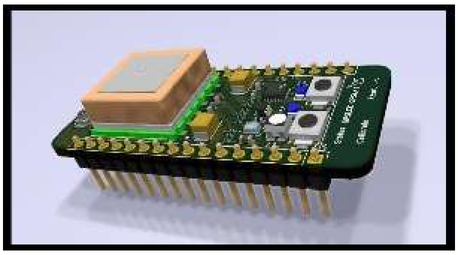
OpenFly Telemetry ©

Inertial navigation board

OFT001 v1



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OpenFly Telemetry overview

OpenFly Telemetry is an open source project aiming to provide telemetry and navigation capabilities for model airplanes and drones through open source hardware and software. It uses various on-board sensor capabilities such as GPS, Accelerometers, Gyroscopes, Magnetometers, Pitot tubes, temperature sensors, battery voltage and current sensors, RPM sensors, etc. to provide the operator or algorithms with data for manual or automated corrective actions. The algorithms are some time autonomous and resides in the model, are sometimes on ground with the receiver or nearby connected devices or are sometimes even in distant clouds.

The OFT modules can also be placed in the module base of the transmitter to enrich the transmitter awareness, e.g. Position, direction and additional communication capabilities such as Bluetooth and WIFI.

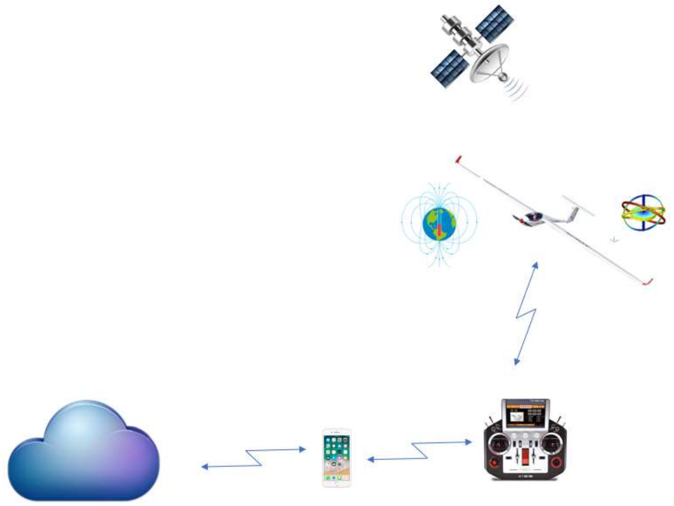


Figure 1: OpenFly Telemetry basic idea

OpenFly Telemetry (OFT) system description

OFT has two basic components: the Ada fruit ESP32 Huzzah feather processor board and the OFT system board. The ESP32 processor board obviously holds the software and algorithms for telemetry and navigation. The system board interfaces with the radio receiver and it's telemetry and servo busses. The system is modular, and you can compose your choice of capabilities by stacking various OFT boards on top of each other.

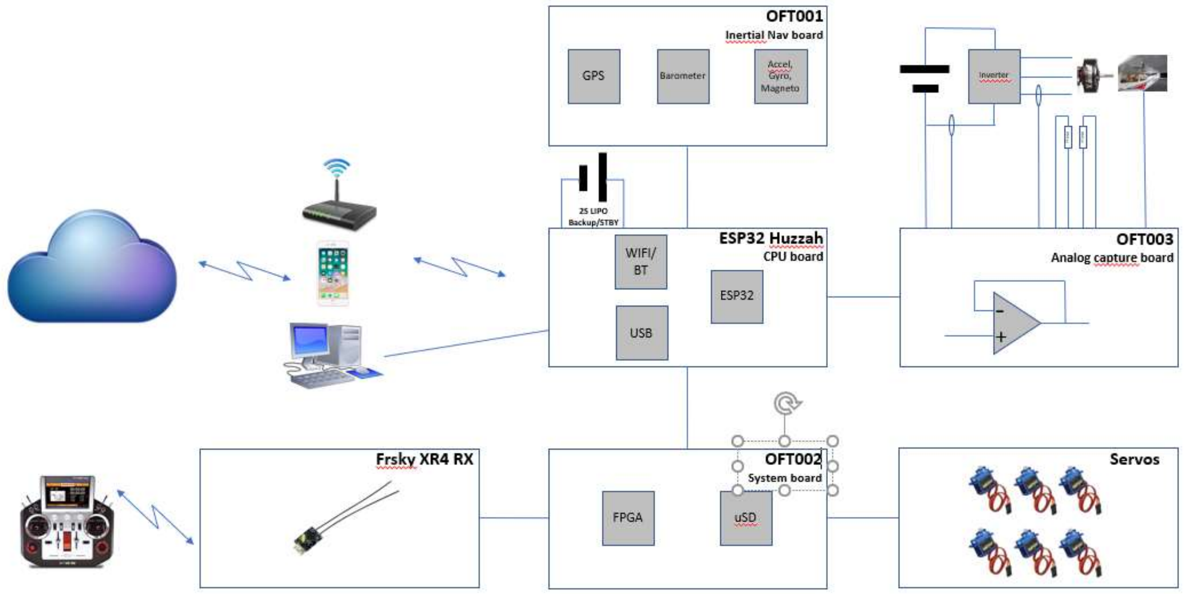


Figure 2: OpenFly Telemetry system view

OFT is based out of the Ada fruit ESP32 Huzzah feather processor board. This board hosts a ESP32 processor with two 32 bit general cores, 2 float processors and one ultra-low-power co-processor from Esperessif (https://www.espressif.com/). Furthermore, the ESP32 board provides wireless connectivity through Bluetooth and WIFI as well as ensuring continuous power supply through an optional 2S designated LIPO, which feeds the servos and the receiver- should the main supply drain.

The ESP32 mother board connects to several telemetry acquisition boards in a mother-daughter board/shield configurations.

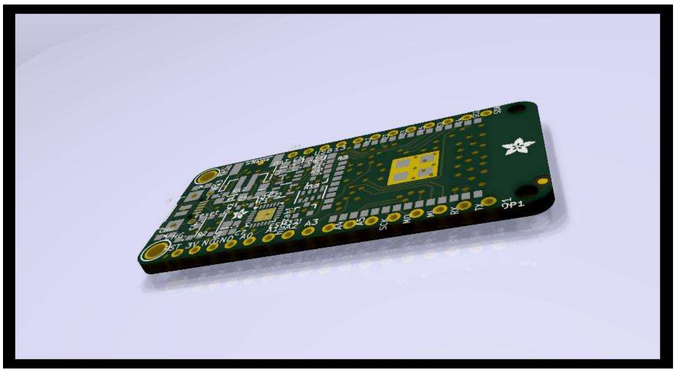


Figure 3: Ada fruit ESP32 Huzzah feather board

For the on-board use cases (as opposed to the TX bay use case), the bottom most shield in the stack holds the OFT System board. The system board has an FPGA that connects to the radio receiver through the S.PORT for telemetry data and the SBUS for servo output. The FPGA will allow the processor to mix in servo corrections from the processor, transmitting upstream telemetry data, as well as receiving upstream telemetry and servo information from the transmitter.

The system board interconnects with the radio control receiver through its S.PORT and SBUS.

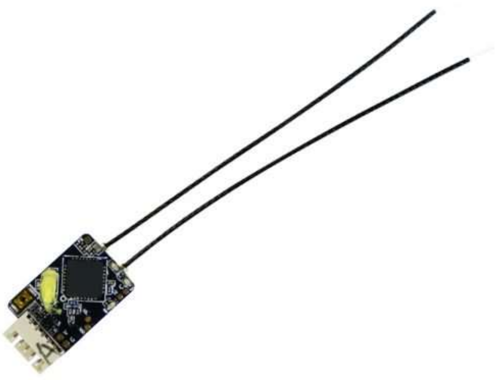


Figure 4: Frsky XR4 2.4 GHz MIMO CDMA receiver with S.PORT- (telemetry) and SBUS (Servos) connections

The OFT001 v1 Inertial navigation board

The OFT001 v1 Inertial navigation board captures navigational data, such as GPS positioning, 3D acceleration data, 3D Gyroscopic data, 3D Magnetic data, Barometric pressure, Temperature and Humidity. These data are provided to the ESP32 processor card (and any other shield cards) through I2C and RS232. These data will be filtered, processed and transferred by the ESP32 card and the OFT System card FPGA. It is still to be seen if we can/will implement a high-performance Inertial navigation fuse fixed point Kalman filter in the FPGA, or if it is better done in SW?

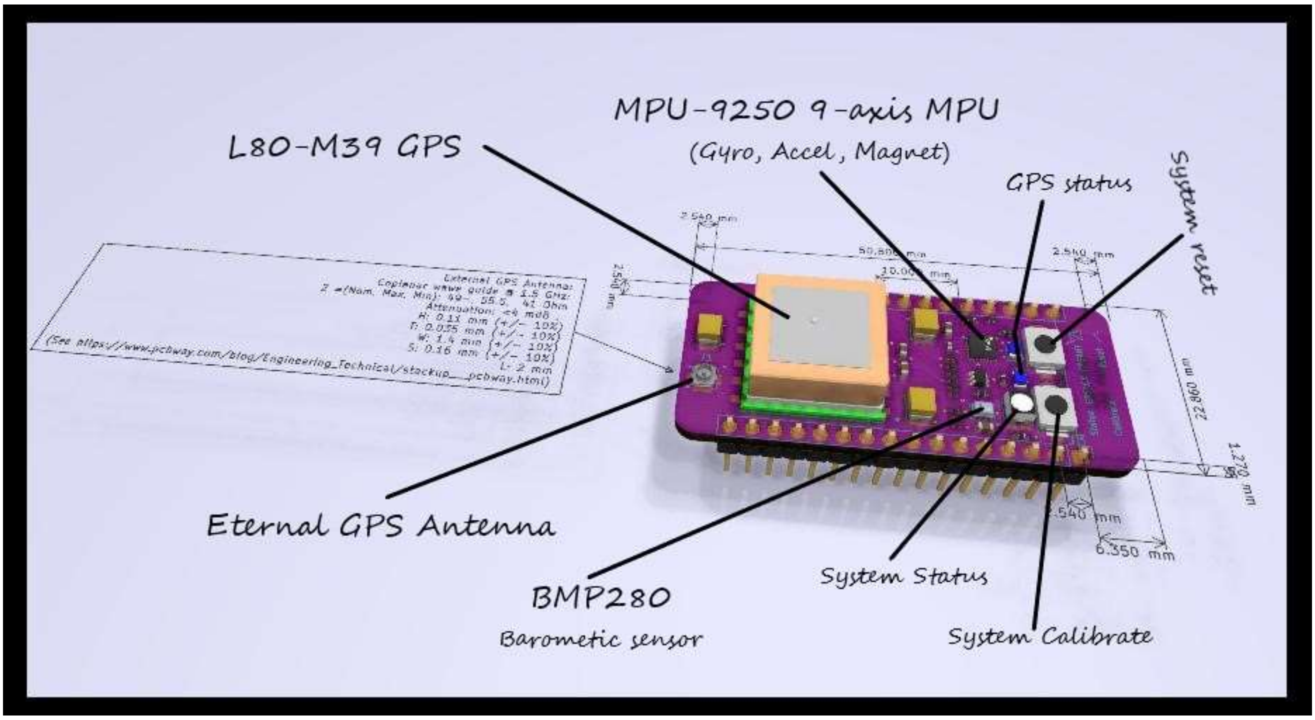


Figure 5: OFT001 v1 Inertial navigation card overview

The OFT001 v1 card has a L80-M39 GPS with a built-in patch antenna and an optional connector for an external 50 Ohm active antenna; an MP-9250 3D axis Accelerometer, Gyroscope and Magnetometer; and a BMP280 Barometric pressure- humidity- and temperature sensor. The communication with these sensors have been segmented so that the MPU runs on it's own high speed I^2C channel allowing fast updates and possibly from a the OFT System card FPGA, the BMP280 on a shared I^2C channel with many, while the GPS communication happens over an RS232 serial channel using the NMEA protocol.

There is one green LED indicator for GPS lock, one orange LED indictor for External GPS antenna use, and an RGB LED for generic system status indication driven from the ESP32 CPU board. There are also two push buttons: one which is connected to the overall system reset, and another multi-purpose push button intended for system calibration activities.

It is important that OFT001 v1 sits on the top of the mother-daughter board stack (unless an external GPS antenna is used) to achieve a good GPS signal.

Cupper layers have been kept out from ESP32 Bluetooth and WIFI PCB antennas to not deteriorate signal strength.

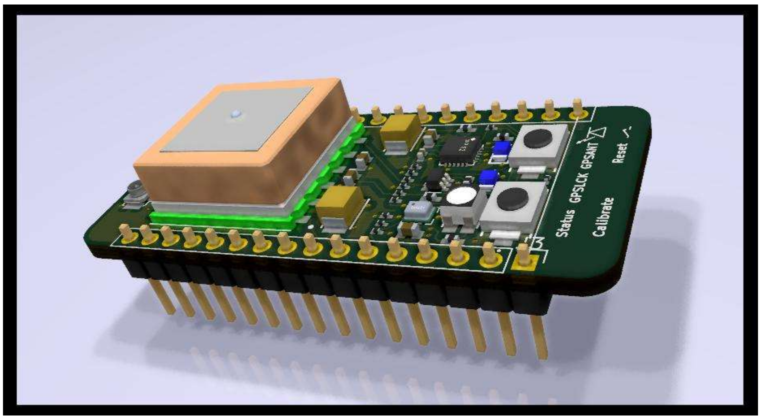


Figure 5: OFT001 v1 3D simulation – Front to the right

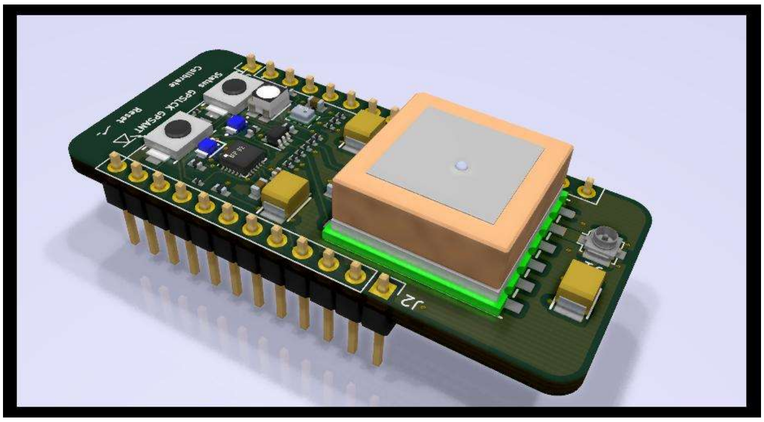


Figure 6: OFT001 v1 3D simulation – Front to the upper left

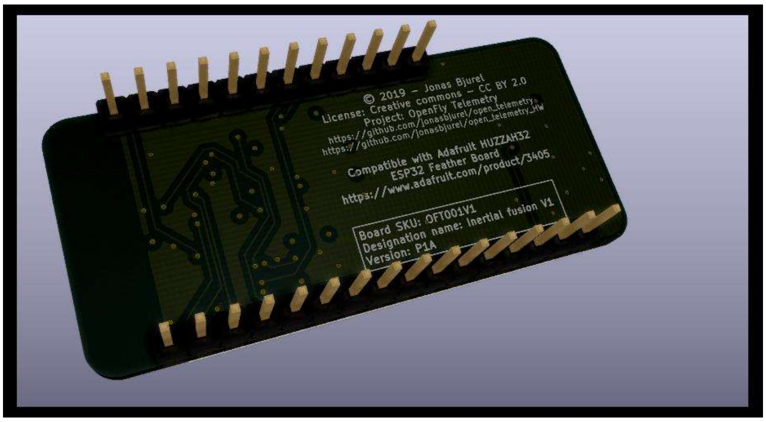


Figure 7: OFT001 v1 3D simulation – Back view

OFT001 v1 pin-out

OFT001 12 pin header (J2)	ESP32 HUUZZAH 12 pin header (JP3)	ESP32 silicon	Comments
1 - N/C	VBAT		
2 - N/C	EN		
3 - N/C	VBUS		
4 – RED LED	IO13_A12		Red system status led
5 – BLUE LED	IO12_A11		Blue system status led
6 – GREEN LED	IO27_A10		Green system status led
7 - N/C	IO33_A9		
8 - N/C	IO15_A8		
9 - N/C	IO32_A7		
10 - N/C	I14_A6		
11 - I2C_0_SCL_3V	SCL		Common non-critical I^2C
12 - I2C_0_SDA_3V	SDA		Common non-critical I^2C

OFT001 16 pin header (J3)	ESP32 HUUZZAH 16 pin header (JP1)	ESP32 silicon	Comments
1 – INT_0	IO21		Interrupt from MPU9250
2 - I2C_1_SDA_3V	IO17		Critical MPU I^2C
3 - I2C_1_SCL_3V	IO16		Critical MPU I^2C
4 - N/C	MISO		
5 - N/C	MOSI		
6 - N/C	SCK		
7 - CALIB	A5_IO4		System calibration button
8 - UART_1_CLIENT_RXD	A4_IO36		L8-M39 GPS UART (NMEA)
9 - UART_1_CLIENT_TXD	A3_I39		L8-M39 GPS UART (NMEA)
10 – N/C	A2_I34		
11 – N/C	A1_DAC1		
12 – N/C	A0_DAC2		
13 - GND	GND		
14 – N/C	N/C		
15 - +3.3V (VDD)	+3.3V		
16 - RESET	RESET		2-Way reset

OFT001 Ext GPS Ant. (J1)	Comments
1 – AGND	External active GPS antenna ground with VDD DC applied for power feed
2 – EXTANT	External active GPS antenna signal with +

OFT001 v1 addressing

I2CBus	Addr	Function	Comments
0	0x77 (0x76[1])	BME280	
1	0x68 (0x69[2])	MPU9250	

1) Alternative address if NULL resistor R4 is mounted
2) Alternative address if NULL resistor R7 is mounted

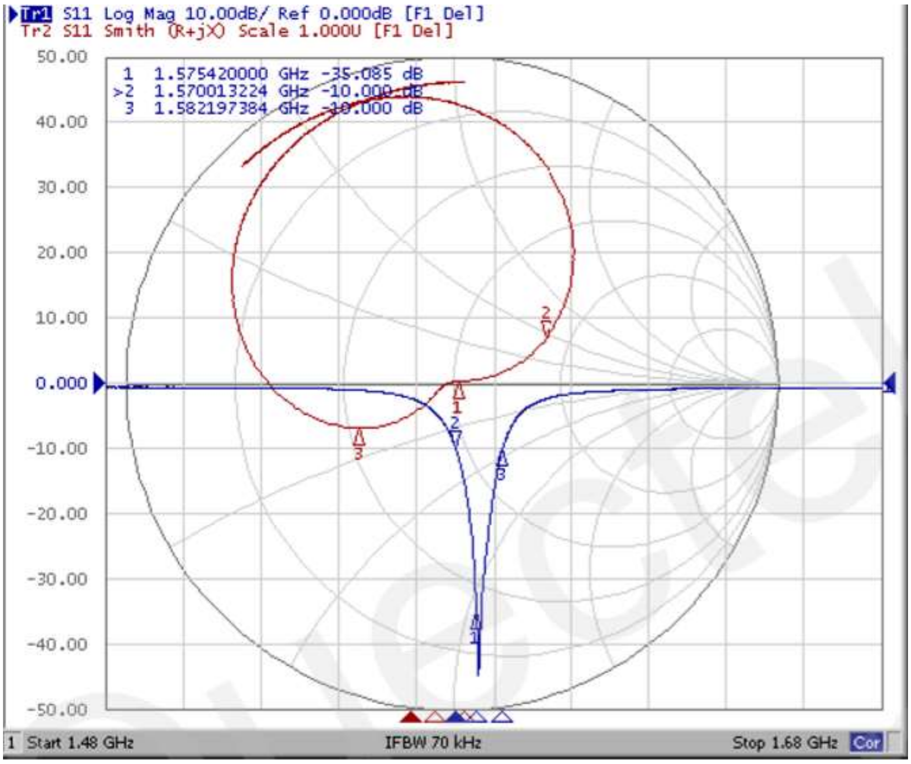
OFT001 v1 operating specifications

Operational conditions:

Parameter	Nom	Max	Min
Voltage	3.3 V	3.6 V	3.0 V
Current	30 mA +	120 mA +	-
Power dissipation	100 mW	400 mW	-
Ambient temp	-	85 degC	-40 degC

GPS antenna operational conditions:

The built in GPS patch antenna provides the following characteristics (probably not really true!?):



Following external GPS antenna characteristics applies:

Parameter	Value
DC feed:	3.6V – 2.5V
DC current:	<???
Center frequency:	1575.42MHz
Band width:	>5MHz
VSWR:	<2 (Typ.)
Polarization:	RHCP or Linear
Noise figure:	<1.5dB
Gain (antenna):	>-2dBi
Gain (embedded LNA):	20dB (Typ.)
Total gain:	>18dBi(Typ.)

OFT001 v1 schematics

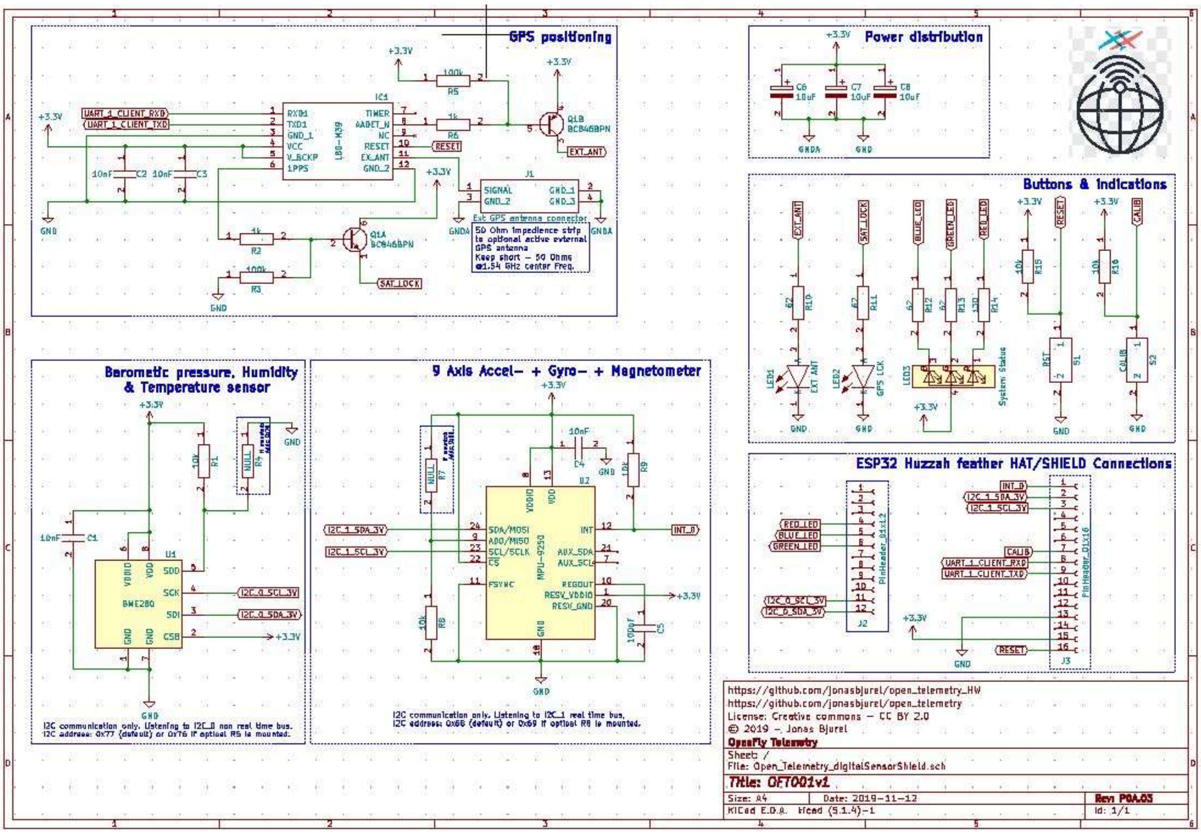


Figure 8: OFT001 v1 circuit schematics

OFT001 v1 - third party data sheets

L80-M39 GPS receiver:
http://docs-emea.rs-online.com/webdocs/147d/0900766b8147dbf2.pdf

BME280 Barometric pressure sensor:
https://ae-bst.resource.bosch.com/media/_tech/media/datasheets/BST-BME280-DS002.pdf

MPU9250 9-Axis Accelerometer, Gyroscope and Magenetometer:
http://43zrtwysvxb2gf29r5o0athu-wpengine.netdna-ssl.com/wp-content/uploads/2015/02/PS-MPU-9250A-01-v1.1.pdf

TRI-color system status LED

https://docs.broadcom.com/docs/AV02-4194EN

GPS status LEDs

https://docs-emea.rs-online.com/webdocs/156b/0900766b8156b2c9.pdf

OFT001 v1 PCB implementation

KICAD 5.1.4 has been used to develop the schematics and PCB design. It is targeted for a 4 layer FR4 1.6 mm PCB with a minimum of 6 mil inch track width- and spacing, and a tolerance of 10%. Minimum via drills is 0.3 mm.

PCB Stack-up

The PCB stack-up used is the one produced by PCBway (https://www.pcbway.com/orderonline.aspx)

4-layer PCB standard stackup

Thickness	Copper thick	Laminated chart	
1.6mm±10%	1oz		Copper 1 18 um--plating to 35um Dielectric 1-2 0.11 mm dielectric constant 4.29 Copper 2 35 um Dielectric 2-3 1.13 mm dielectric constant 3.96 Copper 3 35 um Dielectric 3-4 0.11 mm dielectric constant 4.29 Copper 4 18 um--plating to 35um

Figure 9: OFT001 v1 – 4-layer PCB stack-up

Front/top Signal Cupper layer

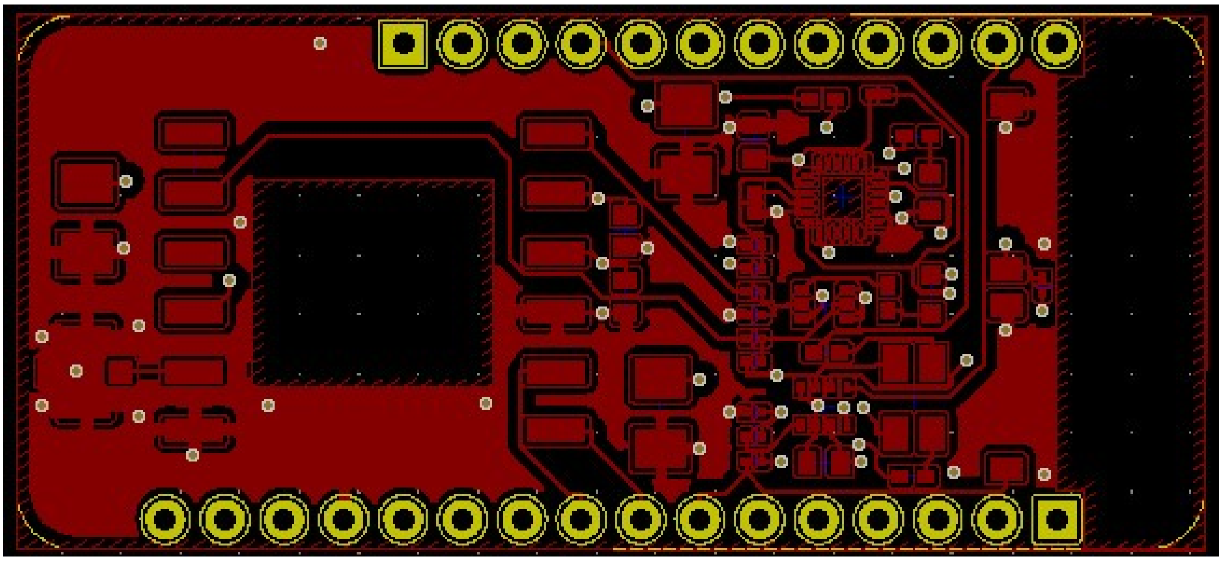


Figure 10: OFT001 v1 - Front/top Signal Cupper layer

Back/bottom Signal CU layer

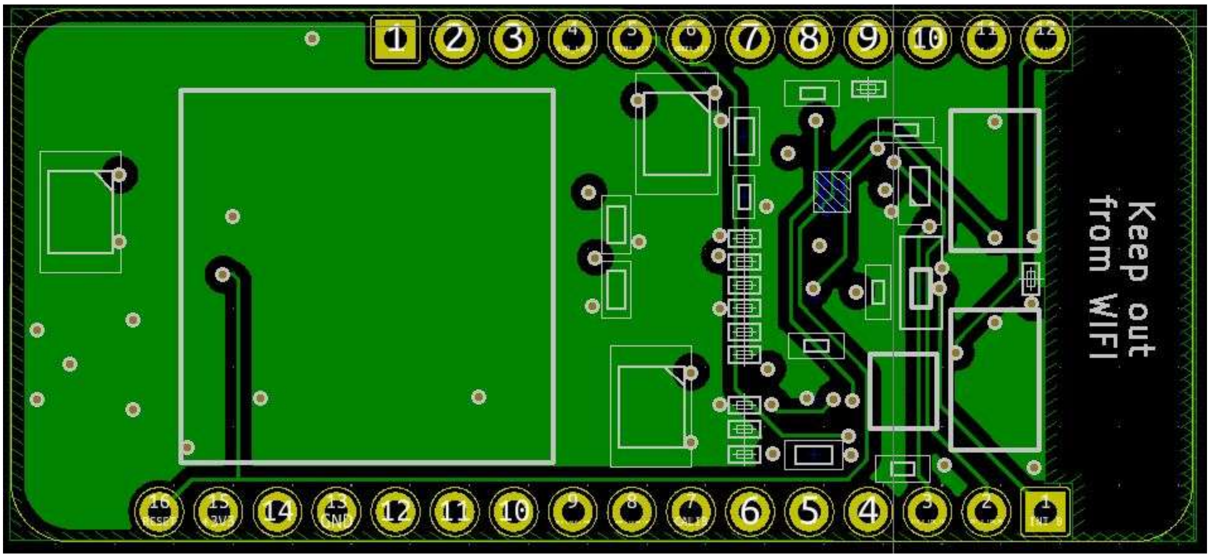


Figure 11: OFT001 v1 - Back/bottom Signal CU layer

Top/front embedded GND CU layer

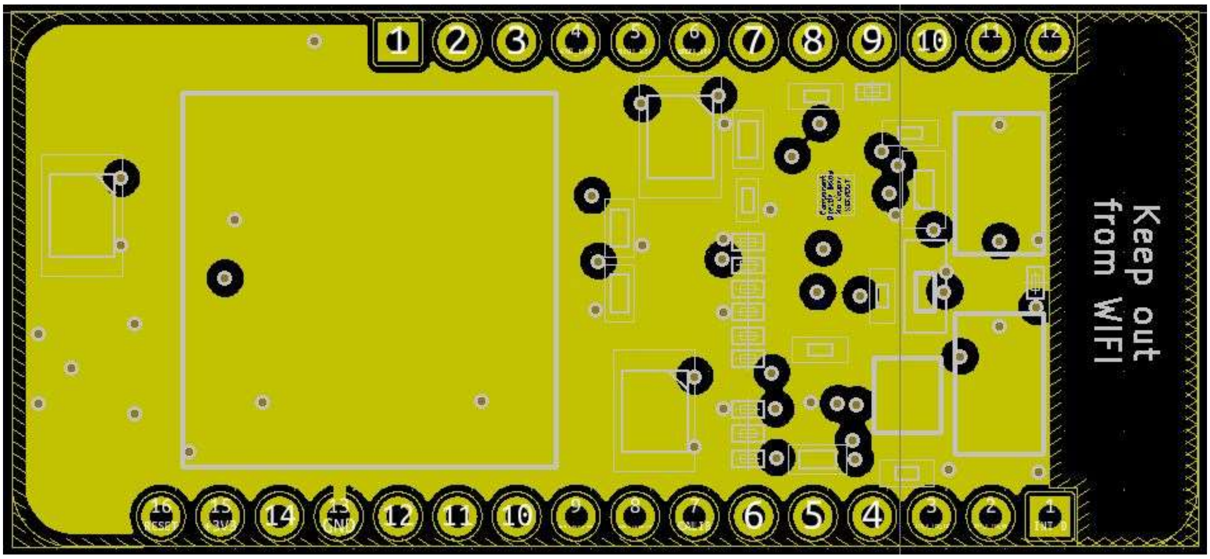


Figure 12: OFT001 v1 - Top/front embedded GND CU layer

Back/bottom embedded VDD/3.3V CU layer

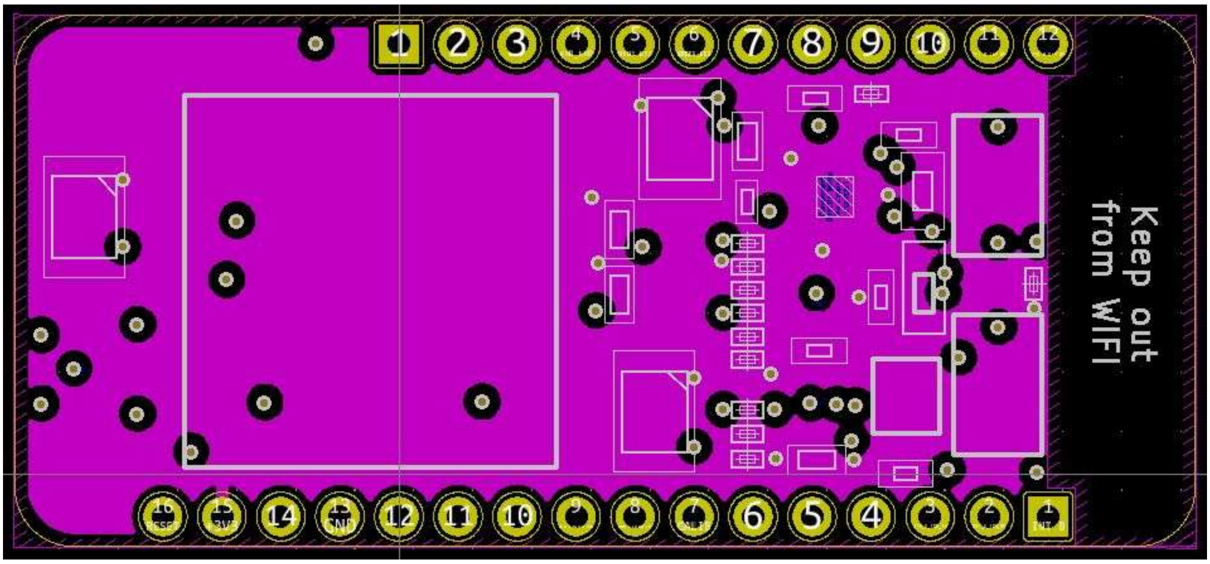


Figure 13: OFT001 v1 - Back/bottom embedded VDD/3.3V CU layer

Front mask

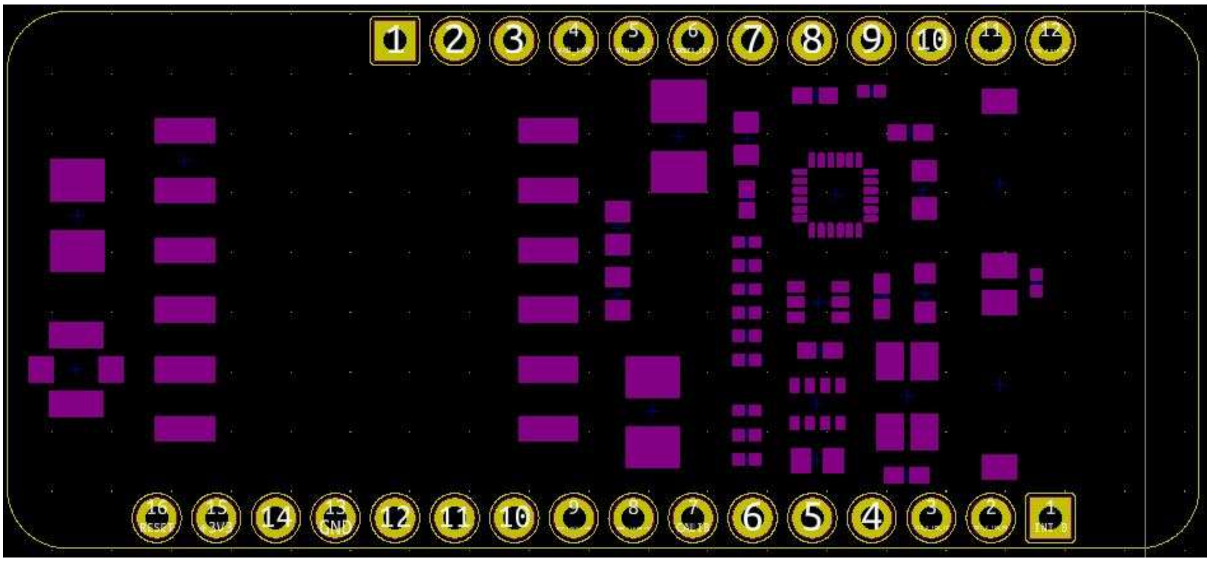


Figure 14: OFT001 v1 - Front mask

Front paste

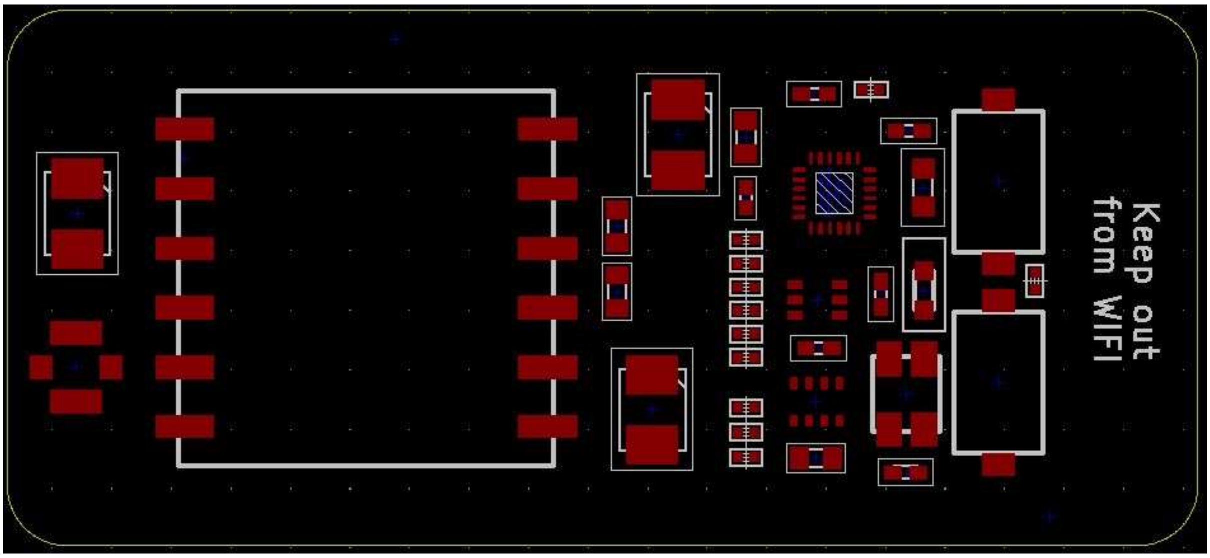


Figure 14: OFT001 v1 – Front paste

Back mask

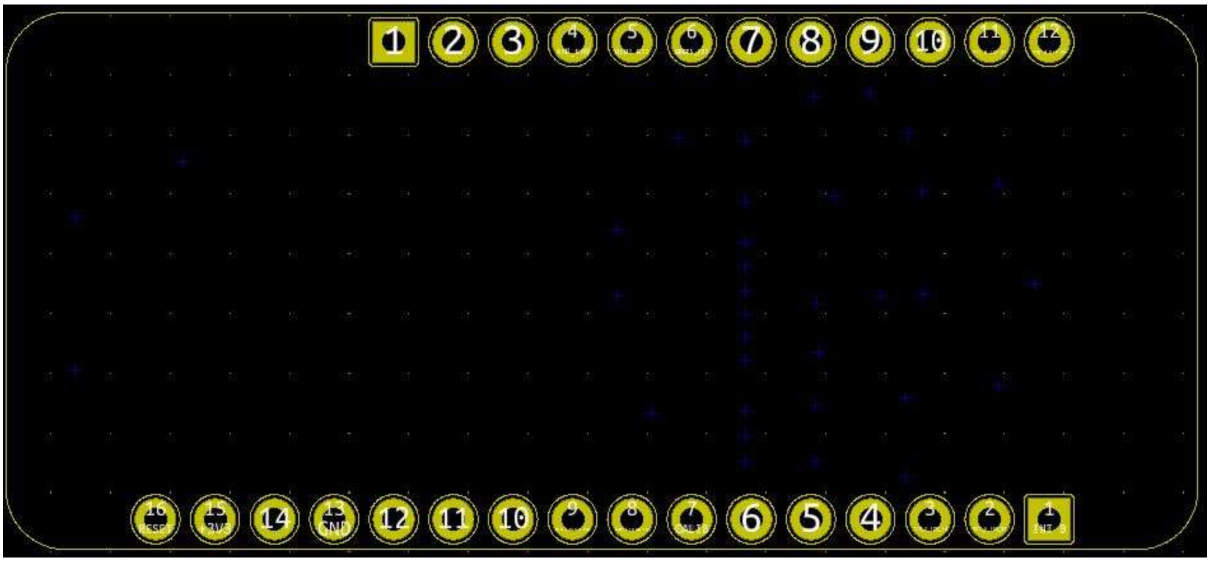


Figure 15: OFT001 v1 – Back mask

Front silk

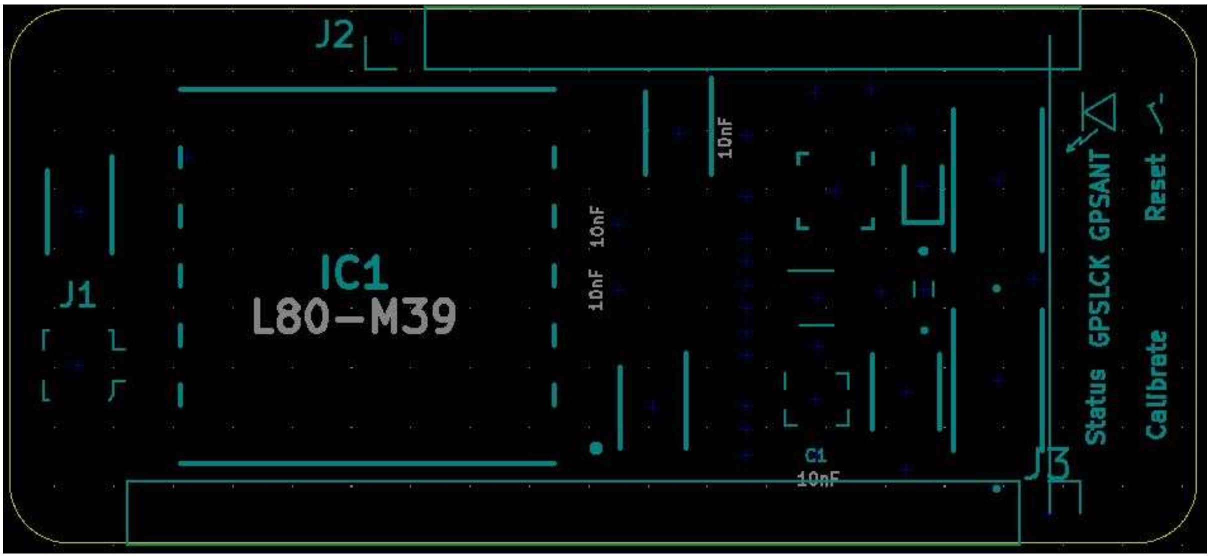


Figure 16: OFT001 v1 – Front silk

Back silk

Figure 17: OFT001 v1 – Back silk

Various user meta data layers

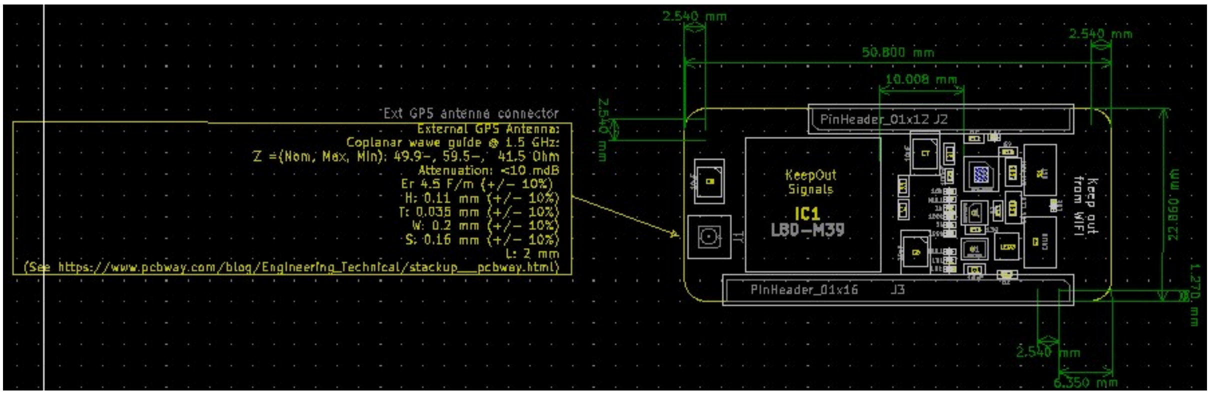


Figure 18: OFT001 v1 – Various user meta data layers

External GPS antenna Impedance matching

The external GPS antenna trace needs to be carefully impedance matched to 50 ohms in order to get the signal losses low and to avoid reflections. Based on PCBWay PCB substrate stack-up, the top cupper strip thickness (T) is estimated to be 35um (+/- 10%), the distance to next ground layer (H) is estimated to be 0.11 mm (+/- 10%), and the dielectric permittivity in between is estimated to be 4.5 F/m @ 1.5 GHz (I need to recalculate with 4.29 Nominal instead).

With the constraints of 6 mil inch strip widths/spacing we end up with a 0.2 mm (W) strip width, and a 6 mil/0.16 mm (S) horizontal spacing to earth - forming a coplanar wave guide with a ground plane, of roughly 2 mm length (L) matching the 50 Ohm antenna strip impedance.

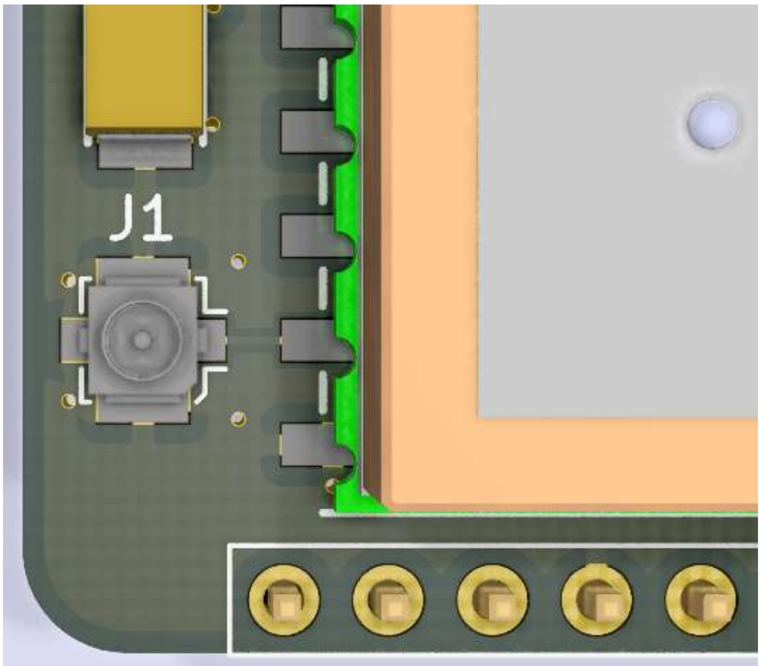


Figure 19: OFT001 v1 – External GPS antenna layout

With this layout, it is expected that tolerances of non-impedance-controlled PCB manufacturing for this strip to stay in between 41-55.5 Ohms, and losses to be less than 10 mdB.

Since the 1.5Ghz GPS wavelength in cupper is roughly 2 dm (100 times the strip length), a few reflections due to impedance matching imperfections should not degrade the antenna signal significantly.

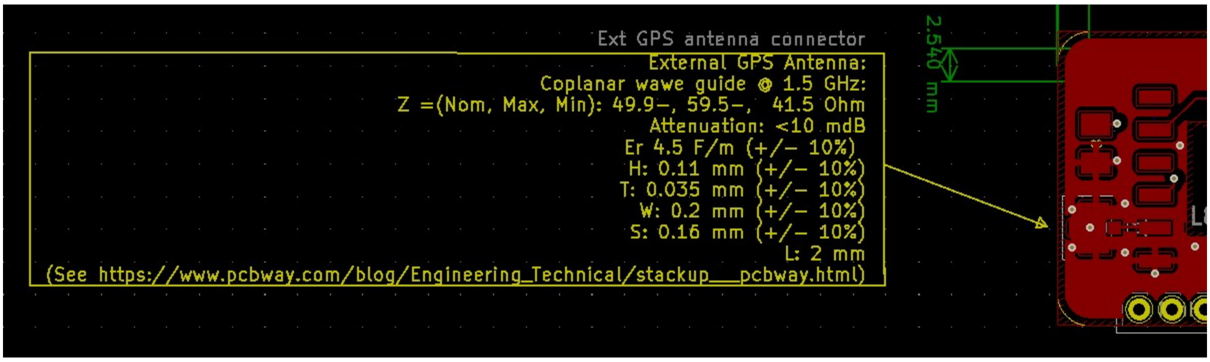


Figure 20: OFT001 v1 – External GPS antenna layout – top CU layer

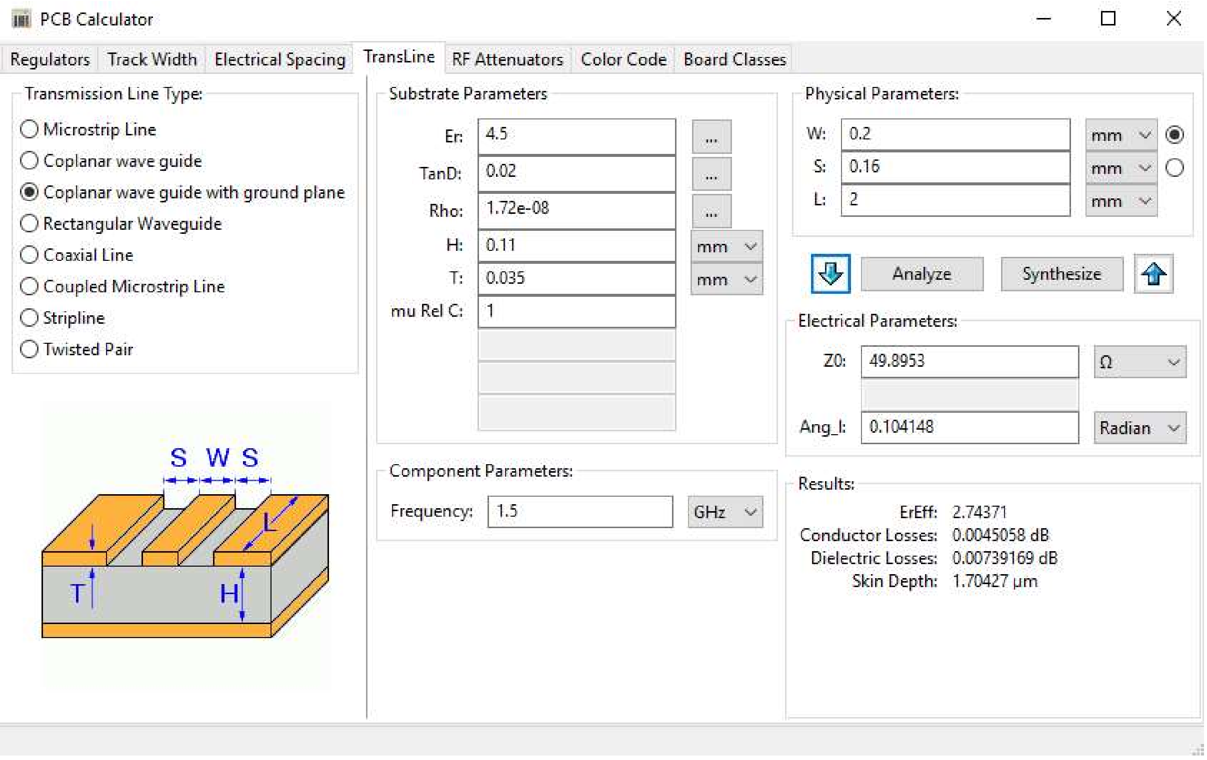


Figure 21: OFT001 v1 – External GPS antenna – Impedance calculations

Appendix A – ESP32 Mother board reference

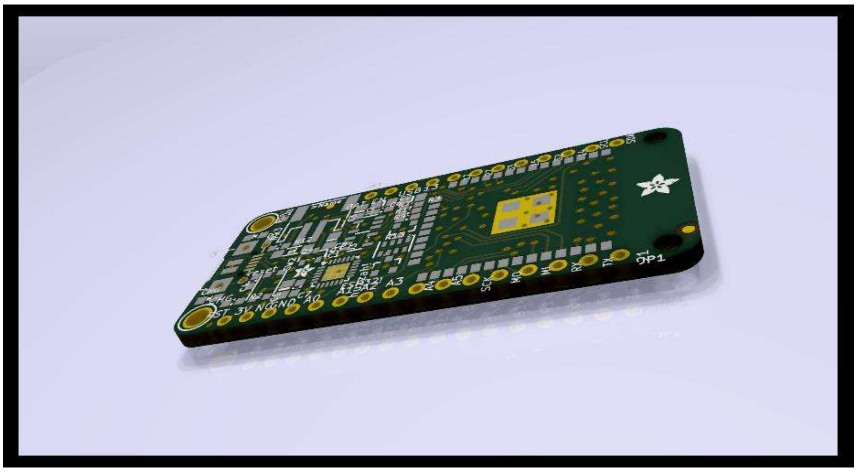


Figure 22: Ada fruit ESP32 Huzzah Feather board

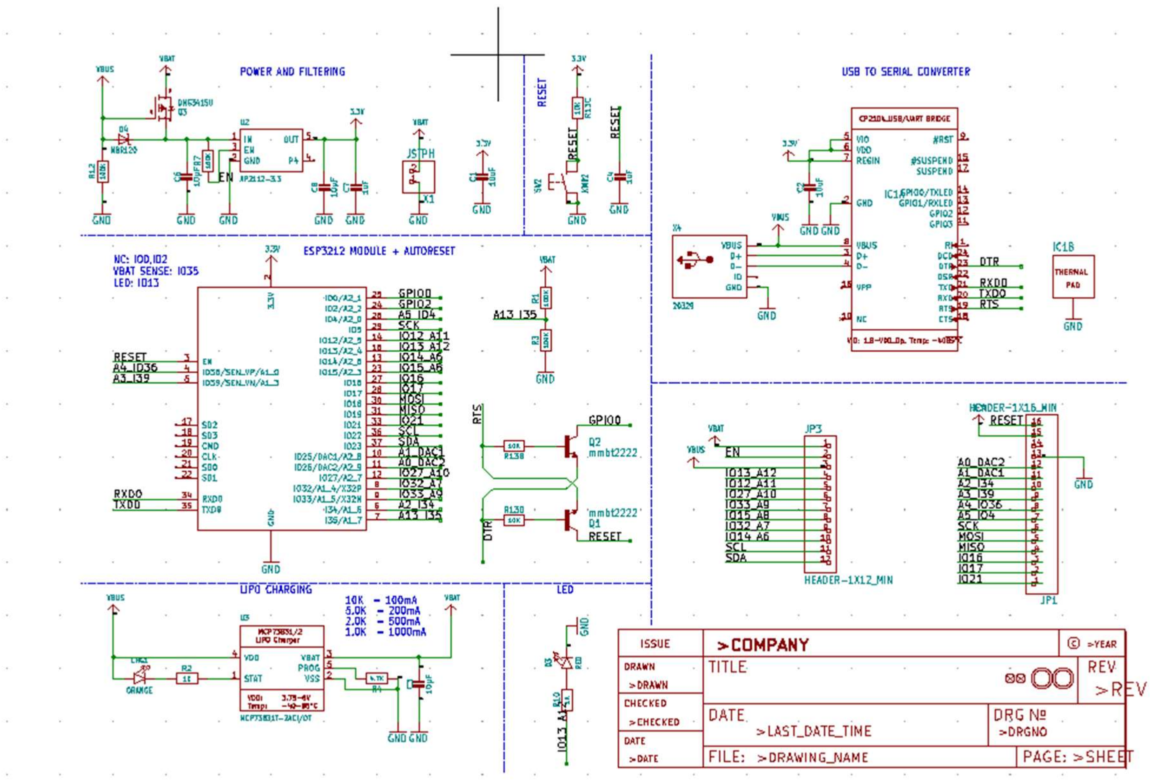


Figure 23: Ada fruit ESP32 Huzzah Feather board schematics

Appendix B – OFT001 v1 Build of material

ref	value5	footprint	datasheet	part	description
J1	Ext GPS antenna connector	Open_Telemetry:U.FL_Molex_MCRF_73412-0110_Vertical	http://www.molex.com/pdm_docs/sd/734120110_sd.pdf	73412-0110	50 Ohms, MCRF, PCB Vertical Jack Receptacle, SMT, 1.25mm Mounted Height
IC1	L80-M39	Open_Telemetry:L80-M39	http://docs-emea.rs-online.com/webdocs/147d/0900766b8147dbf2.pdf	L80-M39	L80 GPS Module
C6	10uF	CAPPM3528X210N	https://api.kemet.com/component-edge/download/datasheet/T491B106K016AT7280.pdf	T491B106K016AT7280	Tantalum Capacitors - Solid SMD 16V 10uF 1311 10% ESR=2ohms
C7	10uF	CAPPM3528X210N	https://api.kemet.com/component-edge/download/datasheet/T491B106K016AT7280.pdf	T491B106K016AT7280	Tantalum Capacitors - Solid SMD 16V 10uF 1311 10% ESR=2ohms
C8	10uF	CAPPM3528X210N	https://api.kemet.com/component-edge/download/datasheet/T491B106K016AT7280.pdf	T491B106K016AT7280	Tantalum Capacitors - Solid SMD 16V 10uF 1311 10% ESR=2ohms
C3	10nF	Open_Telemetry:CAPC1608X87N	https://api.kemet.com/component-edge/download/datasheet/C0603C103K4RACTU.pdf	C0603C103K4RACTU	KEMET - C0603C103K4RACTU - CAP, 0.01F, 16V, 10%, X7R, 0603
R2	1k	Open_Telemetry:RESC0603X26N	https://www.digikey.se/en/datasheets/yageo/yageo-pyu-r_marking_2	RC0201JR-071KL	YAGEO - RC0201JR-071KL - RES, THICK FILM, 1K, 5%, 0.5W, 0201, REEL
R6	1k	Open_Telemetry:RESC0603X26N	https://www.digikey.se/en/datasheets/yageo/yageo-pyu-r_marking_2	RC0201JR-071KL	YAGEO - RC0201JR-071KL - RES, THICK FILM, 1K, 5%, 0.5W, 0201, REEL
R3	100k	Open_Telemetry:RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-07100KL	YAGEO - RC0201JR-07100KL - RES, THICK FILM, 100K, 5%, 0.5W, 0201
R5	100k	Open_Telemetry:RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-07100KL	YAGEO - RC0201JR-07100KL - RES, THICK FILM, 100K, 5%, 0.5W, 0201
R8	10k	RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-0710KL	THICK FILM CHIP RESISTORS
R9	10k	Open_Telemetry:RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-0710KL	THICK FILM CHIP RESISTORS
R1	10k	Open_Telemetry:RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-0710KL	THICK FILM CHIP RESISTORS
C4	10nF	Open_Telemetry:CAPC1608X87N	https://api.kemet.com/component-edge/download/datasheet/C0603C103K4RACTU.pdf	C0603C103K4RACTU	KEMET - C0603C103K4RACTU - CAP, 0.01F, 16V, 10%, X7R, 0603
C5	100nF	Open_Telemetry:CAPC1005X55N	https://content.kemet.com/datasheets/KEM_C1002_X7R_SMD.pdf	C0402C104M8RACTU	Multilayer Ceramic Capacitors MLCC - SMD/SMT 10volts 0.1uF X7R 20%
LED1	EXT ANT	Open_Telemetry:LEDC1608X65N	https://docs-emea.rs-online.com/webdocs/156b/0900766b8156b2c9.pdf	SML-D13DWT86A	ROHM SML-D13DWT86A, SML 608 nm Orange LED, 1608 (0603) Milky White SMD package
S1	RST	Open_Telemetry:ATS2D1G	http://www.mouser.com/ds/2/60/ats-1100738.pdf	ATS2D1G_NC_LFS	Tactile Switches 1VA 32VDC 50mA On-(On) Sldr IP54
S2	CALIB	Open_Telemetry:ATS2D1G	http://www.mouser.com/ds/2/60/ats-1100738.pdf	ATS2D1G_NC_LFS	Tactile Switches 1VA 32VDC 50mA On-(On) Sldr IP54
C1	10nF	Open_Telemetry:CAPC1608X87N	https://api.kemet.com/component-edge/download/datasheet/C0603C103K4RACTU.pdf	C0603C103K4RACTU	KEMET - C0603C103K4RACTU - CAP, 0.01F, 16V, 10%, X7R, 0603
C2	10nF	Open_Telemetry:CAPC1608X87N	https://api.kemet.com/component-edge/download/datasheet/C0603C103K4RACTU.pdf	C0603C103K4RACTU	KEMET - C0603C103K4RACTU - CAP, 0.01F, 16V, 10%, X7R, 0603
R15	10k	Open_Telemetry:RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-0710KL	THICK FILM CHIP RESISTORS
R16	10k	Open_Telemetry:RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-0710KL	THICK FILM CHIP RESISTORS
R10	62	Open_Telemetry:RESC1005X40N	http://www.yageo.com/documents/recent/PYu-RC0402_51_RoHS_L_6_r.pdf	RC0402JR-0762RL	Thick Film Resistors - SMD 62 OHM 5%
R11	62	Open_Telemetry:RESC1005X40N	http://www.yageo.com/documents/recent/PYu-RC0402_51_RoHS_L_6_r.pdf	RC0402JR-0762RL	Thick Film Resistors - SMD 62 OHM 5%
R12	62	Open_Telemetry:RESC1005X40N	http://www.yageo.com/documents/recent/PYu-RC0402_51_RoHS_L_6_r.pdf	RC0402JR-0762RL	Thick Film Resistors - SMD 62 OHM 5%
R13	62	Open_Telemetry:RESC1005X40N	http://www.yageo.com/documents/recent/PYu-RC0402_51_RoHS_L_6_r.pdf	RC0402JR-0762RL	Thick Film Resistors - SMD 62 OHM 5%
LED2	GPS LCK	Open_Telemetry:SMLD15YWT86	http://www.rohm.com/web/global/datasheet/SML-D13FW/sml-d13x-e	SML-D13FWT86	ROHM SML-D13FWT86, SML 566 nm Green LED, 1608 (0603) Milky White SMD package
R4	NULL	RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-070RL	YAGEO (PHYCOMP) - RC0201JR-070RL - RES, THICK FILM, 0R, 5%, 0.05W, 0201
R7	NULL	RESC0603X26N	http://www.yageo.com/documents/recent/PYu-RC0201_51_RoHS_L_8.pdf	RC0201JR-070RL	YAGEO (PHYCOMP) - RC0201JR-070RL - RES, THICK FILM, 0R, 5%, 0.05W, 0201
R14	130	Open_Telemetry:RESC1005X40N	http://www.vishay.com/docs/20035/dcrcwe3.pdf	CRCW04022130RJNED	RESISTOR, 0402 130 Ohms +/-5% 0.063 W

Appendix C – OpenFly Telemetry repositories

OFT HW Repositories:

https://github.com/jonasbjurel/open_telemetry_HW

OFT SW Repositories:

https://github.com/jonasbjurel/open_telemetry

OFT SW Platform Repositories:

https://github.com/jonasbjurel/coreNoStopRTOS

3PP dependency Repositories:

ESPRESSIF
FREERTOS
ADAFRUIT ESP32

Appendix D – OpenFly Telemetry WIKI

TBD