EUROPEAN SPALLATION SOURCE

ESS BPM RF Front-End
Hardware Manual

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Reviewers		
Approver		

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Date	Revision	Description	Authors
08–July-2016	0.1	Initial draft.	Rafael A. Baron,
12-July-2016	0.2	Schematics review of the digital devices and I2C addresses	Hinko Kocevar
19-July-2016	0.3	Schematics review of the RF chain and analog circuits	Hooman Hassanzadegan
	1.0	Prototype version for manufacturing	Rafael A. Baron

Contents

1. GENERAL INFORMATION

- **About the document:** This manual is intended to describe the BPM RF Front-End hardware designed by the ESS beam diagnostics team. Information about the hardware configuration, block diagrams, specific schemes, as well as board manufacturing documentation is provided.

- **If some part of the text is important it will be noted with the signals that are described in what follows.**

Conventions

DANGER

Indicates that death or severe personal injury will result if proper precaution are not taken.

Warning

Indicates that death or severe personal injury may result if proper precautions are not taken.

Caution

Indicates that minor personal injury can result if proper precautions are not taken.

Notice

Indicates that damage to equipment can result if proper precautions are not taken.

Information

Indicates information that we think you should have read to save your time by avoiding common problems. Important suggestions that should be followed will also be marked with this sign.

- Design reference name: RFFE_ESS_BPM_v1
- Manager: Rafael A. Baron
- Last production: *Prototype*

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2. Introduction

The RF Front-End electronics is the analog processing part of the BPM electronics, designed for calibration, filtering and gain control of the RF signals sourced by the BPM sensors. The BPM RF Front-End electronics is composed by one PCB containing the supply scheme, RF calibration, amplification, RF filtering, gain control, temperature monitoring and voltages monitoring. The RF Front-End is also used as a patch panel since N-type connectors are used on the input and SMA connectors on the output.

The RF signals are processed at the RF frequency and they are then digitized in another board. In the ESS BPM system, the RF signals are downconverted using a MicroTCA.4 RTM (DWC10LF) and the Struck SIS8300 AMC board.

3. Hardware Characteristics:

- 8 RF channels + 1 RF reference channel with configurable center frequency from 30 MHz up to 6 GHz[1].
- Internal low noise and shielded AC-DC converter.
- Internal calibration scheme for phase and amplitude compensation based on an external RF reference.
- N-type input connectors and SMA output connectors
- Input trigger for fast calibration switching and FPGA synchronization.
- Eight temperature sensors available for measurements of temperature gradients.
- Internal EEPROM, real time clock, serial number and voltages monitoring available on the I2C bus.
- Ethernet interface[2].
- COTS mechanical enclosure from Metcase[3].

- Table 1: Specifications for the RF Front-end electronics[4].

Parameter	Value	Comments
Max Input Power	20 dBm	For max attenuation and operating bellow P0.1dB
RF Chain Gain	35 dB	
RF chain attenuation	30 dB	
Center Frequency	100 - 800 MHz	Configurable center frequency
Bandwidth (3 dB)	100 MHz	
Bandwidth (60 dB)	200 MHz	
Crosstalk	>50 dB	For max gain @ 352 and 704 MHz
Nonlinearity[5]	0.1 dB	Over 80 dB input range (-80 dBm to 0 dBm)

[1] The same PCB can be used and the Bandpass filter can be changed. The same footprint can be used up to 1.8 GHz. For frequencies above 1.8 GHz, another filter must be used and some modifications on the PCB might be needed. The frequency of the RF amplifier and attenuators is limited to 6 GHz. Some PCB layout modifications are needed for operating at higher frequencies.
[2] No support needed for internal Microcontroller since a commercial Ethernet-to-I2C mezzanine board is used.
[3] Part number M4919115, model Versamet 19" 1U x 6.49".
[4] When not specified, the performance is measured for the standard configuration of attenuators (10 dB). Temperature operation: -20 ºC to 50 ºC.
[5] Nonlinearity is defined as Pout vs Pin deviation from the linear fit of the RF chain linear response for a specific attenuators configuration.

Noise Figure	10 dB	Estimated for 5 dB attenuators
Temperature Dependence	TBD	
MTBF	280.000	hours
Dynamic Range	60 dB	

4. Hardware Description

Eight RF channels with configurable center frequency from 100 MHz up to 800 MHz, providing up to 30 dB of gain, controllable gain and bandpass filtering. A calibration scheme based on a reference RF signal distribution is also available. [6]

4.1 Block diagram

The RF Front-End board has the following generic block diagram:

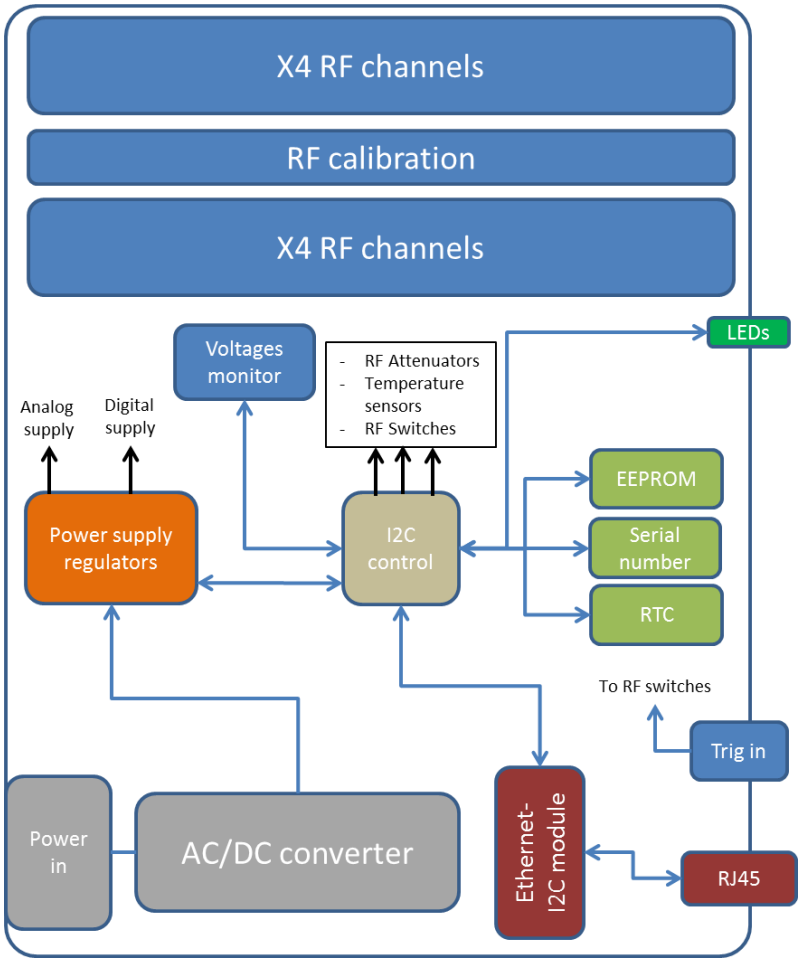


Figure: Block Diagram of the RF Front-End

[6] The RF amplifiers and attenuators limits the RF frequency to 6 GHz. Some PCB layout modifications are needed if necessary to run the RF channels for frequencies higher than ~ 1 GHz.

4.1.1 RF Chain

- 8 RF channels for RF processing, including RF filter, and amplifiers
- One reference channels capable of distributing the RF reference signal to all the RF channels
- One filtered RF reference channel is available for sampling.

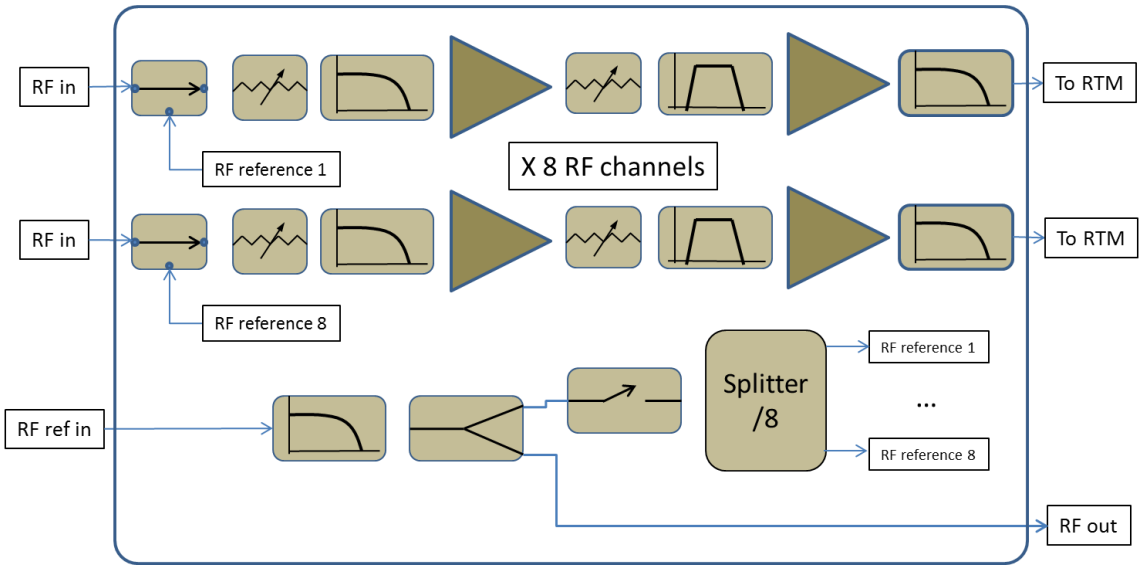


Figure: RF chain block diagram.

4.1.2 I2C bus

The PCB has an internal I2C bus connected according to the block diagram as follows

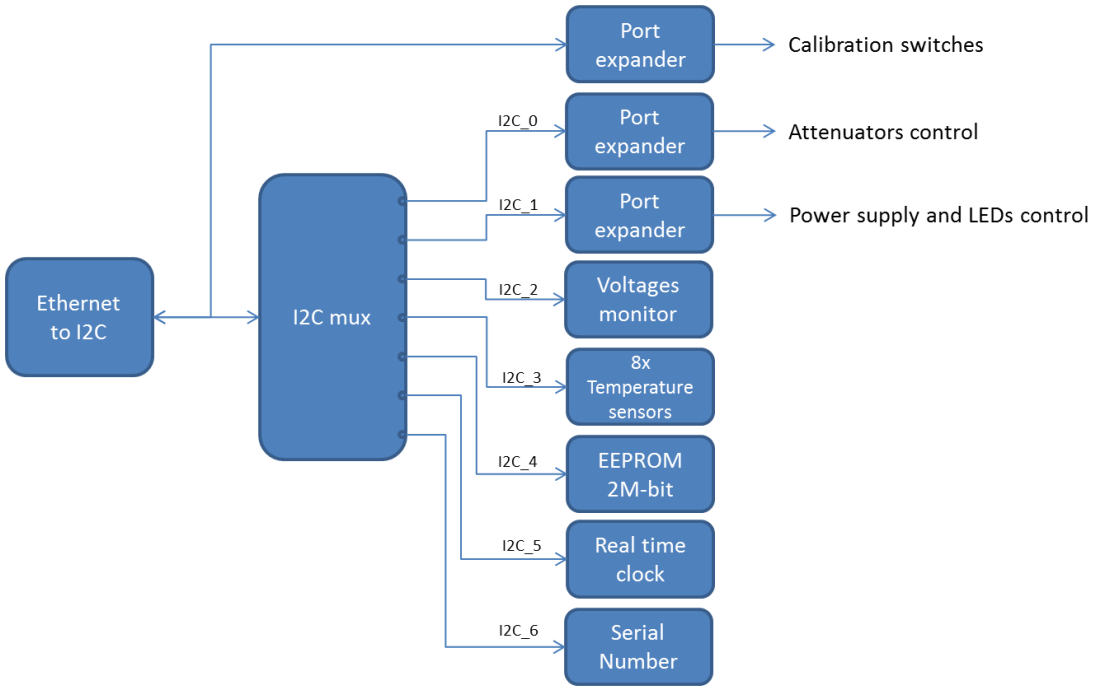


Figure: I2C bus implemented on the RF Front-End electronics.

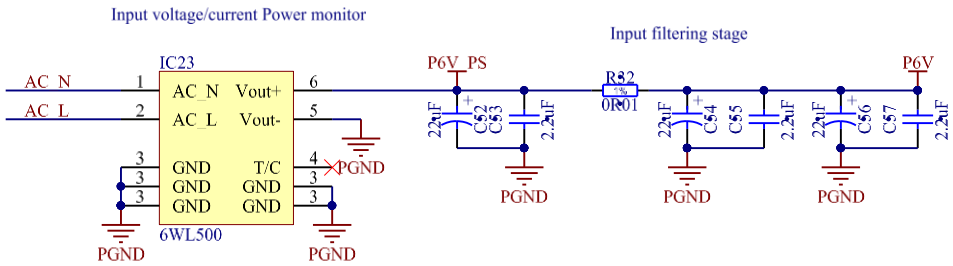
4.2 Interfaces

The board has the following interfaces:

- Ethernet connector:
  - The Ethernet interface is implemented using an industrial mezzanine board, part number XT-PICO, from the company AK-Nord. The mezzanine board basically works as an Ethernet to I2C bus translator.
- Trigger input:
  - SMA through-hole, right angle connector. Directly connected to the RF calibration switches for external control of the calibration signals. TTL and CMOs inputs, logic level VIH >2 Volts, 10k Ohm input impedance.
- 9 RF inputs:
  - N-Type Through-hole, right angle connectors.
- 9 RF outputs:
  - SMA through-hole, right angle connectors.
- Power connector
  - Fuse, power cable and switch available in the same connector.
- 3 LEDs:
  - Connected through 330 Ohms resistors to the port expander.

4.3 Power supply

The RF Front-End has an internal low noise, low EMI and high reliability AC/DC converter. Internal filtering circuits and power distribution for the analog and digital devices are designed. Additional supply filtering is provided to all the RF devices in order to filter high frequency components that might couple from one RF path to the other through the power supply. Follows the power supply scheme:



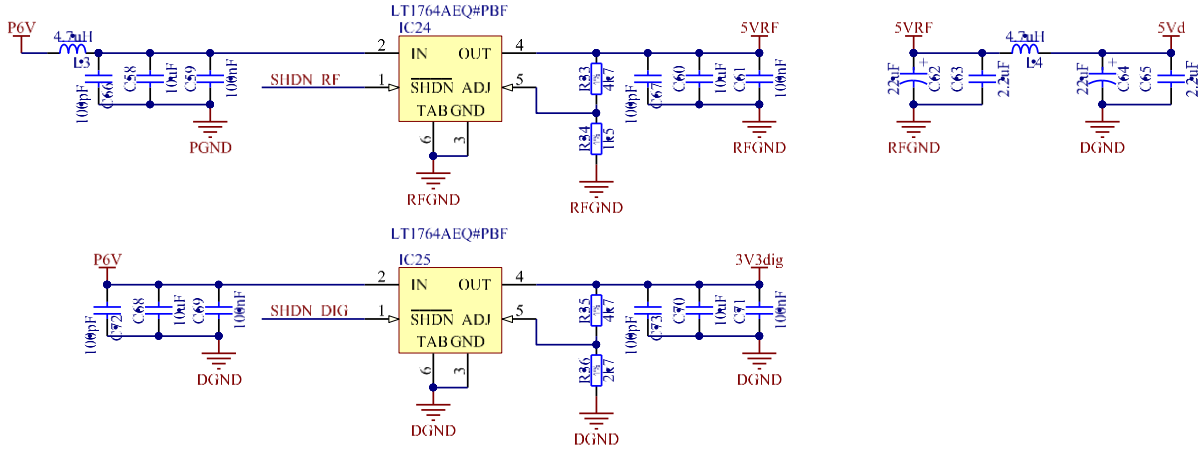


Figure: The power supplied to the analog and RF devices are highly isolated from the power supplied to the digital devices. Additional RF filters are implemented near to the each RF device.

4.4 Mean Time to Failure – MTTF[7]

MTTF estimation was made based on information provided by the IC manufacturers and considering the critical parts of the design. The power supply is the main device responsible for the MTTF number.

Part number	Description	Qty/ board	MTTF (hours)	Failure rate (1/hours)	Q factor
MASW-008543	RF switch	8	6,00E+09	1,33E-09	9,33E-10
HMC624ALP4ETR	RF attenuator	16	2,80E+08	5,71E-08	4,00E-08
LFCN-490D	RF LPF	16	1,57E+08	1,02E-07	7,13E-08
ADL5611	RF amplifier	16	3502012625	4,57E-09	3,20E-09
BPF-A600	RF BPF	8	1,63E+08	4,91E-08	3,44E-08
LT1764	Voltage regulator	1	1097535494	9,11E-10	6,38E-10
6WL500	AC/DC PS	1	2,17E+05	4,60E-06	3,22E-06
ADP-2-9	Power Splitter	8	2,36E+07	3,39E-07	2,37E-07
				MTTF system (Hours)	2,77E+05
				MTTF system (Years)	31,65
				90% confidence level, 50 °C	

Table: MTTF estimation for each RF Front-End electronics PCB, which comprises 2 RF Front-End electronics, or 8 RF channels.

4.5 Typical Performance Characteristics

To be tested with the first prototype

[7] The military standard reliability estimation procedures were followed MIL-HDBK-217.

4.6 PCB design

Some considerations and comments about the PCB design:

- 6 Layers PCB with RF layer, digital signals layer and power/ground planes.
- PCB cut to separate RF channels from Power supply and digital circuits, improving thermal stability and grounding scheme.
- Shielding for each 2 RF channels.
- Calibration circuit symmetrical 4 by 4 RF channels.
- Shielding plate holders available for the las amplifier of each RF chain.
- Channel-to-channel Phase matched calibration signals.
- On-board PCB soldered, AC/DC converter.
- On-board soldered standoffs for PCB fixing on the mechanical enclosure.

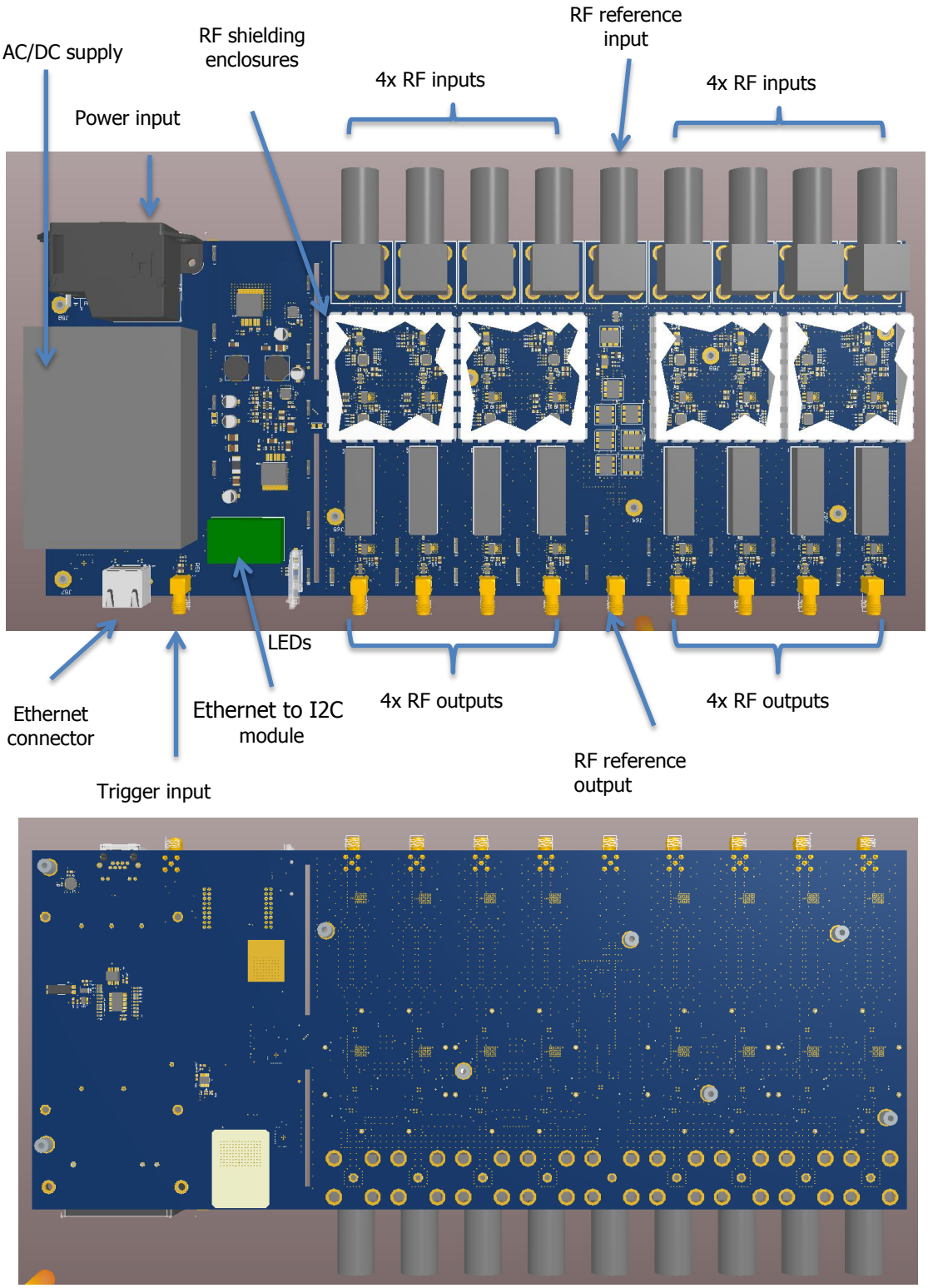


Figure: PCB design of the RF Front-End.

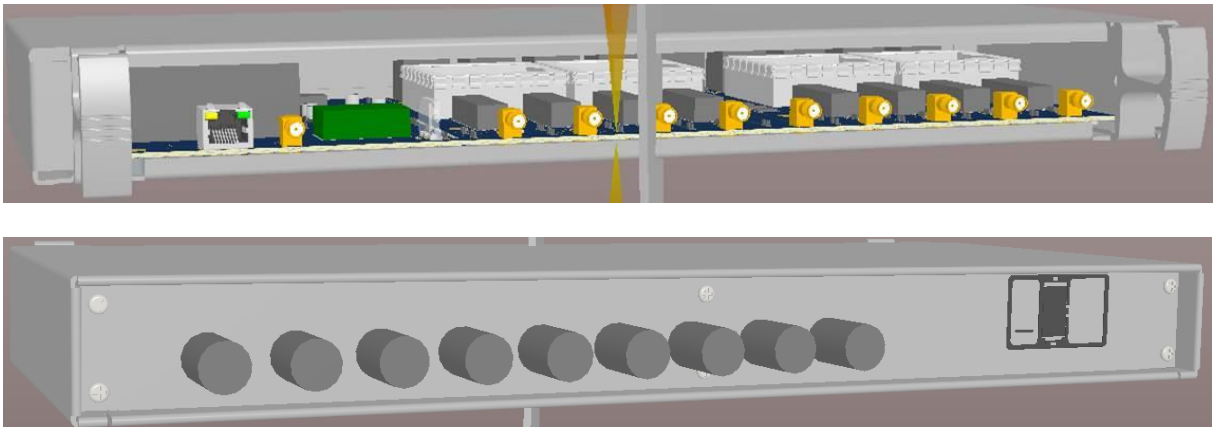


Figure: Front and rear panels of the RF Front-End enclosure.

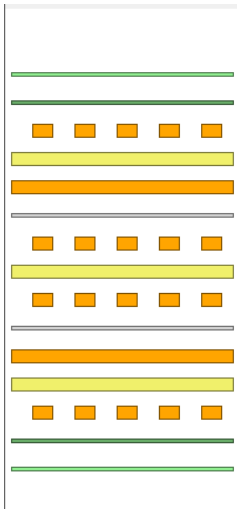
5. Manufacturing Specifications

Design references			
Name	ESS-BPM-RFFE_v1		
File name(s)			
Engineer	Rafael Antonio Baron		
E-mail	rafael.baron@esss.se		
Fone	+46-72-179 22 89	Date	07 July 2016

Mechanical characteristics	
External size (mm)	151.4 mm x 369 mm
Thickness (mm)	1.6 mm
Multilayers	6 layers
Min track width (mm/mils)	10 mils
Min Hole size (mm/mils)	15 mils
Laminate	FR-4
Pre-preg	FR-4
Finish Copper	
External layers (µm)	35 µm
Holes walls (µm)	25 µm
Internal Layers-Planes (µm)	35 µm
Internal Layers-Signals (µm)	35 µm
Board finishing requirements	
Silkscreen on top layer (color)	Green
Silkscreen on bottom layer (color)	Green
Surface Finishing	ENIG – Electroless Nickel / Immersion Gold according to IPC-4552
Thickness	Ni: 3 µm min, 6 µm máx. Au: 0.05 µm min, 0.125 µm máx

Additional Information	
Impedance test	No
Packaging requirements	No
Documentation to be delivered	Manufacturing report
Additional control quality requirements	No

Board Stackup Information



Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant	Pullback (mil)	Orientation
Top Overlay	Overlay						
Top Solder	Solder Mask/...	Surface Mat...	0.4	Solder Resist	3.5		
Top Layer	Signal	Copper	1.4				Top
Dielectric 1	Dielectric	Core	10	FR-4	4.2		
Internal Plan...	Internal Plane	Copper	1.417			20	
Dielectric 3	Dielectric	Prepreg	20		4.2		
Signal Layer 1	Signal	Copper	1.417				Not Allowed
Dielectric 5	Dielectric	Core	10		4.2		
Signal Layer 2	Signal	Copper	1.417				Not Allowed
Dielectric 4	Dielectric	Prepreg	5		4.2		
Internal Plan...	Internal Plane	Copper	1.417			20	
Dielectric 2	Dielectric	Core	10		4.2		
Bottom Layer	Signal	Copper	1.4				Bottom
Bottom Solder	Solder Mask/...	Surface Mat...	0.4	Solder Resist	3.5		
Bottom Over...	Overlay						

6. Appendix

6.1 I2C IC's addresses

I2C addr*	A2	A1	A0	I2C bus	Device (IC designator)	Output	Function	Part Number
1110011 (E6h)	0	1	1	bus_main	IC9	I2C_0 … I2C_7	I2C mux	PCA9548APWR
0100101 (4Ah)	1	0	1	bus_main	IC3	P00 … P17	Calibration RF switches	TCA9555
1010000 (A0h)	-	-	-	bus_6	IC12	-	Serial Number IC	DS28CM00R-A00+T
1010001 (A2h)	-	-	-	bus_5	IC13	-	Real Time Clock	PCF85063TP/1Z
10100xx (A0h - AEh)	0	x	x	bus_4	IC11	-	EEPROM	M24M02-DRMN6TP
1001000 (90h)	-	0	0	bus_3	IC14	-	Temperature sensor	TMP100
1001111 (9Eh)	-	x	1	bus_3	IC15	-	Temperature sensor	TMP100
1001001 (92h)	-	0	x	bus_3	IC17	-	Temperature sensor	TMP100
1001110 (9Ch)	-	1	1	bus_3	IC18	-	Temperature sensor	TMP100
1001100 (98h)	-	1	0	bus_3	IC19	-	Temperature sensor	TMP100
1001101 (9Ah)	-	1	x	bus_3	IC20	-	Temperature sensor	TMP100
1001010 (94h)	-	0	1	bus_3	IC21	-	Temperature sensor	TMP100
1001011 (96h)	-	x	0	bus_3	IC22	-	Temperature sensor	TMP100
1001000 (90h)	0	0	0	bus_2	IC16	-	Voltage monitor	LTC2991
0100001 (42h)	0	0	1	bus_1	IC8	P00 … P17	PS / LEDs control	TCA9555
0100011 (46h)	0	1	1	bus_0	IC4	P00 … P17	Attenuators control	TCA9555

Table: I2C addresses for the ICs placed on the I2C busses of the RF Front-End