Power Supply Testing:
400 Hz Operation

White Paper by:
Brian Rinehart
Special Projects Technical Director
TABLE OF CONTENTS

Contents

EXECUTIVE SUMMARY .......................................................................................................................... 3
INTRODUCTION ........................................................................................................................................ 3
BACKGROUND ......................................................................................................................................... 3
TEST PHILOSOPHY, THEORY OF TEST ................................................................................................. 3
TEST CANDIDATES ................................................................................................................................. 5
RESULTS AND OBSERVATIONS ............................................................................................................. 6
CONCLUSIONS ....................................................................................................................................... 8
ABOUT THE AUTHOR .......................................................................................................................... 8
ABOUT CRYSTAL GROUP INC. .............................................................................................................. 8
EXECUTIVE SUMMARY

Crystal Group power supplies are 400 Hz compatible as evidenced with empirical test data. After appropriate loading was calculated for each supply, the minimum and maximum operating voltages as published on Crystal and competitor vendor data sheets for each supply was recorded and used to confirm start-up operation at 440 Hz under load at low and high temperature extremes. All power supplies that Crystal Group deploys for airborne applications have passed thermal, extended stress testing, and various load testing at 440 Hz. In general, Crystal Group does not advocate operating a commercial power supply at 400 Hz at its 50/60 Hz maximum voltage rating unless 400 Hz PF correction has been designed into the circuit.

INTRODUCTION

Crystal Group often receives requirements to accommodate 400 Hz power input on servers, switches, displays, and in general, any equipment targeted for certain airborne installations. Additionally, Crystal products are often vetted against competitor products where compliance to 400 Hz requirements may be claimed or publicly advertised as compliant. The purpose of this paper is to provide documentation that Crystal provided supplies are 400 Hz compatible, and back that claim with empirical test data. This documentation is intended to be shown publicly via website and manufacturer’s representatives and to mitigate the customer concerns.

BACKGROUND

Crystal Group Engineering has previously tested a few power supplies at 400 Hz input, and the results of that testing have been the basis for claiming compliance when products are fielded into 400 Hz power source environments. Neither formal procedures nor results of these investigations were published and Crystal Engineering has retained no formal record of these tests, procedures, or results. As a result, substantiating anything meaningful to back claims or provide credibility to 400 Hz compliancy statements has been incomplete until now.

TEST PHILOSOPHY, THEORY OF TEST

Most commercial power supplies are typically rated for input frequencies listed as 47-63 Hz for intended operation at 50 Hz or 60 Hz as available from most fixed residential and commercial power mains worldwide. The purpose of testing and documentation in this paper is not to validate vendor specifications, but rather to provide confidence in claiming compliant operation outside the stated vendor specifications, namely at 400 Hz, suitable for use with airborne power buses. In order to provide compliance with margin and eliminate borderline passing scenarios, a ten percent margin is being added to the nominal frequency to present a worst case operating condition, i.e., operational stress testing is being performed at 440 Hz rather than 400 Hz. Given that sensitivities or peculiarities may be presented at specific frequencies and not limited to frequency input extremes such as 440 Hz, 400 Hz spot checking as part of normal operation was also performed.

Appropriate loading for each power supply was based on 90% of the highest power rail capacity up to 95% of the overall rated power specified. It is worth noting that the highest power rail capacity is
typically 12 VDC and the capacity of other rails relative to 12 V tends to contribute insignificantly to
the overall power rating of a given supply. This consideration, combined with a common topology
for multiple rails in a given supply, and the convenience of managing a single common test set-up,
all provided sound engineering justification for concentrating on the highest capability rail for a
given supply. Further, as a matter of policy and practice, Crystal Group selects power supplies for
given applications rated such that they are never loaded above 85% for a given application. This
guarantees operating margin in every application, including those with 400 Hz power input.

After appropriate loading was calculated for each supply, the minimum and maximum operating
voltages as published on vendor data sheets for each supply was recorded and used to confirm
start-up operation at 440 Hz under load at low and high temperature extremes. Finally, after basic
operation at room temperature and startup operation at low and high voltage and at low and high
temperature, stress testing (repeated on/off cycling) with 90% loading at low and high voltage at
high temperature was performed for each power supply under test.

In summary, the following six conditions were evaluated for each power supply. Passing all seven
of these tests constitutes the criteria for deeming a given power supply applicable for operation in
a 400 Hz harsh environment.

- Basic operation at room temperature
- Start-up operation at cold temperature (-40°C) with low voltage input
- Start-up operation at cold temperature with high voltage input
- Start-up operation at high temperature (+55°C) with low voltage input
- Start-up operation at high temperature with high voltage input
- Stress testing (repeated on/off cycling) at high temperature with low voltage input
- Stress testing at high temperature and high voltage input

The list of test equipment utilized and a simple block diagram are shown below in Table 1 and Figure
1 respectively. The actual test set-up is pictured in Figure 2.

<table>
<thead>
<tr>
<th>Description</th>
<th>Make &amp; Model</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows 7 Laptop Computer</td>
<td>(Not critical)</td>
<td>Control and Monitoring</td>
</tr>
<tr>
<td>Digital Power Supply Load</td>
<td>HP 6060B</td>
<td>Medium Power DC Loading</td>
</tr>
<tr>
<td>Analog Power Supply Load</td>
<td>Crystal Engineering</td>
<td>High Power DC Loading</td>
</tr>
<tr>
<td>AC Frequency Generator</td>
<td>Elgar 2501P (1) or 1251P (2)</td>
<td>400 Hz Source and PF Monitor</td>
</tr>
<tr>
<td>Temperature Chamber</td>
<td>Thermatron</td>
<td>Low and High Temperature Testing</td>
</tr>
<tr>
<td>Current Probe</td>
<td>HP 1146A</td>
<td>Waveform Monitoring, Electrical Current</td>
</tr>
<tr>
<td>Differential Voltage Probe</td>
<td>Agilent N2791A</td>
<td>Waveform Monitoring, Voltage</td>
</tr>
<tr>
<td>Oscilloscope</td>
<td>Tektronix MSO 4054B</td>
<td>Waveform Monitoring</td>
</tr>
<tr>
<td>Electronic Power Switch</td>
<td>Crystal Engineering</td>
<td>Cyclical Stress Screening</td>
</tr>
</tbody>
</table>
TEST CANDIDATES

Approximately 30 power supply part numbers were examined for applicability to 400 Hz power supply testing, including 1U and 2U models intended for internal chassis use as well as bricks intended for external chassis use. Units that are no longer used on active products and whose likelihood of future use were eliminated. Additionally, two other models were eliminated due to known duplication in topology and circuitry. The following table shows some units considered for testing:
RESULTS AND OBSERVATIONS

All of the power supplies tested passed the thermal, stress test, and low/high voltage operation criteria at 440 Hz. However, there is one very important parameter that must be considered in deeming a power supply appropriate for operation in a 400 Hz environment. This parameter is known as power factor, commonly abbreviated as PF. In layman’s terms, PF is a measure of how much reactance (frequency sensitive resistance) there is that causes an out of phase relationship between the current and the voltage. The higher the PF (desired), the lower the reactance and the more current is in phase with the voltage. The lower the PF (undesired), the higher the reactance and the more out of phase is the current with respect to the voltage. The lower the PF and out of phase the current is with the voltage, the more real power is needed to perform the same level of work compared to in phase current and voltage. This results in the need for higher power generation capability on the aircraft. While most of the power supplies tested include power factor correction in their respective electrical designs, it is clear that these PF circuits were designed for operation at 50-60 Hz (consistent with data sheet specifications). See Figures 3 and 4 for examples of poor and good power factor measurements.

<table>
<thead>
<tr>
<th>Crystal PN</th>
<th>Manufacturer</th>
<th>Description</th>
<th>Used On</th>
</tr>
</thead>
<tbody>
<tr>
<td>V11775PFC</td>
<td>JAF/Zippy</td>
<td>460W 1+1</td>
<td>Various RS + Mandiant</td>
</tr>
<tr>
<td>V11799PFC</td>
<td>Seasonic</td>
<td>600W 2U</td>
<td>RS Product Line</td>
</tr>
<tr>
<td>EDV-00119</td>
<td>Zippy</td>
<td>600W 1+1</td>
<td>RS Product Line</td>
</tr>
<tr>
<td>EDV-00226</td>
<td>Zippy</td>
<td>1350W 1U N+1</td>
<td>RS639</td>
</tr>
<tr>
<td>EDV-00272</td>
<td>Seasonic</td>
<td>250W 1U</td>
<td>RS101X2, RE08, RS111, etc.</td>
</tr>
<tr>
<td>EDV-00302</td>
<td>Zippy</td>
<td>600W 1+1</td>
<td>RS Product Line</td>
</tr>
<tr>
<td>EDV-00324</td>
<td>Zippy</td>
<td>760W 1+1</td>
<td>Various RS/IS</td>
</tr>
<tr>
<td>EDV-00351</td>
<td>Seasonic</td>
<td>460W 1U</td>
<td>RS Product Line</td>
</tr>
<tr>
<td>EDV-00364</td>
<td>Zippy</td>
<td>500W 1+1</td>
<td>RS262S17G, RFB Products</td>
</tr>
<tr>
<td>EDV-00412</td>
<td>Zippy</td>
<td>1200W 1+1</td>
<td>RS3, RS4 Products</td>
</tr>
<tr>
<td>EDV-00586</td>
<td>Super Micro</td>
<td>960W 12V 1U</td>
<td>RS126L24X2</td>
</tr>
<tr>
<td>EDV-00597</td>
<td>Interface Masters</td>
<td>460W 1U</td>
<td>IM Switches</td>
</tr>
<tr>
<td>EDV-00335</td>
<td>Elpac</td>
<td>150W 18V Brick</td>
<td>RE Product Line</td>
</tr>
</tbody>
</table>
When the supplies are operated at 440 Hz with no PF correction or PF correction not rated to 400 Hz, there are a few generalizations that can be made:

**Figure 3.** 400 Hz waveform at 240 VAC with 10% supply loading. Besides the waveform distortion, note the significant lagging in current to the voltage. PF in this case is only 0.26—not suitable for high voltage airborne applications. Fortunately, typical airborne power busses do not operate at 240 VAC.

**Figure 4.** 400 Hz waveforms at 115 VAC and 90% supply loading. PF is 0.98, perfect for 400 Hz aircraft installations.

When the supplies are operated at 440 Hz with no PF correction or PF correction not rated to 400 Hz, there are a few generalizations that can be made:
• PF is voltage sensitive. The higher the input voltage, the lower the measured PF values tend to be. For this reason, it is not recommended to operate any power supply not designed with 400 Hz PF correction at its maximum 50/60 Hz voltage rating of the supply. Fortunately, nominal aircraft bus voltage at 400 Hz is 115 VAC and this is not an issue.
• PF is temperature sensitive. At high temperatures, a reduction in PF of about 0.05 can generally be observed compared to room ambient or cold temperature operation.
• PF is load sensitive. The higher the load, the higher the observed PF value. The lower the load, the worse the PF readings tend to be.

Again, these are generalizations and not necessarily hard rules for every power supply, especially if a supply was specifically designed for power factor correction at 400 Hz.

CONCLUSIONS

All power supplies that Crystal Group deploys for airborne applications have passed thermal, extended stress testing, and various load testing at 440 Hz. In general, Crystal Group does not advocate operating a commercial power supply at 400 Hz at its 50/60 Hz maximum voltage rating unless 400 Hz PF correction has been designed into the circuit. However, since most power supplies Crystal Group deploy maintain a 240 VAC or higher maximum rating, all of these are deemed appropriate for aircraft platform voltages of 115 VAC nominal at 400 Hz, consistent with the testing herein.

ABOUT THE AUTHOR

Brian Rinehart is a Special Projects Technical Director with Crystal Group. He has been with the company since 2010. Prior to Crystal Group, Brian was a Senior Engineering Manager at Rockwell Collins for several years. Brian received BSEE, in RF and DSP Communication from Iowa State University.

ABOUT CRYSTAL GROUP INC.

Crystal Group Inc., an employee-owned small business located in Hiawatha, Iowa, USA, is a technology innovation leader specializing in both custom and COTS products for defense, government and industrial markets since 1987. Crystal Group designs and manufactures installation-ready rugged servers, displays, networking devices, embedded systems, power supplies and storage devices that fit critical applications in demanding environmental conditions.


crystalrugged.com