An Early Lionel Type V Transformer

I've always liked the Type V. One of these was my first transformer bigger than the starter set types. It went up to 25 Volts, and could control four separate tracks. Assuming that only a couple of trains were active at any one time, 150 Watts was enough. They remain available, often at quite low prices if you are willing to work with one having issues. So it was that I happened to acquire a "V" on eBay that had had issues including odd knobs that had been used to replace the originals. When I received it, it would hum but didn't seem to do much else so I put it aside as a project for later. Later came, and when I went to fix it I found that the transformer had a number of oddities that seem to indicate that it is a very early production version of this transformer. Since then, other similar transformers have been found. This paper documents the differences between this early V and the more normal version and attempts to define a design history.

It turns out that this particular early variation of the V transformer is pictured and described in Lionel's 1940 Catalog. Figure 1 showing a close-up view of the faceplate from that catalog. The catalog lists the V as giving 0-25 Volts. The 1939 catalog, the first to feature the V and the Z, shows a similar transformer with a different faceplate with the power and short indicators at the bottom instead of the top corners. The 1942 catalog shows the more familiar V, and lists it as 6-25 Volts. 1942 has the Z but no V, and the V reappears in 1945 with the image from the 1939 catalog (but no Z). By 1947, both transformers are back.

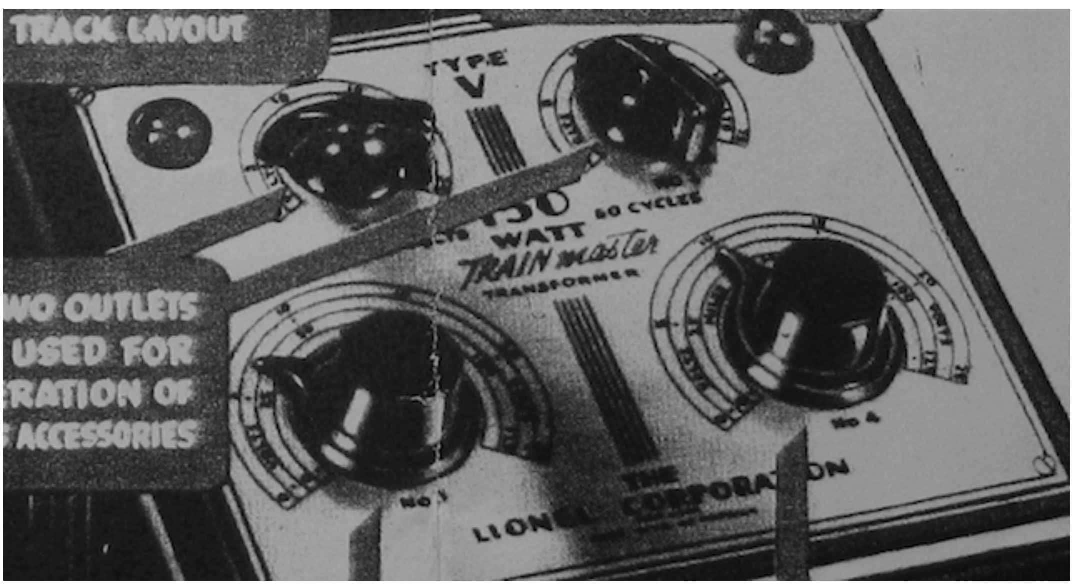


Figure 1 Early V transformer as shown in the Lionel 1940 Catalog

The differences from the more usual "V" transformers are described below.

1. The controls are numbered 1, 2, 3, and 4 without the terminal post pair letters A-U, B-U, C-U and D-U. Figure 2 below shows this on the faceplate. Figure 3 shows the matching labeling of the terminals. Also of note, the faceplate is embossed (actually acid etched chrome plated brass), not just printed aluminum as some later V transformers are.

(I do have another V with an embossed faceplate with the normal A-U, etc. numbering.) The Doyle book on prewar Lionel shows a picture of a V, as seen in Figure 4, but it has the normal A-U etc. terminal identifications. Were the numbered terminals a prewar feature and the terminals lettered after the war? Doyle does not report on any variations in Type V pre-war transformers, nor does Greenburg. Note that Doyle also shows the red and green short and power indicators reversed, and using colored bulbs instead of caps.

Figure 2 Early V transformer faceplate

Figure 3 V Transformer Terminals

Figure 4 Pre-war V Transformer photo, Doyle

2. The transformer secondary Voltages run 0V to 25V (not 6V to 25V).

This is not just a cosmetic feature. The transformer has controls that give the full range of 0V continuously up to 25V. This is not true of other V or Z type transformers that I have seen (except a corresponding early Z). Notice that the faceplate marking does show that the lowest end starts at 0 Volts. The numbers for various Voltages are correctly spaced out for 0, 5, 10, 15, 20 and 25 Volts. While this feature does not match the more normal late V and Z transformers, it does match to picture from the 1939 Lionel Catalog that Doyle reprints in his book, as shown in Figure 5 below, and the 1940 catalog as shown earlier. Note that the faceplate design pictured in 1939 is different than that of the early V being described. The short and power indicator lamps are placed at the bottom instead of the top corners. It has neither numbers or terminal identifications for the controls. Perhaps this was an only advanced illustration that was different from what was actually manufactured. I've never seen a transformer that looked like this picture, but it does have in common with the early V the starting Voltage of 0V instead of 6V.

Figure 5 Catalog Image of V Transformer (1939) from Doyle

3. There are some oddities of an exterior nature. The early V faceplate has registration notches at the control shaft holes, with corresponding pins in the bakelite case, to limit the range of motion of the knobs. See Figure 6. The shaft itself is a simple round shaft without any registration flat or other alignment aid, meaning that the knobs needed to have setscrews. Figure 7 shows two types of knobs as seen from the underside. Both seem to be legitimate V or Z knobs. Both have setscrews and fit flush with the faceplate. In this particular transformer, two of the setscrews were broken and could not be easily loosened. This makes removal of the knobs and faceplate difficult. Note in Figure 3 that the screws holding the front panel in place are slotted as in the 1940 catalog rather than hex head as in the Lionel Repair manual. They seem to be original. (Slotted front panel screws were found on all early V and Z transformers examined.)

Figure 6 Control shaft

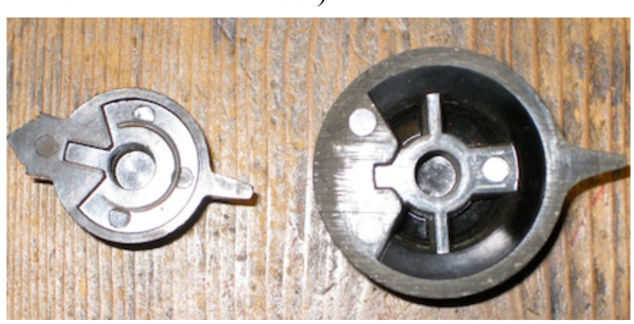


Figure 7 Control knobs (underside)

4. The biggest differences are the electrical features inside the transformer. The transformer itself is relatively simple. It is formed on a rectangular loop stack of laminations similar to the later V and Z transformers of this type. The secondary side of the coil is shown in Figure 88, along with the #3 and #4 control shafts and bearing plate. Notice the absence of bearing plate supports for the indicator lamps. The bearing assembly is different from those in the postwar Repair Manual. The indicators are molded into the bakelite upper shell.

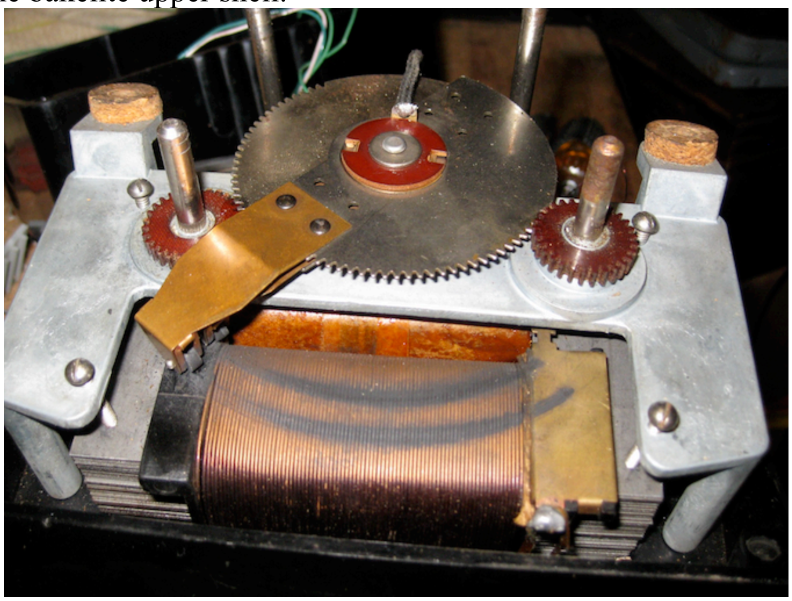


Figure 8 Bearing Plate Assembly and Transformer Secondary Windings (from Top)

In contrast, a more typical later V transformer has the bearing plate assembly, shown from the primary (front) side pictured in Figure 9.

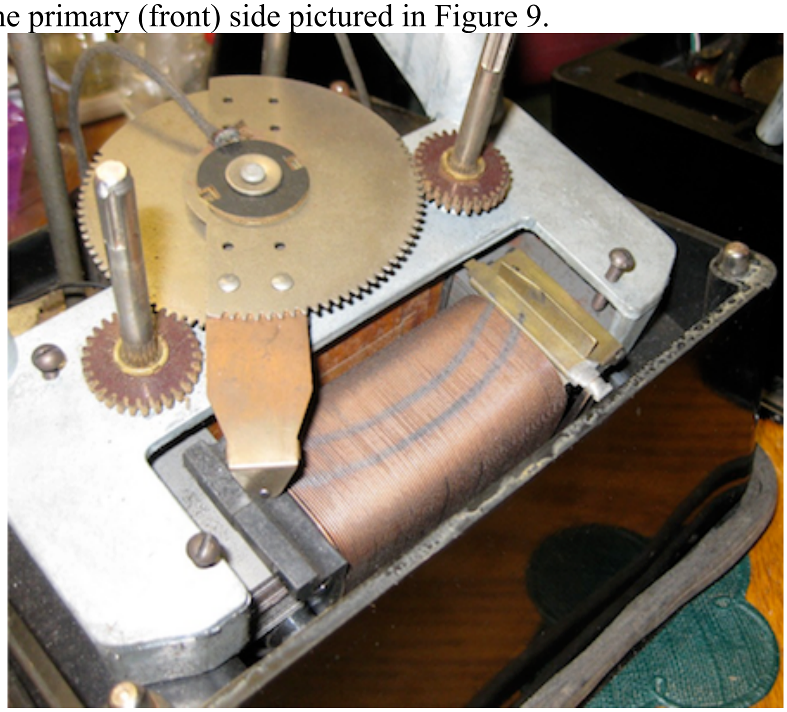


Figure 9 Normal V transformer secondary coil

Note that the more usual model has “stops” at either end of the travel path of the roller, in brass on the right (at 25V) and plastic at the left (for 0 Volts). No stops are used on the early V coil, since the stops are effected with the knobs and registration pins.

There is an interesting implication. For the early V, all knobs had the same angular range of motion, and identical markings on the faceplate. But, the actual cut in and maximums would be closer to the center of the range of motion for the #2 and #4 controls, since their rollers are slightly farther from the pivot point. In the later transformer with stops on the coil, the #2 and #4 knobs (B-U and D-U) don’t have quite the angular range of motion as #1 and #3, so the inscriptions for 6V and 25V have been moved toward the center. The decorative bands, however, remained the same. Take a close look at the markings for the C-U and D-U dials on a later V or Z.

The early V also has a “cut out” on the roller arm for the fiber gear in the odd V (not visible in Figure 9), and the roller arm is secured on the top side of rather than the bottom side of the gear assembly. Note the registration tooling of the shafts to accept press-on knobs in Figure 9, in contrast to smooth round shafts needing setscrews in Figure 8.

The more typical transformer has about 97 turns on the secondary side for about 18 or 19 Volts, since the remaining 6V is from a different winding that is over the primary, compared to about 83 turns for the early V (for about 25 Volts). This implies that the primary for the late V has more turns also than the primary for this early V.

The primary side is seen in two views shown in Figure 10. What is remarkable here is that there are two thin wires coming out from the primary coil. One can also discern that these wires are not part of the primary coil at all, but an extra secondary winding on top of the primary. Indeed, an Ohmmeter confirmed no connectivity between either of these wires and the primary or secondary. These thin wires seem to be AWG26 magnet wire, the same as the “extra” secondary coil, of which they are simply the loose ends. These are connected to the power indicator lamp. Both wires were a bit charred with the insulation missing at points. It would appeared that the wires may have shorted together or suffered similar damage. (In repairing the transformer, these wires were taped down safely and other wires with normal insulation were run to the power lamp.)

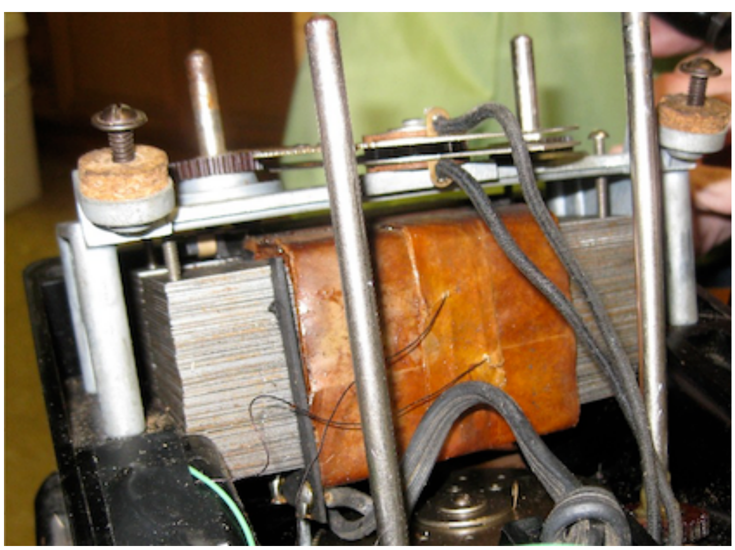


Figure 10 Early V transformer primary coil with 6 V secondary over it

The primary of a more typical V transformer is shown in Figure 11. In this transformer a 6 volt winding is also wound over the primary. Note the much heavier gauge wire. One can also see in Figure 11, above the much smaller core, the lamp holders mounted on arms extending toward the back of the transformer case (toward the viewer), which are absent in the early V transformer.

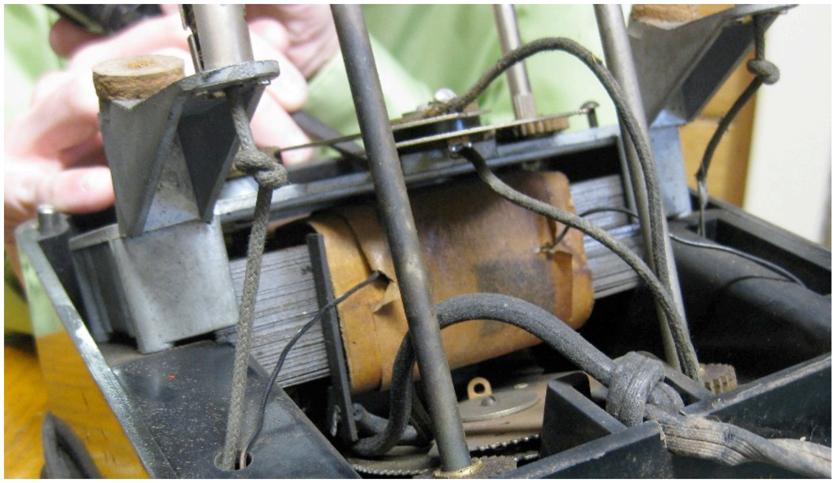


Figure 11 Normal V transformer primary

So, it would seem that the power indicator lamp has its own private low power secondary coil! This makes sense, since the main secondary (running from 0V to 25V) has no convenient place where a 6 (or 12) Volt tap could be taken. This small secondary provides 6 Volts for the indicator only. The use of unsecured, fairly lengthy (about 9 inches) magnet wire in connecting to the power on light seems hazardous. In more usual V or Z transformers the much heavier 6 Volt secondary winding over the primary winding (as seen in Figure 12) provides both the power lamp Voltage and the 6 Volts on top of which the controllable power winding is connected, giving the more usual 6V to 25V Voltage range. (That is the arrangement shown in the Lionel Repair Manual.) The magnet wire from this 6V secondary is also unprotected, but the two wires are led to opposite sides of the transformer, are not as long, and are not flexed when the transformer is opened. So, there is little chance of the thin magnet wire insulation being a hazard.

5. Something else to notice is the transformer core size. The lamination stack is about 2 inches in vertical depth. That's "Z" size rather than the usual "V" size. Yet, the primary resistance is about 4.5 Ohms, rather than the approximately 3 Ohms measured for a "Z". (The inductance of the primary is much closer to that of a Z rather than of a late V.) It would seem that this early V used the Z core but a special large V primary winding using a slightly lighter gauge wire than the corresponding Z model. Possibly at the time this was made there was only one type of bearing plate and lamination stack used for both V and Z. It would seem that the only difference between early versions of the V and Z was the primary wire gauge and circuit breaker. A photo of a late Z transformer showing the lamination stack is shown in Figure 12 below. Note also the doubled heavy 6V secondary wires and the relatively crude holes punched under the short indicator pocket to allow various wires to pass to the bottom compartment.

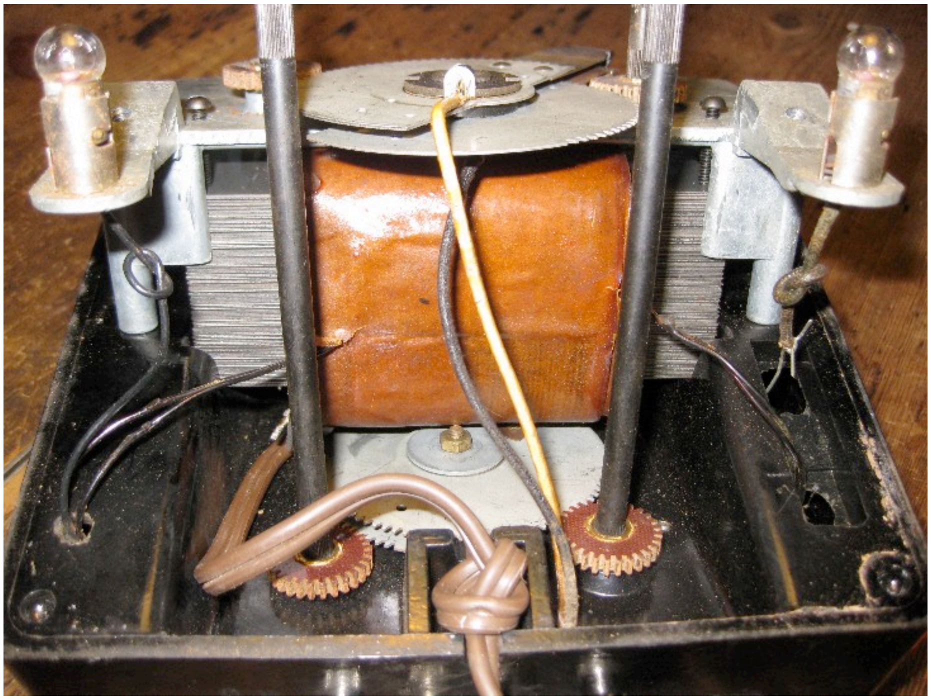


Figure 12 Z (assumed postwar) transformer interior showing large lamination stack

6. As mentioned earlier, the bulb sockets for power indication and short circuit are molded into the upper case, rather than being mounted to the bearing plate assembly as in the later V transformers. The upper case is shown in Figures 13 and 14. Notice that in Figure 14 the AWG26 wires from the 6V secondary to the pilot light can be seen, and the wires to the circuit breaker for the short indicator light are also visible. (As pictured the shaft is missing for the #2 knob. The setscrew was broken. Efforts to remove the knob pulled out the shaft, a hazard on these transformers. This can be fixed but it's not trivial.)

Figure 13 Top Case of Early V transformer   Figure 14 Top case from below

The short indicator base is seen in Figure 15 from below (after replacing the wires), and the power indicator socket is seen in Figure 16 from above. Both are similar. The short indicator is across the circuit breaker with a 60 Ohm resistor in series. One transformer of this type came with clear 6 Volt bulbs in both sockets and no colored caps. The other still had a green plastic power cap, melted onto the light bulb, which is probably original. (The bulbs could be replaced with colored bulbs to match the Doyle picture, shown in Figure 4 earlier, but put the power lamp in its usual place on the right, which is consistent with its connection to the "auxiliary" 6 Volt secondary. I'm surprised at the reversal of red and green in the Doyle photo. Were there versions of the V with these reversed? Or is the Doyle photo wrong?) Placement of the sockets on the upper bakelite case would seem to be inconvenient for manufacture and repair. Long wires are needed and extra care would be required with the AWG26 magnet wire for the power indicator. Note in Figure 15 the registration pin for the control next to the hole for the shaft.

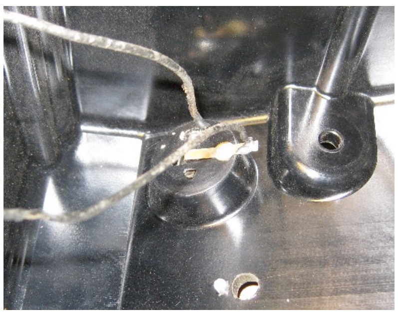


Figure 15 Indicator lamp (inside)

Figure 16 Indicator lamp socket (outside)

A later V upper case is seen in Figures 17 and 18 below. This is from a transformer with some of the features of the early V, such as case registration pins described later, so perhaps it is something of a transition unit. Notice the much larger holes for the control shafts and the lack of lamp sockets. From below, it is apparent that the case is a crude modification of the "early" version case of the V and Z, having the lamp fittings roughly knocked out. The knob holes are also much rougher and have no registration pins. The roughness of the modification is hidden by the nameplate.

Figure 17 Later V top case

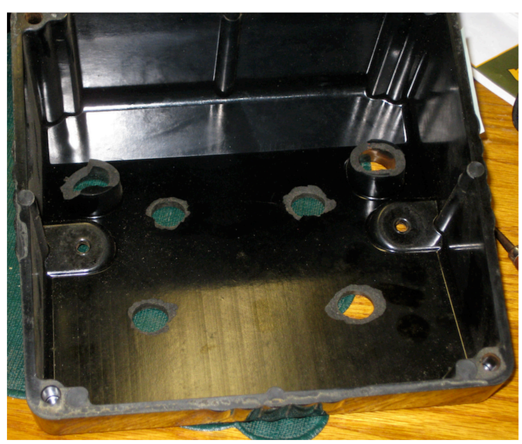


Figure 18 Later V top case (from below)

Interestingly, the Z transformer (shown earlier) has a top cover that has been redesigned for the larger holes and missing sockets, shown in Figure 19. The holes are much cleaner. Perhaps the later (postwar?) transformers have this nicer top piece, and the later prewar ones those crudely modified? Note the registration pins at the corners for aligning to the bottom of the case (described later) are now molded in.

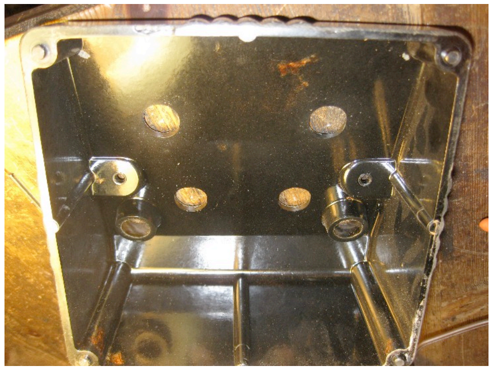


Figure 19 Z top of case from below

7. The circuit breaker was mounted in the bottom compartment of the transformer (as is normal). There is a cutout area of the appropriate size and shape for the circuit breaker under the short indicator lamp, as shown in Figure 20, in both early and later types of V, but it is not used in either. The "phantom view" of the V transformer in the 1940 catalog shows a circuit breaker in this pocket, for which it was apparently designed. One can also see in the corner a hole for an aligning pin to register the top shell to the bottom shell. The top shell has matching holes. In one example of this transformer registration pins were present. Without the pins, registration was effected only by the two screws attaching the top housing to the bearing plate assembly. A close inspection of the holes in one of the early V transformers showed little or no wear – it did not look like pins had ever been in the holes. The other one had pins, as seem in Figure 14, and the Z used for comparison has molded plastic protrusions in place of pins seen in Figures 12 and 19.

Figure 20 Molded slot for circuit breaker

The circuit breaker is seen in Figure 21. The short indicator has a resistor in series and is wired across the circuit breaker. The variable primary lead comes in at left and the wire to the common terminals is at right (only AWG18!). Notice the loose soldered connection between the resistor and the pilot light. (The original wires shown here had to be replaced.)

Figure 21 Circuit breaker and associated circuit (lower compartment)

In summary, this particular early type V transformer is odd in having a 0V to 25V range for the controlled Voltages. That in turn made necessary a special secondary winding for the power on indicator (the alternatives being the use of a 24V bulb across the full secondary, or the use of a power wasting resistor). The unusually large lamination stack is also quite surprising. Various other physical oddities from the usual late V's seen also are present, such as the round control pins, registration pins for the knobs, and indicators molded into the upper case.

This may be the earliest production version of the V, assuming none similar to the 1939 catalog picture turn up. Many of the features seen are either undesirable or more expensive from a production standpoint. For example, the faceplate registration pins serve to limit the movement of the control shafts, but that requires proper alignment with the setscrews. The same purpose is more easily and directly accomplished in the later V with stops for the control arms. The winding of a separate coil just for the power on indicator seems quite undesirable, and the use of thin magnet wire for hookup is problematic not only for manufacturing but also for safety. Most of all, the heavy lamination stack meant that the production cost of this transformer was essentially identical to that of a Z, and the complexity of stocking two very similar sets of windings for the same core to vary power would seem counterproductive.

Additional information on the V design history was found in the form of a document auctioned on eBay that was Lionel's original drawing of the late V faceplate. The document sold for $127.50, beyond my price range. However, the photos of the document posted by the seller, Bob at "hirailfarms," provide important information that relates to the history of the "V" transformer. Those photos are included here with his permission. Figure 22 shows a photo of the document as a whole.

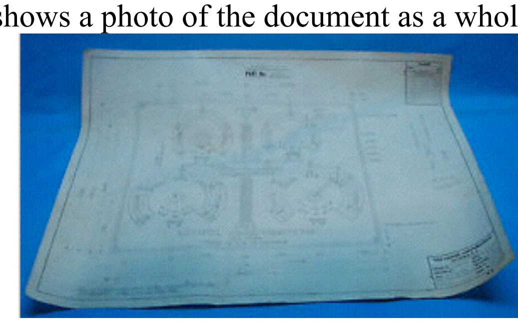


Figure 22 The Lionel V faceplate drawing (whole)

Figure 23 shows the center of the drawing in enough detail to be legible. (These photos were screen shots from the eBay listing.) The seller describes it as 17" x 22" in size. It is an original drawing rather than a blueprint. The drawing identifies the part as "V-220".

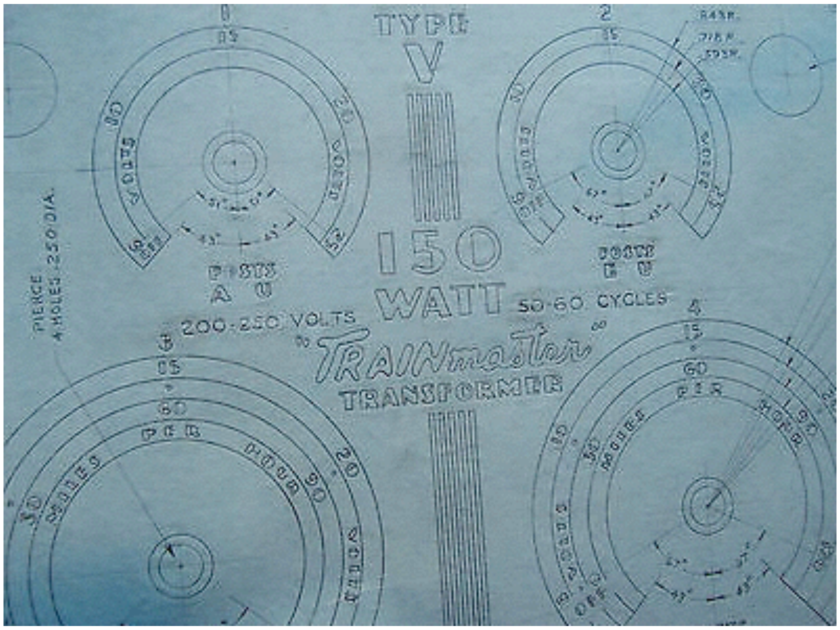
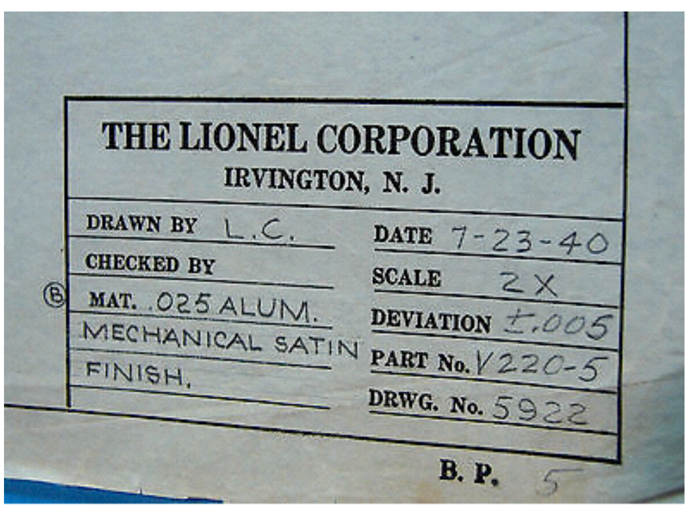


Figure 23 Detail from center of the drawing

It is clear from the drawing that this is the faceplate for the "standard" late type V transformer, rather than the early one, or the late "red" (reversed colors) versions. What is perhaps of most interest is the date for the drawing, given as July 23, 1940, as shown in Figure 24. This date establishes a time frame for the transition from the early to the later versions of the transformer. Interestingly, the pictures of the V in the Lionel catalogs of 1940 and 1941 continue to show the faceplate (as well as the specifications) of the early V transformer rather than this one.



THE LIONEL CORPORATION
IRVINGTON, N. J.

DRAWN BY L.C.	DATE 7-23-40
CHECKED BY	SCALE 2X
MAT. .025 ALUM.	DEVIATION ±.005
MECHANICAL SATIN	PART No. V220-5
FINISH.	DRWG. No. 5922

B. P. 5

Figure 24 Photo of document label showing date.

Another important detail given in the drawing is the history of changes, shown in Figure 25. This gives a date of May 22 1946 for a process change for the faceplate.

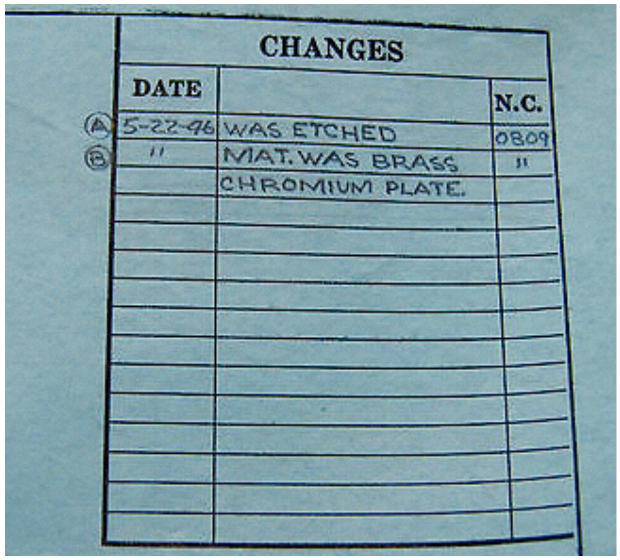


Figure 25 Drawing change history

These change remarks establish that the earlier versions of the late V faceplate were "etched". For early V transformers, and also many later ones, the print pattern is laid in mechanical depressions etched into the brass, perhaps using acid through a wax mask or some similar process. The faceplates were then chromium plated. This drawing seems to establish that this changes sometime subsequent to May 1946, although the change note does not say what the change was to. Many late transformers have aluminum faceplates rather than chrome plated brass, no doubt less expensive after World War 2 when aluminum would have become plentiful. A similar change is observable in the Z transformer faceplate.

Other details of the drawing reflect changes in the mechanics of the transformer. The early V relied on mechanical stops using a pin protruding through the faceplate to limit mechanical motion of the rollers used to set the terminal Voltages. Because the knobs were identical for left and right controls (inner and outer arms/rollers), the arc of travel for the controls were identical. Figure 26 below shows detail from the drawing around the C-U and D-U knobs. The angle from centerline to the 6V and 25V positions for the C-U knob is 51 degrees. The corresponding angle for the D-U knob is 67 degrees.

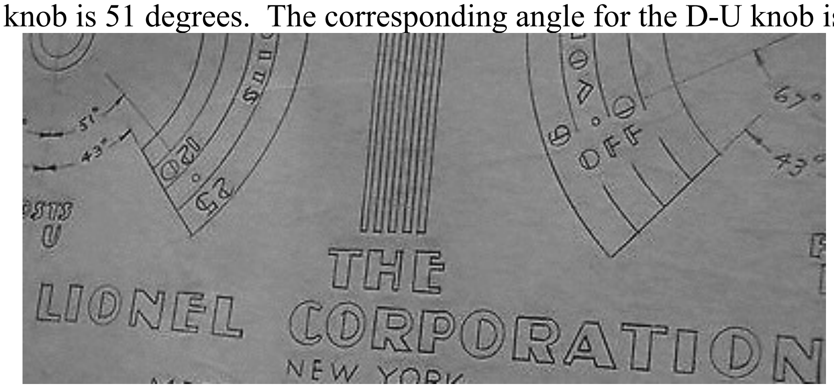


Figure 26 Drawing detail around lower control knobs.

One other important detail in the drawing is that the lettering is to be black except red for the “Trainmaster” lettering. This settles the issue of whether the black or the red lettered faceplates came first; apparently the red ones are later. Of the late type V transformers, my observation has been that the red faceplates may not be a majority, but they are numerous (and do not seem to command a price premium). The shift to the opposite color scheme is not noted on this drawing. I have not seen a similar color reversal on any other transformer. It may be that the 1947 transformers’ faceplates were printed in one run and this was a printing error seen as tolerable by Lionel management. None of the catalogs show the red faceplate, so this may indeed have been accidental.

The information from this drawing, together with that from the catalogs, and examination of various transformers of different types, allows the construction of a tentative variation history for the V transformer as shown in Table 1.

Table 1 Tentative V Transformer Variation History

Variation	Catalogs	Characteristics	Dates
Prototype	1939	0-25V, pilot and short indicators at bottom, Controls labeled No 1,2,3,4, and other	Never seen
Earliest	1940, 41	0-25V, pilot and short lights at top, Controls labeled No 1,2,3,4 (No A-U etc.), Z type core, lights mounted on upper shell, Etched brass (chrome plated) faceplate	1939 (-40?)
Transition	none	6-25V, pilot and short lights at top, Roughly modified case, case registration pins, Electrically similar to late V (small core), Etched brass (chrome plated) faceplate	1940 (?)
Late, etched	1946,7(?)	6-25V, pilot and short lights at top, Controls labeled A-U, B-U etc., Etched brass (chrome plated) faceplate	1941-47(?)
Late, print	1946,7(?)	6-25V, pilot and short lights at top, Controls labeled A-U, B-U etc., Printed aluminum faceplate	1946-47(?)
Late, red	1946,7(?)	6-25V, pilot and short lights at top, Controls labeled A-U, B-U etc., Aluminum faceplate, colors reversed	1947 (?)

Quite a few of this early V were made. At the TCA York meet in April, 2013 two similar transformers were found (one of which was purchased) of about two dozen to 30 V’s inspected. Since then several have appeared on eBay, among many later varieties. The numbers found would seem likely to correspond approximately to one year’s production.

Another question has been, was there a similar Z? The catalog describes a similar Z, and finally one has been found, as well as a possible transition transformer with the early faceplate but otherwise identical to late varieties. The early Z seems identical to the early V except for the transformer primary winding and the faceplate Z identification.

Figure 27 shows the primary winding and transformer core for the early Z. Note that this transformer has a lightweight secondary for the pilot light just as the V does, but that this winding is not centered on the primary. The transformer had apparently been repaired at some point in the distant past, and it is supposed that the insulating sleeves were added to the small magnet wire to the pilot light at that time. The other features seem identical to the early V, including setscrew knobs with registration pins, registration pins for the case, lights mounted on the top case as shown in Figure 28, and the 82 turn secondary coil with no stops.

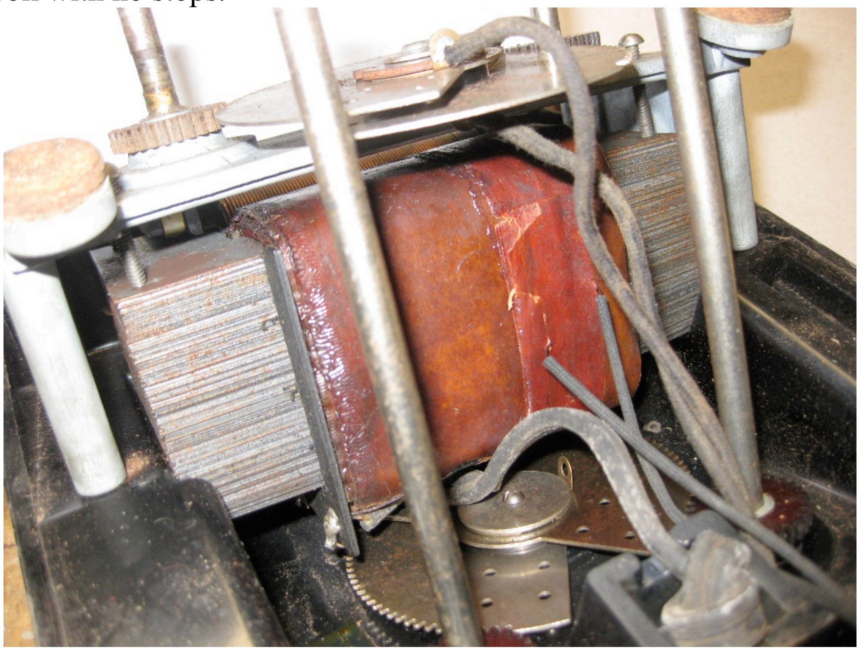


Figure 27 Early Z core, primary and pilot windings.

Figure 28 Early Z case top

The seeming “transition” Z transformer faceplate is shown in Figure 29. It is identical to the early Z faceplate except that the holes for the knobs have been enlarged. The enlargement appears to be a factory operation, closely resembling the late faceplate. This was the only feature shared with the early transformer. The faceplate was affixed with hex screws rather than slotted. It is possible that someone substituted this faceplate on an ordinary late transformer, but that wouldn’t explain the well made punchings for the enlarged holes.

Figure 29 Early Z transition faceplate

Doyle does not list but one version of the V for prewar and one for postwar, and the Greenberg postwar accessories book lists only one for postwar. Only one is listed in the prewar accessories book too. Yet red printed faceplates are commonly seen, and apparently the early versions are not too rare. So, it would seem that these sources just don't consider transformer features worth detailing except something "important" like the difference between the 250 and 275 Watt ZW's. However, assuming that this is an early V, it is definitely very different and may have interest beyond its current utility.

A knowledgeable TCA member who reconditions transformers and sells them stated that this odd V variant was an early version of the V. He considers it undesirable and will not work on them. He cited the problem of the shafts coming out when removing the knobs as a particular problem.

Another question is whether there any particular advantages to having this transformer rather than the usual V type? (In asking this, I assume repairs are made to address the power indicator wiring safety problem.) Considering the advantage of a Voltage going down to zero, the answer would seem to be "not much difference in value" because few things run on less than 6 Volts. Perhaps this expanded low Voltage range will permit keeping an E unit active without moving a locomotive, for engines that are so easy to move that 6 Volts is too much. The transformer would, however, be a good bench AC supply as a piece of test equipment, when one might need some really low Voltages occasionally. With a 5V 10A fixed transformer connected from the common to ground, it can supply 6-30V, useful for running pre-war standard gauge equipment, assuming one does not need the lower part of the range from 0 to 5V. Such fixed transformers cost about $15 plus shipping.

A more interesting question concerning utility is whether this transformer can handle much more than the usual V 150 Watt rating would suggest. The lower impedance primary (than the usual V) and bigger core suggest the transformer might handle more than 150 Watts, though perhaps not up to 250 Watts. In effect, it is closer to being a "Z" than a "V". However, as the primary winding is of a smaller gauge than for a Z, as resistance measurements suggest, this transformer may have characteristics that dissipate a bit more power in the primary for a given power out. It still seems better able to handle a load than the normal V which has part of the secondary on top of the primary, limiting dissipation. (Of course, a different circuit breaker would be needed to support a larger current draw.)

Figure 30 below shows how the Z, this transformer, and a standard V respond to various loads (nominally one to four 12 Ohm resistors attached to each of the four outputs). The late V seems to have a higher output Voltage under light loading but the output Voltage declines more rapidly with load, while the early V maintains its output Voltage as well as the Z, but at about a Volt lower for a given load. Figure 24 shows this in terms of power delivered to the load. Because the late V has a higher impedance it draws less current (and wastes less power) under no load conditions. The early V despite having a lower input impedance than the late V and more winding resistance than a Z, still has dissipation no worse than the Z although it doesn't deliver quite as much power either. My assessment is that the early V seems to be worth approximately 200 Watts as Lionel seems to recon the power of similar transformers, and should probably operate well with a 10A circuit breaker similar to that of the 190W rated KW. The late Z and early Z are very close in performance.

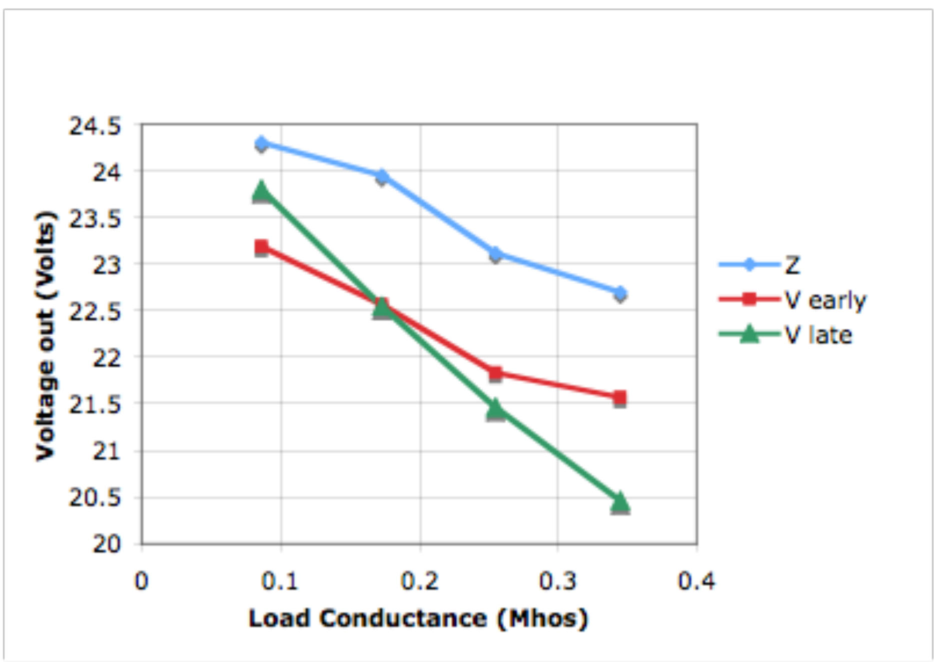


Figure 30 Transformer output as a function of load for Z, early V, late V

Appendix A addresses the electrical and power issues in greater depth. Data measured for various transformers as well as the early V allow comparisons. In addition, a series of measurements were made under load, resulting in the figures given above.

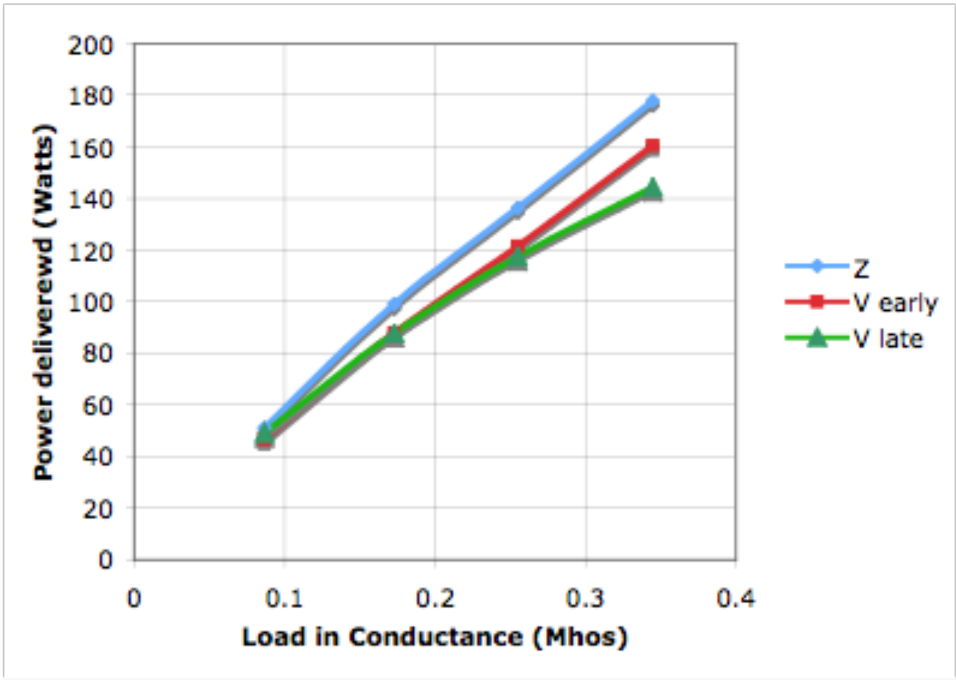


Figure 24 Power delivered for comparable loads for Z, early V, late V

Later, after an early Z transformer (apparently identical to the early V except for the primary resistance), Voltage output versus load was repeated. This time a different physical transformers were used. It was found that Voltage settings under load for the different circuits were “fiddly”, that is, slight perturbations would cause significant Voltage variations. It was difficult to get consistency. For the graph shown below in Figure 25, the best consistent value was used for each transformer for a given load, and averages used when there was remaining inconsistency. Even so, the late V Voltage measurement under the heaviest load seems to be an anomaly, and is considerably lower than the earlier data. Even so, it seems clear that the early V and Z types are indistinguishable in performance, while the late V clearly has poorer performance.

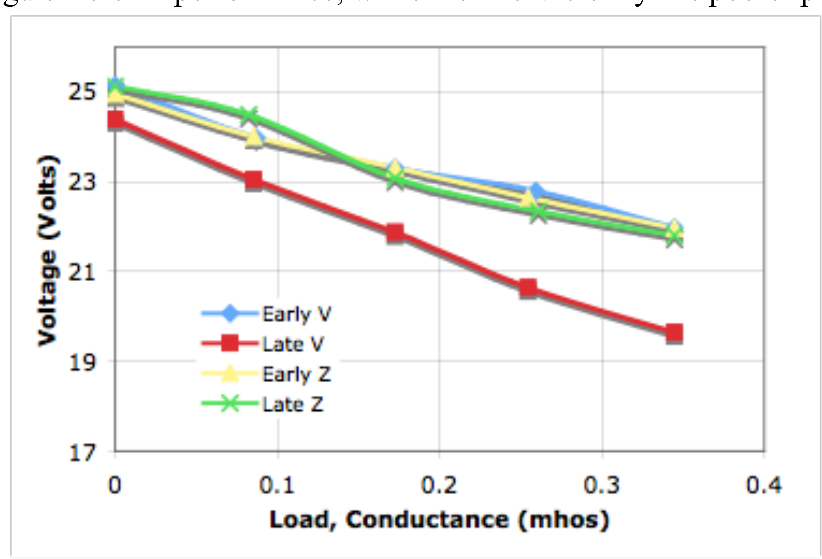


Figure 25 Transformer Voltage performance versus load, including early Z

It is interesting that the V disappears by the 1942 catalog. If Lionel was making both the V and the Z, and selling the V for $2 less (as the 1940 catalog has it) yet the V was just as expensive to produce as the Z, it would make sense to get rid of the V pending redesign. When the V does reappear in the catalog (not in 1945, but by 1947) it must be the scaled down V with the smaller core as described in the Lionel postwar repair manual. (Not only would Lionel have saved in manufacturing but in shipping. The Z is 12.0 lb, the early V is 11.7 lb, and the late V 10.2 lb.) Yet, many early V transformers having the etched faceplate exist, and when would they have been made except prior to 1946 when the faceplate was converted to printed aluminum? So, there are still some interesting issues out there. Likely Lionel continued to sell V transformers even though they were not cataloged.

References:

Doyle, David, *Standard Catalog of Lionel Trains, 1900-1942*, KP Books, Iola, WI, 2005.
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http://en.wikibooks.org/wiki/Electronics/Transformer_Design, June 12, 2013

Thanks to Mr. Robert J. Winkler, whose Lionel transformer manuscript of October, 2011 helped serve as an inspiration for this investigation. Thanks also to others who have supplied information and encouragement in this endeavor, including Mr. Herb Miller, Mr. John Thompson, Mr. Stephen West, Mr. Jeff Kane, and my father, Mr. John Gilmer.

Appendix A Electrical Characterization

Schematic:

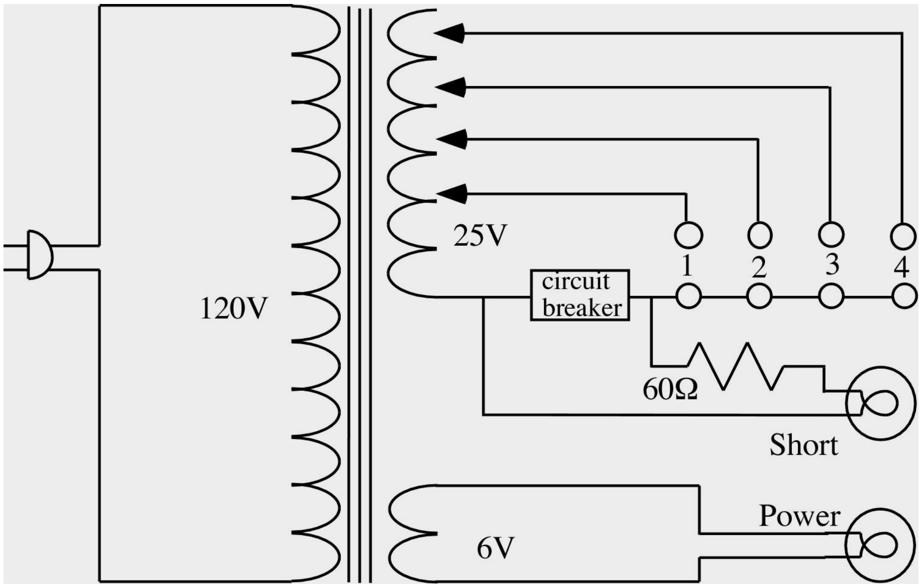

Figure A-1 Schematic of Early V type transformer

Measurements (all made on the newly acquired "V"):

Resistance and Voltage measurements were made with a METEX M-4650CR digital multimeter using the lowest range available, 200 Ohms for resistance measurements. AC Voltages were measured with the same device using the 200 Volt scale. Inductance measurements were made at 120Hz with an EXTECH LCR meter model 380193.

The laminations stack:

Each lamination in the transformer stack is "C" shaped. These are arranged with varying numbers alternating each way to provide a magnetic circuit for the transformer. Because there is no "end piece" each lamination remains open at one end. So, at each end of the transformer laminations total only one half of the full stack thickness of silicon iron. The dimensions of the laminations are shown in Figure A-2 below.

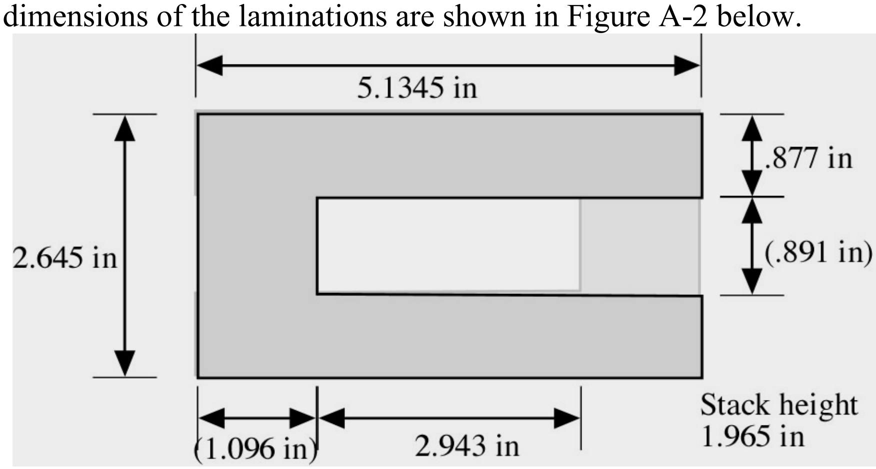

Figure A-2 lamination dimensions

The cross section of the core through the coils is .877 in x 1.965 in = 1.723 in^2. The length of the magnetic circuit is estimated at 10.8 inches, but because of the open ends the length is equivalent to 11.8 inches once the half density of iron at the ends is taken into account. The inductance of the primary can be estimated based on the number of turns: (83 turns / 25V for secondary) x 120 V for primary = 398 turns for primary. Inductance = Permeability x N^2 A/length, where N is the number of turns, A the core cross sectional area, and length the length of the magnetic circuit. Using a relative permeability (compared to air) for silicon-iron at low signals of 1200, and the permeability of air as $4\pi x10^{-7}$ Webers/meter-A-Turn, we calculate 88.4 mH for the inductance, which is fairly close to the inductance measured later. At more normal large currents the expected permeability of silicon iron is about 5 times greater, so the inductance would be about five times greater as well. These estimates for silicon-iron are approximate; material properties can vary significantly.

The size of the core is a primary determinant of the power handling capability of the transformer. A simplified approach to transformer design described at http://en.wikibooks.org/wiki/Electronics/Transformer_Design, gives the formula applicable to 60 Hz transformers having a magnetic flux density of 12,000 Gauss: a = .1725 sqrt(P), where a is core area in square inches and P is power. Using the formula indicates a capacity of about 100 Watts for this core. The implication is that Lionel expects the flux density to be considerably larger than 12,000 Gauss (with increased core losses and decreased efficiency as a result), and the rated transformer power may not be sustainable indefinitely. Note that this same core is used in the Z and ZW (rated 250 Watts). The same source gives a formula for the turns per Volt ratio, T=4.85/a = 2.296 turns/Volt, or .44 Volts per turn. This V (if we assume a rated 25V output from 83 turns) comes in at .30 Volts/turn. That is in the ballpark, but again shows that this transformer is a bit outside the norm.

Primary (120VAC) coil:

Physical size: wire diameter measured at about .021 or a bit more in diameter with caliper. This was a difficult measurement, because only the very ends were exposed, and there may have been some flexing of the caliper or pinching of the wire. A diameter of .021 in gives an area of .000346 square inches. AWG22 has a diameter of .02535 inches and an area of .000505 square inches. AWG23 is .0226 inches and .000400 square inches. AWG24 is .0201 inches and .0003173 square inches. It was assumed that the coil was AWG22 (assumed to be a more commonly available size than AWG23) and then measurements made to test that hypothesis. AWG 24 may appear closer, but the AWG22 assumption seemed to work well for resistance, and the wire just seemed to look bigger than AWG24. The coil was about (1¼ + 2¼) x 2 inches per turn, so about .583 feet per turn. The length of the coil was 2 ¾ inches in length. If the nominal 83 turn secondary produces 25 Volts, 398 turns would be needed for a 120V primary under ideal conditions, requiring 232.4 feet of wire. At AWG 22 resistance is 16.14 Ohms/Kfeet so one would expect a primary resistance of about 3.75 ohms. The observed resistance was 4.3 Ohms. This seems consistent. AWG23 would have had a primary resistance of 4.7 Ohms, and AWG24 5.97 Ohms. (Might it be possible that the wire suffered stretching while being wound? The values for size and resistance are for 20 degrees and room temperature was slightly higher, but that should not have made much difference. It's also possible that the wire is somewhat less than ideal annealed copper.) If AWG22 was used, with a diameter of .02535 inches assumed, 398 turns would require 10.1 inches of windings (at the size assumed) hence 3.67 layers. Allowing for insulation and a bit of spacing four layers is a reasonable assumption. (Later electrical measurements, 123VAC in giving 24V out, suggests that the number of primary turns is about 425 for 3.92 layers and 4.00 Ohms, quite close to the observed value.)

Electrical: Resistance measured at the coil was 4.30 Ohms. Measured at the plug the resistance was 4.4 Ohms. Inductance and AC resistance and Q was measured. A tabulation of measurements is given as Table A-1, with all measurements taken at the plug. A second transformer of the same sort is tabulated in Table A-2. Comparable data for a other transformers are shown as Tables A-3 to A-8. All measurements made with a resistor across the secondary are made with either #3 or C-U as applicable at maximum.

Table A-1 Primary Coil Impedance Measurements, early V transformer (#2)

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load/no pilot	120Hz	94.27	6.478	11.235
No load/no pilot	1KHz	78.63	9.913	50.04
No load, pilot in	120Hz	92.82	4.924	14.54
No load, pilot in	1KHz	66.23	2.332	178.87
10Ω at #3, no pilot	120Hz	87.62	3.472	19.874
4Ω at #3, no pilot	120Hz	77.75	2.428	24.73

notes: Pilot light resistance 3.33 Ohms (cold). Primary DC resistance 4.4 Ohms

Table A-2 Primary Coil Impedance Measurements, early V transformer (#1)

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load/no pilot	120Hz	94.51	5.592	13.3
No load/no pilot	1KHz	79.24	9.50	52.25
No load, pilot in	120Hz	92.28	4.086	17.436
No load, pilot in	1KHz	60.39	1.826	208.0
10Ω at #3, no pilot	120Hz	89.18	3.629	19.00
4Ω at #3, no pilot	120Hz	85.64	3.015	21.90

notes: Pilot light resistance 3.16 Ohms (cold). Primary DC resistance 4.55 Ohms

Table A-3 Primary Coil Impedance Measurements, Z transformer (postwar?)

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load/no pilot	120Hz	97.59	7.263	10.356
No load/no pilot	1KHz	80.63	9.854	51.64
No load, pilot in	120Hz	95.75	5.272	14.161
No load, pilot in	1KHz	62.80	1.862	202.2
10Ω at #3, no pilot	120Hz	87.47	2.98	22.68
4Ω at C-U, no pilot	120Hz	75.44	2.011	28.91

notes: Pilot light resistance 3.05 Ohms (cold). Primary DC resistance 2.95 Ohms

Table A-4 Primary Coil Impedance Measurements, ZW transformer (250W type)

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load/no pilot	120Hz	192.61	10.10	15.035
No load/no pilot	1KHz	164.82	10.14	102.63
No load, pilot in	120Hz	187.09	4.918	29.36
No load, pilot in	1KHz	101.53	1.287	496.7
10Ω at C-U, no pilot	120Hz	188.35	5.422	26.77
4Ω at C-U, no pilot	120Hz	187.31	5.060	28.57

notes: Pilot light resistance 3.15 Ohms (cold). Primary DC resistance 3.14 Ohms

Table A-5 Primary Coil Impedance Measurements, type V transformer (postwar #1)

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load/no pilot	120Hz	202.8	7.025	22.24
No load/no pilot	1KHz	164.88	11.40	9.629
No load, pilot in	120Hz	170.08	2.214	59.42
No load, pilot in	1KHz	40.56	.7186	355.3
10Ω at C-U, no pilot	120Hz	186.54	3.229	44.54
4Ω at C-U, no pilot	120Hz	180.01	2.775	50.05

notes: Pilot light resistance 2.98 Ohms (cold). Primary DC resistance 6.66 Ohms

Table A-6 Primary Coil Impedance Measurements, type V transformer (postwar #2)

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load/no pilot	120Hz	190.22	5.789	25.12
No load/no pilot	1KHz	154.08	10.39	93.52
No load, pilot in	120Hz		3.175	44.25
No load, pilot in	1KHz	71.97	.9781	463.6
10Ω at C-U, no pilot	120Hz	186.54	3.229	44.54
4Ω at C-U, no pilot	120Hz	180.01	2.775	50.05

notes: Pilot light resistance 3.12 Ohms (cold). Primary DC resistance 5.88 Ohms

Table A-7 Primary Coil Impedance Measurements, type VW transformer

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load/no pilot	120Hz	179.18	5.639	24.59
No load/no pilot	1KHz	139.66	11.15	78.55
No load, pilot in	120Hz	166.83	3.099	41.58
No load, pilot in	1KHz	72.67	1.071	426.4
10Ω at C-U, no pilot	120Hz	173.64	4.135	32.35
4Ω at C-U, no pilot	120Hz	169.51	3.502	37.66

notes: Pilot light resistance 3.00 Ohms (cold). Primary DC resistance 6.76 Ohms

Table A-8 Primary Coil Impedance Measurements, type KW transformer

Conditions	Frequency	L(mH)	Q	R(Ohms)
No load (no pilot)	120Hz	178.65	8.613	16.034
No load (no pilot)	1KHz	148.78	13.13	71.60
10Ω at B-U	120Hz	170.56	4.209	31.26
4Ω at B-U	120Hz	166.68	3.580	35.94

notes: Pilot light resistance 3.00 Ohms (cold). Primary DC resistance 6.76 Ohms

Some explanation of the quantities measured is in order. The meter used can measure characteristics at either of two frequencies, 120 Hz or 1 KHz. The coil inductance is nominally independent of frequency, but because of parasitic effects and other less than ideal behavior, measured inductance does depend somewhat on frequency. Inductance impedes the flow of current by $Z_L = j\omega L$ where ω is the angular frequency (377 radians per second for 60 Hz), L the inductance, and j indicates an imaginary value: the current is 90 degrees out of phase lagging the Voltage. The value R is the real AC resistance to the flow of current, which includes not only the DC resistance but core losses and other effects. The overall impedance $|Z_{total}| = \text{sqrt}(Z_L^2+R^2)$. So, for example, under no load conditions at 120 Hz (the frequency at which measurements were taken) one might expect 120 Volts on the early V transformer to see:

$$
\begin{aligned}
|Z_{total}| &= \text{sqrt}\ (\ (2\pi fL)^2 + R^2) \\
&= \text{sqrt}(\ (2\pi \text{ rad/cycle } 60 \text{ cycles/sec } 94.27\text{mH } 1000\text{mH/H})^2 + (11.235\Omega)^2\ ) \\
&= 37.3\ \Omega
\end{aligned}
$$

For 120 Volts, one would expect to see I=V/Ztotal = 120V/37.3Ω = 3.2A (big!). However, it turns out that actual current at 60 Hz is much, much less. It is about .36A. The reason for the big difference seems to be the magnetic properties of silicon steel, the material commonly used for transformer laminations. (The 1940 catalog specifies that the core uses silicon steel.) While material properties can vary, the inductance under small signal conditions can easily be a factor of 6 smaller than under optimum conditions. In this case we see a factor of 9 difference. It is reasonable to assume that Lionel used similar materials for the cores of all of these transformers, whose manufacture was all probably within a decade or so. However, the impedance measurements in tables A-1 to A-8 are still useful as a way of comparing different transformers.

The value of Q, the "quality" factor, is the ratio of Z_{total} to R, a higher ratio under no load conditions being very desirable because it means little to no power is being wasted. The value of Q does not always come out exactly because the measurements fluctuated a bit and were not recorded exactly simultaneously. Q is useful for showing how heavily loaded the transformer is. When Q drops below 1, the "real" component of power is getting large relative the inductive "imaginary" component. Both components (the overall current) contribute to heating of the primary winding (I^2R losses).

It is worth noting that the two early V units are fairly consistent in their characteristics, and are closer to the "Z" transformer in characteristics than any others. The Z does have somewhat lower primary resistance. A reasonable hypothesis is that the V and Z transformer primaries are almost identical except for the V having a smaller diameter wire, presumed to be AWG22, versus what must probably be AWG20 in the Z. (The resistance differences are not absolutely conclusive, however, since the cord was included, and it was difficult to get consistent DC resistance measurements at the plug.)

Secondary (pilot 6V) coil:

Physical size: wire diameter measured at about .014 inches with caliper (average of several readings) giving area of .000196 square inches. Identified as AWG 26 (.0159 inch diameter, .0001996 square inches, 40.81 Ohms/Kfeet at 20°C). Each turn approximately (2¼ in + 1½ inches) x 2 = .625 ft/turn. Coil length about 5/16 to 3/8 inch. The loose winding ends were about 9 inches long to pilot light.

Electrical: Resistance measured as .71 Ohms after adjustment for meter zero. (At 40.81 Ohms/foot, this would imply 17.4 feet. Subtracting 1.5 feet for the leads, one would expect 25.4 turns. At .016 inch diameter (conductor only) 25 turns would give .40 inches of winding length, which is about right. (If the main secondary of 83 turns gives the nominal 25V, one would expect 7.5V for this secondary.)

Inductance .264 mH (Q .20) 1.0 Ohms AC resistance at 120 Hz.

Voltage, with bulb removed and the primary measured at 123.05V at the plug: 6.68 Volts

Secondary (variable 25V winding) coil:

Physical size: about 3mm x 1mm (not measured precisely – later, measured and I can't find the numbers. About equivalent to #11 wire in cross section). 83 turns counted. Electrical measurements: Resistance was too low to be measured with accuracy. 4.01 mH and a resistance of .04 Ohms or less. (measured at the coil terminals).

Voltage, with knob set for maximum (25V nominally): 24.15V at #3 or #4; 24.00 Volts at #1 or #2 (Primary Voltage at the plug: 123.05 Volts) (Note: the difference in Voltage is about right; #1 and #2 contact the underside of the coil, which is ½ turn short of where #3 and #4 contact the coil. At 83 turns/25 Volts, a ½ turn gives a difference of .15 volts.)

Based on the inductances measured (the ratio of the squares), one would expect to see 23.3 Volts at this secondary. The 24 Volts measured is acceptably close. (The inductance measurements are made at 120 Hz rather than 60 Hz, which introduces a bit of error. Still, these measurements are useful for testing consistency.)

Current measurements:

With the transformer operating, Voltage and current measurements were made for the primary under different operating conditions Using the test circuit shown below. After measuring resistances, the actual Voltage multiplier was found to be 95.98 to get line Voltage, and the Voltage used to measure current divided by .30 Ohms.

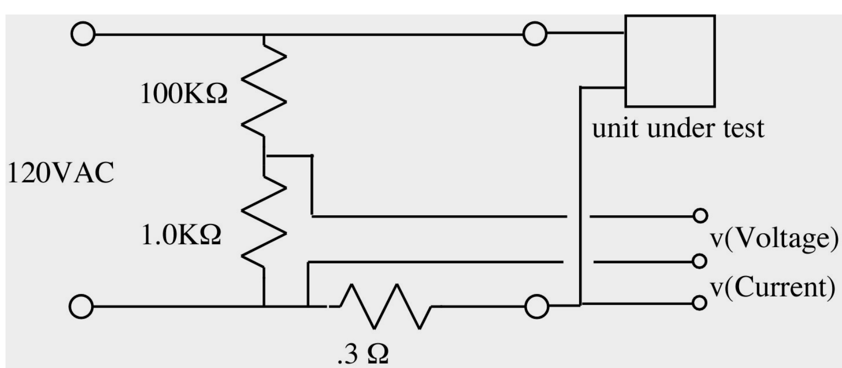

Figure A-2 Test circuit schematic

Table A-9 summarizes the operating conditions observed. Note that the current drawn (measured by the METEX meter mentioned earlier reading AC Volts) is smaller than might be expected based on the 120 Hz impedance data. The nonlinear transformer core is believed to be the explanation. Table A-10 is data for a (late) Z.

Table A-9 Operating measurements, Early V

Conditions	v_V(Volts)	AC Volts	v_I(Volts)	Current(A)
No pilot	1.307	124.8	.1099	.366
Pilot on	1.305	124.6	.1102	.367
Pilot and 10Ω on #3	1.303	124.4	.1917	.639*

* The 10W resistor across terminals #3 had 19.7 V across it (nominally 38 Watts), although by the time this measurement was made the 5W resistor was very hot.

Table A-10 Operating measurements, late Z

Conditions	v_V(Volts)	AC Volts	v_I(Volts)	Current(A)
No pilot	1.294	123.7	.1315	.438
Pilot on	1.297	124.0	.1333	.444
Pilot and 10Ω on #3	1.296	123.9	.2224	.741*

* The 10Ω resistor across terminals C-U had 23.6V across it (briefly) (nominally 56W)

Additional similar measurements were made later with the aid of an oscilloscope used to discern the separate real and imaginary components of the primary current. Figure A-4 illustrates a typical low load current as a function of time. This particular figure shows the early V with a 12 Ohm resistor load at about 24 Volts. The "Imaginary" current peak at 90 degrees (and -90 degrees) stays at about .110 Amperes regardless of the load. The "real" component of the current rises from about .06 A with no load to .11 A as seen here and progressively to .16 A, .20 A, and .23 A as additional 12 Ohm loads are added for each of the four outputs. Table A-11 gives the specifics for the early V, and Tables A-12 to A-15 give similar data for other transformers for comparison.

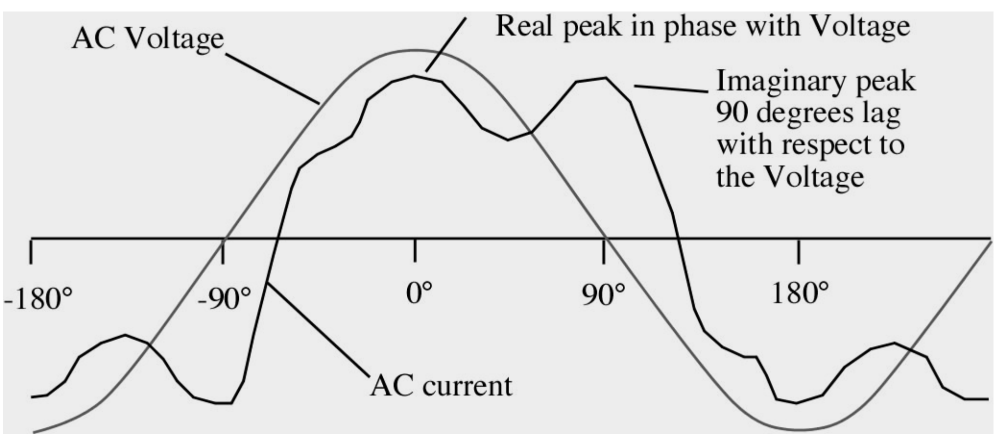

Figure A-4 Oscilloscope Current measurements

Table A-11 Early V Transformer Operation under Load

Circuits loaded	Vout(V_{rms})	Pout(W)	Ireal(A_{peak})	Iimag(A_{peak})	Imeter(A_{rms})	Pin(W)
No load			0.60	1.13	.40	51.3
#3	23.19	46.5	1.13	1.13	.65	96.7
#3, 4	22.57	88.0	1.60	1.07	.89	136
#3, 4, 2	21.83	122	2.00	1.07	1.12	171
#3, 4, 2, 1	21.57	160	2.33	1.07	1.37	199

The four load resistors were nominally 12 Ohms each. The resistors attached to the respective four terminals were measured as 11.15, 12.13, 11.57, and 11.58 Ohms. Real and imaginary components were measured with an oscilloscope using the test circuit shown earlier in Figure A-3, and could only be read to 5% accuracy, or in some cases of the lower currents maybe to 10%. The meter used for Imeter was the METEX DVM mentioned earlier. It seems not to be a true rms meter; those measurements are suspect.

Table A-12 Z Transformer Operation under Load

Circuits loaded	Vout(V_{rms})	Pout(W)	Ireal(A_{peak})	Iimag(A_{peak})	Imeter(A_{rms})	Pin(W)
No load			0.46	1.40	.52	39.4
#3	24.30	51.0	1.20	1.40	.80	103
#3, 4	23.95	99.1	1.87	1.40	1.09	160
#3, 4, 2	23.12	136	2.27	1.40	1.35	194
#3, 4, 2,	22.70	178	2.67	1.40	1.64	228

Table A-13 Later V Transformer Operation under Load

Circuits loaded	Vout(V_{rms})	Pout(W)	Ireal(A_{peak})	Iimag(A_{peak})	Imeter(A_{rms})	Pin(W)
No load			0.60	0.53	.21	51.3
#3	23.80	49.0	1.20	0.53	.48	88.2
#3, 4	22.55	87.9	1.87	0.53	.77	160
#3, 4, 2	21.46	118	2.00	0.67	1.03	171
#3, 4, 2, 1	20.46	144	2.33	0.80	1.22	199

Table A-14 KW Transformer Operation under Load

Circuits loaded	Vout(V_{rms})	Pout(W)	Ireal(A_{peak})	Iimag(A_{peak})	Imeter(A_{rms})	Pin(W)
No load	(seem too low!)		0.60	0.67	.23	51.3
A-U	15.0		0.93	0.67	.37	79.6
A,B-U	14.7		1.20	0.67	.51	103
Ax2R's,B-U	13.65		1.33(?)	0.67	.62	114
A,Bx2R's-U	13.3		2.27	0.67	.76	194

Table A-15 ZW (250W) Transformer Operation under Load

Circuits loaded	Vout(V_{rms})	Pout(W)	Ireal(A_{peak})	Iimag(A_{peak})	Imeter(A_{rms})	Pin(W)
No load			0.67	0.53	.27	57.3
D-U	18.89	30.8	1.07	0.53	.43	91.6
D,A-U	18.75	60.7	1.33	0.67	.62	114
D,A,B-U	18.80	90.2	1.67	0.80	.81	143
D,A,B,C-U	18.48	118	2.00	0.80	1.01	171

Concerning the above tables, note that with the lower output Voltages of the KW and ZW transformers result in comparatively lighter loads. For example at the approximately 24 Volts put out by a Z or V a 12 ohm resistor dissipates 48 watts, while at the 19 Volt output of a ZW it dissipates only 30 watts. The KW transformer tested may have some problems on the secondary side. It was difficult to get consistent output Voltage readings, and those reading seem way too low. Its circuit breaker acts at too low a Voltage, and indeed started to trip at the approximately 4.4A load with all four paralleled resistors present. In all cases, there would have been some internal transformer loading for the secondary resistance, circuit breaker and wiring.

A few things are interesting and worth noting. One is the consistency of the imaginary component even as the real component changes for most transformers. The exception is the later V transformer. Under heavier loads, the imaginary component associated with the AC inductance of the primary rises, indicative of core saturation, hence lowering of effective inductance, and as a consequence increasing core dissipation. Under the heavier loads, the late V is reaching its limits. The power it delivers with all four resistors driven is about 140 Watts, approaching the nominal rating of the transformer. On the other hand, the early V (which maintains its output Voltage better) delivers 155 watts and shows no sign of core saturation at all. The Z transformer (with a higher output Voltage still) delivers 172 Watts to this same load also without showing signs of core saturation.

Later Voltage and current measurements:

After noticing anomalies in data collected for different loads on different circuits, additional data was collected in July 2014 for a set of transformers including early and late V and early and late Z. A different set of transformers was used that for the earlier data, so some of the variations from earlier data may be variability in characteristics, perhaps most likely due to variations in the silicon steel characteristics, or variations in coil winding. Also, resistance in the transformer due to the circuit breaker and connections, particularly the roller to coil connections, may vary. The roller/coil variations are quite noticeable, and the same terminal Voltage under maximum setting can vary with small variations in the knob placement. To get the data below, many settings were tried (and data given), with the best consistent values (or an average of best available) used for analysis.

For all of these measurements, the resistances connected were "R1" on circuit #1 (A-U for late transformers), R2 on circuit 2, and so forth. Resistances (all nominally 12 Ohms) were measured as 11.09, 12.15, 11.50, and 11.71 Ohms respectively (at room temperature). The resistors (20 Watts?) did get pretty hot, and there may have been a little value drift, but that is assumed negligible. The current measurement is in Volts (rms) across a .3 Ohm resistance in series with the primary. The current measurements are useful when judging consistency when comparing Voltage readings. Readings marked "*" were used as useful representatives for constructing a performance graph. Voltages were measured at the resistance for the first circuit mentioned in each case. Readings are listed in the order taken.

Table A-16 Early V Voltage vs Load raw data:

Configuration	V(V)	I(V)	Configuration	V(V)	I(V)	Configuration	V(V)	I(V)
None(D)	25.15	.1633	C	22.78	.1999	B+A	22.63	.2623
C*	23.82	.2047	C+D*	23.30	.2811	B*	23.41	.1995
D	22.67	.2008	C*	24.12	.2041	None		.1638
C	22.67	.2008	C	22.86	.1997	C	22.93	.2005
B*	23.49	.2010	C+D	22.09	.2753	C+D*	23.25	.2814
C	24.13	.2040	C+D+B*	22.60	.3644	C	23.07	.2006
A	23.03	.1915	C+D*	23.40	.2800	C+D*	23.26	.2792
None		.1641	C	23.04	.2006	C+D+B*	22.58	.3569
			B	23.25	.1989	all*	21.98	.4350

Table A-17 Late V Voltage vs Load raw data:

Configuration	V(V),	I(V)	C	22.78	.1999	D+C+B	18.93	.3031
None(D)	24.34	.0997	C+D	20.44	.2236	All*	17.91	.3741
D	20.90	.1454	C+D*	20.55	.2210	D*	23.06	.1521
C*	23.08	.1534	B*	23.13	.1513	D+A*	21.85	.2392
B	21.65	.1455	B+A	20.58	.2259	D+A+B*	20.86	.3134
A	22.78	.1488	D*	23.06	.1526	All*	17.64	.3786
D*	23.06	.1528	D+C	19.90	.2284			

Table A-18 Early Z Voltage vs Load raw data:

Configuration	V(V),	I(V)	C+D	21.80	.3006	B+A+C	21.63	.3744
None(D)	24.96	.2074	A*	24.08	.2419	All*	20.96	.4513
D	22.26	.2352	A+B*	23.30	.3055	A	22.56	.2373
C	22.62	.2360	A+B+C*	22.64	.3798	A+B	21.90	.2996
B	22.90	.2354	All*	21.96	.4589	A+B+D	21.26	.3761
A	22.02	.2380	A+C+D*	22.65	.3814	All	20.56	.4533
A*	23.97	.2422	A+D*	23.37	.3068	A+C+D	21.08	.3776
D	22.61	.2365	A*	24.02	.2409	A+C	21.77	.3001
B	22.84	.2347	B	22.95	.2339	A	22.46	.2367
C	22.53	.2362	B+A	22.34	.2987			

Table A-19 Late Z Voltage vs Load raw data:

Configuration	V(V),	I(V)	A	22.80	.2418	C+A	21.96	.3037
None(D)	25.13	.2237	A+B	22.37	.2991	C	22.44	.2476
D	23.50	.2499	B	23.04	.2480	D	24.30	.2530
C*	24.41	.2518	B+A	22.26	.3081	D+B	22.98	.3101
B*	24.39	.2516	B	22.84	.2475	D+B+A*	23.23	.3900
A	22.41	.2508	C*	24.54	.2530	All*	21.80	.4715
A	22.70	.2497	C+D	21.87	.3099	D+C+A	22.28	.3872
D*	24.31	.2533	C+D+B*	21.46	.3831	D+C	22.80	.3094
D+C*	23.08	.3181	All*	20.98	.4609	D	23.40	.2498
C*	24.56	.2531	C+D+A	21.55	.3835			

Collecting the "best" of these data gives Table A-20 from which a graph shown as Figure A-5 below is drawn.

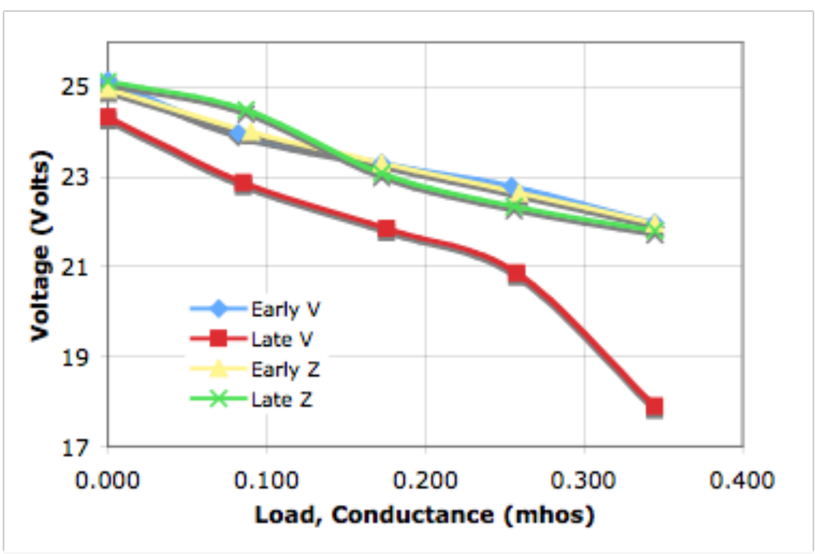

Figure A-5 Transformer Voltage vs Load for early and late V and Z transformers

Table A-20 Transformer data for graph

Early V Loads	added Resistance	total Conductance	Voltage
0		0.000	25.15
1	C(R3)	0.082	23.98
2	C+D(R3+R4)	0.172	23.3
3	CDB (R2,3,4)	0.255	22.79
4	all	0.345	21.98
Late V			
Loads	Resistance	Conductance	Voltage
0		0.000	24.34
1	D(R4)	0.085	22.87
2	D+A(R1+R4)	0.176	21.85
3	DAB(R1,2,4)	0.258	20.86
4	all	0.345	17.91
Early Z			
Loads	Resistance	Conductance	Voltage
0		0.000	24.96
1	A(R1)	0.090	24
2	A+B(R1,2)	0.172	23.3
3	ABC(R1,2,3)	0.259	22.64
4	all	0.345	21.96
Late Z			
Loads	Resistance	Conductance	Voltage
0		0.000	25.13
1	C(R3)	0.087	24.5
2	C+D(R3,4)	0.172	23.08
3	CDBavw DBA	0.256	22.34
4	all	0.345	21.8

The data for the late V seems anomalously low, and despite the use of all four circuits, there may be some weakness in the current path that accounts for this seemingly too-low Voltage. It may also be that at this point the core is saturating. (The early V tripped its circuit breaker shortly after the maximum load data was collected, and continued to break under a 3 circuit load, so it may be that the late V was close to a break under these conditions.)

Despite the variability and difficulties with repeatability of the data, the early V and both Z models behave remarkably similar. The late V is clearly in a different class. What this exercise does not address is the issue of sustainability. Under no load conditions the late V draws less current, and does so under other load conditions as well (although supplying less power). That should mean that the late V would not heat up as much internally. The early V would seemingly dissipate more power inside the primary winding at different power levels compared to the Z models, and this may give reason to limit the maximum sustained power to a level lower than that of the Z types. How much lower has not yet been determined.

(One transformer reseller has sold an early V transformer and described it as having a larger power handling capability than a standard V. He cut a hole of about 2 inches in diameter under the transformer winding to allow additional ventilation as a way to compensate. I believe the transformer was provided with a 10A breaker so it could bear a heavier load.)

Under maximum load and power delivered, the respective currents for early V, late V, early Z, and late Z can be calculated from the current indicating Voltages by dividing by .3 Ohms, the current measuring resistor value. That gives internal power dissipation in the primary and power delivered values shown in Table A-21 below. Note that the resistance measurements were made at the plug. The early Z may well have the same low resistance as the late Z, with cord and measurement error accounting for the small difference. The current rms numbers should be good. It is clear that the late V must have lighter or longer primary winding wire (to get a larger resistance) than the early V, which is apparently lighter than the primary wire for the Z.

Table A-21 Power Dissipation under maximum load:

Type	Primary Current I(rms)	Primary dissipation(W)	Power delivered(W)
Early V (4.46Ω)	1.45	9.4	167
Late V (5.65Ω)	1.26	9.0	109
Early Z (2.93Ω)	1.53	6.9	166
Late Z (2.63Ω)	1.57	6.5	164

Conclusions so far concerning electrical characteristics:

The early V transformer has characteristics close to those of a Z transformer, much closer than to later versions of the V or any other later transformer. It has a similar impedance and has the same large heavy core, albeit with a somewhat higher resistance. So, the natural question is whether it can deliver power like a Z, rather than just the nominal 150 Watts at which the transformer and its later cousins are rated.

The answer is that it isn't just a Z with a smaller circuit breaker, but it is close. There does seem to be a definite difference in the primary winding resistance. This early V seems to use AWG22 wire, and the Z perhaps AWG20. (If the Z has 398 turns of AWG20 wire at 10.15 Ohms for Kfeet, one would expect 2.36 Ohms, which is close to the measured value of 2.95 Ohms including the cord. The Z probably has 4% fewer turns to give 25 instead of 24V out at no load. The higher Z secondary Voltage and lower Z impedance measurements and higher no-load current at 120VAC all suggest the Z has somewhat fewer turns on the primary. The larger number of turns turns, slightly higher inductance, and higher resistance all mean that for a given power this early V will lose more Voltage in the primary winding and dissipate more heat than the Z. If dissipation becomes excessive, temperatures rise and copper resistance goes up, increasing dissipation.

It was noted that the Z maintained Voltage to various loads better than did this early V, but the Voltage drops per unit of additional load are similar. In later measurements, no significant difference was found. That may be due to individual unit variations. In contrast, under heavier loads a later V Voltage drops about twice as fast.

Core losses (and heating) should be comparable to a Z at similar power. The V primary does not have a big part of the secondary on top of it as does the late Z or V transformers, so it may be easier for the primary to get rid of heat. The KW primary seems to have a resistance as large as or larger than this early V, and it is rated 190 Watts. This transformer should able to handle power at least at a level comparable to the KW, likely more.

The key question is whether the early V dissipates more power losses inside the transformer than a Z. Taking the difference between power in and power out shows that the early V dissipates less internally than the Z at most loadings, in the vicinity of 50W compared to 60W for the Z. The late V is a little worse than the early V. However, it is not clear that these measurements were made with enough accuracy to be conclusive.