KYMETA™

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Kymeta RF Safety Analysis
October 2017

Table of contents

Table of figures

Tables

1 Introduction

This report provides an analysis of independent, third-party laboratory measurements of radio frequency (RF) power density near the Kymeta™ KyWay™ 1, 70 cm diameter K_u-band satellite earth station terminal (the "Terminal"). This RF safety study examines the operation of the Terminal with 16 watts input power. Kymeta's previous RF safety study examined the operation of the Terminal with 8 watts input power.

The Terminal's antenna will operate at elevation angles between 15° and 90° relative to horizontal. Operation at elevation angles less than 15° is inhibited by terminal on-board software such that no RF energy can be radiated from the antenna. If the software process responsible for generating pointing commands attempts to scan the main beam to an elevation angle lower than 15°, the block upconverter (BUC) is muted such that RF power is no longer delivered to the antenna.

The Terminal is comprised of the Kymeta mTenna^{u7} antenna subsystem module ("Antenna") as well as off-the-shelf RF components (low-noise block downconverter, diplexer, and BUC). The Antenna is a flat-panel, electronically scanned array that performs beam steering through a reconfigurable holographic metamaterial effect.

The following use cases are examined:

- Fixed (non-mobile): the Terminal will be mounted on the ground, on a raised platform, or on a roof-top.
- Earth Station Aboard Vessel (ESV): the Terminal will be mounted aboard a maritime vessel. Typical deployment will be on a platform at or near the highest point of the vessel.
- Vehicle Mounted Earth Station (VMES): the Terminal will be horizontally mounted on the roof of a vehicle.

2 Reference documents

2.1 FCC RF guidelines

OET Bulletin 65 sets forth the following guidelines for maximum permissible exposure (MPE) applicable to the K_u-band emissions of the Terminal:

(1) General Population/Uncontrolled: 1 mW/cm^2 averaged over 30 minutes

(2) Occupational/Controlled: 5 mW/cm^2 averaged over 6 minutes

2.2 IEEE guidelines

IEEE standard C95.7-2014 "Recommended Practice for RF Safety Programs, 3 kHz – 300 GHz," provides guidance for implementing an RF safety program. These recommendations were used in preparation of this report.

3 Third-party laboratory testing

The Terminal was tested for RF power density values by CKC Laboratories, a certified EMI/EMC laboratory, at their Fremont, California facilities. The testing was performed by employees of CKC in a 36 × 20 × 20 ft. anechoic chamber.

The Antenna was positioned in a horizontal orientation on a remote-controlled turn table. A calibrated power density probe was placed on a vertically oriented fiberglass mast for which the vertical (1) and horizontal axes (2) could be remotely controlled. All three axis controls (comprising a cylindrical coordinate system) were utilized to capture measurements and fully assess the RF power density levels in the 3-dimensional space around the Terminal.

A top-down diagram of the chamber with the test setup, with pictures, is shown in Figure 1 and Figure 2.

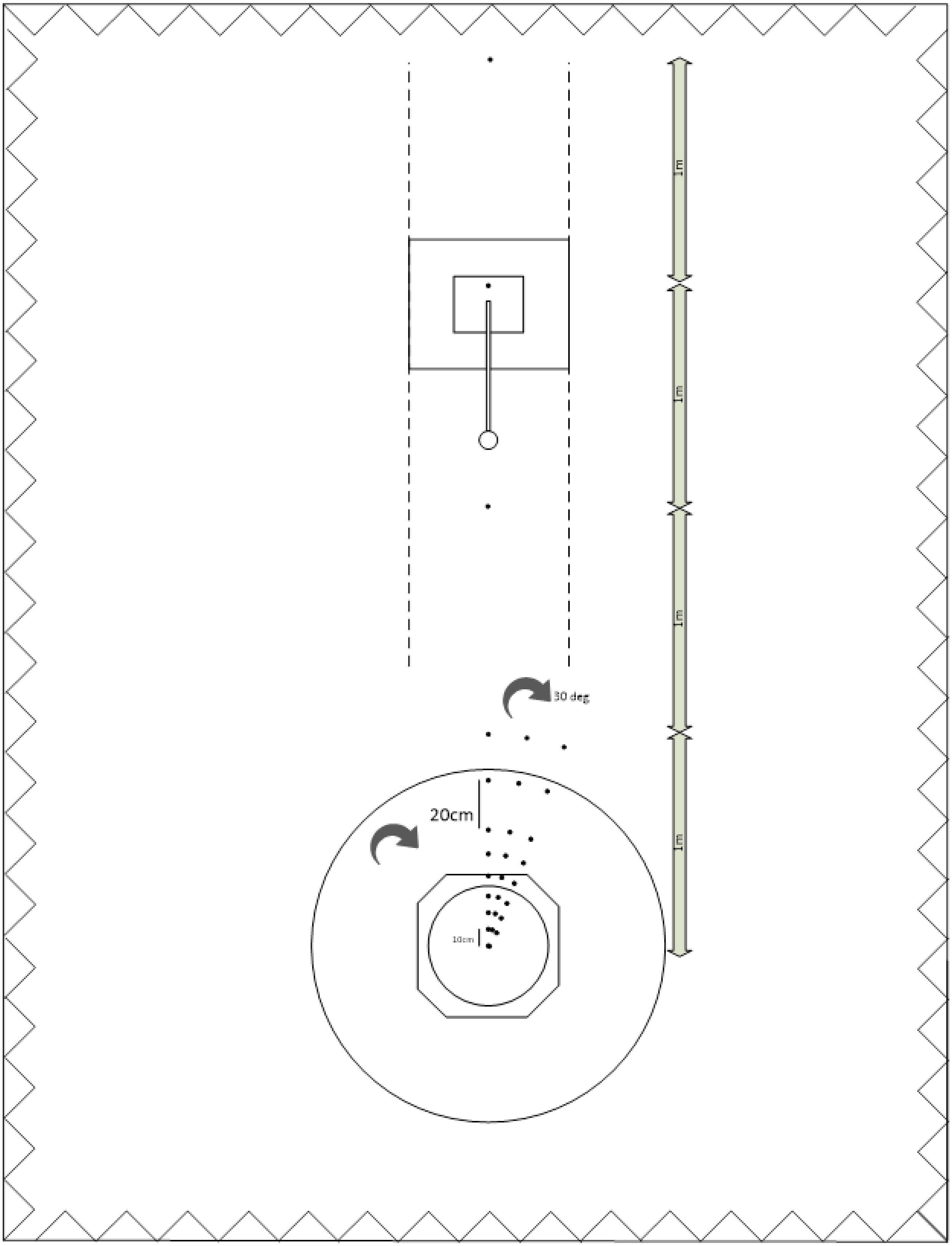

Figure 1: Chamber layout, top-down view

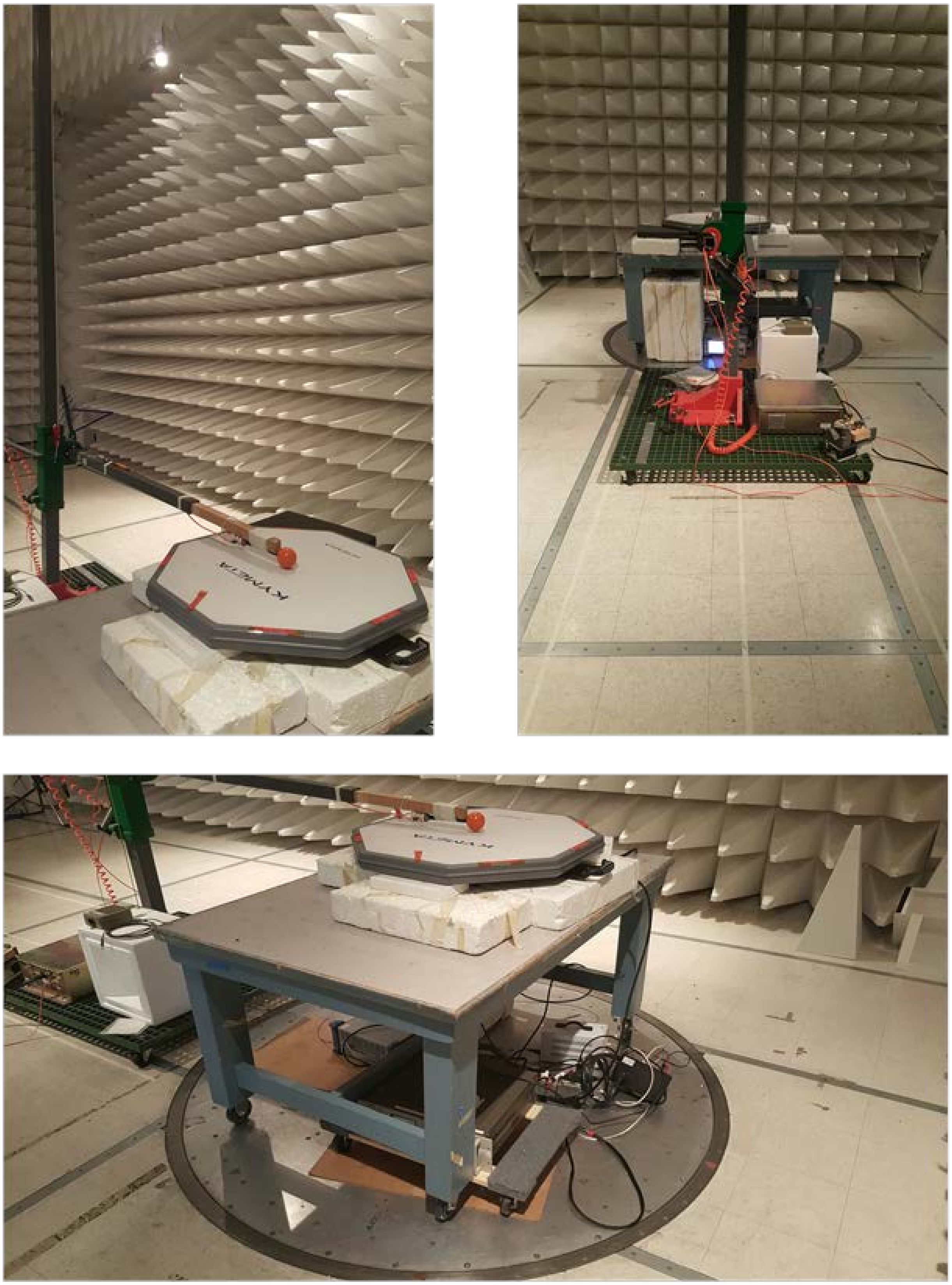

Figure 2: Chamber pictures

An AR FL7060 Isotropic Electric Field Probe was used for all measurements, with an operating dynamic range of 2 to 1000 V/m. Considering the specified sensitivity of 2 V/m (0.00106 mW/cm^2), it was deemed appropriate to use 4 W input power as reference, then scale to 16 W linearly. This approach results in minimum detectable power density of 0.00106 x 16 / 4 (16 W scaled from 4 W reference) = 0.00424 mW/cm^2 when scaled to 16 W. This resolution is sufficient considering the 1 mW/cm^2 MPE level requirement.

The uncalibrated frequency response of this probe is ±3 dB for the 10 MHz to 60 GHz range as show in Figure 3.

The probe's typical isotropic deviation response is ±1.5 dB, with linearity of ±0.5 dB.

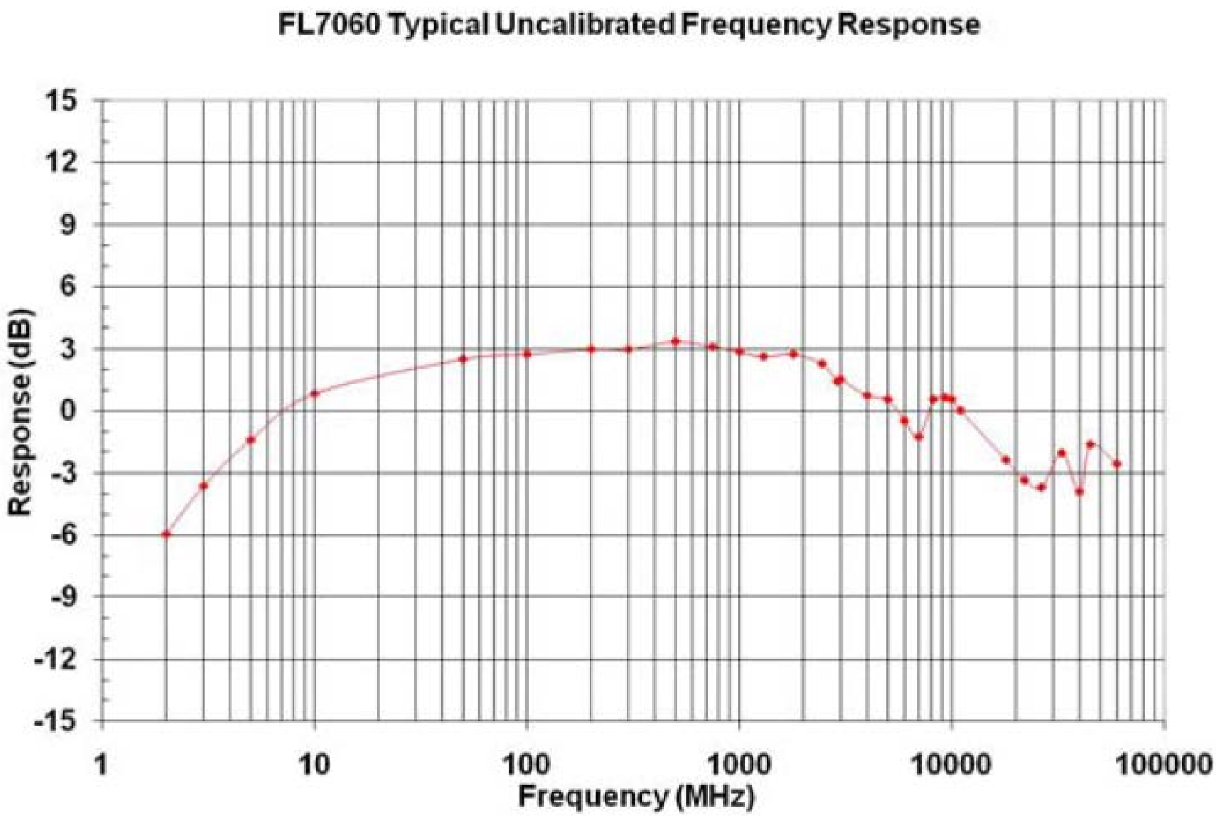

Figure 3: Typical uncalibrated frequency response for FL7060 probe

The probe correction factor at 14.5 GHz was computed by taking the average of the three orthogonal polarization element factors (see Figure 4).

Date of Calibration: Tuesday, November 22, 2016
Date Printed: Tuesday, November 22, 2016
Customer Name: AR, RF/Microwave Instrumentation
Probe Manufacturer: AR
Probe Model: FL7060
Probe Serial No.: 0346573
Temperature (Deg C): 22
Humidity (%): 45
Notes:
CAL CERT #: 161117-133112-df4fb1

Frequency Response at 15V/m

Freq MHz	Mult X	dB X	Mult Y	dB Y	Mult Z	dB Z
2	2.37	7.48	2.23	6.97	1.52	3.63
3	1.73	4.74	1.67	4.45	1.25	1.94
5	1.29	2.21	1.26	2.00	1.08	0.67
10	0.98	-0.21	0.97	-0.23	0.95	-0.41
50	0.75	-2.46	0.76	-2.39	0.82	-1.73
100	0.72	-2.83	0.73	-2.78	0.79	-2.01
200	0.69	-3.20	0.69	-3.24	0.77	-2.31
300	0.64	-3.84	0.63	-3.95	0.70	-3.04
500	0.65	-3.75	0.63	-3.96	0.71	-2.99
750	0.67	-3.49	0.64	-3.93	0.72	-2.86
1000	0.71	-3.01	0.67	-3.46	0.78	-2.18
1300	0.64	-3.90	0.60	-4.37	0.69	-3.26
1800	0.66	-3.56	0.63	-4.03	0.71	-2.98
2450	0.68	-3.40	0.64	-3.92	0.72	-2.91
2900	0.75	-2.51	0.70	-3.07	0.80	-1.97
3000	0.77	-2.25	0.73	-2.76	0.83	-1.59
4000	0.89	-0.97	0.85	-1.41	0.95	-0.43
5000	0.88	-1.11	0.86	-1.29	1.01	0.06
6000	0.85	-1.39	0.84	-1.54	0.88	-1.07
7000	1.11	0.91	1.10	0.83	1.27	2.05
8200	0.86	-1.35	0.89	-1.00	0.92	-0.70
9300	0.77	-2.23	0.79	-2.01	0.86	-1.34
10000	1.14	1.14	1.20	1.59	1.42	3.03
11000	0.67	-3.51	0.71	-3.00	0.75	-2.51
18000	1.30	2.27	1.36	2.65	1.59	4.04
26500	1.20	1.55	1.31	2.35	1.38	2.78
33000	1.19	1.53	1.19	1.51	1.32	2.40
40000	1.19	1.54	1.22	1.72	1.28	2.13
45000	1.03	0.26	1.12	0.98	1.07	0.59
60000	0.94	-0.54	0.89	-1.01	0.84	-1.51

Figure 4: Frequency calibration factors for FL7060 probe

Linear interpolation between the closest calibration frequencies of 11 GHz and 18 GHz was used to estimate the average correction factor applicable at 14.5 GHz. This value turns out to be +0.025 dB (i.e., the probe is expected to read LOW by 0.025 dB).

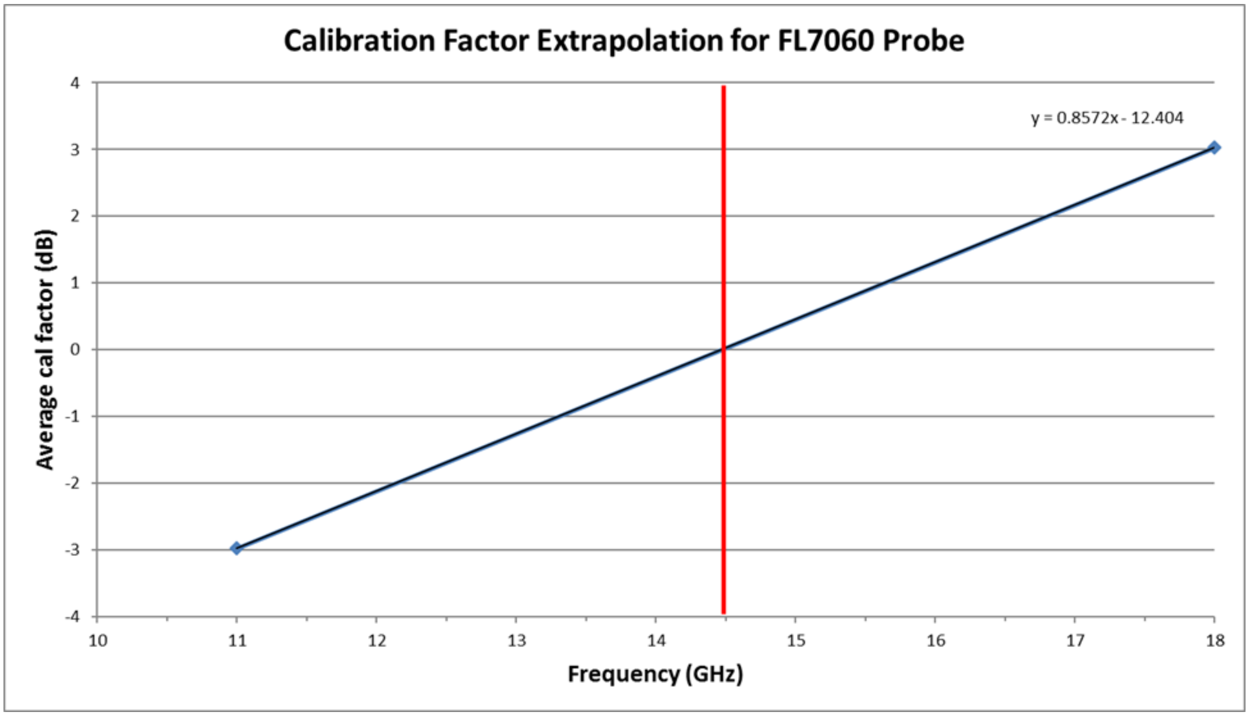

Figure 5: Correction factor extrapolation at 14.5 GHz

It was deemed the correction factor relevant to 14.5 GHz frequency is so small that no adjustments were required to the measured data.

4 Test parameters and procedures

The measurements were made using a 16 W BUC operating at an input reference power of 4 W. The reference power level of 4 W was confirmed with both an internal BUC power monitor, as well as a spectrum analyzer. Figure 6 shows the power calibration setup diagram. The raw data were then linearly scaled to the 16 W power level requested in the application for blanket authority.

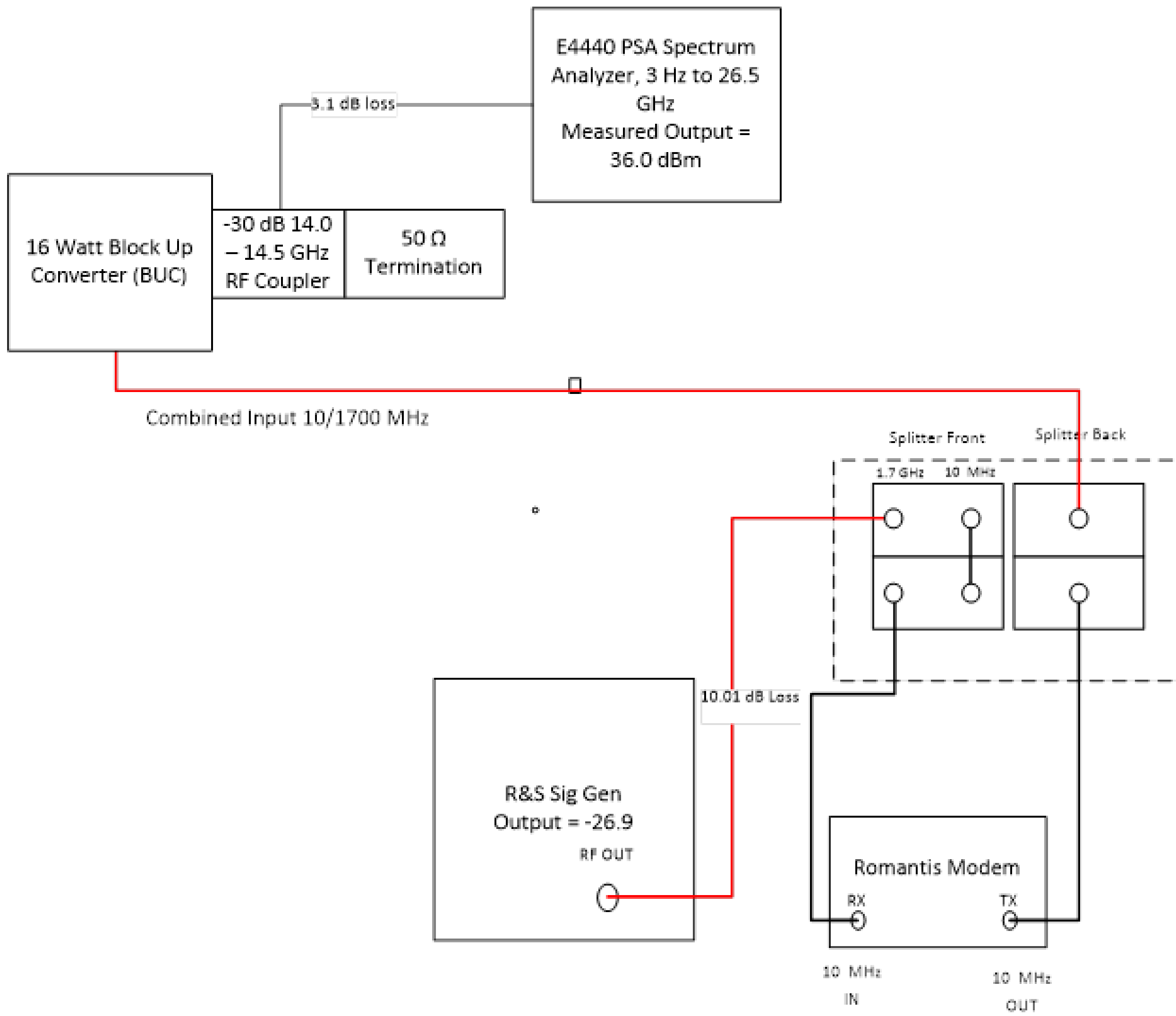

Figure 6: Input reference power calibration diagram

During operation, the Terminal transmits bursts of energy towards the target satellite only at designated times assigned by the network (a TDMA system). The Terminal will typically operate at a duty cycle of 10%. However, if sufficient satellite system capacity is available, the Terminal can operate up to a 30% duty cycle to accommodate maximum uplink data transfers. All representations of power density in this report assume the maximum case of a 30% duty cycle. For the power density measurements described in this report, the Terminal BUC operated at 100% duty cycle and power densities were subsequently scaled to the 30% duty cycle value.

The Terminal is capable of performing transmit and receive functions from the same antenna aperture. This functionality requires a diplexer feed system which combines, but also frequency filters, the transmit and receive signals. For this test, the 16 W BUC was connected to the appropriate diplexer port, while the receive port was terminated with a 50 Ω load. The BUC requires a 10 MHz reference signal to turn on; this was supplied from a Romantis modem (UHP-1000 evaluation prototype). The 10 MHz reference signal was summed with the intermediate frequency (IF) signal coming from a signal generator to produce a 14.5 GHz continuous wave (CW) signal (corresponding to the 100% duty cycle mentioned above) feeding the antenna. A detailed diagram of this setup is shown in Figure 7.

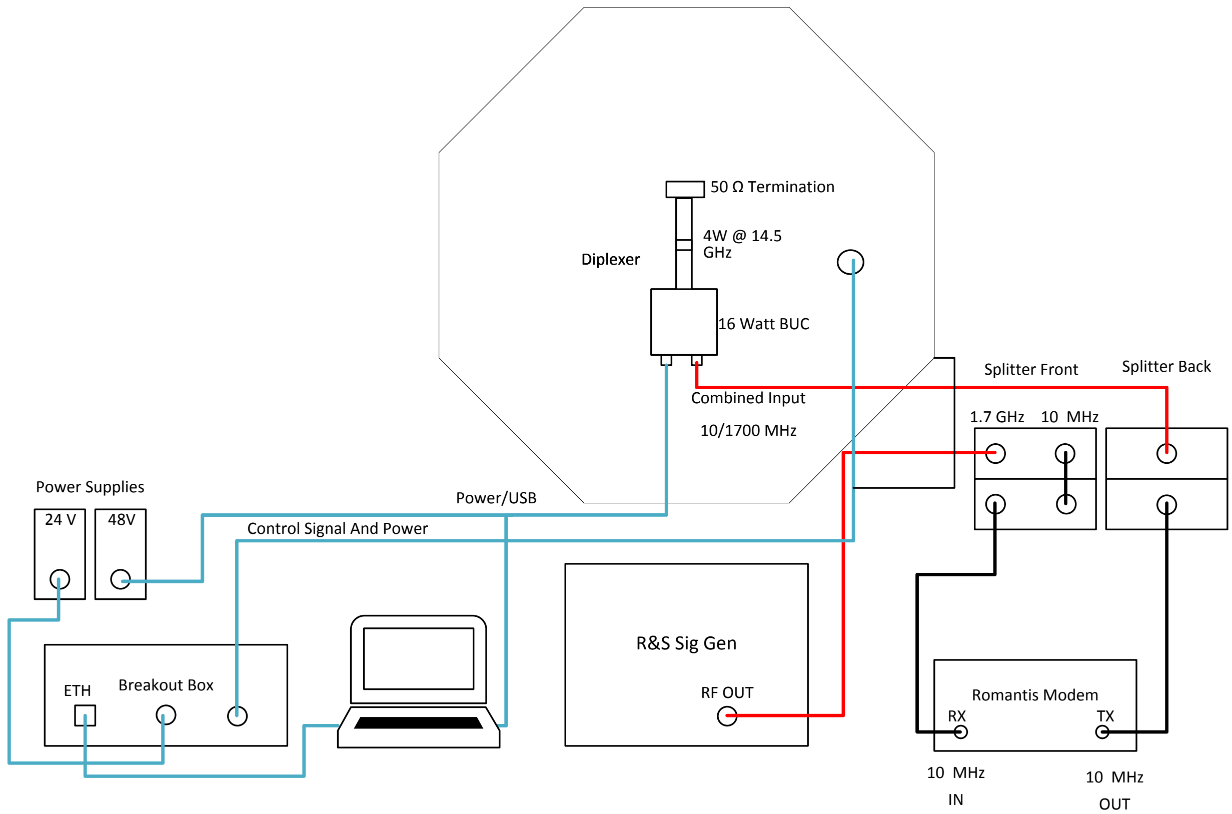

Figure 7: Kymeta terminal - transmit diagram

RF power density measurements were taken at the following locations relative to the antenna position:

- Radial distance from center of antenna (centimeters): 0, 10, 20, 30, 40, 50, 60, 80, 100, 200, 300
- Height above the face of the antenna (centimeters): 0, 10, 20, 30, 40, 50, 100, 200, 300
- Angular rotation around the center of the antenna: 0° to 360° in 30° steps

In the graphs in the following section, power densities less than 1 mW/cm^2 are shown as green circles, power densities between 1 and 5 mW/cm^2 are shown as orange circles, and power densities greater than 5 mW/cm^2 are shown as red circles. Because the power densities for operations at 16 W do not exceed 5 mW/cm^2, there are no red circles in the graphs below.

5 Test Measurements

Test measurements certified by CKC Laboratories are set forth in the spreadsheet attached as Exhibit 1. Visual presentations of the test measurements are discussed and shown below.

The raw measurements were taken in V/m (field strength), but the analysis was performed with respect to power density specifications. The formula used to relate the two is given here:

$$PD\ (\frac{mW}{cm^2}) = \frac{(\frac{\mathrm{V}}{\mathrm{m}})^2\ \times\ 1000}{FSI\ \times\ 10000}$$

Where FSI is free space impedance, 377 Ω.

This expression was then scaled by P (power = 16 W), DC (duty cycle = 30%) and RefP (reference power = 4 W) to produce the plots presented in this section.

$$PD\ (\frac{mW}{cm^2}) = \frac{(\frac{\mathrm{V}}{\mathrm{m}})^2\ \times\ P\ \times\ DC\ \times\ 1000}{RefP\ \times\ FSI\ \times\ 10000}$$

Figure 8 through Figure 25 show a top-down view of radiation level MPE zones. Each polar plot represents one specific height plane above the antenna surface. Note that the center point in each of the polar plots was measured 12 times (like every other radial plane, in 30° increment rotations of the turn table), then averaged for the value at the single central point and plotted. In these figures the blue octagon represents the outer dimensions of the Kymeta antenna. The blue circle represents the 70 cm active diameter of the Kymeta antenna.

Each scaled value of power density is represented by a colored dot in the figures: green represents scaled values less than 1 mW/cm^2, orange represents scaled values in the range of 1 mW/cm^2 to 5 mW/cm^2 and red represents scaled values exceeding 5 mW/cm^2.

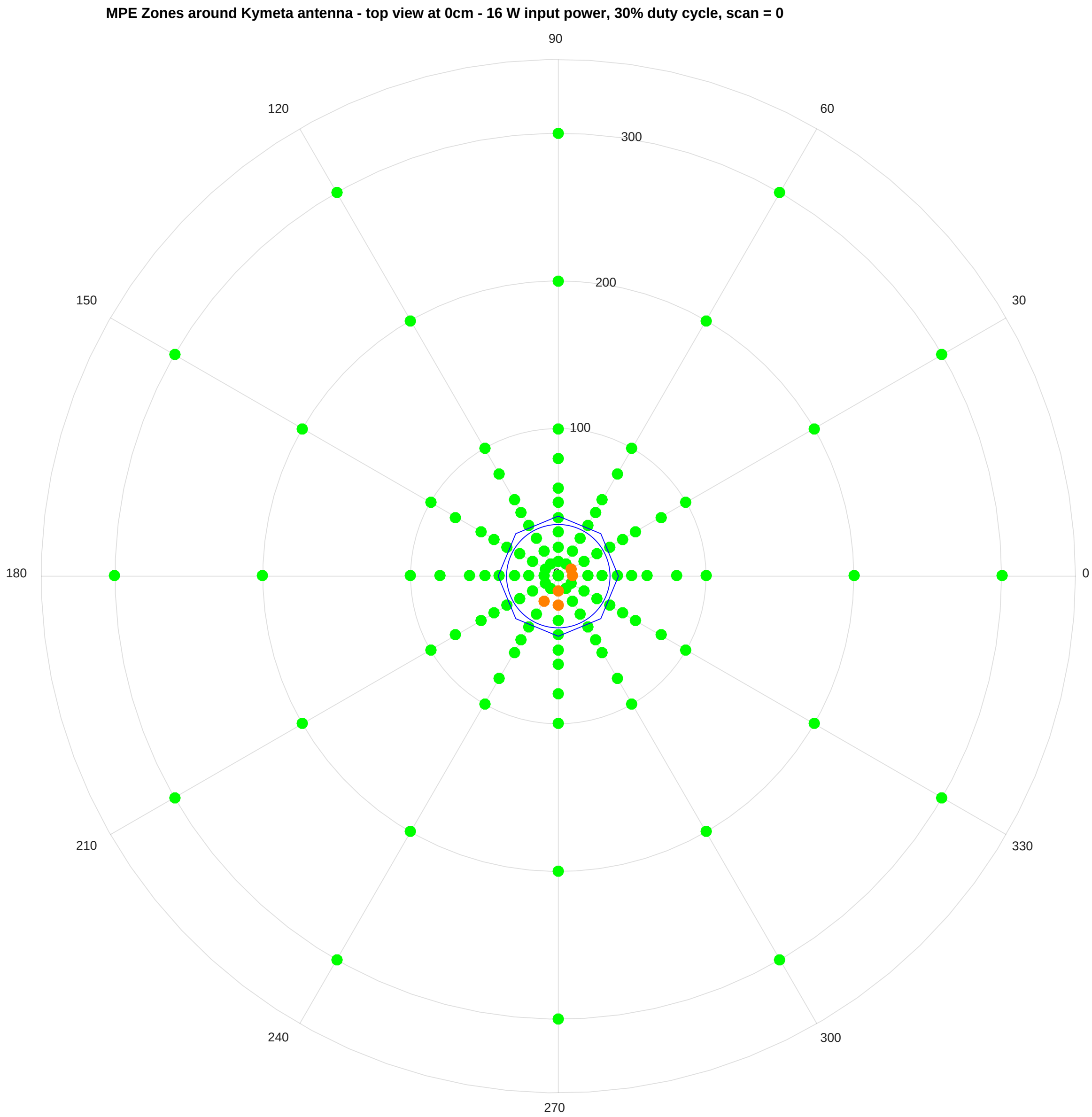

Figure 8: Height 0 cm, 16W input power with 30% Duty Cycle, Scan 0˚

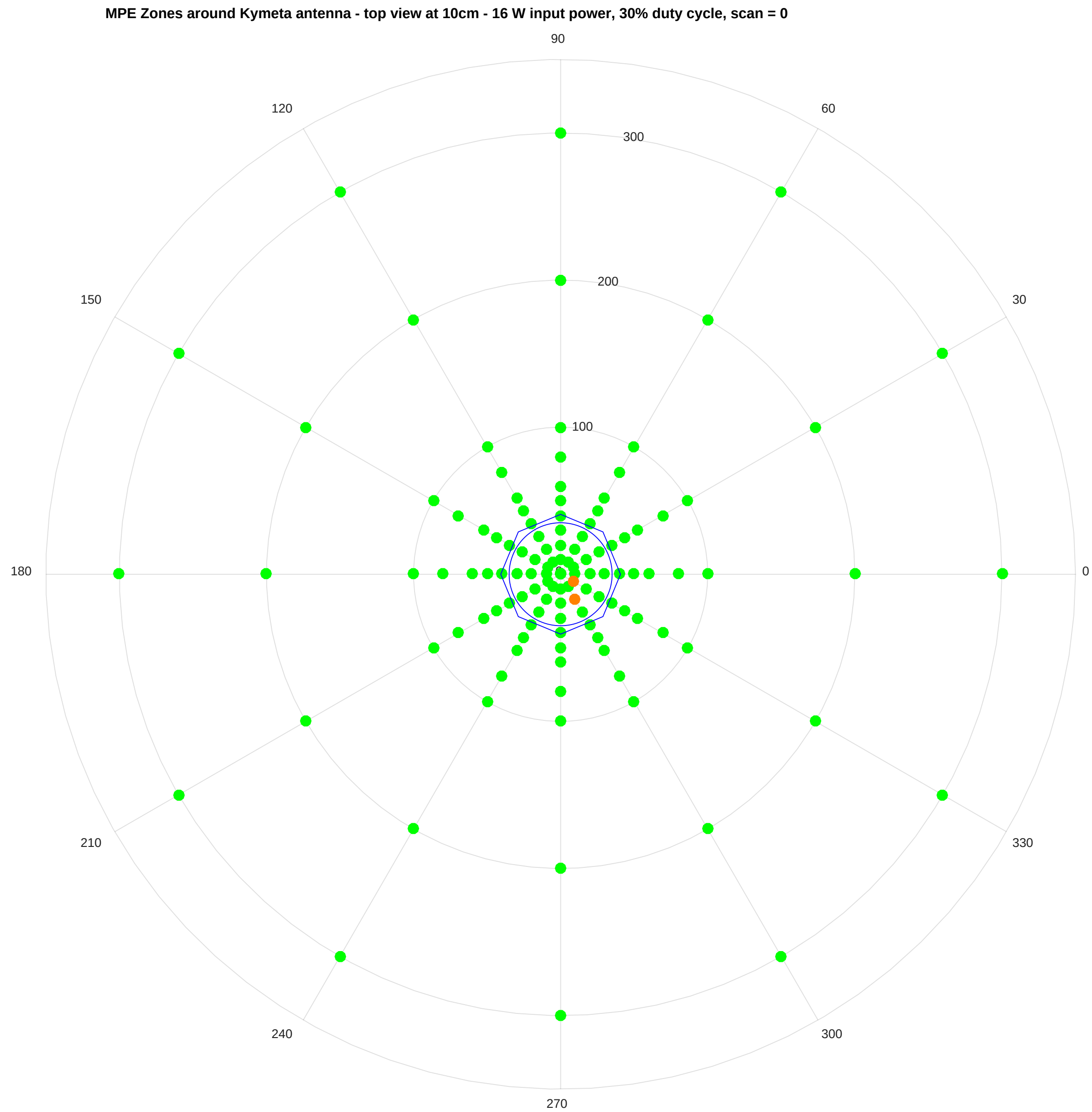

Figure 9: Height 10 cm, 16W input power with 30% Duty Cycle, Scan 0˚

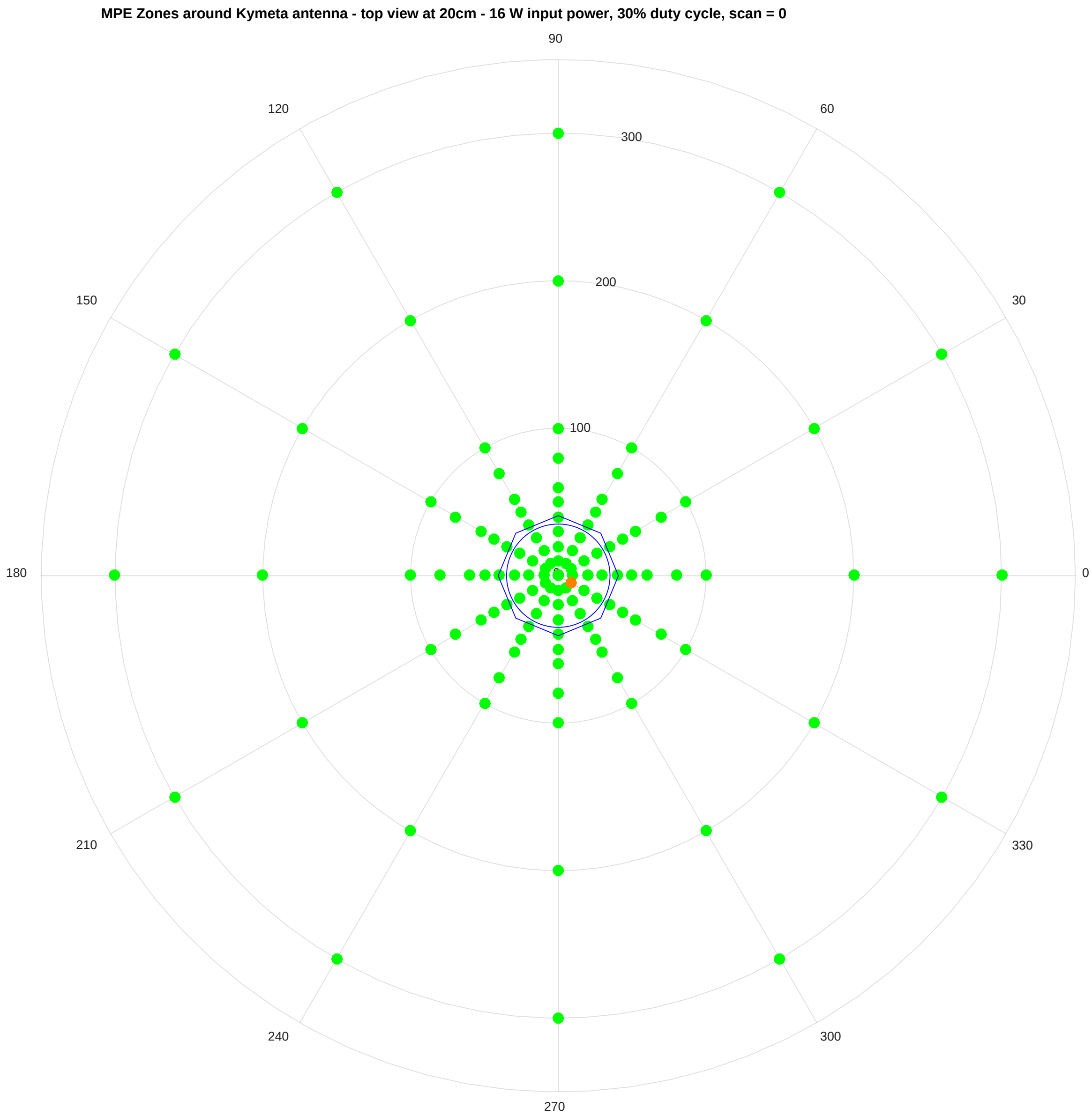

Figure 10: Height 20 cm, 16W input power with 30% Duty Cycle, Scan 0˚

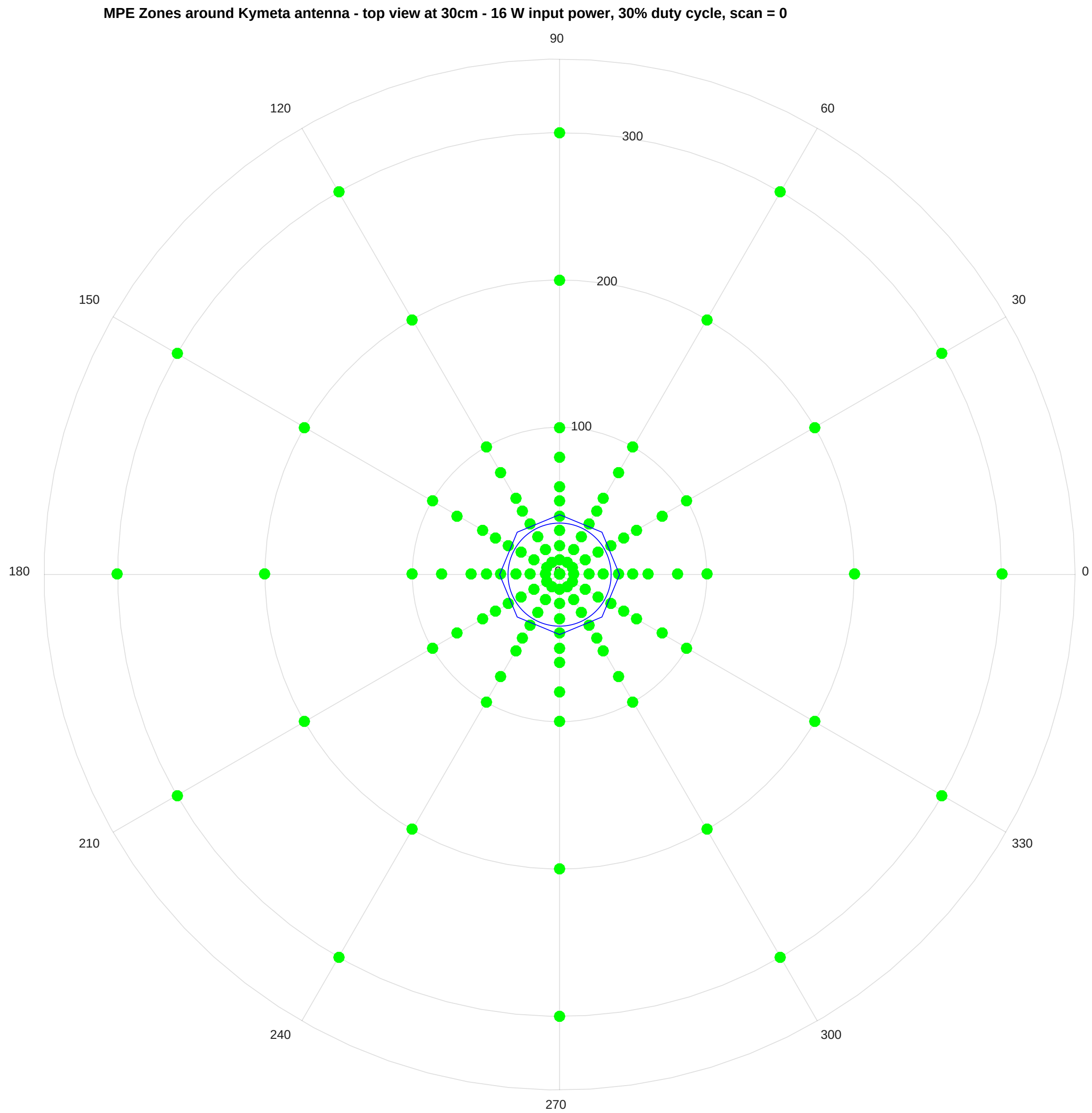

Figure 11: Height 30 cm, 16W input power with 30% Duty Cycle, Scan 0˚

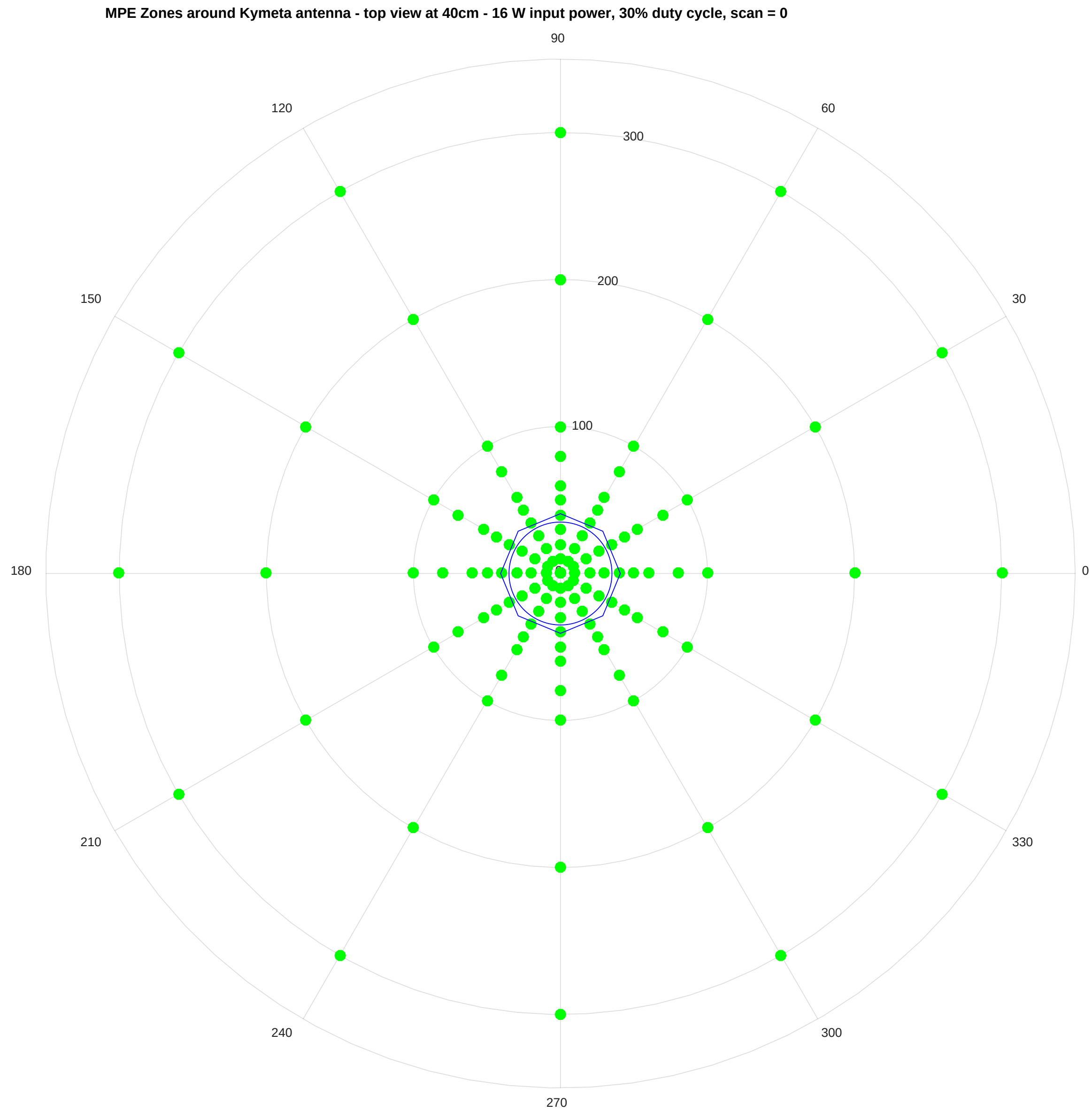

Figure 12: Height 40 cm, 16W input power with 30% Duty Cycle, Scan 0˚

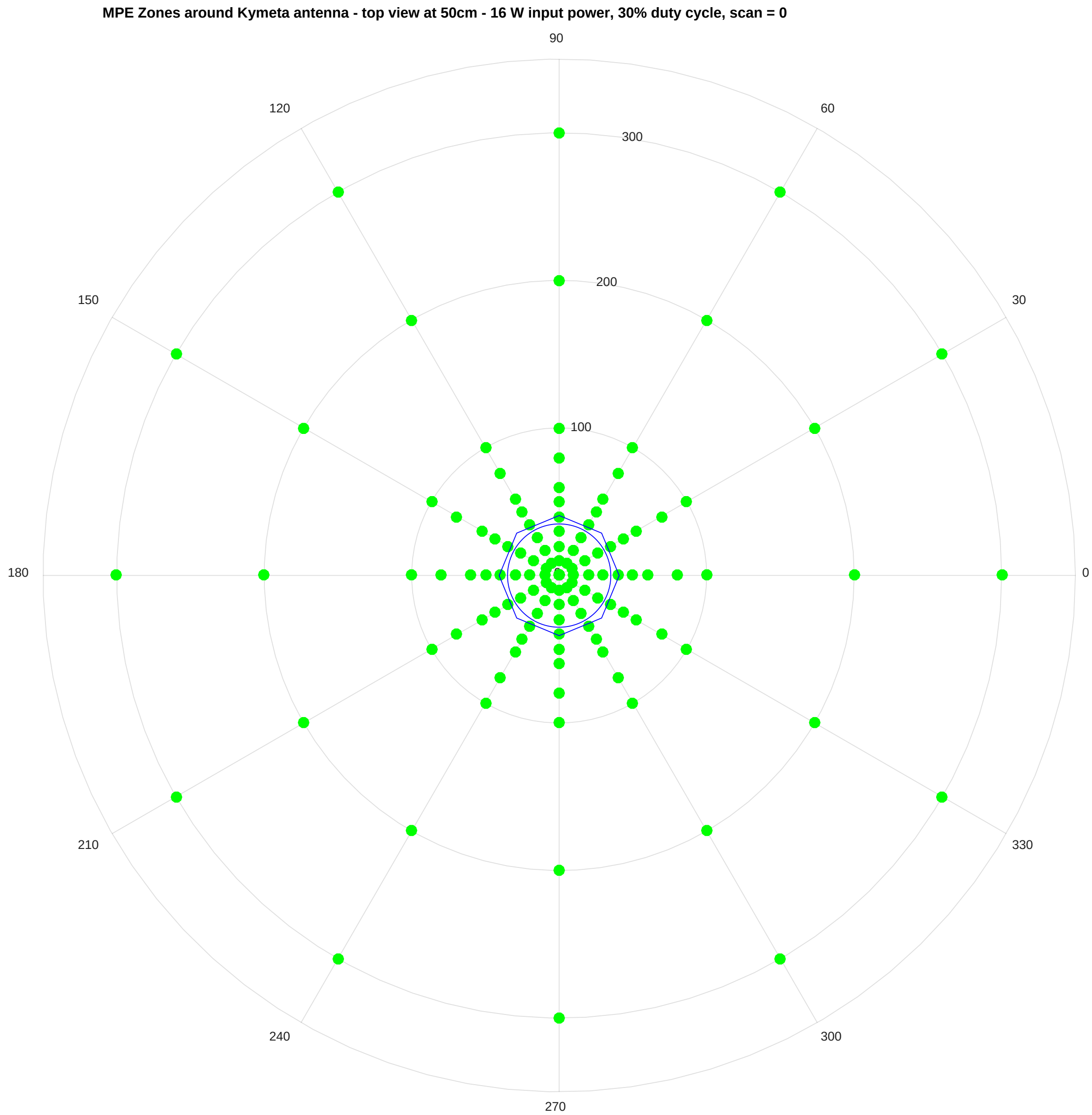

Figure 13: Height 50 cm, 16W input power with 30% Duty Cycle, Scan 0˚

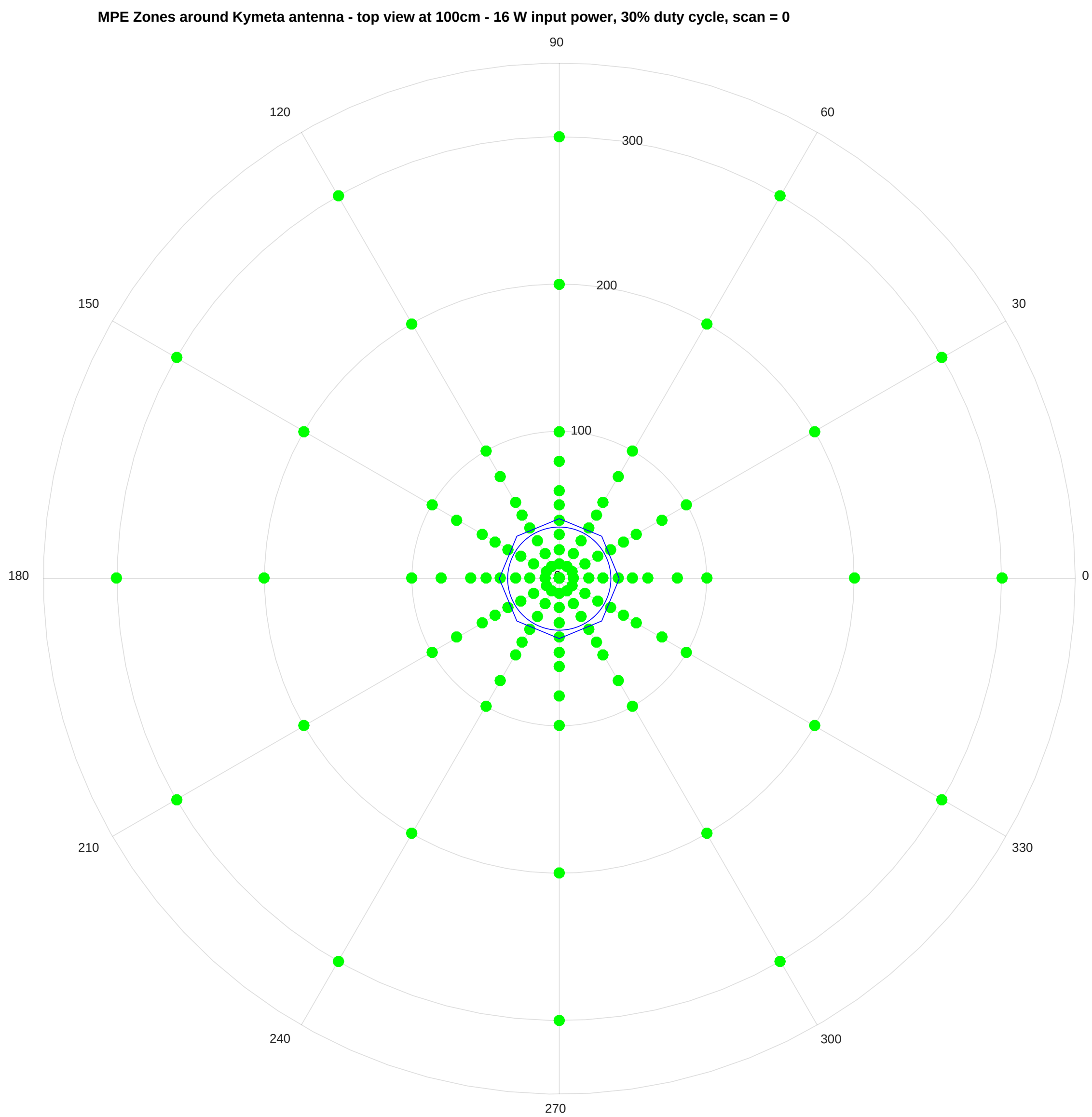

Figure 14: Height 100 cm, 16W input power with 30% Duty Cycle, Scan 0˚

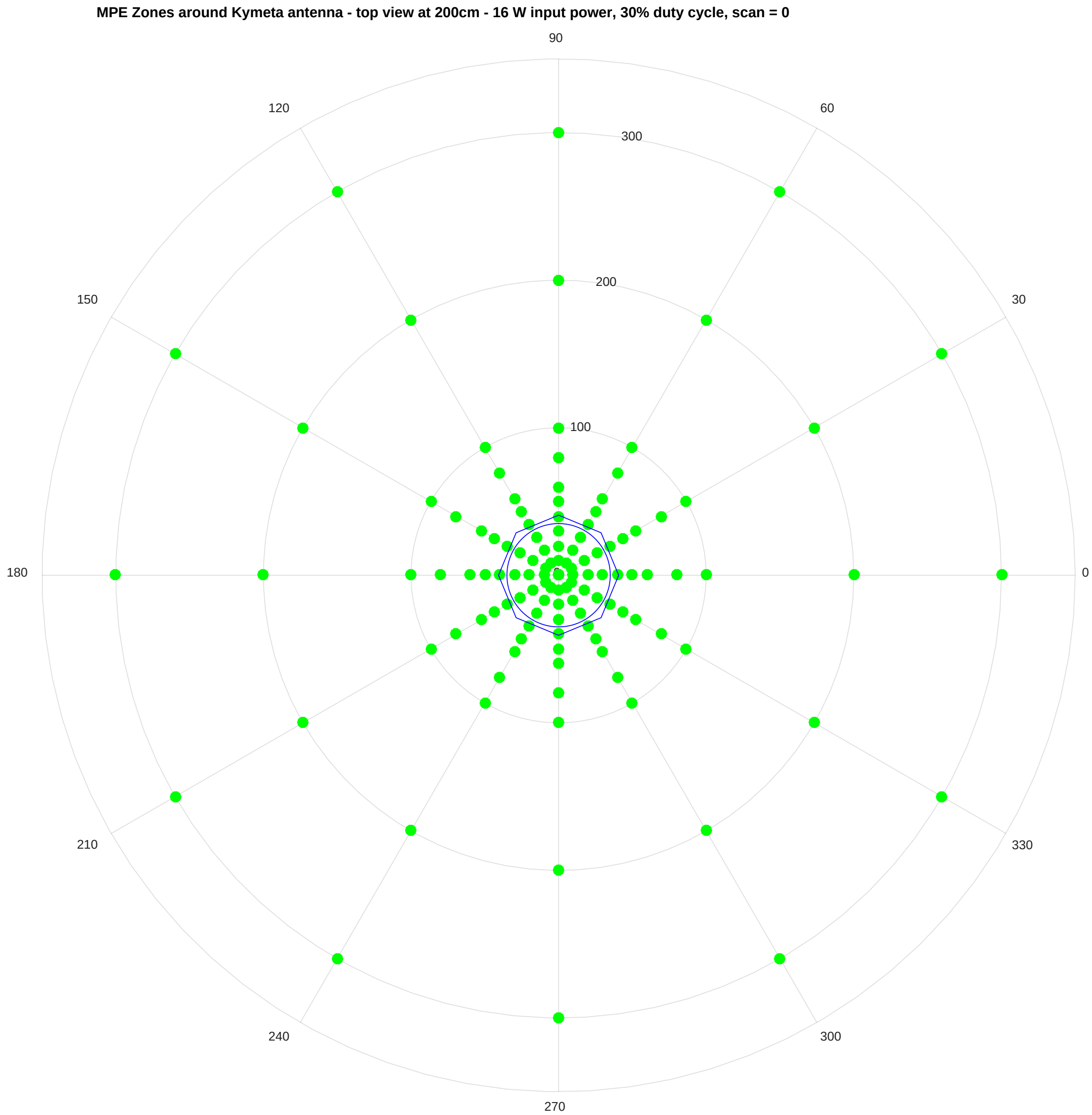

Figure 15: Height 200 cm, 16W input power with 30% Duty Cycle, Scan 0˚

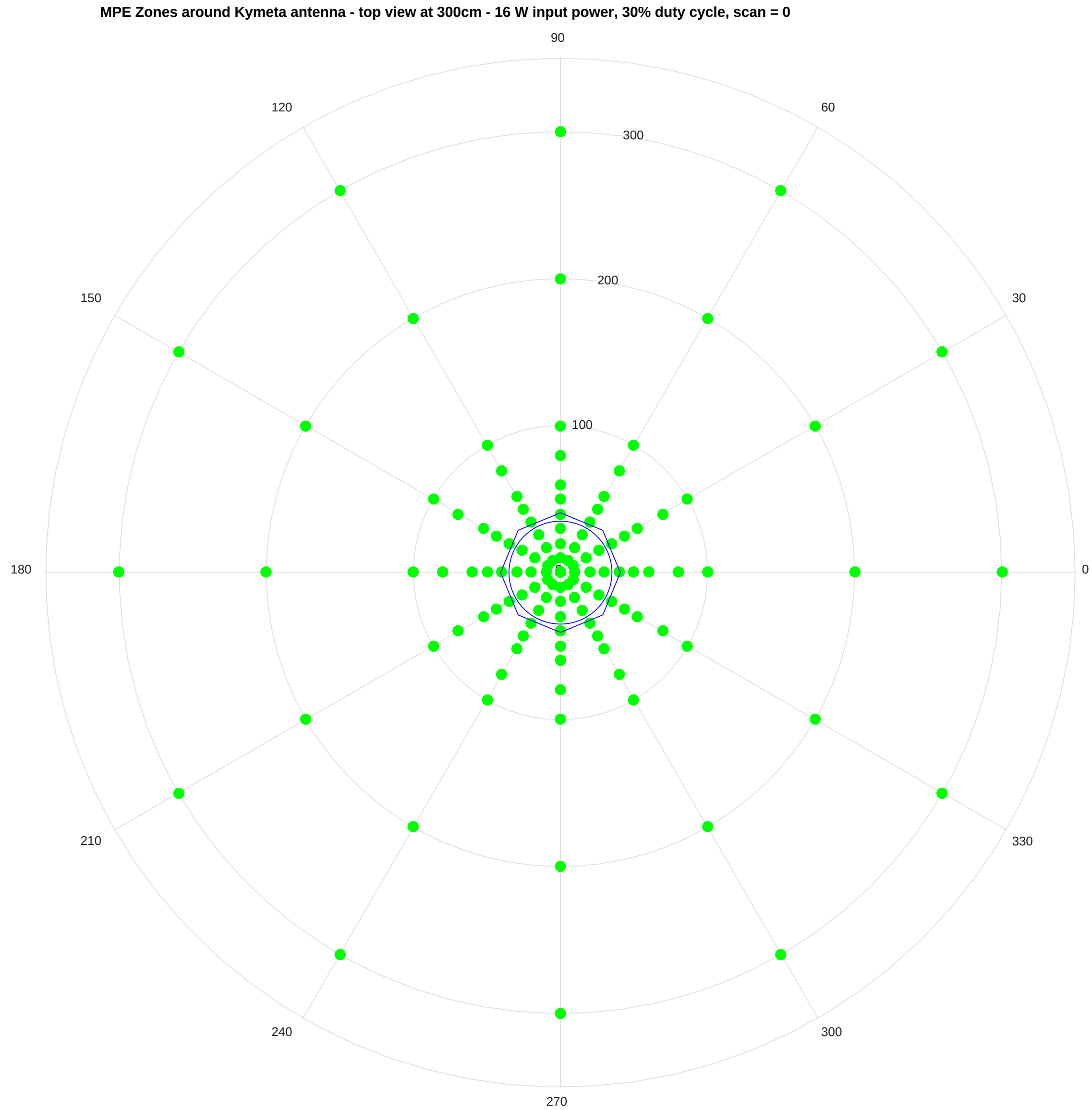

Figure 16: Height 300 cm, 16W input power with 30% Duty Cycle, Scan 0˚

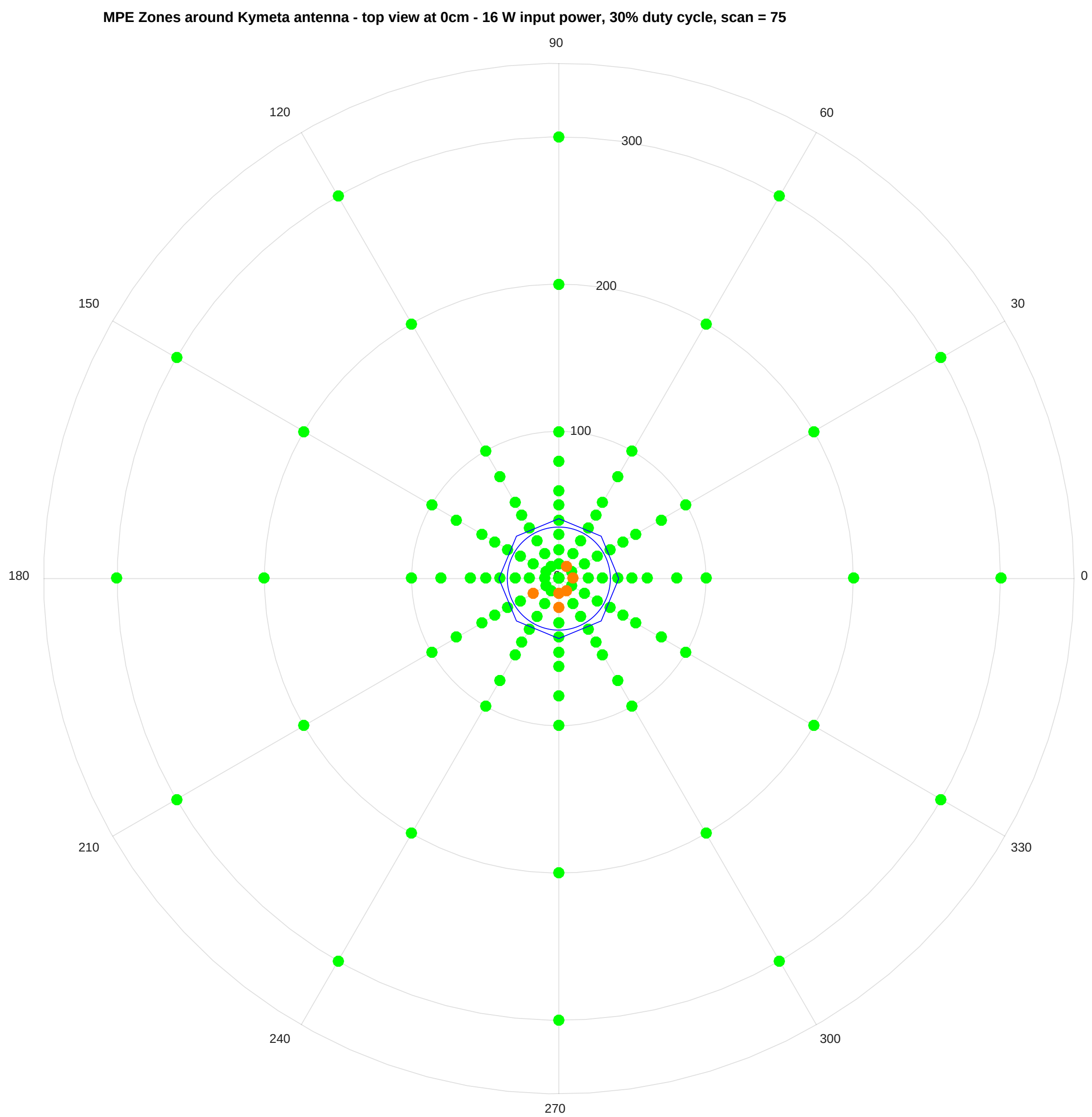

Figure 17: Height 0 cm, 16W input power with 30% Duty Cycle, Scan 75˚

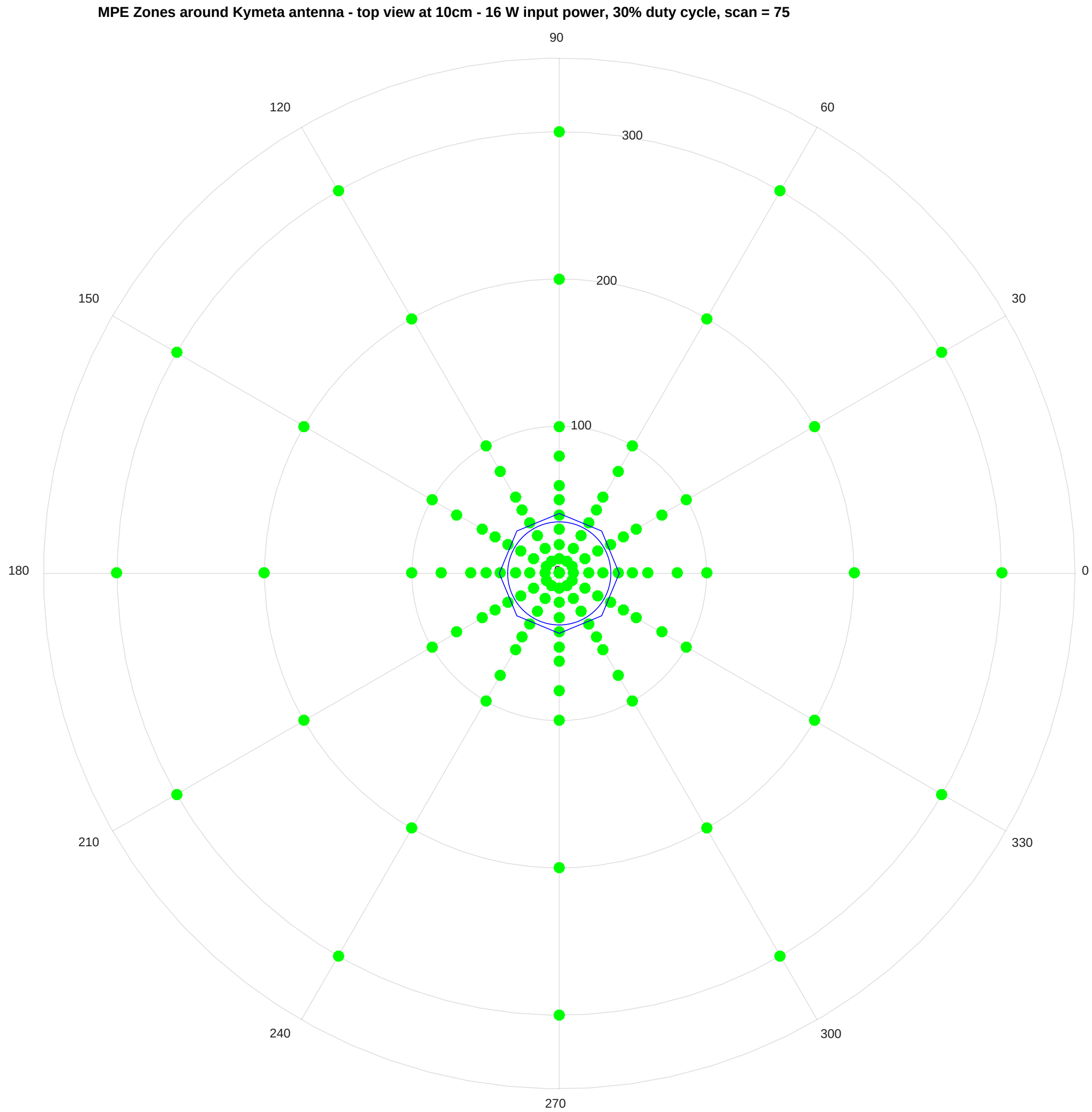

Figure 18: Height 10 cm, 16W input power with 30% Duty Cycle, Scan 75˚

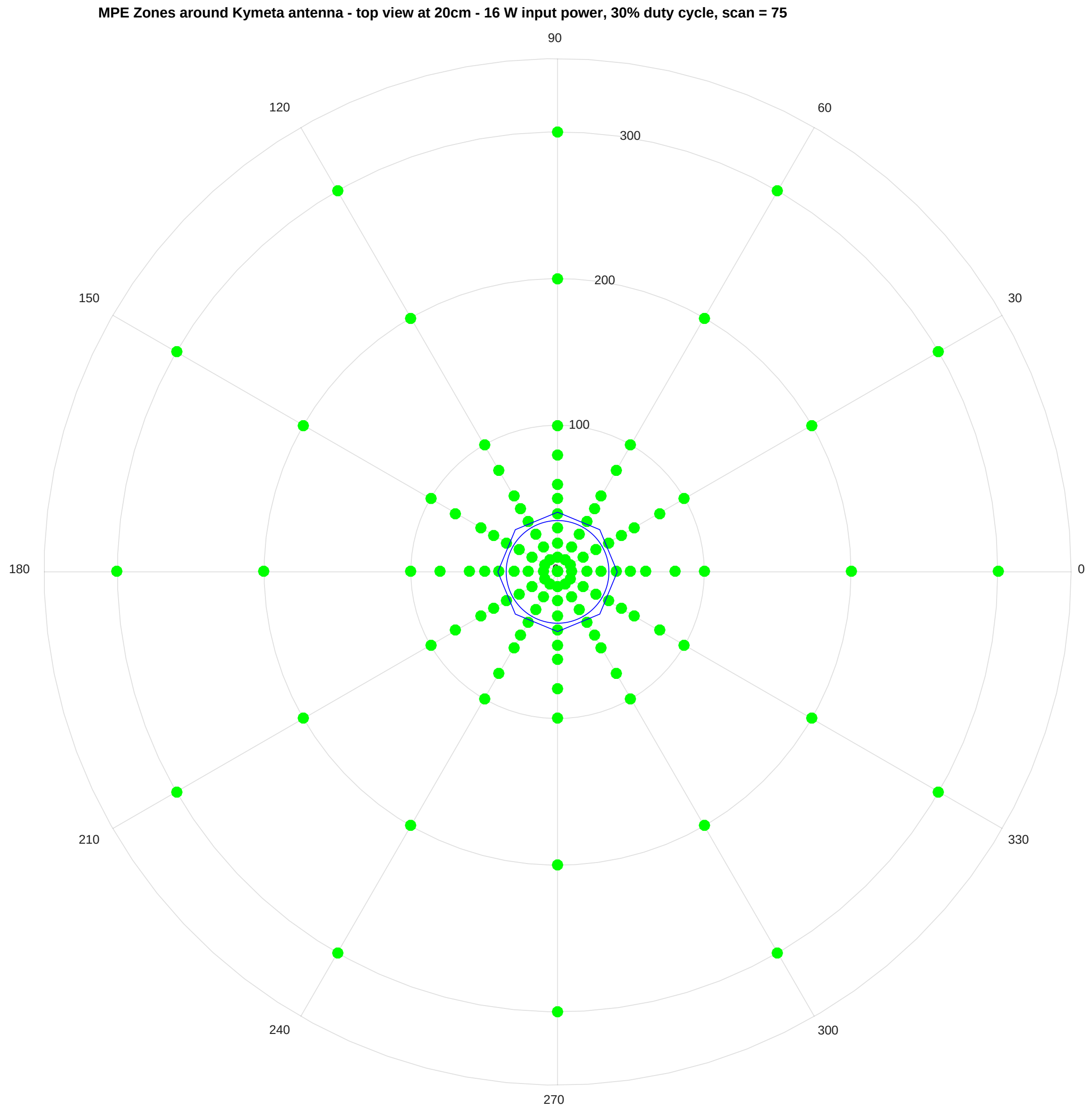

Figure 19: Height 20 cm, 16W input power with 30% Duty Cycle, Scan 75˚

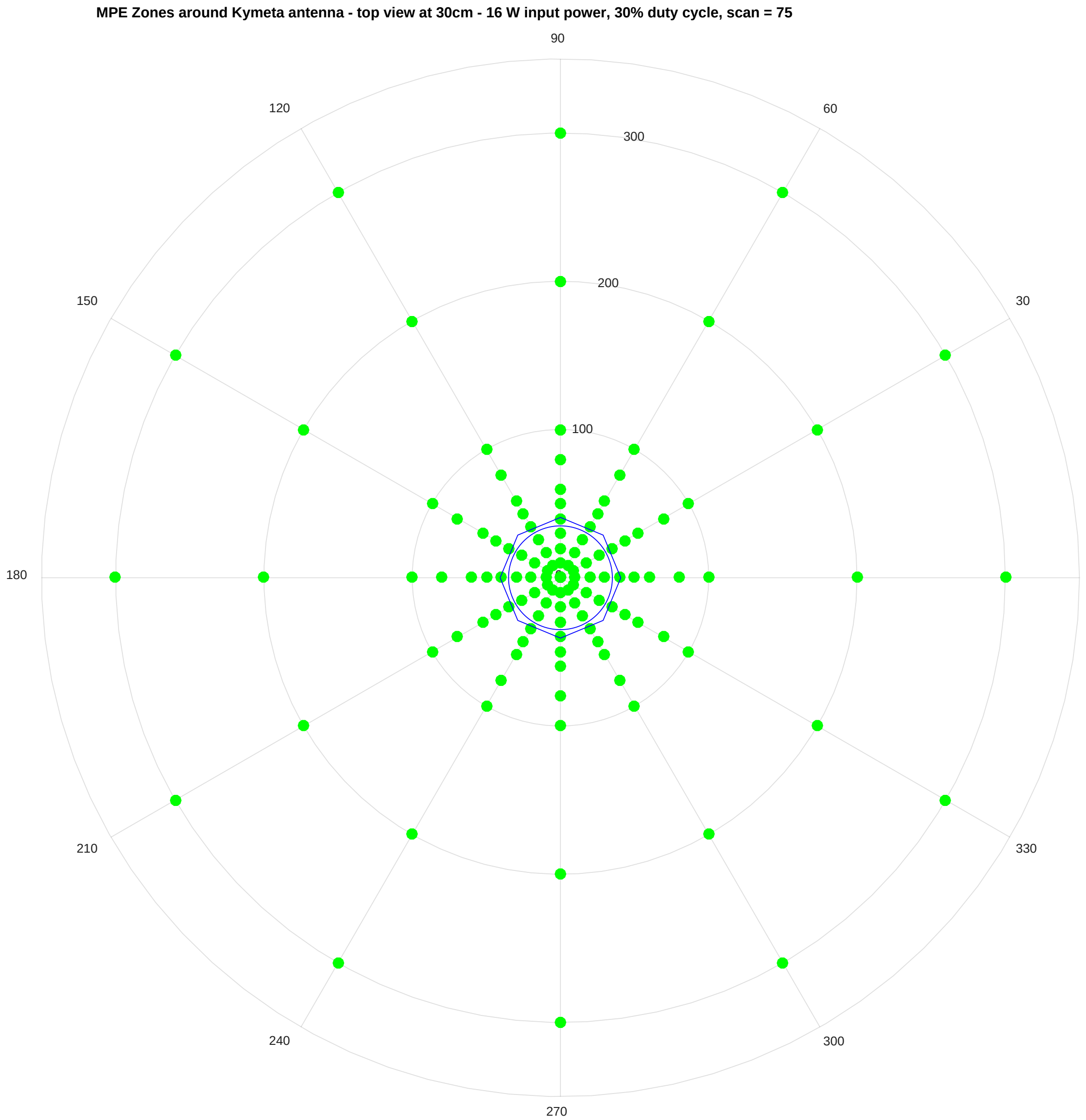

Figure 20: Height 30 cm, 16W input power with 30% Duty Cycle, Scan 75˚

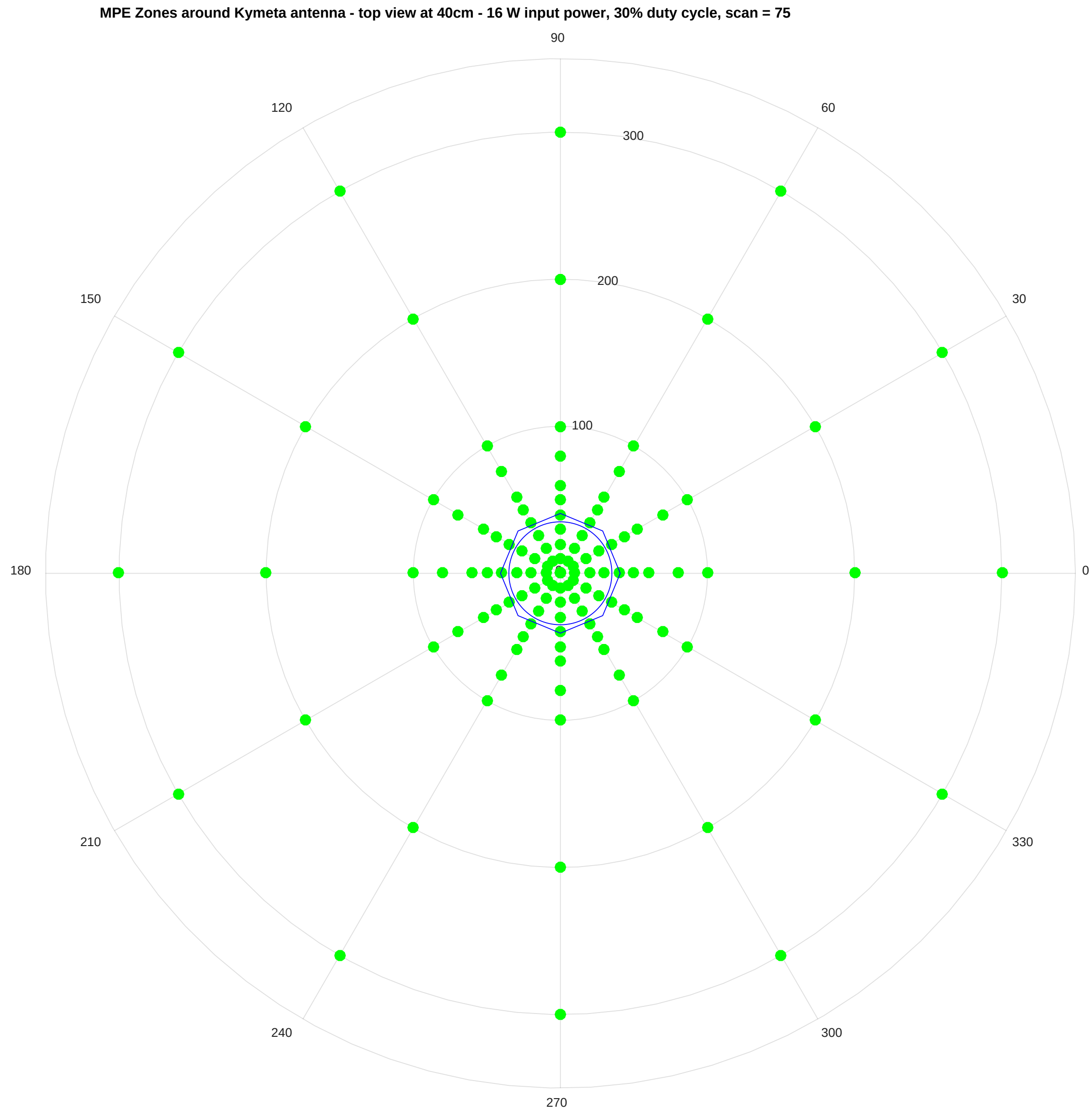

Figure 21: Height 40 cm, 16W input power with 30% Duty Cycle, Scan 75˚

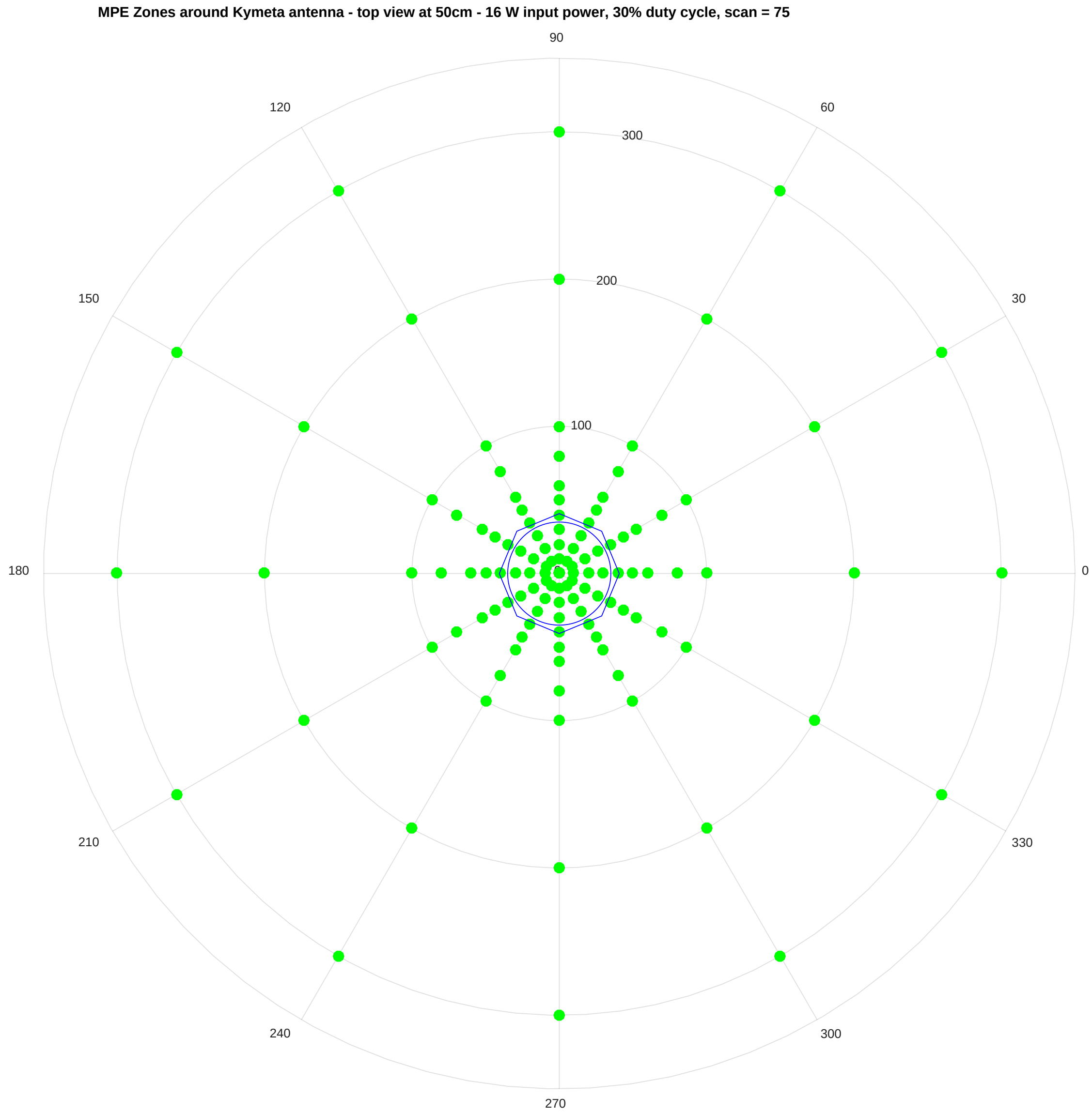

Figure 22: Height 50 cm, 16W input power with 30% Duty Cycle, Scan 75˚

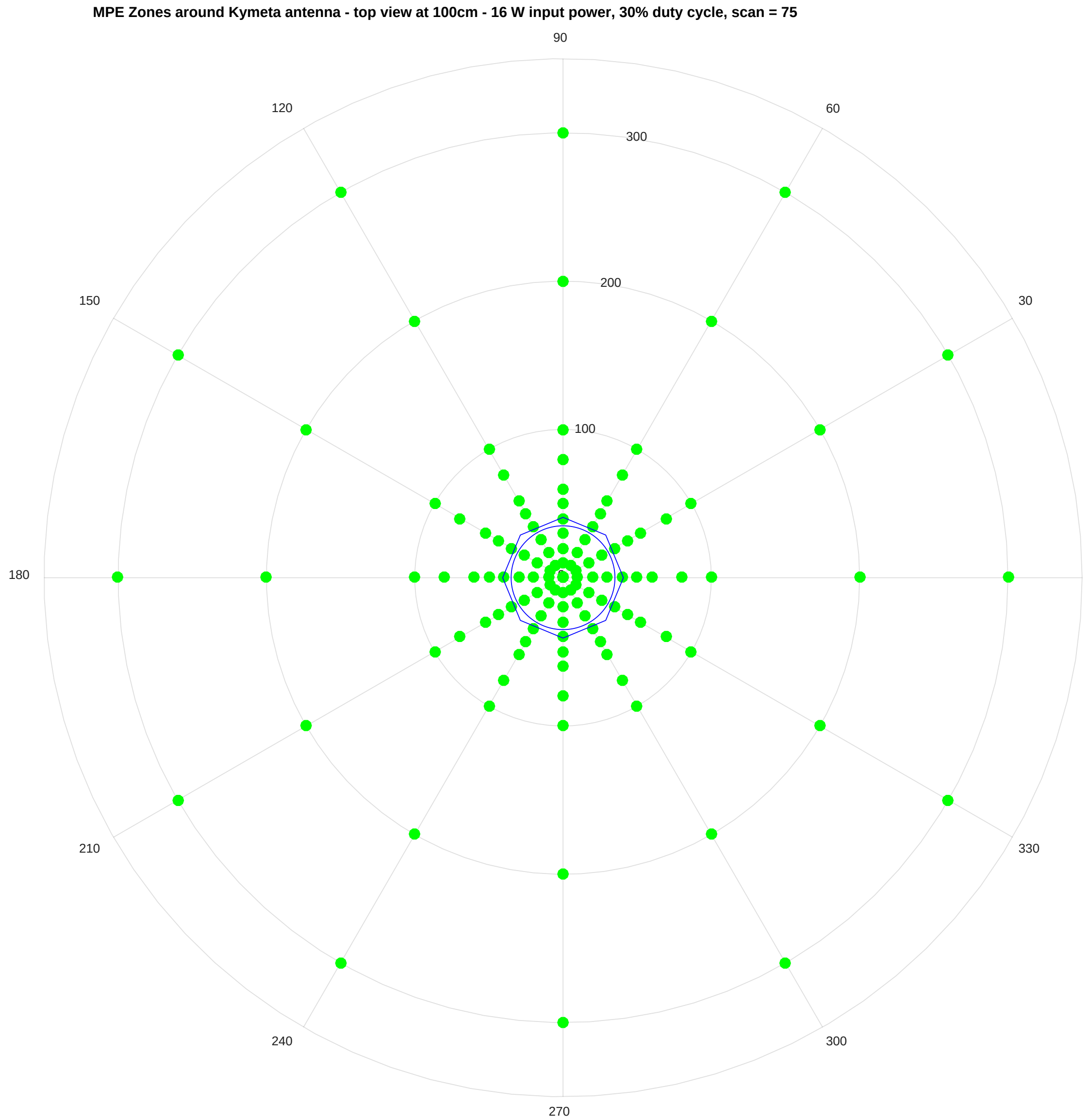

Figure 23: Height 100 cm, 16W input power with 30% Duty Cycle, Scan 75˚

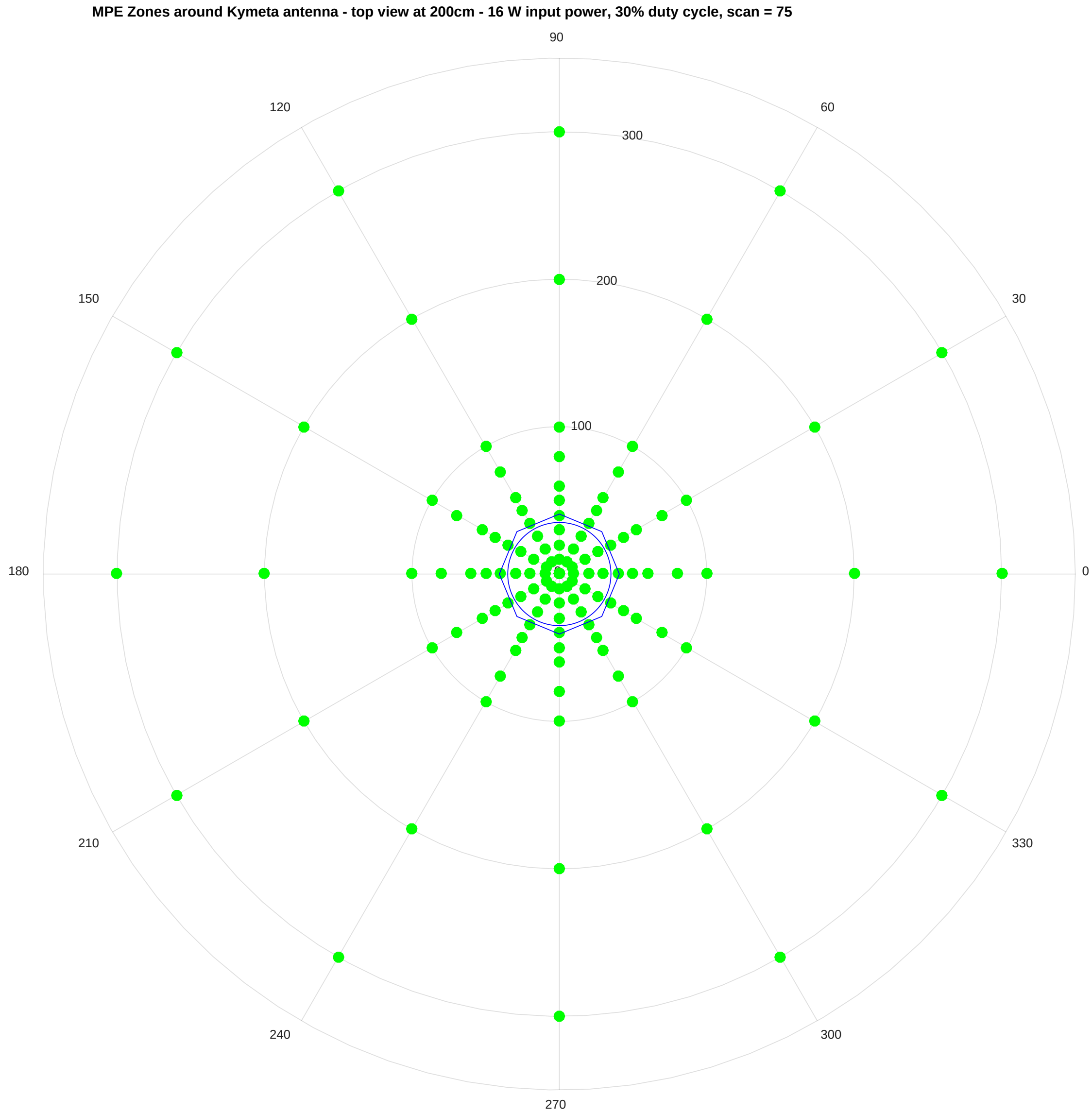

Figure 24: Height 200 cm, 16W input power with 30% Duty Cycle, Scan 75˚

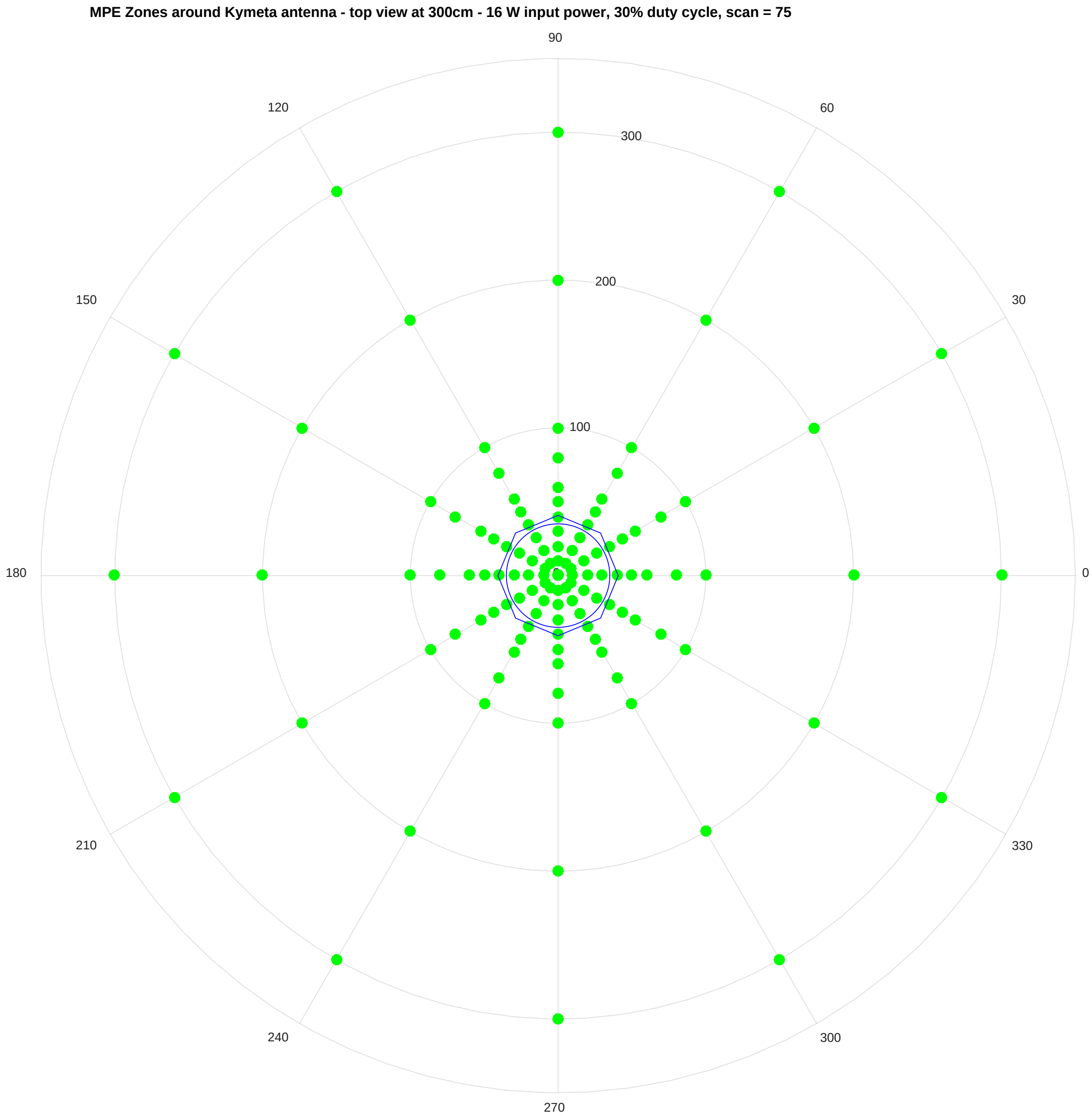

Figure 25: Height 300 cm, 16W input power with 30% Duty Cycle, Scan 75˚

6 RF Analysis for the Back of the Terminal

The back radiation of the Antenna is significantly lower than that of the forward directed (main lobe) radiation, producing power densities much less than the public, uncontrolled MPE limits. RF exposure of the driver and passengers of a VMES is further reduced because of the shielding effect afforded by the metallic backplane of the Antenna as well as the vehicle roof.

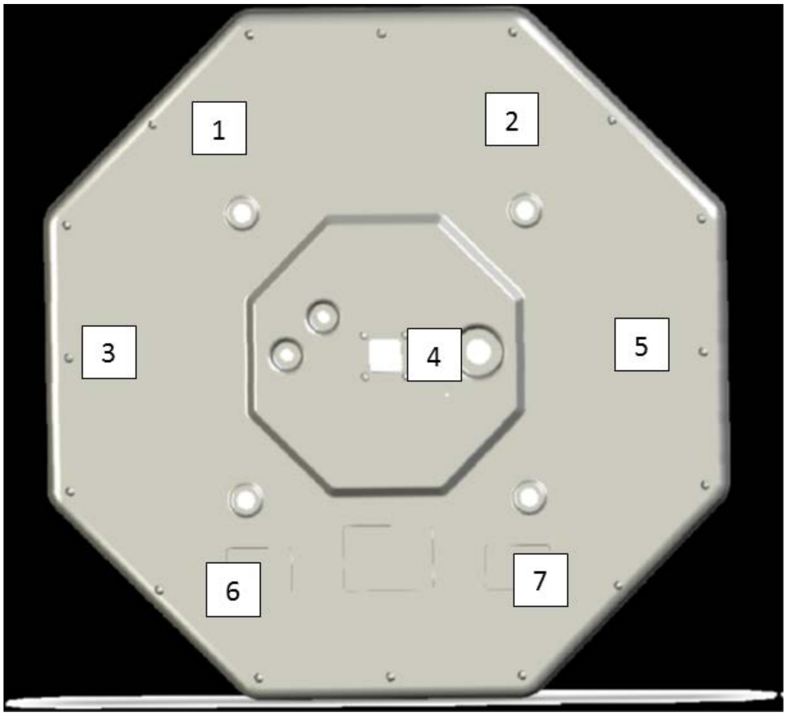

Figure 26: Solid model of the back of the KyWay 1 antenna module showing measurement locations for the RF power density measurements

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

	Measured Data (mW/cm^2)	
Location	**1" from the back of the antenna**	**3" from the back of the antenna**
1	0.000	0.000
2	0.000	0.000
3	0.000	0.000
4	0.0054	0.0027
5	0.000	0.000
6	0.000	0.000
7	0.000	0.000

Table 2: Scaled power density levels at the back of the KyWay 1 antenna module (16 W input power, 30% duty cycle)

	Scaled Data (mW/cm^2)	
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	0.01296	0.00648
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000

Figure 26 shows the location of power density measurements behind the Antenna. These measurements were performed by Kymeta in its own anechoic chamber using an AR SM40G RF survey meter (AR RF/Microwave Instrumentation) and SHE3M40G Isotropic Electric Field Probe with an operating dynamic range of 0.5 to 350 V/m. This translates to minimum detectable power density of 0.0000663 mW/cm^2, entirely sufficient to detect the values associated with this measurement.

These measurements were performed using a 2 watt BUC. The raw data is shown in Table 1. The data were scaled to 16 watts and a 30% duty cycle and tabulated in Table 2. As is clear in the table, the RF power density presented from the back side of the terminal is substantially below the general population uncontrolled exposure limits for operations at 16 watts.

7 General RF safety analysis

The RF measurements performed on the Antenna indicate that only low values of power density will exist near the Kymeta Antenna and only within a very small volume of space is there the potential for power densities to exceed the FCC general public MPE. Nonetheless, Kymeta is committed to embracing the elements in IEEE Standard C95.7-2014, Recommended Practice for RF Safety Programs, to ensure compliance with the relevant FCC MPEs. Exposure of the public to this limited volume of space during normal operation of the Antenna is deemed to be a very low probability event given the close proximity that one would have to be to enter the region where the public MPE could be exceeded (*i.e.*, within 20 cm above the inner portion of the Antenna). More specifically, power density measurements show the following for operation of the Terminal at 16 watts, with a maximum duty cycle of 30%:

There are no “red” zones (*i.e.*, which would be represented by red dots in the various figures) – that is, potential RF exposure near the Antenna never exceeds the occupational/controlled MPE level of 5 mW/cm^2.

There are, however, several “orange” zones – that is, the RF power density exceeds the general population/uncontrolled MPE level of 1 mW/cm^2, but is less than the occupational/controlled MPE level of 5 mW/cm^2.

The “orange” zones are found in the following locations:

- Vertical: At 0, 10 and 20 cm from the surface of the antenna (at 0° scan angle). At 75° degree scan angle, the only “orange” zone is on the surface of the antenna. For the purposes of this analysis, Kymeta assumes a worst case of 0° scan angle.
- Horizontal: Within 20 cm radius from the center of the antenna. Conversely, the outer 20 cm of the physical antenna is within a “green” zone in all tests. A “green” zone represents an area where the measured RF power density is less than the general population/uncontrolled MPE level of 1 mW/cm^2.

Stated differently, the “orange” zone is limited to a small 20 cm radius by 30 cm high cylinder. Kymeta will refer to this as the “Orange Zone Cylinder.”

Finally, measurements directly behind the antenna are all in the “green” zone – measured power density is well below the general population/uncontrolled MPE level of 1 mW/cm^2.

8 Fixed use case analysis

Kymeta Terminals will typically be deployed for commercial use on private property. In order to ensure that the general population does not have access to the Orange Zone Cylinder, Kymeta will do the following:

- Add a label to the bezel of the Antenna radome stating: “NOTICE – Radiofrequency fields may exceed FCC limits for the public within 20 cm of the center of the Antenna” (or substantially similar wording).

- Instruct customers to post one or more signs around the Antenna stating: "NOTICE – Radiofrequency fields may exceed FCC limits for the public within 20 cm of the center of the Antenna" (or substantially similar wording).
- In unusual cases where the Terminal is not in a secured area inaccessible to the public, Kymeta will instruct customers to install an indicative barrier around the Antenna. The unlikely scenario of a member of the general public accessing the immediate region above the center of the Antenna is deemed analogous to a condition of transient exposure that would exist for only a very short duration.

In addition, Kymeta will provide a training manual instructing customers to shut down the transmitter whenever maintenance work is to be performed on the Antenna and providing RF safety awareness information to the operator and those responsible for use of the Terminal.

9 ESV use case analysis

Kymeta Terminals will be deployed on commercial vessels and private yachts, typically in non-accessible areas on platforms at or near the highest point of the vessel. In order to ensure that the general population does not have access to the Orange Zone Cylinder, Kymeta will do the following:

- Add a label to the bezel of the Antenna radome stating: "NOTICE – Radiofrequency fields may exceed FCC limits for the public within 20 cm of the center of the Antenna" (or substantially similar wording).
- Instruct customers to post one or more signs around the Antenna stating: "NOTICE – Radiofrequency fields may exceed FCC limits for the public within 20 cm of the center of the Antenna" (or substantially similar wording).
- In unusual cases where the Terminal is not in a secured area inaccessible to the public, Kymeta will instruct customers to install an indicative barrier around the Antenna. The unlikely scenario of a member of the general public accessing the immediate region above the center of the Antenna is deemed analogous to a condition of transient exposure that would exist for only a very short duration.

In addition, Kymeta will provide a training manual instructing customers to shut down the transmitter whenever maintenance work is to be performed on the Antenna and providing RF safety awareness information to the operator and those responsible for use of the Terminal.

10 VMES use case analysis

Kymeta Terminals will be deployed horizontally on the roof-top of various vehicles, including buses, trucks, trains, RVs, and heavy vehicles. Figure 27 is a graphic of the "Orange Zone Cylinder" above a vehicle.

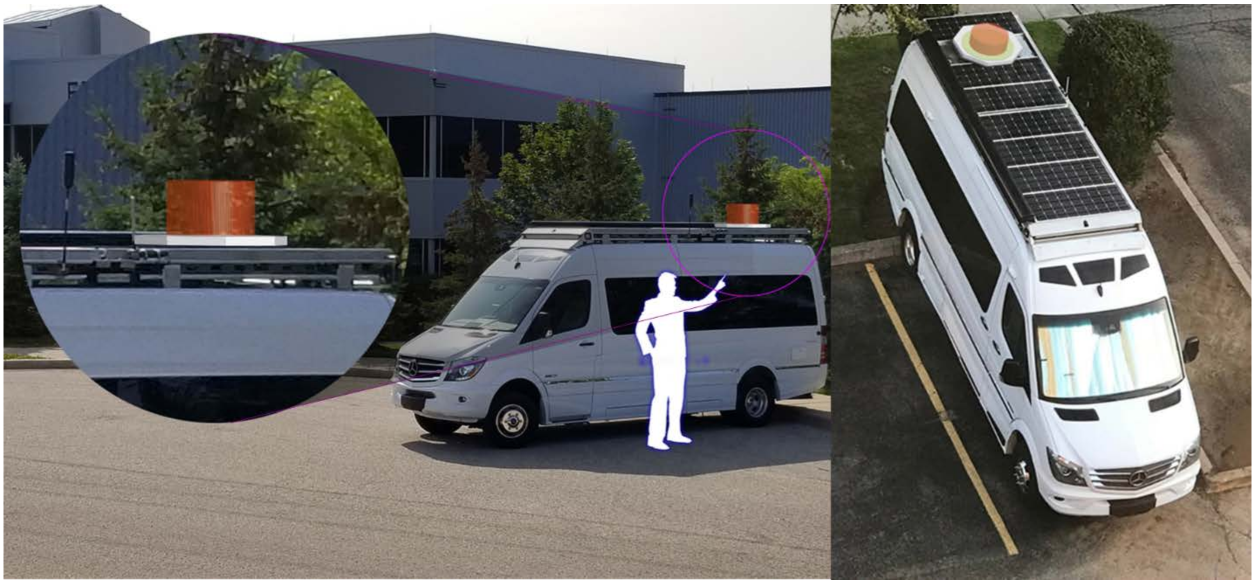

Figure 27: The orange zone cylinder above an ASM mounted vehicle

In order to ensure that the general population does not have access to the Orange Zone Cylinder, Kymeta will do the following:

- Add a label to the bezel of the Antenna radome stating: "NOTICE – Radiofrequency fields may exceed FCC limits for the public within 20 cm of the center of the Antenna" (or substantially similar wording).
- Kymeta will instruct customers to keep people off the roof of the vehicle unless the TX function is turned off. The unlikely scenario of a member of the general public accessing the immediate region above the center of the Antenna is deemed analogous to a condition of transient exposure that would exist for only a very short duration.

In addition, Kymeta will provide a training manual instructing customers to shut down the transmitter whenever maintenance work is to be performed on the Antenna and providing RF safety awareness information to the operator and those responsible for use of the Terminal.