean and well restored.

The final elements of the physical restoration were the faceplate and knobs. I was able to acquire these from Vintage Vibe, which was an incredible resource for this project. The man that started this company was an experienced electric piano technician that decided to re-create and manufacture parts for vintage electric pianos. This company also builds and sells their own electric pianos, called Vintage Vibe Electric Pianos. Dale Brown from the Audio Maintenance Shop for MTSU Department of Recording Industry helped me to purchase a new set of their volume and tremolo knobs for the Wurli, as well as a brand new faceplate. I decided to purchase the faceplate for the non-student model Wurlitzer, as this model has a vibrato label as opposed to an input select label. While this is not historically accurate to this piano, it is more practical for its intended use **(See App. B, 8)**.

Electrical Restorations

Part One - AC Restoration

From the start of the electrical restoration, I knew a few things that needed to be fixed before the Wurlitzer would be safe to use. The original power cable was frayed, and it was not grounded. The AC mains fuse was blown, and needed to be moved to a location that was easily accessible (the original fuse design had it soldered to a small board to the left of the amplifier board.) In addition, the power wires that ran through the Wurlitzer body needed to be organized, dressed to reduce cable clutter, and placed in areas that would not interfere with the sensitive signal coming from the pickup and the pre-amplifier.

Most modern equipment interfaces with 120 volt wall voltage through a 3-pin IEC standard NEMA 5-15 connector. These are the standard sockets found in most modern American homes. These plugs provide a “neutral” pin that measures zero volts relative to ground, a “hot” pin that measures approximately 120 volts relative to ground, and a safety “ground” pin that gives a low-resistance path to earth ground in the event of an electrical short in the current path. Devices such as this Wurlitzer, which have internal power supplies and use high voltages in their operation, should be connected to this earth ground to prevent electrocution. The lack of a ground pin on the original Wurlitzer was incredibly unsafe, and needed to be fixed first. I cut off the original 2-prong cable, and brainstormed a few ways to add a new cable. I decided to add a three-prong cable that could be disconnected and replaced easily if need be. The most commonly used type is the IEC standard C14 Connector, which terminated on the other end to a NEMA 5-15 connector. This is the standard “kettle plug” that is found on many devices.

I had two ideas for altering the location of the power cable. The first idea I had was to cut a hole near the upper left side of the piano and insert the C14 receptacle. The advantage to this is that it allows for a shorter path for the full 120v AC from the wall, which is safer. The disadvantage is that it requires a precision cut in the original body of the Wurlitzer, which would be difficult and unforgiving. My other idea was to repurpose the now unused classroom interconnect port to hold the receptacle. This ends with a longer path for the 120 V AC, but it does not increase the length from the original, so it is not unsafe. Additionally, this path will be covered by the front panel, which already has a high voltage warning label. This idea also allows for the receptacle to be slightly recessed, which can prevent it from being damaged. Additionally, the Wurlitzer 206 has two symmetrical interconnectivity ports, which leaves another port open to be used for an external fuse holder.

In order to have these AC connections be both functional and aesthetically pleasing, I decided to create small wood frames in which I would insert the receptacle and the fuse holder. I have done some woodworking, but I had never attempted anything such as this, so this was somewhat of a learning curve for me. I used a small wood hand saw to cut out the rough shape of the wood, and I used a Dremel to carve out the center for the fuse holder and the receptacle. The fuse holder went very smoothly, and I was able to center it well on the first try. The receptacle, however, took several tries for me to get right. On the first attempt, I bored out too large of a hole in the center, and the receptacle sat unevenly in the small wooden panel **(See App. B, 9)**. The second attempt looked better, but was not very durable. It stuck out of the Wurlitzer's rear panel enough that it cracked during transport from my recording session. My final design recesses the receptacle enough that it will not get caught and break like the second one. To clean up the final two panels, I used boiled linseed oil to bring out the natural wood grain for the piece. While these two items will not be seen often, I wanted to ensure that they were built for longevity, and I wanted them to look professionally made.

The next step was to clean up and strategically organize the AC lines running throughout the piano. I used a combination of non-permanent stick-on cable organizers and zip ties to keep the power organized within the cabinet itself. On the amplifier, I tried a trick that I found when looking through the Vintage Vibe electric piano restoration tips. This tip suggested running the power lines along the edge of the amplifier rail, and shielding it. This method effectively hides the power cables, but it also accomplishes something else. It serves to distance the AC from sensitive preamp signals, and the shielding is an extra layer of protection that grounds electromagnetic interference that might be caused by the incoming power. To do this, I used gaffer's tape to secure some of the AC lines to the edge of the amp rail. Gaffer's tape does not leave any sticky residue, and is very strong and unlikely to come off. Atop of the gaffer's tape, I added conductive copper tape as the shielding material. As the amp rail is both chassis and circuit ground for the amplifier, touching the copper tape shielding to the amp rail grounds it effectively **(See App. B, 10)**.

Part Two - Amplifier Restoration

The amplifier restoration for the Wurli was the most time consuming and detailed aspect of this project. Starting this restoration, I was fairly new to electronics, and diving into the electrical operation of the Wurlitzer taught me a great deal as I progressed. I spent time analyzing schematics and circuit descriptions to understand the operation of the Wurlitzer audio amplifier, and about the importance of each stage in its amplification. Alton assisted me in looking over the schematics and explaining why the amplifier was designed in the way it was.

The Wurlitzer 200 series amplifiers use some of the earliest versions of printed circuit boards. These are composed of different materials from modern circuit boards and look atypical compared to a board you would see in a recent device. The Wurlitzer 206 that I worked on was the second revision of the 200 series amplifiers, and had a couple features that improved upon the original design. For example, the resistor in series with the reedbar was lowered in value, and an additional series resistor was added, allowing these resistors to dissipate less power, yet still have a similar total series resistance. As explained earlier, components handling less power will be less likely to malfunction, which is vital in this case. These two resistors are critical; “Because R56 is in series with the output, the supply can deliver only a very small amount of current to the reedbar, minimizing shock hazard” (Wurlitzer Company, N.D.).

One of the first things that I found when removing the amplifier PCB was that some of the original printed traces had been broken off. This can commonly happen when electronics are moved around, exposed to a wide range of temperatures, or significantly aged. While I did not know the exact cause of this breakage, I had to find a way around the issue. I was able to add jumper wires along the original current path on the underside of the PCB. I used lower gauge (thicker) jumper wire to ensure the longevity of these connections.

Anyone with experience working with vintage analog electronics knows the components that go bad the most often: electrolytic capacitors. Electrolytic capacitors, or “caps” are made using a liquid electrolyte and a metal conducting plate. Over time, these components will lose some of their electrolyte and start to dry up and become “leaky.” As this happens, these components can cause electrical shorts. A capacitor is not supposed to pass direct current if it is operating correctly. If a capacitor is leaky, however, some direct current will pass through the component. This can lead the amplifier to stop working, damage other components, or leak high voltages into the wrong parts of a circuit. This is especially dangerous if the caps are in the power supply section of the circuit, as these are generally handling the highest voltages. From the beginning of my research, I learned that it was absolutely critical to replace all of the electrolytic capacitors on the amplifier board.

To continue on with the restoration, I researched the best types of electrolytic capacitors to purchase for the Wurlitzer to aid in both longevity, stability, and sound quality. This led me down a path of learning about different materials used in making capacitors, and how they affect the sonic quality of the alternating current signal that passes through them. Through my reading, I learned that aluminum foil electrolytic capacitors generally reproduce audio signals more accurately than tantalum foil capacitors, which can sound harsh and inconsistent in their frequency response. They can also have a non-linear transient response that can distort and compress the signal entering them (Stamler, N.D.). Part of this is due to their poor performance in aspects such as dielectric absorption, which is a capacitor's tendency to slightly recharge after it has been discharged. Small non-linearities such as these can impact a capacitor's ability greatly (Kundert, 2021). With this in mind, I looked to replace the original electrolytic capacitors with new aluminum foil electrolytics. There are a range of qualities in the market, and many manufacturers are not optimizing their products for use in audio circuits. However, companies such as Panasonic and Nichicon make high quality audio-grade electrolytic capacitors that exhibit lower ESR (equivalent series resistance) specifications and a more linear frequency response. I chose to buy as many of these types that were available for the values that I required for the Wurlitzer. All of the capacitors I bought were rated for stability up to 105 degrees Celsius, which is a high standard for these types of capacitors. Many lower-tier electrolytics are only rated for 85 degrees Celsius.

A few of the other capacitors that I replaced were capacitors known as "tropical fish" capacitors **(See App. B, 11)**. These capacitors are made from metallized polyester film. They are generally very stable and are regularly seen in many vintage audio circuits such as guitar amplifiers and effects pedals. These capacitors are generally sought after due to their less aggressive high frequency response. While these would not have normally needed to be replaced, many of the ones on the Wurlitzer's amplifier board were cracked due to heat and exposure. I replaced these with a similar type of metallized polyester cap nicknamed "orange drop" capacitors. While these capacitors do not have the mythological history behind them, they are still produced. Modern component production generally yields much more consistent, stable, and reliable results than the 1970's era components previously mounted in the circuit.

Most electronics built in the 60s and 70s used carbon composition resistors. These have a tendency to add noise to the circuit and can become unstable over time (Schroeder, 2020). In order to increase the longevity of this Wurlitzer, I replaced the carbon composition resistors in the most sensitive area of the circuit, the pre-amplification stage. In this stage, circuit noise is closer in level to the incoming signal, and it would get amplified evenly with the piano's signal. The replacement components that I inserted into the circuit were metallized film resistors. These are more stable, and add less noise to the circuit. Being modern components, their measured values are also closer to their rated resistance ratings.

Another common point of failure for older analog electronics is components that handle the most amount of power. These components deal with higher voltages, higher currents, and operate under a higher temperature than many of the other components in these circuits. The critical components in this Wurlitzer to check were the power transistors. This matched pair of transistors work together to do the final amplification stage of the signal before it reaches the speakers. There is one NPN (negative, positive, negative) transistor that is setup to handle the positive top half of the waveform. There is one PNP (positive, negative, positive) transistor that is setup to handle the negative bottom half of the waveform. These two work in unison to reproduce the full waveform from the Wurlitzer's preamp **(See App. B, 12)**.

Knowing that these transistors are more likely to fail, I removed them from the circuit and inserted them into the transistor tester that the Audio Maintenance Shop has. Upon testing these transistors, I found that one of them was unfit to be kept in the amplifier. It was measured as having a very low "beta" value, which meant that the transistor had low current gain and could not act as an effective current control device. Similar to capacitors, transistors can also become leaky over time. A leaky transistor can no longer maintain the correct resistance to reverse bias, and will start to allow current to flow when the transistor is not on. In the Wurlitzer amplifier circuit, this can result in heavy distortion or even damage the speakers. After some time researching replacement components, I was unable to find the original transistors used in the circuit. I was, however, able to find the specifications of the originals and look for similar or equivalent replacements. I was able to find a PNP/NPN matched pair of near equivalent power transistors from the company NTE. These new transistors had a different arrangement of their pins, so I had to switch the circuit wiring slightly to accommodate.

When examining the bad transistor, and its location in the circuit, I realized that there could have been a reason other than merely age that it stopped working. Connected to the base of that transistor is a protection diode that is placed in the circuit to prevent reverse current flow. I removed this diode from the circuit and checked it using my multimeter. The diode read as very resistive in the reverse bias, which was correct. In the forward bias, however, the diode was measured as having a very high resistance. This is not how a diode is supposed to act, meaning that somewhere in this piano's lifetime, this component had failed. For longevity's sake, I not only replaced this diode, but I replaced the other rectifier diodes in the circuit. Keeping the original diodes would have had no effect on the sound of the amplifier; they would have only been a risk to the circuit. I was able to replace these with a modern production of the same model of diode, a general purpose 4007 diode.

Part Three - Additions and Modifications

A feature that the base model of the Wurlitzer 200 series had was a tremolo circuit. It operates by creating a low-frequency oscillator that operates at about 5.75 hz. This is created by feeding the 180 degree output of a signal transistor back into itself, and shifting it to an additional 180 degrees so that it causes a regular, additive pulse to this signal. Because of the time delay caused by the phase-shifting capacitors, the constructive feedback interference slowly increases the signal level, and then dies off as it loses this sudden burst of power. This is an oscillation. Its speed is determined by the resistor values within the phase-shift network, which are pre-selected in a Wurlitzer 200 amplifier. Once this oscillation is started, the amount it is sent to the main signal is controlled with the "vibrato" control. This depth control controls the amount of the oscillated signal that is sent to ground versus the amount that is fed to the pre-amplification stage. This will oscillate the amplitude of the signal by a maximum of about 50 percent on a correctly operating amplifier (Wurlitzer, N.D.).

In the student model Wurlitzer Electric Pianos, the amplifiers were identical to the rest of the 200 series models, except when it came to the tremolo circuit. In the student models, the tremolo circuit was bypassed with a jumper that ran across points 1 and 12 on the amplifier PCB. This jumper bridges TR4, TR5, and TR6, as well as the resistor-capacitor filter matrix, which is the part of the circuit that is used for the low frequency oscillator element of the amplifier. Instead of having a secondary tremolo control potentiometer, the student models had a three position stepped potentiometer to allow a student to select the source from which they would listen to on their device. The way that these pianos were meant to be set up was in a classroom, with one leader “teacher’s” piano, and other follower “student pianos.” These were all connected together through multi-pin connections in the rear of each piano. These connections carried signals from the teacher’s piano and the other pianos in the ensemble to allow interconnectivity in the classroom setting **(See App. B, 13)**.

Be it that this Wurlitzer is to stand alone in a studio, the tremolo circuit had much more practical use than any of the original classroom circuitry. I removed the input for the mic, the switching apparatus for the “ensemble” feature, and the stepped potentiometer for the output selector. I also removed the jumper bridging the tremolo circuit within the amplifier. I added a variable potentiometer to replace the old stepped one, and I connected it to points 1 (negative/ground), 12 (wiper), and 13 (positive). This allows for precise variability of the tremolo depth.

To follow the original design of the non-student Wurlitzer 200 series amplifiers, I added an auxiliary output to this piano. This signal can be used for recording a clean D.I. signal straight from the amplifier. The auxiliary output is sourced after the pre-amplification stage, but before the power amplification stage. This outputs a signal level that is louder than the signal coming directly from the tone reeds, but not quieter than the signal coming from the speakers. This allows plenty of headroom for recording purposes. I installed this auxiliary output in the same location as the original headphone output, which is under the keybed on the player’s left side.

Mechanical Restoration

The mechanical state in which this Wurlitzer was originally in was unsuitable for playing. The unit was missing five tone reeds and two hammers. While some of the tone reeds had kept their tune over the years, others were out of tune and needed adjustment. Part of this tuning adjustment involved adjusting the voicing of the Wurlitzer, which affects the tone of individual notes. Additionally, some of the key let-off adjustments were slightly off, and several dampers were not correctly muting the reeds. The Wurlitzer 200 series manual was a critical source of information in this process. This manual thoroughly documents the best ways to adjust and regulate the mechanics of the Wurlitzer's action.

Fortunately, the two missing hammers were easily replaced. The second "parts Wurli" in storage, as well as a box of extra Wurli parts in the RIM Shop, had the right hammers to replace the missing ones. Wurlitzer 200s have three different types of hammers of three different thicknesses. The largest of the three are designated for the bass notes, and the smallest for the treble notes. It is critical to make sure that the replaced hammers are of the right size, otherwise the key will not be struck evenly with the adjacent keys.

The reeds needed much attention, as they are the core of the Wurlitzer's sound. Three of the missing reeds were present on the "parts Wurli," so I was able to recover them for use in this piano. The other two needed to be replaced. Vintage Vibe recreates Wurlitzer 200 reeds, and sells tuned, untuned, and blank reeds. Through the maintenance department, I acquired two new untuned reeds to fill the two gaps (notes F3 and G3).

Tuning the Wurlitzer was the most time consuming portion of the mechanical restoration. Fine tuning adjustments for the reeds can be made by shifting it forwards or backwards. Shifting the reed forwards will lengthen the reed, causing a slightly slower vibration. This can flatten the note approximately 10 cents. Moving the reed backwards does the opposite. This method is effective with the lower notes, although it takes a great deal of trial and error. The reed must loosened, shifted slightly, then tightened again. A critical part of this is to maintain the reed's lateral position. Tightening the reed when it is too close to the pickup can result in a harsh tone, or worse, a potential short between the positively charged pickup and the grounded reeds.

If a reed's pitch is too low or high to be adjusted with the first method, the solder on its end must be reshaped. A reed that is too sharp needs additional solder. This will weigh down the end of the reed causing it to vibrate slower. The catch to this, however, is that the tone of the reed is affected by the solder on the end. To achieve a proper tone, the solder must be filed down to a trapezoidal shape at the end of the reed. Thus, a sharp reed would need plenty of extra solder to both flatten the pitch and shapen it correctly. The method that I found was the most effective for this was to file the initial shape, and then count the number of laps I made with my file on each face of the reed, subtracting solder slowly. I would attach the reed back onto the harp, and test. This action would be repeated until the note is on pitch. If the note is too low, the tuning would consist of the filing process only.

I had to make several passes of tuning on this Wurlitzer. It took hours just to achieve a correct pitch on several notes, so I split it up into different sessions. An additional hurdle that I had to manage was that of the higher reeds. Some of the higher reeds are grouped in pairs. When I needed to tune just one in a pair, I had to remove the other as well. This meant that I had to align both reeds to be in tune at the same time, as each reed's position would affect the other. These higher notes took the most amount of time, as they required a high level of patience and finesse.

After the tuning process, I moved on to the voicing adjustment. This involved regulating the distance between the reeds and the pickups. The two adjustments I could make for this were lateral adjustments of the reeds relative to the pickup surrounding them, and a vertical adjustment of the pickup itself. I adjusted the lateral motion of the reeds first. To do this, I would play through the keys chromatically, and stop when I heard a note that was harsher or mellower than the others. A harsher tone would require me to move the reed closer to the center of the pickup. The pickup would produce fewer harmonics, resulting in a smoother tone. A more mellow tone on a reed would require me to move the reed closer to one side of the pickup in order to produce more harmonics for note.

The second adjustment I made for the Wurlitzer's voicing was to the pickup itself. Moving the pickup vertically affects the loudness of the note. The pickup consists of two toothed metal bars, so the only way to do this is with a screwdriver. While I was nervous to do this at first, I consulted the Wurlitzer manual to make sure I was making my adjustments properly. On the notes that were too quiet, I gently used a flathead screwdriver to bend the pickup tooth slightly upwards or downwards to match the consecutive notes.

The final parts of the mechanical alignment process were adjusting the let-off and damper height. The let-off adjusts the amount of key press before the hammer is struck. If this is too high, the hammer runs the risk of breaking off its reed. If this is too low, the reed will be struck too softly, and the tone will sound weak and quiet. In order to adjust this, I used a let-off tool specifically designed for Wurlitzer action. This tool had already been purchased by the maintenance shop, so I was able to use it for my adjustment. There were five keys that needed their let-off screw raised, and the adjustments were minimal. This slight change, however, contributed greatly to the overall mechanical regulation.

In order to adjust the damper height, a long screw that runs vertically through the damper assembly to the whip assembly must be adjusted. This process involved playing all of the notes, and loosening the damper screws on notes that sustained after the key was released. I had to be careful not to loosen these too much, however, as this could potentially dip the keys if tension is not present. Loosening the damper screws just beyond the threshold seemed to be the most appropriate method.

Evaluation

Part One - Recording

Recording the Wurlitzer was an incredibly important step in this process for me. I wanted an opportunity to show off the instrument I had been working on, but also to use my skills that I have developed over the last three years to present it in a well recorded piece. I wanted to choose a song that carried some history in it, and one that would work well with a full-band instrumentation. I landed on Donny Hathaway's arrangement of John Lennon's "Jealous Guy." The original track was recorded in 1971, and Donny Hathaway released his version in 1972. The version first released by Hathaway was live, and featured both piano and Wurlitzer. I decided to consolidate the two parts into just a Wurlitzer part, and switch the lead guitar for a lead saxophone. I kept the arrangement similar to Hathaway's, but I moved the key down a third from G major to E major. I also added a solo section out of the second verse. To transition from that section into the final chorus, I wrote a short walk down from the fourth note of the key to the root of the key.

While I wanted this to stand alone as its own recording, I wanted to pay a heavy homage to Donny Hathaway's amazing playing, and his ability to play and improvise live with a band. To achieve this, I recorded most of my track live. The drums, Wurlitzer, bass, vocals, and saxophone solo were all recorded together. This allowed for a looser performance and added to the "live feel" of the track. The rest of the additions, such as the background vocals, guitar, and tambourine were all layered on top of this original live take **(See App. B, 14)**.

Another way that I set out to achieve a more “vintage” sound in my recording was with my microphone choices. Many of the microphones used in the early 70s lacked some of the high frequency clarity that some modern microphones boast. This was one of the reasons for many songs from this era having a less “bright” or “harsh” tonality to them. One such microphone is the Sony C37, which I decided to use on the lead vocal of this track. This microphone has a tame high frequency response, but has a very rich upper-mid frequency response, which allows for clear vocals without the sibilant “ess” and “tee” sounds that some modern microphones can produce. Two other vintage sounding microphones that I used were Coles 4038 ribbon microphones. Also known as the “iron mic” due to its clothing-iron-like shape, the Coles 4038 is known as a very rich and warm sounding ribbon microphone. I used a pair of these as overhead mics for the drums, as their diminished high frequency characteristic leads to smooth cymbals and deep, punchy snare and toms **(See App. B, 15 and 16)**. Finally, I used a pair of Neumann TLM 103s to mic both of the Wurlitzer’s front speakers. While they are not vintage microphones, the Neumann TLM 103s have a reduced high frequency response similar to the other microphones that I used **(See App. A, 1)**.

Part Two - Comparison

Two other Wurlitzer 206s that were once alongside each other in a classroom were restored at some point. These two pianos reside in MTSU's recording studios A and B. In order to evaluate how my restoration stacked up to the other two, I brought them all into Studio A. I set them up beside each other, and I invited people to come and play them. The volunteers came and tried each piano one at a time, and they wrote down their thoughts about each. I created a scorecard for each Wurlitzer, and outlined several points to look for when playing them. These points included Playability, Tone Quality, and Noise.

The Wurlitzer from Studio A (Wurlitzer 1 on my judge sheet) scored fairly well. My volunteers commented that there were a few notes that sounded quieter than the others, but the tone was overall relatively even. According to my submissions (and also my own observation) the tone of this Wurli was a little more subdued, with less mid-frequency tone. To my ear, this piano sounded more like a Wurlitzer 200a, which was the successor to the 200. These amplifiers produced less harmonics than the 200, which gave them a more mellow tone. This Wurlitzer was also described as being quieter than the other two. Out of the three, the Studio A Wurli 206 was described as having the most in-tune reeds, which indicated to me that I needed to do another couple of tuning passes on mine. The volunteers noted that this Wurlitzer had some 60 cycle hum, but low noise.

The Wurlitzer from Studio B (Wurlitzer 2 on my judge sheet) sounded very distorted. The submissions from my volunteers all stated this, and commented on its tone quality. The mechanical action on this Wurlitzer was a little rough, and made more noise than the other two. Additionally, it had some 60 cycle hum from the AC power. This Wurlitzer was also marked as having little noise in the amplifier. Aesthetically, it looked the most rough and discolored, with the keys taking on a yellowish hue and the plastic top looking greyer than the others.

The Wurli 206 that I have been working on received very high marks for tone. My volunteers described it as having a “more lively tone,” and wrote that it sounded even across the instrument. The tuning was better than the Wurli from Studio B, but not quite as good as the Wurli from Studio A. The action received good ratings as well; the volunteers noted that it felt comfortable to play, and the keyboard tone was not overpowered by loud mechanical noise. My project Wurli had some 60 cycle hum, but slightly less than the other two Wurlis. I suspect a possible reason for this could have been the additional shielding that I put in place for the incoming AC lines. My volunteers wrote that this Wurli had somewhat of a hiss issue, which was not as apparent in the other two Wurlitzers. Some of the components that I had yet to replace were the signal transistors. These can be known to produce some circuit noise, so I will continue to test and alter this amplifier in order to improve its sound quality.

Summary and Conclusion

This restoration process brought me to the edge and beyond in many different areas. My skills as an electronics engineer were expanded drastically as I learned about the operation and inner workings of the Wurlitzer's amplifier. My mechanical knowledge was challenged as I learned how to adjust the action of the keys. My woodworking skills developed as I took several attempts to create panels for the piano's fuse and AC receptacle. My musical knowledge was tested as I spent many hours tuning and adjusting the tone and intonation of the piano. My audio engineering skills were put to test as I recorded the Wurlitzer live alongside other instruments.

Overall, I am proud of where I have gotten with this Wurli in a year, and hearing it alongside two other Wurlitzers which had been previously restored made me feel good about my successes. I have not done a perfect job at restoring this Wurli 206, but it is something that I will continue improving and working on in my final year at MTSU. I will take this knowledge with me after I graduate, and I hope to have the opportunity to own my own Wurli one day. It excites me to know that when I am gone, this piano will be used by many students, and will end up on many recordings coming out of the program in which I spent so much time and energy. I hope the future MTSU musicians, engineers, and producers will find the inspiration in this instrument that first captured me a year ago.

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Appendix A - List of Terms

Wurlitzer Electric Piano - Electric piano manufactured by the Rudolph Wurlitzer Company. Also known as a Wurlitzer, a Wurlitzer EP, or a Wurli.

Tolex - Textured vinyl material used in covering some Wurlitzer EP models, guitar cabinets, books, and upholstery.

Key Bushing Felts - Recessed felts on the underside of a key. These recessions match up with pins on the keybed, and help the key to stay in place. Felt is used to eliminate friction and key noise.

Tremolo - A periodic modulation of the amplitude of a signal. Most Wurlitzers have this effect built in, but it is labeled as "Vibrato." True vibrato, however, is a modulation of pitch, which cannot be done within the circuits present on Wurlitzers.

Reed - Also known as a tone reed. These are flat pieces of metal cut to specific lengths. A certain amount of solder is added on the tip to achieve the correct pitch for each note.

AC - Alternating Current. An electrical signal that constantly changes its current direction. This type of current is present at every wall socket, and it is the type of current that represents electrical audio signals.

DC - Direct Current. A steady current that is used within most devices to provide constant voltages.

Amplifier - Electrical circuit used to increase the amplitude of a signal.

Pre-amplifier - Also called a preamp. These types of amplifiers handle smaller signals, such as the signal from a microphone, or from the pickup on a Wurlitzer.

Dremel - Multi-purpose tool used for cutting, drilling, sanding, etching, and carving.

Electromagnetic Interference - Undesired noise in a signal path that originates from outside the path. This can be caused by radiated electrical or magnetic fields from virtually any device.

Printed Circuit Board (PCB) - PCBs are used to allow complex circuits to be stably created, and they usually do not require additional wires to make electrical connections. These connections are instead printed onto the board.

Reedbar - The part of a Wurlitzer that holds the pickup. This is responsible for transducing the vibration of the reeds into an AC voltage.

Electrical Short - An unintended current path within a circuit. This can be a potential hazard, especially in high voltage and high current circuits.

Capacitor - Electrical component that stores a DC charge. In audio circuits, capacitors can be used to couple amplification stages together, as they will pass an AC signal without passing any DC. Capacitors can also be used to filter unwanted frequencies in AC circuits.

ESR - Equivalent Series Resistance. Ideal capacitors have no DC resistance. There is, however, an amount of inherent resistance that is present from the design of the component. A lower ESR rating for a capacitor is more ideal, and will result in a lower voltage drop across the component.

Transistor - An electrical semiconductor used for non-mechanical switching or AC signal amplification.

Diode - A semiconductor used for circuit protection and power rectification. These components allow current to flow in only one direction.

Forward/Reverse Bias - Forward bias is a state in which a diode is "on" and allows current to flow. Reverse bias is a state in which a diode is "off" and will not allow current to flow.

Tantalum - Element with the atomic number of 73. It is a conductive transition metal used in some electrical components.

Constructive Interference - An addition to a signal that reinforces it, increasing its overall amplitude.

Potentiometer - A resistor with a variable value. These generally have a set maximum resistance and a minimum resistance. Also known as a "pot". The center "wiper" moves along the resistive portion of the potentiometer to change the resistance.

D.I. Signal - Direct Injection Signal. This type of audio signal is a pre-amplified signal that has only been processed in the electrical domain. Commonly used for recording bass guitars and electric pianos.

Cents - Musical description of frequency relative to a pitch. There are 100 cents in one half step interval (B to Bb), and 200 cents in a whole step interval (B to A).

Harmonics - Stacked tones above a fundamental pitch of a note. These additional tones cannot be individually discerned; they blend with the fundamental to create the timbral portion of a pitch. The brain uses harmonics to discern a piano playing a Bb from a flute playing a Bb, for example.

Harp - The part of a Wurlitzer to which the reeds attach. This piece is separated into two halves for low and high notes.

Whip - The part of a piano action that transfers the energy from the key press to the fly.

Fly - The part of a piano action that transfers the energy from the whip to the hammer. This part is designed so that the hammer will strike the note and fall quickly, even when the key is still depressed.

Hammer - The part of a piano action that strikes the note. Hammers on a Wurlitzer are attached to a pivot joint that connects to the main rail.

Appendix B - Media

1: Recording

The following is a link to the recording I made of “Jealous Guy” by John Lennon and arranged by Donny Hathaway. This song features the Wurlitzer 206 electric piano live alongside a band.

Jealous Guy - Brady Armstrong Honors Thesis.wav

Appendix C - Photos

Picture 1:

Wurlitzer 112: One of the first commercially available Wurlitzer Electric Pianos

Source: Wikimedia Commons

Picture 2:

Wurlitzer 112 advertisement, June 11, 1956.

Source: [Doc Wurli]

Picture 3:

Ray Charles playing a Wurlitzer 120, sometime between the late fifties and early 60s.

Source: [Doc Wurli]

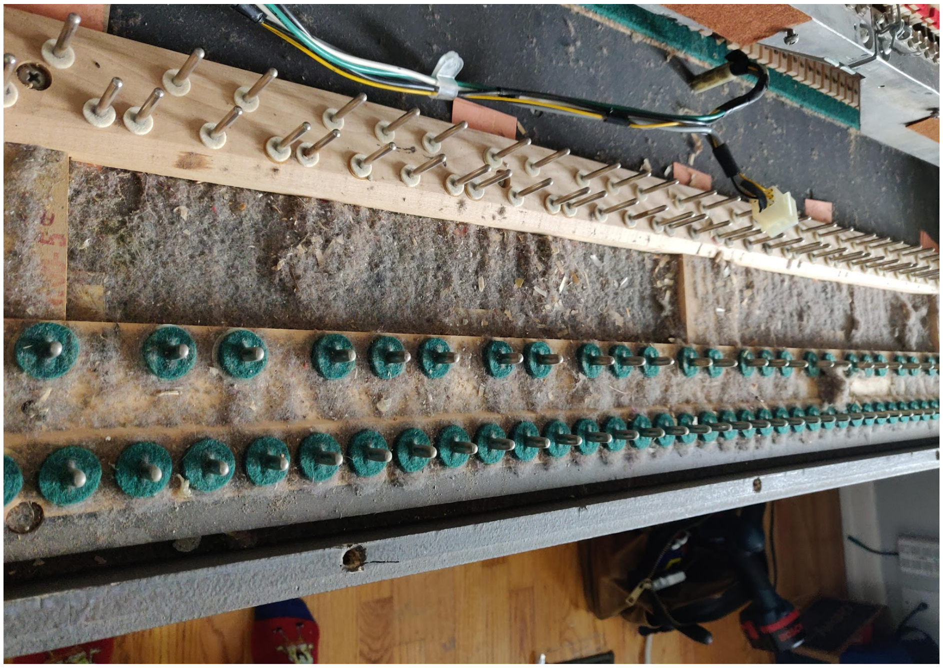
Picture 4: Full body of Wurlitzer 206 in its original condition.

Picture 4.1:

Keybed and amplifier in original condition.

Picture 5:

Years of dust and grime under the keybed



Picture 6:

Front panel of the Wurlitzer after cleaning with convertible top cleaner

Picture 7:

Gluing the Tolex down

Picture 8:

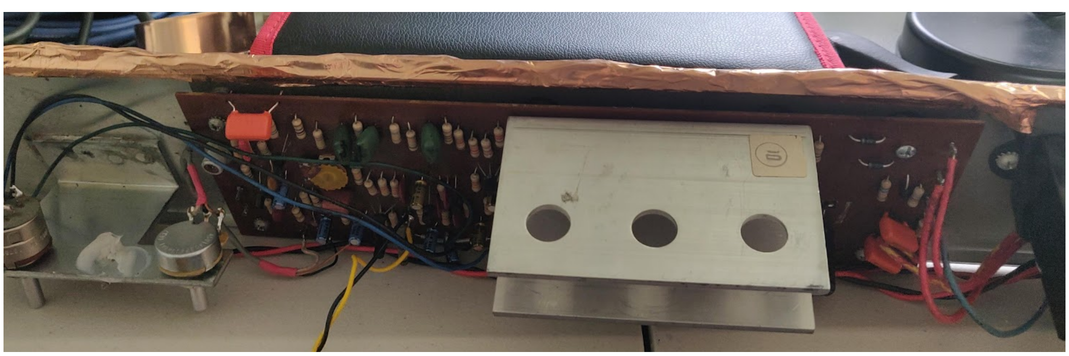
New Wurlitzer knobs and faceplate from Vintage Vibe.

Picture 9:

First attempt at making a panel to hold the receptacle. Cuts were off and the hole was bored too large.

Picture 10:

Shielding of AC lines. Note the copper tape running along the back edge of the amplifier rail.



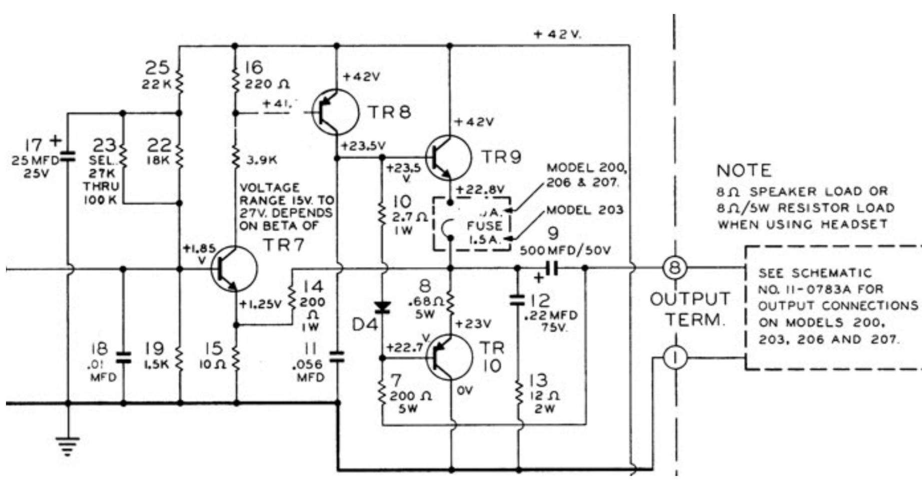
Picture 11:

Tropical Fish Capacitors. Varying colors represent the values of the capacitors.

Source: [StackExchange Blog]

Picture 12:

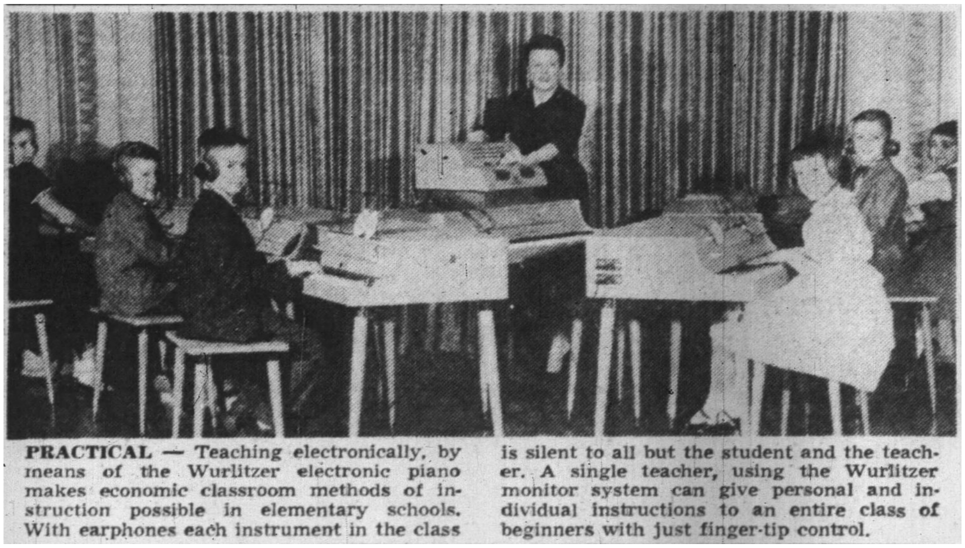
Power amplification stage of the Wurlitzer 206. Note TR9 (NPN transistor handling the top half of the waveform) and TR10 (PNP transistor handling the bottom half of the waveform)



Source: Wurlitzer 206 Amplifier Schematic

Picture 13:

Wurlitzer classroom circa 1956. This classroom is using earlier models, most likely around the time of the 120 models. The “Teacher” model of this line was the model 820.



PRACTICAL — Teaching electronically, by means of the Wurlitzer electronic piano makes economic classroom methods of instruction possible in elementary schools. With earphones each instrument in the class is silent to all but the student and the teacher. A single teacher, using the Wurlitzer monitor system can give personal and individual instructions to an entire class of beginners with just finger-tip control.

Source: [Tropical Fish Vintage]

Picture 14:

Setup for the recording session. Franke Burgarino (Left), Me (Center), Will Thorley (Right). Off camera is my bassist, Garrett Tonos.

Picture 15:

Sony C37a Vintage tube mic used for vocals on my recording of "Jealous Guy."

Picture 16:

Coles 4038 ribbon microphone. A pair of these microphones was used for the overhead mics on the drums for "Jealous Guy."

Source: Mixdown Mag