Clara Rockmore RCA Theremin Report

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Contents

1 Introduction

On 27 and 28 March, 2012, Andrew Baron and Mike Buffington came to the Musical Instrument Museum (MIM) in Phoenix to study Clara Rockmore's RCA Theremin (serial number 100006), which was known to have been modified by the instrument's inventor, Leon Theremin. The purpose of the visit was to establish the extent to which this instrument had been modified, and to conduct dynamic tests under power. A summary of Leon Theremin's modifications, and what each would have meant to Clara as a performing artist, appears in section 9. A summary of the modified parts of the circuit appears in the Appendices.

Powered testing enabled us to evaluate how its performance parameters[1] differ from a standard production version, how these differences may have enhanced the instrument's performance and what these differences might have enabled Clara to do more easily. Dynamic testing also provided an opportunity to document a baseline of specific live data, that would be of value in the event future repairs are needed.

This report documents the data we were able to compile over a two-day period of study, the nature of the modifications, the discovery of a defect and details of its repair, and the operating condition of the instrument before and after the repair. We found the instrument to be essentially operational as we understood it would be, since Peter Sherman had demonstrated it at the MIM at an earlier date.

Our mission was originally intended to be the study of the modifications made by Leon Theremin and Bob Moog, essential data documentation, and vacuum tube testing. However, this extended to reconditioning of various electrical connections and the minor repair noted above. Finally, a set of waveform photographs was made to document the current voice of the repaired theremin, and to serve as a visual reference to facilitate future repairs.

Naming convention

In this report, to more clearly differentiate between the instrument "theremin" and the inventor "Theremin," we use the inventor's Russian name *Termen* when referring to him or his work on this instrument.

A note on octave ranges

There is a difference between the actual (measurable) octave range, the repeatable octave range and what Clara would likely have perceived as the usable octave range.

This can best be explained by stating that the highest and lowest notes are inherently subject to a certain amount of instability; i.e., they tend to drift in the physical space of the playing arc while the broader mid portion of the pitch range remains relatively stable in space. Thus, a measurable range may be found to have gained or lost a note or two at each end when measured subsequently. The repeatable range represents the total pitch response that can be

[1] Range, linearity (interval spacing), tone quality, sensitivity and responsiveness, etc

measured with certainty in a multiple sampling. Therefore, for practical playing purposes, an instrument with a measurable octave range of six octaves and a repeatable range of five octaves, might have been considered by Clara to have a usable range of three octaves.

2 Defects Noted

- One wire connection and the insulation on a number of wires were found to be compromised. Wire insulation degradation was noted in two categories:
  - Dry rot, not immediately hazardous (primarily limited to the pair of wires serving the UX-199 filament).
  - Mouse damage, severing one wire entirely and damaging three others. The dismembered wire was from the secondary winding of an interstage transformer and initially appeared to be missing. Two sections of the wire were later found inside the cabinet, photographed, and bagged. Peripheral damage to a second transformer wire and the outer insulation on two additional wires in the instrument chassis (Figure 1) were noted, but do not pose risk to the safe operation of the instrument. The damage is limited primarily to the wires noted above, with no droppings or other evidence within the otherwise clean chassis and cabinet. The severed connections were limited to one inter-stage transformer wire and one solder lug on the voltage divider.

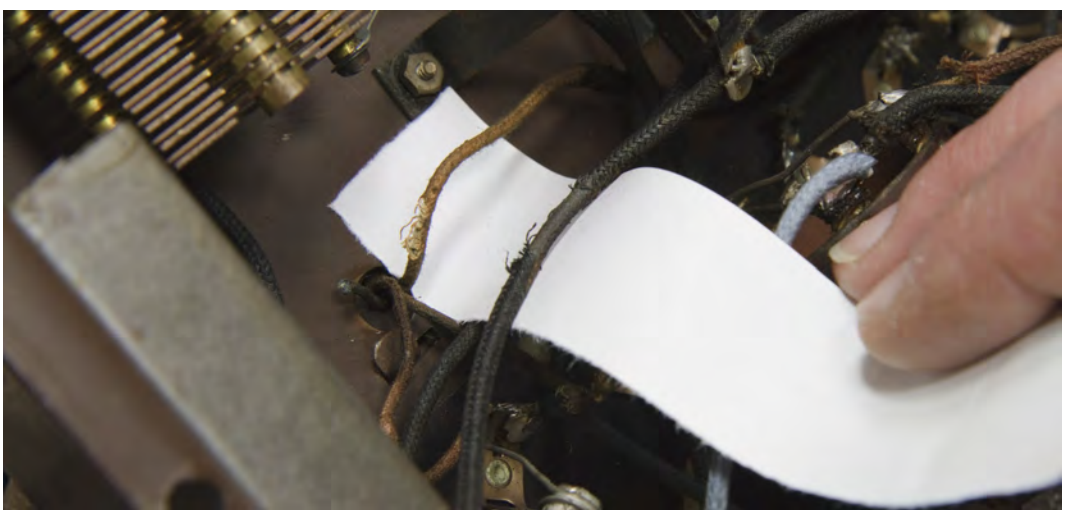


Figure 1: Outer insulation wire damage.

- The UX-199 vacuum tube tested very weak (see 7.1 Vacuum Tube Test Results).

- Dull, oxidized electrical contacts that can adversely affect performance and reliability were evident in numerous locations. Locations included: Resonance and induction coil retaining nuts and wire lugs, Hold-down nuts and threaded posts on the capacitor stacks, all 44 stacked capacitor eyelets, 36 vacuum tube pins and 36 tube socket contacts.

3 Performance Factors

- A range of five actual octaves was observed, from approximately C2 to C7. This range is slightly more than half of an octave lower than a stock RCA Theremin at the bottom end, and a little more than half of an octave higher, at the top end.
- A notable degradation of sound quality toward the low end of the range was observed. Tone quality in the mid to upper ranges was better than typical RCA theremins.
- Volume response was found to be slightly faster than a stock RCA. This may reflect modifications as well as optimization of the volume oscillator trimmer adjustment.
- Total available volume was impressively high, given that the RCA's built-in amplifier has less than one watt audio output (0.79 W). We understood from our prior research that a JBL M31–4 speaker is especially well-suited for efficiency with the RCA amplifier.
- All components and prior work appear to date from the 1930s and the October 1998 work done at Moog Music. No evidence of other repairs or components manufactured at other times is noted.

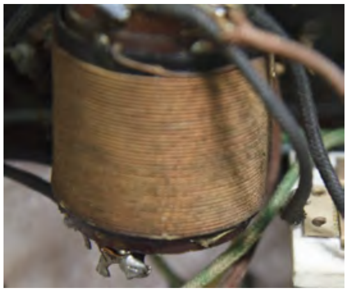
4 Prior Modifications

4.1 Lev Termen Modifications: 1930s

One of the mysteries yet to be solved is whether Termen's extensive modifications were made prior to, or after his falling out of communication with Clara (prior to mid to late 1933, or from late 1936). Initial indications are that the work dated from the early 1930s, although it's quite possible that modifications were done on more than one occasion.

Termen's modifications were found to be much more extensive than we expected. We knew in advance that he had augmented the factory circuit with his "trademark" capacitor stacks (to facilitate convenient calibration of pitch oscillator frequencies; see Appendices), and that there was a tone control added to the front panel of the cabinet.

What we didn't know until now is that in addition to the two modifications noted above, the three oscillator coil forms under the metal chassis had been stripped of their factory



(a) Volume Oscillator

(b) Fixed Pitch Oscillator

(c) Variable Pitch Oscillator

Figure 2: The three re-engineered oscillator coils.

wires and were re-wound by Termen to entirely different specifications based on his own calculations. The concentrated coil and the volume resonant coils were also significantly altered. This involved winding six new coils and removing hundreds of turns of wire from the volume coil and the concentrated coil, within the base of the pitch control resonant coil (PCRC).

Figure 3: Altered concentrated coil located inside the PCRC.

4.1.1 Cabinet Modifications

The theremin has metal reinforcements on the outside and inside of the cabinet, to strengthen the legs. We have seen similar reinforcements on two theremins built by Termen: the 1933–1934 Theremin Studio theremin housed in an RCA Theremin cabinet, and the 1929–1930 possible RCA prototype theremin in a visually similar but non-RCA Theremin cabinet.

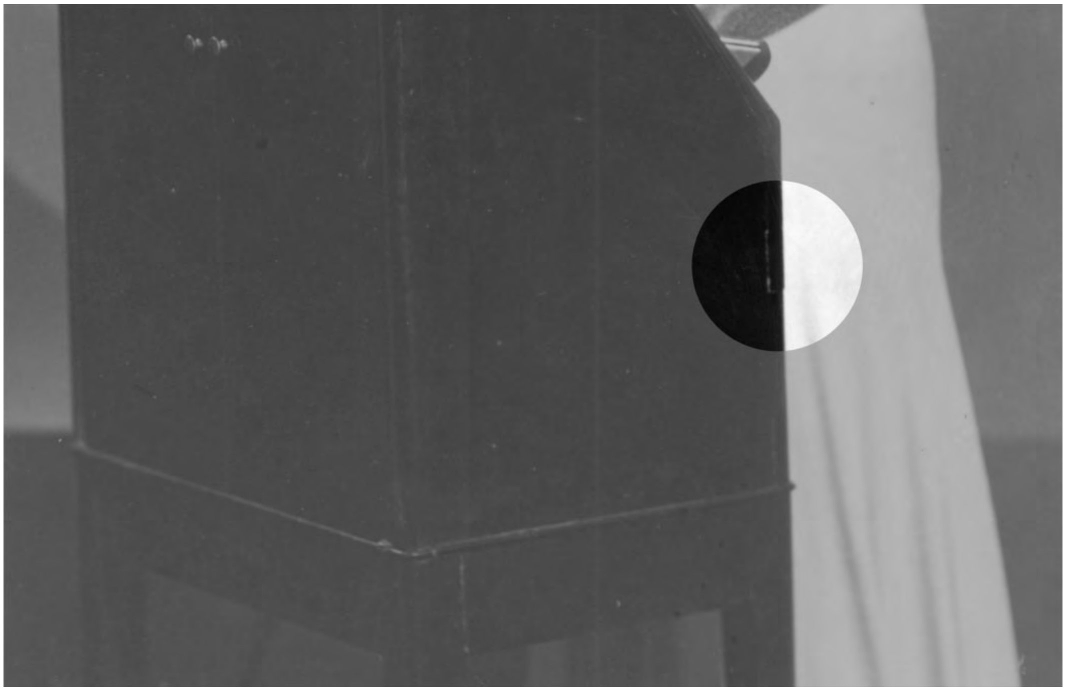


Figure 4: The crack in the cabinet occurred prior to this 1932 photograph.

The front panel of the cabinet had separated slightly, and had been reinforced by screws. A detail from a circa 1932 promotional photo of Clara with this theremin (Figure 4) shows this separation. The metal brackets were installed after this photo was taken.

4.2 Bob Moog and Stephen Dunnington[2] Modifications: October 1998

The work performed by Bob and Stephen can be summarized as serving four primary purposes:

- Safety, with a new grounded AC power cord and ground bus extending to both chassis. Additionally, several of the original fabric-insulated wires in and around the chassis were replaced with new fabric covered wire (with modern core insulation).
- Stability and updating of connecting cables. Stability updates included the installation of two sets of terminal strips on the cabinet floor to serve as junctions for all wire connections between power and speaker cords, chassis grounds and tone control.
- Components added and/or replaced. An AC line noise filter (capacitor wired from one side of the AC power line to ground) was installed, a capacitor that is part of the tone

[2]Bob's inscription bears the name Dunningham, which is incorrect

control was replaced (at one of the terminal strips), and a capacitor across the amplifier audio output terminals was added or replaced. A new output transformer was installed on the cabinet floor.

- Updating of the wiring (in addition to all new wiring relating to the above changes), involved eliminating an earlier custom arrangement in which the speaker output was hard-wired with high-voltage cable for the older style of speaker originally used with the theremin; replacing it with simple two-conductor speaker wire for the more up to date permanent-magnet speaker.

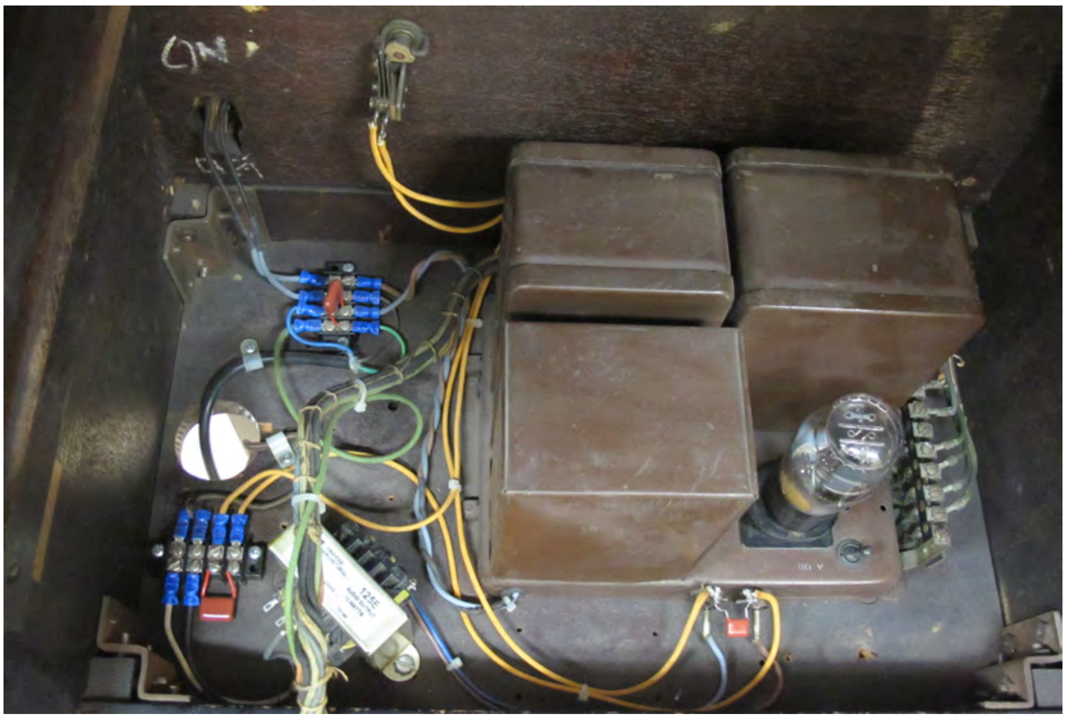


Figure 5: The modifications done by Bob Moog in 1998.

Finally, it appears that tube test results at that time warranted the replacement of two of the vacuum tubes; the 24A and the 27 in socket positions I and II.

5 Repairs Made by Theremin Experts: 27 and 28 March 2012

5.1 Repaired Transformer Wire

An otherwise simple repair was complicated by the fact that the damaged wire had been sheared where it enters the chassis, making access extremely limited (Figure 6).

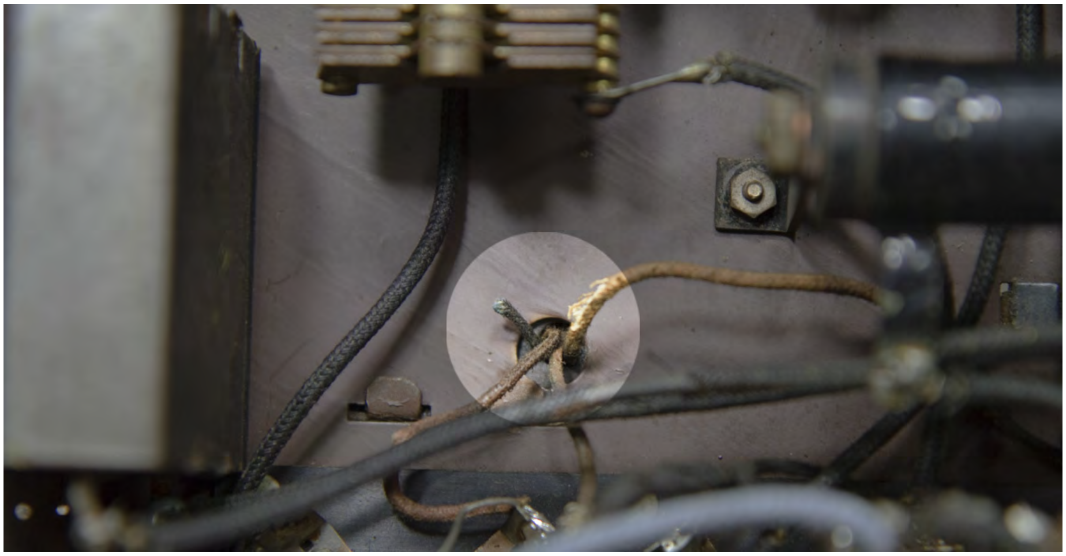


Figure 6: Transformer wire damage: the highlighted black wire was found severed.

Removing the transformer to facilitate access would have involved invasive procedures and consequently was not considered to be appropriate. Removing the transformer would have risked damage to the paint and structural integrity of the mounting tabs.

Only a $\frac{5}{16}''$ stub of stranded wire remained at the level of the metal chassis. Complicating the repair further, the strands of the transformer wire are very fine; approximately as thin as the woven fabric strands of the surrounding insulation. A dental tool was used to tease apart the woven insulation on the remnant wire, and the insulating fibers were then removed, leaving $\frac{1}{8}''$ of insulation at chassis level, and about $\frac{3}{16}''$ of exposed wire strands.

Oxidization of the wire could have compromised effective soldering, so the strands were fanned and lightly shaved to expose bright metal, twisted and formed into a tight hook, and then tinned with solder. A length of 1929 RCA wire of the same gauge and insulating material was soldered to the prepped wire; the joint then insulated with heat-shrink tubing. The schematic was consulted to establish the correct junction for the other end of the wire (grounded side of 550 Ω divider resistor). The terminal was cleaned and the wire soldered.

5.2 Multiple Contacts Reconditioned

Multiple contacts compromised by oxidization were polished using a fiberglas burnishing tool. These included all tube pins, sockets, coil wire posts, all stacking capacitor assemblies, etc., as noted at the end of section 2 on page 5.

5.3 Repair Results—Improved Performance Factors

At the start of day two the instrument was powered up and tested to check the functional outcome of our repairs. Improvements were noted as follows:

Pitch range
Notably improved as a result of the restored transformer connection, now covers a range of six actual octaves from slightly below C1 to slightly above C7, representing a gain of one full octave, or about 2.5 octaves greater than a standard production RCA.

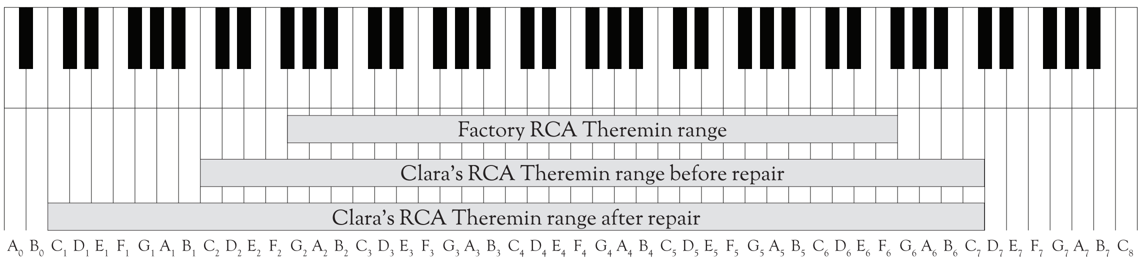


Figure 7: The range of a stock RCA Theremin and Clara's RCA before and after repairs.

Tone quality
The second notable improvement was to the tone quality, which following the repair was cleaner and more transparent across the entire range, and very much improved in the middle and low end of the range. The audible distortion/degraded sound heard on the first day was essentially eliminated after the repair. As tuned by Termen for Clara, there would normally be some desirable distortion of the wave-shape (as opposed to pure sine wave), but the goal of this type of distortion is to enhance or enrich the sound. The timbre that we heard after the repair is characteristic of these desirable qualities.

6 Measurements

6.1 Electrical Measurements

The goal of obtaining electrical measurements was to establish a base line for further study. By comparing the electrical characteristics of Clara's RCA Theremin to the standard production model, we can better understand the extent and reasons for Termen's modifications and begin to assess how these technical differences translate to functional differences that would have made this particular instrument better suited to Clara's artistic needs.

Obvious results of Termen's modifications are the additional octaves and improved tone quality. Further study of the electrical measurements will shed light on how he was able to achieve these results, and may reveal additional engineered details that contributed to the sensitivity, linearity and stability of the instrument.

A summary of the types of measurements, and junctions from which they were taken appears below. For detail and actual figures, refer to the Appendices.

- Frequency Measurements: *Variable* Pitch Oscillator, at full clockwise (100% Meshed[3]), and full counterclockwise (0% Meshed) settings of the control knob, at distances of hand-proximity at approximately 5 feet, 1 foot, six inches, one inch and fingers touching antenna. Frequencies were measured at control grid and plate of the type 27 variable pitch oscillator tube.
- Frequency Measurements: *Fixed* Pitch Oscillator, clockwise, center and counterclockwise settings of the control knob, at distances of hand-proximity at approximately 5 feet, 1 foot, six inches, one inch and fingers touching antenna. When all circuits are functioning normally, there should be no material change in the frequency of the fixed pitch oscillator, in relation to hand position, as was found to be the case during these tests. Frequencies were measured at control grid and plate of the type 27 fixed pitch oscillator tube.
- Voltage Measurements taken at the *Variable* Pitch Oscillator control grid and plate. Monitored line voltage of 117 VAC, voltage switch on the SPU in 120 position.
- Voltage Measurements taken at the *Fixed* Pitch Oscillator control grid and plate. Monitored line voltage of 117 VAC, voltage switch on the SPU in 120 position.
- The six windings on the three oscillator coil forms (one for the volume circuit, two for the pitch circuits) were measured in circuit for resistance and inductance.
- The two windings in the Pitch Control Resonant Coil (solenoid winding on large form, concentrated coil inside base) were measured for resistance and inductance.
- The trio of parallel capacitors inside the PCRC was measured for total capacitance.
- The Volume Resonant Coil (solenoid windings on large form only) was measured for resistance and inductance.
- The "tone resistor" at the control grid of the 24A mixer tube (grid cap) was measured for resistance. It is to be noted that in this case the tone resistor is not an RCA-manufactured component, indicating that it was likely part of the modifications personally conducted by Termen.
- The eleven mica capacitors in the capacitor stacks were individually documented (value in microfarads; MFD).

[3]Mesh refers to the plates of the variable capacitors that are adjusted with the control knobs.

- The values of the three replaced capacitors (1998) in the lower cabinet were documented.
- The manufacture and model of the 1998 output transformer were noted.
- The manufacture and model of the speaker driver were noted.
- All tubes were tested on a Hickok type 534 Mutual Conductance tube tester.
- Oscilloscope waveforms, taken at the audio output terminals, were photographed at various points throughout the pitch range, and with the tone control switch in each of two positions.

6.2 Antenna Measurements

In addition to electrical measurements, the physical density of both antennas (by weight) was compared to standard production antennas.

Although the antennas on Clara's RCA appear similar to the factory-made units, they are in fact custom-made. Physically the same size, the pitch antenna which on the standard production unit is hollow, on Clara's RCA is solid. The stock RCA pitch antenna weighs 7.2 ounces. The six-ounce heavier customized antenna on Clara's RCA measures 13.2 ounces.

The added density, in combination with other improvements, may contribute to an improved responsiveness in the pitch circuits of Clara's RCA. We have also noted that when using Clara's custom pitch antenna, the low end of the pitch range increases by ± one-half octave when compared to the stock RCA antenna.

The custom volume (*loop*) antenna was found to be 2.6 ounces lighter, weighing 9.2 ounces compared to 11.8 ounces for the stock RCA volume antenna.

7 Vacuum Tubes

The vacuum tubes in the instrument are labeled I through VIII, corresponding to their socket positions. Vacuum tubes IV through VII appear to be of 1930 to 1932 manufacture. Vacuum tubes I and VIII date from circa 1933. Vacuum tubes II and III were likely replaced (with vintage replacements) in 1998 by Bob Moog.

7.1 Vacuum Tube Test Results

The installed set of tubes were found to be good or borderline acceptable, with the exception of the UX-199, which is weak enough to cause possible problems with the volume response. We recommend that it be rejuvenated using prescribed procedures[4] or replaced to improve

[4] Recommended procedure for rejuvenation of the UX-199 is found on page 441 of "Radio Physics Course" (second edition) by Alfred Ghirardi.

future reliability of the instrument.

Tube	Tube Type	Test Result	Manuf. Spec.	Quality Test	Shorts	Leakage
I	UY-227	840	1000	Fair	OK	OK
II	UY-224	820	1000	Fair	OK	OK
III	UY-227	950	1000	Strong	OK	OK
IV	UY-227	970	1000	Strong	OK	OK
V	UX-199	255	425	Weak	OK	OK
VI	UY-171	1290	1650	Fair	OK	OK
VII	UY-171	1260	1650	Fair	OK	OK
VIII	UX-280			P1: Low, P2: Low	OK	OK

Table 1: Tube test results.

7.1.1 Relevance of Termen's 1930s Test Result of Tube VII (UX-171A)

If Termen was using the same protocol as we employed in the tube testing; i.e., first figure is actual test result, second figure is manufacturer's specified mutual conductance rating in Micromhos, then Termen's test result (Figure 8) verifies our test result and vice-versa.

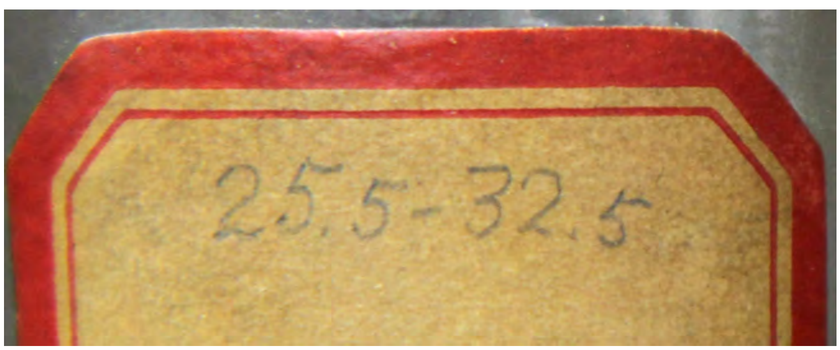


Figure 8: Termen's markings on tube label VII: test number followed by reference number

To add substance to this supposition, we need to make an assumption that Termen was using state-of-the-art tube testing equipment at his laboratory: a mutual conductance type of tester. If Termen employed a tester with a calibrated mutual conductance meter, his results can simply be scaled to compare to RCA's Micromho rating for the UX-171A. Scaling both the test number and reference number by the same multiplier (here we've chosen the integer 50 to get close to the stated Micromho specification of 1620 in the RCA tube manual *R-10* from 1932) can be seen in equations 1 and 2:

$$25.5 \times 50 = 1275 \quad (1)$$

$$32.5 \times 50 = 1625 \qquad (2)$$

We see that Teremen's adjusted Micromho reading of 1275 is extremely close to our Micromho reading of 1260. Termen's reading is slightly higher, as we would expect it to be with somewhat fewer hours of use on that tube at the time of Termen's test.

In order to more precisely equate Termen's result to the later RCA standard of 1650 Micromho (which we used in our tests), we would then scale the test result and manufacturer's rating by a multiplier of 50.77, as shown in equations 3 and 4:

$$25.5 \times 50.77 = 1294.635 \qquad (3)$$

$$32.5 \times 50.77 = 1650.025 \qquad (4)$$

Termen's scaled test result, compared to our reading of 1260, again shows a reasonable relationship between two readings that were taken about 78 years apart.

By comparing these readings, we can also conclude that Clara's RCA was subjected to relatively little cumulative operating time, between Termen's test, and the time of Clara retiring this instrument in favor of Termen's custom theremin; such time perhaps being limited to the dozens or hundreds of hours at most.

8 Diamond Speaker

The speaker that accompanies Clara's RCA Theremin is mounted on a rhombus frame, elevated to head-level by supportive pipe. This speaker design is often called a diamond speaker or a *Carnegie Hall* diamond speaker, since ten RCA Theremins were demonstrated with this style of speaker in Carnegie Hall on April 25, 1930.

8.1 Measurements and Documentation

Clara's diamond speaker consists of a heavy, solid mahogany base, $20'' \times 20''$, 4 inches high, with a gable roof with a slope of approximately 12 degrees. The base is made of laminated wood boards (between 1.5 and 2 inches thick) with solid panels for the roof ($\frac{27}{32}''$ thick) secured with nails around the perimeter, hidden under the finish. The speaker poles consist of four steel schedule 40 pipe; two poles each side, coupled in the middle serving as supports to hold up the square baffle board. The baffle board is $\frac{7}{8}''$ thick 2-ply veneered wood, covered on the front with speaker cloth and a metal woven grille, and contained by a frame of steel angle stock. Each piece of the angle stock is attached to the board with three screws on the side. One angle stock piece has the words "Made in Germany" stamped into it. This material could have come from Termen's time in Germany and traveled with him to the US.

Figure 9: The 10 Victor Theremin ensemble in 1930.

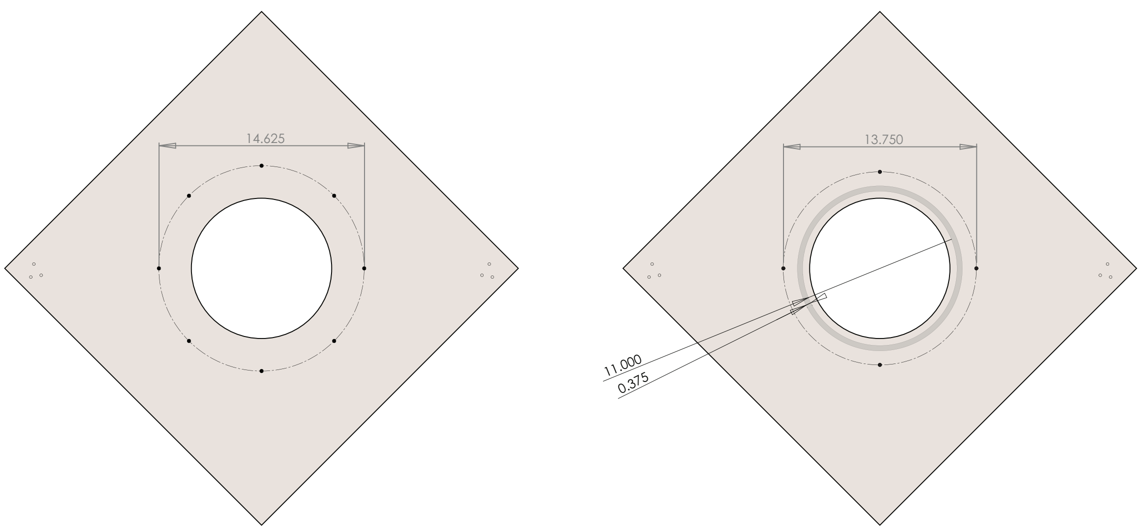


Figure 10: Left illustration shows current hole configuration for JBL speaker. Right illustration shows location of 4 mounting holes for an RCA 106 Loudspeaker and impression from the insulating ring, normally hidden under the JBL speaker.

8.2 Speaker Driver History

The current speaker driver, which may date to circa 1970s, is attached to the baffle board, is a JBL M31–4 (with a matching transformer mounted on the cabinet floor of the theremin). The original speaker driver was an RCA 106 Electrodynamic Loudspeaker, as evidenced by a different set of mounting holes on the baffle board. The JBL speaker uses eight mounting holes evenly spaced around a circle that is $14\frac{5}{8}''$ in diameter. RCA 106 Loudspeakers use four mounting holes evenly spaced around a circle that is $13\frac{3}{4}''$ in diameter. See Figure 10 for a visual comparison of the mounting holes.[5]

8.3 Speaker Origin and Other Evidence

Photos of Theremin Studio in 1930 have various diamond speakers behind the instruments and performers. Some speakers have major differences but most look similar to Clara's (for example, one has a closed baffle with an angled front grille). While it is clear that Clara's diamond speaker originated from Theremin Studio, it is also possible that Clara's could be one of the speakers photographed. She likely would have received her speaker along with the theremin after these photos were taken. However, a close inspection of the photographs reveals that many of the speakers do not show a visible pipe coupling like Clara's.

This is the only complete circa 1930 diamond speaker known to survive. The remnants of a diamond speaker exist in a Termen-built theremin currently owned by Gene Segal[6]. This speaker's baffle board was cut down and attached to a cabinet with wheels on which the theremin is also attached. Inside, an RCA 106 Loudspeaker is screwed to a $\frac{7}{8}''$ thick, dark-stained baffle board, which has the same grille cloth and metal weave grille as Clara's. A notable difference is that an 8″ diameter speaker hole was cut into the board, unlike the 10″ diameter found in Clara's (which, due to the stain around the hole, is likely original).

It is possible that a diamond speaker accompanies Henry Solomonoff's left handed Termen-built theremin (current owner and location unverified). Lucie Rosen's RCA Theremin would have likely had a diamond speaker with it, as seen in an old photo of Lucie playing her RCA. The location of Lucie's RCA and diamond speaker is currently unknown.

9 Modification Study

Summary of Seven Modifications Made By Termen in the 1930s

- Wire coils are modified with different wire and/or non-standard number of turns.

[5] Figure 16 in the Appendices shows all the visible holes in the back of the baffle board: two sets of speaker holes, others unidentified.

[6] See http://rcatheremin.com/30right.php

- Capacitor stacks on four separate platforms, adding a total of 11 additional capacitors, have been mounted to the rear of the upper chassis shelf. The capacitor stacks are wired to the pitch and volume oscillators.
- The volume modulator tube, type UX-120 has been replaced with a type UX-199.
- Custom antennas have been installed.
- A panel-mounted two position tone-control switch has been added.
- The tone resistor on the 24A mixer tube has been replaced or installed with a non-RCA unit.
- Tubes were selected for best sound and stability, and hand-numbered on paper labels for socket position. Note that there are three type 27 tubes used; two in the pitch oscillators, and one in the audio preamplifier. Although the tube types are the same, installing them in a different order than specified can affect the tone quality.

A summary of what Lev Termen did (Technical Application), and what these changes would have meant for Clara (Practical Result).

The information presented below is based on preliminary observations only. Further study is recommended to verify the accuracy of the comments and improve the content.

9.1 Pitch Range and Space-Control Interface

9.1.1 Increased Pitch Oscillator Frequencies

Technical Application
Substantial alterations to the coil windings and their associated capacitances (a combination of the RCA capacitors and the total values of the added capacitor stacks), radically raised the pitch oscillator frequencies from the normal 172–175 kHz of the standard RCA Theremin to approximately 234 kHz. A wider difference frequency was thus obtained.

Practical Result
This translated to a substantially augmented pitch range, adding more than an octave to the bass and about half an octave to the treble. Unusually good linearity (interval spacing) and stability are also noted with this instrument.

9.1.2 Reduced Concentrated Coil

Technical Application
Hundreds of turns of wire were removed from the concentrated coil (located inside the base of the PCRC), reducing it to nearly half of its original resistance and inductance.

Practical Result
This may have effectively increased the capacitance of Clara's pitch hand, enabling it to be a larger percentage of the total, giving her a greater frequency swing with her small hand, and making the instrument more responsive to smaller motions of the fingers and hand. The solid pitch antenna may have had played a part in this formula.

9.2 Tone Quality

9.2.1 Tone Resistor at 24A Control Grid

Technical Application
The resistor located at the end of the wire that connects to the top of the 24A mixer tube has an important role in balancing the input of the sine wave from the fixed pitch oscillator, with the input of the sine wave from the variable pitch oscillator. The resistor found at this location was a non-RCA type, and can be assumed to have been hand-selected and installed by Termen.

Practical Result
Careful selection of this resistor will yield the most pleasing tone quality or "voice" of the instrument.

Figure 11: Non-RMA color coded 14,100 Ω resistor.

9.2.2 Pitch Oscillator Tube Selection

Technical Application
Auditioning different tubes for installation in the two pitch oscillator sockets can materially alter the tone quality. The tubes installed in these sockets on Clara's RCA were changed from the originally installed set, when the instrument was still relatively new, implying that

tone-tests may have been done by Termen (possibly working with Clara) to achieve the best combination of pitch tubes.

Practical Result
Careful selection or auditioning of the pitch tubes will further optimize the tone quality. Possible significance to determining whether Termen's modifications to Clara's theremin took place in the early 1930s or later, is that the factory engraving on the base of the pitch tube in socket position one is known to have been in production in 1933. Likewise, the style of glass on this tube wasn't in common use until early 1933.

9.2.3 Added Tone Switch

Technical Application
A two-position rotary switch has been added to the vertical front panel of the cabinet, and wired to selectively shunt or disconnect a 0.12 μF capacitor across the speaker pin jacks of the Socket Power Unit.

Figure 12: This two-position rotary tone switch was added by Termen.

Practical Result
The added switch would have given Clara a choice of two tonal qualities. In actual observation it was found that the tone quality of the instrument when this switch is in the

counterclockwise position was not as pleasing as that heard in the clockwise position.[7]

9.3 Volume Response

9.3.1 Volume Modulator tube substitution

Technical Application

Termen replaced the factory-specified UX-120 (volume modulator) tube with a type UX-199. The tube in this socket position provides the necessary plate current to the audio preamplifier, through which the mixer output (audible range) passes. It accomplishes this through a special oscillator circuit that converts the physical up-and-down movement of the performer's hand into the rapid heating and cooling of the volume modulator's filament, which in turn allows a greater or lesser amount of current to flow in the preamplifier.

Using the UX-199 tube in place of the UX-120 enables a more rapid response time as a result of reduced thermal lag, due to the smaller cross-section of the UX-199's filament. It has also been found to increase the preamplifier output. It is notable that Termen also specified the UX-199 in the instrument that we believe to be the likely prototype that he provided to RCA and not the UX-120 that RCA employed.

Practical Result

Faster, more sensitive space-control of the volume.

9.3.2 Volume Oscillator Modifications

Technical Application

Further augmentation of the volume circuit is seen in modifications that alter the operating frequency of the volume control oscillator. As seen with the pitch oscillators, complete rewinding of the oscillator coils has been done, and auxiliary outboard capacitor stacks have been mounted to the chassis shelf. Additionally, the volume antenna has been made with less mass than the standard RCA volume antenna.

One further difference of note is that the Volume Resonant Coil has been significantly altered and has a split winding, with a large gap on the coil form between the windings. Additional research is needed to establish the effect this change would have on the volume circuit.

Practical Result

We believe the alterations to the volume oscillator operating frequency were made to maximize the sensitivity of the volume circuit.

[7] The capacitor currently installed to work with this switch is a replacement from the 1998 Moog work. It may not accurately reflect the electrical value of the capacitor originally installed in this position, due to variations in standards or updated calculations.

Figure 13: Volume coil with center windings removed and ends joined.

10 Maintenance Recommendations

While Clara's RCA Theremin can be classified as stable, the following recommendations will enable the functional condition of the instrument to be maintained and verified. The recommended interval is approximately once every two years.

10.1 Power Up

Connect the speaker and plug the power cord into a metered variac. Bring up to full line voltage gradually, while monitoring current consumption on an ammeter. Gradually increase the voltage to 117 VAC over the course of two or three minutes, as long as current consumption remains less than about 0.8 amp. Normal current consumption may be close to 0.6 amps at 117 VAC. There are no electrolytic capacitors in the power supply, so a slower power-up does not give any additional advantage.

10.2 Function Testing

When the instrument has been brought up to line voltage, test the function of the pitch and volume circuits by playing the instrument. Also note the total octave range at this time and document the result. Compare with prior findings to verify that no deterioration of the volume or pitch circuits has occurred.

10.3 Tube Testing

At the time of this report, the UX-199 volume modulator tube was found to be very weak. At the next opportunity this tube should be rejuvenated, as noted in the report, or replaced. Note that any replaced tubes should not be discarded, as all except socket positions II and III have been installed in this instrument since the early 1930s, and some of them have labels with Termen's hand-writing.

Tube testing at regular intervals is not necessary, as this instrument does not currently accrue enough hours of playing time to cause significant depletion of tube strength, except as noted with the UX-199. If difficulties arise, then tube testing is warranted, and should be a normal part of the troubleshooting procedure.

At the time of biennial maintenance, all exposed wiring should be inspected for insulation problems. At the time of this report, all external high-voltage wiring was determined to be safe. The only exposed wiring that appears to be compromised are the two wires that lead from the UX-199 filament inductance coil (on the volume resonant coil), to the UX-199 socket (factory-marked UX-120).

10.4 Speaker Driver Physical Orientation (Optional)

Due to the micro-gap voice coil clearances in the type of JBL speaker that Clara's RCA Theremin employs, it may be subject to voice coil friction if left for extended periods in the same physical position. This friction is caused by minuscule changes in the uniformity of the large paper cone. The result is a degradation of the sound quality, with a buzz or audible distortion in the sound quality, which may be more noticeable at certain frequencies. Therefore it is recommended that the speaker be removed from the diamond-shaped baffle (mounting panel), rotated 180 degrees and reattached during scheduled maintenance.

11 Recommended Additional Research and Service

This report is based on a body of data and photographs collected over a limited period of approximately 19 hours on site. Further research and action is recommended as follows:

- Obtain physical dimensions of coil windings, with wire gauge and number of turns noted where practical.
- Document frequency and voltage readings of the volume oscillator, at varied settings of the control and hand position.
- Measure the thickness, outside and inside diameter of the concentrated coil.
- Obtain readings of the parallel factory-installed fixed capacitors in the pitch and volume oscillator circuits.
- Obtain milliamp reading at the volume modulator plate, as per RCA Service Notes page 9, section 3d. Reading can be taken via the rejuvenation device with the switch position open.
- Obtain a verification set of photographed oscilloscope waveforms at the audio output, including both positions of the tone control.
- Photograph the waveforms at both pitch oscillators, and the volume oscillator outputs.
- Photograph the waveforms at the mixer output/preamp input and preamp output/power amp input junctions.
- Rejuvenate the UX-199 volume modulator tube (Termen substitution) and document the new reading.
- Replace the wire pair that connects the volume modulator filament to the induction coil, using appropriate materials.
- Check all playing functions and pitch range (as per maintenance recommendations).

Appendices

A Electrical Measurements

A.1 Pitch Oscillator Frequency

Frequency measurements were taken at the grids of each pitch oscillator tube with a FLUKE 79 DMM. When the DMM is connected, it's normal for the frequency to shift slightly due to the loading effects of the DMM and its connecting leads. Thus, zero beat will not be obtainable. Frequencies were measured at three different positions of the pitch control knob: fully clockwise (100% Meshed), centered (50% Meshed), and fully counterclockwise (0% Meshed), at distances of hand-proximity at approximately 5 feet, 1 foot, six inches, one inch and fingers touching antenna.

A.1.1 Frequency Measurements: *Variable* Pitch Oscillator

Control knob (Clockwise: 100% Meshed)

5 feet	234.0–234.1 kHz (varied)
1 foot	233.8 kHz
6 inches	233.4 kHz
1 inch	232.2 kHz
Touching	231.4 kHz

Control knob (Center: 50% Meshed)

5 feet	234.1 kHz
1 foot	233.9 kHz
6 inches	233.4 kHz
1 inch	232.3 kHz
Touching	231.4 kHz

Control knob (Counterclockwise: 0% Meshed)

5 feet	234.0 kHz
1 foot	233.8 kHz
6 inches	233.4 kHz
1 inch	232.2 kHz
Touching	(not noted)

A.1.2 Frequency Measurements: *Fixed* Pitch Oscillator

No change with proximity on the *Fixed* Pitch Oscillator measurements.

Control knob (Clockwise: 100% Meshed)

From 5 feet to touching	235.2 kHz

Control knob (Center: 50% Meshed)

From 5 feet to touching	234.5 kHz

Control knob (Counterclockwise: 0% Meshed)

From 5 feet to touching	233.9 kHz

A.2 Pitch Oscillator Voltage Measurements

Taken at *control grid* (G1) and *plate* with monitored line input voltage of 117 VAC, control knobs at center position, voltage switch in 120 position.

Variable **Pitch Oscillator**

Plate at 5 feet	46.2 VDC	
Plate at 1 inch	16 to 18 VDC	
G1 at 5 feet	−8.5 VDC	3.87 VAC
G1 at 1 foot	−9.0 VDC	
G1 at 1 inch	−10.7 VDC	4.0 VAC

Fixed **Pitch Oscillator**

Plate, from 5 feet to 1 inch (no change)	45.4 VDC	
Plate, touch antenna	45.3 VDC	
G1 at 5 feet	−14.2 VDC	21.7 VAC
G1 at 1 foot		21.5 VAC
G1 at 1 inch or touching	−14.1 VDC	21.7 VAC

A.3 Coil Resistance and Inductance Measurements

A.3.1 Pitch Control Resonant Coil (PCRC)

Two windings on two forms, measured out of circuit for resistance and inductance.

Solenoid winding	429 Ω	41.3 mH
Concentrated coil	57.5 Ω	4.3 mH

A.3.2 Volume Resonant Coil

Combined windings[8] on one form measured out of circuit for resistance and inductance.

Solenoid winding	147.7 Ω	6.3 mH

[8] Note that this is the combined resistance of the two solenoid windings, which are separated on the form and connected by a diagonal turn of wire.

A.3.3 Oscillator Coils

Six windings on three forms, measured in circuit for resistance and inductance.

Pitch oscillator (Variable), inner winding	1.5 Ω	0.12 mH
Pitch oscillator (Variable), outer winding	1.6 Ω	0.128 mH
Pitch oscillator (Fixed), inner winding	1.6 Ω	(false reading) 0.0 mH
Pitch oscillator (Fixed), outer winding	1.7 Ω	0.13 mH
Volume oscillator inner winding	0.5 Ω	0.0 mH
Volume oscillator outer winding	0.5 Ω	0.0 mH

A.4 Tone resistor at 24A Tube Grid Cap

Early type, white body, cast metal ends, not Radio Manufacturers' Association (RMA) color coded: 14,100 Ω.

A.5 Capacitors

A.5.1 Capacitor Stacks

A 0.00005 μF mica capacitor is in series from left terminal of fixed-pitch stack to ground. Parallel to this unit is a modern capacitor of equivalent value.

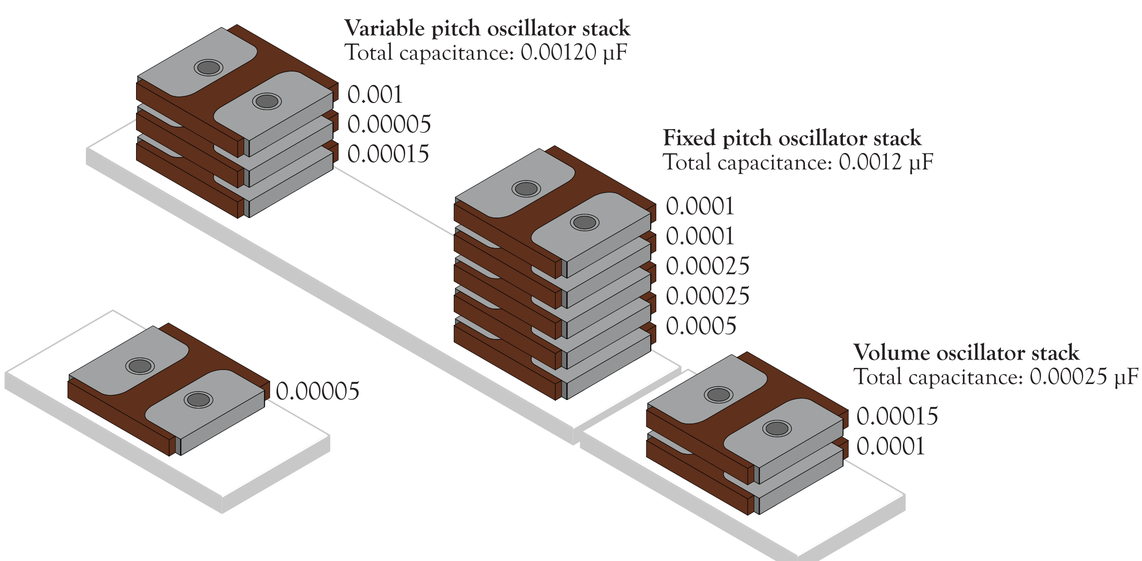


Figure 14: Termen's capacitor stack modifications, values in microfarads. These assemblies are not found in stock RCA Theremins.

A.5.2 PCRC Parallel Capacitor Trio in Base of Form

Capacitance: 2.4 nF

A.5.3 Capacitors mounted to terminal strips and SPU audio output terminals

Line voltage filter (on 1998 forward terminal strip)	0.12 μF	630V
Tone switch capacitor (on 1998 rear terminal strip)	0.12 μF	630V
Audio output terminal filter[9]	0.022 μF	630V

A.6 Audio Output Transformer

Make: Hammond
Model: 125E
Primary resistance: 1200–25000 Ω
Power rating: 15 Watts

Connections: Primary from SPU output terminals to outer two lugs; Secondary center lugs, top and bottom (terminals 2 & 5 = 4,100 Ω resulting total primary impedance when connected to 4 Ω speaker). UX-171A output tube is rated at 4,800 Ω load resistance with plate voltage of 180 V.

A.7 Speaker Driver

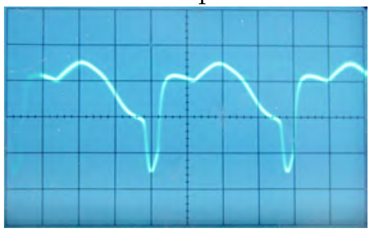
Make: James B. Lansing Sound, Inc. (JBL)
Model: M31–4
Serial number: 11054
Diameter: 15 inch
Impedance: 4 Ω

[9] This capacitor should be internal to the power supply in its factory configuration. At time of study, the SPU was not removed from the cabinet for verification of possible redundancy.

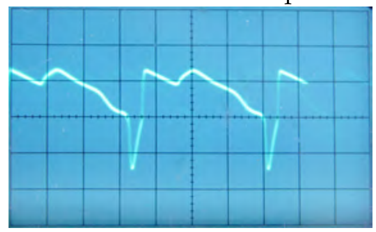
B Oscilloscope Waveforms

Tone knob in clockwise position

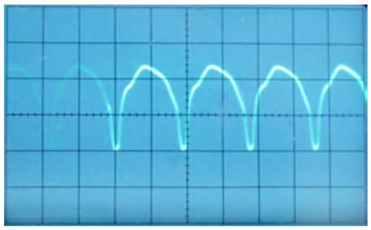
Tone knob in counter clockwise position



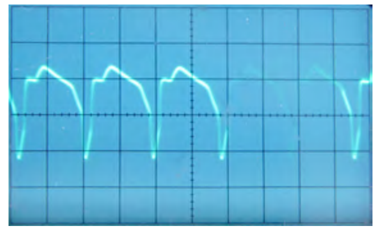
(a) C3, 2 *ms/div*



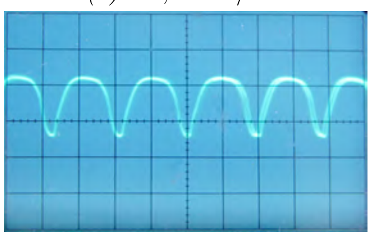
(b) C3, 2 *ms/div*



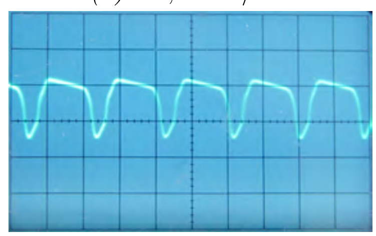
(c) C4, 2 *ms/div*



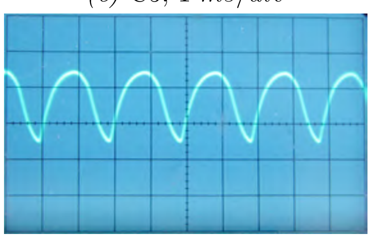
(d) C4, 2 *ms/div*



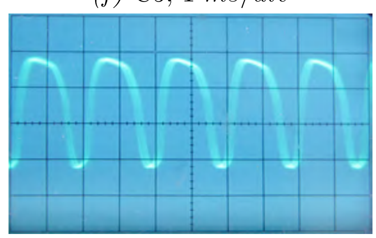
(e) C5, 1 *ms/div*



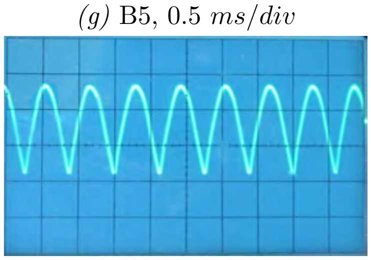
(f) C5, 1 *ms/div*



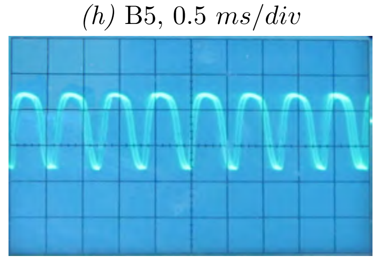
(g) B5, 0.5 *ms/div*



(h) B5, 0.5 *ms/div*



(i) G6, 0.5 *ms/div*



(j) G6, 0.5 *ms/div*

Figure 15: Waveforms shown above depict the output at various octaves at both positions of the tone control knob. All readings are at 20 volts per division, with horizontal progression in milliseconds per division as shown.

C Speaker Measurements

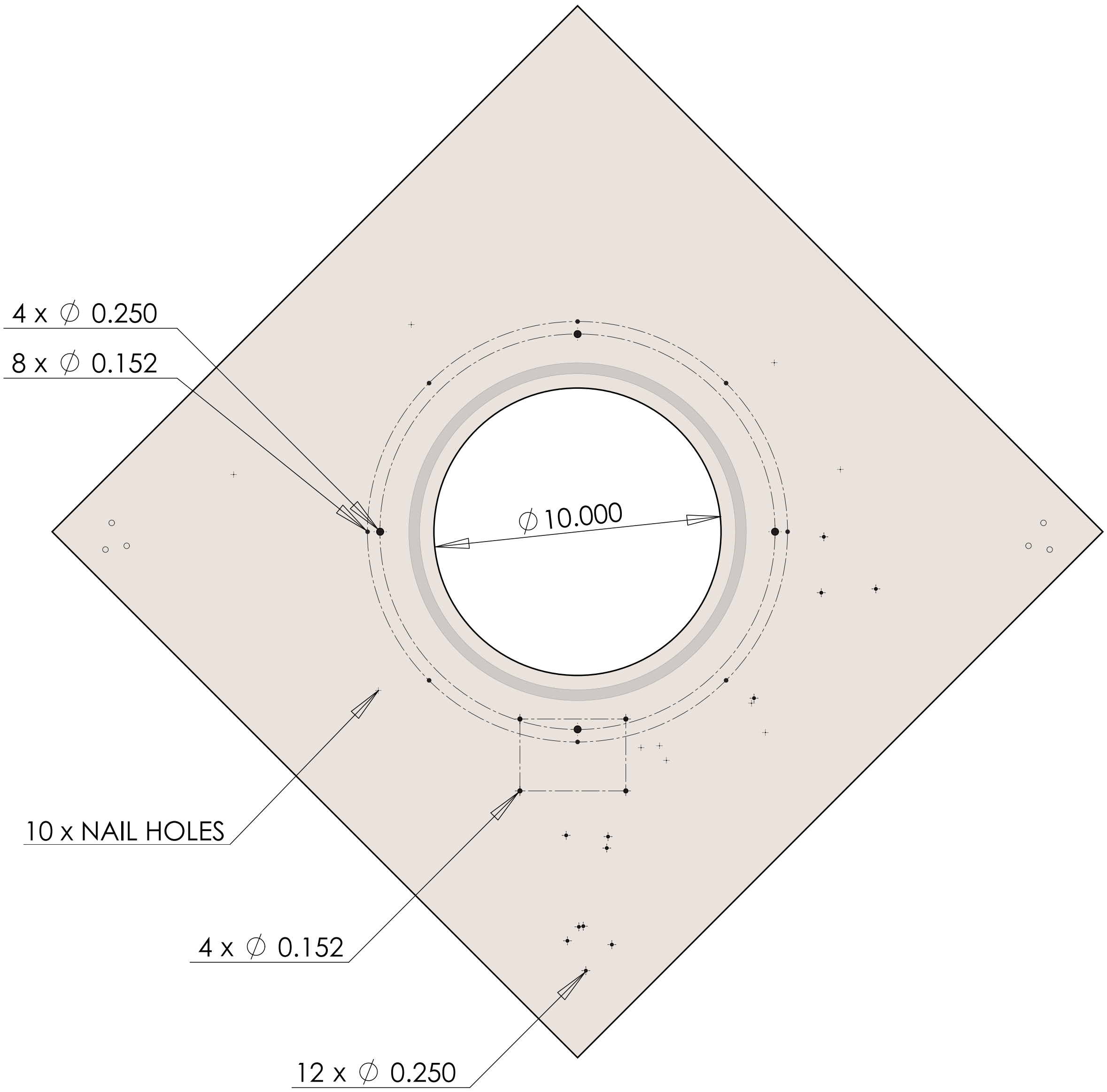


Figure 16: Baffle board with holes.