**File No.** 0091-EX-CN-2016
**Appendix A**

## QUESTION 7: PURPOSE OF EXPERIMENT

### Narrative Summary

Space Exploration Technologies Corp. ("SpaceX") is a U.S. space technology company headquartered in California, with additional launch and test facilities in Florida and Texas.

The antenna installation will be used to perform radiofrequency ("RF") testing in support of SpaceX's Commercial Crew Transportation Contract and Commercial Resupply Services Contract with the National Aeronautics and Space Administration ("NASA"). The specific event covered is the CREW-VE-106 verification event as specified in CCT-REQ-1130: ISS Crew Transportation Services Requirements, Revision D, Revision F, SSP 50808: ISS to COTS Interface Requirements Document. In addition, the installation will also perform Falcon 9 launch vehicle acceptance testing to support the GPS III Evolved Expendable Launch Vehicle ("EELV") and NASA Launch Services ("LSP") contracts. Technical details in following section.

The purpose of our experiment is to perform hardware and software development testing for SpaceX ground station equipment used in support of Falcon and Dragon development, to meet specific milestones for the Commercial Crew Transportation Contract, the Commercial Resupply Services Contract and to perform required RF checkouts on the Falcon 9 vehicle in production. The Falcon 9 acceptance testing is in direct support of NASA LSP and EELV as well as indirect support of all Dragon contracts. The installation will be comprised of multiple elements: A ground station test rack located within the factory containing RF equipment under test, a parabolic tracking antenna located on the roof of the facility, a boresight antenna used for calibrating the tracking dish, Falcon 9 vehicles in production within the factory, Dragon vehicles in production within the factory, and a mobile test transmitter used within the factory.

The orbital uplinks and the re-radiation tests will comprise the greatest level of emitted radio frequency power; however, the antenna used to transmit is a directional tracking antenna. It will only transmit while its target is in view and sufficiently above the horizon (at least 5 degrees) to prevent unwanted interference to the ground. The open air hardware in the loop testing will radiate outdoors using a fixed directional antenna, but with a maximum power level of 0dBm and a placement near the center of the

building, path loss ensures that the signal will be attenuated substantially before it leaves the SpaceX property. The Falcon and Dragon vehicle acceptance testing will occur inside the factory and should not cause substantial emission to the outside, due to path loss and attenuation caused by the building structural material.

**Contract information:**

**Commercial Crew Transportation Contract:**
Government Contract #: NNK14MA74C
Government POC: Deb Cole
POC Phone: 321-867-0834

**Commercial Resupply Services Contract**
Government Contract #: NNJ09GA04B
Government POC: Yaranet Marquez
POC Phone: 281-244-8562

**GPS III (EELV) Contract**
Government Contract #: FA8811-16-C-0001
Government POC: June (Dzung) Dom
POC Phone: 310-653-3696

**NASA LSP Contract**
Government Contract #: NNK10LB02B
Government POC: Norman (Rob) Wolfinger
POC Phone: 321-867-8592

Please contact Max Comess for technical details:
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310-363-6565

Please contact Julie Jiru for contractual details:
Julie.jiru@spacex.com
+1 (310) 363-6848

**Modes of Operation:**

The system will be operated in multiple modes as illustrated below:

Re-Radiation:

The re-radiation tests will involve a Dragon 1 or Dragon 2 vehicle under development inside the factory. This Dragon will be connected via hardline to the antenna system on the roof. The tracking antenna will act as a re-radiation system and will transmit Dragon's return frequencies to TDRS and to the ISS C2V2 radio. In addition, it will transmit C2V2 and/or ground downlink frequencies at the same time to test the ability of all vehicles to withstand interference and maintain lock. These frequencies will be transmitted at up to 70dBm as required to maintain the link to vehicles on orbit. Table 1 contains a complete list. Schematics of the Dragon 1 re-radiation setup are shown in Figure 1 and schematics of the Dragon 2 re-radiation setup are shown in Figure 2.

*Table 1: Frequencies for Re-Radiation from the Orbital Systems 2.4AEBP3.0 Tracking antenna.*

| Center Freq [MHz] | Modulation | Emission Designator | Output Power | ERP | Lower Freq | Upper Freq |
|---|---|---|---|---|---|---|
| 2287.5000 | SS-SOQPSK | 4M80G1D | 20W | 6095W | 2285.10000 | 2289.90000 |
| 2040.5675 | BPSK ½ Rate | 5K60G1D | 20W | 6095W | 2040.56470 | 2040.57030 |
| 2216.0000 | PCM/FM | 2M46F1D | 20W | 6095W | 2214.77000 | 2217.23000 |
| 2216.0000 | PCM/FM | 567KF1D | 20W | 6095W | 2215.71650 | 2216.28350 |
| 2287.5000 | SS-SOQPSK | 4M80G1D | 20W | 6095W | 2285.10000 | 2289.90000 |
| 2106.4000 | SS-BPSK | 4M31G1D | 20W | 6095W | 2104.24500 | 2108.55500 |
| 2203.2000 | SQPN/SQPSK | 4M15G1D | 20W | 6095W | 2201.12500 | 2205.27500 |
| 2028.7500 | SS-BPSK | 4M15G1D | 20W | 6095W | 2026.67500 | 2030.82500 |
| 2216.0000 | PCM/FM | 3M81F1D | 20W | 6095W | 2214.09500 | 2217.90500 |

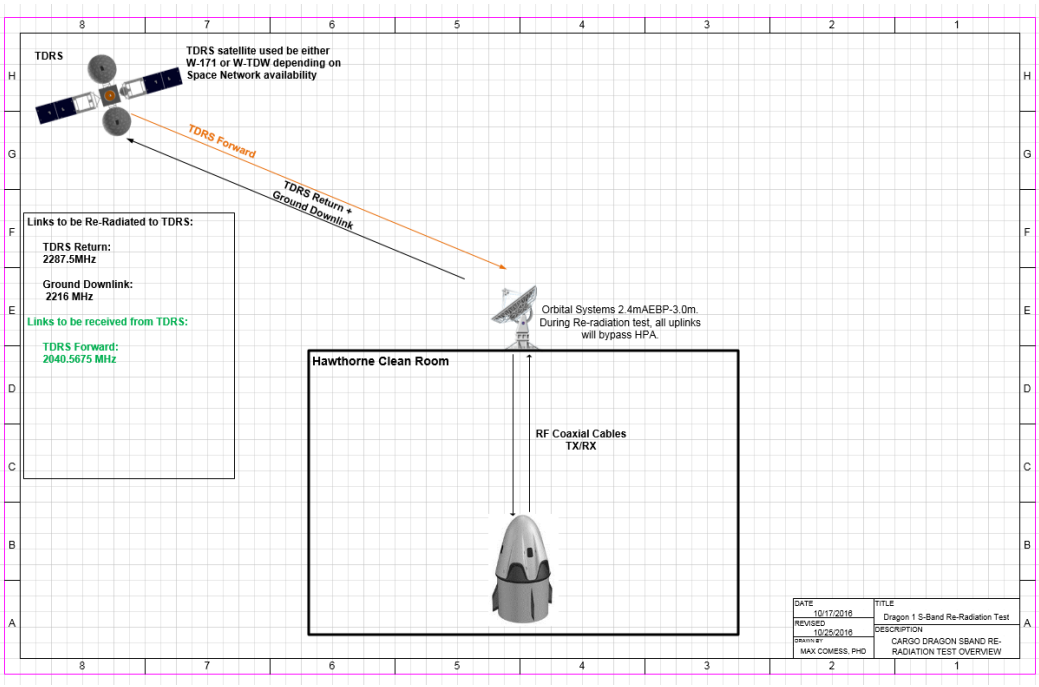


*Figure 1: Dragon 1 Re-Radiation Test*

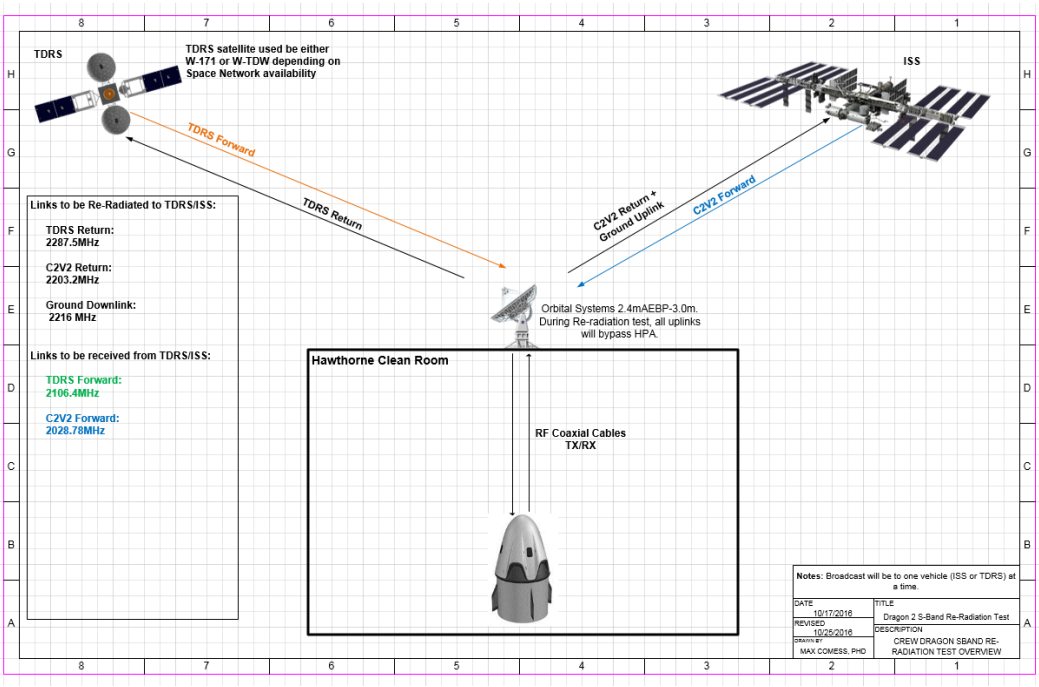


*Figure 2: Dragon 2 Re-radiation Test*

Command uplink:

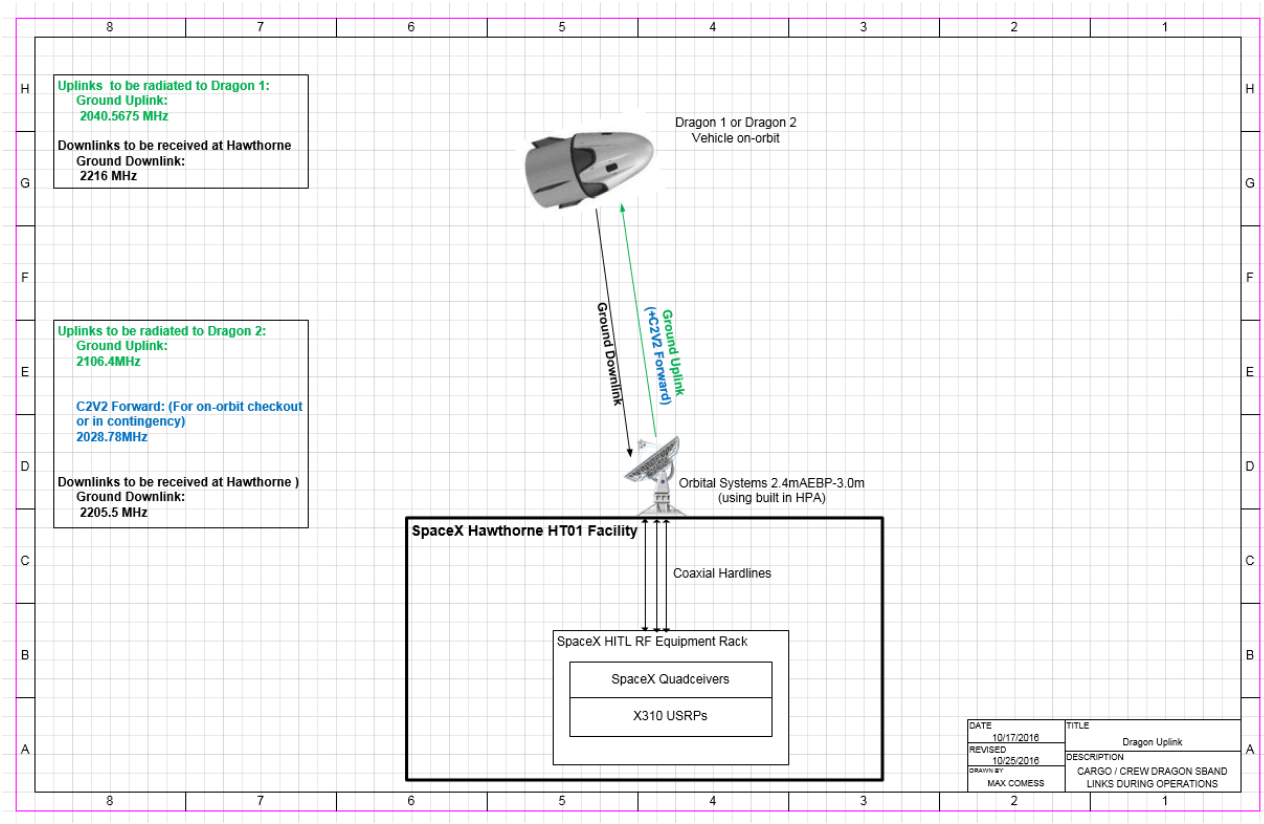


*Figure 3: Command Uplink*

While operating as a normal SpaceX ground station, the Orbital Systems tracking antenna will transmit the standard Dragon uplink frequencies of 2040.5675MHz or 2106.4000MHz at up to 70dBm to a Dragon 1 or Dragon 2 vehicle on orbit as displayed in Figure 3. In addition, the ground station will have the capability to transmit the C2V2 Forward frequency to perform on-orbit checkouts.

Hardware-In-The-Loop Test:

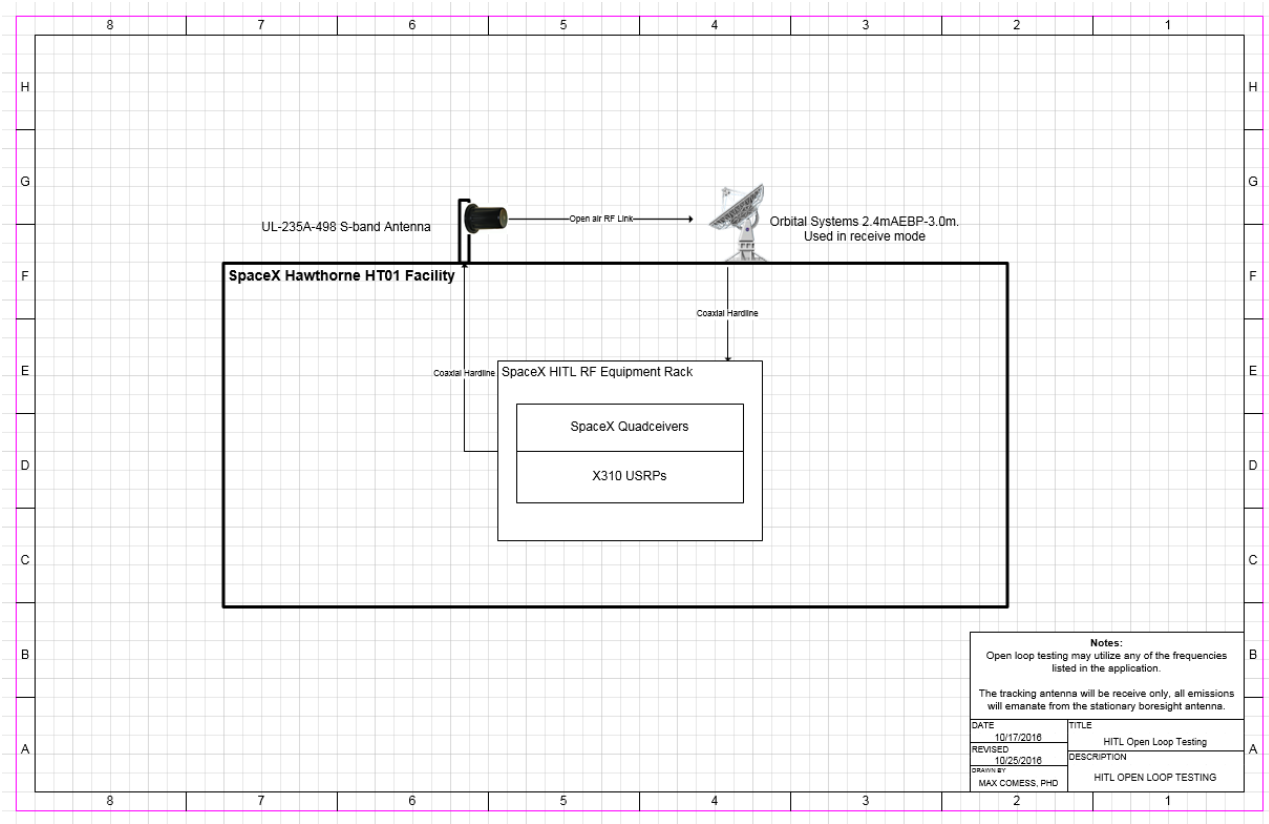


*Figure 4: Open loop RF testing*

During Hardware-In-The-Loop (HITL) development testing the Orbital System transmitter will not be used to transmit to orbit. Instead, the primary focus is on development of receivers and other ground station hardware elements and on development of software to control the position of the tracking antenna. A small boresight antenna (UL-235A-498) will be used for open loop testing. It will receive power inputs of no greater than 0dBm at the boresight antenna's input terminal, and will be operated across all frequencies requested in form 442. A schematic is shown in Figure 4.

Falcon acceptance testing:

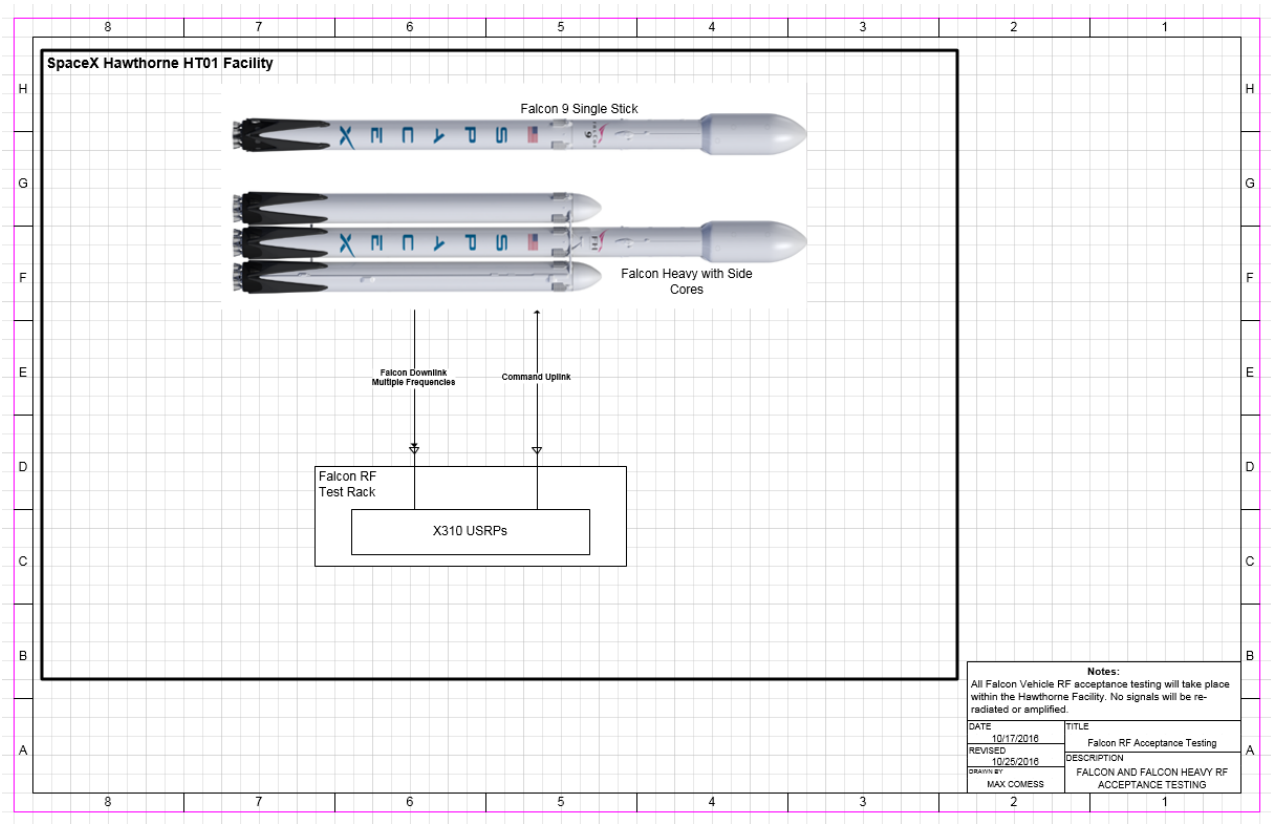


*Figure 5: Falcon Vehicle Acceptance Testing*

Falcon acceptance testing will take place on the factory floor. It does not involve the tracking or boresight antennas. The Falcon vehicle transmitters will radiate up to 20W inside the factory during testing and will transmit on the frequencies in table 2 and as shown in Figure 5. In addition, a command transmitter will be used to test the command receive systems on the booster stages of the Falcon vehicle, also listed in table 2.

*Table 2: Vehicle acceptance testing inside the factory*

| Center Freq [MHz] | Modulation | Emission Designator | Output Power | ERP | Lower Freq [MHz] | Upper Freq [MHz] |
|---|---|---|---|---|---|---|
| 2090.0000 | BPSK | 800KG1D | 1mW | 2mW | 2089.60000 | 2090.40000 |
| 2221.5000 | RNRZ-L-15 PCM/FM | 3M27F1D | 20W | 40W | 2219.86500 | 2223.13500 |
| 2273.5000 | RNRZ-L-15 PCM/FM | 3M27F1D | 20W | 40W | 2271.86500 | 2275.13500 |
| 2213.5000 | RNRZ-L-15 PCM/FM | 3M27F1D | 20W | 40W | 2211.86500 | 2215.13500 |
| 2251.5000 | RNRZ-L-15 PCM/FM | 3M27F1D | 20W | 40W | 2249.86500 | 2253.13500 |
| 2211.0000 | RNRZ-L-15 PCM/FM | 3M22F1D | 20W | 40W | 2209.39000 | 2212.61000 |
| 2255.5000 | RNRZ-L-15 PCM/FM | 3M22F1D | 20W | 40W | 2253.89000 | 2257.11000 |
| 2232.5000 | RNRZ-L-15 PCM/FM | 3M22F1D | 20W | 40W | 2230.89000 | 2234.11000 |
| 2272.5000 | RNRZ-L-15 PCM/FM | 3M22F1D | 20W | 40W | 2270.89000 | 2274.11000 |
| 2211.0000 | RNRZ-L-15 PCM/FM | 4M14F1D | 20W | 40W | 2208.93000 | 2213.07000 |
| 2255.5000 | RNRZ-L-15 PCM/FM | 4M14F1D | 20W | 40W | 2253.43000 | 2257.57000 |
| 2232.5000 | RNRZ-L-15 PCM/FM | 2M90F1D | 20W | 40W | 2231.05000 | 2233.95000 |
| 2272.5000 | RNRZ-L-15 PCM/FM | 2M90F1D | 20W | 40W | 2271.05000 | 2273.95000 |
| 2370.5000 | SOQPSK-TG | 4M88G1D | 20W | 40W | 2368.06250 | 2372.93750 |
| 2382.5000 | SOQPSK-TG | 4M88G1D | 20W | 40W | 2380.06250 | 2384.93750 |

**Hardware Used:**

Orbital Systems 3m tracking antenna:

*Figure 6: Orbital Systems 2.4AEBP-3m Tracking Antenna*

The primary component of our system will be an Orbital Systems 2.4AEBP-3m Elevation Over Azimuth Antenna positioner with a 3m parabolic reflector. The entire system will be capable of receiving and transmitting in the S-band between 2,000 MHz and 2,400 MHz. The antenna positioner contains an integrated high power amplifier (HPA) which can an input signal up to 20W and when combined with the mechanical gain of the dish will yield an EIRP of +70dBm. This HPA operates from 2000 to 2120 MHz and will be used only for conventional uplink. For the re-radiation tests the uplink signal will bypass the built in HPA.

Boresight Test Antenna:

*Figure 7: UL-235A-498 11dB high gain antenna*

A small test antenna independent of the tracking dish will be used for calibration of the tracking antenna and for open loop RF testing. The antenna used will be a UL-235A-498, made by antennas.us. This antenna will be mounted on the roof of our Hawthorne facility near the tracking antenna.

Ettus X310 USRP

One of the transceivers used on the ground station will be an Ettus Research X310 USRP. The X310 features 2 transceivers and 2 pure receivers, with a maximum power level before compression of 0dBm.

*Figure 8:Ettus X310 USRP*

SpaceX Quadceivers:

The other ground station transceiver is a custom build SpaceX Quadceiver (P/N 00111303). The Quadceiver features 4 receive inputs and one transmitter output, with a maximum power level before compression of 0dBm.

Falcon Vehicle:

SpaceX will perform RF checkouts with the Falcon vehicle inside the factory. The antenna used is a proprietary SpaceX built antenna used on the Falcon, P/N 00716147. The transmitter used on board the vehicle is a Quasonix, P/N QSX-VSR-110-20S. The Quasonix transmitter is capable of generating a maximum power of 20W.

Dragon 1 Vehicle:

Dragon 1 generates a bit stream within the Dragon 1 Flight Computer (PN 0056725). This bit stream is sent to the Dragon Transmitters (Quasonix P/N QSX-VSR-110-20S?). The transmitters are used to generate all of Dragon's S-band emissions and operate at a power of up to 20W. During normal in flight operations it would then be broadcast by Dragon's antennas, but during re-radiation testing the signal will be transmitted via co-axial cable to the transmitting antenna.

Dragon 2 Vehicle:

Dragon 2 generates baseband RF within the Dragon 2 Flight Computer (PN 00439215), by the Comm Card modules. It is then amplified by the Dragon 2 antenna driver (PN 00344352), which functions as a power amplifier, to a power of ~20W. During normal in flight operations it would then be broadcast by Dragon's antennas, but during re-radiation testing the signal will be transmitted via co-axial cable to the transmitting antenna.