RFFE_v2

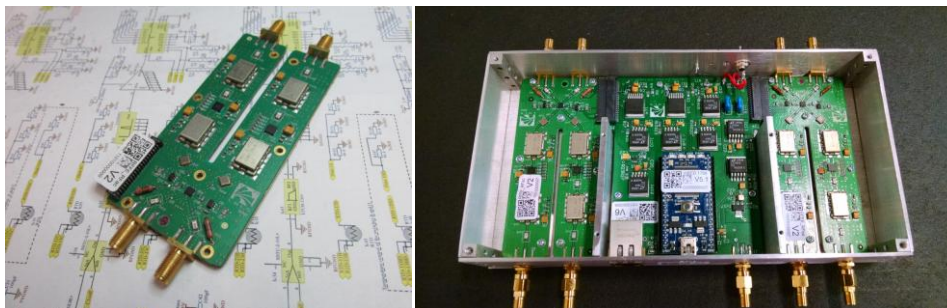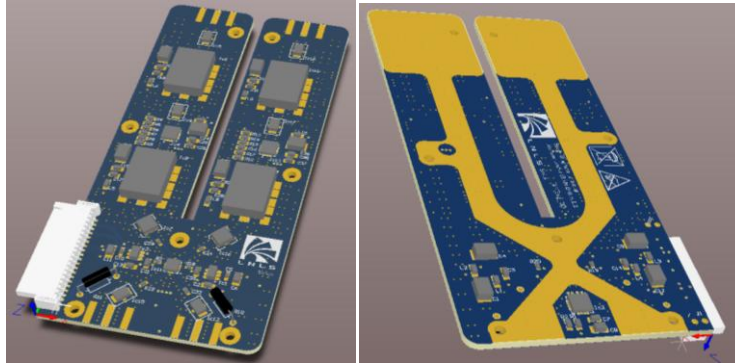*RFFE_v2 hardware manual*

January 2014 – April 2014

Brazilian Synchrotron Light Laboratory
Beam Diagnostics Group (DIG)

- Design reference name: RFFE_v2
- OHWR link: http://www.ohwr.org/projects/bpm-rffe
- Manager: Rafael Antonio Baron
- Last production: Beam Diagnostics Group, Brazilian Synchrotron Light Source, 15 units, jan/2014.

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Date	Revision	Description	Authors
01/12/2013	0.1	Initial draft.	Rafael A. Baron,
26/10/2014	0.2	Revision of block diagrams	Rafael A. Baron
07/01/2015	0.3	General comments added	Rafael A. Baron

Table of Contents

1. General information

- **About the manual:** This manual is intended to describe about the RFFE_v2 hardware designed for the BPM electronics of the Brazilian Synchrotron Light Source, Sirius Project. There are information about the specific schemes that are implemented on the board, about the devices chosen (when necessary), and about manufacturing process.
- **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.

2. Introduction

The RFE electronics is the analog processing part of the BPM electronics system designed by the LNLS Beam Diagnostics Group for the Sirius synchrotron accelerator.

The RFFE electronics is composed by three boards. The RF analog electronics for channels A and C, the analog electronics for channels B and D and by the digital control board. This manual is related to the two RF analog conditioning boards, that are intended to provide gain, calibration and filtering to the RF beam signals that come from 25 meter of cables from the Beam position Monitor.

The two RF analog boards are similar in terms of schematic and layout, except by small adjustments on the interface connector, that is placed on opposed extremes. The RFFE control board is in the middle of the two RF analog boards.[1]

Follows the RFFE specifications.

Table 1: Specifications of the BPM RF Front-End electronics[2].

Parameter	Value
Dynamic Range	40 dB
Noise Figure[3]	< 10 dB
Crosstalk	< -40 dB
Bandwidth (3 dB)	80 MHz
1 dB Compression Point	> 20 dBm
MTBF in user beam delivery	20 years

2.1 Hardware Characteristics:

- Two RF channels providing Active Gain Control with attenuation ranging from 0 dB up to 30 dB.
- The central frequency can be changed by a footprint compatible SAW filter. From 400 MHz up to 550 MHz.
- High linear design, achieving less than +-0.001 dB nonlinearity over -35 dBm to -10 dBm
- On-chip Crossbar switching that improves drift and noise performance from ~DC up to half the switching frequency
- Input LPF before RF active devices are used in order to avoid peak voltages
- Physically separated channels to provide better electromagnetic isolation
- High Reliability connectors. Footprint compatible with other standard connectors
- Temperature control for the input LPF in order to keep its insertion loss constant

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[1]More details about the mechanical enclosure can be seen on section 3.7.
[2] All the specifications are for the standard configuration of attenuators (10 dB). Temperature operation: -20 ºC to 50 ºC.
[3] The Noise Figure depends on the attenuator configuration.
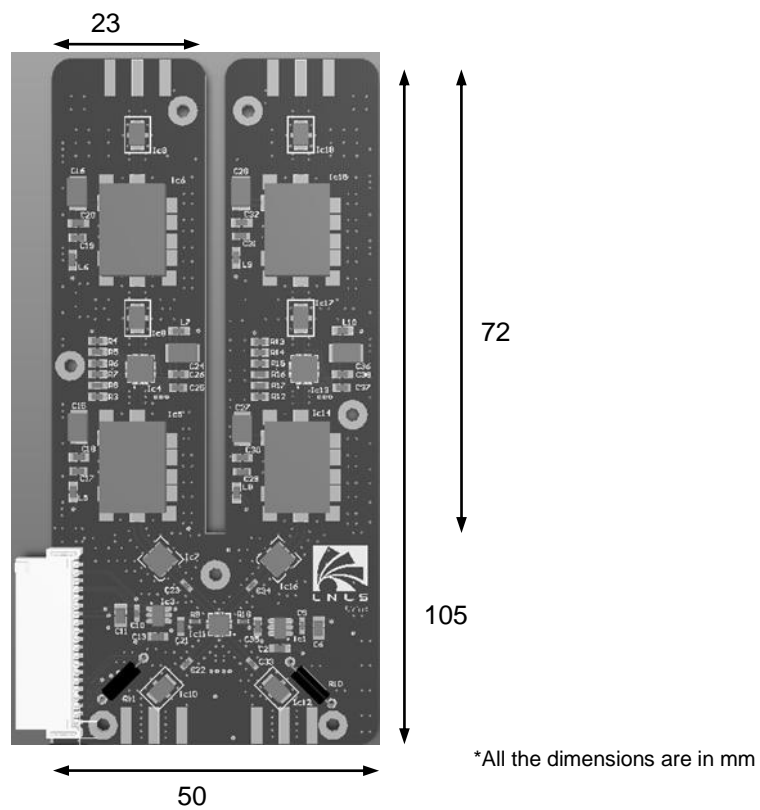
2.2 Safety Instructions

⚠️ **DANGER**

Do not operate this electronics in potentially explosive atmosphere
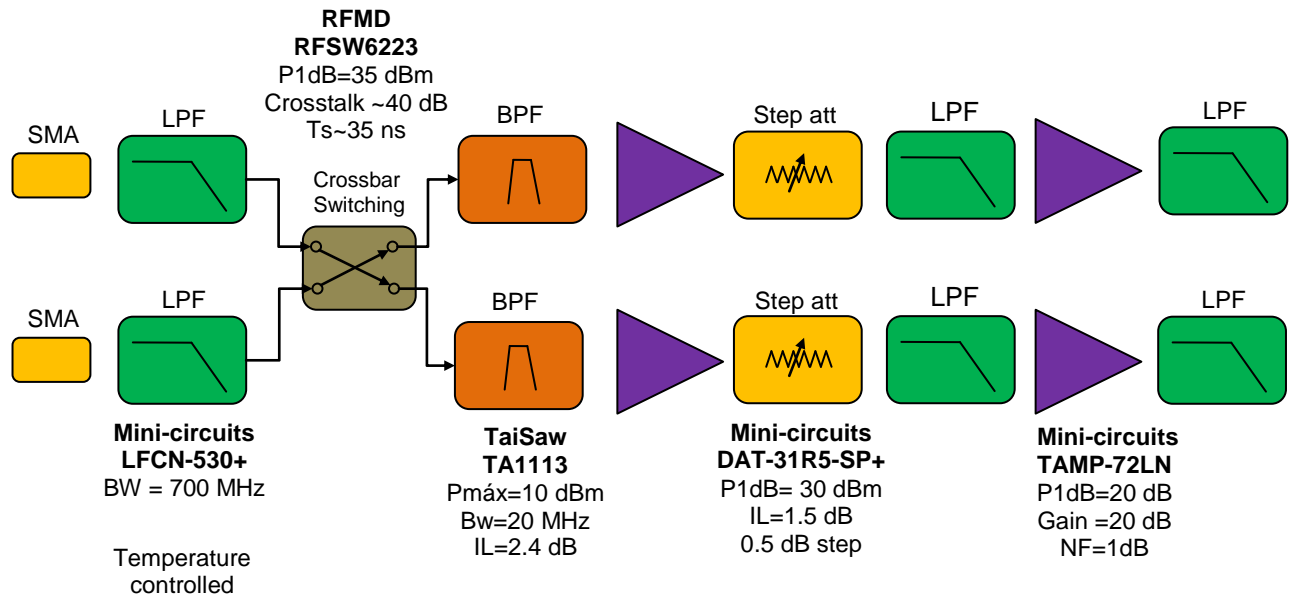
3. Technical Overview

On this section it will be described about the hardware characteristics and detailed schematic description

3.1 Mechanical Drawings

*All the dimensions are in mm

3.2 Block Diagram

- Input Low pass filter
  - The peak voltages on the input of the electronics can excite a nonlinear behavior. For these reason a LPF is necessary before the first amplifying stage.
- Switches
  - High linear (P1dB>30 dBm), well-matched (S11<-20 dB), high isolated (crosstalk < -40 dB), fast (ts < 100 ns) and stabilized switches were necessary to achieve a good performance.
- Amplifiers
  - High linear, low noise amplifier is required for the first amplifying stage of the electronics. For the last amplifying stage, it is better to use higher P1dB amplifiers in order to better use the full scale of the ADC.
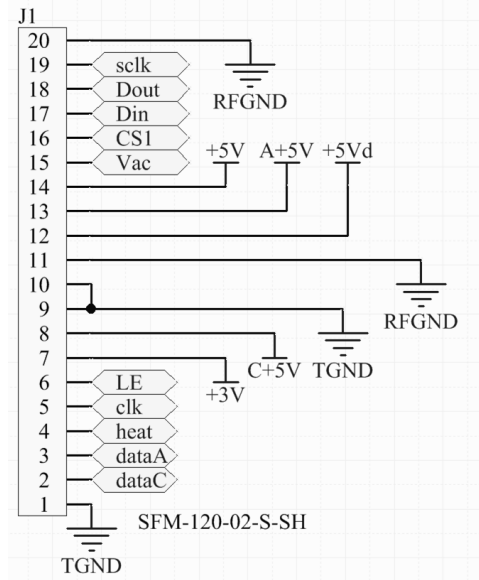
⚠️ **Notice**

- Do not exceed the Max input Power of 10 dBm on the electronics. It can permanently damage the devices.

3.3 Interfaces

The board has an interface connector that provides the clean power supply for RF amplifiers, attenuators and switches (3V and 5 V), digital signals for attenuators programming, SPI interface for the temperature monitor IC, two different grounding nodes (one for RF and another for digital signals) and a signal for the feedback loop of the temperature controller.
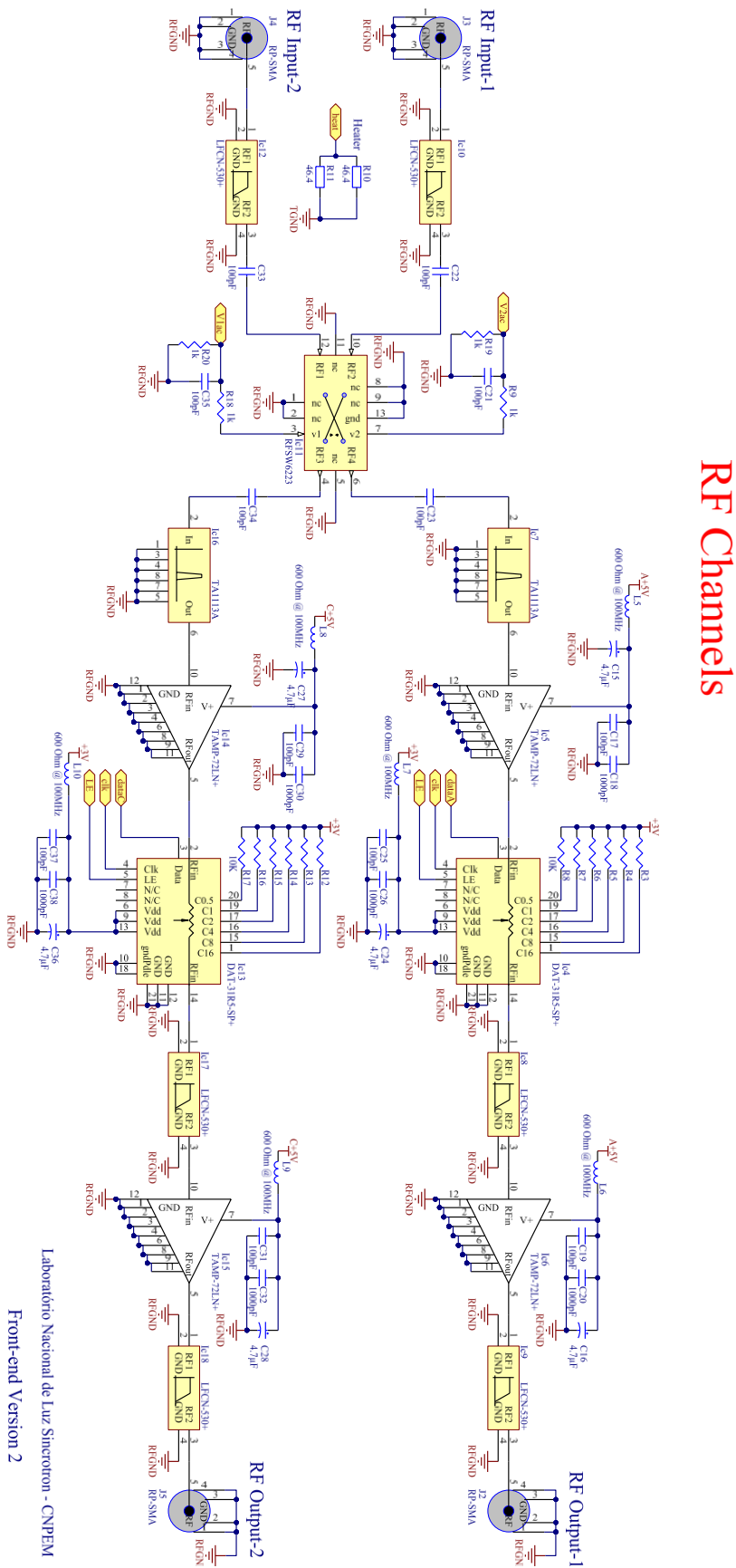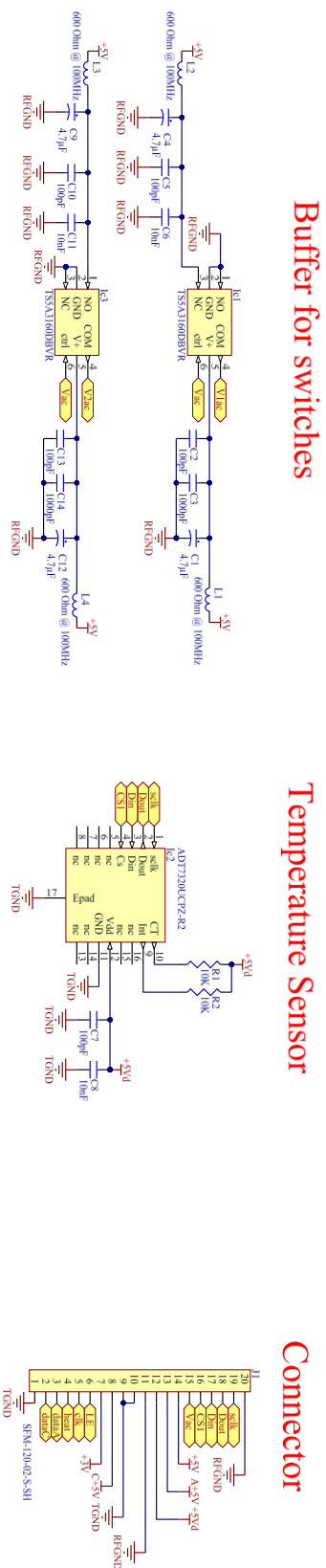
Pin number	Pin Name	Function	Current/voltage ratings
1	TGND	*Ground node for digital and temperature control circuits.*	
2	dataC	*Data pin. Attenuator, channel C[4].*	
3	Data	*Data pin. Attenuator, channel C.*	
4	Heat	*Temperature control Pin. The temperature control loop is implemented via resistor as actuator. The Heat pin.*	
5	Clk	*Clock pin for the serial interface of the RF attenuators.*	
6	LE	*Latch enable pin for the RF attenuators.*	
7	+3V	*Voltage pin for the RF attenuators. It go to the supply pin via an input filtering stage to avoid Crosstalk.*	*1 mA máx*
8	C+5V	*Input pin to the RF amplifiers, channel C. This pin go to supply pin vi an input filtering stage to avoid Crosstalk.*	*250 mA máx*
9	TGND		
10	TGND		
11	RFGND	*Ground node for the RF devices.*	
12	+5Vd	*5 Volts input supply for the digital devices. Temperature monitor.*	*10 mA máx*
13	A+5V	*Input pin to the RF amplifiers, channel A. This pin go to supply pin vi an input filtering stage to avoid Crosstalk.*	*250 mA máx*
14	+5V	*Supply voltage for the control pin of the crossbar switch.*	*1 mA máx*
15	Vac	*Control Pin for the crossbar switch. It controls the analog switch that provide for the crossbar switch a clean control voltage.*	*10 mA máx*
16	CS1	*Chip select for the SPI communication with the temperature monitor[5].*	
17	Din	*Data input for the SPI communication with the temperature monitor IC.*	
18	Dout	*Data output for the SPI communication with the temperature monitor IC.*	
19	Sclk	*Clk pin for the SPI communication with the temperature monitor IC.*	
20	RFGND		

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[4] Refer to the RF attenuator datasheet for details. Minicircuits, part number: DAT-31R5-SP+.
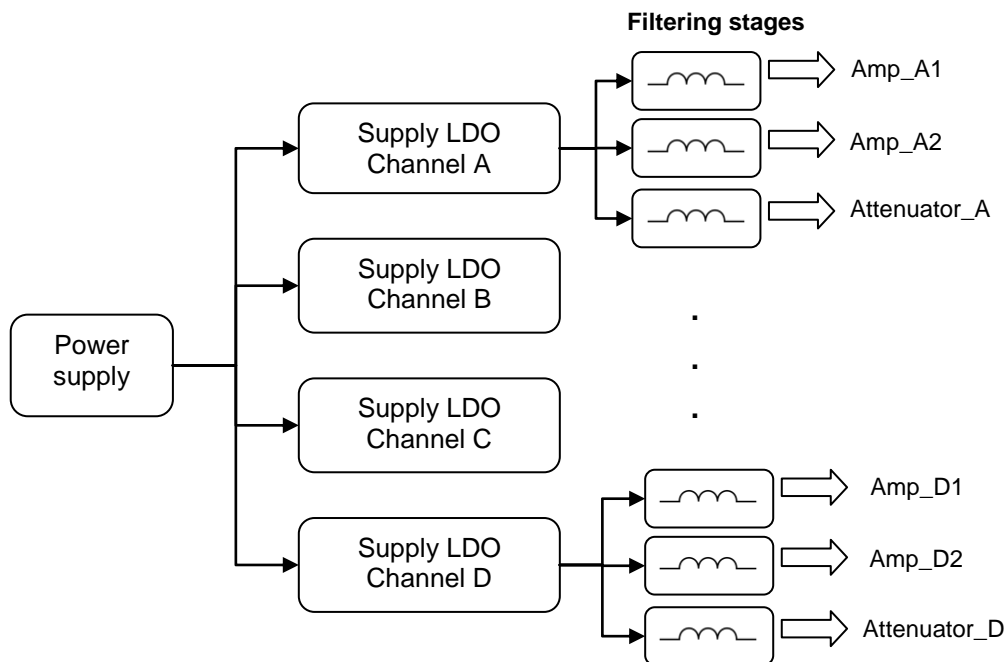[5] Refer to the temperature monitor IC datasheet for details about the SPI interface. Analod Devices, part number: ADT7320.

3.4 Schematics

3.4.1 Power supply

General block diagram of the Power Supply

Filtering stages

Power Supply Schematic:

- One input filtering stage for each channel/device, isolating each active device

3.4.2 Switching scheme

- The crossbar switching is implemented using DPDT switches from RFMD, RFSW6223.
- The "Buffer for switches" was designed because the switch is supplied and controlled through the same pin. This scheme provides a fast transition between 0 (0 V) and 1(5 V) state with a clean supply.
- Low *On* resistance switch is used to swap between clean supply and control voltage and the ground.
- Different capacitors in parallel were used because as the RF switch has a very small power consumption, the small capacitors feed it during the transition time. After the transient, the RF switch is fed by a clean supply.

3.4.3 Temperature sensor

- The temperature sensor is reliable and has high repeatability.
- *The only long term data the manufacturer have is for 500 hours (in the data sheet). Drift was specified at 0.0073 °C.*
- *Long term drift typically drifts as a √time (in hours). The drift for 20 years is estimated as 0.14 °C[6].*

3.4.4 Connector
- The connectors are SAMTEC high reliability ones
- 1.27 mm pitch. Compatible with standard footprints.

- [6] *This is based on typical value taken during characterization, and is certainly not production tested or guaranteed.*".

3.4.5 Mean Time between failures - MTBF

MTBF estimation based on MILD-HDBK-217[1]

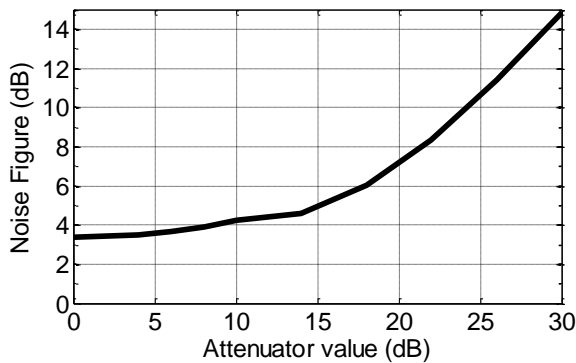| Devices	Qty/RFFE	MTBF (million hours @25 °C)	MTBF (million hours @30 °C)	MTBF (million hours @35 °C)	MTBF (million hours @50 °C)	MTBF (million hours @60 °C)
ADC-10-4+	0	2083.3	1974.8	1873.6	1557.8	1348.1
BPF-C495	0	213.3	205.1	196.4	171.1	154.23
DAT-31R5-SP+	4	144	92	59	15.64	6.42
GSWA-4-30DR	0	157.2	142.8	125.8	79.1	47.7
HSWA2-30DR	0	758	481	312	81.15	33.3
LFCN-530+	12	170.2	170.2	170.2	170.2	170.2
SBTC-2-10L	0	156.5	151.3	146.4	131.2	121.1
TAMP-72LN	8	144.3	139.4	134.5	129.6	119.8
LT1764A	4	1097	1097	1097	1097	1097
Capacitors / resistors	50	1000	800	700	600	500
TCA6424	2	4180	3800	3600	3300	3000
DAC7554	2	1000	800		600	500
LT3080/LTC1964	10	1000	800		600	500
MBED	1	200	190		170	160
Capacitors / resistors (control board)	50	1000	800		600	500
System Reliability (Million hours)		**0.941513426**	**0.786924247**	**0.687492433**	**0.479162684**	**0.308904357**
System MTBF estimation (years)		***107.478***	***89.8315***	***78.480***	***54.6989***	***35.26***

Notice

- Do not operate the electronics at temperatures higher than 50 ºC. It will decrease the expected lifetime.
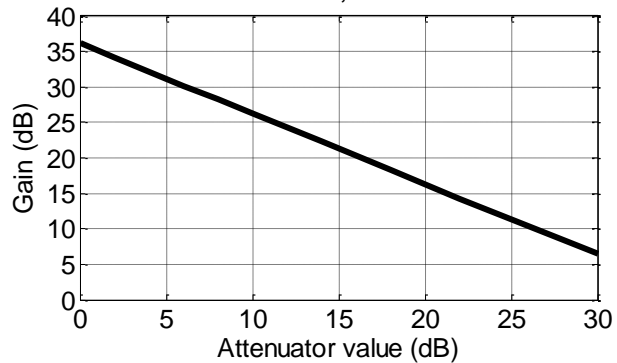
3.5 Typical Performance Characteristics

The results presented on this section show the typical characteristics for an RF channel of the RFFEv2 electronics.
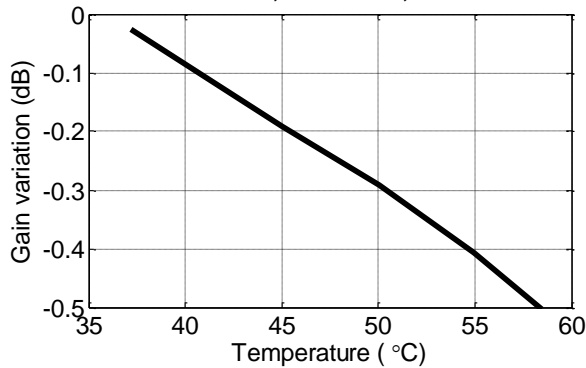

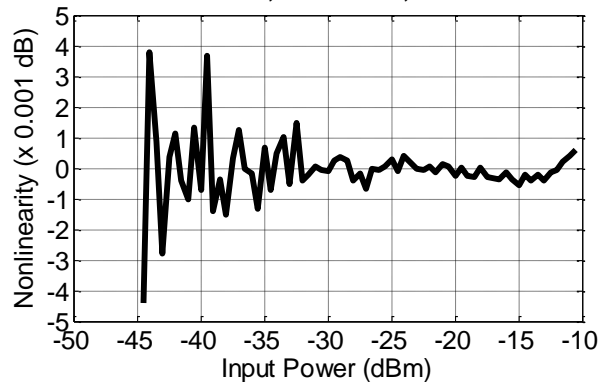**Noise Figure vs RFFE attenuator,
Fin = 500 MHz, Pin = 0 dBm**

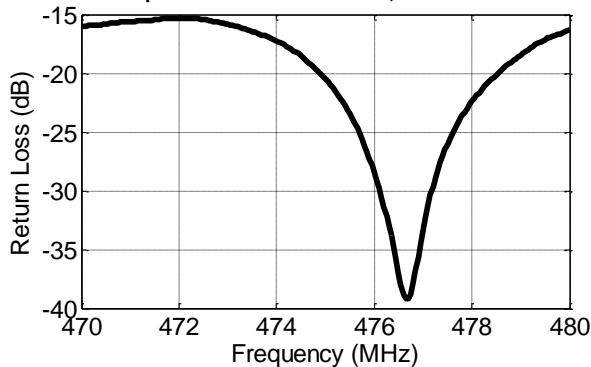**Gain vs RFFE attenuator,
Fin = 500 MHz, Pin = 0 dBm**

**Gain variation vs Temperature,
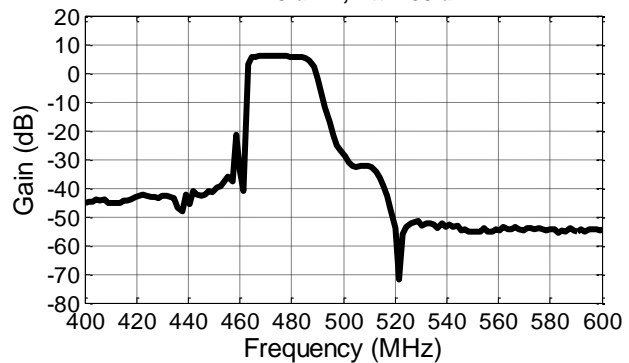Fin = 500 MHz, Pin = 0 dBm, Att = 10 dB**

**Linearity Error vs Input Power,
Fin = 500 MHz, Pin = 0 dBm, Att = 10 dB**

**Return Loss vs Frequency.
Optimized for 476.066 MHz, Pin = 0 dBm**

**Gain vs Frequency. Optimized for 476.066 MHz,
Pin = 0 dBm, Att = 30 dB**

**RF Switch stabilization time, 3 dB step,
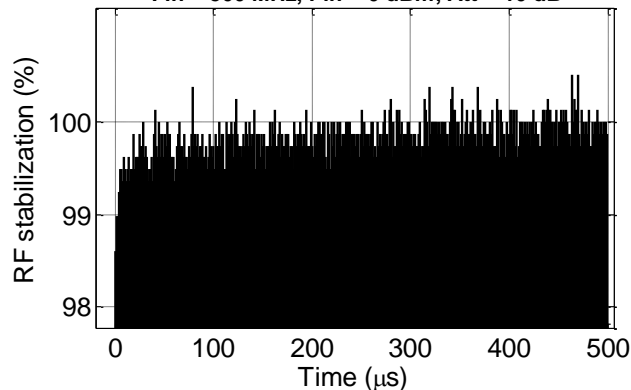Fin = 500 MHz, Pin = 0 dBm, Att = 10 dB**

Figure: Stabilization time of the RF switch, ~400 µs for 100% of RF.
90 % of RF stabilization time is ~40 ns.

3.6 PCB Design

- Symmetric switching scheme
- Designed with Rogers RO4350 20 mils thickness laminate on RF layer
- Improved grounding schemes
- Temperature control on the LPF before the switching scheme
- Temperature sensor on the bottom side
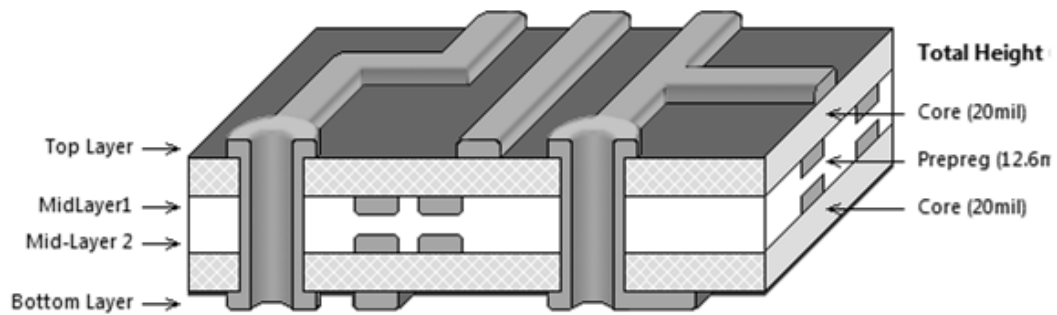- Enclosure as shielding and thermal stabilizer
- SMA connectors screwed on the Enclosure
- 4-layers, 117x50 mm.
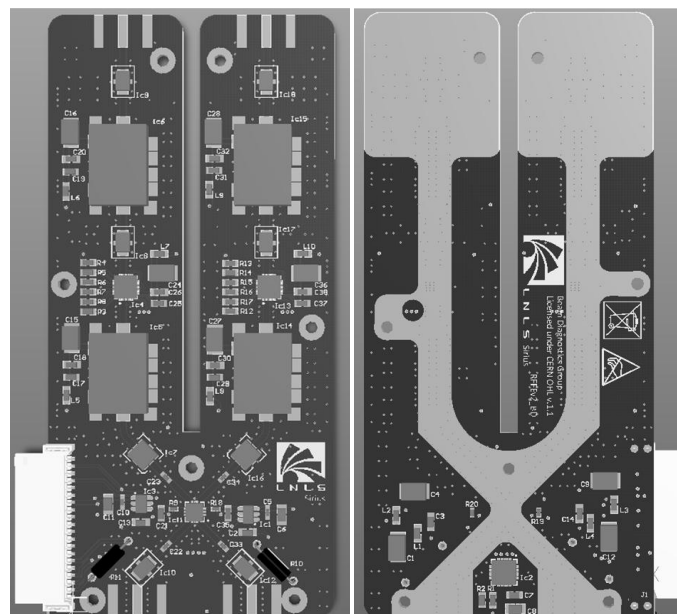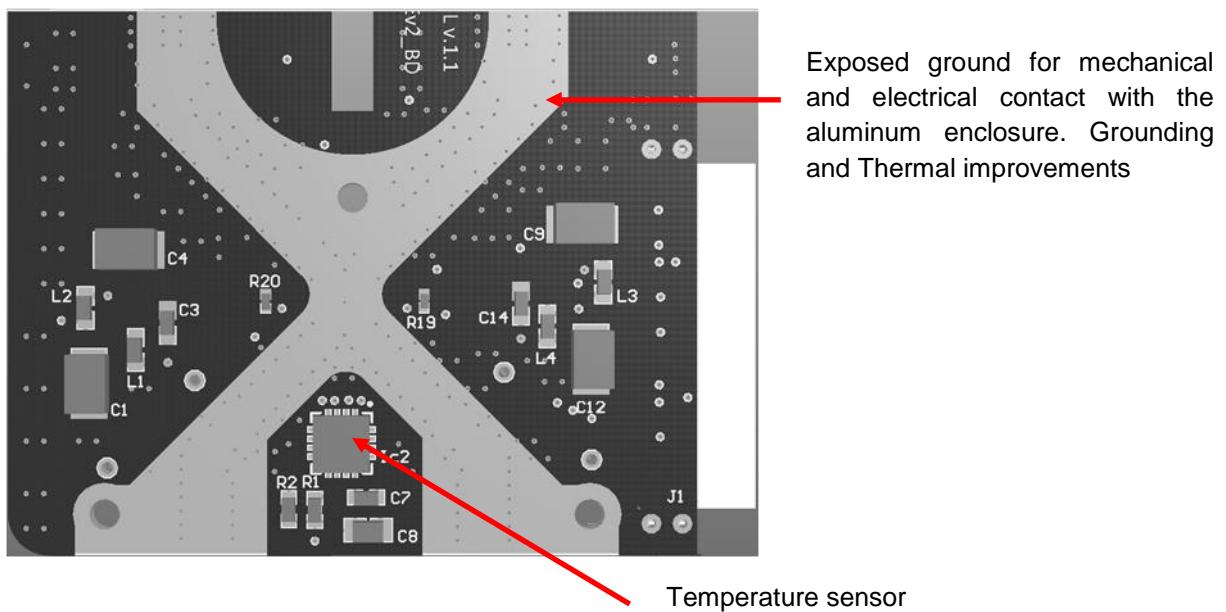

Figure: Layer stack manager

Figure: Top and bottom side

Amplifier

Amplifier

BPF

Switch

Heaters

Temperature sensor (bottom side)

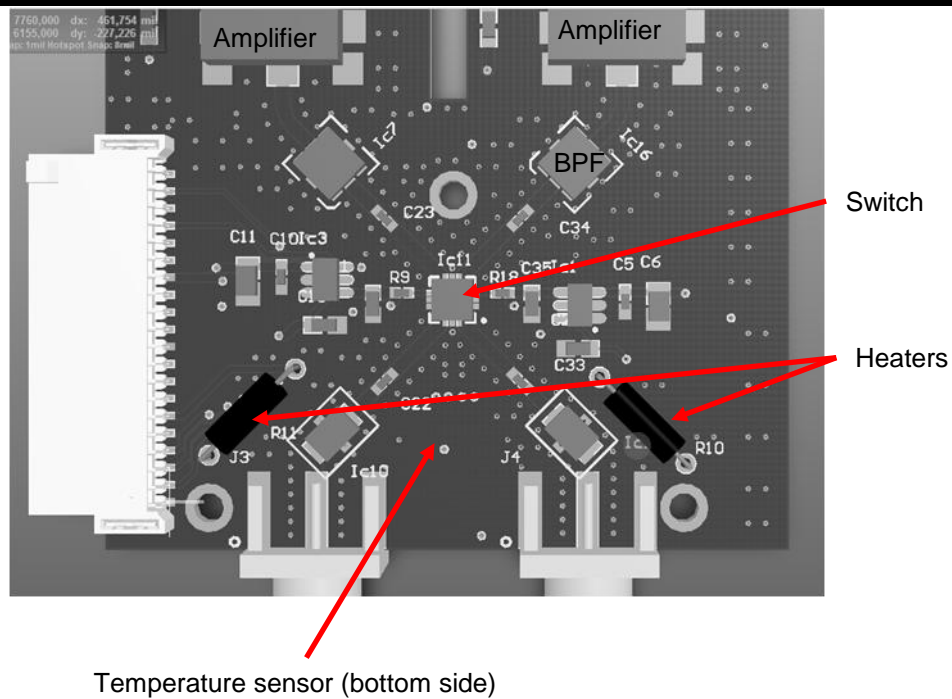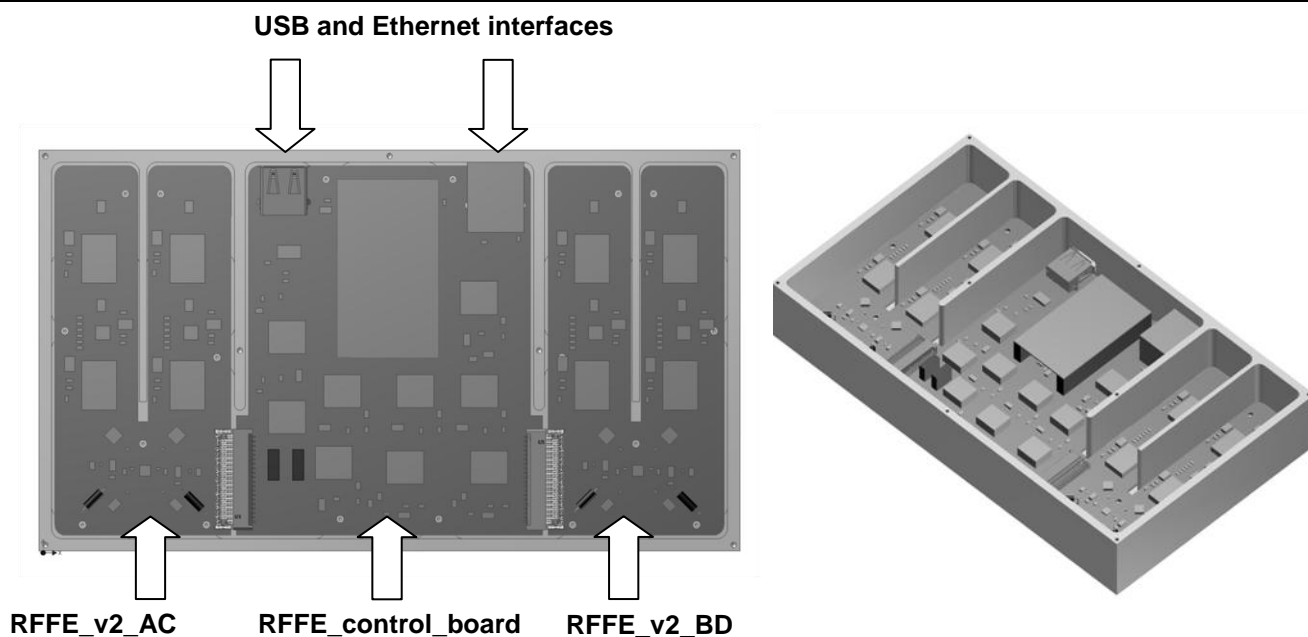Exposed ground for mechanical and electrical contact with the aluminum enclosure. Grounding and Thermal improvements

Temperature sensor

3.7 Mechanical Assembly

The boards are assembled in a customized mechanical enclosure that provide appropriate shielding and thermal dissipation for the hardware.

USB and Ethernet interfaces

RFFE_v2_AC   **RFFE_control_board**   **RFFE_v2_BD**

4. PCB Fabrication Requirements

Design references			
Name	RFFE_V2		
File name(s)	RFFE_v2_AC	RFFE_v2_BD	
Designer	Rafael Antonio Baron		
E-mail	dig@lnls.br		
Fone	+55 19 3512-5071	Date	30/01/2014

Mechanical characteristics	
External size (mm)	50 mm x 105 mm
Thickness (mm)	1.6 mm
Multilayers	4 layers
Min track width (mm/mils)	
Min Hole size (mm/mils)	
Laminate	RO4350 on top layer
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
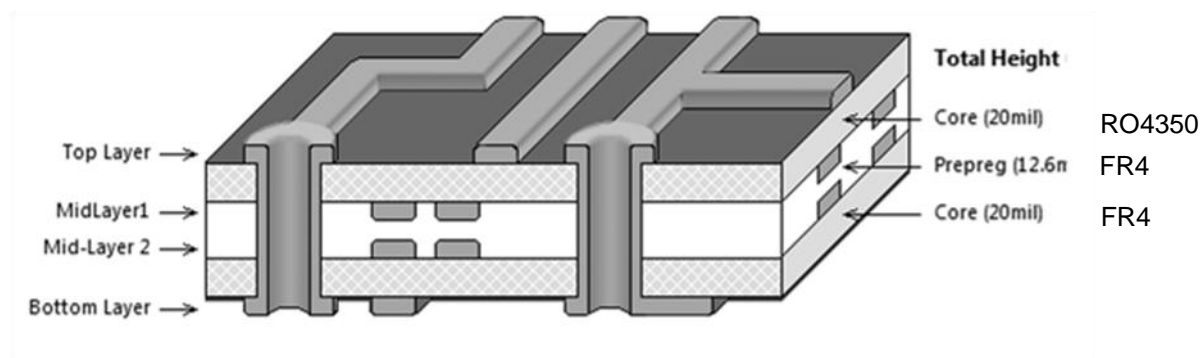
Silkscreen on top layer (color)	Green
Silkscreen on bottom layer (color)	Green
Surface Finishing	ENIG – Electroless Nickel / Immersion Gold according to IPC-4552
Thickness	Ni: 3 μm min, 6 μm máx. Au: 0.05 μm min, 0.125 μm máx

Additional Information

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

Board Stackup Information

			Laminate/pre-preg	Thickness (mm/mils)
Layer 1	RF signals			
Layer 2	RF Ground Plane		RO4350	20 mils
Layer 3	Digital signaling		FR4	20 mils
Layer 4	Ground Plane + Digital signals		FR4	20 mils

5. References

[1] "Military Handbook - Reliability Prediction of Electronic Equipment," Department of Defense - United States of America, 1990.