Introduction:

360° Test Labs has been retained to perform a failure analysis upon provided failed 12V/2.5A battery charger samples, as seen to the right. The label on the chargers identifies them as provided by ..., model #XX-00025(P) 2.5 Amp battery chargers. Each charger also has a round yellow sticker with either a letter N or letter R, and a unique 6-digit number. The purpose of the stickers is unknown, but thought likely to be the client's internal-use tracking number.

Follow-Up to De-potting:

Several chargers were disassembled by removal of the plastic case, which revealed that the electronic circuitry had been potted by the manufacturer. The composition of the hard, black epoxy-like potting compound is unknown, but has proven impervious to numerous de-potting solvents. Client personnel were successful in de-potting most of the AC input circuitry end of the PC board but due to the numerous small resistors, diodes and transistors on the DC output end of the board, almost all of that circuitry is still unknown.

However, after reverse-engineering the AC input and DC output circuitry, engineers were able to conduct voltage and oscilloscope tests, and found at least four resistors of which one or more have failed on most of the units provided. Another unit appears to have been hit by a high voltage spike such as from a nearby lightning strike, and the four power rectifier diodes in the AC input circuitry were found bad. The following details 360°'s results.

Results

When 360° Test Labs' engineers checked for the proper operating voltage being applied to the IC3843BN, an IC identified as the Pulse Width Modulator (an ON Semiconductor type UC3843BN 8-pin DIP), it was found that no two chargers appeared to be producing exactly the same results. Further checks found that while the high voltage bridge rectifier and filter capacitor are working on most of the chargers (including a 2 ampere fuse at the input to the bridge rectifier), the voltage being applied to the UC3843BN varies widely from 0 to 15 VDC.

Two resistors provide bias and operating voltage to the PWM chip, and a third is apparently part of a snubber network associated with the pulse transformer: A 1.2 megohm ½ watt; a 220 kilohm 1-watt; and a 56 kilohm, 1-watt unit.

Of 10 of 13 chargers judged safe to be tested with 120VAC, four showed some output voltage ranging from about 10.8 to 27 VDC, and five showed no output or output in the millivolt range. Checks of the voltages being applied to the PWM IC found three chargers getting voltage through all three resistors and all the rest appearing to have either shorted PWM chips or open resistors. One charger, however, showed no output voltage from the high voltage bridge rectifier. The table on the following page details the measured voltages and resistances, as well as comments on failed components found, repairs made, and results of the repairs.

The actual nomenclature of the three input resistors cannot be discerned on the several de-potted units available as either the original printing on the PC board has been wiped off by the potting compound or by the de-potting chemicals used by 360° Test Labs. Thus, for our internal reference, engineers have called the three resistors Ra, Rb and Rc, as shown in the table that follows.

The AC input resistance was measured at the end of the cable to be connected to the AC line; similarly, the DC output resistance was measured at the end of the cable to be connected to the battery. Note that in the table, infinite resistance is indicated by a series of dashed lines in the respective table cell.

Due to the potting compound, the actual intended resistance cannot be read from the resistor body; instead, since a preponderance of Rc resistors appeared to measure around 56 kilohms and that is a standard resistance value, engineers surmised that Rc is supposed to be 56 kilohms. Similarly, Rb resistors appeared to center around 220 kilohms which is also a standard value. Engineers were able to read two of the color bands on resistor Ra and have surmised that resistor value is supposed to be 1.2 megohms.

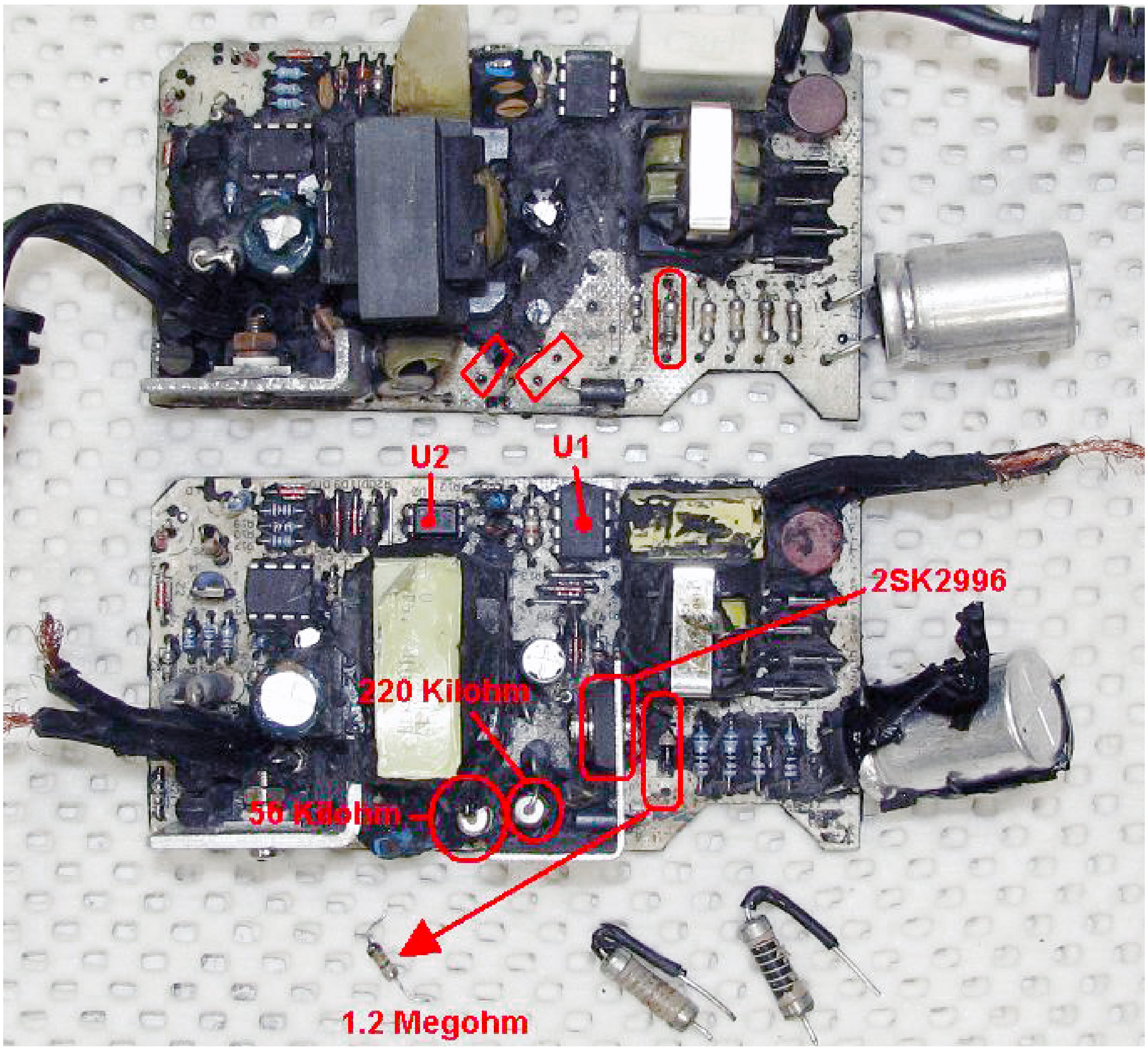
Yellow Sticker Number	S/N	AC Input Res. (ohms)	DC Output Res. (ohms)	Vout (VDC)	Ra (ohms, nom. 1.2M)	Rb (ohms, nom. 220K)	Rc (ohms, nom. 56K)	Comments
N676968	031504273CT	0.5M	36K	10.8	1.9M	242K	64K	Open 2.4K; replaced, now regs @ 13.5
R611782	091201735CT	0.6M	35K	0	------	------	2G	No HV; all 4 diodes in bridge rectifier open
N676813	092600233CT	1M	32 ohms	0	NA	NA	NA	Unique failure mode; not de-potted
R611896	032004264CT	0.5M	35K	27	------	310K	------	Unique failure mode
N676962	031502090CT	0.5M	36K	0	------	------	------	Replaced all 3 open input resistors, regs @ 13.5
Client De-Potted Unit	?	1M	35K	0	------	------	58K	
N676945	091900593CT	0.6M	0.4 ohms	NA	------	99M	69K	Un-repairable due to chemical damage
R611892	092601329CT	1.2M	NA	NA	------	------	74K	Un-repairable due to chemical damage
N677545	034600592CT	1.1M	36K	11.87	2.2M	222K	56K	Open 2.4K; replaced, now regs @ 13.5
N677292	034009716CT	1.1M	34K	11.18	1.2M	219K	56K	Open 2.4K; replaced, now regs @ 13.5
R611697	092002573CT	1.2M	36K	0	1.6M	------	83K	Damaged PCB during de-potting. Replaced only Rb, output is now 13.5 no load, 12.8 @ 10 ohms
N6677682	034122009CT				-------	420K	70K	Un-repairable due to chemical damage
R612433	093201347CT	1.2M	35K	0	------	------	------	Replaced all 3 open input resistors, regs @ 13.5

Notes:

1. Resistances are shown in ohms, kilohms (K), megohms (M) or gigohms (G).
2. Infinite resistance is denoted by dashed lines (-------) in a cell.
3. Empty cells mean the parameter has not been measured.

Note that most of the chargers evaluated appeared to have suffered at least two resistor failures, and at least two had all three resistors fail (“fail” being defined as the measured resistance having doubled in value or more).

Further investigation and close examination of the charger with no HV output at all indicates that it most likely suffered lightning damage, as all four bridge rectifiers, and the three resistors, are essentially open; yet, the fuse did not blow. Close examination of the PC board traces shows the solder joints on the PC traces carrying the HV, and the three resistors, appear to be slightly darkened compared to other adjacent solder joints of other parts of the circuitry. This unit has not been de-potted on the component side, so any other damage caused by a lightning strike cannot be discerned, but engineers would not expect to be able to tell due to potting compound residue sticking to components. The following photo shows the location of Ra, Rb and Rc.



U1 is the UC3843BN PWM chip; U2 is an optocoupler which provides feedback between the PWM chip and the output side of the charger. Another 8-pin DIP IC seen on the left side of the boards above is U3, a LM358N dual op amp. Immediately to the left of U3 is U4, a 2.5 VDC programmable reference diode. The 2SK2996 is the N-channel high power MOSFET switching transistor that drives the power transformer on the left side of the board. On the top board, the two red rectangles show where Rb and Rc were mounted; the rounded rectangle to the right is the 1.2 megohm resistor Ra. The two large resistors seen on the work surface below the lower pictured board were removed from the upper pictured board; the smaller, ¼ watt resistor was removed from the lower board.

Calculations:
Engineers calculated the current through, and power dissipated within, the two dropping resistors, assuming a worst case where the resistors had the full high-voltage applied; the table below shows the results.

Resistor (ohms)	Estimated Free Space Resistor Power Rating (Watts)	120VAC			240VAC		
		VDC	Ires (amps)	Pres (watts)	VDC	Ires (amps)	Pres (watts)
1200000	0.25	166	0.000138	0.022963	321	0.000268	0.085868
220000	1.0	166	0.000755	0.125255	321	0.001459	0.468368

The estimated power rating listed for each resistor assumes the resistor is mounted in free air at 25°C and thus receives some convection cooling. Resistors must be derated in power as their temperature rises. The chargers, however, are solidly potted, with no possibility of cooling air reaching any component. Thus, as components heat up, their temperature will continue to rise until a point comes where the case of the charger is able to dissipate sufficient power as to keep the internal component temperatures at some equilibrium temperature.

The table above shows the power dissipated within each of the two resistors assuming the worst case high voltage is continuously applied (the 56K, 1-watt resistor is not included as it appears to be part of a snubber network rather than a bias voltage dropping resistor). The 220K resistor appears to provide operating power to the PWM chip, and normally will drop the HV down to about 15VDC for the chip. As can be seen above, the 220K resistor can dissipate as much as 0.47 watts when the charger is operating from 240 VAC. The 1.2 megohm resistor should be operating well within its power dissipation rating whether the charger is operating from 120VAC or 240VAC.

The schematics attached at the end of this report have been drawn by 360°'s engineers based upon what can be seen on the PC boards of several units that have been mostly de-potted. Where possible, resistor values were determined by measurement and confirmed, where possible, by examination of the remnants of color bands on de-potted resistors. Capacitors generally, however, will have to be measured as any markings have been obscured by the potting or de-potting compounds.

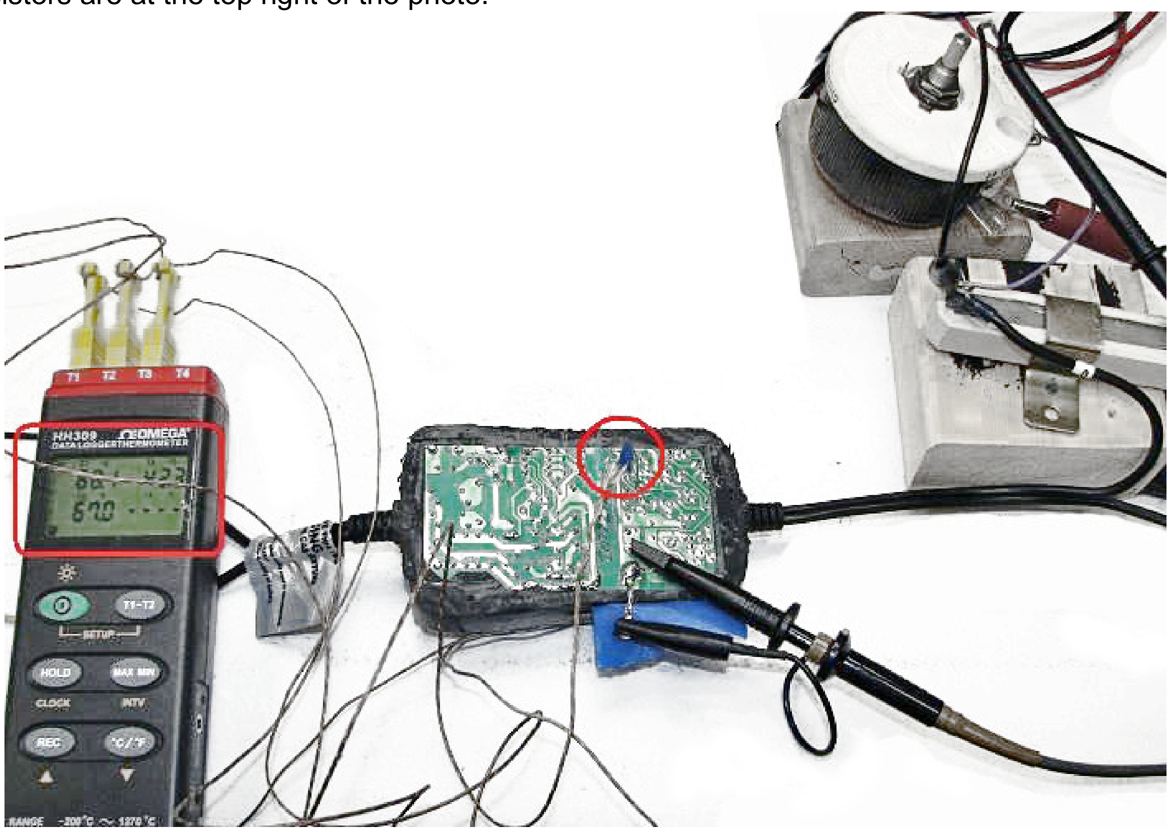
Repairs:
Additional work on all repairable units has restored five units to apparently-proper working condition by the replacement of various resistors. In addition to the three resistors previously mentioned (Ra, Rb and Rc), a 2.4 kilohm (probably rated at 1/6th watt) resistor in the output regulator was found open on at least three units. It is possibly noteworthy that all three of these units did NOT have an outright input resistor failure, however (although the values of several of the input resistors appeared to be somewhat off, such as 1.9 megohm on unit I076908 and 2.2 megohm on unit I077545). Other units found with open input resistors were repaired by replacement of the failed resistors.

The 2.4 kilohm resistor failures might be explained by consideration of the power dissipated. This resistor drops the Vcc voltage of about 13 VDC (when the charger is working properly) to 2.5 VDC for the reference diode, U4. Thus, there is approximately 10.5 volts across the resistor. Ohm's law says the current through the resistor is thus about 4.4 milliamperes, so the power dissipated is about 46 milliwatts.

However, the resistor is mounted flat on the PC board and obviously gets no cooling other than conduction through the potting compound. Typical data sheets for both carbon film as well as metal film resistors state the resistors are rated to be able to operate at full power to 70°C. At 100°C, they should be derated to about 66%, and to 50% at about 110° C.

To test this theory, engineers set up repaired unit I0077292 by applying a resistive load sufficient to cause the unit to just begin to limit its output current (it was found to limit at about 2.38 amperes where the output voltage had dropped out of regulation to about 12.8 VDC). The charger was operated at 120VAC. Temperature was measured on the top and side of the plastic charger case, and on the body of the replacement 2.4 kilohm metal film resistor. The unit was allowed to operate under load for several hours while sitting on a table and eventually reached a case temperature of about 68° C. The resistor reached about 45° C, but when mounted within the case, would obviously be at least as warm as the case plus its own power dissipation of almost 50 milliwatts. It should be recalled that these temperatures were measured on the outside of the case, and the internal temperature is likely to be at least 10° C warmer.

The unit under test is shown in the following photo. The datalogger thermocouple thermometer display (red-rectangle highlighted) shows from left top, left down, then right top: 68.1°, 67.0°, and 43.3°, all Centigrade, for the top of the charger case (laying on the table), the side (held on the case by blue tape), and the 2.4 kilohm resistor (barely visible in the red circle). The load resistors are at the top right of the photo.

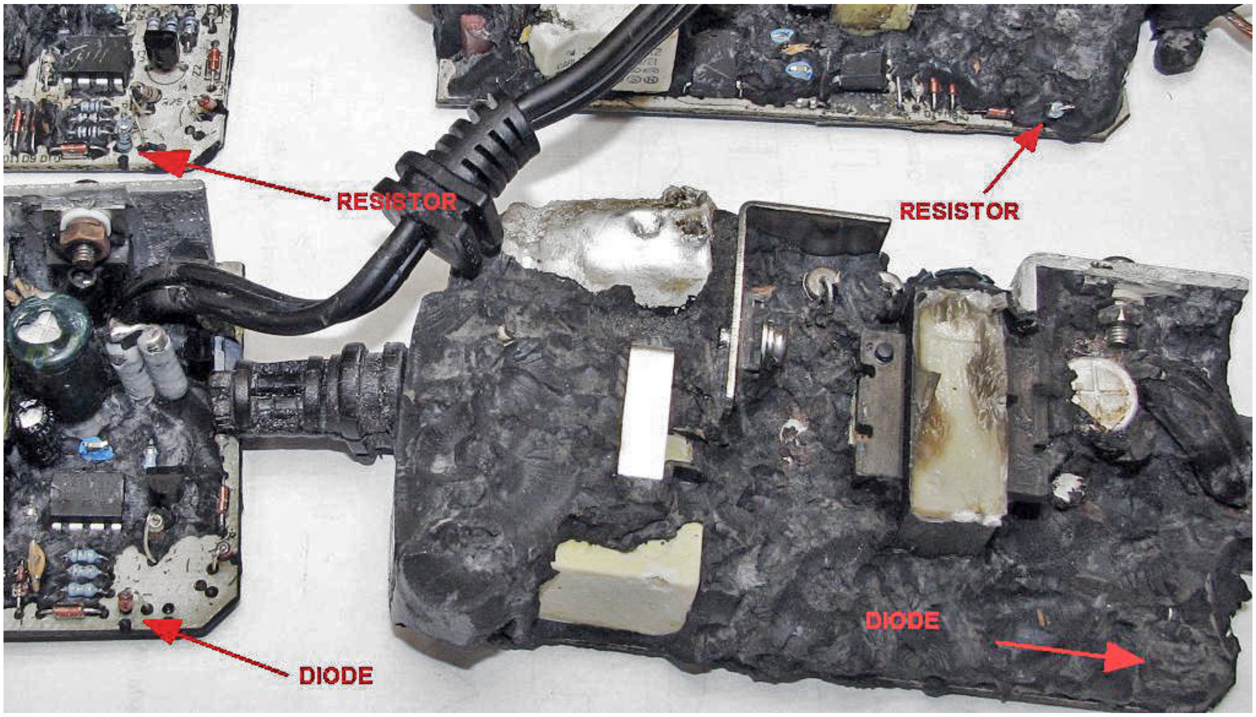


Thus, it is quite possible that the 2.4 kilohm resistor could be overheating and so opening up.

The failure of the input resistors, however, especially if the chargers are operating from 120VAC, seems more difficult to blame on temperature since only at 240VAC are they dissipating as much as half their rated power. At 120 volts, neither appear to be dissipating more than about 1/8th their rated dissipation up to 70° C. However, Rc, the 56K resistor, did fail in at least 3 of 12 chargers not suspected of lighting damage. Significantly increased value above the nominal 56 kilohms is found in these chargers, and in several other chargers where both of the other two resistors also failed. Thus, it seems possible that the input resistors may also have overheated, particularly if these chargers were operated from 240VAC.

However, it these chargers were being operated from 120VAC, another explanation for failure must be found. One possible consideration is that the protective coating on these resistors interacted with the potting compound which may have eroded the layer, then attacked the resistor elements. If there are few or no failures of these resistors in non-potted units, this possibility would be even more suspect. Because the potting compound changes the appearance of this protective coating significantly, 360°'s engineers are unable to determine the likelihood of this possibility.

Other Observations:
Engineers found at least two of the chargers appear to have 51 ohm resistors installed on the output side of the chargers in series with diode D10. However, 10 of the 12 de-potted chargers appear to have a diode installed in this location on the PC board (this is noted on the schematic). Engineers do not know the cause or significance of this change. The units with resistors are the unit de-potted by Cliient (whose serial number is unknown to 360°), and unit I076945 (serial number indicates it was manufactured during the 19th week of 2009). The following photo shows the location of these parts.

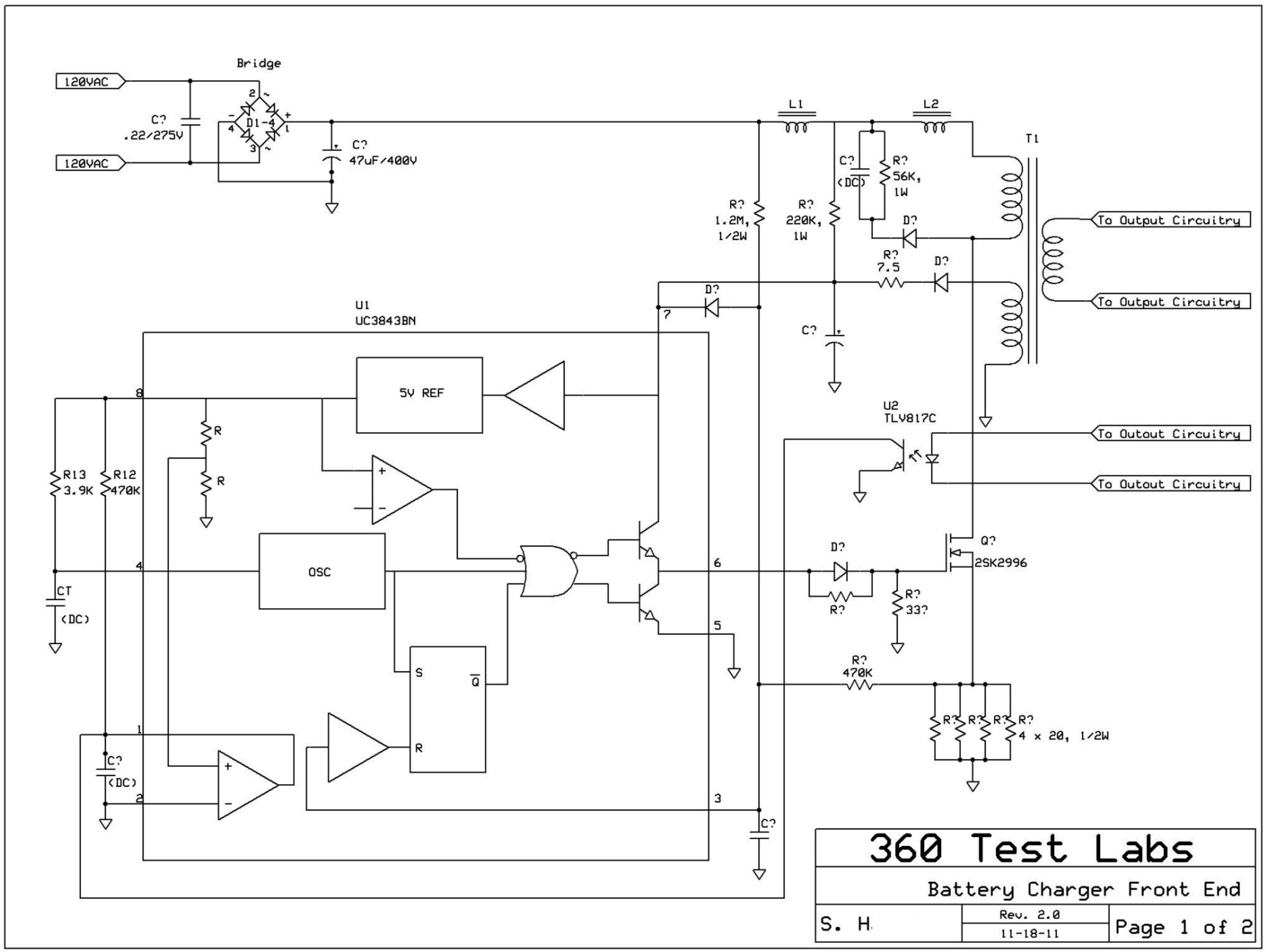


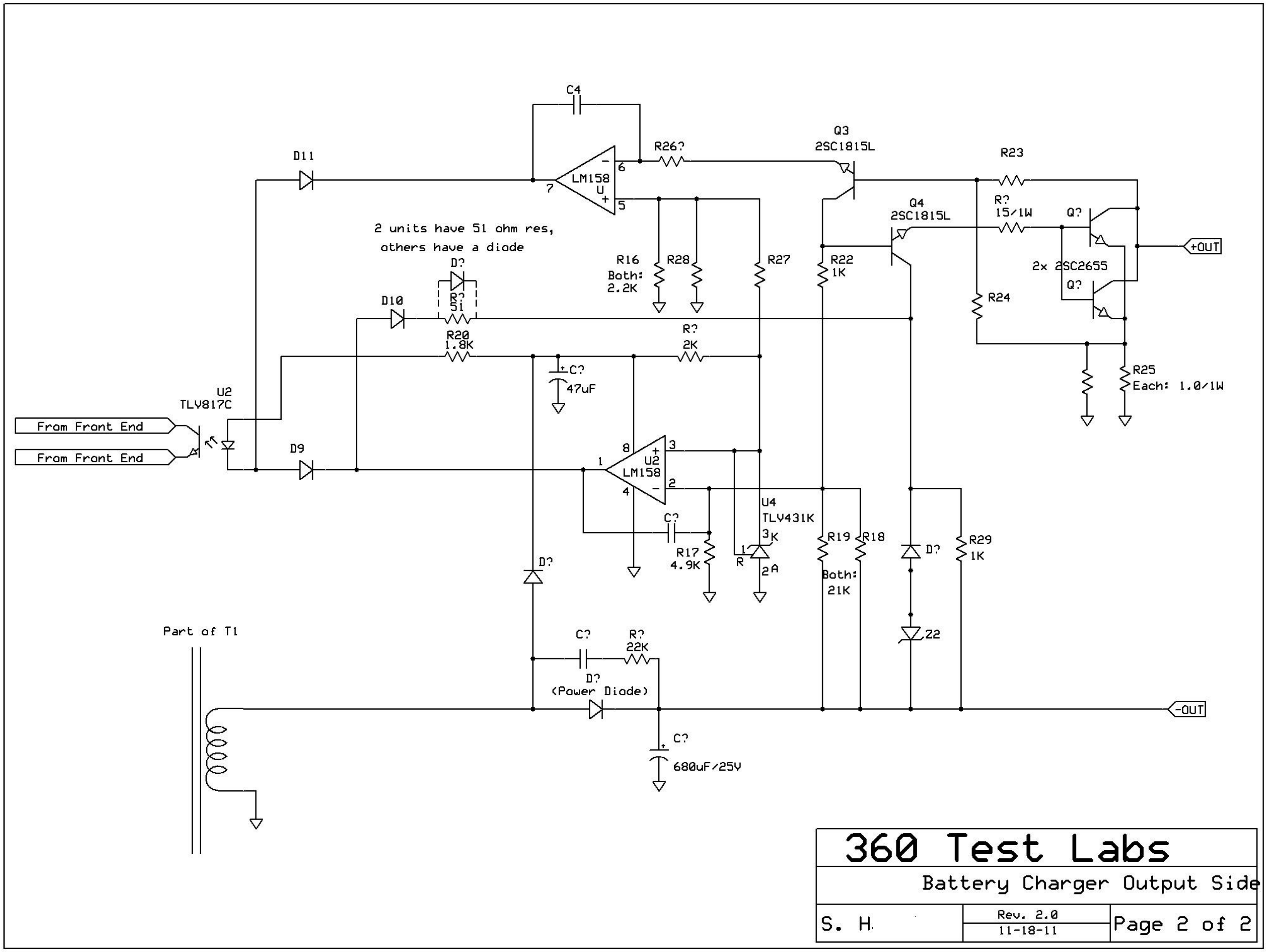
In addition, engineers note that **<u>there is no HV transient protection</u>** at the input to the chargers, such as to protect the units from nearby lightning strikes. Although there is a 0.22 µF capacitor across the AC line input to the chargers, this capacitor will not attenuate a long-lasting transient (several tens of microseconds). Its purpose, rather, is to filter and prevent conduction of high frequency switching spikes onto the AC line from the charger itself. A fuse in series with such an appliance cannot act fast enough to protect against such a transient or spike. Often, such transient/spike protection is provided by a Metal Oxide Varistor (MOV) connected across the AC line, which, under normal line voltage conditions, does not conduct, but when a high voltage spike appears on the line, conducts very heavily when the spike exceeds the line voltage by more than the voltage rating of the MOV (typically about 260 volts for a 240VAC-powered appliance).

Conclusions

The failure mode of most of the provided chargers appeared to be damaged or destroyed resistors, most likely due to power over-dissipation, almost certainly due to the chargers having been potted. Larger, higher-power resistors would likely prevent such failures. One charger appeared to have suffered damage from a high voltage spike or transient such as would be caused by a nearby lightning strike.

Developed Front End and Output Side Schematics Follow


120VAC
120VAC
Bridge
C?
.22/275V
D1-4
C?
47uF/400V
L1
L2
T1
R?
1.2M,
1/2W
R?
220K,
1W
C?
(DC)
R?
56K,
1W
D?
R?
7.5
D?
D?
C?
To Output Circuitry
To Output Circuitry
U1
UC3843BN
5V REF
R
R
R13
3.9K
R12
470K
OSC
CT
(DC)
S
Q
R
C?
(DC)
U2
TLV817C
To Outout Circuitry
To Outout Circuitry
Q?
2SK2996
D?
R?
R?
33?
R?
470K
R? R? R? R?
4 x 20, 1/2W
C?
360 Test Labs
Battery Charger Front End
S. H.
Rev. 2.0
11-18-11
Page 1 of 2


C4
D11
LM158
R26?
Q3
2SC1815L
R23
Q4
2SC1815L
R?
15/1W
Q?
+OUT
2 units have 51 ohm res,
others have a diode
D?
R?
51
D10
R16
Both:
2.2K
R28
R27
R22
1K
2x 2SC2655
R24
R20
1.8K
R?
2K
C?
47uF
R25
Each: 1.0/1W
U2
TLV817C
From Front End
From Front End
D9
U2
LM158
U4
TLV431K
R17
4.9K
R19
R18
Both:
21K
R29
1K
Z2
Part of T1
C?
R?
22K
D?
(Power Diode)
-OUT
C?
680uF/25V
360 Test Labs
Battery Charger Output Side
S. H.
Rev. 2.0
11-18-11
Page 2 of 2