CaribouLite[-ISM] Datasheet

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IL000002

This product is certified open hardware

This Document

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For an up-to-date version of this document refer to Cariboulabs.co official Github page at: https://github.com/cariboulabs/cariboulite

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PLEASE READ CHAPTER 10 – "WARNINGS, RESTRICTIONS, AND DISCLAIMER"

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2 FIGURES

3 TABLES

4 CHANGE HISTORY

No.	Date	Change Description	Author
1	10/20/2021	First revision	D.M.

5 INTRODUCTION

CaribouLite is a dual-channel SDR (Software Defined Radio) platform, a Raspberry-Pi extension (HAT) and an SDR-dedicated FPGA development platform. With CaribouLite, your Raspberry Pi computer becomes a self-contained dual-channel radio Tx/Rx spanning a wide tunable frequency spectrum.

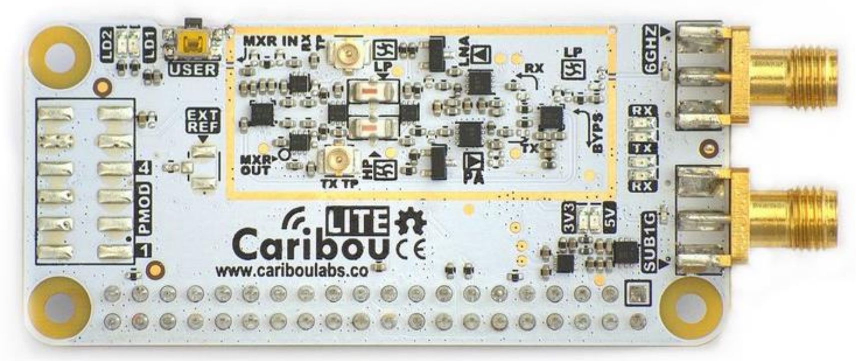

Figure 1 CaribouLite top view

CaribouLite provides **full control on its components, including the FPGA**, its firmware, and all supporting software. It allows writing custom FPGA application with the deeply integrated IceStorm toolchain. Many Verilog modules such as SPI and SMI can be reused for to support your custom application and even other projects.

Table 1 Frequency Bands

Version	Channel 1 (Sub-1GHz)	Channel 2
CaribouLite	389.5-510 MHz and 779-1020 MHz	30-6000 MHz
CaribouLite-ISM		2400-2483.5 MHz

A note about the frequency range: The actual frequency capabilities of the board have been tested to exceed the above. For instance, the lower bound of the wide channel was tested to achieve down to 1MHz. Nevertheless, due to the specifications of the used components, we stick with the official specs, letting the SDR community to drive the actual specifications of the board further to their limits. In addition, two exclusion regions exist in the wide tunable (6 GHz) region: **2398.5-2400 MHz and 2483.5-2485 MHz**

The 4 MSPS I/Q samples (both Tx and Rx) are transmitted over the RPI's secondary memory interface, where CaribouLite acts as a high throughput memory peripheral.

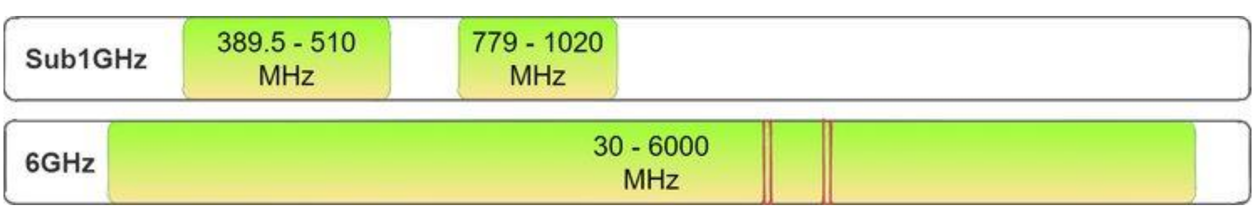

Figure 2 CaribouLite Operational frequency ranges (Tx & Rx)

Both versions have internal accurate TCXO clock-sources. They also have fully controllable read / write 8-bit expansion port (PMOD) to support advanced features such as direction finding, GPS synchronization, and more.

CaribouLite contains a low noise amplifier and Tx power amplifier (up to 13 dBm in the modem's native frequency bands).

On the software side, Raspberry Pi's high-level APIs like Soapy / GNU Radio, and Jupyter notebooks are fully supported, through which the HAT's complete feature-set can be accessed.

Important note: CaribouLite was designed to be used on top of the official Raspberry-Pi host with 40-pin expansion headers. Any use of the CaribouLite with different types of board has not been tested and may cause malfunction, or even cause permanent damage to either CaribouLite, the host-board or both.

6 CONNECTING UP CARIBOULITE

To connect CaribouLite and operate it, please follow the next steps:

Prerequisites:

1. Raspberry-Pi with 40-pin connector (pins).
2. Antennas.

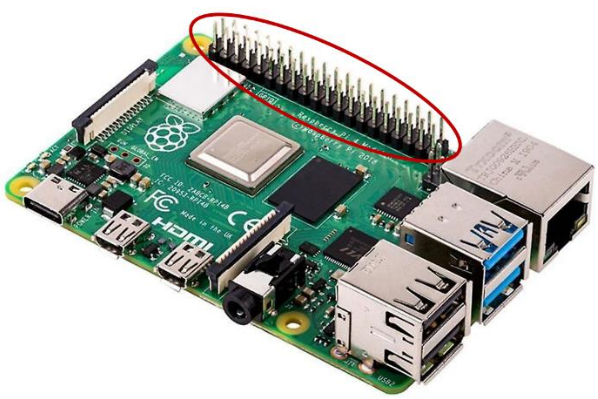

Figure 3 Raspberry Pi pins

Steps to connect:

1. Carefully assemble the CaribouLite board – make sure none of the pins are offset
2. Connect antennas to CaribouLite, optionally connect keyboard / mouse / screen to the RPI
3. Power the Raspberry-Pi and wait till it boots
4. Check that the 5V and 3.3V LEDs are on.

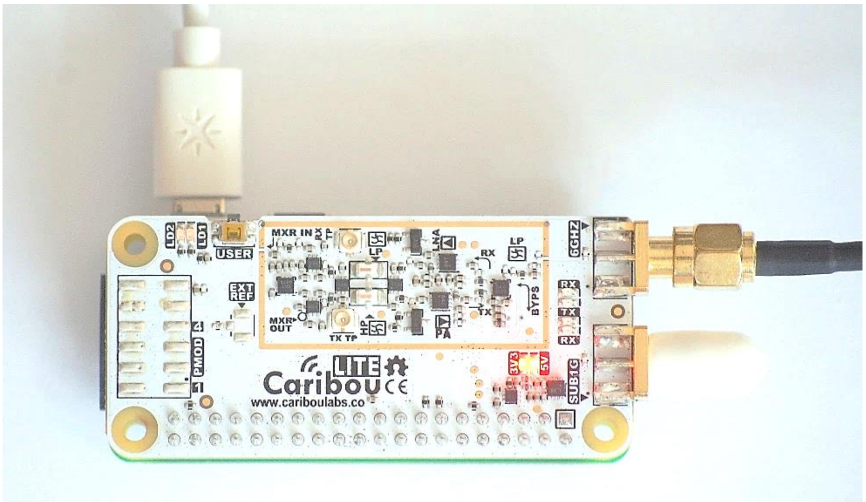

Figure 4 Powered-on CaribouLite + RPI Zero

7 HARDWARE

7.1 BLOCK DIAGRAM

7.1.1 System Blocks

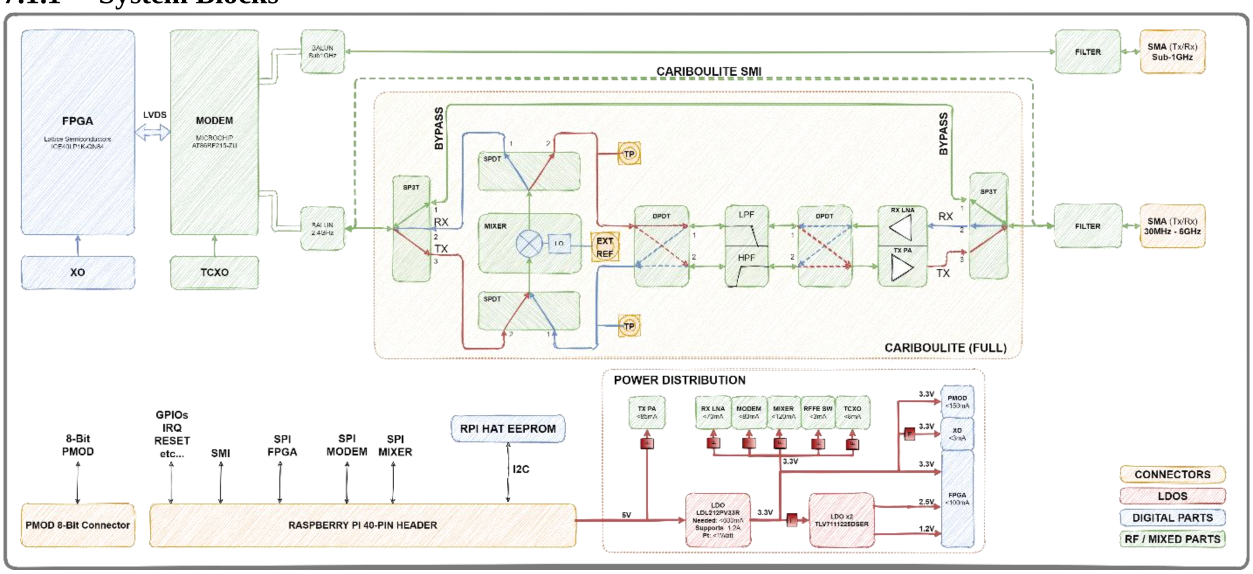

Figure 5 System block diagram

CaribouLite system block diagram (Figure 5) shows the main building blocks of the board.

It also shows the difference between the two versions of the system (see dashed line bypassing the front-end block). In CaribouLite-ISM, the whole front-end block is absent. Instead, a bypass route connects the antenna port directly to the modem.

Distinguishing the two versions of the system is possible through the configuration resistors on the bottom of the board. In CaribouLite, none of the resistors is populated, while in the ISM version, CFG0 resistor is assembled.

Version	Configuration Read (by FPGA)
CaribouLite	CFG[3:0] = '1111'
CaribouLite-ISM	CFG[3:0] = '1110'

7.1.2 Power Section

Power is provided to the board by the Raspberry Pi (5V), which is converted to 3.3V, 2.5V, and 1.2V to operate the system. Power rails are filtered and isolated using ferrite beads (see Figure 6).

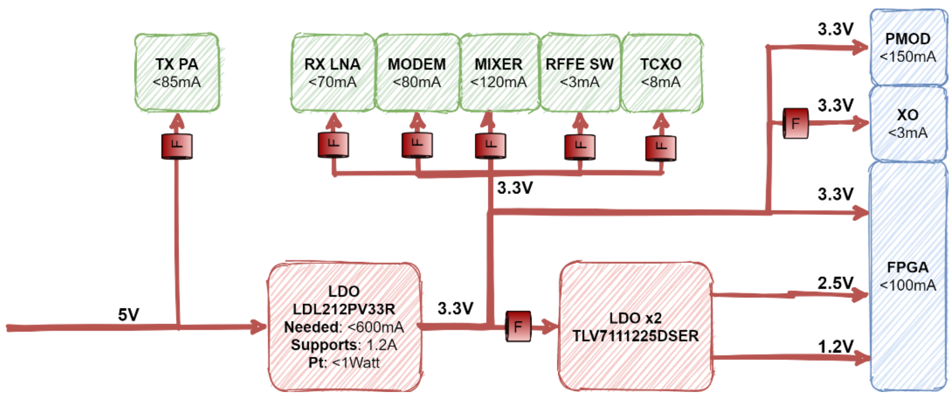

Figure 6 Power distribution

7.1.3 RF Front-End

CaribouLite-ISM version has a minimal RF frontend that interfaces the modem's RF ports to the antenna ports on the board. It contains two integral baluns (one for each channel) and matching networks, designed specifically to be used for the AT86RF215 chipset.

The CaribouLite 6GHz version, on the other hand, connects the 2.4GHz channel to an up/down-converter circuit that allows it tune up to 6 GHz and down to 30 MHz as shown in Figure 7. The figure shows five possible RF paths – (1) Bypass, (2) RX up conversion, (3) RX down conversion, (4) TX up conversion, and (3) TX down conversion.

The bypass path uses the modem's native 2.4GHz Tx/Rx channel for reception and transmission. The other paths incorporate a frequency mixer IC (RFFC5072) as the frequency up/down-converter.

When in paths (2) and (3), an LNA pre-amplifies the incoming signal. In paths (4) and (5), a PA amplifies the mixer output for transmission. Both LNA and PA are based on the same low-noise RF amplifier by MACOM.

The low/high pass filters are selected using two DPDT (crossover) switches by CEL. All RFFE control signals originate within the FPGA firmware, including LNA / PA shutdown commands.

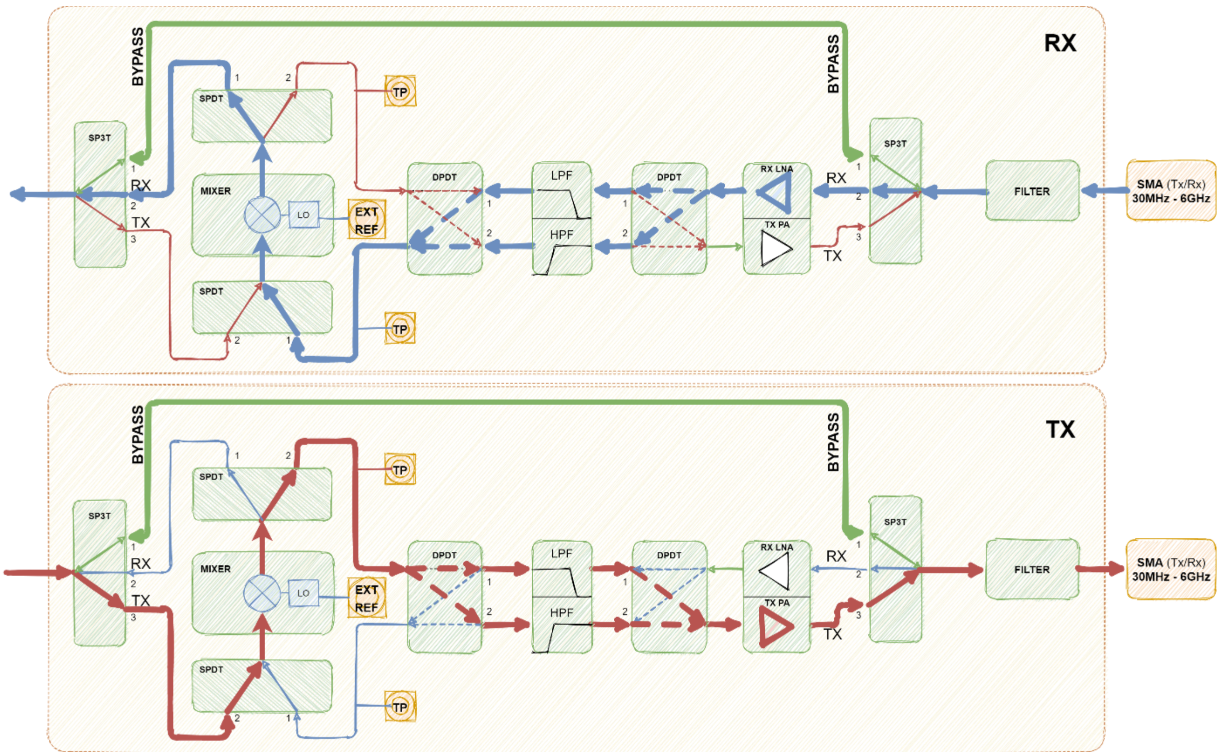

Figure 7 CaribouLite RF frontend

Important Note: Though tinkering with the RFFE control signals is possible through the open-source firmware and software, one must consider that the controlled components and ICs are very sensitive to misconfiguration. Thus, any tweaking may cause malfunction and permanent damage to the system.

7.2 Operation Conditions

The following table contains the hardware operational limits for which CaribouLite boards have been tested. Wider limits may be possible, though not recommended.

Table 2 Operation limits

Name / Description	Min	Max	Notes
Raspberry Pi interface (40-pin header)			
pin2, pin4	4V	6V	Typically, 5V
Current – CaribouLite (I_{sys})	TBD	TBD	
Current – CaribouLite-ISM ($I_{sys,ism}$)	TBD	TBD	

Voltages on any other pin (40-pin connector)	-0.2V	3.4V	
PMOD interface (10-pin header)			
Voltage output range (V_{OL}, V_{OH})	0-0.4 V	2.9-3.3 V	
Input high voltage (V_{ih})	-0.3V	0.8V	
Input low voltage (V_{il})	2.0V	3.5V	
Maximal current drawn from Pin11, Pin 12 (I_{max})	-	150 mA	
RF Ports			
Input power channel #1 – Sub-1GHz	-	10 dBm	Absolute maximum rating
Input power channel #2 – 2.4GHz (CaribouLite-ISM)	-	10 dBm	
Input power channel #2 – 30-6000MHz (CaribouLite)		4 dBm	
Maximal input DC voltage on both RF connectors	-	±2V	Typically, zero DC should be applied
Output power Channel #1 – Sub-1GHz	10 dBm	15.5 dBm	
Output power Channel #2 – 2.4GHz (CaribouLite-ISM)	10 dBm	14.5 dBm	
Output power Channel #2 – 30-6000 GHz (CaribouLite) • 30 - 1000 MHz • 1000 - 2400 MHz • 2400 - 2483.5 MHz • 2483.5 – 3500 MHz • 3500 – 6000 MHz	TBD	TBD	
Clock reference accuracy	-	2 PPM	TCXO
IP1dB Channel #1 - Sub-1 GHz	-	-28 dBm	Calculated
IP1dB Channel #2 - 2.4 GHz (CaribouLite-ISM)	-	-25 dBm	Calculated
IP1dB Channel #2 - 30-6000 MHz (CaribouLite)	-	-5 dBm	
Frequency tuning resolution – Channel #1 – Sub-1GHz	~100Hz	~200Hz	
Frequency tuning resolution – Channel #2 – 2.4GHz	~400Hz		
Frequency tuning resolution – Channel #2 – 30-6000 MHz (*) within the 2400-2483.5 MHz band the previous row should be used	~1.5Hz		

Important Note: operating CaribouLite[-ISM] outside the above specification margins may damage the system, or its host (Raspberry Pi).

7.3 CONNECTORS

7.3.1 Raspberry Pi 40-pin Header

CaribouLite operates over Raspberry Pi boards with 40-pin interface. Pin-header polarity on the RPI side is assumed (see Figure 3), while the CaribouLite a 40-pin socket. Some Raspberry-Pi boards (e.g., RPI Zero) need these pin-header to be explicitly mounted.

7.3.2 RF SMAs

The SMA connectors mounted on the CaribouLite are female connectors (NOT reversed-polarity), see Figure 8.

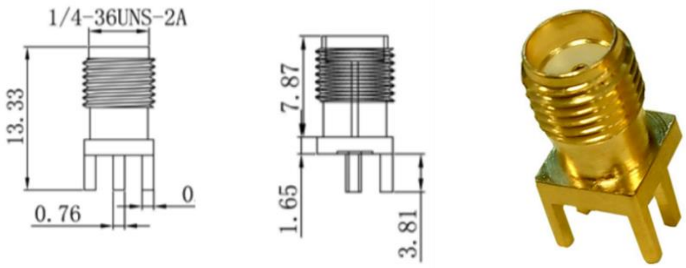

Figure 8 CaribouLite SMA connectors

Restrictions exist over the maximal allowed DC voltage and the maximal RF power applied to these ports, and they are described in Table 1. Both RF ports are ESD protected by a TVS diode.

7.3.3 PMOD Connector (unmounted)

The PMOD connector is not mounted on board by default due to its additional height, which may be unnecessary for some applications. Nevertheless, this port allows access to I/O lines on the FPGA and 3.3V power.

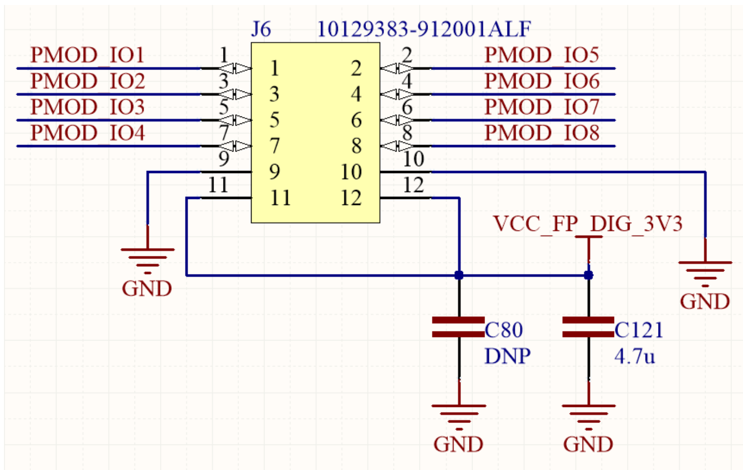

Figure 9 PMOD connector

As described above, the PMOD connector is a 2x6 (12-pos) 0.1” pin-header. It provides power to a peripheral. The maximal current draw from the header is specified in Table 2.

7.3.4 Tx / Rx Test-Points (unmounted)

Two RF test points may be mounted on the tops side of the board - See Figure 10. In addition to the U.FL RF connectors, two capacitors have to be mounted on the marked locations (1nF 0402 will suffice).

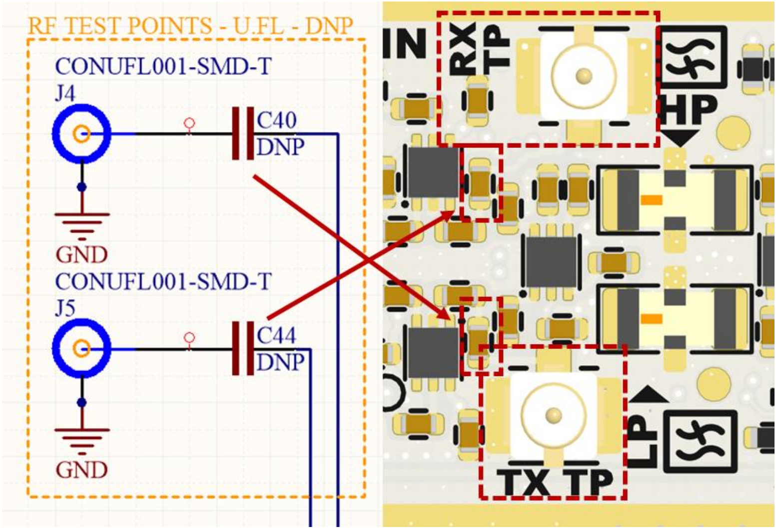

Figure 10 RF test-points

7.4 LED Indicators

Figure 11 shows the LED indicators populated on the CaribouLite (and ISM) boards.

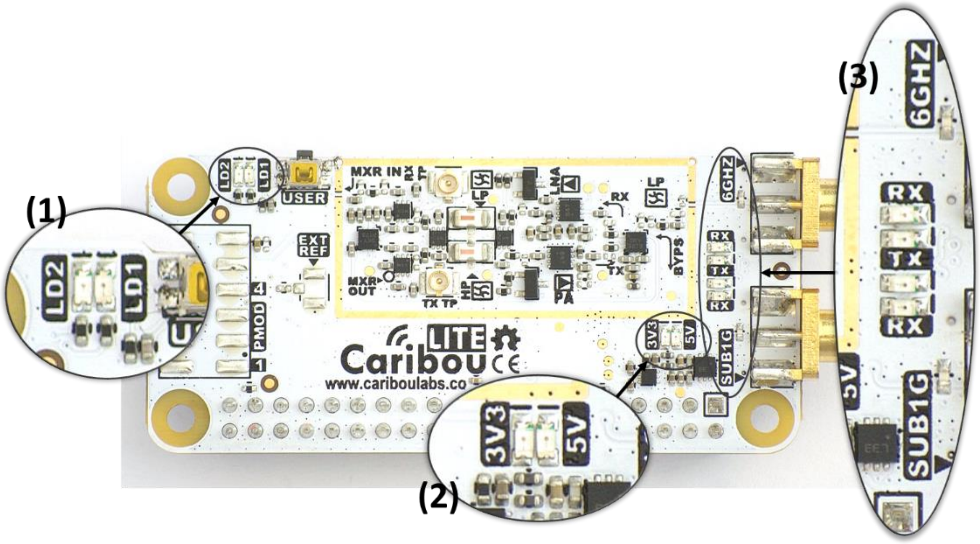

Figure 11 CaribouLite LED indicators

Descriptions:

(1) Operational "user" LEDs: controlled by the FPGA through an API command (SPI) of any custom behavior specified by the user.
(2) Power LED indications: indicating the existence of 5V input (from the RPI) and 3.3V output from the LDO.

(3) Tx/Rx LED indications: controlled by the MODEM, these LEDs show (for each radio) the state of the channel. The top pair shows the state of the 6GHz (or 2.4GHz in ISM) channel status, while the bottom pair shows the status of the Sub-1GHz channel.

7.5 Switch Operation

A push button named "USER" is located near the user LED indicators. This button has two roles

1. A general-purpose user programmable push-button for synchronization, operational input, PTT, etc.
2. Write-enable signal for the HAT EEPROM device – to reconfigure the EEPROM mounted on the bottom device with board information, this button needs to be pushed all along the programming period.

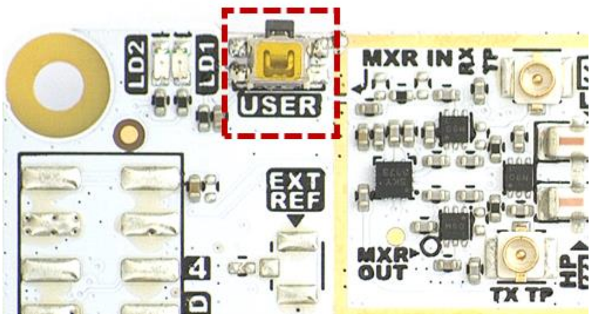

Figure 12 Push button

7.6 FPGA Resources

Important Note: Some of the FPGA IC's pins are intentionally grounded to improve the ground plane flow on the PCB. Explicitly driving them from the FPGA firmware may cause high current draws and even permanently damage the system. The grounded pins are: A44, B34, and A12.

The following table describes the systems resources and logical interconnections

Table 3 FPGA signal resource list

No.	Name	FPGA Chip			RPI Header 40-pin		Signaling Standard	Initial State	Mode	Description
		Bank	Pin	Pin Name	Header Pin	SoC Pin				
1	io_pmod0	1	B24	IOR_65	-	-	LVCMOS 3.3V	LOW	I/O	General purpose I/O signals Used for outputting discrete signals, synchronizing
2	io_pmod1	1	A31	IOR_64	-	-	LVCMOS 3.3V	LOW	I/O	
3	io_pmod2	1	B23	IOR_23	-	-	LVCMOS 3.3V	LOW	I/O	
4	io_pmod3	1	B21	IOR_57	-	-	LVCMOS 3.3V	LOW	I/O	
5	io_pmod4	1	A25	IOR_53	-	-	LVCMOS 3.3V	LOW	I/O	
6	io_pmod5	1	A26	IOR_55	-	-	LVCMOS 3.3V	LOW	I/O	

7	io_pmod6	1	A27	IOR_58	-	-	LVCMOS 3.3V	LOW	I/O	
8	io_pmod7	1	B20	IOR_56	-	-	LVCMOS 3.3V	LOW	I/O	
9	o_mixer_fm	1	A32	IOR_66	-	-	LVCMOS 3.3V	LOW	O	Mixer operation with FM modulation to form a BFSK communication scheme
10	o_mixer_en	1	B22	IOR_61_GBIN2	-	-	LVCMOS 3.3V	LOW	O	Mixer IC enable signal
11	o_rx_h_tx_l	1	A33	IOR_68	-	-	LVCMOS 3.3V	LOW	O	Front-end control signals
12	o_rx_h_tx_l_b	1	A35	IOR_71	-	-	LVCMOS 3.3V	HIGH	O	
13	o_tr_vc1	1	A34	IOR_69	-	-	LVCMOS 3.3V	LOW	O	
14	o_tr_vc1_b	1	B27	IOR_72	-	-	LVCMOS 3.3V	HIGH	O	
15	o_tr_vc2	1	B26	IOR_70	-	-	LVCMOS 3.3V	LOW	O	
16	i_glob_clock	1	A29	IOR_60_GBIN3	-	-	LVCMOS 3.3V	-	I	125MHz
17	o_iq_tx_p	3	B4	IOL_5A	-	-	LVDS 2.5V	LOW	O	LVDS output - Negated
18	o_iq_tx_n	3	A5	IOL_5B	-	-	LVDS 2.5V		O	
19	o_iq_tx_clk_p	3	A10	IOL_9A	-	-	LVDS 2.5V	LOW	O	LVDS output - Negated
20	o_iq_tx_clk_n	3	B8	IOL_9B	-	-	LVDS 2.5V		O	
21	i_iq_rx_09_p	3	B3	IOL_4A	-	-	LVDS 2.5V	-	I	LVDS input - Not negated
22	i_iq_rx_09_n	3	A4	IOL_4B	-	-	LVDS 2.5V		I	
23	i_iq_rx_24_p	3	B1	IOL_2A	-	-	LVDS 2.5V	-	I	LVDS input - Negated
24	i_iq_rx_24_n	3	A2	IOL_2B	-	-	LVDS 2.5V		I	
25	i_iq_rx_clk_p	3	B2	IOL_3A	-	-	LVDS 2.5V	-	I	LVDS input - Not negated
26	i_iq_rx_clk_n	3	A3	IOL_3B	-	-	LVDS 2.5V		I	
27	i_config0	0	B29	IOT_77	-	-	LVCMOS 3.3V	HIGH	I (PU)	Resistor based configuration inputs. These inputs should be configured as internal pull-ups (CaribouLite-ISM – config0 = '1')
28	i_config1	0	A40	IOT_80	-	-	LVCMOS 3.3V	HIGH	I (PU)	
29	i_config2	0	B30	IOT_79	-	-	LVCMOS 3.3V	HIGH	I (PU)	
30	i_config3	0	A41	IOT_82	-	-	LVCMOS 3.3V	HIGH	I (PU)	
31	i_button	0	B31	IOT_81	-	-	LVCMOS 3.3V	HIGH	I (PU)	Push button input (dual usage)
32	o_led0	0	A38	IOT_76	-	-	LVCMOS 3.3V	LOW	O	Marked as LD1
33	o_led1	0	A39	IOT_78	-	-	LVCMOS 3.3V	LOW	O	Marked as LD2
34	o_shdn_rx_lna	0	A46	IOT_90	-	-	LVCMOS 3.3V	HIGH	O	Shutdown (1) RX LNA
35	o_shdn_tx_lna	0	B36	IOT_93	-	-	LVCMOS 3.3V	HIGH	O	Shutdown (1) the TX PA
36	i_smi_addr1	0	A43	IOT_84_GBIN1	7	GPIO4	LVCMOS 3.3V	-	I	3-bit SMI address
37	i_smi_addr2	0	A48	IOT_95	5	GPIO3	LVCMOS 3.3V	-	I	
38	i_smi_addr3	0	A47	IOT_92	3	GPIO2	LVCMOS 3.3V	-	I	

39	o_smi_read_req	1	B19	IOR_52	18	GPIO24	LVCMOS 3.3V	LOW	O	SMI read request - data needs to be read out by the master (RPI)
40	o_smi_write_req	2	A19	IOB_41	22	GPIO25	LVCMOS 3.3V	LOW	O	SMI write request - more data is needed to be pushed by the master (RPI)
41	i_smi_soe_se	2	B15	IOB_42_CBSEL0	31	GPIO6	LVCMOS 3.3V	-	I	SMI read-enable input from the master (RPI)
42	i_smi_swe_srw	2	B13	IOB_38	26	GPIO7	LVCMOS 3.3V	-	I	SMI write-enable input from the master (RPI)
43	io_smi_data0	2	A16	IOB_34	24	GPIO8	LVCMOS 3.3V	-	I/O	SMI 8-bit data bus
44	io_smi_data1	2	B11	IOB_33	21	GPIO9	LVCMOS 3.3V	-	I/O	
45	io_smi_data2	2	B10	IOB_32	19	GPIO10	LVCMOS 3.3V	-	I/O	
46	io_smi_data3	2	B12	IOB_36_GBIN4	23	GPIO11	LVCMOS 3.3V	-	I/O	
47	io_smi_data4	2	B14	IOB_40	32	GPIO12	LVCMOS 3.3V	-	I/O	
48	io_smi_data5	2	A20	IOB_43_CBSEL1	33	GPIO13	LVCMOS 3.3V	-	I/O	
49	io_smi_data6	2	A13	IOB_30	8	GPIO14	LVCMOS 3.3V	-	I/O	
50	io_smi_data7	2	A14	IOB_35_GBIN5	10	GPIO15	LVCMOS 3.3V	-	I/O	
51	o_miso	2	B17	IOB_44_SDO	35	GPIO19	LVCMOS 3.3V	LOW	O	SPI for programming and control / status (refer to ICE40 RM)
52	i_sck	2	A23	IOB_46_SCK	40	GPIO21	LVCMOS 3.3V	-	I	
53	i_ss	2	B18	IOB_47_SS	12	GPIO18	LVCMOS 3.3V	-	I	
54	i_mosi	2	A22	IOB_45_SDI	38	GPIO20	LVCMOS 3.3V	-	I	
55	i_creset	-	A21	CRESET_B	37	GPIO26	LVCMOS 3.3V	-	I	Reset IC
56	o_cdone	-	B16	CDONE	13	GPIO27	LVCMOS 3.3V	HIGH (*)	O	Programming done
57	gnd	3	A12	IOL_12B	-	-	LVCMOS 2.5V	LOW	I	Do not use! Permanently connected to GND
58	gnd	0	B34	IOT_89	-	-	LVCMOS 3.3V	LOW	I	
59	gnd	0	A44	IOT_86	-	-	LVCMOS 3.3V	LOW	I	

8 OPERATION

8.1 FLASHING THE HAT-EEPROM

The HAT EEPROM contains board information (S/N, version, etc.), and the device tree to load when RPI boots. The EEPROM data structure follows RPI's recommendations for HAT device. The device is flashed by the manufacturer and shipped with a unique identification (UID) in its EEPROM.

In cases of EEPROM modifications, re-flashing, UID regeneration by the user, please refer the project's GitHub page at: https://github.com/cariboulabs/cariboulite/tree/main/docs/flashing

8.2 Examples

Example code, in various languages, and a getting started guides can be found in out GitHub page at:

https://github.com/cariboulabs/cariboulite/tree/main/examples

9 Mechanical Information

9.1 Dimensions and Weight

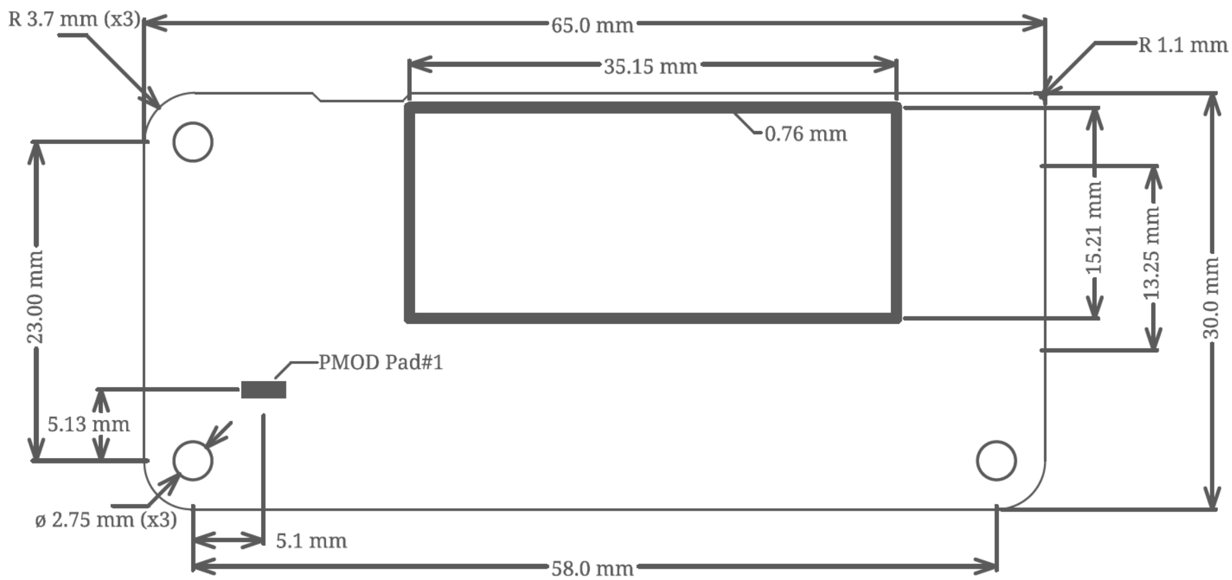

Figure 13 Board dimensions

Board weight: 25 grams

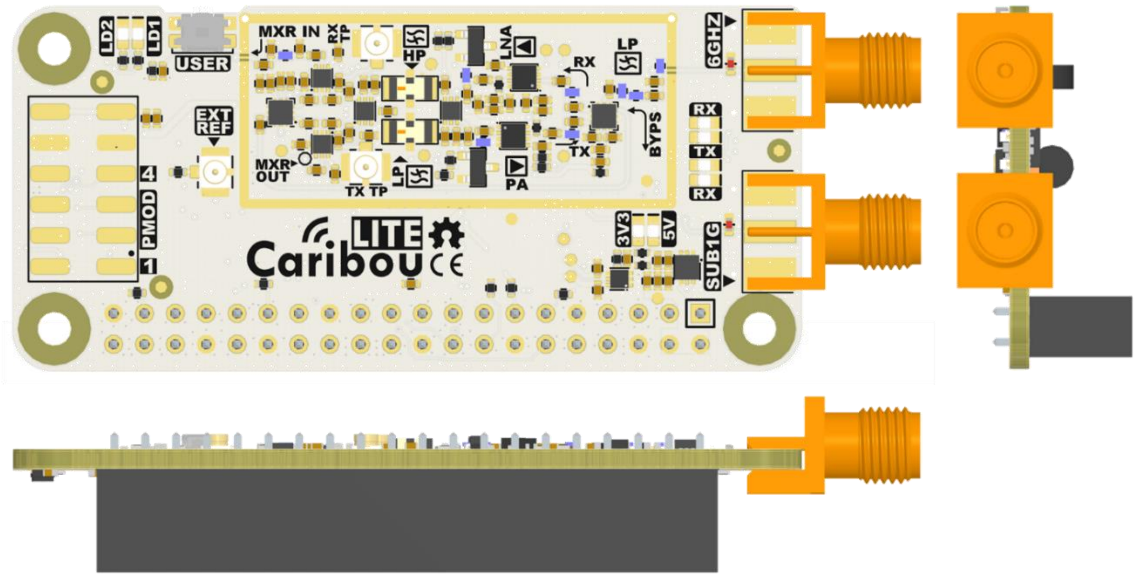

Figure 14 CaribouLite 3D-view

Notes:

1. PMOD connector (J6) is not assembled by default but supplied with the kit as a loose component.
2. RF optional connectors and test points (J4, J5, J7) shall not be assembled by default. It is up to the user to mount them as needed.

9.2 Component Locations

Full assembly information, manufacturing files and bill of materials can be found in:

https://github.com/cariboulabs/cariboulite/tree/main/hardware

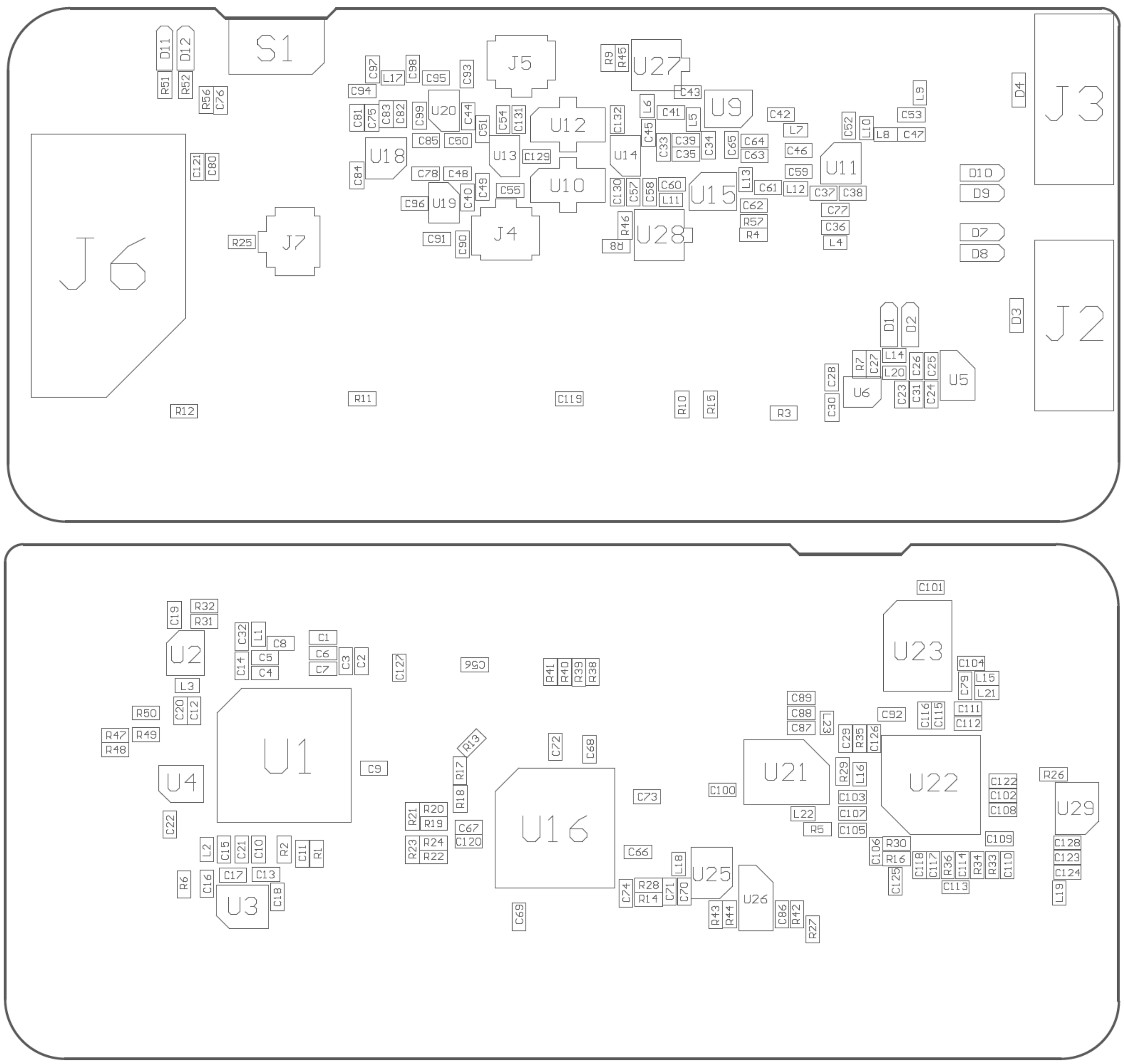

Figure 15 Top and bottom layers assembly drawing

10 WARNINGS, RESTRICTIONS, AND DISCLAIMER

David Michaeli and CaribouLabs.co, provide the CaribouLite and CaribouLite-ISM boards under the following conditions: The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies Supplier from all claims arising from the handling or use of the goods.

For Feasibility Evaluation Only, in Laboratory/Development Environments as a testing and evaluation purposes. The CaribouLite (including CaribouLite and CaribouLite-ISM boards) is not a complete product. It is intended solely for use for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. It should not be used as all or part of a finished end-product.

Your Sole Responsibility and Risk you acknowledge, represent, and agree that:

1. You have unique knowledge concerning Federal, State, and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of the **CaribouLite for evaluation, testing and other purposes**.
2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors, or designees, using the CaribouLite. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the CaribouLite and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.
3. Since the CaribouLite is not a completed product, it may not meet all applicable regulatory and safety compliance standards which may normally be associated with similar items. You assume full responsibility to determine and/or assure compliance with any such standards and related certifications as may be applicable. You will employ reasonable safeguards to ensure that your use of the CaribouLite will not result in any property damage, injury, or death, even if the CaribouLite should fail to perform as described or expected.

It is important to operate the CaribouLite (and CaribouLite-ISM) within Supplier's recommended specifications and environmental considerations per the user guidelines. Exceeding the specified CaribouLite ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury, or death.

During normal operation, some circuit components may have temperatures greater than 60°C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, FPGA, RF component and amplifiers which can be identified using the CaribouLite schematic located at the link this Datasheet. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use the CaribouLite.

Please read the Datasheet and, specifically, the Important Notes, Warnings and Restrictions notices in the Datasheet prior to handling the product. These notices contain important safety information about temperatures, voltages, operation, and handling. No license is granted under any patent right or other intellectual property right of Supplier covering or relating to any machine, process, or combination in which such Supplier products or services might be or are used. The Supplier currently deals with a variety of customers for products, and therefore our arrangement with the user is not exclusive. The Supplier assume no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify, and hold the Suppliers, its licensors, and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of the CaribouLite that is not in accordance with the terms of the agreement. This obligation shall apply whether Claims arise under law of tort or contract or any other legal theory, and even if the CaribouLite fails to perform as described or expected. Safety-Critical or Life-Critical Applications: If you intend to evaluate the components for possible use in safety critical applications (such as life support) where a failure of the Supplier's product would reasonably be expected to cause severe personal injury or death, such as devices which are classified as FDA Class III or similar classification, then you must specifically notify Suppliers of such intent and enter into a separate Assurance and Indemnity Agreement.