Electronics Online Challenge

Raider Robotics - MSOE1
Submission Date: 12/7/2020

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1. Introduction

We chose to disassemble a Segway i2 SE PT. A teammate obtained the Segway in non-working condition with hopes of reconstructing the device. We wanted to understand how one of the first self-balancing mobility devices on the market functions internally. There is little information on the Segway published, and we state where assumptions were made.

2. Component Summary

Ref #	Chip Identifier	Description	Documentation	Quantity
1	16126797 AU195 02		Not Found	1
2	24C04WQ K525W	I2C Bus EEPROM	Actual	2
3	37021 58M C66L		Not Found	1
4	37021 58MCD29		Not Found	2
5	431AV PAHF		Not Found	1
6	55 84 K0		Not Found	1
7	56A504M HCT04	(TI) Hex Inverter	Similar	2
8	56A5NLM HCT4051M	(TI) Demultiplexer	Actual	3
9	59A2VHM TLC2254	(TI) Op Amp	Actual	2
10	66C1HCM HCT4053M	(TI) Multiplexer	Similar	1
11	7438 543C G68V		Not Found	1
12	8L05A POIB8	Positive Voltage Regulator	Similar	2
13	A 7840 0611	Isolation Amplifier	Similar	4
14	A82C250 4R4T0 n5064		Not Found	1
15	BL05A POIB8		Not Found	2
16	CHAQ LMC64 82AIM	(TI) Operational Amplifier	Actual	1
17	CRLNLMG1 32B1M		Not Found	3
18	IR 2136S 0515	Three-phase MOSFET Driver	Actual	2
19	IRFP250N G3 DB	N-Channel Power MOSFET	Actual	12
20	K0204 FQA 70N15	N-Channel QFET MOSFET	Actual	1
21	K537 TOP414G 35721A	DC/DC PWM Switch	Actual	1
22	P185B MM74HCT 244WM	Octal 3-State Buffer	Actual	1
23	P56AB 98752		Not Found	1
24	PVI 1050 NS 0538I4N	Photovoltaic Isolator	Actual	1
25	TMS 320LF2406APZA	(TI) DSP Controller	Actual	1
26	TMS320 980 F2808ZGHA	(TI) DSP Controller	Actual	2
27	LC07A 63K E01R	(TI) Hex Buffer	Similar	2
28	VD251 58M L6E	(TI) CAN Transciever	Actual	1
29	ATMEL620 25P1024	SPI Serial EEPROM	Similar	1

Table 1: Table containing all major components found within the Segway

2.1. Component Images

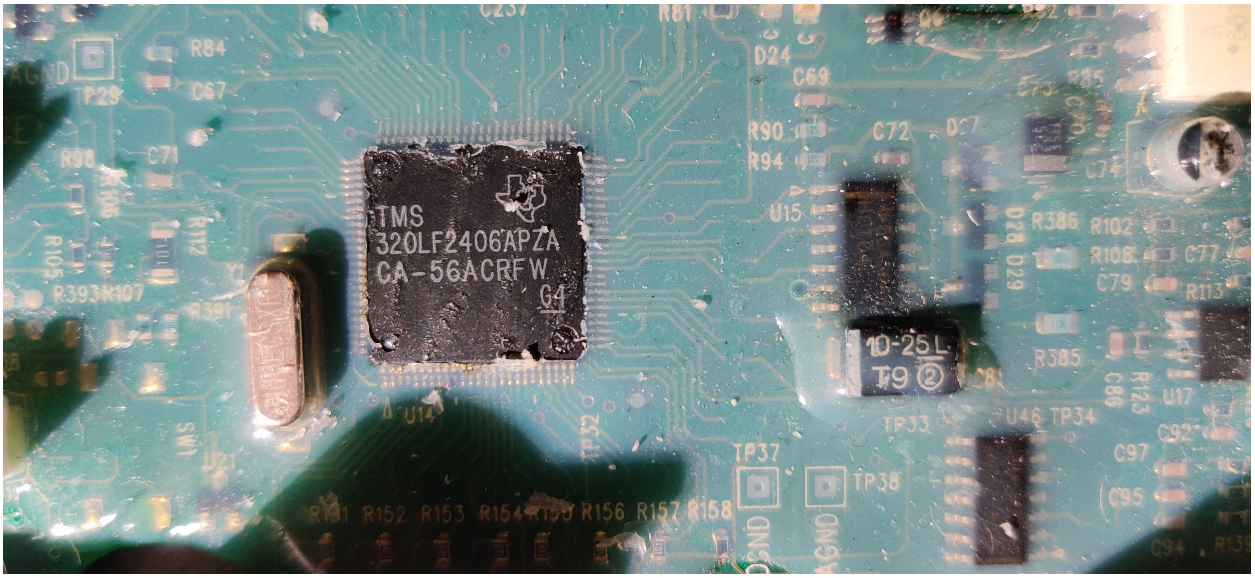

Figure 1: Close-up of a Primary Control Unit DSP (Component 25) and it's respective traces covered in Conformal Coating

2.2. Annotated PCB Images

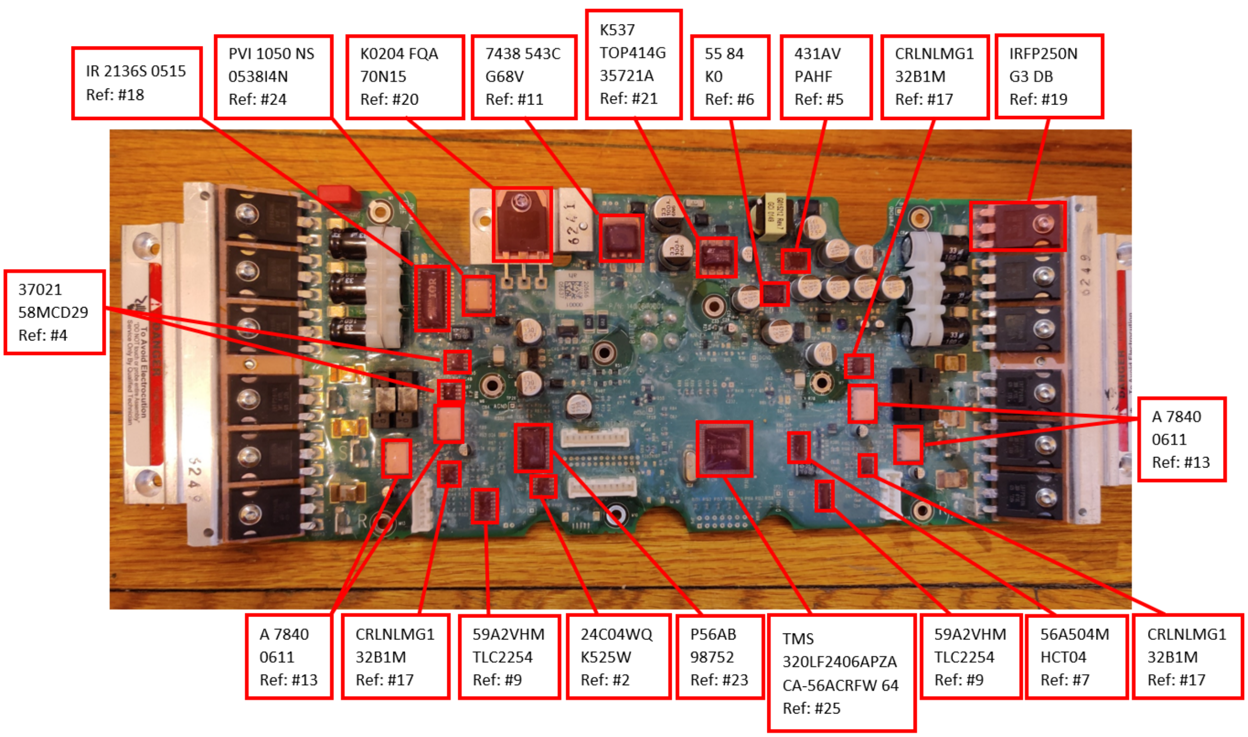

Figure 2: Chip Annotations for the front of a Primary Control Unit

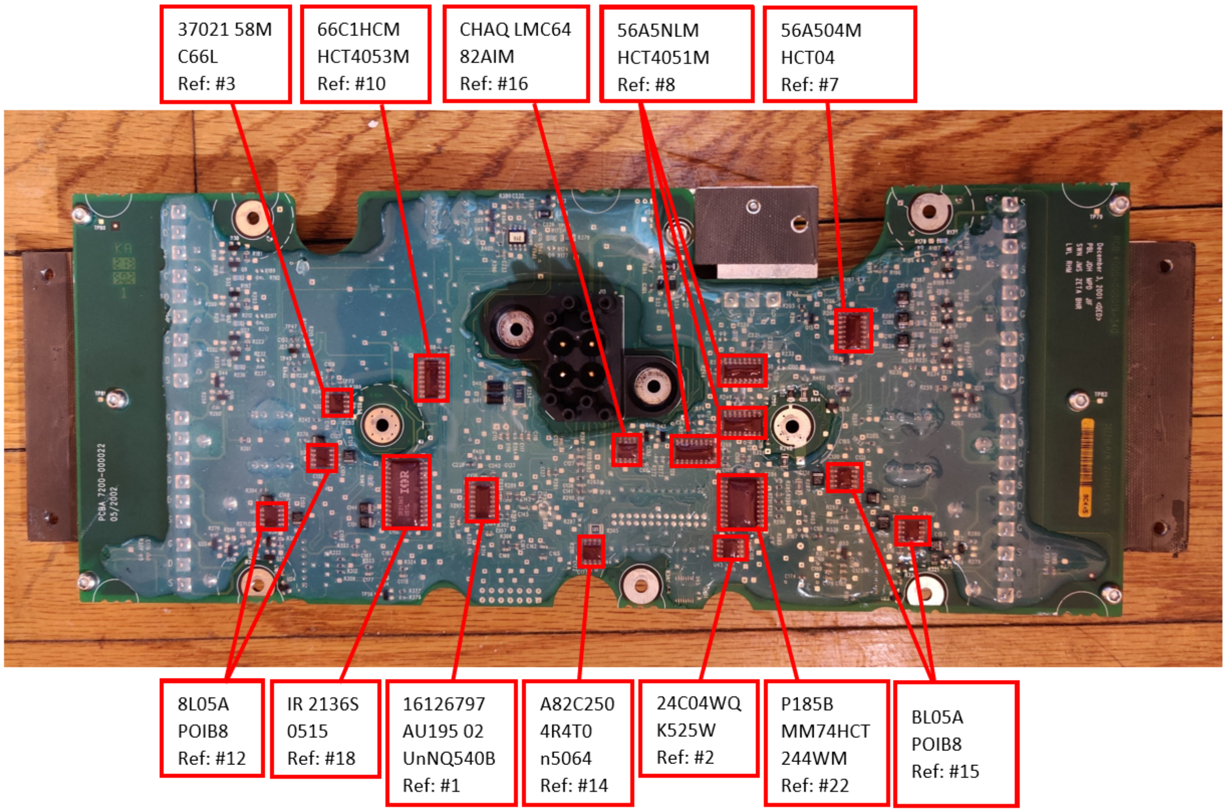

Figure 3: Chip Annotations for the back of a Primary Control Unit

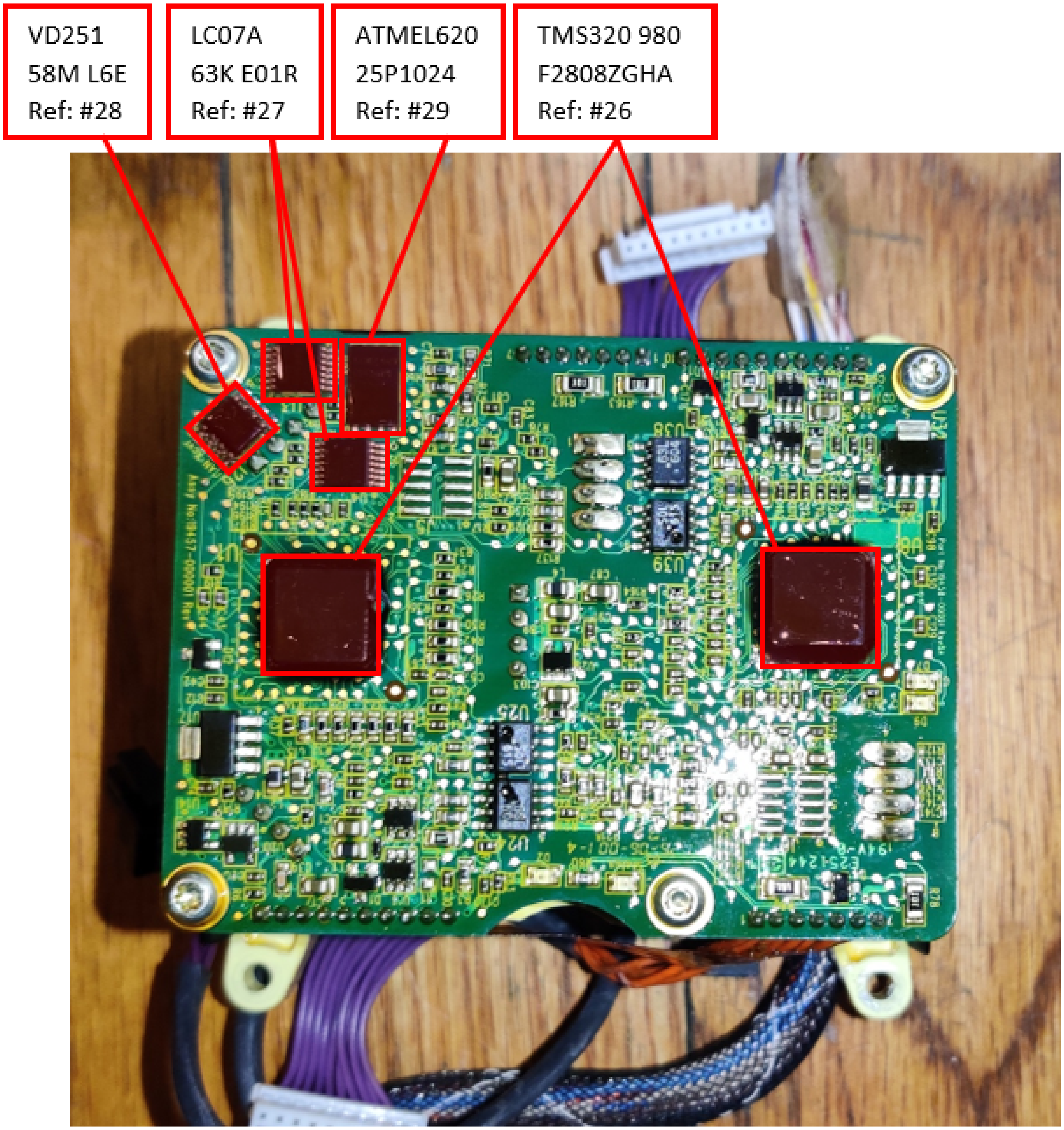

Figure 4: Annotated view of the main Sensing Unit PCB, with focus on the primary IC components

3. Findings

Focusing on two of the most important components:

- Sensing Unit (SU)
- Primary Control Unit (PCU)

3.1. Sensing Unit

The sensing unit is located in the center of the Segway and consists of 5 simple IMU sensors. Referencing Figure 19, the shared PCB between the IMUs contains two TI TMS320980 DSP (Component 26), a TI VD251 CAN Bus Transceiver (Component 28), and an ATMEL SPI Interface (Component 29), plus two TI LV07A Hex Buffers (Component 27). The TI DSP components provide data fusion between the IMUs, in close proximity to protect from motor-generated noise. We believe the presence of two DSP components both serves for redundancy, and to allocate one DSP to supply fused sensor data to each PCU.

As shown in Figure 17, each IMU is in a different orientation to account for sensor-specific bias instability and angular random walk, allowing for a partial mechanical cancellation of various biases present in the sensors.

We assume the board utilizes the high-speed SPI interface to send fused orientation data to the PCU (master) and CAN connecting all major components for system-specific diagnostics relayed to the Segway handheld control.

3.2. Primary Control Unit

The PCU contains most of the Segway's components and handles motor control. The Segway contains two identical PCUs, each connecting directly to each three-phase motor, shown in Figure 14. Being three-phase with a six-phase input, we believe this to be for redundancy. The PCU contains a TI TMS320LF240 DSP. This DSP likely manages the battery system (with three demultiplexers - Component 8) which utilizes I2C communications for battery state/ management. We assume the DSP also handles motor position/rotation data, current sensing data, and orientation data from the sensing unit to perform adjustments during travel, keeping the rider upright. The DSP has separate program and data memory spaces. This not only allows for simultaneous instruction fetch and execution but also for simultaneous transfers between memory spaces. This removes the need to interrupt the process flow to fetch external instructions (such as reading from sensor SPI data), allowing the component to perform without halting.

4. Conclusion

There is so much we couldn't detail here. We learned so much about the intricacies of a complicated real-time system, intuitive sensor shielding and processing, and how the Segway becomes a “smart device” through I2C, SPI, and CAN communications between modules for system health checks and data transfer.

5. Disassembly Figures

5.1. Segway Exterior

Figure 5: Front view of the assembled Segway, including all trim pieces

Figure 6: Segway platform with rubber trim pieces removed

Figure 7: Side wheel trim piece firmly mounted to the platform

Figure 8: Segway charging port (rear) with rubber trim pieces removed

Figure 9: Dual Steel Battery Bays for the Segway. Each battery connector supports 74V connections and I2C communications

5.2. Segway Interior

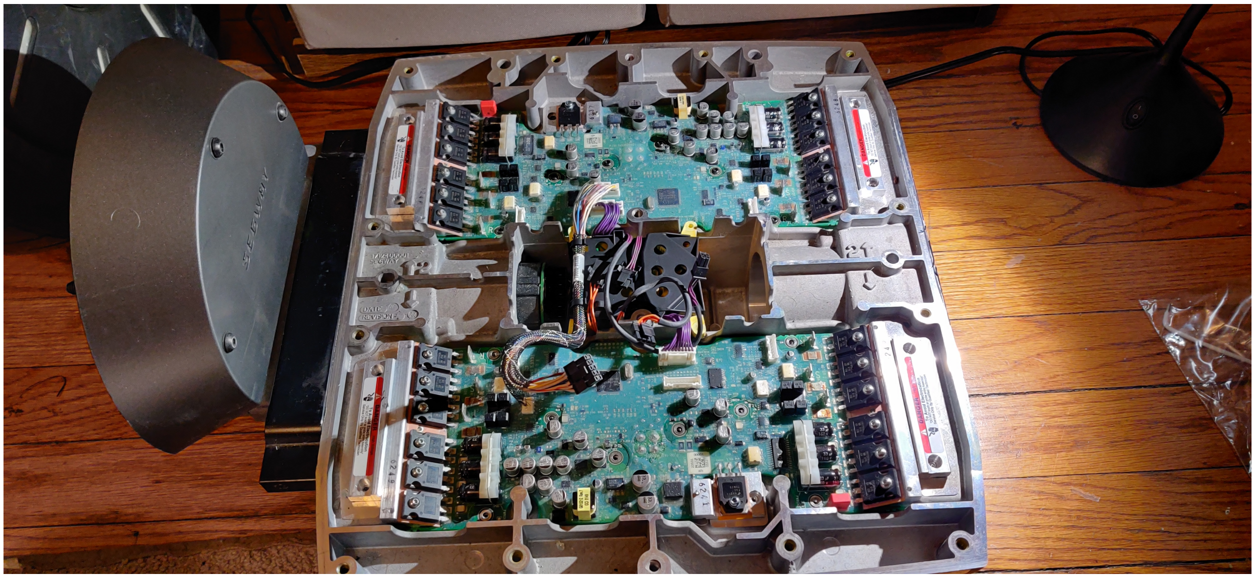

Figure 10: Segway Chassis without one wheel well and the platform, which exposes both Primary Control Units and the Sensing Unit in the center

5.2.1 Primary Control Unit

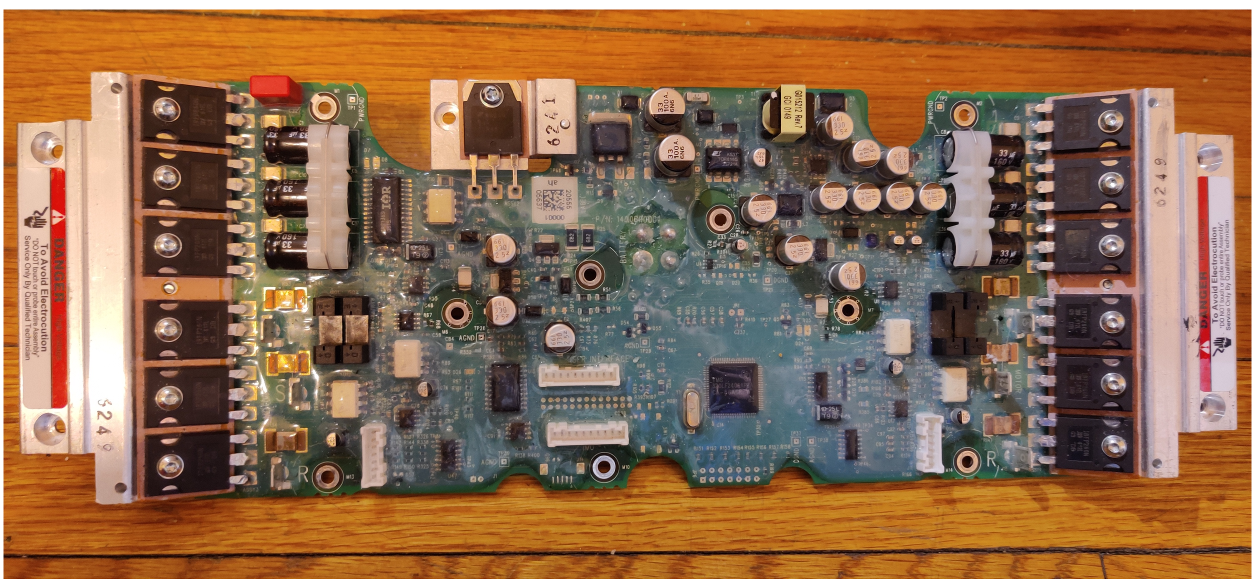

Figure 11: Top of one of the two Primary Control Units, covered in Conformal Coating surrounding the surface mount components

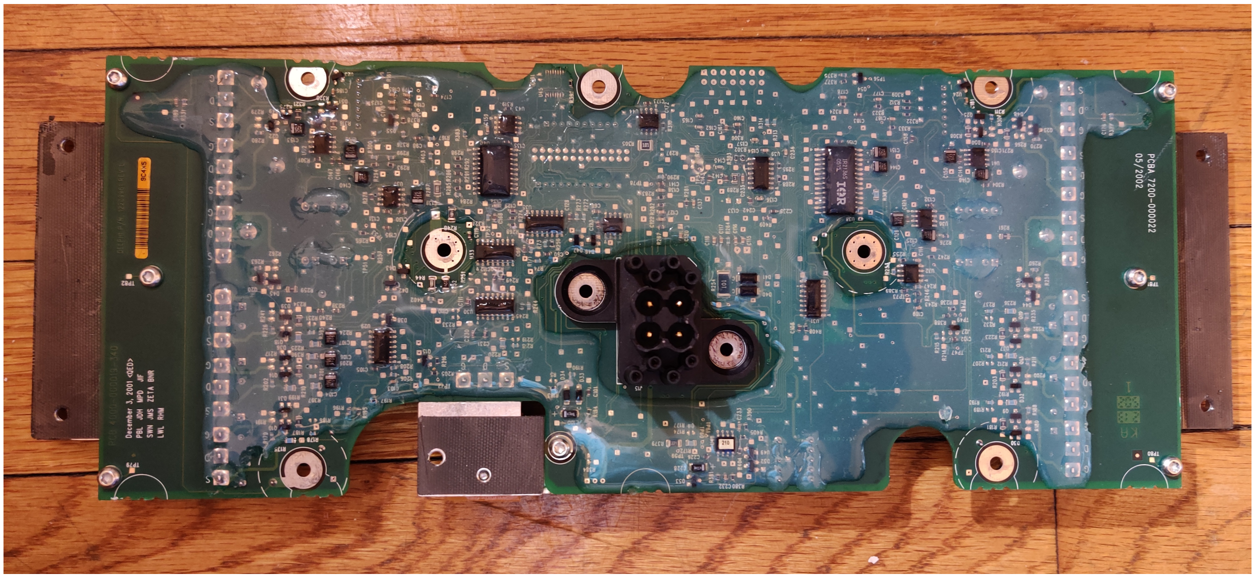

Figure 12: Bottom of one of the two Primary Control Units, covered in a thick layer of Conformal Coating

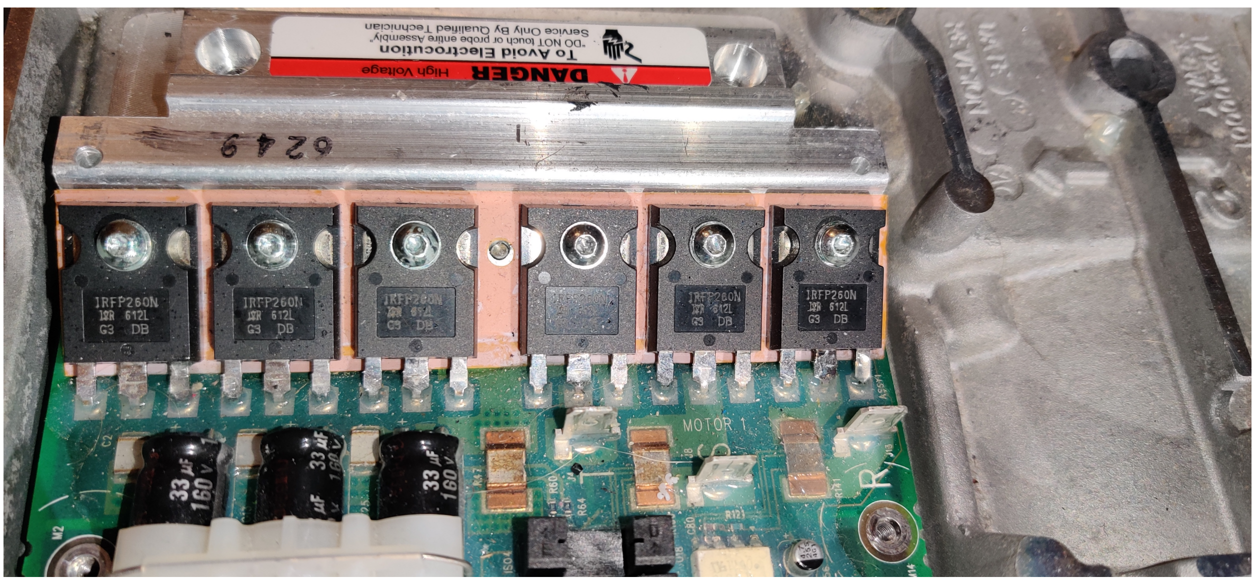

Figure 13: Motor Driver MOSFETS (Component 19) on one side of a Primary Control Unit

5.2.2 Segway Motors & Motor Driver PCB

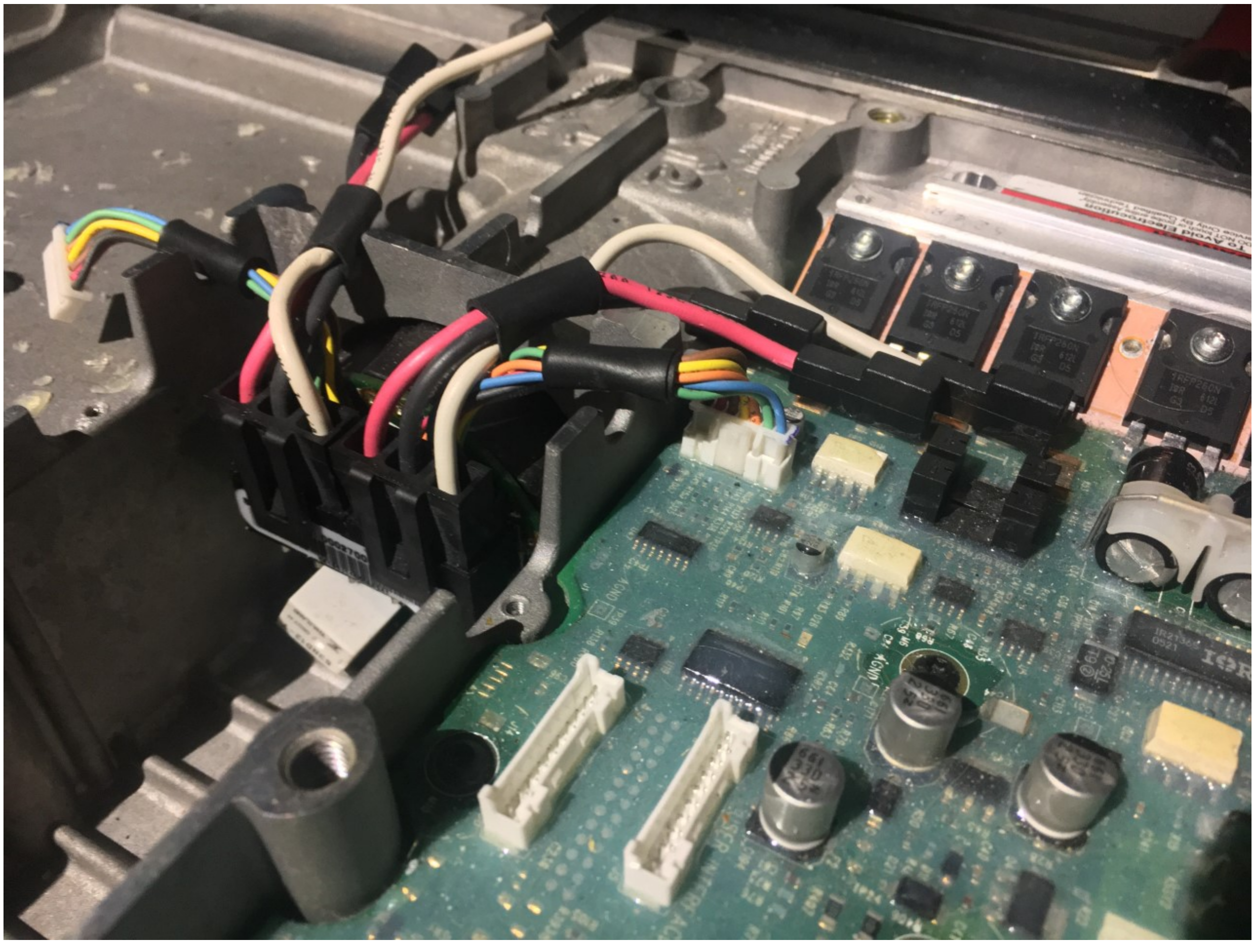

Figure 14: Close-up of the input connections from both Primary Control Units, sharing duplicate three-phase inputs)

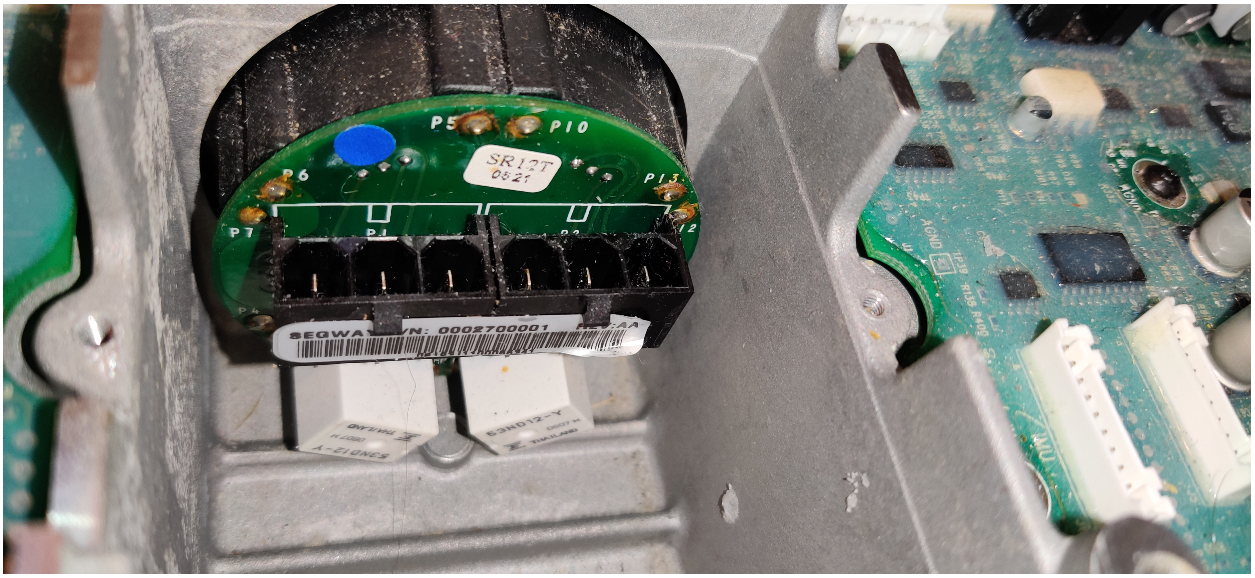

Figure 15: Close-up of the PCB Shield on the motor, with dual three-phase inputs (one for each Primary Control Unit)

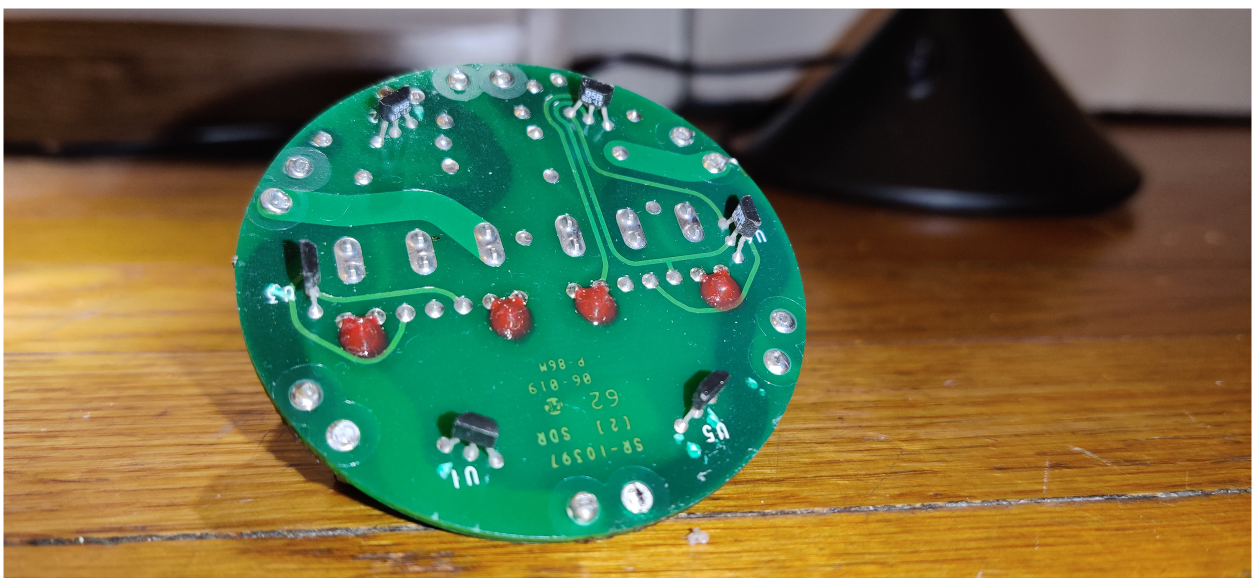

Figure 16: Rear view of the Motor PCB after removing from the motor, with 6 hall effect sensors, to measure rotor position

5.2.3 Sensing Unit

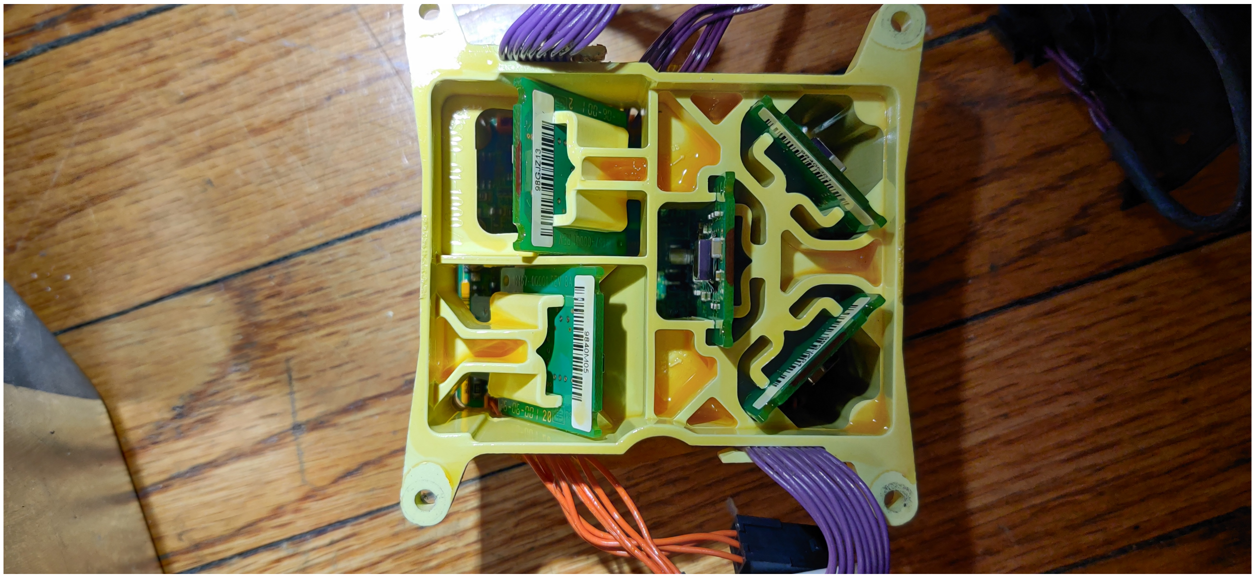

Figure 17: Top view of the Sensing Unit, with the cast IMU holder keeping the IMUs from moving out of position

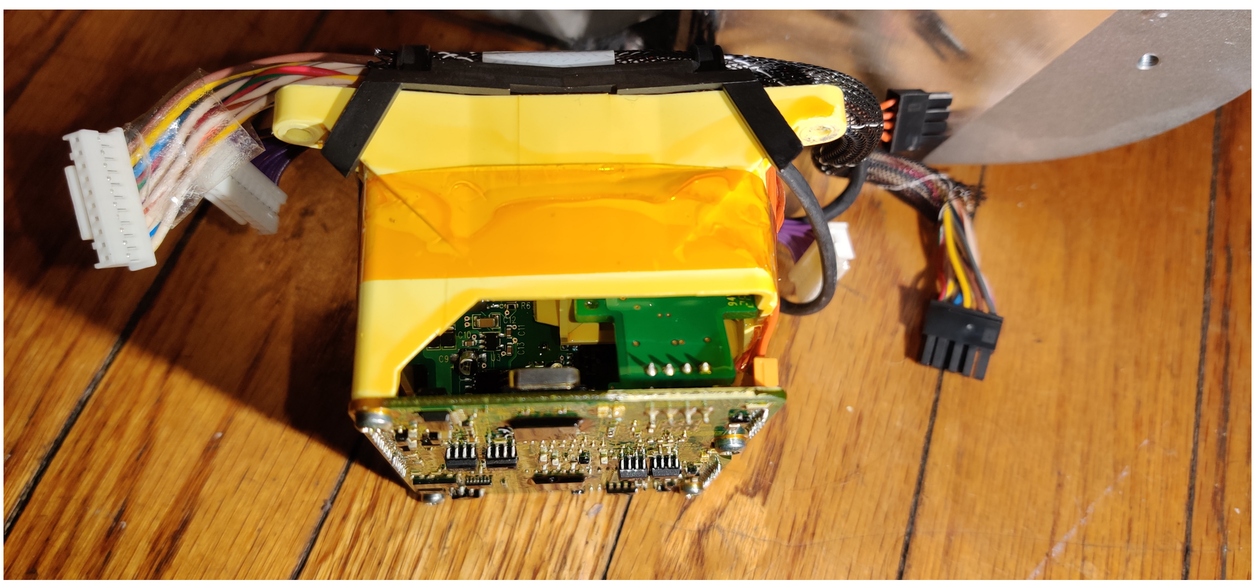

Figure 18: Side view of the Sensing Unit, with the cast IMU holder attached to the module

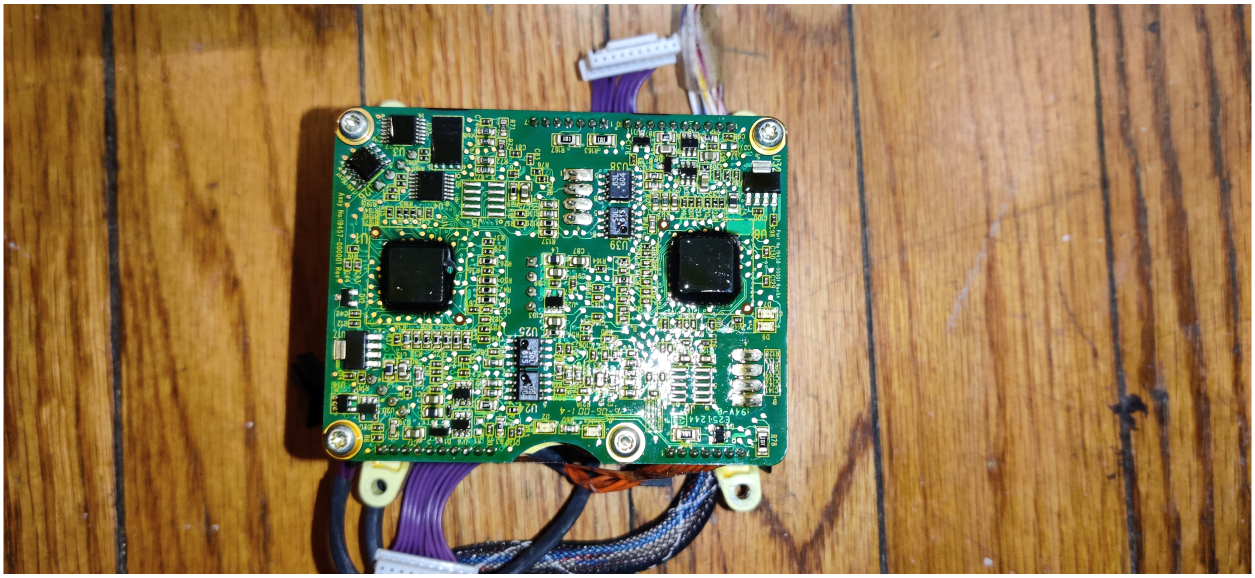

Figure 19: Bottom view of the Sensing Unit containing the IMU units, placed on center below the platform