Design of S-Band Transceiver for CubeSat Structure Satellites

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***Abstract*—CubeSat structure satellites have limited communication ability as a result of limited power and size, as well as low cost transceivers. The communication between CubeSat and the Earth station therefore faces a lot of risks such as impairing transceiver performance and degrading mission data throughput. In this paper, a design of S-band transceiver for telemetry, tracking and control (TT&C) is presented for use onboard CubeSat satellites. The transceiver can provide a measured 96 Kbps of data rate with maximum output power of 39.3 dBm (∼8.5 W) and an overall volume of 87.4 × 93.4 × 20 mm^3 with total mass of 252 grams including aluminum housing.**

***Index Terms*—CubeSat, S-band transceiver, nano-satellites, micro-satellites.**

I. Introduction

CubeSat is considered as a revolutionary technology in the field of nano and micro satellite research and development. The particularity of the CubeSats is the standardization of shape and size, which has led to them becoming the most popular of all nano satellites today. These platforms are made up of a stack of basic volumes (10 × 10 × 10 cm^3), named "1U." An extension of the CubeSat platform can be double (2U), triple (3U) or more. CubeSat has many outstanding advantages in terms of physical architecture (compact size and light), short fabrication time, low cost and easy deployment. From these superior characteristics, research and development of CubeSat sub-systems are increasingly attractive to researcher so far.

S-band transceivers have been developed for CubeSat since the 2000s and there are some 3U CubeSat has been completed such as GeneSat-1 [1] - [3], MAST [4] and CANX-2 [5] - [6]. Because free space path loss is higher in S band while S-band system is commonly used for high speed communication, S-band transceiver is required to provide more power and receive sensitivity. In this study, the design of S-band transceiver for CubeSat TT&C subsystem with power and data throughput improvement is presented.

II. Transceiver Architecture

The block diagram of the S-band transceiver is presented in Fig. 1. It is composed by a receiver and a transmitter section sharing common circulators and antenna; thus, the transceiver can receive and transmit data simultaneously. For our design, 24 Volt DC Power Supply is used for the transceiver operations

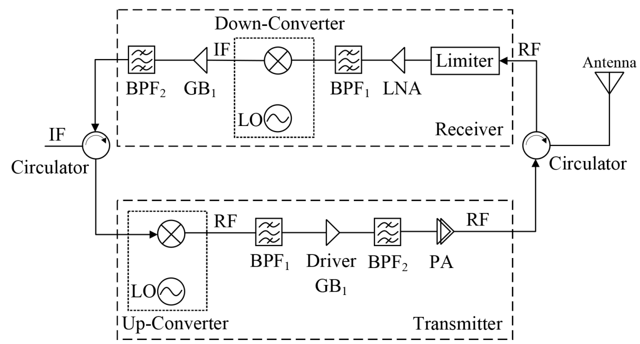


Fig. 1. Block diagram of the proposed S-band transceiver.

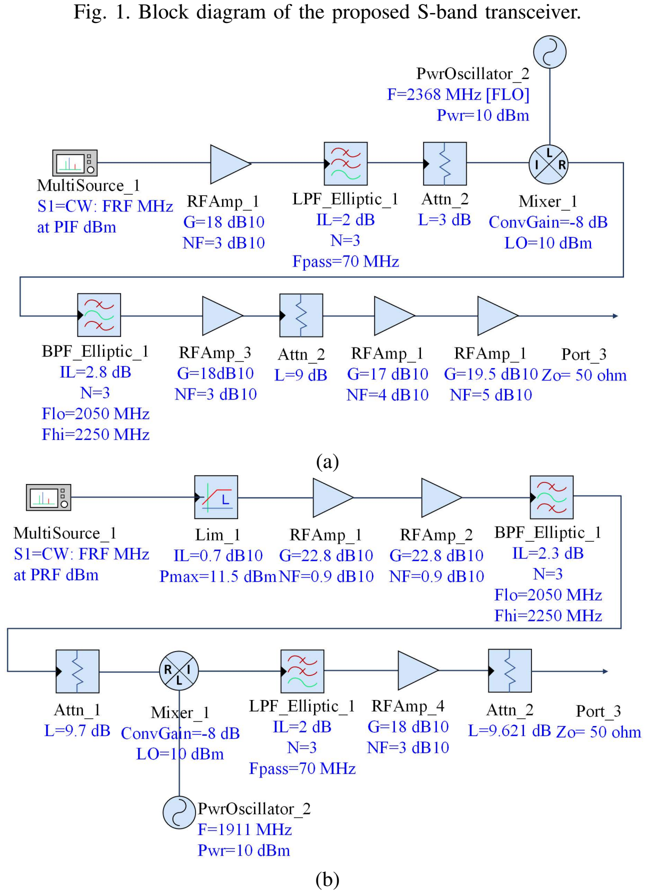
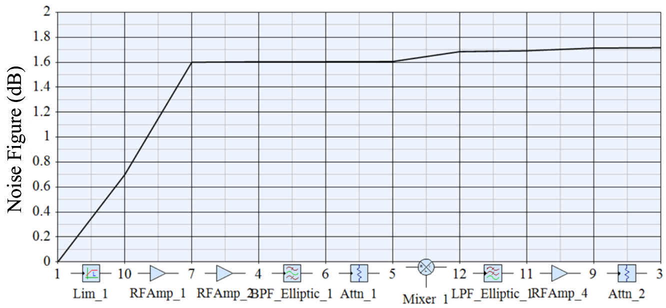
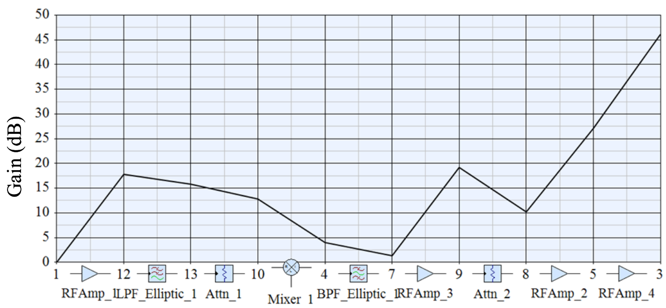


Fig. 2. The receiver (a) and transmitter (b) of the S-band transceiver are modeled by using SystemVue software.



(a)



(b)

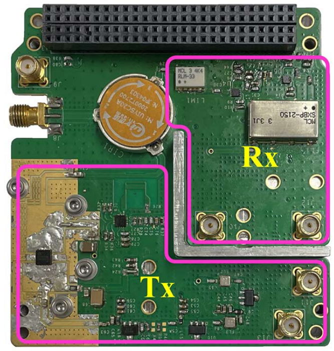
Fig. 3. Simulation results: (a) Noise Figure of the receiver and (b) Gain of the transmitter.

and the transceiver DC power requirement are mainly set by the transmit power amplifier. In receive mode, 2051 MHz radio frequency (RF) signal received from the antenna is sent to limiter, low noise amplifier (LNA) and RF band pass filter (BPF1) to eliminate noise. The RF band-pass filter (BPF1) to minimize noise. The signal is then transformed to 140 MHz intermediate frequency (IF) signal by down-converter. Finally, received IF signal is amplified and filtered by gain block (GB) and IF band-pass filter (BPF2) before sending to digital signal processor (DSP) module. In transmit mode, 140 MHz IF signal is transformed to 2228 MHz RF signal by an Up-Converter. Received RF signal is then amplified and filtered by pre-amplifier (Driver), RF band-pass filters (BPF1 and BPF2) and power amplifier (PA) before sending to the antenna.

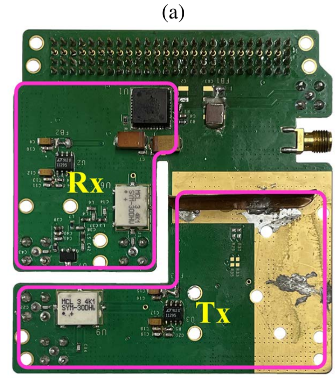
The receiver and transmitter of the S-band transceiver are modeled by using SystemVue software as shown in Fig. 2. The simulation shows that the calculated noise figure (NF) of the receiver and gain of the transmitter are 1.7 dB and 46 dB,respectively as shown in Fig. 3. Note that the PI attenuators modeled by Attn_linear components as shown in Fig. 2 are implemented in the design in order to handle the gain easily after fabrication.

III. Implementation and Measurement

Finally, the transceiver layout is performed using Cadence software and its passive and active components are implemented on 4-layer RO5880 Laminates PCB with the dimensions of 87.4 $\times$ 93.4 mm^2 as shown in Fig. 4. The aluminum housing and copper heatsink are also designed and fabricated to ensure not only the mechanical strength but also

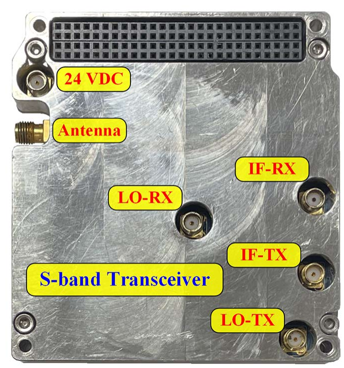


(a)

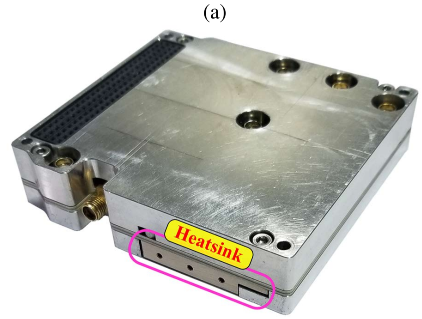


(b)

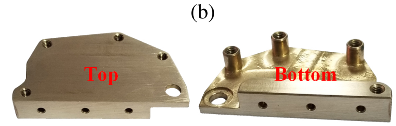
Fig. 4. PCB board design of the proposed S-band transceiver: (a) Top layer, and (b) Bottom layer.



(a)



(b)



(c)

Fig. 5. Aluminum enclosure of the proposed S-band transceiver: (a) Top view, (b) Perspective view and (c) Copper heatsink.

TABLE I.
MEASUREMENT RESULTS

Receiver Characteristics		Values	Transmitter Characteristic		Values
Frequency	[MHz]	2051	Frequency	[MHz]	2228
Sensitivity	[dBm]	-84.0	Gain	[dB]	45.0
NF	[dB]	3.2	P_{outmax}	[dBm]	39.3
Gain	[dB]	20.0	Uplink	[Kbps]	96.0
Downlink	[Kbps]	96.0			

TABLE II.
A COMPARISON IN TT&C TRANSCEIVER CHARACTERISTICS AMONG CUBESATS.

Parameters	Unit	Proposed	[1-2]	[3]	[4]	[7]
Transmitter power	W	8.5	1.0	1.0	0.5	1.0
Sensitivity	dBm	-84	-105	–	–	–
Data Rate	Kbps	96	83	83	15	–
Mass	Gram	116	75	–	–	196

the electrical functions of the transceiver. It can be seen from Fig.5 that the size of S-band transceiver is fully compatible with a CubeSat platform. The total volume of the S-band transceiver is 87.4 × 93.4 × 20 mm^3 while the total mass was found at 252 and 116 grams with and without aluminum housing, respectively. After fabrication, characteristics of the proposed S-band transceiver are measured and summarized in Table I. Because receiver and transmitter are designed on the same PCB and they are operated simultaneously, the noise caused by electromagnetic interference (EMI) is unavoidable. As a result, the measured Noise Figure (3.2 dB) is larger than simulated one (1.7 dB). Table I shows that the proposed transceiver can provide data rate up to 96 Kbps and maximum output of 39.3 dBm and these are better in comparison to those ones exhibited by some other reports as summarized in Table II.

IV. SPACE ENVIRONMENT TEST

Space environment tests, such as thermal cycling, thermal vacuum cycling, vibration and shock, are conducted for the fabricated prototype. The S-band transceiver during the tests are shown in Fig. 6. Test conditions are follows.

1. Thermal cycling test:
   - Testing standard: MIL-STD-1540C
   - Temperature range: -40 ^{o}C ∼ +50 ^{o}C
   - Cycles index: 10 cycles
   - Duration time: 40 hours
2. Thermal vacuum cycling test:
   - Testing standard: GSFC-STD-7000
   - Vacuum chamber pressure: 5 × 10^{-6} Pa
   - Shroud temperature: -185 ^{o}C
   - Temperature range: -12 ^{o}C ∼ +40 ^{o}C
   - Temperature changing rate: 1 ^{o}C/hour
   - Cycles index: 1.5 cycles (1 worst hot + 2 worst cold)
   - Duration time: 72 hours
3. Sinusoidal vibration test:
   - Testing standard: GSFC-STD-7000

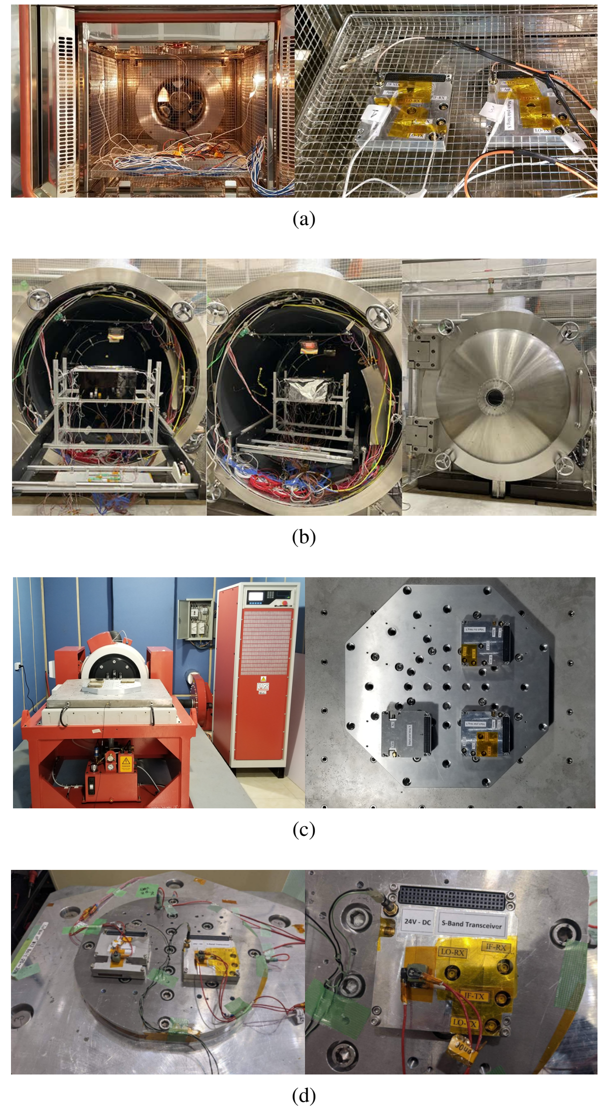


Fig. 6. The S-band transceiver during the tests: (a) Thermal cycling test, (b) Thermal vacuum cycling test, (c) Sinusoidal vibration and random vibration test, (d) Shock test.

   - Loading direction: 3 axis
     - x axis:
       * 5∼100 Hz
       * acceleration: 3.125 g
     - y, z axis:
       * 5∼100 Hz
       * acceleration: 2.15 g
   - Scan rate: 2 oct/min
4. Random vibration test:
   - Testing standard: GSFC-STD-7000
   - 20 Hz: 0.01 g^2/Hz
   - 80 Hz: 0.079433 g^2/Hz
   - 500 Hz: 0.159956 g^2/Hz
   - 2000 Hz: 0.080728 g^2/Hz
   - Loading direction: 3 axis
   - Duration per direction: 2 oct/min

- Grms: 14.72 G

5. Shock test:
   - Testing standard: MIL-STD-1540C
   - Test level:
     - 100-1000 Hz: + 12 dB/oct
     - 1000-3000 Hz: 1000 G
     - tolerance: -3 dB
   - Loading direction: 3 axis

After the space environment test, the appearance of the transceiver is not changed. The function of the module works normally. The measured results show a negligible difference between the transceiver performance after the space environment tests compared with the previous performance.

V. CONCLUSION

An improved transmit power and data throughput S-band transceiver for CubeSat is presented. A prototype of the proposed transceiver has been fabricated and measured. The measured results show the S-band transceiver can provide a data rate up to 96 Kbps with maximum output power of 39.3 dBm ($\sim$8.5 W). To ensure of the proposed transceiver works well in the experimental environment, we tested on the space environment, such as thermal cycling, thermal vacuum cycling, vibration, and shock. The space environment tests show that the S-band transceiver has undergone rigorous testing. In summary, the S-band transceiver proposed in this article, which demonstrates accomplished performance, reliability, and high stability, can be applied to similar CubeSat platform.

ACKNOWLEDGMENT

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