

## EMC Analysis for Challenger

### Introduction and Summary of Results

The overall goal of the Challenger mission is to develop a space based method to distribute secure system keys (SSH keys) for Internet of Things devices.

In connection with Experimental License Application number 0130-EX-CN-2021, the FCC has requested an EMC Analysis for the uplink, 401.3 MHz with 2.4 kHz bandwidth.

This report provides a domestic and international electromagnetic compatibility study with existing users, as required by the FCC. The FCC OET and FCC International Bureau databases were searched, as was the ITU SNS database for space and ground operations. Appendix shows the search results and evaluation of each operation found, with respect to level of coordination required.

This report concludes that no interference is expected, with any of the operators identified.

### Power Flux Density at Earth Surface, In Band and Out of Band

The Dorji Model DRA818U transceiver is used on the Satellite. Out of the antenna, it will deliver a maximum EIRP of 7.7 dBW = 5.89 Watts EIRP.

The power roll off of the transmitter is:

Attenuation dB	Frequency Offset kHz
0	0
-3	1.4
-20	2.2
-40	6
-60	12

### Power Spectral Density Analysis

#### Downlink:

Considering the total EIRP of the transmitting signal, 7.7 dBW, to be approximately uniformly distributed over the operating bandwidth of 2.4 kHz, this results in an in band power spectral density (PSD) of -26.1 dBW/Hz.

From the power roll off data, the out-of-band PSD at frequencies located beyond 12 kHz away from the carrier frequency is attenuated by 60 dB or more relative to the in-band frequencies resulting in an out-of-band PSD of  $-26.1 - 60 = -86.1$  dBW/Hz, or less for these frequencies.

**Potential for GEO interference:**

The out-of-band frequencies of the transmitted signal will be further attenuated by propagation pathloss from the Challenger orbiting in low Earth orbit at 550 km, to the GOES satellite orbiting in geosynchronous orbit at 35,768 km. The minimum value of the corresponding pathloss for 401 MHz band with a wavelength of 0.748 m is 175.48 dB, and corresponds to the minimum distance of 35,479 km between the Challenger and a GOES satellite. Thus, the out-of-band PSD at a potential satellite receiver operating in a bandwidth that is 12 kHz away or more from the operating bandwidth of the Challenger radio is  $-86.1 - 175.48 = -261.58$  dBW/Hz, equivalent to  $-241.58$  dBW per 100 Hz.

**Uplink:**

The Dorji Model DRA818U transceiver is used on the ground station. With directional antennas and power amplifier, it will deliver a transmit power of 25.8 dBW = 380 Watts EIRP from the ground station, located in Akron, PA.

Considering that the in-band power of the transmitting signal is approximately uniformly distributed over the operating bandwidth of 2.4 kHz, this results in an in band power spectral density of  $380W / 2.4 \text{ kHz} = 0.158 \text{ W/Hz}$  or  $-8.01 \text{ dBW/Hz}$ . However, if the ITU convention is applied for Spacecap calculations, the PSD would be calculated over a minimum of 4 kHz,  $380W / 4 \text{ kHz} = 0.095 \text{ W/Hz}$  or  $-10.2 \text{ dBW/Hz}$ . Here we will use the more conservative value of  $-8.01 \text{ dBW/Hz}$ .

The out-of-band power of the transmitting signal is mostly in the adjacent 1 kHz to the left and to the right of the operating band. The out-of-band PSD at frequencies beyond 12 kHz away from the carrier frequency is attenuated by 60 dB relative to the in-band frequencies resulting in an out-of-band PSD of  $-8.01 - 60 = -68.01 \text{ dBW/Hz}$ , or greater, for frequencies beyond 12 kHz from the carrier. This applies in other words to all emissions outside the range 401.288 to 401.312 MHz.

The out-of-band frequencies of the transmitted signal will be further attenuated by propagation pathloss from the ground station to the GOES (or any out of band receiving) satellite orbiting in geosynchronous orbit at 35,768 km, which for the 401 MHz band (0.748 m wavelength) is equal to 175.58 dB. Thus, the out-of-band PSD at a potential satellite receiver operating in a bandwidth that is 12 kHz away or more from the operating bandwidth of the Challenger radio, is  $-68.01 - 175.58 = -243 \text{ dBW/Hz}$ , which is also equivalent to  $-223 \text{ dBW}$  per 100 Hz.

The interference analysis calculations are summarized in the following table:

Item Label	Item	Downlink	Uplink
A	Peak transmit power [dBW], EIRP from Antenna	7.7	25.8
B	In-band radiated Power Spectral Density (PSD) [dBW/Hz]	-26.1	- 8.01
C	Transmitting spectrum roll off at frequencies >12 kHz away from center frequency [dB]	60.00	60.00
D	Path loss to Geo Orbit receiver [dB]	175.48	175.58

Item Label	Item	Downlink	Uplink
E	Out-of-band PSD at Geo Orbit receiver, B-C-D [dBW/Hz]	-261.58	-243
F	Out-of-band PSD at Geo Orbit receiver E+20 [dBW per 100 Hz]	-241.58	-223
G	In band PSD at Geo Orbit receiver, B-D [dBW/Hz]	-181.58	-163

Based on values E and F, above, out of band interference with geo orbit satellite receivers will not occur, either for the uplink beam, or the downlink beam.

## Domestic Operator Search

From the FCC OET and FCC International Bureau databases, lists of satellite systems using the 401 to 401.6 MHz band was collected and shown in Tables 1 and 2 below. None of these operations are expected to have interference for reasons cited in the Comments associated with each.

## Site / Frequency / Market Search Results

**Search Criteria:** Frequency Range = 401 MHz through 401.6 MHz, Box Search: Start Coordinates = 24° 33' 18" N 81° 46' 43" W End coordinates=47° 36' 28" N 122° 20' 6" W, Currently Licensed and Pending Facilities, May 10 2021

OET Experimental Licensing System Database							
<b>Callsign:</b> <a href="#">WI2XSC</a>	<b>File Number:</b> <a href="#">0008-EX-CR-2021</a>	<b>Licensee:</b> Blue Origin	<b>FRN:</b> 00249 40371	<b>Issue Date:</b> 04/01/2021	<b>Expiration:</b> 04/01/2023	<b>Radio Service:</b> XT	<b>Status:</b> Granted
<b>Site Address:</b>		<b>State:</b> TX	<b>County:</b> CULBERSON	<b>Mobile Coordinates:</b> 31° 27' 6" N, 104° 45' 46" W			
<b>Frequency:</b> 401.20000000 M Comment: Ground receiver, outside frequency, and outside footprint.							
<b>Callsign:</b> <a href="#">WJ2XIG</a>	<b>File Number:</b> <a href="#">0094-EX-CM-2019</a>	<b>Licensee:</b> Colorado Space Grant Consortium	<b>FRN:</b> 00151 45931	<b>Issue Date:</b> 09/17/2019	<b>Expiration:</b> 04/01/2021	<b>Radio Service:</b> XR	<b>Status:</b> Granted
<b>Site Address:</b> UC Boulder Discovery Learning Center		<b>State:</b> CO	<b>County:</b> BOULDER	<b>Fixed Coordinates:</b> 40° 0' 28" N 105° 15' 42" W		<b>Mobile Coordinates:</b> 40° 0' 28" N, 105° 15' 42" W	
<b>Frequency:</b> 401.36500000 M Comment: Outside frequency, and outside footprint.							

<b>Callsign:</b> <a href="#">WI 2XQM</a>	<b>File Number:</b> <a href="#">0652-EX-CR-2020</a>	<b>Licensee:</b> Insitu	<b>FRN:</b> 00068 43577	<b>Issue Date:</b> 02/01/2021	<b>Expiration:</b> 02/01/2023	<b>Radio Service:</b> X D	<b>Status:</b> Granted
<b>Site Address:</b>	<b>State:</b> WA	<b>Fixed Coordinates:</b> 45° 42' 24" N 121° 27' 30" W		<b>Mobile Coordinates:</b> 45° 42' 24" N, 121° 27' 30" W			
<b>Frequency:</b> 401.50000000 M Comment: Outside frequency, and outside footprint.							
<b>Site Address:</b> Boardman Bombing Range	<b>State:</b> OR	<b>Fixed Coordinates:</b> 45° 44' 54" N 119° 47' 38" W		<b>Mobile Coordinates:</b> 45° 44' 54" N, 119° 47' 38" W			
<b>Frequency:</b> 401.50000000 M Comment: Outside frequency, and outside footprint.							
<b>Callsign:</b> <a href="#">W K2XLV</a>	<b>File Number:</b> <a href="#">0677-EX-CN-2019</a>	<b>Licensee:</b> Insitu	<b>FRN:</b> 00068 43577	<b>Issue Date:</b> 10/15/2019	<b>Expiration:</b> 10/01/2021	<b>Radio Service:</b> X D	<b>Status:</b> Granted
<b>Site Address:</b> Fixed operations within 1 kilometer radius	<b>State:</b> OR	<b>Fixed Coordinates:</b> 45° 44' 54" N 119° 47' 38" W		<b>Mobile Coordinates:</b> 45° 44' 54" N, 119° 47' 38" W			
<b>Frequency:</b> 401.00000000 - 406.00000000 M Comment: Outside Footprint							
<b>Site Address:</b>	<b>State:</b> WA	<b>Fixed Coordinates:</b> 45° 42' 24" N 121° 27' 30" W					
<b>Frequency:</b> 401.00000000 - 406.00000000 M Comment: Outside footprint.							
<b>Site Address:</b> Boardman Bombing Range	<b>State:</b> OR	<b>Mobile Coordinates:</b> 45° 44' 54" N, 119° 47' 38" W					
<b>Frequency:</b> 401.00000000 - 406.00000000 M Comment: Outside footprint.							
<b>Callsign:</b> <a href="#">WI 2XWO</a>	<b>File Number:</b> <a href="#">0165-EX-CR-2021</a>	<b>Licensee:</b> The Boeing Company	<b>FRN:</b> 00015 83483	<b>Issue Date:</b> 06/01/2021	<b>Expiration:</b> 06/01/2023	<b>Radio Service:</b> X T	<b>Status:</b> Granted
<b>Site Address:</b> White Sands Missile Range Space Harbor	<b>State:</b> NM	<b>Mobile Coordinates:</b> 32° 57' 0" N, 106° 27' 0" W					
<b>Frequency:</b> 401.40000000 - 406.00000000 M Comment: Outside frequency, and outside footprint.							
<b>Site Address:</b> White Sands Missile Range	<b>State:</b> NM	<b>Mobile Coordinates:</b> 33° 38' 24" N, 106° 36' 35" W					
<b>Frequency:</b> 401.40000000 - 406.00000000 M Comment: Outside frequency, and outside footprint.							
<b>Site Address:</b> Dugway Proving Grounds	<b>State:</b> UT	<b>Mobile Coordinates:</b> 40° 10' 12" N, 113° 28' 11" W					
<b>Frequency:</b> 401.40000000 - 406.00000000 M Comment: Outside frequency, and outside footprint.							
<b>Site Address:</b> Edwards Air Force Base	<b>State:</b> CA	<b>Mobile Coordinates:</b> 34° 57' 0" N, 117° 49' 58" W					
<b>Frequency:</b> 401.40000000 - 406.00000000 M Comment: Outside frequency, and outside footprint.							

<b>Site Address:</b> Wilcox Playa		<b>State:</b> AZ	<b>Mobile Coordinates:</b> 32° 8' 24" N, 109° 50' 59" W				
<b>Frequency:</b> 401.40000000 - 406.00000000 M Comment: Outside frequency, and outside footprint.							
<b>Callsign:</b> <a href="#">W J2XZK</a>	<b>File Number:</b> <a href="#">0881-EX-CN-2018</a>	<b>Licensee:</b> Tyvak Nano-Satellite System	<b>FRN:</b> 00234 08065	<b>Issue Date:</b> 08/12/2019	<b>Expiration:</b> 08/01/2021	<b>Radio Service:</b> XT	<b>Status:</b> Granted
<b>Site Address:</b>	<b>State:</b> CA	<b>County:</b> SAN DIEGO	<b>Fixed Coordinates:</b> 32° 53' 49" N 117° 12' 36" W		<b>Mobile Coordinates:</b> 32° 53' 49" N, 117° 12' 3" W		
<b>Frequency:</b> 401.12000000 M Comment: Outside frequency, and outside footprint.							
<b>Callsign:</b> <a href="#">W J2XZG</a>	<b>File Number:</b> <a href="#">0880-EX-CN-2018</a>	<b>Licensee:</b> Tyvak Nano-Satellite Systems	<b>FRN:</b> 00234 08065	<b>Issue Date:</b> 08/12/2019	<b>Expiration:</b> 08/01/2021	<b>Radio Service:</b> XT	<b>Status:</b> Granted
<b>Site Address:</b>	<b>State:</b> CA	<b>County:</b> SAN DIEGO	<b>Fixed Coordinates:</b> 32° 53' 49" N 117° 12' 3" W		<b>Mobile Coordinates:</b> 32° 53' 49" N, 117° 12' 3" W		
<b>Frequency:</b> 401.16000000 M Comment: Outside frequency, and outside footprint.							
<b>Callsign:</b> <a href="#">W K2XAJ</a>	<b>File Number:</b> <a href="#">0987-EX-CN-2018</a>	<b>Licensee:</b> Tyvak Nano-Satellite Systems	<b>FRN:</b> 00234 08065	<b>Issue Date:</b> 04/27/2020	<b>Expiration:</b> 05/01/2022	<b>Radio Service:</b> XT	<b>Status:</b> Granted
<b>Site Address:</b>	<b>State:</b> CA	<b>County:</b> SAN DIEGO	<b>Fixed Coordinates:</b> 32° 53' 49" N 117° 12' 3" W		<b>Mobile Coordinates:</b> 32° 53' 49" N, 117° 12' 3" W		
<b>Frequency:</b> 401.20500000 M Comment: Outside frequency, and outside footprint.							

**OET Experimental Licensing System Files: 8**

International Bureau Filing System Database						
<b>Callsign:</b> <a href="#">E 181423</a>	<b>File Number:</b> <a href="#">SESLIC2018081602287</a>	<b>Applicant:</b> Haras Development	<b>FRN:</b> 0027 738202	<b>Grant Date:</b> 09/11/2019	<b>Expiration:</b> 09/11/2034	<b>Status:</b> ATP N Sub-System: SES
<b>Site:</b> 1	<b>Description:</b> Ohio	<b>City:</b> Dublin	<b>State:</b> OH	<b>County:</b> FRANKLIN	<b>Coordinates:</b> 40° 6' 15.4" N, 83° 11' 58.4" W	
<b>Frequency:</b> 00000401.00000000-00000402.00000000 Comment: Outside frequency						
<b>Callsign:</b> <a href="#">E1 81423</a>	<b>File Number:</b> <a href="#">SESMOD2019102101351</a>	<b>Applicant:</b> Haras Development	<b>FRN:</b> 002773 8202	<b>Expiration:</b> 09/11/2034	<b>Status:</b> AFPN Sub-System: SES	

<b>Site:</b> 1	<b>Description:</b> Ohio	<b>City:</b> Dublin	<b>State:</b> OH	<b>County:</b> FRANKLIN	<b>Coordinates:</b> 40° 6' 2.68" N, 83° 11' 51.22" W	
<b>Frequency:</b> 00000401.30000000 00000401.00000000-00000402.00000000 <b>Comment:</b> USASAT-30A. Directional antenna, not in beam.						
<b>Callsign:</b> <a href="#">E1 81611</a>	<b>File Number:</b> <a href="#">SESMOD20191 12101544</a>	<b>Applicant:</b> Maris Developments	<b>FRN:</b> 002773 7741	<b>Expiration:</b> 09/11/2034	<b>Status:</b> AFPN <b>Sub-System:</b> SES	
<b>Site:</b> 2	<b>Description:</b> Oregon	<b>City:</b> Boardman	<b>State:</b> OR	<b>County:</b> MORROW	<b>Coordinates:</b> 45° 51' 16.96" N, 119° 37' 53.08" W	
<b>Frequency:</b> 00000401.30000000 00000401.37500000 00000401.50000000 <b>Comment:</b> Out of Footprint.						
<b>Callsign:</b> <a href="#">E 940536</a>	<b>File Number:</b> <a href="#">SESRWL20 20041700418</a>	<b>Applicant:</b> O RBCOMM License Corp.	<b>FRN:</b> 0004 379202	<b>Grant Date:</b> 04/20/2020	<b>Expiration:</b> 05/17/2035	<b>Status:</b> AT <b>PN Sub-System:</b> S ES
<b>Site:</b> 1	<b>Description:</b> CONUS	<b>City:</b> OCILLA	<b>State:</b> GA	<b>County:</b> IRWIN	<b>Coordinates:</b> 31° 30' 3" N, 83° 11' 58" W	
<b>Frequency:</b> 00000137.00000000-00000401.00000000 <b>Comment:</b> Outside frequency						
<b>Callsign:</b> <a href="#">E 940537</a>	<b>File Number:</b> <a href="#">SESRWL20 20041700419</a>	<b>Applicant:</b> O RBCOMM License Corp.	<b>FRN:</b> 0004 379202	<b>Grant Date:</b> 04/20/2020	<b>Expiration:</b> 05/17/2035	<b>Status:</b> AT <b>PN Sub-System:</b> S ES
<b>Site:</b> 1	<b>Description:</b> CONUS	<b>City:</b> ST. JOHNS	<b>State:</b> AZ	<b>County:</b> APACHE	<b>Coordinates:</b> 34° 27' 21" N, 109° 33' 17" W	
<b>Frequency:</b> 00000137.00000000-00000401.00000000: <b>Comment:</b> Outside Frequency						
<b>Callsign:</b> <a href="#">E 940538</a>	<b>File Number:</b> <a href="#">SESRWL20 20041700420</a>	<b>Applicant:</b> O RBCOMM License Corp.	<b>FRN:</b> 0004 379202	<b>Grant Date:</b> 04/20/2020	<b>Expiration:</b> 05/17/2035	<b>Status:</b> AT <b>PN Sub-System:</b> S ES
<b>Site:</b> 1	<b>Description:</b> CONUS	<b>City:</b> EAST WENATCHEE	<b>State:</b> WA	<b>County:</b> DOUGLAS	<b>Coordinates:</b> 47° 33' 4" N, 120° 10' 30" W	
<b>Frequency:</b> 00000137.00000000-00000401.00000000 <b>Comment:</b> Outside footprint, outside frequency.						
<b>Callsign:</b> <a href="#">E 140109</a>	<b>File Number:</b> <a href="#">SESMOD20 17100201096</a>	<b>Applicant:</b> Planet Labs Inc.	<b>FRN:</b> 0021 516331	<b>Grant Date:</b> 12/05/2017	<b>Expiration:</b> 12/15/2029	<b>Status:</b> ATP <b>N Sub-System:</b> SE S
<b>Site:</b> LAS CRUCES-1	<b>Description:</b> Las Cruces, New Mexico	<b>City:</b> Las Cruces	<b>State:</b> NM	<b>Coordinates:</b> 32° 16' 48" N, 106° 45' 0" W		
<b>Frequency:</b> 00000401.27000000-00000401.33000000 <b>Comment:</b> Outside Footprint						

**International Bureau Filing System Files: 7**

**Table 3: List of Satellite Systems from ITU SNS Online Ground and Space, 401.25 to 401.35 MHz with USA, CAN or MEX ADM/ORG.**

ADM	ITU ID	Satellite Name	BR IFC ID	Center Freq. (Mhz)	Bandwidth (Khz)	Status	Comment
CAN	113540650	GHGSAT-D	2773	402	2000	Active	GHG: Correspondence indicates no concerns.
CAN	118545050	KELYPISIS	2871	401.5	1000	Active	Kepler: Correspondence indicates no concerns.
CAN	117545422	MULTUS	2874	401.075	1850	Active	Inuvik Canada ground station beyond our footprint. No Impact.
USA	118545243	CUPID	2902	400.15, 402	53.7 dn 34 up		Note 1
USA	120545187	ELECTRON USA-1	2941	400.15, 402	45	None	Note 1
USA	118545259	GLOBAL-A	2925	401, 401.5, 400.86, 400.89	30		Note 1
USA	113540399	INSIGHT	2764	397.5	15000	None	Out of our Footprint (Mars)
USA	115545100	MARCO	2823	397.5	15000	None	Mission Complete
USA	116545103	MARS 2020	2831	397.5	15000	None	Out of our Footprint (Mars)
USA	110540768	MAVEN	2934	405	32		Note 1
USA	117545328	LEMUR-2-3	2867	401.5	1000	Active	Spire correspondence shows no concerns.
USA	107540739	NPOESS	2831	402	2000	Inactive	No impact
USA	118545180	RADIX	2906	401.3	114		No Longer In Service
USA	113540648	USASAT-30F	2788	401.5	1000	Active	Fairbank AK Ground station beyond our footprint. No impact.
USA	119545083	USASAT-30H-LM	2911	400.48 400.52	40		Note 1
USA	120545275	USASAT-30L	2943	401	34		Note 1
USA	113540040	USOCEAN	2757	401.25	23		Note 1
USA	120545208	USOCEAN-CS	2945	401.261	23		Note 1

Note 1: For frequency range, Challenger signal is below noise floor.

Note 2: For Mexico, None Found

Table 4 summarizes the identified relevant operators with whom coordination actions have been taken, and the outcome of the coordination effort. Details for each effort are included in the appendix.

Operator	Action	Outcome
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GHG	Contacted GHG, supplied data.	No objections identified, Coordination in progress.
Spire	Contacted Spire, supplied data.	No objections identified, Coordination in progress.
Kepler Communication	Contact Kepler, supplied data.	No objections identified, Coordination in progress.

**Table 4: Summary of Coordination Efforts**

### **GHG Coordination**

GHGSat operates in the range from 401 to 403 MHz. Carrie Rhoades at GHG was contacted, and she stated that there would be no impact on their operations. See Appendix 3 for a letter from GHG confirming this position.

### **Spire Coordination**

Coordination discussions are ongoing with George John, Lead Legal & Regulatory Counsel Spire Global, Inc. See Appendix 4 for the latest communication from Spire.

### **Kepler Coordination**

Kepler Communications operates in the range from 401 to 402 MHz. They have ground stations in Toronto, Canada; Svalbard, Norway; and New Zealand. Discussions with Nick Spina, Director Launch & Regulatory Affairs at Kepler Communications. His focus was on potential interference by satellites transmissions, with the receiver at the Toronto ground station. Directional beam of the receiver antenna should reduce risk of interference to acceptably low levels.

### **Conclusion**

There is no expectation at this time that our satellite and US earth station operations will interfere with any known systems.



## Appendix 1 GHGSAT Coordination Letter

----- Forwarded message -----

From: <[carrie.herzog@ghgsat.com](mailto:carrie.herzog@ghgsat.com)>

Date: [Fri, Sep 14, 2018](#) at 9:46 AM

Subject: Re: FCC Frequency Coordination

To: Erin Puckette <[ep2hk@virginia.edu](mailto:ep2hk@virginia.edu)>

Cc: Stephane Germain <[stephane.germain@ghgsat.com](mailto:stephane.germain@ghgsat.com)>, Marcela Arias <[mam@ghgsat.com](mailto:mam@ghgsat.com)>, Mike Miller <[mlmiller@sterksolutions.com](mailto:mlmiller@sterksolutions.com)>

Hi Erin,

We have completed our analysis.

We believe that your operations will not interfere with GHGSat's Operations.

Given this information, we consider this coordination as complete.

Thank you,

Regards,

### **Carrie Herzog**

Data Processing and Operations Specialist  
GHGSat Inc.

3981 St-Laurent, Suite 500

Montréal, QC H2W1Y5>

Tel : +1-514-847-9474 x218

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## Appendix 2 Latest Communications with Spire Global

----- Forwarded message -----

From: **George John** <[george.john@spire.com](mailto:george.john@spire.com)>

Date: [Tue, Sep 25, 2018](#) at 6:24 AM

Subject: Re: UVA Cubesat Project - Licensing Coordination

To: Erin Puckette <[ep2hk@virginia.edu](mailto:ep2hk@virginia.edu)>

Cc: Robert Sproles <[robert.sproles@spire.com](mailto:robert.sproles@spire.com)>

Don't worry about it. We know it's a rigorous process!

Talked to the engineering team and they are kindly requesting you submit the full spectral mask for uplink and downlink for the range of 150MHz -1700MHz. They also need to know your transmit duty cycle for both up and downlink.

Thanks,  
George

On [Mon, Sep 24, 2018](#) at 7:56 PM Erin Puckette <[ep2hk@virginia.edu](mailto:ep2hk@virginia.edu)> wrote:  
Hi George,

Sorry for the delay, I've been at vibration testing. For the markers given, the spectral density will be insignificant for all but 402.7 MHz. The roll off value there would be on the order of -128.861 dB.

Let me know if you need anything else.

Erin Puckette