Microhard MHX2420 Orbital Performance Evaluation Using RT Logic T400CS

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ABSTRACT

A major upfront cost of building low cost Nanosatellites is the communications sub-system. Most radios built for space missions cost over $4,000 per unit. This exceeds many budgets. One possible cost effective solution is the Microhard MHX2420, a commercial off-the-shelf transceiver with a unit cost under $1000.

This paper aims to support the Nanosatellite community seeking an inexpensive radio by characterizing Microhard's performance envelope. Though not intended for space operations, the ability to test edge cases and increase average data transfer speeds through optimization positions this radio as a solution for Nanosatellite communications by expanding usage to include more missions.

The second objective of this paper is to test and verify the optimal radio settings for the most common cases to improve downlinking. All tests were conducted with the aid of the RT Logic T400CS, a hardware-in-the-loop channel simulator designed to emulate real-world radio frequency (RF) link effects.

This study provides recommended settings to optimize the downlink speed as well as the environmental parameters that cause the link to fail.

INTRODUCTION

The purpose of this study is to optimize the data throughput of the Microhard radio for a generic Low Earth Orbit (LEO) pass by measuring the impact of the Microhard radio settings with the use of the RT Logic path simulator.

The Microhard MHX2420 is becoming a common asset for Nanosatellite missions due to its very low cost, despite lower performance. O/OREO (Organism/Organic Exposure to Orbital Stress) is a NASA Ames Research Center Nanosatellite that uses this transceiver as a ground station. Though not designed for space flight operations, similar Microhard radios have successfully flown in space, founding the expectation that the MHX2420 can survive the space environment. This, along with performance improvements and a greater understanding of the edge cases, inspires confidence in the radio and its capabilities.

The RT Logic T400CS is a hardware-in-the-loop testing system that allows real time simulation of a mission powered by Satellite Took Kit (STK). The setup includes two Microhard radios (one representing the satellite and the other acting as a ground station) connected individually to the T400CS. The T400CS then simulates an orbital pass-over by inputting different path parameters.

The following are some of the conditions that the RT Logic is capable of simulating:

- Additive White Gaussian Noise
- Doppler
- Gain
- Receiver Noise
- Time Delay

The RT logic is a useful tool that can be used to optimize the satellite-to-ground station link for a variety of Microhard radio configuration settings, such as the hop frequency. The time delay and Doppler orbital parameters may have significant impacts on the link if the ground station and satellite do not align their hop frequency. Thus, it is important that all link conditions are taken into account to ensure the link is optimized for real-life environmental conditions as opposed to those in the lab.

SETUP

Hardware Setup

To simulate an orbital environment the RT Logic digitizes the raw analog signal, which is put through the internal signal processor. That signal is then converted back to analog and is outputted to one of the links. These links were separated through the use of circulators and attenuated with 50 dBm of attenuation to reduce the input power. An individual channel simulator in the RT Logic controlled each link. The hardware setup used during the experiment is shown below in Figure 1.

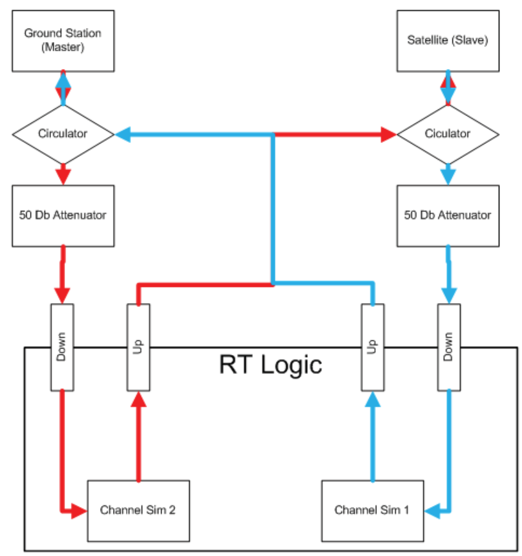

Figure 1: Hardware Setup

The ground station and satellite were individually connected to two computers not shown on the diagram.

Software Setup

Two laptops were used to facilitate file transfers between the Microhard radios and to monitor the data throughput rates. These file transfers are used to simulate the satellite sending a file to the ground station. Each laptop used Tera Term as the configuration terminal and Zmodem as the file transfer protocol. The file sent was a 640kB JPEG. The Baseline settings for the ground station and satellite Microhard radios are shown in Tables 1 and 2, respectively. The frequencies of both Microhard radios were restricted to fit inside the 40 MHz bandwidth of the RT Logic.

Table 1: Master (Ground Station) Baseline Settings

Setting	Value	Setting	Value
Operating Mode	S101=0	Serial Baud Rate	S102=1
Wireless Link Rate	S103=1	Network Address	S104=5400
Static Mask	S107=****	Output Power, dBm	S108=25
Hop Interval	S109=9	Data Format	S110=1
Packet Max Size	S112=255	Packet Retransmissions	S113=5
Repeat Interval	S115=3	Character Timeout	S116=10
Roaming	S118=1	Average RSSI, dBm	S123=-50
Network Type	S133=1	Destination Address	S140=2
Repeater Y/N	S141=0	Serial Channel Mode	S142=0
Sleep Mode	S143=0	Sleep time, sec	S144=60
Wake time, sec	S145=10	LEDs brightness, %	S149=100
Sync Mode	S150=0	Fast Sync timeout hops	S151=100
Address Tag	S153=0	Multimaster Mode	S154=0
FEC Mode	S158=0	Sniff Search Sleep	S169=60
Sniff Search Wake	S170=30	Protocol Type	S217=0
Sniff Timeout, hops	S237=10	Channel Access Mode	S244=0
Sync Timeout	S248=512	M hop alloc timeout	S251=10

Table 2. Slave (Satellite) Baseline Settings

Setting	Value	Setting	Value
Operating Mode	S101=2	Serial Baud Rate	S102=1
Wireless Link Rate	S103=1	Network Address	S104=5400
Static Mask	S107=****	Output Power, dBm	S108=25
Hop Interval	S109=9	Data Format	S110=1
Packet Max Size	S112=255	Packet Retransmissions	S113=5
Repeat Interval	S115=3	Character Timeout	S116=10
Roaming	S118=1	Average RSSI, dBm	S123=-50
Network Type	S133=1	Destination Address	S140=1
Serial Channel Mode	S142=0	Sleep Mode	S143=0
Sleep time, sec	S144=60	Wake time, sec	S145=10
LEDs brightness, %	S149=100	Sync Mode	S150=0
Fast Sync timeout hops	S151=100	Address Tag	S153=0
Multimaster Mode	S154=0	FEC Mode	S158=0
Sniff Search Sleep	S169=60	Sniff Search Wake	S170=30
Protocol Type	S217=0	Sniff Timeout, hops	S237=10
Channel Access Mode	S244=0	Sync Timeout	S248=512
M hop alloc timeout	S251=10		

TESTING METHODOLOGY

The objective of the tests was to both uncover any potential problems with using the Microhard radio in a space environment and to optimize the link. The testing was conducted in two phases:

1. Static Test Phase: The aim of these tests was to gain insight into the effects on the overall system by changing various settings on the Microhard radio and RT Logic. This understanding helped to characterize the edge cases and to determine the optimal settings for the Microhard radio.

2. Dynamic Test Phase: These tests allow the user to simulate an orbit by making assumptions about a real orbit.

RELAVENT CONFIGUARTION SETTINGS

To optimize the Microhard radio link, there are several register settings that can be changed. Changing these settings have tradeoffs and should be optimized for specific orbital conditions.

1. Serial Baud Rate: The serial baud rate defines the rate at which the radios communicate to an attached serial device.

2. Wireless Link Rate: The wireless link rate determines the rate of RF communications that occur between devices (i.e. Microhards) in a network. It should be noted that if the wireless link rate is greater than the serial baud rate, the overall data transfer rate is limited to that of

the serial baud rate. It should be further noted that although faster wireless link rates result in greater throughput, for each 'step' increase in the wireless link rate, there is an approximate 1dB reduction in signal sensitivity.

3. Hop Interval: The hop interval determines the rate at which radios in a network change frequency. Longhop intervals usually result in the greatest data throughput, whereas short hop intervals may decrease the latency of small packets.

4. Packet Max Size: The packet max size determines the maximum number of bytes that can be encapsulated in a packet. Large packet sizes may produce the highest data throughout, but are more likely to become corrupted. If a packet becomes corrupted, it must be retransmitted.

5. Forward Error Correction (FEC) Mode: FEC is a technique used to check for errors in packets at their destination. In doing this, the throughput increases for long-range or noisy communications by reducing the number of packet retransmissions. FEC, however, consumes bandwidth and can decrease the throughput for low noise situations.

Table 3: Master (Ground Station) Optimized Settings

Setting	Value	Setting	Value
Operating Mode	S101=0	Serial Baud Rate	S102=1
Wireless Link Rate	S103=1	Network Address	S104=5400
Static Mask	S107=****	Output Power, dBm	S108=25
Hop Interval	S109=19	Data Format	S110=1
Packet Max Size	S112=255	Packet Retransmissions	S113=5
Repeat Interval	S115=3	Character Timeout	S116=10
Roaming	S118=1	Average RSSI, dBm	S123=-50
Network Type	S133=1	Destination Address	S140=2
Repeater Y/N	S141=0	Serial Channel Mode	S142=0
Sleep Mode	S143=0	Sleep time, sec	S144=60
Wake time, sec	S145=10	LEDs brightness, %	S149=100
Sync Mode	S150=0	Fast Sync timeout hops	S151=100
Address Tag	S153=0	Multimaster Mode	S154=0
FEC Mode	S158=7	Sniff Search Sleep	S169=60
Sniff Search Wake	S170=30	Protocol Type	S217=0
Sniff Timeout, hops	S237=10	Channel Access Mode	S244=0
Sync Timeout	S248=512	hop alloc time	S251=10

Table 4. Slave (Satellite) Optimized Settings

Setting	Value	Setting	Value
Operating Mode	S101=2	Serial Baud Rate	S102=1
Wireless Link Rate	S103=1	Network Address	S104=5400
Static Mask	S107=****	Output Power, dBm	S108=25
Hop Interval	S109=19	Data Format	S110=1
Packet Max Size	S112=255	Packet Retransmissions	S113=5
Repeat Interval	S115=3	Character Timeout	S116=10
Roaming	S118=1	Average RSSI, dBm	S123=-50
Network Type	S133=1	Destination Address	S140=1
Serial Channel Mode	S142=0	Sleep Mode	S143=0
Sleep time, sec	S144=60	Wake time, sec	S145=10
LEDs brightness, %	S149=100	Sync Mode	S150=0
Fast Sync timeout hops	S151=100	Address Tag	S153=0
Multimaster Mode	S154=0	FEC Mode	S158=7
Sniff Search Sleep	S169=60	Sniff Search Wake	S170=30
Protocol Type	S217=0	Sniff Timeout, hops	S237=10
Channel Access Mode	S244=0	Sync Timeout	S248=512
M hop alloc timeout	S251=10		

To optimize the Microhard radio for space operations, the settings for the FEC and hop interval were changed. The hop interval was increased from a 20ms baseline to 150ms in the optimized settings. Increasing the hop rate increases the data transfer throughput because the Microhard radio changes frequencies less often and it makes the transfer of large packets more efficient. The Reed-Solomon FEC was found to produce the greatest overall throughput. This increases the size of individual packets but decreases the throughput for long-range or noisy communications by reducing the number of packet retransmissions. In optimizing these settings, the Microhard radio did better overall for all of the tests.

RESULTS

AWGN Static Test

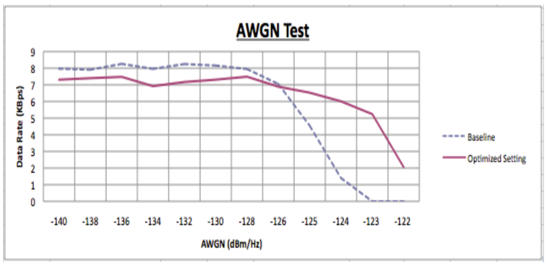

Figure 2: Effect of Varying AWGN on the Data Transfer Rate

The graph in Figure 2 describes the behavior of the Microhard radio when applying additive white Gaussian noise (AWGN). This noise is a form of black body radiation that is generated from warm bodies such as the Sun and Earth. The dotted line represents the baseline settings and shows that the quality of the link drops below 4 kBps at about -125 dBm/Hz of noise. This can be compared to the optimized settings, which are represented by the solid line on the graph. The throughput of the latter settings starts to decrease at about -123 dBm/Hz. For (LEO), the expected noise will be approximately -138dBm/Hz. This results in a margin of almost 16dB/Hz for the Microhard radio.

Time Delay Static Test

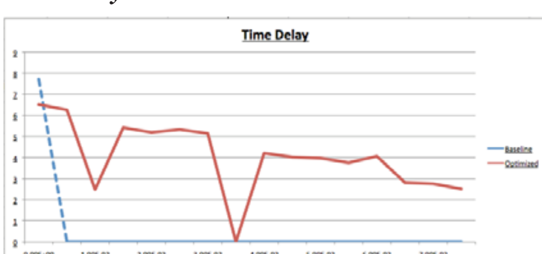

Figure 3: Effect of Varying Time Delay on the Data Transfer Rate

The time delay describes the amount of time a packet takes to travel from a source to its destination. This delay results from a multitude of factors, some of which include distance, transmission errors, and the processing capabilities of the sending and receiving systems.

Figure 3 shows the differences between the optimized and baseline settings for time delays within LEO, 200km (.667ms) to 2000km (6.67ms). While using the baseline settings, the data throughput began to decrease towards 0 bps at around 0.5ms. This can be compared to the optimized settings where the data throughput decreases at a slow constant rate, with the exception of two dips. These dips in throughput occur at 10ms and 35ms and were verified multiple times. More details regarding the anomaly can be found in the Discussion.

Doppler Effect Static Test

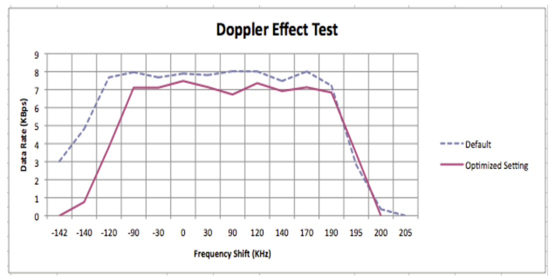

Figure 4: Effect of Varying Doppler Frequencies on the Data Transfer Rate

The Doppler Effect can be described as the change in frequency of a wave due to the movement of the source relative to the observer. In satellite communication, when a satellite approaches a ground station there is a positive Doppler shift, whereas after a satellite passes over the ground station there is a negative Doppler shift. This causes the change in frequency referred to as the Doppler Effect. The Doppler Effect equation for Electromagnetic waves is

$$\Delta f = f_0\sqrt{\left(\frac{v \pm v_r}{v \pm v_s}\right)} - f_0 \qquad (1)$$

where v is the velocity of waves, v_r is the velocity of the receiver, v_s is the velocity of the source, f_0 is the emitted frequency and Δf is the shift in frequency. This equation indicates that the maximum Doppler Effect for LEO using a 2.4 GHz transceiver will not exceed ±70 KHz. Figure 4 shows that the frequency shift from the Microhard radio is ±140 KHz yielding a ±70KHz as a frequency margin.

Gain Static Test

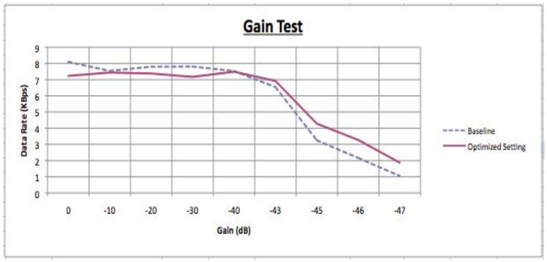

Figure 5: Effect of Varying Gains on the Data Transfer Rate

To test the effect of gain on the Microhard radio, the link connection was gradually attenuated at a fixed interval. The data throughput was then measured to see the effect. The results show that the data throughput remained at a constant 7 kBps until the gain reached -43 dB, at which point the data rate slowly started to decrease. It should be noted that initially, the baseline throughput was higher than the optimized throughput because of the FEC. However, as the gain increased, the optimized throughput decreased at a slower rate and at greater-attenuated values, yielding superior optimized throughput.

The gain can be calculated using the Free Space Loss (FSL) equation:

$$FSL = 32.45 + 20\log(d) + 20\log(f) + G_{Tx} + G_{Rx} \tag{2}$$

where d is the distance in km, f is the frequency in MHz, and G_{Tx} and G_{Rx} represent the transmitter and receiver antenna gains relative to an isotropic source in dBi, respectively. O/OREOS data was used to estimate receiver antenna gains (G_{Tx} + G_{Rx}) to be 155dB. The distance is estimated to be 500km for a LEO and the frequency of the Microhard radio is 2.415GHz. Using this value, the equation shows that for a Microhard radio operating in LEO, the FSL should be -14dB. The acquired FSL value is within the expected gain range of the Microhard radio.

Receiver Noise Static Test

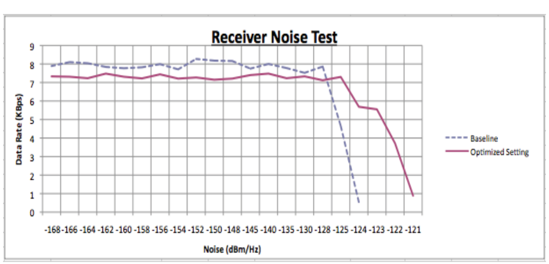

Figure 6: Effect of Varying Receiver Noise on the Data Transfer Rate.

Figure 6 shows the relationship between receiver noise and the data throughput rate. When noise is applied to the receiver's communication link using baseline settings, the data throughput begins to decrease around -125dB/Hz. This can be compared to the optimized settings where the data throughput begins to drop off at approximately 122dBm/Hz.

DISCUSSION

Microhard radios are popular for space-to-ground communication due to their ease of use, powerful capabilities, and relatively low price point. Using RT Logic to strengthen this communication link highlights important points of interest and recommendations for future use.

In addition to their built in capabilities, further optimization of the Microhard radios can improve their operational capabilities for the extreme environment of space.

1. Default Setting: The default settings come preconfigured on all new Microhard radios.
   - Baud Rate: 9600 bps
   - Wireless Link Rate: 172800 bps
   - Hop Interval: 20 ms
   - Packet Max Size: 255 bytes
   - Forward Error Correction: None
2. Baseline Settings: These settings were used as the baseline settings for all tests. The baud rate and wireless link rate are changed from the default settings.
   - Baud Rate: 115200 bps
   - Wireless Link Rate: 115200 bps
   - Hop Interval: 20 ms
   - Packet Max Size: 255 bytes
   - Forward Error Correction: None
3. Optimized Settings: The optimized settings increase the hop interval and apply Reed-Solomon as a method of Forward Error Correction.

- Baud Rate: 115200 bps
- Wireless Link Rate: 115200 bps
- Hop Interval: 150 ms
- Packet Max Size: 255 bytes
- Forward Error Correction: Reed-Solomon

To optimize the Microhard radio for use on a satellite, the baud rate, wireless link rate, hop interval, and FEC modes were characterized.

To increase the overall throughput of the radio, the first settings altered were the baud rate and wireless link rate. These determine the rate at which the Microhard radio transfers data to other radios as well as attached serial devices. By increasing the wireless link rate and baud rate of the transceiver to 115200 bps, the Microhard radio is able to achieve a high data throughput. Increasing the baud rate beyond 115200 bps was considered but not implemented because the higher baud rate decreased sensitivity, thus decreasing the overall quality of the transfer.

Next, the hop interval, which determines the rate at which modems in a network change frequency, was characterized. The hop rate should be adjusted in unison with the maximum packet size such that when the packet size is small, the hop rate is short and vice versa. The hop rate interval should also be adjusted to match the expected noise on the link so that if the expected noise is high, the hop rate is longer.

Finally, FEC is used to check packets for errors at their destination. In order to implement FEC, network bandwidth is used to transmit coding bits, decreasing the throughput. This can be seen in the graphs for low orbital noise parameters where the baseline setting's throughput is consistently greater than the throughput value for the optimized settings. However, as the orbital noise parameters increase, the optimized setting's throughput decreases, but at a slower rate than the baseline settings. Consequently, when the RT Logic applies high orbital noise parameters, the optimized settings will have a higher throughput.

An interesting anomaly in the time delay data occurred when the Microhard radios were configured with the optimized settings. For time delays approximately around 10ms and 35ms, the data throughput drops. Further tests showed that dips in throughput varied with the FEC Mode and hop interval settings. Although other variables impact the time delay results, the combination of the FEC and hop rate can result in communication errors between radios at the MAC layer. Such errors can arise from acknowledgement packets not received by the master radio. When synchronizing between frequency hops, the master disseminates synchronization request messages at predefined frequencies. The master then waits a specified amount of time for the slave to respond with an acknowledgement packet. If the master does not receive a response, it will 'hop' to the next frequency and poll there. Therefore, if the master does not receive an acknowledgement, the Microhard radios will not synchronize and data will not be sent. This effect causes long pauses in the data stream as observed during testing.

CONCLUSION

The Microhard MHX2420 can be an inexpensive, powerful tool for space-to-ground communications. Following a myriad of tests, the Microhard MHX2420 has been characterized and optimized for space operation, proving to be reliable when properly configured. Tests indicated that five main configuration settings impact the data throughput of the radios: baud rate, wireless link rate, max packet size, FEC, and hopping frequency. Changing each setting has tradeoffs and should be configured to meet the specifications of a specific mission. In optimizing these configurations, the Microhard MHX2420 stands out as one of the best options for low cost Nanosatellite missions.

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