ATOMS 99-07

Repair and Maintenance of Regeneration PC Boards

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1. Introduction

The regeneration PC boards in the Telescope Drive System implement a simple control loop to drain excess power from the motor's DC bus. The extra power originates in the motors due to the generator effect. The Kollmorgan amplifiers convert the AC signals from the motors into a voltage on the DC bus. When the DC bus exceeds 350 volts, the regeneration cards switch in a 12 ohm resistor to bleed off the extra power. When the DC voltage drops below 350V the resistors are disconnected.

Failures in the Regeneration boards have been a minor operations problem. It is possible to get a regeneration board repaired by the manufacture (Maccon, Inc). However, repairs are quite expensive and generally require 6 to 8 weeks. To alleviate this problem, Arecibo Observatory initiated a program to reverse engineer this design. As a result of this effort, we are able to perform in-house repairs of damaged regeneration boards. Furthermore, a related effort ware initiated to produce of a new PCB board that is pin compatible with the original design. The new board is essentially a direct copy and therefore interchangeable with the existing boards. The information in this document references the new design, but most information applies to the old board as well. They even share common reference designators. The only significant difference is some additional circuit protection components that were installed on the Arecibo board. Also, some of the original parts were difficult to procure so they were replaced with modern versions, which occasionally required different PC footprints.

A schematic of the new Arecibo Regeneration PC board is appended to this document. All new parts have reference designators of 100 or greater. (i.e. D100, C101, etc). This schematic represents the most up-to-date selection of values for the discrete components. Please note, some of the values printed on the PCB silkscreen have changed. Use the values from the appended schematic.

2. Failure Modes

During the first year of operation after the upgrade, it became clear that Regeneration modules were susceptible to failures. When they fail, they normally destroy the IGBTs (T4 and T5) and the inductive kick back diode (D42). Also, it is not uncommon to destroy the IGBT drive circuit (T2, T3 and D41). Finally, in some cases, the clamping diode D37 will also fail. This failure mode indicates a large DC voltage spike on the DC bus. If the actual board is not burned too badly, it is possible to repair the unit and reuse the board. This document will present some information for repair and testing of this design.

The details of the failure mechanism are still unclear, but we have identified two possible problems that could be related to this failure. After a regeneration failure, it is recommended that you check these items to see if they could be responsible for the fault. First, check the cables to the regeneration resistors. Both of the leads to the regeneration resistors reside at high voltages, so a short to chassis can cause a large current to pass thorough the regeneration board.

Next, it might be worth checking the soft-start circuit in the pertinent Kollomorgan power supply. If the soft start circuit fails, it may be possible for it to continue operating, but simply not have soft start. This would cause an abrupt rise in DC bus voltage during power-up. The only way to check this problem is to open the power supply and see if there is any damage to the PTC resistor and diodes that implement soft-start.

3. Regeneration Bench Test

Testing regeneration boards in the telescope chassis is not recommended. A serious failure in the regeneration circuitry is potentially dangerous, so a bench test was created to perform most tests off-line. This bench test is sketched in figure 1. A permanent text fixture was constructed with the major sections of this test.

3.1. Some Notes on the Test Fixture

- The +600V Power Supply can quickly discharge the substantial boards capacitance by manually turning the voltage adjustment knob to 0 volts. Simply turning-off the supply will drain the charge at a much slower rate and could cause arcing if the connector is hastily removed.
- R1 dissipates nearly 7 watts, and therefore gets rather hot to the touch. This is normal
- The current limiting resistor (88 ohms) in the test fixture permits setting the power supply voltage greater than the nominal DC bus trip voltage of 350 volts. Above 350 volts, the regeneration board will act like a shunt regulator, with power dissipation and regeneration rate increasing linearly with power supply voltage.

3.2. Setting the Regeneration Trip Point (Potentimeter P1)

The potentiometer P1 sets the regeneration trip point. The LM311 compares the set voltage produced by P1 to scaled down copy of the DC bus (via R6 and R7). If the DC bus voltage exceeds the trip point, regeneration will be initiated. It is important that ALL regeneration boards be set for approximately the same trip voltage. Otherwise, the board with the lowest trip voltage will tend to carry most of the load. Also, if the trip voltage is set too low, the regeneration board will attempt to pull down the line voltage, because the DC bus voltage is an unregulated rectification of the line voltage. Generally, this situation initiates a DC bus fault from the Kollomorgan power supply and an error message from the driver system. By default, the boards purchased from Macon are shipped with trip points of 325 volts, which produce this fault condition. Always chechg incoming regeneration boards for proper trip voltage.

The nominal trip point for the DC bus is +350 volts. This translates into a potentiometer output of about +6.2 Volts (IC2 pin 3). From experience, I have found that the trip point tends to change with temperature (Fortunately, the trip point increases with temperature, which is a more stable configuration because boards that are carrying an excess load will tend to heat up and raise their trip points). The following procedure should be used to set the trip point of a regeneration board.

1. Connect the regeneration board to the test stand. Attach a DC meter between to IC2 pin 3 (i.e. the output of the potentiometer). Slowly raise the power supply voltage until it reads 250 volts. Be sure the current limit is turned up to the maximum 1.7 amps. At this point there should be a stable +14 volt supply voltage on the board (TP2).
2. Adjust the P1 potentiometer to produce a voltage of approximately +6.2 volts (as measured at IC2 Pin 3). Turn down the DC voltage to 0 (using the voltage adjustment knob on the Power supply) and disconnect IC2 pin 3. Next attach the DC meter to the output of the DC supply. Note, this connection must be made at the power supply, i.e. before the 88 ohm resistor. Next, attach a scope to test point 3 (TP3).
3. Raise the power supply voltage until the meter reads 360 volts. At around 350 volts, the TP3 should start a steady stream of pulses, which indicates regeneration. These pulses should be +6 volts high and last approximately 1 msec (see next section for information on pulse duration). The period between pulses will be proportional to the supply voltage, thus the higher the supply voltage, the faster the pulses appear (however, the power supply voltage should have little or no impact on the pulse width). At 360 volts, there should be approximately 1 pulse every 10-500 msec (before final adjustment of P1, the rate could vary quite a bit
4. Raise the DC bus voltage to 400 volts. The power supply should indicate a current of about 1 amp. Let the board run in this mode for about 1 hour. Be sure the fan is on to cool the power resistors. If necessary, adjust P1 to produce a current draw of 0.7 and 1.3 amps.
5. After 1 hour, turn the DC bus voltage to 351.0 volts. The board may or may not be regenerating at this point. Turn the potentiometer until a regeneration pulse appears every 400msec. This procedure avoids the difficulty of directly setting the trip point at 350 volts, which is difficult to achieve precisely.
6. Finally repeat steps 4 and 5 (including the 1 hour wait) and recheck. The trip will have drifted slightly from the old mark, but it should be close and require no more than 1/16 of turn of the pot to correct.
7. You're Done and the board is ready to use!

Regeneration Hysteresis and Time Constant

The feedback circuitry around IC2 creates hysteresis that sets a minimum period for a given regeneration cycle. Thus, once regeneration has been triggered, the circuit will continue regeneration, even if the DC bus drops below 350 volts. Hysteresis improves stability and also reduces switching losses in the IGBT. Consequently, Arecibo Observatory has slightly increased the nominal hysteresis from the original Maccon design to take advantage of these benefits. The original design produced regeneration pulse of about 250 µsec, while the new component values produce a nominal pulse width of about 750µsec.

This period is a function of a number of components, including R9,R7, C11, R8 and to a lesser degree R6, C15, IC2 and C1-C7. Because of the number of components involved, the regeneration pulse width could vary substantially from board to board. Acceptable pulse width is nominally 750 µsec, but it can range between 500 µsec to 1500 µsec. However, a period substantial beyond this range should be investigated and corrected.

Low-Voltage Hold Circuit

The circuitry associated with the transistors T6,T7 and T8 appears to function as a power-up hold. It forces the open-collector output of LM311 to 0 volts when the DC bus is low to block any spurious regeneration. (Note this is our speculation, since the designer's intention is unknown to us) When the DC bus voltage is less than 100 volts, transistor T8 will disable any attempts to initiate regeneration by pulling the comparator output low (TP3). At around 120 volts, the circuit goes unstable and causes the collector of T7 to oscillate on and off. This disconcerting behavior seems to be acceptable, because at this point in the power up sequence, the LM311 is operating correctly (output held low) and therefore oscillations from the power-up circuit never impact regeneration. When the DC bus reaches 200 V, the oscillations stop and regeneration is now completely controlled by the LM311 comparator (i.e. T8 is forced OFF).

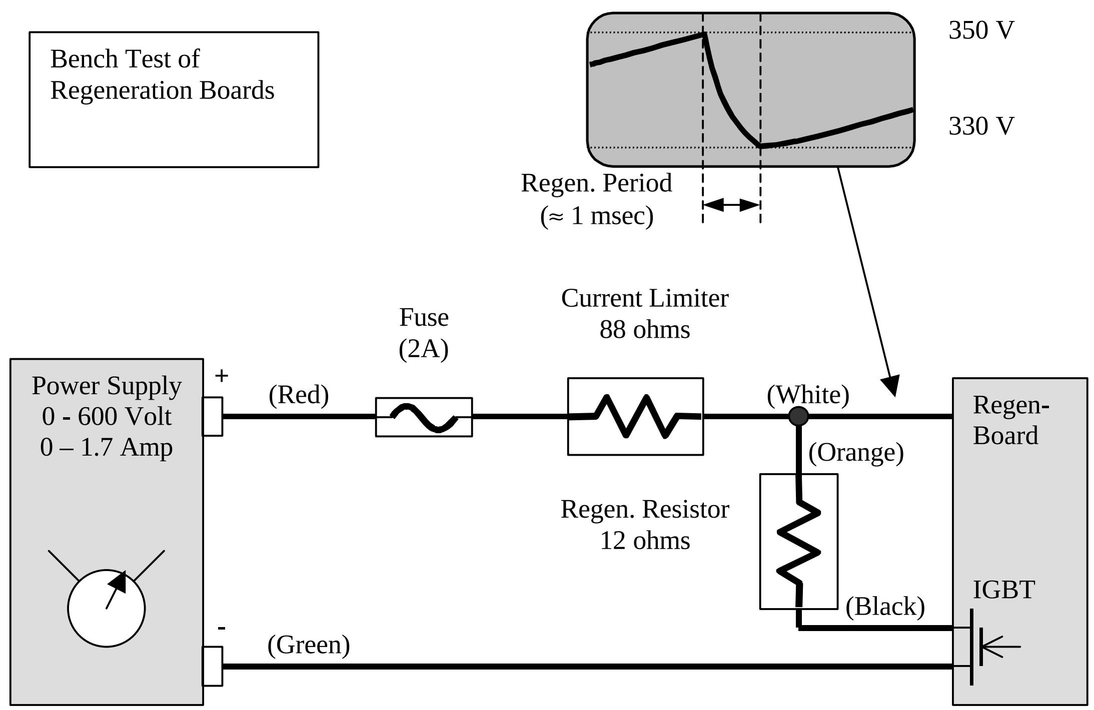
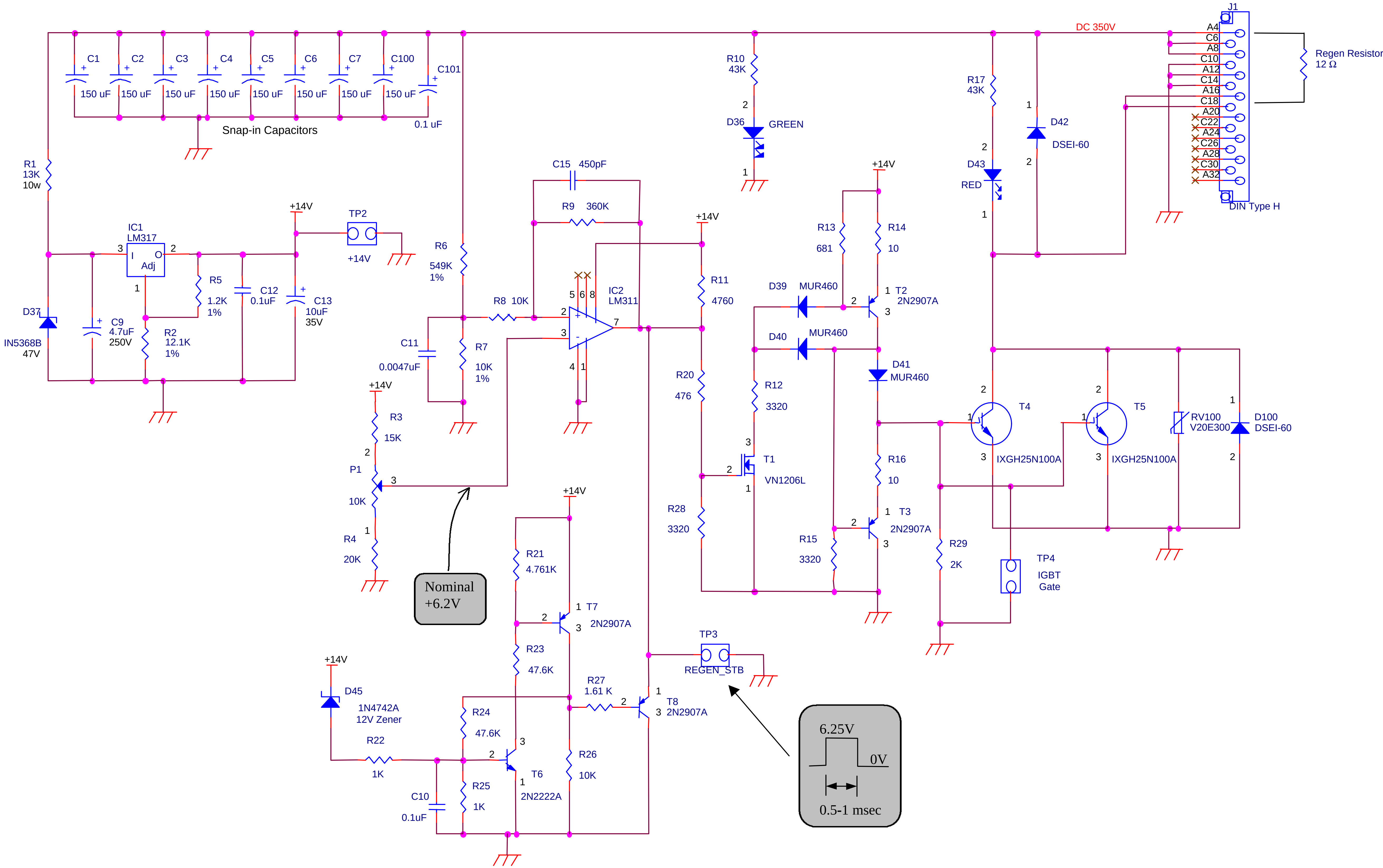


Figure 1 – Regeneration Board Bench Test

Reference Designator	Description	Manufacture	Part #	**Value**
C1-C7, C100	Capacitors	Cornell-Dubler Mallory	381LX151M450K022 LPX181M450H1P3	150 µF 180 µF
M100	Metal-Oxide Varsistors	Harris	V20E300	
D42,D100	Protection Diodes	IXYS	DSEI-60-12A	
T4,T5	IGBT	IXYS IXYS	IXGH25N100A IXGH25N100U1	
R1	Power Resistor	Caddock	MS313-13.7K-1%	13.7 KΩ, 10W
D37	Zener Diode	Motorola	IN5368B	47 Volts
T2-T3,T7-T8	NPN Transistor	Motorola	2N2907A	
D41	Diode	Motorola	MUR460	
T6	PNP Transistor	Motorola	2N2222A	
IC1	Voltage Regulator (Var)	Motorola	LM317MT	
IC2	Comparator (Open Collect)	Motorola	LM311J-8	
C9	Electrolytic Capacitor	Sprague	TVA1601	4uF/350 WDC
C11	Cer. Capacitor			0.0047uF
R10,R17	Power Resistor	Caddock Dale	MS260-39K-1% CW-5 5% 43K	39 KΩ, 6W 43 KΩ, 5W
D43	Red LED	Industrial Dev.	5300H1	
D38	Green LED	Industrial Dev.	5300H5	
J1	Type H Din	Harting	09-06-115-2911	
T1	MosFET	Temec/Siliconix	VN1206L	
C101	Cer. Capacitor	Sprague	5GAP10	0.1µF/450V
D45	Zener Diode	Motorola	IN4742A	12 Volts

Figure 2 - Selected Component Part Numbers (Some indicate alternative sources or part number



DC 350V
J1
A4
C6
A8
C10
A12
C14
A16
C18
A20
C22
A24
C26
A28
C30
A32
DIN Type H
Regen Resistor
12 Ω
C1
C2
C3
C4
C5
C6
C7
C100
C101
150 uF
0.1 uF
Snap-in Capacitors
R1
13K
10w
D37
IN5368B
47V
IC1
LM317
I
O
Adj
C9
4.7uF
250V
R5
1.2K
1%
R2
12.1K
1%
C12
0.1uF
C13
10uF
35V
+14V
TP2
R6
549K
1%
C11
0.0047uF
R7
10K
1%
R8 10K
C15 450pF
R9 360K
IC2
LM311
R3
15K
P1
10K
R4
20K
Nominal
+6.2V
R10
43K
D36
GREEN
R11
4760
R20
476
R28
3320
R12
3320
T1
VN1206L
R13
681
R14
10
D39
MUR460
D40
MUR460
D41
MUR460
T2
2N2907A
R16
10
T3
2N2907A
R15
3320
R17
43K
D43
RED
D42
DSEI-60
T4
T5
IXGH25N100A
RV100
V20E300
D100
DSEI-60
R29
2K
TP4
IGBT
Gate
R21
4.761K
T7
2N2907A
R23
47.6K
R27
1.61 K
T8
2N2907A
TP3
REGEN_STB
D45
1N4742A
12V Zener
R22
1K
R24
47.6K
R25
1K
C10
0.1uF
T6
2N2222A
R26
10K
6.25V
0V
0.5-1 msec