VHF RF Front-End multi-channel: compact and efficient solution for VDES

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Marco Bonaventura
marco.bonaventura@dwave.it

https://connectivity.esa.int/projects/vocs

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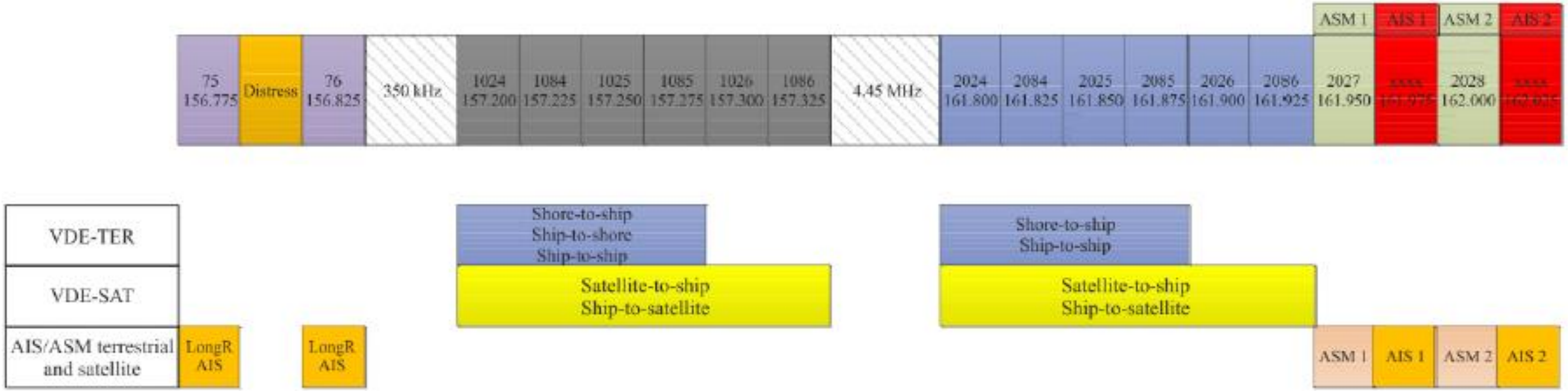
A. ABSTRACT

Front-End VHF per payload satellitare: un sistema compatto ad alta efficienza per la ricetrasmissione con standard VDE-SAT.
Lo scopo della tecnologia sviluppata è di fornire una soluzione per il supporto alla ricetrasmissione secondo lo standard di comunicazione marittima VDE-SAT (ITU-R M.2092-1 02/2022). La soluzione proposta in questa presentazione si focalizza sul Front-End in radio frequenza che utilizza la banda VHF.
L'architettura proposta definisce due dispositivi: uno di trasmissione ed uno di ricezione del segnale. Questi, insieme all'antenna e alla piattaforma di processing, compongono il payload satellitare minimo per supportare l'applicazione di comunicazione VDE-SAT.
L'attività qui presentata è un estratto del bando ESA: ITT ESA AO/1-10687/21/UK/AL "Breadboarding of Critical Technologies Enabling VHF Data Exchange Payloads" recepito dal consorzio con la creazione del progetto VOCS (Vde system On board data processing for Cubesat Satellites). Per ulteriori informazioni si faccia riferimento al seguente link: https://connectivity.esa.int/projects/vocs.
L'attività si è concentrata in primo luogo sul trasmettitore ed in particolare sull'amplificatore di potenza, dato che è l'elemento dominante nei consumi elettrici del payload. L'amplificatore è stato selezionato attentamente in funzione della potenza da erogare e della tipologia del segnale modulato. Inoltre sono state analizzate delle tecniche di efficientamento dello stadio di amplificazione quando non sono presenti tutti i canali fisici.
Sono state analizzate e realizzate due diverse architetture dette VOCS-1 e VOCS-2 che implementano rispettivamente le funzionalità Half-Duplex e Full-Duplex. Gli studi effettuati indicano che la funzionalità Full-Duplex richiede in aggiunta un Duplexer per aumentare l'isolamento del ricetrasmettitore.
La soluzione finale realizza le funzionalità con una efficienza fino a tre volte maggiore rispetto alle migliori soluzioni presenti sul mercato, mantenendo al contempo la massa e l'ingombro a valori decisamente inferiori.
I miglioramenti elencati rendono la soluzione complessiva adatta ai micro e nano satelliti. DWave sta realizzando quindi l'adattamento dell'elettronica verso un form-factor Cubesat. Il risultato verrà presentato in anteprima.

B. VHF Maritime Communication Overview

AIS: (Maritime) Automatic Identification System, it provides information to maritime radar. It was born to avoid vessel collision, it is similar to ADS-B for aircraft.
Starting from 2005 it was implemented S-AIS: Satellite AIS. The primary goal was to collect large number of AIS messages.
Also, the AIS standard was enhanced to support ASM (Application Specific Messages) using dedicated VHF bands.

Recently a new standard is emerging: VDES (VHF Data Exchange System) defined by ITU M.2092 (February 2022). It provides additional bands and features to previous standards.
We mainly focused on the VDE-SAT for LEO Satellite solution.



C. VOCS project description

VOCS activity is funded by ESA within the activity ESA: ITT ESA AO/1-10687/21/UK/AL "Breadboarding of Critical Technologies Enabling VHF Data Exchange Payloads". Further details can be found here:

https://connectivity.esa.int/projects/vocs

The activity is currently approaching the Final part of the project. DWave has focused on the following:

- RF Front End (transponder) system design
- RF Front End (transponder) electronics design
- Forward Link (Satellite Payload) modulation design and implementation
- Forward Link (Terminal) demodulation design and implementation
- FL and RL HDL algorithms implementations

The other partners are: MBI Srl (Prime) and Thales Alenia Space Italy

D. VOCS Architecture

The chosen architecture was selected to provide enough resources to the signal processing, but at the same time reducing the power consumption of the solution compared to the previous state of the art. The modulation and demodulation are implemented mostly on the Programmable Logic to guarantee performance and power efficiency.

The implemented solution assumes to use (today NanoCom SDR MK2/MK3)

- Gomspace NanoDock SDR

\+ NanoCom TR-600 module

\+ NanoMind Z7000 module

Alternatively, also AlenSpace solutions are usable:

- TREVO: modular high performance SDR
- TOTEM: flight proven high performance SDR

Any other SDR based on Zynq device (Z-7020 or better) is usable. The processing platform uses less than 5W electrical power.

The provided solution is fully compliant to the Radio-Astronomic emission requirements in particular related to 150.5-153MHz for any antenna with gain below 16dBi.

The solution was customized to the following antennas:

- Gomspace NanoCom ANT-6F VHF
- Oxford VHF Yagi Antenna

E. VOCS Architectures

Two different architectures have been evaluated:

- VOCS-1: supports TDD (Time-Division-Duplexing), Half Duplex, VDE-SAT and it is realised for pico-satellite and nano-satellites;
- VOCS-2: it is the most generic implementation Full Duplex of VDE-SAT but requires a VHF duplexer. It should be used in nano-satellites and micro-satellites.

The presentation here is focusing on VOCS-1 architecture because it is the most compact (and lighter) solution even if VOCS-2 is presented in a single slide.

The Cubesat implementation is considered only for VOCS-1.

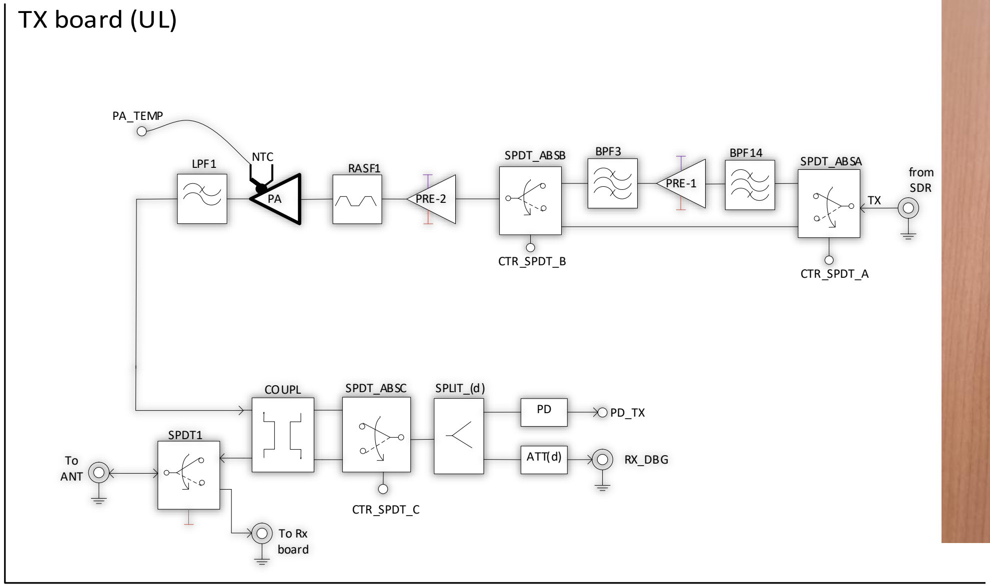
Both VOCS-1 and VOCS-2 are designed to be compatible with a reception of the AIS and ASM packets.

F. RF-FE VOCS-1 HD TX Architecture

The figure below shows the architecture design for prototype version of VOCS TX board.

From the right, the input signal coming from the SDR is filtered and pre-amplified by a series of SAW filters, a custom radio-astronomical suppression filter (RASF1) and two LNA's (PRE-1 and PRE-2). The signal is then amplified using a GaN technology high power amplifier (PA) and filtered with a low pass filter (LPF1) to remove high frequency harmonics. The output signal is connected to an ANTENNA.

In the commercial version, some parts and sensors used for prototype debug and measurements are removed for a smaller size package.
The figure below shows a front device photo.



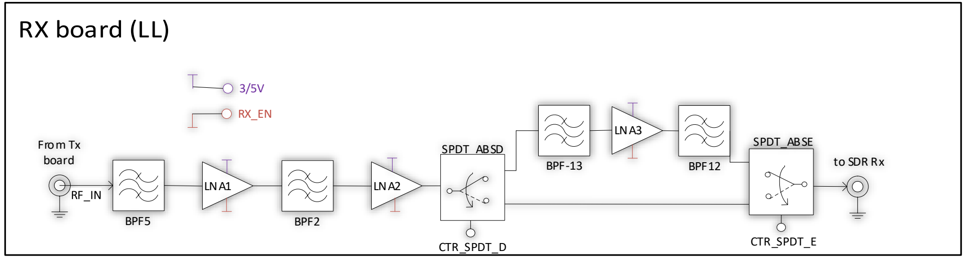
G. RF-FE VOCS-1 HD RX Architecture

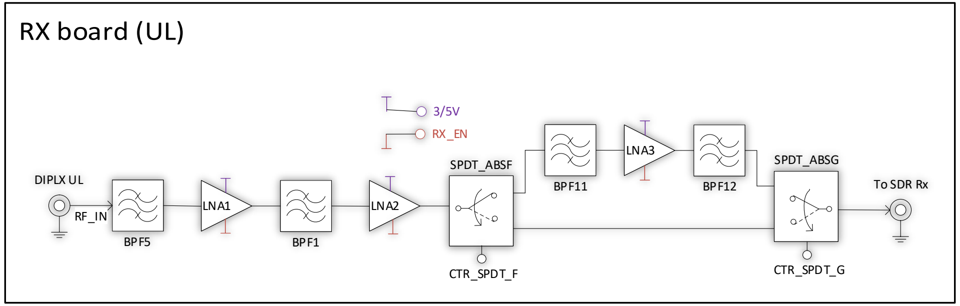
The figure below shows the architecture design for prototype version of VOCS RX board. Two receiver paths are integrated working at VDE SAT UL and LL bands.

From the left, the input signal coming from the antenna is filtered and pre-amplified by a series of custom band pass filter (BPF5), SAW filters (BPF2 or BPF1), SAW filters (BPF13 or BPF11) and three LNA's (LNA1, LNA2 and LNA3) stages.

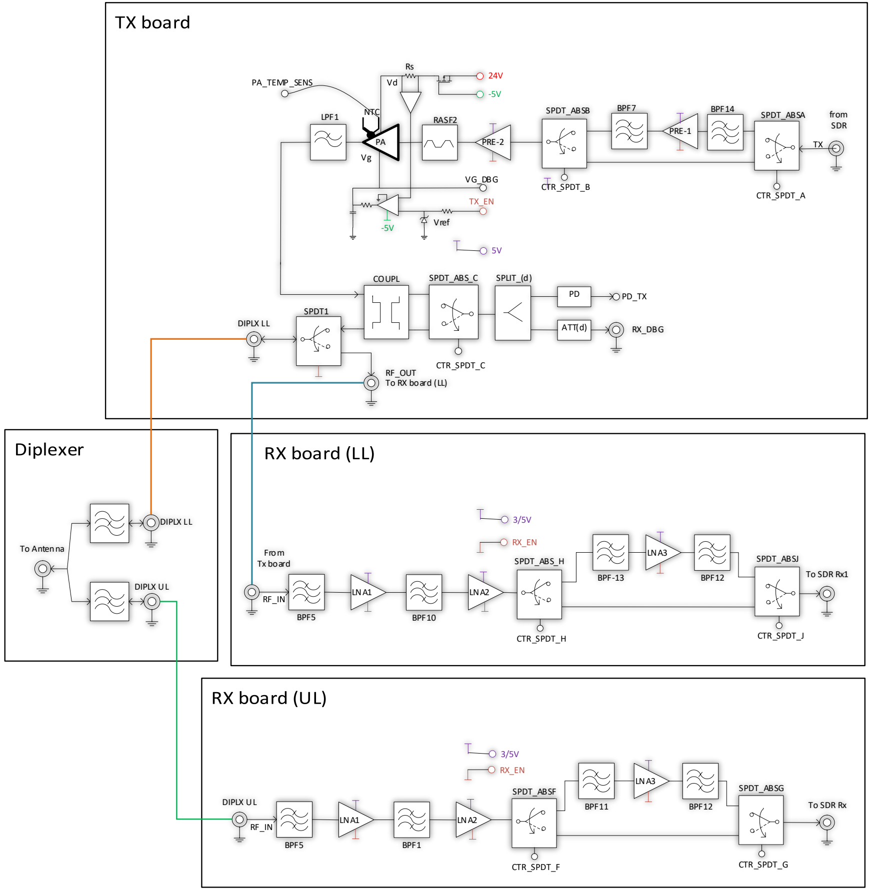
The output signal can be processed by the SDR board.

In the commercial version, used for prototype debug and measurements are removed for a smaller size package. The figure below shows a front device photo.

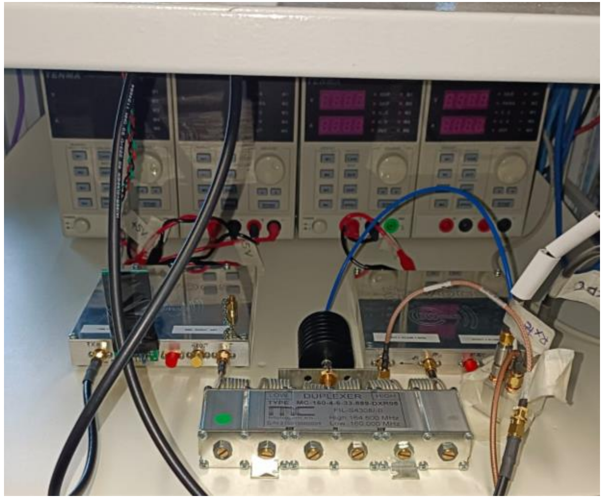




H. RF-FE VOCS-2 FD Tx/Rx Architecture



The Full Duplex architecture requires a Duplexer to improve the isolation between transmitter and receiver.



I. VOCS-1 and VOCS-2 power consumption

VOCS-1	"Initial target" Power consumption [PAE]	"Final Realistic Hardware Configuration" Power consumption [PAE]
Tx Board: PA	5.0W [12.6%] {All LinkID}	2.20W [28.7%] {All LinkID except 27} 3.91W [16.2%] {All LinkID including 27}
Tx Board: Other circuits	2.0W	0.82W
Rx Board	0.5W	0.65W

VOCS-1
An input bit indicating LinkID27 (8-PSK) presence is enough to reduce the average power consumption.
The output conducted power is 28 dBm = 0.63 W
A single transmition channel is supported.

The average power consumption of the overall RF Front-End with a duty cycle of 50% is **1.8W**.

VOCS-2	"Initial target" Power consumption [PAE]	"Final Realistic Hardware Configuration" Power consumption [PAE]
Tx Board: PA	7.5W [4.6%] {All LinkID}	2.72W [12.7%] {All LinkID except 27} 5.60W [6.2%] {All LinkID including 27}
Tx Board: Other circuits	2.0W	0.82W
Rx Board	2x0.5=1.0W	2x0.65=1.3W

VOCS-2
An input bit indicating LinkID27 (8-PSK) presence is enough to reduce the average power consumption.
The maximum output conducted power is 25.4 dBm = 0.347 W
Up to three transmitted channels are supported.

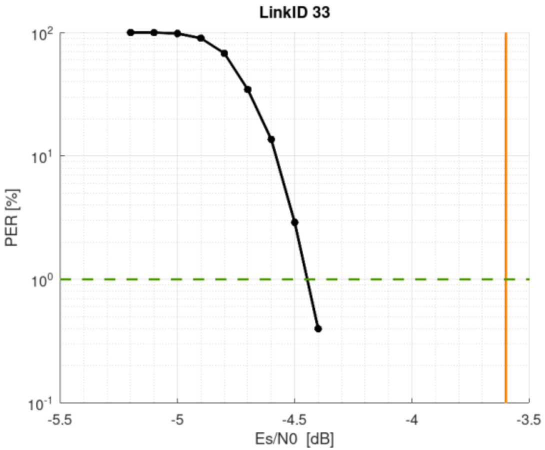
L. VOCS-1/2 Packet Error Rate curve

VOCS-1 and VOCS-2 payloads have been extensively tested in their performances according to an agreed test-plan.

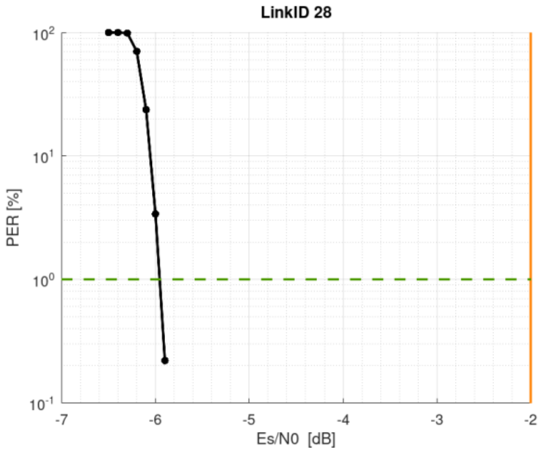
A crucial verification has been carried out by sending and demodulating tens of thousands of packets within a laboratory setup. The Packet Error Rate (PER) of all downlink waveforms (LinkID, as defined by ITU M.2092), equals 1% at an Es/N0 level which is more severe than the Es/N0 recommended in ITU M.2092. This proves the implementation is successful.

In the below figures the black PER curves comes from data, while the vertical orange line is the recommended Es/N0.

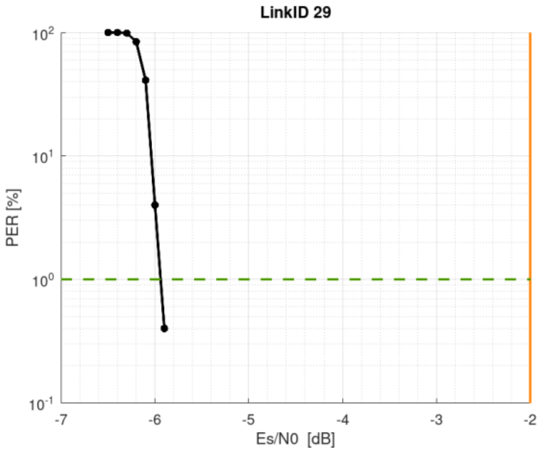
LinkID 33
BPSK
BW = 50 kHz



LinkID 28
BPSK
BW = 100 kHz



LinkID 29
BPSK
BW = 150 kHz



M. Cubesat RF-FE Specifications

RF-FE TX Board

- ❑ Voltage Supplies for HPA, LNA, RF Switch and control logic:
  - i. 12V, max 611mA (internally limited)
  - ii. +5V, 500mA
- ❑ Output signal peak power: 5W
- ❑ VDES Signal Output Power: 29dBm
- ❑ MCX RF Connectors

- ❑ Weight: 0.350Kg
- ❑ Fits Standard PC104

- ❑ Interfaces:
  - TX RF input: receive RF signal from SDR
  - RX RF output: RF signal to be provided to the RX path
  - ANTENNA RF input/output: RF bidirectional signal (half-duplex)
  - 2x I/O CMOS 3.3V for control signals: TX Enable, RF Switch SPDT control for forward/reverse power detector measurement
  - 2x analog outputs: Power Detector level and temperature level
  - 1x digital output: PA ShutDown Alarm

RF-FE RX Board

- ❑ Voltage Supply: +5V
- ❑ Max Current: 250mA
- ❑ Signal Output Gain: ~45dB
- ❑ MCX RF Connectors.

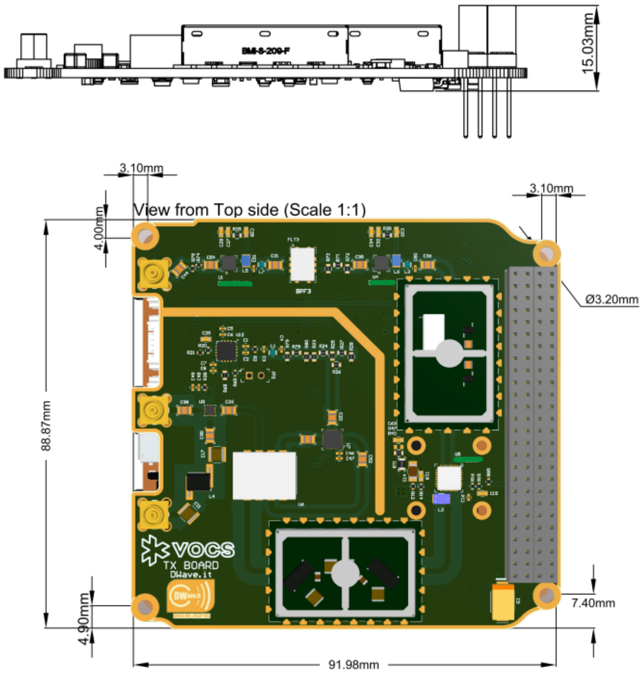
- ❑ Weight: 0.2Kg
- ❑ Fits Standard PC104

- ❑ Interfaces:
  - RX IN: RF received signal input
  - RX OUT: amplified RF output signal route to SDR
  - I/O CMOS 3.3V for RX Enable

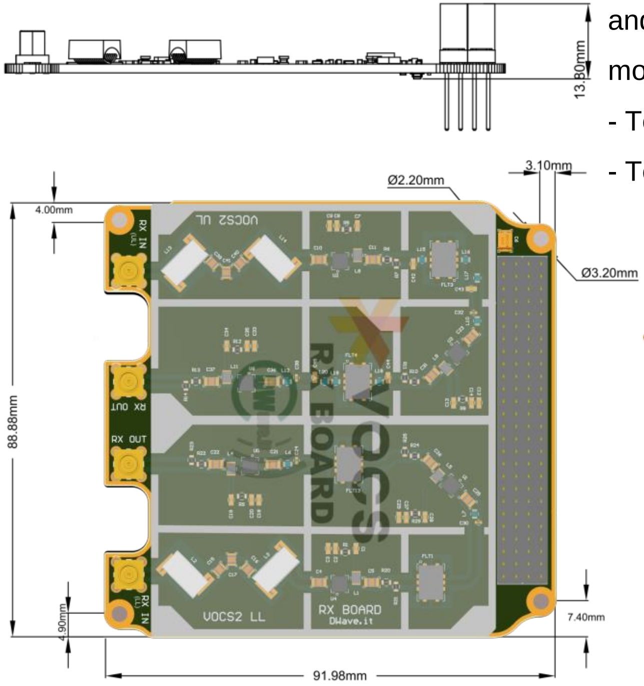
N. Cubesat RTX Mechanical Drawing

A CubeSat compliant commercial VOCS Board was developed compatible with GOMSpace NanoDock SDR dimension and many other Cubesat solutions providers.

RF-FE TX Board

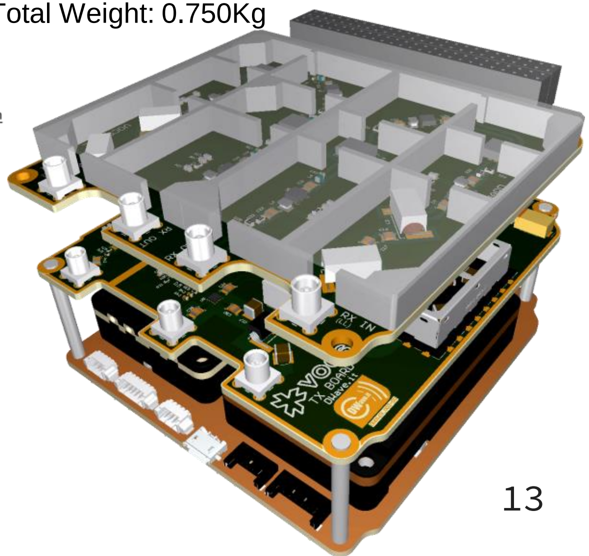


RF-FE RX Board



The figure below shows the 3D view of the VOCS Board commercial assembled with TX and RX Board, GOMSpace NanoDock SDR and GOMSpace NanoCom TR-600 and Z7000 modules.

- Total Dimensions: 90x96x65mm
- Total Weight: 0.750Kg



Questions?

If you have any question any new project proposal, feel free to contact us:

marco.bonaventura@dwave.it
Telephone: +39 0492611038