# ISS Power Inverter Electromagnetic Emissions with Distorting Loads

Engineering Directorate
Propulsion and Power Division

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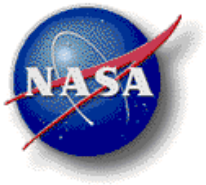
Baseline
November 2014

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**ISS Power Inverter Electromagnetic Emissions with Distorting Loads**
**November 2014**

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# Change Record

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# 1. Introduction

This document describes the results of EMI tests conducted to evaluate the EMI emissions of a 120VDC ISS Power Inverter operating with loads that cause its output to be distorted.

# 2. Scope

This document is relevant to the following hardware:

Table 1: Applicable hardware

| Description | OPSNOM | NASA Part Number | Original Vendor Part Number |
|---|---|---|---|
| 120VDC ISS Power Inverter | 120 VDC to 120 VAC Inverter | SEG33123254-301 | XPK-1-I-6-1-97 |
| 120VDC ISS Power Inverter | 120 VDC to 120 VAC Inverter | SEG33123254-303 | XPK-1-I-6-1-97 |

Applicability to 28V Inverter: The 28VDC ISS Power Inverter (P/N SEG33123255-301) has an output PWM circuit and filter very similar to that in the 120VDC ISS Power Inverter. The testing described in this document did not includes tests on the 28V Inverter, but the circuit similarities do suggest that the 28V inverter would have similar radiated emissions.

# 3. Background

The inverter handles potential overloads on its output by lowering the effective output voltage to control the output current and keep it to a safe level. It lowers the output voltage by distorting the normal sinewave output waveform. The inverter is designed to do this and it does not cause the inverter to overheat. Engineers at the European Space Agency have expressed a concern that when the output waveform is distorted in this way, the inverter may generate more EMI, either conducted or radiated. The purpose of this test is to measure the emissions when the inverter is operating with a distorted output.

Test dates: 8/27/2014, 8/28/2014

# 4. Reference documents:

| Document No. | Title |
|---|---|
| EMCO-14-018 | EMC Work Order Testing of the European Space Agency EMI/EMC Evaluation of the ISS Inverter |
| JSC-66532 | ISS Power Inverter Commercial AC Load Technical Considerations |
| JSC-66202 | ISS Power Inverter to 120VAC 60Hz Loads Interface Defintion Document (IDD) |
| SSP 30238 | Space Station Electromagnetic Techniques |
| TIA 1291B | Tailoring/Interpretation Agreement |

# 5. Test Configurations and Results

## 5.1 Results for configuration 1:

As noted in section 5.2 of JSC-66532, many commercial and industrial loads, particularly heaters, regulate their power consumption by varying the phase angle at which the resistive load is connected to the AC power source. It is quite plausible to have such a phase controlled load set to a power level less than the inverter maximum power rating.

The test configuration is a phase controlled load set to approximately 90 degrees phase delay and is based on figure 4 of JSC-66532.

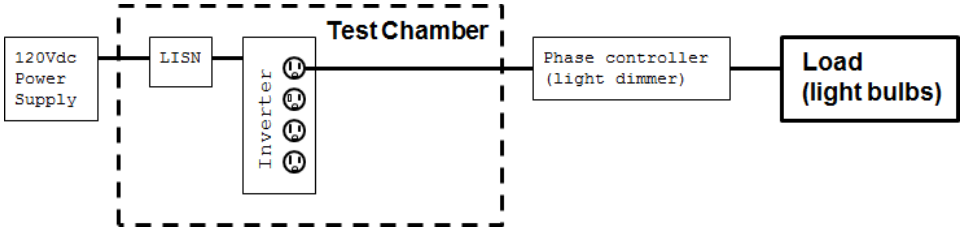


Figure 1: Block diagram of configuration 1.

### 5.1.1 Time Domain

- Input voltage: 120VDC
- Input current:average: 3.48 ADC
- Input current:ripple: 1.72 Ap-p
- Input power : 418 W
- Output current 5.45 $A_{RMS}$
- Output Voltage 99.7 $V_{RMS}$
- Output apparent power 544 VA
- Output Real Power 300 W
- Load Power factor 0.55
- Effective load resistamce: 10.5 ohms

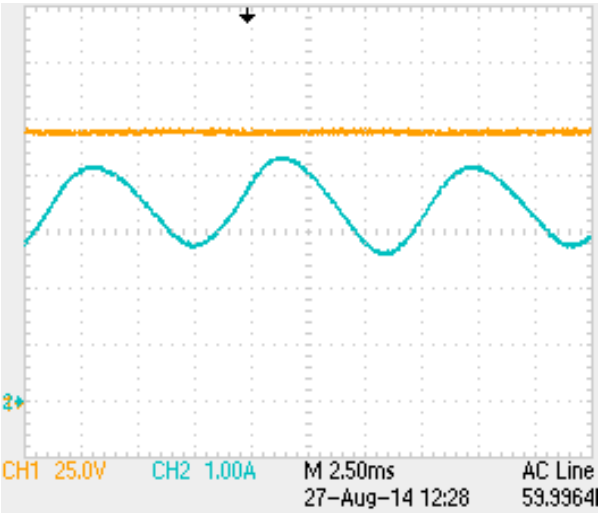


Figure 2: Inverter input current and voltage with configuration 1

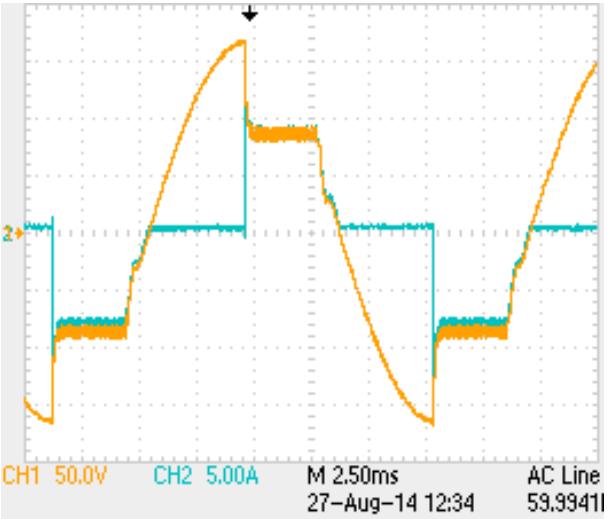


Figure 3: Inverter output current and voltage with configuration 1.

### 5.1.2 Conducted emissions

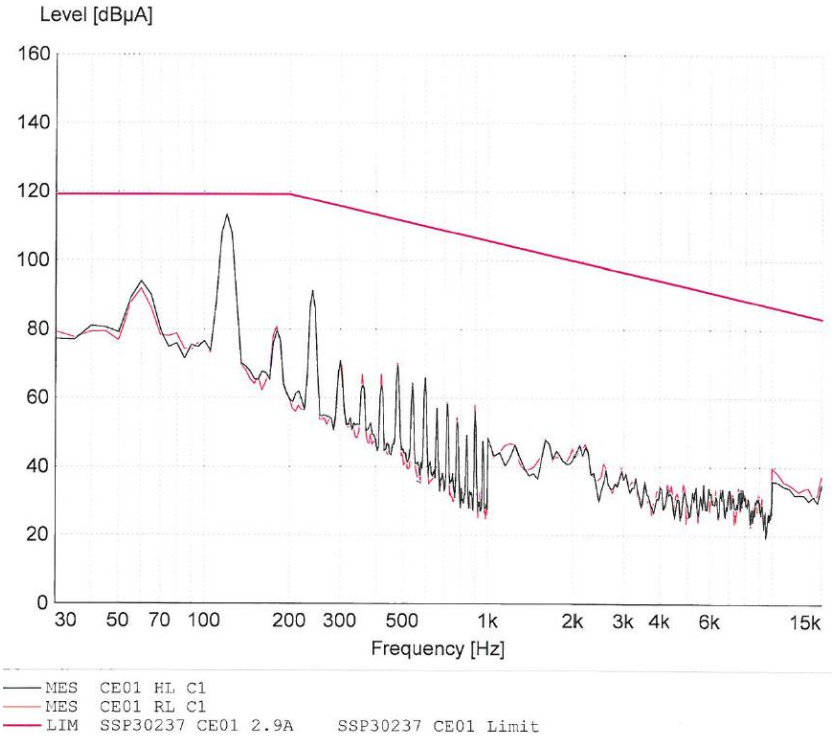


Figure 4: CE01 Inverter conducted emissions with configuration 1 (30 Hz – 15 kHz).

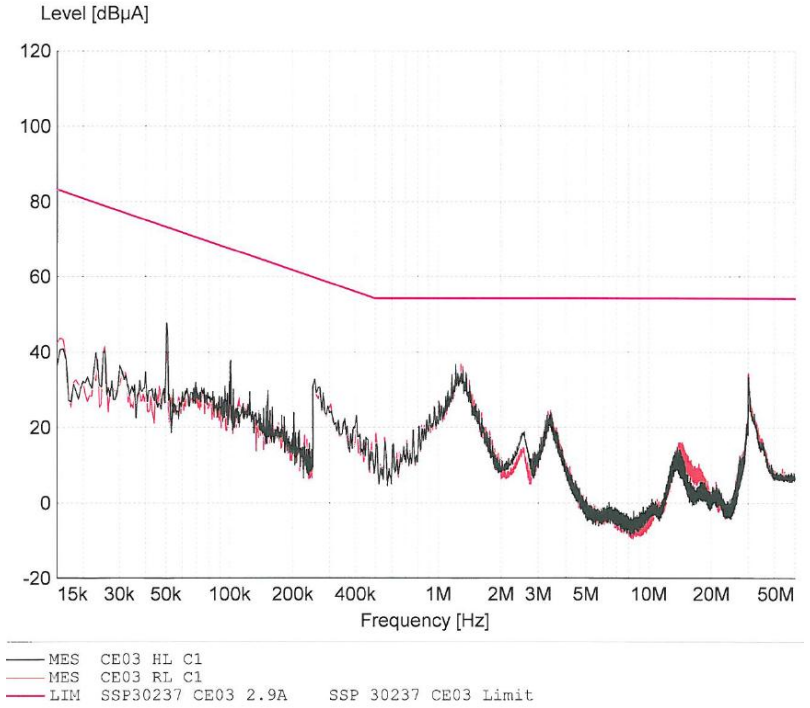


Figure 5: CE03 Inverter conducted emissions with configuration 1 (15 kHz – 50 MHz)

### 5.1.3 Radiated emissions

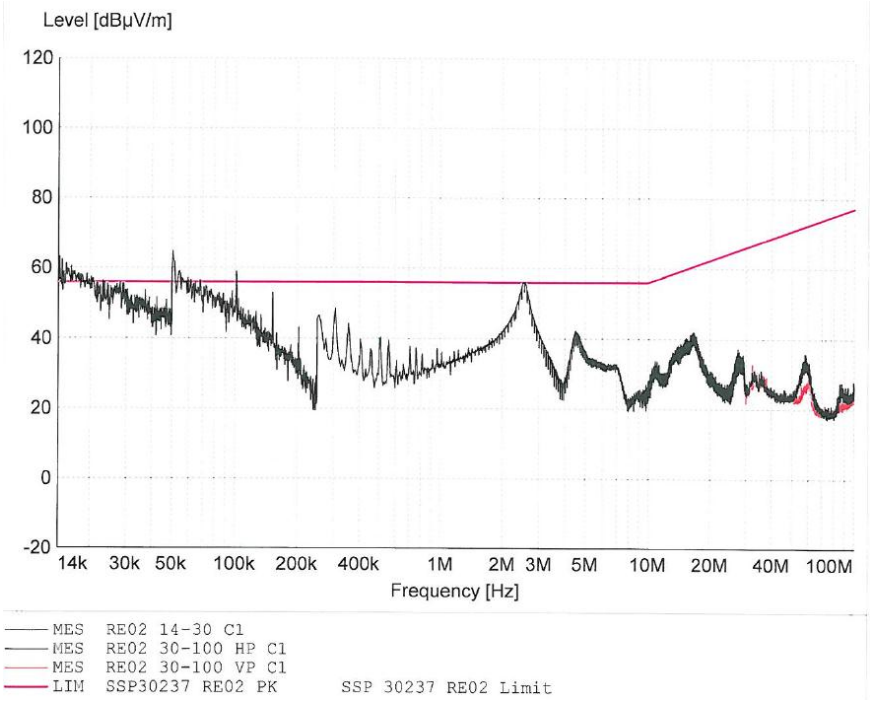


Figure 6: RE02 Inverter radiated emissions with configuration 1.

## 5.2 Results for configuration 2:

This test configuration was designed to show the effects of a straightforward resistive overload. It was interesting to note that the inverter current regulation level (flat top of distorted sine wave) moved up and down over a period of minutes over a range of about +/- 10%. This was most noticeable because it made the inverter input current vary from 6.8A down to 5.6A.

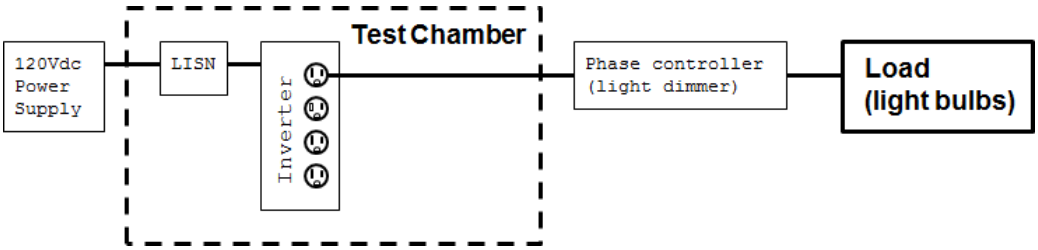


Figure 7: Configuration 2.

### 5.2.1 Time Domain

- Input power : 823 W
- Input voltage: 120VDC
- Input current average: 6.81 ADC
- Input current ripple 2.32 Ap-p
- Output current 7.18 $A_{RMS}$
- Output Voltage 96.7 $V_{RMS}$
- Output apparent power 695 VA
- Output Real Power 682 W
- Load Power factor 0.98
- Effective load resistamce: 10 ohms

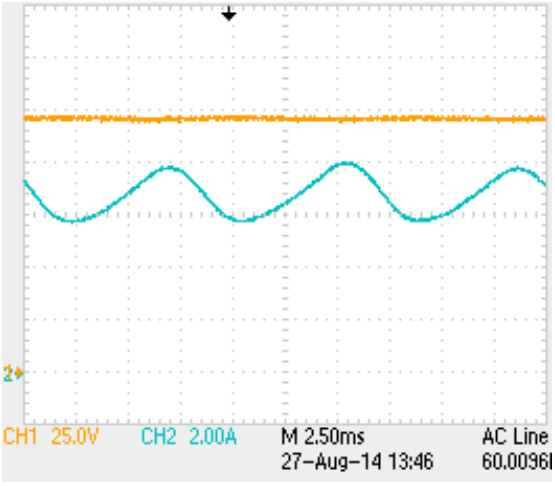


Figure 8: Inverter input current and voltage with configuration 2.

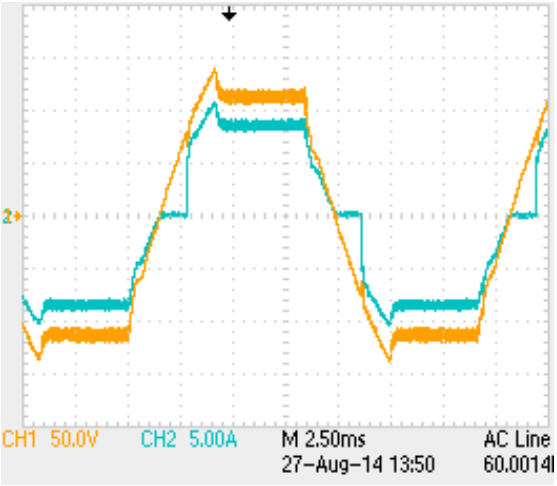


Figure 9: Inverter input current and voltage with configuration 2.

### 5.2.2 Conducted emissions

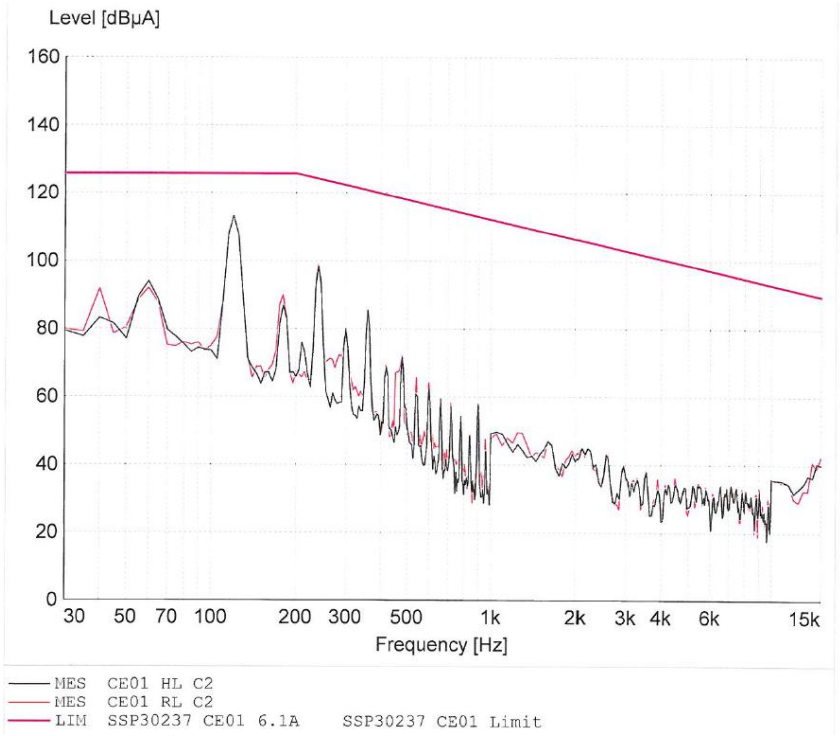


Figure 10: CE01 Inverter conducted emissions with configuration 2 (30Hz – 15 kHz)

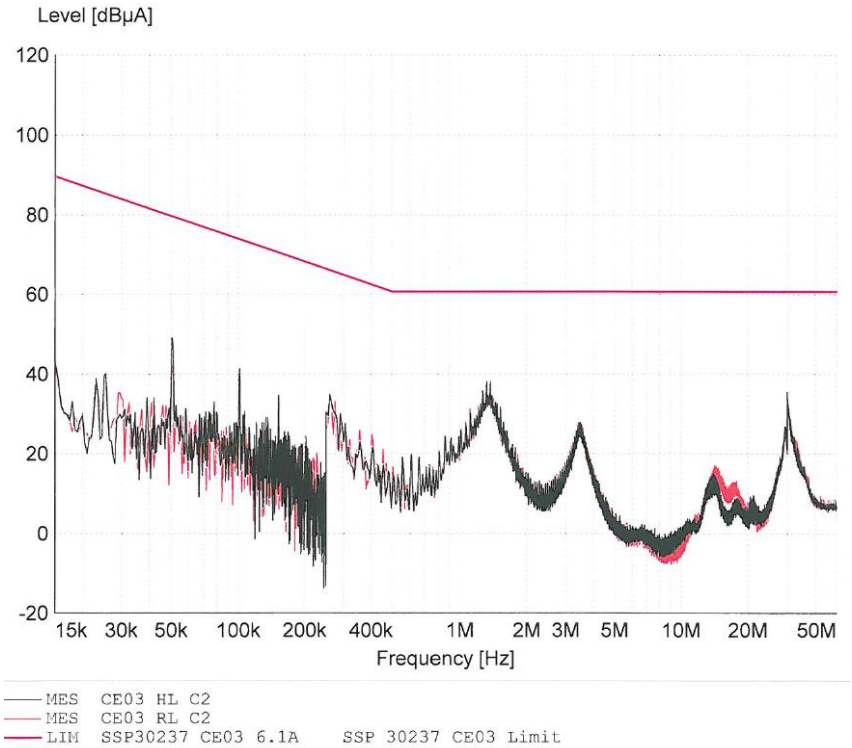


Figure 11: CE03 Inverter conducted emissions with configuration 2 (15 kHz – 50 MHz)

### 5.2.3 Radiated emissions

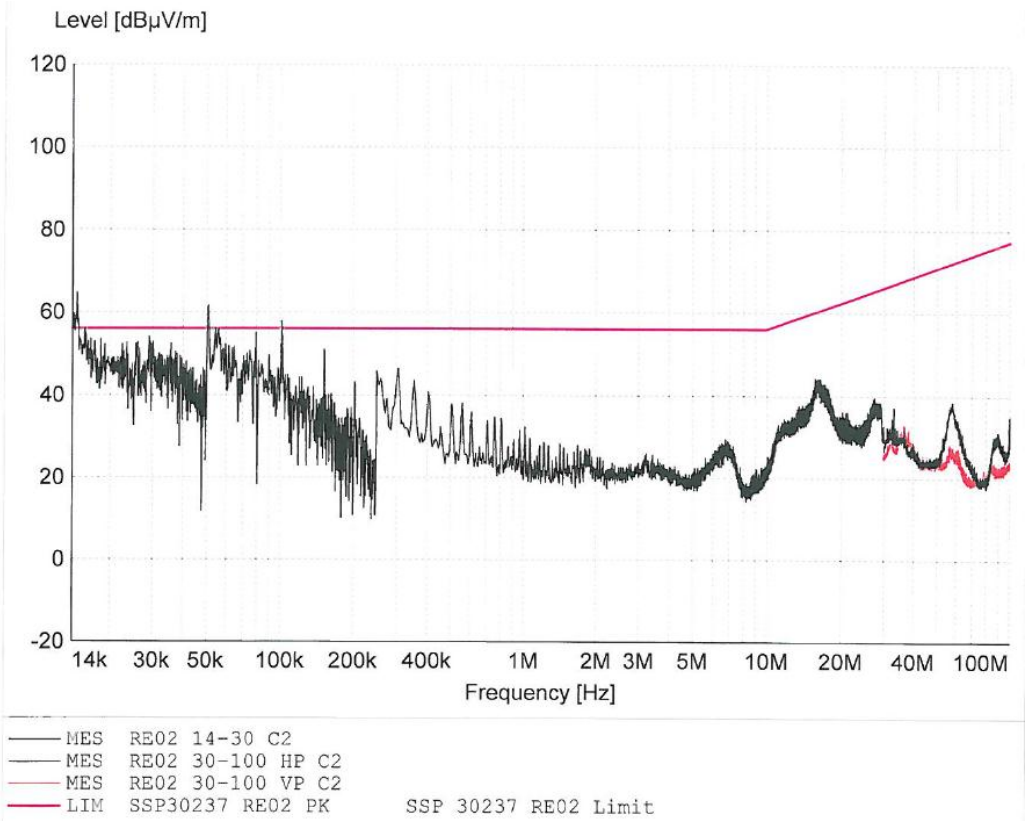


Figure 12: RE02 Inverter Radiated emissions with configuration 2.

## 5.3 Results for configuration 3:

Many commercial loads have a rectifier/capacitor input (JSC-65532 section 7). Configuration 3 consists of four of the COTS AC power adapters for the laptop currently used on the ISS. The output of each AC adapter is loaded with a resistor at 75% of adapter full load. This is quite a realistic load to expect on the ISS eventually.

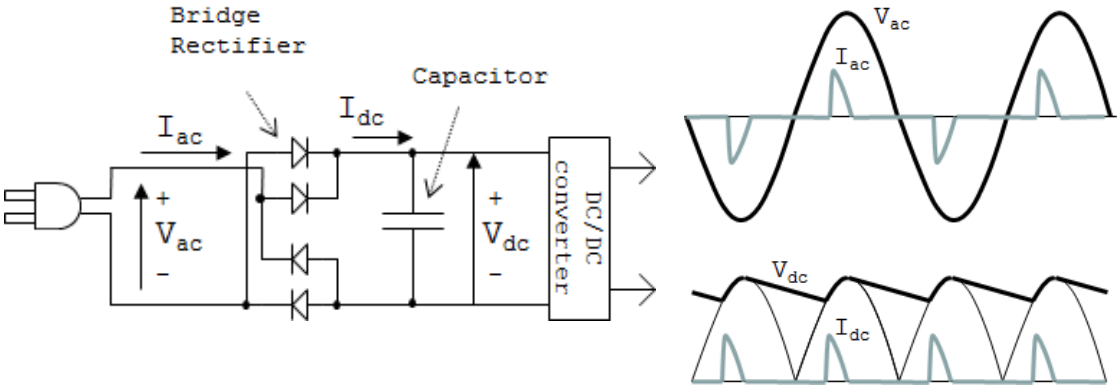


Figure 13: Simplified Rectifier/Capacitor Circuit and Idealized Waveforms

### 5.3.1 Configuration 3:

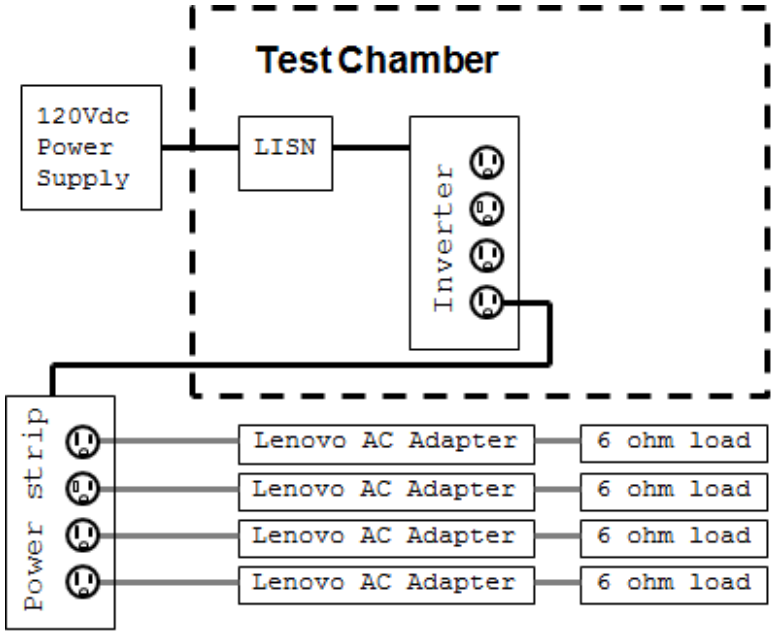


Figure 14: Test configuration 3

### 5.3.2 Time domain waveforms

- Input voltage: 120VDC
- Input current:averaqge: 2.79 ADC
- Input current:ripple: 1.64 Ap-p
- Input power : 337 W

- Output current 3.84 $A_{RMS}$
- Output Voltage 120.3 $V_{RMS}$
- Output apparent power 462 VA
- Output Real Power 310 W
- Load Power factor 0.67

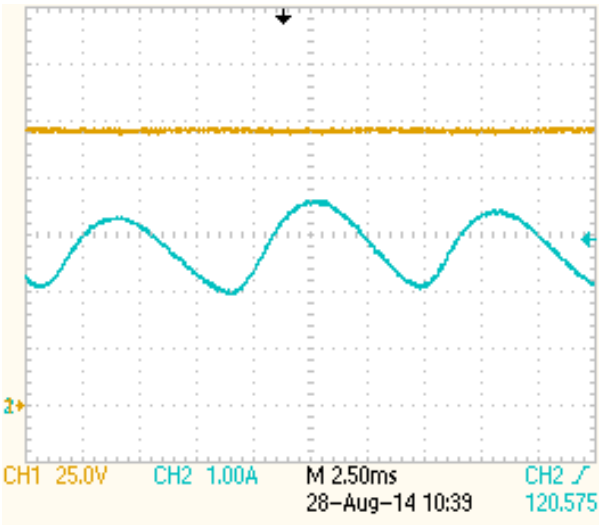


Figure 15: Inverter input current and voltage with configuration 3.

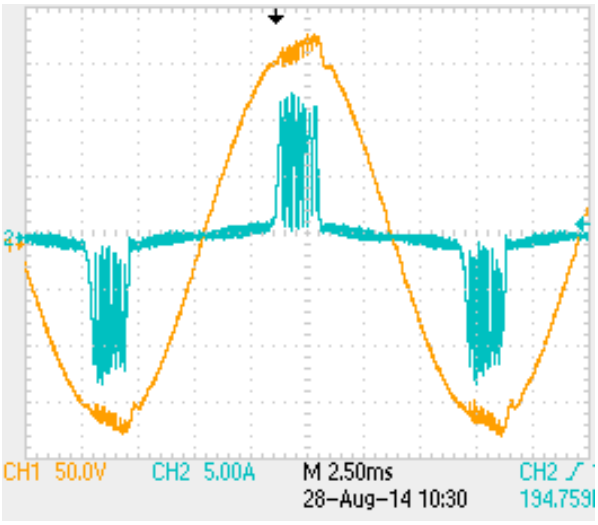


Figure 16: Inverter output current and voltage with configuration 3.

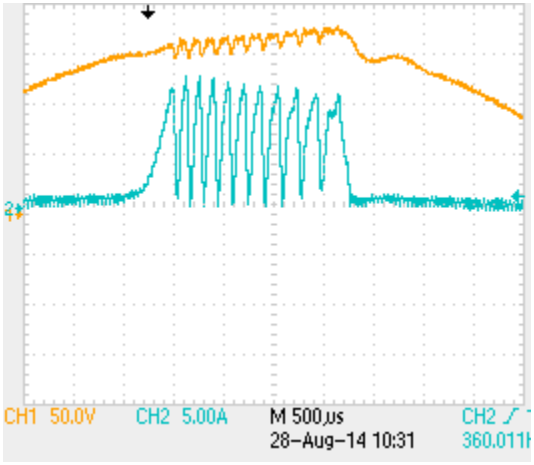


Figure 17: Closeup of inverter input current and voltage with configuration 3.

### 5.3.3 Conducted emissions

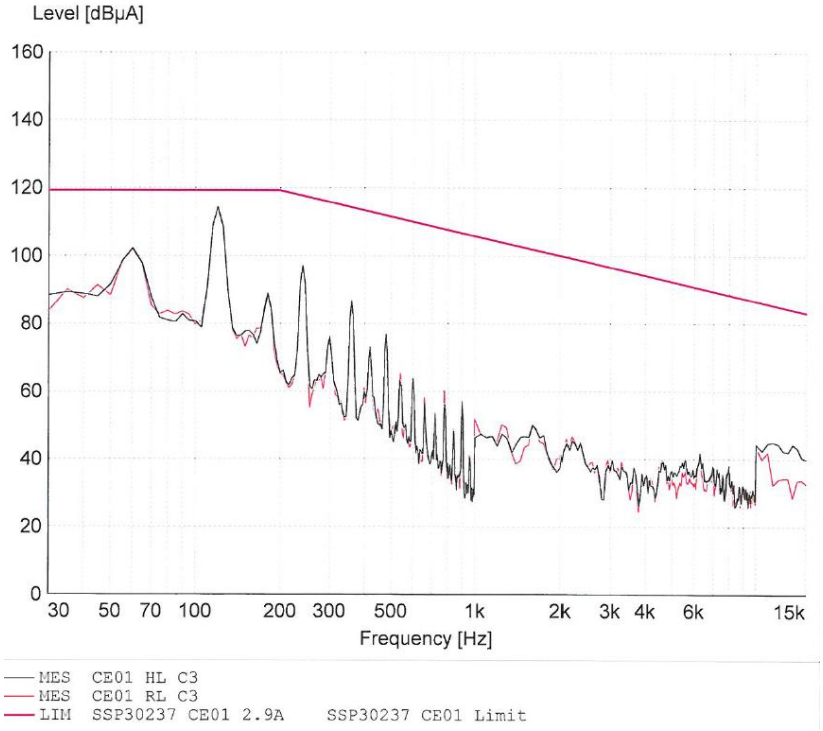


Figure 18: CE01 Inverter conducted emissions with configuration 3 (30 Hz – 15 kHz).

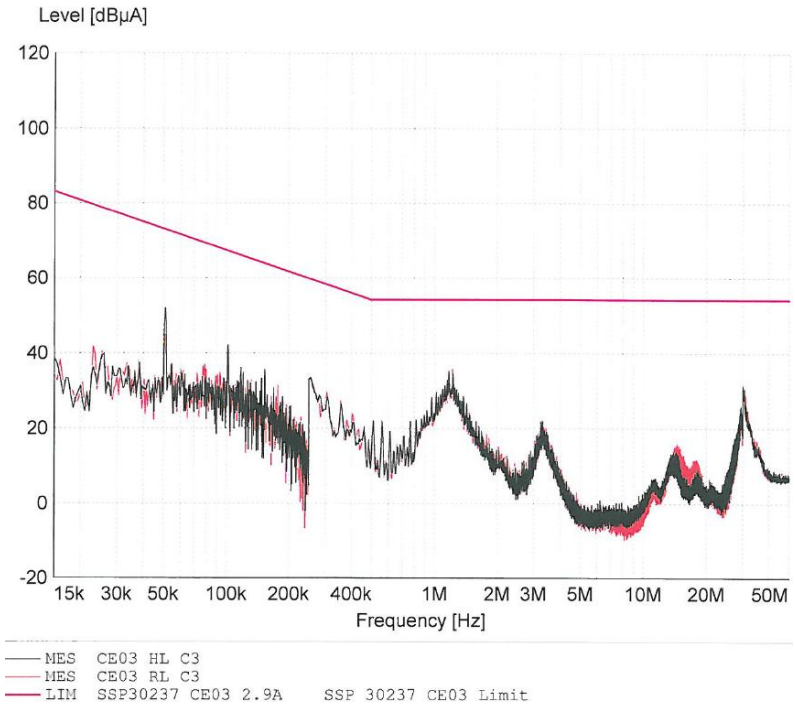


Figure 19: CE03 Inverter radiated emissions with configuration 3 (15 kHz –50 MHz).

### 5.3.4 Radiated emissions

Remarks on results: Notice that the radiation.

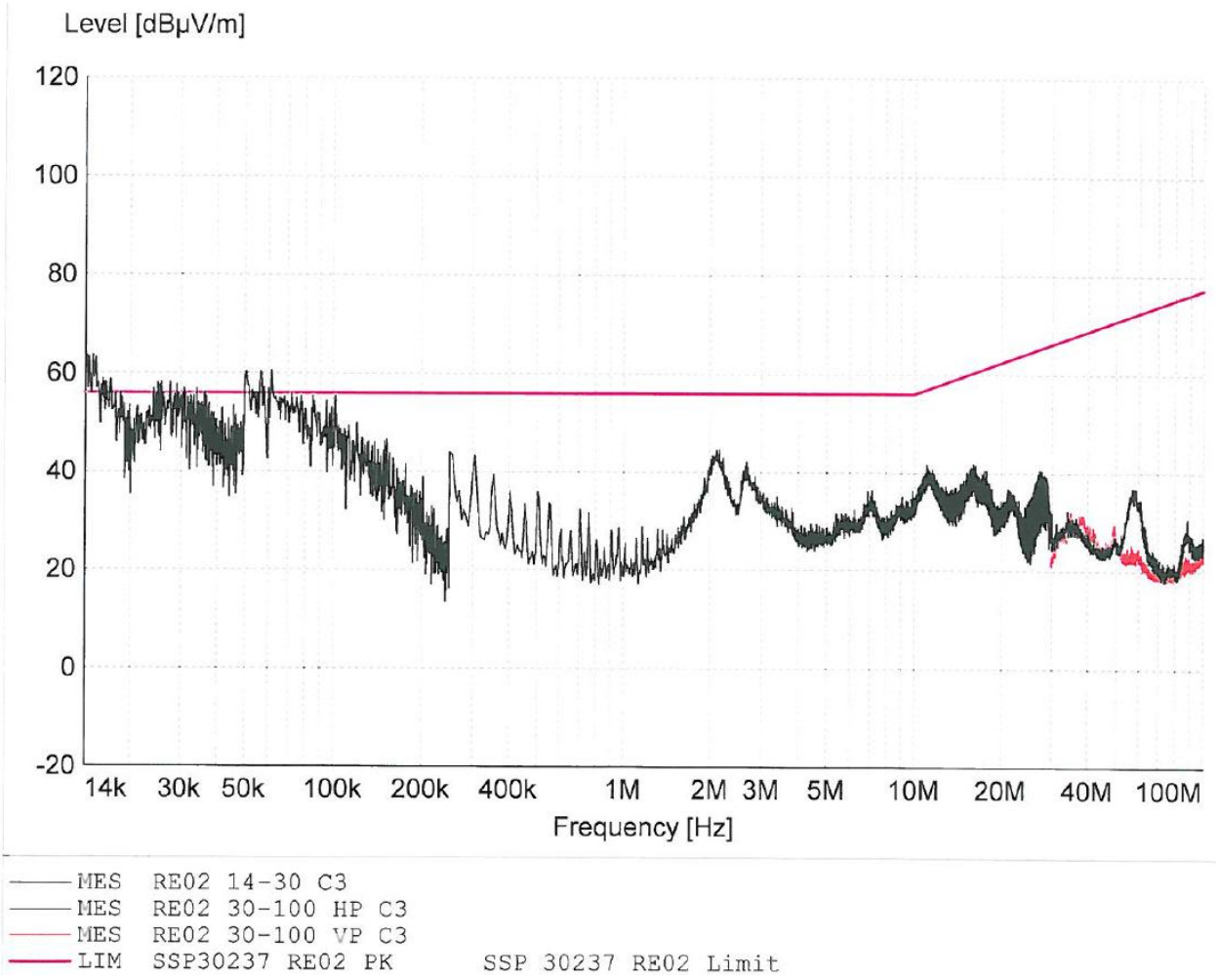


Figure 20: RE02 Inverter radiated emissions with configuration 3.

## 5.4 Nondistorting 250W load for comparison:

This load was a simple 250W resistive load sized to avoid distorting the inverter output.

### 5.4.1 Radiated Emissions of nondistorting load

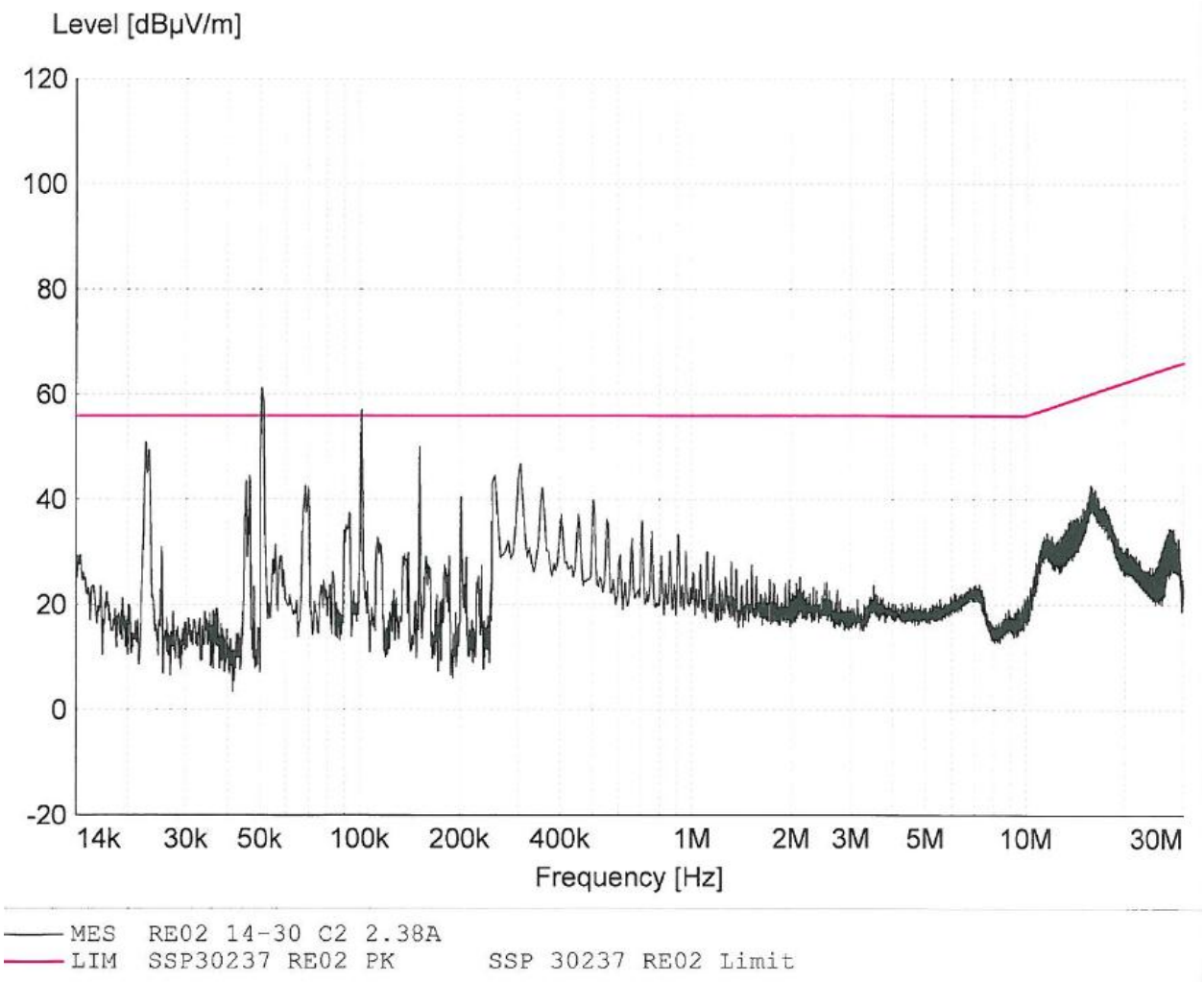


Figure 21: Inverter radiated emissions with non-distorting 250W load for comparison.

# 6. Discussion of results

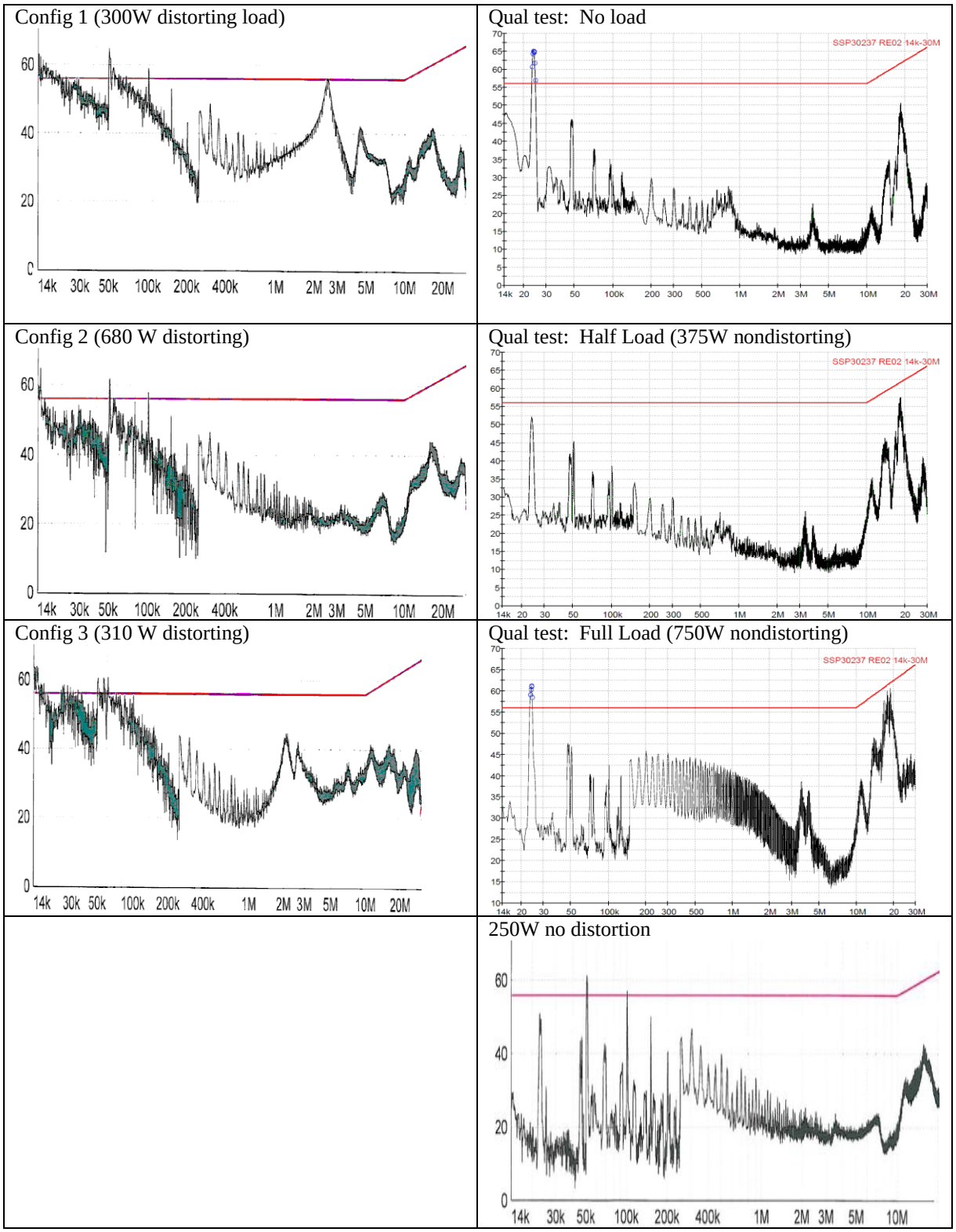


Figure 22: Comparison of RE02 spectra with Qualification test spectra.

## 6.1 Emissions during qual testing:

The ISS power inverter (P/N SEG33123254-301, and later -303) received a tailoring agreement (TIA 1291 B) which allowed certain exceedances of the RE02 requirements.
The rationale given in the TIA is as follows:

> Frequency Management has reviewed the RE02 test data for the Power Inverter. The spurious emissions can be grouped into two categories: 1. Below 1 MHz, 2. Between 16 and 20 MHz. There are no ISS receivers operating below 1 MHz, thus none of the spurious emissions below 1 MHz is expected to cause problem. For the spurious emissions between 16 to 20 MHz, the nearest ISS receiver is MARES operating at 13.567 MHz. MARES, which is a RFID system with a data rate of 0.014 Mbps. The nearest RE02 spurious emission is near 16.85 MHz. The frequency separation of 3.39 MHz is considered sufficient.

## 6.2 Overview of Inverter architecture

Important features relevant to EMI:

- DC/DC converter: switches at approximately 25 kHz. It is a push/pull center tapped topology, so the 2nd harmonic and its multiples dominate the conducted emissions.
- PWM (pulse width modulation) section: switches at approximately 25kHz. Its output filter must be very low loss at 60Hz, which limits the attenuation at the switching frequency. This results in an output voltage ripple of a volt or two superimposed on the the 60Hz output.

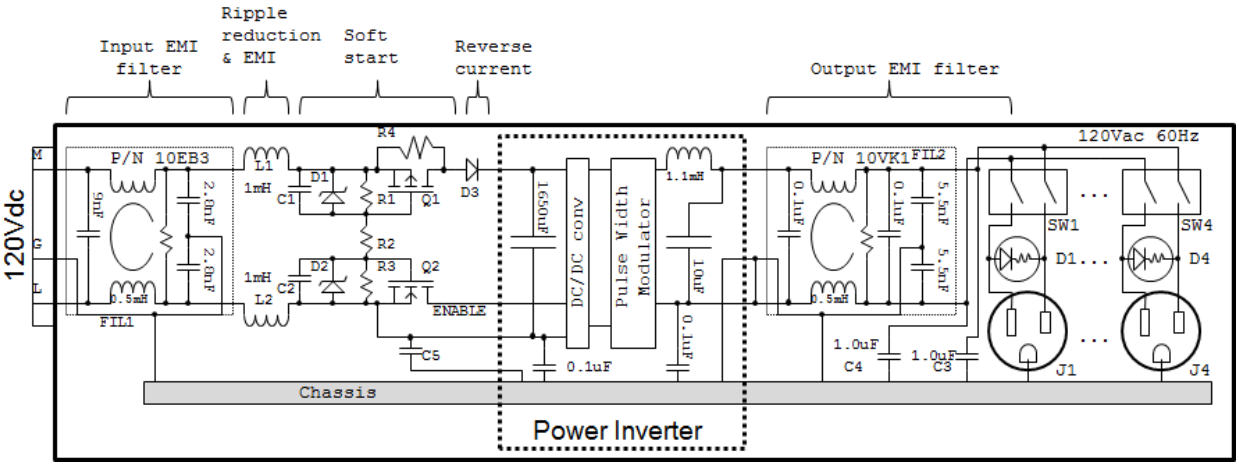


Figure 23: Schematic showing input and output EMI filters

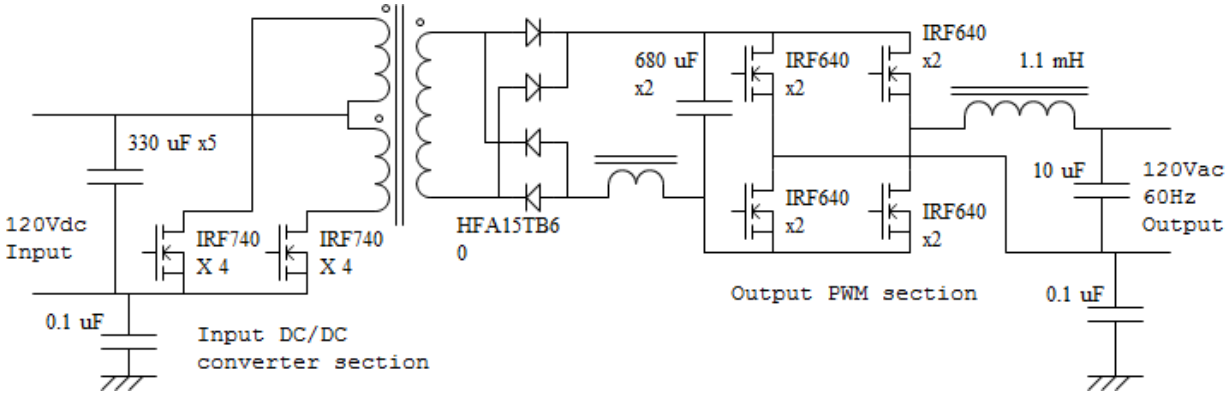


Figure 24: Simplified schematic of Power Inverter center section.

## Appendix A - Acronym List

| | |
|---|---|
| AC | Alternating Current |
| ADC | Amps Direct Current |
| Ap-p | Amps, peak to peak |
| CE01 | Conducted Emissions requirement |
| CE03 | Conducted Emissions requirement |
| COTS | Commodity Off the Shelf |
| DC | Direct Current |
| EMC | Electromagnetic Compatibility |
| EMI | Electromagnetic Interference |
| ISS | International Space Station |
| kHz | Kilohertz |
| LISN | Line Impedance Stabilization network |
| MHz | Megahertz |
| NASA | National Aeronautics and Space Administration |
| OPSNOM | Operational Nomenclature |
| PWM | Pulse Width Modulation |
| RE02 | Radiated emissions requirement |
| RMS | Root Mean Square |
| TIA | Tailoring/Interpretation Agreement |
| V A | Volt Ampere |
| VDC | Volts Direct Current |
| W | Watt |