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Kymeta 40-Watt RF Safety Analysis
March 2019

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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").

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.

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.

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.

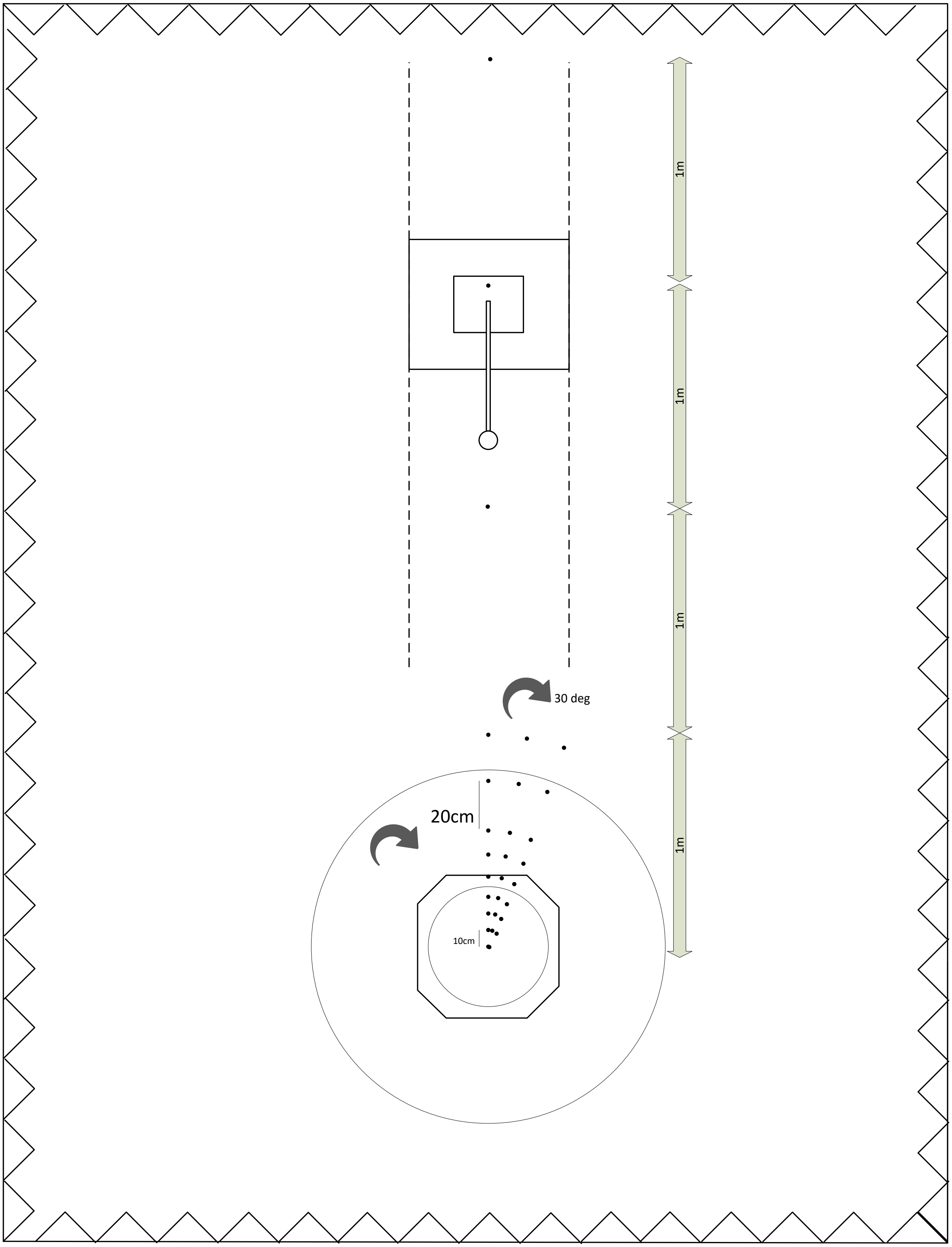

Figure 1: Chamber layout, top-down view

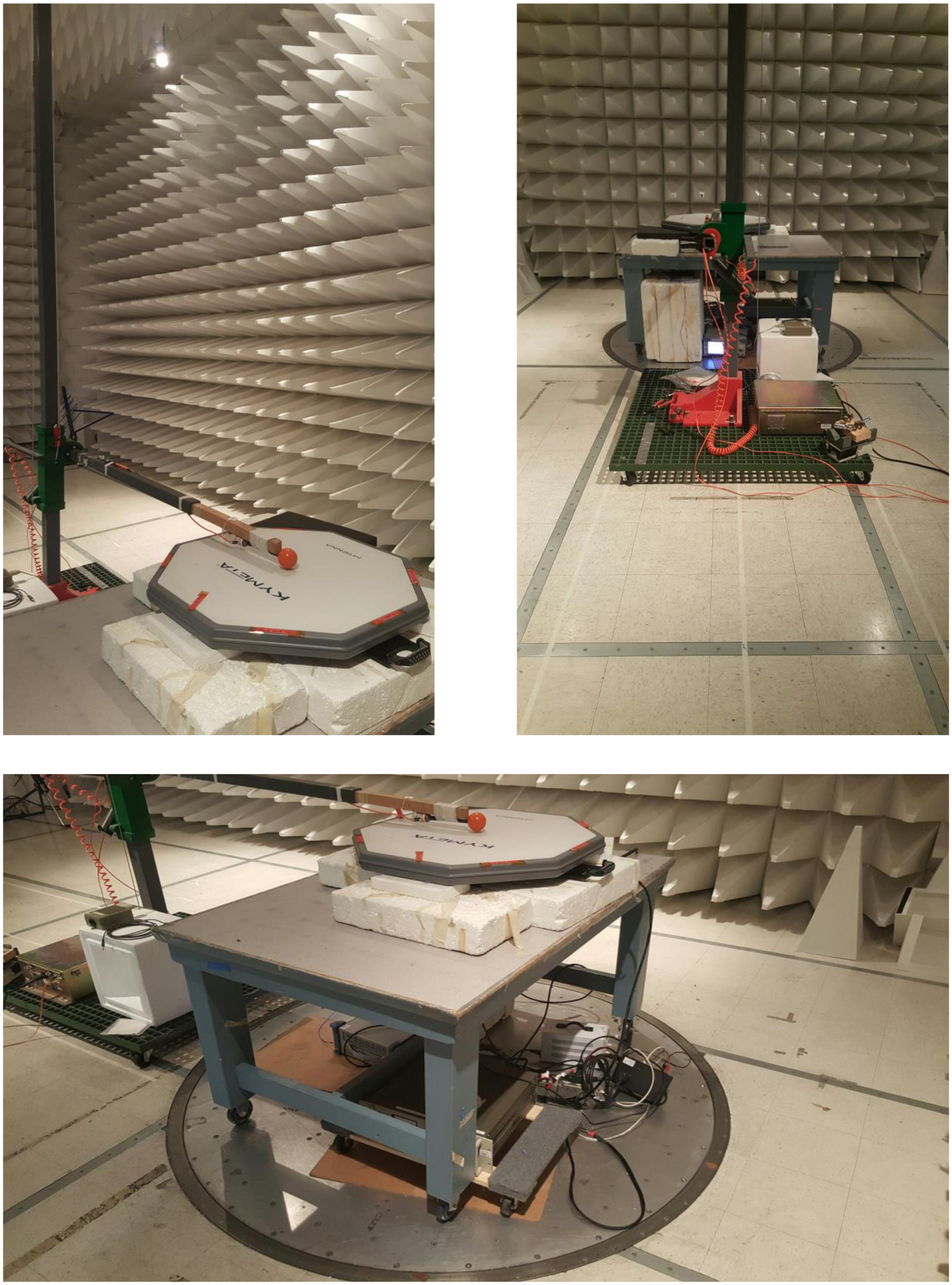

Figure 2: Chamber pictures

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 40 W linearly. This approach results in minimum detectable power density of 0.00106 x 40 / 4 (40 W scaled from 4 W reference) = 0.0106 mW/cm^2 when scaled to 40 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.

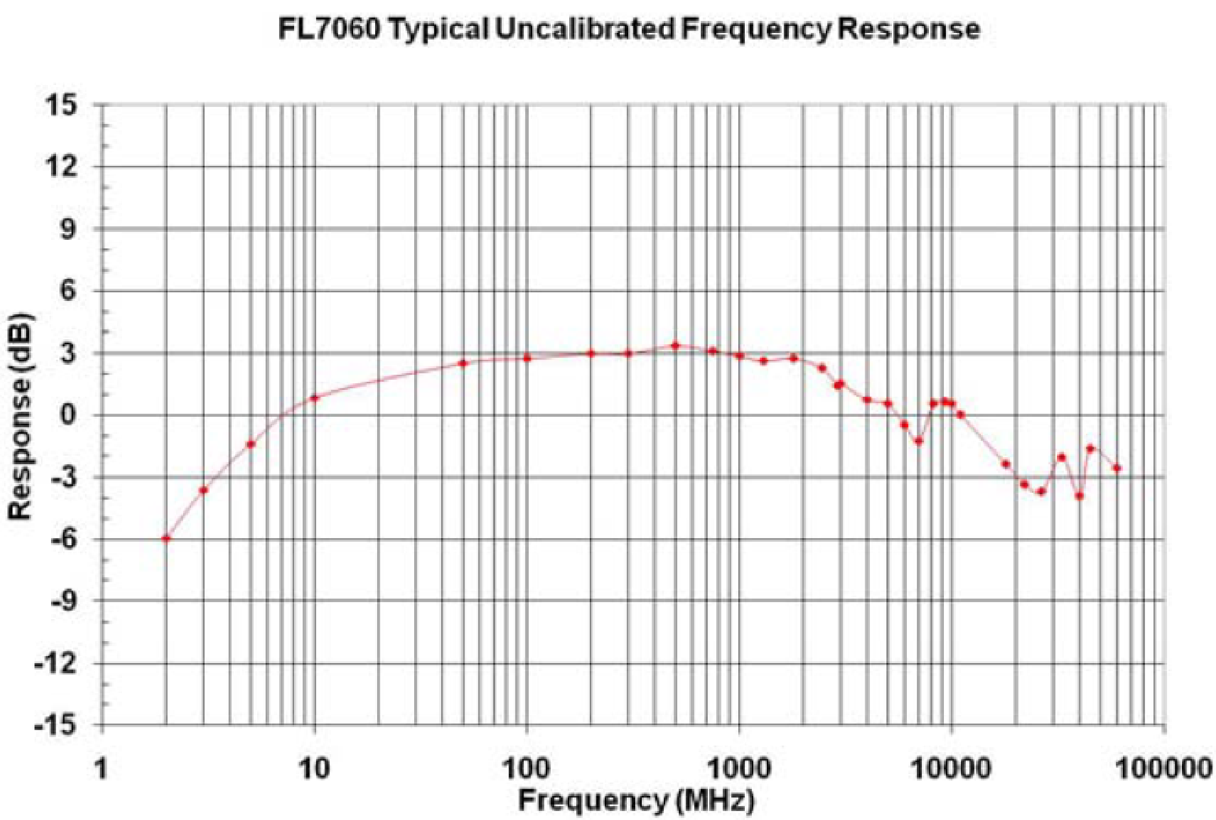

Figure 3: Typical uncalibrated frequency response for FL7060 probe

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).

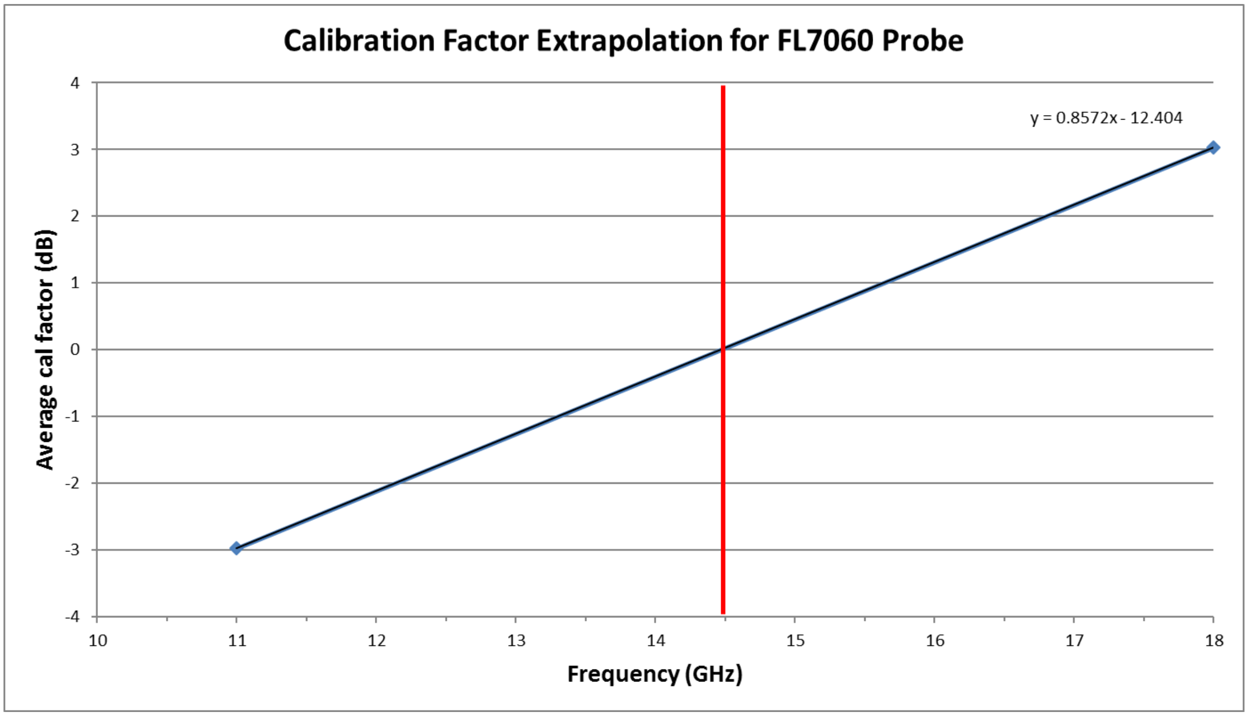

Figure 5: Correction factor extrapolation at 14.5 GHz

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 40 W power level.

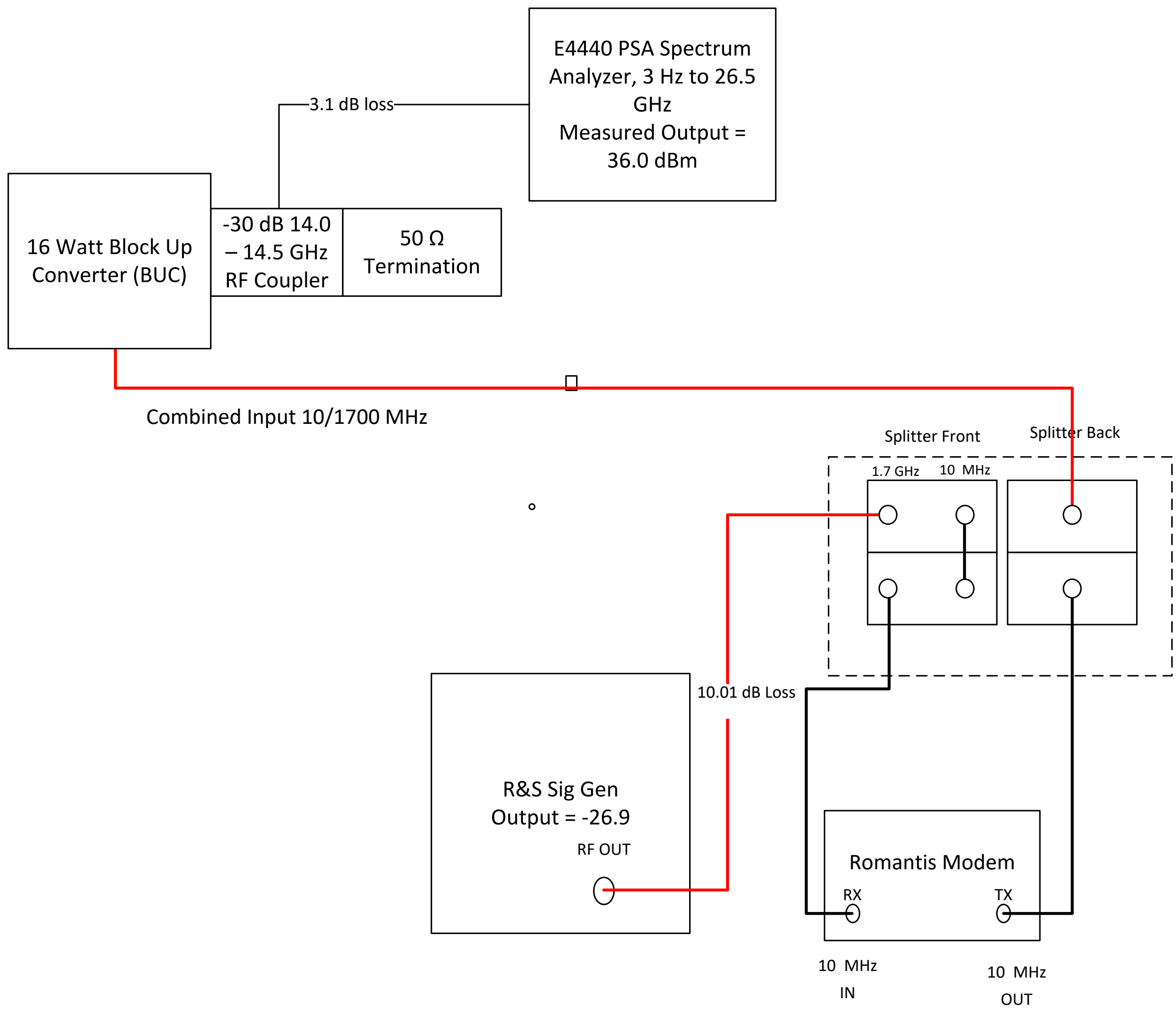

Figure 6: Input reference power calibration diagram

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 extreme 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.

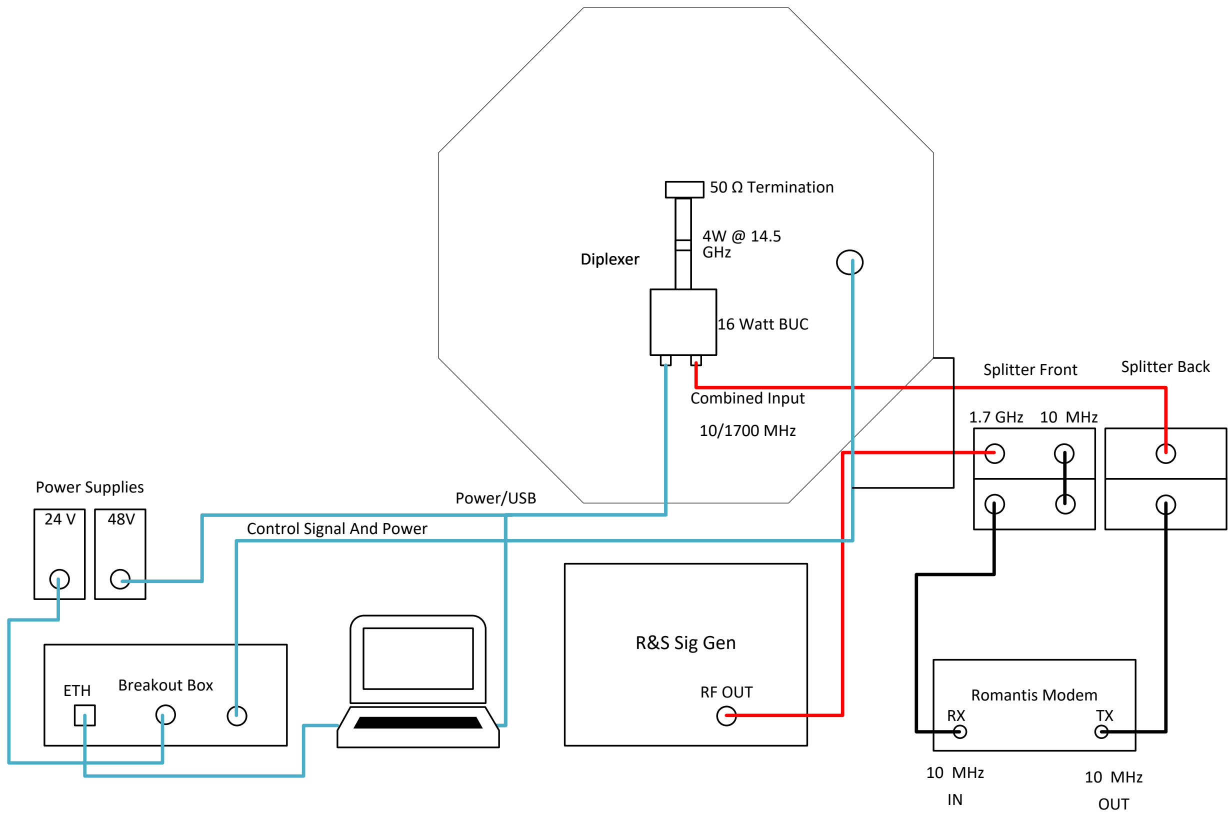

Figure 7: Kymeta terminal - transmit diagram

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.

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 = 40 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.

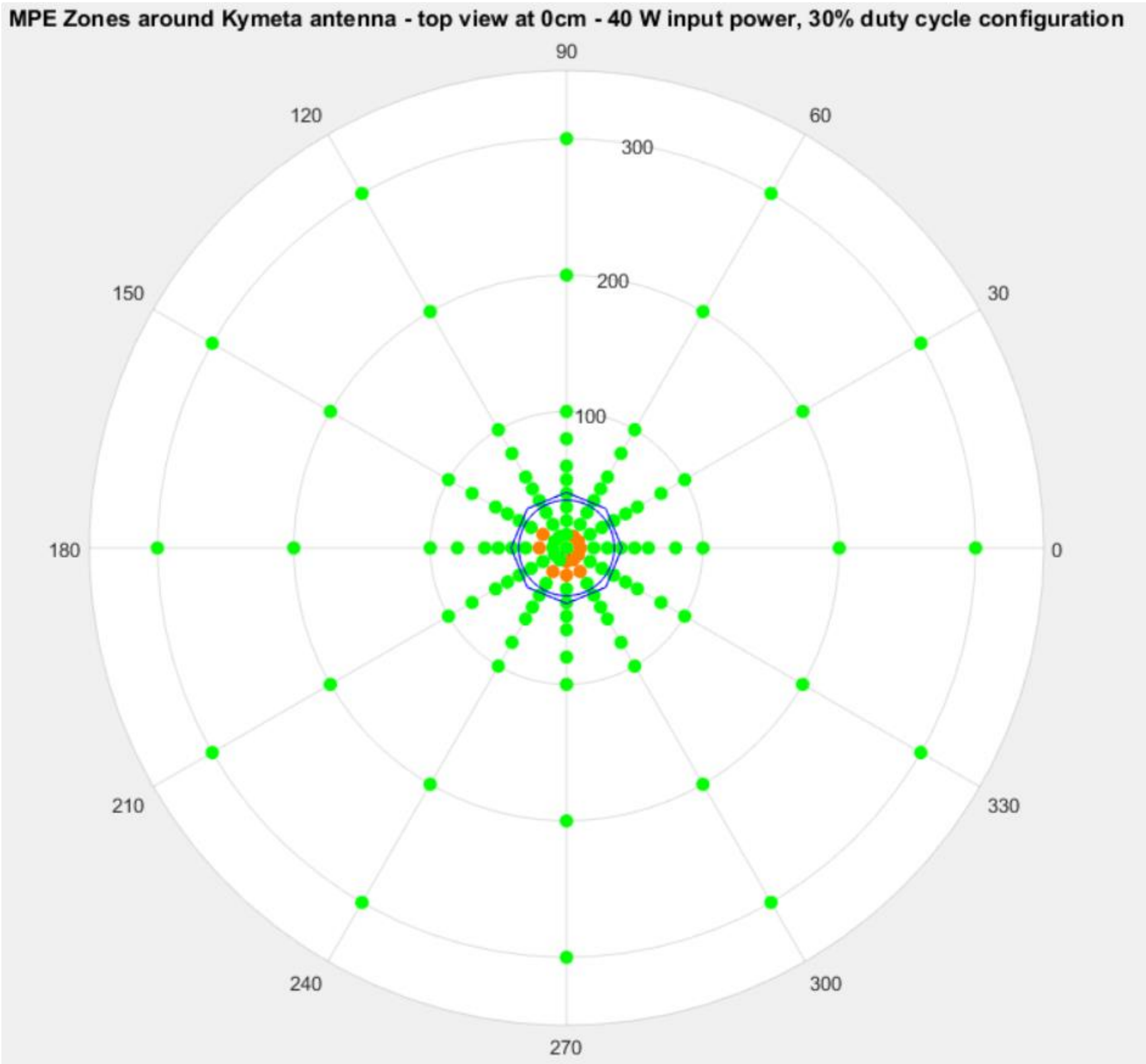

Figure 8: Height 0 cm, 40W input power with 30% Duty Cycle, Scan 0˚

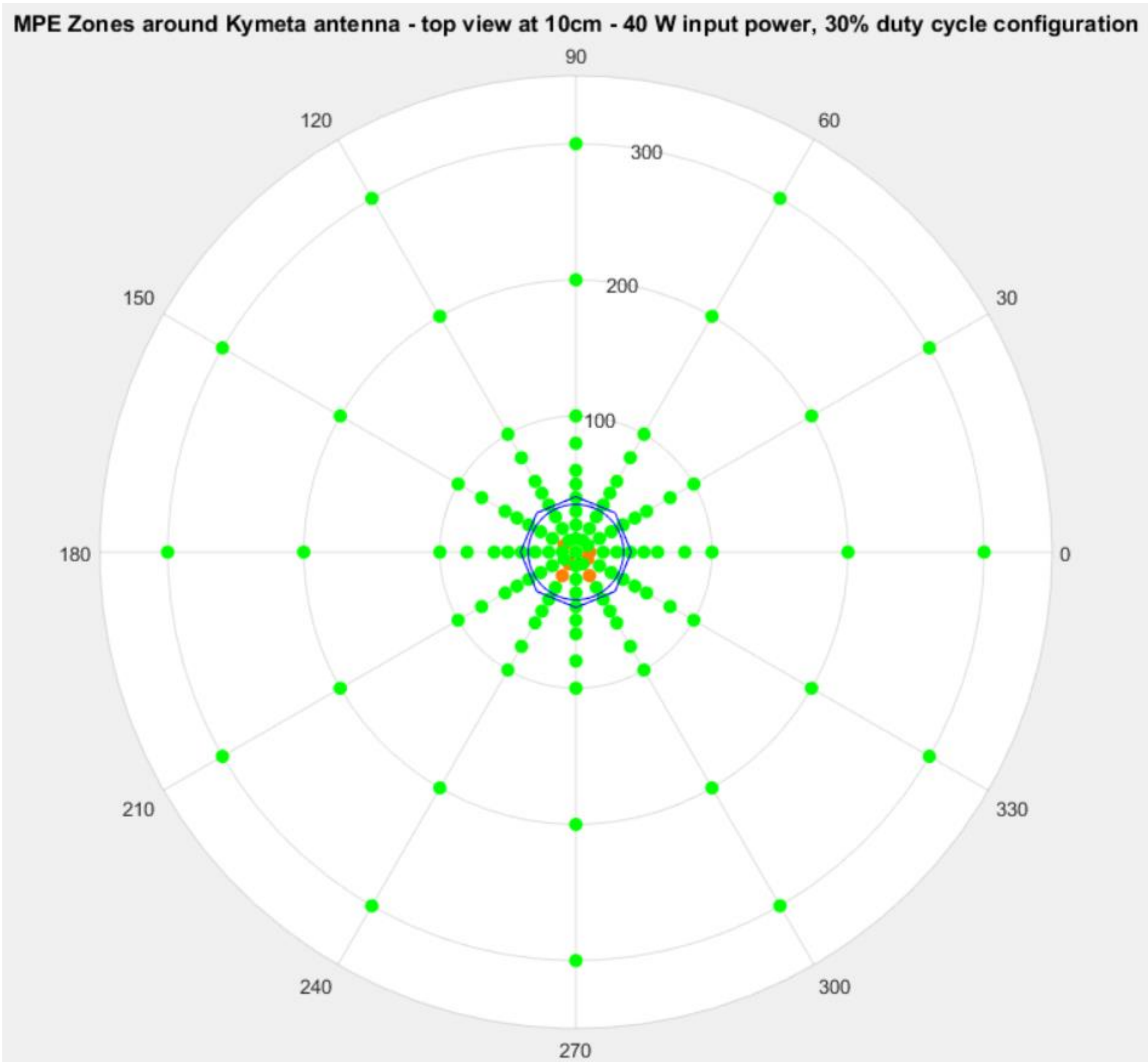

Figure 9: Height 10 cm, 40W input power with 30% Duty Cycle, Scan 0˚

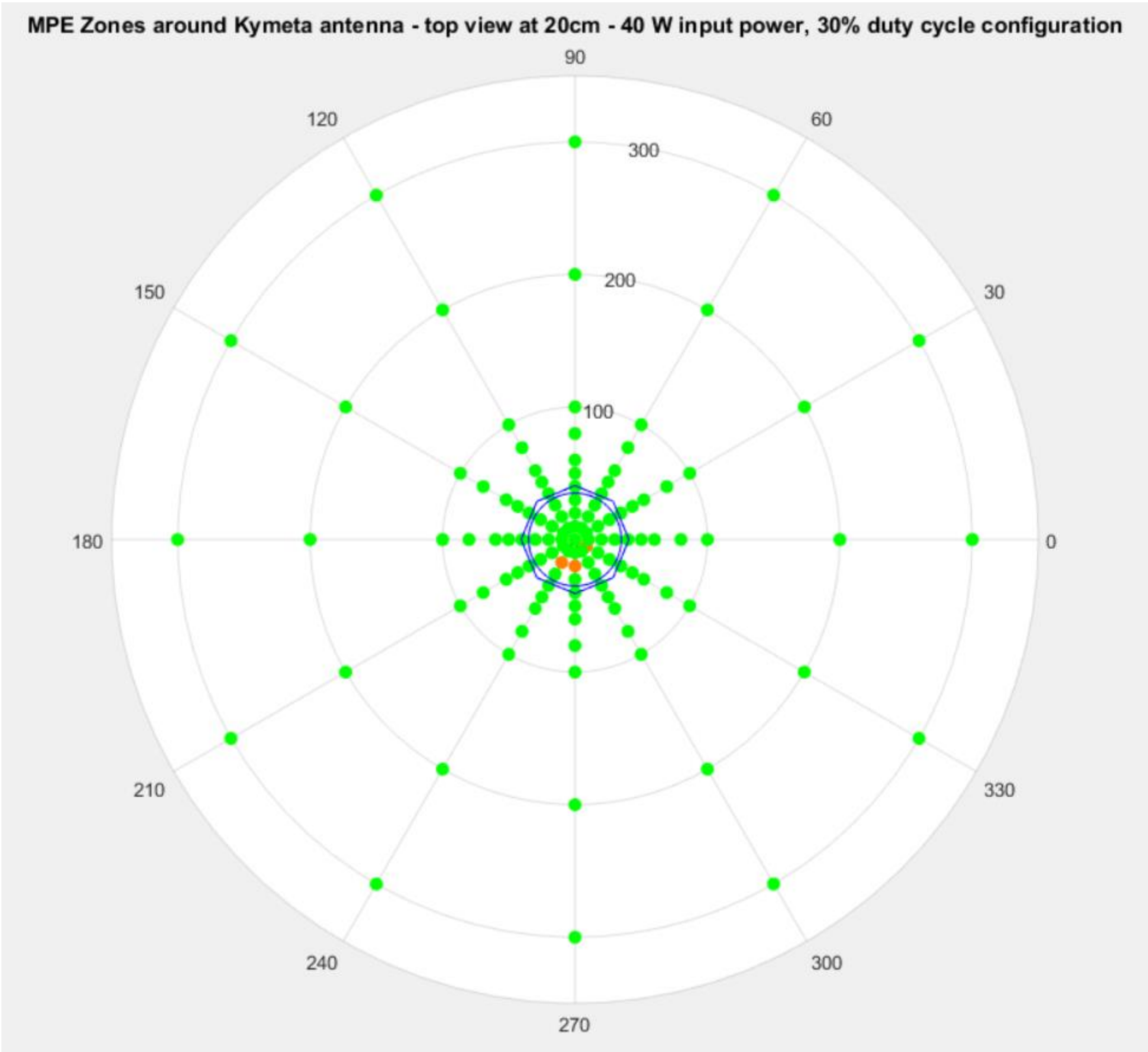

Figure 10: Height 20 cm, 40W input power with 30% Duty Cycle, Scan 0˚

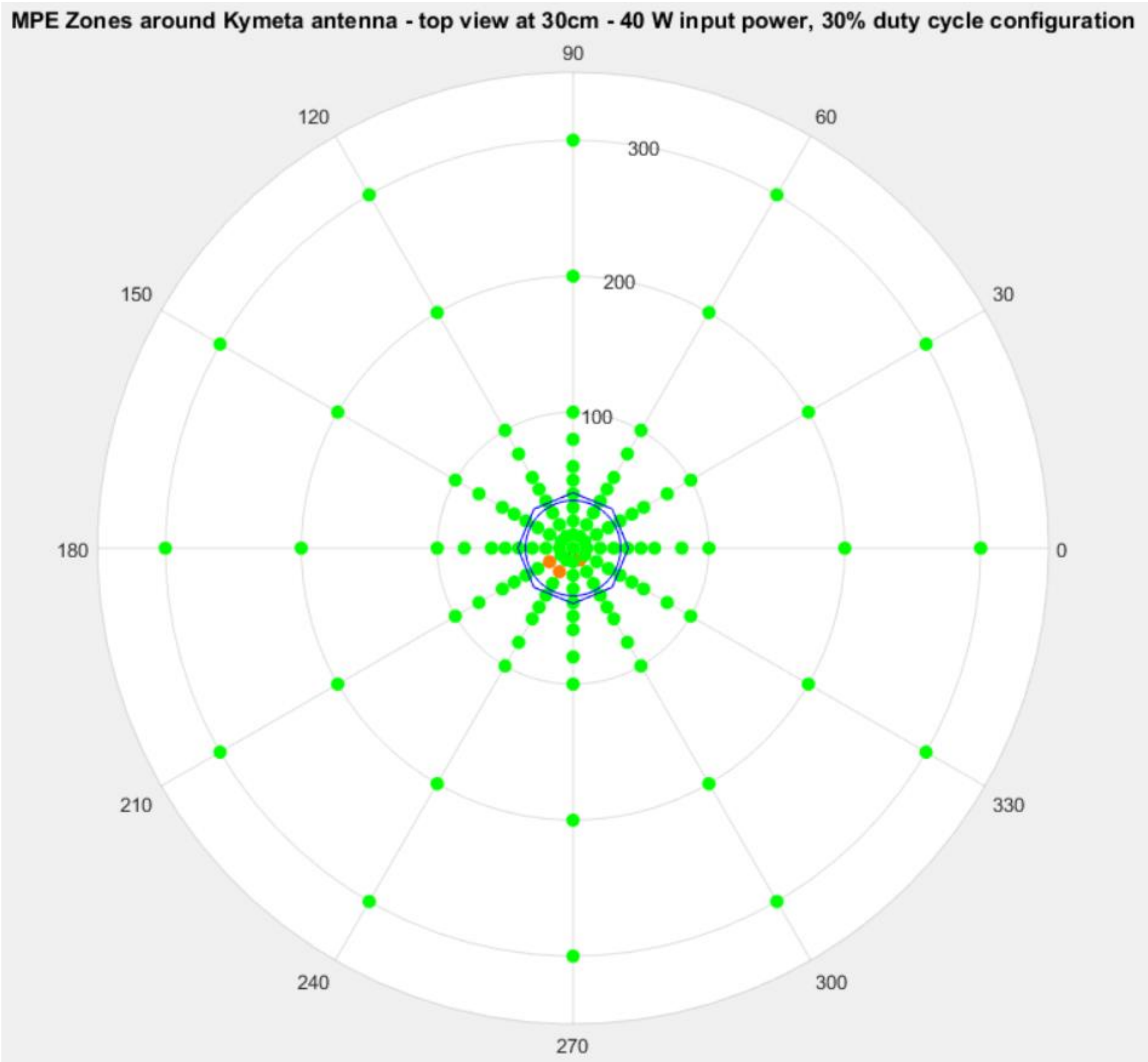

Figure 11: Height 30 cm, 40W input power with 30% Duty Cycle, Scan 0˚

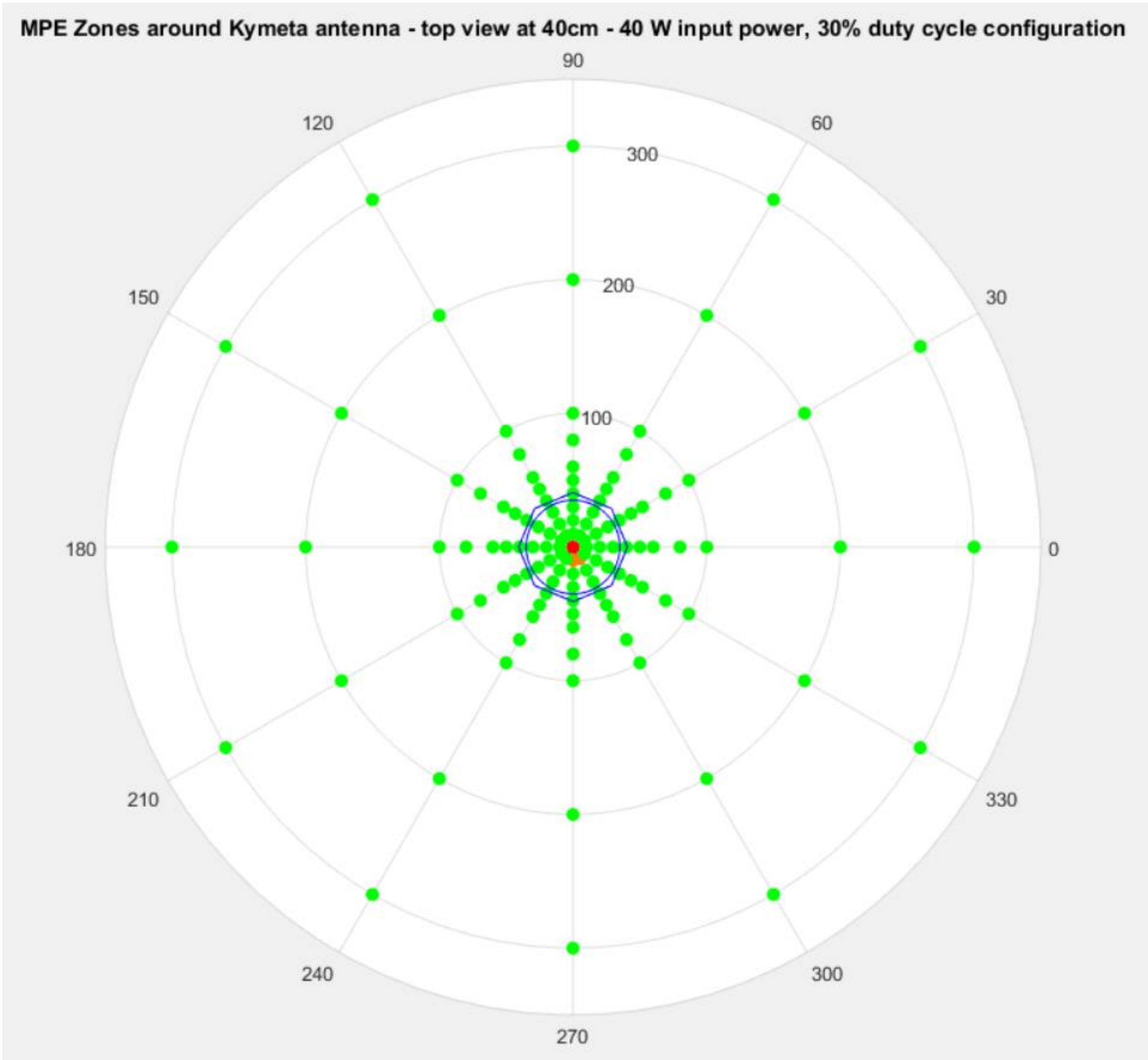

Figure 12: Height 40 cm, 40W input power with 30% Duty Cycle, Scan 0˚

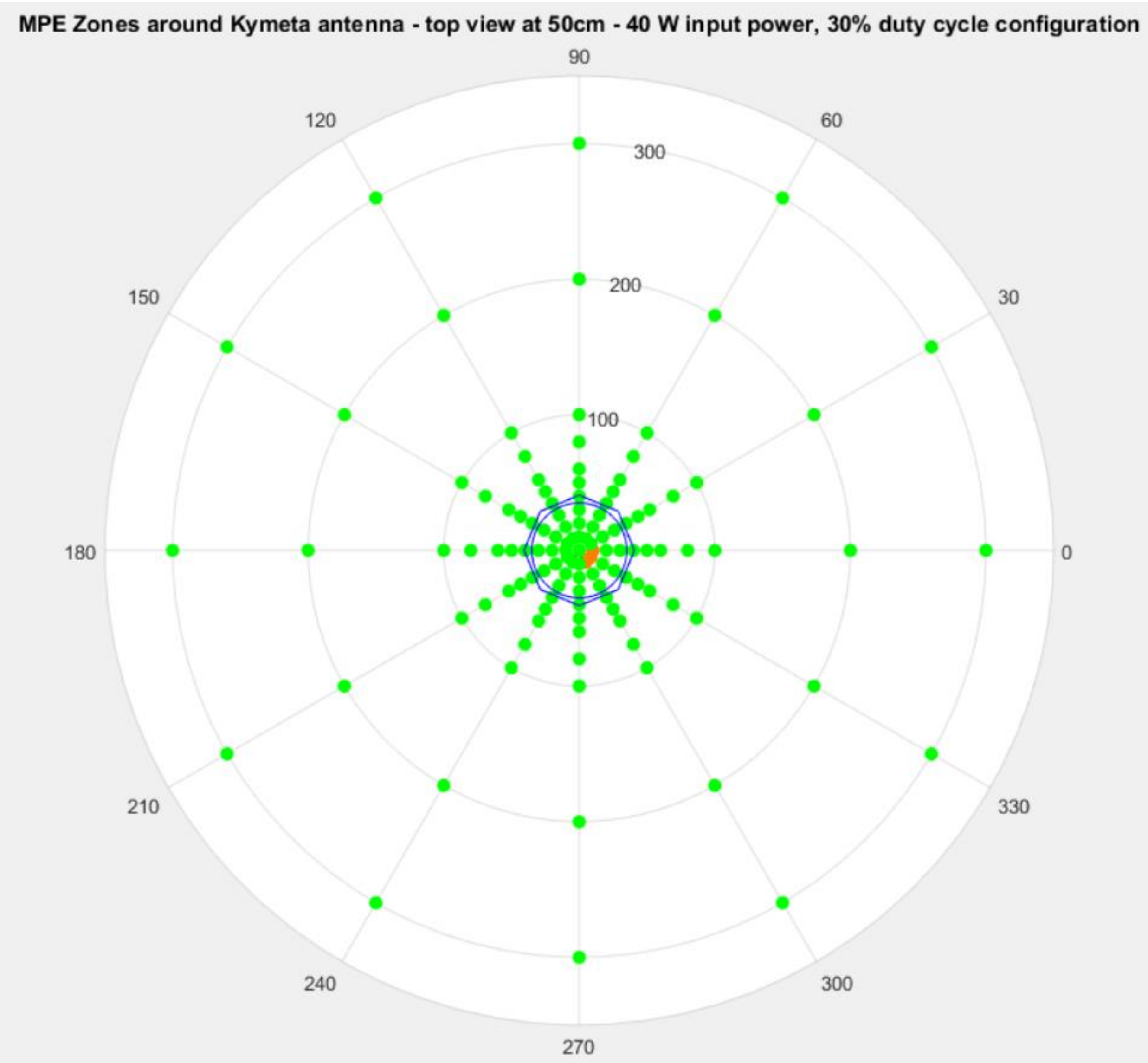

Figure 13: Height 50 cm, 40W input power with 30% Duty Cycle, Scan 0˚

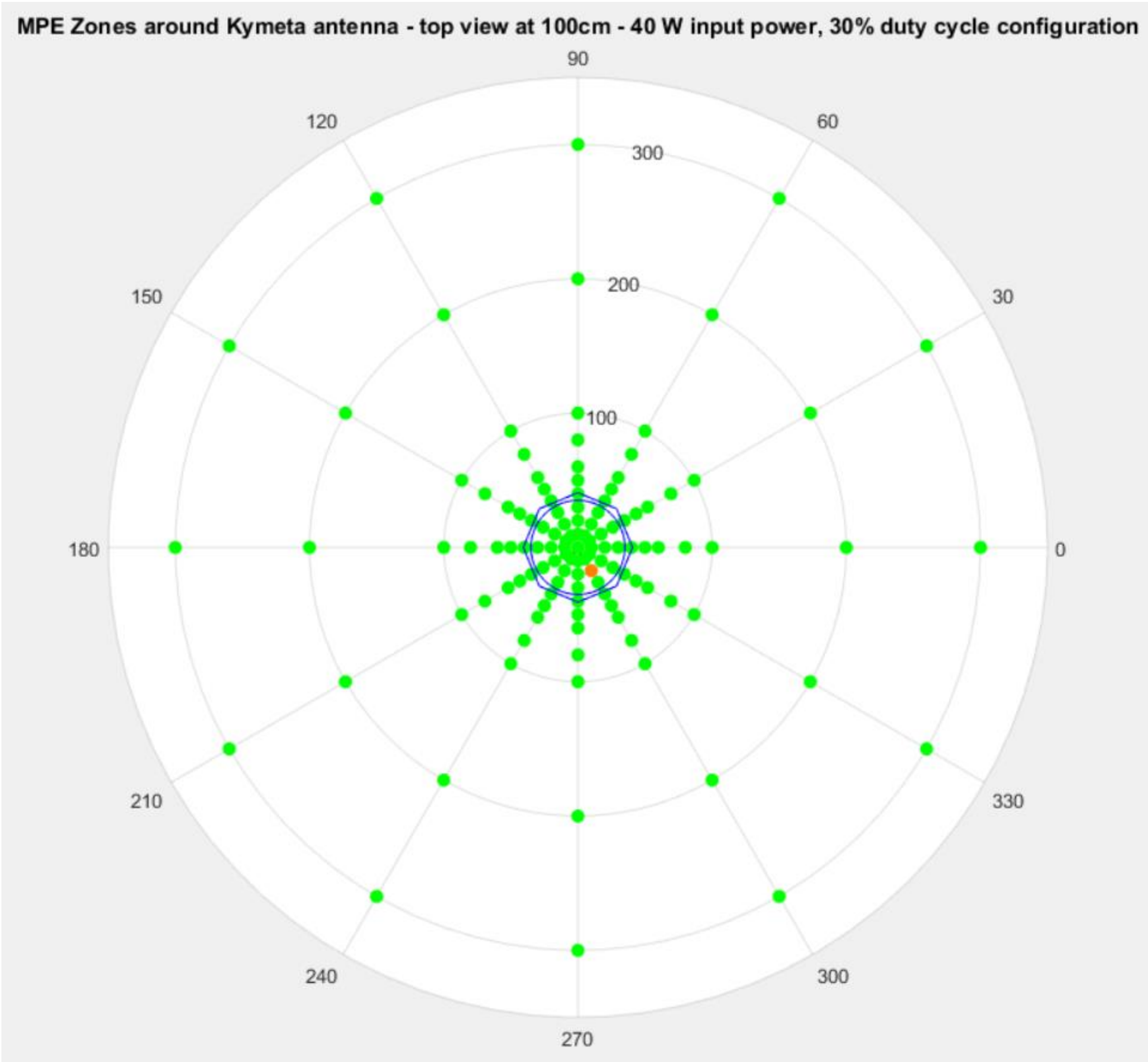

Figure 14: Height 100 cm, 40W input power with 30% Duty Cycle, Scan 0˚

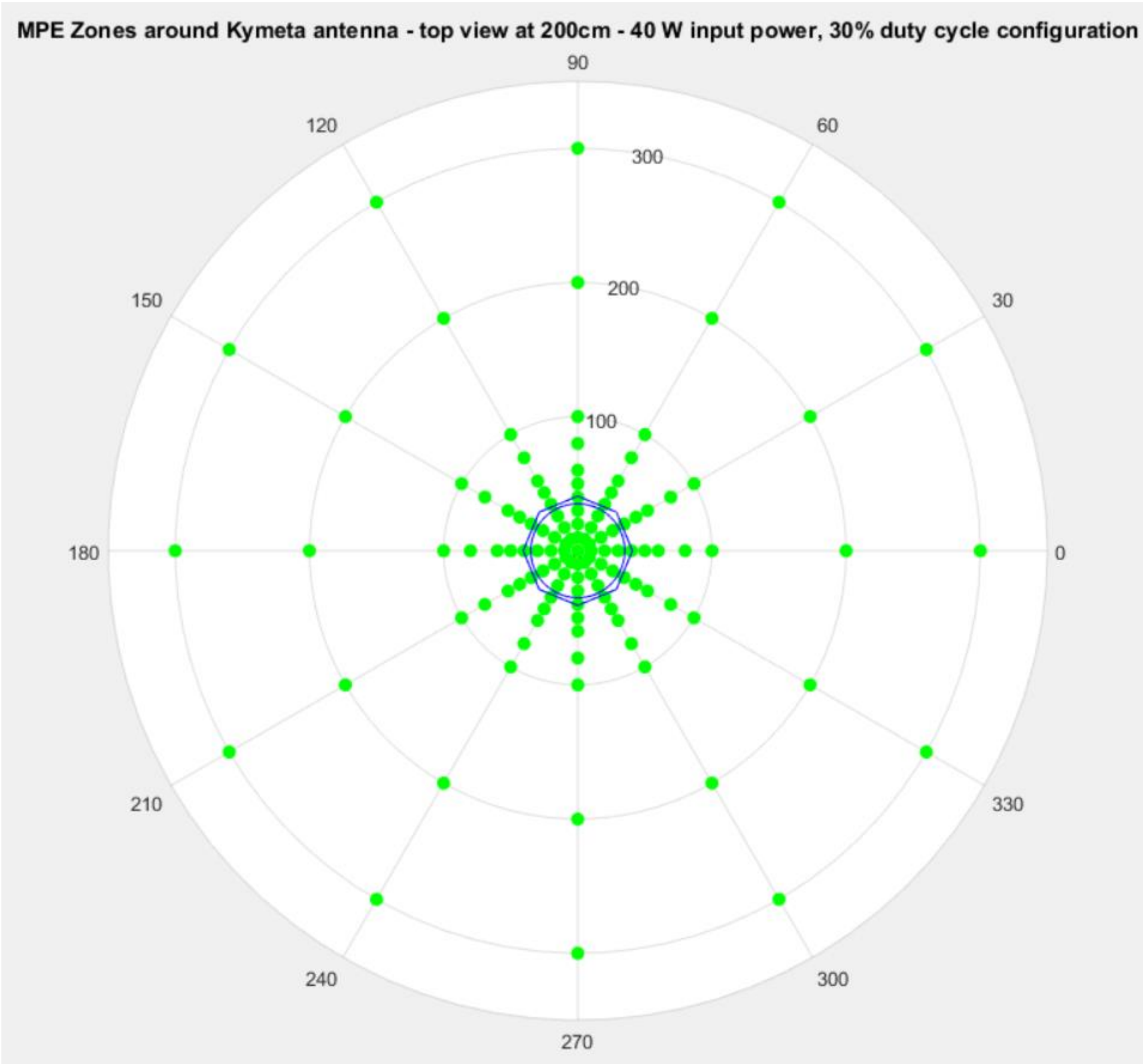

Figure 15:Height 200 cm, 40W input power with 30% Duty Cycle, Scan 0˚

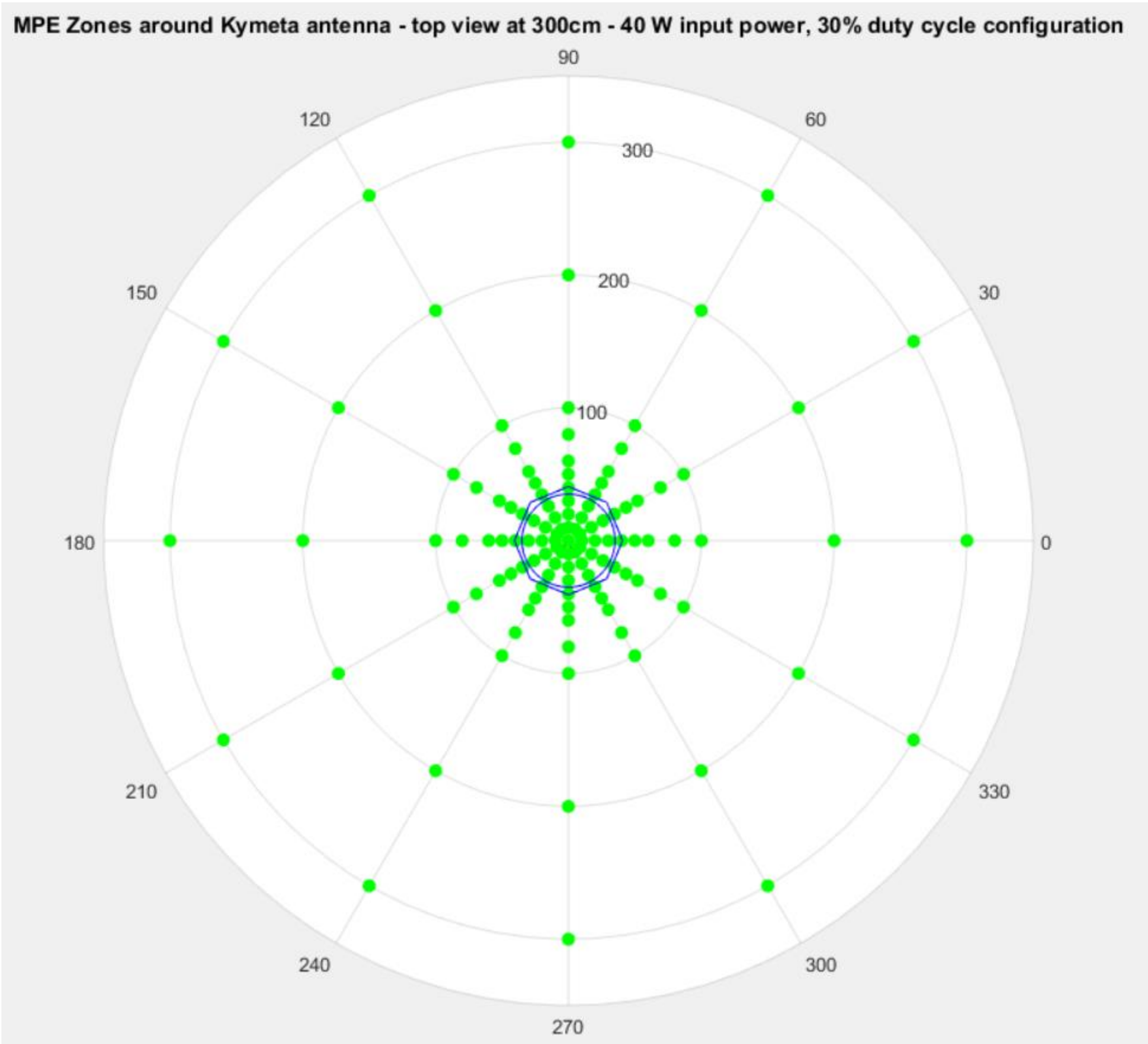

Figure 16: Height 300 cm, 40W input power with 30% Duty Cycle, Scan 0˚

70 Degree Angle

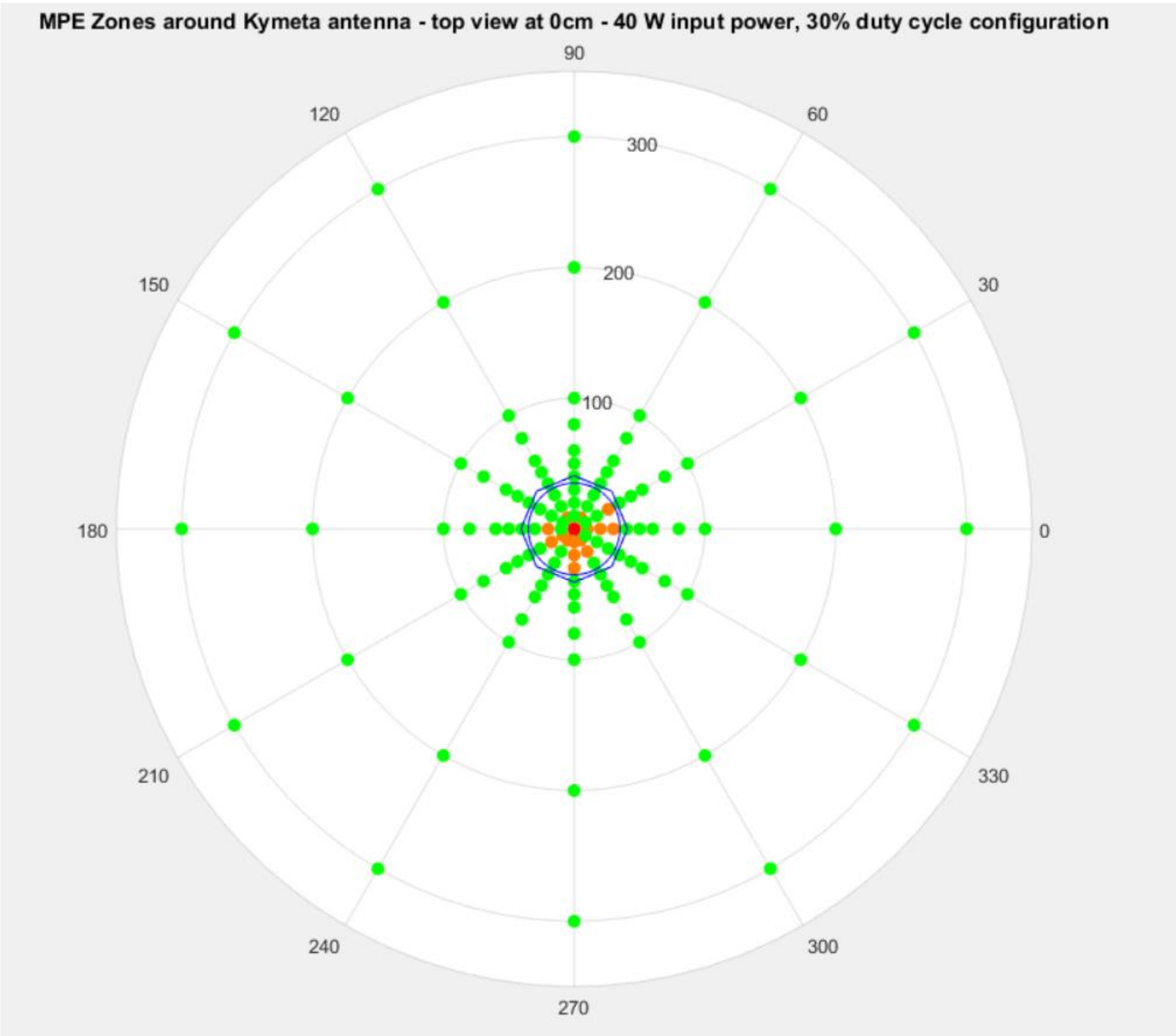

Figure 17: Height 0 cm, 40W input power with 30% Duty Cycle, Scan 75˚

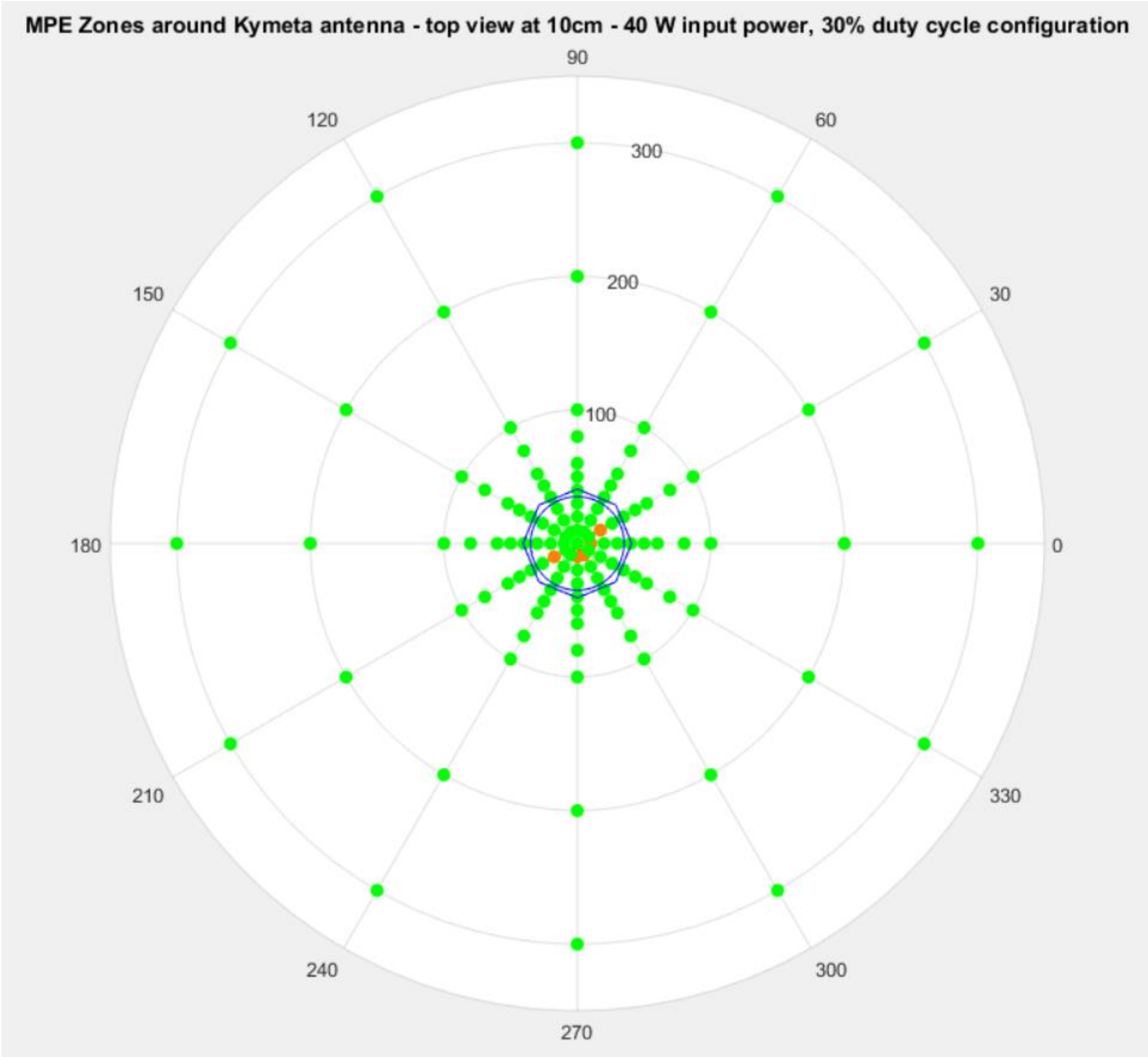

Figure 18: Height 10 cm, 40W input power with 30% Duty Cycle, Scan 75˚

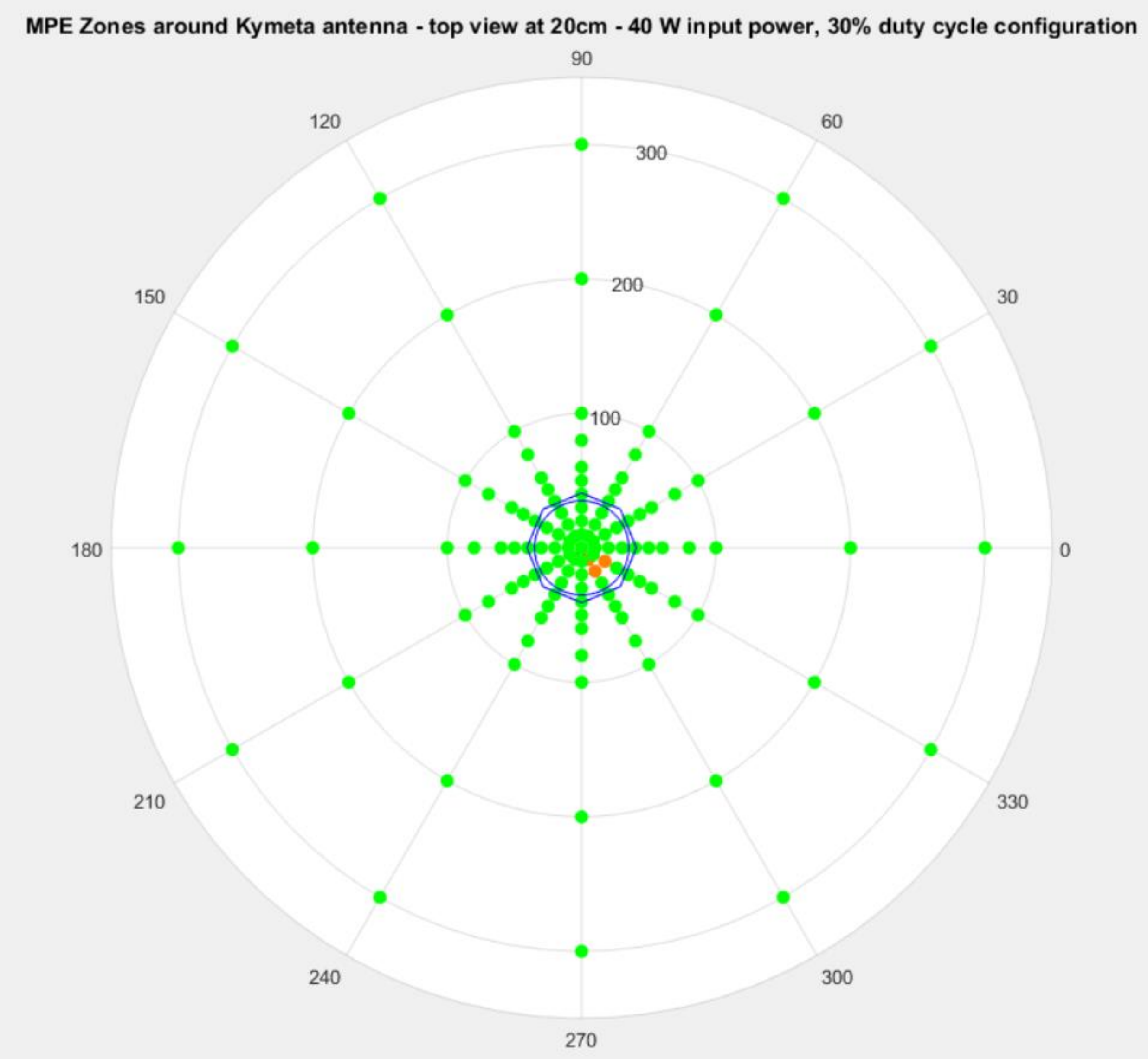

Figure 19: Height 20 cm, 40W input power with 30% Duty Cycle, Scan 75˚

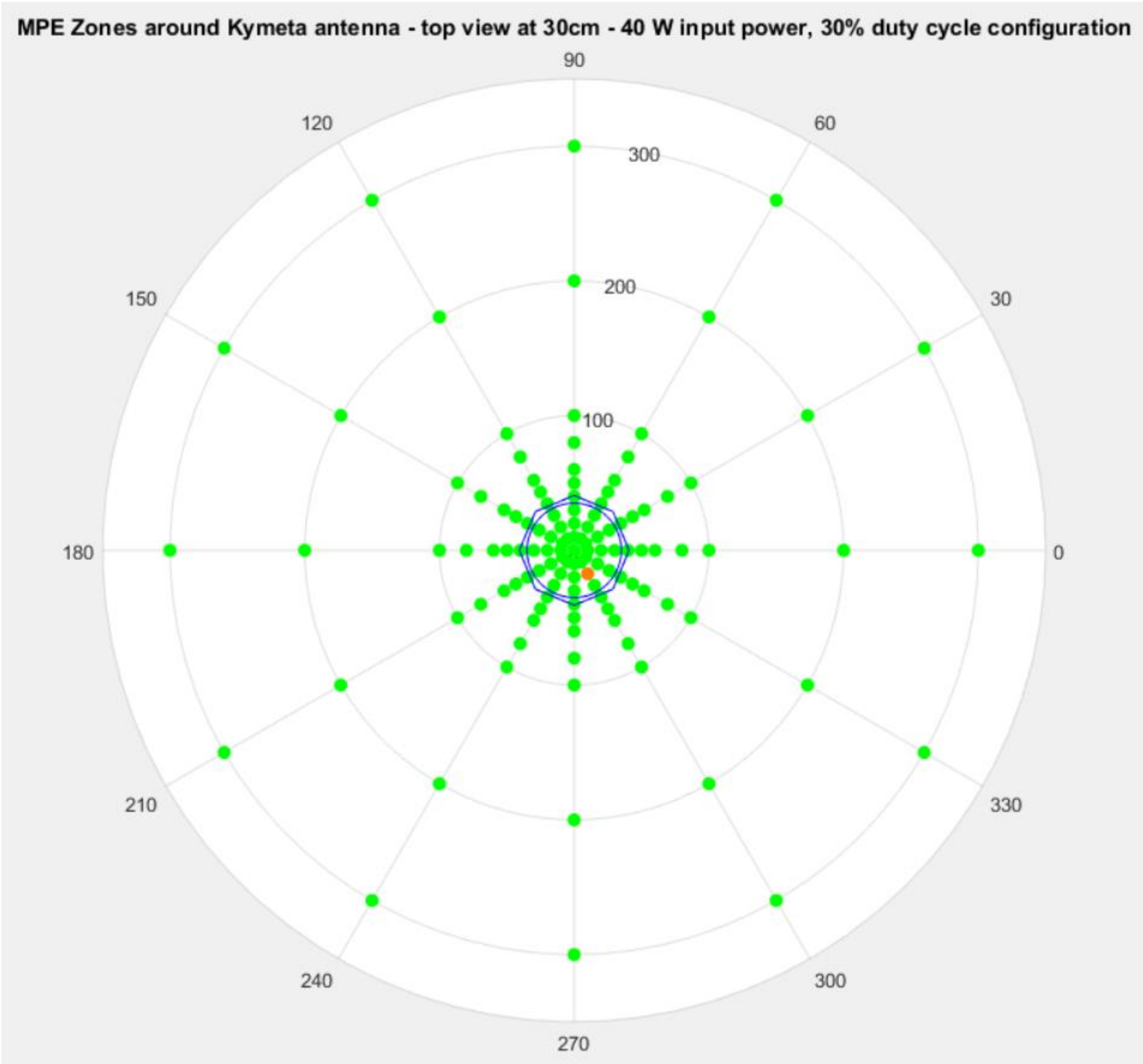

Figure 20: Height 30 cm, 40W input power with 30% Duty Cycle, Scan 75˚

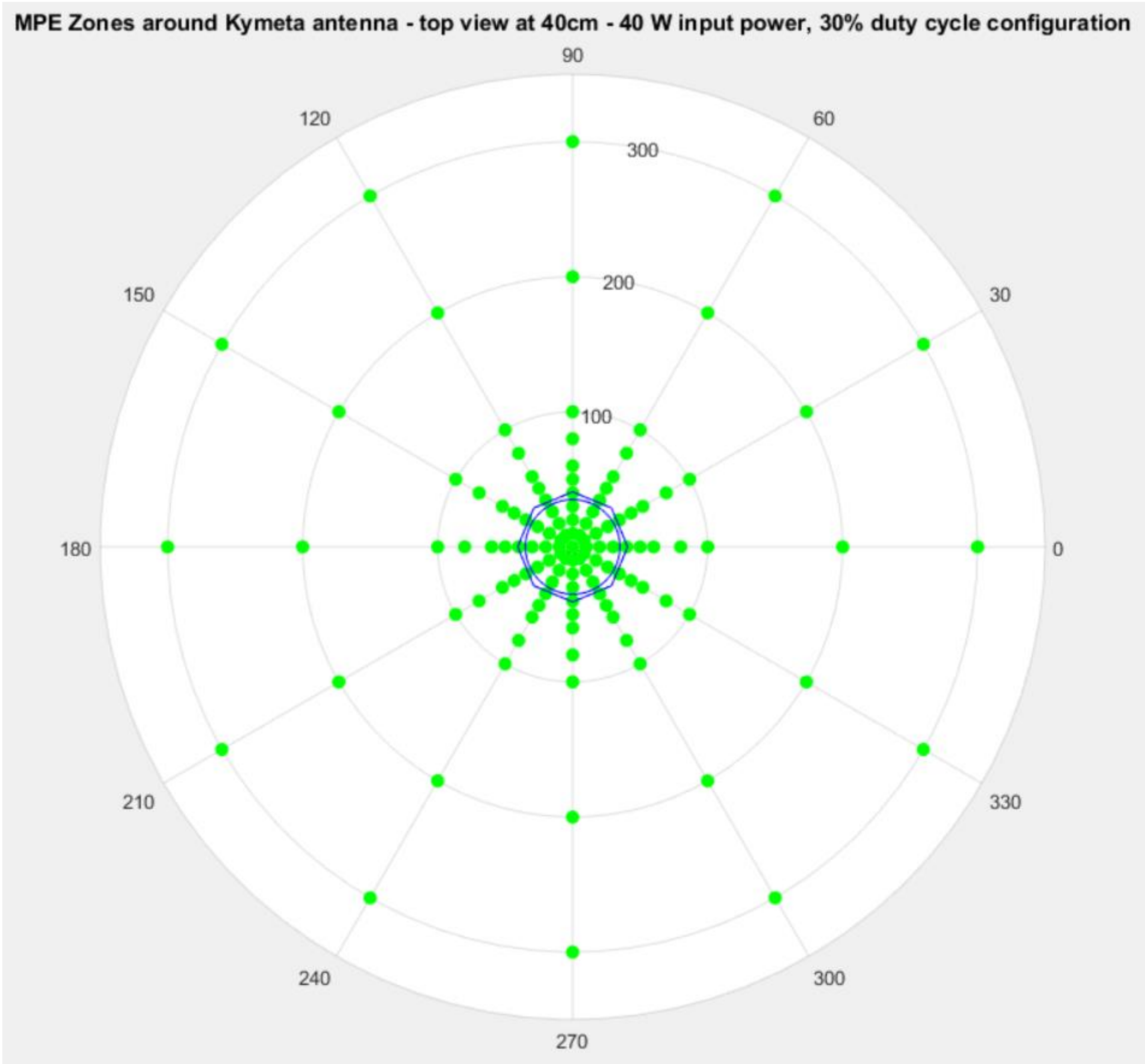

Figure 21: Height 40 cm, 40W input power with 30% Duty Cycle, Scan 75˚

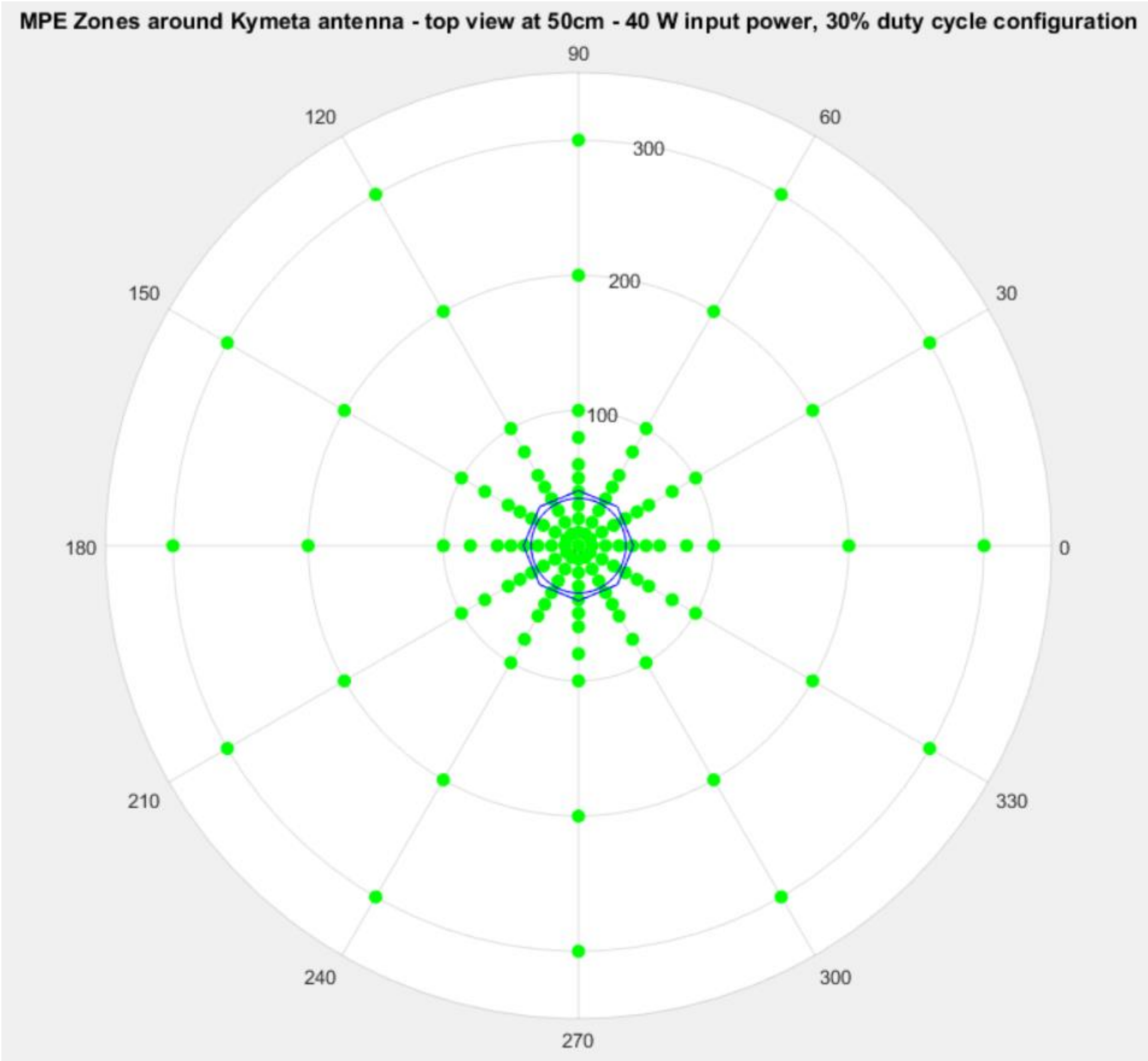

Figure 22: Height 50 cm, 40W input power with 30% Duty Cycle, Scan 75˚

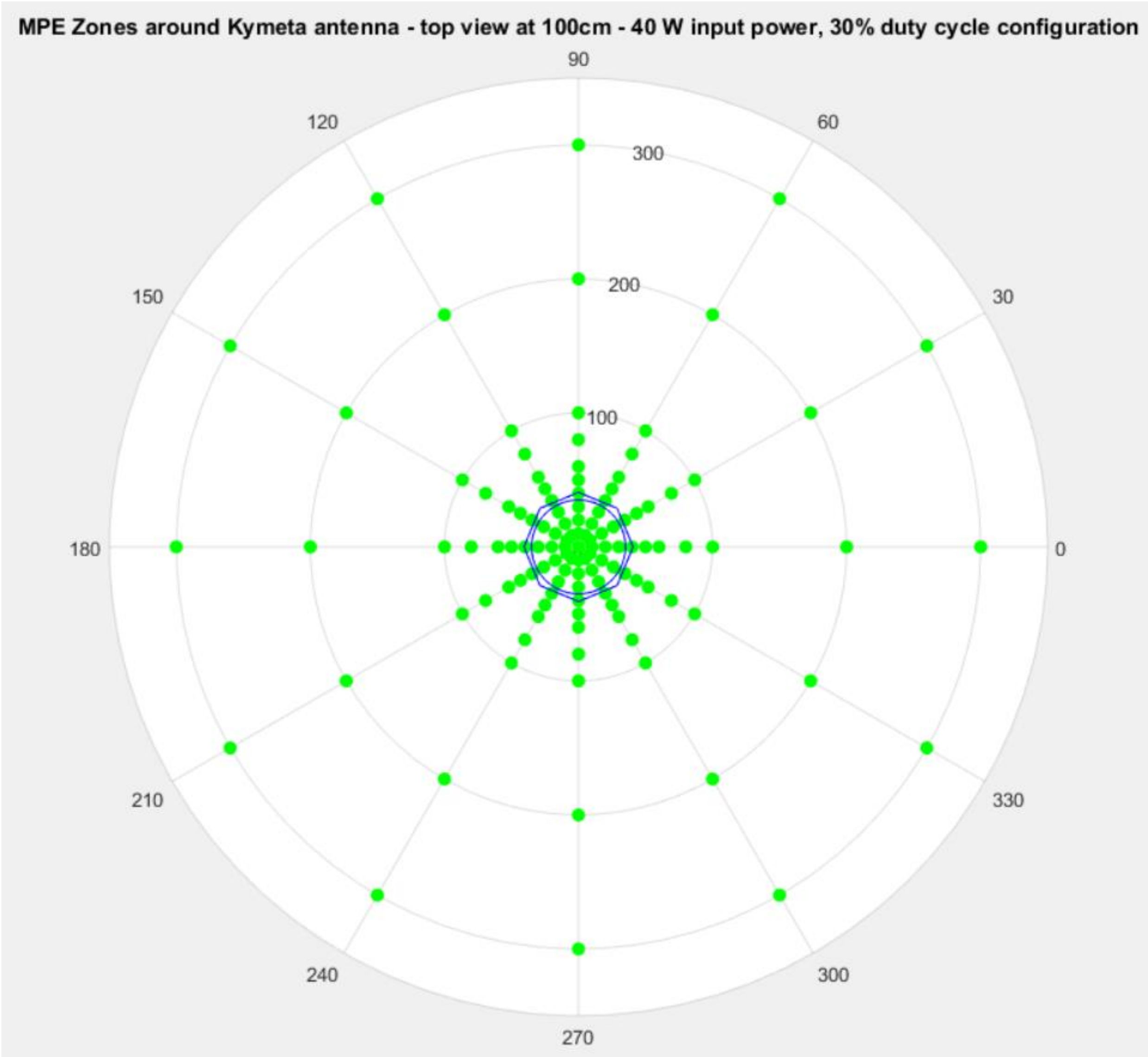

Figure 23: Height 100 cm, 40W input power with 30% Duty Cycle, Scan 75˚

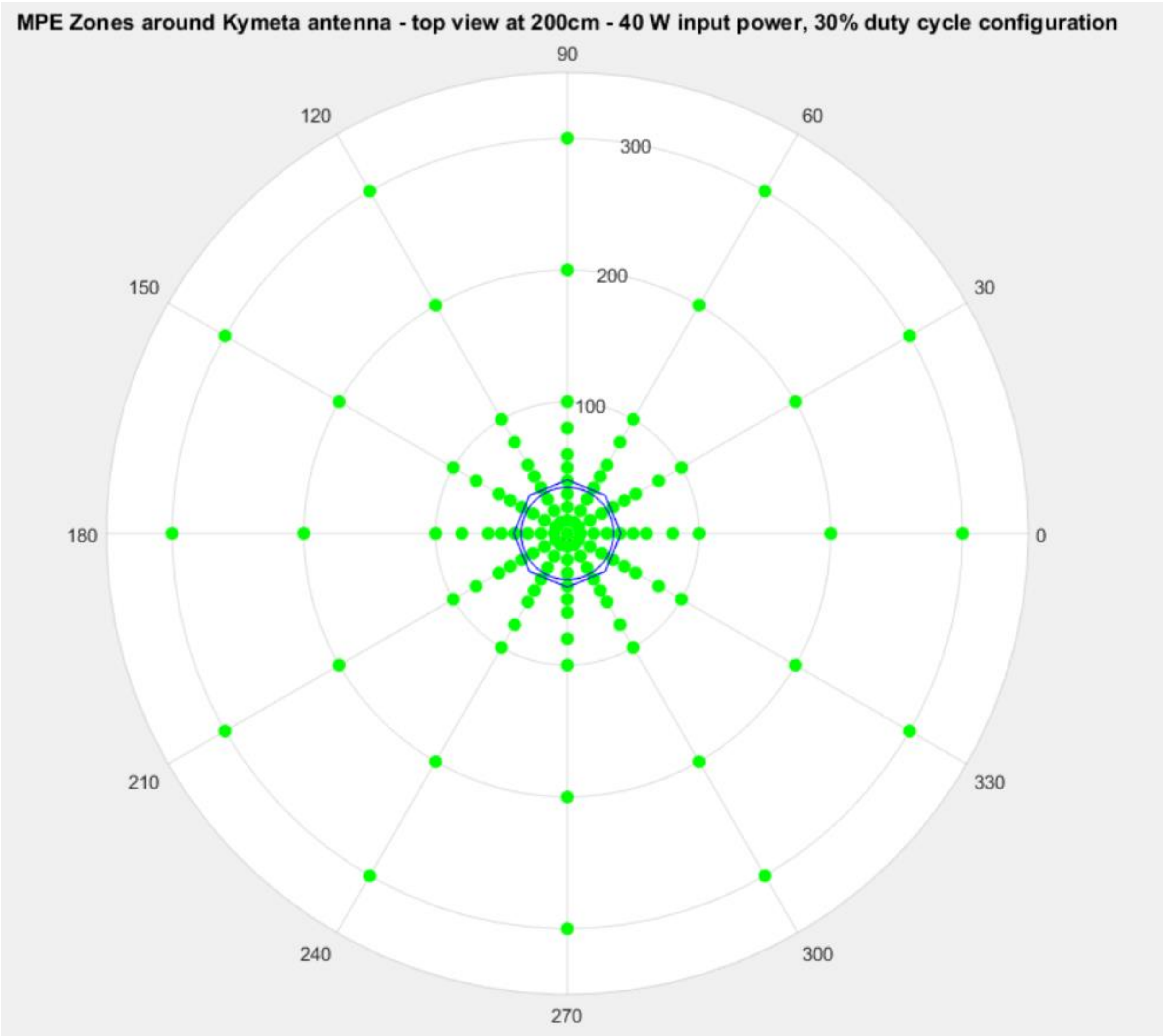

Figure 24: Height 200 cm, 40W input power with 30% Duty Cycle, Scan 75˚

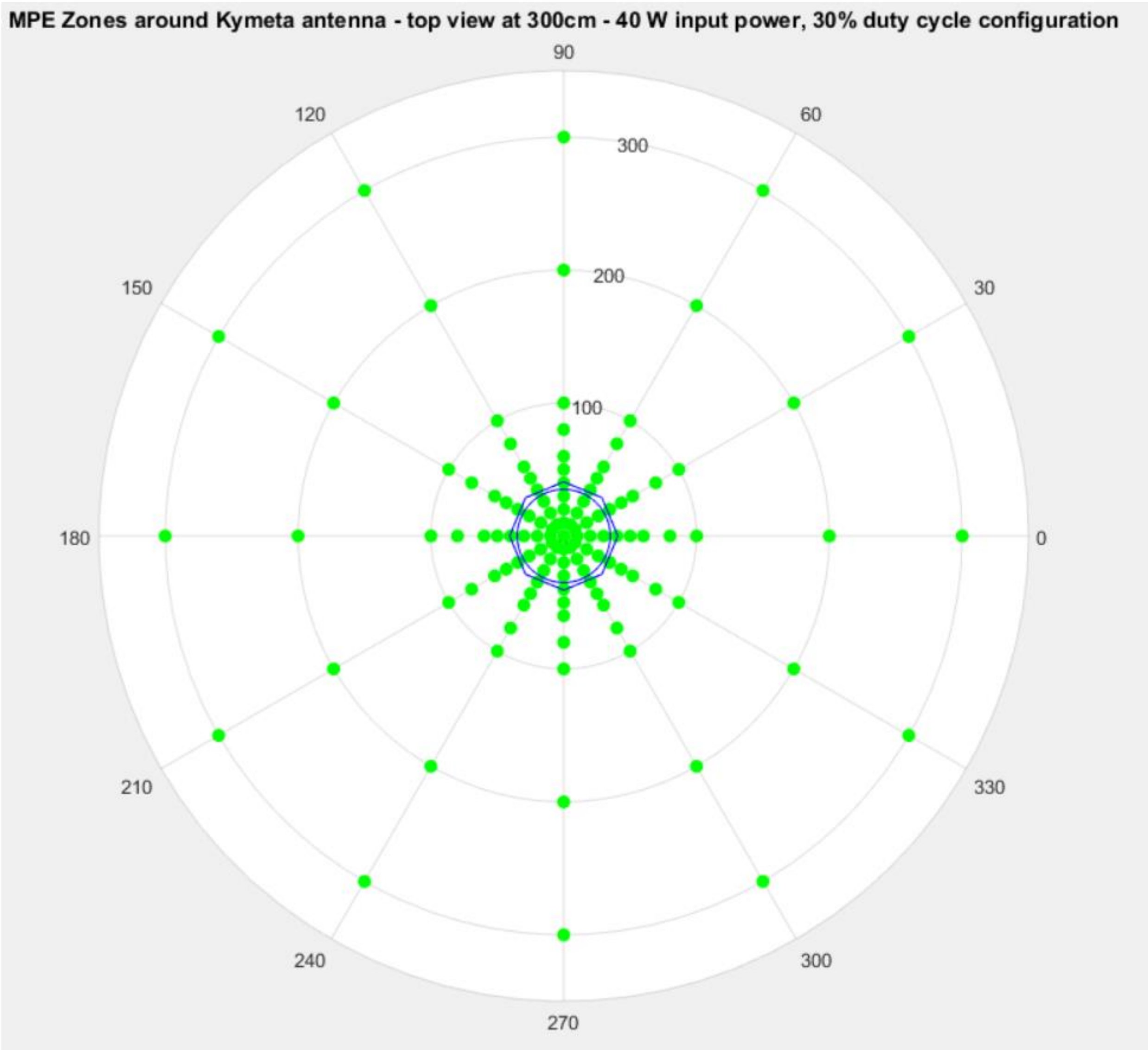

Figure 25: Height 300 cm, 40W input power with 30% Duty Cycle, Scan 75

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6 Summary

The RF measurements performed on the Antenna indicate that only within a very small volume of space directly above the face of the Antenna is there the potential for power densities to exceed the FCC general public MPE level of 1 mW/cm2 or the occupational/controlled MPE level of 5 mW/cm2.

Kymeta employees and contractors requiring access to regions of the antenna that exceed the controlled MPE limits 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, page 9 through 11 and Appendix A, Table 1 on page 67. Antenna power will be switched off whenever maintenance requires access to those regions.

Kymeta will test only from fixed, secured locations on private property. The general public will be further precluded from proximity to the Antenna via physical barriers or visible signage. As a result, the public will not have access to any regions of the antenna that exceed the uncontrolled MPE limits.