A Robust Low Power Communications Architecture for Nano-Satellites

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Abstract— **This paper describes a low power communication architecture for 2U class nano-satellites. The system is designed to operate two links in the UHF and VHF bands, each of which is managed by independent microcontrollers. Impedance matching networks and harmonic filters are designed to ensure that the maximum power is transferred and spurious emissions are within the acceptable limits. It contains a transceiver module on both the links to ensure that in case one link fails, the other can take over. This system is implemented on two separate PCBs. The link budget calculations are shown here for all the communication links.**

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1. INTRODUCTION

With the increasing number of small scale satellites being launched, there is a growing need to make the communication system as simple, power efficient, and robust as possible. According to statistical studies, many nano satellites find it convenient to operate in the Ultra High Frequency (UHF) and Very High Frequency (VHF) bands [1].This architecture is designed to transmit beacon and payload data in the VHF and UHF bands respectively. The beacon is a signal sent out by the satellite, which broadcasts the health status of the satellite, such as battery voltage, satellite's on board temperature, etc. Payload data refers to the mission data collected by the satellite, when it is in orbit. Since there are many low power microcontrollers available in the market today, it is feasible to use two or more in the satellite simultaneously, without worrying too much about the power consumption while getting enhanced reliability.

2. SYSTEM OVERVIEW

This architecture includes a transceiver, a transmitter, a receiver, three RF switches, two power amplifiers, and two microcontrollers to manage the entire system. It uses an independent receiver to gain extra redundancy. Figure 1 shows the block diagram of this architecture.

Basic elements

The system utilizes two links in the VHF and UHF bands respectively, each being capable of transmitting as well as receiving. Both of these links are managed by two independent microcontrollers. In case a link fails, the other one can take over its functions. The hardware of the two links is connected as follows:

(1) The transmitter is connected to one of the input lines of the RF switch. One can add a power amplifier to improve the system link margin. The other input of the switch is connected to the receiver. The output of the switch is connected to an antenna. If required, one can add a band pass filter in between the switch and antenna.

(2) The transceiver, in its default state, transmits payload data through an amplifier. Two RF switches are connected at the input and output of the amplifier, as a method to bypass it in order to receive data.

(3) Over Current Protection Circuits (OCPCs) can be added between the power supply of the Integrated Circuit (IC) and the power bus.

Operation

The satellite's transmitter in the VHF link is initially configured to transmit beacon data, and the receiver is used to receive uplink commands. The transceiver in the UHF link is initially configured to transmit payload data. It is capable of switching to a receiving mode if failure of the receiver in VHF link is detected. When the UHF link is used to receive data, the two RF switches connect to each other through the receive path, bypassing the amplifier. The beacon transmission and uplink reception in the VHF link are time multiplexed to schedule transmission and reception as required. The transceiver in UHF link remains in sleep mode for most of the orbit. It transmits when it passes over a desired ground station, which could be preprogrammed, or when a

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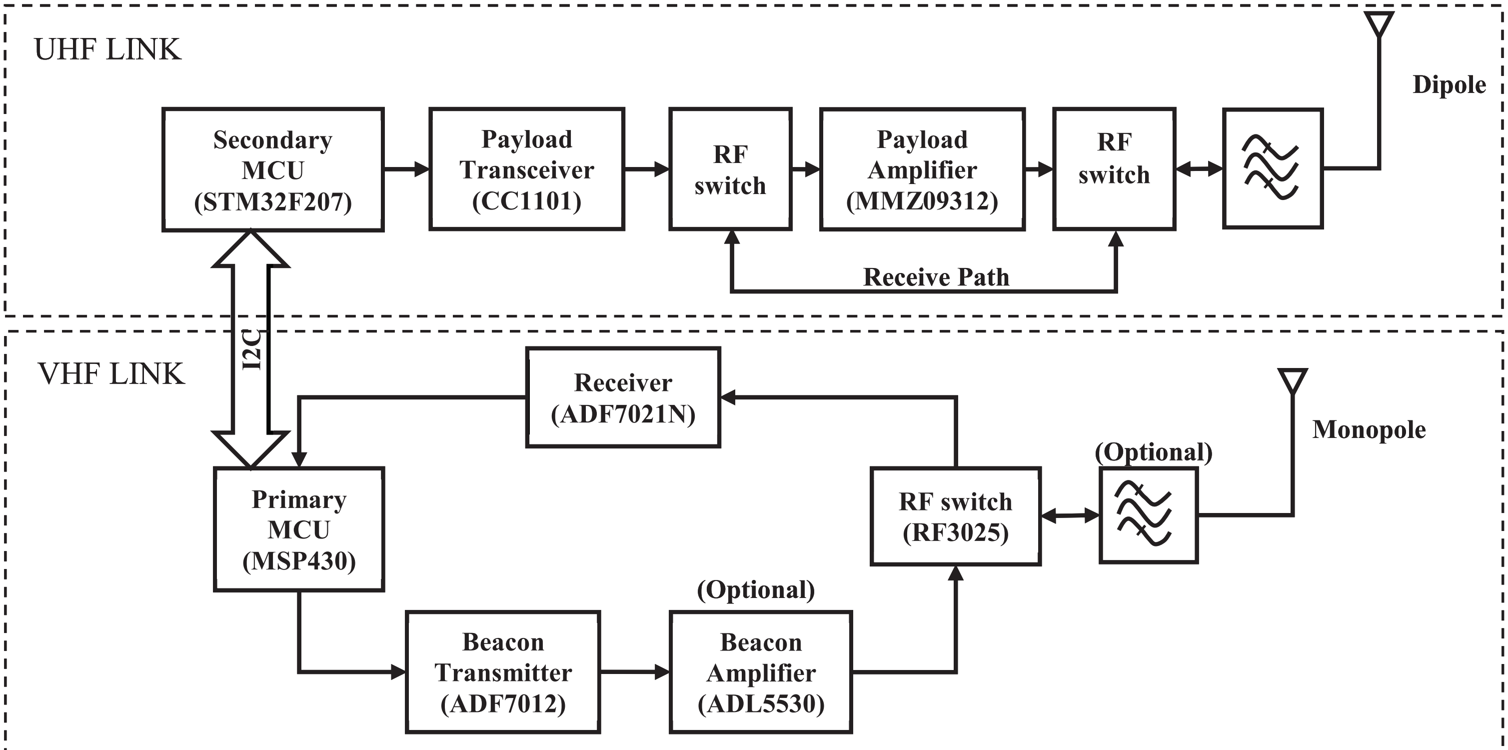

Figure 1. Block diagram of the architecture

ground station requests data. The predetermined ground stations can be detected using an on board GPS module. In case the transceiver has to shift into receive mode, fixed time slots are added for reception during the pass. The use of two microcontrollers gives the added advantage that both the links can be used to downlink data simultaneously. Hence, the effective throughput of data is increased. Since the payload amplifier consumes a lot of power, the transmission in the UHF link is restricted in time. The following detected failures in the VHF link receiver makes the transceiver in UHF link shift to receive configuration over the desired ground station:

(1) In the event of latch up taking place in the receiver IC, it is detected by the OCPC, which notifies the microcontroller about it. The microcontroller disconnects the receiver IC from the main power supply line. This stops the excessive current flow and protects the components, if done quickly. It then restores power and initiates a process to read back the product code of the receiver IC. If it matches, it continues in the normal operation mode. However, if it fails, the receiver shifts to the other link.

(2) The receiver IC gives a logic high output on one of its pins, corresponding to the lock status of the Phase Locked Loop (PLL). If the logic level is low, then the PLL has unlocked. If the PLL unlocks during its reception phase, it is detected by the microcontroller, which in turn resets the receiver and waits for a considerable amount of time, for the line to go high. In the event that it locks again before the time has elapsed, the same line is polled for a certain duration, and if it does not permanently lock till the end, the transceiver in the UHF link is used to receive data. A number of errors which results in the unlocking of PLL are resolved by this.

The beacon must contain a field which indicates which link the receiver is active on. In the event that the UHF link is used for reception, the system shifts the reception operation back to the default state at VHF link after a day, and repeats the process of restarting the receiver.

3. Implementation

The following section gives a brief description of the Integrated Circuits (ICs) which we have used. All of these are Commercially Off The Shelf (COTS) components. Every device chosen for our architecture has its output and/or input ports (wherever applicable) matched to 50 ohms of impedance, which is a followed standard in RF system design.

ADF7012 (Beacon Transmitter)

ADF7012 from Analog Devices is selected to downlink the beacon telemetry. This low power IC, is capable of working in both the UHF and VHF bands, and supports various digital modulation techniques giving a lot of flexibility to the user during the design phase. The microcontroller is interfaced to the IC using a four wire interface. Writing to registers as well as writing the data to be transmitted is done via a bit-banging protocol. An added advantage of using the ADF7012 IC is the control over transmission by detecting the PLL status. Since one should only transmit in the allocated frequency, a

PLL lock detection must be used to restrict the transmission to the desired frequency. In our system, we use this IC to transmit data using the On Off Keying(OOK) modulation format. The data is framed such that it resembles Morse code transmitted at around 15 words per minute (wpm) keying speed or 13 bits per second (bps). If this IC is to be used to transmit at higher data rates, an amplifier and a band pass filter must be used to satisfy the link margin and reduce the harmonic content. Also, using OOK makes reception at the ground station side very simple, since many radio operators can copy 15 wpm Morse code easily.

ADF7021-N (On Board Receiver)

ADF7021-N from Analog Devices is chosen to be the on-board receiver due to its low power consumption and its versatile nature. It primarily modulates and demodulates data using different forms of frequency shift keying, where it supports a wide range of data rates (varying from 0.05 kbps to 32.8 kbps) and frequency deviations which gives the user a lot of freedom to work with. Writing to the registers as well as logging of the received data is done through a bit-banging protocol. The impedance matching network is designed using the data provided in the Analog Device's application note AN-859. A maximum receiver sensitivity of -116dBm was achieved [2].

ADL5530 (Beacon Power Amplifier)

ADL5530 from Analog Devices is a broadband amplifier which can be operated over a supply voltage from 3 to 5V. A maximum output power of 18.4dBm can be achieved at 4.2V. It has minimal passive circuit elements which makes it very simple to implement. This amplifier can be used in cases where a higher data rate transmission is required. A maximum data rate of 1200 bps can achieved with a link margin of 6.7dB.

CC1101 (Payload Transceiver)

During payload data transmission, the data is modulated in binary FSK format. The required Eb/No. for this kind of modulation is around 13dB, which could make the link marginal for some ground stations[3]. To help with this issue, Forward Error Correction (FEC) is used. Forward error correction is a method of obtaining error control in data transmission in which the source (transmitter) sends redundant data and the destination (receiver) recognizes only the portion of the data that contains no apparent errors. A redundant bit may be a complex function of many original information bits. The carefully designed redundancy allows the receiver to detect and correct a limited number of errors. FEC gives the receiver the ability to correct errors without needing a reverse channel to request retransmission of data[4]. Implementing FEC reduces the required Eb/No. value for a given emission, however it lowers the effective data rate due to the addition of extra bits.
The reasons why the CC1101 by Texas Instruments was chosen are:

(1) It has been used several times in the past by other successful satellites.
(2) It has in-built packet handling features, including automatic FEC calculation, two 64 Byte buffers for receiving and transmitting data in bursts, automatic preamble and sync word insertion and automatic CRC calculation.
(3) It consumes a very low power.
(4) The frequency of operation lies in the UHF band.
(5) The IC tracks the center frequency of incoming data, hence allowing the user to correct the receiving frequency by simply 'adding' a frequency offset. This can be used for Doppler shift correction.
(6) The receiver sensitivity is high (about -112dBm at a data rate of 1200 bps).

Keeping these points in mind, we have chosen CC1101 to be the payload transceiver operating in the UHF band. The passive component network values are provided by Texas Instruments for the frequency range of 433 MHz. This makes it very easy for the designer to program the transceiver for frequencies around that range.

MMZ09312B-T (Payload Amplifier)

The MMZ09132BT manufactured by Freescale Semiconductors is a high gain amplifier with a maximum output of 29dBm a gain factor of 33dB. Since this amplifier consumes the most amount of power, one must be conservative in its use.

RF3025 (RF Switch)

RF3025 manufactured by RFMD has a very high isolation (60dB) in the VHF and UHF bands of operation. It has an insertion loss of less than 0.5dB, and features single bit control with operating voltage as low as 3V.

Microcontrollers

The microcontrollers for our system have been chosen based on their power consumption, reliability, and processing power. They run a Real Time Operating System (RTOS) for scheduling the various tasks to be carried out in the satellite.

MSP430F5438A -The MSP430 series of microcontrollers from Texas Instruments is well known for its extremely low power consumption and reliability. It has also been used in several successful small satellites in the past.

STM32F207 –The STM32F207 microcontroller from ST Microelectronics features a 32 bit ARM Cortex M3 architecture. It can be used in cases where high processing power is required.

Radiation Tolerance

In the Low Earth Orbit, the major source of ionizing radiation are trapped electrons and protons. This radiation can cause single event faults[5]. The satellite body is made of polished aluminium, which is coated with white paint, which acts as a shielding material for both electrons and protons[6]. Single Event Latch-Ups (SEL) are counteracted by using an OCPC. Whenever latch up occurs, the current drawn is limited by the OCPC, and the fault is notified to the microcontroller, which in turn makes the OCPC disconnect the device from the supply line. Single Event Upsets (SEU) for the microcontroller are mitigated by using a watchdog timer, which resets the microcontroller when it operates incorrectly. Passive components are chosen such that the effect of radiation on their electrical characteristics is minimal. All resistors, capacitors and inductors are chosen after a derating process while adhering to NASA's recommended derating values. The derating process is used to reduce electrical, mechanical and thermal stress for the components [7].

Power Budget

Table 1 shows the power budget of the system for the above mentioned ICs. The average power generated per orbit using solar-panels in a typical 2U nano-satellite with non-deployable solar panels is 2.5W[8]. Using our architecture, the total power consumed by the communication system during beacon transmission and payload transmission is 98.53mW and 1071.28mW respectively. Since the payload transmission consumes a lot of power, the transmission takes place only over the desired ground stations, which are determined by an on-board GPS module or by sending a telecommand from the ground station requesting data. Even in the event of a battery failure, if the satellite is not in the eclipse region both the downlinks can be established successfully since the total power consumed is less than the average power generated using the solar panels.

Table 1. Power Budget of the System

IC	Current Consumed (mA)	Operating Voltage (V)	Power Consumed (mW)
ADF7012	20	3.3	66
ADF7021-N	25	3.3	82.5
CC1101(Tx)	13.8	3.3	45.54
CC1101(Rx)	16	3.3	52.8
MMZ09312B	200	4.2	840
RF3025	0.2	4.2	.84
MSP430	9.6	3.3	31.69
STM32F207	56	3.3	184.9
Total Power Consumed (Beacon TX)			98.53
Total Power Consumed (Payload TX)			1071.28
Total Power Consumed (VHF Rx)			115.03
Total Power Consumed (UHF Rx)			86.17

4. LINK BUDGET

In this link budget analysis, a typical ground station is considered to have circularly polarized antennas in VHF and UHF bands with a gain of 11dBi each. The antenna temperature is generated mainly due to sky noise (galactic noise and solar noise), ground noise and man-made noise. In the VHF band, sky noise is the greatest natural contributor and it is inversely proportional to frequency. Therefore, the antenna temperature for a VHF antenna is comparatively more than that of the UHF antenna. In general, the required minimum margins are 3 dB for spacecraft downlinks, 6 dB for uplinks, and 12 dB for range safety links [9]. Uplink is done using a transmitter and a high power amplifier in the appropriate frequency. Using our on-board communication architecture, any ground station having a G/T ratio more than -20.6dB/K and -17.6 dB/K for VHF and UHF links respectively can establish a reliable link. Calculation of link budgets were performed by taking the average orbit value of Low Earth Orbit (LEO) satellites (760km) from the UCS satellite database[10]. Frequency of operation for the beacon and uplink was taken to be 145.89 MHz and for that of payload data, it was taken to be 437.8 MHz. The Spacecraft temperature is taken to be 280K.Since, only half lobe of the antenna will be exposed (approximately), antenna temperature can be considered as 152K. Tables 2, 3, 4 and 5 display the link budget of our system. The Free Space Path Loss (FSPL) is given by the equations:

$$FSPL = \left(\frac{4\pi df}{c}\right)^2 \quad (1)$$

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) - 147.55 \quad (2)$$

Table 2VHF Downlink(Beacon)

Transmitting Satellite Details	
Beacon transmitter output power(P_T)	11.7 dBm
Beacon amplifier gain(P_1)	0 dB
RF Switch Insertion loss(P_{l1})	1 dB
BPF insertion loss(P_{l2})	0 dB
Monopole TX antenna gain(G_{ta})	2.3 dBi
EIRP = $P_T + P_1 - P_{l1} - P_{l2} + G_{ta}$	13 dBm
Channel Characteristics	
Antenna pointing losses	1 dB
Polarization loss	3 dB
Atmospheric and Ionospheric losses	1.8 dB
Path loss (elevation angle=15^0)	141.6 dB
Isotropic Signal Level, P_{ISO}	-164.4 dBW
Ground Station Details	
Receiving antenna gain,G_{ra}	11 dBi
Transmission line loss(Antenna to LNA)P_1	0.1 dB
Effective system noise temperature, T_{sys}	1400 K
$G/T = G_{ra} - 10 * \log(T_{sys}) - P_1$	-20.6 dB/K
$S/N = (P_{ISO} + G/T - K)$	43.8 dBHz
Required Data Rate, R	13 bps
$Eb/No = (S/N - 10 * \log R)$	32.6 dB
Modulation used	OOK
Required Eb/No	13 dB
System link margin	19.6 dB

Table 3.VHF Uplink

Transmitting Ground station Details	
Ground Station transmitter output power(P_T)	10 dBW
Total Transmission Line Losses(P_1)	3 dB
Antenna gain(G_{ta})	11 dB
EIRP = $P_T - P_1 + G_{ta}$	18 dBW
Channel Characteristics	
Antenna pointing losses	1 dB
Polarization loss	3 dB
Atmospheric and Ionospheric losses	1.8 dB
Path loss (elevation angle=15^0)	141.6 dB
Isotropic Signal Level, P_{ISO}	-129.4 dBW
Receiving Satellite Details	
Receiving Antenna Gain, G_{ra}	2.3 dBi
Transmission Line Loss(Antenna to LNA), P_1	1 dB
Effective System Noise Temperature, T_{sys}	373 K
$G/_T = G_{ra} - 10 * \log(T_{sys}) - P_1$	-24.4 dB/K
$S/_N = (P_{ISO} + G/_T - K)$	33.8 dBHz
Required Data Rate, R	2400 bps
$Eb/_{No} = (S/_N - 10 * \log R)$	41 dB
Modulation used	FSK
Required $Eb/_{No}$	13 dB
System link margin	28 dB

Further information about the link budget calculations can be found here [11] [12].

Table 4.UHF Uplink

Transmitting Ground station Details	
Ground Station transmitter output power(P_T)	10dBW
Total Transmission Line Losses(P_1)	3 dB
Antenna gain(G_{ta})	11 dBi
EIRP = $P_T - P_1 + G_{ta}$	18 dBW
Channel Characteristics	
Antenna pointing losses	1 dB
Polarization loss	3 dB
Atmospheric and Ionospheric losses	1.5 dB
Path loss (elevation angle=15^0)	150.4 dB
Isotropic Signal Level, P_{ISO}	-137.9 dBW
Receiving Satellite Details	
Receiving Antenna Gain, G_{ra}	1.6 dBi
Transmission Line Loss(Antenna to LNA), P_1	1 dB
Effective System Noise Temperature, T_{sys}	373 K
$G/_T = G_{ra} - 10 * \log(T_{sys}) - P_1$	-25.1 dB/K
$S/_N = (P_{ISO} + G/_T - K)$	65.6 dBHz
Required Data Rate, R	2400 bps
$Eb/_{No} = (S/_N - 10 * \log R)$	31.8 dB
Modulation used	FSK
Required $Eb/_{No}$	10 dB
System link margin	21.8 dB

Table 5.UHF Downlink(Payload)

Transmitting Satellite Details	
Payload transmitter output power(P_T)	-5 dBm
Payload amplifier gain(P_1)	31 dB
BPF insertion loss(P_{l1})	1 dB
Balun Insertion loss (P_{l2})	1 dB
Dipole TX antenna gain(G_{ta})	1.5 dBi
EIRP = $P_T + P_1 - P_{l1} - P_{l2} + G_{ta}$	25.6 dBm
Channel Characteristics	
Antenna pointing losses	1 dB
Polarization loss	3 dB
Atmospheric and Ionospheric losses	1.5 dB
Path loss (elevation angle=15^0)	150.4 dB
Isotropic Signal Level, P_{ISO}	-160.3 dBW
Ground Station Details	
Receiving antenna gain,G_{ra}	11 dBi
Transmission line loss(Antenna to LNA)P_1	0.1 dB
Effective system noise temperature, T_{sys}	700 K
$G/_T = G_{ra} - 10 * \log(T_{sys}) - P_1$	-17.6 dB/K
$S/_N = (P_{ISO} + G/_T - K)$	50.8 dBHz
Required Data Rate, R	2400 bps
$Eb/_{No} = (S/_N - 10 * \log R)$	17 dB
Modulation used	FSK
Coding Technique	Convolutional, Rate = ½, K=4
Required $Eb/_{No}$	10 dB
System link margin	7 dB

5. ANTENNAS

Since our architecture was designed for VHF and UHF frequency bands, taking in account the directivity, size and ease of deployment of the antennas, we have established the design by using a monopole antenna for the VHF band and an Inverted Vee dipole antenna for the UHF band. Every simulation was carried out for the respective antenna on a 2U satellite of dimensions 100mm X 100mm X 227mm. The distance between the antenna and the satellite body is 1mm. The antennas are made of stainless steel tapes with a thickness of 0.2mm. The simulations' and practical results observed are shown below. All the simulations were conducted using Computer Simulation Technology (CST) Student Edition.

Simulation Results for VHF Antenna

The length of the monopole is 573mm and the width is 5mm.

Radiation Pattern –The radiation pattern of the VHF monopole antenna was omnidirectional in the azimuthal plane. A directivity of 2.33dBi was obtained in the earth facing side of the satellite body ($\theta = 90°$). A 2D polar plot of the radiation pattern confirms this. For the 2D polar plot of the VHF monopole antenna a constant phi was taken. The radiation pattern of the monopole with the satellite body is shown in Figure 2 and the 2D polar plot for the same simulation is shown in Figure 3.

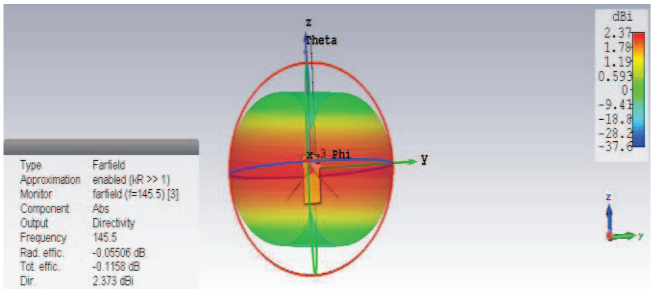

Figure 2. 3D Polar Plot of VHF Antenna

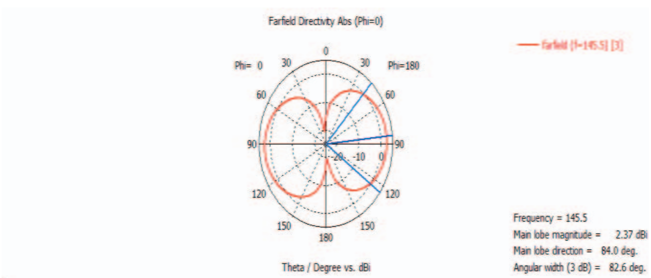

Figure 3. 2D Polar Plot of VHF Antenna

Observed Return Loss (S11) –The antenna and the prototype body of the satellite were connected to a VNA. It was found that the impedance was close to 51.8-12j ohms, which is very close to our transmission line impedance. The return loss was found to be -18.9dB as observed in the graph in Figure 4.

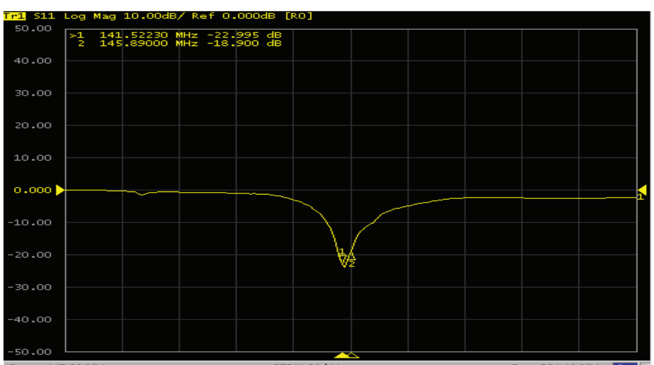

Figure 4. Return Loss Graph of VHF Antenna

Simulation Results for the UHF Antenna

The length of the dipole is 376mm and the feed gap is 4mm. The angle between the two arms is 95°.

Radiation Pattern – The radiation pattern of the UHF dipole antenna was distorted due to spacecraft's structure. The spacecraft's structure can cause electromagnetic scattering, as well as have blockage effects on the antenna's radiation patterns. The scattering can interfere with the antenna's radiation pattern, and can cause severe degradation in gain performance and sidelobes[13]. A directivity of 1.6dBi was obtained in the earth facing side (θ = 90° and ϕ = 0°), but a higher directivity (about 2.8dBi) was obtained in the direction opposite to the face on which the antenna was mounted (θ = 90° and ϕ = 180°). This phenomenon demands further investigation. A 2D polar plot of the radiation pattern confirms this. For the 2D polar plot of the UHF dipole antenna, a constant theta (θ = 90°) was taken. The radiation pattern of the UHF dipole antenna attached to the satellite body is shown in Figure 5. The two dimensional polar plot for the above simulation is shown in Figure 6.

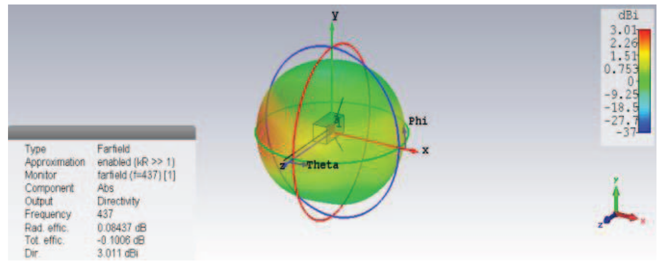

Figure 5. 3D Polar Plot of UHF Antenna

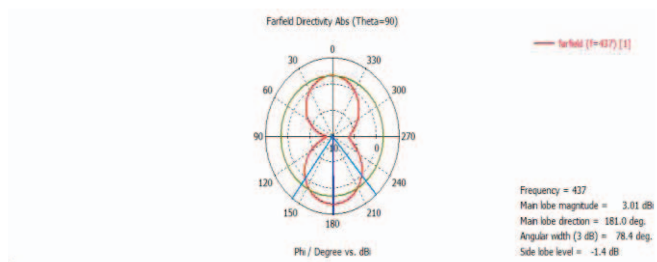

Figure 6. 2D Polar Plot of UHF Antenna

Observed Return Loss (S11) – The antenna and the prototype body of the satellite were connected to a VNA. It was found that the impedance was close to 53.7+4.43j ohms. The return loss was found to be -26.3dB as shown in the graph observed in Figure 7.

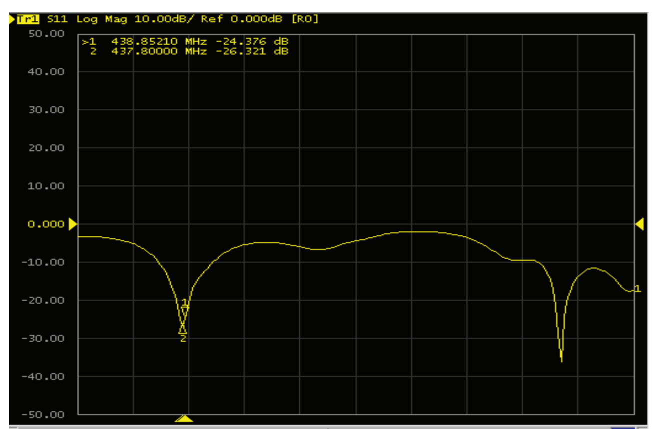

Figure 7. Return Loss Graph of UHF Antenna

Balun

The dipole antenna is fed through a lattice balun. A signal of the desired frequency was passed through the balun and the phase shift between the outputs of both the arms was observed to be almost 180 degrees.

Combination of UHF and VHF antenna

The combination of two antennas permits the use of two frequencies at the same time. From various test results it was found that the UHF antenna does not affect the radiation pattern of the VHF antenna, but the radiation pattern of the UHF antenna is deformed by the VHF antenna.

The solution to mitigate this was found as follows:

(1) Both the antennas should be perpendicular to each other to ensure minimum interference between them, since these antennas do not radiate in their own axis.

(2) The VHF antenna should be a monopole and the UHF antenna should be a Dipole. Since a dipole is symmetric, the distortion introduced in the radiation pattern by the monopole will be less.

6. Simulation and Results

Filters

The Band Pass Filters (BPF) for 145.89 MHz and 437.8 MHz were designed, optimized and simulated using Elsie Filter Design Software. The band pass filter for VHF may be used if required.

Band Pass Filter for UHF Band- The schematic and simulation curve of BPF for 437.8 MHz is shown in figures 8 and 9. There is an insertion loss of around 0.25 dB at 437.8MHz according to the simulation curve. Table 6 gives the numerical values for three points on the obtained curves.

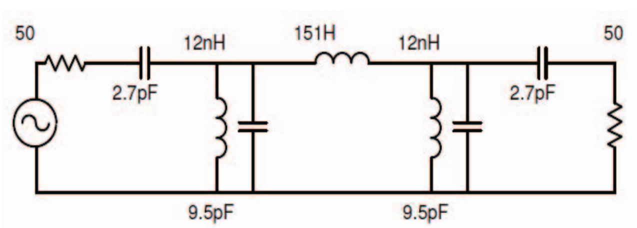

Figure 8. Schematic for 437.8 MHz BPF

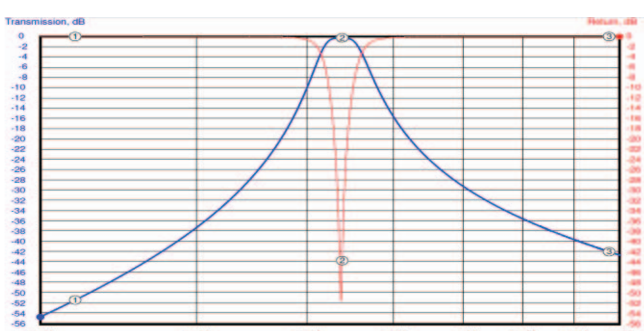

Figure 9. Return Loss Curve for 437.8 MHz BPF

Table 6. Return Loss values of 437.8 MHz BPF

Sr. No	Frequency	Return Loss (S11)	Insertion Loss (S12)
1	218.9 MHz	-0.003 dB	-51.28 dB
2	437.8 MHz	-43.59 dB	-0.255 dB
3	875.6 MHz	-0.005 dB	-41.85 dB

Band Pass Filter for VHF Band- The schematic and simulation curve of BPF for 437MHz is shown in figures 10 and 11. There is an attenuation of 0.51 dB at 145.89MHz according to the simulation curve. Table 7 gives the numerical values for three points on the obtained curves.

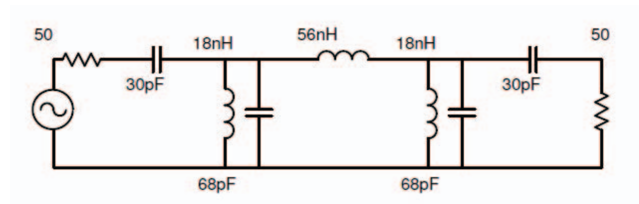

Figure 10. Schematic for 145.89 MHz BPF

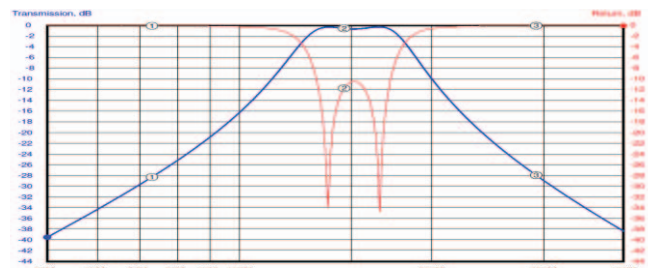

Figure 11. Return Loss Curve for 145.89 MHz BPF

Table 7. Return Loss values of 145.89 MHz BPF

Sr. No	Frequency	Return Loss (S11)	Insertion Loss (S12)
1	72.94 MHz	-0.026 dB	-28.28 dB
2	145.89 MHz	-11.69 dB	-0.512 dB
3	291.78 MHz	-0.015 dB	-27.87 dB

Transmit Characteristics of Transmitters and Amplifiers

The output spectra of the transmitters cascaded with the amplifiers were observed on a spectrum analyzer. The BPFs were not added to the output ports during the tests. The objectives were to see the levels of the spurious emissions and harmonic levels. The results shown in the following sections were taken from the board designed by the authors.

Beacon Transmitter- The beacon transmitter ADF7012 was made to transmit a carrier wave. The levels of spurious emissions were well below the limits. Since the output impedance values for the required frequency range is not provided by Analog Devices, to achieve maximum output power a suitable matching network was designed using a trial and error method. A maximum output power of 11.73dBm was achieved. The harmonic levels observed on the spectrum analyzer are shown below in figure 12.

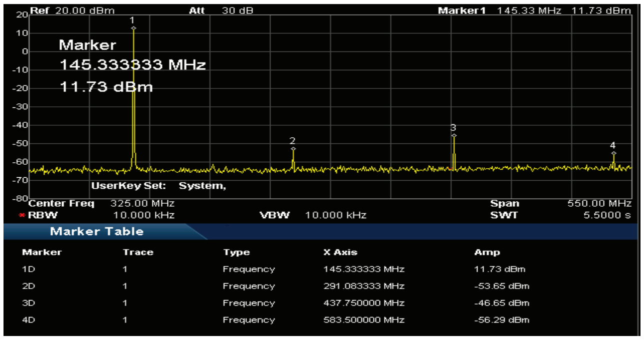

Figure 12. Harmonic levels of beacon transmission

Beacon Amplifier Spectrum- The output spectrum of the beacon amplifier was observed after applying a 0 dBm carrier at its input. Figure 13 shows the output observed on a spectrum analyzer. The harmonic levels are significant enough to require the use of a band pass filter.

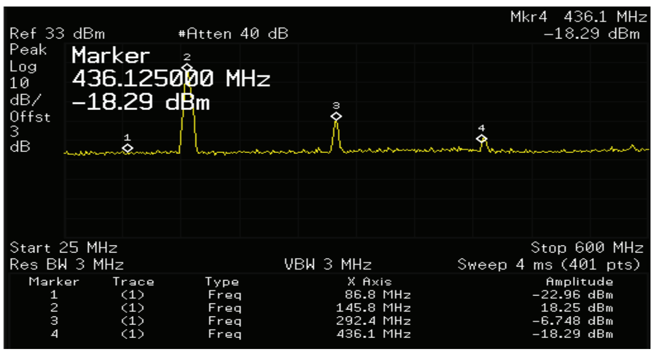

Figure 13. Output spectrum of beacon amplifier

Payload Transmitter- As stated in the datasheet, the harmonic levels of the transmitter were observed to be well within the acceptable limits.

Payload Amplifier- The harmonic levels increase when a high gain amplifier is cascaded at the output of the transmitter. Since the maximum input of the spectrum analyzer was 20dBm, the output from the amplifier was connected to the spectrum analyzer through a 30dB attenuator. The loss due to cables and connectors was 1dB. Figure 14 shows the output spectrum of the amplifier, which has a very high harmonic level content. Hence, a band pass filter is absolutely necessary.

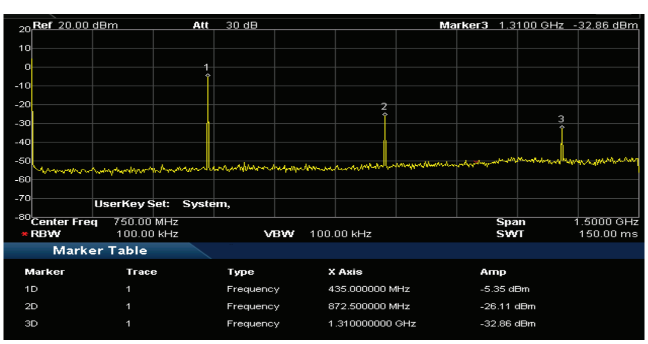

Figure 14. Output Spectrum of Payload Amplifier with input of -5dBm

7. Size and Weight

The system has been implemented on two separate four layered Printed Circuit Boards (PCBs), one for the VHF link, and another for the UHF link. The design layouts are taken as suggested in the datasheets of each IC. The VHF link board shown in figure 15 measures 6.52cms X 6.02cms and weighs around 27 grams.

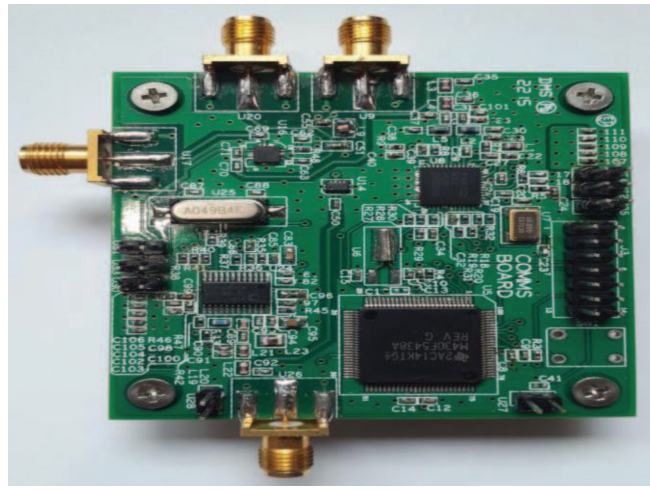
Figure 15. VHF Link Board

The UHF link board as shown in figure measures 7.93cmsX4.40cms and weighs around 23 grams.

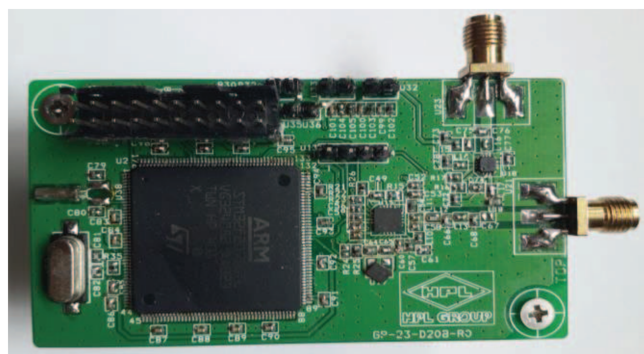
Figure 16. UHF Link Board

The lattice balun shown in figure 17 is a two layered PCB, which spans about 3.31cms X 3.92cms and weighs 8 grams.

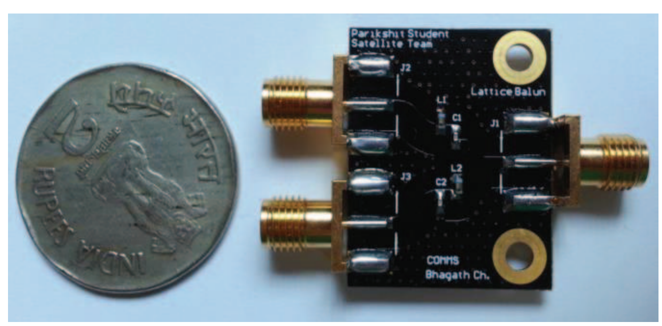

Figure 17. Lattice Balun PCB

Summary

This paper shows that successful communication can be made with any ground station with a G/T ratio more than -20.6 dB/K and -17.6 dB/K for VHF and UHF links respectively by using our architecture. It demonstrates that both the communication links can transmit simultaneously by relying purely on the power supplied by the solar panels. Effective scheduling of the various communication operations can further reduce the power consumed. It also displays how the system can cope with faults on board and shift the operation to the other link accordingly. With the onset of small satellite missions the need to provide a reliable, low power communication system is very crucial. The paper demonstrates a method for the same.

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Biography

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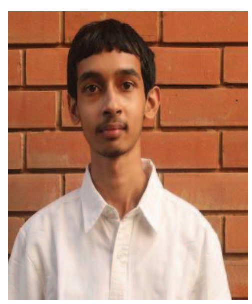

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