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Kymeta RF Safety Analysis

June 2020

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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™ u8, 82 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 u8 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.

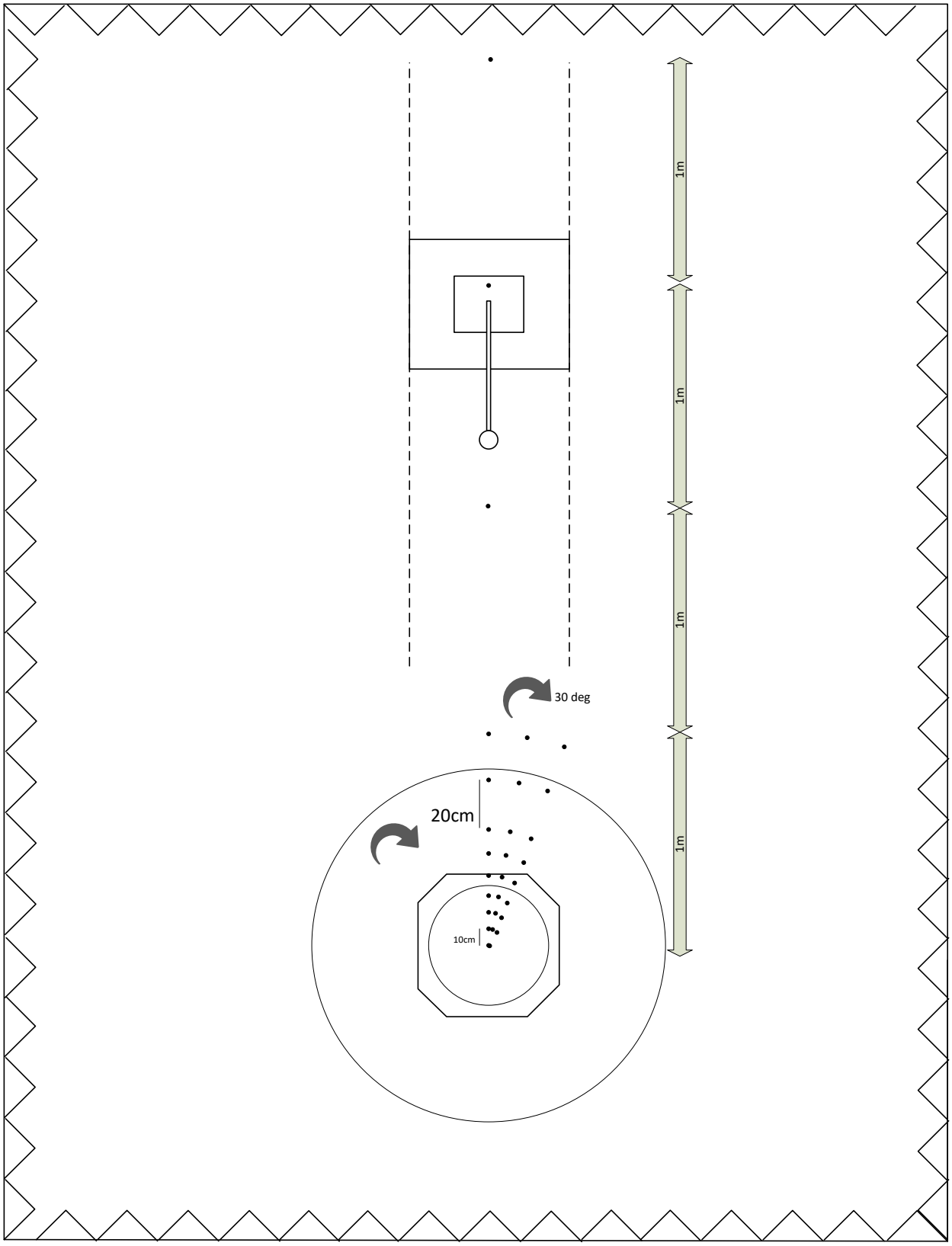
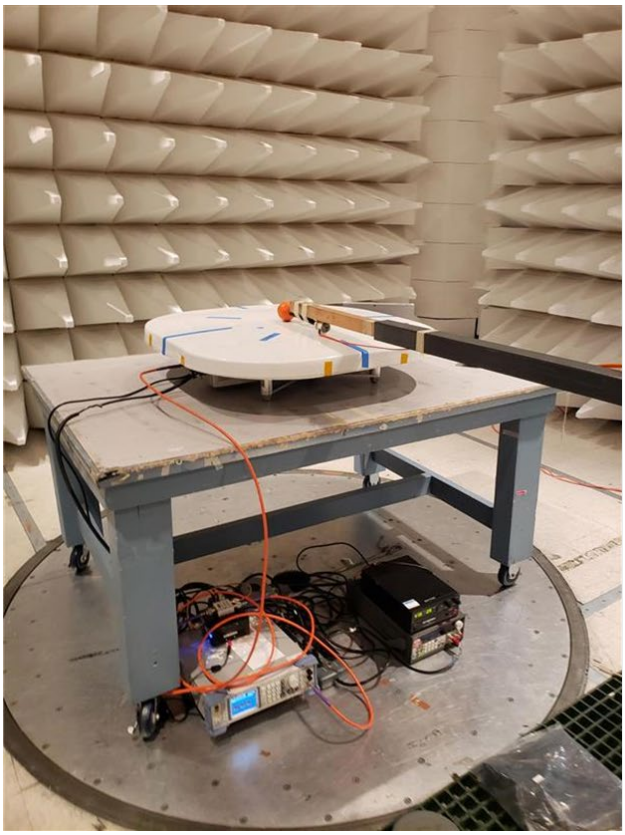


Figure 1: Chamber layout, top-down view



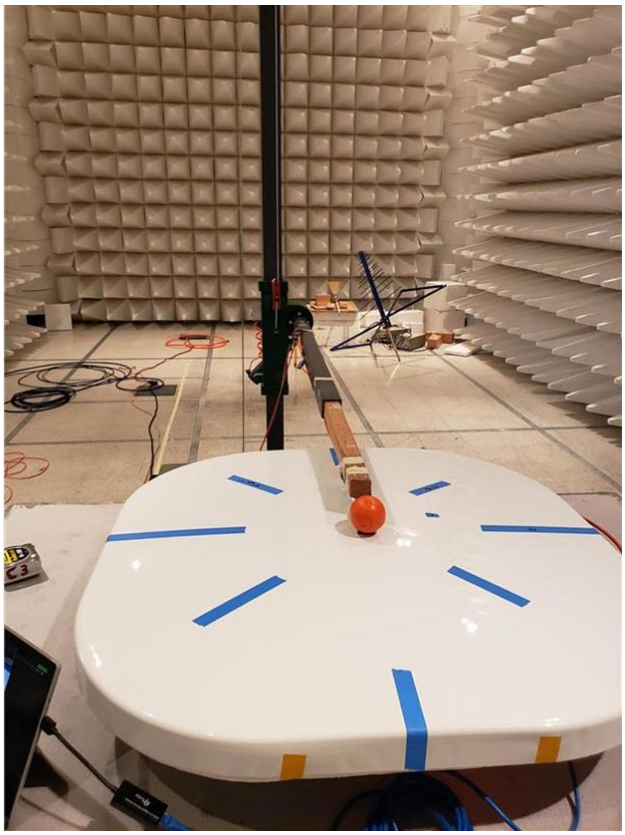


Figure 2: Chamber pictures

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 16.2 W linearly. This approach results in minimum detectable power density of 0.00106 x 16.2 / 4 (16.2 W scaled from 4 W reference) = 0.0043mW/cm^2 when scaled to 16.2 W. This resolution is sufficient considering the 1 mW/cm^2 MPE level requirement.

4 Test parameters and procedures

The measurements were made using a BUC operating at an antenna input reference power of 4 W. The reference power level of 4 W was confirmed using a spectrum analyzer. Figure 3 shows the power calibration setup diagram. The raw data were then linearly scaled to the 16.2 W power level requested in the application for blanket authority.

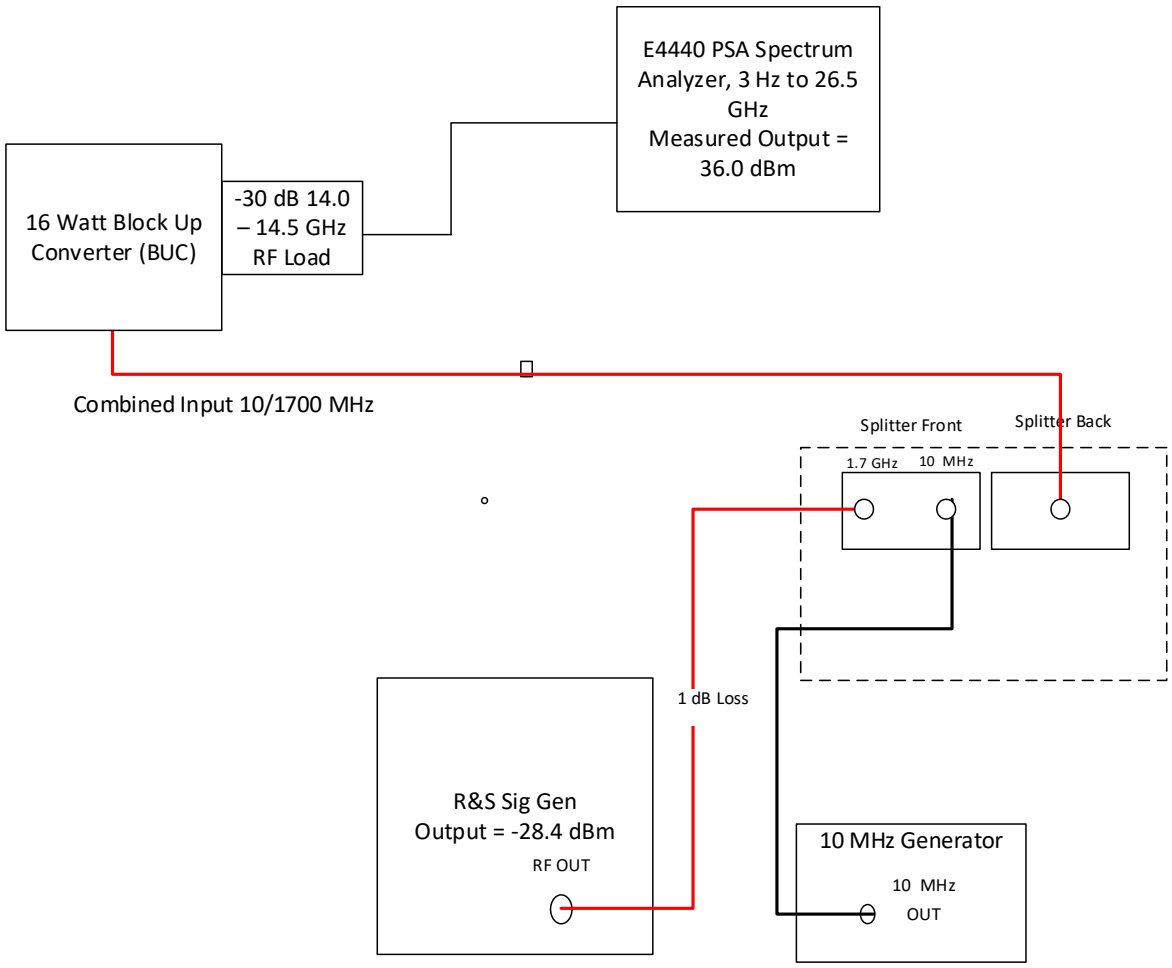


Figure 3: Input reference power calibration diagram

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 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 10 MHz signal generator. 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 4.

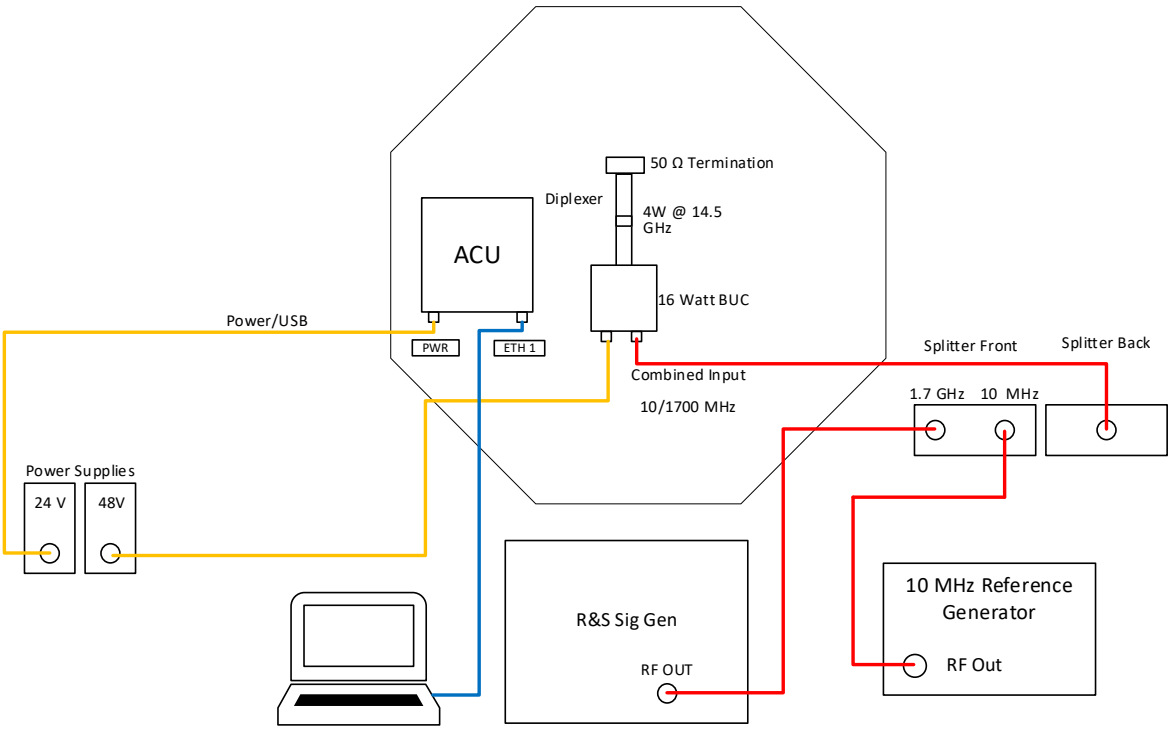


Figure 4: Kymeta terminal - transmit diagram

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 would be shown as red circles. Because the power densities for operations at 16.2 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 spreadsheets 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 = 16.2 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 5 through Figure 22 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 rounded square represents the outer dimensions of the Kymeta terminal. The blue circle represents the 82 cm active diameter of the Kymeta antenna aperture.

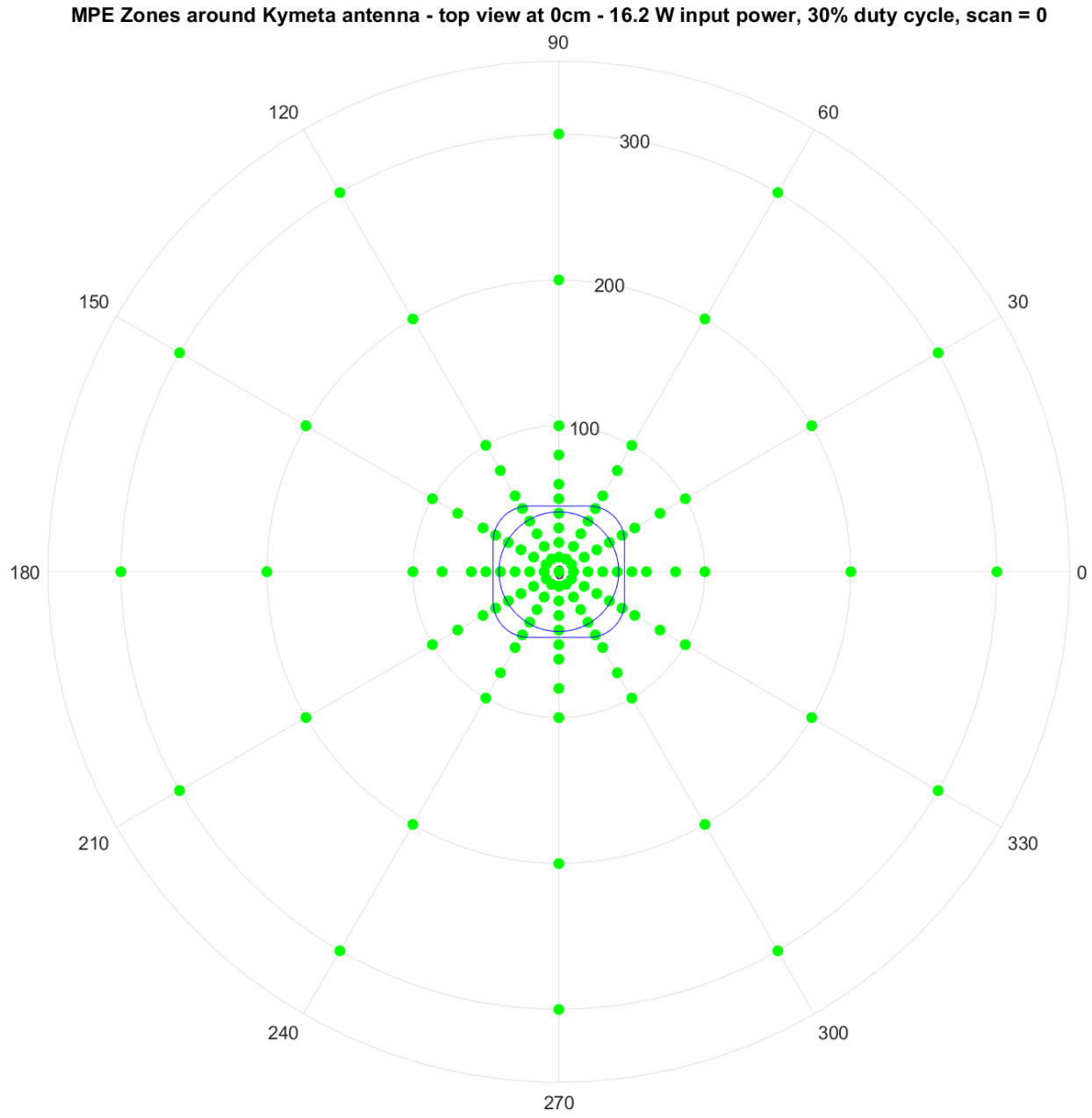


Figure 5: Height 0 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

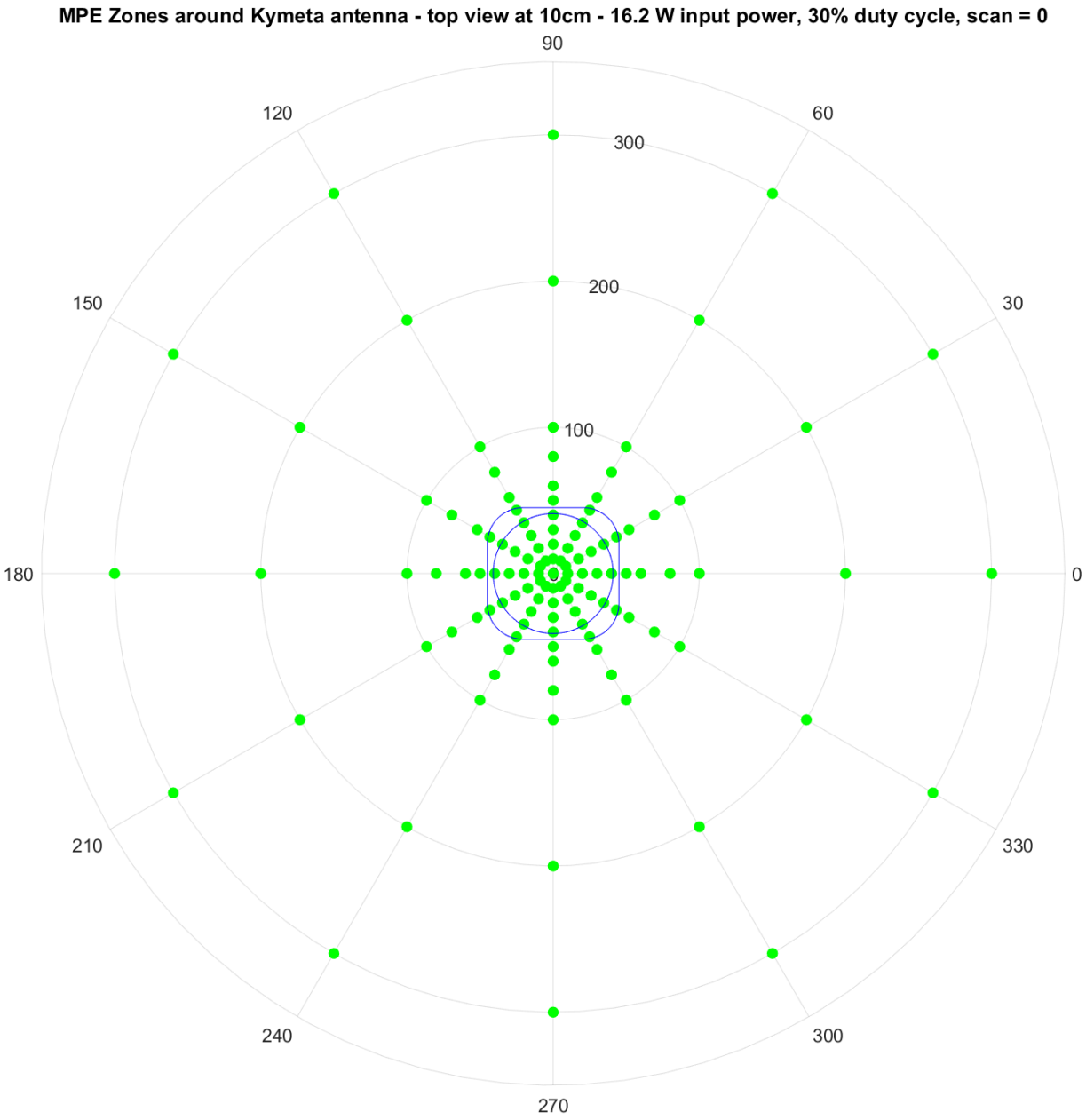


Figure 6: Height 10 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

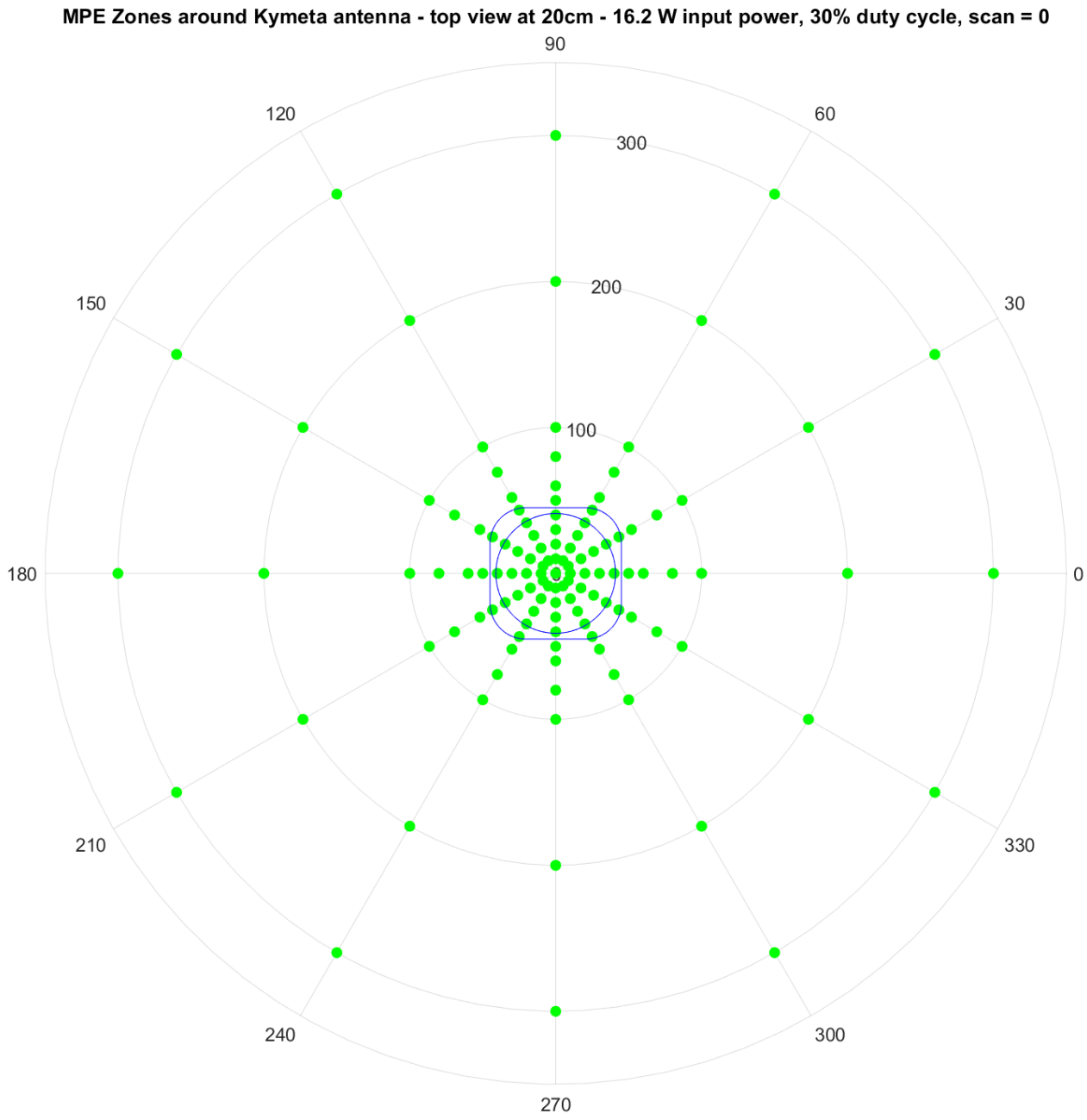


Figure 7: Height 20 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

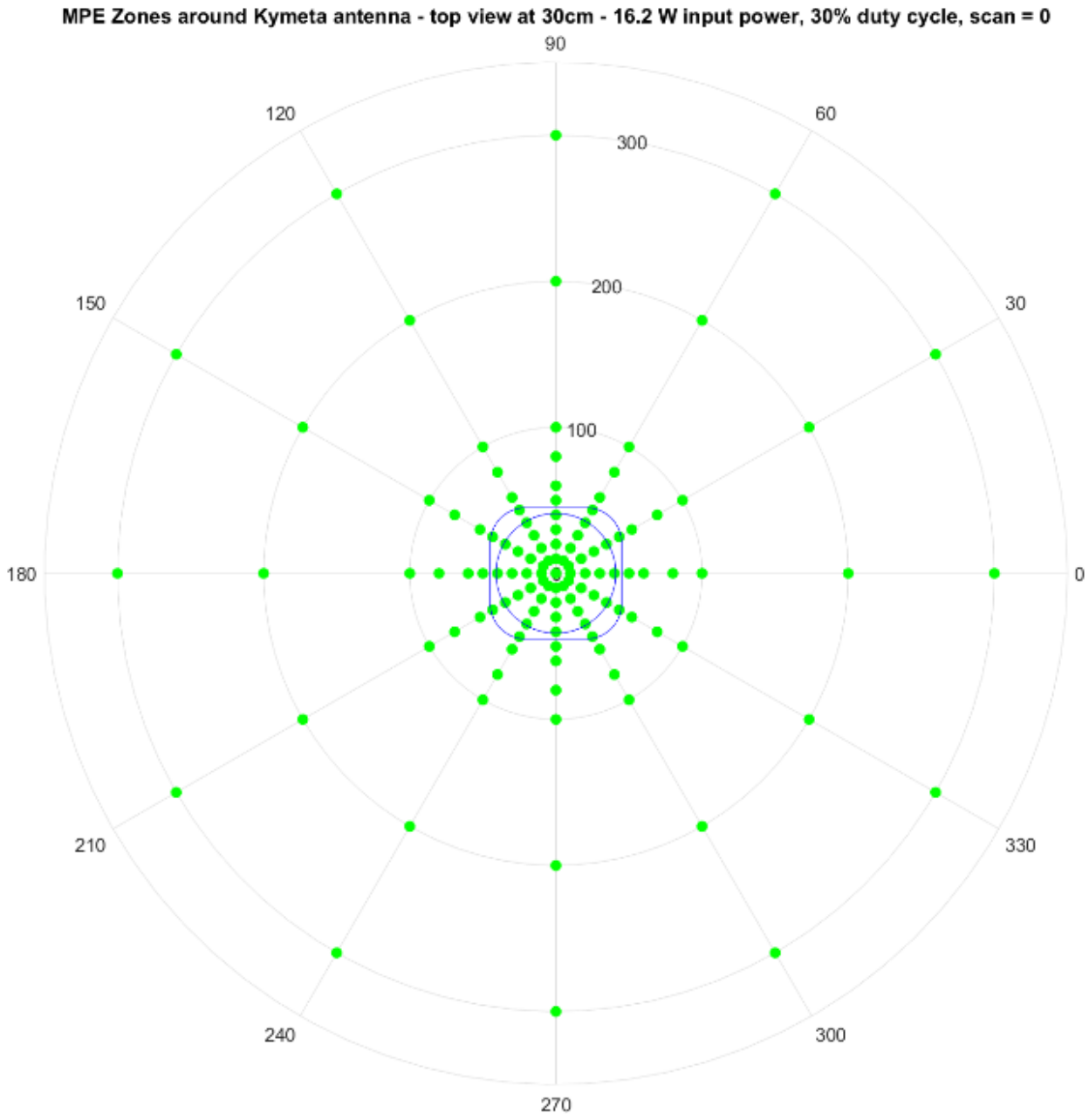


Figure 8: Height 30 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

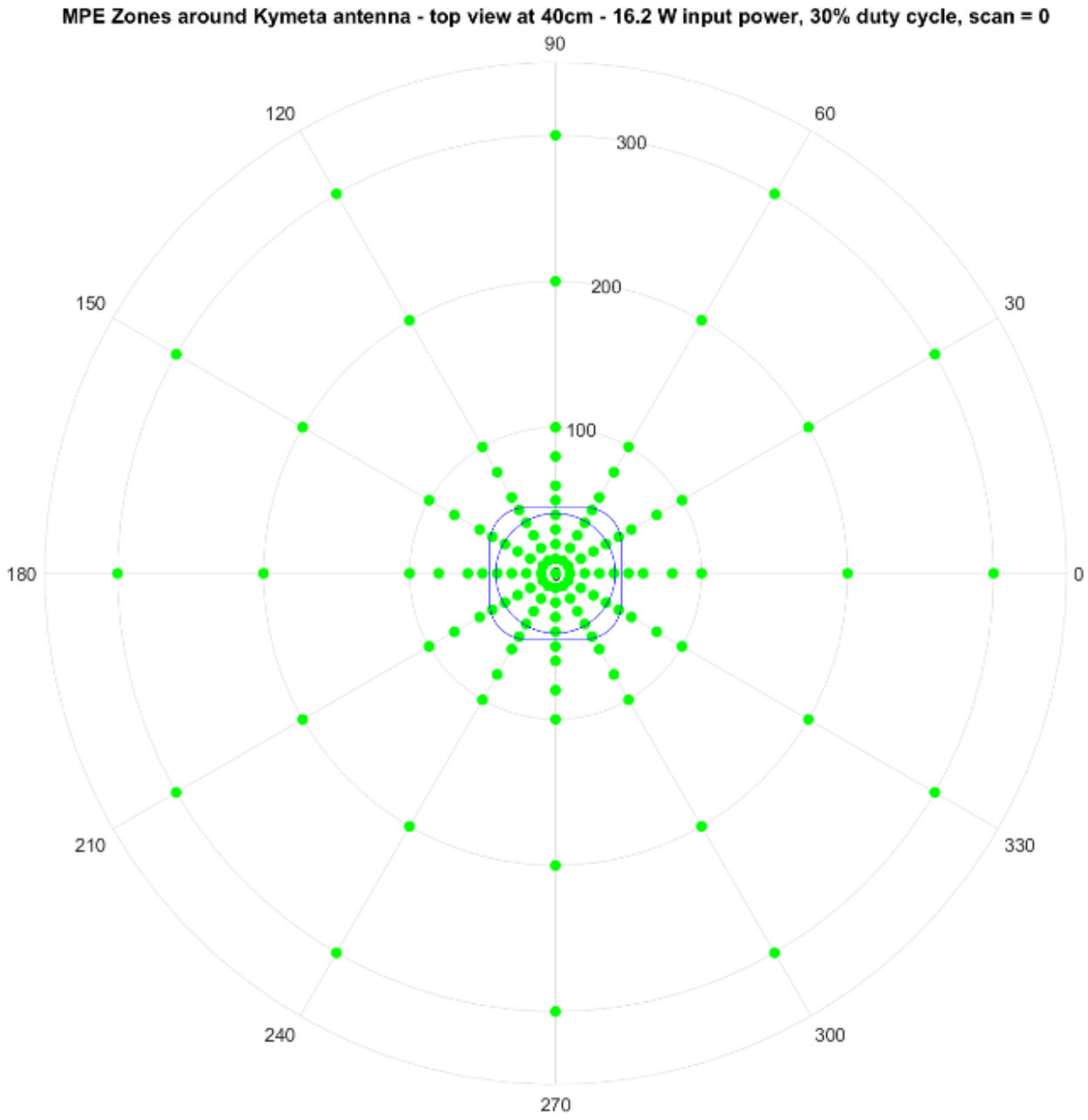


Figure 9: Height 40 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

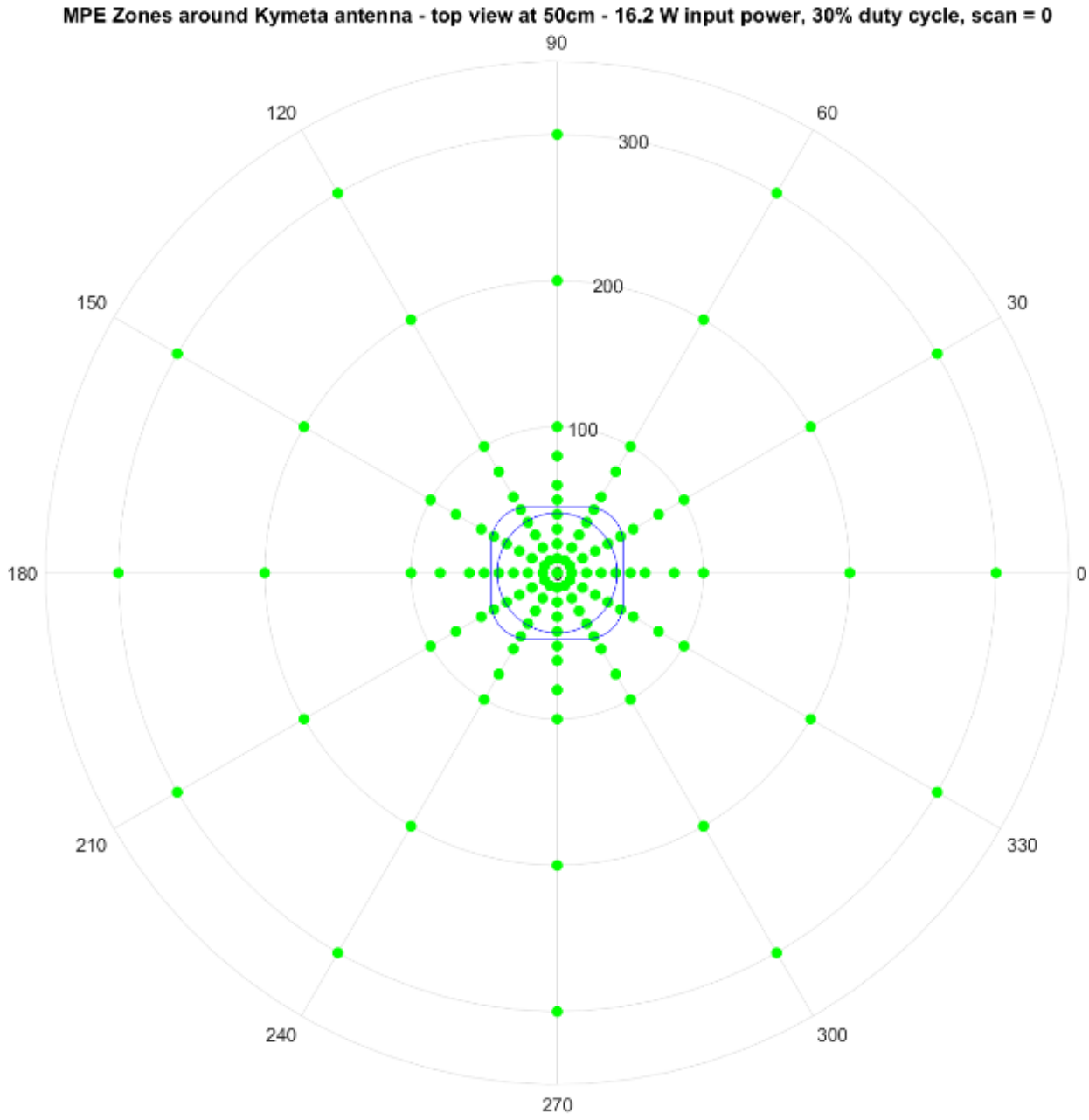


Figure 10: Height 50 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

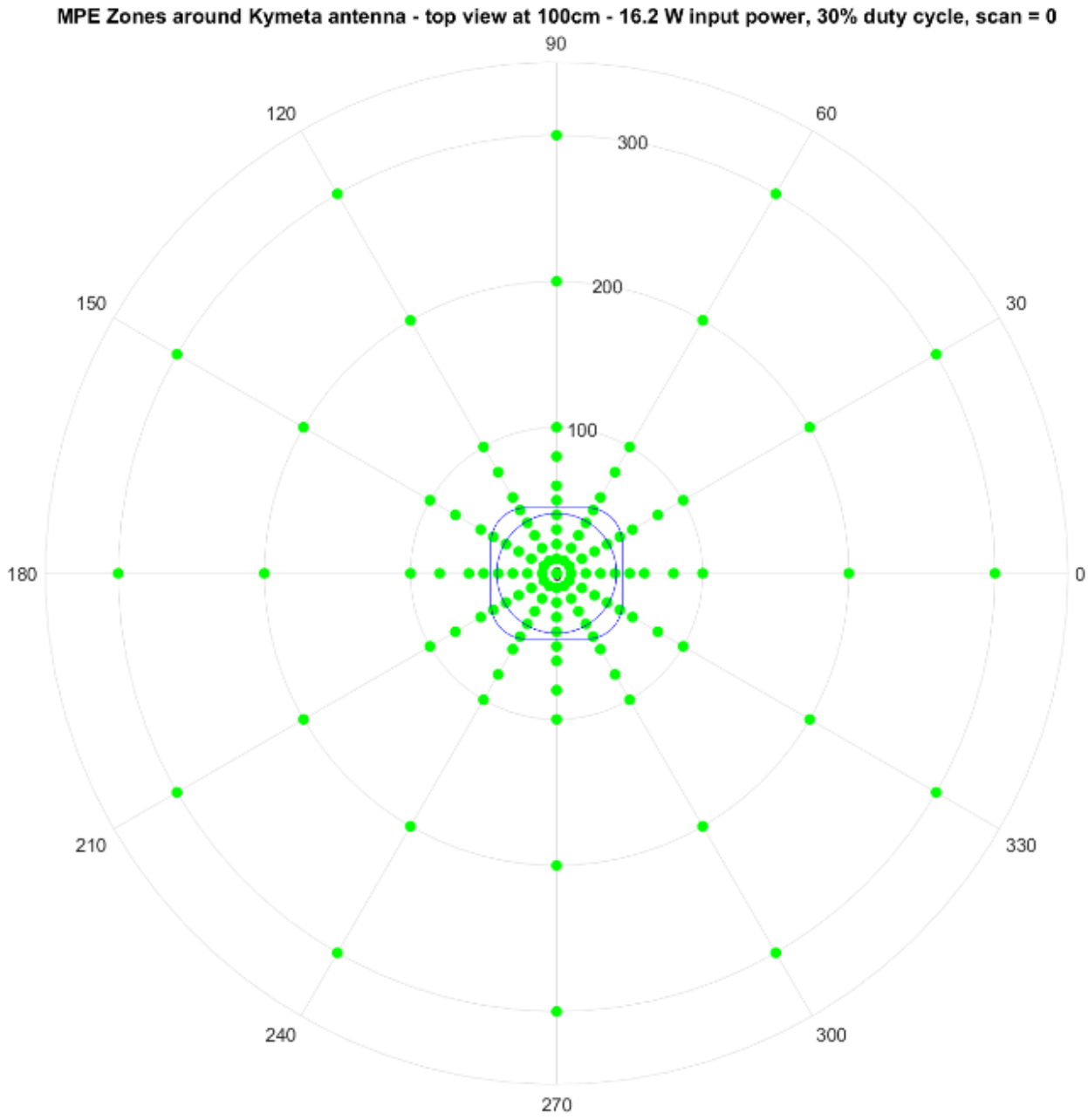


Figure 11: Height 100 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

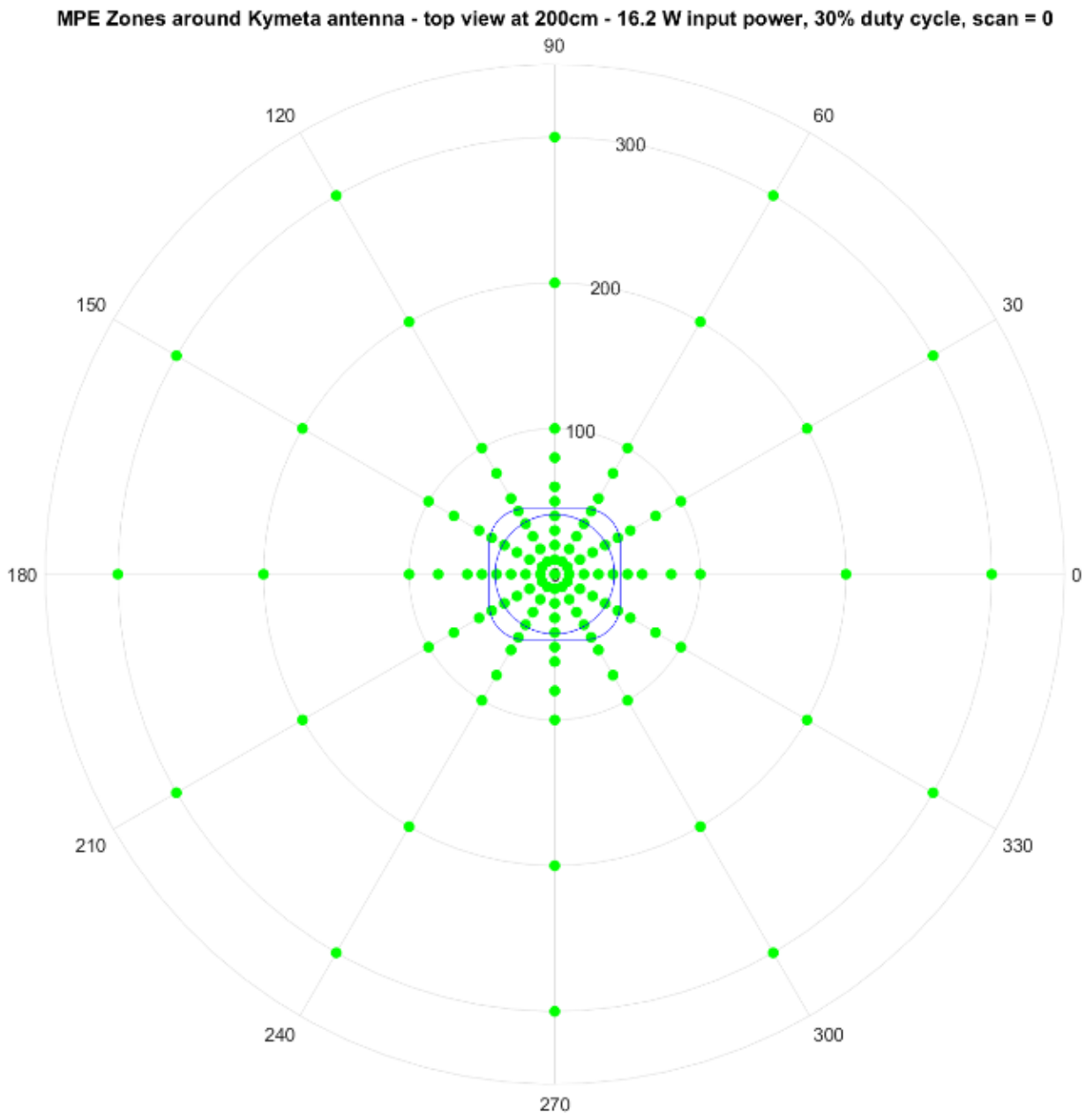


Figure 12: Height 200 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

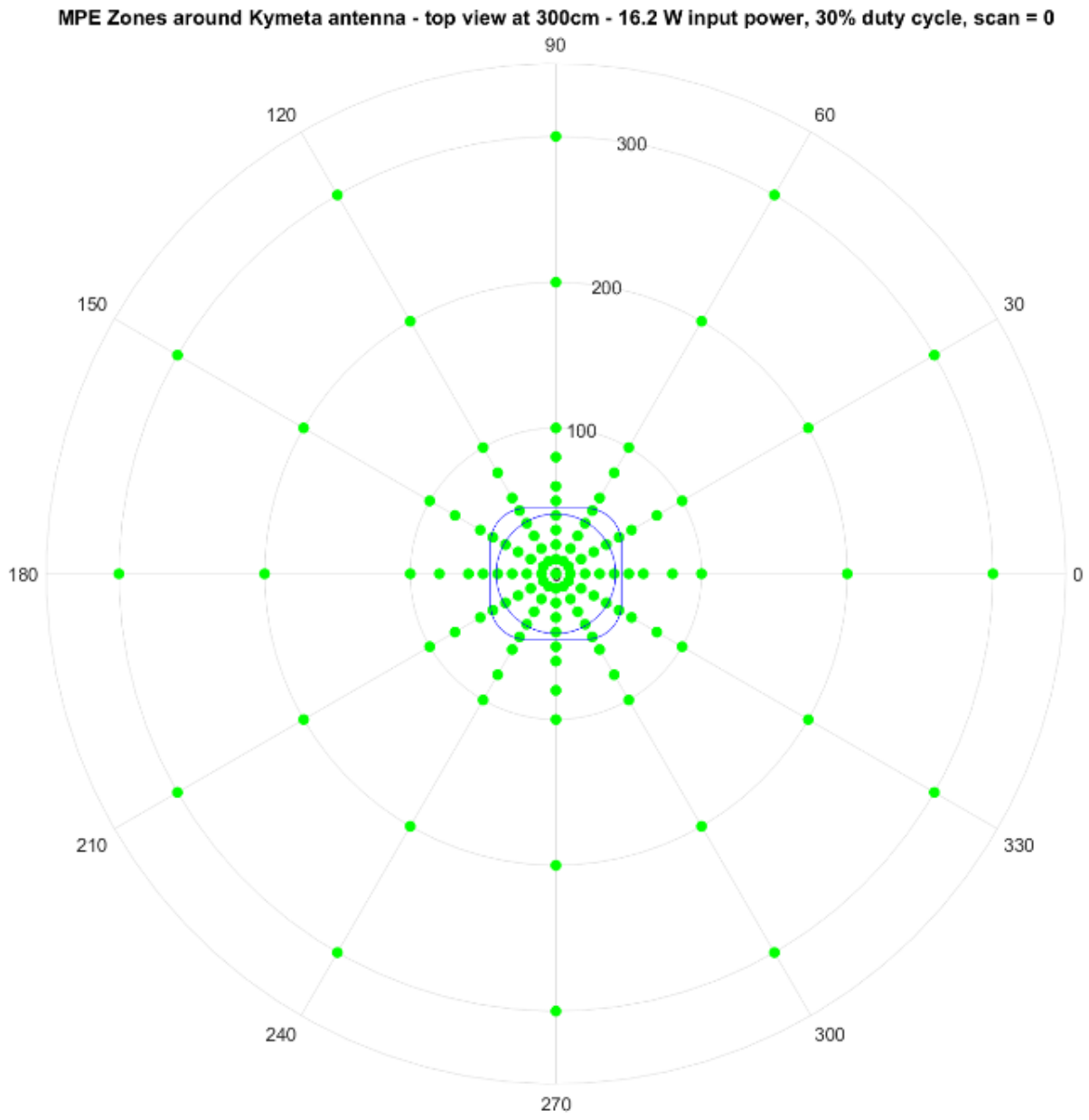


Figure 13: Height 300 cm, 16.2W input power with 30% Duty Cycle, Scan 0˚

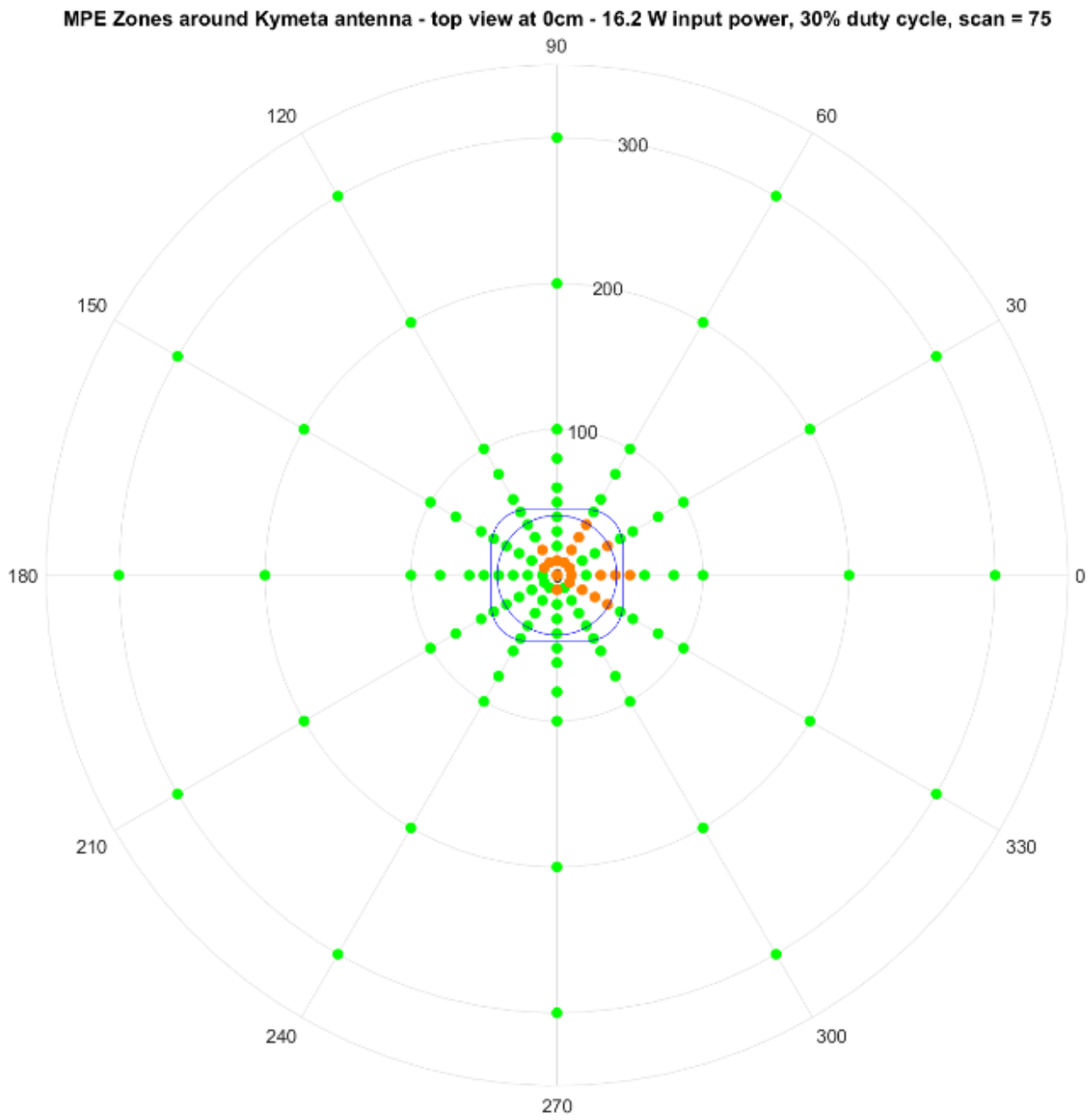


Figure 14: Height 0 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

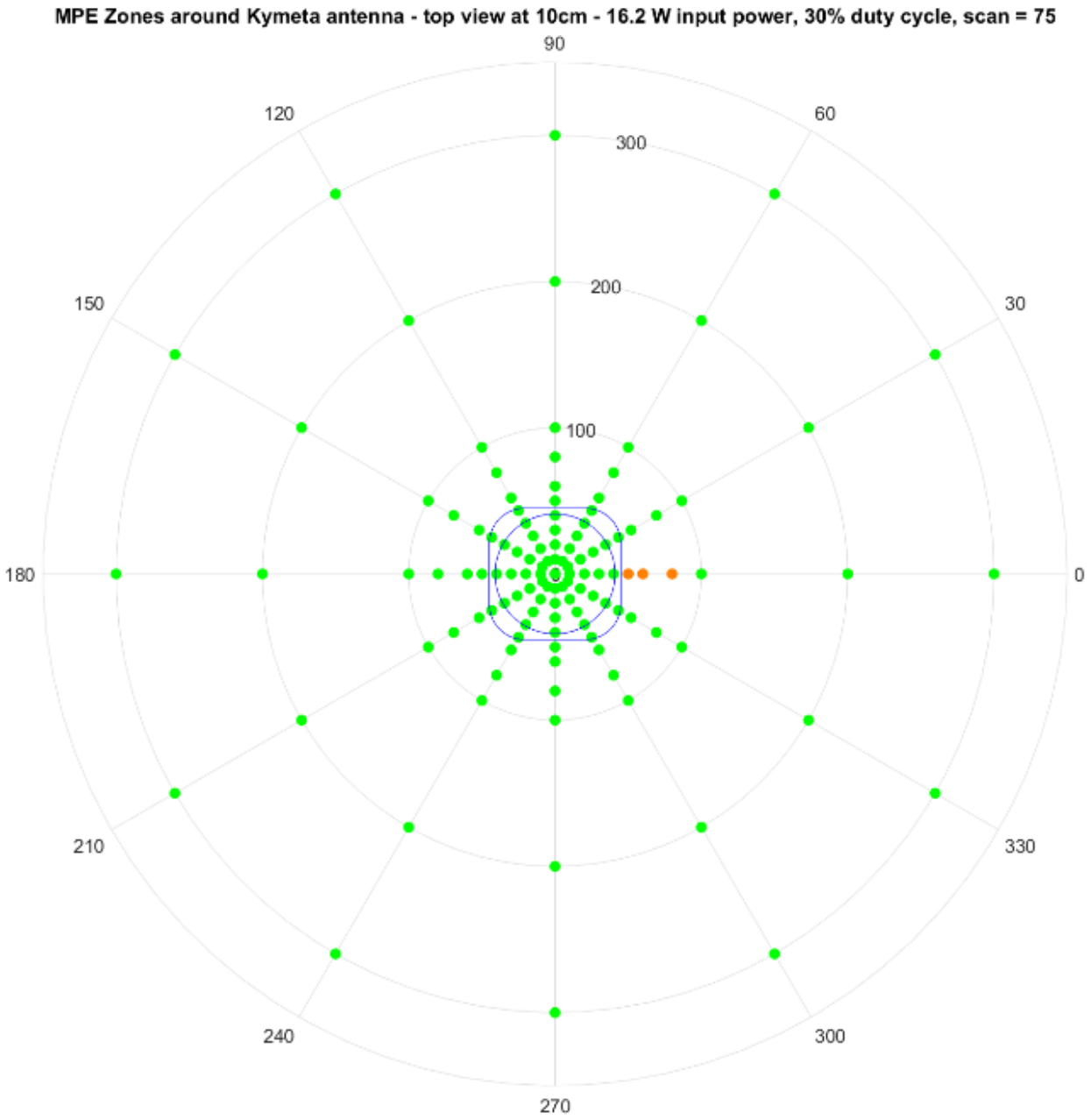


Figure 15: Height 10 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

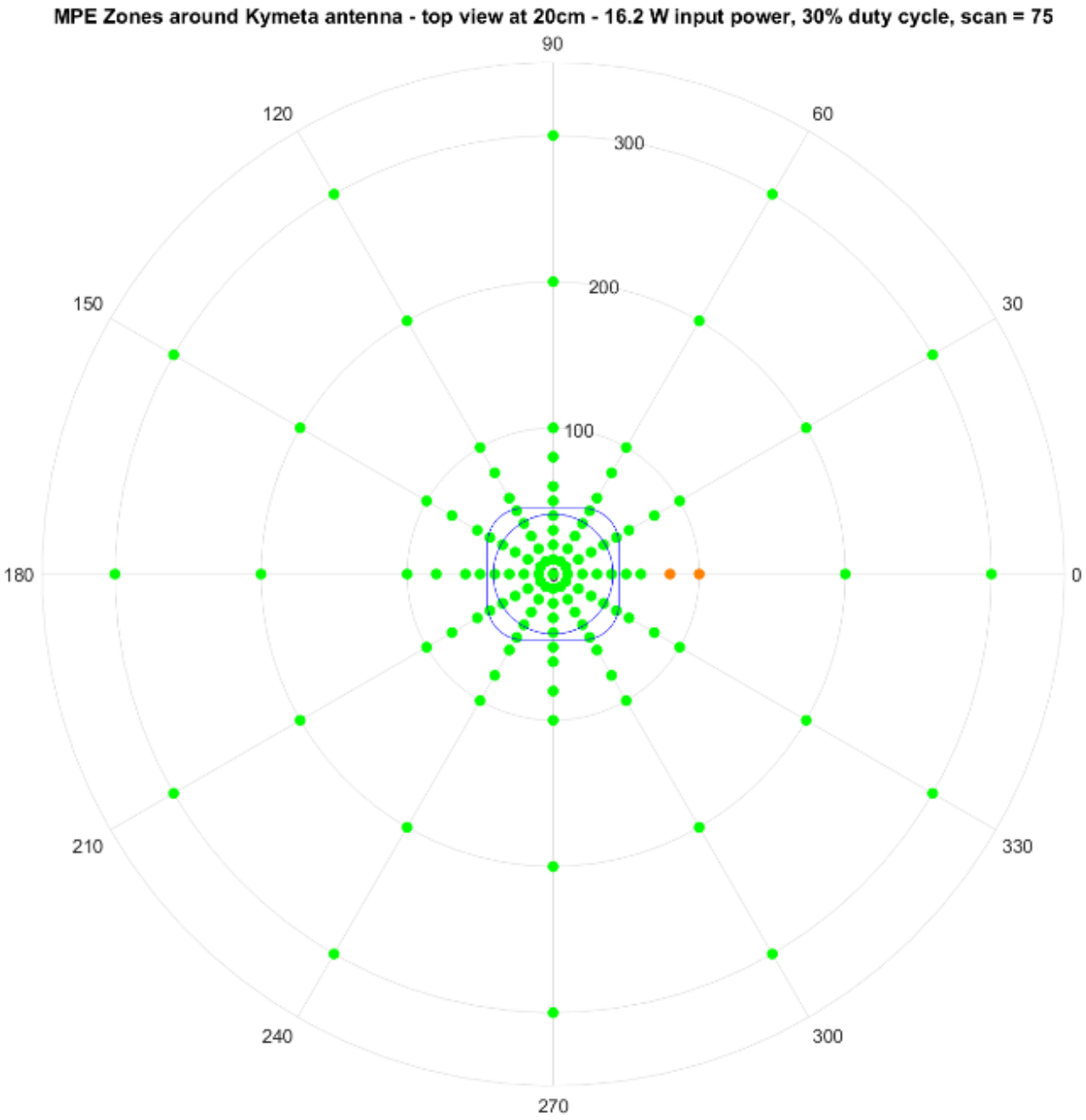


Figure 16: Height 20 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

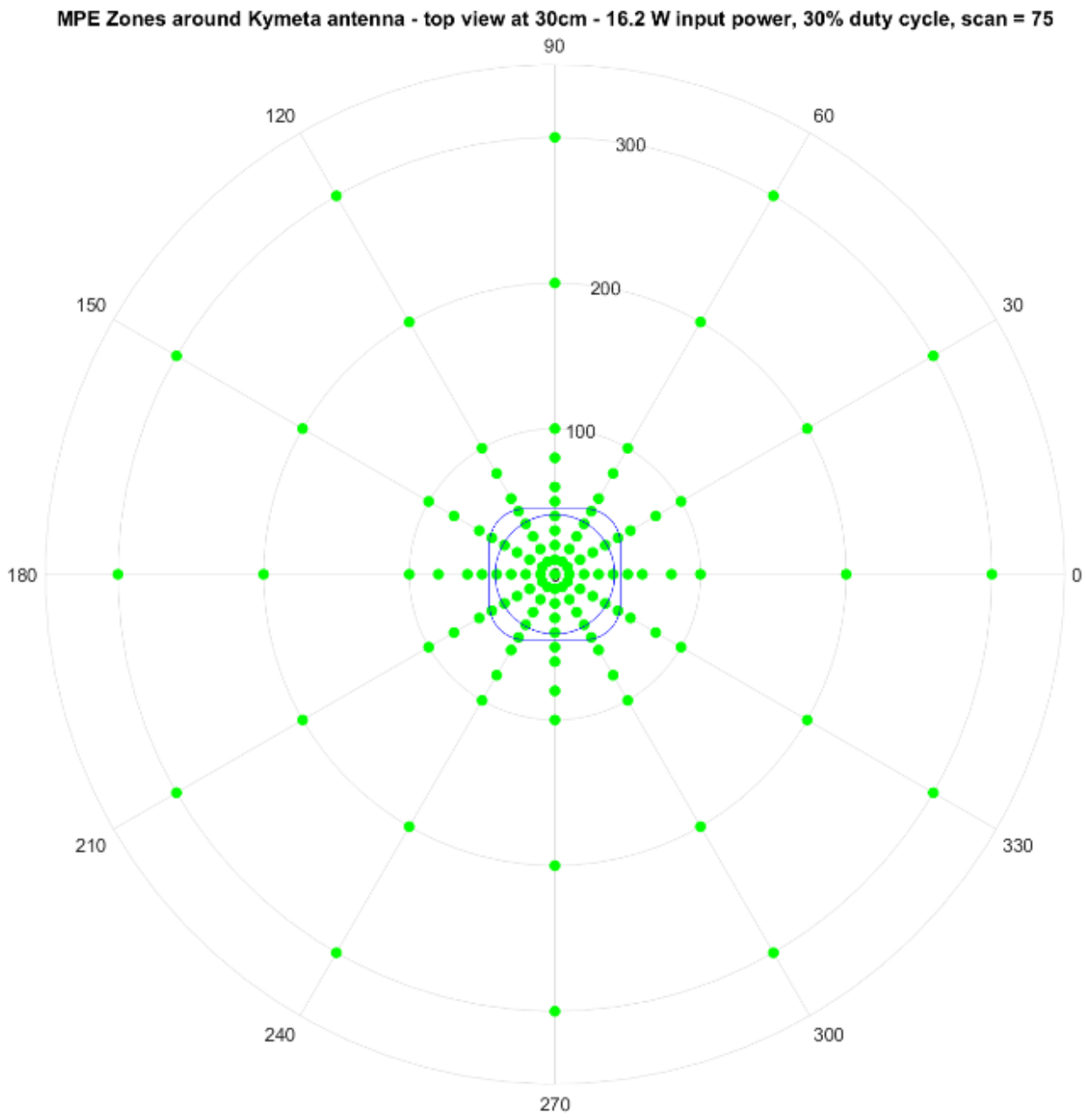


Figure 17: Height 30 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

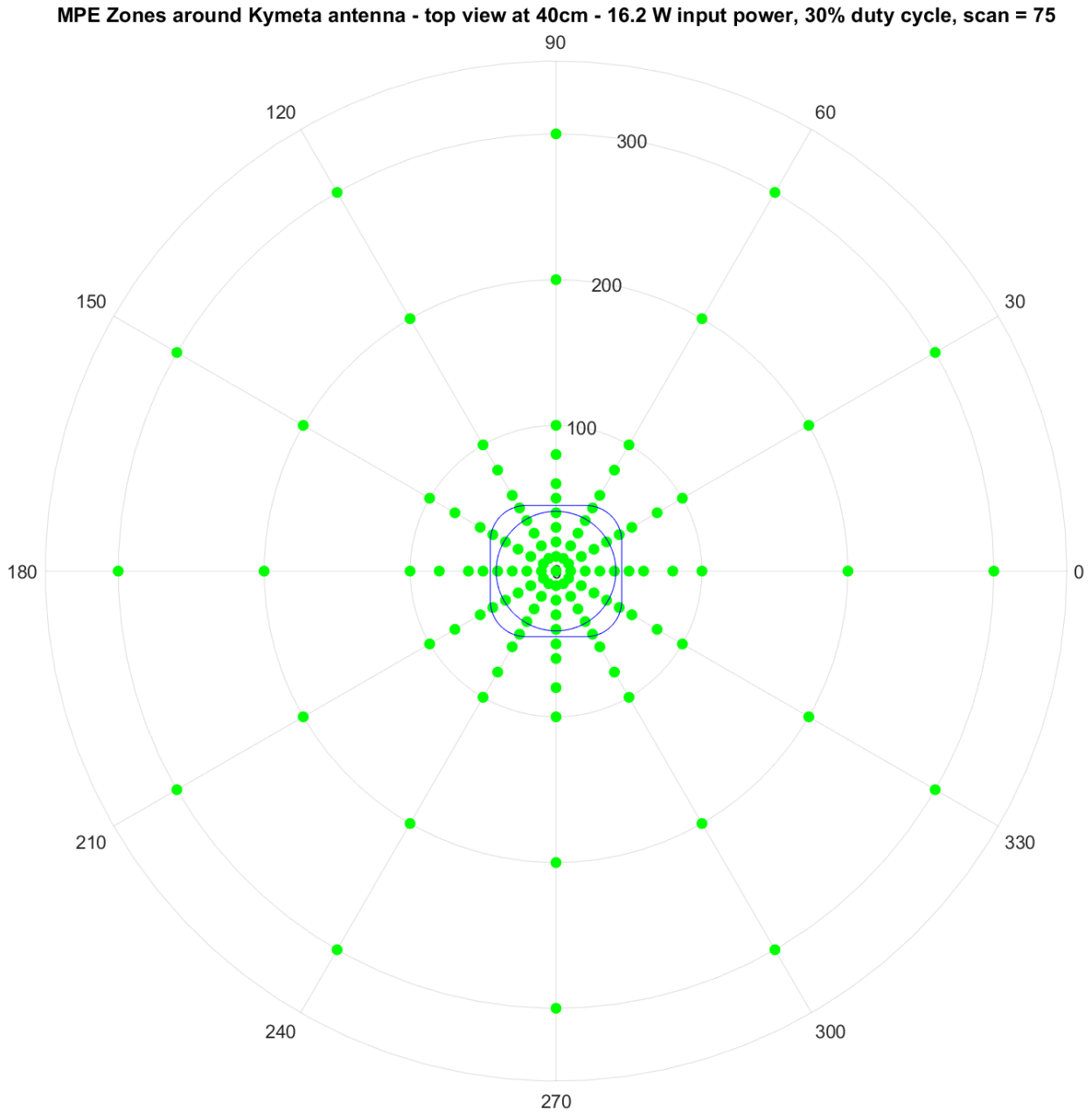


Figure 18: Height 40 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

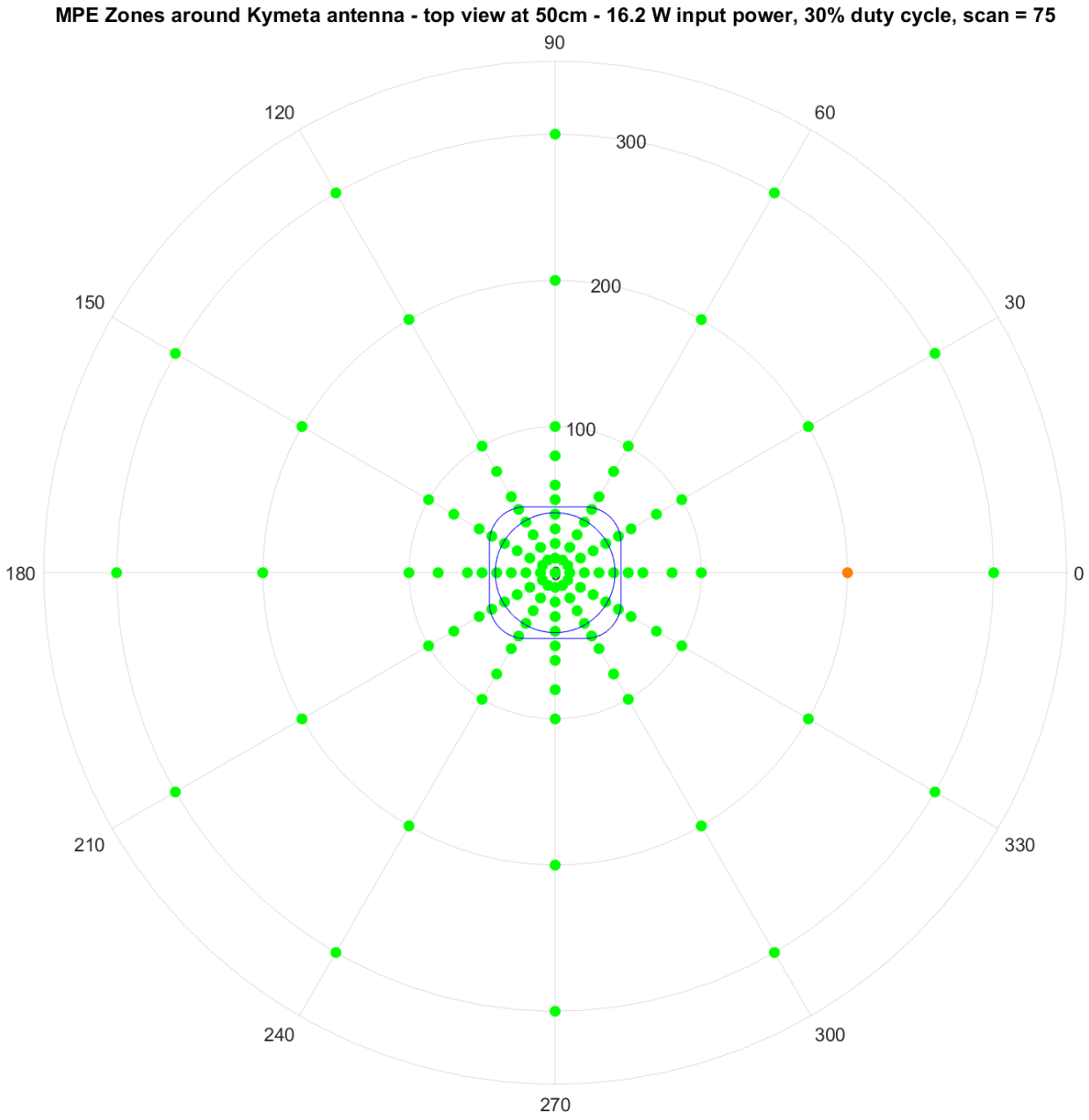


Figure 19: Height 50 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

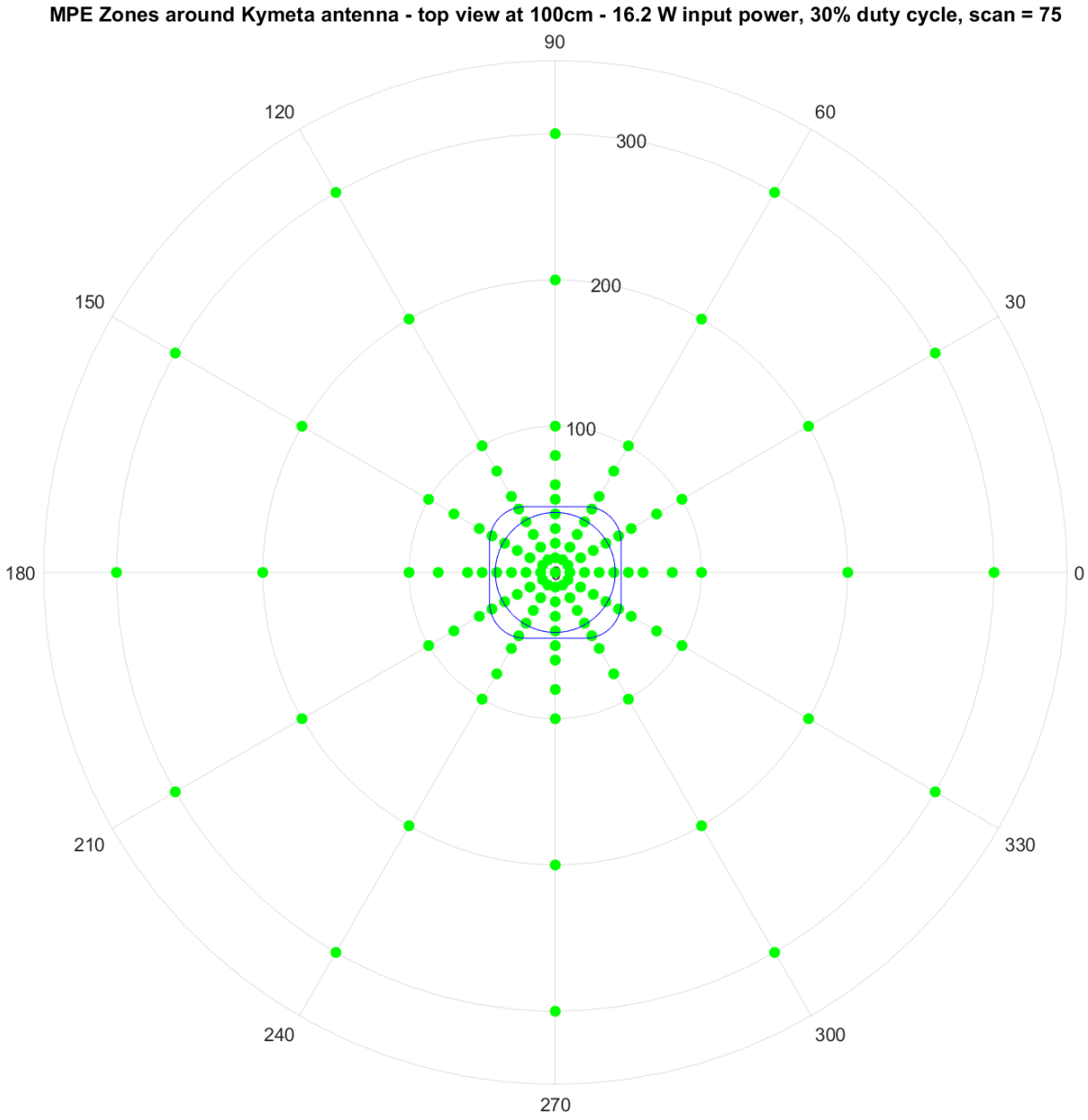


Figure 20: Height 100 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

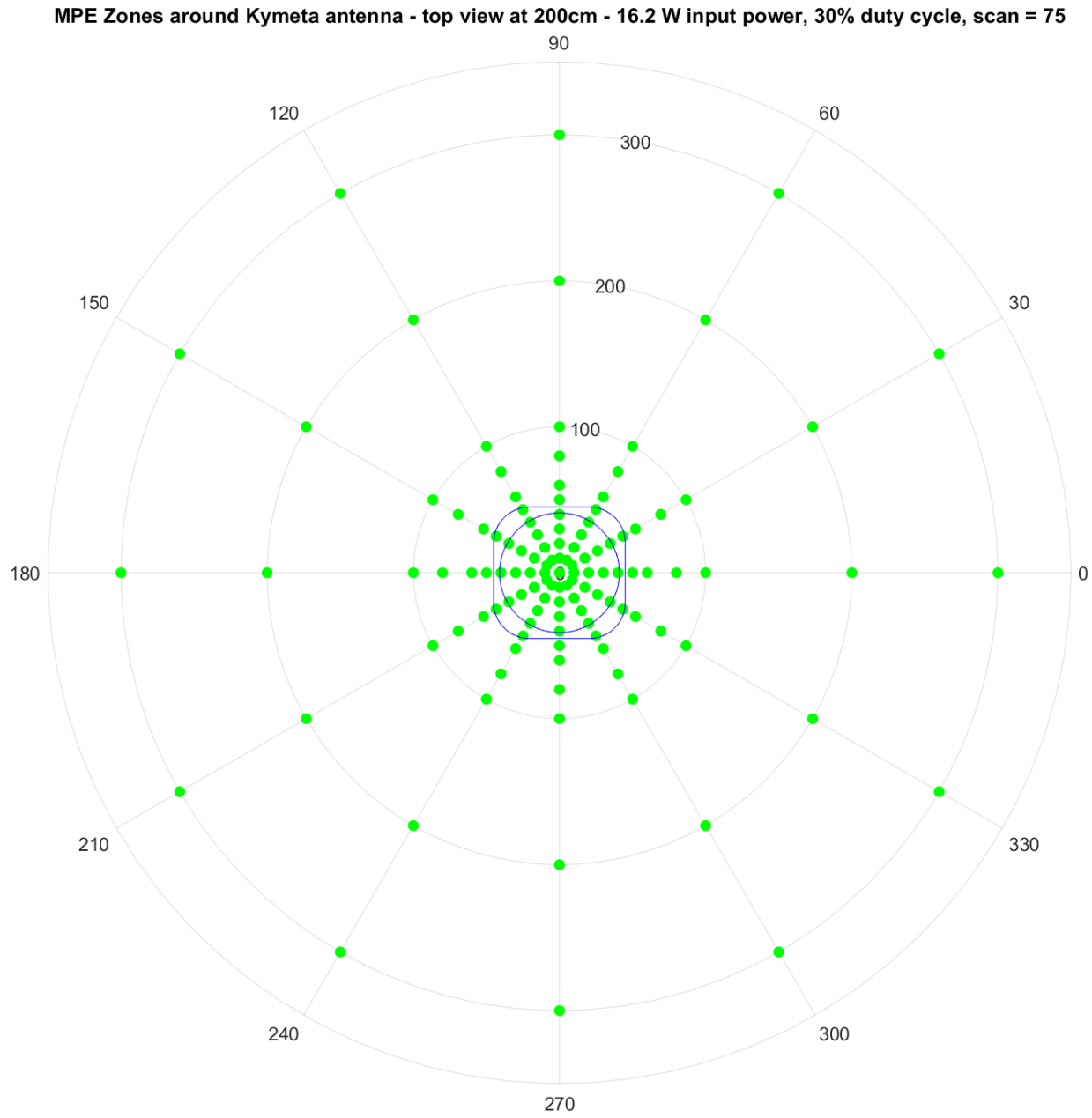


Figure 21: Height 200 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

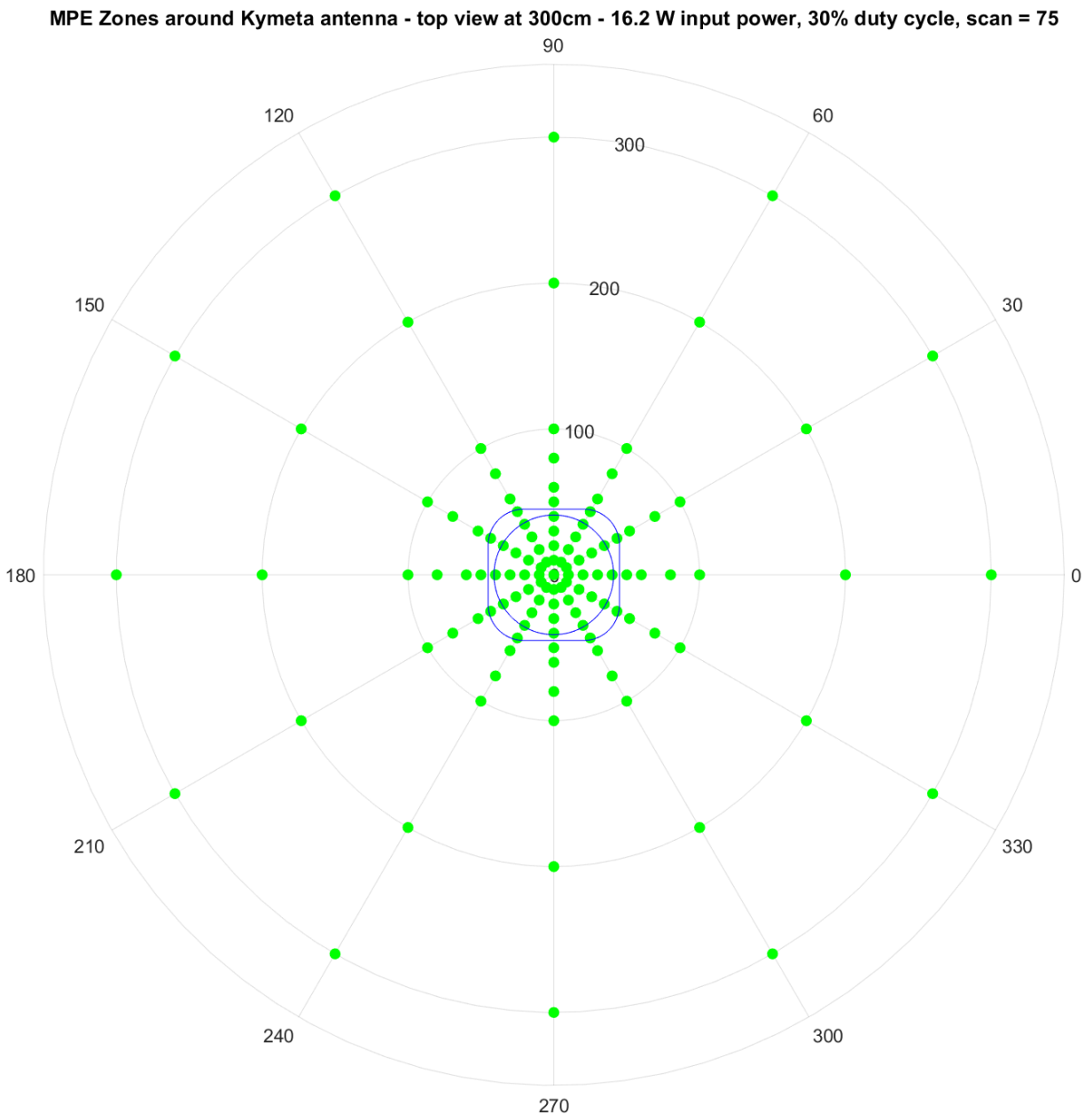


Figure 22: Height 300 cm, 16.2W input power with 30% Duty Cycle, Scan 75˚

6 RF Analysis for the Back of the Terminal

The back radiation of the Antenna mounted on the roof of a VMES is significantly lower than that of the forward directed (main lobe) radiation, producing power densities much less than the 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.

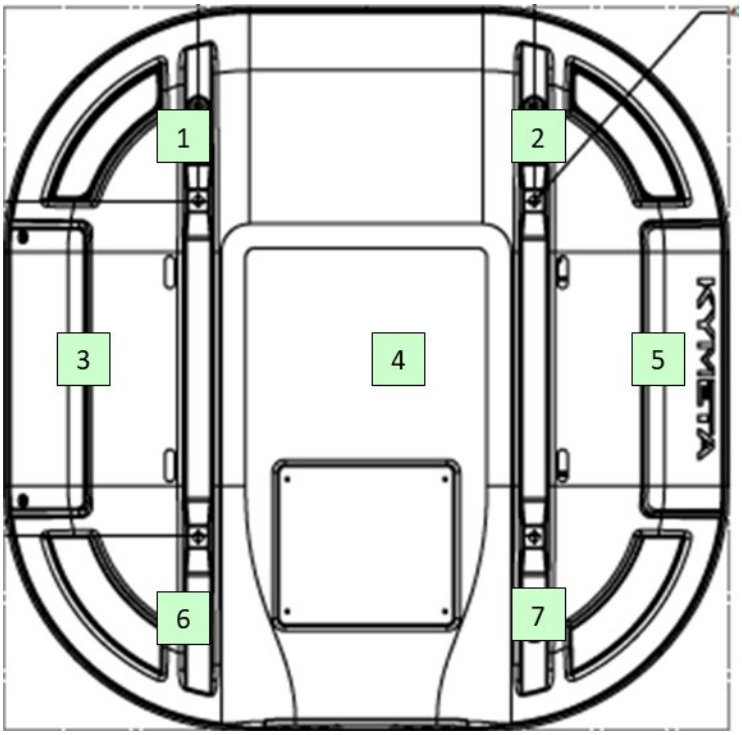


Figure 23: Solid model of the back of the u8 terminal showing measurement locations for the RF power density measurements

Table 1: Measured Power density levels at the back of the u8 Terminal (4 W input power)

	Measured Data (mW/cm^2)	
Location	**1" from the back of the antenna**	**3" from the back of the antenna**
1	0.0000	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 2: Scaled power density levels at the back of the u8 Terminal (16.2W 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	0.00000	0.00000
2	0.00000	0.00000
3	0.00000	0.00000
4	0.02190	0.01090
5	0.00000	0.00000
6	0.00000	0.00000
7	0.00000	0.00000

Figure 23 shows the power density at various locations 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 4 watts to the input to antenna. The raw data is shown in Table 1. The data was scaled to 16.2 watts and a 30% duty cycle. See 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.

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 near the antenna is there the potential for power densities to exceed the FCC general public MPE. Exposure of the public to this limited volume of space during normal operation of the Antenna is deemed to be a low probability event given the close proximity that one would have to be to enter the region where the public MPE could be exceeded. Kymeta will comply with the mitigation measures set forth in the Commission's Second Report and Order, *Targeted Changes to the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields*, FCC 19-126, ET Docket No. 19-226, rel. Dec. 4, 2019.

Power density measurements show the following for operation of the Terminal at 16.2 watts, with a maximum duty cycle of 30%:

There are no "red" zones (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 several "orange" zones where 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. These zones only occur for the 75 degree scan angle (a worst case scenario), at the following locations:

- Vertical: At 0, 10, 20 and 50 cm from the surface of the antenna (at 75° scan angle).
- Horizontal: Within 1.55 m of the edge of the Terminal. The orange zone is limited to angular region that corresponds to the phi pointing direction of the beam.
- 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/cm2.

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, 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 1.55 m of the edge of the Terminal" (or substantially similar wording). "NOTICE" will be printed in blue color. The text of the label will be large enough so that it can be read from the separation distance required for compliance with the general population limit.
- Instruct customers to post one or more signs around the Antenna stating: "NOTICE – Radiofrequency fields may exceed FCC limits for the public within 1.55 m of the edge of the Terminal" (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 Terminal. The unlikely scenario of a member of the general public accessing an Orange zone region near the Terminal 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 any Orange zone, 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 1.55 m of the edge of the Terminal" (or substantially similar wording). "NOTICE" will be printed in blue color. The text of the label will be large enough so that

it can be read from the separation distance required for compliance with the general population limit.

- Instruct customers to post one or more signs around the Antenna stating: "NOTICE – Radiofrequency fields may exceed FCC limits for the public within 1.55 m of the edge of the Terminal" (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 Terminal. The unlikely scenario of a member of the general public accessing an Orange zone region near the Terminal 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. Given the heights of these vehicles (>= 180cm), and the height of the mounted u8 Terminal (>=14 cm), the bodies of people standing next to them will be well below any orange zone.

Also, the u8 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 receiver antenna aperture on the same physical substrate, any sudden change in receiver 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 (e.g. by a bus), transmissions are ceased well within the timeframe required to satisfy the MPE limit.

In order to ensure that the general population does not have access to any Orange zone, 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 1.55 m of the edge of the Terminal" (or substantially similar wording). "NOTICE" will be printed in blue color. The text of the label will be large enough so that it can be read from the separation distance required for compliance with the general population limit.
- Instruct customers to post one or more signs around the Antenna stating: "NOTICE – Radiofrequency fields may exceed FCC limits for the public within 1.55 m of the edge of the Terminal" (or substantially similar wording).

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.