**Danfysik 2016**

# RSMS

## Magnet Power Supply

*ESS raster system*

**DDR RSMS-PS**
Rev A
DF project no: 502446

DANFYSIK A/S
Gregersensvej 8
DK-2630 Taastrup, Denmark

www.danfysik.com
danfysik@danfysik.dk
☎ +45 7220 2400

| Preparation/Review | Signature | Date |
|---|---|---|
| Author:<br>Alexander Elkiær | PAE | 2016-12-22 |
| Check:<br>Christian Nielsen | CN | 2016-12-22 |
| Approved by:<br>Christian Glarbo Pedersen | CGPE | 2016-12-22 |

*Revision History Log:*

| Date: | Rev.: | Init: | Changes: |
|---|---|---|---|
| 2016-12-22 | A | PAE | Initial version |
| | | | |
| | | | |
| | | | |
| | | | |

# Reference Documents

- "Contract concerning the delivery of the raster scanning magnets for the ESS project", AU, 31/5/2016
- "Appendix 1: Technical Specification", AU, March 2016
- "Conceptual Design of Raster Scanning System", AU, 17/02/2015
- "Technical Description and Compliance Matrix", DF, 20/04/2016
- "Programmers Guide Standard CMD", DF, 11/11/2015

# Abbreviation

| | |
|---|---|
| [AU] | Aarhus University |
| [DF] | Danfysik |
| [ESS] | European Spallation Source |
| [RSMS] | Raster Scanning Magnet System |
| [RSM] | Raster Scanning Magnet |
| [PSU] | Power Supply Unit |
| [PS] | Magnet Power Supply |
| [UNIVO] | Universal I/O interface module |

# Term Definition

| | |
|---|---|
| [Pulse] | In the following a pulse is defined as a single period of the triangular waveform producing the scanning motion of the beam. |
| [Burst] | A bust is the continuous collection of pulses, with a given duration. |

# Abstract

This document describes the overall functionality of the RSMS-PS.

# Content

# 1. Introduction

This document contains the detailed design description of the RSMS-PS.

The RSMS-PS consists of several modules. This document describes the functionality of the RSMS-PS as a whole, whereas following modules are described in individual documents:

- Output Converter
- Control Crate
  - Regulation Module

# 2. RSMS-PS Data

| Ref. | Parameter | Requirement: | Comments | |
|---|---|---|---|---|
| 1 | **Input** | | | |
| 1.1 | PSU input line Voltage | 230Vac | ±10%, PH+N+PE<br>Including control voltage | |
| 1.2 | PSU input Line Current | 2.5 A average<br>6 A Peak<br>25A Inrush | Including control current | |
| 1.3 | Input Frequency | 50 / 60 Hz | | |
| 1.4 | Cooling | Air | | |
| 2 | **Output** | | | |
| 2.1 | Output Voltage | ±750 V-peak | Only burst mode operation | |
| 2.3 | Output Current | ±340 A-peak | | |
| 2.4 | Scanning Burst Duration | 3.57 ms. Maximum | Useable raster period | |
| 2.5 | Pre scanning settling time | 500 µs | Burst prior to usable raster period | |
| 2.6 | Pulse burst repetition rate | up to 14 Hz. | Duty cycle =<6%<br>Triggered by ESS | |
| 2.7 | Output current shape | Triangle | Load dependent | |
| 2.8 | Synchronization accuracy | <200ns | | |
| 2.9 | Operating Range | 6.9% to 100% | | |
| 2.10 | Operation Frequency | 10kHz to 40kHz | | |
| 2.11 | Absolute accuracy | 1% | Amplitude accuracy | |
| 2.12 | Absolute accuracy Repeatability | 1% | First to last pulse in a burst (usable period) | |

| **Ref.** | **Parameter** | **Requirement:** | **Comments** | |
|---|---|---|---|---|
| 2.13 | Absolute accuracy<br>Repeatability | 1% | Burst to burst | |
| 2.14 | Stability | 0.5% | ±10% Mains; ±5% Load<br>±10° C Air; 8 Hours | |
| 2.15 | OFFSET (Symmetry) | <1% | Of full current | |
| 2.16 | Output Earth Connection | Minus DC- Link voltage | Earth connected to minus of the DC Link voltage | |
| 3 | **Load** | | | |
| 3.1 | Magnet Load | 7.8μH ±10%<br>9mΩ ±10% | With cable and termination filter in parallel | |
| 3.2 | Cable | 4 x 16mm$^2$ shielded cables | 30m<Length<35m<br>Two cables connected in parallel to reduce cable inductance | |
| 4 | **Protection** | | | |
| 4.1 | Internal Interlocks<br>Turns PSU OFF | Over-Current<br>Over-Voltage<br>Mains failure<br>PSU Over Temp.<br>Regulation failure | > 130%<br>> 120%<br>-20% V line<br>> 80° C<br>Missing OK signal from module | |
| 4.2 | External Interlocks<br>Turns PSU OFF | EXT 1<br>EXT 2<br>EXT 3 | | |
| 5 | **Interface** | | | |
| 5.1 | RS422 | Remote | DF Protocol | |
| 5.2 | Current setting resolution Digital | 16 bit | Input value “DDD.D” Amp, D=[0-9]<br>No conversion from beam energy<br>E.g.: 332.5 A | |
| 5.3 | Pulse freq. setting | 12 bit | Input value “DDDD” in x10 Hz | |
| 5.4 | Output Current Read Back Digital | 8 bit plus sign | Peak sample and hold<br>1 sec sample time<br>Cleared when PSU is OFF | |
| 5.5 | DC Link Voltage Read Back Digital | 8-bit incl. sign | 1 sec sample time | |
| 5.6 | Front Panel Control | Yes | M-Panel. (See M-Panel manual) | |
| 5.7 | Software<br>Status signals<br>(Locally and Remotely accessible) | PSU ready<br>ON / OFF<br>REM / LOC<br>Aux supply +15 V<br>Aux supply +5 V<br>Aux supply -15 V | Bit expressing “in regulation”<br>Bit expressing main power is ON<br>Bit expressing line in status<br>Internal supply status “DDD” in V<br>Internal supply status “DDD” in V<br>Internal supply status “DDD” in V | |
| 5.8 | Hardware Timing input signals | Sync. Freq.<br>Pre-Trig<br>Polarity | | |

| Ref. | Parameter | Requirement: | Comments | |
|---|---|---|---|---|
| 5.9 | Hardware Timing and status output signals | Trig Permit<br>Beam Run Permit<br>Status<br>I-Ready<br>Missing CLK | | |
| 5.10 | B-DOT | 10 V | Must be terminated with a 50Ω resistor | |
| 5.11 | Remote control protocol | DF Standard. | | |
| 6 | **Cooling** | | | |
| 6.1 | Cooling | Air | From front to back<br>Capacitor charger PS is cooled from the side to back. | |
| 6.2 | Power dissipation | Load: 347W<br>Cable: 3576W<br>Load Filter: 1850W<br>PSU: 2017W | Calculated figures.<br>Real life may differ slightly | |
| 7 | **Mechanical** | | | |
| 7.1 | Size | 19” rack mounted<br>8U high<br>650mm. deep | To be mounted four pieces in a rack (Rack to be delivered by ESS) | |
| 7.2 | Connection Mains | Rear | 2 x IEC C13/C14 connection | |
| 7.3 | Connection Output | Rear | 8 x $16mm^2$ screw terminals<br>2 x clamps for strain relief and grounding of cable screen. | |
| 7.5 | Weight | <75kg | Estimated | |
| | | | | |
| 8 | **Misc.** | | | |
| 8.1 | Relative Humidity | <90% | Non-condensing | |
| 8.2 | Norms | CE<br>EN-61010-1<br>IEC 61508 | European<br>Safety<br>Safety | |

# 3. RSMS-PS Functional Description

The Raster scanning power supply is designed to drive a magnet with a 10 kHz to 40 kHz symmetrical triangle current in bursts of 4.2ms, with a repetition frequency of up to 14 Hz, synchronized to external reference signals provided by ESS.
For exact PS data please refer to section 2.

The pulse height (output current) within the burst are settable from local or remote interface. Trigging the bursts are carried out through light guide signals from ESS control.

Figure 2 below shows the definition of the output current waveform.

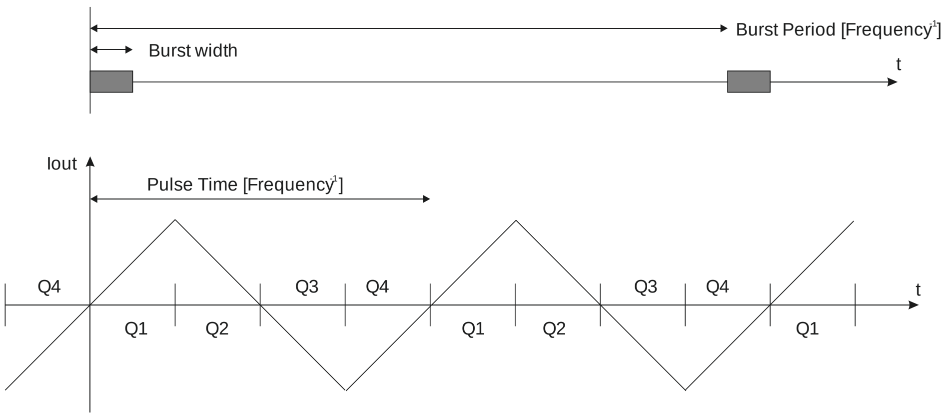



Figure 1

The modules making up the RSMS-PS are:

- Input Converter (Capacitor Charge PS)
- Output Converter
- Control Crate
- Output Cable
- Inductive Load (scanner magnet) with cable matching filter

The block schematic presented in Figure 2 of chapter 3.1 shows what forms the whole RSMS-PS.

## 3.1. Block Schematic of the Modules Forming the RSMS-PS

The figure below shows a block schematic of the RSMS-PS.

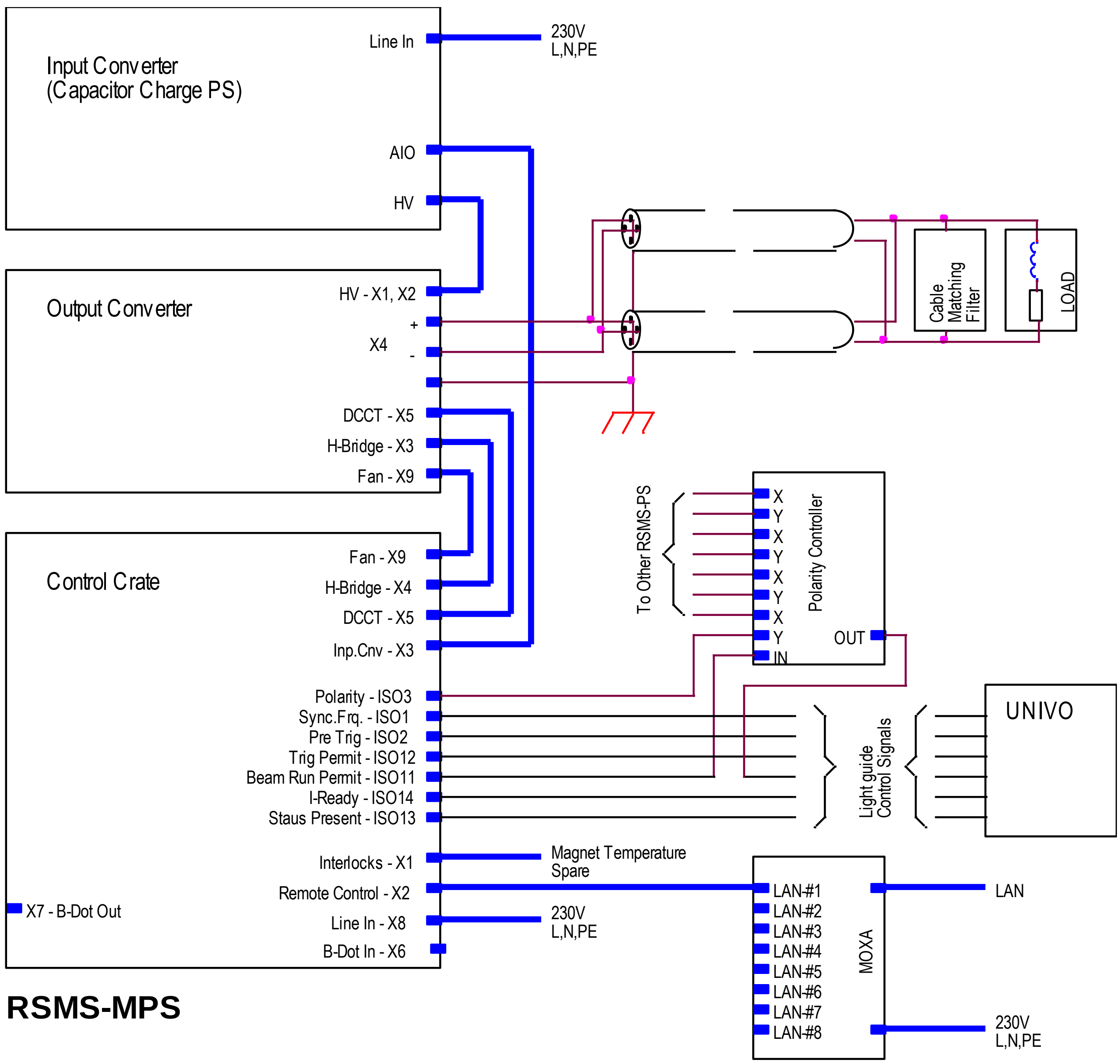



Figure 2

## 3.2. Functional Block Schematic of RSMS-PS

The block schematic in Figure 3 below shows the functionality of the RSMS-PS.

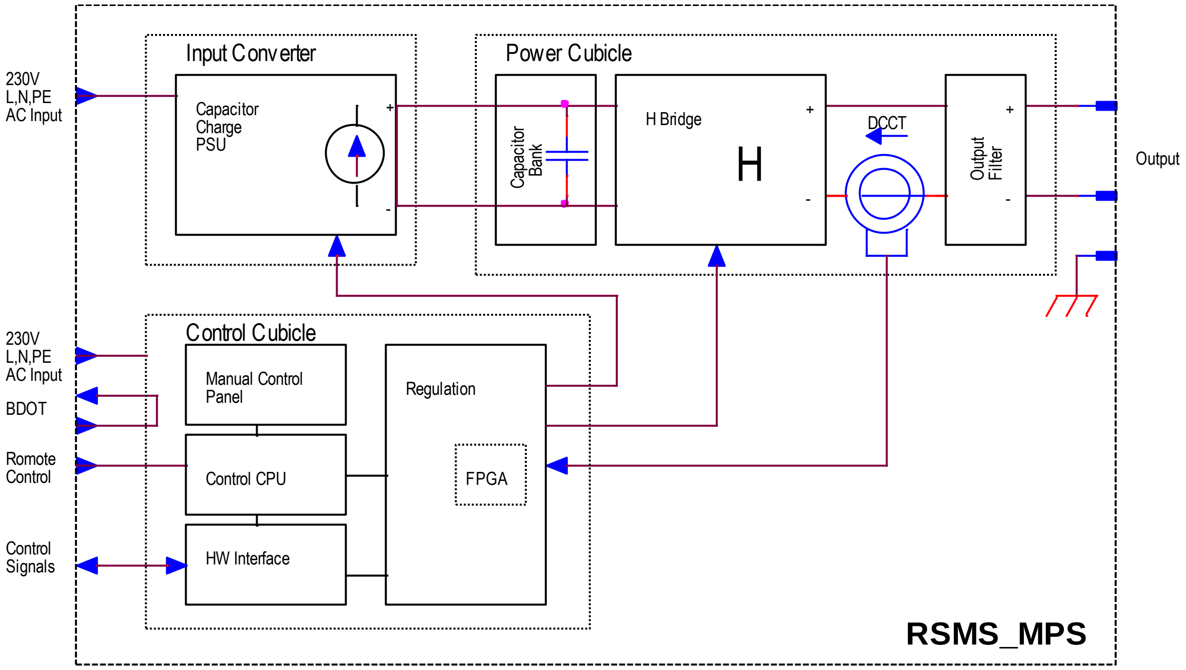



Figure 3

## 3.3. Functional working of RSMS-PS

This chapter describes the working principle of the power supply from a step-by-step use.

- A desired output current is set (locally or remotely)
  - A predicted DC-Link voltage is given to the input converter
- A desired output pulse frequency is set (locally or remotely)
  - The counters in the regulation control are set to the desired pulse frequency
- The PS is turned ON
  - The input converter will be enabled and charge the capacitor storage bank up to the predicted level
  - When the predicted DC-Link voltage level is reached, the signal "Trig Permit" is given
- The ESS control issues a "Pre-Trig" signal
  - The signal "Trig Permit" is cleared
  - The power supply starts pulsing with the initial polarity given by the "Polarity" input signal
  - After x number of pulses, the "Beam Run Permit" signal is issued.
  - Pulsing continues for 4.2ms (measured from the "Pre Trig" leading edge)
  - The input converter starts delivering energy to the capacitor bank (constant current) as soon as it sees that the voltage start dropping.

- After the burst
  - The capacitor bank will be charged back to the level given by the regulation module within the burst period time. If the output current level differs from the set value, the predicted DC-Link value is modified accordingly, so the next burst will be closer to the set value. After some bursts the output current level will be within the specification. When the output current level is within ±1% of the set value, the signal “I-Ready” is given.
- Above procedure continues for every “Pre Trig” signal until a new set value is given. If so a new predicted start DC-Link value is set.

As the input converter is only able to charge (not discharge) the capacitor bank, and a new lower set value requires a lower DC-Link level, a bleeder circuit is foreseen. A new lower value takes a little longer time to reach than a higher output current value.

**Constrains in the working function:**

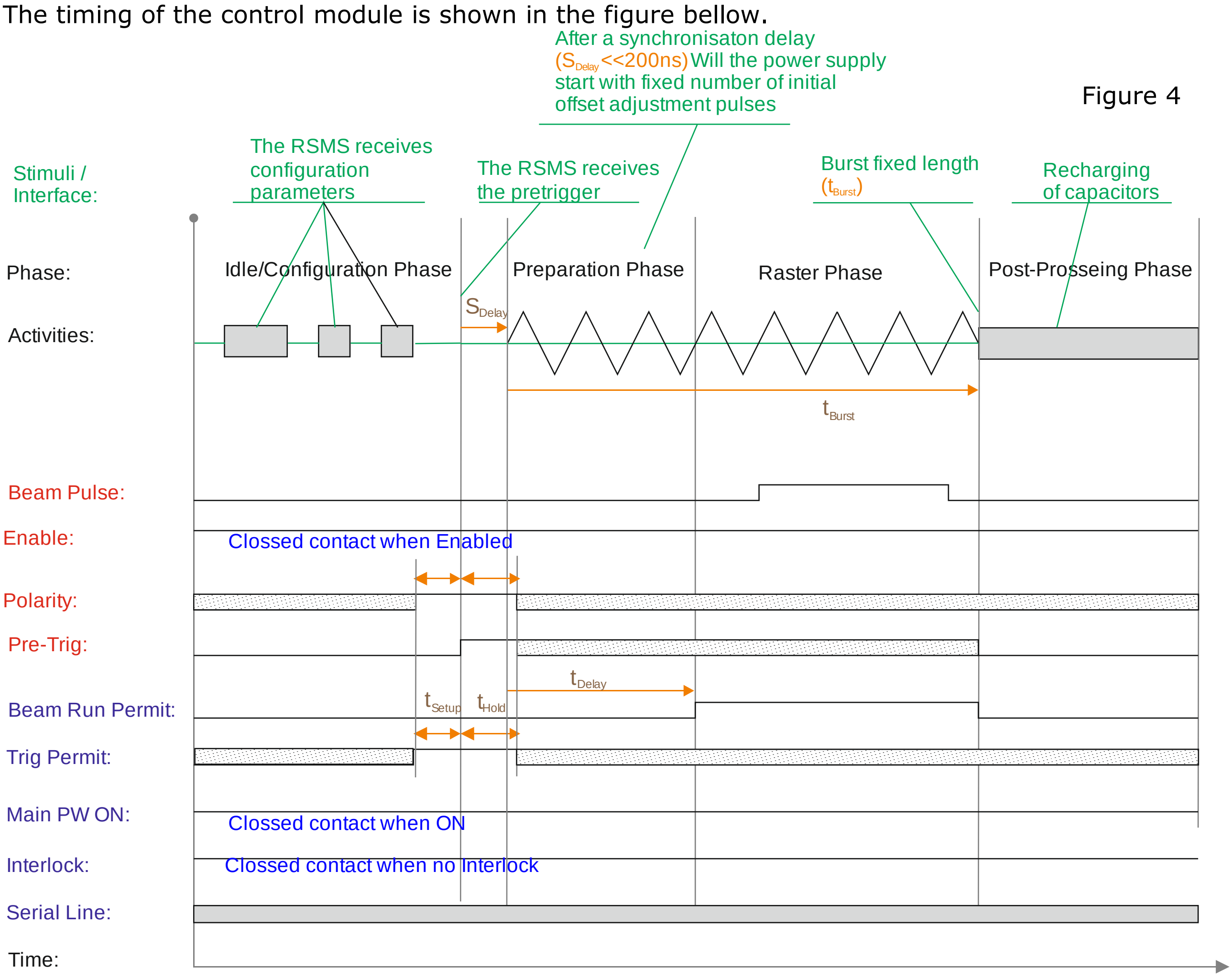
- If a “Pre Trig” signal is given before valid “Trig Permit” no burst will be generated but the warning signal “Status Present” is supplied.

The functionality is also illustrated with the timing diagram and signal declarations given in the next chapter.

### 3.3.1. Timing

The timing of the control module is shown in the figure bellow.

Figure 4




| | |
|---|---|
| Sync. Frequency *(Input)* | To facilitate synchronization between multiple systems, all timing will refer to an external 88MHz clock. (If the external clock is missing, an internal clock has to take over.) |
| Pre-trig *(Input)* | Active signal to start the raster burst.<br>After receiving the Pre-trig signal, the RSMS-PS will start the raster burst within the allowed timing jitter of max 200ns. (The time it takes to synchronize to the clock).<br>The raster sequence will continue for a predefined fixed time duration; which default is set to 4.2ms. (Parameter setup during factory test, not to be changed regularly). |
| Polarity *(Input)* | Depending on the Polarity input signal, the burst sequence must start with positive or negative current depending on the polarity input signal. The interpretation of this signal is as follows:<br>High signal = Start positive<br>Frequency above 10kHz = Start negative<br>Low/No signal = Start negative, set the warning signal and tell the system 8500 CPU |

| | |
|---|---|
| Trig permit<br>*(Output)* | When the RSMS is ready to receive a pre-trig signal, a "trig permit" signal is issued. This indicates that all parameters have been processed and the PSU is ready to output raster bursts.<br>Note! The trig permit marks that the power supply is ready to deliver pulses. The trig permit signal can therefore be valid prior to any configuration changes. When changing settings, the trig permit signal may go false until the power supply has re-settled and is ready for pulsing. |
| Beam Run Permit<br>*(Output)* | After a given fix number of pulses (parameter setting), the offset (if any) has been canceled and the Beam Run Permit signal is set active. This indicates that the output current has settled and a beam can be initiated.<br>This signal is generated regardless of the current accuracy. The "READY" feed-back signal will indicate if the just produced burst was within the specification or not. The "READY" signal is evaluated after each burst.<br>The Beam Run Permit signal is set inactive after end of burst. |
| Missing Clock<br>*(Output)* | When Low indicating that the external clock is missing, and the FPGA has automatically switched to the internal clock. |
| Main power ON<br>*(Output)* | Closed contact indicating that the PSU is turned ON for operation.<br>Given by the main ON relay |
| Interlock<br>*(Output)* | Closed contact indicating that an interlock is present<br>Given by the control CPU |
| Ready<br>*(Output)* | Indication that the peak current amplitude of the previous burst was within the specification. |
| Status<br>*(Output)* | Status/Warning available on remote line |
| Enable<br>*(Input)* | Bursts can only be issued when the power supply is enabled. Active high. |

## 3.3.2. Timing Constrains

**Timing:**

| | | |
|---|---|---|
| $t_{setup}$ | Setup time the "Trig Permit" signal must be valid before the "Pre-Trig" signal can be issued. This time is the same as for the polarity signal validation. | >20ns |
| $S_{delay}$ | Synchronization time before output current pulses | ¼ pulse time +100ns |
| | Synchronization time jitter | <20ns |
| $t_{hold}$ | Minimum time before the RSMS removes the "Pre Trig" signal or the Polarity signal may be changed. There is no maximum time, that is signals can or may stay active constantly. | >200ns |
| $t_{delay}$ | Time delay before the beam run permit signal is issued | 4 pulse times +<200ns |
| $T_{Burst}$ | Raster burst duration | =4.2ms ±22µs |

# 4. Modules making the RSMS-PS

## 4.1. PSPS Input Converter

The input converter (capacitor charging PS) is an off-the-shelf power supply from the company "hivolt.de". Please see attached document.

## 4.2. Output Converter

The Output Converter is described in detail in the document "502446 DDR-Output Converter RevA.pdf"

## 4.3. Control Crate

The PS control is described in detail in the document "502446 DDR-Control Crate Rev-A.pdf"

### 4.3.1. Regulation Module

The PS Regulation topology is described in detail in the document "502446 DDR-Regulation Module Rev-A.pdf"

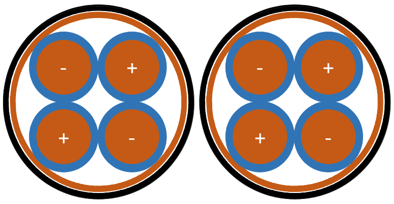
## 4.4. Output Cable

Two parallel cables, each 4x16mm$^2$ + shield, is foreseen as cable between the power supply and the load. Each cable will carry output and return in a "star quad" configuration to reduce stray inductance and EMI, and the two cables in parallel will reduce effective inductance further.

This cable (one cable in the "star quad" configuration) has the following characteristics, verified through calculation and measurements:

**16mm$^2$ cable measurement (One cable )**

| | | |
|---|---|---|
| Inductance per m | 142 | nH/m |
| Capacitance per m | 0.233 | nF/m |
| Resistance per m @40kHz | 5.3 | mΩ/m |
| Resistance per m @29kHz | 4.56 | mΩ/m |
| Characteristic impedance | 24.7 | Ω |
| Inductance (33m) | 4670 | nH |
| Capacitance (33m) | 7.68 | nF |
| Resistance @ 40kHz (33m) | 175 | mΩ |
| Resistance @ 29kHz (33m) | 150 | mΩ |



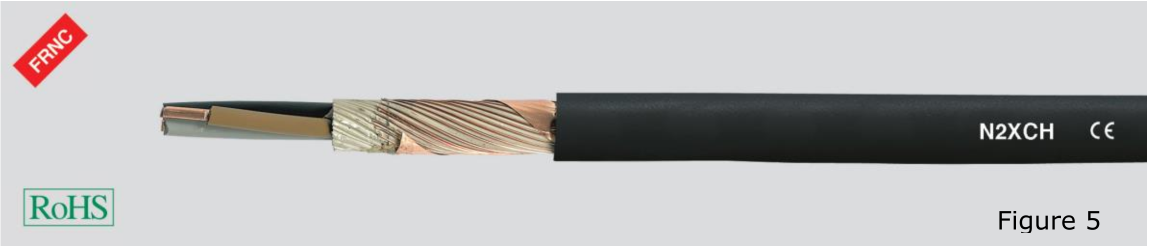



Figure 5

## 4.5. Load with cable matching filter

The ferrite raster magnet is assumed to be an ideal inductance with a small series resistance. Parasitic components (inter-winding capacitance and dynamic resistance change due to skin effect) are low has negligible influence.

**Load data**

| | | |
|---|---|---|
| Inductance | 7.8 | µH |
| Resistance | 9 | mΩ |

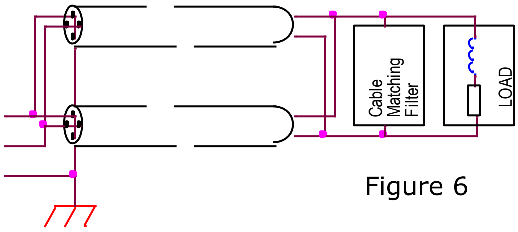



Figure 6

For the magnet description please refer to separate document.

Since fast switching signals are transmitted on relatively long output cables (thereby acting as a transmission line), a matching filter is required to prevent unwanted reflections on the output cables.

The matching filter will be a combination of differential-mode and common-mode RC networks. The resistive elements are matched with the combined characteristic impedance of the cables, and the capacitive elements are matched with the cable delay to ensure the filters effectiveness while blocking lower frequency voltage, thereby reducing power dissipation in filter resistors.

To keep the stray and parasitic inductance low and distribute power dissipation, several parallel thick film resistors will be used.

**Cable matching filter**

| Filter | Comp. | Type | Loading |
|---|---|---|---|
| Differential mode filter | 4 x 68R<br>1 x 33nF | Vishay RCH50S68R00JS06<br>Kemet 73QN2330(1)30(2) | $105W_{AVG}$, $1200V_{pk}$<br>$600V_{pk}$, $70A_{pk}$ |
| Common mode filters | 2 x 33R<br>1 x 33nF | Vishay RCH50S33R00JS06<br>Kemet 73QN2330(1)30(2) | $26W_{AVG}$, $600V_{pk}$<br>$600V_{pk}$, $36A_{pk}$ |
| Effective differential mode | 11.22R<br>49.5nF | | $157W_{AVG}$ |

The load matching filters will be assembled on an aluminium heat sink mounted on one of the magnet girder legs.

# 5. Interface

## 5.1. HW Interfaces

The HW interfaces to the RSMS-PS are:

- 230V/50Hz line power
- HW control signals (electrical and fibre optic)
- Remote control serial line
- B-Dot signal
- Output terminals

### 5.1.1. 230V Line power

The Input Converter and the Control Crate are supplied with 230V / 50Hz on individual IEC C13/C14 connections. Their power demands are:

- Input Converter: 8A Peak (1800W)
  3A Average (690W)
  25A inrush current
- Control Crate (X8): 1.5A Average (345W) {On X10}

### 5.1.2. HW Control Signals

Signal descriptions can be found in document "502446 DDR-Control Crate Rev-A.pdf"

Potential free contact inputs/outputs for state signalling and interlock input:

**X1 on Control Crate**

| Pin | Name | Value | I/O | Description |
|---|---|---|---|---|
| 1-2 | Enable | NC | I | External closed contact to enable PS |
| 3-4 | Main PW ON | NC | O | Normally Closed contact when PS is turned ON |
| 5-6 | /INTL | NC | O | Normally Closed contact when PS is interlock free |
| 7-8 | INTL#1 | NC | I | Normally Closed Contact for interlock input 1 |
| 9-10 | INTL#2 | NC | I | Normally Closed Contact for interlock input 1 |
| 11-12 | INTL#3 | NC | I | Normally Closed Contact for interlock input 1 |

Fiber optic inputs/outputs for high speed synchronization, trigging and control:

**ISO1-15 on control cubicle**

| Plug | Name | | I/O | Description |
|---|---|---|---|---|
| ISO1 | Sync. Clk. | | I | External Synchronization Clock 88 MHz (HFBRX24XZ Series) |
| ISO2 | Pre-Trig | | I | Pre-trig signal telling PS to start a pulse burst (HFBRX24XZ Series) |
| ISO3 | Polarity | | I | Sets the starting pulse polarity (HFBRX24XZ Series) |
| | | | | |
| ISO11 | Beam Run Permit | | O | Beam may be issued (HFBRX14XZ Series) |
| ISO12 | Trig Permit | | O | PS ready to start a pulse burst (HFBRX5XXX Series) |
| ISO13 | Status | | O | Status available on serial line (HFBRX5XXX Series) |
| ISO14 | I-Ready | | O | Output current within 1% of set value (HFBRX5XXX Series) |
| ISO15 | Missing Clock | | O | External clock missing. Automatically switched to internal clock. Active Low (No light) (HFBRX5XXX Series) |

### 5.1.3. Remote Serial Interface

Connector X2 (DB9, female) on the Control Crate rear provides an RS-422 interface for remote control of the power supply.

For available commands and protocol, please refer to "Programmers Guide Standard CMD.pdf"

**X2, Remote Serial Interface**

| Pin | Name | Value | I/O | Description |
|---|---|---|---|---|
| 1 | | | | |
| 2 | RxD- | - | I | - Receive |
| 3 | TxD- | - | O | - Transmit |
| 4 | | | | |
| 5 | GND | - | - | Ground |
| 6 | RxD+ | - | I | + Receive |
| 7 | TxD+ | - | O | + Transmit |
| 8 | | | | |
| 9 | - | - | - | - |

Note: The receive line is terminated with 250Ω. The transmit line must be terminated with 250Ω at the receiver point.

### 5.1.4. B-Dot

The B-Dot signal comes from a single winding on the magnet with an amplitude of 51V and a square wave shape like the voltage applied to the magnet. Transferring this high frequency square shaped signal 35 meter requires an impedance matched transfer line as shown in the simulation circuit Figure 7.

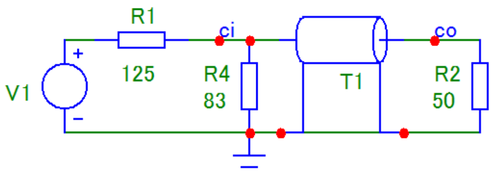



Figure 7

The matching impedance will influence the magnet field by: 125+83//50=156.2Ω or 326.5mA.
The total Ampere turns of the magnet is
4*340=1360A so the B-Dot influence on the magnet Ampere turns is 240ppm.

Note! The influence of the B-Dot pickup coil on the magnet field may be twice as it is placed only around one leg.

The level and impedance matched B-Dot signal that comes from the magnet is passed without modification from the input BNC plug (X6, Control Crate rear) to the output BNC plug (X7, Control Crate front). The signal level is given in section 2**Error! Reference source not found.**.

Important: The output signal on the BNC plug must always be terminated by a 50Ω resistor. If connected with a 50Ω cable the termination has to be mounted at the end of the cable.

### 5.1.5. Output terminals

The output terminals (X4) located at the rear of the Output Converter cabinet has multiple screw connections suited for the multi conductor cables. An angled, panel feed-through terminal block type is foreseen, allowing easy output cable connection from below. Below the output terminals, saddle clamps provide mechanical relief and terminates the screens of the output cables to the output converter cabinet (chassis/ground).

Figure 8: Output cable screw terminals

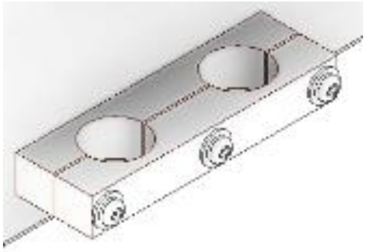


Figure 9: Output cable saddle clamp