National Aeronautics and Space Administration

DC to DC Converter Testing for Space Applications: Use of EMI Filters and Thermal Range of Operation

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ABSTRACT

Several tests were performed on Interpoint and International Rectifier (IR) direct current (DC) to DC converters to evaluate potential performance and reliability issues in space use of DC to DC converters and to determine if the use of electromagnetic interference (EMI) filters mitigates concerns observed during previous tests. Test findings reported here include those done up until September–October 2008. Tests performed include efficiency, regulation, cross-regulation, power consumption with inhibit on, load transient response, synchronization, and turn-on tests. Some of the test results presented here span the thermal range -55°C to 125°C. Lower range was extended to -120°C in some tested converters. Determination of failure root cause in DC/DC converters that failed at thermal extremes is also included.

1.0 INTRODUCTION

Hybrid microcircuit DC to DC converters are utilized in numerous flight systems but have failed continuously in space hardware [1].

The work described in this report is a result of tests performed under the FY08 NEPP task "Failure modes and reliability of DC to DC converters." Several of these tests were designed during the performance of a large inter-center task sponsored by the NASA Engineering and Safety Center (NESC) in FY06 and FY07 to develop recommendations for specifying parameters and test methods for DC to DC converters. A comprehensive test matrix was generated by the NESC converter team, encompassing needs identified at various NASA centers [2].

Tests reported included measurements at the ends of the military thermal range or as defined by vendors (-55°C to 125°C) and, for most tests, input voltages were varied (minimum, nominal, and maximum); resistive loads were also varied. Datasheets were utilized as guidelines to determine frequency ranges, minimum/maximum voltages, loads, expected recovery times, and other user information; however, some of the tests performed were in violation of the datasheets because such use could and has occurred in flight applications.

Testing with manufacturer-recommended EMI filters was not included in the NESC test matrix; however, EMI filters are used in flight applications and can potentially mitigate some of the performance issues of these converters that were identified in FY07.

In this NEPP FY08 task, tests that compared performance with and without manufacturer-recommended EMI filters were carried out. Additionally, testing below the military thermal range (-55°C) were performed with the aim to determine the lowest temperature of operation and to explore methods to extend this range in some commercial DC/DC converter models. Test results reported here do not include electromagnetic compatibility (EMC) tests.

2.0 EXPERIMENTAL DETAILS

DC/DC Converters Tested

Tests were performed on all the converters listed in Table 1. Table 1 also lists converters that were tested under the NESC study (in FY07) as well as some of their most important flight applications.

The AFL2812D is a 96-watt output, positive and negative 12V dual output converter manufactured by International Rectifiers (IR). The IR datasheet revision PD-94458C was used for reference in our tests. One hundred percent load was set for 4 amps for each of the 12V outputs.

The ART2815T is a 30-watt converter with positive and negative 15V outputs, plus one- third positive 5V output. The IR datasheet revision PD-94528B was used in this work. One hundred percent load was set at 1.5 amps for 5V output; one hundred percent load was set at 0.75 amps for 15V output.

The ASA2812D is a 5-watt output converter with positive and negative 12V dual output. The IR datasheet revision PD-94540A was used for reference. One hundred percent load was set at 0.2 amps per channel.

The MFL2812D and MFL2815S are 65-watt converters. The former has double positive and negative 12V outputs, and the latter has one 15V positive output. They are built by Interpoint, or Crane Aerospace & Electronics. The Rev D – 20060601 version of their datasheet was used in these tests for reference.

Table 1. List of DC/DC converters included in this study with corresponding EMI filters and their flight use. This work did not include testing with and without EMI filters for the AFL, ARH, and SMHF converters.

Converter Model(s)	Filter Model(s)	Space Flight Applications	Comments
MFL2815S, MFL2812D, Interpoint	FMD28-461 (7-amp output current) FME28-461 (15-amps output current)	MSL (several), Aquarius, Hubble space telescope (several), Vegetation Canopy Lidar (VCL) in EOS, HIRDLS (part of TES tropospheric emission spectrometer); SRTM, 2005 E.O.; SIRTF, Cloudsat, Wide Field Camera 3 (WFC3); 2005 D.S.; ST7 (space technology 7); Lunar Reconnaissance Orbiter (LRO)	Report for MFL2812D: IOM 5145-08-001
ART2815T, IR	ARF461	MER, ACRIM, 2007 D.S.; 2002 E. O.; 2005 D.S.; 2008 E.O.	
ASA2812D, IR	AFM704A	DS1, EMLS, MARS01, ACRIM, MLS, SIRTF, Shuttle Radar Topography Mission (SRTM)	
AFL2812D, IR	N/A	Lunar architecture team (LAT); EMLS (on Aura), microwave limb sounder (MLS); TES, Space infrared telescope facility (SIRTF); Active Cavity Radiometer Irradiance Monitor (ACRIM)	IOM 5145-08-003
ARH2812D	N/A	MER, 2007 D. S.; 2008 E.O.	IOM 5145-08-002
SMHF2805D	N/A	MSL, NIRCam, MER, 2001 D.S.; 2005 D.S. 2; 2007 D. S.; 2005 E. O.; OMI (Ozone monitoring instrument); Aquarius, HIRDLS (part of TES tropospheric emission spectrometer); 2009 D.S.; 2009 E.O.; MARS01, Ocean Surface Topography Mission (OSTM); Space cube, Diviner (on LRO); SXI	IOM 5145-08-004

Tests Performed

The following tests were performed in some of the working converters listed in Table 1.

- Load regulation and cross regulation
- Efficiency
- Power consumption with inhibit and no load
- Transient load response
- Synchronization
- Turn-on
- Stability margins (only on converters with sense pins)
- Overload current and short circuit current power consumption and recovery voltage/time

The following tests were performed on failed converters:

- Infrared (IR) imaging after turn-on (while connected) for comparison of heating spots between working and failed AFL2812D converters.

Test Set-Up (General)

This involved temperature control, safety precautions, and common test equipment.

Temperature Control and Monitoring

All DC/DC converters were tested at room temperature using a finned heat sink. A small fan was also used to lower the temperature when the converters were fully powered up. Thermocouples were T-type. They were mounted on thermal tape between the heat sink and the converters with a plate bolted on the converters to make good thermal contact. Figure 1 shows pictures of this set-up.

When tests were performed at -55°C and at 125°C, a Sigma Systems M30 computer controllable thermal chamber was used. The system’s testing capabilities include both cycling and static temperature testing at extreme temperatures from -175°C to 250°C. With small thermal masses, the chamber achieved a ramp rate between temperatures above 10°C/min. Inert atmosphere testing was achieved through a built-in gas purge (using nitrogen). Adjustable, fail-safe, over-temperature and under-temperature protection was built into the system and is active in both manual operation and remote operation. Secondary redundant, fail-safe apparatuses were installed for flight parts testing. The test chamber is 33cm (L) x 25cm (W) x 33cm (H) and has eight 7.6cm x 1.3cm door feed troughs and one 5cm side port. Figure 2 shows the chamber both closed and with a converter inside ready for tests. Manual control was used in these tests since the device thermocouple temperature was used (rather than the chamber thermocouple reading). At full load there was sometimes a small discrepancy, so the chamber temperature was adjusted accordingly.

Temperatures were recorded for the DC measurements, and other measurements were performed only when the real temperature (as read by the thermocouple) was within positive or negative 3°C of the nominal temperatures. Nominal temperatures were 25°C, -55°C, and 125°C. The thermal chamber can achieve closer temperature control (easily within one-half of a degree), but the thermal margins stated were used to perform the tests in a more timely manner.

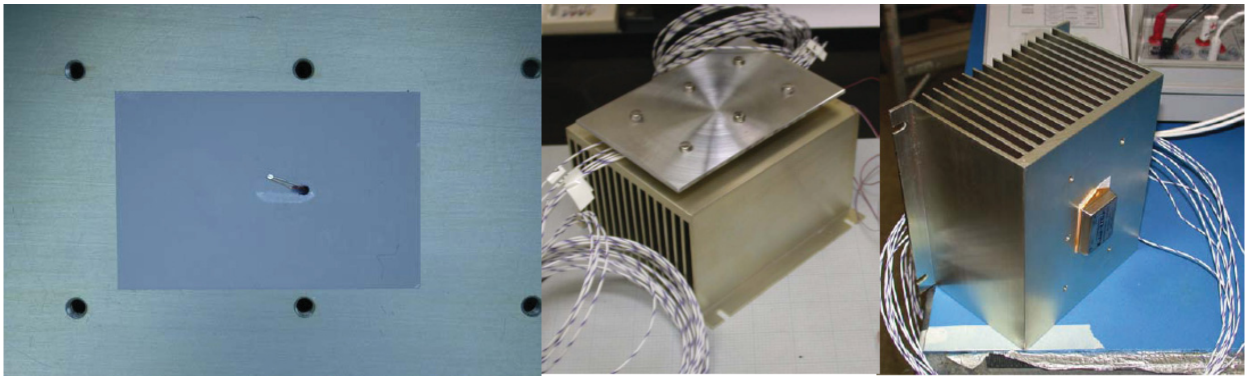


Figure 1. The top picture shows T type thermocouple mounted on electrically insulating tape on a finned heat sink. The converter is mounted directly above thermocouple and a holding plate is bolted above to make pressure contact to thermocouple. The bottom figures shows devices mounted with leads on heat sink/thermocouple. The converter/plate attachment and wiring configuration depend on the geometry of the converters tested.

Figure 2. Thermal chamber used in all DC/DC converter tests at -55°C (and below) and 125°C. Tests were also performed at room temperature before closing the chamber and bringing it to temperature to ensure measurements were as expected.

Safety Precautions

- Wear electrostatic discharge (ESD) straps and ESD coat.
- Disable output from power supply when not using.
- Do not turn converter on without some load (at least 10%).
- Make sure input wires are rated to take input current (important for higher power converters).
- To prevent the converter from going into oscillation mode, make sure that enough voltage and current are supplied as the power supply is turned on. Do not gradually turn on power supply (except when explicitly required by the stated test condition, as in one type of turn-on test) but, rather, set to minimum (or higher) voltage stated in specification sheet and use the converter's inhibit function or an input switch so the converter is instantly turned on rather than gradually turned on.

Test Equipment Used

- HP 6060B 3-60V and 0-60A-300W electronic loads (as many as converter outputs)
- HP 6654A DC power supply (stable and provides enough power for the 96-watt converters)
- Temperature controller (data acquisition switch unit) Agilent 34970A
- FLUKE 77 Series II multimeter (only for monitoring)
- Agilent 34401A digital multimeter (for measurements)
- Switch (field effect transistor [FET] or mercury) and small power supplies as needed for switch (only for start-up tests)
- Pulse generator: HP 8112A (only for synchronization tests)
- Oscilloscope: Tektronix TDS 3014B (for start up, synchronization, and load transient response tests)
- Precision resistors (one for each output and one for the input current measurements) Dale 0.1 ohm (50 watts) for testing this converter
- Capacitor boards (101 uFarad chip capacitors) and electrolytic capacitors
- Heat sinks and thermocouple (to regulate and monitor temperature)
- Agilent 4395A network/spectrum/impedance analyzer and Ridley frequency analyzer (for stability margins tests)
- Thermal chamber to perform measurements at -55°C and at 125°C
- Current probe: Tektronix (AM 503 current probe amplifier)

2.1 Efficiency, Regulation, Cross-regulation, Regulation with Capacitive Loads, and Power Consumption with Inhibit and No Load

Efficiency of a converter is defined as: % efficiency = 100 * (Power out/Power in). Regulation is defined as: % regulation = 100 * (Vout any load - Vout nominal)/(Vout nominal). A slightly different definition for voltage regulation is used in [2]. To avoid confusion, the voltage regulation is given as a straight voltage value in the figures presented in this report. The set-up for these measurements is illustrated in Figure 3.

All measurements were done for the three values of input voltage: minimum, nominal, and maximum (set by the vendor's datasheet). For the AFL2812D, they are 16V, 28V, and 40V. For the ART2815T, they are 19V, 28V, and 50V. For the ASA and the MFL models, they are 16V, 28V, and 40V (like the AFL2812D).

For cross-regulation, the load is set to 50% on one output, and voltage regulation is tested from the other output at varying loads (10%, 20%, 30%, 40%, and 50% resistive loads). The test is then repeated by setting the other output to 50% and performing the tests on the output that was originally set to 50% load.

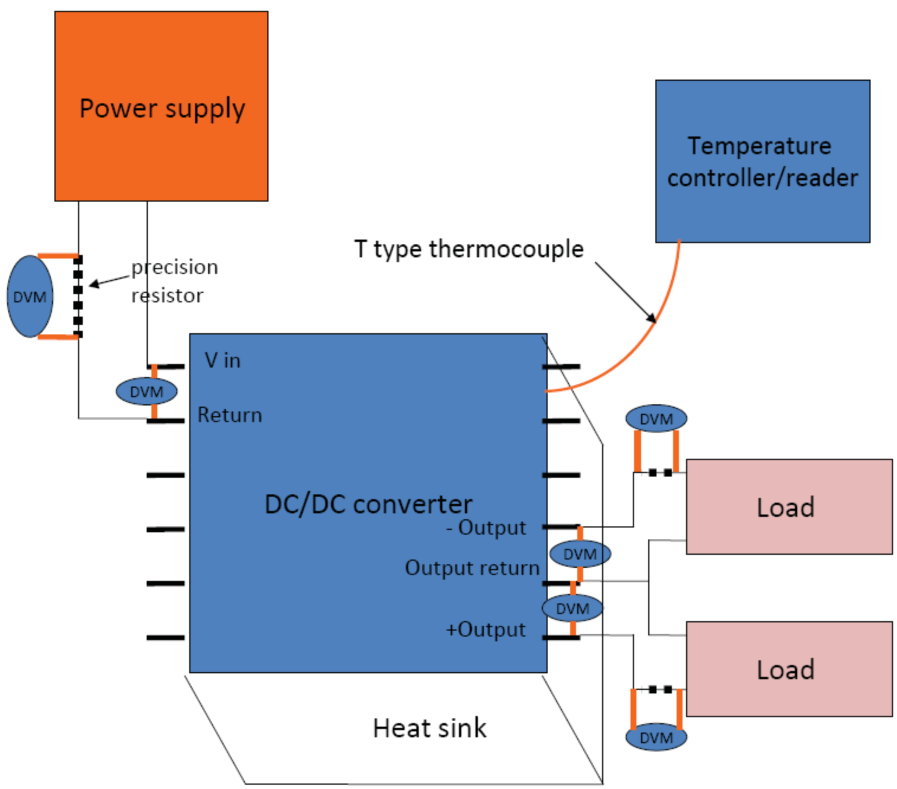


Figure 3. Set-up diagram for efficiency, voltage regulation, and cross-regulation measurements. Wire lengths were 2–3 feet; gauges were 18 or 22 feet for smaller signals.

2.2 Load Transient Response

This test determines the relative performance of the converter's feedback circuitry. This test also gives a qualitative indication of the adequacy of stability design margins with respect to the converter's feedback loop design. The test set-up diagram to evaluate the converter's response to a transient load is shown in Figure 4.

Slew rates between the two loads should be as fast as possible and need to be faster than 1A per 1µS. The electronic load's fastest slew rate should be fast enough to handle this (as an example, Agilent loads can switch up to 5A per µS; other manufactures' loads may be used).

For dual output models like the AFL2812D, each output is tested by setting one output to non-pulsed, constant operation at 50% and the other output at a pulsed operation with step 25% to 50% resistive load. For the ART2815T, which is a triple output converter, two of the outputs are set to 33% load, while the output being tested is pulsed from 10% to 33% load for the regular load transient step response and from 2% to 33% for the low load transient response test.

With the intent to simulate some flight applications that use DC/DC converters with very small loads, this test was changed to also include low load step transient response. In this case, the fixed output was kept at 50% but the pulsed output was pulsed from 2.5% to 25% in dual output converters, from 5% to 50% in single output converters, and from 2% to 33% in triple output converters. Results from this test are also shown in this report.

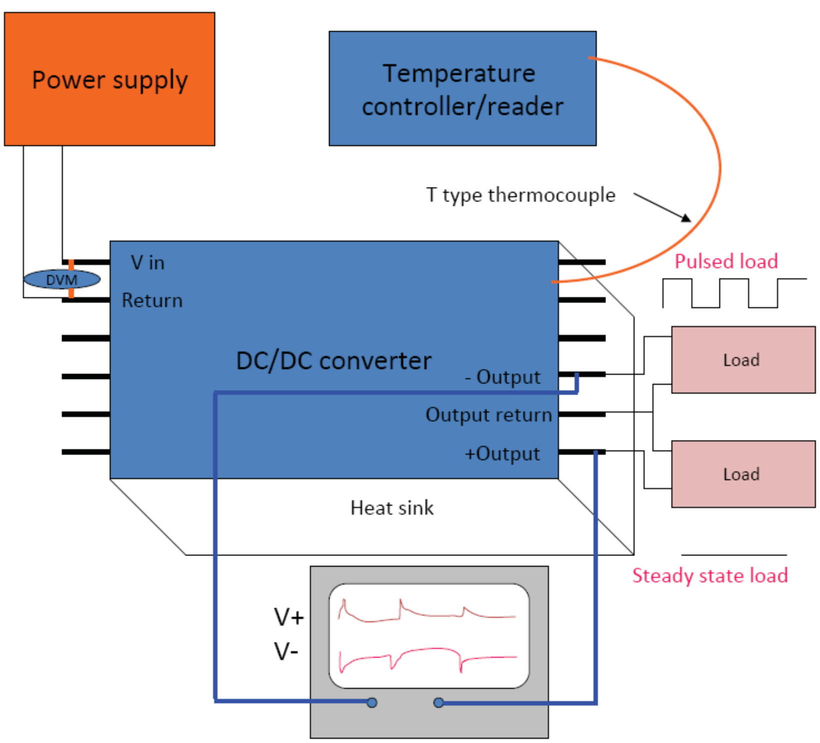


Figure 4. For the load transient response measurements. For a single output converter, the single load is pulsed from 25% to 50%. For dual output converters, one load is pulsed and the other load is kept constant. Both outputs are monitored on oscilloscope, and voltage overshoot and recovery times are measured. For dual output converters, loads are as follows: regular load—one side 50%, the other side pulsed from 25% to 50%; low load—one side 50%, the other side pulsed from 2.5% to 25%. For a triple output converter, two loads are kept constant at 33%, while the output being tested is pulsed from 10% to 33%. If capacitors are included they are in parallel with the output that is being pulsed.

Anomalies were discussed with the manufacturer, and IR engineers pointed out that it is stated in the specification sheet that it is not recommended to use the converter with less than a 20:80 load split between the positive and negative outputs. For this reason, this test was later modified (for other converter models) so that the vendor-recommended 20:80 load split was not violated; however, a greater than 20:80 split was still used in some of the tests since some flight applications use them in this manner. Also, a passive load was used on the non-pulsed output during later tests per the vendor's recommendation. For the AFL tests described here, electronic loads were used on both outputs; the conditions were:

	Fixed load	Stepped load
Normal load transient	50%	25% to 50%
Low load transient	50%	2.5% to 25%

A gentler low load transient was also used:

	Fixed load	Stepped load
Low load transient	25%	2.5% to 25%

In order not to violate the manufacturer's 20:80 load split, the low load transient response test was also performed with these settings:

	Fixed load	Stepped load
Low load transient	10% with passive load	2.5% to 25%

This test condition does not violate the 20:80 split at any one time (before or after the pulse) between the two outputs that are recommended in the datasheet.

The input voltages tested were low, nominal, and high per vendor datasheets.

The test was configured by connecting both outputs to an oscilloscope. Even if only one output is pulsed, both outputs will have a small voltage overshoot. The tests were done at the different resistance loads described previously.

The electronic load (we are using HP 6060B) was programmed so that loads can be pulsed, while the other electronic loads were set to a fixed value (50%, for example). The scope traces were collected at a couple different time scales. Measurements of voltage overshoot and recovery times are evident from these scope traces.

When any anomaly was seen performing this test, collecting information on the actual current transients (we used the Tektronix AM 503 current probe amplifier) brought valuable insight. Depending on the nature of the trouble, current waveforms should be collected at the input and both outputs (or at minimum the pulsed output). This was done with this converter for low load transient response tests since some anomalies were observed. Figure 4 shows a diagram for this test set-up.

2.3 Synchronization

This test verifies that the output voltage is synchronized with a pulse of a certain frequency (per vendor datasheet) when the unit locks to an external synchronization signal.

For the AFL2812D, the synchronization range is between 500 and 700 KHz; for the ART2815T it is 225 to 275 KHz; and for the ASA2812D it is 500 to 600 KHz (per vendor datasheets). A diagram of this test set-up is shown in Figure 5.

To perform the test, the output of a pulse generator (square wave, 50% duty cycle, 4.5 ns rise and fall times) is connected to the synch signal input pin. The outputs are monitored on an oscilloscope, and the waveform and the converter's output are performed. Traces from the pulse generator waveform and both outputs are collected at a couple of representative time scales for each voltage input, load, frequency, and signal amplitude tested. Low and high signal amplitude for these converters are 2V and 10V (AFL), respectively.

Scope traces were collected only for the following conditions: 28V input, 100% loads, lowest and highest allowed (per datasheet) signal pulse, and minimum and maximum frequencies per each converter.

Unless anomalous results were seen, pass/fail tests were done for the following conditions: 10%, 50% and 100% load values. They were also tested at the minimum, nominal, and maximum input voltages as well as all frequencies specified in the data sheets. Additional tests at 10% below the minimum frequency and 10% above the maximum frequency were also performed. Results are only shown for the nominal conditions (see previous paragraph) and for the additional conditions only when anomalies were found.

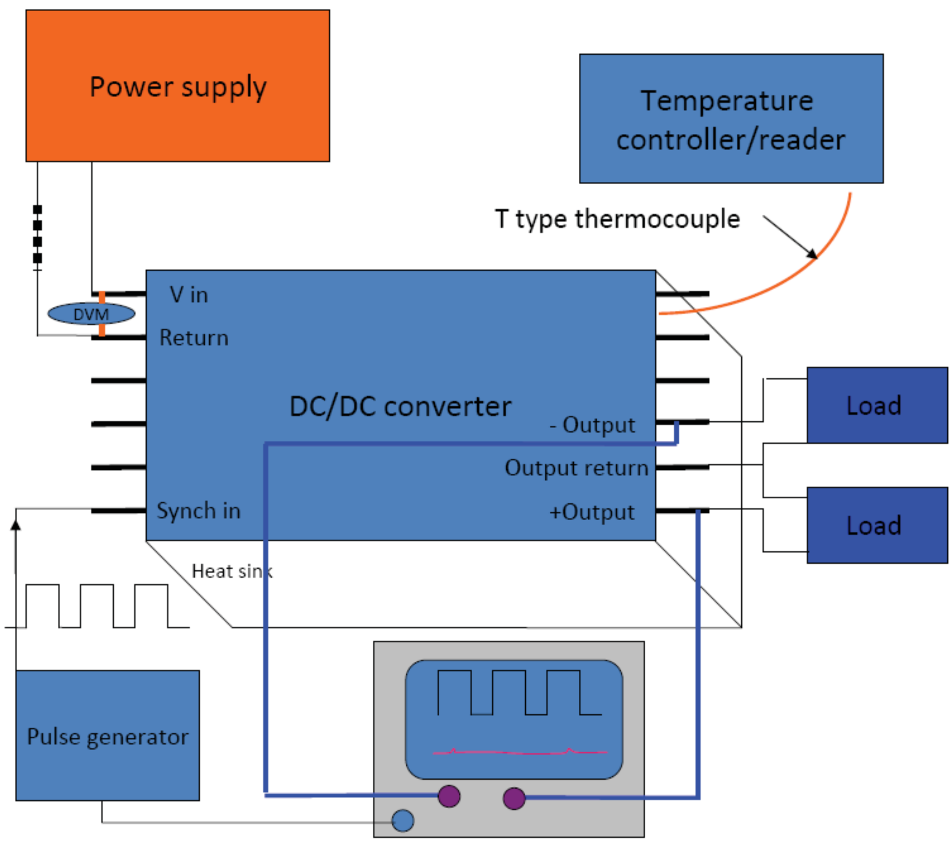


Figure 5. This test verifies that the output voltage is synchronized with an external pulse of a certain frequency. Synchronization for the AFL2812D is 500 to 700 KHz; for the ART2815T it is 225 to 275 KHz; and for the ASA2812D it is 500 to 600 KHz (per vendor datasheets).

2.4 Turn-on

A diagram for these tests is shown in Figure 6. Turn-on comprises four different tests:

1. The first test has the power source on with the converter first inhibited and then uninhibited. This was done for minimum, nominal, and maximum input voltages.
2. The second test applies the input voltage to the converter using a switch. Either an FET or a mercury switch may be used. Since Hg switches are permitted at the Jet Propulsion Laboratory (JPL), Hg switches were used when bounceless switches were required. Input power (voltage) and the converter output(s) are recorded on an oscilloscope simultaneously. This measures the delay time to achieve full regulation as well as any voltage overshoots. This test was performed for all three input voltages.
3. The third test is similar to the second test but uses an input switch circuit that has a few milliseconds delay ramp. Tests were repeated using large capacitors in parallel with the input power. However, these oscillations still persisted for some conditions, probably due to the inherent resistance of the switch. A recent meeting and information exchange with the vendors indicated that these tests were expected to be performed using the inhibit release function after the converter was fully powered up. Vendor datasheets do not specify this test condition, and reconciling test methods/flight applications/vendor datasheets is still in progress.
4. The fourth test is to determine at what voltage the converter starts to run. A voltage ramp is required and needs to be slow enough to determine when the converter starts. This particular test was done manually, since the turn-on is too slow to be captured on an oscilloscope. After ramp-up and turn-on, the input voltage to the converter is ramped down and the voltage at which the converter turns off is noted. This test, by its nature, can only be done near the minimum voltage, and it is done at both full load and minimum load. Minimum load was arbitrarily chosen as 10% for the tests shown here.

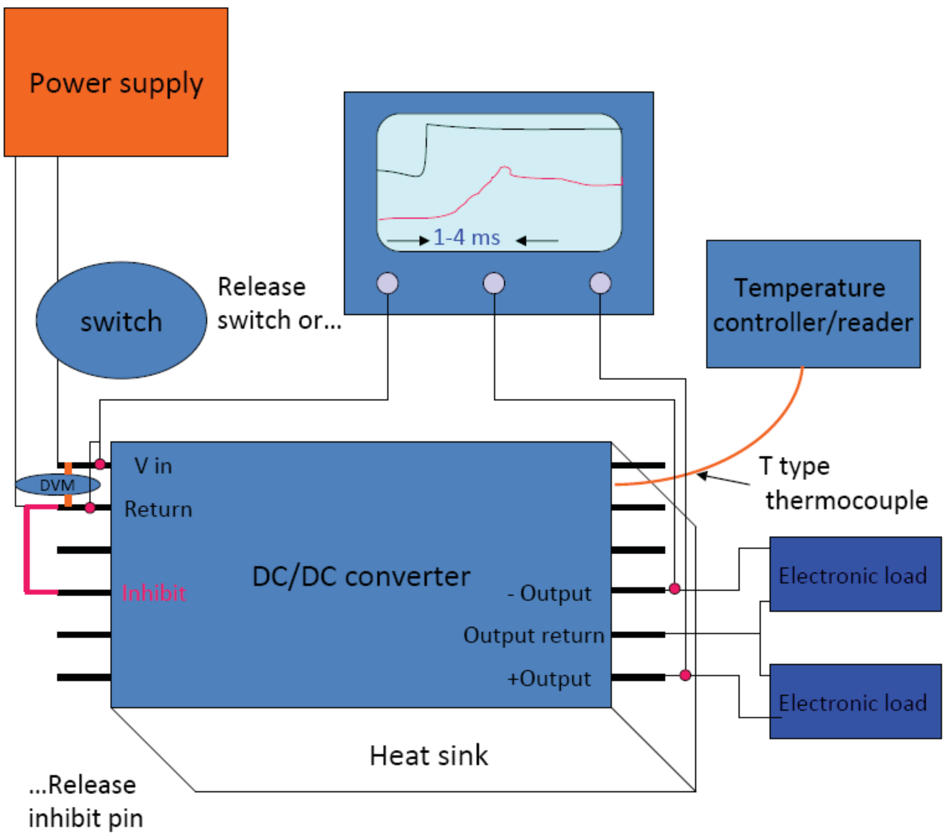


Figure 6. Set-up diagram for turn-on tests.

2.5 Stability Margins

This test was performed on the MFL2815S since it is the only converter in the group tested that has a sense pin.

To perform this test, the converter is connected, as shown in Figure 7. This measurement can be done using a Ridley network analyzer as well as an Agilent network analyzer. In tests performed in FY07, results coincided, except where the converter operated in the discontinuous mode (below 18% load for this converter) and when the input radio frequencies (RF) signal was too large.

The test set-up diagram for measuring gain and phase margins is shown in Figure 7. An RF signal of an appropriate magnitude is sent out of a network analyzer or similar instrument. After an isolation transformer, the signal is connected to either side of a small resistor (about 100 ohms), placed between the sense positive line and the positive output. Signals B and A are monitored on both sides of such a resistor as illustrated in the figure. The magnitude, phase, and frequency of the RF signal from both A and B are monitored and compared. Phase changes and magnitude changes are recorded as a function of frequency. To establish the gain margins, the gain is read at the frequency at which phase margins are zero. To read the phase margins, phase is read at the frequency at which gain is one (or zero if using dB). These are expected to roughly follow design guidelines (at least 10 dB gain and 45-degree phase margins) throughout the range of load percentages and input voltages used and at room temperature as well as temperature extremes (-55°C and 125°C). These tests are planned to be performed on MFL2815S in FY09.

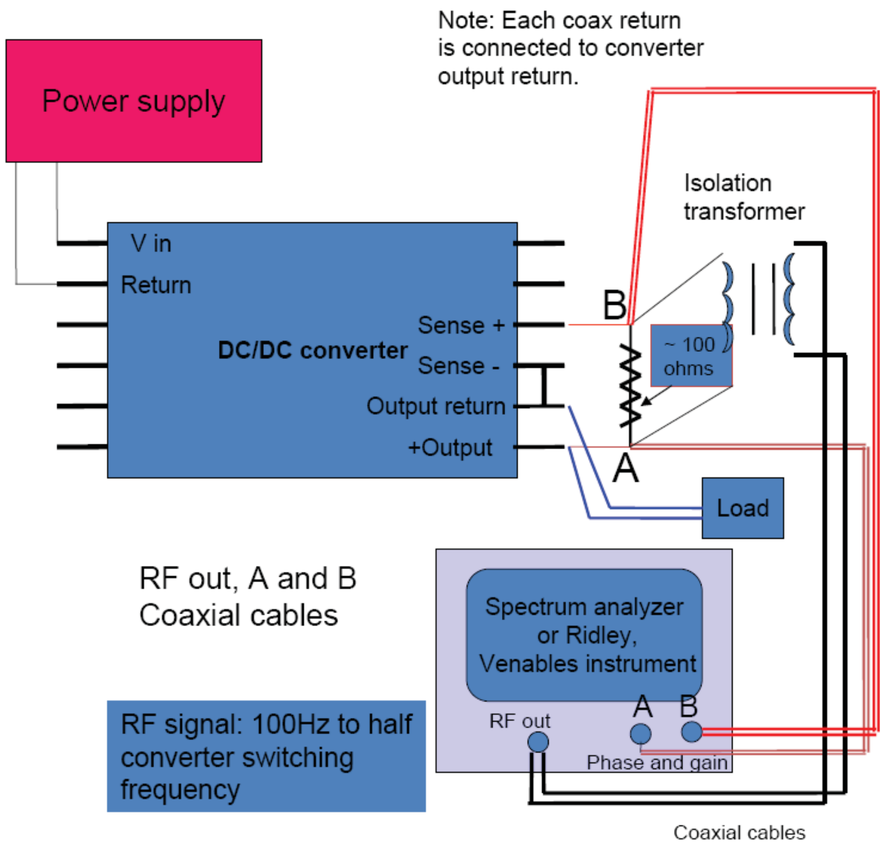


Figure 7. Set-up diagram for stability margins (open loop gain) measurements.

2.6 Power Consumption with Overload Current and Short-Circuit Recovery

This test is illustrated in Figure 8. Overload current consists of setting one output to 50% load and the other output to 200% load. The objective of the test is to confirm that the converter goes into the "overload" trip mode. This happens when the emergency feedback loop detects a set current higher than a predetermined amount (pre-set by the manufacturers). This mode is not zero volts, but a certain set value (1V or so in the AFL). Short-circuit test (or short-circuit power consumption) is done by setting one output to 50% and shorting the other output. This was done using a switch in between the two outputs and recording the traces on a scope.

The short-circuit/overload tests were performed last due to danger of converter failure. These tests were performed for the entire thermal range on the AFL2812D. This converter appeared to survive all these tests, but subsequent testing showed that motorboating occurred no matter which input conditions were used. This malfunction was investigated during the performance of this task, and a failure analysis (described in Section G) was carried out.

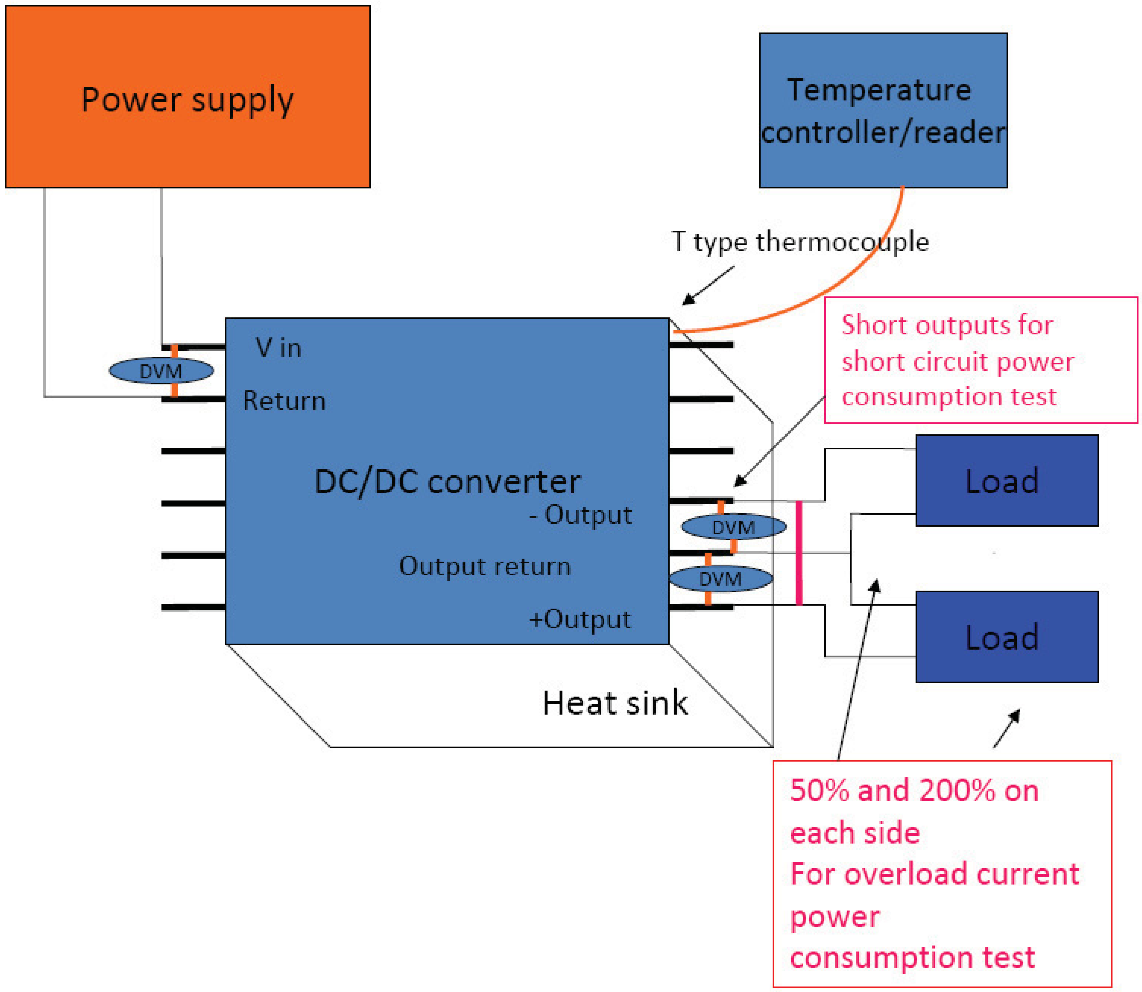


Figure 8. Set-up diagram for short-circuit and current overload tests.

3.0 RESULTS DISCUSSION

Results are discussed mostly for tests performed at room temperature (25°C), although some tests were performed at high temperature (125°C) and at low temperature (-55°C or below).

3.1 Efficiency, Regulation, Cross-Regulation, Regulation with Capacitive Loads, and Power Consumption with Inhibit and No Load

Figure 9 shows the results of testing efficiency (in the manner described previously) for the ASA2812D and the ART2815T converters at room temperature. It can be seen that the efficiency drops dramatically below 20% load for the ART2815T, which maintains a significantly high efficiency above that load, mainly for minimum and nominal input voltages. The rise in efficiency versus load for the ASA2812D is much more gradual and does not reach the high efficiency values that the ART2815T does.

Figure 10 shows room temperature voltage regulation as a function of load for both types of converters at minimum, nominal, and maximum input voltages. A common expression for regulation is: % regulation = 100 * (Vout any load - Vout nominal)/(Vout nominal). However, vendors' datasheets normally give the value in mV, so voltage was plotted here for better comparison across different converters and for easier checks with datasheets.

Figures 11 and 12 show plots of cross-regulation for minimum, nominal, and maximum input voltages for the ASA2812D and ART2815T converters. At room temperature the regulation from the positive output is very steady and almost independent of load and input voltage for the main output (positive 5V) on the ART2815T.

Table 2 shows the values for power consumption under inhibit and under no load for all three values of input voltage at room temperature for the ASA2812D. As shown in the table, the power consumption is lower with inhibit than without any load.

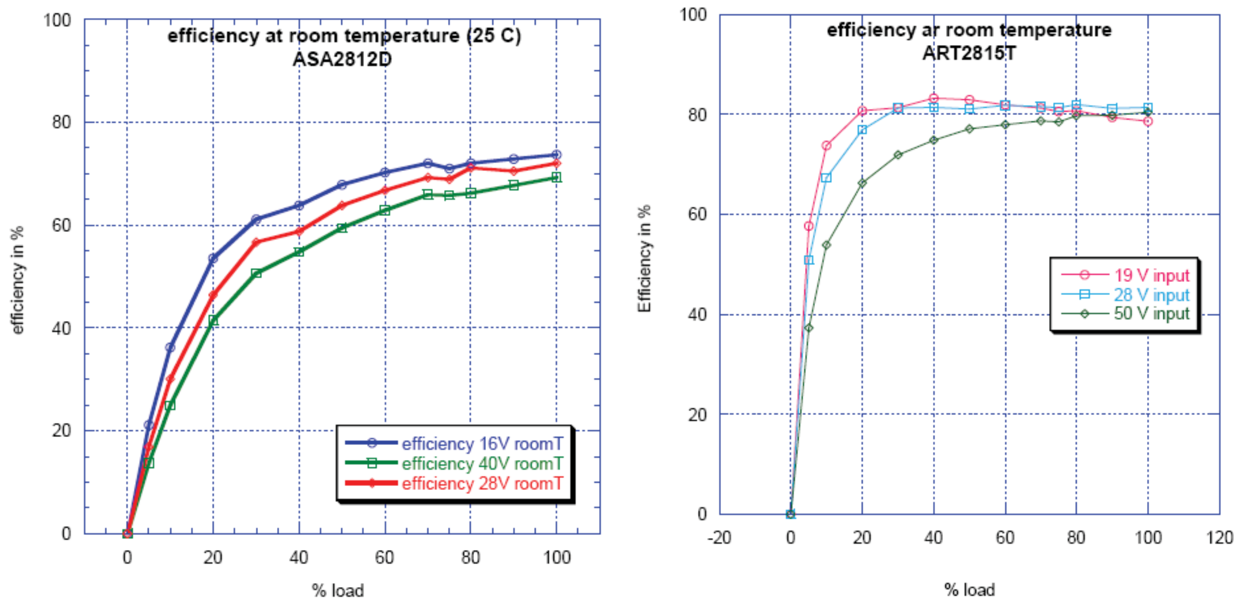


Figure 9. Efficiency as a function of load for the ASA2812D (top); and the ART2815T (bottom). Both converters were tested at minimum, nominal, and maximum input voltages.

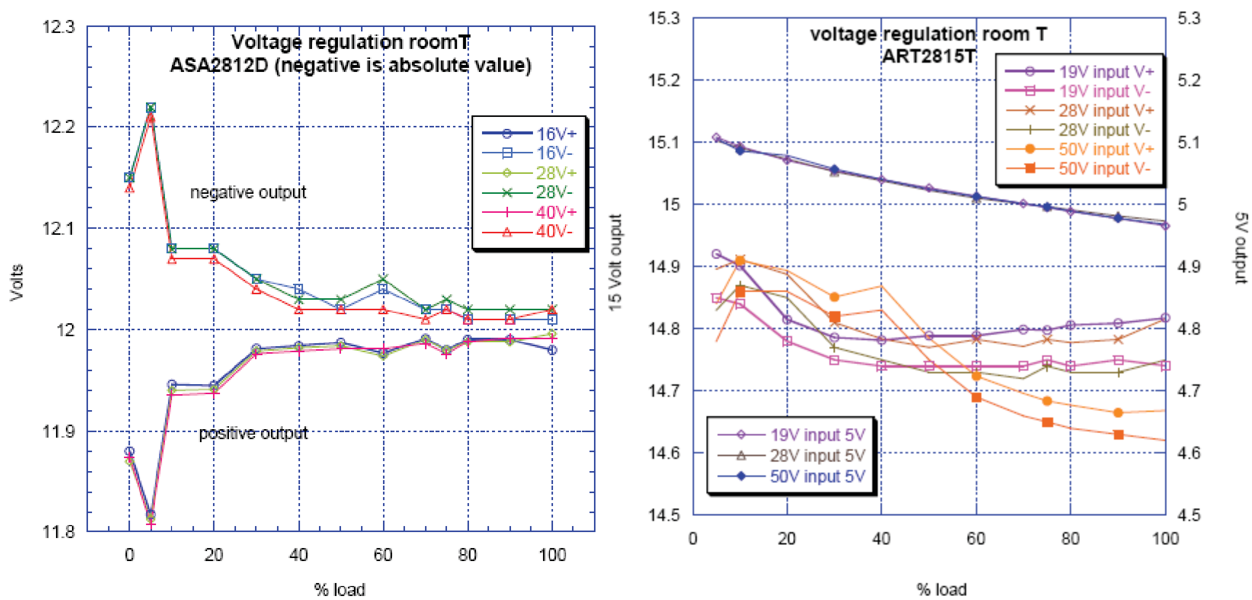


Figure 10. Voltage regulation at room temperature for the ASA2812D and the ART2815T DC/DC converters. Values from negative output are negative 12V; absolute value used here for ease of plotting on same graph. A common expression for regulation: % regulation = 100 (Vout any load - Vout nominal)/(Vout nominal). However, vendor datasheets normally give the value in mV, so voltage was plotted here for better comparison across different converters and for easier checks with datasheets.

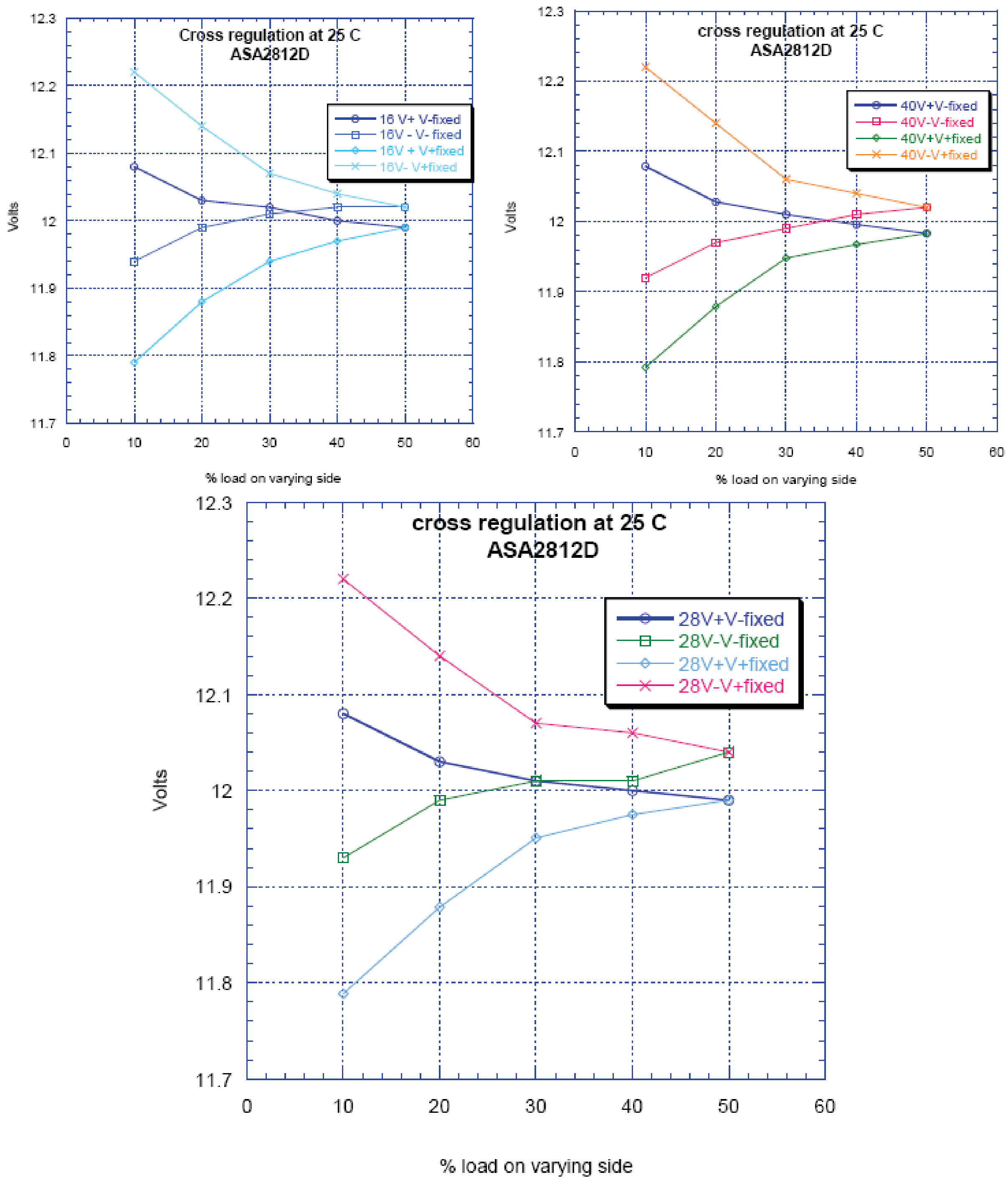


Figure 11. Cross-regulation in voltage values from both outputs (these are negative for the negative output). Raw voltage values allow easier comparisons and are straightforward to interpret (rather than using a cross-regulation formula). Cross-regulation for each separate input voltage is shown.

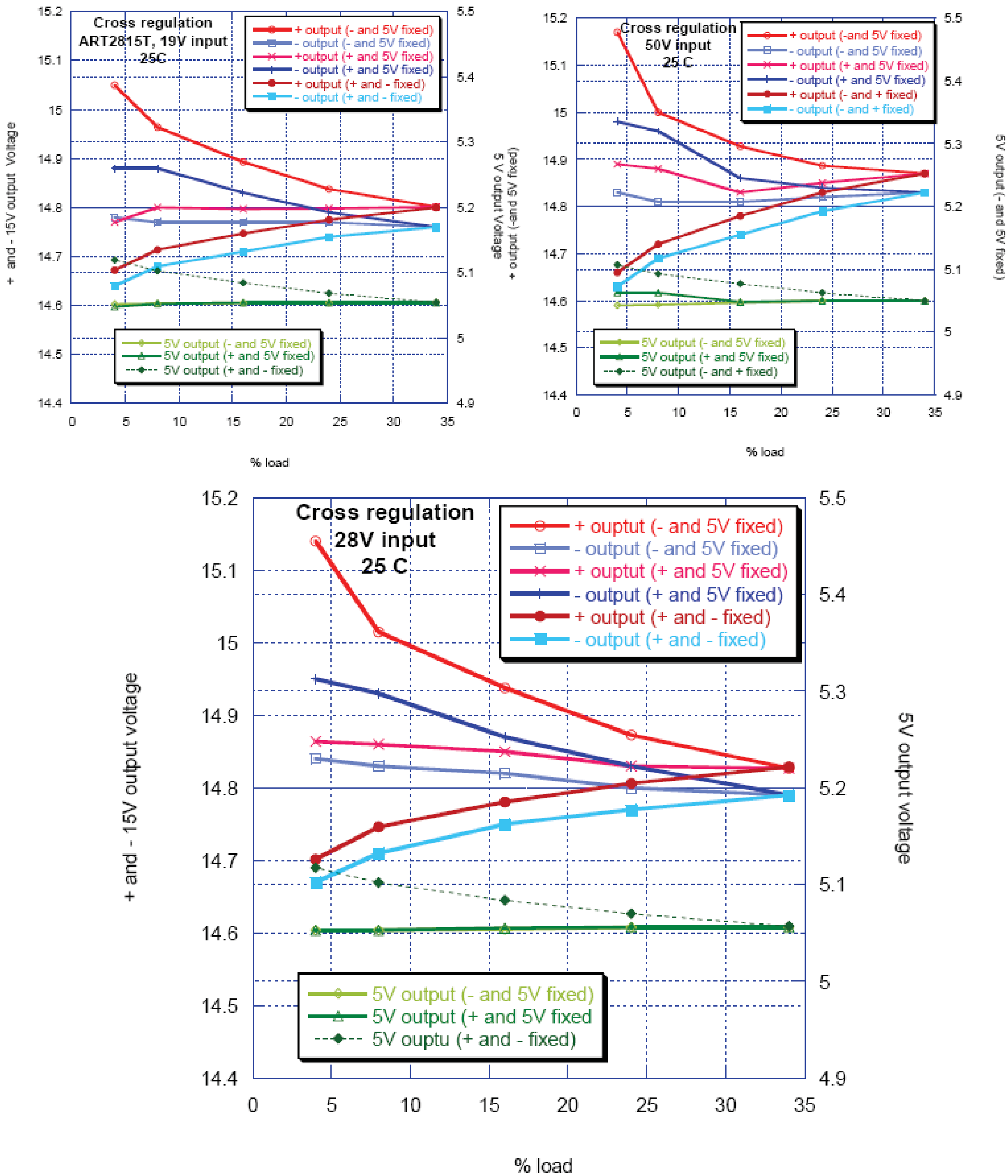


Figure 12. Cross-regulation in voltage values from both outputs (these are negative for the negative output). Raw voltage values allow easier comparisons and are straightforward to interpret (rather than using a cross-regulation formula). Cross-regulation for each separate input voltage is shown.

Table 2. Power consumption with both inhibit and without any load on the converter for the ASA2812D at room temperature.

ASA2812D	Room Temperature (25°C)		Cold (-55°C)		Hot (125°C)	
Input Voltage	Inhibit	No Load	Inhibit	No Load	Inhibit	No Load
16V	0.160	0.928	-	-	-	-
28V	0.336	1.120	-	-	-	-
40V	0.480	1.520	-	-	-	-

3.2 Load Transient Response

In this test, the output (electronic load) was programmed so there is a pulsed load on one of the outputs. This was done for all three values of input voltage, pulsing all outputs, and using standard load pulses and low load pulses. After meeting with manufacturers, further tests were added to this matrix under conditions modified to accommodate the manufacturers' recommendations. There are also issues with load balancing in the performance of this test; however, the vendor's recommendations, datasheets, and user-end test methods are still to be fully reconciled.

Figures 13–21 show the results of load transient response tests done on the ART2815T DC/DC converter at the three different values of input voltages when one output is allowed to pulse and the other two outputs are kept constant at a fixed load of 33%.

The datasheet for this converter states a maximum voltage overshoot of 0.2V (200mV) and a maximum recovery time of 0.2 ms (.002 sec). It can be seen in most of the plots shown in Figures 13–21 that, although both voltage overshoot values and recovery times are larger and longer when the small load steps were used (bottom graph in Figures 13–21), they do not exceed specifications in the datasheet. Testing conditions that result in longer recovery times (longer then the specified 0.2 ms) are seen in these plots. Recovery time is compromised at all three input values when the positive 15V output is pulsed from 2% to 33%. However, even though this converter does not quite meet performance specifications under these conditions, it continues to operate normally and does not go into an abnormal large output voltage oscillation mode as seen with the AFL2812D (shown in Figure 22).

Potential issues and anomalies seen in these converters were shared and discussed with the manufacturer. According to design engineers at IR it is necessary to have both loads balanced at all times so, while there is balance at 25% and 50%, loads are unbalanced for half the duty cycle (2.5% to 50%). Feedback loops in the converter also have a delay in adjusting the output when the loads are very small and when the converter operates on discontinuous mode. Another recommendation was to keep the non-pulsed load passive. High-voltage-rated precision resistors were used in lieu of the electronic loads to obtain the plots shown in Figure 22.

Figure 22 shows results from load transient response tests using the manufacturer-provided fixture on their older converter D model (date code 95) and JPL devices (flight residuals with date code 03). JPL has three units for the AFL2812D, and all perform as shown on the right at 40V. Two of the units showed the anomalies at the nominal voltage (28V). As seen in Figure 22, the top graph shows the behavior under the same pulsed load is acceptable (some longer than desired ringing, but the oscillations dampen to nothing). On the lower graph, however, large output oscillations are seen for half the duty cycle. The models are supposed to be the same; however, it seems there must have been some changes in the design since these different date code models behave so differently under the exact same conditions.

Serious potential issues in the performance and space use of these DC/DC converters are apparent from these latter plots (Figure 22). While the behavior from pulsed loads ranging from 25% to 50% is as expected, load transient response to low loads shows several anomalies. The prolonged ringing (damped oscillator) seen under many conditions show voltage overload and underload for tens of milliseconds. More serious than the prolonged (but dampened) oscillatory behavior are the instances of motorboating. At times these large output voltage oscillations are seen for half the duty cycle (and sometimes even longer). Tests were done for passive loads set at 25% and for passive loads set at 10% since flight applications of DC/DC converters do not always allow 20:80 load balancing and it is useful to know the consequences of not following this practice. If load unbalancing with low load transients will be part of the converter operation during flight, then this information can be used for risk mitigation, or a different converter might be chosen.

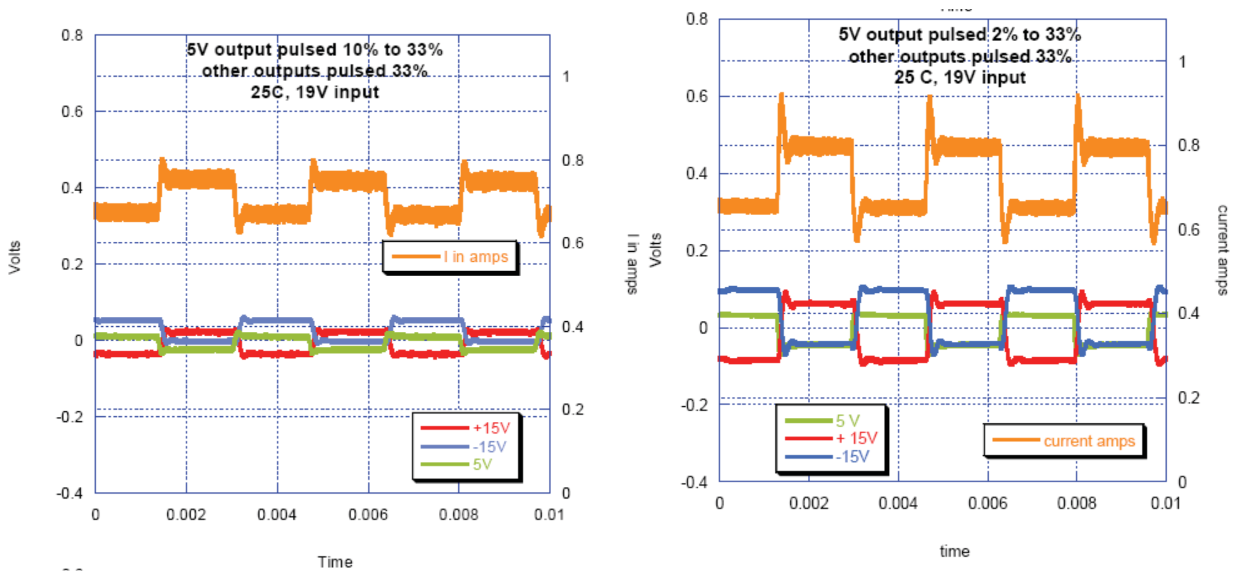


Figure 13. Load transient response tests done on the ART2815T for 19V input when the positive and negative 15V outputs are kept at 33% load (not pulsed) and the (main) 5V output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load. The output current was also monitored, shown plotted against the second y axis.

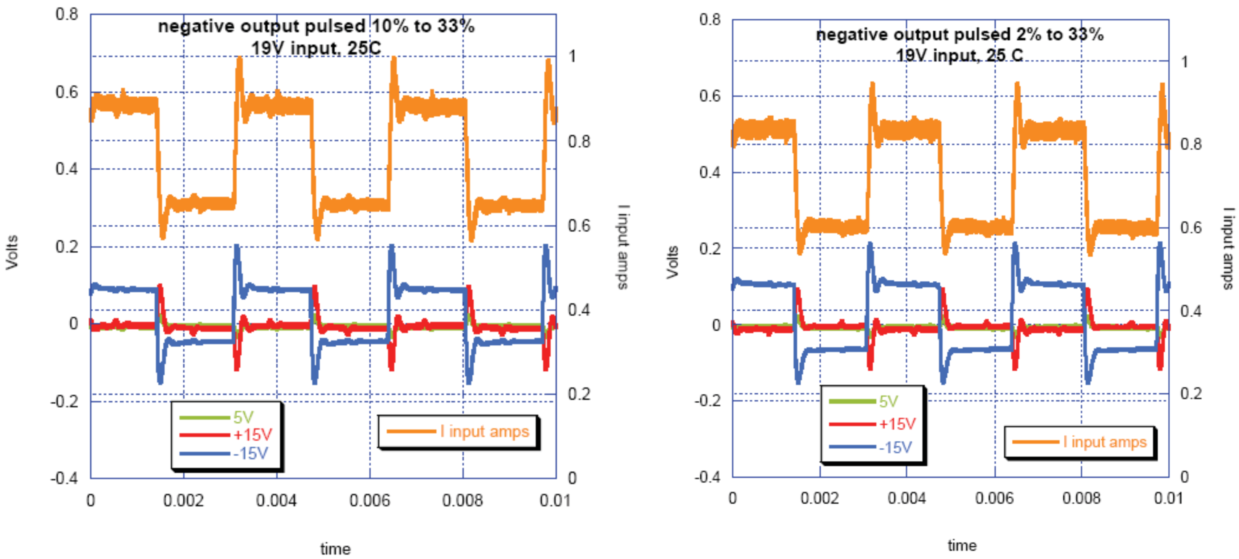


Figure 14. Load transient response tests done on the ART2815T for 19V input when the positive 5V and 15V outputs are kept at 33% load (not pulsed) and the negative output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

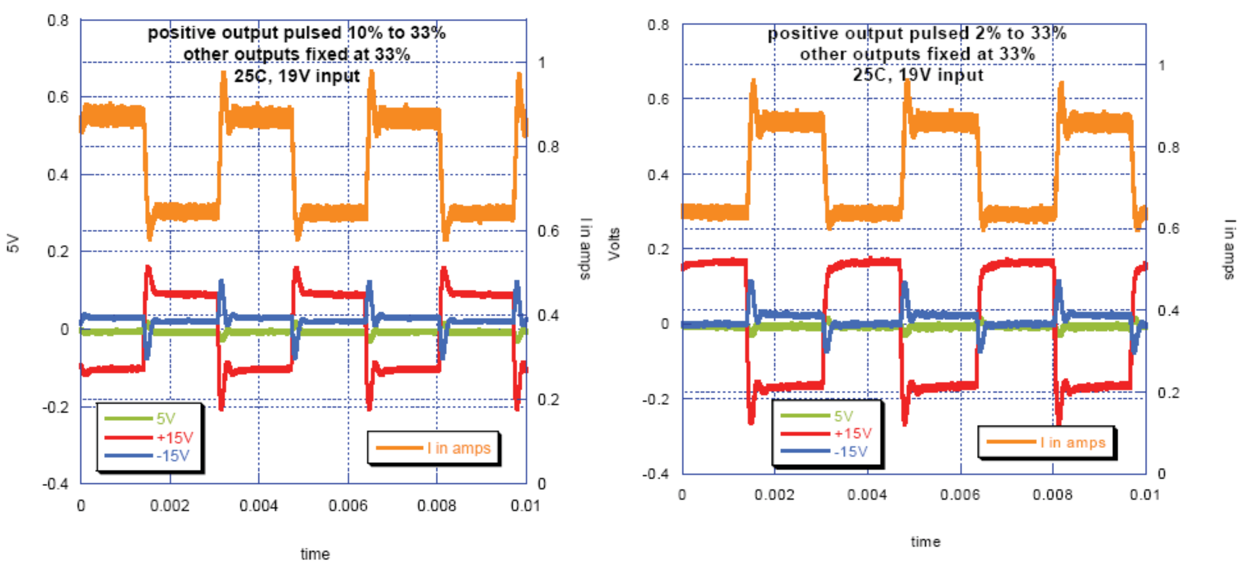


Figure 15. Load transient response tests done on the ART2815T for 19V input when the positive 15V output is pulsed and the other outputs are kept at 33% load (not pulsed). Shows results when pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

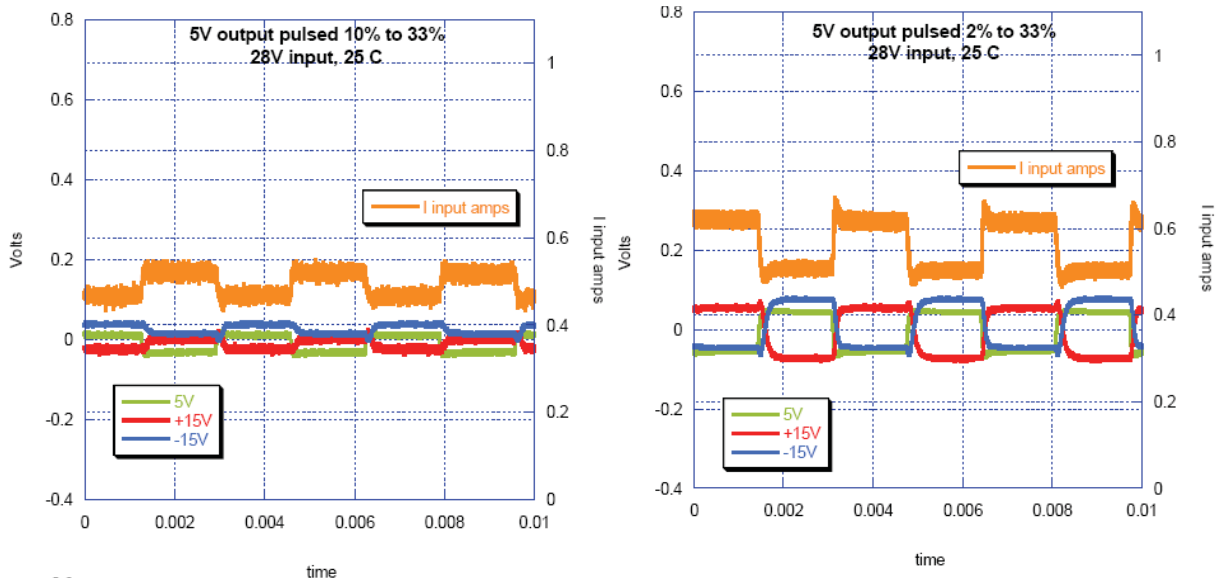


Figure 16. Load transient response tests done on the ART2815T for 28V input when the positive and negative 15V outputs are kept at 33% load (not pulsed) and the main 5V output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

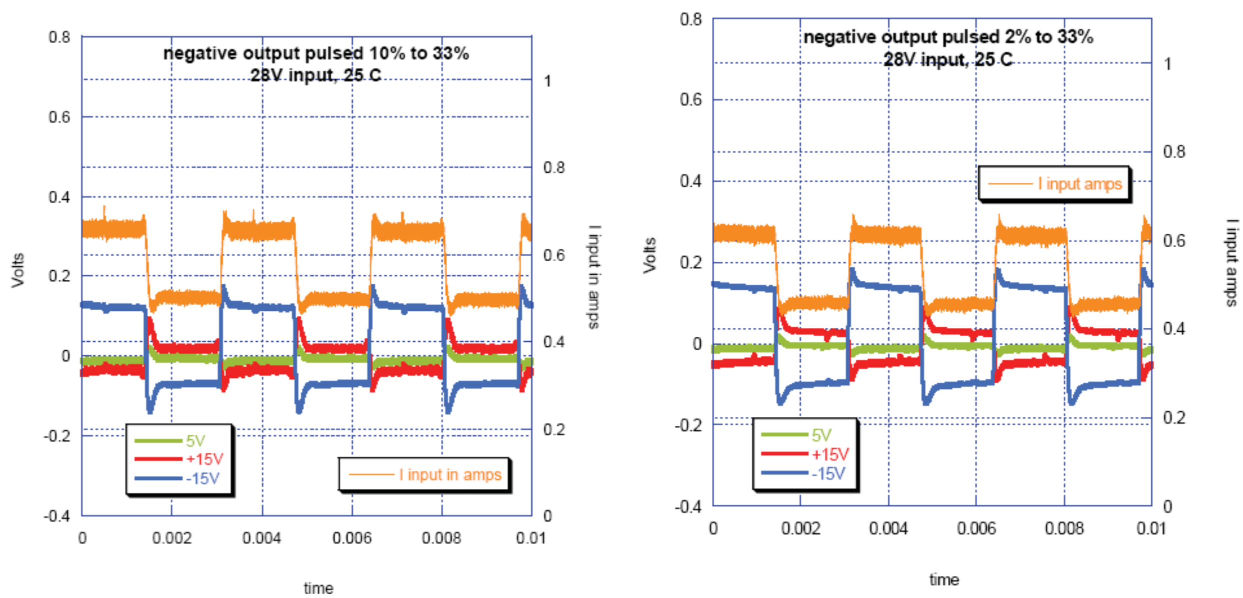


Figure 17. Load transient response tests done on the ART2815T for 28V input when the positive outputs are kept at 33% load (not pulsed) and the negative 15V output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

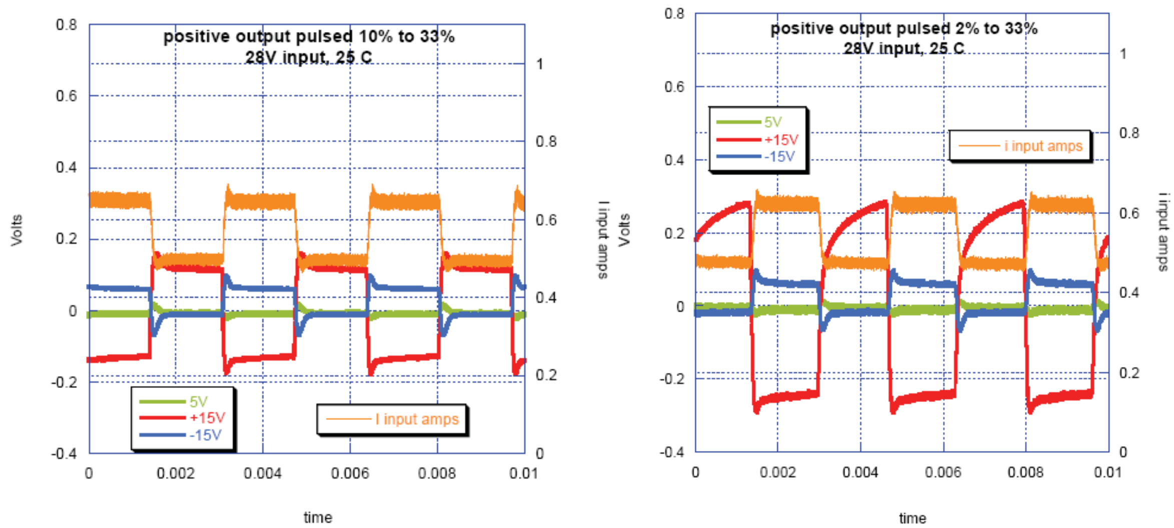


Figure 18. Load transient response tests done on the ART2815T for 19V input when the positive 5V and negative 15V outputs are kept at 33% load (not pulsed) and the positive 15V output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

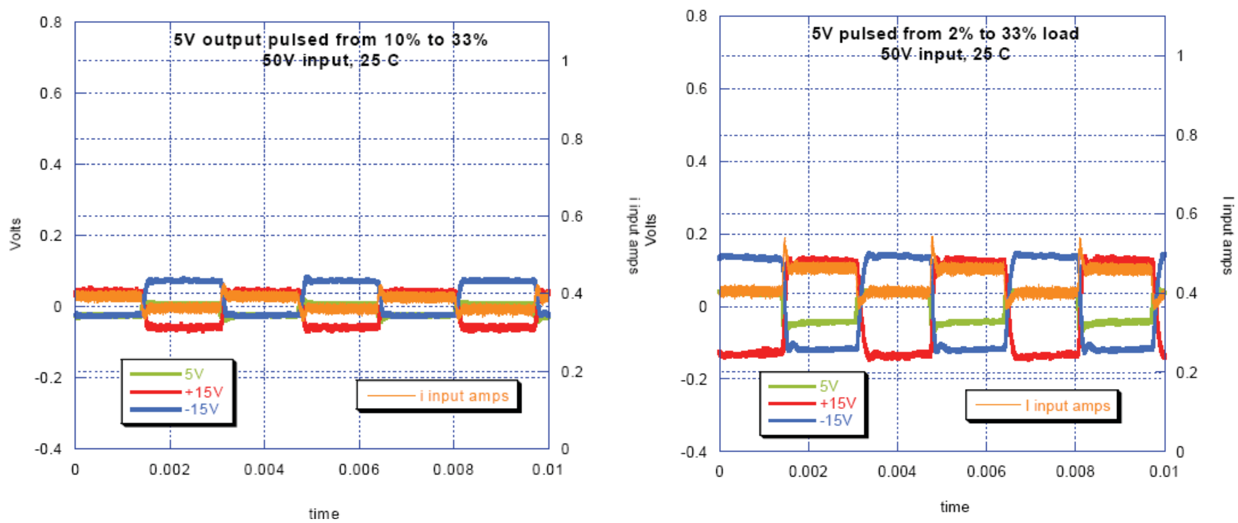


Figure 19. Load transient response tests done on the ART2815T for 50V input when the positive and negative 15V outputs are kept at 33% load (not pulsed) and the (main) 5V output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

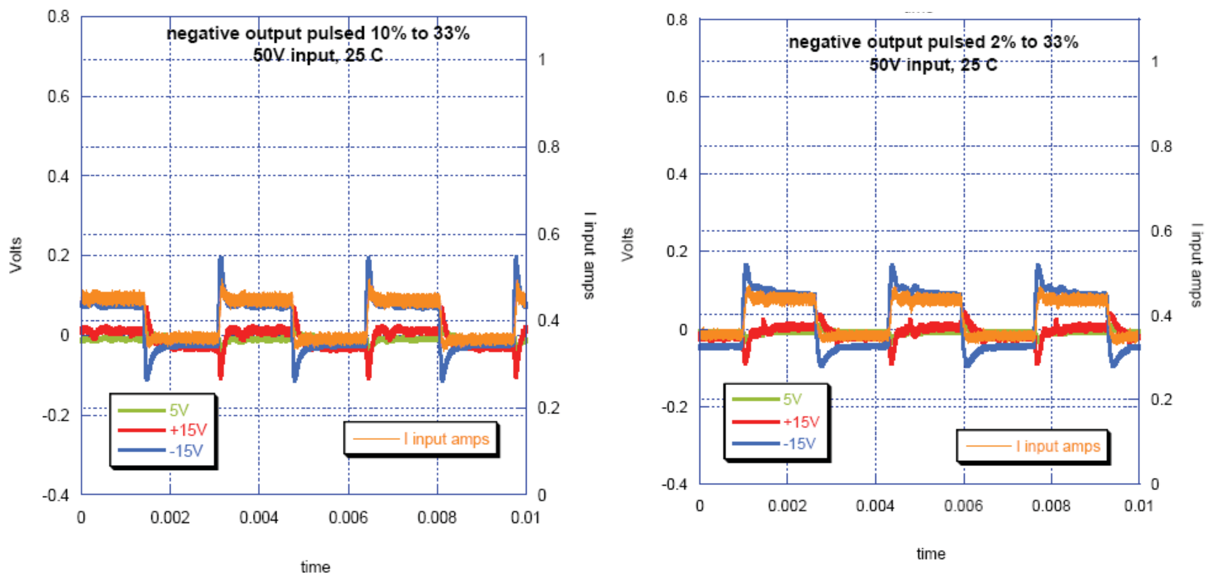


Figure 20. Load transient response tests done on the ART2815T for 50V input when the positive outputs are kept at 33% load (not pulsed) and the negative 15V output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

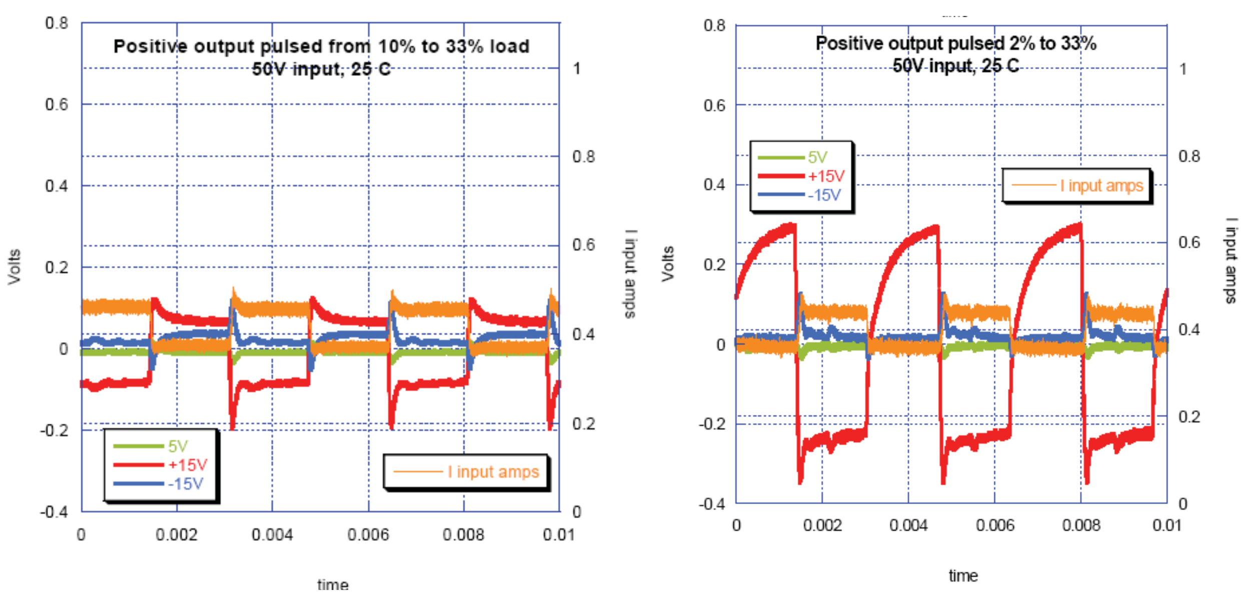


Figure 21. Load transient response tests done on the ART2815T for 19V input when the positive and negative 15V outputs are kept at 33% load (not pulsed) and the (main) 5V output is pulsed from 10% to 33% (top) and from a very low load (bottom) from 2% to 33% load.

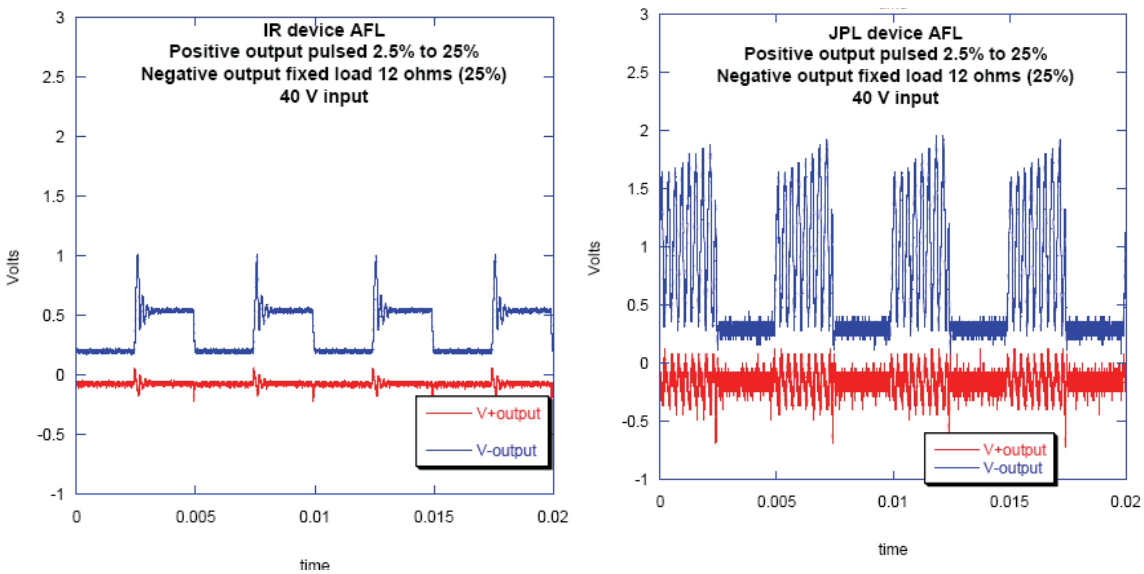


Figure 22. Results from same test using the manufacturer-provided fixture on their older converter AFL2812D model (date code 95) and JPL devices (flight residuals with date code 03). JPL has three units, and all perform at 40V (as shown on the bottom graph). Two of the units showed the anomalies at the nominal voltage (28V).

3.3 Synchronization

Synchronization was evaluated at room temperature (25°C) and low temperature (-55°C) for the ART2815T DC/DC converter. The datasheet for this converter states frequency ranges from 225 KHz to 310 KHz and maximum and minimum pulse heights of 10V and 5V, respectively.

The test matrix that was followed includes checking synchronization at 10%, 50%, and 100% loads; all three input voltages (19V, 28V, and 50V); at minimum and maximum pulse amplitudes; at minimum and maximum frequencies per the datasheet; and 10% below minimum (202 KHz) and 10% above maximum (341 KHz). A total of four plots were taken: at minimum and maximum frequencies, minimum and maximum pulse amplitudes, at the nominal input voltage (28V), and at full load. Additionally, the same four plots were taken using the EMI filter recommended for this converter (the ARF461). Plots other than the four described were taken only when anomalies were observed.

Figures 23–26 show these plots at room temperature and nominal input voltage under the conditions described previously. The figures show the synchronization test performed without (top) and with (bottom) the EMI filter. The same types of plots are shown in Figures 40–43, taken at low temperature (-55°C).

Synchronization was also checked under all the conditions stated; they are not shown if they did not show any anomaly. The plots shown in Figures 27–31 show that under some conditions the converter failed to synchronize and the use of the EMI filter did not correct this problem. Namely, when attempting to synchronize at 10% below the minimum recommended frequency, synchronization failed for some combinations of input voltages, loads, and pulse heights.

Figures 32–39 show another case where synchronization showed some anomalies. The top plots of the figures where traces were taken without using the EMI filter show that synchronization does happen, but larger scale oscillations are also present. These can be seen when the time scale is expanded. In this case, the EMI filters remedied the situation for some of the input voltage/pulse height/load combinations but not for others (see Figures 36–39).

Figures 44–57 show that under low temperature operation (-55°C), synchronization behaves similarly to that at room temperature. Synchronization fails for some conditions when the frequency is dropped to 10% below the specified minimum, and this problem was not mitigated by the use of the EMI filter. Similar to in-room temperature testing, at 50V input voltage for some conditions and 10% above the maximum frequency, the EMI filters are effective at correcting the longer time scale output voltage oscillations.

While it was observed that there are anomalies with synchronization in these tests, it should be mentioned that the specification sheet does not recommend operation below or above the specified minimum and maximum synchronization frequencies. Therefore, the fact that some problems arise when effectively operating the converter against manufacturers' recommendations does not rule out use of this converter. These tests are performed only because synchronization frequencies below and above the manufacturers' recommendations have been encountered in past flight applications or during tests performed for space qualification of these converters. In the case of the ART2815T, failure to synchronize does not result in large enough voltage oscillations or any other anomalies that would compromise the integrity of the converter even when using below or above the specified frequency range. These problems have been encountered in the testing of other space DC/DC converters [3].

The synchronization was also tested at temperatures below -55°C for the ART2815T. One of the tests was performed to determine if synchronization will still work at 10% below the minimum specified frequency. In this case the minimum was 225 KHz, so it was lowered to 202 KHz (10% less). One of the anomalies observed was that, for low pulses (4.5V), there was no synchronization at such low frequency. The lowest frequency that will still synch appeared to be dependent on temperature, so this (loss of synch) frequency was measured. A test was performed without the EMI filter to determine any shift in minimum synchronization frequency. Prior tests indicated that the filter does not affect this converter response in this application (lack of synch below 225 KHz). The dependence of minimum synchronization frequency versus temperature are plotted in Figure 58.

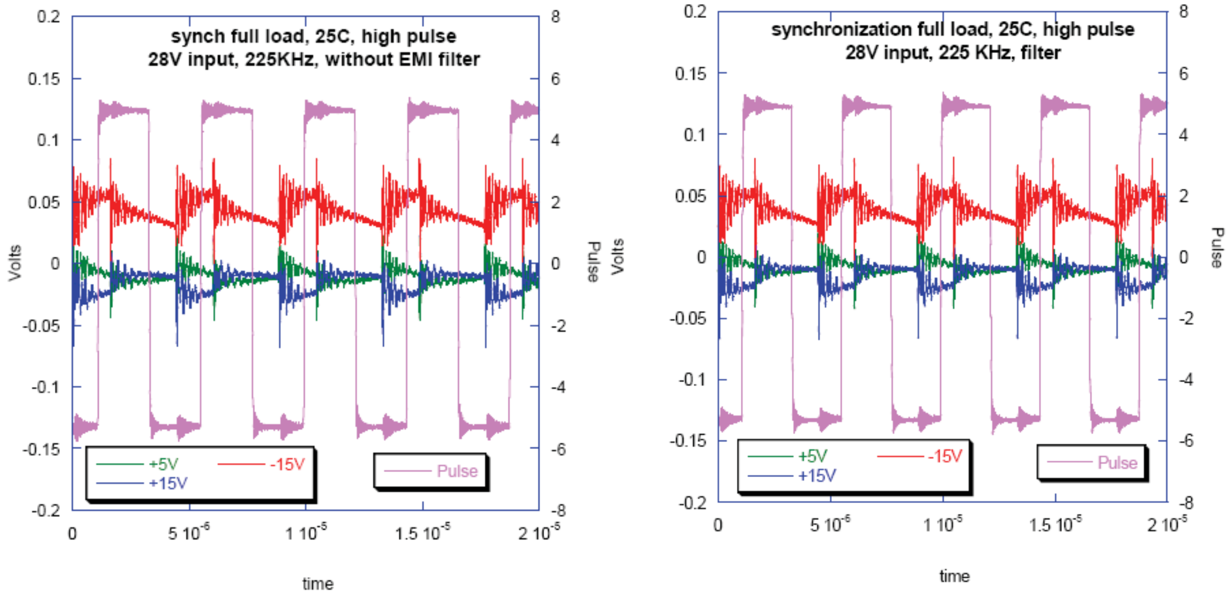


Figure 23. Plots for 28V input synchronization for the ART2815T DC/DC converter at room temperature with high pulse levels and at minimum recommended frequency (225 KHz). The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

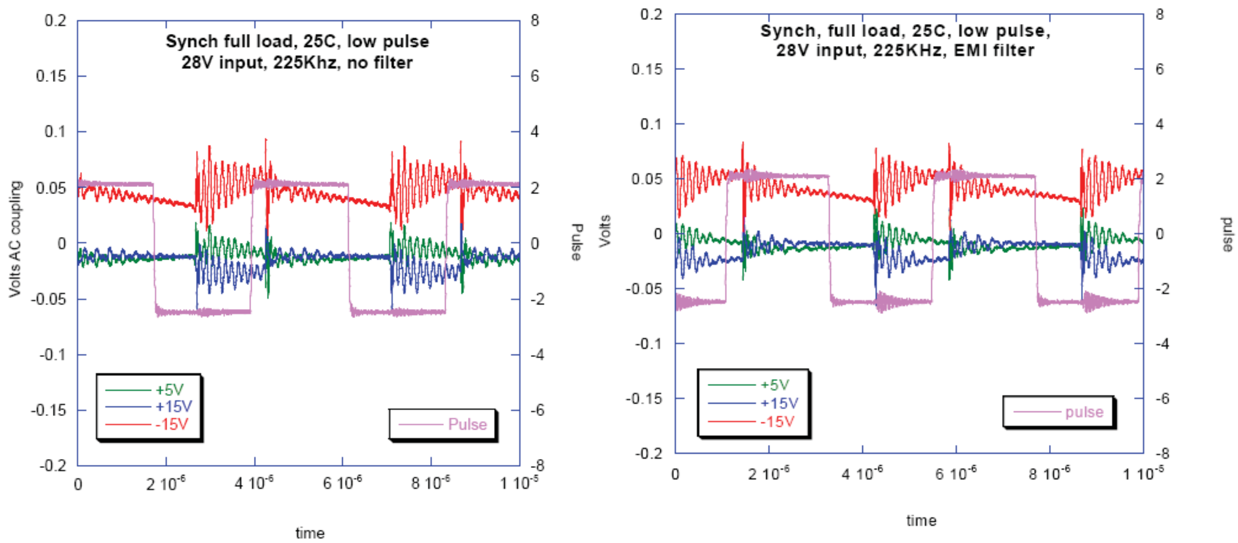


Figure 24. Plots for 28V input synchronization at room temperature with low pulse levels and at minimum recommended frequency (225 KHz). The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

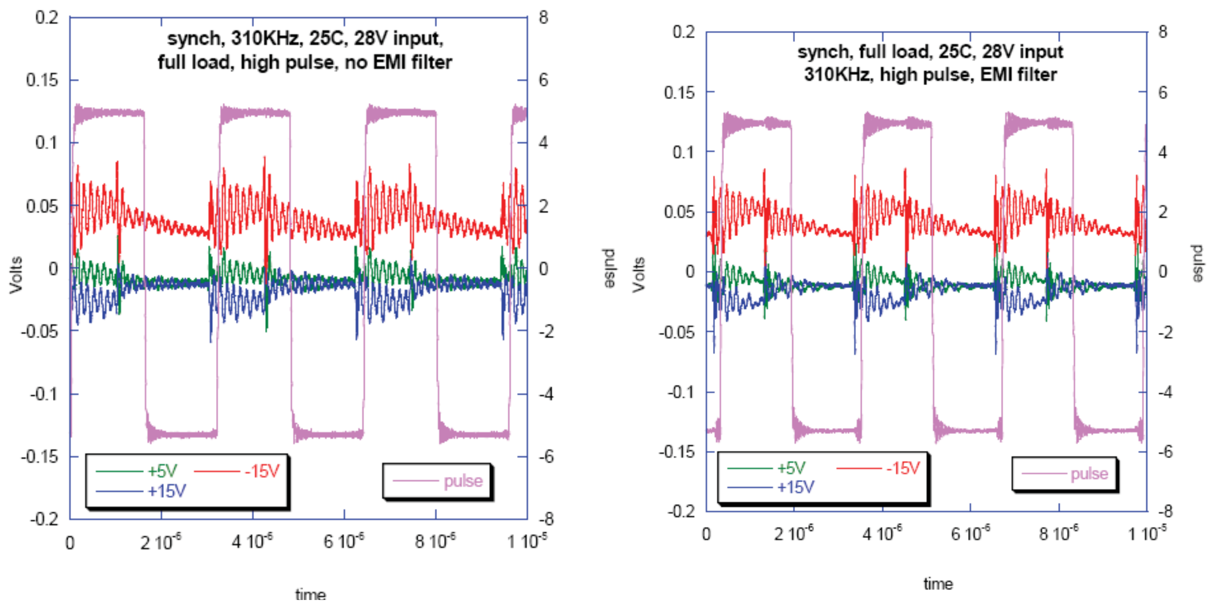


Figure 25. Plots for 28V input synchronization at room temperature with high pulse levels and at maximum recommended frequency (310 KHz). The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

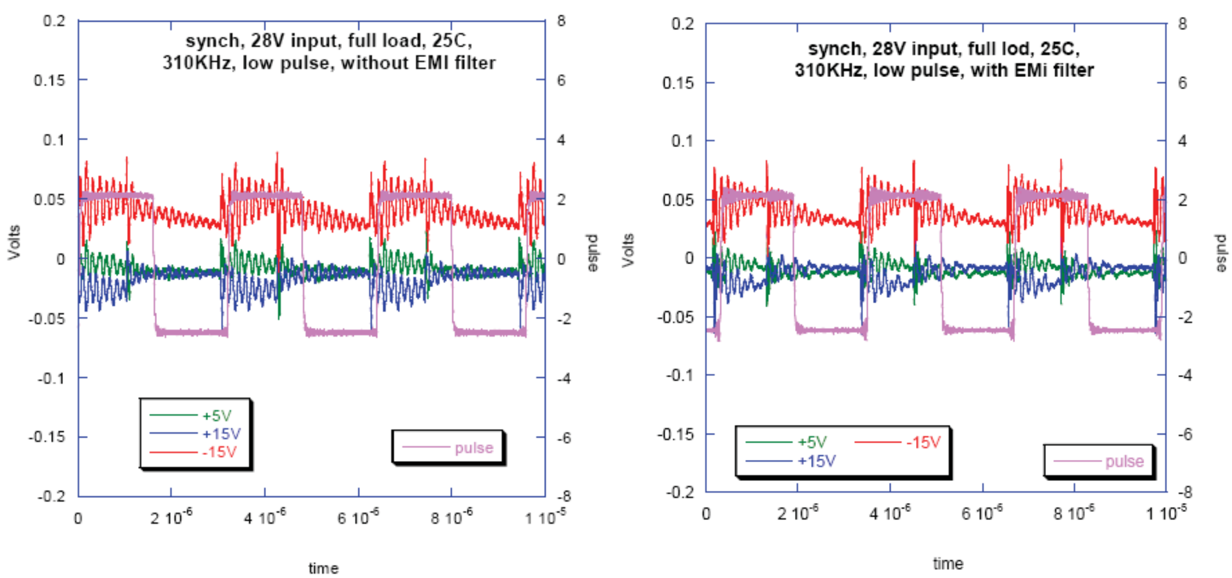


Figure 26. Plots for 28V input synchronization at low pulse levels and at maximum recommended frequency (310 KHz). The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

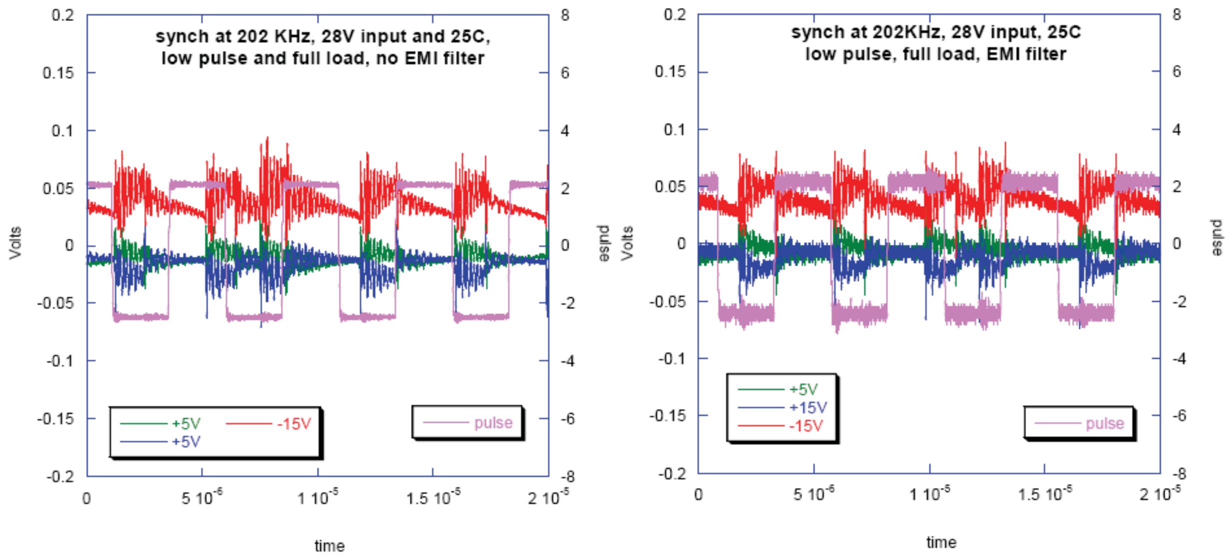


Figure 27. Plots for 28V input synchronization at low pulse levels and at 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization.

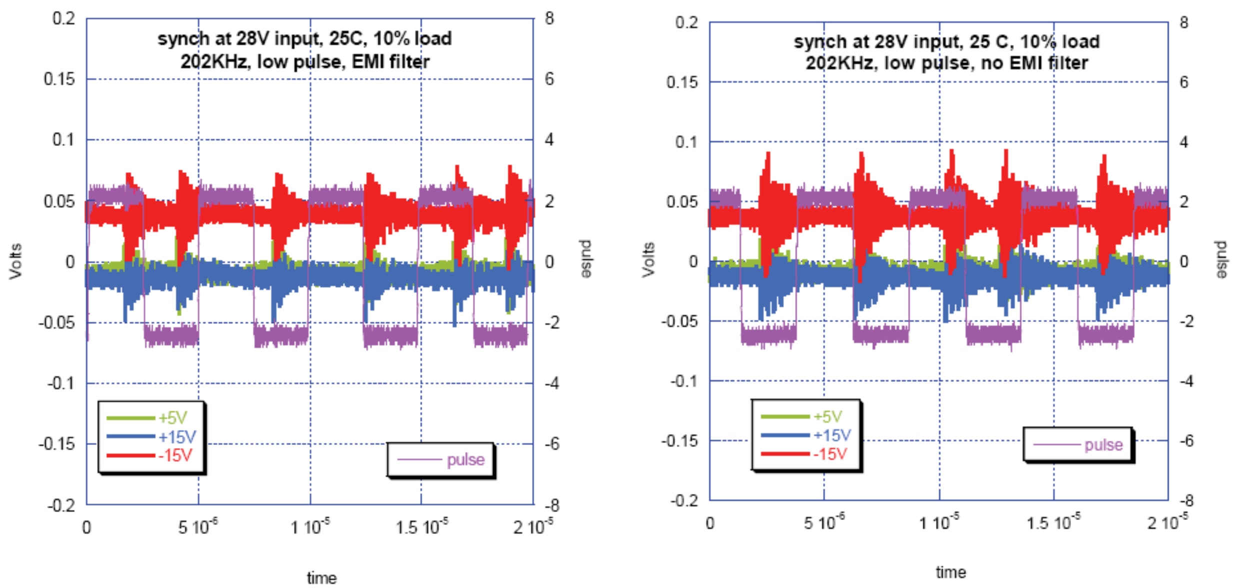


Figure 28. Plots for 28V input synchronization at low pulse levels, 10% load, and at 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the plot below shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization.

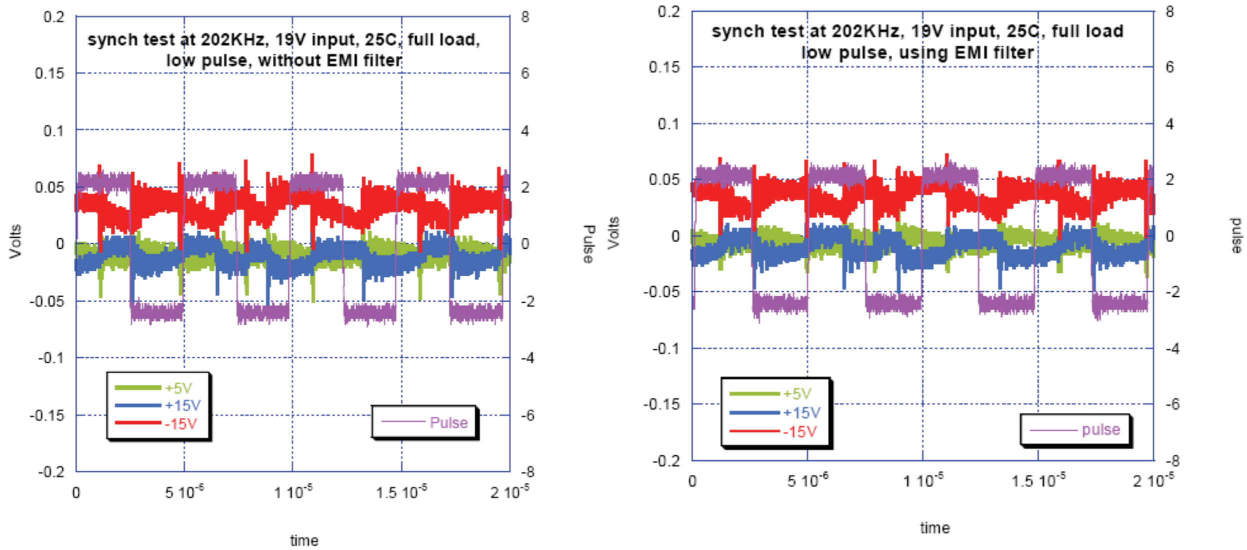


Figure 29. Plots for 19V input, full load synchronization at low pulse levels and at 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization.

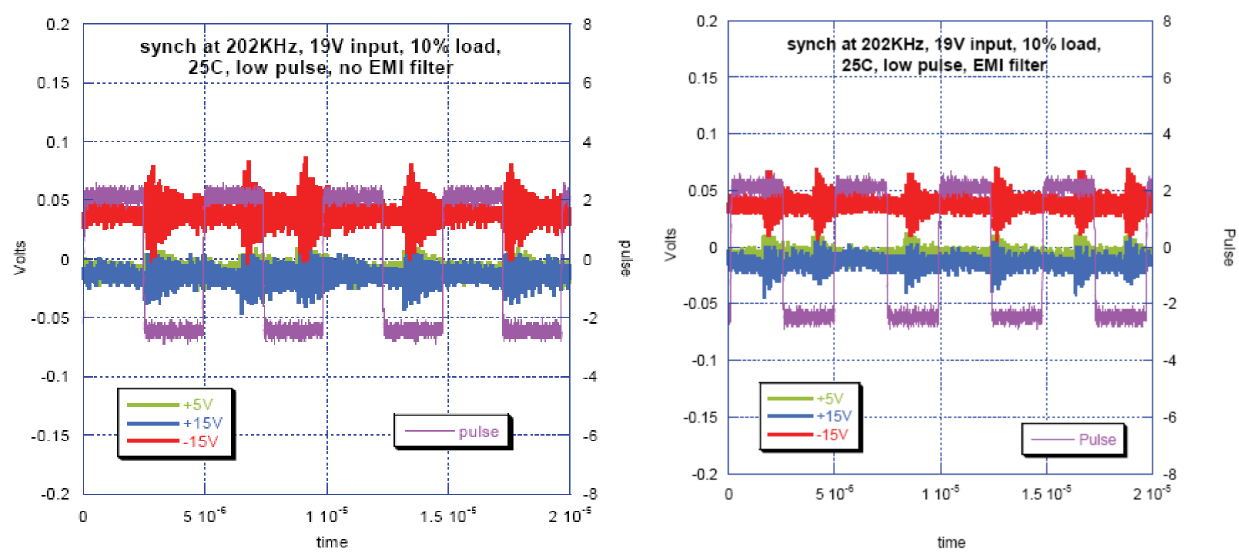


Figure 30. Plots for 19V input synchronization at low pulse levels, 10% load, and at 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization.

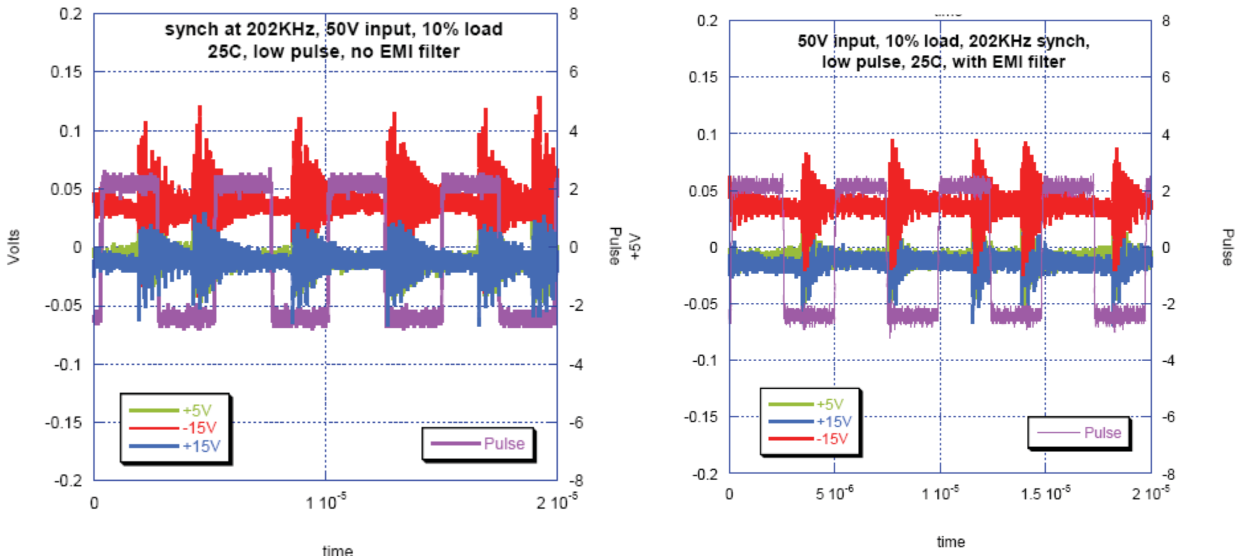


Figure 31. Plots for 50V input synchronization at low pulse levels, 10% load, and at 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the plot below shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization.

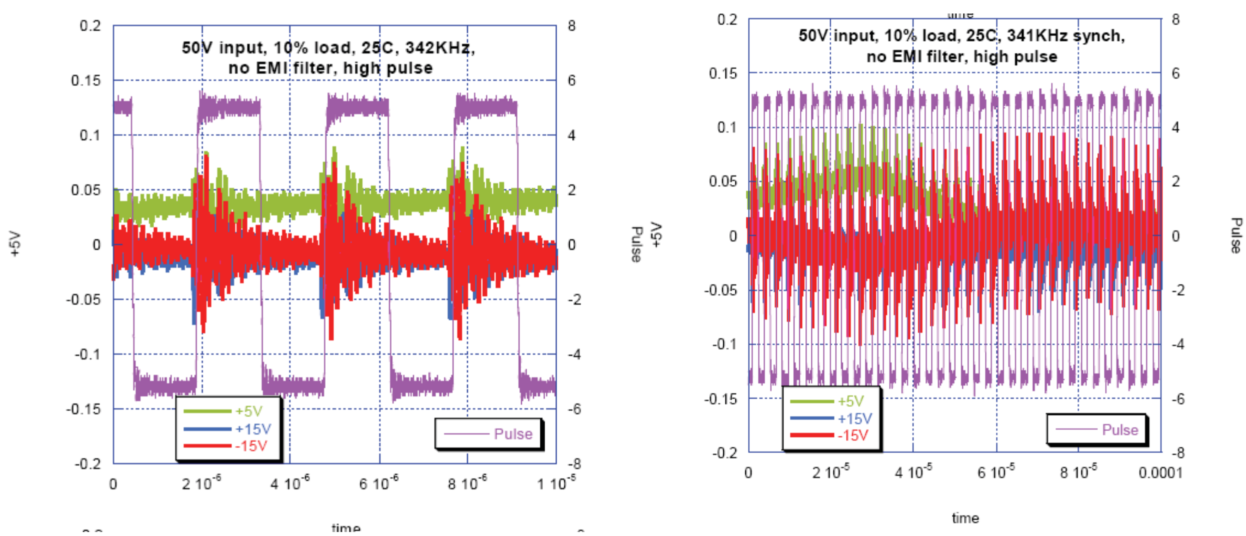


Figure 32. Room temperature synchronization test for 50V input, high pulse heights, 10% over maximum frequency without the EMI filter. The converter synchronizes but also adds a larger scale oscillation that is not obvious unless the scope trace is taken on a longer time scale. The top graph shows conditions which seem fine, but the bottom shows that the oscillations are significant in magnitude when seen on a longer time scale.

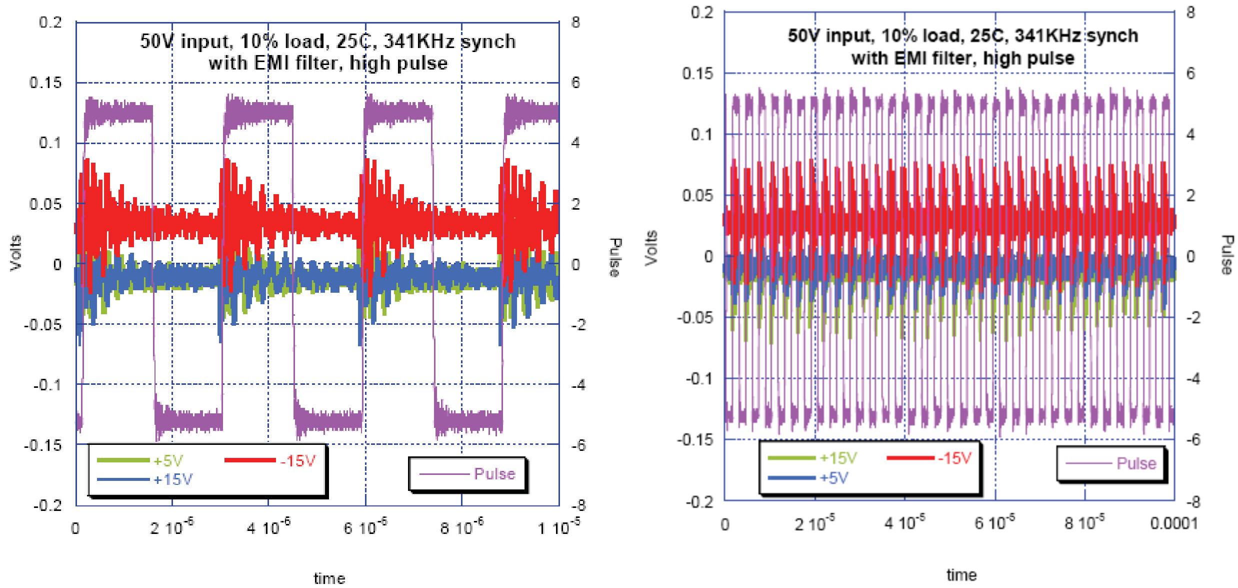


Figure 33. Room temperature synchronization test for 50V input, high pulse heights, 10% load, and 10% over maximum frequency taken with EMI filter. The converter synchronizes and observing it at the longer time scale indicates that the filter is effective to correct the longer time scale oscillations seen in the previous graphs (see Figure 32).

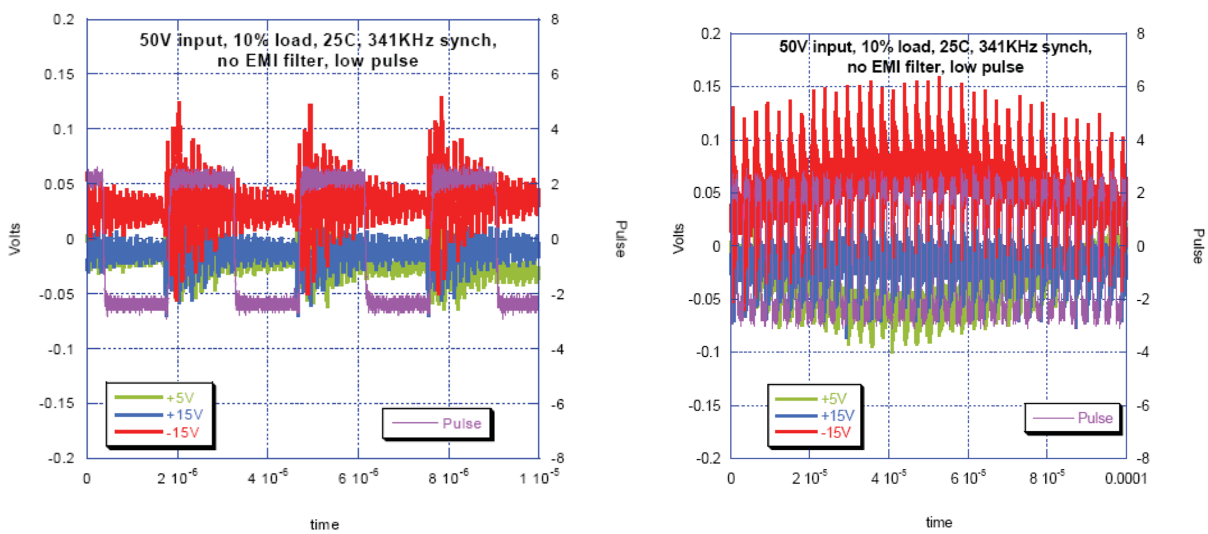


Figure 34. Room temperature synchronization test for 50V input, low pulse heights, 341 KHz (10% above maximum frequency), and 10% load. The converter synchronizes but also adds a larger scale oscillation that is not obvious unless the scope trace is taken on a longer time scale, seen on the bottom graph.

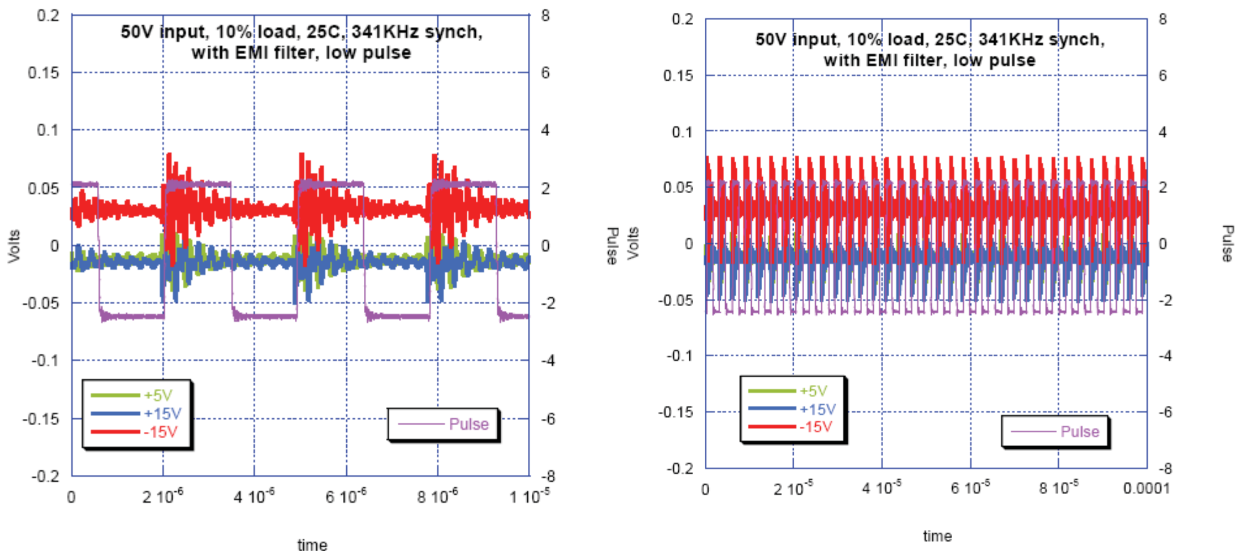


Figure 35. Room temperature synchronization test for 50V input, low pulse heights, 10% load, and 10% over maximum frequency taken with the EMI filter. The converter synchronizes, and observing it at the longer time scale indicates that the filter is effective to correct the longer time scale oscillations that are seen in the previous graphs (see Figure 34).

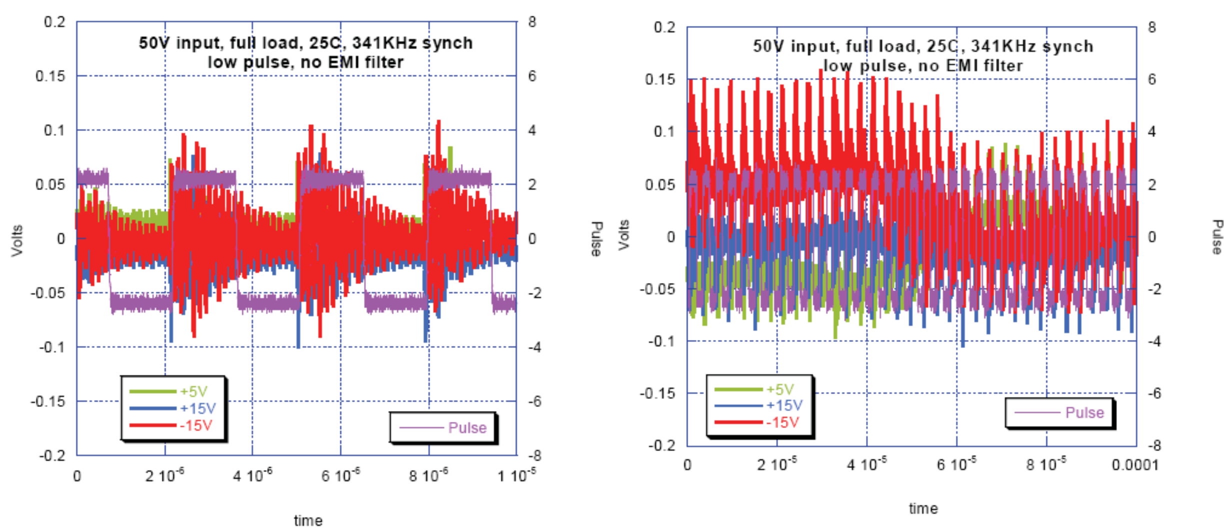


Figure 36. Room temperature synchronization test for 50V input, full load, and high pulse heights at 341 KHz (10% above maximum frequency) and full load. The converter synchronizes but also adds a larger scale oscillation that is not obvious unless the scope trace is taken on a longer time scale.

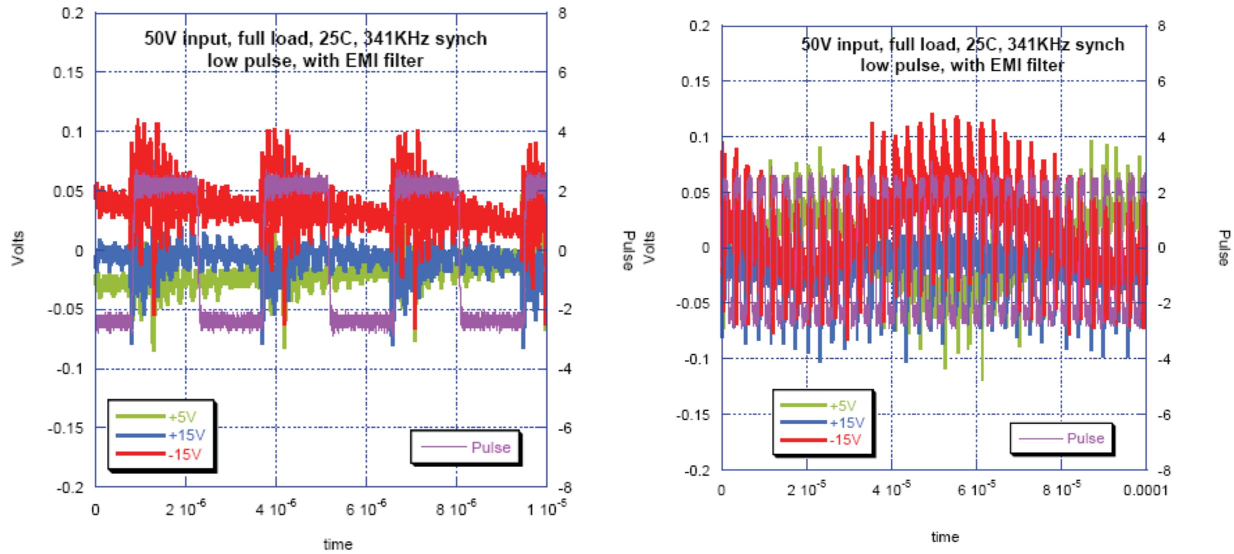


Figure 37. Room temperature synchronization test for 50V input, low pulse heights, full load, and 10% over maximum frequency taken with the EMI filter. The converter synchronizes; however, observing it at the longer time scale indicates that the filter is ineffective to correct the longer time scale oscillations seen in the previous graphs (see Figure 36).

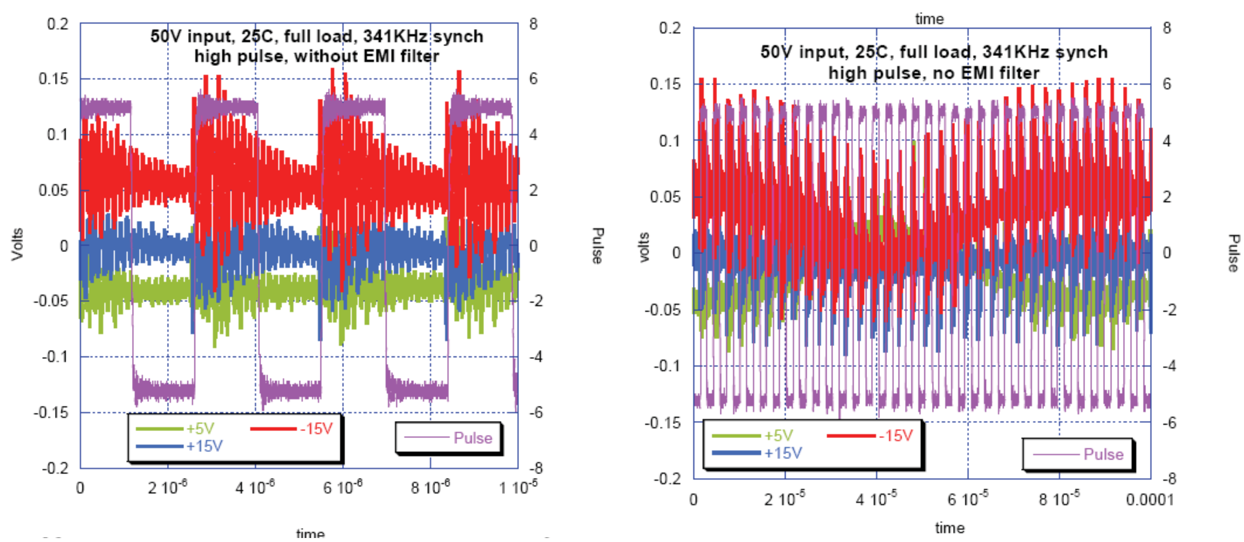


Figure 38. Room temperature synchronization test for 50V input, high pulse heights, 341 KHz (10% above maximum frequency), and full load. The converter synchronizes but also adds a larger scale oscillation that is not obvious unless the scope trace is taken on a longer time scale.

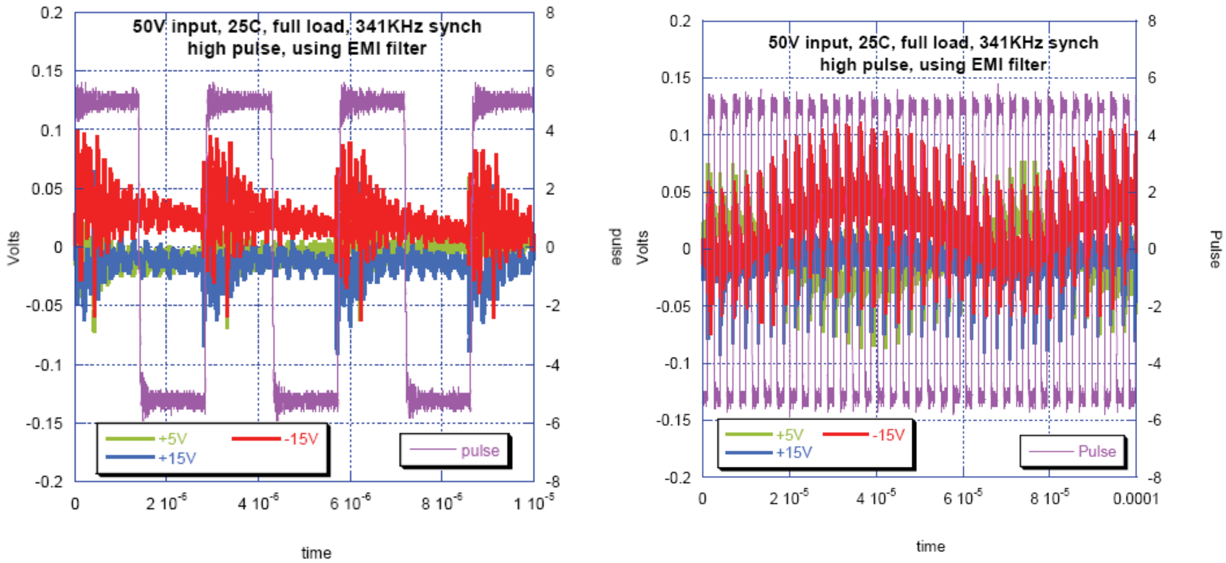


Figure 39. Room temperature synchronization test for 50V input, high pulse heights, full load, and 10% over maximum frequency taken with the EMI filter. The converter synchronizes; however, observing it at the longer time scale indicates that the filter is ineffective to correct the longer time scale oscillations that are seen in the previous graphs (see Figure 38).

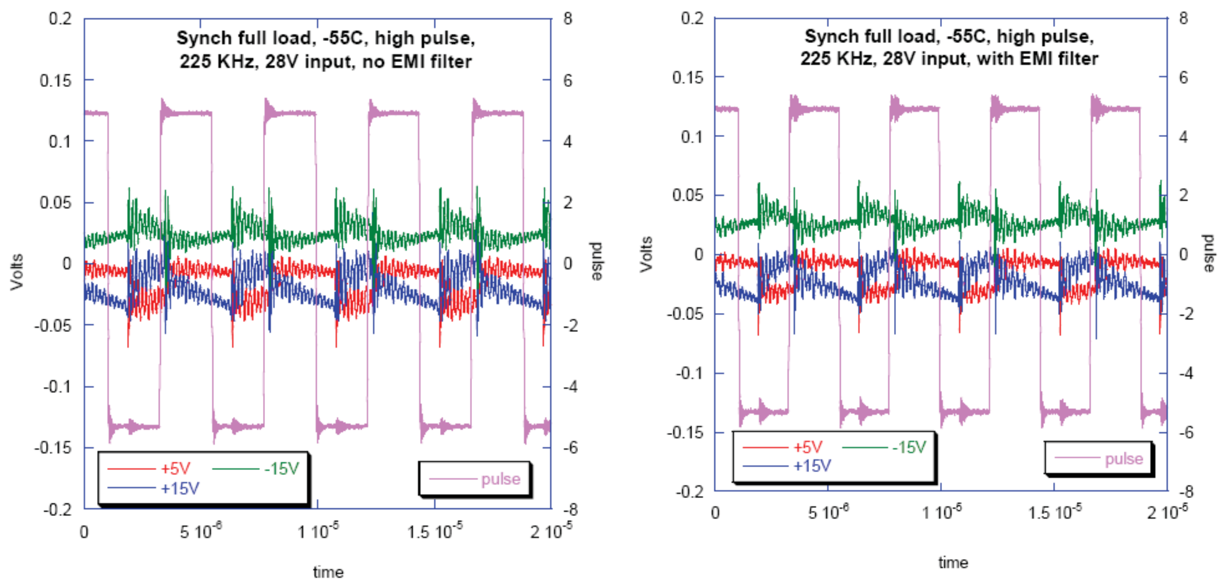


Figure 40. Low temperature plots for 28V input synchronization at high pulse levels and at minimum recommended frequency (225 KHz) and full load. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

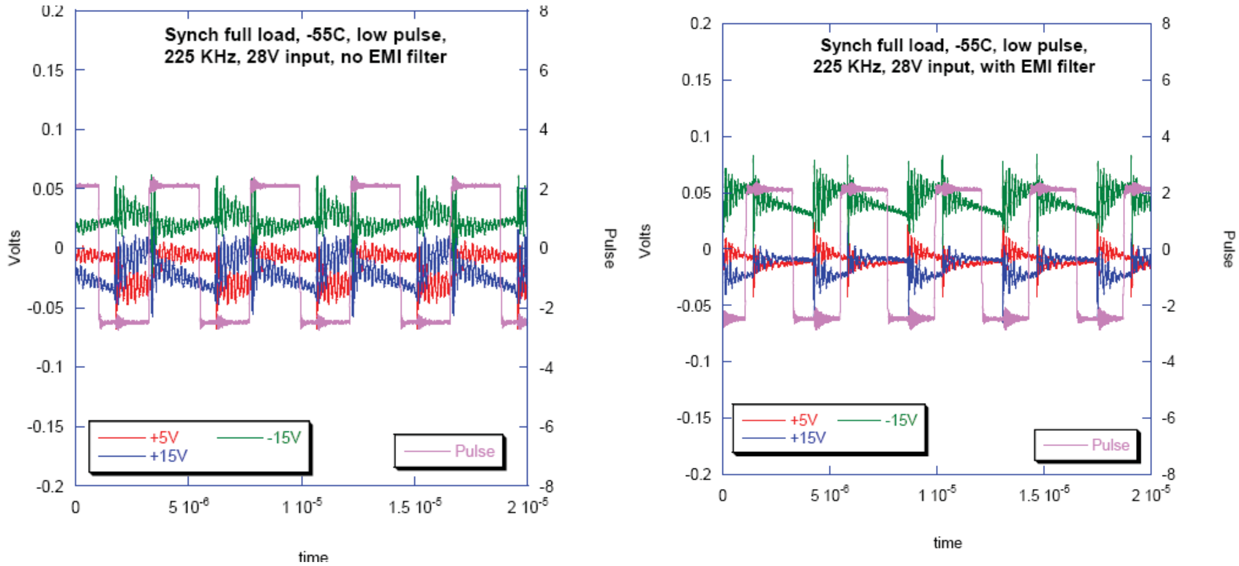


Figure 41. Low temperature plots for 28V input synchronization at low pulse levels and at minimum recommended frequency (225 KHz). The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

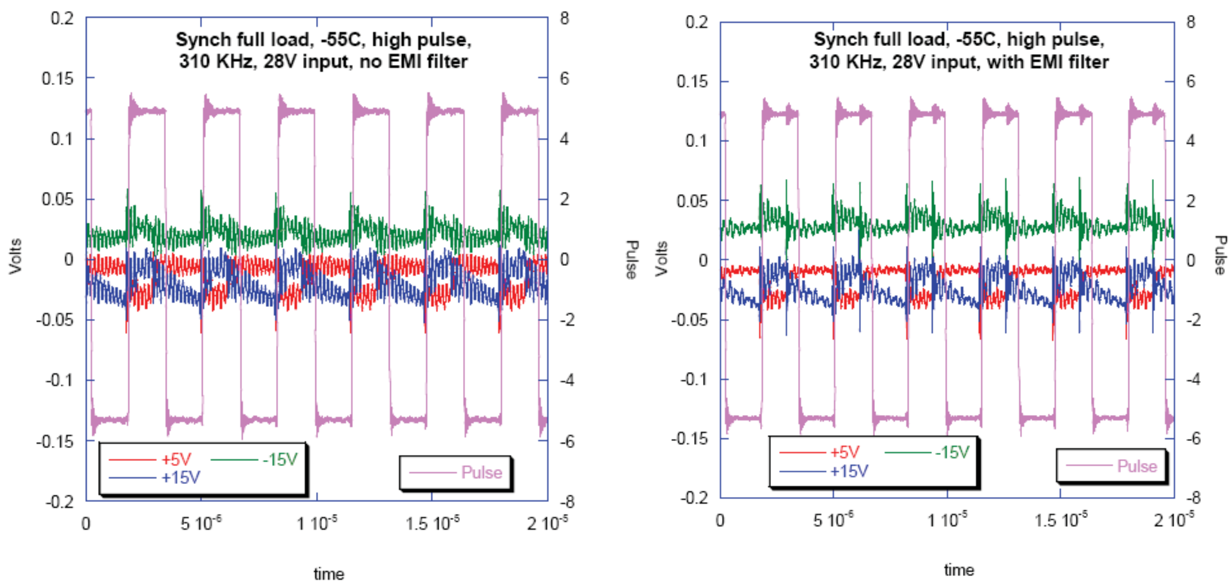


Figure 42. Low temperature plots for 28V input synchronization at high pulse levels and at maximum recommended frequency (310 KHz). The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

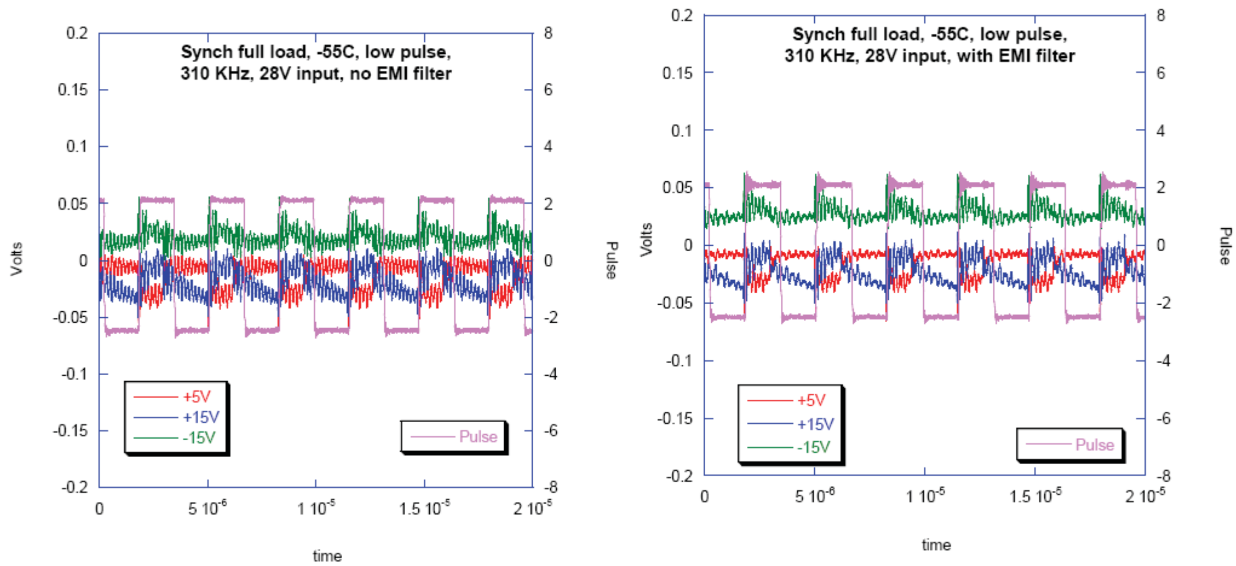


Figure 43. Low temperature plots for 28V input synchronization at high pulse levels and at maximum recommended frequency (310 KHz). The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show normal synchronization.

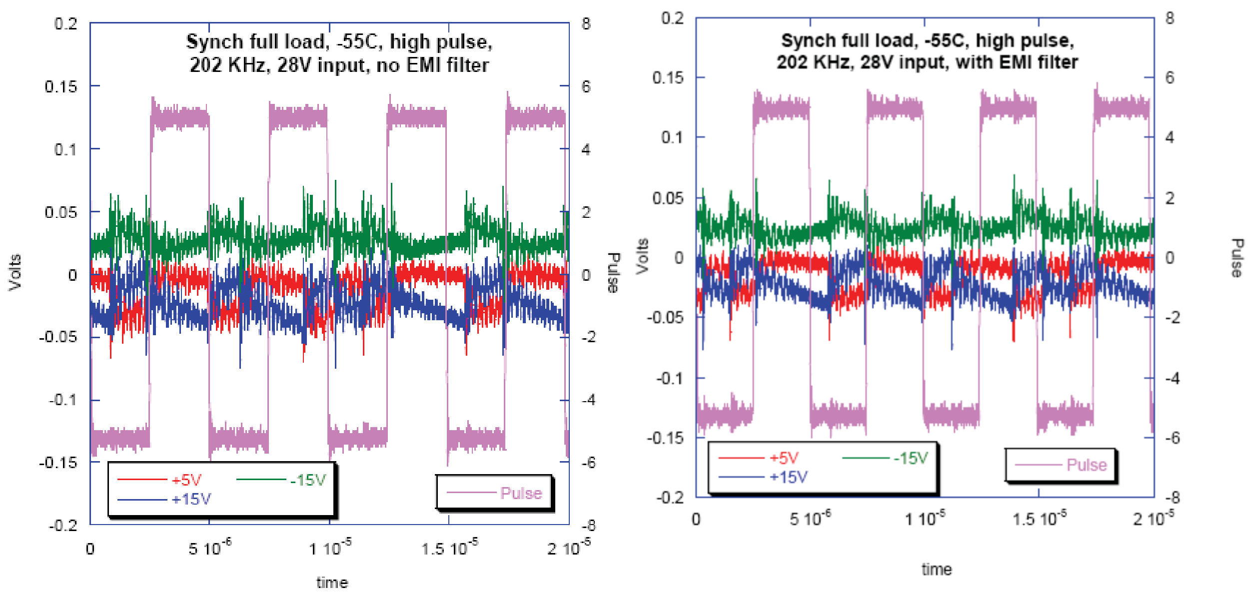


Figure 44. Plots for 28V input and full load at high pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

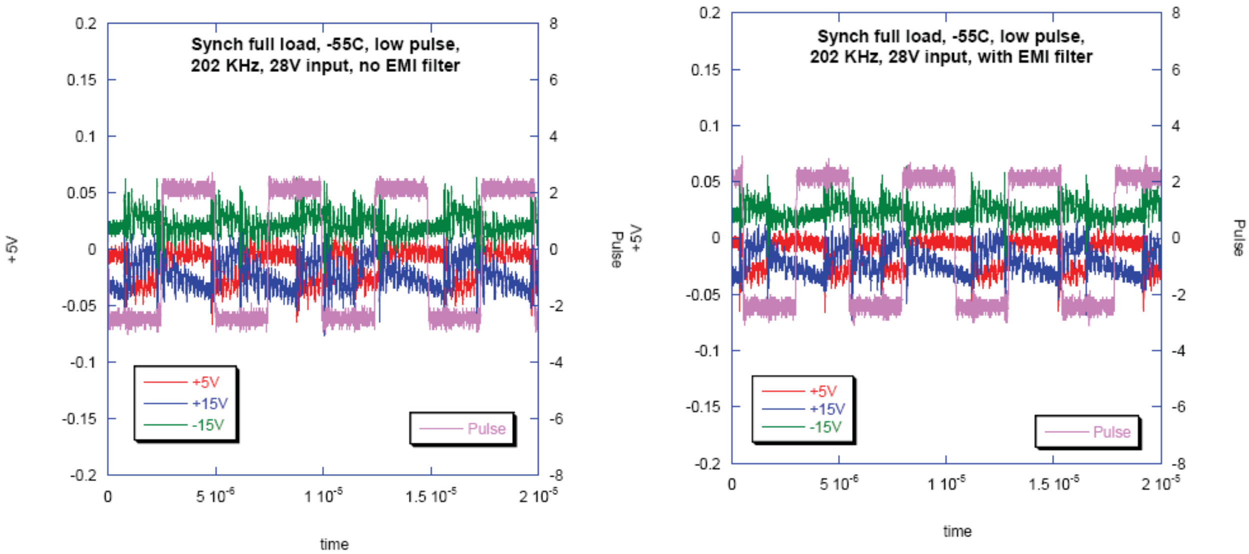


Figure 45. Plots for 28V input and full load at low pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

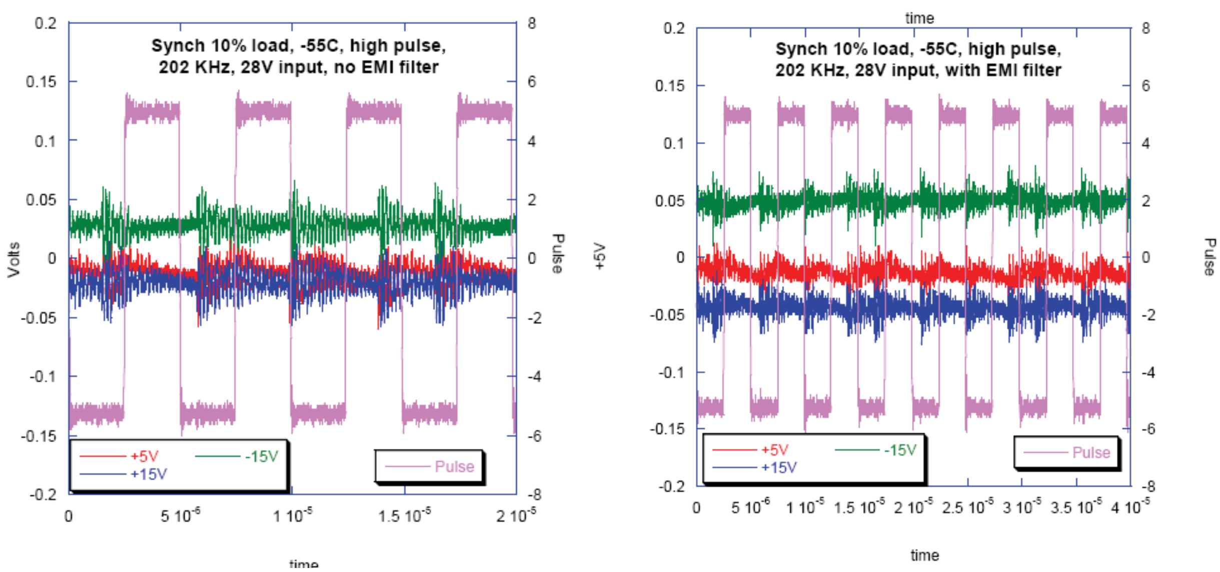


Figure 46. Plots for 28V input and 10% load at high pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

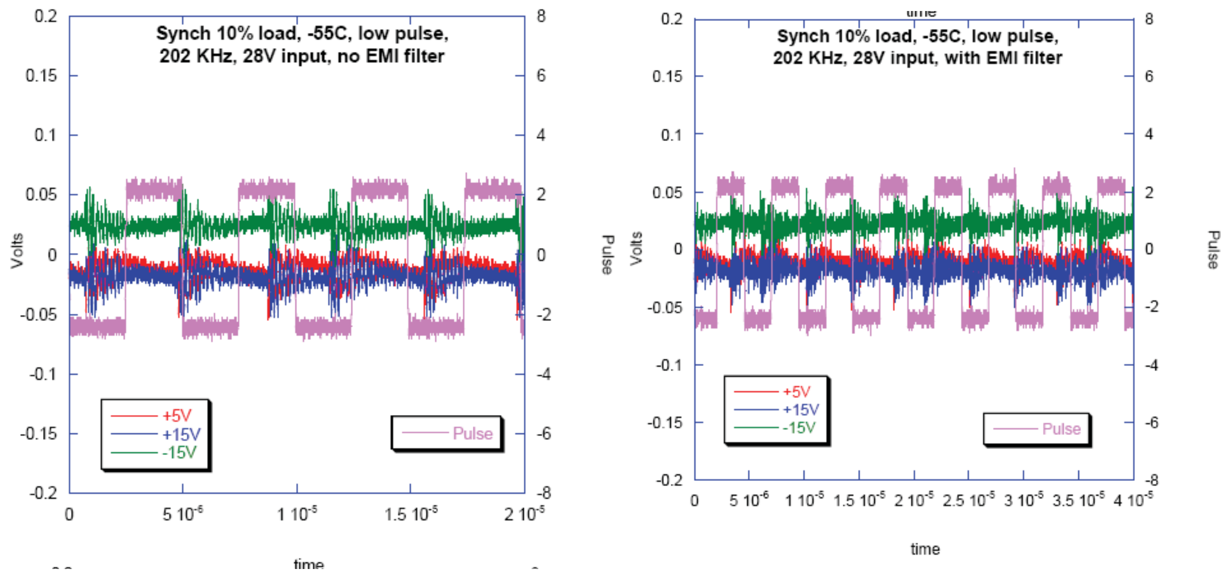


Figure 47. Plots for 28V input and 10% load at low pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

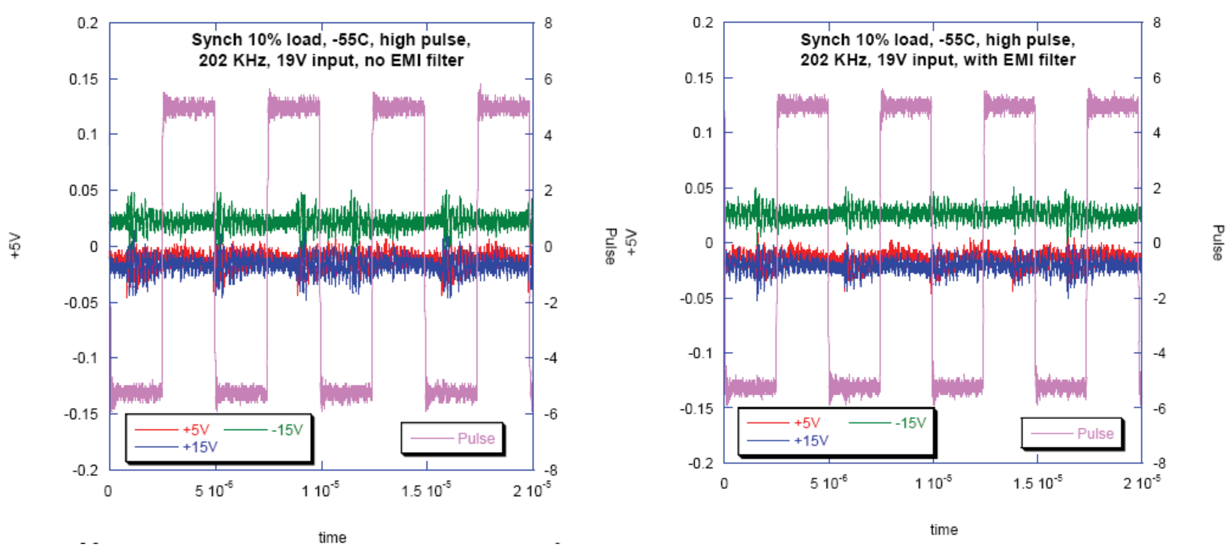


Figure 48. Plots for 19V input and 10% load at high pulse levels and at 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

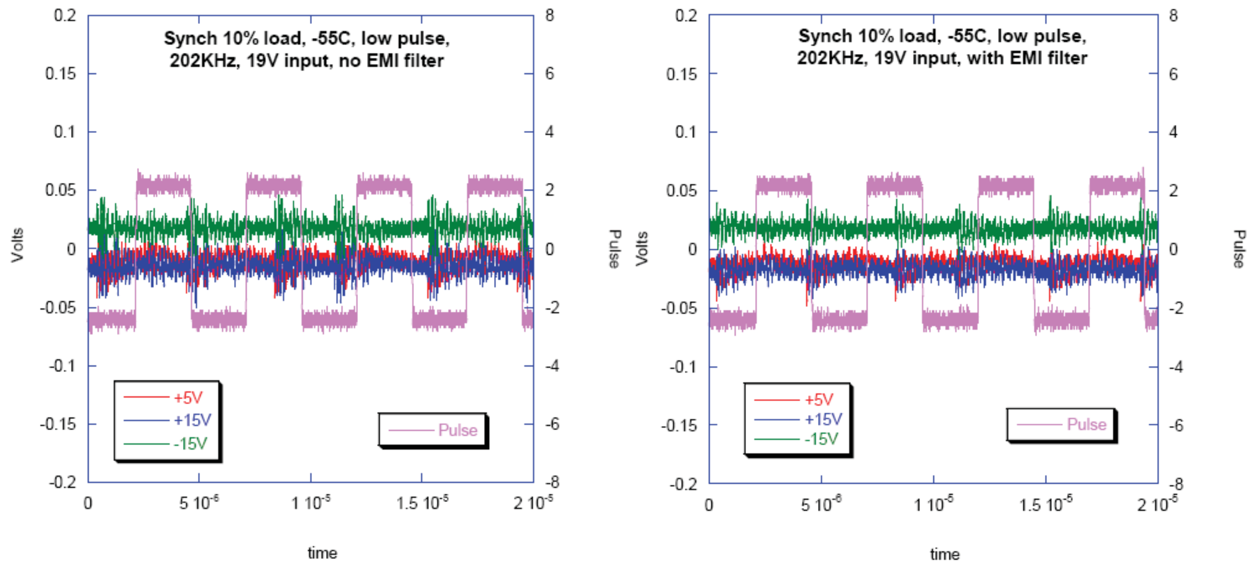


Figure 49. Plots for 19V input and 10% load at low pulse levels and at 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

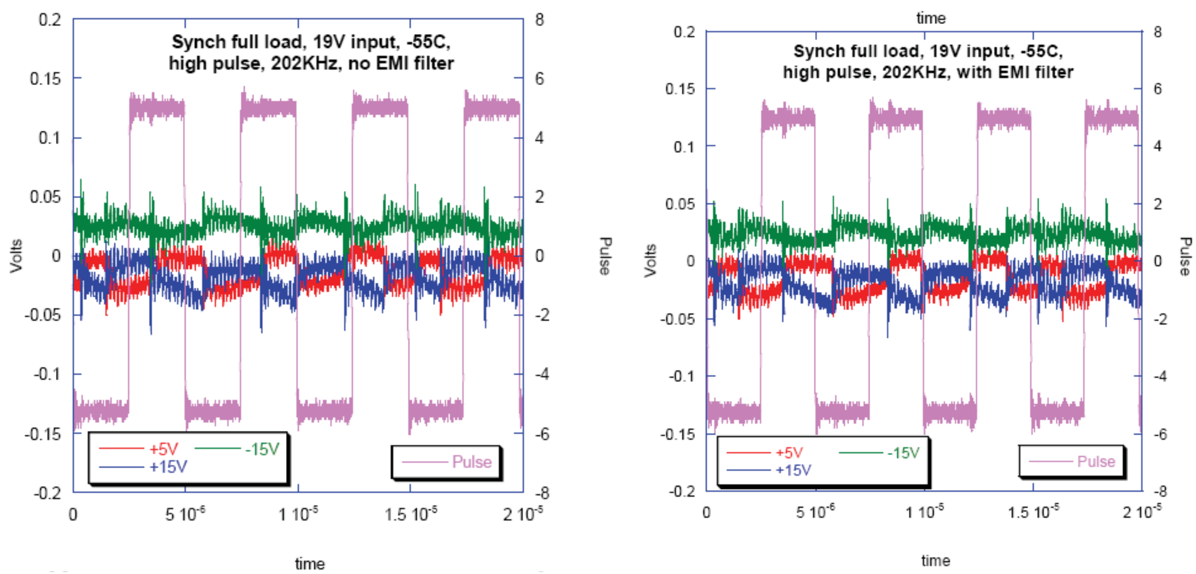


Figure 50. Plots for 19V input and full load at high pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

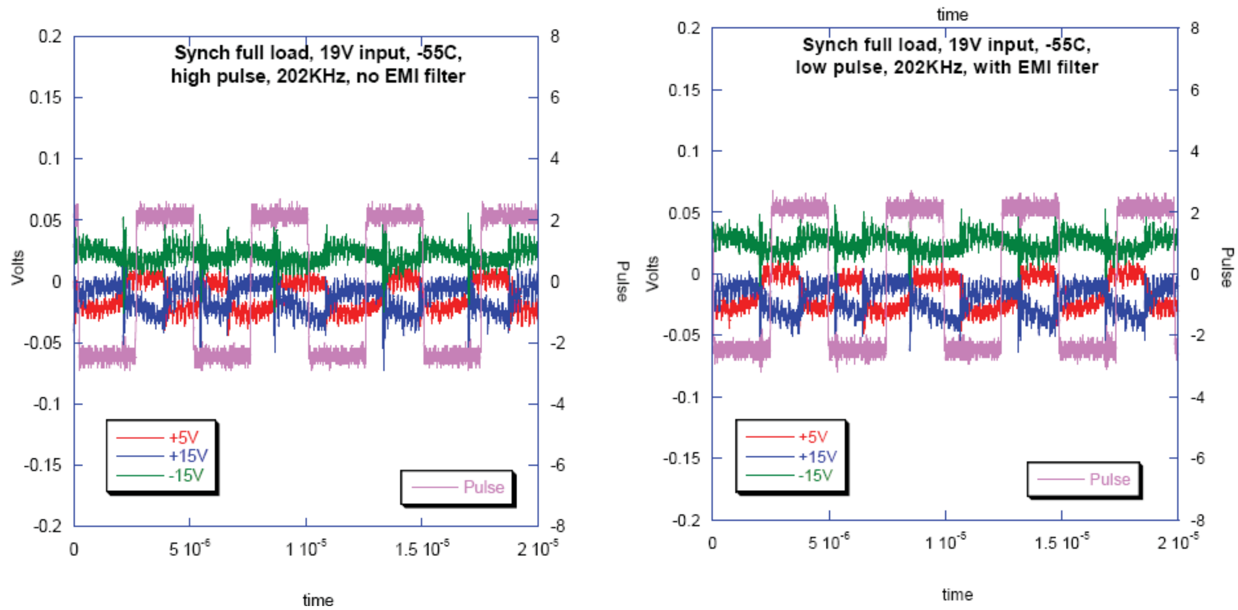


Figure 51. Plots for 19V input and full load at low pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

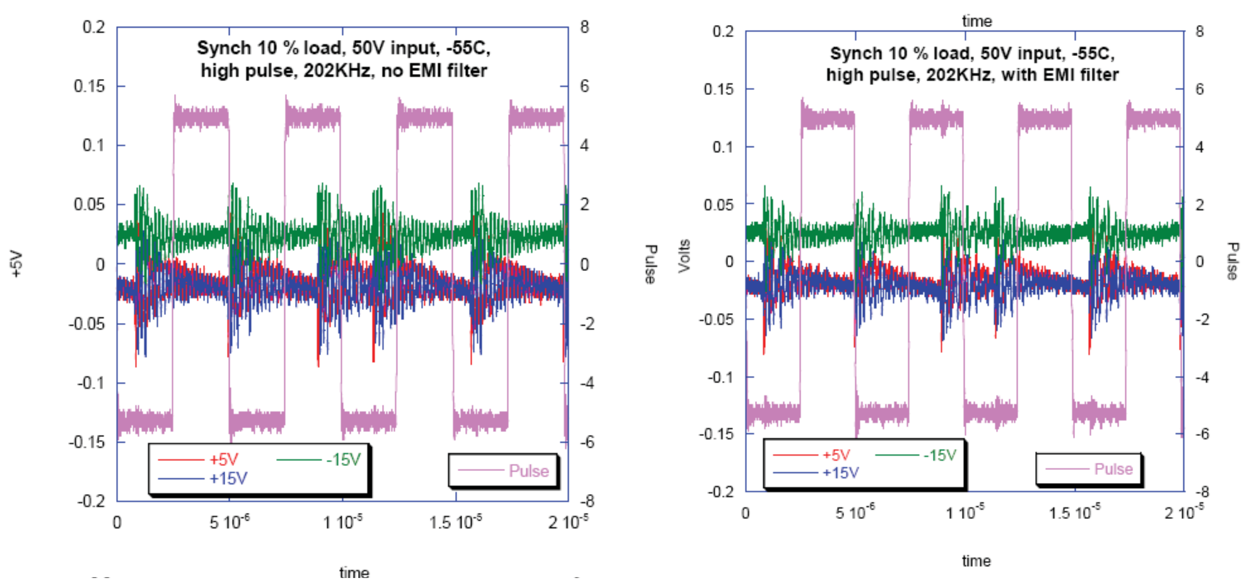


Figure 52. Plots for 50V input and 10% load at high pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

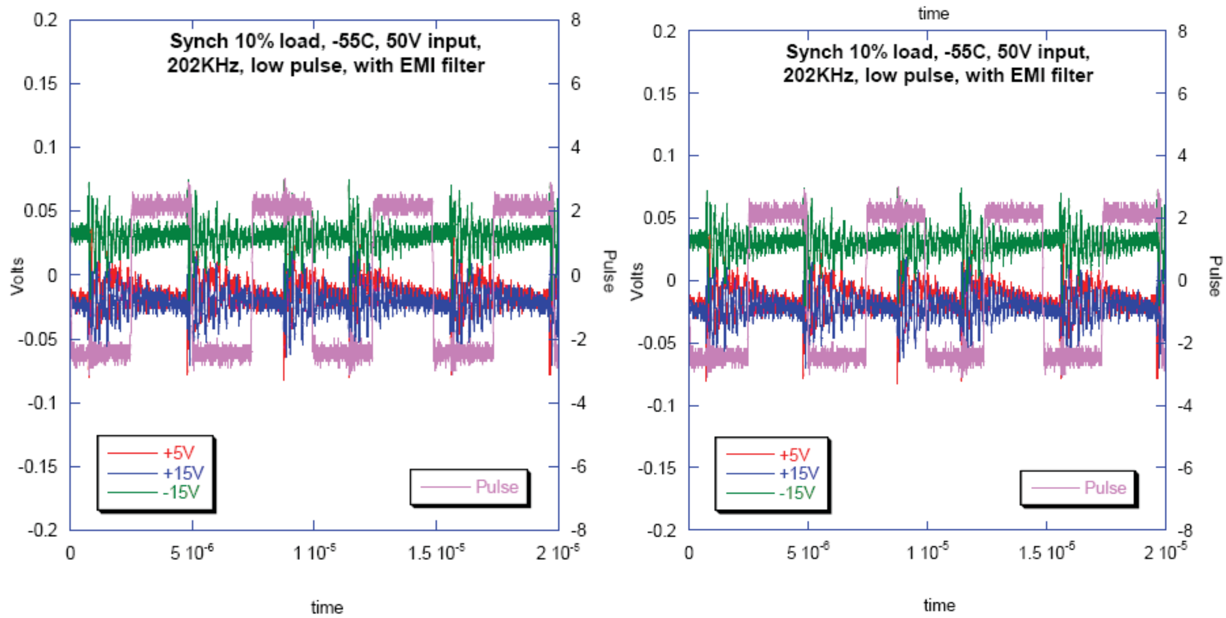


Figure 53. Plots for 50V input and 10% load at low pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

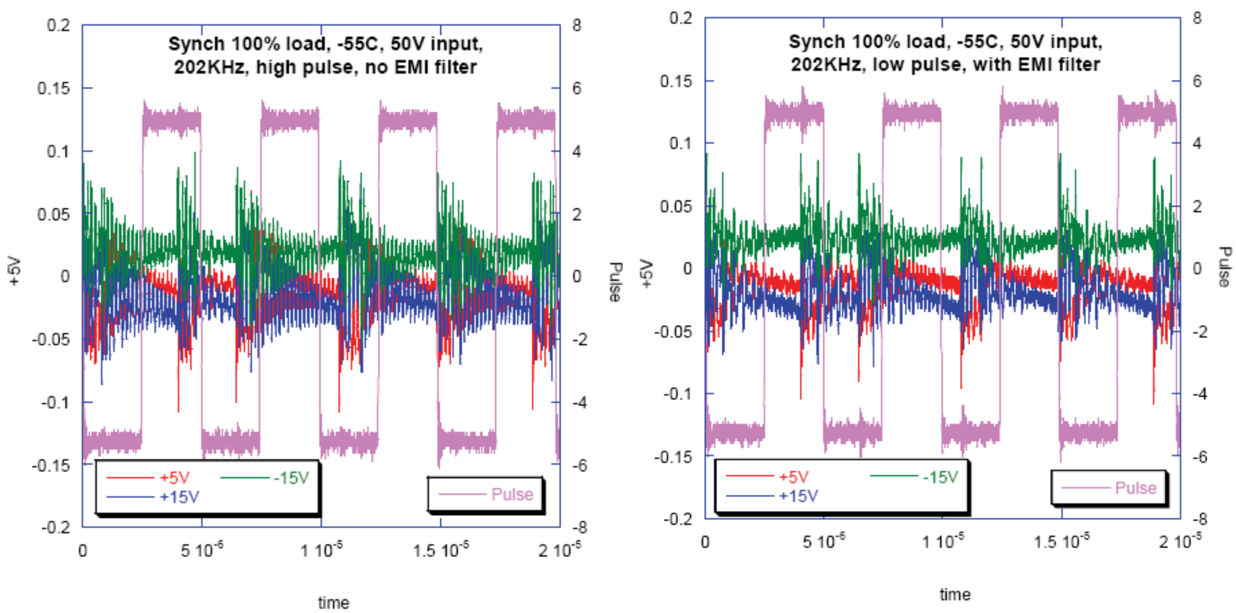


Figure 54. Plots for 50V input and full load at high pulse levels and 10% below minimum recommended frequency. The top plot shows results without the EMI filter, and the bottom plot shows results from using the ARF461 EMI filter. Both show faulty/abnormal synchronization at low temperature.

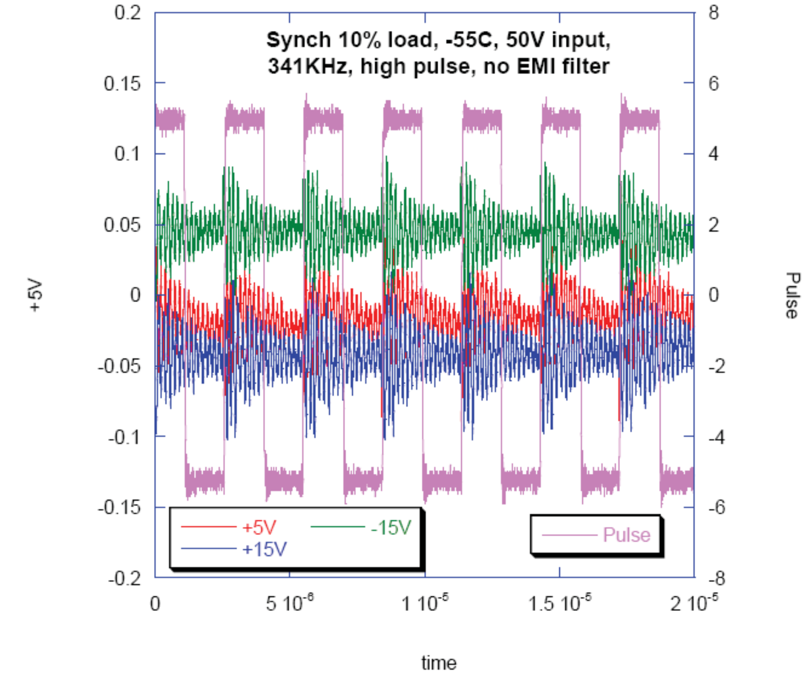


Figure 55. Plot taken under conditions that gave abnormal synchronization at low temperature. Tests were performed without EMI filters. Introducing the EMI filter resolved the anomaly (not shown). Plot for 50V input and 10% load at high pulse levels and at 10% above maximum recommended frequency. This plot does not show any anomalies because oscillations only show under a longer time scale (see Figure 56).

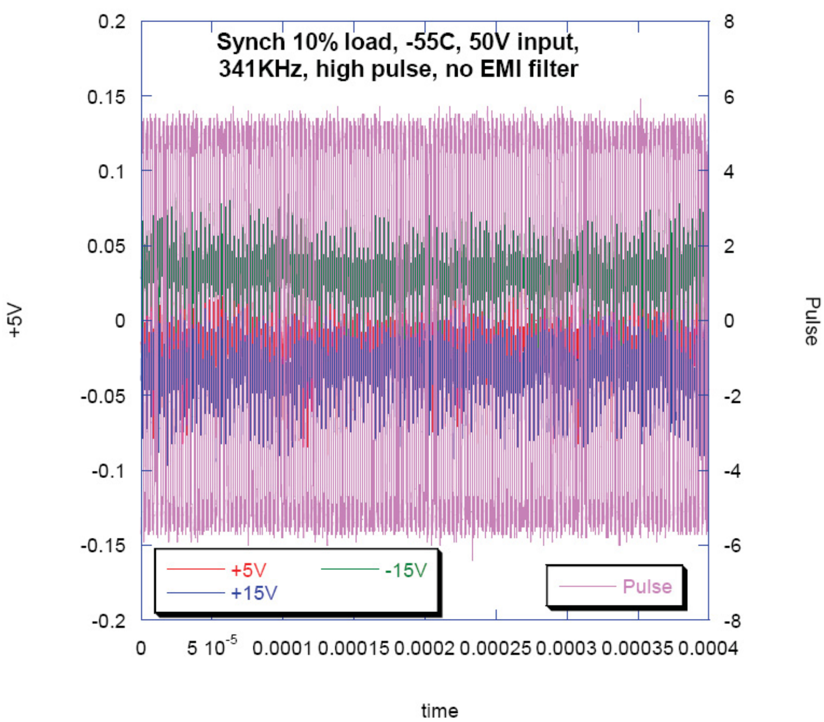
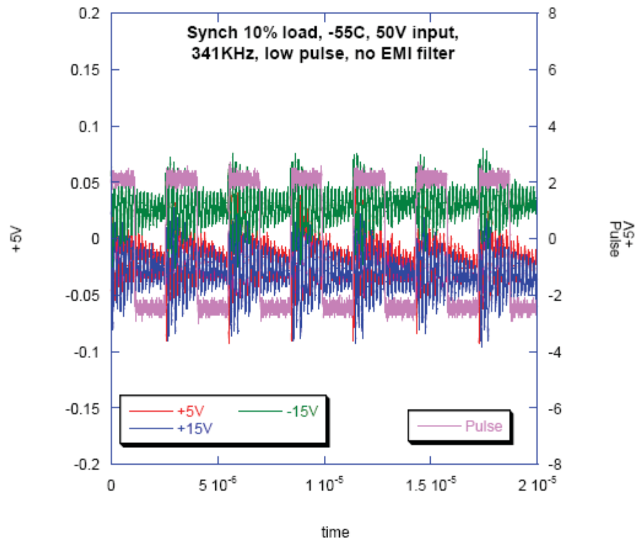


Figure 56. Plot for 50V input synchronization at high pulse levels and at 10% above maximum recommended frequency. Shows results without the EMI filter and some oscillations on a longer time scale.



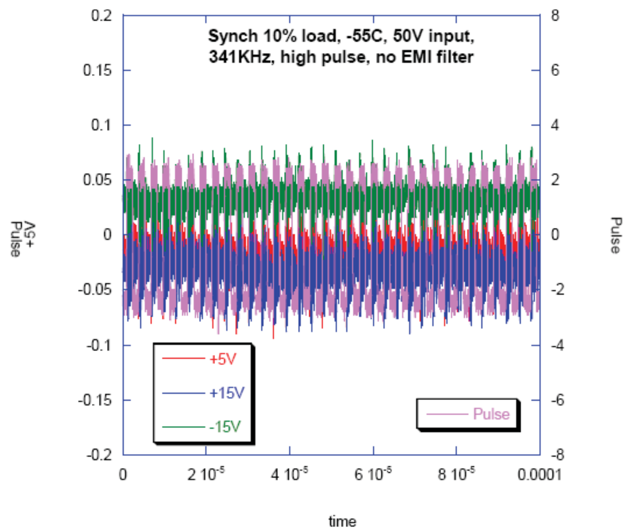


Figure 57. Low temperature synchronization test for 50V input, full load, and high pulse heights at 341 KHz (10% above maximum frequency). The converter synchronizes but also adds a slight larger scale oscillation that is not obvious unless the scope trace is taken on a longer time scale

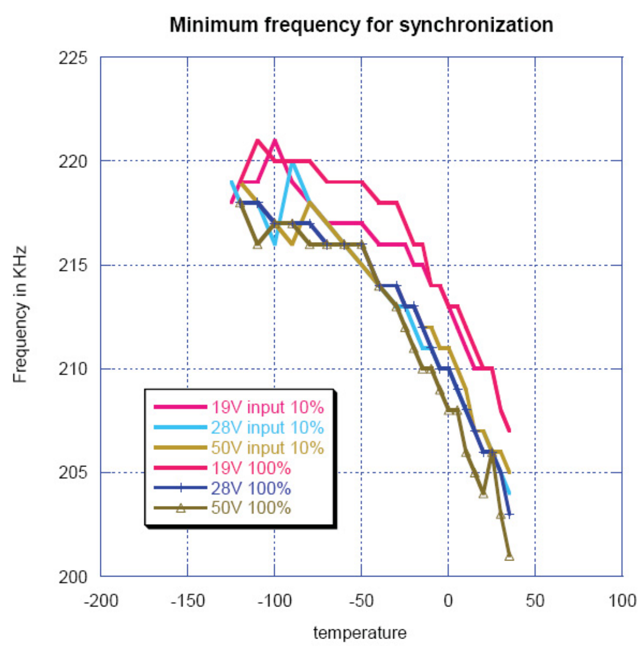


Figure 58. ART2815T DC/DC converter testing at low temperatures. A shift in minimum frequency is needed for synchronization, measured over a range in frequencies. This converter does not regulate normally below 110°C.

3.4 Operation of the Converter Below -55°C

Further tests were conducted, taking the converter to the lowest temperature in which it would operate in order to determine if it would work below -55°C and, if not, what problems could be expected. The converter performance was monitored as the chamber temperature was decreasing and, since there were anomalies noted at -125°C, the device was not cooled below this temperature.

While trying to measure at -125°C, the converter output voltages were no longer positive and negative 15V and positive 5V but, rather, close to the input voltage (26V and 46V for 28V and 50V inputs, respectively). At 100% load there were large voltage oscillations (no steady output) at 28V and 50V input. Only 19V input was somewhat measurable. For 10% load and -125°C, large output voltage oscillations were observed for 50V output; the outputs for 28V and 19V inputs were steady otherwise.

Upon warming up the chamber to return to normal operation range (above -100°C), the following was observed:

- At 120°C, there was no motorboating (large output voltage oscillations); however, the converter did not regulate to the right values. At 50V input, the regulation was 46V and 16V (rather than 15V and 5V). At 28V input and 10% load, the regulation was 26V and 9V; for full load and the same input voltage, the regulation was 23V and 7V. For 19V input, the regulation was around 17V and 6V (instead of 15V and 5V).
- At 110°C, the regulation was off (just like at 120°C) when the load was set for 10%; however, the converter regulated to just a little over 15V and 5V when the load was set to 100%. In other words, voltage regulation did not work for small load, but it did work for full load.

The chamber was brought to higher temperatures, and full regulation was achieved for all values of input voltage and any load for temperatures of -100°C and above.

Data collection for synchronization was continued up to -40°C, and the converter was running normally without any apparent problem (data were already available from -40°C all the way up to 35°C).

The chamber was then warmed up to room temperature with the input voltage off. More detailed tests are planned to test regulation as a function of temperature up (and down) to the point where regulation is far from the specified positive and negative 15V and positive 5V. From the preliminary observations described previously, it appears to be from 110°C to 120°C, depending on input voltage and loads.

When the chamber was at room temperature, the converter's performance was tested again. The converter was motorboating (large output voltage oscillations) for any value of input voltage and any value of load, with and without a synchronization pulse. It was not possible to stop it from oscillating.

Since annealing has been known to "fix" some converters' problems, the chamber was brought to 80°C, maintained at that temperature about an hour, then brought down in to 25°C to re-measure. The ART2815T was still giving large output voltage oscillations. It was turned on for just a few minutes to test various load and input conditions to see if a steady regulated voltage value could be obtained. Unfortunately, this did not work and, while the converter did not exactly break, it is unusable.

A failure analysis was carried out for this converter; details are provided in Section G.

3.5 Turn-on

Turn-on tests were carried out for both the ASA2812D and the ART2815T.

Figures 59–67 show results for room temperature turn-on tests for the ART2815T. These figures compare side-by-side traces taken with and without the EMI filter recommended for this converter (ARF461). There were very few concerns from turn-on testing with this converter, and the number and severity of anomalies with this test are minimal compared with previous results [4].

Among the anomalies is the “false” start that is seen when using the 2 ms delay ramp switch. No problems were encountered with the bounceless turn-on switch (very fast turn-on with no delay). The traces that compare turn-on results when using the 2 ms delay switch with the ARF461 filter show that, while not completely eliminating the surge or false start, it does minimize its severity in this converter.

Figures 68–73 show turn-on test results for the ASA2812D converter. The EMI filter for this converter was not used in this test since the output voltage turned on without any anomalies. There is, however, a slightly noisier output signal than observed in the more sophisticated converters.

Table 3 shows results of manual ramp turn-on and turn-off for this converter at room temperature.

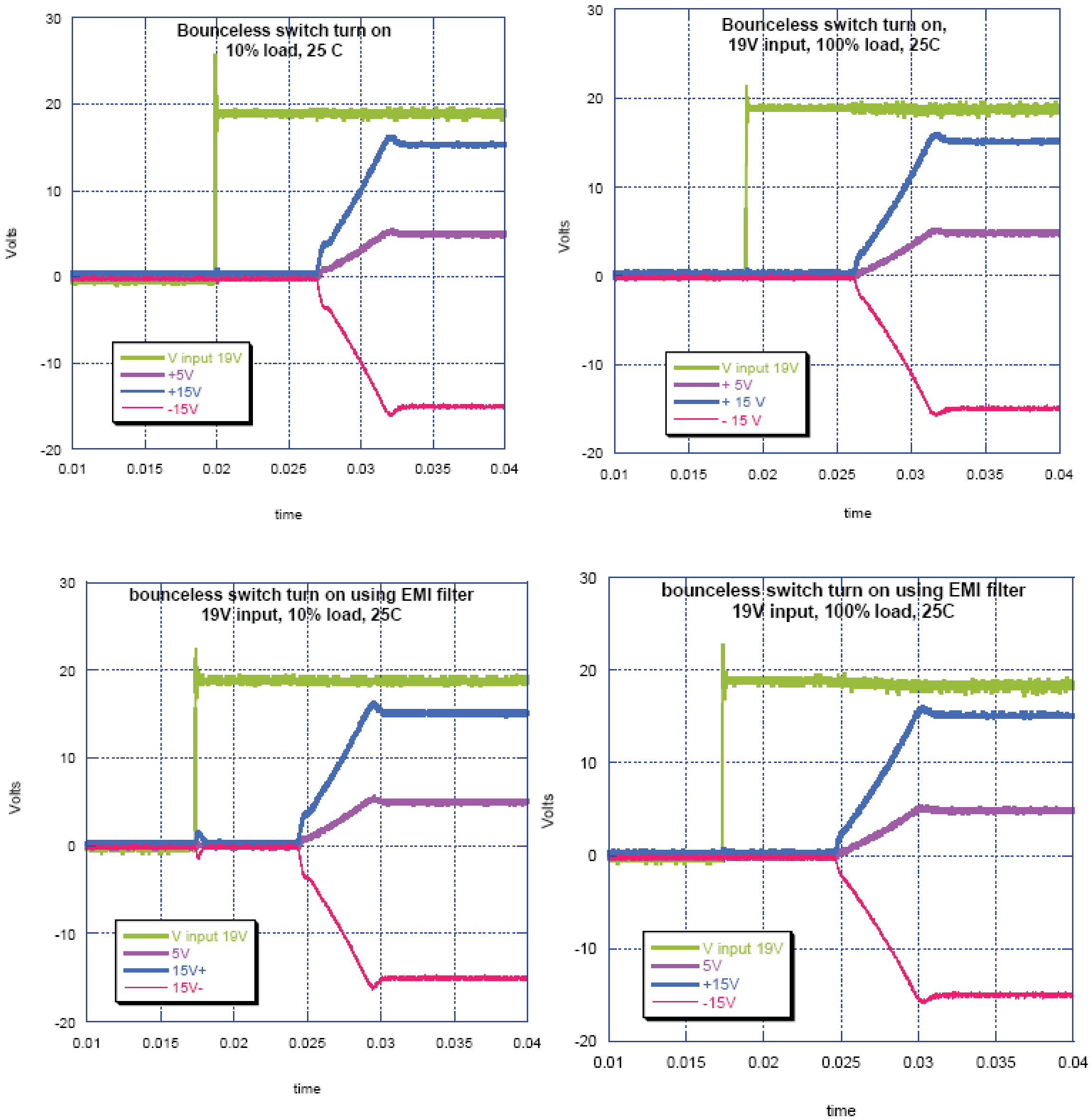


Figure 59. Turn-on tests performed on the ART2815T DC/DC converter using a bounceless switch (an Hg switch works well). These are for 19V input. The top two traces show results for 10% load and 100% load, respectively, without using an EMI filter. The bottom two traces show the same test but using the ARF461 EMI filter.

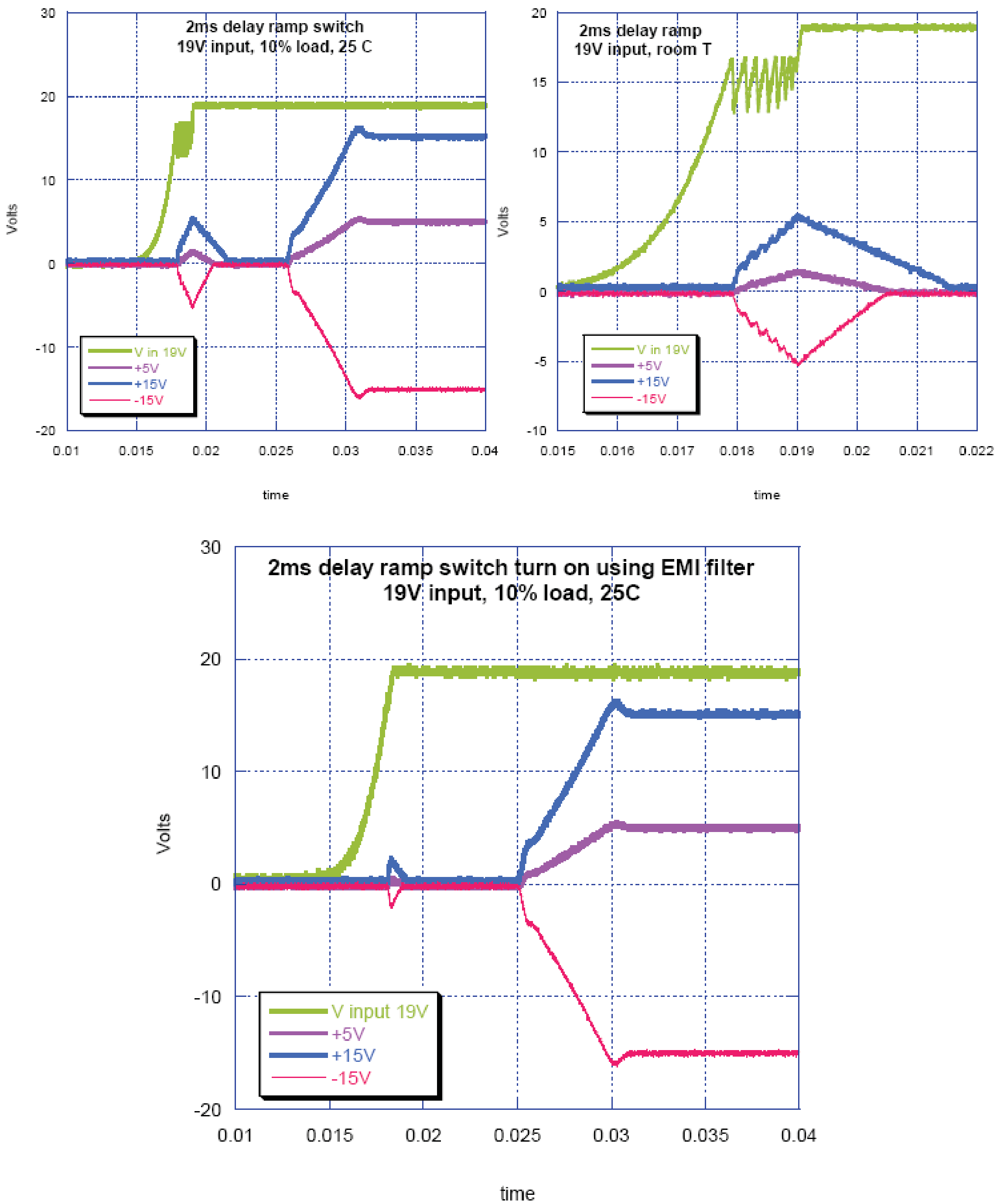


Figure 60. Turn-on tests using a 2 millisecond delay ramp switch. These are for 19V input. The top two traces show results for 10% load without using an EMI filter. The bottom two traces show the same test but using the ARF461 EMI filter.

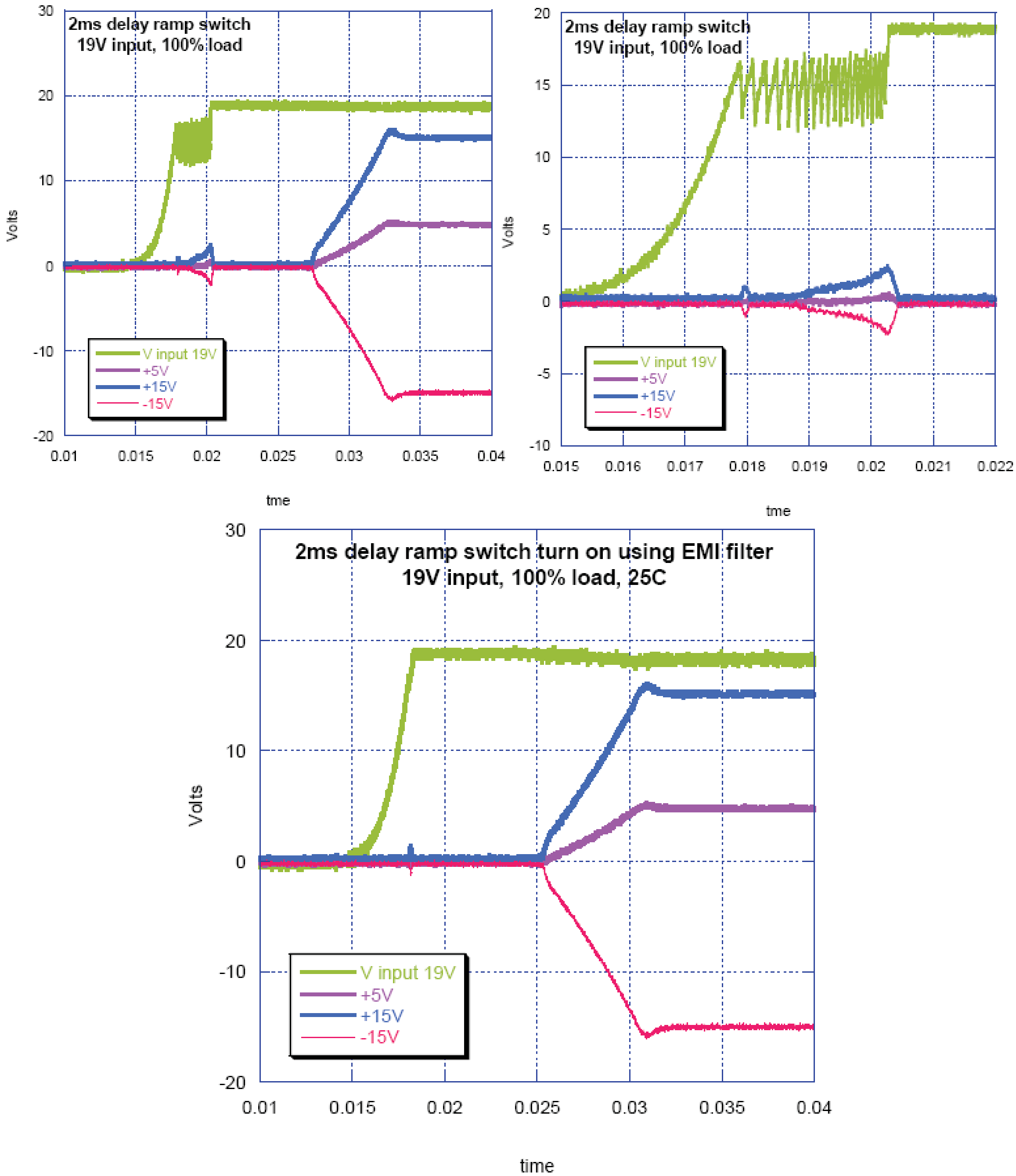


Figure 61. Turn-on tests using a 2 ms delay ramp switch. These are for 19V input. The top two traces show results for 100% load without using an EMI filter. The bottom two traces show the same test but using the ARF461 EMI filter.

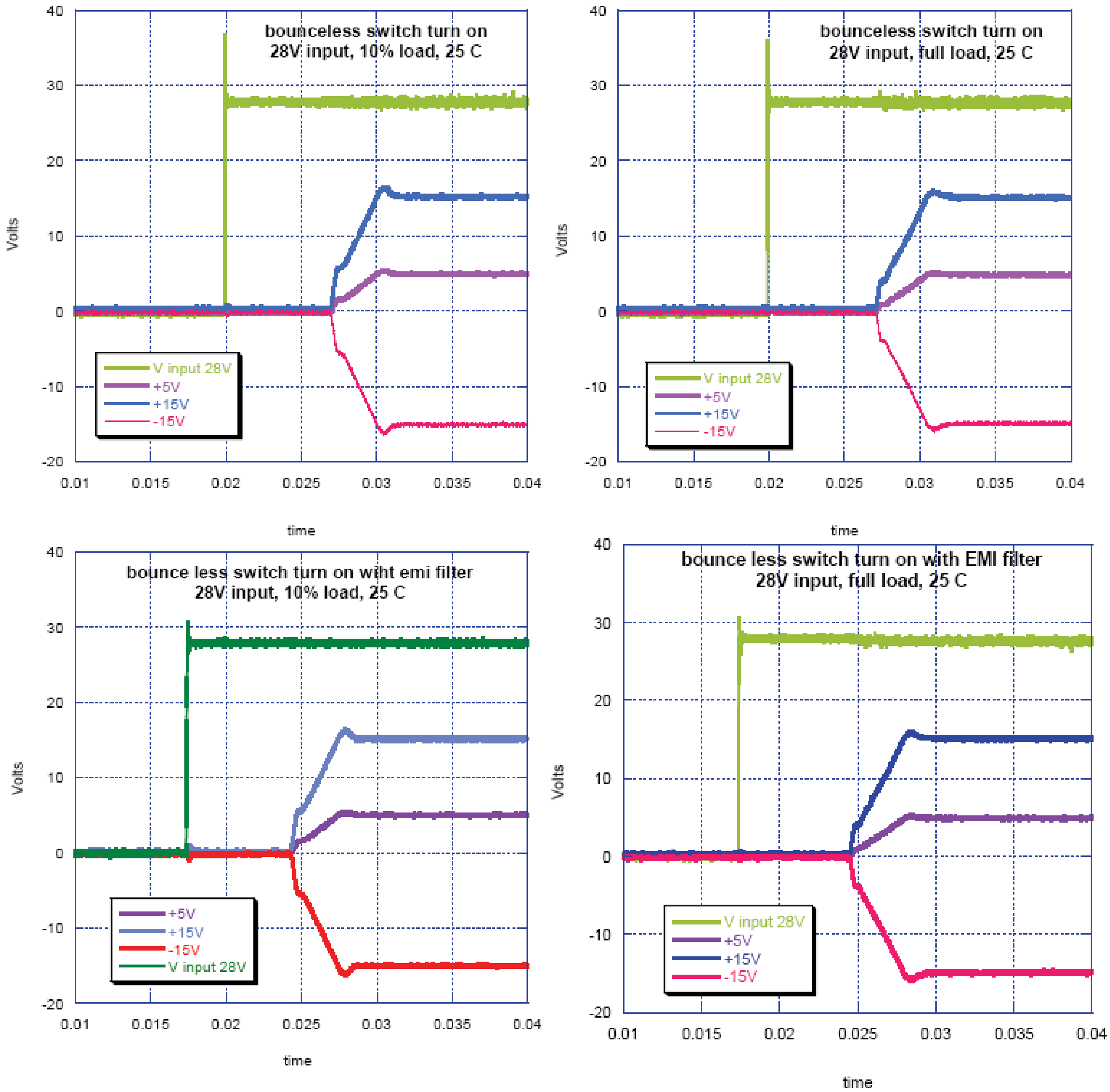


Figure 62. Turn-on tests using a bounceless switch (an Hg switch works well). These are for 28V input. The top two traces show results for 10% load and 100% load, respectively, without using an EMI filter. The bottom two traces show the same test but using the ARF461 EMI filter.

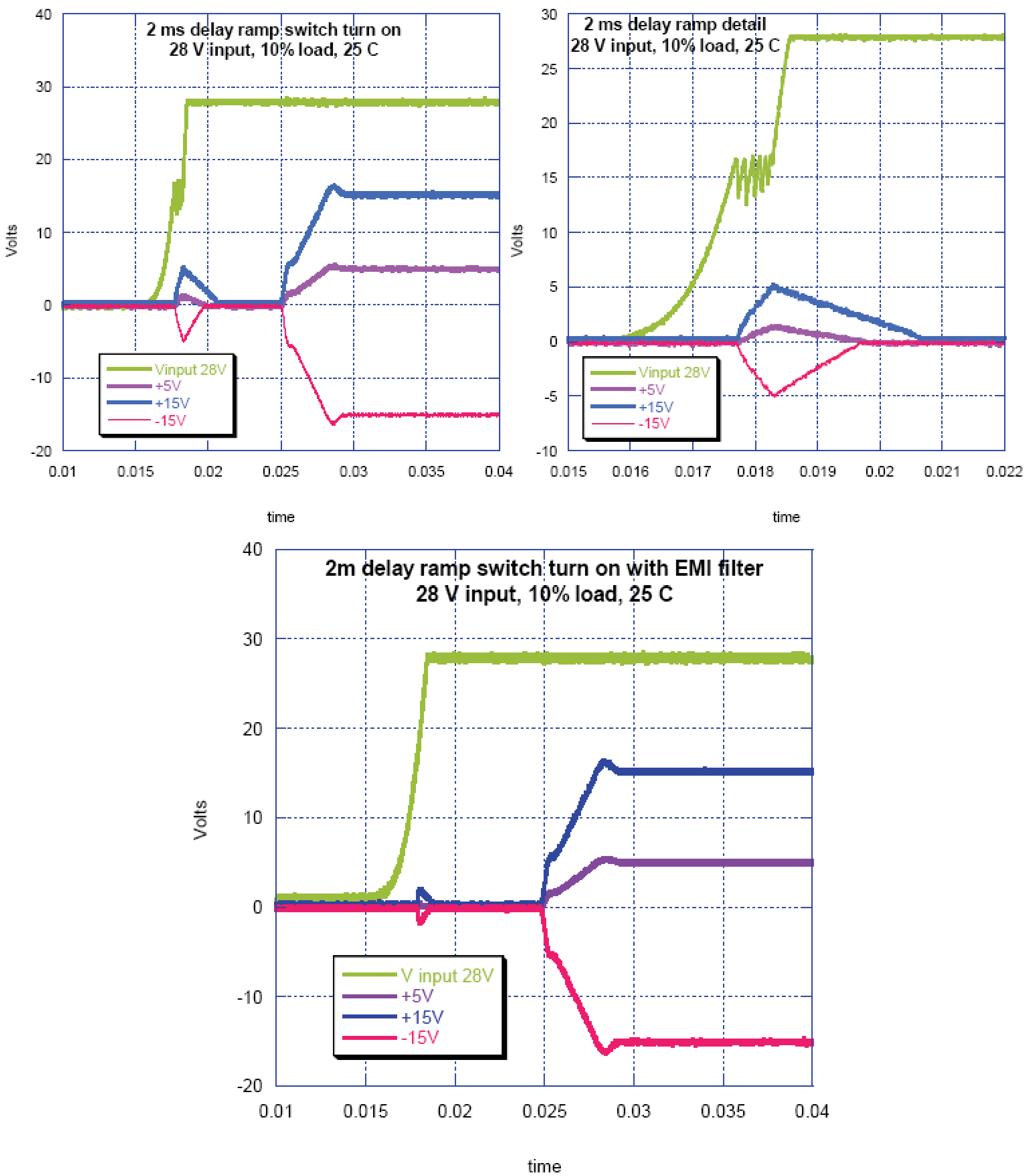


Figure 63. Turn-on tests using a bounceless switch (an Hg switch works well). These are for 28V input. The top two traces show results for 10% load without using an EMI filter. The bottom trace shows the same test but using the ARF461 EMI filter.

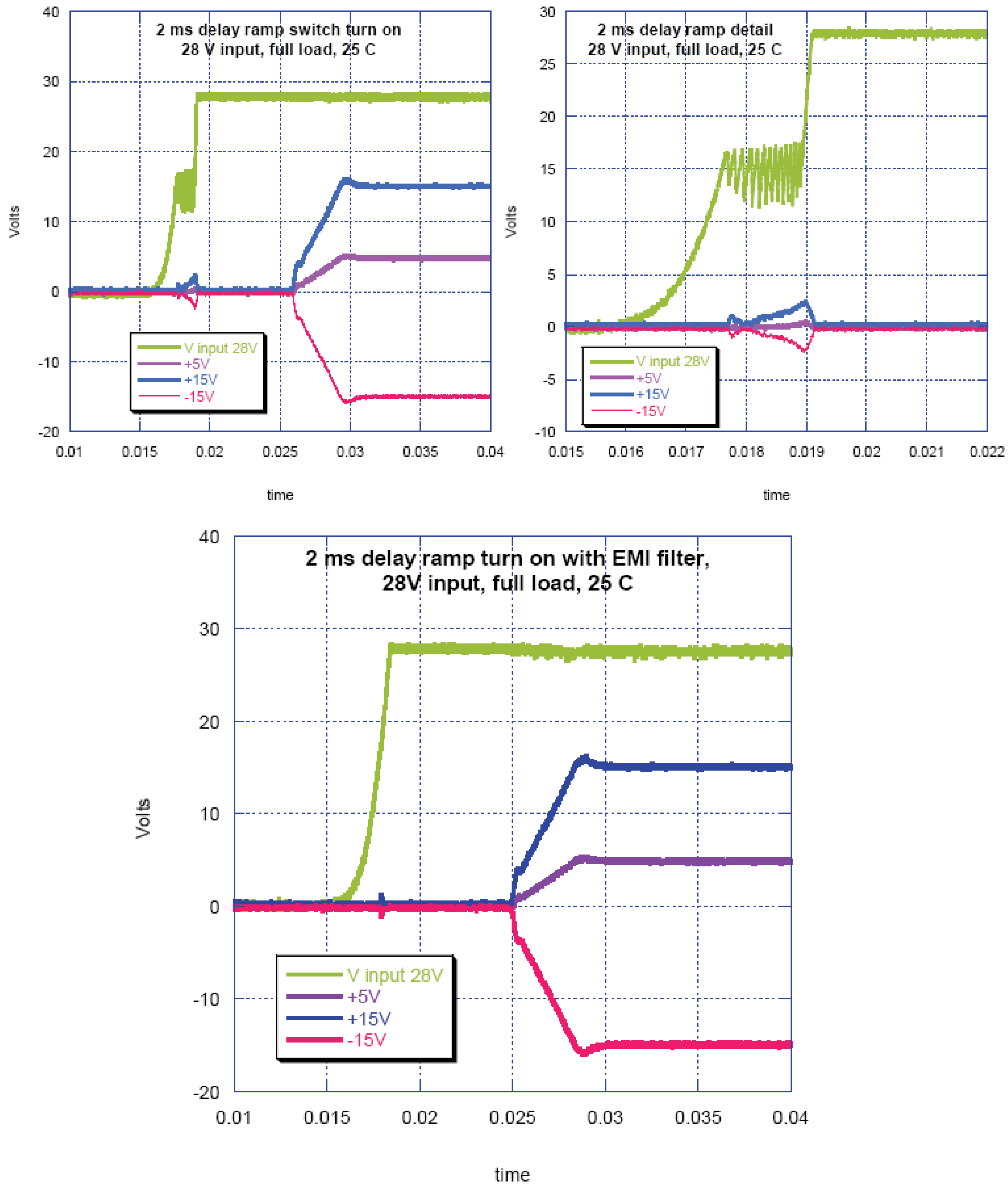


Figure 64. Turn-on tests using a 2 ms delay ramp switch. These are for 28V input. The top two traces show results for full load without using an EMI filter. The bottom trace shows the same test conditions but using the ARF461 EMI filter.

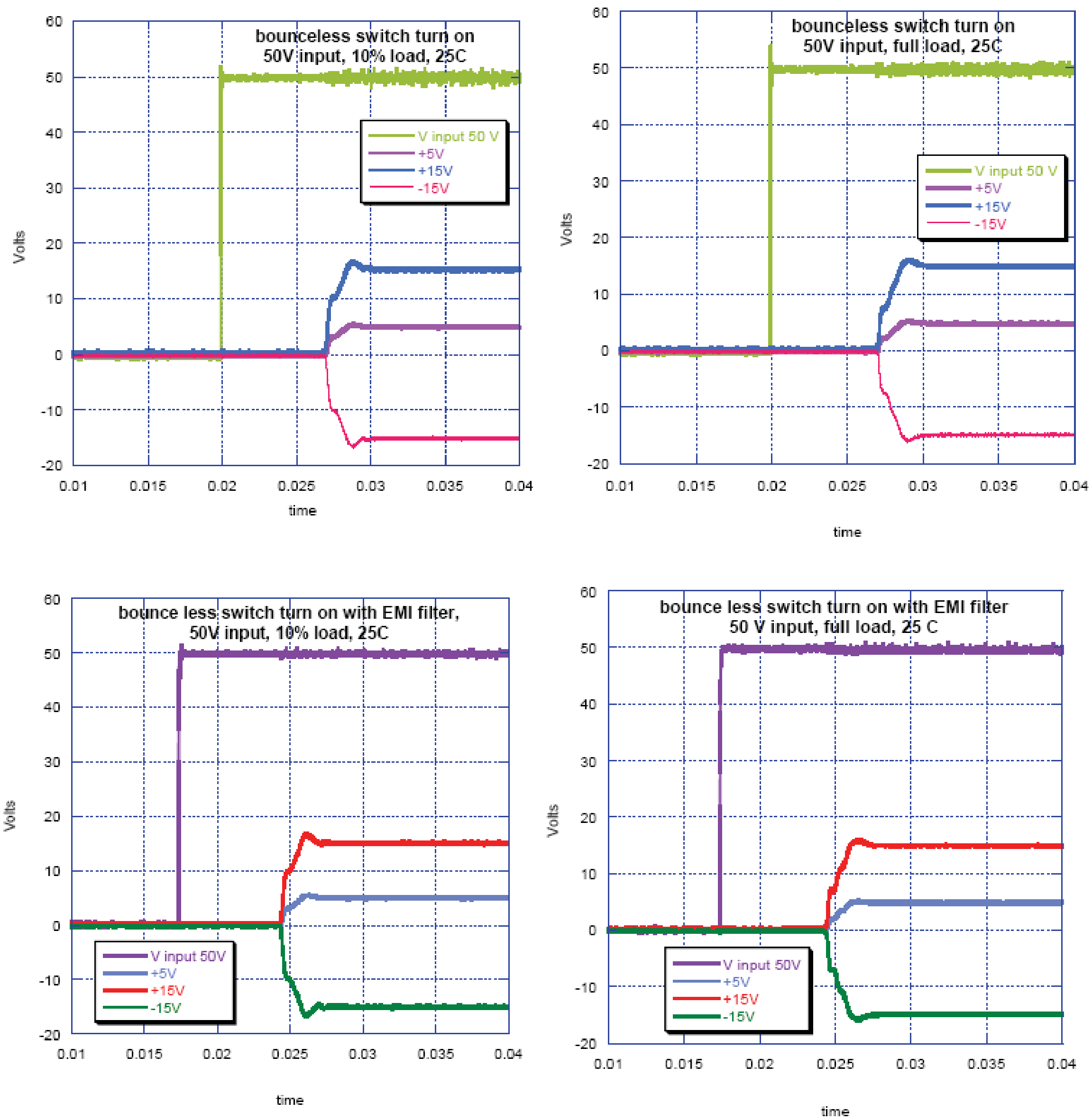


Figure 65. Turn-on tests using a bounceless switch (an Hg switch works well). These are for 50V input. The top two traces show results for 10% load and 100% load, respectively, without using an EMI filter. The bottom two traces show the same test but using the ARF461 EMI filter.

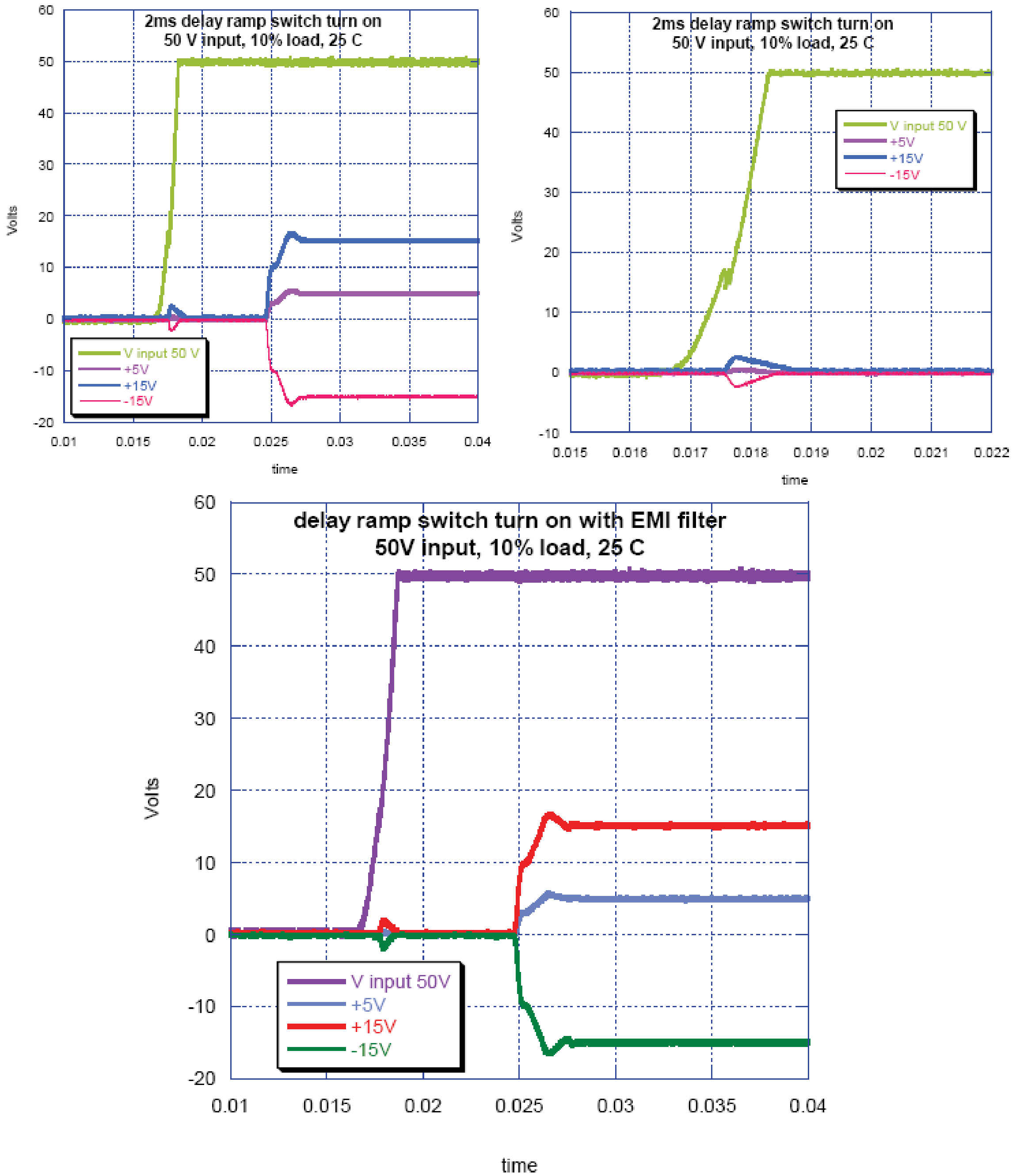


Figure 66. Turn-on tests using a 2 ms delay ramp switch. These are for 50V input. The top two traces show results for 10% load without using an EMI filter. The bottom trace shows the same test conditions but using the ARF461 EMI filter.

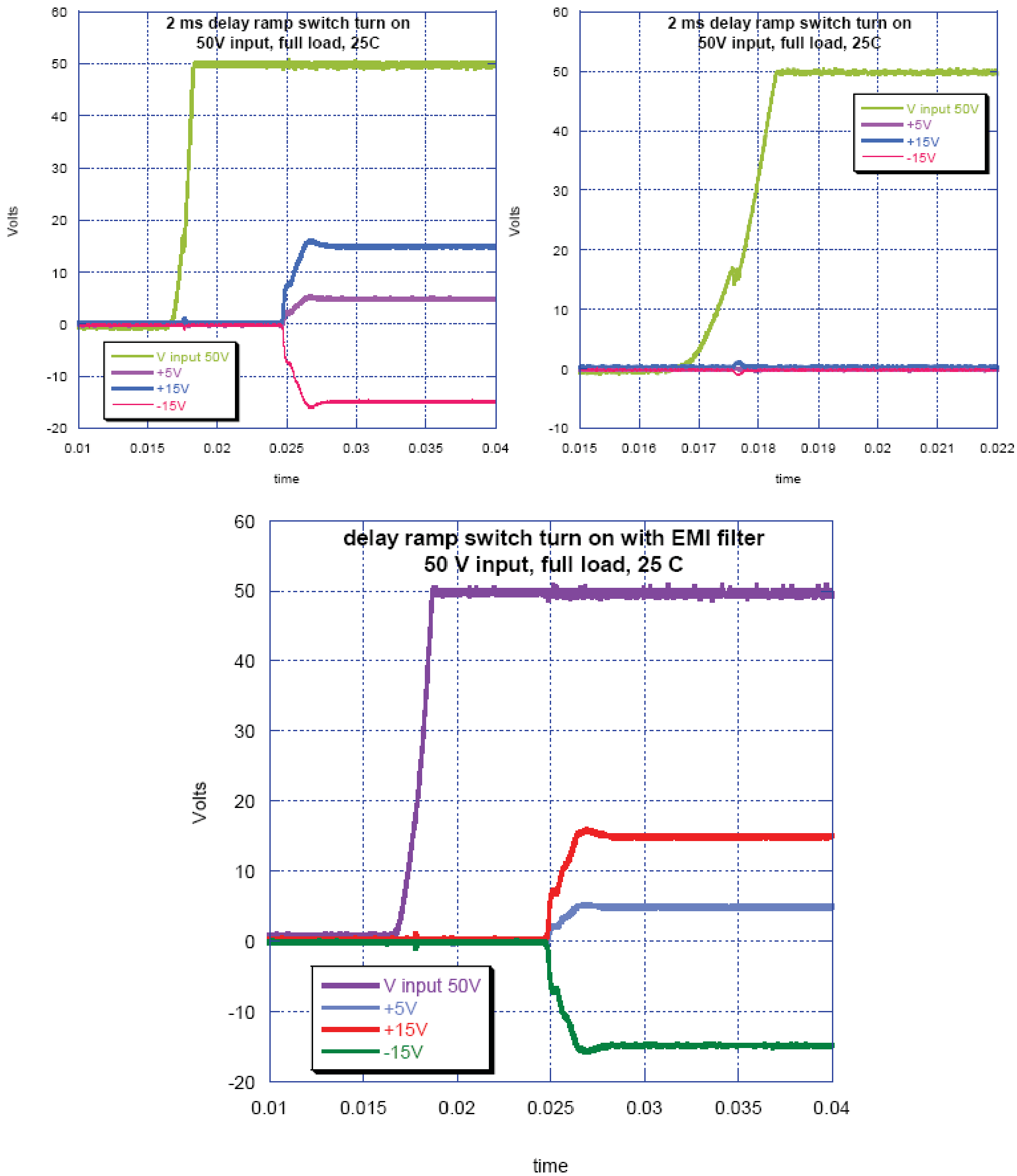


Figure 67. Turn-on tests using a 2 ms delay ramp switch. These are for 50V input. The top two traces show results for 100% load without using an EMI filter. The bottom trace shows the same test conditions but using the ARF461 EMI filter.

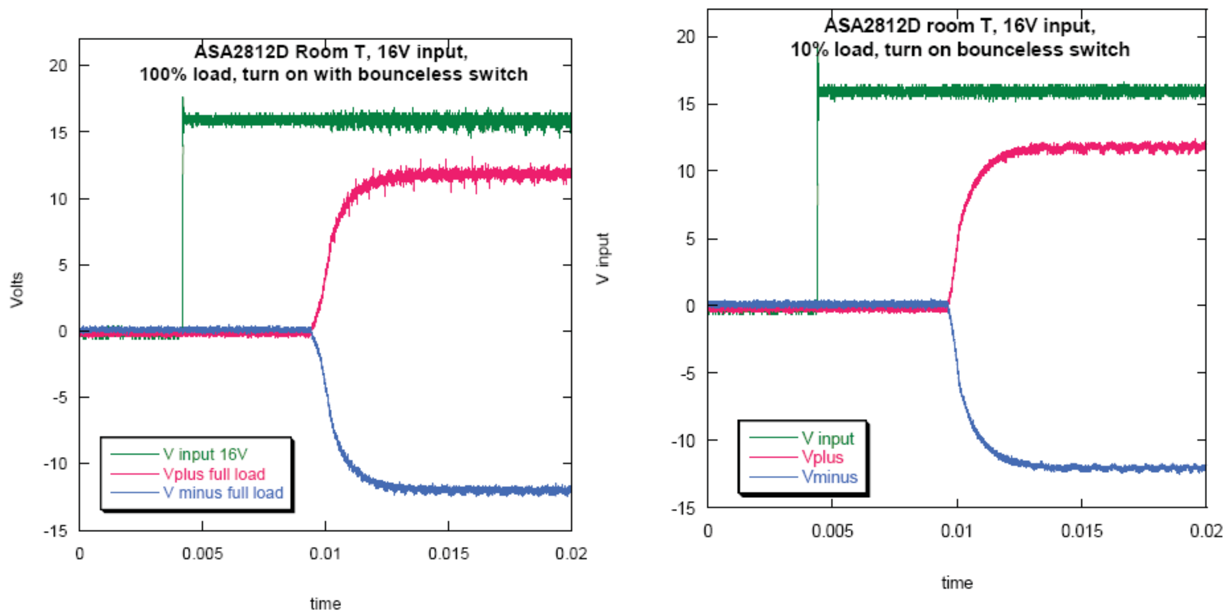


Figure 68. Room temperature turn-on tests for the ASA2812D DC/DC converter using an Hg bounceless switch and no EMI filter. These are for 16V input. The top trace shows results for 100% load, and the bottom trace shows the same test conditions except using 10% load.

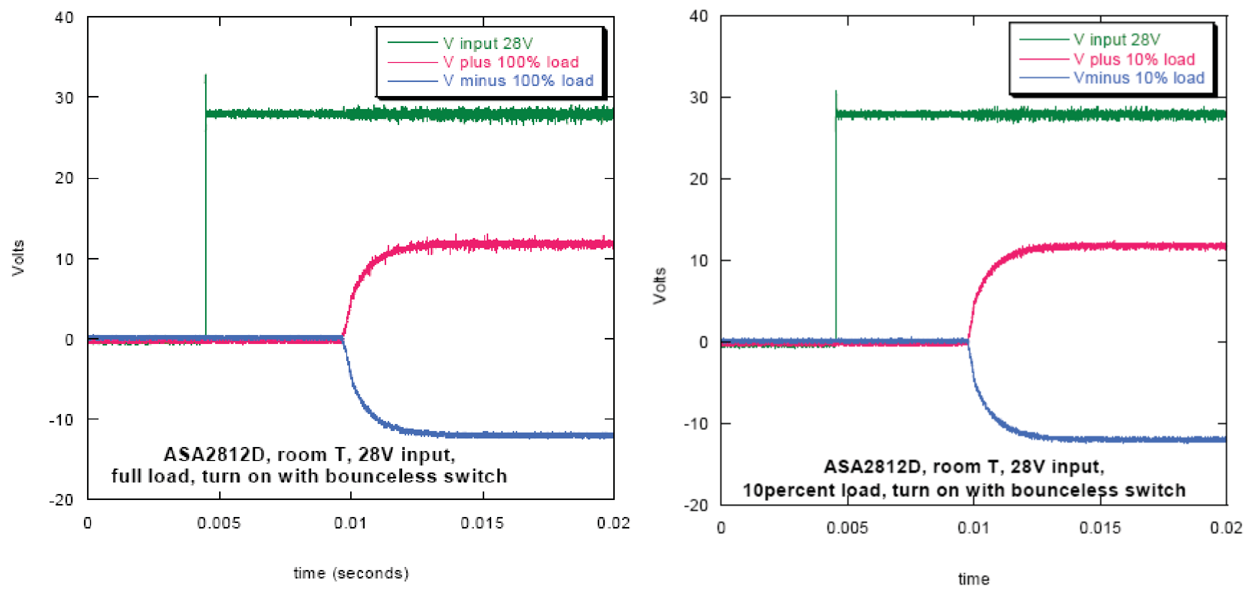


Figure 69. Room temperature turn-on tests using an Hg bounceless switch and no EMI filter. These are for 28V input. The top trace shows results for 100% load, and the bottom trace shows the same test conditions except using 10% load.

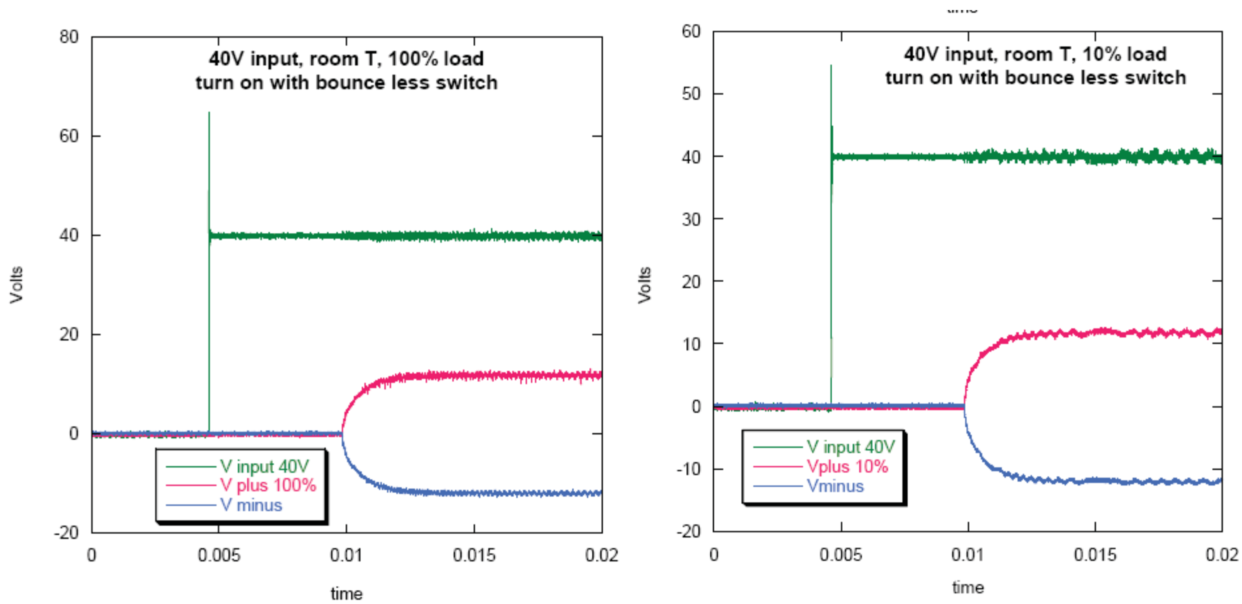


Figure 70. Room temperature turn-on tests using an Hg bounceless switch and no EMI filter. These are for 40V input. The top trace shows results for 100% load, and the bottom trace shows the same test conditions except using 10% load.

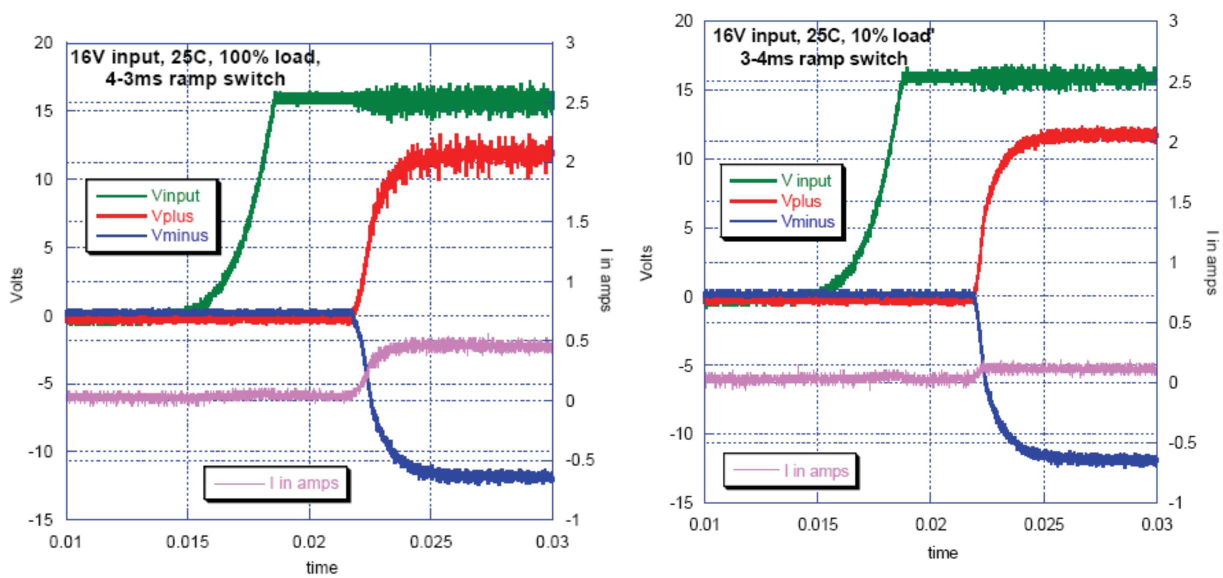


Figure 71. Room temperature turn-on tests using a millisecond delay ramp switch and no EMI filter. These are for 16V input. The top trace shows results for 100% load, and the bottom trace shows the same test conditions except using 10% load.

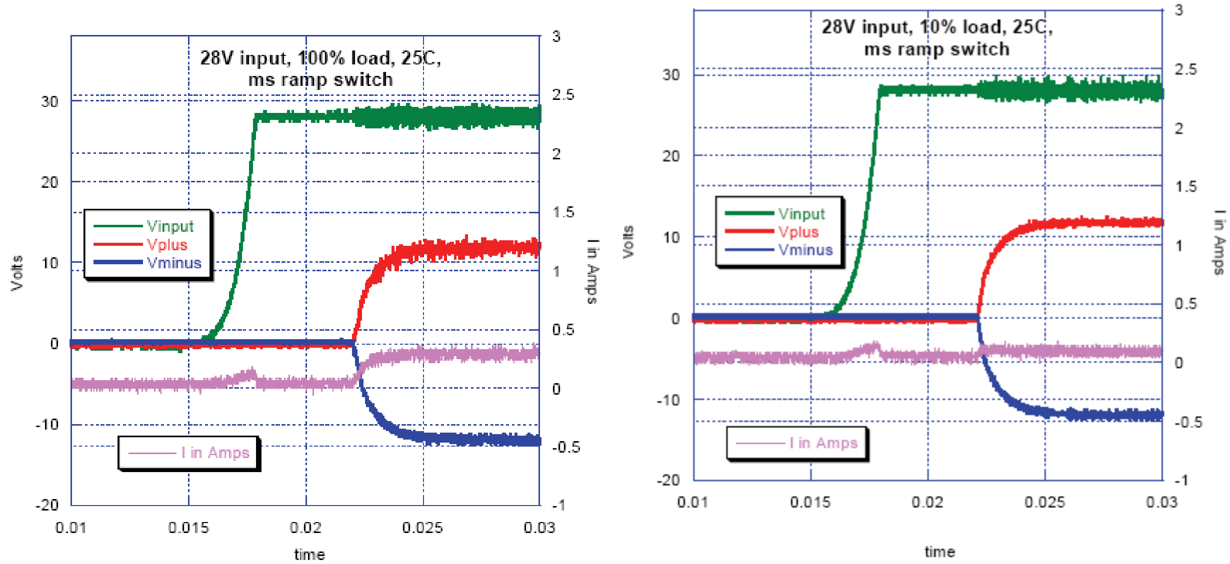


Figure 72. Room temperature turn-on tests using a millisecond delay ramp switch and no EMI filter. These are for 28V input. The top trace shows results for 100% load, and the bottom trace shows the same test conditions except using 10% load.

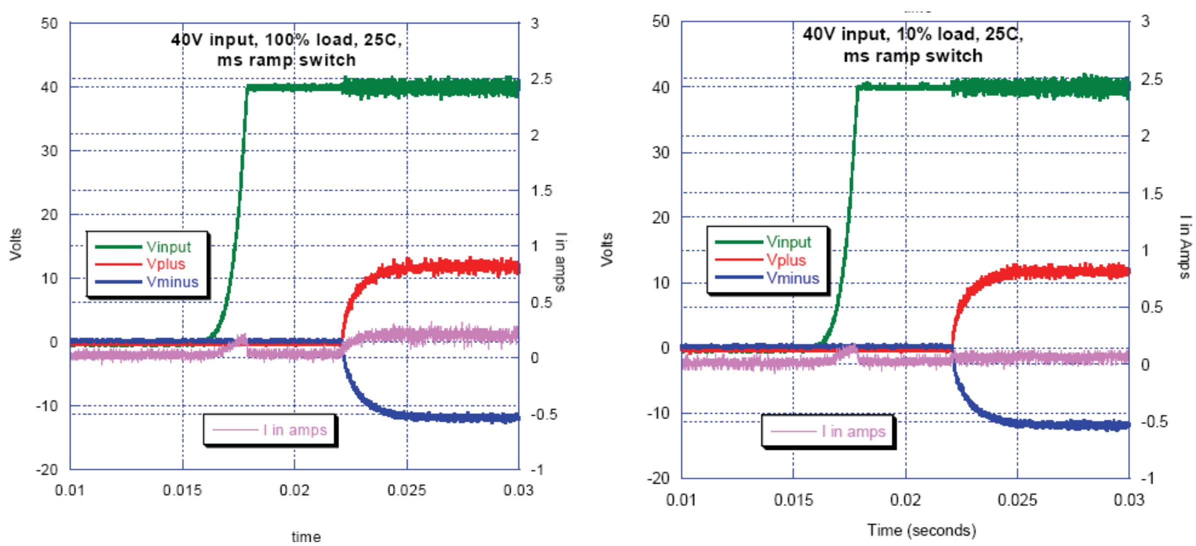


Figure 73. Room temperature turn-on tests using a millisecond delay ramp switch and no EMI filter. These are for 40V input. The top trace show results for 100% load, and the bottom trace shows the same test conditions except using 10% load.

Table 3. Manual turn-on/off room temperature test for converter ASA2812D.

	Turn on/off voltage 25°C (ASA2812D)
10% ramp-up	Converter starts to show some current above 8.9V. At 9.05V it is fully on.
10% ramp-down	At 8.87V converter turns off completely.
100% ramp-up	Converter is fully off up to 9.05V input. From 9.05V to 10.43V, the output voltage has large oscillations (motorboating). Fully on and stable at input voltage of 10.43V and above.
100% ramp-down	Converter shows large oscillations in its output voltage with input voltage below 10.43V and down to 8.85, when it turns itself fully off.

3.6 Current Overload and Short-Circuit Tests

Current overload and short-circuit tests were performed on one of JPL's AFL2812D units. These are described in detail and the scope traces plotted in a previous report [5].

The AFL2812D appeared to function normally even after the short-circuit and overload tests at high temperature; however, further tests done on it at room temperature a couple weeks later indicated that no matter the input, the converter stayed in motorboating mode; that is, "stuck" with a large oscillatory voltage output. Measuring the power consumption with no load and inhibit (tested for the previous task) indicates that the amount of power on the input is about six times greater than the power-out after the emergency feedback loop circuit trips to the safe mode. This large amount of power dissipates into heat in the converter, which is already at base plate temperature 125°C for the tests at the high end of the thermal scale. This large amount of power dissipated could possibly raise the temperature of the input or output transistors (or other elements) to as high as 175°C and cause failure.

The root causes of this failure or malfunction have been investigated in this work; the failure report is summarized in the following section.

3.7 Failure Reports: AFL2812D AND ART2815T

3.7.1 Failure of ART2815T

As explained in Section C on synchronization testing, this converter was operated normally but taken as low as -120°C. Other than lack of regulation (voltage output went unregulated and was very high, up to 46V for 50V input), the converter worked during the low temperature tests. However, upon bringing the temperature back up to 25°C, the converter was found to be "stuck" oscillating.

The converter was de-lidded and examined optically. One of the four output tantalum capacitors was found to be burned (not operational). Figure 74 shows an image of the de-lidded converter with one of the output capacitors showing an obvious "burn." This failure seems very similar to what was seen in the -108°C failure for Phoenix [6], even though the failed converter was a different model made by a different manufacturer.

The pulse width modulator (PWM) circuit that controls the duty cycle apparently stops working below a certain temperature (observed to be from -110°C to -120°C depending on load and input voltage). The PWM controls the voltage by adjusting duty cycle but, when it does not function, the duty cycle goes 100% and the output voltage ends up being very close to the input voltage, rather than the specified positive or negative 15C DC. When this happens, the output capacitor experiences a much larger voltage (measured up to 46V rather than the positive or negative 15V). Examination of the failed component shows it to be a tantalum capacitor rated for a maximum of 35V. At lower temperatures there is also a potential increase in series resistance, and thermal gradients associated with this could also be a problem.

To continue this work and determine if the converter can survive colder temperatures, the four output capacitors in this model will be replaced with similar capacitors but rated at a higher voltage (50V rather than 35V). While this strategy might make the converter survive temperatures below -80°C, making it functional at such low temperatures would require re-designing the circuit with the PWM.

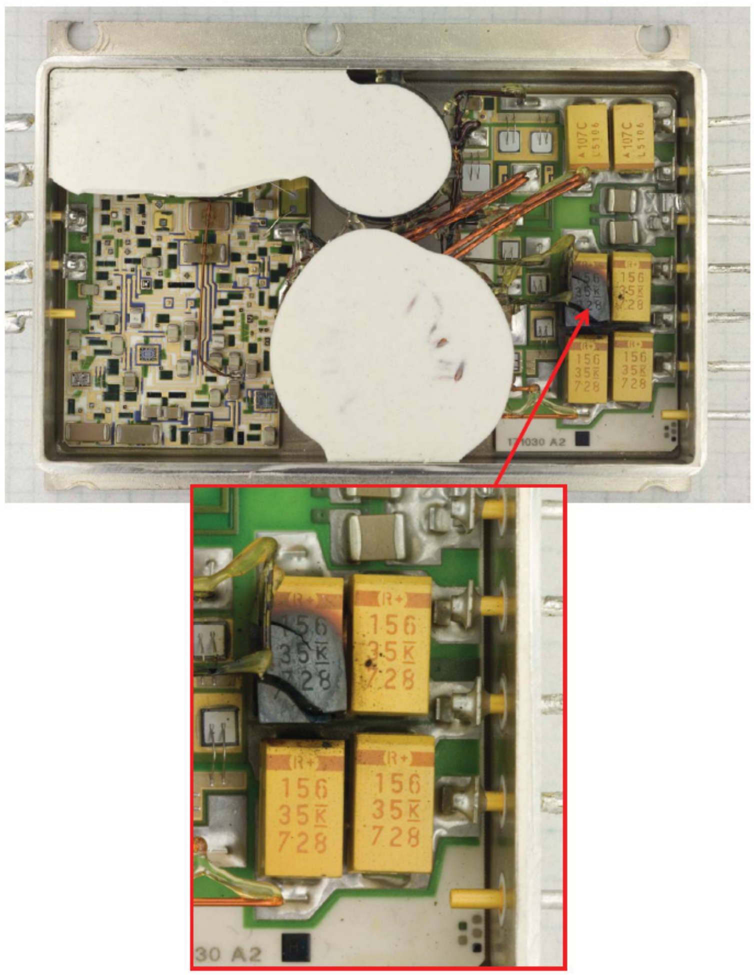


Figure 74. Burned capacitor on the output of ART2815T DC/DC converter after low temperature testing (below military range). This converter showed large voltage oscillations regardless of test conditions after it was brought down to -125°C.

3.7.2 Failure of AFL2812D

Since JPL owns three units of the AFL2812D of the same date code and the “failed” AFL2812D unit did power up, it was possible to compare the IR images upon turn-on in one of the working units with the non-working (oscillating) unit. In this side-by-side comparison, one unit functions within specs and the second unit is “stuck” motorboating. This means that whatever the temperature, load, or input voltage, the output is not steady but exhibits large voltage oscillations. Figure 75 shows the experimental set up with both units de-lidded and powered up, examined using an infrared camera. Both units were also independently monitored using T-type thermocouples. The working unit showed an increase in temperature from 23°C to about 26°C in a few minutes of operation. By contrast, the oscillating unit rose in temperature from 23°C to 40°C within a few seconds of operation.

Figure 76 shows the AFL2812D unit that is operating normally showing differential heat distribution upon turning on. This is to be compared with IR images of the same converter in the unit that failed (or got stuck oscillating) shown in Figure 77. Figure 77 shows the non-operational AFL2812D differential heat distribution upon turning on. When these images are compared (Figures 77 and 78), it is obvious that the heat distribution is completely different. Video recording immediately after turn-on indicates the diode at the output heats up first. Figure 78 shows optical images around the area of the damaged output diode (bottom) as compared with the same area in the working AFL converter. Slight pin points are obvious from the bottom image, even though these would have been very difficult to find without the assistance of the infrared imaging.

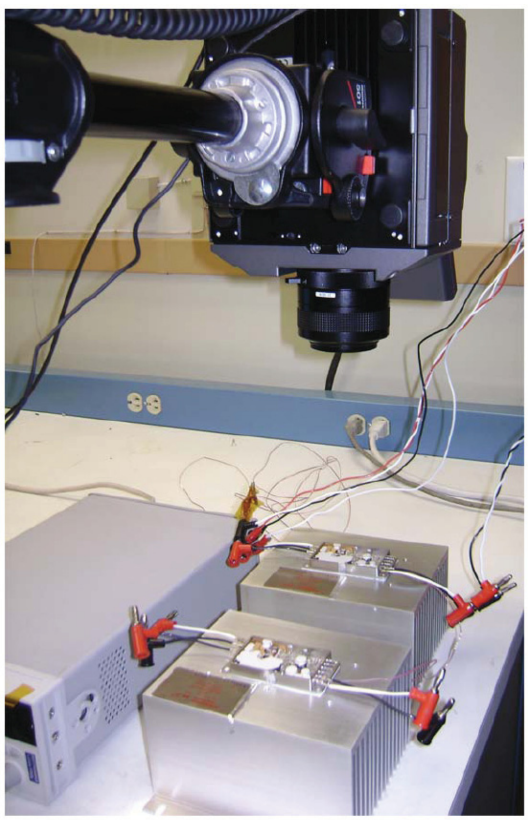


Figure 75. Test set-up comparing the IR image heat distribution evolution upon turn-on in working and nonworking AFL2812D converters.

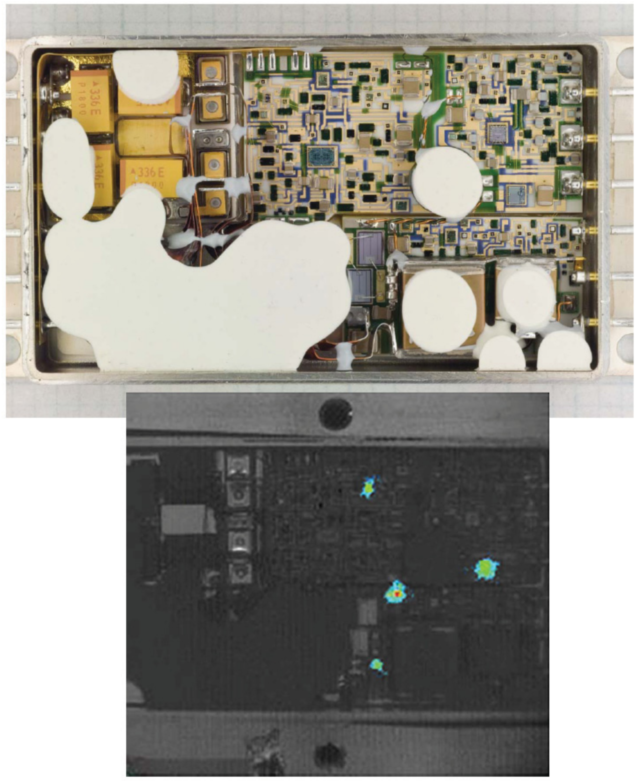


Figure 76. Optical image (top) and IR image (bottom) after turn-on in a working AFL2812D unit.

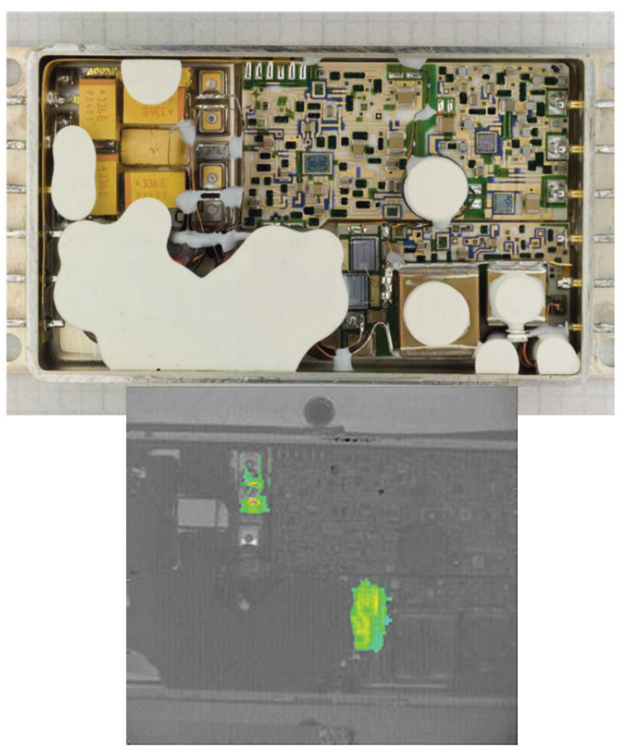


Figure 77. Non-operational unit for converter "D" showing differential heat distribution upon turning on. This is to be compared with IR images of the same converter in a unit that is running or functioning within specifications (shown in Figure 76). Video recording immediately after turn-on indicates the diode at the output heats up first.

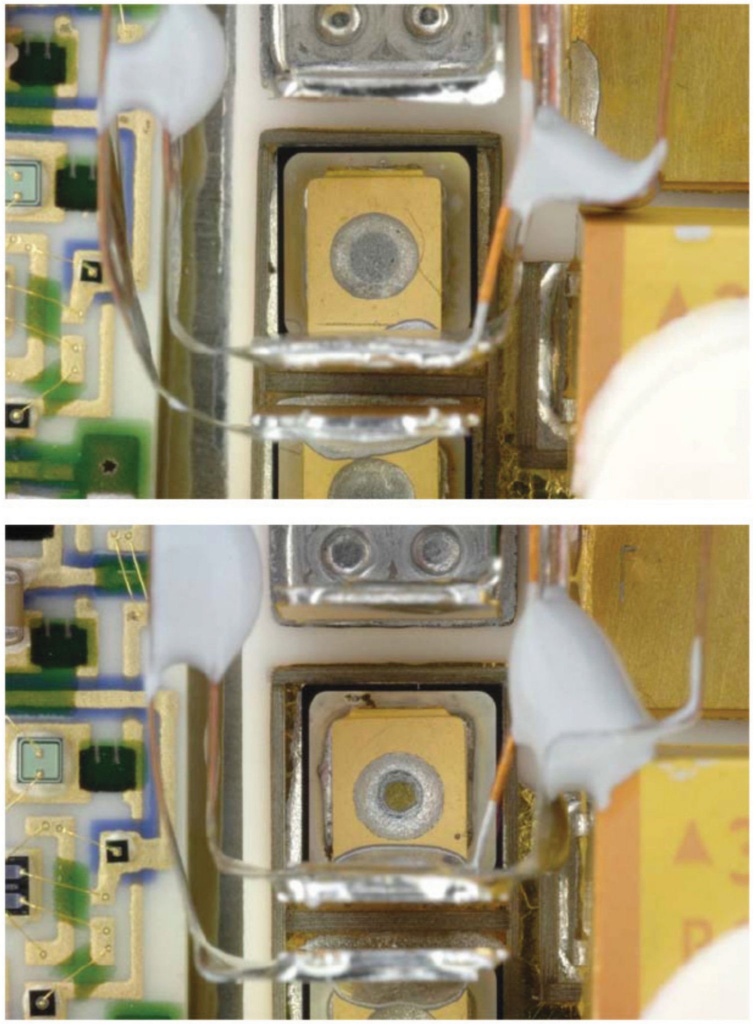


Figure 78. Optical images of the area around the output diode in an AFL2812D converter that is operating normally (top) and the one that is “stuck” oscillating after high temperature short-circuit and current overload tests (bottom). The output diode shows pin pricks that indicate damage to the diode.

4.0 SUMMARY

Tests were performed on a DC/DC converter that has been used in past, present, and future flight applications.

1. Comparison of test results with and without manufacturer-recommended EMI filters shows that:
   - EMI filters do not correct lack of synchronization when attempting to synchronize below minimum frequency in the ART2815T.
   - EMI filters mitigate some of the problems when attempting to synchronize above-maximum frequency but not all of the anomalies related to this measurement in the ART2815T.
   - EMI filters mitigate some of the “false start” voltage increase (which is more like a voltage surge) seen in the ART2815T when using ms delay ramp switches.
2. Results with low load pulsing during the load transient response tests done on the AFL2812D indicate that the later date code models of this converter have a slightly different circuitry, making later models more susceptible to large voltage oscillations when testing with low load transients.
3. Synchronization tests performed at room temperature and at -55°C were virtually identical; however, further reduction of the ambient temperature will:
   - Change the minimum synchronization frequency
   - Fail the converter below a certain temperature (still to be determined; ours did not survive -125°C)
4. Short-circuit/current overload tests will dangerously raise some components’ temperatures much higher than the 125°C nominal temperature and can result in converter failure when these tests are performed at 125°C.

5.0 REFERENCES

[1] Plante, J., DC/DC Converters User Database, NEPP site (http://nepp.nasa.gov).
[2] Barr, Cunningham, Facto, Nieraeth, Plante, Rutledge, Sharma, Shue, and Vorperian, NASA Guidelines for Selection and Applications of DC/DC Converters, May 2008.
[3] Leon, R., JPL Inter Office Memorandum 5145-08-001.
[4] Leon, R., JPL Inter Office Memorandum 5145-08-003.
[5] Leon, R., JPL Inter Office Memorandum 5145-08-004.
[6] Nguyen, T., MSL Interpoint converter application WCA guidelines and user's guidelines, Rev. A, 2 May 2007.