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DESIGN AND PROTOTYPING OF A RADIO FREQUENCY – PHOTOVOLTAIC MODULAR DEPLOYABLE GROUND POWER RECEIVER FOR APPLICATION IN A SPACE SOLAR POWER ARCHITECTURE

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Abstract

Space Solar Power presents a compelling alternative to traditional energy sources with wide ranging applications in both defense and disaster recovery. The space segment consists of satellite-based elements collecting unfiltered solar energy. Such energy is then converted into DC power through photovoltaics, and into RF or optical energy. The resultant wireless energy is then beamed to an Earth receiver. Here, a large area structural rectenna array receiver collects the microwaves and converts the energy back to useable DC power. Then, it can be stored and distributed. Numerous technologies for such a system are still in their preliminary or prototype stages, with some elements not yet demonstrated to a larger applicable or practical stage. A modular deployable ground power receiver is an example of such a key component. A novel approach to wireless power reception of a space solar power system based on a modular deployable ground power receiver architecture is presented. Such architecture integrates both microwave and solar energy collection and conversion elements into a modified 20-ft ISO shipping container. A high-level requirements analysis, a detailed CAD model, and a ¼ scale prototyped receiver module is presented as a result of this effort. Such prototype demonstrates modularity, scalability, and operational deployment functionality for future Space Solar Power applications.
Keywords: Space, Solar, Satellite, Ground System, Modular, Microwave

Acronyms/Abbreviations

CAD – Computer Aided Design.
DC – Direct Current, RF – Radio Frequency.
FOB – Forward Operating Base.
MDGPR – Modular Deployable Ground Power Receiver.
NASA – National Aeronautics & Space Administration.
ISO – International Organization for Standardization.
SBSP – Space Based Solar Power
SSP – Space Solar Power

1. Introduction

Space Solar Power (SSP) is a wireless power transmission concept that has been researched for decades by government organizations and the commercial aerospace industry. Peter Glaser of NASA first proposed the idea of a Solar Power Satellite in 1968, and later was granted a patent in 1973 [1]. The concept involves collecting effectively, uninterrupted solar energy in space and converting it into electricity using photovoltaics on satellites orbiting the earth. This power is then used to drive a power beaming system that wirelessly transmits the collected energy, to receivers on earth. Depending on the orbit, SSP as a constellation of satellites, or as a monolithic system in Geosynchronous orbit, could be unaffected by night-time, weather conditions and seasonal variation, which are typical setbacks with traditional ground-based solar systems. SSP itself has challenges in technological, economic, legal, operational and schedule standpoints. Such challenges are addressed in various government studies such as the 2007 National Security Space Office, Space-based Solar Power (SBSP) Assessment [2] and in the 2009 U.S. Naval Research Laboratory SBSP study [3].

The average intensity of solar energy reaching the top of the atmosphere directly facing the Sun is about 1,360 watts per square meter (W/m^2) or 126.3 watts per square foot (W/ft^2), according to measurements made recent NASA satellite missions [4]. This energy is then absorbed and reflected by the atmosphere and clouds. Then further hardware inefficiencies reduce the power output to approximately 15 W/ft^2 on land surfaces [5]. For efficiency reasons, it would be more desirable to collect the significant 1,360 W/m^2 of available energy and transmit it to the earth in a highly efficient process. Space Solar aims so solve this problem.

Although several small-scale prototypes of space hardware have been developed as a result of research studies [6], mass specific power (W/kg) in hardware prototypes will need to increase by at least an order or magnitude of what is currently demonstrated. Additionally, with the exception of few, validated SSP specific hardware has not been produced in the United States to date, with most development occurring in Japan [7].

1.1 Problem Statement

The U.S. Military currently is largely dependent on a single source of energy, liquid hydrocarbon fuel such as Jet Propellant (JP-8) fuel. Fuels such as JP-8 are essential to operate its forward deployed forces and support overseas operations. A lapse in fuel delivery created by political instability and various other factors can create a significant energy resiliency problem [2]. Diversification of military energy resupply could reduce dependency on liquid fuel and increase operational resiliency. Furthermore, electrification of military assets including unmanned systems could create a significant increased demand for clean, constant, global, and scalable electrical power. A suggested additional application can be implemented when natural disasters that critically impact an areas existing power grid [8]. Recovery efforts require a rapid and reliable power solution to bring essential infrastructure such as hospitals, emergency operation centers, traffic management, and other services, back online whilst power is repaired and restored. Both defense and disaster recovery applications of space solar can have a significant benefit from the development of a tactically deployable power receiver to satisfy operational and transport requirements in theatre. Still no relevant applicable work has been done in this area to date.

1.2 Research Objective

The principle objective of this project is to present a novel approach to an integrated radio frequency-photovoltaic (RF-PV), modular deployable ground power receiver (MDGPR) system architecture. Development of this proposed receiver segment is expected to assist with future architecture developments. This can help by increasing the SSP overall technology readiness level. Active research and successful deployments of SSP can be assumed to become critical into garnering future investment by government and private entities. Additionally, maturation of system technologies such as this, can directly support the ability to perform integrated technology demonstrations at progressively increased scale and capability.

1.3 Space Solar Architecture

Space Solar architecture can be broken down into a space-based satellite segment and a ground or Earth segment. The space segment consists of elements collecting unfiltered solar energy, converting it into DC power through photovoltaics, and into microwave (RF) or optical energy, where it is then beamed to the Earth segment. Here a large area structural element called a rectenna, collects the microwaves and converts the energy back to useable DC power, where it can then be stored and distributed. Figure 1 depicts the major components described above.

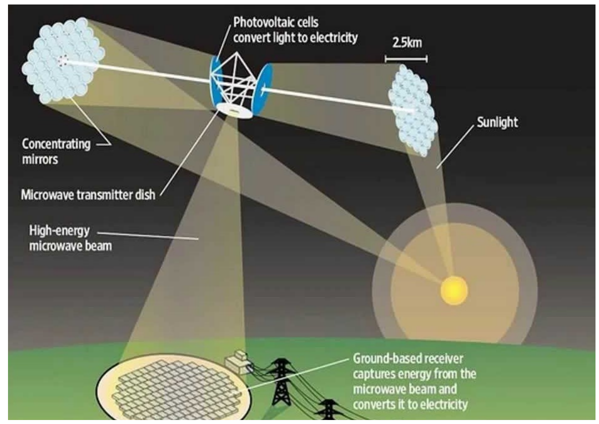

Fig. 1. RF space solar concept; depiction is not to scale [9]

2. Project Requirements

Specific requirements and constraints were identified in order to begin with the engineering process. Requirements were segmented into stakeholder and MDGPR specific requirements. A detailed list of requirements is outlined in Appendix A.

The driving requirement of the receiver is that the “building block” or otherwise, 10 containers, shall output power of no less than 200-kW. This requirement was derived from the basic assumption of 2-kW per day and 100 personnel on a small forward operating base. It is important to note that 2-kW per day is a rough estimate difficult to prove given variations in base sizes. SSP has been pitched in a variety of scenarios for both utility base load power and more niche application such as military forward bases. The most remote bases such as combat outposts have the greatest potential to prove this power source benefit. It is expected for SSP to reduce the risk of roadside bombs and eliminate the difficulty of supplying liquid fuel to locations such as a mountain-top. The Sustainable Forward Operating Bases [10] report provides a substantial background on U.S FOB design and operations, invaluable to this project.

2.1 Case study

A case study using former combat outpost (COP) Hanson in Marjah, Afghanistan, was used as a scenario to analyse the capabilities for this project. It provided from an aerial perspective, specific area constraints. Such constraints include an estimation of area used by fuel tanks, an open area potentially used for parking, and protective tactical offsets which were deemed to be critical in the layout of the base. Figure 2 shows a Google Earth image of the Hanson outpost [11]. This case study is provided in more detail in Appendix B. COP Hanson been a publicly available image, showed a useable area in the center of the base of 60-m^2. This area is identified largely as a parking area for vehicles and as a road fork, allowing vehicles to access different locations of the base. This land, due to its openness and flat prepared surface could be a prime location to setup the receiver system. The fork could be transformed into a roundabout allowing the egress of vehicles on base. Due to the varied architecture of combat outposts, a 60-m^2 area may be unavailable at all locations, this also means that the population of the base could vary significantly, requiring less power. In either situation, SSP may not be the solution to power supply.

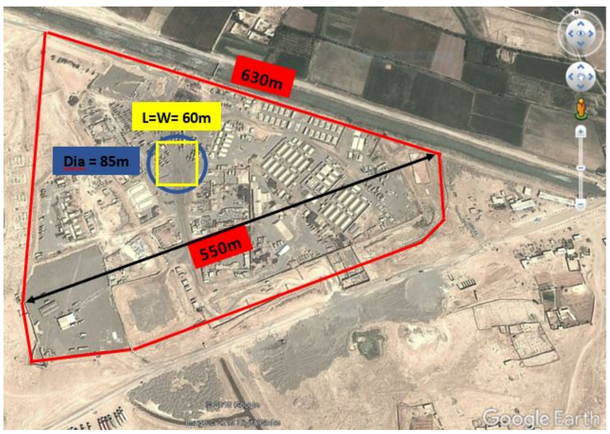

Fig. 2. Google Earth imagery of former Combat Outpost Hanson, Marjah, Afghanistan used in this case study [11]

2.2 The Shipping Container

The very basic design requirement of this project was to ensure the receiver package would be integrated into a 20-ft ISO shipping container. Shipping containers are the primary means by which the U.S military transports goods around the world [12]. It is important for both economical and logistical reasons that this package follows this tradition.

2.3 Photovoltaic integration

The novel approach to this receiver concept was the integration of photovoltaics (PV) into the receiver containment structure. PV is an established means of renewable energy on earth and is also used as a primary power source for satellites in space and some combat operations in theatre. It is important for the security and resiliency of this proposed architecture that a dual power source be integrated where possible. The shipping containers used in this proposal in multiples of 10 contain a significant amount of surface area on their side walls that could be used to mount solar panels, hence the self-imposed requirements of PV into this receiver concept.

3. Receiver Package Structural Design

Various structural concepts were considered for this proposal and are described in Appendix A. Concepts were weighed based on the following criteria. Modularity, Design Complexity, Deployability, Cost, Stability, Thermal Control, and PV Panel Integration. The proposed Container presented below in Figure 3. This design approach seeks to satisfy in a practical and scalable way, the need to contain the SSP receiver system in an elegant manner by seamlessly integrating sustainable technologies in a mechanically reliable approach.

3.1 Gullwing Container Design

The selected concept proposed in this project was named the "Gullwing Container". This concept provided for a significant amount of PV collection area spread across the side walls, real-time sun angle adjustment via actuating L-shaped side doors, through-container passive cooling, and self-containing battery storage.

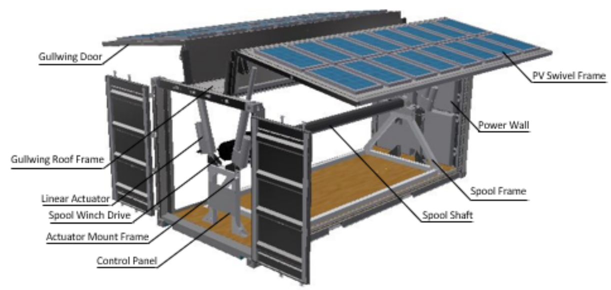

Fig. 3. Modular Deployable Ground Power Receiver developed as a result of this project

An important factor in choosing this concept was the elegant way in which it supports a large amount of solar collection area while maintaining the structural integrity shipping containers are known for. Each long side of the shipping container supports approximately 133-ft^2 of flat surface area, or 266-ft^2 per container. With the average solar power density on Earth of 15-W/ft^2 [5], 3,990-W can be converted to electricity per container. When considering 10 containers in the building block, this sum to approximately 40-kW of power. Proving a substantial supplement to a renewable power delivery system. The power provided by this concept could potentially smoothen out the power-time curve, providing a buffer when the RF signal may be attenuated during the day depending on the orbit and various other factors.

3.2 Rectenna Spool System

The rectenna itself was not prototyped in this project due to scope. Instead, several assumptions were generated based off calculated values from power beaming physics including an average intercepted power density of 50-W/m^2, assumptions are elaborated in Appendix C. The rectenna used in this package was assumed to be an array of flexible PCB patch antennas on a large sheet dimensioned to absorb RF transmitted at 5.8-GHz. The rectenna sheet is rolled onto a spool frame; described below in Figure 4, similar to traditional tarpaulin pool covers. The drive system used in this prototype was a 2500lb wirelessly controlled utility winch with a gear ratio of 153:1. This ratio allowed for a slow and controlled retraction of about 13-ft/min [13]. The winch's existing spool was modified to be used as an adapter to directly drive the spool shaft. Figures 5 and 6 show the current prototyped parts and Figure 7 shows the assembly. Due to the long length of this sheet and the certainty of dirt and debris covering it during deployment, a dual-purpose bush-guide is proposed to be integrated on the spool frame to ensure a clean flat and reliable spooling operation. This brush-guide is still under development and therefore not presented in this paper.

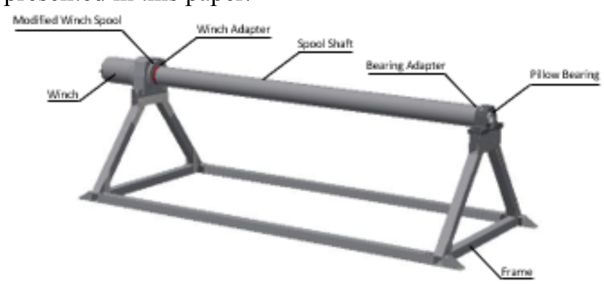

Fig. 4. Rectenna Spool developed as a result of this project

3.3 *Modified Roof Frame*

In order to integrate L-shaped Gullwing Doors, a modification to the roof of the container was necessary to bear the load of the doors. This structure described in Figure 5 was designed for simple fabrication and easy assembly whilst maintaining the rigidity of the shipping container. Cylindrical steel tubes were welded flush to the frame and Nylon bushings were pressed into the hinge tubes to maintain a low friction hinging motion reducing the chance of binding in the hinge. Weather-stripping was secured to the top of the roof frame over the hinge as there would be a possibility of a leak in the case of rain. Sealing this container from the elements is a significant issue incurred as a result of modifying the existing container but can be mitigated.

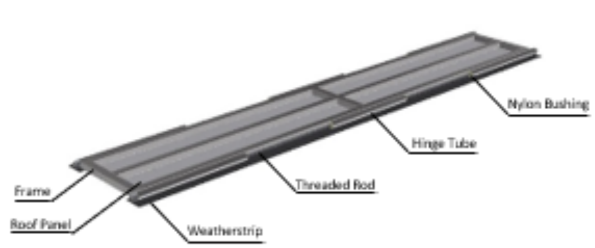

Fig. 5. Modified Roof Frame developed as a result of this project

3.4 *Gullwing Door*

The major structural decision in this project was to integrate L-shaped doors onto the sides of the container. The doors are rotated on hinge tubes about a long shaft that runs along the roof frame shown in Figure 5. The door frame is comprised of square steel tubing welded together at 90-degree angles. As shown in Figure 5, the roof is stiffened using a rib tube to prevent twist along the long beam. The linear actuators controlled by the user are pinned on the actuator mount frame; depicted in Figure 3, mounted to the underbase of the container, and connected via pin to the top of the Gullwing Door shown in Figure 5. This frame has proven to be easy to fabricate on a short schedule due to its simplicity. Prototype pictures for some of the assemblies discussed are presented in Appendix D.

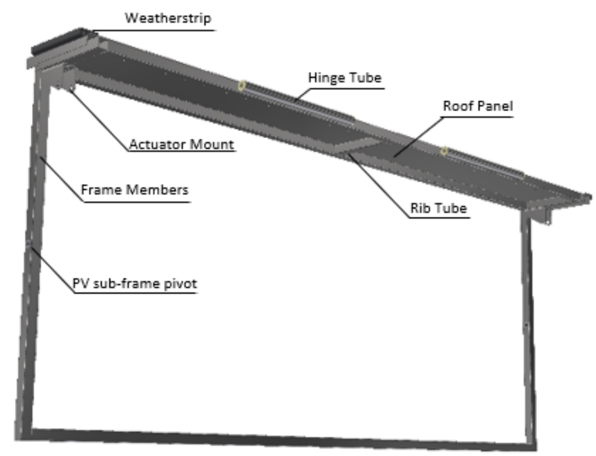

Fig. 6. Gullwing Door developed as a result of this project

4. Discussion

As identified in the problem statement, little to no work has been invested into ground systems development for Space Solar Power. The space segment benefits from government research funding and media attention due to the word, "space". Though, Space Solar is not just space, as in any space capability, ground systems play the crucial role of enabling that capability. In fact, Space Solar can only be possible and proven, if ground systems are advanced at the same pace. This project has demonstrated that shipping containers are extremely versatile in nature and should be considered as the prime packaging solution for a deployable highly-modular system to suit defence and disaster recovery applications of Space Solar. Additionally, this project has demonstrated that a spool mechanism could be a prime candidate for a thin-film like rectenna material. The extension and retraction of a flexible array of patch antennas is certainly within the realm of possibility and needs urgent development efforts to enable this capability. Manufacturing such a large sheet containing sensitive electrical components will require significant funding and a highly diverse team of engineers. Integrating photovoltaics into the structure of the container is certainly possible and does provide an added layer of energy security. Photovoltaics does however, add an added layer of complexity that could be judged depending on the scale of its deployment, to be minimal in its added benefit. Managing scope of this project proved to be difficult as there were so many capabilities that could have been integrated into this system, however, the budget and schedule limited the team to focusing on the 3D CAD model and fabrication work required to build the structure. Future work is encouraged by the authors to be coordinated with stakeholders directly involved with the development of Space Solar Power.

5. Conclusions

The Modular Deployable Ground Power Receiver project has been a tremendous learning opportunity for the team of students attending Texas A&M University – Corpus Christi. Students applied problem solving skills to develop scaled prototyped ground equipment for a space power concept that is becoming closer to reality every year since inception. Students used project management skills to control the financial backing and project development process. Students applied engineering and manufacturing competency to quickly build a ¼ scale structural model on schedule and under budget. The final assembly of this project is expected to be completed by mid-November 2019 with final capstone design presentations shortly after. Development of this ground system for Space Solar Power is important to effectively realize a variety of possible concepts to weigh when large space programs are undertaken.

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Appendix A (Requirements Outline)

Stakeholder Requirements

- Mission Requirements
  - The MDGPR shall:
    - Receive RF energy at 5.8 GHz from a satellite(s) in space.
    - Convert RF energy at 5.8 GHz to DC electricity at 60 Hz.
    - Collect solar energy.
    - Convert solar energy to DC electricity at 60 Hz.
    - Store the collected energy with in the confine of each individual container.
    - Deliver electricity to a power management and distribution center.
    - Output power of no less than 200-kW
- Operational Deployment Requirements
  - The MDGPR shall:
    - Require a deployable area of no less than 100m^2.
    - Require prior land surveying and debris removal.
    - Require a restricted access offset perimeter of 5-m.
    - Deploy out of a 20-ft Modified ISO shipping container.
    - Retract the receiver without human intervention.
- Transportation Requirements
  - The MDGPR shall:
    - Be transported by military helicopter.
    - Be maneuvered by military forklift.
- Environmental Requirements
  - The MDGPR shall:
    - Operate in winds of up to 50-mph.
    - Operate in wet conditions.
    - Operate within a temperature range of -10degC to 50degC.

MDGPR Requirements

- Container Structural Requirements
  - The MDGPR shall:
    - Be capable of lifting its side doors with minimal human intervention.
    - Support the weight of the receiver spool.
    - Support the weight of 4 TESLA Powerwall's on the rear wall.
- Rectenna Receiver Requirements
  - The MDGPR shall:
    - Collect RF energy at a maximum of 100W/m^2.
    - Collect RF energy at an average of 50W/m^2.
- Solar Panel Requirements
  - The MDGPR shall:
    - Have solar panels mounted to the inside side wall of the shipping container.
    - Have side walls that rotate 180 degrees around a central axis.
    - Have side walls that lock in place at 180 degree.
    - Require minimal human intervention to rotate the wall frame.
    - Output a power of no less than 160 W/m^2.
- Battery Requirements
  - The MDGPR shall:
    - Store its own power within TESLA Powerwall packs.
    - Store the system equally divided power at 50% normal output for at least 12 hours.

Appendix B (COP Hanson Case Study)

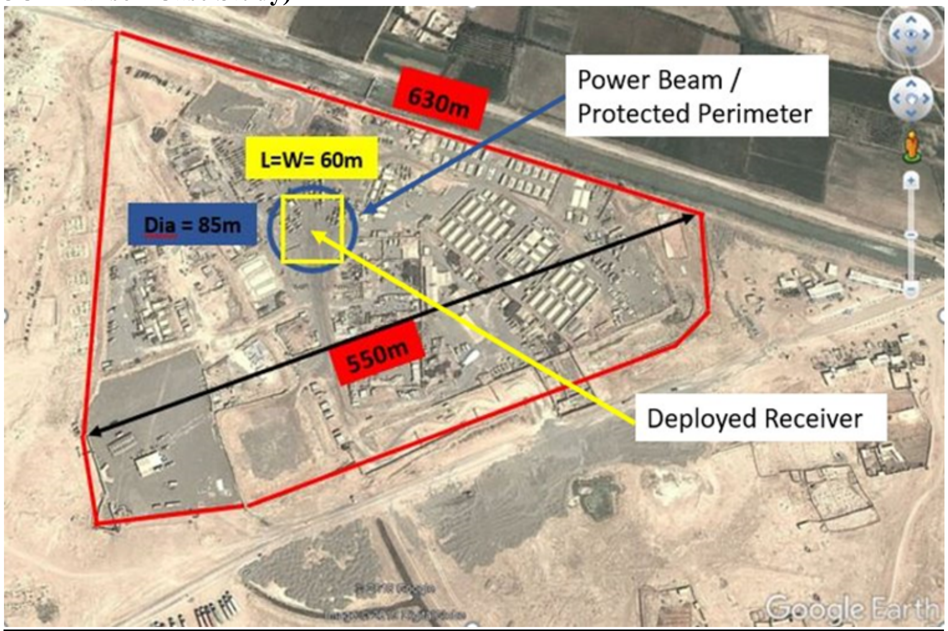

Fig. 2. Google Earth imagery of former Combat Outpost Hanson, Marjah, Afghanistan used in this case study [11]

The figure above is of Combat Outpost Hanson in Marjah Afghanistan. Hanson has since been decommissioned and this image is publicly available and was obtained from google earth.

Energy is vitally important to operations in a remote combat outpost. Currently, deployed units rely on JP8 to meet their energy needs. This fuel is brought in by a convoy of trucks, over IED laden roads. This method not only puts military logisticians, who aren't necessarily trained to fight, at risk, but this also creates a strategic choke point. If the enemy was to cut off friendly units from their fuel source, all the technology of modern 21st century warfare that we enjoy would become useless. We would not only lose our ability to conduct mounted patrols, but our situational awareness and even communications could be lost.

Our project aims to address this strategic risk by designing a modular deployable ground power receiver that can rectify energy that has been transmitted via a space solar power station. Through our calculations, using only 10 units, enough power can be rectified to meet the energy needs of this entire combat outpost. As you can see in this image, the yellow box shows the required area to be covered by rectifying antennas. The blue circle is the diameter of the power beam and would need to be cordoned off as a safety precaution.

Near the bottom left corner of the yellow box, there are three JP8 fuel bladders. This can be used for comparison to the yellow box. It should be noted that the rectifying antenna array does not require significant additional area.

Appendix C (Assumptions and Calculations)

Assumptions

- Rectenna is a large flexible printed circuit board with an array of circularly polarized patch antennas
- Rectenna can be spooled on a 6-inch diameter shaft
- Each container has a maximum rectenna area of 4-m wide by 100-m long
- The average intercepted power density across the rectenna is 50-Wm^2
- 20,000-W power output per container using the average power density
    - 10 containers 'building block' = 200-kW
- The IEEE safety limit in a controlled area is 100-W/m^2 requiring a protected perimeter

Power Beaming Calculation Sheet

Input Power Requirement							
Power Received (Required)	Power Transmitted (Output)	Area of Transmitter	Wavelength	Far Field Distance	Area of Reciever	Diameter of Receiver	Diameter of Transmitter
P_r (GW)	P_t (GW)	A_t (km^2)	λ (mm)	D (km)	A_r (km^2)	d_r (km)	d_t (m)
0.0002	1.3	143.9	51.8	7066.7	1.44	0.04	428
P_r (kW)	P_t (kW)	A_t (m^2)	λ (m)	D (m)	A_r (m^2)	d_r (m)	
200	1,300,000	143872.4	0.0518	7066738.7	143.53	42.47	

$$P_r = \frac{P_t A_t A_r}{\lambda^2 D^2} \quad where\ D > \frac{2d^2}{\lambda}$$

$$A_r = \frac{P_r \lambda^2 D^2}{P_t A_t} \quad where\ D > \frac{2d^2}{\lambda}$$

	m2
Area Required	143.5

Summary of determined dimensions				
	m	mm	ft	in
D_{rolled}	1.28	1,275.64	4.19	50.22
D_{shaft}	0.15	152.39	0.50	6.00
Panel Thickness	0.01	12.70	0.04	0.50
Deployed Panel Length	100.00	100,000.00	382.10	4,585.20

Deployed Area (m^2) [per container]:	m^2 400.00	Assumed Power Density Selection: 50	Power Output per Container: 20,000.00
Weight of Rectenna on Spool (kg) [2kg/m^2]:	800.00	Power Desired (W)[see input power req table]:	200,000
Weight of Shipping Container (kg) [empty w/ support material]:	4000	Required Number of Shipping Containers:	10
Gross Weight of Container w/Array (kg)[subj. to change]:	4800		

Useable Volume In Shipping Container For Reciever							
	m	ft	in		m^3	ft^3	in^3
Length	4.00	13.12	157.49	Volume	17.95	633.90	1,095,374
Width	2.01	6.58	78.95				
Height (avail)	2.24	7.34	88.10				

$$D_o = \sqrt{\frac{4Lt}{\pi} + D_i^2}$$

Input Diameter of Shaft and Deployed Length Desired				
	m	ft	in	
Diameter (spool) D_o	2.24	7.35	88.19	*max available (height)
Diameter (shaft) D_s	0.10	0.33	4.00	*subject to change
Length (deployed) L	100	328.10	3937.20	

$$t = \frac{\pi(D_o^2 - D_i^2)}{4L}$$

	in	
Thickness (panel)	1.55	(max possible)

Appendix D (Prototype Progress Pictures)

Fig. 7. Shaft to bearing adapter

Fig. 8. Shaft to winch drive adapter

Fig. 9. Winch drive adapter

Fig. 10. Roof frame assembly complete

Fig. 11. Beginning assembly with gullwing doors

Fig. 12. Spool frame and shaft assembly complete

Appendix D (3D CAD Model Screenshots)

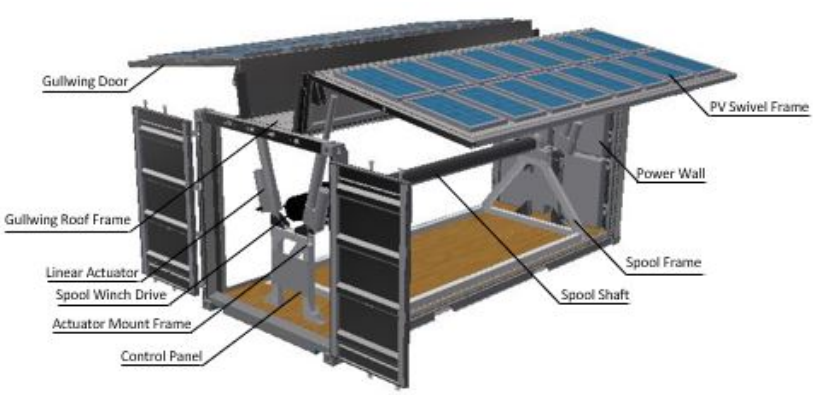

Fig. 13. Labelled open container module without rectenna spool

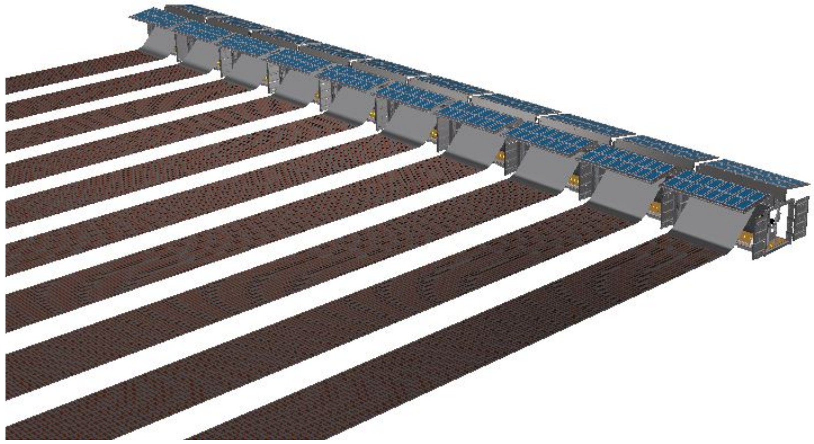

Fig. 14. (10) 'Building Block' Deployed Container Modules with rectenna deployed

References

[1] Glaser PE. Power form the Sun: Its Future. Science. 1968 Nov 22: Number 3836: Vol 162.
[2] Rouge JD. Space-Based Solar Power As an Opportunity for Strategic Security: Phase 0 Architecture Feasibility Study. Washington, D.C.: National Security Space Office; 2007. 75 p. Report No.: 0.1. Supported by National Security Space Office.
[3] Johnson WN, Akins K, Armstrong J, Cheung K, Henshaw G, Huynh S, Jaffe P. Space-based Solar Power: Possible Defense Applications and Opportunities for NRL Contributions. Washington, D.C.: 2009. 107 p. Report No.: NRL/FR/7650--09-10,179. Supported by the Office of Naval Research.
[4] Lindsey R. Climate and Earth's Energy Budget [internet]. National Astronautics Space Administration, Earth Observatory; 2009 Jan 14 [cited 2019 Mar 7]. Available from: https://earthobservatory.nasa.gov/features/EnergyBalane/page1.php
[5] Zientara B. How much electricity does a solar panel produce? [internet]. Solarpowerrocks.com; 2012 [cited 2019 Mar 7]. Available from: https://www.solarpowerrocks.com/solar-basics/how much-electricity-does-a-solar-panel-produce/
[6] Jaffe PJ. A SUNLIGHT TO MICROWAVE POWER TRANSMISSION MODULE PROTOTYPE FOR SPACE SOLAR POWER [dissertation]. [Maryland]: University of Maryland; 2013. 144 p.
[7] Japan Aerospace Exploration Agency. Research on the Space Solar Power Systems (SSPS). [internet]. [cited 2019 October 6]. Available from: http://www.kenkai.jaxa.jp/eng/research/ssps/sspsindex.html
[8] Gallucci M. Rebuilding Puerto Rico's Power Grid: The Inside Story. [internet]. IEEE Spectrum; [cited 2019 October 6]. Available from: https://spectrum.ieee.org/energy/policy/rebuilding puerto-ricos-power-grid-the-inside-story
[9] Totty M. "Wall Street Journal," 19 October 2009. [internet]. Available: https://www.wsj.com/articles/SB1000142405274870346604574461342682276898.
[10] Noblis. Sustainable Forward Operating Bases. [internet]. Strategic Environmental Research and Development Program (SERDP); 2010 May 21 [cited 2019 October 6]. Avaliable from: https://apps.dtic.mil/dtic/tr/fulltext/u2/a571503.pdf
[11] Google earth V 2.3.25576. (May 12, 2011). Marjah, Afghanistan. 31° 31' 17.20"N, 64° 07' 21.40"E, Eye alt 5113 feet. Maxar Technologies 2019. Google Earth Pro [May 13, 2019]
[12] Ret. Col. Bates. J. Containerizing the Joint Force. [internet]. [cited 2019 October 6]. Available from: https://alu.army.mil/alog/issues/marapr05/joint.html
[12] BADLAND WINCHES . Owner's Manual and Safety Instructions. Harbor Freight. [manual]. Available from: https://manuals.harborfreight.com/manuals/61000 61999/61297.pdf