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1. REPORT DATE *(DD-MM-YYYY)* 10032017	**2. REPORT TYPE** Technical					**3. DATES COVERED *(From - To)*** 22122016 - 10032017
4. TITLE AND SUBTITLE Payload Inrush Investigation – GVR-BOT Technical Report						**5a. CONTRACT NUMBER**
						5b. GRANT NUMBER
						5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Ty Valascho, Kayla Gomes						**5d. PROJECT NUMBER**
						5e. TASK NUMBER
						5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army, Tank Automotive Research Development and Engineering Command (TARDEC) Warren, MI 48397						**8. PERFORMING ORGANIZATION REPORT**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army, Tank Automotive Research Development and Engineering Command (TARDEC) Warren, MI 48397						**10. SPONSOR/MONITOR'S ACRONYM(S)**
						11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION / AVAILABILITY STATEMENT UNCLASSIFIED: Distribution Statement A. Approved for public release; distribution is unlimited.						
13. SUPPLEMENTARY NOTES The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an Official Department of the Army position, policy, or decision, unless so designated by other documents.						
14. ABSTRACT GVR-BOTs supplied to customers were experiencing issues during boot when certain payloads were connected. It was determined that the root cause was inrush from the power supply that was being used. Two electrical hardware modifications and one software modification were tested and all were confirmed to fix the problem.						
15. SUBJECT TERMS GVR-BOT, robot, inrush						
16. SECURITY CLASSIFICATION OF: **UNCLAS / DIST A**			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Ty Valascho	
a. REPORT DIST A	**b. ABSTRACT** DIST A	**c. THIS PAGE** DIST A	~~A~~	17	**19b. TELEPHONE NUMBER *(include area code)*** (586) 459-7485	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

US Army - TARDEC

Payload Inrush Investigation

GVR-BOT Technical Report

Tyrus Valascho, Kayla Gomes
3-10-2017

Executive Summary:

GVR-BOTs supplied to customers were experiencing issues during boot when certain payloads were connected. It was determined that the root cause was inrush from the power supply that was being used. Two electrical hardware modifications and one software modification were tested and all were confirmed to fix the problem. The software modification was least intrusive for GVR-BOT customers and is recommended as the long-term solution for this issue.

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Background

Initial Problem Report

On December 7, 2016 it was reported to the GVR-BOT team that a fielded robot was experiencing issues when a particular payload was connected before initial startup of the robot.

The GVR-BOT design has 3 embedded hardware modules: Mobility (PN: 0007), Flipper (PN: 0008), and Pwr Mgt (PN: 0003). Each of these hardware modules contains a bootloader and application software. When these embedded circuit boards are started up, the bootloader software executes first and determines if the user has requested that new application software is going to be loaded by checking an EEPROM location. The EEPROM location can have three different logical values:

1. Normal operation (bootloader passes execution to the application software)
2. Software reflash intended (bootloader waits for reflash command – do not pass control to application software)
3. EEPROM location corruption (bootloader waits for reflash command – do not pass control to application software)

When the issues occurred, the GVR-BOT customer was finding that the EEPROM location was getting corrupted and the bootloader software was not passing control to the application software after reboot. This was only happening when a particular payload was connected. The user reported that this problem was occurring intermittently on the Flipper board and Mobility board.

Initial Investigation

The team gathered information about the issue and requested that the user try several tests to gather additional data on the failures.

The findings of this initial investigation were:

- The payload that was causing the issue was found to be a quad-core i7 COM Express processor board powered by an M4-ATX-HV 6-34V Intelligent ATX Power Supply from Mini-Box.com. The Part Number of the i7 COM Express processor board was not provided.
- Measuring current during startup, they found that with the external payload connected to the GVR-BOT, the current load was less than 2.5 A at 28 VDC.
- The problem did not occur if 2 battery cradles and at least 3 batteries were used to supply power.
- Several delay settings of the ATX power supply were tested, but did not seem to fix the issue.

Issue Investigation

Recreating the problem

It was decided that the first step in resolving the issue would be to recreate what the users were experiencing.

Three M4-ATX-HV power supplies were purchased and an i7 COM Express board was used as the device being powered from the power supply. It is unknown whether the i7 COM Express board was the same model that the customer was using.

Test Configuration 1 was used for this issue recreation portion of the investigation. A block diagram of the test configuration is shown in Figure 1 and a photograph of the actual testing equipment in Figure 2.

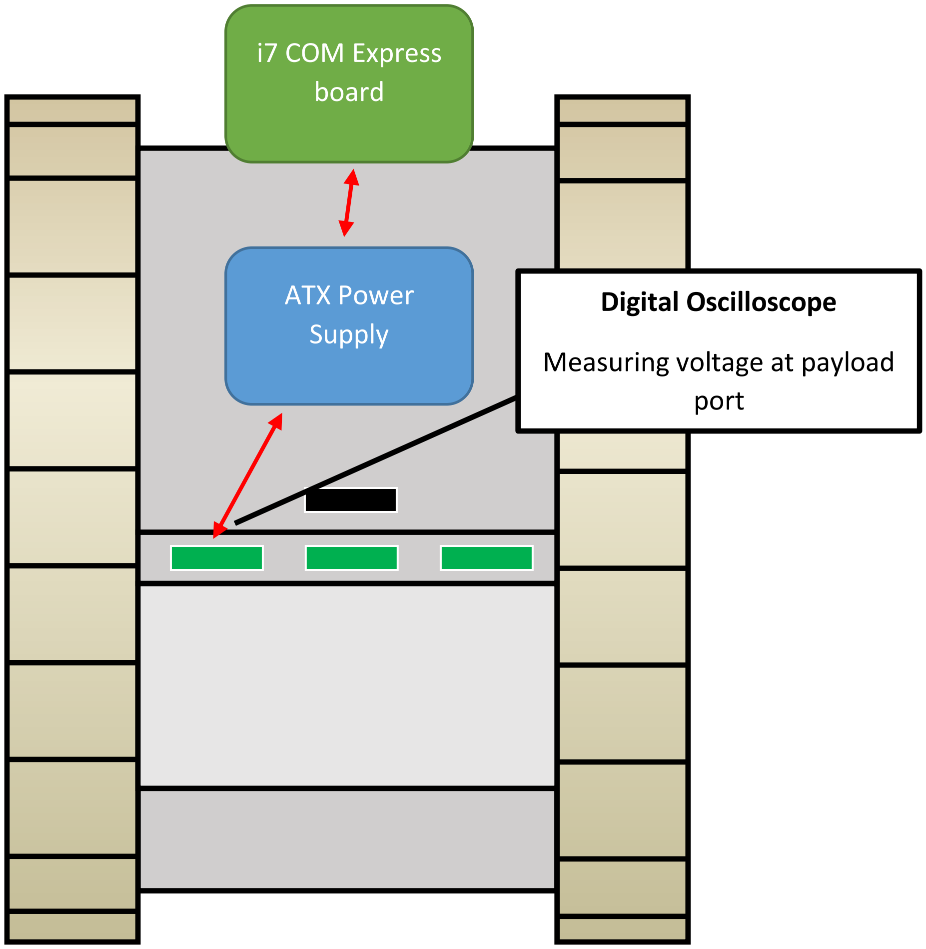

Figure 1 –Block Diagram of Test Configuration 1

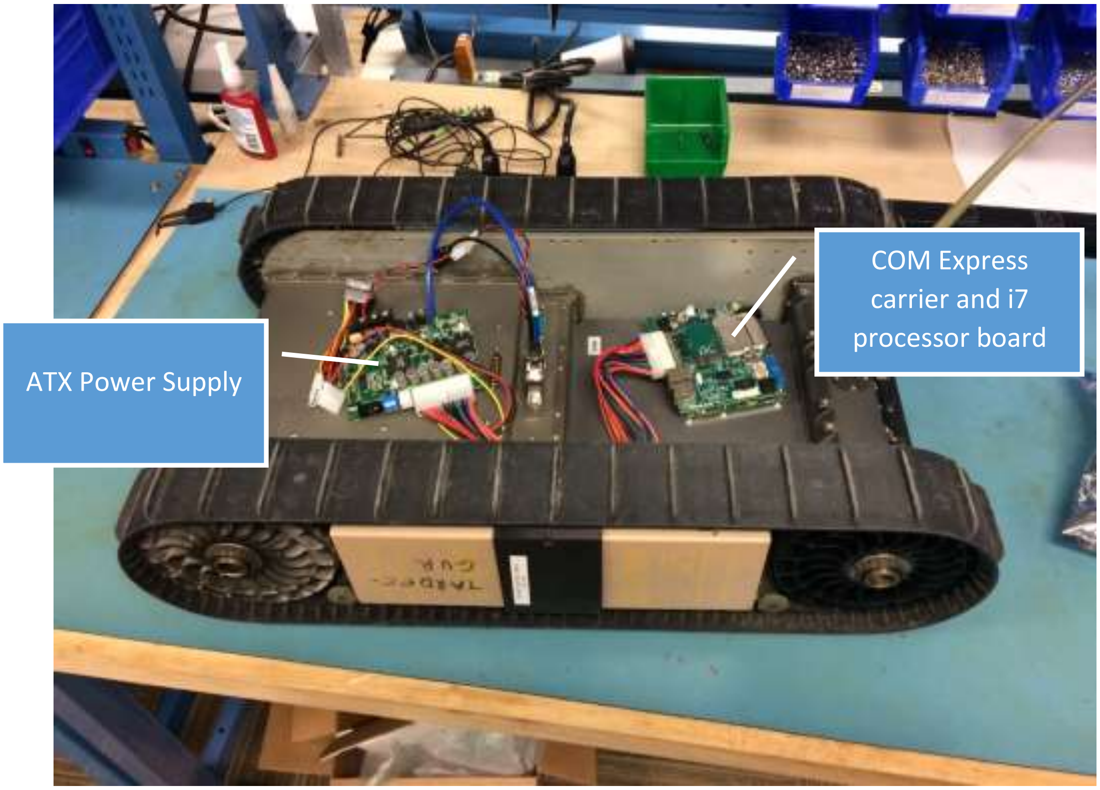

Figure 2 – Photograph of Test Configuration 1

The exact parts used for this initial investigation are provided in Table 1.

Table 1 - Components Used for Initial Investigation

Product	Manufacturer	Part Number	Serial Number
Robot	TARDEC-GVR	GVR-BOT Gen 1.2	GVR-BOT-037
ATX Power Supply	Mini-Box.com	M4-ATX-HV	EEC21154712036
COM Express carrier board	Acromag	ACEX4405-L Rev. D	T1251ACEX4405003
i7 COM Express	Adlink	COM 840-R-32	CA06NB6030

The ATX Power supply was plugged into Payload Port P2 on the robot. The ATX Power Supply provided power to the i7 COM Express system (carrier board + COM Express module).

The issue was easily recreated using this setup. Several test runs with different configurations were performed to gather more information.

These tests consisted of connecting different combinations of the ATX Power Supply and COM Express payload, then powering the robot on while an Oscilloscope was recording the GVR-BOT bus voltage. After the robot was powered on completely, a "failure" was indicated if one or more boards remained in bootloader mode. A "success" was noted if all three embedded boards were running application software and not in bootloader. If a failure occurred, the embedded board was manually placed back into application mode using the GDT (GVR-BOT Diagnostic Tool) and the robot was powered down. It would then be powered back on with no loads on the Payload Ports to verify no board remained in bootloader mode.

This initial testing established that the issue was being caused solely by the ATX Power Supply and the presence of a payload "upstream" of the power supply was not related to the problem. It also showed that within the first millisecond of powering on the robot, the presence of the ATX Power Supply was pulling the GVR-BOT Bus Voltage down below 5 VDC (Volts Direct Current).

All failure occurrences happened with the Mobility board only going into bootloader mode. During the entire testing and investigation of this issue, no other circuit boards were observed to remain in bootloader mode. This did not exactly match what the customer had reported, since they had also seen the Flipper board remain in bootloader mode.

A plot of the three combinations tested and the resulting bus voltage values over time is presented in Figure 3.

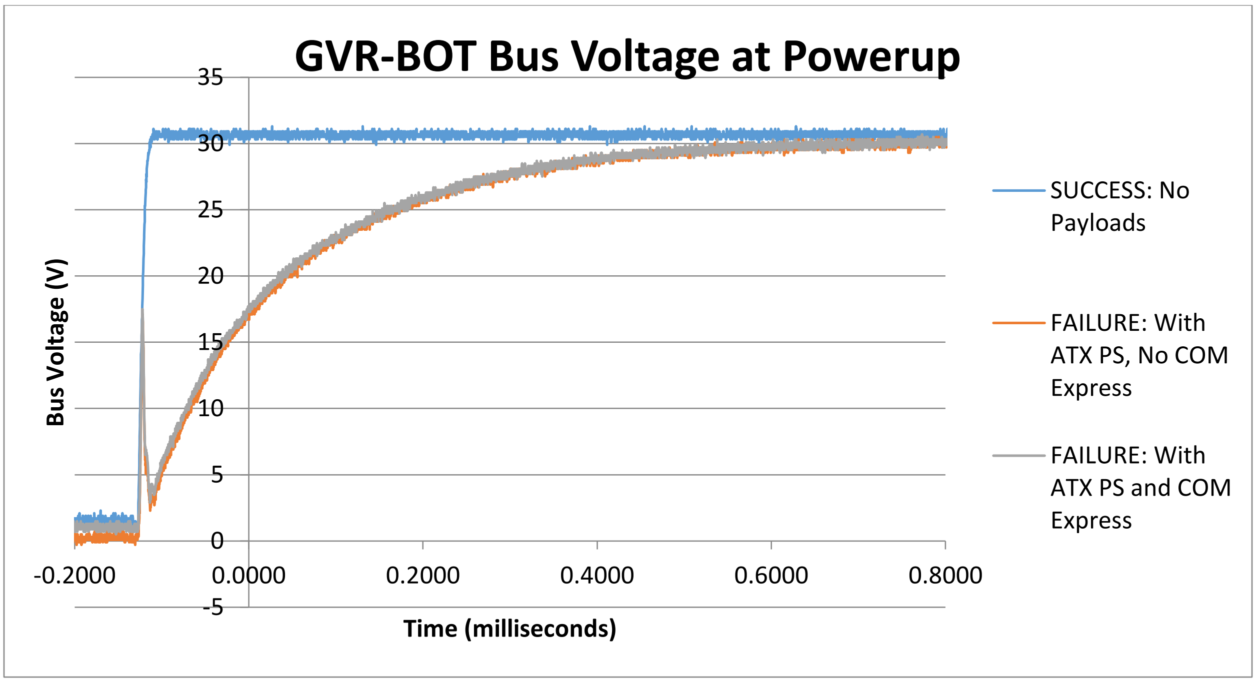

Figure 3 - GVR-BOT Bus Voltage using Different Payload Combinations

Issue Characterization and Solution Attempts

Once the problem could be reliably reproduced, the team began to characterize the issue by testing more configurations.

The working theory at this phase of the investigation was that the root cause was inrush current of the M4-ATX-HV ATX Power Supply which dragged the GVR-BOT Bus voltage down to an unacceptably low value. This was causing a timing, reset, or EEPROM corruption issue with the embedded circuit boards and causing them to incorrectly stay in bootloader mode.

ATX Power Supply Changes

The M4-ATX-HV ATX Power Supply has a USB interface and software that allows the behavior of this product to be modified. Several changes to possible timing were modified, but all appeared to change only the output of the power supply which would not have any impact on the problem if it was related to inrush on the input.

Testing confirmed that plots of bus voltage with and without configuration changes to the ATX Power Supply were indistinguishable.

In addition, there is a DIP switch onboard the M4-ATX-HV which allows configuring the output of the Power Supply to be delayed 5 seconds. Similar to the changes above, however, this only changes the output and has no effect on the inrush current being produced by the input of this device and therefore did not solve the issue. This configuration change was tested by TARDEC-GVR and also by the customer, and it was confirmed by both parties that this did not reduce the likelihood of the issue occurring.

The M4-ATX-HV product is designed to power embedded computers in an automotive environment, so it is understandable that the effect of this device's inrush current on a car battery would not be a concern. In a small robot the batteries are somewhat smaller and more limited in capacity. Inrush levels of tens of amperes are significant in this environment.

Adding Inrush Regulation Hardware

The team then decided to add hardware to regulate the inrush current and also measure this effect by adding an active current sensor to the test setup.

The new test setup - Test Configuration 2 - is displayed in Figure 4 and shows the addition of instrumentation and the location of the inrush regulation hardware.

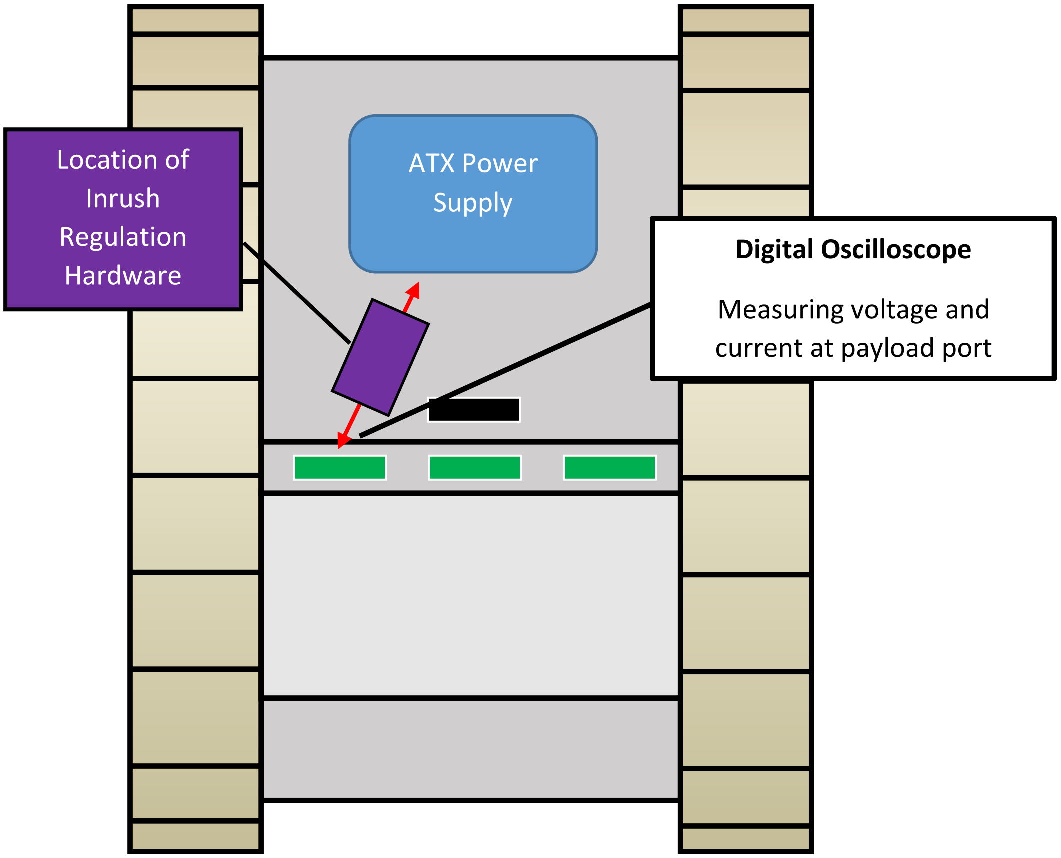

Figure 4 - Test Configuration 2 Block Diagram

A photograph of the actual test setup including instrumentation is provided in Figure 5.

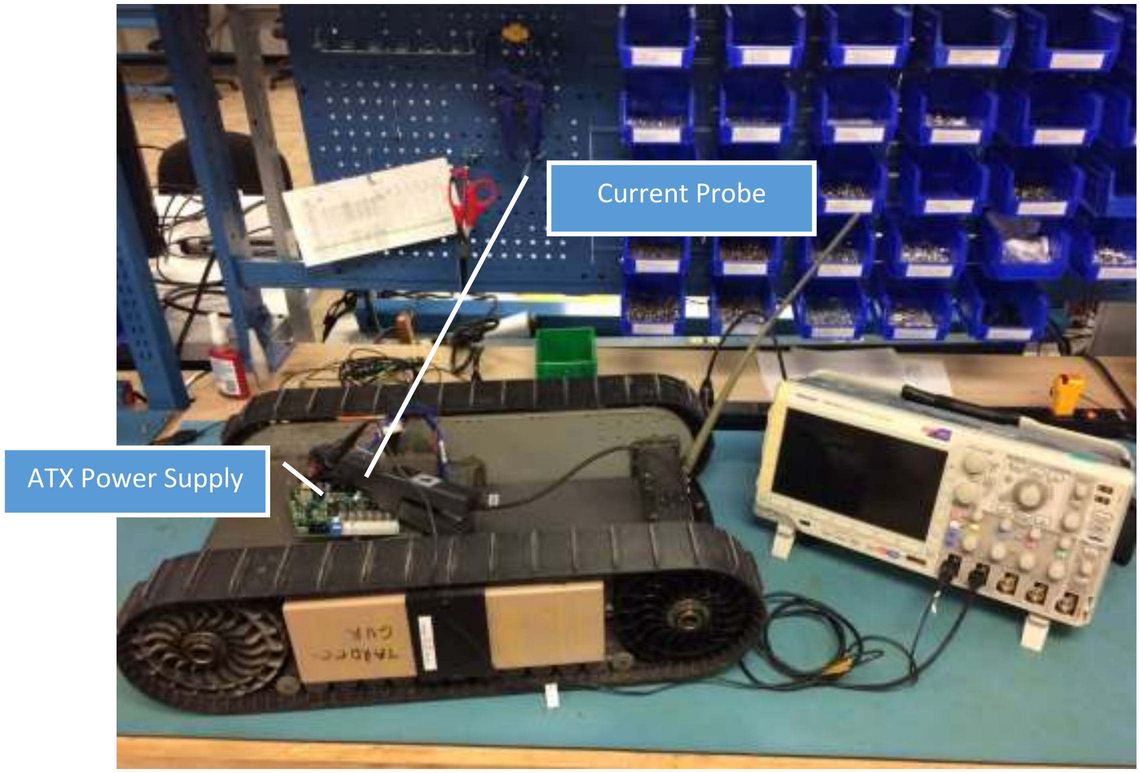

Figure 5 - Photograph of Configuration 2 with Instrumentation

Mechanical Switch / Delaying the ATX Power Supply

The first solution that was tested was the addition of a mechanical switch which allowed the payload to be turned on after the robot had been switched on. This solved the problem completely, even if the payload was turned on immediately after the robot, within 1 second. However, having to throw a mechanical switch after turning on the robot presented a cumbersome solution that many customers would find unsatisfactory.

Adding Resistance

The second solution that was attempted was to add an inrush current limiter to the input power line to the ATC Power Supply. Fixed resistor solutions were used as the electrical hardware. Testing was then performed using Test Configuration 2.

First, high power resistors were placed in between the ATX Power Supply and the robot's Payload Port. A 20 Ohm resistor and a 25 Ohm resistor was used for this testing. The specific parts were the Dale-Vishay RH05025R00FC02 (25 Ohm) and Dale-Vishay RH05020R00FC02 (20 Ohm), images of which are provided in Figure 6.

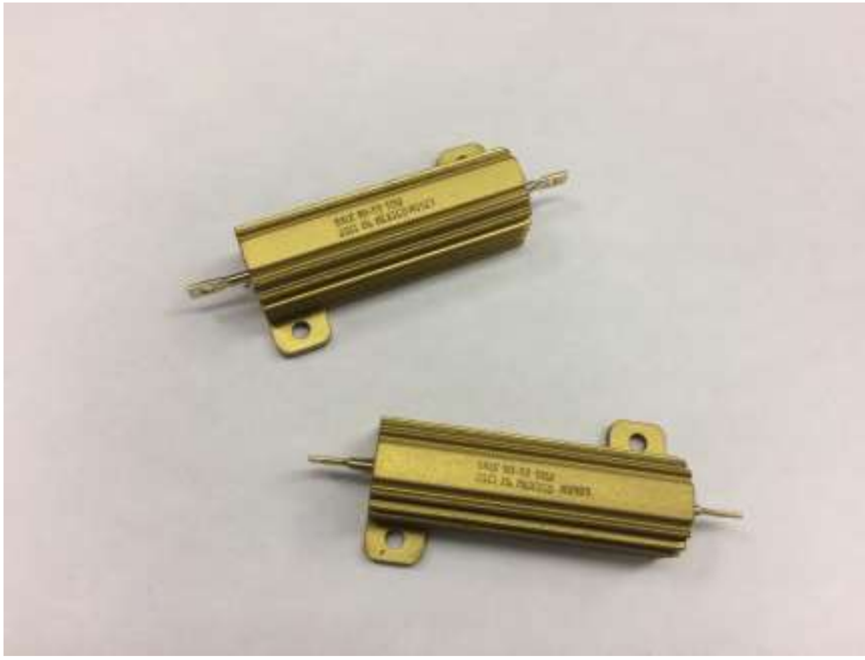

Figure 6 - Dale-Vishay Wire-wound Resistors

Both resistance values successfully solved the problem. However, these resistors became very warm which was not an acceptable solution. It was also felt that such high resistances were not necessary to correct the problem and merely wasting energy by generating waste heat. This wasted energy would be consumed the entire time the robot is running, not just at startup. The lowest resistance necessary to solve the problem would be preferred.

Because very low resistance (less than 1.0 Ohm) / high power resistors were not readily available in the laboratory during this test, lengths of 18 AWG wire were used instead. Approximately 5 meters of cable were used and the resistance of this cabling measured at 0.3 Ohms. This solution was also found to successfully resolve the issue.

Three trials of each resistance were performed and the results summarized in Table 2.

Table 2 - Summary of Inrush Regulation Resistance Testing

Resistance (Ohms)	Trial 1	Trial 2	Trial 3	Notes
0.0	Failure	Failure	Failure	Baseline – 0.1 m cable
0.3	Success	Success	Success	5 m of cabling
20.0	Success	Success	Success	Resistor became very warm
25.0	Success	Success	Success	Resistor became very warm

Inrush Current vs Bus Voltage

The inrush current of the ATX Power Supply was found to be causing the voltage to drop to an unacceptably low value during system startup. To give a better understanding of the relationship between inrush current and bus voltage, data from an unsuccessful test run is provided in Figure 7, with the max inrush current and lowest voltage drop identified.

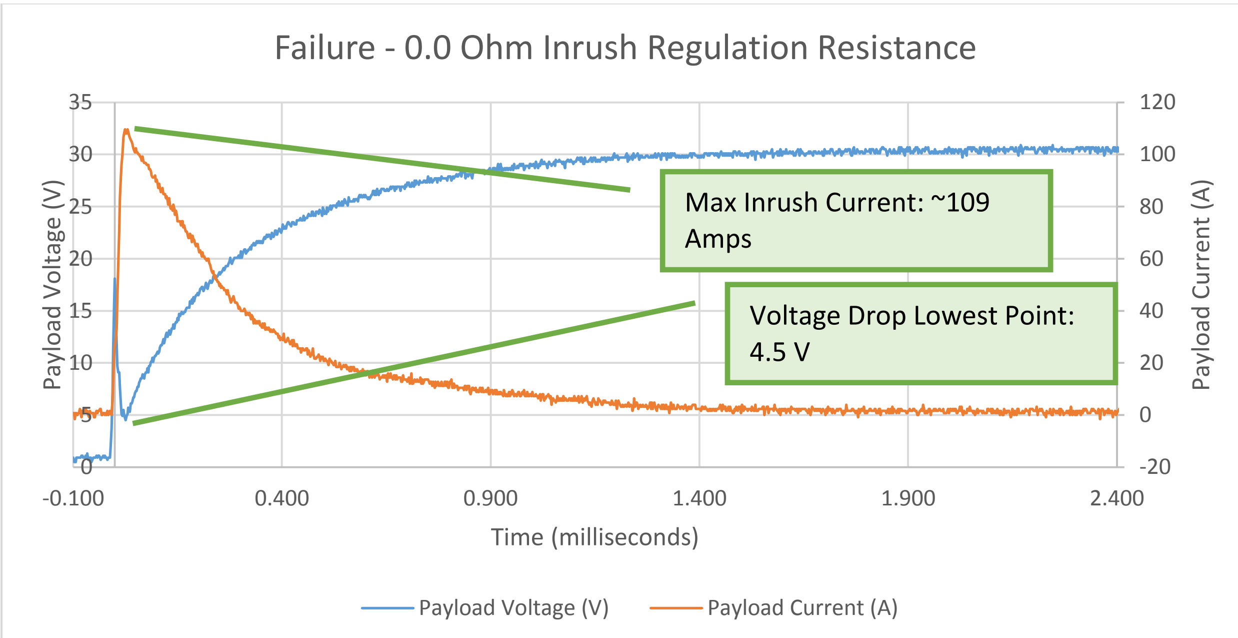

Figure 7 - Inrush Current and Voltage during Failure Event

By contrast, a plot of a successful test run using 0.3 Ohm inrush current limiting resistance is provided in Figure 8.

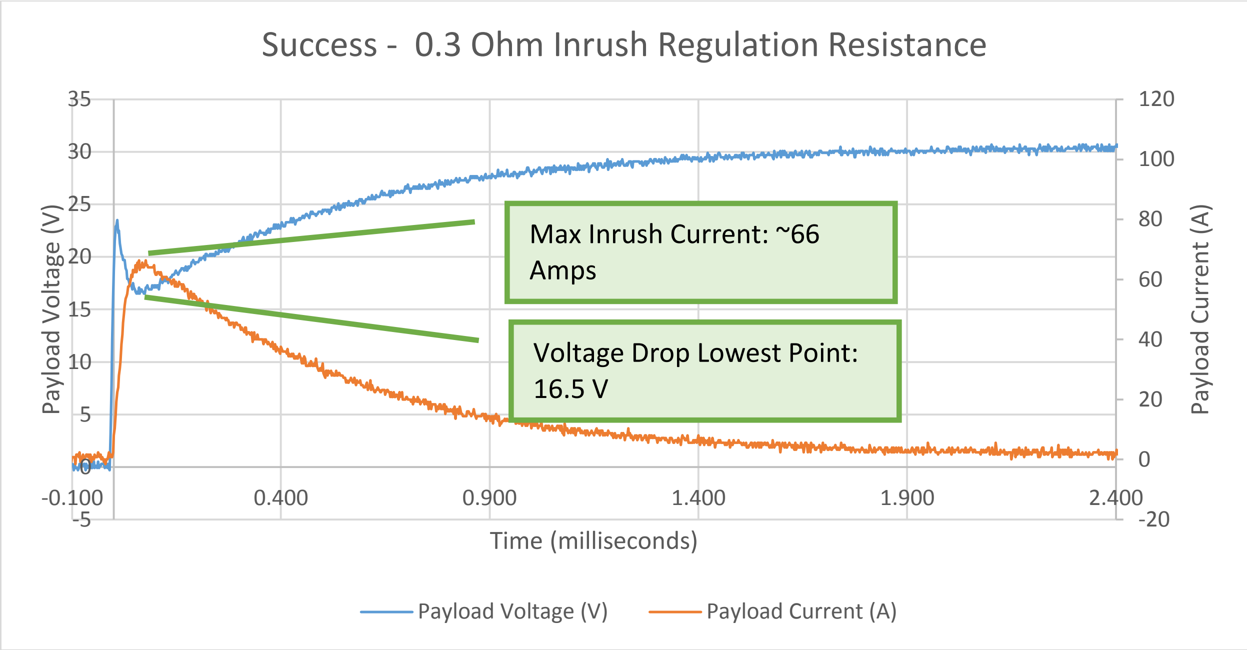

Figure 8 - Inrush Current and Voltage during Successful Event

These two graphs show the effect of even a small resistance on the inrush current that is being supplied by the robot. This resistance reduces the amount of inrush by about 40%, which appears to be enough to reliably fix the issue on the one robot it was tested on.

In terms of the robot failures that the customer experienced, the lowest voltage drop during the startup sequence and possibly the timing of when it occurs relative to the robot being powered on is probably most important to discovering the root cause.

This can be seen readily in Figure 9, where the voltage drop of several power up sequences are plotted against each another.

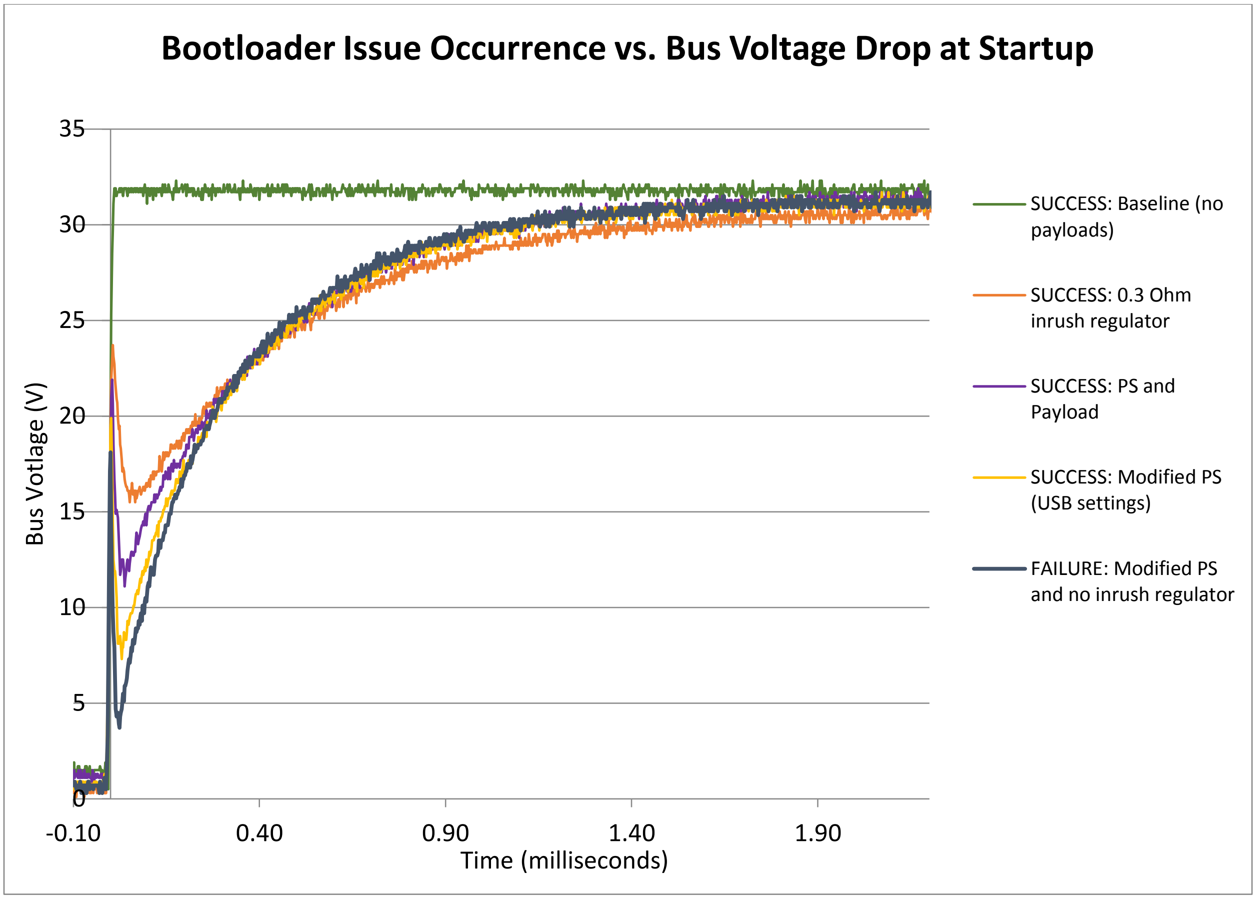

Figure 9 - Bootloader Issue Occurrence vs. Bus Voltage Drop during Startup

As can be seen by the plots, every test run where the robot's Bus Voltage falls below 7 VDC during system boot results in a failure. All test runs where this voltage does not fall to that level is a successful power up.

At this point in the investigation, it still could not be determined if the failure is due to the actual voltage level that the system dips down to, the timing of that dip in voltage, or some other factor.

Software Modifications

A software solution was also attempted so the customer won't need to add any additional hardware to the system for these inrush conditions.

To test this change, a different test configuration was used called Configuration 3. This configuration was a bench top testing environment and did not contain a fully assembled robot. This allowed measurement of signals that are internal to the robot and inaccessible from without. A photograph of Test Configuration 3 is provided in Figure 10.

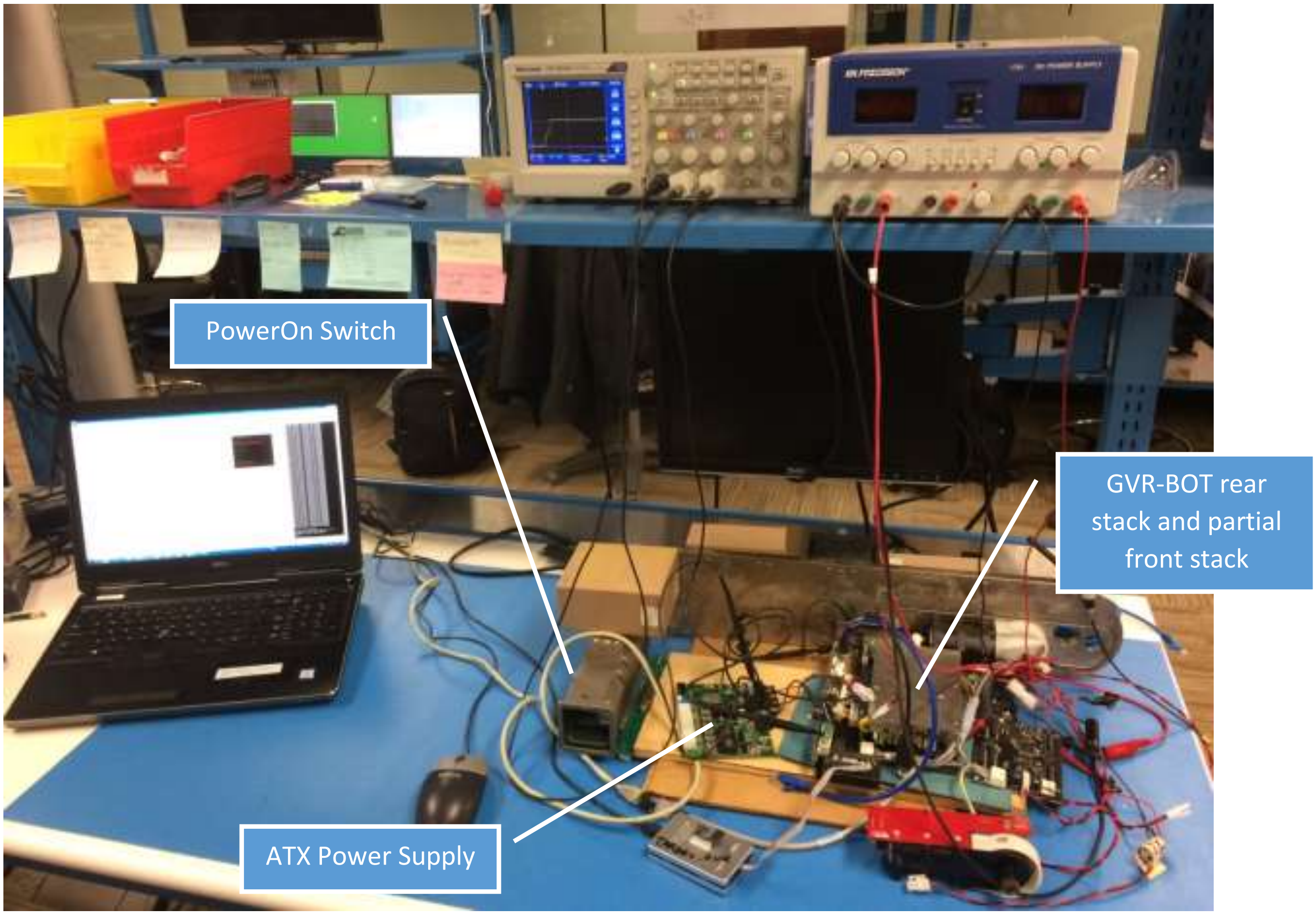

Figure 10 – Photograph of Test Configuration 3 with Instrumentation

Test Configuration 3 consisted of a partial GVR-BOT with all internal circuit boards exposed to allow measurement of voltage and other signals inside the robot. An ordinary battery cradle and standard batteries were used for power, exactly like an ordinary GVR-BOT. For this testing, not all internal components of the robot were included. Mostly notably, the RadioRouter Board, Radio, and Right/Left Motor Drivers were excluded. It was felt that these components were extraneous when testing the effects of external inrush on the GVR-BOT system.

The test procedure was similar that used for the previous testing in this investigation. A robot was powered up with the baseline software while an oscilloscope was measuring the PowerOnSw voltage, GVR-BOT Bus voltage, and Payload Port P3. The GVR-BOT Bus Voltage was measured at J9 power connector of the 0007 Mobility board. When the robot powered up, it was determined if any internal circuit board was in bootloader mode. If not boards were in bootloader, the test was considered successful, otherwise failure was recorded. This same procedure was then used to evaluate the software modification.

To understand the software modification that was made, background information on the power up hardware within the GVR-BOT should be provided.

When the PowerOn Switch of the GVR-BOT is pressed, it pulls the PowerOnSw Line in the robot to ground, which causes battery power to be routed to a 5 V regulator and then a 3.3 V regulator, which powers on the Main Processor and the Pwr Mgt Board. Meanwhile, the Pwr Mgt Board controls 6 Power MOSFETs to provide individual GVR-BOT Bus power to the rest of the GVR-BOT System. Four of these power MOSFETs control each of the four Payload Ports individually and the remaining two MOSFETs control power to the rest of the GVR-BOT system: Radio, Mobility Board, Flipper Board, etc.

The control of these Power MOSFETs is performed by the SW10 Power Management software. In the most recent release of SW10 Power Management software, Release 0.2.4, the four Payload Port MOSFETs are enabled almost immediately when the application software begins. The GVR-BOT Bus Power MOSFETs are enabled by the bootloader software so that the Main Processor is powered on whether the Pwr Mgt Board is in bootloader mode (waiting for reprogramming) or application mode. In this software release, all 6 MOSFETs are enabled within 100 milliseconds – the GVR-BOT Bus is enabled at about 50 milliseconds after PowerOnSw is activated, and the Payload Port MOSFETs at about 90 milliseconds after PowerOnSw is activated. This behavior is demonstrated in Figure 11, which is an example of a failed attempt to boot the system with the ATX Power Supply attached – the Mobility board during this test did not go to application mode.

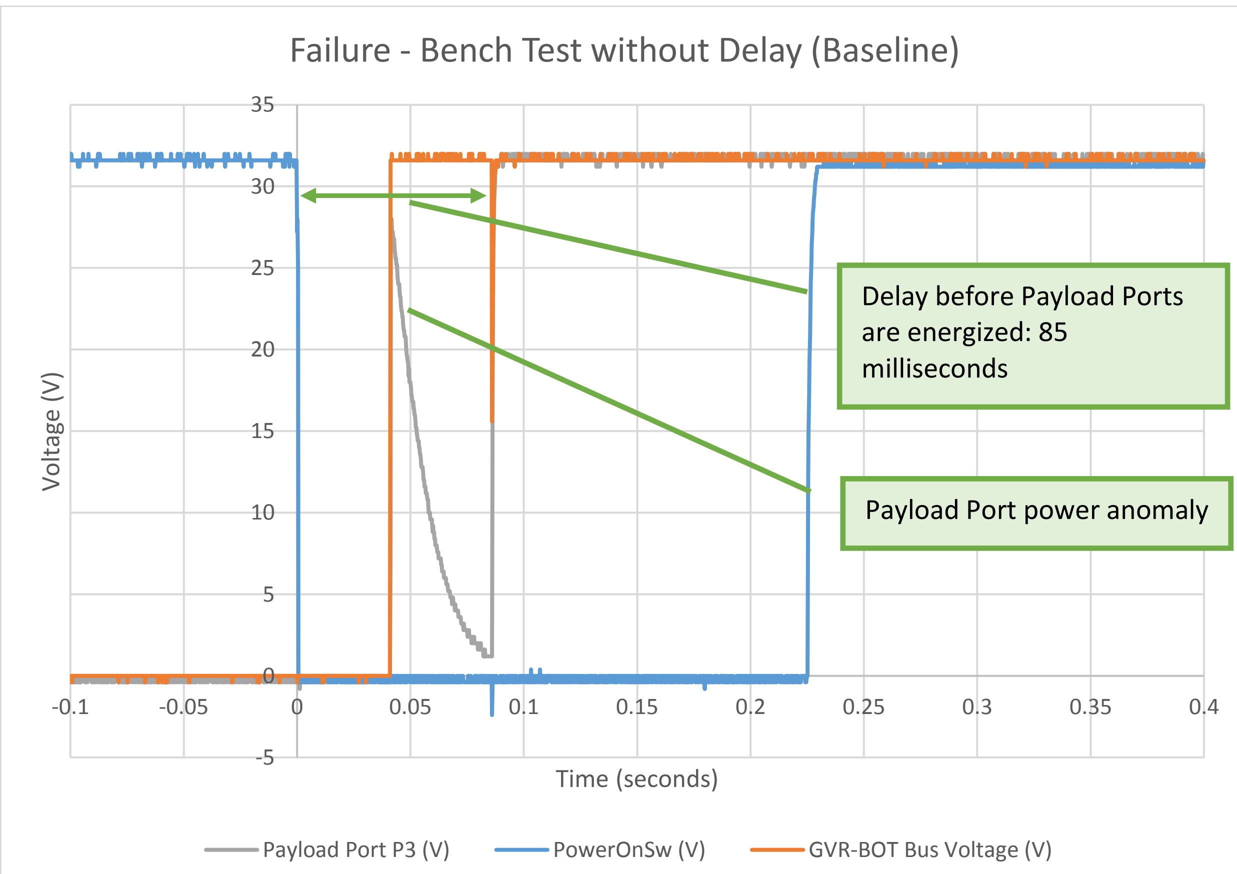

Figure 11 - Bench Test with Baseline Software

An unexplained issue that was observed in this testing was the appearance of a brief, un-intended enabling of the Payload Port which occurs simultaneously with the GVR-BOT Bus Voltage becoming active. This should not be happening and the Payload Port power appears to be quickly disabled, but the voltage decay takes about 40 milliseconds. Further testing determined this anomalous behavior was being experienced at all four Payload Ports.

A software change was tested where enabling of the Payload Ports MOSFET was delayed by about 200 milliseconds, giving a chance for “internal inrush” current within the GVR-BOT system to abate before any additional inrush from the payload ports is experienced by the system.

The solution was tested 12 times using Configuration 3. It was then tested 3 times on GVR-BOT-037 and 3 times on GVR-BOT-004. This change appeared to fix the bootloader issues experienced by the robot in all cases tested. An example plot of a successful test is provided in Figure 12.

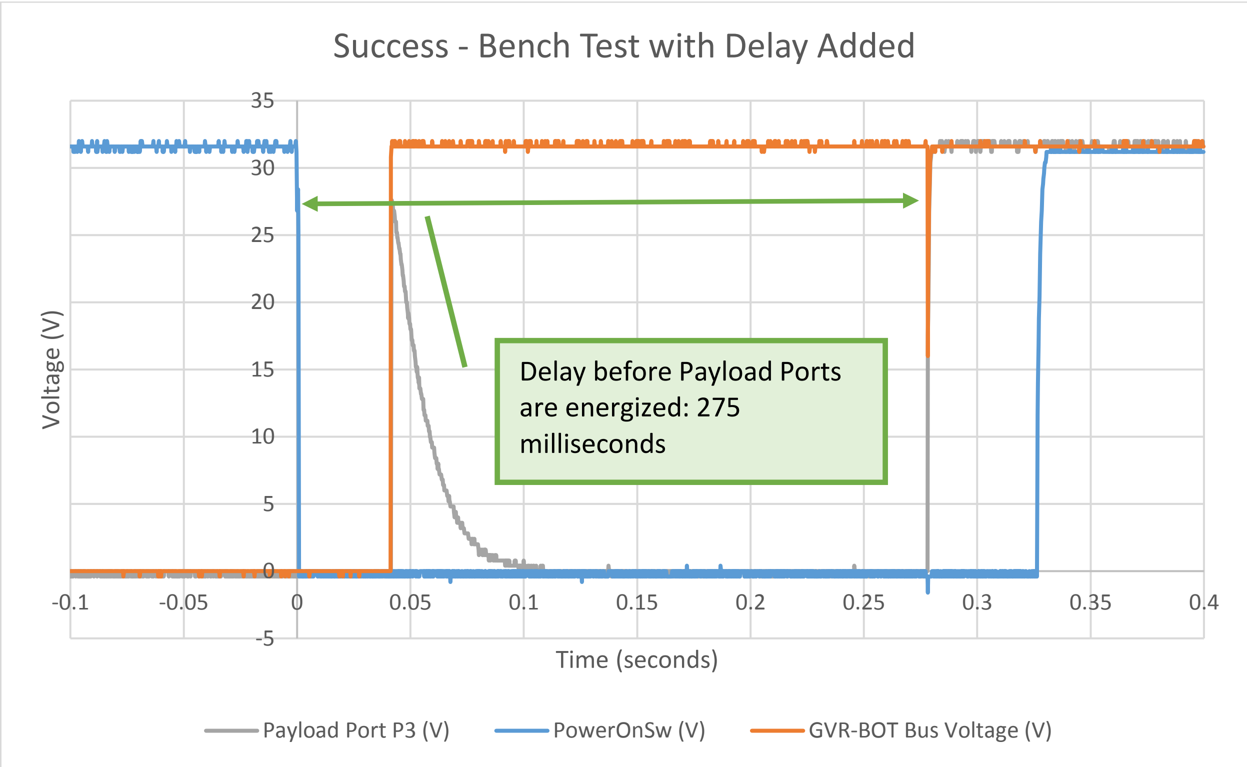

Figure 12 – Bench Test with Delayed Payload Port Enabling

In this graph, the delayed Payload Port activation is clearly seen when compared with the baseline graph in Figure 11. The amount of time between system start and energizing of the payload ports went from 85 milliseconds to 275 milliseconds.

Conclusions and Recommendations

It was determined during testing that the root cause of the customer issue was inrush from a power supply connected to the robot’s Payload Port during startup.

3 independent solutions were found to fix the issue:

- A manual switch to delay startup of the power supply
- An inrush regulation resistance of 0.3 Ohms between the payload port and power supply

- A software delay on enabling the payload port power connections

Of these three, the software delay was found to have the least impact on the customer and is recommended to be the chosen solution.

In addition, an unusual Payload Port power anomaly was found that resulted in a brief enabling of Payload Port power, then disabled. The entire event lasts about 50 milliseconds, but appears on every Payload Port during every power up of the system. It is recommended that the root cause of this anomaly be found.