# Technical Appendix

# Technical Appendix

## A.1 Scope

This Technical Appendix provides further explanation of how Higher Ground LLC's satellite-based messaging and light email system will operate and the underlying technical basis for avoiding harmful interference to other licensed operations.

## A.2 General Description

Higher Ground's SatPaq earth station terminals (SatPaqs) are embedded in smartphone cases and communicate bi-directionally with conventional C band geosynchronous satellites. SatPaqs offer a seamless extension of consumer texting and light email, particularly in areas lacking sufficient terrestrial mobile network coverage. SatPaqs may also be used in Internet-of-Things (IoT), industrial control and management, and other applications.

## A.3 Frequencies of Operation

SatPaq earth stations will operate in the following frequency ranges:

| | |
|---|---|
| Uplink: | 5925 to 6425 MHz |
| Downlink: | 3700 to 4200 MHz |

## A.4 Service Area

Higher Ground seeks authority to operate SatPaqs in the contiguous United States, Hawaii, Alaska, Puerto Rico and the US Virgin Islands.

## A.5 Earth Station Antenna Pattern

Figures A-1 and A-2 below show the SatPaq earth station antenna gain pattern. The antenna is a simple, rectangular quad-patch antenna (0.06 m. x 0.04 m. in size) with approximately 9 dBi of gain. It can be operated in either vertical or horizontal polarization.[1] In the elevation plane or in the azimuth plane, the pattern is virtually the same. The antenna pattern is typical of a simple, one-pole antenna design.

The antenna input power is 1 Watt (0 dBW). The peak EIRP using a 9 dBi antenna is 9 dBW.

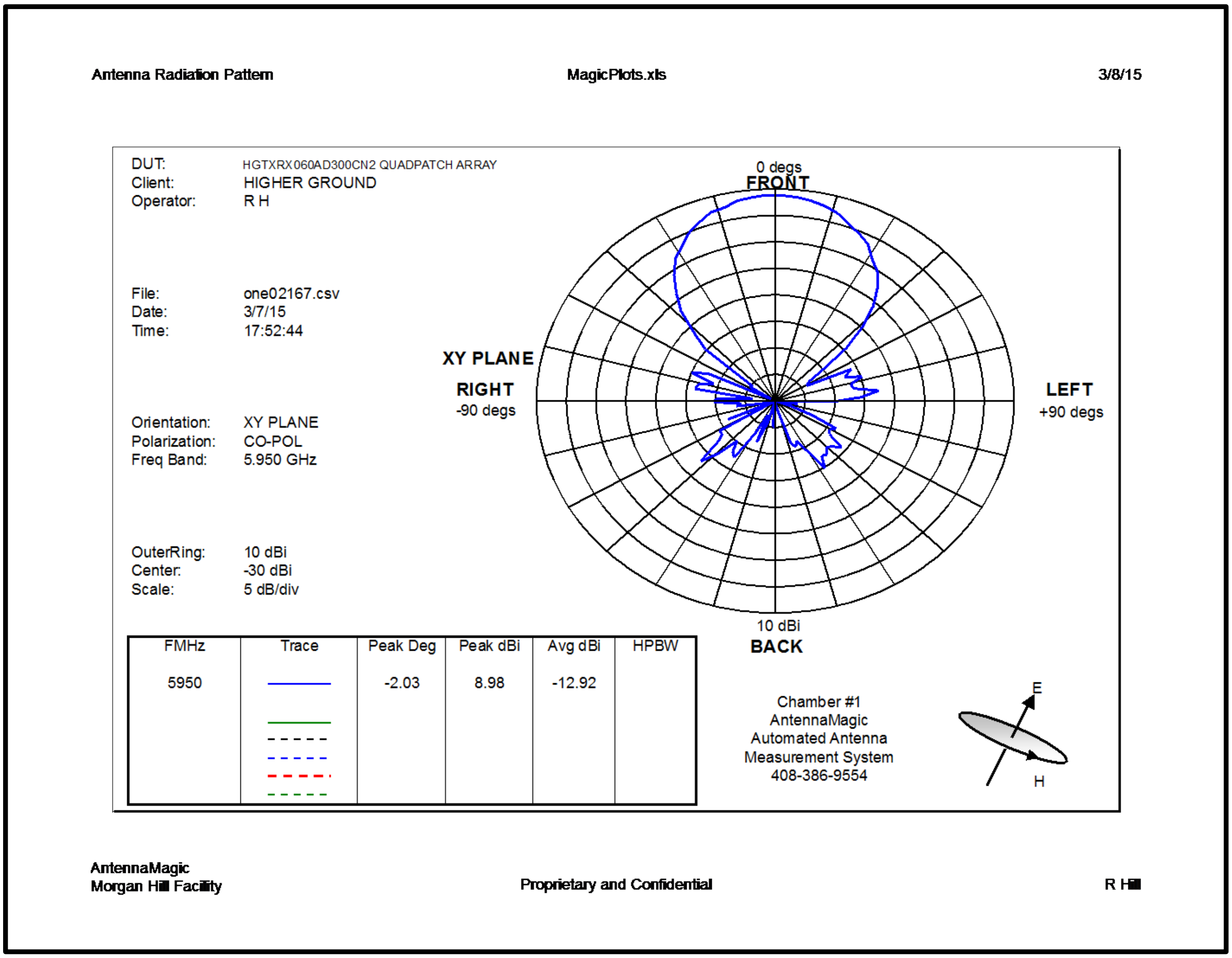


**Figure A-1 - Earth Station Antenna Pattern (Azimuth)**

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[1] The early models of the SatPaq may have only one polarization available.

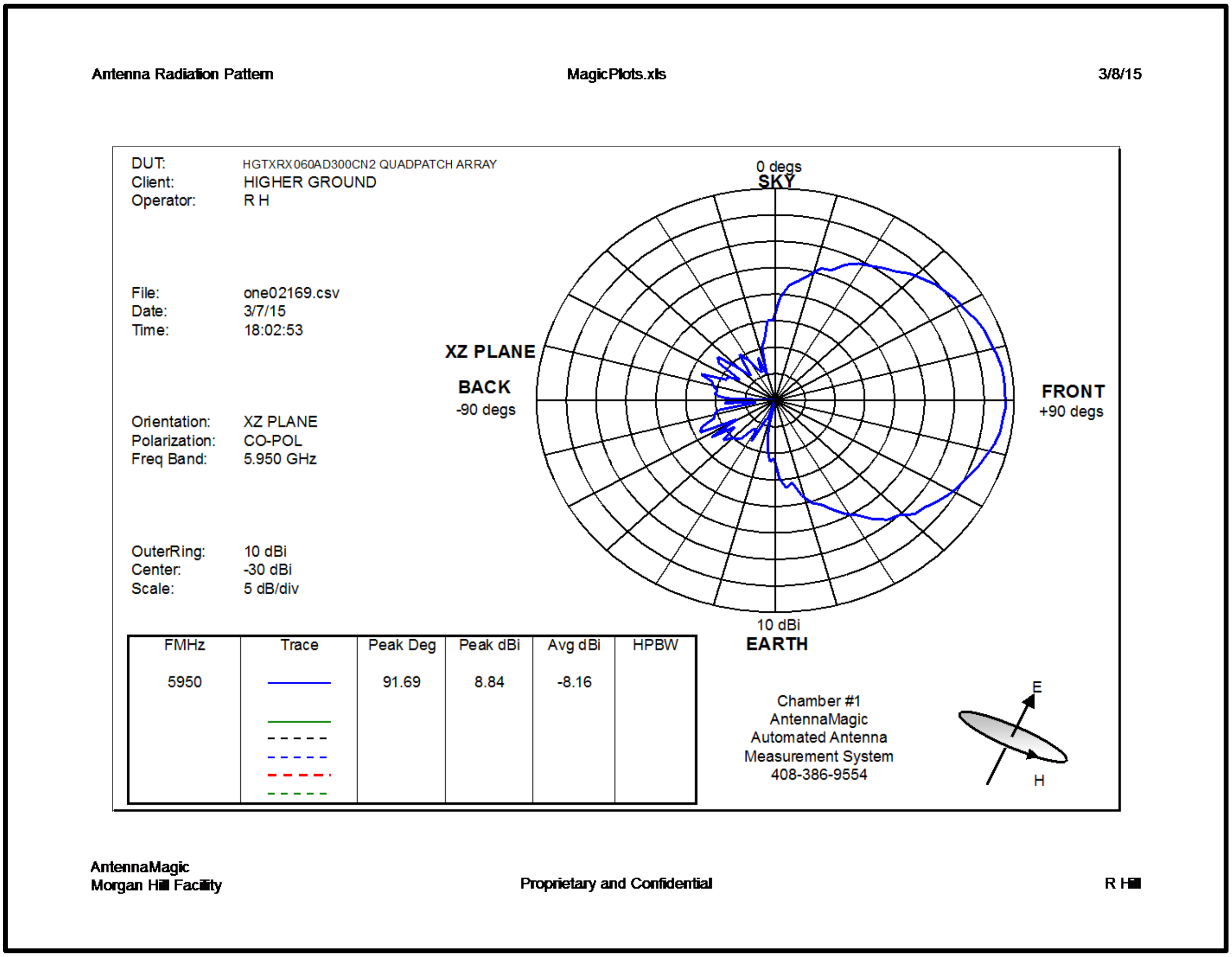


**Figure A-2 - Earth Station Antenna Pattern (Elevation)**

Table A-1 shows the gain pattern and EIRP for the SatPaq earth station, ranging from 0 to 90 degrees off bore-site.

| Degrees off Bore-site | Gain (dBI) | EIRP (dBW) |
|---|---|---|
| 0 | 9 | 9 |
| 15 | 7.5 | 7.5 |
| 30 | 3 | 3 |
| 45 | -8 | -8 |
| 60 | -28 | -28 |
| 75 | -17 | -17 |
| 90 | -20 | -20 |

**Table A-1 - Gain Pattern / Table for Quad Patch Antenna (XY & XZ Plane)**

## A.6 Single Point of Control

The SatPaq network provides for a single point of control at each gateway earth station (SatPaq Network Control) (initially, three gateway stations – one gateway for each satellite), making SatPaq earth stations a permission-based operation that can be shut down if necessary. Specifically, no SatPaq will transmit until it synchronizes with the spread spectrum signal that the satellite transmits (authentication).

The SatPaq network matches a SatPaq's geocoordinates with a look-up table that incorporates ULS database information for all C Band Fixed Service point-to-point (PtP) licensees/applicants and identifies Protection Zones for the PtP receivers. It manages the SatPaq return-path transmission authority for all locations to prohibit operations on potentially interfering frequencies within a Protection Zone or from out-of-country locations. See Section A.8.

The SatPaq network also manages the number of concurrent (i.e., co-incident) SatPaq transmissions to stay within the CDMA limits of Section 25.218 of the FCC's rules, providing interference protection to other satellites. See Section A.7.

Consistent with Section 25.271 of the FCC's rules, the SatPaq Network Control can promptly suspend any SatPaq operations by turning off the satellite synchronization broadcast, should there be a need to shut off the service, for example if there were a notification by another licensee of harmful interference or a notification from the FCC.

## A.7 Interference Protection to Other Satellites

### A.7.1 Compliance with FCC's Off-axis EIRP Mask

SatPaqs are designed to ensure no harmful interference to other satellites in compliance with the FCC's two-degree spacing requirements. The transmit antenna is a simple patch array that has a 3 dB power loss at +- 20 degrees on each side of the bore-sight and conforms to the off-axis EIRP mask prescribed under Section 25.218(d) of the FCC's rules.

The SatPaq will use a combination of spread spectrum and proper antenna pointing to stay below the transmit mask set forth in Section 25.218(d). The devices will use Direct Sequence Spread Spectrum (DSSS) to spread their emissions across approximately 8 MHz of spectrum (33 dB). This technique moves the SatPaq's bore-sight, peak power density down from 9 dBW to -24 dBW (4 KHz). More importantly, the off-axis, bore-sight power density stays significantly below the transmit mask limits for all conditions.[2] Table A-2 below shows the off-axis EIRP level of the earth station antenna for a) the geostationary plane; b) the horizon plane; and c) the elevation plane.[3]

Section 25.218(d) allows for N simultaneous, co-channel DSSS transmitters provided that those concurrent operations stay below the transmit mask. The point at which the change in the transmit mask is at a minimum (highlighted in yellow) is the place that we compute this number (N). We compute (N) to be a maximum of 109 concurrent transmissions (10**2.04) for each channel.

The SatPaq Network Control controls all SatPaq communications and will ensure that this limit is never exceeded. The process of possibly delaying a transmission by a second or two for a text message, should that be necessary, has no impact on consumer usability.

| Off-axis Angle (deg.) | FCC Mask 25.218(d1) | Geo Plane (dBW/4 KHz) | Delta to the Mask | FCC Mask 25.218(d2) | Horizon Plane (dBW/4 KHz) | Delta to the Mask | Elevation Plane (dBW/4 KHz) | Delta to the Mask |
|---|---|---|---|---|---|---|---|---|
| **0** | | | | | | | | |
| **1** | | -24 | | | -24 | | -24 | |
| **2** | 18.8 | -24 | 42.8 | | -24 | | -24 | |
| **3** | 14.4 | -24.2 | 38.6 | 17.4 | -24.2 | 41.6 | -24.2 | 41.6 |
| **4** | 11.2 | -24.4 | 35.6 | 14.2 | -24.4 | 38.6 | -24.4 | 38.6 |
| **5** | 8.8 | -24.5 | 33.3 | 11.8 | -24.5 | 36.3 | -24.5 | 36.3 |

[2] The SatPaq's power levels are also substantially below the FCC's EIRP spectral density limit for earth station on vessels (ESVs). Section 25.204(h) of the FCC's rules specifies the limit of EIRP spectral density towards the radio horizon – for an ESV along the horizon the limit is 17 dBW/1 MHz or -7 dBW/ 4 KHz. A SatPaq's maximum power density in any direction is 9 - 36 dBW, or -24 dBW/4 KHz – *some 17 dB below the limit.*

[3] Because the antenna is so small, increments of 0.1 degree would be in the measurement noise. Table A-2 therefore shows increments of 1 degree off-axis up to 10 degrees.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **6** | 6.8 | -24.6 | 31.4 | 9.8 | -24.6 | 34.4 | -24.6 | 34.4 |
| **7** | 5.3 | -24.7 | 30.0 | 8.2 | -24.7 | 32.9 | -24.7 | 32.9 |
| **8** | 5.3 | -24.8 | 30.1 | 6.7 | -24.8 | 31.5 | -24.8 | 31.5 |
| **9.2** | 5.3 | -24.9 | 30.2 | 5.4 | -24.9 | 30.3 | -24.9 | 30.3 |
| **10** | 4.3 | -25 | 29.3 | 4.3 | -25 | 29.3 | -25 | 29.3 |
| **15** | -0.1 | -25.5 | 25.4 | -0.1 | -25.5 | 25.4 | -25.5 | 25.4 |
| **20** | -3.2 | -27 | 23.8 | -3.2 | -27 | 23.8 | -27 | 23.8 |
| **25** | -5.6 | -27.5 | 21.9 | -5.6 | -27.5 | 22.9 | -27.5 | 22.9 |
| **30** | -7.6 | -28 | **20.4** | -7.6 | -28 | 22.4 | -28 | 22.4 |
| **35** | -9.3 | -33 | 23.7 | -9.3 | -33 | 23.7 | -33 | 23.7 |
| **40** | -10.7 | -37 | 26.3 | -10.8 | -37 | 26.2 | -37 | 26.2 |
| **45** | -12.0 | -41 | 29.0 | -12.0 | -41 | 29.0 | -41 | 29.0 |
| **48** | -12.7 | -43 | 30.3 | -12.7 | -43 | 30.3 | -43 | 30.3 |
| **50** | -12.7 | -46 | 33.3 | -12.7 | -46 | 30.3 | -46 | 30.3 |
| **55** | -12.7 | -56 | 43.3 | -12.7 | -56 | 30.3 | -56 | 30.3 |
| **60** | -12.7 | -61 | 48.3 | -12.7 | -61 | 30.3 | -61 | 30.3 |

**Table A-2 - Compliance with Section 25.218(d) Transmit Mask**

With regard to antenna pointing, the SatPaq transmitter will be activated only when it is within 15 degrees of the required pointing angle to the satellite. The SatPaq will use the many sensors in the smartphone (e.g. its GPS coordinates and bearing) to enable activation/deactivation of the SatPaq transmitter. A SatPaq transmission will be disabled within 100 msec. if this pointing angle envelope is ever exceeded. The transmission can be quickly enabled again (and the message resumed) once the SatPaq is pointing back to the desired direction. This process is fast enough to permit mobile operation of the SatPaq for many consumer recreation activities (*e.g.,* hiking, boating, and horse-back riding) without causing any compromising interference to satellites.

### A.7.2 Concurrent Transmitters

The SatPaq operates under Section 25.218(d) for the return path signal. This regulation defines the transmit mask (dBW in 4 KHz) for all operations. Since we are operating with DSSS spread spectrum, we are subject to the 10 Log (N) factor with N being the number of concurrent transmitters.

The return path is spread over a signal 8 MHz wide. This provides a 33 dB reduction in power spectral density, compared to the original signal EIRP of 9 dBW – or the transmit mask floor moves to -24 dBW (4 KHz). See Figure A-3.

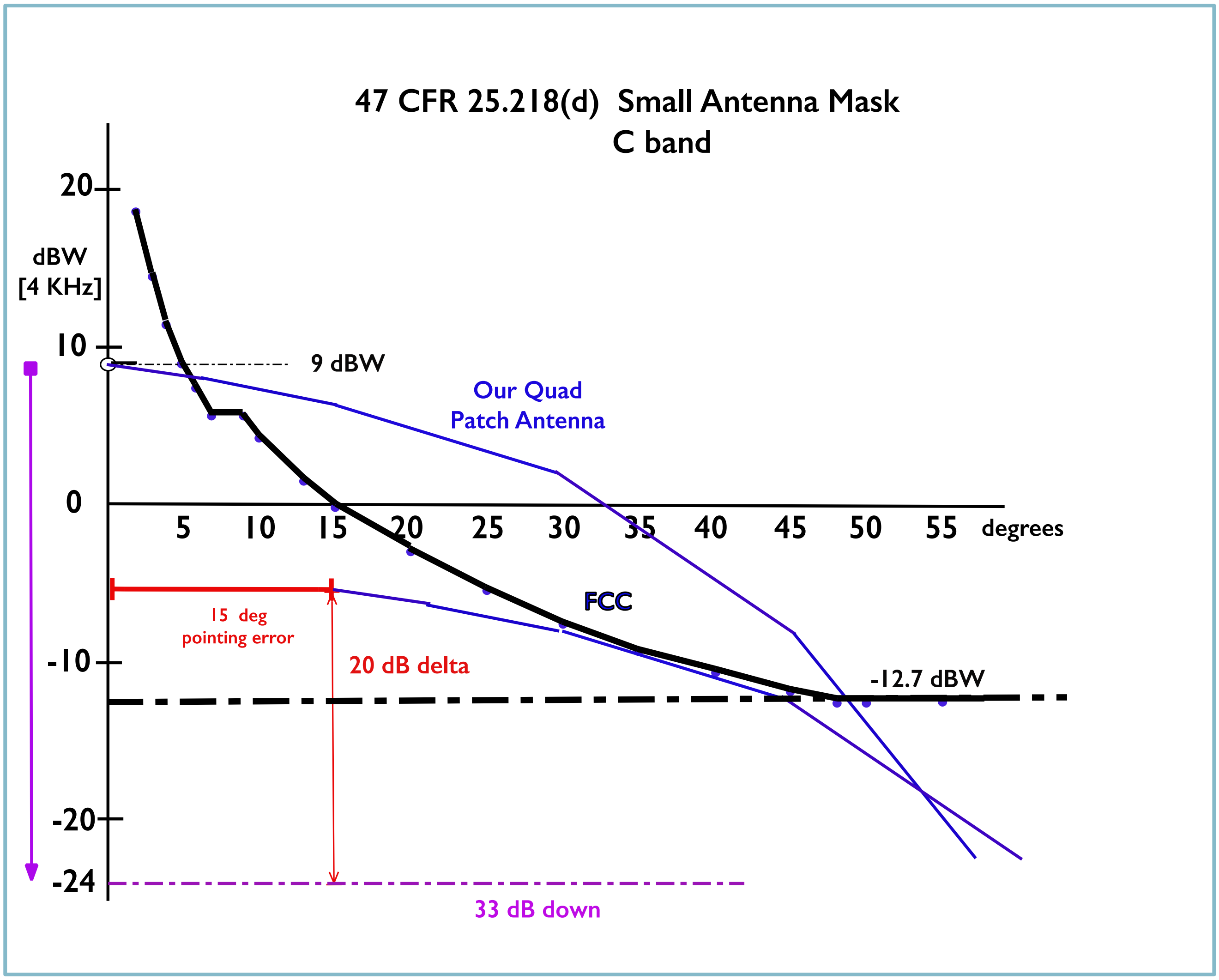


**Figure A-3 47 CFR 25.218(d) Compliance**

Figure A-3 above shows the FCC transmit mask associated with small antennas for C Band (black line, labeled FCC). We show first the simple gain pattern of our quad patch antenna with a peak power of 9 dBW (blue line, the top line). Then, we show the repositioning of this quad patch gain line down to a tangent point below the FCC mask via the spreading of the signal (red and blue line). This allows us to determine the number of concurrent transmitters inclusive of a 15 degree pointing angle error, for any channel.

The number of concurrent transmitters can be determined starting with the floor PSD (-24 dBW (4 KHz)) and computing the number N where the total, co-channel simultaneous density approaches but stays below the transmit mask. One can see that this new limit is now about 20 dB higher. It is essentially the same result as Table A-2. Therefore, the equation is:

$$N = \text{Floor}\left(10^{(20/10)}\right)$$

or N = 100 (or so) simultaneous, co-frequency transmitters.

Approximately one hundred SatPaqs can transmit on each channel and stay below the 47 CFR 25.218(d) transmit mask.

Therefore, Higher Ground will operate with no more than 100 concurrent SatPaq transmitters at a given frequency to ensure interference protection to other satellites.

## A.8 Interference Protection to Point-to-Point Microwave

### A.8.1 Protection from SatPaq Uplink Interference

#### A.8.1.1 Introduction

Higher Ground has developed a robust interference protection regime to ensure SatPaqs will not cause harmful interference to PtP operations. This is achievable due to the sufficient frequency, spatial, and satellite diversity available at C band frequencies. As explained below, each PtP receiver in the band will be assigned a Protection Zone, wherein SatPaqs will be subject to heightened interference protection requirements to ensure no harmful interference to a PtP receiver. The process is explained below.

The earth is a wonderful attenuator at microwave frequencies. Therefore, signals at C band that travel beyond the PtP receiver antenna will stop either at the point where the signal hits a hill or at the curvature of the earth. See Figure A-4.

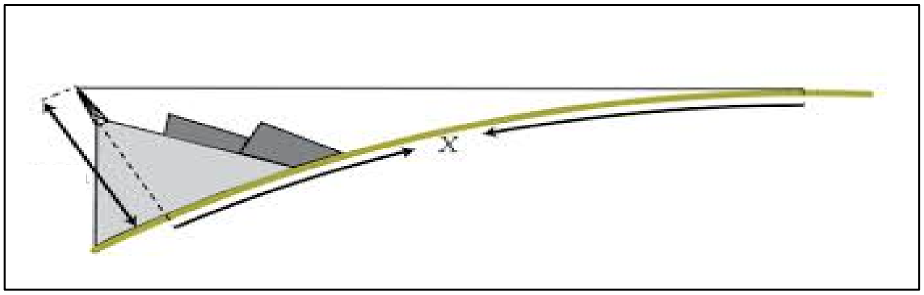


**Figure A-4 Line of Sight Graphic for Microwave Communications**

The limiting distance for line-of-sight communications like microwave communications is defined by the formula:

| |
|---|
| Radio Horizon (mi) = SQRT of (2 x *Height*) |

where: the Height (ft.) is the sum of the antenna tower + height above sea level

By way of example, the height of a PtP transmit tower might be on the order of 50 feet on top of a 300 foot (or so) hill. This would define a maximum communications range of about 26.5 mi to a sea level receiver. One would add 2.8 miles to this number because a SatPaq will typically be held 4 feet above the earth.[4]

We can now define a Receiver Acceptance Cone (RAC). Note that one interferes with receivers, not transmitters. So the receiver side of the microwave PtP link is the only acceptance cone at issue. The receiver side is shown with a red dot throughout the document.

The RAC is the physical zone in which a third-party transmitter might interfere with the PtP receiver (see Figure A-5). The maximum communications range for a PtP transmission is the distance (D).[5] The length of the triangle (D) is defined at microwave frequencies by the PtP transmitter antenna's height above sea level (H) and the curvature of the earth. The angle of this triangle is defined by the PtP receiver antenna characteristics. PtP microwave antennas are typically two or three meters in diameter,

[4] Should the SatPaq be more than 4 ft. above ground, then the distance D would be appropriately increased.

[5] The back lobe circle around the receiver is addressed in Section A-8.1.6.

which defines a 1.7 degree (or less) acceptance angle (3 dB), although ULS contains information regarding smaller or larger receiver dishes and this data will be accounted for as well.

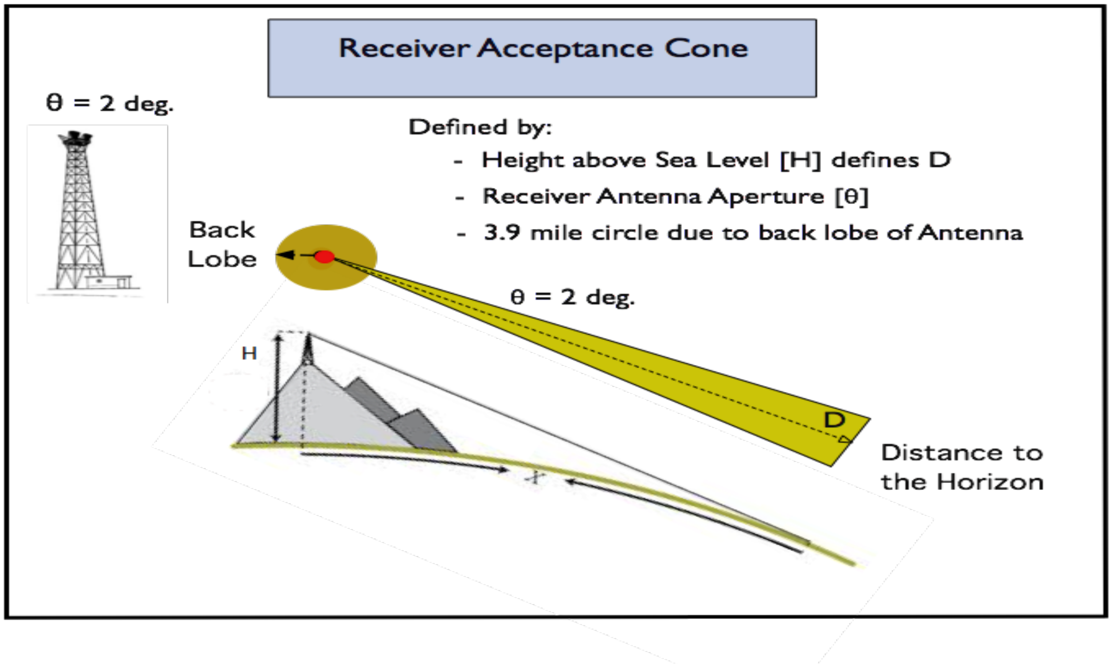


**Figure A-5 - Receiver Acceptance Cone**

### A.8.1.2 Protection Zones

To make the process failsafe, a substantial safety factor is added to the physical RAC. This results in a much larger triangle called the Protection Zone. See Figure A-6 below. Whereas the typical angle of receiver acceptance for a typical microwave dish is 2 degrees, we will define our protection acceptance angle to be ten times larger and set it at 20 degrees (1/18 of a 360 degree circle). Whereas the typical microwave link has a communications distance of 20 to 30 miles, we will define our exclusion zone triangle to be twice as long and set it at 50 miles long (or longer if necessary[6]). Therefore, a typical Protection Zone will have an area of approximately 435 square miles or $((3.14) * ((50^2)/(18))$[7] as compared to the area of the Receiver Acceptance Cone, just 16 square miles.

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[6] Extreme differences in antenna height may require the computation of a longer triangle.

[7] Plus the Close Proximity Circle (See A.8.1.6) around the receiver.

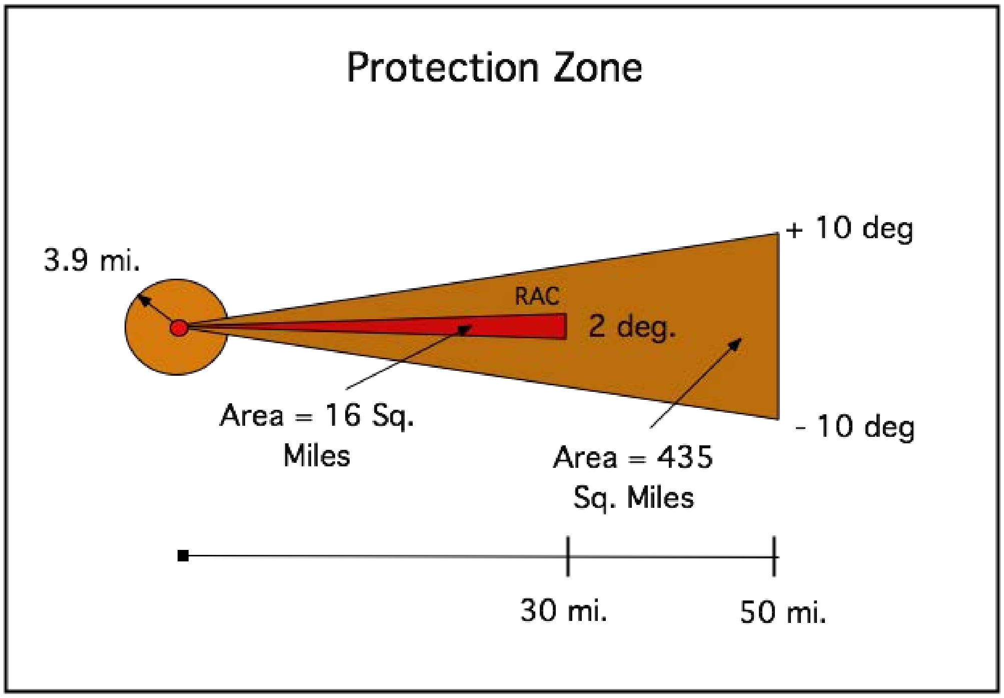



**Figure A-6 - Protection Zone**

### A.8.1.3 Use of the FCC ULS Database

The FCC ULS database is the authority for identifying PtP operations in the C band. From this database, we can determine the location and orientation of each PtP receiver, and identify a RAC – and a Protection Zone – for each receiver. When this ULS data is combined with real-time location information from a SatPaq seeking to transmit, the SatPaq system has all the information necessary to prevent any harmful interference to PtP operations.

The SatPaq network will maintain an updated, relevant subset of the ULS database pertaining to C band, Fixed Service PtP licensed pairs and applicant pairs, including the coordinate locations/orientation of PtP receivers, the frequencies of the PtP, and its antenna height, height above mean sea level, and receiver polarization.

Thus, when a SatPaq initiates its request to transmit and submits its geocoordinates, Higher Ground's algorithm will analyze the ULS dataset for nearby PtP operations and determine the appropriate frequency for transmission. Just as with cellular communications, the SatPaq network will direct the SatPaq to a channel that will not cause harmful interference with another operator. This will be accomplished via a look-up table.[8] The look-up table, or a portion of it, may be off-loaded to the SatPaq, enabling the SatPaq to identify and select a suitable frequency to request transmission with SatPaq Network Control. At all times, SatPaq Network Control will ensure that the database is updated to ensure PtP operations are properly accounted for.

This SatPaq network system is the self-coordination process.

Any error in the FCC ULS database would manifest as if the coordination process was not completely coordinated. The statistics showing how this error still never rises to an interference level that could be considered harmful is documented in Section A.8.1.8.

#### A.8.1.4 Initial Synchronization Process

Our satellites will send out a regular, repeating broadcast on the SatPaq hailing frequency at 3702.5 MHz (downlink) (alternate, pre-arranged frequencies are possible too). This broadcast accomplishes the following: a) it provides frequency and timing symbols to decode the direct sequence spread spectrum signal (forward path communications); and b) it informs the SatPaq how to respond. A SatPaq will initially transmit to the satellite using the designated hailing frequency 5927.5 MHz (uplink) (or an alternate, pre-arranged frequency), providing its geocoordinates. The SatPaq network will use the ULS database look-up table to direct the SatPaq to operate on frequencies that do not interfere with nearby PtP operations. This process of initial synchronization is outlined in Figure A-5 below.

[8] The look-up table will have been prepared (and updated) in advance of the SatPaq communications.

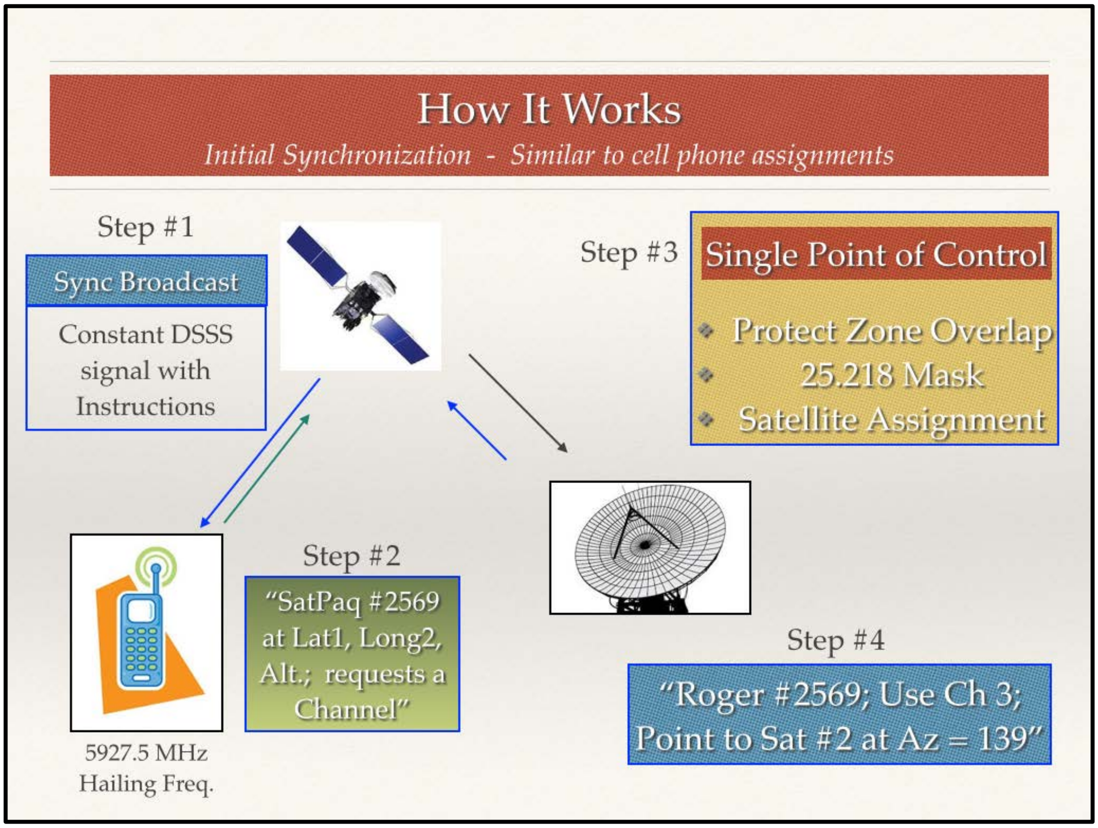



**Figure A-7 - How it Works**

When a SatPaq requests service by transmitting on the 5927.5 MHz hailing frequency (or an alternate, pre-arranged frequency), it will send along its current geocoordinates. From the coordinates, the SatPaq network will now make some decisions. It will need to evaluate:

- which frequency channel to assign to not interfere with any nearby PtP transmitters (determined via data from the ULS Look-up Table);
- how many simultaneous, co-frequency SatPaq's can be scheduled to talk to stay below the Section 25.218(d) transmit mask (in one satellite receiving beam);
- which is the better satellite (Pacific or Atlantic) for the SatPaq to use.

This assignment (the channel, the satellite and the assignment to talk) is then established.

### A.8.1.5 Hailing Frequency

The 5927.5 MHz frequency is the primary hailing frequency for uplink transmissions. This frequency is at the center frequency of the 5925-5930 MHz segment of the C band; a low-bandwidth, lightly-used channel. According to the ULS database, there are 18 PtP links active today in the entire United States between 5925.1 and 5930 MHz.

| XMTR Call Sign | Freq. | XMTR Bearing | Pol. | Total Elev.(ft) | RCV Bearing | Total Elev. (ft) | Point North? | Radio Horizon (mi) |
|---|---|---|---|---|---|---|---|---|
| WCE217 | 5928.75 | 123.5 | V | 518 | 303.5 | 548 | Yes | 7.8 |
| WGF58 | 5927.5 | 24 | V | | 204 | | No | |
| WLR549 | 5926.25 | 328 | H | | 148 | | No | |
| WLW366 | 5926.25 | 62.5 | H | | 242.5 | | No | |
| WMM923 | 5927.5 | 18.5 | V | | 198.5 | | No | |
| WMM923 | 5927.5 | 124.4 | V | 1450 | 304.4 | 1335 | Yes | 15.2 |
| WMQ211 | 5927.5 | 305.3 | V | | 125.3 | | | |
| WMQ270 | 5927.5 | 240.2 | V | 1157 | 62.2 | 55 | Yes | 46.9 |
| WMQ536 | 5927.5 | 63.9 | V | | 243.9 | | No | |
| WMQ660 | 5927.5 | 247.7 | H | 430 | 67.7 | 555 | Yes | 15.8 |
| WMQ660 | 5927.5 | 349.6 | H | | 169.6 | | No | |
| WPNJ399 | 5926.25 | 54.9 | V | | 234.9 | | No | |
| WMQ811 | 5927.5 | 6.6 | V | | 186.6 | | No | |
| WMR809 | 5926.5 | 192.9 | V | 1329 | 12.9 | 1050 | Yes | 23.6 |
| WNTJ326 | 5928.75 | 248.5 | V | | 68.5 | | No | |
| WPNJ518 | 5926.5 | 174.1 | V | 486 | 354.1 | 450 | Yes | 8.5 |
| WPTD331 | 5929.575 | 96.8 | V | 330 | 276.8 | 350 | Yes | 6.3 |
| WQKZ948 | 5928.75 | 162.2 | H | 450 | 342.2 | 690 | Yes | 21.9 |

**Table A-3 - Active PtP Microwave Links between 5925.01 MHz and 5930.0 MHz (US)**

From the northern hemisphere to communicate with a geosynchronous satellite, the SatPaq must be pointed in a southerly direction to the equatorial plane, where the geosynchronous satellites reside. Of these 18 links, only 8 have receivers that point in a northerly direction. Thus, if the PtP receiver exclusion zone points south, there is no possibility that the SatPaq can interfere with the PtP link.[9]

[9] Except for within the Close Proximity Circle (see A.8.1.6) surrounding the 18 PtP receiver (within 3.9 miles) at which frequency diversity would be employed.

Each SatPaq will have a look-up table of the Protection Zones associated with these 8 south-facing PtP receivers.[10] For these eight zones, the SatPaq Network Control may direct the SatPaq to only one of our satellites to ensure no interference. But, in all cases, the SatPaq network either will find some communications path to our satellite without causing harmful interference to the nearby PtP receiver or will not allow SatPaq transmissions.

### A.8.1.6 Close Proximity Circle to PtP Receivers

Higher Ground has also accounted for a protected area behind and to the side of a PtP receiver to ensure that the SatPaq will never cause harmful interference – even at very close proximity. We do this by analyzing first the typical received signal noise power of a PtP receiver and then maintaining the SatPaq signal level far below that noise floor.

With an assumption of a high performance receiver (6 dB NF), we add 6 dB for additional noise immunity. For our 8 MHz BW signal (69 dB), that means that the received noise power in 8 MHz is:

Target Interference Power = -174 + 69 + 6 - 6 = -105 dbm

We can now compute the stand-off distance (D) behind the PtP receiver for where the SatPaq power is the same noise power as the Boltzman (natural) noise. For the antenna gain behind the PtP dish, we will use Gr = -40 dBi per Figure A-6.

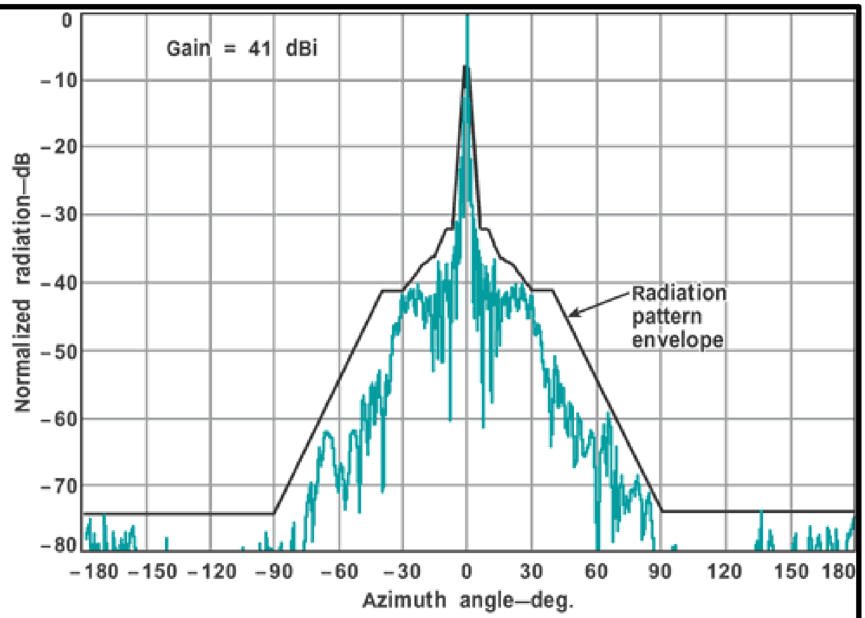
$$P_r = EIRP + G_r - 20Log(\frac{4\pi D}{\lambda})$$

$$D = \frac{\lambda}{4\pi} \cdot 10^{(\frac{EIRP + G_r - P_N}{20})}$$

[10] Updates will be sent to the SatPaq to keep this list current.

For Pn = -105 dBm; EIRP = 39 dBm; and Gr = - 40 dBi;  λ = 0.05 meter; the behind-the-dish stand-off distance (D) = 630 meters.  For the sidelobes, Pn = -105 dBm, EIRP = 39 dBm; Gr = -20 dBi; λ = 0.05 meter; and the side stand-off distance (D) = 6300 meters (3.9 miles).

This means that the transmission of a SatPaq signal from any distance greater than 630 meters behind the dish and/or 6300 meters to the side will be 6 dB or more below the Boltzmann (natural) noise floor.




2. This radiation pattern is typical for a microwave antenna, with side-lobe signals being generated at significant levels at azimuth angles out to ±90 deg.

**Figure A-8    Gain Pattern for Typical (2 meter) PtP Microwave Dish**

This defines a key-hole shaped transmit mask with a 6300 meter (3.9 mile), no-transmit circle around the antenna (the Close Proximity Circle) and then a Protection Zone triangle along the acceptance bearing.  See (once again) Figure A-6.

### A.8.1.7    Diversity Techniques

In order for a SatPaq to possibly interfere with a PtP receiver, there must be an overlap in frequency/polarization, and the SatPaq must look down the throat of a PtP microwave receiver horn or be in very close proximity.  As described above, the SatPaq network will typically use frequency diversity to assign the SatPaq to another frequency if there is a possibility of interference to a PtP receiver within a Protection Zone. There are several additional communications tools that can be put in place to avoid any risk of interfering as well.[11] In addition to frequency diversity, there are also satellite (or orientation) diversity and polarization diversity. We focus here on satellite diversity. Polarization diversity involves switching to the opposite antenna diversity to reduce coupling, a common technique.

With regard to satellite diversity, the SatPaq system will operate initially with three geosynchronous satellites. There will always be one geosynchronous satellite in the westerly direction and one in the easterly direction to handle occlusions from mountains. The SatPaq Network Control will select the likely best available satellite based on location. Then, if this direction does not provide a good signal because of the occlusion, the SatPaq Network Control will orient the SatPaq to the appropriate azimuth for the other satellite.

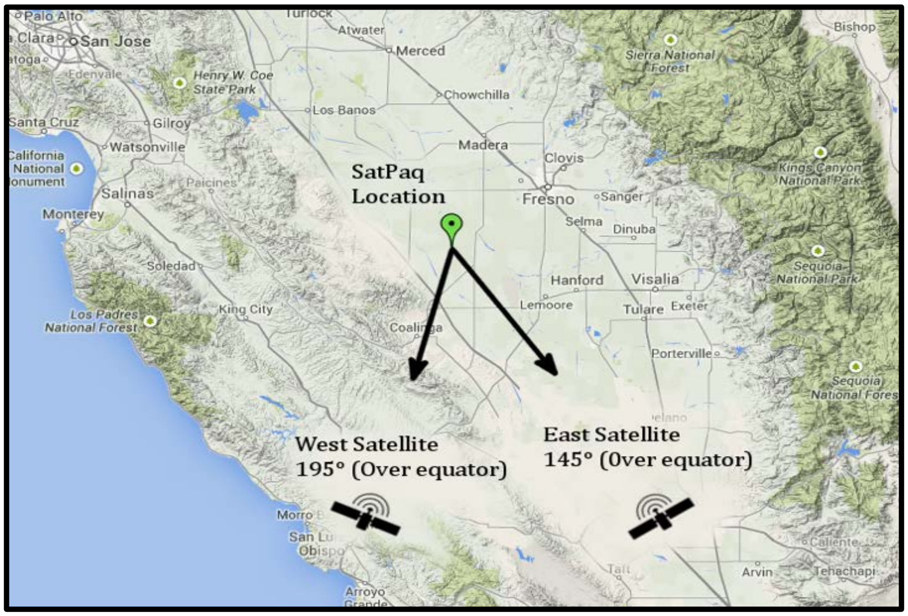



Figure A-9 - Azimuth Angles due to Satellite Diversity

We can switch to another azimuth angle whenever there is a potential interference to a PtP link within a Protection Zone. This change will likely provide a 40 to 60 degree difference in azimuth look angle. See Figure A-9.

Let's look at several maps with some real PtP link data. We will further explain the geometry and the Go/No-go decision making process. In Figures A-10 through A-13 below, the red dots are PtP receivers and the green squares are PtP transmitters. The red dots also represent the Close Proximity Circles.

[11] The SatPaq network will use frequency diversity whenever a SatPaq is within 3.9 miles of any PtP receiver (the Close Proximity Circle). The SatPaq Network Control will select either frequency or satellite diversity whenever a SatPaq is inside the Protection Zone of a north-facing PtP receiver.

Figures A-10 and A-11 show the position and orientation of PtP links in the Sierra Foothills in CA. Note that there are few PtP links in this rural area. Finding a frequency and bearing that will work in the hills and mountains is quite easy. In Figure A-10, if the SatPaq initially targets the Pacific satellite, there could be risk of interference to a PtP link at 5974 MHz. So, we would classify this as a No-go situation at 5974 MHz. Or, using satellite diversity, targeting the Atlantic satellite would pose no risk of interference at 5974 MHz. Figure A-11 shows that switching to 5945 MHz would then be a Go condition for both the Pacific and Atlantic satellites.


**Figure A-10 - 5974 MHz near Jackson, CA**

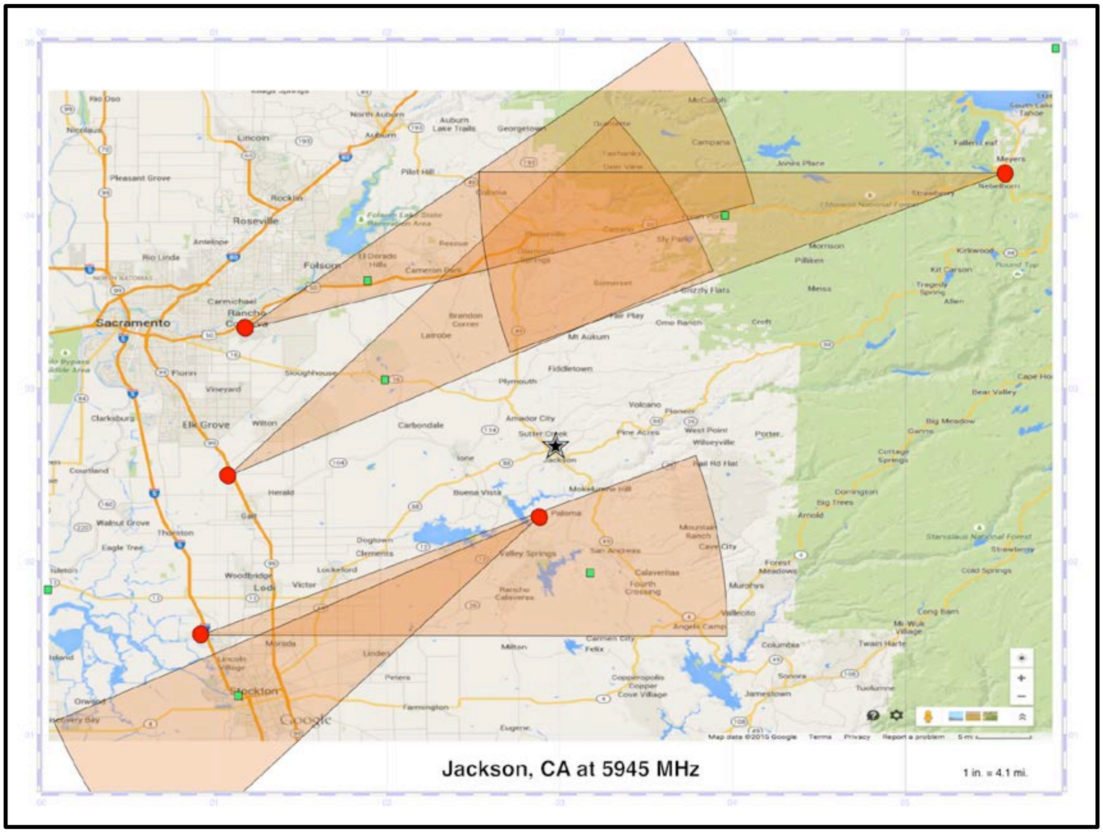



**Figure A-11 - PtP links at 5945 MHz near Jackson, CA**

Figures A-12 and A-13 show the position and orientation of PtP links in a major metropolitan area near San Francisco (not the likely use case for the SatPaq). Even in an area of this high density, it is still not difficult to identify a channel that will guarantee no interference to the PtP links. Figure A-12 shows a situation with real PtP links at 5945 MHz for the SF Bay Area. A SatPaq could transmit in a westerly direction to a Pacific satellite and there would be zero possibility of interference. However, if the SatPaq were assigned to the Atlantic satellite, there would be a possibility of interference at 5945 MHz. So, SatPaq transmissions would be moved to another channel; in Figure A-13, to 5974 MHz.

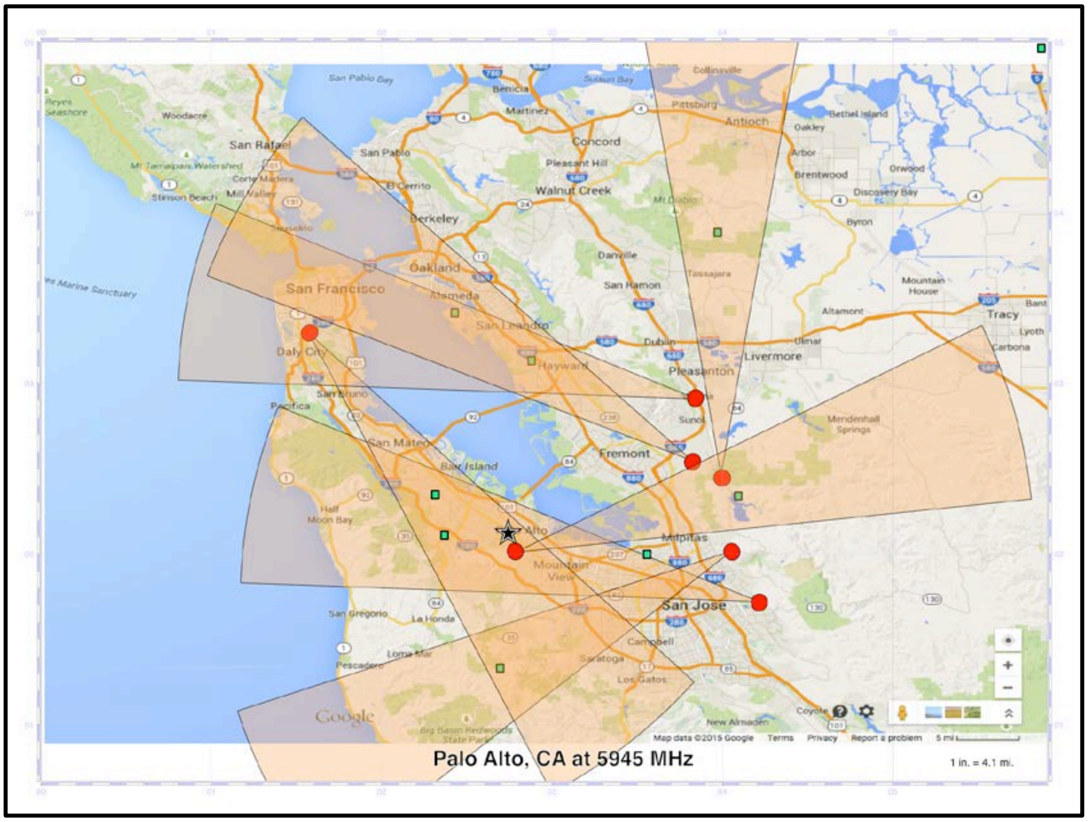



**Figure A-12 - 5945 MHz near Palo Alto, CA**

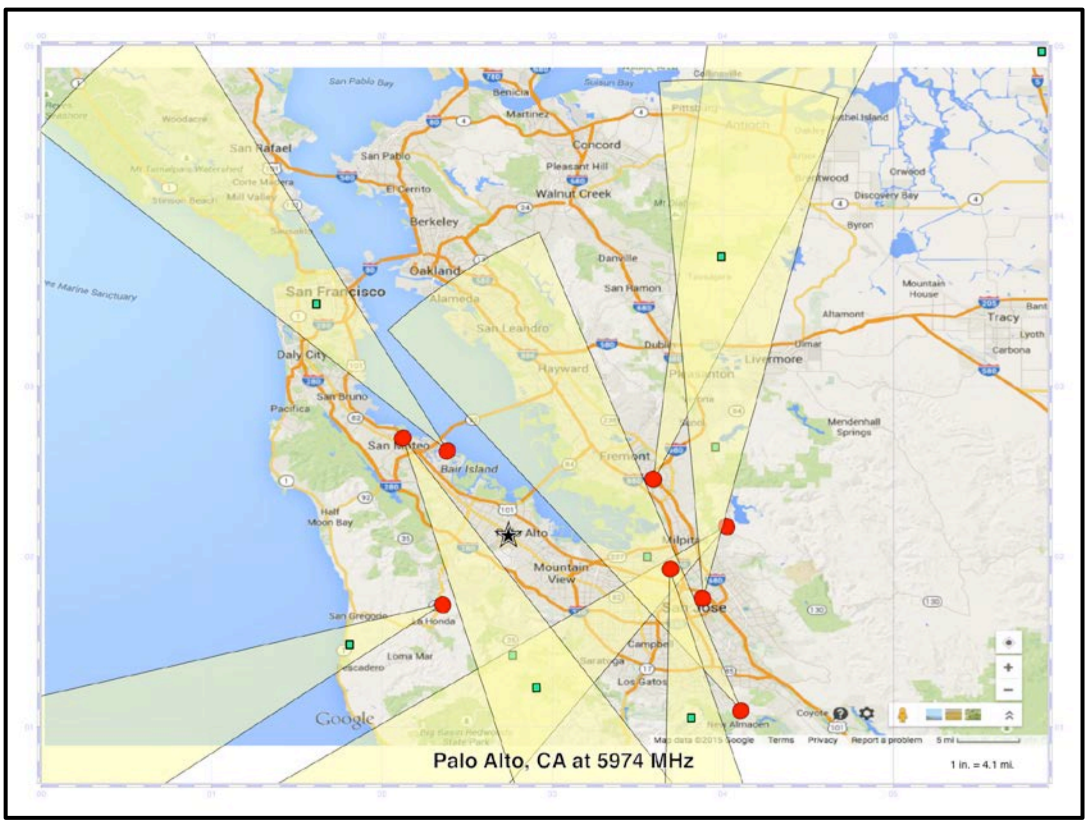
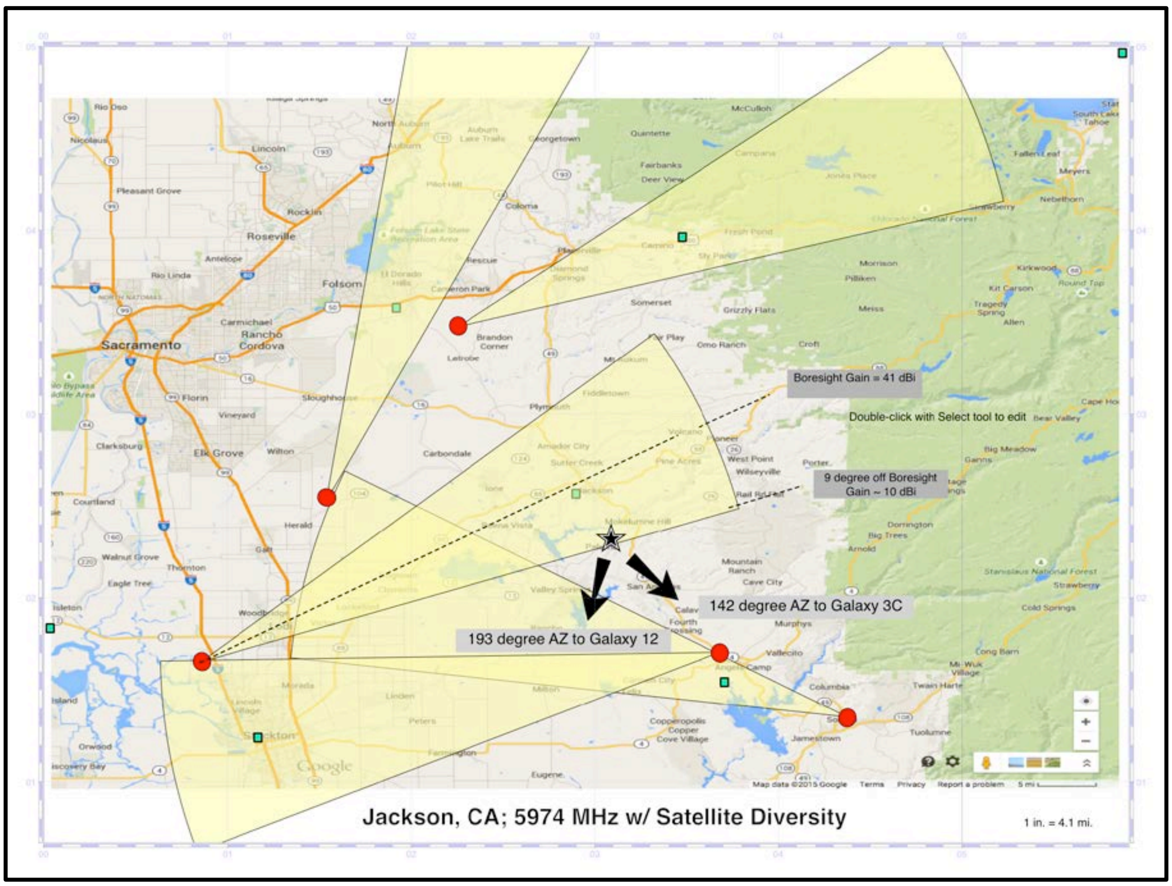



**Figure A-13 - 5974 MHz near Palo Alto, CA**

In Figure A-14, we show an example of choosing satellite diversity.  Here, a switch to the East Coast satellite (on this same 5974 MHz channel) can be confidently computed by using the antenna gain parameters of both the PtP receiving antenna (Gr) and the gain of the SatPaq antenna (Gt).

In this case, the SatPaq is located in a Protection Zone which then requires additional detailed analysis. But, the receiving antenna gain is down 30 dB with the SatPaq position 9 degrees off of PtP bore-sight and, in addition, the transmit antenna gain is down 30 dB when the SatPaq points at Galaxy 3C (azimuth 142 degrees).

Using the stand-off equation of Section A.8.1.6, we can compute the stand-off distance for any interfering signal to not be of concern (or less than 6 dB below the Boltzman noise floor).  For Pn = -105 dBm; EIRP = 39 dBm; and Gr = - 30 dBi;  Gt = -30 dBI;  $\lambda$ = 0.05 meter; the stand-off distance is 63 meters.  In this case, the SatPaq is 40 miles away, far greater than 63 meters and not of concern.



Jackson, CA; 5974 MHz w/ Satellite Diversity

**Figure A-14  -  Satellite Diversity**

The SatPaq Network Control will make the choice of frequency diversity, satellite diversity, or polarization diversity by selecting the minimal potential for harmful interference. Since the data are time-invariant, the analysis can be completed prior and stored in a look-up table (with PtP information updated regularly).

### A.8.1.8 Statistical Ceiling of Interference

Section A.8.1.2 above explains our process for self-coordination via Protection Zones. This self-coordination process will work extremely well to ensure that there is no interference to PtP operators. But in addition to the analysis above, the following statistical analysis demonstrates just how low the risk of interference really is to PtP operations.

To do so, we compute the potential for interference to PtP operations in a hypothetical, completely random (un-coordinated) process. Of course that will not occur. But it is a mathematically useful worst-case analysis to demonstrate just how low the threat of interference is.

Herein, we compute the time between two instances of interferences to a single PtP receiver. This will set the ceiling of interference from hypothetical un-coordinated communications. *Self-coordination can never be worse than this ceiling number and will be significantly better.* But using this statistical analysis, we show that this worst-case measurement of time between interference to a single PtP receiver will never rise to a level of interference that one could call harmful.

For this calculation, we shall assume that there are 1 million SatPaqs in use,[12] each SatPaq sends five messages per month (2 seconds each),[13] and there are 10,000 active, north-facing PtP receivers.[14] There are also 3.8 million square miles for the entire US.[15]

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[12] Someday we hope to have 1 million SatPaqs in use.

[13] This number is based in part on a USDA report, "Outdoor Recreation in American Life," which provides information on the number of days Americans engage in outdoor recreational activities. See USDA Forest Service Southern Research Station, Outdoor Recreation in American Life (1999).

[14] Total number of active PtP links divided by two to account for just the north-facing receivers.

[15] United States: Country Overview, Location and Size *available at* http://www.nationsencyclopedia.com/economies/Americas/United-States-of-America.html.

To estimate the extent of interference caused by SatPaqs to PtP receivers, we will calculate below an approximate average time interval between a random occurrence of interference at a given PtP receiver and a second occurrence of interference at that same PtP receiver. This time interval is the reciprocal of the product: [(Message Rate) x P(Interference)]. Message Rate is the average number of messages per unit time when interference occurs, and, P(Interference) is the probability that SatPaqs would cause interference to a PtP receiver.

P(Interference) can also be interpreted as the probability that one or more SatPaqs would be pointing to a PtP receiver's RAC. Let's divide the country into RAC bins. The number of RAC bins in the country is (3.8e6 square miles total area)/(16 square miles area for one RAC) = 237,500.

P(Interference) = (Probability that there are 1 or more SatPaqs in a RAC) * (Probability that a SatPaq is pointing toward a PtP receiver) * (Probability that there would be a PtP Receiver in a RAC bin) = ("SatPaq Probability") * ("Pointing Probability") * ("PtP Rx Probability"). Let's calculate these 3 probabilities.

There are 1 million SatPaqs and 237,500 RAC bins. The average number of SatPaqs in a RAC bin ("Density") is 1e6/237,500= 4.21. Hence, (Probability that there are 1 or more SatPaqs in a RAC) = SatPaq Probability= 1.0.

The probability of an interfering SatPaq pointing correctly is an angle of 30 degrees out of 360 degrees (30/360) or 0.083.[16] Hence, (Probability that a SatPaq is pointing toward a PtP receiver) = Pointing Probability = 0.083.

Finally, let's determine the probability that there is at least one PtP receiver in a RAC bin. (Should there be no PtP receivers in the bin, there is then no possibility of interference.) This number is the number of north-facing receivers divided by the number of RAC bins (10,000 / 237,500) or 0.042. Hence, (Probability that there would be a PtP Receiver in a RAC bin) = PtP Rx Probability = 0.042.

[16] This number comes from the worst case pointing error of +- 15 degrees (see Section A.7.2)

Thus, the probability of a SatPaq causing interference to a PtP receiver when there is at least one SatPaq in that RAC bin, P(Interference), is the multiplication of SatPaq Probability x Pointing Probability x PtP Rx Probability or:

P (Interference) = 1.0 x 0.083 x 0.042 or 0.003486

We now compute the average rate at which the messages are transmitted in a RAC bin. This rate, Message Rate, is [(Average Number of SatPaqs in a bin or "Density")* ((Message Rate of one SatPaq)] = [(4.21)* (5/(30x24x3600))] or [4.21 SatPaqs* 1.9e-6 msgs/second for one SatPaq] = 8e-6 msgs/second. Call this "Message Rate."

Hence, an approximate average time interval between a random interference at a single PtP receiver followed by the second interference at that same PtP receiver, as mentioned above, is 1/[: (Message Rate) x (P(Interference))] or Time Interval between Interference Occurrences = 1 / (8e-6 x 0.003486) or about 35 million seconds. This equates to 405 days or about 13 months.

In summary: *with complete un-coordination there would be one 2-second message occurrence every 13 months to a single PtP receiver if there are one million SatPaqs.* This is the ceiling number. This says that if the self-coordination process was ineffectual and/or if the data in the ULS database was completely inaccurate, the time between interference from a million SatPaqs to a single PtP receiver would be 13 months. Self-coordination will (of course) provide a robust interference protection regime. But this analysis serves to demonstrate that even in an un-coordinated scenario, the SatPaq simply would not cause harmful interference.

### A.8.1.9 Cognitive Sharing of Frequencies

Here we explain the mathematics to determine the number of independent channels needed so that a non-overlapping channel can be found.

Statistical analysis can be used to find the number of channels needed to maintain a certain level of performance. We will use for this analysis our standard Protection Zone with a 50-mile length triangle and a 20-degree acceptance cone.

In order for a SatPaq (in the Northern Hemisphere) to communicate with a geosynchronous satellite, it will need to be pointed southwards toward the satellite. Therefore, only PtP receiver acceptance cones that are north-facing (one half) warrant review.[17]

Of these 50%, only those whose 20-degree Protection Zone cone lines up with the SatPaq to satellite vector will pick up the SatPaq transmission. Again because of uniform distribution, each 20-degree orientation slot is a 1/18 probability. The total probability of interference is then 1/18 times 1/2 or 1/36.

> The probability of a non-overlapping transmission is 1 minus the probability of a problematic transmission or (1 - 1/36) or 35/36. The probability of a non-overlapping transmission in the presence of two PtP receivers is (35/36) x (35/36) or $(35/36)^2$. To transmit safely on a channel with R number of receivers, the probability is $(35/36)^R$.
>
> Or for given R, the probability (P) of a success (non-overlapping transmit) is $Ps=(35/36)^R$. The probability that the SatPaq transmission would cause interference to one or more PtP receivers (i.e. the probability of failure if we have only one channel that is shared) is Pf = (1-Ps).

Now let's discuss the concept of N multiple channels (or frequencies). If instead of one channel with R receivers, there are two channels each with R receivers, then the chance of a successful (non-overlapping) transmission is higher.

> This is the same as doing two trials independently. Mathematically it's the same if we reshuffled the receivers and checked again if we were still non-overlapping (binomial distribution). At least one of these trials needs to work. The probability of at least one of the two trials succeeding is the sum of the probability that both succeeded and the probability that only one succeeded. All we need is at least one trial (channel) to work and it can happen multiple ways so the probabilities are summed.

### For 2 Channels

$$P(\text{at least one success}) = \underbrace{P_s^2}_{\text{(both succeed)}} + \underbrace{2 P_s P_f}_{\text{(only one works)}}$$

[17] For simplicity, we will use the Close Proximity Circle around each PtP receivers (North and South) as a no-transmit zone; irrespective of the SatPaq transmit orientation, although finer calculations could show otherwise.

The second term is multiplied by 2 because a) either the first channel could work and the second will not OR b) the first will not work and the second could. This comes from N choose K; where N is number of channels and K is how many we want to work successfully.

### For 3 Channels

For 3 channels, we need either all three to work, two to work or one to work. All these probabilities need to be summed up and multiplied by the appropriate N choose K coefficient. (There are 3 ways only two of the three could work and 3 ways only 1 of the 3 could work.)

$$P(\text{at least one success}) = P_s^3 + 3*P_s^2*P_f + 3*P_s*P_f^2$$

Now let's discuss the concept of receiver density. The receiver density determines how many PtP receivers are within the 50 mile circle around the SatPaq. **The 50 mile radius has an area of approximately 7850 square miles. This area, multiplied by the likely PtP** density,[18] gives the number of receivers in the area - we call this *R*. From analyzing the ULS database, a typical value for R is about three PtP receivers sharing the same channel in this 50 mile radius region. To be conservative, we will double this. This zone is highlighted in yellow.

| | N = 1 | N = 2 | N = 3 | N = 4 |
|---|---|---|---|---|
| **P (ok to xmit) for R = 6** | 0.844 | 0.975 | 0.996 | 0.999 |
| **P (ok to xmit) for R = 8** | 0.798 | 0.959 | 0.992 | 0.998 |
| **P (ok to xmit) for R = 10** | 0.754 | 0.939 | 0.985 | 0.996 |

**Table A-4 - Probability of Successful Communications using Frequency Diversity**

From this data it shows that with only two channels to choose from, the SatPaq could find a non-interfering channel over 90% of the time. In an area of higher density, it may make sense to go to three channels. It does not take too many additional channels to build a high confidence of communications.

[18] There are approximately 20,000 active PtP receivers. There are 3.8 million square miles in the US. Half of the PtP receivers are pointed north and there are 8 PtP (mainly 30 MHz) channels. Therefore, the typical PtP channel density is 0.0004 per square mile.

Not included in this calculation is the SatPaq ability to operate in an orthogonal polarization to avoid any interference.  This improvement will also greatly increase the probabilities.

### A.8.2 Protection from Satellite Downlink Interference

The SatPaq network complies with FCC and ITU power flux density limits designed to protect the terrestrial PtP radio links from downlink interference. *See* 47 C.F.R. § 25.208(c).  A table of compliance for each of the three initial geosynchronous satellites (Galaxy 12, Galaxy 3c, and Galaxy 19) is provided in Tables A-5, A-6 and A-7.

We may choose to increase the forward EIRP, but will in all cases stay below the PFD mask.

Digital Carrier (250KG2D)

| Elevation Angle (deg.) | 0 | 5 | 10 | 15 | 20 | 25 | 90 |
|---|---|---|---|---|---|---|---|
| **EIRP (dBW)** | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| **Occupied BW (KHz)** | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| **D/L EIRP Density (dBW/4 KHz)** | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 |
| **Spreading Loss (dB/m$^2$)** | 163.4 | 163.3 | 163.2 | 163.0 | 162.9 | 162.8 | 162.1 |
| **Max. PFD (dB/m$^2$/4 KHz)** | -152.4 | -152.3 | -152.2 | -152.0 | -151.9 | -151.8 | -151.1 |
| **PFD Limit (dB/m$^2$/4KHz)** | -152 | -152 | -149.5 | -147 | -144.5 | -142 | -142 |
| **Margin (dB)** | 2.4 | 2.3 | 4.7 | 7.0 | 9.4 | 11.8 | 11.1 |

**Table A-5 - Power Flux Density Calculations for Galaxy 12**

Digital Carrier (250KG2D)

| Elevation Angle (deg.) | 0 | 5 | 10 | 15 | 20 | 25 | 90 |
|---|---|---|---|---|---|---|---|
| **EIRP (dBW)** | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| **Occupied BW (KHz)** | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| **D/L EIRP Density (dBW/4 KHz)** | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Spreading Loss ($dB/m^2$)** | 163.4 | 163.3 | 163.2 | 163.0 | 162.9 | 162.8 | 162.1 |
| **Max. PFD ($dB/m^2/4$ KHz)** | -152.1 | -152.0 | -151.1 | -151.0 | -150.9 | -150.8 | -150.1 |
| **PFD Limit ($dB/m^2/4KHz$)** | -152 | -152 | -149.5 | -147.0 | -144.5 | -142 | -142 |
| **Margin (dB)** | 2.4 | 2.3 | 4.7 | 7.0 | 9.4 | 11.8 | 11.1 |

**Table A-6 - Power Flux Density Calculations for Galaxy 3c**

Digital Carrier (250KG2D)

| **Elevation Angle (deg.)** | **0** | **5** | **10** | **15** | **20** | **25** | **90** |
|---|---|---|---|---|---|---|---|
| **EIRP (dBW)** | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| **Occupied BW (KHz)** | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| **D/L EIRP Density (dBW/4 KHz)** | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 |
| **Spreading Loss ($dB/m^2$)** | 163.4 | 163.3 | 163.2 | 163.0 | 162.9 | 162.8 | 162.1 |
| **Max. PFD ($dB/m^2/4$ KHz)** | -152.4 | -152.3 | -152.2 | -152.0 | -151.9 | -151.8 | -151.1 |
| **PFD Limit ($dB/m^2/4KHz$)** | -152 | -152 | -149.5 | -147.0 | -144.5 | -142 | -142 |
| **Margin (dB)** | 2.4 | 2.3 | 4.7 | 7.0 | 9.4 | 11.8 | 11.1 |

**Table A-7 - Power Flux Density Calculations for Galaxy 19**

## A.9 Radiation Hazard Analysis

The study in this section analyzes the potential RF human exposure levels that could result from the Electro Magnetic (EM) fields of a Higher Ground 5.9 GHz Quad Patch antenna, operating with a maximum power at the antenna connector of 1 Watt. The mathematical analysis performed below complies with the methods described in the FCC's Office of Engineering and Technology, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields: Additional Information for Amateur Radio Stations*, Supplement B to OET Bulletin 65 (Ed. 97-01, Nov. 1997) ("OET-65").

OET-65 defines "mobile devices" as transmitting devices designed to be used in other than fixed locations. The SatPaq is a general population (consumer) product that fits this definition.

Mobile devices are to be evaluated with respect to the Maximum Permissible Exposure (MPE) limits defined in Section 1.1310 of the FCC rules:

For frequencies above 1500 MHz and for the general population:

- Uncontrolled Exposure Limit: 1.0 $mW/cm^2$ – averaged over 30 minutes (defined by device duty cycle).

- Furthermore, mobile devices must be used in such a way that the separation distance of at least 20 cm is normally maintained between the transmitter's radiating structure and the body of the user or nearby person.

The SatPaq has a maximum RF power out of the amplifier of 1 watt. The maximum antenna gain for the transmit antenna (far-field) is 9 dBi.[19] This means that the maximum EIRP of the SatPaq in any direction is 9 dBW.

The SatPaq's lithium power cell defines the device duty cycle. The battery can only source high current for peak pulses of duration 5 seconds or less. Thereafter, the battery cannot provide high current for the next 5 seconds. This 50% peak duty cycle limit will be managed via microcomputer control for the device. In normal use, SatPaqs are expected to average approximately 5 messages by satellite per month.

In addition, the SatPaq has an inherent 20 cm, break-beam infrared sensor on the antenna. If any obstruction is within 20 cm from the antenna, the transmit beam will be immediately turned off.

Now we compute the power density at the minimal distance. The equation is shown below.

---

[19] This analysis is performed for the far field region ($2D^2/\lambda$) only because with an antenna this small (5 cm x 5 cm), the far field region begins very close to the antenna itself and certainly within the limits appropriate to Maximum Permissible Exposure.

$$S\ (mw/cm^2) = (EIRP) / 4 * pi * R^2 * Duty\ Cycle$$

$$S = ((7.9) / ( 4 * 3.14 * 400)) * 0.5$$

At the minimal distance of = 20 cm, the field strength is 0.78 $mw/cm^2$. This is below the limit of 1 $mw/cm^2$.

The following parameters were used in the calculation:

| Input Parameter | Value | Unit | Notes |
|---|---|---|---|
| Antenna Size | 5 x 5 | cm | |
| Antenna Transmit Gain | 9 | dBi | |
| Transmit Frequency | 5.9 to 6.4 | GHz | |
| Power Input to the Antenna | 1 | Watts | |
| EIRP (dBW) | 9 | dBW | |
| EIRP (watts) | 7.9 | watts | |
| Max. Device Duty Cycle (TDMA) | 50 | % | Over 10 sec. |