**Before the**
**Federal Communications Commission**
**Washington, DC 20554**

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| Kymeta Corporation Application for Blanket License to Operate 5,000 Ku-Band Transmit/Receive Vehicle Mounted Earth Stations (VMESs") and 1,000 Ku-Band Transmit/Receive Earth Stations on Vessels ("ESVs") | )<br>)<br>)<br>) | File No. SES-LIC- ___________<br>Call Sign: ___________________ |

## APPLICATION FOR BLANKET LICENSE

Kymeta Corporation ("Kymeta") respectfully requests that the Commission grant a blanket license authorizing Kymeta to operate 5,000 Ku-band technically identical transmit/receive vehicle mounted earth stations ("VMESs") and 1,000 transmit/receive earth stations on vessels ("ESVs") operating in Ku-band Fixed Satellite Service ("FSS") frequencies. Grant of the requested authority is consistent with Commission rules, policy and precedent, and will serve the public interest by enabling Kymeta to deploy its innovative broadband mobility terminals to serve a wide variety of customers.

## I. INTRODUCTION

Kymeta has developed an innovative, next-generation antenna for satellite communications that will reduce the cost of broadband deployment and enable entirely new applications for satellite technology. The Kymeta flat panel antenna uses software and metamaterials technology to electronically and dynamically steer the antenna beam from a flat thin film transistor ("TFT") panel to track the target satellite. The Kymeta technology enables thinner, lighter, more efficient, and less expensive antennas compared to traditional satellite antenna technologies. The reduced cost and form factor offer the potential to substantially broaden not only the scope of uses, but also the addressable market for satellite technologies. This application represents the first implementation of this new technology – broadband mobility for certain vehicular and maritime applications using Ku-band FSS spectrum.

## II. DESCRIPTION OF KYMETA KYWAY TERMINAL

Kymeta's KyWay 1 terminal (the "Terminal") uses software and metamaterials technology to electronically and dynamically steer the antenna beam from a flat thin film transistor ("TFT") panel to track the target satellite. The KyWay 1 Terminal combines transmit and receive capabilities in a single aperture (although the transmit and receive functions are controlled separately). In VMES applications, the antenna will be mounted horizontally on the top of a vehicle (such as a train, bus, commercial truck, or a civilian armored vehicle). In ESV applications, the antenna will typically be mounted on a platform or surface at or near the highest point of the vessel.

The Terminal uses electronic beam steering to track the target satellite. The receive antenna employs a closed-loop pointing algorithm to track the target satellite with the transmit antenna pointing being continuously slaved to the resulting pointing vector.

Table 1 summarizes important transmit and receive characteristics of the Terminal.

**Table 1. KyWay Terminal Characteristics**

| **Specification** | **Antenna and Terminal Data** |
|---|---|
| Antenna dimensions | 70 cm diameter (antenna is circular) |
| Transmit Band | 14.0 – 14.5 GHz |
| Receive Band | 10.95 – 11.2 GHz; 11.45 – 11.7 GHz; and 11.7 – 12.2 GHz<br><br>Note: Kymeta does not claim interference protection from any authorized terrestrial stations for downlink operations in the 10.95 – 11.2 GHz and 11.45 – 11.7 GHz bands. |
| Maximum EIRP | 47 dBW @ 0 degree scan |
| Transmit Gain | 32.9 dBi at 14.0 GHz |
| Polarization | Linear or circular |

## III. The Commission Has Previously Granted Authorization for Mobile Ku-band FSS Flat Panel Antennas

The Commission has considerable experience in reviewing and granting authorization for Ku-band flat panel antennas, including antennas with electronically steered beams, as follows:

- In 2001, the Commission granted authority for The Boeing Company ("Boeing") to operate up to 800 Ku-band electronically steered flat panel phased-array mobile earth stations aboard aircraft earth stations.[1]

- In 2013, the Commission granted authority for ThinKom Solutions, Inc. to operate a flat panel VMES terminal.[2] The Commission also granted authority for the terminal to communicate with any satellite on the Permitted Space Station List.

- In 2014, the Commission granted authority for Gogo LLC ("Gogo") to modify an existing blanket license to add up to 1000 ThinKom flat panel earth station aboard aircraft ("ESAA") terminals.[3]

- In 2015, the Commission granted authority for Boeing to operate up to 100 ESAA terminals, including electronically and mechanically steered, phased-array flat panel antennas.[4]

- In 2016, the Commission granted authority for Panasonic Avionics Corporation to add up to 1000 single-panel, phased array antennas to its existing ESAA blanket license.[5]

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[1] File No. SES-LIC-200011204-0230, Call Sign E000723, granted Dec. 21, 2001 by *Order and Authorization*, DA-01-30008, 16 FCC Rcd 22645 (Int'l Bureau). Grant of this application included a waiver of the Aeronautical Mobile Satellite Service rules.

[2] File No. SES-LIC-20120822-00768, Call Sign E120174, granted March 8, 2013 (Int'l Bureau).

[3] File No. SES-MFS-20140801-00625, Call Sign E120106, granted Dec. 22, 2014 (Int'l Bureau). The ThinKom antenna, which is based on variable inclination continuous transverse stub ("VICTS") array technology, implicates issues similar to those of other flat panel antennas.

[4] File No. SES-LIC-20140922-00748, Call Sign E140097, granted March 13, 2015 (Int'l Bureau).

[5] File No. SES-MFS-20160819-00730, Call Sign E100089, granted October 26, 2016 (Int'l Bureau).

## IV. KYMETA'S TERMINAL COMPLIES WITH THE RULES IN SECTION 25.222 GOVERNING ESVs AND SECTION 25.226 GOVERNING VMESs

Kymeta's Terminal complies with all relevant provisions of Sections 25.222 and 25.226.

Table 2 provides a summary of these requirements.

**Table 2**
**Information Required by Sections 25.222 and 25.226**
**(Vehicle Mounted Earth Stations)**

| Requirement | Citation to Information Provided | Text Discussion |
|---|---|---|
| ESV:<br>25.222(a)(1)(i)(A), (B), and (C);<br>25.222(b)(1)<br><br>VMES:<br>25.226(a)(1)(i)(A), (B), and (C);<br>25.226(b)(1) | Compliance with off-axis EIRP spectral density standards<br><br>Note: These provisions incorporate Section 25.115(g)(1). | IV.A |
| ESV:<br>25.222(a)(1)(ii)(A);<br>25.222(b)(1)(iii)<br><br>VMES:<br>25.226(a)(1)(ii)(A);<br>25.226(b)(1)(iii) | Certification (from the equipment manufacturer) stating that the antenna tracking system will maintain a pointing error of less than or equal to 0.2° between the orbital location of the target satellite and the axis of the main lobe of the earth station antenna. | IV.B |
| ESV:<br>25.222(a)(1)(iii)(A);<br>25.222(b)(1)(iii)<br><br>VMES:<br>25.226(a)(1)(iii)(A);<br>25.226(b)(1)(iii) | Certification (from the equipment manufacturer) that the antenna tracking system is capable of ceasing emissions within 100 milliseconds if the angle between the orbital location of the target satellite and the axis of the main lobe exceeds 0.5°, and transmission shall not resume until such angle is less than or equal to 0.2°. | IV.C |
| ESV: 25.222(a)(3)<br><br>VMES: 25.226(a)(3) | Not applicable. Kymeta's Terminals do not simultaneously transmit in the same frequencies to the same target satellite. | IV.D |
| 25.226(a)(4) | Not applicable: Kymeta is not planning to use a contention protocol. | IV.E |

| | | |
|---|---|---|
| ESV: 25.222(a)(4); 25.222(b)(5)<br><br>VMES: 25.226(a)(5); 25.226(b)(6) | 24/7 Point of Contact in the U.S. (including phone number and address), with authority and ability to cease all emissions from the earth stations: | IV.F |
| ESV: 25.222(a)(5)<br><br>VMES: 25.226(a)(6); 25.226(b)(6) | A certification that the applicant shall comply with the requirement to record and retain transmit data for each earth station. | IV.G |
| ESV: 25.222(a)(6) | Operators communicating with vessels of foreign registry must maintain detailed information on each vessel's country of registry and a point of contact for the relevant administration responsible for licensing ESVs. | IV.H |
| ESV: 25.222(a)(7) | Operators shall control all ESVs by a Hub earth station located in the United States, with limited exception. | IV.I |
| VMES: 25.226(a)(9); 25.226(b)(8) | Applicant shall demonstrate that the earth station is capable of automatically ceasing transmission upon the loss of synchronization or within five seconds upon loss of reception of satellite downlink signal, whichever is shorter. | IV.J |
| ESV: 25.222(b)<br><br>VMES: 25.226(b) | FCC Form 312 and associated Schedule B. | IV.K |
| ESV: 25.222(b)(4)<br><br>VMES: 25.226(b)(4) | An exhibit describing the geographic areas in which the earth stations will operate. | IV.L |
| ESV: 25.222(b)(6)<br><br>VMES: 25.226(b)(8) | ESV and VMES: Applicant shall submit a radio frequency hazard analysis. | IV.M |
| ESV: 25.222(c)<br><br>VMES: 25.226(c)(1) and (2) | Protection of NASA TDRSS Facilities operating in the 14.0 – 14.2 GHz band: The terminal will use GPS to ensure compliance. | IV.N |
| ESV: 25.222(d)<br><br>VMES: 25.226(d)(1) | Protection of Radio Astronomy Services (RAS) operating in the 14.47 – 14.5 GHz band: The terminal will use GPS to ensure compliance. | IV.O |
| Points of communications | Permitted Space Station List | IV.P |

**A. Off-Axis EIRP Spectral Density**

Kymeta's Terminal complies with the off-axis effective isotropically radiated power ("EIRP") power spectral density ("PSD") standards (the "off-axis mask") set forth in Sections 25.222(a)(1)(i) and 25.226(a)(1)(i). Exhibits A and B to the Technical Appendix consist of comprehensive tables and a series of measured antenna patterns demonstrating compliance with the off-axis mask.

**B. Antenna Pointing and Tracking**

Kymeta certifies that the Terminal's tracking system will maintain a pointing error of less than or equal to 0.2 degrees between the orbital location of the target satellite and the axis of the main lobe of the earth station antenna. The receive antenna employs a closed loop pointing algorithm to track the target satellite with the transmit antenna pointing being continuously slaved to the resulting pointing vector. The tracking algorithm is resistant to capture by adjacent satellite signals and is capable of ceasing its own transmission in the event that it detects unintended satellite tracking and tracking errors in excess of 0.5 degrees.

**C. Cessation of Emissions**

Kymeta certifies that the Terminal's tracking system is capable of ceasing emissions within 100 milliseconds if the angle between the orbital location of the target satellite and the axis of the main lobe exceeds 0.5 degrees, and that transmission will not resume until such angle is less than or equal to 0.2 degrees. The receive antenna employs a closed loop pointing algorithm to track the target satellite with the transmit antenna pointing being continuously slaved to the resulting pointing vector. The Terminal employs self-monitoring and issues a mute command to the transmit modem when a tracking problem is encountered. The detection and mute function execution is done in less than 100 milliseconds.

### D. Variable Power Control

Kymeta's Terminals transmit on individually assigned frequencies and time slots. As a result, regardless of the number of authorized terminals, only one terminal transmits to any given satellite at any given time – and thus, the addition of terminals will not increase the risk of interference.

### E. Contention Protocol

Kymeta does not, at this time, plan to use contention protocol. If in the future Kymeta implements contention protocol, Kymeta certifies that it will ensure that such use will be reasonable in order to prevent harmful interference to authorized spectrum users.

### F. Point of Contact

A 24/7 point of contact with the authority and ability to cease all emissions from the earth stations will be maintained.

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### G. Recording and Retention of Transmit Data

Kymeta certifies that the transmit data for each Terminal will be recorded and retained as required. Specifically, data will be recorded at time intervals of no greater than every five minutes for VMES terminals and twenty minutes for ESV terminals while the earth station is transmitting. The following data will be recorded: vehicle or vessel location (latitude/longitude), transmit frequency, channel bandwidth and satellite used. These records will be time annotated and maintained for at least one year.

**H. Communications with Vessels of Foreign Registry**

For ESV operations from vessels of foreign registry, the following information will be maintained: detailed information on each vessel's country of registry and a point of contact for the relevant administration responsible for licensing the ESV. ESVs on foreign vessels will be operated in accordance with the FCC's rules and relevant terms of any license granted to Kymeta by the Commission.

**I. Location of Hub Earth Stations for ESV Operations**

All operations, regardless of the location of the gateway earth station, will be controlled by a Network Operations Center in the United States and that NOC will have the capability and authority to cause an ESV on a U.S.-registered vessel to cease transmitting if necessary.

The Terminals will be operated across the globe, sometimes with satellites that do not have a "footprint" in the United States. It will not be possible, then, to control all ESVs by a gateway earth station located in the United States. To the extent necessary, Kymeta seeks a waiver of Section 25.222(a)(8) which requires that "operators shall control all ESVs by a Hub earth station located in the United States …" in the case of certain operations by non-U.S.-registered vessels communicating with a gateway earth station not located in the United States. As noted above, regardless of the location of the gateway earth station, ESV operations will be controlled by a Network Operations Center in the United States and that NOC will have the capability and authority to cause an ESV on any vessel, regardless of the flag country, to cease transmitting if necessary.

**J. Cessation of Transmission upon Loss of Synchronization or Satellite Reception**

The Terminal automatically ceases transmission upon the loss of synchronization or within 100 milliseconds upon loss of reception of the satellite downlink signal, whichever is shorter. The transmit modem function will only operate in the presence of a receive signal. Any loss of lock or synchronization of the receive signal will automatically cause cessation of transmissions.

**K. FCC Form 312 and Schedule B**

Kymeta has completed and submitted FCC Form 312 and Schedule B, together with the required application fee.

**L. Geographic Areas in Which the Earth Station will Operate**

Kymeta requests authority to operate the VMES and ESV Terminals in the continental United States ("CONUS"), Alaska, Hawaii, and U.S. territories and possessions, as well as territorial and international waters (in the case of ESVs).

**M. Radio Frequency Hazard Analysis**

Kymeta provides a radio frequency ("RF") hazard analysis as Exhibit C to the Technical Appendix. Kymeta also states that installation of VMES terminals will be performed by qualified installers.

**N. Points of Communication**

Kymeta seeks authority to communicate with all satellites on the Permitted Space Station List.

**O. Protection of NASA TDRSS Facilities**

VMES and ESV licensees proposing to operate in the 14.0-14.2 GHz (Earth-to-space) frequency band within 125 km of the NASA Tracking and Data Relay Satellite System ("TDRSS') facilities at Guam and White Sands, New Mexico are subject to coordination with NASA through NTIA's Interdepartmental Radio Advisory Committee (IRAC). Kymeta will use GPS to ensure that it does not operate in the 14.0 – 12.2 GHz sub-band within 125 km of NASA's TDRSS facilities at Guam and White Sands until and unless it completes such coordination. Kymeta acknowledges that it is required to notify the International Bureau once it has completed such coordination.

**P. Protection of Radio Astronomy Services ("RAS")**

VMES and ESV licensees proposing to operate in the 14.47 – 14.5 GHz sub-band in the vicinity of RAS observatories observing in the 14.47-14.5 GHz band are subject to coordination with the National Science Foundation ("NSF"). Kymeta will use GPS to ensure that it does not operate in the 14.47 – 14.5 GHz sub-band within the delineated coordination radius of the RAS facilities listed in Table 1 to Section 25.226(d)(2) until and unless it completes such coordination. Kymeta acknowledges that it is required to notify the International Bureau once it has completed such coordination.

## V. PUBLIC INTEREST SHOWING

Kymeta has developed an innovative, next generation Terminal for satellite communications that will reduce the cost of broadband deployment and enable entirely new uses of satellite technology. The Kymeta technology enables thinner, lighter, more efficient, and less expensive antennas compared to traditional satellite antenna technologies. The reduced cost and form factor offer the potential to substantially broaden not only the scope of uses, but also the addressable market for satellite technologies. This application represents the first implementation of this new technology – broadband mobility for certain vehicular and maritime applications using Ku-band FSS spectrum.

## VI. CONCLUSION

Kymeta requests that the Commission expeditiously grant this application for a blanket license.

Respectfully submitted,

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February 23, 2017

# TECHNICAL APPENDIX

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## EXHIBIT A

## DESCRIPTION OF THE TERMINAL

Kymeta has developed an innovative, next generation antenna for satellite communications that will reduce the cost of broadband deployment and enable entirely new uses of satellite technology. Kymeta's KyWay 1 terminal (the "Terminal") uses software and metamaterials technology to electronically and dynamically steer the antenna beam from a flat, thin film transistor ("TFT") panel to track the target satellite. The Terminal combines transmit and receive capabilities in a single aperture.

Off-axis EIRP spectral density is managed on an individual terminal basis. Only one terminal transmits at a given time and in a given bandwidth so management of aggregate emissions is not required. The off-axis EIRP spectral density of an individual terminal is a function of its transmit signal bandwidth, input power to the antenna, the projection of the antenna gain pattern along the geostationary arc, and antenna pointing error. Input power to the terminal is controlled by limiting the output power of the modem. Integrated software monitors the scan and skew angles and automatically adjusts the output power of the modem.

One attribute of an electronically steered flat panel antenna is its level of scan loss. Scan loss refers to the decrease in gain that occurs as a flat panel antenna operates at an increased scan angle. The antenna gain falls off nearly as the cosine of the scan angle. The design specifications for the Terminal allow for operating scan angles of up to 75° (*i.e.* 15° elevation angle). At a minimum, the Terminal can acquire and maintain track within a cone extending to a 75 degree scan from vertical over a full 360 degrees of azimuth.

Flat panel antennas by nature exhibit changes in antenna pattern (especially sidelobe content) as a function of scan angle. Kymeta conducted extensive testing of its antenna to ensure compliance with FCC regulations. In Table 1 below, Kymeta includes data for 16 test cases that are representative of the overall antenna performance. For these 16 test cases, Kymeta submits PSD plots and PSD vs. off-axis angle data. In Table 2 below, Kymeta submits a summary table of expected performance for a total of 96 test cases, evaluating two frequencies, four theta angles, three phi planes, two polarizations, and two skew orientations.

*Table 1: Highlighted test cases and expected performance*

| Theta | Phi | LPA | Skew | Freq | PSD Max | % Exceedance Spurious Sidelobes |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 14 | 16.38 | 0% |
| 0 | 0 | 0 | 0 | 14.5 | 13.07 | 0% |
| 0 | 0 | 0 | 90 | 14 | 14.9 | 0% |
| 0 | 0 | 0 | 90 | 14.5 | 13.54 | 0% |
| 30 | 0 | 0 | 0 | 14 | 16.29 | 0% |
| 30 | 0 | 0 | 0 | 14.5 | 16.59 | 0% |
| 30 | 0 | 0 | 90 | 14 | 14.97 | 1% |
| 30 | 0 | 0 | 90 | 14.5 | 15.06 | 1% |
| 45 | 0 | 0 | 0 | 14 | 14.82 | 0% |
| 45 | 0 | 0 | 0 | 14.5 | 15.53 | 0% |
| 45 | 0 | 0 | 90 | 14 | 13.03 | 1% |
| 45 | 0 | 0 | 90 | 14.5 | 12.01 | 2% |
| 60 | 0 | 0 | 0 | 14 | 13.08 | 0% |
| 60 | 0 | 0 | 0 | 14.5 | 13.22 | 0% |
| 60 | 0 | 0 | 90 | 14 | 9.09 | 0% |
| 60 | 0 | 0 | 90 | 14.5 | 9.95 | 4% |

*Table 2: Overall summary with 96 test cases*

| Theta | Phi | LPA | Skew | Freq | PSD Max | % Exceedance Spurious Sidelobes |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 14 | 16.38 | 0% |
| 0 | 0 | 0 | 0 | 14.5 | 13.07 | 0% |
| 0 | 0 | 0 | 90 | 14 | 14.9 | 0% |
| 0 | 0 | 0 | 90 | 14.5 | 13.54 | 0% |
| 0 | 0 | 90 | 0 | 14 | 15.75 | 0% |
| 0 | 0 | 90 | 90 | 14 | 17.81 | 0% |
| 0 | 0 | 90 | 90 | 14.5 | 12.93 | 0% |
| 0 | 110 | 0 | 0 | 14 | 16.18 | 0% |
| 0 | 110 | 0 | 0 | 14.5 | 12.23 | 0% |
| 0 | 110 | 0 | 90 | 14 | 16.46 | 0% |
| 0 | 110 | 0 | 90 | 14.5 | 15.48 | 0% |
| 0 | 110 | 90 | 0 | 14 | 16.41 | 0% |
| 0 | 110 | 90 | 0 | 14.5 | 13.62 | 0% |
| 0 | 110 | 90 | 90 | 14 | 16.62 | 0% |
| 0 | 110 | 90 | 90 | 14.5 | 15.67 | 0% |
| 0 | 260 | 0 | 0 | 14 | 15.4 | 0% |
| 0 | 260 | 0 | 0 | 14.5 | 11.78 | 0% |
| 0 | 260 | 0 | 90 | 14 | 15.38 | 0% |
| 0 | 260 | 0 | 90 | 14.5 | 13.99 | 0% |
| 0 | 260 | 90 | 0 | 14 | 16.23 | 0% |
| 0 | 260 | 90 | 0 | 14.5 | 13.64 | 0% |
| 0 | 260 | 90 | 90 | 14 | 17.04 | 0% |
| 0 | 260 | 90 | 90 | 14.5 | 11.68 | 0% |
| 30 | 0 | 0 | 0 | 14 | 16.29 | 0% |
| 30 | 0 | 0 | 0 | 14.5 | 16.59 | 0% |
| 30 | 0 | 0 | 90 | 14 | 14.97 | 1% |
| 30 | 0 | 0 | 90 | 14.5 | 15.06 | 1% |
| 30 | 0 | 90 | 0 | 14 | 16.32 | 0% |
| 30 | 0 | 90 | 0 | 14.5 | 15.57 | 0% |
| 30 | 0 | 90 | 90 | 14 | 15.32 | 0% |
| 30 | 0 | 90 | 90 | 14.5 | 16.04 | 2% |
| 30 | 110 | 0 | 0 | 14 | 16.44 | 0% |
| 30 | 110 | 0 | 0 | 14.5 | 16.77 | 0% |
| 30 | 110 | 0 | 90 | 14 | 14.2 | 0% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 30 | 110 | 0 | 90 | 14.5 | 16.51 | 0% |
| 30 | 110 | 90 | 0 | 14 | 16.97 | 0% |
| 30 | 110 | 90 | 0 | 14.5 | 17.37 | 0% |
| 30 | 110 | 90 | 90 | 14 | 15.73 | 1% |
| 30 | 110 | 90 | 90 | 14.5 | 16.37 | 0% |
| 30 | 260 | 0 | 0 | 14 | 16.25 | 0% |
| 30 | 260 | 0 | 0 | 14.5 | 16.74 | 0% |
| 30 | 260 | 0 | 90 | 14 | 13.45 | 0% |
| 30 | 260 | 0 | 90 | 14.5 | 14.96 | 0% |
| 30 | 260 | 90 | 0 | 14 | 16.9 | 0% |
| 30 | 260 | 90 | 0 | 14.5 | 16.93 | 0% |
| 30 | 260 | 90 | 90 | 14 | 15.84 | 0% |
| 30 | 260 | 90 | 90 | 14.5 | 16.1 | 0% |
| 45 | 0 | 0 | 0 | 14 | 14.82 | 0% |
| 45 | 0 | 0 | 0 | 14.5 | 15.53 | 0% |
| 45 | 0 | 0 | 90 | 14 | 13.03 | 1% |
| 45 | 0 | 0 | 90 | 14.5 | 12.01 | 2% |
| 45 | 0 | 90 | 0 | 14 | 16.19 | 0% |
| 45 | 0 | 90 | 0 | 14.5 | 15.96 | 0% |
| 45 | 0 | 90 | 90 | 14 | 13 | 0% |
| 45 | 0 | 90 | 90 | 14.5 | 13.99 | 1% |
| 45 | 110 | 0 | 0 | 14 | 14.89 | 0% |
| 45 | 110 | 0 | 0 | 14.5 | 15.92 | 1% |
| 45 | 110 | 0 | 90 | 14 | 10.91 | 0% |
| 45 | 110 | 0 | 90 | 14.5 | 14.15 | 0% |
| 45 | 110 | 90 | 0 | 14 | 15.52 | 0% |
| 45 | 110 | 90 | 0 | 14.5 | 16 | 0% |
| 45 | 110 | 90 | 90 | 14 | 13.62 | 0% |
| 45 | 110 | 90 | 90 | 14.5 | 14.08 | 0% |
| 45 | 260 | 0 | 0 | 14 | 14.85 | 0% |
| 45 | 260 | 0 | 0 | 14.5 | 15.28 | 0% |
| 45 | 260 | 0 | 90 | 14 | 12.06 | 0% |
| 45 | 260 | 0 | 90 | 14.5 | 11.27 | 0% |
| 45 | 260 | 90 | 0 | 14 | 16.04 | 0% |
| 45 | 260 | 90 | 0 | 14.5 | 15.93 | 0% |
| 45 | 260 | 90 | 90 | 14 | 12.24 | 0% |
| 45 | 260 | 90 | 90 | 14.5 | 13.11 | 1% |
| 60 | 0 | 0 | 0 | 14 | 13.08 | 0% |
| 60 | 0 | 0 | 0 | 14.5 | 13.22 | 0% |
| 60 | 0 | 0 | 90 | 14 | 9.09 | 0% |
| 60 | 0 | 0 | 90 | 14.5 | 9.95 | 4% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 60 | 0 | 90 | 0 | 14 | 14.68 | 0% |
| 60 | 0 | 90 | 0 | 14.5 | 14.63 | 0% |
| 60 | 0 | 90 | 90 | 14 | 9.16 | 0% |
| 60 | 0 | 90 | 90 | 14.5 | 10.18 | 0% |
| 60 | 110 | 0 | 0 | 14 | 13.54 | 0% |
| 60 | 110 | 0 | 0 | 14.5 | 14.16 | 0% |
| 60 | 110 | 0 | 90 | 14 | 7.12 | 0% |
| 60 | 110 | 0 | 90 | 14.5 | 9.68 | 0% |
| 60 | 110 | 90 | 0 | 14 | 14.55 | 0% |
| 60 | 110 | 90 | 0 | 14.5 | 14.4 | 0% |
| 60 | 110 | 90 | 90 | 14 | 9.68 | 0% |
| 60 | 110 | 90 | 90 | 14.5 | 10.02 | 0% |
| 60 | 260 | 0 | 0 | 14 | 12.83 | 0% |
| 60 | 260 | 0 | 0 | 14.5 | 13.6 | 0% |
| 60 | 260 | 0 | 90 | 14 | 9.36 | 0% |
| 60 | 260 | 0 | 90 | 14.5 | 11.02 | 0% |
| 60 | 260 | 90 | 0 | 14 | 14.58 | 0% |
| 60 | 260 | 90 | 0 | 14.5 | 14.26 | 0% |
| 60 | 260 | 90 | 90 | 14 | 9.88 | 0% |
| 60 | 260 | 90 | 90 | 14.5 | 10.44 | 0% |

Due to the blanket nature of this application, Kymeta focused on meeting the tangent-to-GEO-arc mask. Whether one applies the tangent or orthogonal mask will in large part depend on the geographic location of the terminal in question. In high latitude areas, the stricter tangent mask is designed to protect neighboring satellites which are “left and “right” from the target satellite with respect to the terminal. In low latitude areas, the stricter tangent mask is designed to protect the same neighboring satellites, which are now “back” and “forth” relative to the terminal. In essence, the definition of tangent and orthogonal changes as a function of geographic area from where the terminal is operating. Therefore, Kymeta performed all analyses against the stricter tangent mask, to demonstrate compliance regardless of the terminal’s geographic location. See Figure 1 below for a comparison of tangent and orthogonal masks, with the reference antenna pattern applied.

*Figure 1: Comparison of Tangent and Orthogonal Masks*

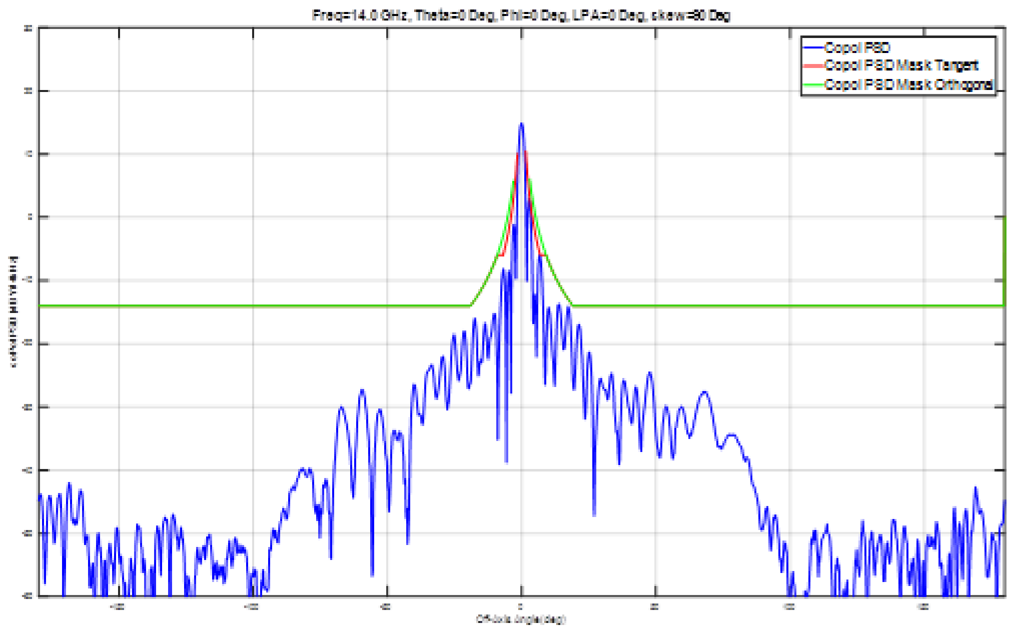

**EXHIBIT B**

**OFF-AXIS EIRP SPECTRAL DENSITY PATTERNS**

The Terminal meets the off-axis limits on EIRP spectral density as defined in Sections 25.222 and 25.226, and set forth below. Table 1 to Exhibit A includes data for 16 test cases that are representative of overall antenna performance. Attachment 1 to Exhibit B includes the patterns for the 16 test cases plotted against the relevant FCC off-axis PSD masks, which are set forth below. Attachment 2 to Exhibit B is an Excel spreadsheet providing a table of performance for a total of 96 test cases, evaluating two frequencies, four theta angles, three phi planes, two polarizations, and two skew orientations.

**Off-Axis EIRP Spectral Density Limits**

(i)(A) Off-axis EIRP spectral density emitted in the plane tangent to the GSO arc, as defined in §25.103, shall not exceed the following values:

| | | |
|---|---|---|
| | | |
| 15-25logθ | dBW/4 kHz | for 1.5° ≤ θ ≤ 7°. |
| −6 | dBW/4 kHz | for 7° < θ ≤ 9.2°. |
| 18-25logθ | dBW/4 kHz | for 9.2° < θ ≤ 19.1°. |
| −14 | dBW/4 kHz | for 19.1° < θ ≤ 180°. |

Where theta (θ) is the angle in degrees from a line from the earth station antenna to the assigned orbital location of the target satellite. The EIRP density levels specified for θ > 7° may be exceeded by up to 3 dB in up to 10% of the range of theta (θ) angles from ±7-180°, and by up to 6 dB in the region of main reflector spillover energy.

(B) The off-axis EIRP spectral density of co-polarized signals shall not exceed the following values in the plane perpendicular to the GSO arc, as defined in §25.103:

| | | |
|---|---|---|
| 18-25logθ | dBW/4 kHz | for 3.0° ≤ θ ≤ 19.1°. |
| −14 | dBW/4 kHz | for 19.1° < θ ≤ 180°. |

Where θ is as defined in paragraph (a)(1)(i)(A) of this section. These EIRP density levels may be exceeded by up to 6 dB in the region of main reflector spillover energy and in up to 10% of the range of θ angles not included in that region, on each side of the line from the earth station to the target satellite.

(C) The EIRP density of cross-polarized signals shall not exceed the following values in the plane tangent to the GSO arc or in the plane perpendicular to the GSO arc:

| | | |
|---|---|---|
| 5-25logθ | dBW/4 kHz | for 1.8° ≤ θ ≤ 7.0°. |

Where θ is as defined in paragraph (a)(1)(i)(A) of this section.

# EXHIBIT C

# RADIATION HAZARD STUDY

KYMETA®
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# RF Safety Analysis for the Kymeta® KyWay™ 1 Satellite Earth Station Terminal

02/22/2017

## Contents



## Figures



## Tables

# 1 Introduction

The purpose of this report is to provide an analysis characterizing radio frequency (RF) radiation levels for Kymeta Corporation's (Kymeta) KyWay™ 1 satellite earth station (terminal) consisting of an electronically steered array antenna and associated electronics. The antenna will be mounted on the top of a vehicle (such as a train, bus, commercial truck, or a civilian armored vehicle) (VMES), or on a platform or surface at or near the highest point of a maritime vessel (ESV). These areas will only be accessible to trained personnel and inaccessible to the general public.

The formulas used in Sections 2 through 7 of this analysis are consistent with the guidelines provided in OET Bulletin No. 65, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, Edition 97-01. The FCC guidelines specify maximum permissible exposure (MPE) limits for two categories: (1) general population/uncontrolled and (2) occupational/controlled exposure limits. The general population/uncontrolled exposure limit is specified as 1 $mW/cm^2$ averaged over 30 minutes while the occupational/controlled limit is specified as 5 $mW/cm^2$ averaged over 6 minutes.

The antenna will operate between the elevation angles of 15° and 90°. The terminal will use an amplifier with a maximum power level of 25 W. In this analysis, power density will be characterized at the minimum and maximum elevation angles of 15° and 90°. Additionally, operational RF safety considerations will be analyzed and discussed.

Table 1 defines the major parameters used in the analysis.

**Table 1: Definition of parameters used in the analysis.**

| Parameter | Symbol | Value |
|---|---|---|
| Input power (W) | P | 25 |
| Gain (dBi) | G | 32.89 |
| Antenna area ($cm^2$) | A | 3,848 |
| Antenna diameter (cm) | D | 70 |
| Frequency (GHz) | f | 14.5 |
| Wavelength (cm) | $\lambda$ | 2.07 |
| Total antenna efficiency | $\eta$ | 0.172 |
| Directivity reduction factor @ 15° elevation | $\eta'$ | 0.151 |

## 2 Antenna Surface Region Analysis

Equation 1 defines the power density at the surface of the antenna for RF hazard assessment purposes.

$$S_{Surface} = \frac{4P}{A} = 26.0mw/cm^2 \quad (1)$$

The power density at and just above the surface of the antenna is not compliant with the controlled and uncontrolled MPE limits. RF power will be shut off automatically whenever an aperture obscuration is detected (see Section 9: Cessation of RF Transmissions). Vehicle operators, maintenance personnel, and technicians requiring access to this region of the antenna will be properly trained and made aware of the potential for exposure and the time-averaging considerations specified in OET Bulletin 65 Edition 97-01, pages 9 through 11 and Appendix A, Table 1 on page 67. In addition, maintenance requiring access to this region will be conducted when the antenna is in non-transmit (receive-only) mode or with the antenna power switched off.

## 3 Antenna On-Axis Near-Field Region Analysis

Equation 2 defines the near-field region from the center of the antenna, and Equation 3 defines the power densities in the near-field region for 15° and 90° elevation angles.

$$R_{nf} = \frac{D^2}{4\lambda} = 5.92m \quad (2)$$

$$S_{nf\_Elevation\_90^o} = \frac{16\eta P}{\pi D^2} = 4.5mW/cm^2 \quad (3)$$

$$S_{nf\_Elevation\_15^o} = \frac{16\eta\eta' P}{\pi D^2} = 0.67mW/cm^2$$

Where $R_{nf}$ represents the near-field distance from the center point of the antenna along the main beam axis, and $S_{nf\_elevation\_90^o}$ and $S_{nf\_elevation\_15^o}$ denote power densities in the near-field region when the transmitted beam is at the lowest and highest operational elevation angles.

The power density level at the 90° elevation angle in the near-field region is not compliant with the MPE limits for uncontrolled exposure, but the power density level at the 15° elevation is compliant with the uncontrolled MPE limits. As indicated previously, the area around the antenna is a controlled environment that will not be accessible by the general public. In addition, RF power will shut off automatically whenever a main beam obscuration is detected (see Section 9: Cessation of RF Transmissions). Power density levels are compliant with the controlled MPE limits in the antenna near-field region.

## 4 Antenna On-Axis Transition Region Analysis

The transition region exists between the end of the near-field region and the beginning of the far field region. The power density in this region varies inversely with distance R and is represented by Equation 4.

$$S_t = \frac{S_{nf} * R_{nf}}{R} \qquad (4)$$

Where $S_t$ represents the power density in the transition region. Table 2 contains calculated power densities for various distances in this region.

**Table 2: Power density in the transition region.**

| Distance (m) | Power Density at 90° Elevation (mW/cm²) | Power Density at 15° Elevation (mW/cm²) |
|---|---|---|
| 5.92 | 4.47 | 0.67 |
| 8.4 | 3.15 | 0.47 |
| 10.9 | 2.43 | 0.37 |
| 13.4 | 1.97 | 0.30 |
| 14.2 | 1.86 | 0.28 |

The power density levels are compliant with the uncontrolled MPE limits at 15° elevation angle for all distances in the transition region. Power density limits are not compliant with the uncontrolled MPE limits at 90° elevation angle throughout the transition region. As indicated herein, however, the area around the antenna is a controlled environment that will not be accessible to the general public. In addition, RF power will shut off automatically whenever a main beam obscuration is detected (see Section 9: Cessation of RF Transmissions). Power density levels at 15° and 90° elevation angles are compliant with controlled MPE limits.

The transition regions are skyward with an unobstructed view from the antenna at the top of the vehicle or vessel towards the target satellite. The controlled area around the terminal and open area above the terminal in the direction of the target satellite are necessarily unoccupied, ensuring that the general public will not be subject to RF radiation above the uncontrolled exposure limits. Appropriate training manuals will ensure that operators and maintenance technicians will not be subject to excessive levels of RF radiation.

## 5 Antenna On-Axis Far-Field Region Analysis

Equation 5 defines the far-field region from the center of the antenna, and Equation 6 defines the power density in the far-field region.

$$R_{ff} = \frac{0.6 * D^2}{\lambda} = 14.2m \quad (5)$$

$$S_{ff} = \frac{P * G_{factor}}{4\pi R^2} \quad (6)$$

Where $G_{factor}$ is defined as $10^{(G/10)}$, $R_{ff}$ represents the end of the transition region and the beginning of the far-field region, and $S_{ff}$ is power density in the far-field region.

Using Equation 6, the distances for compliance with uncontrolled exposure limits are as follows:

- Distance for uncontrolled MPE Compliance @ 90° Elevation = **19.7 m**
- Distance for uncontrolled MPE Compliance @ 15° Elevation = **7.6 m**

The distances for compliance with controlled exposure limits are as follows:

- Distance for controlled MPE Compliance @ 90° Elevation = **8.80 m**

Again, these regions are skyward with an unobstructed view from the antenna at the top of the vehicle or vessel towards the target satellite. The controlled area around the antenna and open area above the antenna in the direction of the target satellite are necessarily unoccupied, ensuring that the general public will not be subject to RF radiation above the uncontrolled exposure limits. Appropriate training manuals will ensure that operators and maintenance technicians will not be subject to excessive levels of RF radiation.

## 6 Antenna Off-Axis Near-Field and Transition Region Analysis

OET Bulletin 65 prescribes that at a point of interest about one diameter away from the main beam axis the power density level is estimated to be a factor of 100 or 20 dB lower than that of the peak of the beam. Equation 7 provides the power density level in this area.

$$S_{nf\_off-axis} = \frac{S_{nf}}{100} = 0.045 \text{ mW/cm}^2 \quad (7)$$

This level is compliant with controlled and uncontrolled MPE limits. This RF safety analysis examines off-axis RF hazard scenarios, below, and concludes that there are no material safety concerns in the off-axis case.

# 7 Antenna Off-Axis Far-Field Region Analysis

The far-field antenna radiation pattern can be used to compute power density at an off-axis angle formed between the central antenna axis and the desired point. The on-axis power density at 14.2 m, which represents the beginning of the far-field region, is 1.92 mW/cm². For example, at a point about 2.7° away from the center line (off-axis region) while the antenna is pointed at 90° elevation, the power density is reduced by about 16.45 dB, as shown in Figure 1, resulting in a power density of approximately 0.04 mW/cm².

This level is compliant with controlled and uncontrolled MPE limits. This RF safety analysis examines off-axis RF hazard scenarios and concludes there are no material safety concerns in the off-axis case.

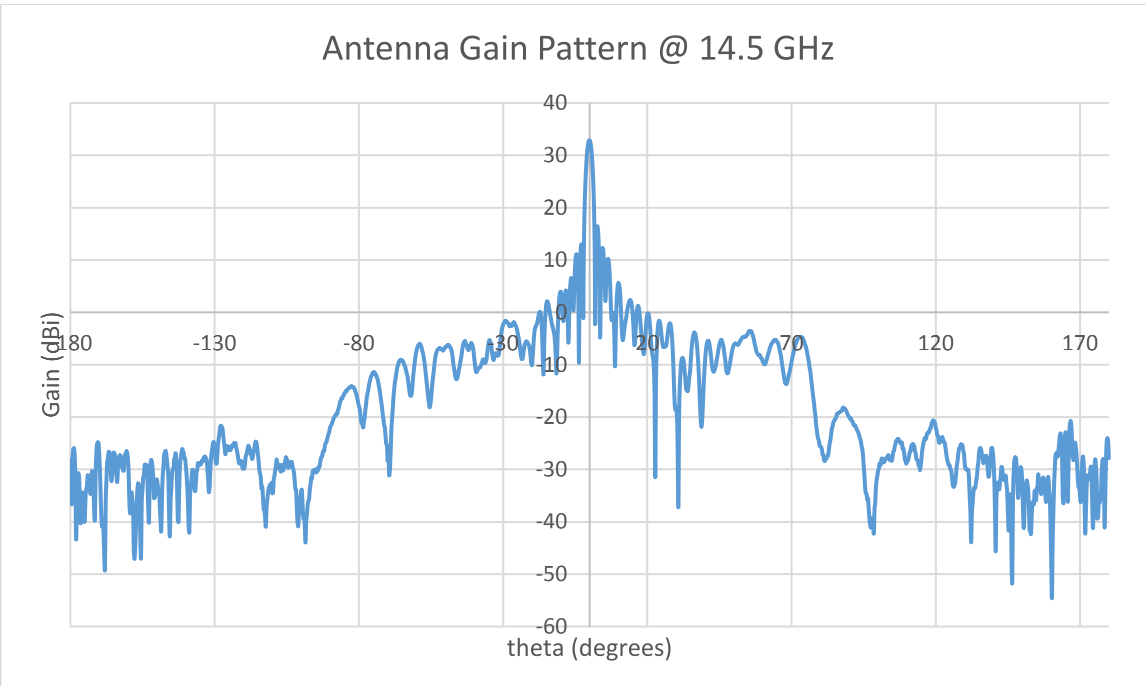


**Figure 1: Far-field measured radiation pattern of the 70 cm Ku-band antenna at 14.5 GHz**

# 8 Operational RF Safety Considerations

RF safety involving neighboring vehicle occupants, KyWay 1 terminal-equipped vehicle occupants, and pedestrians in the vicinity of the VMES is discussed and analyzed in this section. The KyWay 1 terminal employs a mechanism to detect obscurations to the antenna aperture, and ceases transmission within 100 ms upon detection of an obscuration (see Section 9 for additional details). In all cases in which the power density exceeds MPE limits, the power shuts off automatically to ensure compliance with the limits.

## 8.1 Neighboring Vehicle RF Safety

The following example is chosen to represent the worst-case operational scenario with respect to occupants in a neighboring vehicle:

- A VMES equipped with a Kymeta 70 cm Ku- band antenna and a double decker bus are in their respective lanes.
- The road is assumed to be flat.
- Passenger's height on-board the bus is assumed to be 1 foot below the roof.
- The antenna's center point is mounted along the centerline of the VMES.
- Antenna aperture is coplanar with the roof of the VMES.
- The terminal is transmitting with a maximum power level of 25 W.

Using the geometry shown in Figure 2, we compute that the maximum angle that clears the top edge of the bus and accommodates a line of sight beam in the direction of the satellite is about 36.8° amounting to an elevation angle of 53.2°, based on Equations 8 and 9 respectively.

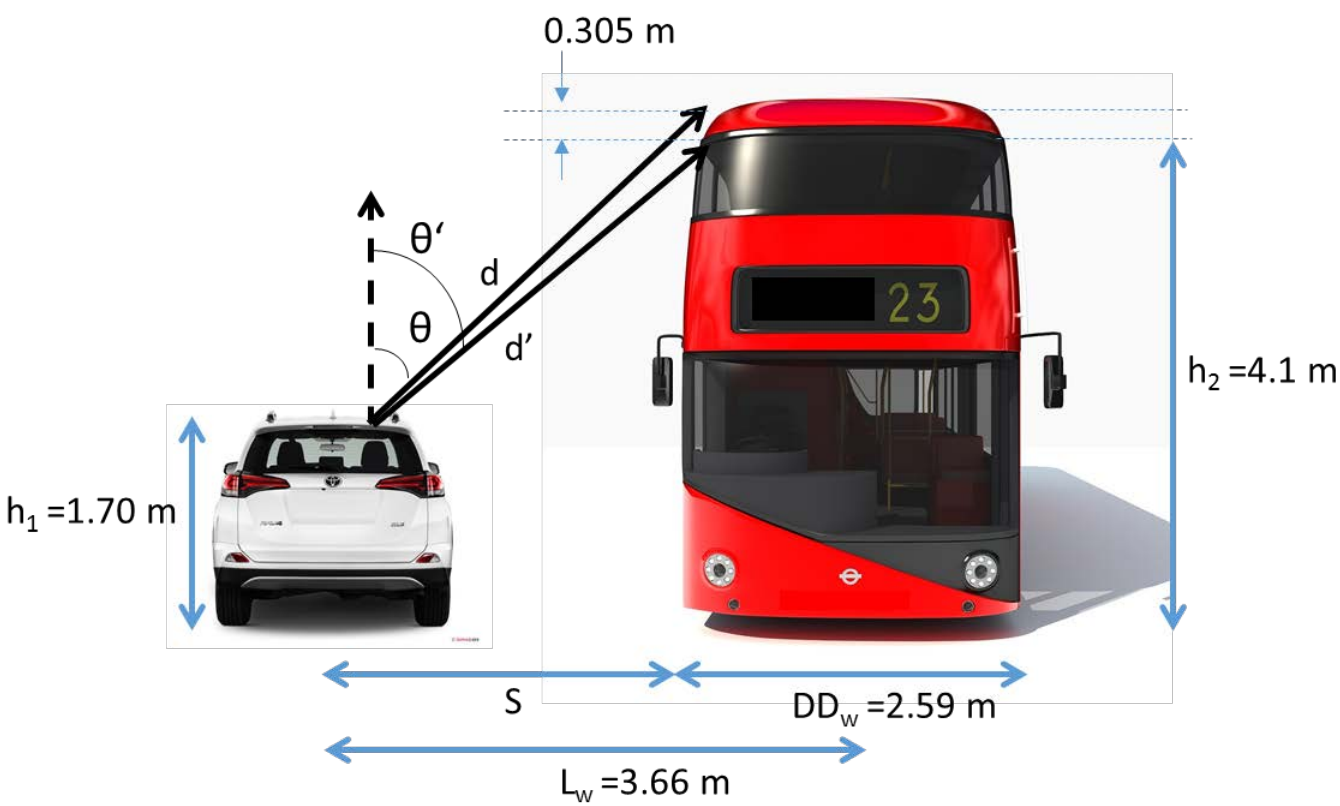


**Figure 2: Geometry and dimensions associated with an extreme operational scenario**

$$\theta = ARCTAN\left(\frac{S - D/2}{h_2 - h_1} = \frac{L_w - \frac{DD_w}{2} - D/2}{h_2 - h_1}\right) = 36.8° \quad (8)$$

**Elevation Angle = 90 – θ = 53.2°** (9)

The distance d′ from approximately 2 inches from the edge of the active aperture to a passenger aboard the double decker is computed in Equation 10, as follows:

$$d' = \sqrt{(S - D/2 - l)^2 + (h_2 - h_1)^2} = 3.3 \text{ m} \quad (10)$$

Where $l$ is the distance from the edge of the active aperture to the origination of the $d'$ vector (2 inches in this scenario).

The electromagnetic fields just outside the active antenna aperture drop off precipitously. Moreover, about 2″ away from the edge of the active aperture, the power density is expected to be greater than 10 dB or an order of magnitude lower than the peak of the beam in the direction of the satellite in the near field region of the antenna[1]. Thus, using Equation 11, the power density level seen by the passenger is computed as follows:

$$S_{nf\_off-axis\_2inch} = \frac{S_{nf}}{10} = 0.45 \text{ mW/cm}^2 \quad (11)$$

This level is compliant with controlled and uncontrolled MPE limits. This RF safety analysis examines off-axis RF hazard scenarios and concludes there are no material safety concerns in the off-axis case.

## 8.2 VMES Occupant RF Safety

The back radiation of the antenna mounted on the roof of a VMES is significantly lower than that of the main lobe radiation, producing power densities well below the uncontrolled MPE limits. The driver and passengers of a VMES are further shielded from any harmful RF radiation by the metallic backplane of the ASM.

Figure 3 shows the various locations behind the antenna where power density measurements were taken. These measurements were performed in an anechoic chamber using a Holaday model 3200 RF survey meter. Table 3 shows the measured power densities for the locations indicated in Figure 3 with an input power level of 2 W. Table 4 shows power densities for the same locations scaled with an input power level of 25 W.

[1] Near field measurements performed at Kymeta on the 70 cm Ku-band antenna show a 10 dB decrease in power density from the edge of the active aperture to 2 inches away from the edge of the active aperture

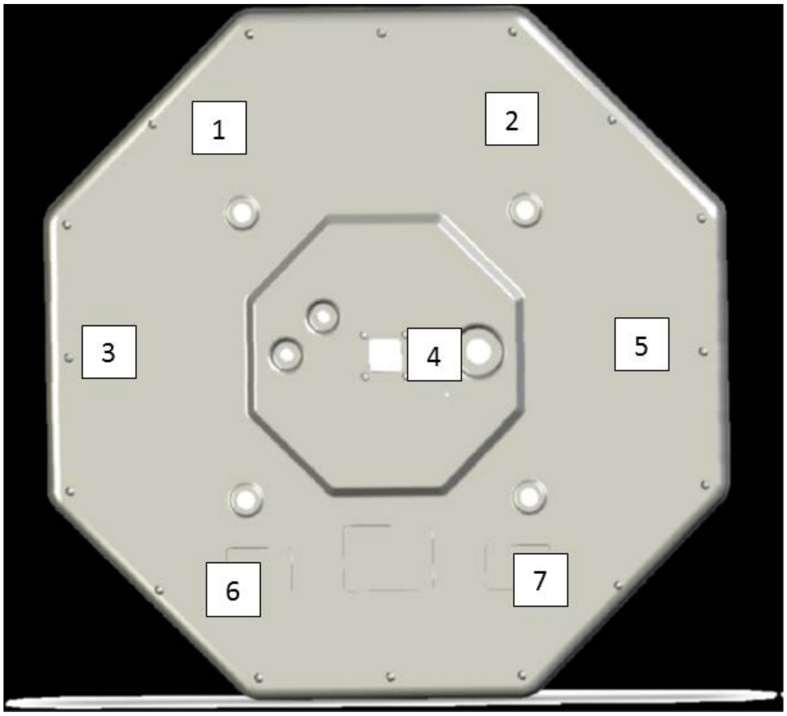


**Figure 3: Solid model of the back of the KyWay 1 antenna module showing measurement locations for the RF power density analysis**

**Table 3: Measured power density levels at the back of the KyWay 1 antenna module (2 W input power)**

| | Measured Data (mW/cm²) | |
|---|---|---|
| **Location** | **1″ from the back of the antenna** | **3″ from the back of the antenna** |
| 1 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 |
| 4 | 0.0054 | 0.0027 |
| 5 | 0.0000 | 0.0000 |
| 6 | 0.0000 | 0.0000 |
| 7 | 0.0000 | 0.0000 |

**Table 4: Scaled power density levels at the back of the KyWay 1 antenna module (25 W input power)**

| | Scaled Data (mW/cm²) | |
|---|---|---|
| **Location** | **1" from the back of the antenna** | **3" from the back of the antenna** |
| 1 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 |
| 3 | 0.0000 | 0.0000 |
| 4 | 0.0675 | 0.0338 |
| 5 | 0.0000 | 0.0000 |
| 6 | 0.0000 | 0.0000 |
| 7 | 0.0000 | 0.0000 |

The power densities at the back of the antenna determined for 25 W input power are compliant with controlled and uncontrolled MPE limits. This RF safety analysis concludes that there are no material safety concerns for vehicle occupants.

## 8.3 RF Safety of Pedestrians in Vicinity of VMES

The scenario chosen to analyze a pedestrian in the vicinity of the VMES is as follows:

- Vehicle is a Toyota RAV4.
- Vehicle width is about 1.73 m.
- The pedestrian is located about 1.02 m away from the centerline of the vehicle (about 0.3 m away from the side of the vehicle).
- Pedestrian's height is about 6.5 feet or about 1.98 m.

Using the geometry shown in Figure 4, Equation 11 computes the maximum angle to be 67.2° amounting to an elevation angle of 22.8°. The resulting computed power density at this elevation angle is about 1.2 mW/cm². The power density level exceeds MPE limits for an uncontrolled environment. However, terminal operators will be trained to secure the area around the terminal to create a controlled environment. (It is not necessary to secure such an area in the in-motion context because individuals do not have access to the tops of trains, buses, and commercial vehicles while they are in motion). Thus, while stationary operation of the KyWay 1 terminal will not comply with uncontrolled MPE limits, the more appropriate level is the controlled MPE limit for which the terminal operator can control access to the area in the immediate vicinity of the terminal.

$$\theta = ARCTAN\left(\frac{S - D/2}{h_2 - h_1}\right) = 67.2° \qquad (11)$$

Elevation Angle = 90 - $\theta$ = 22.8°

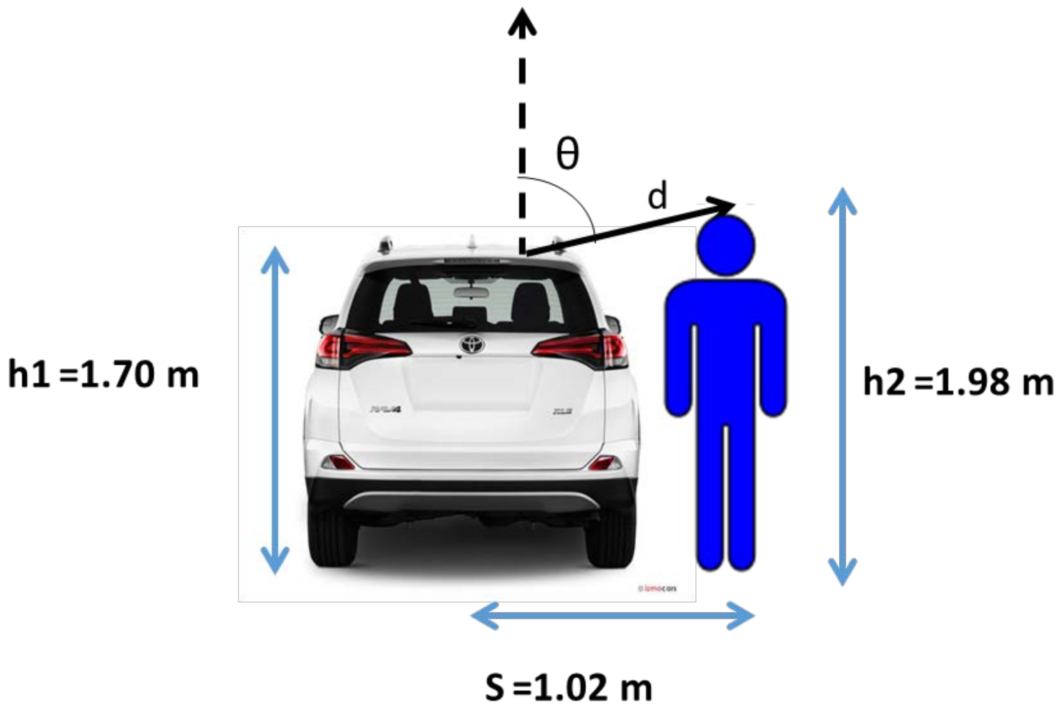


**Figure 4: Pedestrian or stationary observer in the vicinity of the VMES**

## 8.4 RF Safety in ESV Applications

In ESV applications, the antenna will be mounted in a restricted area, not accessible to the general public, so the controlled environment limits apply in these areas.

Operators and maintenance technicians requiring access to the antenna and its immediate surroundings will be trained to follow proper RF safety procedures to comply with the FCC MPE governing occupational exposure. These procedures will include stopping terminal operation and using caution when working in certain regions close to the antenna and the transmitted beam of RF energy.

# 9 Cessation of RF Transmissions

## 9.1 Aperture obscurations

The KyWay 1 terminal employs a mechanism to detect obscurations to the antenna aperture and stop RF transmission within 100 ms upon detection of an obscuration. Because Kymeta technology locates both the transmit and receive antenna apertures on the same physical substrate, any sudden change in receive signal strength, as measured by the on-board tracking receiver, is interpreted as an obscuration of the transmit aperture. Thus, in situations where an object or person blocks the line of sight between the terminal and the target satellite (e.g., by a bus), transmissions are ceased well within the timeframe required to satisfy the MPE limits.

## 9.2 Minimum Elevation Angle

The elevation angle of the KyWay 1 VMES is not permitted to be less than 15°. The on-board software limits the ability of the terminal to scan at elevation angles lower than 15°.

# 10 Summary

The terminal will be mounted on the top of a vehicle or a maritime vessel for stationary and in-motion use. The area above and adjacent to the terminal will not be accessible to the general public, so the controlled environment limits apply in these areas.

As described above, the regions in which power density exceeds MPE limits are those skyward areas above the transmit antennas and towards the target satellite. These areas must have an unblocked line of sight for the terminal to sync with the target satellite and thus be able to transmit. As a result, such areas must be unoccupied. In all cases, the terminal will cease all transmissions to ensure compliance with the MPE limits.

Operators and maintenance technicians requiring access to the antenna and its immediate surroundings will be trained to follow proper RF safety procedures to comply with the FCC MPE governing occupational exposure. These procedures will include stopping terminal operation and using caution when working in certain regions close to the antenna and the transmitted beam of RF energy.

**EXHIBIT D**

**TECHNICAL CERTIFICATION**

I, Ryan A. Stevenson, hereby certify that I am:

- the technically qualified person responsible for the preparation of the technical information contained in the Application, including the Technical Appendix and its Exhibits;
- that I am familiar with Part 25 of the Commission's Rules; and
- that I have either prepared or reviewed the technical information submitted in the Application and found it to be complete and accurate to the best of my knowledge and belief.

Signed: [signature]
Dated: 2/23/2017

Ryan A. Stevenson
Vice President and Chief Scientist
Kymeta Corporation