U12 Resistor Investigation

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Document Purpose

The Backplane/Power Distribution subassembly, has been experiencing failures of its U12 component which buffers signals to the USB oscilloscope.

This document will lay out the investigations that have been performed regarding a potential solution to these failures. The addition of a resistor on the In+ pin of the U12 & U18 operational amplifiers on the backplane was tested, and the results are displayed in this document, along with a potential implementation, and requests for further information.

Initial Reasoning

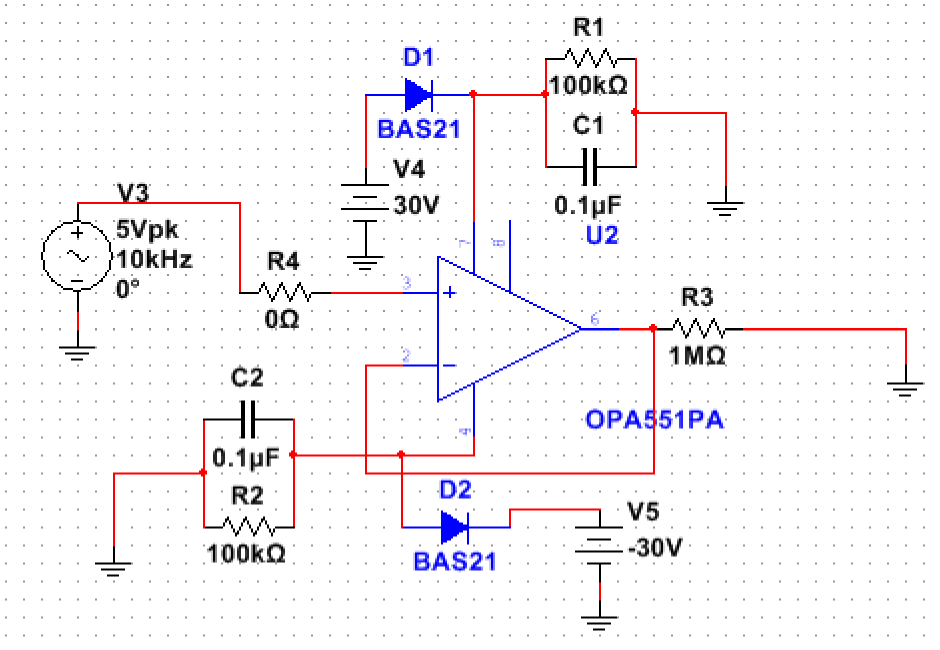
According to the <redacted document #>, the leading cause that was attributed to the failure of the U12 chips in past investigations was a large transient voltage that was generated from the interaction of the internal function generator and the UUT. The <doc> states that the belief was that the transients were faster than could be accounted for by the internal clamping circuitry of the OPA551. However, the datasheet for the OPA551 says the following

> "The OPA55x features internal clamping diodes to protect the inputs when voltages beyond the supply rails are encountered. However, input current must be limited to 5mA. In some cases, an external series resistor may be required."

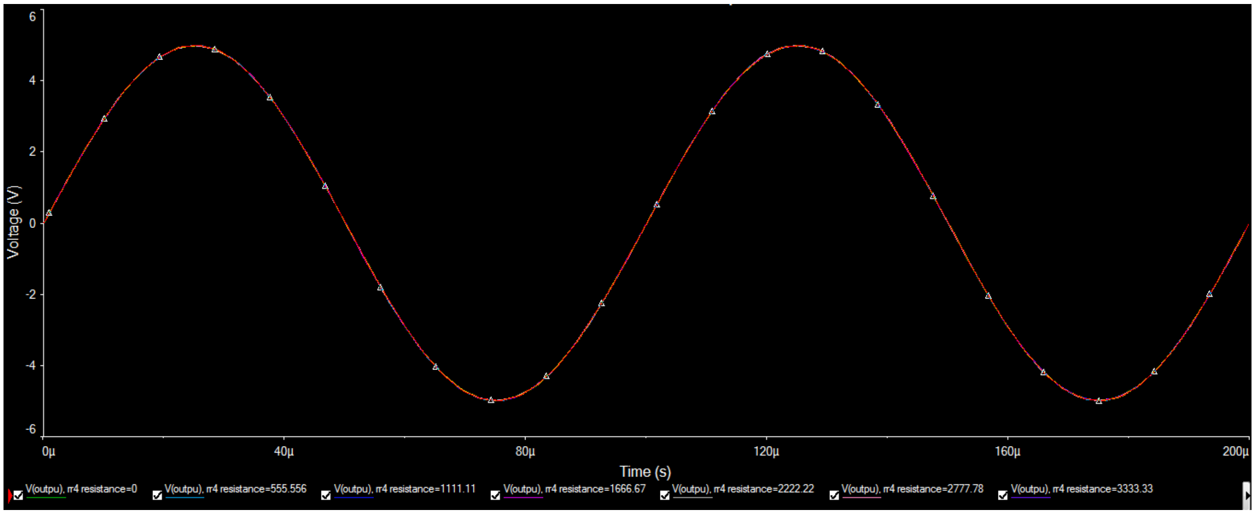
This series resistor does not exist in the current design. It is the belief of the investigating team that if transient voltages are occurring in the test set, the current software solution is inadequate, and that the most feasible solution is the addition of a resistor on the In+ pin of the U12 chip.

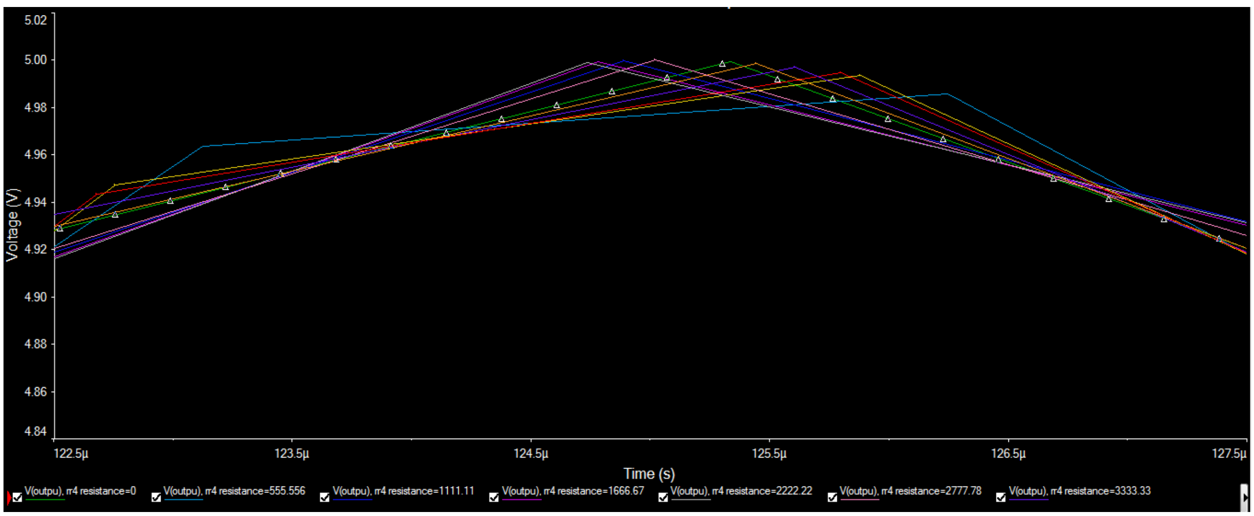
Simulations

Software simulations were performed using an OPA551 model in National Instruments Multisim to investigate the effect that the addition of an input resistor would have on the signals being passed through the U12 chip. The simulation circuit was created exactly as seen in the test set schematic, and is shown in Figure 1. The resistor R4 is the resistor being investigated in this document. It does not exist in the current backplane assembly, but is recommended by the datasheet.



The input signal was a 5Vp-p signal at 10kHz. 10kHz was chosen because it is the highest frequency generated by the function generator in the test set. A simulation was performed that measured the output signals of the circuit when R4 was between 0-5kΩ. This can be seen in Figure 2 and Figure 3 below. Figure 2 (large voltage scale) shows very similar traces at a coarse view. Figure 3 shows a finer view of the results. Each individual trace in Figure 3 represents a different R4 resistor value. The differences between the signals at each resistor value is miniscule, around a 2µs range of phase distortion and 20mV of gain distortion. It is unlikely this would affect the performance of the test set in any appreciable way.





These simulation results led to the determination that the addition of a reasonably small resistor should not affect the frequency or gain response of the buffer circuit in a significant way. It is important to note, the Multisim OPA551 model was not capable of simulating faults, so the amount of protection offered by the resistor could not be tested via simulation.

Gain Response, & Failure Voltage Testing

The next test performed was aimed at answering the following questions:

1. Would the gain response be as unaffected in reality as it was in the simulation?
2. What additional protection would be provided to the OPA551 with the addition of different resistor values?

To test this, the same circuit seen above was physically assembled. The input signal was provided by a 400 Hz AC generator at varying voltage levels. The low frequency during this test was a limitation of the AC generator, but was not considered a significant limiting factor, as the frequency would not influence the answers to the above questions.

What was discovered was that the gain was unaffected by resistor values ranging from 0 - 5.5kΩ. However, the protection afforded by these resistors was significant, and can be seen in Figure 4 below.

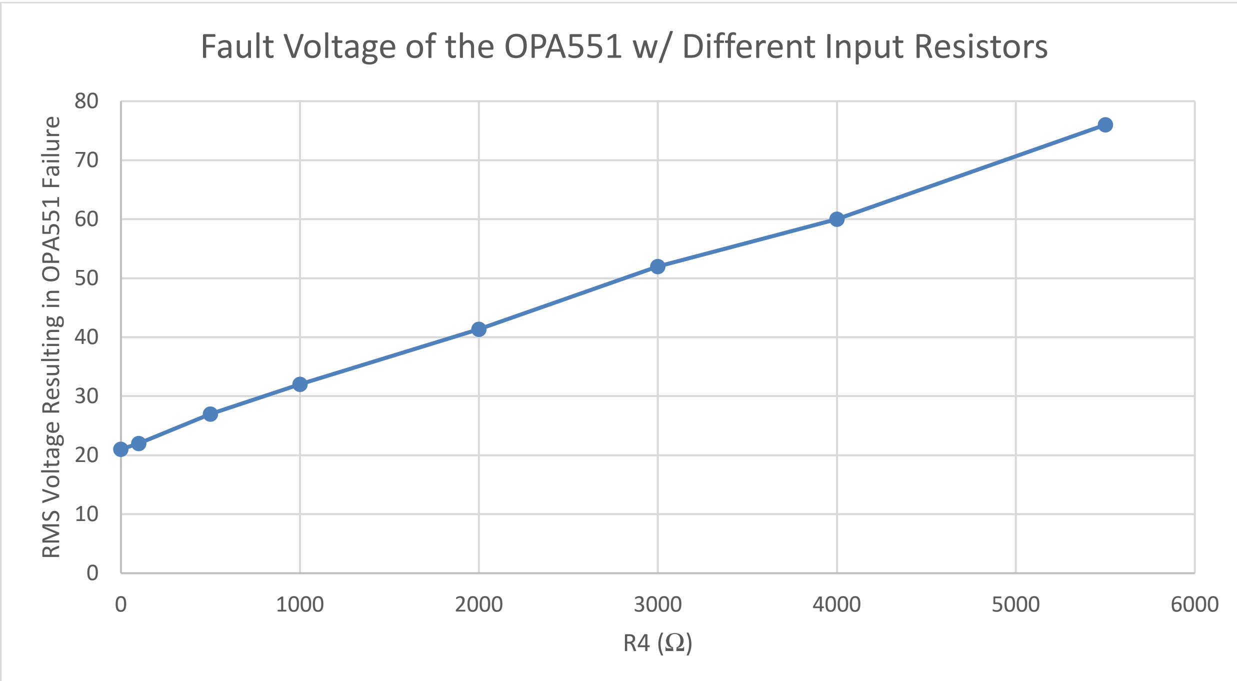


Figure 4 - Voltage required to break an OPA551 with different resistor values on the In+ pin.

While the OPA551 failed at a voltage of 21Vrms (60V p-p) without a resistor, it could withstand over 50Vrms (~140V p-p) with the addition of a 3kΩ resistor, and even over 70Vrms (198V p-p) with the addition of a 5.5kΩ resistor. It is unlikely that any transient signal would reach this high of a voltage.

Harmonics Testing

The next step was to verify that the frequency response of the buffer circuit was not affected to a large degree by the addition of a resistor on the In+ pin. This was performed by using the Fast Fourier Transform (FFT) function on an oscilloscope to view the first 20 harmonics of the output signal generated by the OPA551 buffer circuit. This was performed over a range of resistor values, starting with 0Ω, and going up to 5.5kΩ. The input signal was a sine wave at 5Vp-p, at frequencies of 300Hz, 5kHz, and 10kHz. This frequency range covers the full spectrum of the test set during testing. The results can be seen in the figures below.

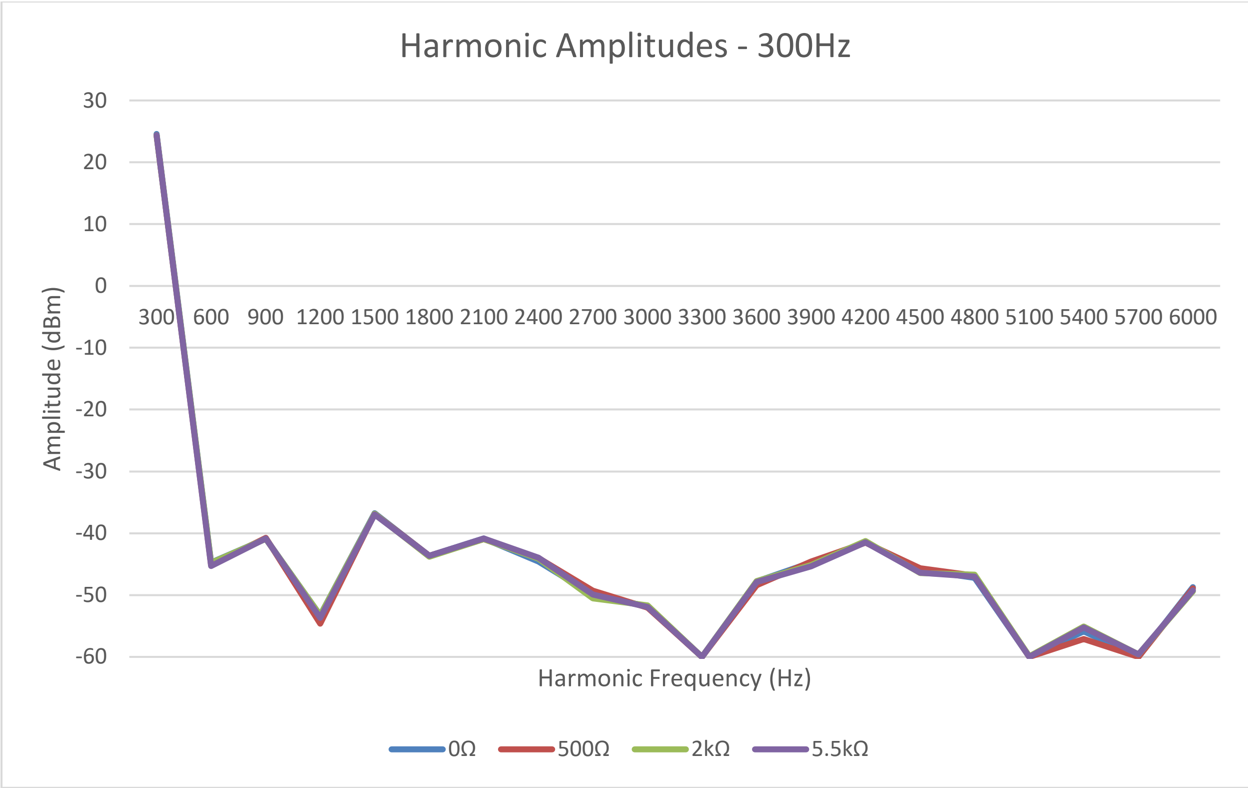


Figure 5 - Amplitudes of harmonics generated by the OPA551 buffer circuit when different resistor values were on the In+ pin.

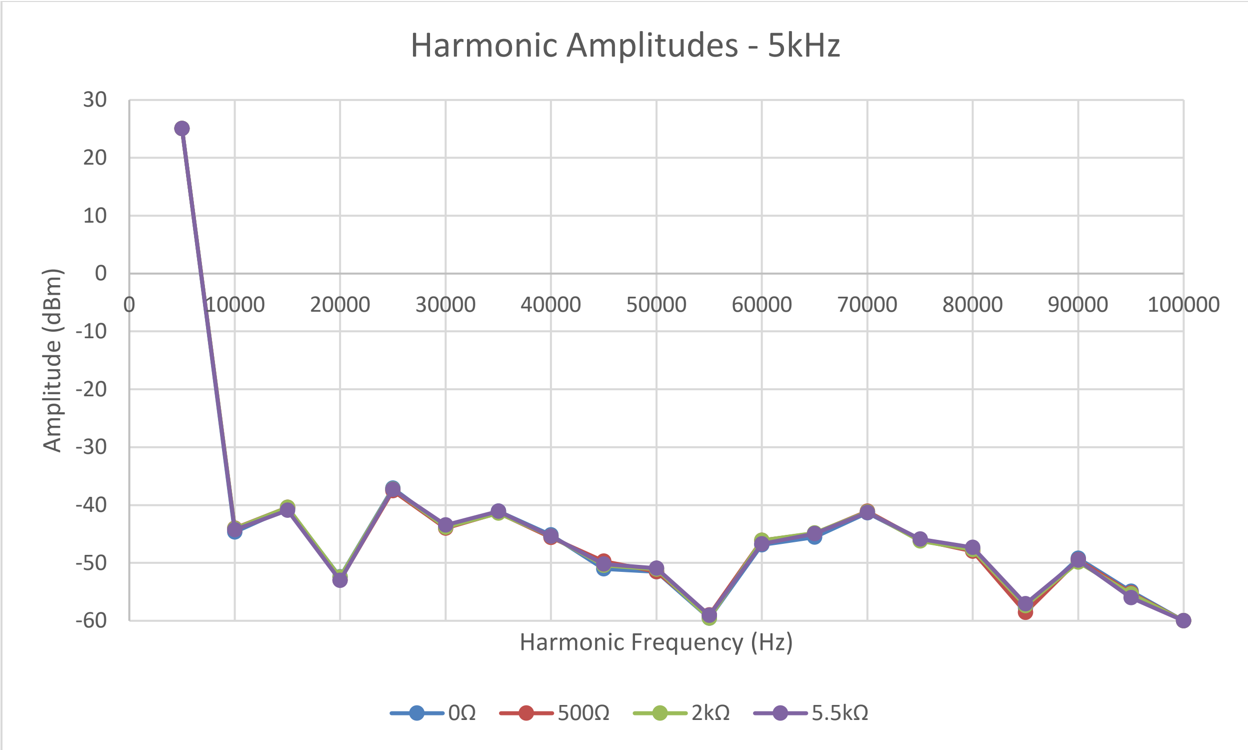


Figure 6 - Amplitudes of harmonics generated by the OPA551 buffer circuit when different resistor values were on the In+ pin.

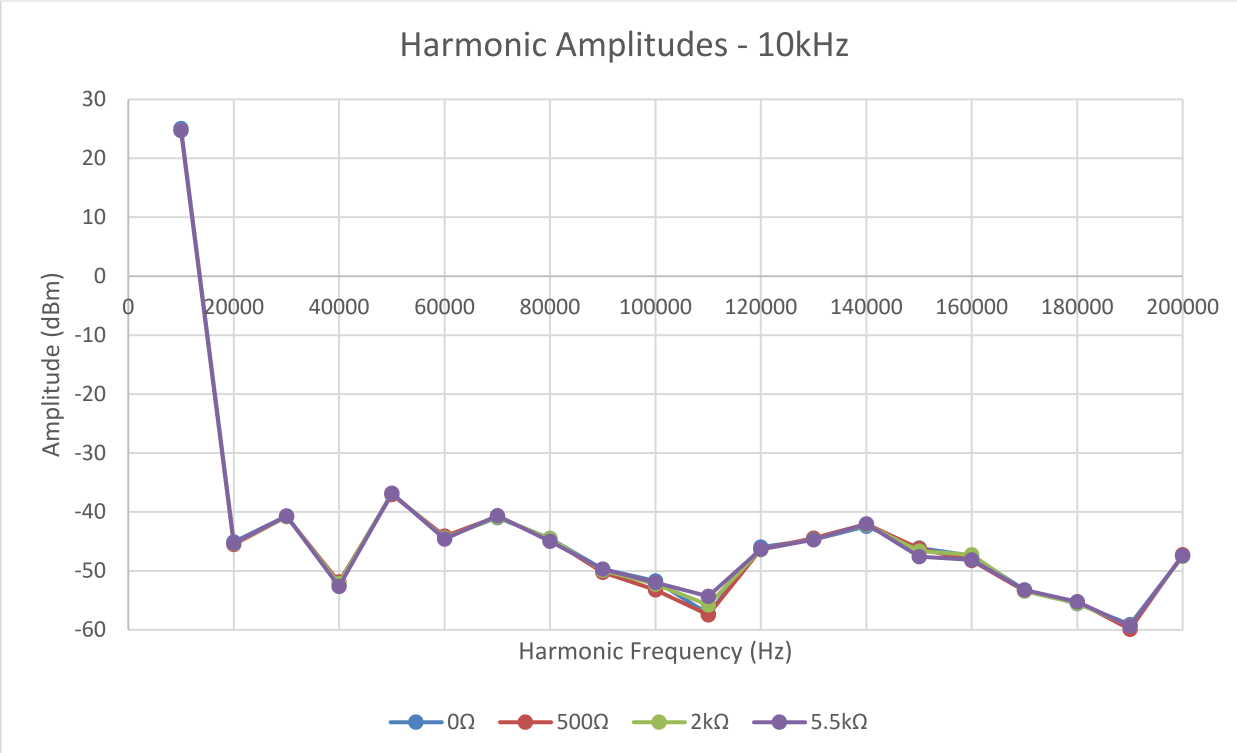


Figure 7 - Amplitudes of harmonics generated by the OPA551 buffer circuit when different resistor values were on the In+ pin.

The majority of data points indicate that the frequency response is largely unaffected by resistor values of these sizes. However, it is apparent that there are some outliers. This is likely attributed to the low sample size used during this test, which was only 3 samples per resistor value, per frequency. But, due to the lack of a clear trend in the data, it seems logical to conclude that the resistor value may not be the sole reason for these outliers. Noise, as well as natural variations in the signal response, also likely play a role in these deviations.

THD Testing

To further test the effect of the resistor values on the circuit, testing was performed on the UUT with the addition of various resistor values. This was done by altering an backplane circuit card to allow for the addition of this input resistor, without changing any additional circuitry. The Total Harmonic Distortion (THD) measurements that were given by the test set were recorded. This was performed with resistor values of 0Ω, 100Ω, 1kΩ, 2kΩ, 3kΩ, 4kΩ, and 5.5kΩ. This was done with the X^{th}, and Y^{th} tests listed in the test for this UUT, because these two tests utilized the U12 chip to analyze the THD of signal received by the UUT. This allowed the team to investigate how the addition of this resistor would affect the actual testing results of the test set. 30 samples were taken for all tests with all resistor values to supply a confident result.

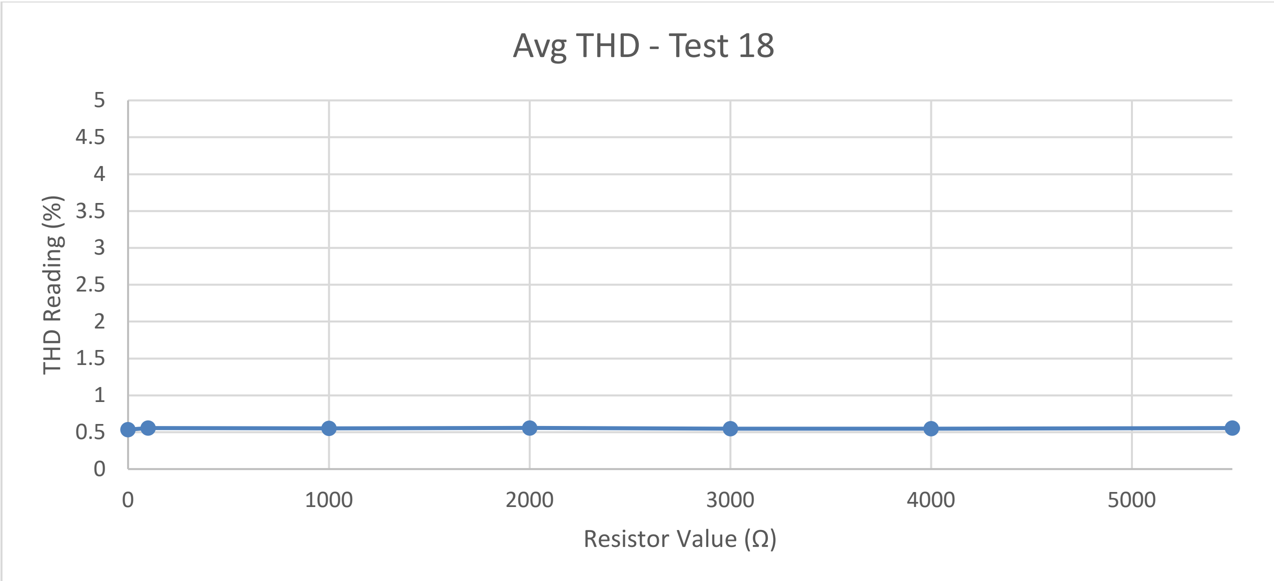


Figure 8 - THD results when running test #18 on the UUT with different resistor values.

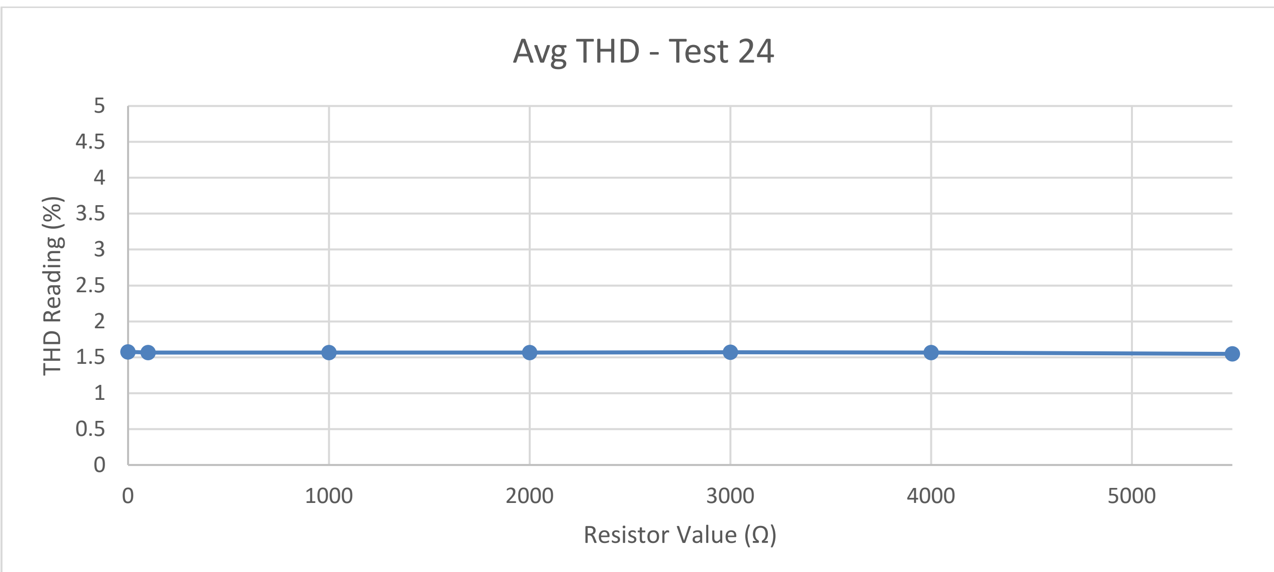


Figure 9 - THD results when running test #24 on the UUT with different resistor values.

The results indicate that the resistor values do not significantly alter the test results that were gathered by the test set during testing with the UUT. The Y-axis of both of the above charts are the ranges accepted by the tests to mark the UUT as "Good". For both tests, the range of average THD results was less than 0.03%. On the x-axis, 0 represents the test set as it is currently designed. Because the data did not display a trend based on resistor values, and because the range of results was so minimal, most of this difference is likely due to noise, and normal data distribution. The total acceptable range of values for these tests is 0-5%. The range of values in these tests were 0.5357-0.558% and 1.547-1.575%. The total range of testing values accounts for only 0.6% of the total acceptable range, indicating that it is extremely unlikely that the resistor would affect the outcome of testing.

Potential Proposal

Adjusting the PCB design of the backplane card to incorporate this resistor could cause significant effort. However, the addition of the resistor could be performed with a relatively low work load, low cost, and minimal redesign by incorporating the OPA551 and resistor onto a separate PCB.

The current U12 and U18 chips are a through-hole package. In the place of these through-holes, a small PCB designed to fit the board layout could to be mounted onto this location. The PCB would connect all of the same connections that are present in the current design, with the addition of the input resistor investigated in this document. See Figure 10 for an example of how this PCB could be laid out. Figure 11 is an example of the form factor for the replacement (SMT component to DIP package adapter).

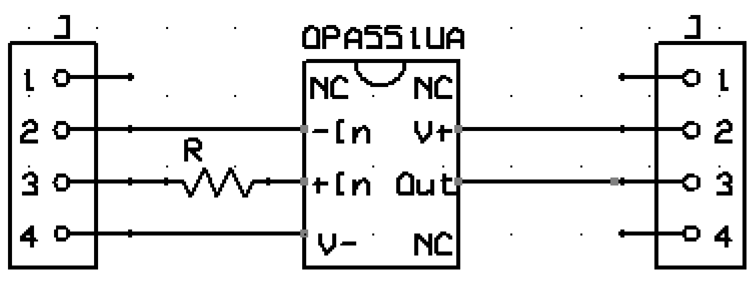


Figure 10 - Example schematic showing how the new external PCB could be designed.

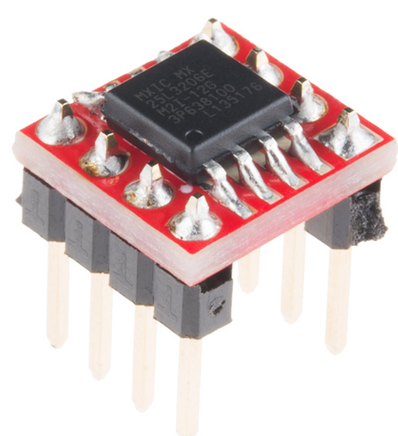


Figure 11 – DIP to SMT Adapter

This strategy would remove any need for electrical connections on the backplane to be redesigned. De-soldering the current U12 and U18 chips, and soldering header pins in their stead are the only necessary changes that would need to happen to the backplane. Performing this, and then plugging the new PCB onto the headers would complete the retrofit.

This change would provide two positive benefits. It would provide protection against transients in the test set, solving the most likely failure condition for the U12 chip. Further, it would decrease the maintenance requirements for failed U12 chips. Now, instead of the LRU being the subassemblies, the LRU could be the small inexpensive PCB which contains only the OPA551 and a resistor. The replacement of the U12 and U18 chips would be made trivial, cheap, and could easily be performed by the maintainers.

Summary

The simulations and tests described in this document provide the investigating team with confidence that the addition of a resistor on the In+ pin of the U12 buffer circuit will not negatively impact the testing capabilities of the test set. Further, it is clear that the addition of this resistor can offer significant protection against over voltage conditions. If transient signals are the issue, it is likely that this solution would prove sufficient.

Further, the introduction of an additional PCB could prove a benefit for maintenance reasons. A one-time adjustment of backplane cards to de-solder the U12 chips, and to add header pins, would decrease the LRU for the maintainers from the backplane card, to a small, inexpensive PCB which is extremely simple to install.

Further investigation needs to be performed to determine whether or not transient signals are the definite cause of the U12 chip failures. This is the leading theory at the moment of writing this document, but no hard proof has been gathered that allows the team to be 100% certain.

Additional information or documentation would be extremely helpful in formulating future investigations to help determine the exact cause of this issue.