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*Sam Hussey*
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## Abstract

A stand alone, mobile photovoltaic power system along with a cable deployment system was designed and constructed to take part in the Desert Research And Technology Studies (RATS) lunar surface human interaction evaluation program at Cinder Lake, Arizona. The power system consisted of a photovoltaic array/battery system. It is capable of providing 1 kW of electrical power. The system outputs were 48 V DC, 110 V AC, and 220 V AC. A cable reel with 200 m of power cable was used to provide power from the trailer to a remote location. The cable reel was installed on a small trailer. The reel was powered to provide low to no tension deployment of the cable. The cable was connected to the 220 V AC output of the power system trailer. The power was then converted back to 110 V AC on the cable deployment trailer for use at the remote site. The Scout lunar rover demonstration vehicle was used to tow the cable trailer and deploy the power cable. This deployment was performed under a number of operational scenarios, manned operation, remote operation and tele-robotically. Once deployed, the cable was used to provide power, from the power system trailer, to run various operational tasks at the remote location.

## 1.0 Desert RATS Campaign Background, Fall 2007

The Desert Research and Technology Studies (RATS) program is run out of NASA Johnson Space Center. The purpose of the program is to demonstrate operational concepts for various types of projected lunar activities that would be carried out in the assembly and operation of a manned lunar outpost. The results from these activates are then incorporated into Lunar Architecture Team studies.

The Desert RATS field test took place from September 6 to 14, 2007 at Cinder Lake, Arizona. A satellite view of this test area is shown in Figure 1.1. This area is an expanse of crushed volcanic stone, as shown in Figures 1.2 and 1.3, located outside of Flagstaff Arizona. This terrain provided a good simulation of operation on the lunar surface. This is the same testing ground that was utilized in the 1960’s for developing the Apollo rover.

Some of the types of activities that were performed at this test site for the 2007 Desert RATS campaign included:

- A Site survey for lunar outpost using the Science, Crew, Operations and Utility Testbed (SCOUT) rover.
- Deployment of a solar power system with 200 m power transmission cables.
- Astronaut habitat module interaction.
- Astronaut coring using power supplied from the remote photovoltaic power system.
- Demonstrate Lithium-ion battery technologies for the astronaut spacesuit planetary life support system (PLSS) during extra-vehicular activity (EVA) operations.

The goal of these activities was to acquire quantitative data on human-robot interaction that can be used to compare the effectiveness of different operational scenarios. This was accomplished by measuring the work efficiency of robots, humans, and human-robot teams while performing representative tasks. Also the tasks were performed to evaluate the effects of 5 to 10 sec time delay on tele-robotic operations. This represents the delay that would occur during communications between the Earth and lunar surface.

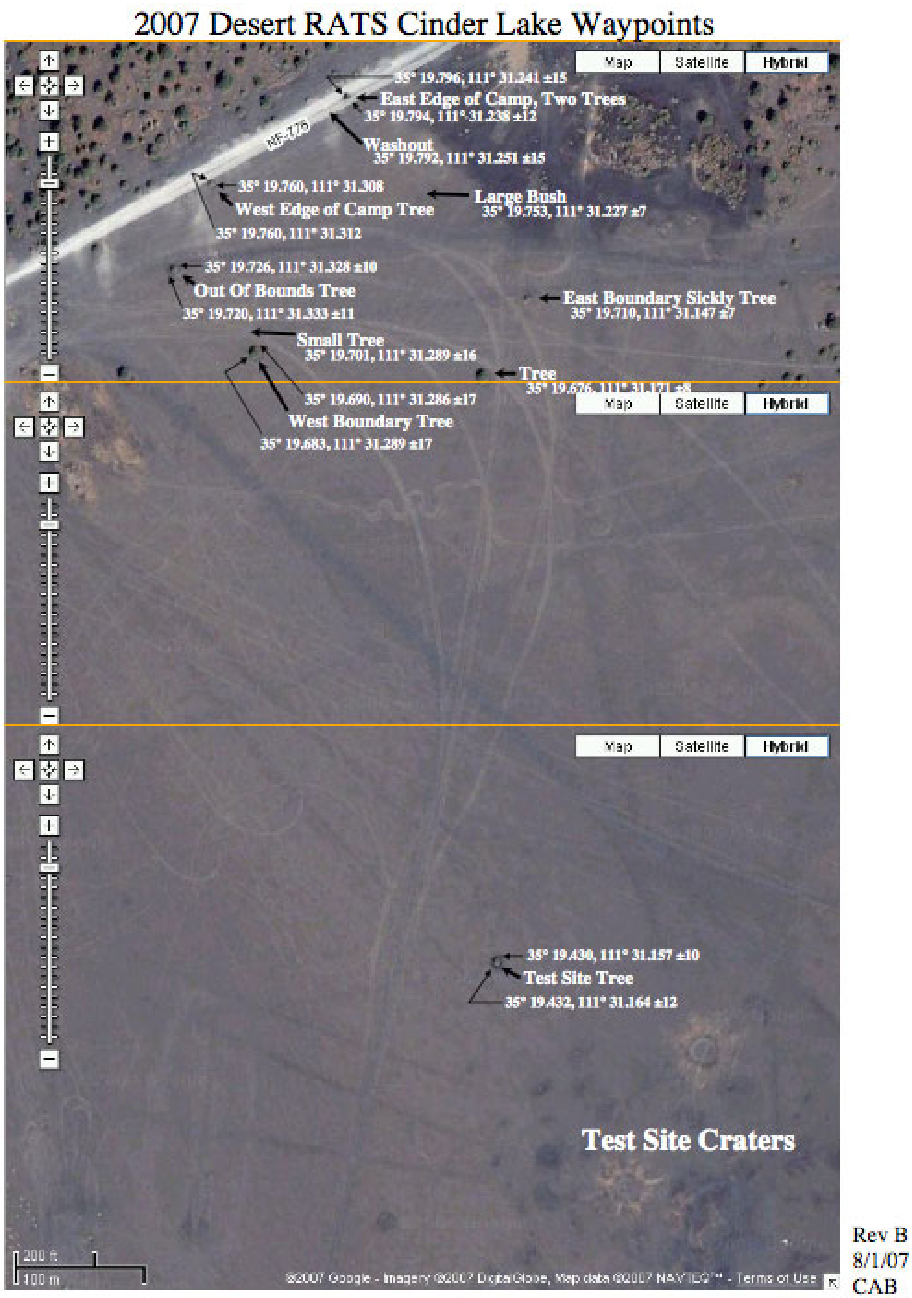


Figure 1.1.—Satellite View of Cinder Lake Test Site.

Figure 1.2.—Cinder Lake Arizona.

Figure 1.3.—Crushed Volcanic Rock at Cinder Lake.

## 2.0 Photovoltaic Array and Cable Deployment System

A lunar base or outpost will require a power production and distribution system to operate effectively. Power to support a habitat, surface operations, In-Situ Resource Utilization (ISRU) and high rate communication needs would eventually approach 50 kWe or more. To power all of the functions of a base, multiple power systems will need to be combined together and connected to the loads to form a grid similar to what is done on Earth.

The power systems for human exploration missions on the Moon will likely be stand alone systems of a size that it would be considered a separate payload item and not integrated as a subsystem of other elements. These systems could vary in type and output. The two main types of distributed power systems are solar photovoltaic and nuclear fission. These types of systems would be autonomously deployed on the surface and attached to a power gird system for powering a base or outpost. An example of a stand-alone solar photovoltaic system is shown in Figure 2.1 and nuclear systems are shown in Figures 2.2 and 2.3. Once this type of modular stand-along power system is deployed it will need to be attached to the grid through a power cable and control electronics. The ability to connect these diverse power sources and have them operate as a single system is a critical aspect to the implementation of a long-term human presence on the lunar surface.

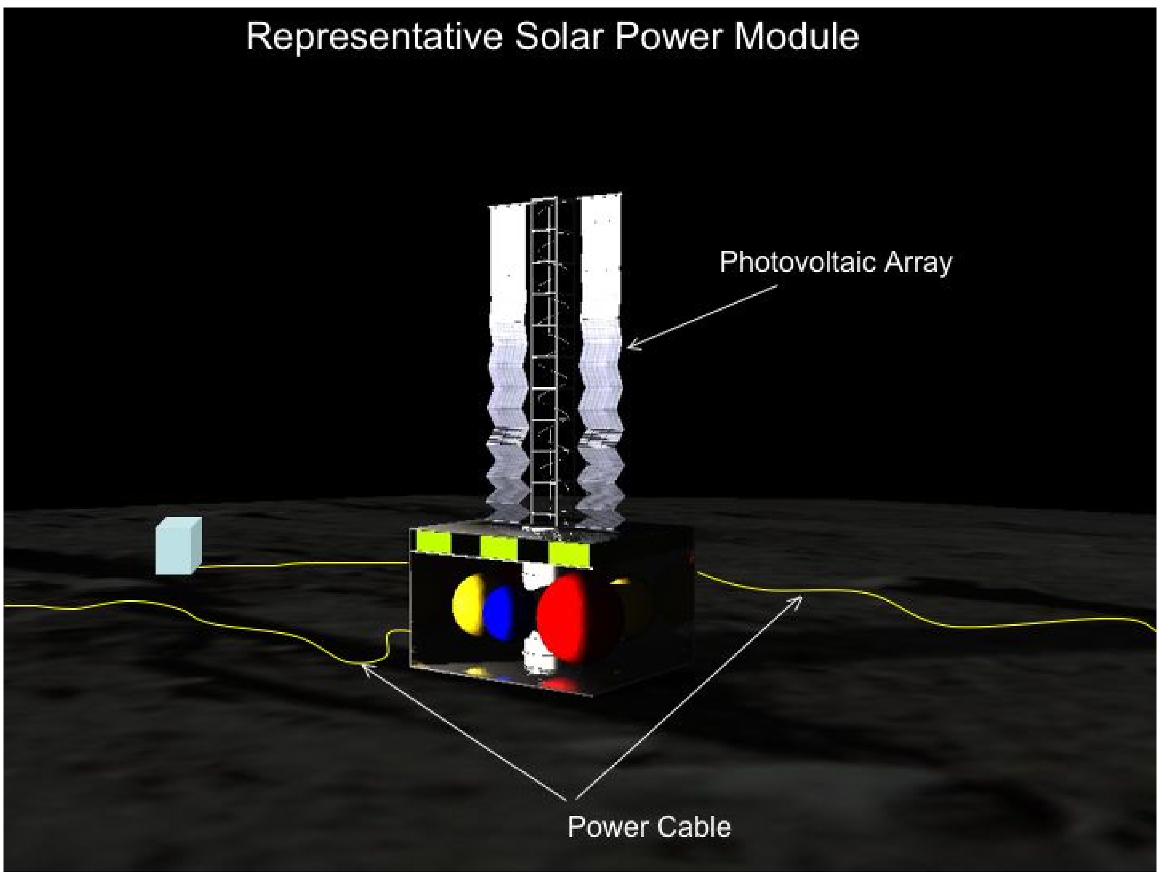


Figure 2.1.—Stand-Alone Solar Photovoltaic Power System Concept.

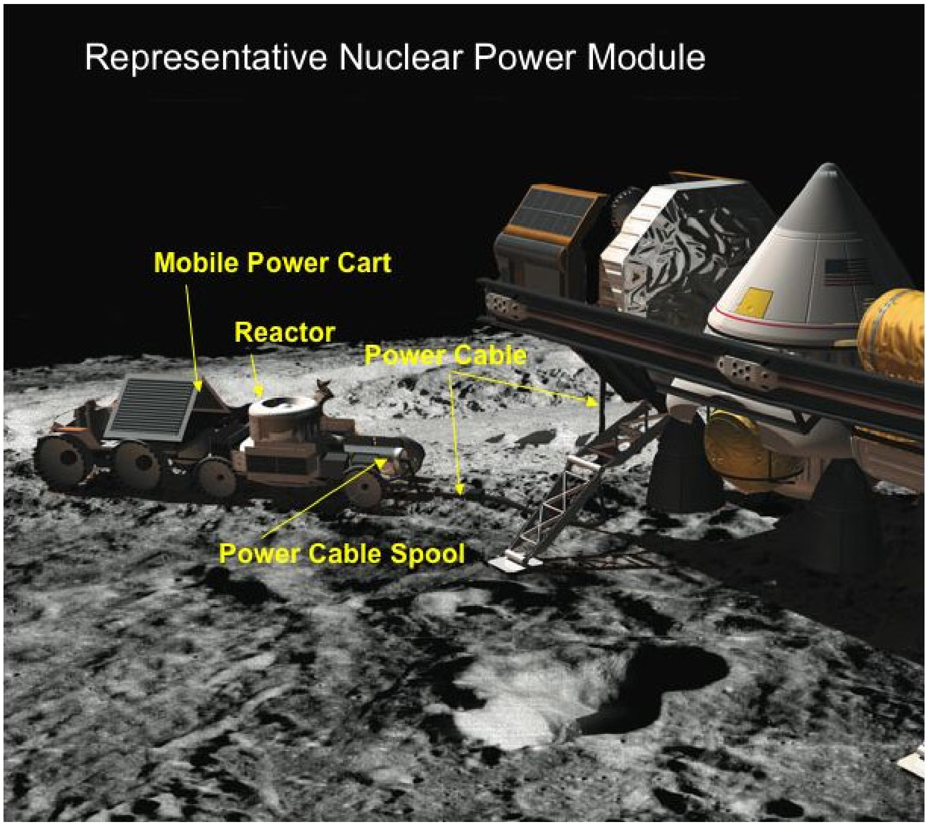

Figure 2.2.—Vehicle Based Self-Contained Nuclear Power System Concept.

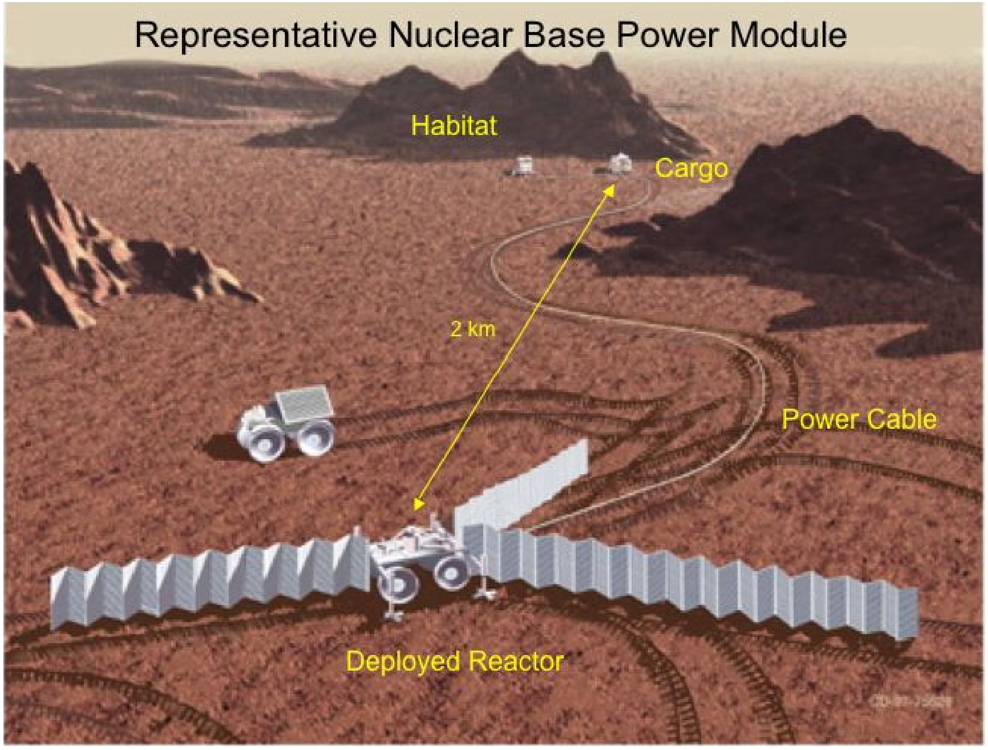

Figure 2.3.—Deployed Nuclear Reactor Concept.

Distributing the power from the power system(s) to the loads is required irrespective of the power system technology or which build up strategy that is utilized. This requires laying a cable from one location to another. The distances can range from 10's of meters to kilometers. There are a number of issues with laying cable over undulating and rocky terrain on the Lunar surface that will need to be addressed in order to effective and reliable system. The main issue is operating within the harsh lunar environment, such as large day-night temperature swings, vacuum and high ultraviolet (UV) light exposure. These conditions affect the cable design, the deployment (and possibly retraction) system design and the cable placement. Astronauts could accomplish the system deployment and cable connections. However, depending on the mission, and power system type it may require "autonomous" or supervised tele-operations to deploy the cable. There are limited terrestrial analogs to help guide the design of both the cable and its deployment.

The application of a power system and cable deployment system to the Desert Rats program and site conditions is an ideal first step in evaluating the implementation and deployment of a power distribution system on the lunar surface. This type of exercise will help identify issues with robotic or crew attended deployment and will provide insight into more efficient and effective cable deployment hardware design.

This type of exercise can also resolve questions concerning the "degree of difficulty" for remote, robotic deployment of power system distribution cables by deploying a power cable from one location to another over representative lunar or Mars terrain.

The use of a stand-alone solar photovoltaic power system also will contribute to the effective evaluation of the cable deployment system. This type of power system and the power conditioning and connections required are representative of those that would be encountered on a lunar system.

The total system utilized to evaluate the cable deployment process consisted of a cable deployment trailer and a separate trailer based, stand-alone photovoltaic power system.

The cable deployment trailer had a powered mechanical spool for paying out and retrieving the cable. There was a tension sensing system on the cable reel that would adjust the cable deployment speed to match the speed of the deployment rover thereby providing little or no tension on the cable and reducing the force needed by the rover to pull the trailer.

The photovoltaic power system trailer had deployable arrays that provided a maximum of 1 kW of power. The system also had batteries for providing peak power and power electronics to provide the desired output as well as maintain a charge on the batteries. The output voltage of the trailer was 120 and 220 V AC with 48 Vdc available.

The cable trailer carried a 200-meter cable, which was connected and powered by the photovoltaic power system trailer. The cable deployment trailer was pulled by the SCOUT rover, which unreeled the cable. The extended cable was used to provide power for representative loads, such as; lights, motor loads (augers) and switching power supplies.

The design requirements for the cable deployment trailer and photovoltaic power system to meet the objectives of the evaluation were:

- Portable stand alone photovoltaic (PV) Node (1 kW)
- Generate conditioned power w/minimal power management and distribution (PMAD) gear
- Cable deployment mechanism to:
  - Automate deployment action
  - 200 meters of cable (<5% Voltage Drop per regulation)
  - Minimize HW interface to Scout (Desert Rats rover)
- Scheme for easy deployment of arrays and cable
- PMAD meets National Electrical Code
- Capable of operating at the Cinder Lake test site
- Provide a set of receptacles at load end of cable
- Show that cable deployment while traveling over rough terrain is viable
- Power real & notional loads at PV node and 200 meters away (work site)

- Lights, chargers for Scout and other battery loads and
- Drill motor w/auger bit

- Minimize operations required to deploy PV/cable to allow for seamless work efficiency measurements
- Decouple control of cable deployment from Scout
- Collect operational data and gain experience applicable to later designs

## 3.0 Photovoltaic Power System

The photovoltaic power system is a stand-alone power system capable of providing AC (both 120 and 220 V AC) and DC (48 V) power to nearby loads and the cable deployment trailer. The power system was designed to meet the requirements of the National Electric Code related to photovoltaic power systems (Ref. 1). The main components of the photovoltaic power system consist of the following items, which are illustrated, in Figure 3.1.

- Photovoltaic array consisting of 20 individual panels
- Battery bank consisting of 4 lead acid batteries
- Battery charge controller and array peak power tracker
- DC (48 V) to AC (110 V) inverter
- AC (110 V) to AC (220 V) converter

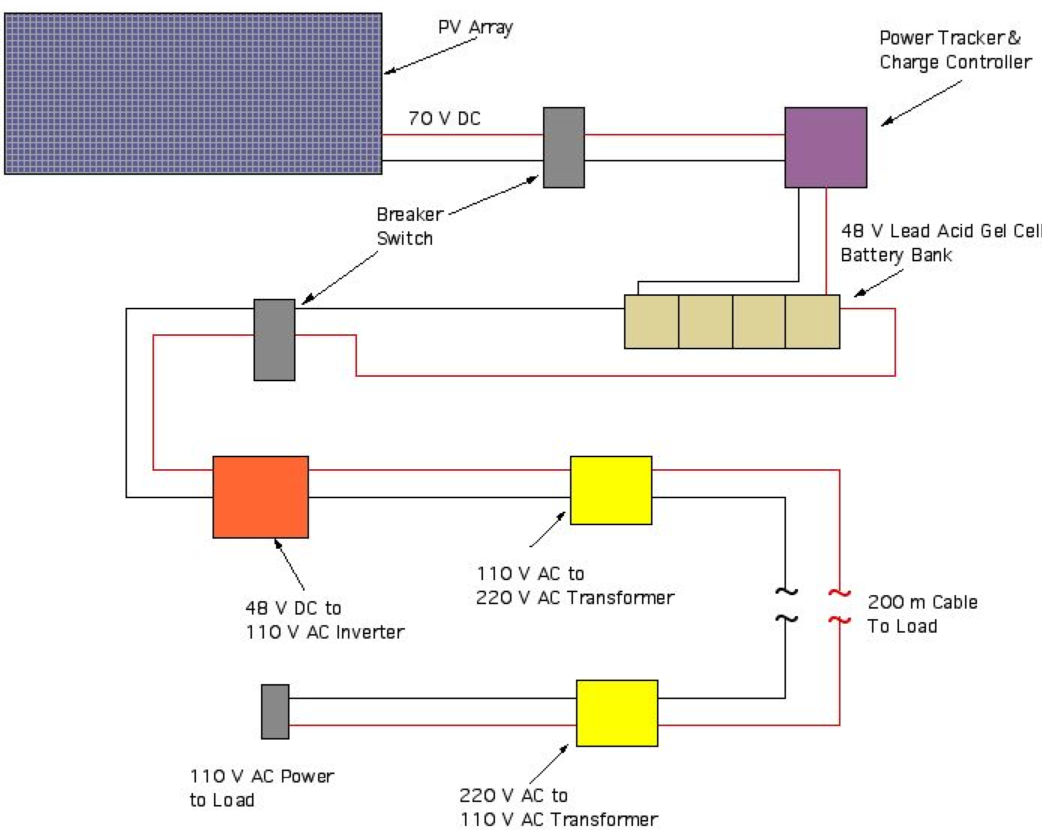


Figure 3.1.—Photovoltaic Power System Main Components and Layout.

The power system is to be housed on a standard landscape trailer modified to be used accommodate the PV array and other components of the system. The trailer used for this project is a landscape trailer manufactured by International Trailer model 6 by 12. It measures 12 ft in length and 6 ft in width. The base trailer is steel framed with a wood floor. The modifications to the structure of the trailer are as follows:

- The floor is covered with 1/2 in. outdoor plywood.
- On top of the plywood is placed a 1/8 in. grooved rubber mat. The mat is glued down and attached along the edges using aluminum angle.
- A box frame is constructed off of the base of the trailer. The frame runs the length of the trailer and is 4 ft high. It is used as the support for the solar arrays and to cage in the remaining components of the system. The frame is made out of 2 by 2 in. T6061 square tube aluminum.
- Stainless steel wire mesh is mounted to the inside of the box frame. The wire mesh has diamond shaped holes 1.5 by 0.75 in. and the wire thickness is 0.125 in. The wire mesh is attached to the box frame with 1 in., T6061 flat aluminum stock that is 1/8 in. thick.
- A set of access doors is located on the hitch end of the trailer. The access doors are made of a T6061 aluminum frame with the stainless steel mesh mounted on the inside. The access doors are each 3 ft in width and 4 ft high.
- A storage box is mounted on the back of the trailer underneath the array panels.
- The box frame is to be fitted with a canvas cover to protect the system from dust and weather during travel. The cover is custom-made to fit over the box frame and snaps are used to secure it for easy attachment and removal.

A diagram of the framework attached to the trailer is shown in Figure 3.2 and the trailer layout is shown in Figure 3.3. The access doors are located on the hitch end of the trailer and the solar array is located on the back end.

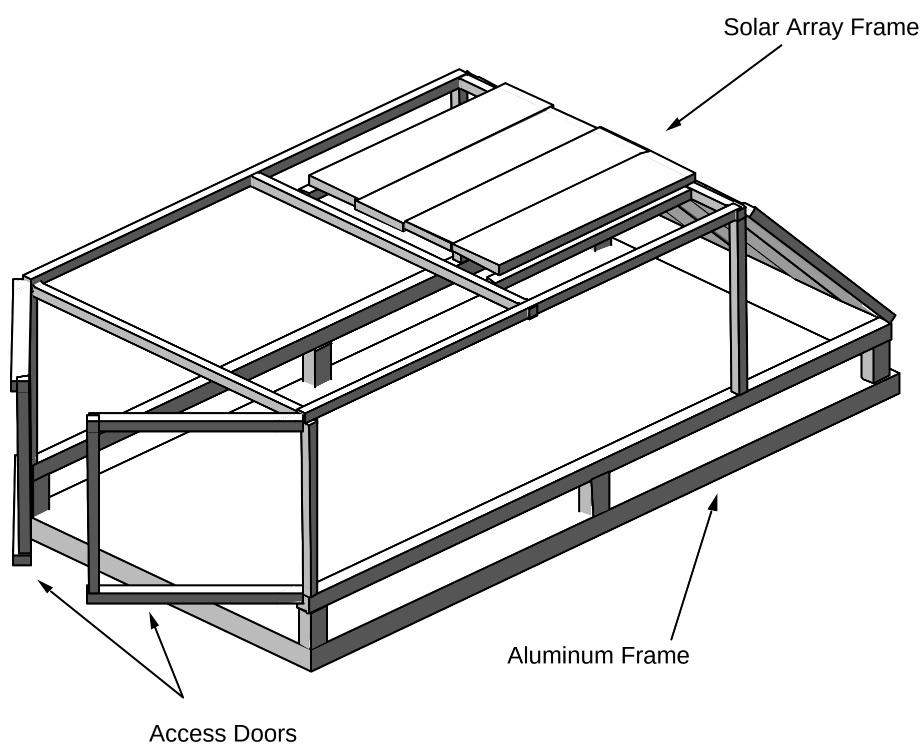


Figure 3.2.—Trailer Structural Diagram.

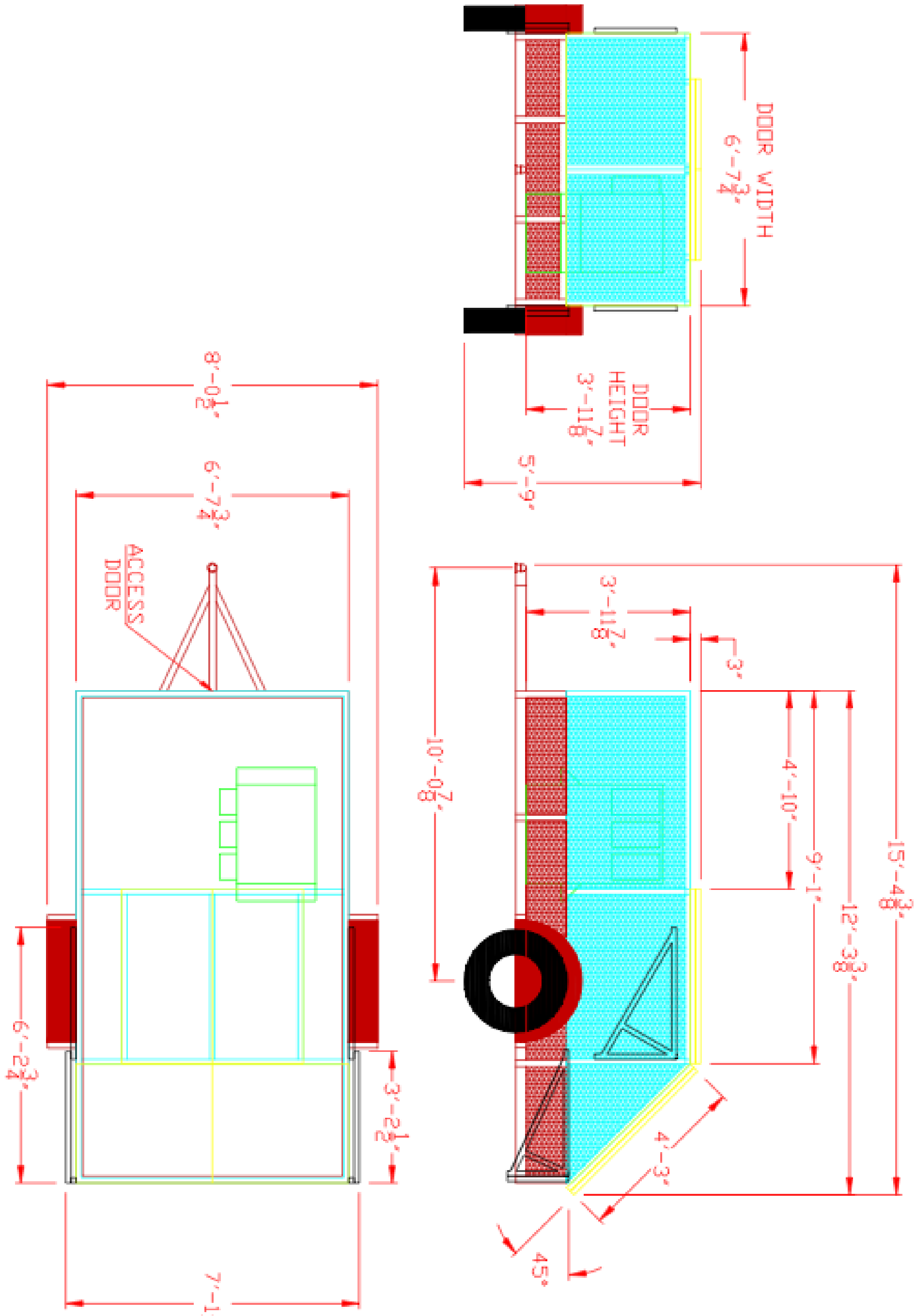


Figure 3.3.—Dimensional Drawing of PV Power System Trailer.

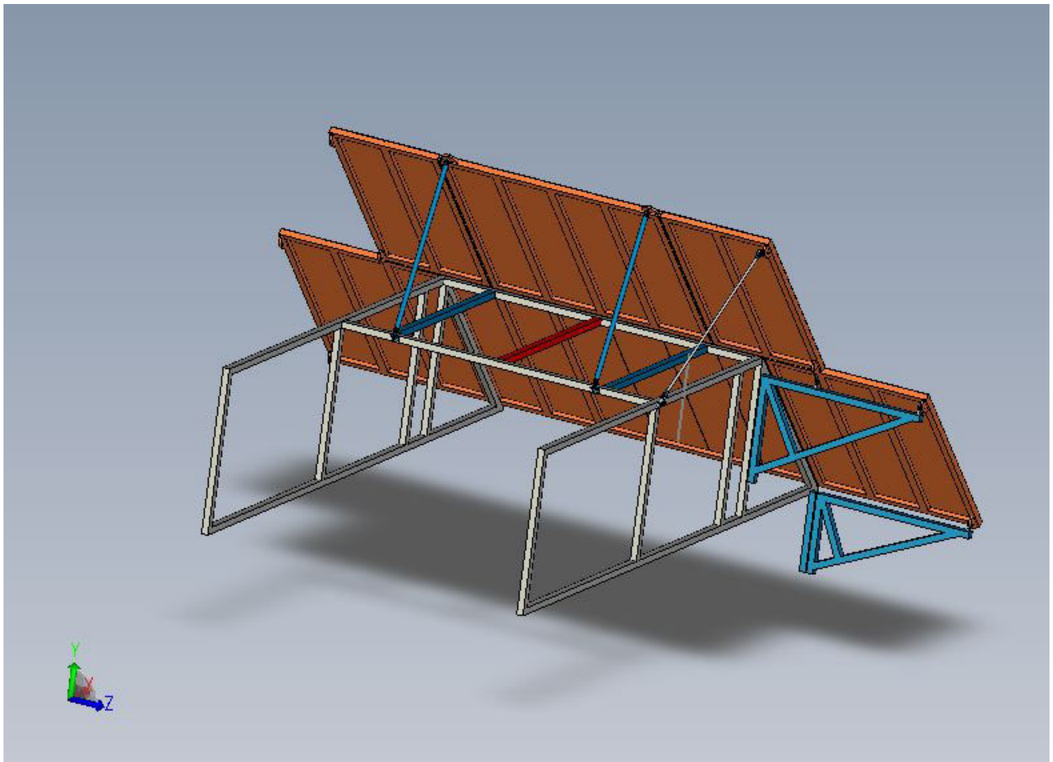


Figure 3.4.—Solar Array Support Structure.

The power system uses a photovoltaic array consisting of 20 Siemens M55 panels. The panels are mounted in an aluminum angle, T6061 frame. The frame is oriented 45° to the horizontal when deployed. The array is configured into two levels. The lower level consists of 12 panels, 6 central panels are mounted in a fixed frame and on either side of the central panels there are three panels mounted in a hinged frame. The hinged frame is attached to the central frame with a stainless steel piano hinge. The outer panels fold over the central panels when in the stowed position. When opened each outer panel is secured in position with a triangular support. A drawing of this support structure is shown in Figure 3.4

The upper level consists of 8 panels. There are 4 centrally mounted panels housed in a frame and two outer panels on each side also housed in a frame. These outer panels are hinged to the central panels with a stainless steel piano hinge. The bottom of the central panel is hinged to the top of the box frame. The outer panels fold over the central panel and the central panel is laid flat on the top of the box frame when in the stowed position. When opened the central panel is raised to a 45° angle and supported with two stainless steel tubular supports. Due to the weight of the upper array panels two hydraulic assist cylinders were incorporated to help in raising the upper panels. The supports are attached to the trailer box frame with a rotating joint hinge. Once the central panel is raised the outer panels are opened. They are held in their opened position with tubular stainless steel rods attached to the box frame with a rotating joint hinge. The solar array in it stowed and deployed configuration is illustrated in Figure 3.5. An image of the support structure for the deployed upper panels is shown in Figure 3.6. The fully deployed array is shown in Figure 3.7.

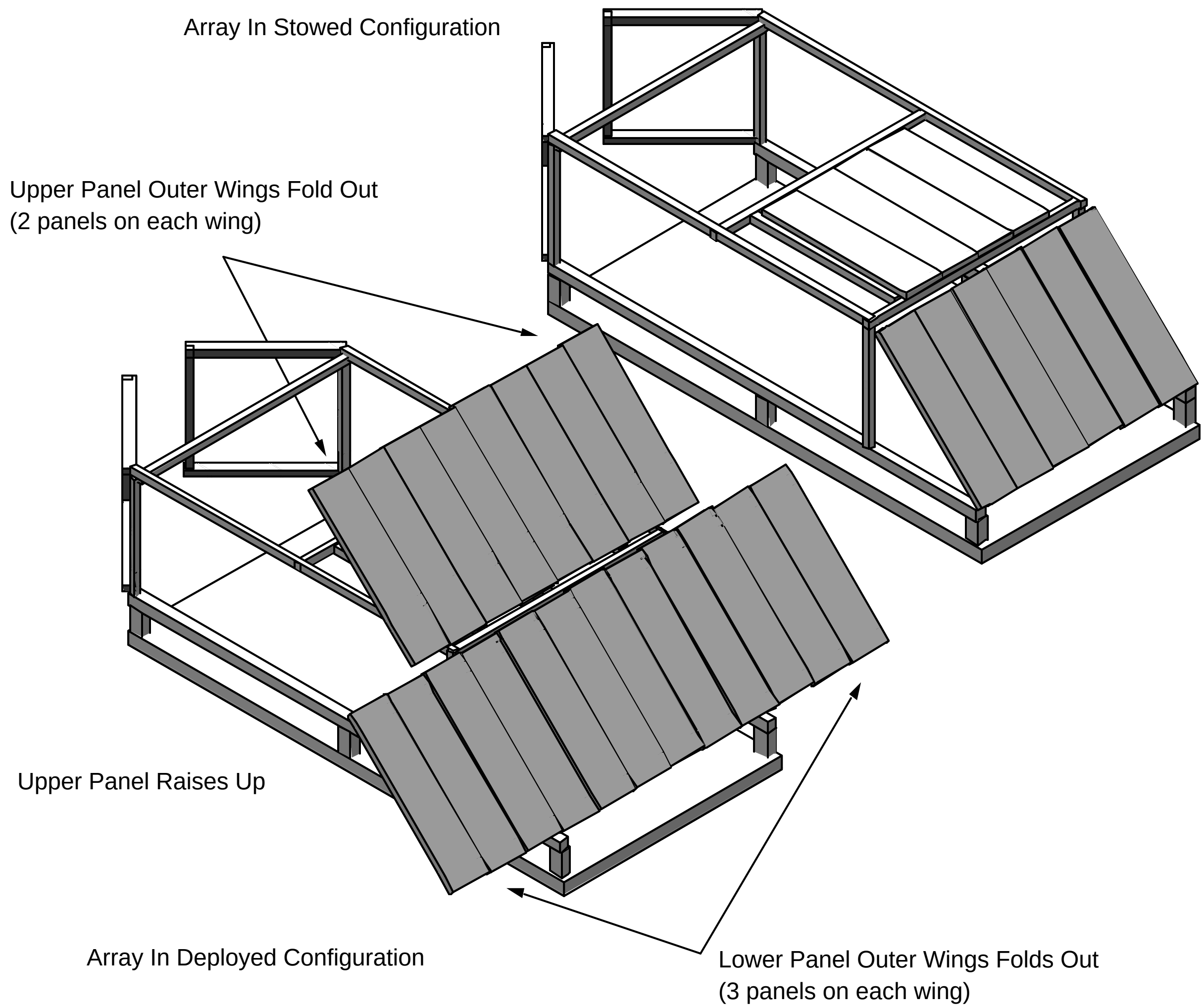


Figure 3.5.—Stowage and Deployment Scheme for the Photovoltaic Array.

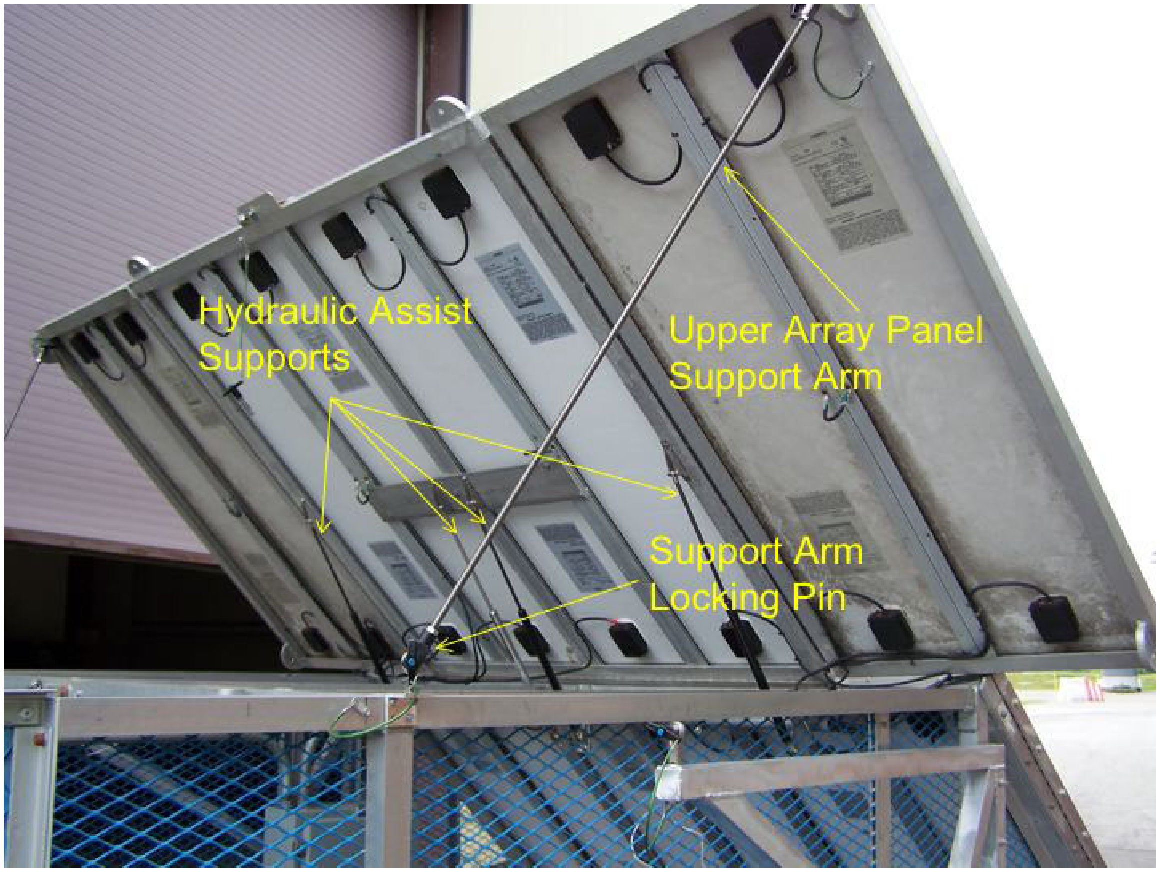


Figure 3.6.—Deployed Upper Array Panels and Support Arms.


Figure 3.7.—Photovoltaic Power System Fully Deployed Array.

The array panel frames are secured into position, both while deployed and stowed, using locking pins. These locking pins are T handled, 3/8 in. diameter, stainless steel pins. The use of these pins eliminates the need for any tools during deployment and stowage of the array. During deployment the pins are passed through holes in the end of the supports and through special attachment blocks on the array frame to secure the array in place. When stowed, the pins are used to secure the array panels from opening. The locking pin joints are illustrated in Figure 3.8 and shown in Figure 3.9.

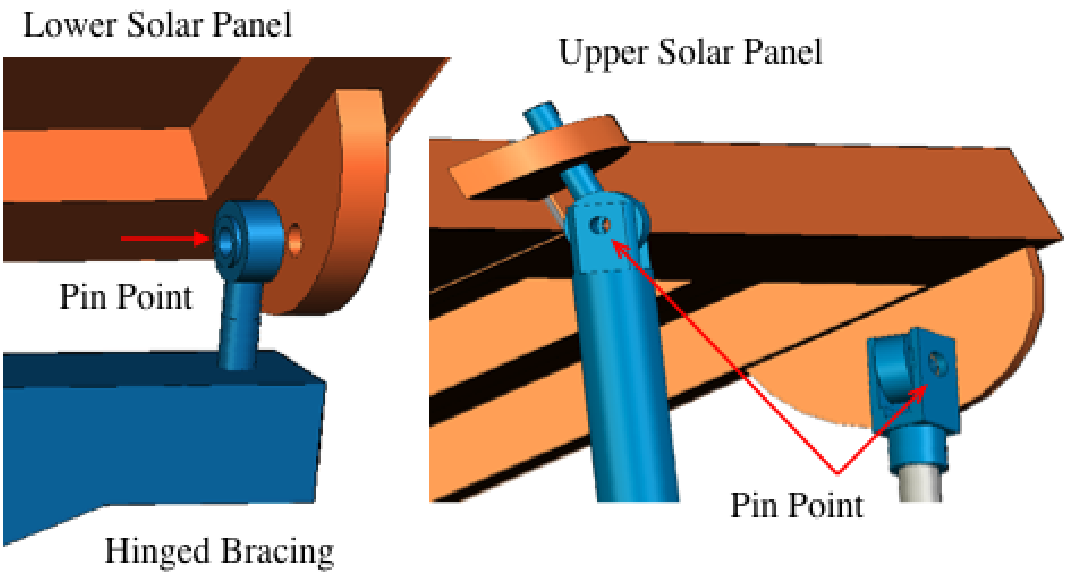


Figure 3.8.—Array Deployment Hinge Joints.

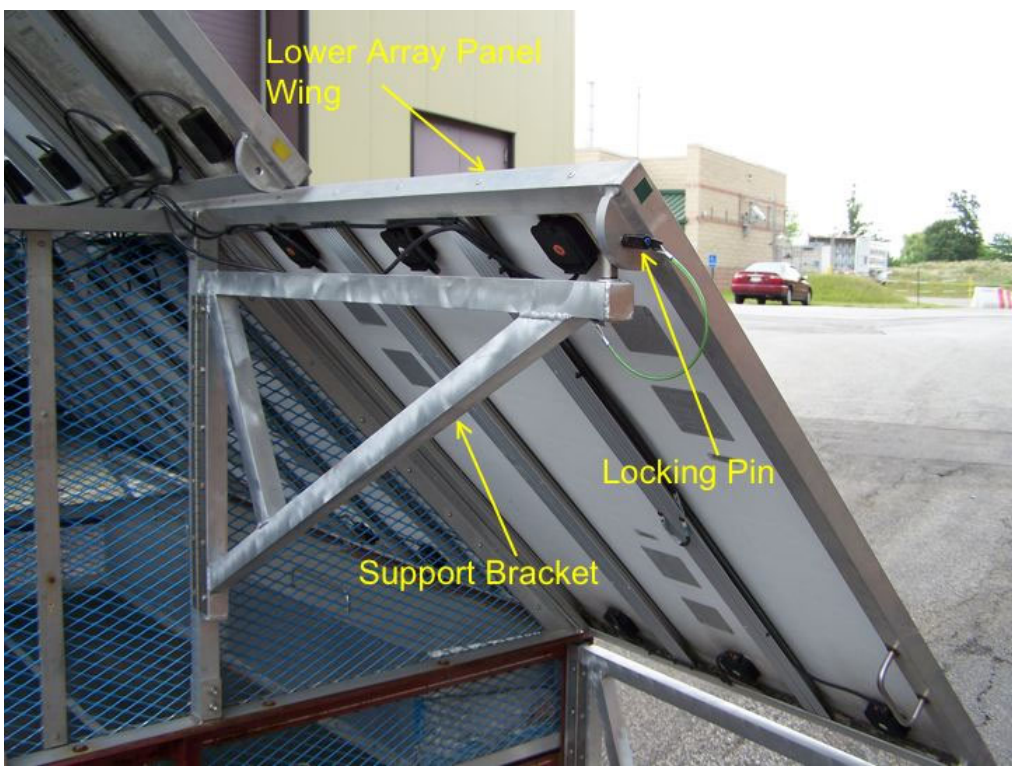


Figure 3.9.—Array Support Bracket and Attachment Pin.

The photovoltaic array consists of 20 Seimans M55 panels, shown in Figure 3.9. The panel specifications are given below in Table 3.1 and the IV curve for the panel is given in Figure 3.10. The panels are wired together through the + / - terminal boxes located on the rear of each panel, shown in Figure 3.11. These boxes are sealed and provide reverse bias diode protection for each array panel.

Figure 3.10.—Seimans M55 Solar Panel.

TABLE 3.1.—SPECIFICATIONS FOR A SEMINES M55 SOLAR ARRAY PANEL (REF. 2)

| ***Solar Cell Type*** | ***Single Crystal Silicon*** |
|---|---|
| **Operating Efficiency** | 14.2% |
| **Short Circuit Current** | 3.35 A |
| **Open Circuit Voltage** | 21.7 V |
| **Maximum Power Current** | 3.05 A |
| **Maximum Power Voltage** | 17.4 V |

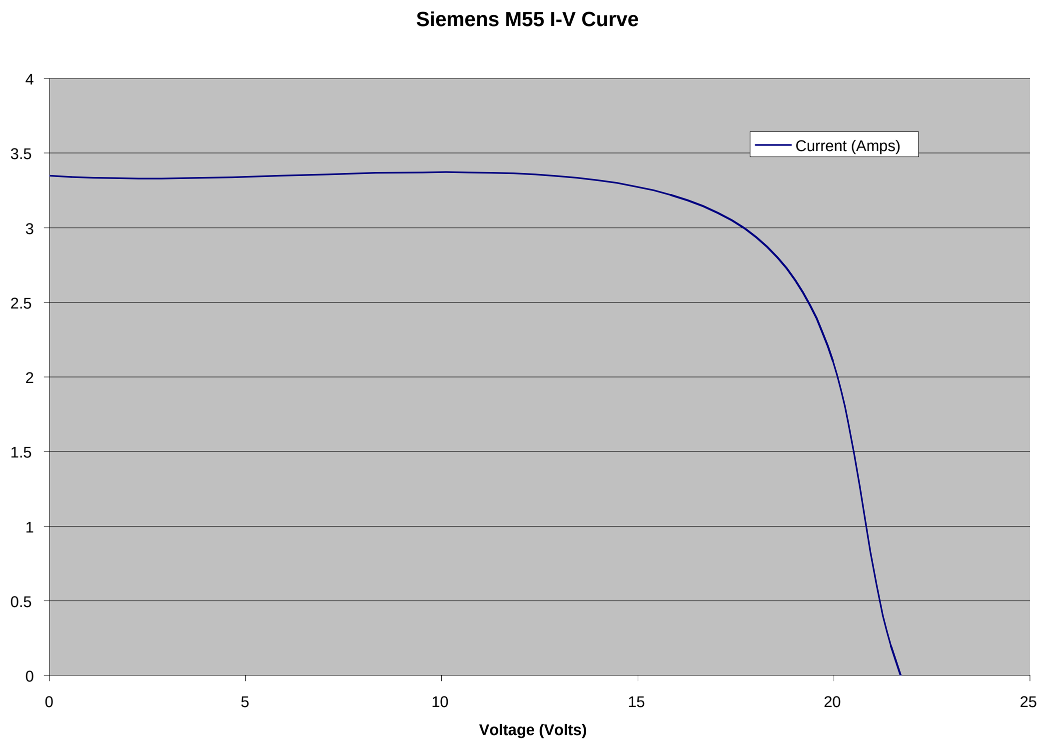


Figure 3.11.—Siemens M55 Solar Panel I-V Curve.

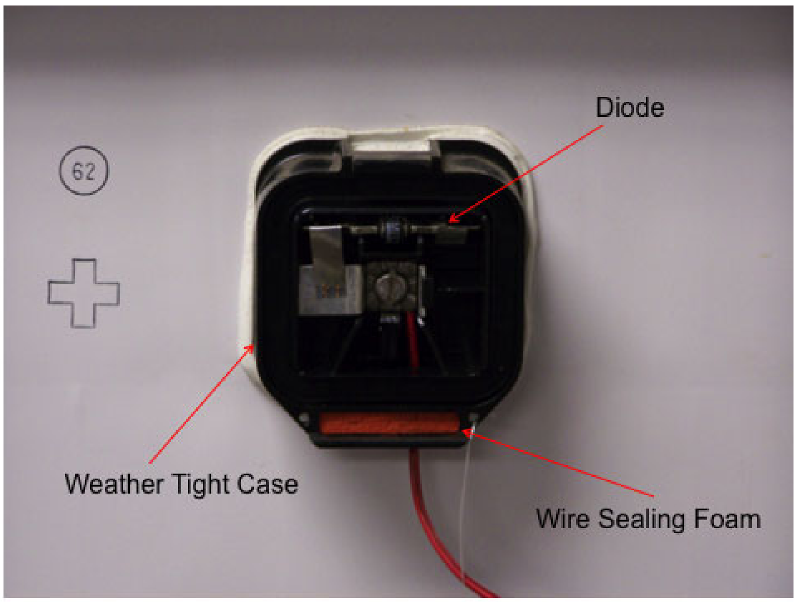


Figure 3.12.—M55 Solar Panel Junction Box.

Groups of four panels are wired together in series, there are five such groupings in the array. This wiring scheme for the array can be seen in Figure 3.13. Each grouping has a peak power output of 212 W with a maximum current of 3.05 A and a voltage of 70 V. Fourteen gauge wire is used to connect the individual panels together. The positive leads from each grouping are brought to a junction box where they are connected to a single bus bar. The negative leads from each grouping are also connected together in a similar manner. Twelve-gauge wire is then used to connect the positive and negative junction boxes to the rest of the system. There is also a manual breaker box on the positive lead out of the junction box. This breaker box is used as a means of electrically disconnecting the array from the system.

Since the solar panels will produce power whenever light is incident on them, there is no direct method for turning the panels off. However, the design of the deployment scheme for the array provides a means of turning the panels off. When the array is in the stowed configuration, the outer panels on both the upper and lower portion of the array are folded over the center panels. This can be seen in Figure 3.5. In this configuration, the cell side of the outer and central panels is facing each other. This effectively shuts the panels off, since little or no light will be able to reach the photovoltaic cells. This ability to effectively turn the array panels off adds significantly to the overall safety of the system.

The arrays were wired in their series/parallel strings in junction box, which was then connected to the main electronics enclosure through a manual breaker. Three breakers were used to isolate various parts of the system. The breakers were used to disconnect the array from the system, disconnect the output of the batteries from the inverter and disconnect the output of the inverter from the converter. These provided a means of isolating various component on the system or the deployment cable. The breakers and junction box are shown in Figure 3.14.

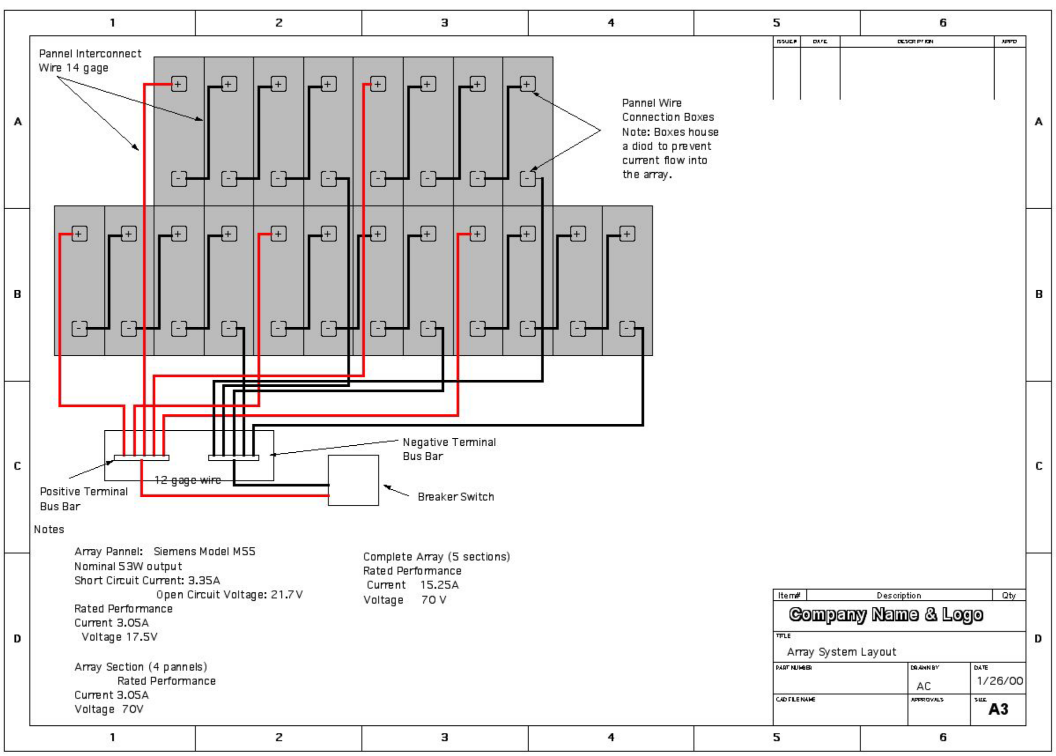


Figure 3.13.—Solar Array Wiring Diagram.

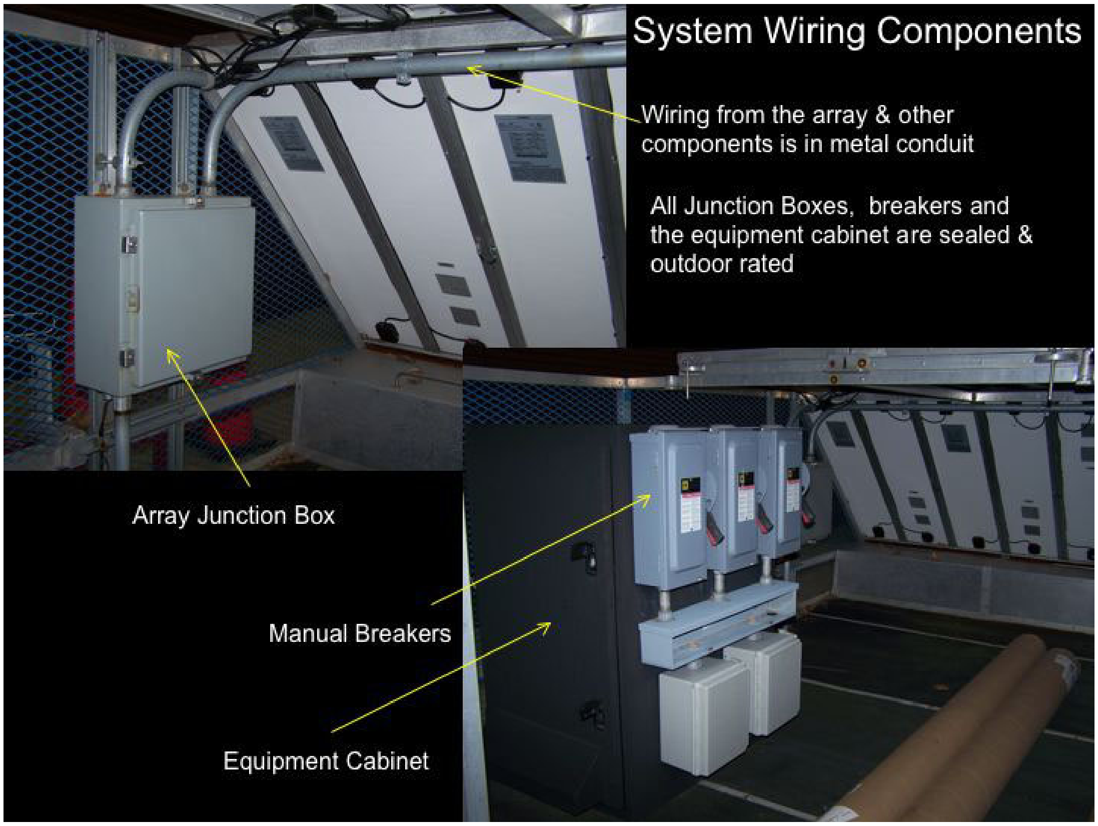

Figure 3.14.—Solar Array Junction Box and System Circuit Breakers.

The other main components of the power system consist of the control electronics and the batteries. The battery charge controller is an Outback MX60 MPPT. This charge controller monitors and charges the battery pack from the array output. It also has a peak or maximum power tracking capability to obtain the maximum output from the solar array. The battery pack consists of four 12 V 74 A-hr gel cell lead acid batteries. A PureSine 1.5 kW inverter was used to convert the 48 V DC output from the array/battery system to 110 V AC. The inverter also provides standard plug outlets so that AC power was on the power system trailer. These components were housed in a sealed weather tight enclosure. The enclosure has a filtered cooling fan system to provide internal air circulation and exchange during operation. The cooling fan is necessary for operation in the warm high-desert environment of Cinder Lake. These components, installed in the cabinet, are shown in Figure 3.15. A close-up picture of each component as well as a brief summary description is given in Figures 3.16 and 3.17. Figure 3.17 also shows the transformer that was used to convert the AC power from 110 V AC to 220 V AC. This transformer was also housed in the cabinet but is not visible in Figure 3.15.

EMI testing of the trailer system was performed to evaluate the possibility of communication interference being generated from the operation of the power system. The test report for the EMI testing is given in Appendix B.

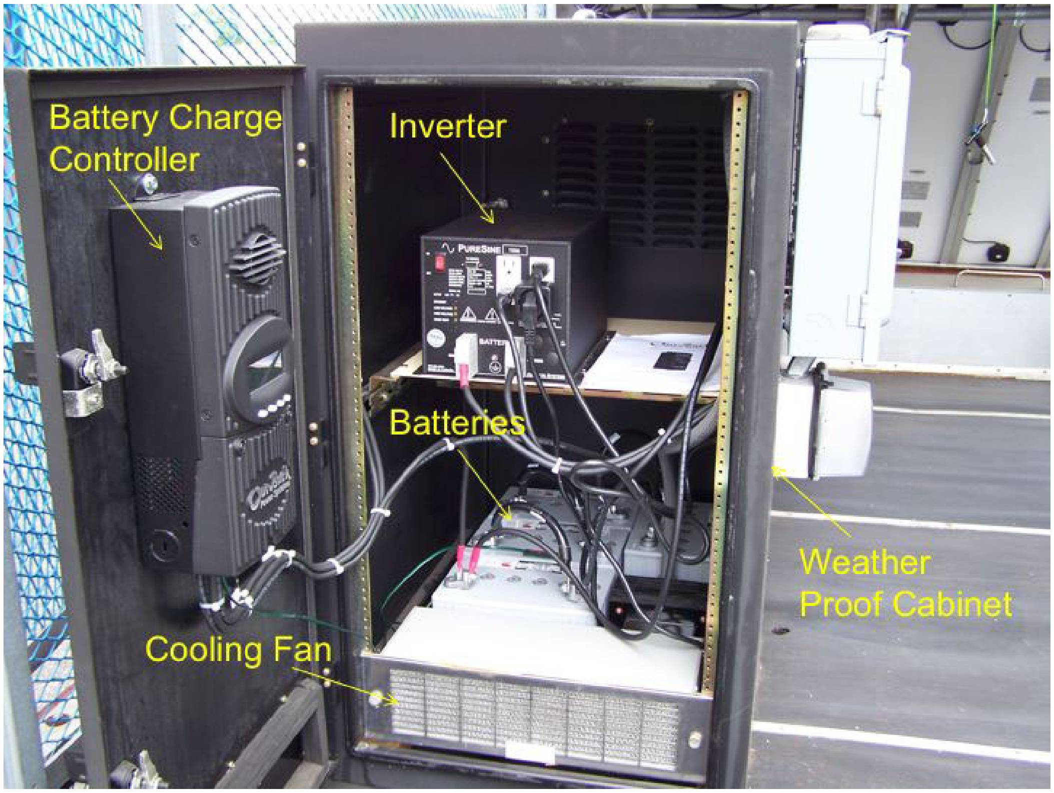


Figure 3.15.—Power System Electronics Enclosure and Power Conditioning Equipment.

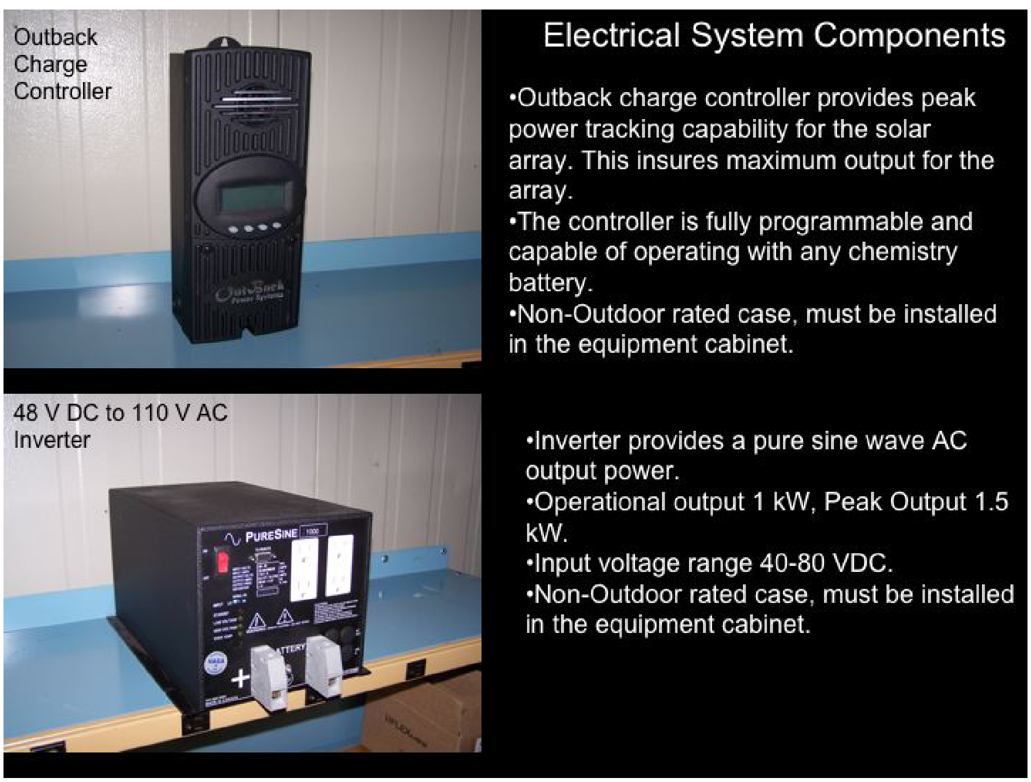


Figure 3.16.—Battery Charge Controller and DC to AC Inverter.


Figure 3.17.—Gel Cell Battery and 110 V AC to 220 V AC Transformer.

## 4.0 Cable Deployment System

The cable deployment system, shown in Figure 4.1, consisted of a small metal trailer with a cable deployment reel and control electronics mounted on it. A diagram of the cable deployment trailer showing its dimensions and general layout is shown in Figure 4.2.

The cable reel contained 200 m (~600 ft) of 10 AWG 3 conductor cable rated at 25 A/600 V with heavy duty, outdoor rated insulation. The total weight of the system was 482 lb of which the cable itself weighed 182 lb. The cable connects to the 220 V AC outlets on the PV power system trailer. 220 V was selected as the operating voltage for transmission through the cable to reduce the voltage drop and corresponding resistance losses through the cable. Table 4.1 shows the voltage drop associated with cables of various gauge wire, operating voltage and wire length. Also shown is the estimated weight of the cable. Both the gauge of the wire and the insulation thickness affects Cable weight. The difference in Table 4.1 between the standard cable and the custom cable is in the insulation. The custom cable has a durable lighter weight insulation that helps reduce the overall cable weight.

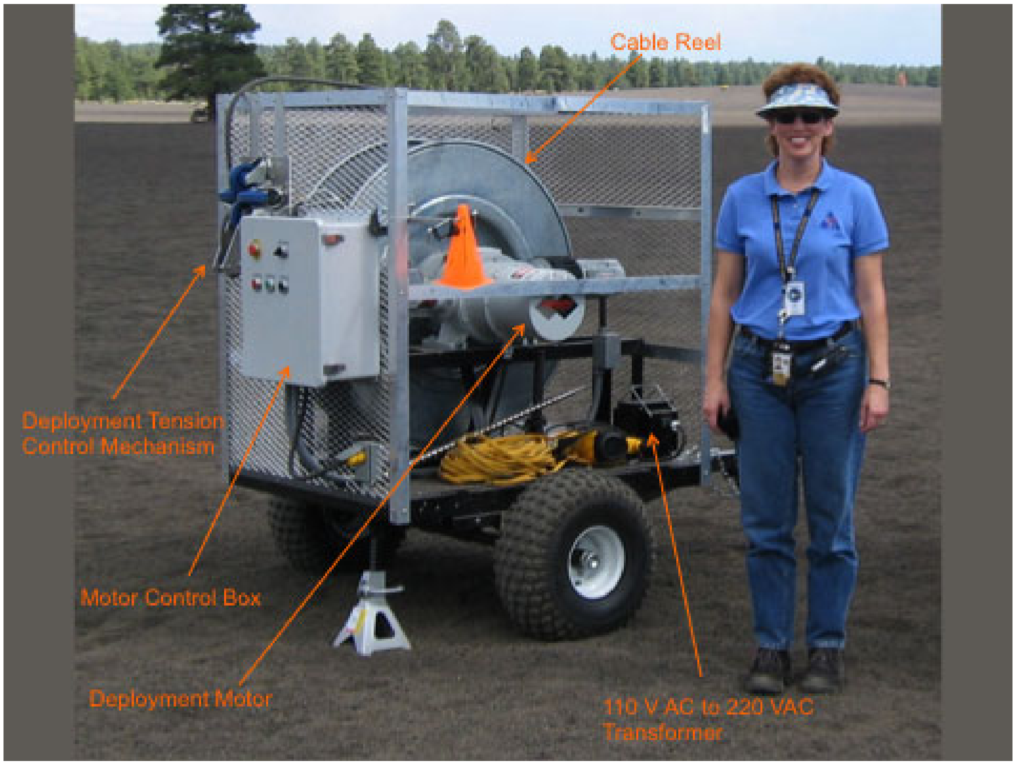


Figure 4.1.—Cable Deployment Trailer.

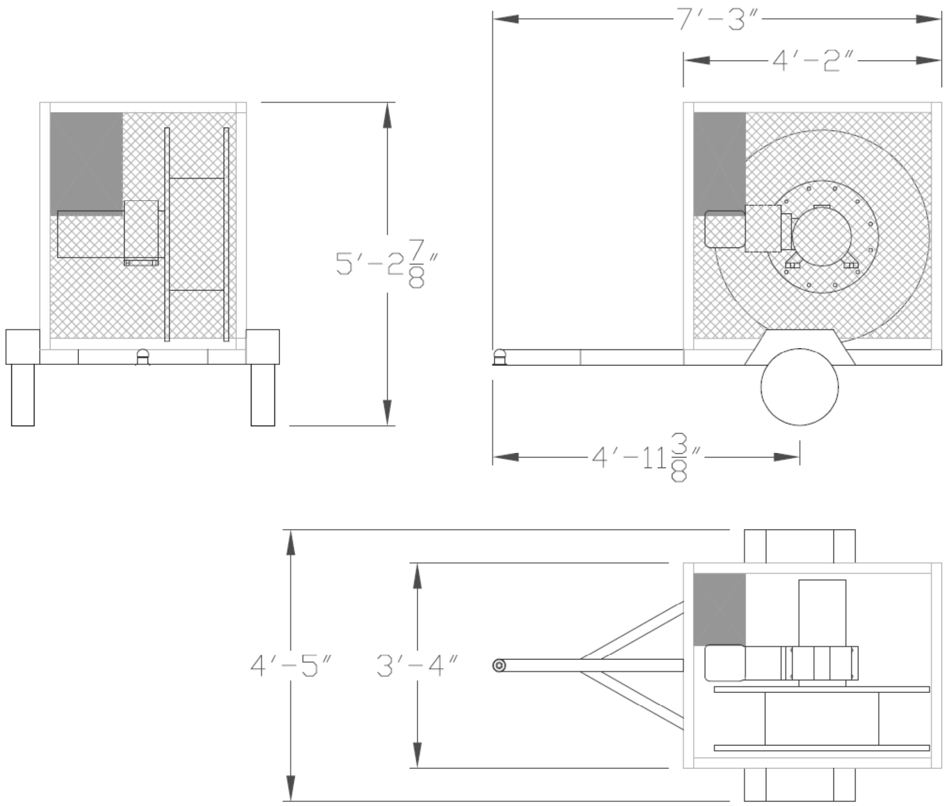


Figure 4.2.—Cable Deployment Trailer Diagram.

TABLE 4.1.—CABLE VOLTAGE DROP FOR VARIOUS WIRE GAUGES, VOLTAGES AND LENGTH

| | Standard Wiring | | | | | | | | Custom Wiring | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance, m | 100 | | | | 200 | | | | 100 | | | | 200 | | | |
| Voltage Drop | <5% | | <7.5% | | <5% | | <7.5% | | <5% | | <7.5% | | <5% | | <7.5% | |
| Voltage | Gage | Lbs. | Gage | Lbs. | Gage | Lbs. | Gage | Lbs. | Gage | Lbs. | Gage | Lbs. | Gage | Lbs. | Gage | Lbs. |
| 120 VAC 1 Ph | 10 | 93 | 10 | 93 | 6 | 495 | 8 | 384 | 10 | 75 | 10 | 75 | 6 | 387 | 8 | 284 |
| 240 VAC 1 Ph | 12 | 75 | 14 | 55 | 10 | 186 | 10 | 186 | 12 | 57 | 14 | 46 | 10 | 150 | 10 | 150 |
| 208 VAC 3 Ph | 12 | 89 | 14 | 69 | 8 | 443 | 10 | 230 | 12 | 77 | 14 | 57 | 8 | 392 | 10 | 191 |
| 480 VAC 3 Ph | 16 | 44 | 16 | 44 | 12 | 177 | 14 | 138 | 16 | 34 | 16 | 34 | 12 | 155 | 14 | 113 |

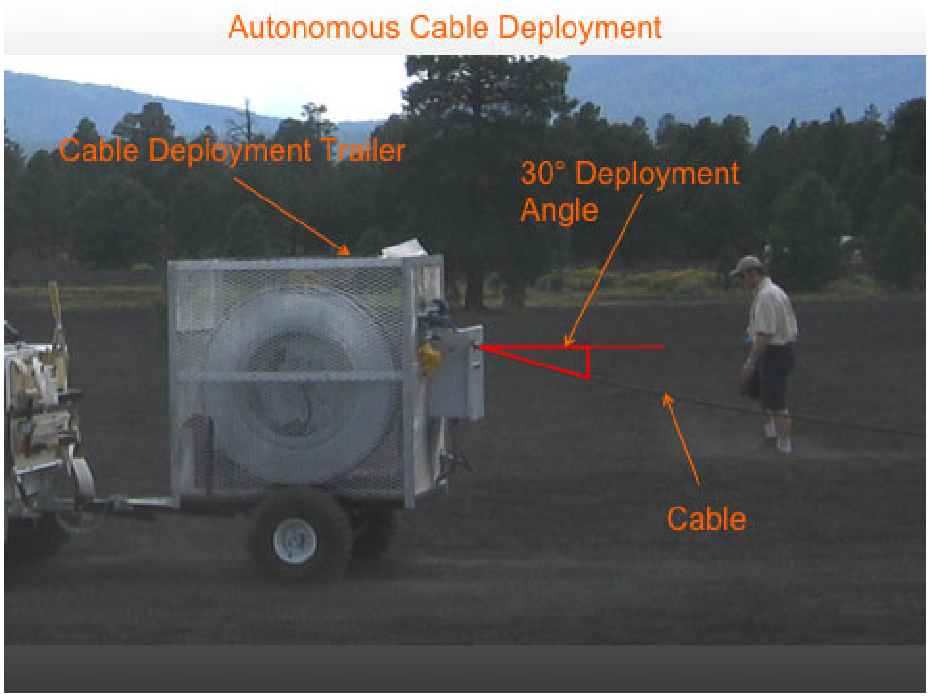


Figure 4.3.—Cable Angle During Deployment.

The drive motor to deploy the cable was powered directly through the cable from the PV power system trailer. This was accomplished through a slip ring at the hub of the cable reel. A 0.5 HP 110 V AC motor was used to turn the reel during deployment and retraction of the cable. The motor drive system is capable of deploying and retracting the cable. The maximum retraction rate for the reel was 200 linear ft per minute.

A mechanism on the outlet of the cable reel monitored the cable angle. The cable angle was used to determine the tension on the cable. The closer the angel was to the horizontal the greater the cable tension. The motor controller monitored the output of the angle sensor. A predetermined angle of approximately 30° between the cable and the horizontal was used as the desired angle. If the angle between the cable and the horizontal decreased below this set point the motor controller would speed up the cable reel increasing the rate of cable payout and thereby increasing the angle back to the set point. If the angle increased beyond the set point, the motor controller would reduce the rate of payout to bring the cable angle back to its set point. This can be seen during the cable deployment shown in Figure 4.3.

In addition to the automatic cable payout capability, the controller had an emergency stop, which could be manually or automatically set. It also had a manual "jog" function in which the cable could be manually payed out or retracted. There was also a visible warning and automatic shutdown of the deployment motor when 50 ft of cable remained on the reel. An electrical diagram of the circuit used to perform some of these functions is shown in Figure 4.4.

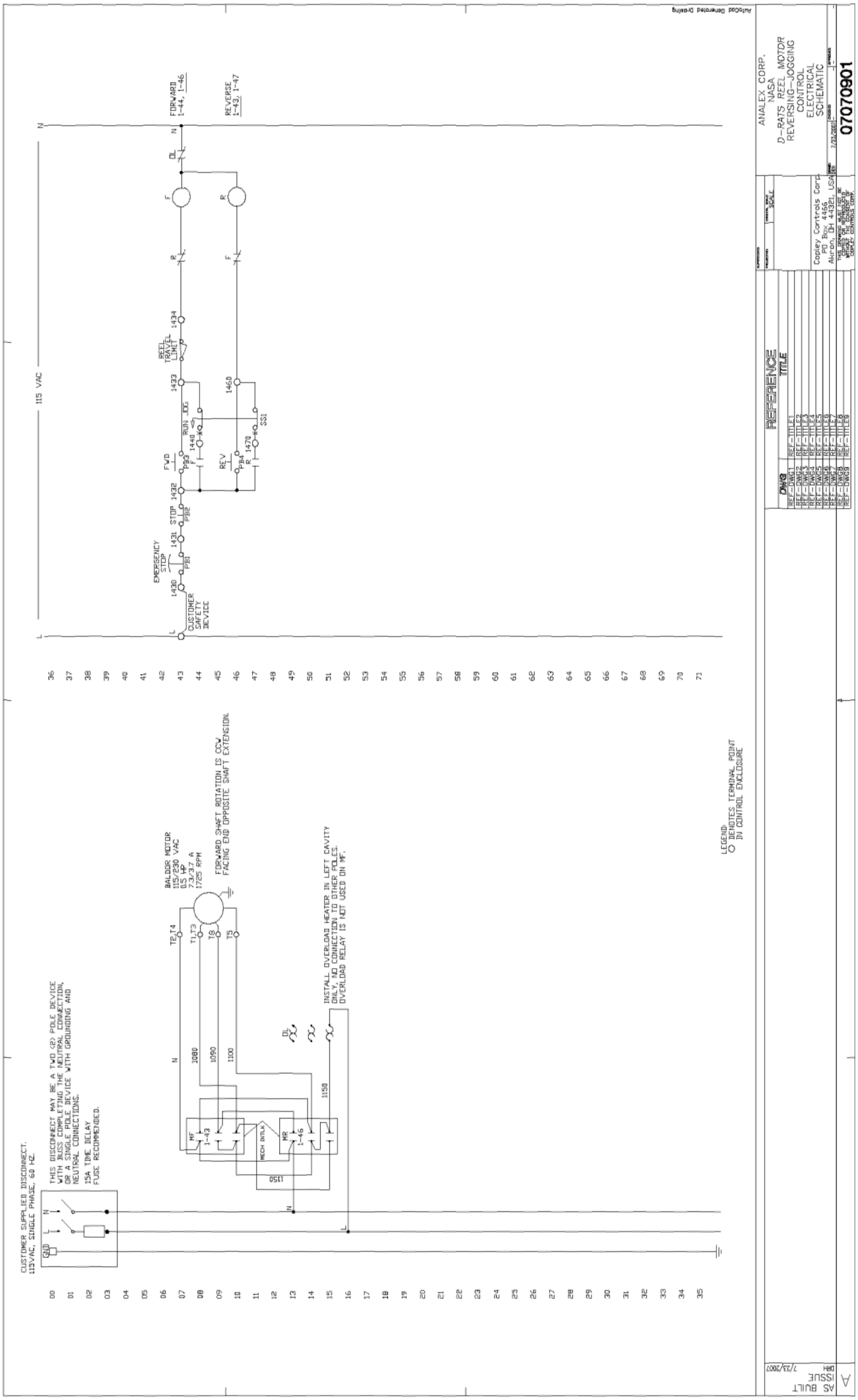


Figure 4.4.—Cable Reel Motor Control Electronics Diagram.

## 5.0 Desert RATS Deployment Testing

The photovoltaic power system was set up and operated to provide remote power to a load 200 m from the trailer. The Scout lunar rover demonstration vehicle, shown in Figure 5.1, performed the power cable deployment. The Scout would pull the cable deployment trailer as the cable reel paid out the cable. Deployment tests were performed with the Scout vehicle being driven manually, tele-robotically (both from at the Cinder Lake location and from the Johnson Space Center (JSC)) and autonomously. These tests were performed to assess the ability of the Scout vehicle to perform this type of task as well as to assess the interaction of astronauts with the deployment of a power cable and photovoltaic system.

In addition to the deployment of the power cable, power was supplied from the PV system through the cable to a load. The load used during the testing was a drill with a 1 m long auger bit for drilling into the crushed volcanic stone. Personnel in astronaut suits performed this activity. This simulated a typical load that the power system would have to provide power for as well as a typical activity that the astronauts would perform on the lunar surface.

Figure 5.1.—JSC's Scout Lunar Rover Demonstration Vehicle.

## 5.1 What Took Place in the Field

Initial setup - Following the August dry run at JSC, we had generated a list of tasks that needed fulfilling prior to a successful deployment of the PV power system and cable using the cable deployment trailer. Because of the nature of the desert floor at Cinder Lake with its gravelly attributes and low angle of repose, which would produce a buildup of cinders in front of a rolling tire, we wanted to decrease the pressure normal to the desert surface as much as practical. Increasing the width of the tires on the cable deployment trailer did this. Larger tires were shipped to the USGS station located on the outskirts of Flagstaff, thanks to the members of the JSC team pointing out this potential problem during the dry run and our teams proactively getting the items to the facility. A minor glitch did occur. We could not mount the new wider tires onto the existing axel structure because the hubs were now too close to the trailer frame for these wider tires. As luck would have it, a weld shop a few miles down the road from Cinder Lake was able to extend the axel that we removed from the trailer. In rapid succession we remounted the axel and new tires. The tires on the PV power system trailer which were narrow also, were not replaced because it was planned that this trailer would be positioned only once during the entire test.

Again at the JSC dry run we experienced shut down of the AC motor controller. This controller is used in conjunction with the servomotor, mechanically coupled to the cable reel that provides the restorative force in determining the longitudinal force on the cable and to counter act the rotational inertia. We were not certain if the controller drop out was due to thermals or a brown out condition on its mains (input line) and we did not have the necessary diagnostics at the dry run to make the determination so conservatism took over. Hence we brought exhaust fans, in the event that the problem would be thermal and a 4 kva inverter (1.5 kva peak rated inverter is how the PV power system is presently sized) if a brown out condition exists. Using the power system as an AC source to charge the portable drill batteries, we mounted the fan in the controller box on the cable deployment trailer and wired to the 120 Vac supply. We delayed replacing the inverters at this time.

Other than a few minor issues due to shipping damage and charging the batteries located in the power system trailer, we were ready to proceed.

The power system trailer and cable deployment trailer were towed to the staging area on Cinder Lake. Once there the photovoltaic power system was deployed. The cable deployment trailer was connected to the PV power system. This initial setup is shown in Figures 5.2 and 5.3. Once both trailers were deployed and connected we were able to power up the cable deployment trailer from the photovoltaic power system for the first time. In fact during the course of the daily runs, we realized that the problem of the AC controller shutting down at the JSC dry run was not thermal, but due to a brown out condition; during the dry runs we ran into inclement weather at Houston so the photovoltaic power system inverter was not used. A 0.75 kva inverter supplied by JSC was employed. The brown out was an attribute of this lower output (invoked a current limit). The larger inverter on the power system trailer remedied this.

Figure 5.2.—Deployed Photovoltaic Power System and Cable Deployment Trailers.

Figure 5.3.—Cable Deployment Trailer Connected to PV System at Base Location.

For the first series of runs a Kawasaki Mule, shown in Figure 5.4, was used as the means of locomotion for the cable deployment trailer. This afforded us the opportunity to make adjustments to the controller and null point of the positioning arm; this is the mechanism that controls the servo speed and through a gear box, the cable reel speed and hence the lineal speed of the cable is controlled indirectly. Because the radius of the cable buildup is continuously changing and the forward velocity of the cable deployment trailer is out of our control, the positioning arm removes all of those variables in its measurement of cable droop. It is through this action of measuring the angular displacement with a pot attached to the positioning arm that tension is regulated. It was during this time that we fixed the null position by adjusting the wiper arm of the pot and system gain by adjusting the min/max frequency of the controller (a crude method, but the only one available to us at the time).

Following the tuning up phase, we progressed to Scout. The cable deployment trailer being attached to Scout is shown in Figure 5.5. It was apparent that Scout had no trouble pulling the cable deployment trailer and simultaneously paying out the cable. The deployment of the cable with the Scout vehicle is shown in Figure 5.6. The cable, reel, electronics and trailer itself tipped the scales at about 700 lb. with the cable on the reel and at the end of a run it weighed about 300 lb. There was no difference in terms of operations (manual, robotic and tele-operated) for the cable deployment trailer. Because we decoupled the operation of the cable deployment trailer from the locomotion (by regulating tension), the various modes of control of Scout did not affect us.

Figure 5.4.—Kawasaki Mule Used for Initial Cable Deployment Tests.

Figure 5.5.—Cable Deployment Trailer Being Attached to Scout.

Figure 5.6.—Cable Deployment With the Scout Vehicle.

Not all pay outs concluded in the same way. For some we would simply rewind the cable onto its reel using the Mule right after a cable pay out and others, personnel in both shirt sleeve and astronauts suits would perform a number of coring task utilizing the drill and auger. The astronauts would us a large hammer drill and auger bit powered from the photovoltaic power system through the paid out cable to core the desert floor and collect samples, as shown in Figure 5.7. This portion of the overall task would take about 10 min and during this time, including cable deployment itself, task efficiency data were recorded. At the end of these runs we would use the Mule to rewind the cable.

It should be noted that electrical noise was not encountered at any time during the matrix of testing. The inverter has a total harmonic distortion of 1.5 percent up to its 50th harmonic. This is considered very low (and desirable) in the industry. The cable itself is a twisted pair with a third wire that we used as a green or ground wire. Because the cable deployment trailer is mobile, the grounding rod was located at the PV power system to establish a reference and the cable deployment trailer was referenced via the third conductor that was also bonded to the photovoltaic power system ground rod. Though the line voltage at the termination of the cable was not measured during these runs, the transformer output (~220 V AC) was measured at NASA Glenn Research Center (GRC) with much larger electrical loads than offered by the coring operation and the cable sizing of 3 percent (@1Kva) regulation assured no brown out condition would exist.


Figure 5.7.—Coring Activity Performed With Remote Power From the PV System.

During our testing we observed that if there was a large speed change (acceleration/deceleration) there is the subsequent undershoot/overshoot of the cable deployment. These abrupt changes in speed proved to be too great for the deployment control system that we had in place. The rotational inertia at the start is much greater that at the end of a run which affected the dynamics of the system. A separate braking scheme would need to be included to emulate a two-quadrant controller. A two-quadrant controller could be used, but dumping the excess rotational energy during the braking would imply superimposing a waveform on the AC mains that would drastically increase the total harmonic distortion (THD) from the present 1.5 percent. This could create a transient noise condition that, though would never show up on an electro-magnetic interference (EMI) spectrum scan, would certainly affect sensitive equipment.

With a brake to dissipate the energy (during deceleration) the system could then operate at a higher gain, which would have the material effect of a tighter regulation of the cable tension control. In this way, the cable deployment dynamics would be decoupled from the locomotion to the first order. At some point, stability would need to be investigated. Because of the change in inertia from start to finish, a change in gain as radius decreases would have a most desirable effect on dynamics and aid in stability. This change could be directly measured with the use of an encoder mounted on the reel's axis.

Each time the cable was paid out; it also had to be rewound. This proved to be somewhat problematic. The servo/controller was wired for reverse direction with feedback and jog in both directions. This helped in the rewind phase, but we immediately ran in to another problem; the cable would accumulate around the center of the reel's width. This resulted in a situation where the cable would get pinched by subsequent cable turns. The next deployment would experience cogging of the reel velocity and even jamming could occur and in fact did once. We rectified this by manually guiding the cable unto the reel in an even fashion. If a cable deployment using a technique similar to this is used, there must be a mechanism in place that automatically lays the cable on the reel like that of a fishing reel or better still, a precision wind as used in the magnetic coil industry for transformers and inductors.

It was instructive to watch the suited astronauts negotiate around objects and their lack of dexterity because of the stiffness and size of the gloves and suits. It would appear to this observer that automation is about the only viable solution to deployment of the photovoltaic power system and setting up the cable deployment trailer such as plugging into the photovoltaic power system, coupling the trailer to Scout and eventually removing the paid out cable from the cable deployment trailer.

Our goal to show the cable deployment was decoupled from locomotion was demonstrated (at least to first order) and we did pay out cable controlling the longitudinal force (tension) on the cable. We did not have the fine control that would be required to be completely successful due to reasons stated above, but did show how we would in fact accomplish such. The salient feature of having power flow through the cable as it is being deployed was demonstrated and does allow the program to make operational decisions that will alleviate some if not all the energy needs during mission buildup for cable deployment. This same feature could be exploited to power up Scout or its derivative and also trenching operations (cable burial) could be performed using this energy.

## 6.0 Proposed Follow-On Development

To continue with the development of modular power systems for the Desert RATS program, a mobile hydrogen production and storage system and fueling demonstration is being considered. This system will utilize the trailer power system developed for the 2007 Desert RATS program. The proposed demonstration system will generate and store hydrogen utilizing the trailer's solar array power system and an electrolyzer that will be mounted on the trailer. The hydrogen will be used to fuel a fuel cell power electric all-terrain vehicle (ATV).

The main components of the system will include:

- Solar array based power system
- Trailer platform
- Hydrogen production and storage
- Hydrogen transfer system
- Electric fuel cell powered ATV

The initial design of the system utilizes and stores only hydrogen. The oxygen produced will be vented. The power system for the ATV will utilize a hydrogen-air fuel cell. However, further development could be performed to transition this to a hydrogen-oxygen based system, providing a test-bed for lunar applications.

The main elements of the hydrogen production and fueling demonstration system are a renewable energy source (in this case a photovoltaic array), an electrolyzer, and a fuel cell. A bank of photovoltaic arrays convert solar energy to electricity to service the electrical loads connected to the system's power bus. Solar power in excess of that drawn off the bus is used to generate hydrogen in the system's water electrolyzer whereupon; the hydrogen is stored for later use by the vehicle.

The most significant advantages of the hydrogen fuel system is that the vehicle can be quickly refueled minimizing any downtime that would be required if it needed to be recharged. Also just adding additional fuel storage capacity, either by utilizing larger tanks or higher-pressure storage, can easily increase the operating duration of the vehicle.

The solar array based power system developed for the 2007 Desert RATS program will be modified to perform the hydrogen production and fueling demonstration. The system shown in Figure 6.1 is trailer based and provides a complete and operational photovoltaic array/battery power system. Utilizing this power system will provide a significant cost and timesavings to the proposed hydrogen production and fueling demonstration program.

The complete hydrogen generation system will be housed on a trailer as shown in Figure 6.2. The system will be comprised of the main components listed below.

- Solar Array
- Batteries
- Electrolyzer
- Power Management Electronics
- Operational Display & Meters
- Ancillary Equipment
- Hydrogen Storage Tanks
- Water Storage Tank
- Fuel Transfer System

Figure 6.1.—Mobile Photovoltaic Power System.

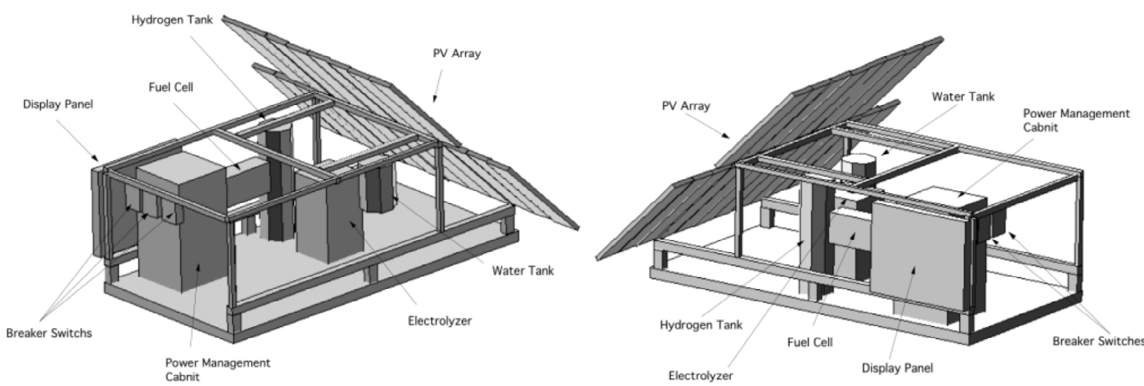


Figure 6.2.—Mobile Power System Component Layout.

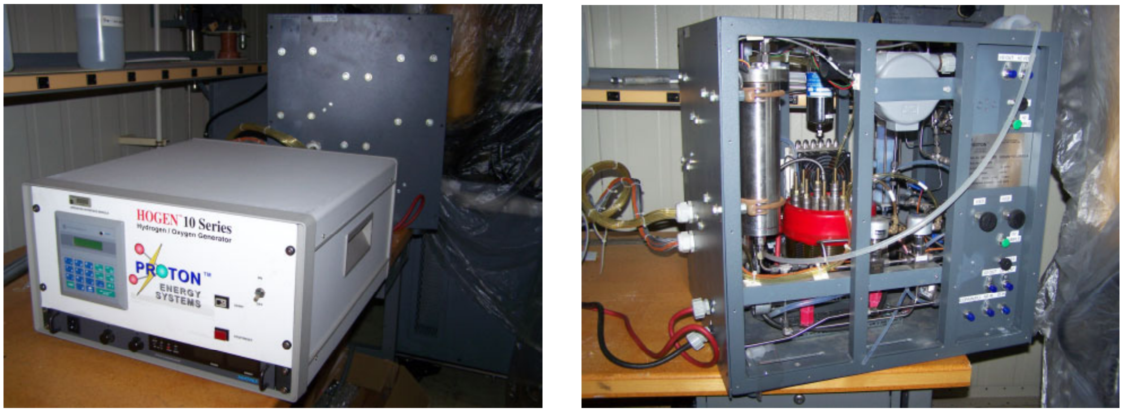

Figure 6.3.—HOGEN 10 Electrolyzer.

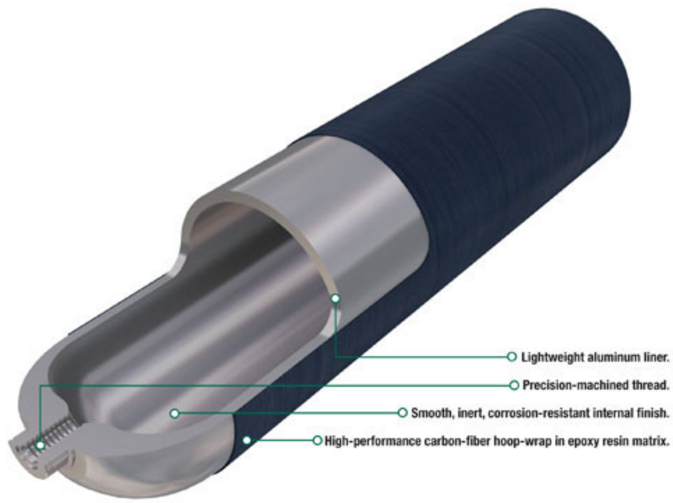

Figure 6.4.—Luxfur Lightweight Composite Hydrogen Storage Tank (Ref. 4).

The electrolyzer and tank storage system will be mounted onto the power system trailer. The electrolyzer which will be utilized is a Proton Energy System’s HOGEN 10 series electrolyzer (Ref. 3), shown in Figure 6.3. This electrolyzer has been in storage for the last few years and was recently refurbished by the manufacturer. The electrolyzer will be operated as a load on the PV power sytem. It can either be connected via the AC output on the inverter, or directly onto the DC power bus.

To store the hydrogen produced a series of tanks will be required. To minimize the weight impact of these tanks on the trailer carbon tanks with an aluminum liner will be utilized. An example of these tanks is shown in Figure 6.4.

In addition to the tanks, a hydrogen detection and dispensing system will also need to be installed. A Matherson TriGas hydrogen detection system had been purchased under a separate program and would be available for use in this project (Ref. 5). The dispensing system will utilize that developed for the automotive industry, an example of which is shown in Figure 6.5.

The other major component to the demonstration system is the electric fuel cell power ATV. This vehicle will be based on a commercially available electric vehicle. An example is shown in Figure 6.6.

Figure 6.5.—Hydrogen Dispensing System (Ref. 6).

Figure 6.6.—Electric ATV (Ref. 7).

The electric vehicle will be modified to operate on fuel cells with hydrogen fuel. Four 1.2 kW Ballard fuel cells will be installed as the main power source. These fuel cells were purchased under another program and would be available for use in this demonstration program. The fuel cells will be connected in groups of 2. Each group will be wired in series to provide a 48 V system bus for the vehicle. This matches the present power system voltage the vehicle utilizes. The present batteries on the vehicle will be removed and replaced with smaller (lower capacity) batteries. The batteries will be used to handle peaks in the power demand during operation.

Hydrogen storage tanks, similar to those on the trailer, will be mounted onto the vehicle and used to store the hydrogen. The dispensing system will be used to fill the hydrogen tanks from the storage tanks on the trailer. The electric drive system on the vehicle will be utilized as is and should be capable of operating in the off-road environment of the demonstration.

The overall goal of this project is the development of a hydrogen fueling demonstration system. The system will be utilized as a technology demonstration, technology testbed and educational tool in the design and development of regenerative power systems for Lunar applications. The development of this manually operated hydrogen generation, storage, and fueling system will establish the groundwork for future development and system automation.

## References


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3. Proton Energy Systems, Product Information, http://www.protonenergy.com/ November 2008.
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5. Mahteson Tri-Gas Product Data Sheet, http://www.matheson-trigas.com, June 1999.
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7. Stealth 4X4 Electric Vehicles Product Information, http://stealth4x4.com/, November 2008.

# Appendix A—Preliminary Hazard List/Analysis

| Haz. No. | Hazardous Condition | Cause(s) | Effect(s) | Severity | Possible Hazard Elimination/ Control Provisions |
|---|---|---|---|---|---|
| 1.0 | Sharp edges, corners, protrusions, pinch points. | 1.1 Hardware design/ purchased includes sharp edges.<br>1.2 Crew member becomes trapped in cable retraction mechanism. | Injury to crew member. | CRIT. | 1.1.1 Inspect hardware for sharp edges, pinch points, etc.<br>1.1.2 Caution/ warning labels if hazard cannot be eliminated by rework.<br>1.1.3 Procedural steps/ training which acknowledge hazard presence.<br>1.1.4 Protective equipment/ gloves, etc.<br>1.1.5 Barricade/barrier to prevent access |
| 2.0 | Battery failure (dependent upon the type of battery being used). | 2.1 Battery/ cell short circuits causing fire/ explosion.<br>2.2 Battery/ cell overheats causing gas leakage/ fire/ explosion.<br>2.3 Battery overcharges causing energetic venting/ explosion.<br>2.4 Battery voltage is driven negative causing flammable gas evolution.<br>2.5 Battery terminals are damaged/ crushed causing instant energy release/ shrapnel. | Injury to crew member.<br>Exposure to toxic vented materials.<br>Hardware damage. | CRIT. | 2.1.1 Over-current/ undercurrent protection/ fusing/ shutdown.<br>2.2.1 Insulation/ cooling equipment.<br>2.3 Provide overcharge protection.<br>2.4.1 Assure cells in battery are evenly performance matched.<br>2.4.2 Assure batteries in series string are evenly performance matched.<br>2.5 Provide structural protection for exposed terminals. |
| 3.0 | Touch temperature. | 3.1 Exposed metallic surfaces become heated by solar radiation. | Injury to crew member.<br>Hardware damage. | CRIT. | 3.1.1 Caution/ warning labels.<br>3.1.2 Protective equipment/ gloves. |
| 4.0 | Electrical Power Distribution. | 4.1 Faulty circuit protection/ electrical design. | Injury to crew member.<br>Hardware damage. | CRIT. | 4.1.1 Use of proper circuit protection devices and wire sizing.<br>4.1.2 Use of proper grounding and bonding processes. |
| 5.0 | Rotating equipment failure. | 5.1 Cable retraction mechanism continues to function after cable jam occurs.<br>5.2 Particulates cause degradation of rotating mechanism. | Crew severe injury.<br>Hardware damage. | CAT. | 5.1.1 Retraction motion sensor for automatic shutdown.<br>5.1.2 Automatic braking mechanism or disengage mechanism to avoid cable snapping/ whipping.<br>5.1.3 Provide cable management system.<br>5.1.4 Provide E-Stop button<br>5.2 Enclose/ protect rotating equipment from particulate contamination. |

| | | | | | |
|---|---|---|---|---|---|
| 6.0 | Electric shock. | 6.1 Crew member receives electrical shock while mating/ de-mating powered connectors.<br>6.2 Inadvertent contact with exposed electrically energized equipment during configuration/ maintenance operations. | Crew injury or death. Hardware damage. | CAT. | 6.1.1 Assure connectors are un-powered during mate/ de-mate operations via isolation switches (two recommended).<br>6.1.2 Provide approved crew procedures.<br>6.2.1 Perform analysis to verify grounding/ bonding requirements are met.<br>6.2.2 Use proper electrical connectors (enclosed/shrouded pins/ sockets, scoop proof, powered sides should terminate in sockets).<br>6.2.3 Use proper fusing/ wire sizing, connector sizing, and no exposed electrical contacts or conductors. |
| 7.0 | Impact from falling/ rolling/ detached equipment. | 7.1 Mobile hardware is not properly secured on uneven terrain.<br>7.2 Loss of control during proximity operations. | Crew injury. Hardware damage. | CRIT | 7.1.1 Search for more appropriate location on level terrain.<br>7.1.2 Use tie-downs/ stakes and brakes (if available). |
| 8.0 | Impact from motorized vehicle or transported cargo. | 8.1 Lack of attention around moving vehicle(s). | Crew injury. Hardware damage. | CRIT. | 8.1.1 Audible signal when vehicle is in motion (especially backward motion).<br>8.1.2 Work area should be inspected for obstacles and steep sloping uneven terrain avoided. |
| 9.0 | Physiological hazards | 9.1 Sun glare/ temporary blindness.<br>9.2 Sand/ grit gets in eyes/ nose/ throat.<br>9.3 Dehydration/ illness.<br>9.4 Reptile/ rodent/ insect toxic exposure.<br>9.5 Noise exposure.<br>9.6 Cuts/ abrasions. | Crew injury. Hardware damage. | CRIT. | 9.1.1 Use of proper eye protection.<br>9.2.1 Use proper face protection or discontinue operations if conditions are extreme.<br>9.3.1 Assure proper hydration and water supply.<br>9.4.1 Proper clothing, cleanliness, and anti-venoms should be readily available.<br>9.5.1 Noise exposure outside of OSSHA acceptable limits and durations requires hearing protection.<br>9.6.1 Well stocked first aid kit should be readily available. |
| 10.0 | Fire | 10.1 Battery failure.<br>10.2 Electrical box/ cable failure.<br>10.3 Gearbox failure.<br>10.4 Flammable materials used. | Crew injury. Hardware damage. | CRIT. | 10. Provide applicable fire detection and suppression equipment for anticipated fire types. |

## Appendix B—EMI Testing Report

# NASA GLENN RESEARCH CENTER

# EMI TEST DATA REPORT

Moon Shot Photovoltaic Power Trailer
Radiated Electric Field Characterization

Prepared by: ______________________
Michael D. Herlacher, Test Engineer
Analex Corporation

Date: 9 Aug 07

# Photovoltaic Power Trailer

## *I. TEST DESCRIPTION*

| | |
|---|---|
| Equipment Under Test: | Photovoltaic Power System, trailer mounted using:<br>20 Multi-Solar cell panels, cell system regulator/controller,<br>Battery charger, Gel-cell marine batteries (4), Inverter,<br>Power switchgear, Long load cable. |
| Ground Support Eq.: | AEMC Instruments model 8230 power analyzer, Data logger, Laptop computer, Incandescent lamps (load) |
| Date of Test: | 1 Aug 07 |
| Test Location: | Power & Avionics Division,<br>EMC Test Lab, Bldg. 332,<br>Open air test site adjacent to buildings 332 & 334 |
| Test Plan: | Verbal arrangement for radiated electric field tests |
| Test Specification(s): | Instrument settings MIL-STD-461,<br>Frequency range SSP-30237 |
| Test Procedure(s): | Per Test Plan and Specifications above |
| EUT Engineer(s): | Sam Hussey, GRC - MCOO<br>Anthony Colozza, Analex Corp.<br>Ian Jakupca, Analex Corp. |
| Test Engineer(s): | Michael Herlacher, Analex Corporation<br>Gary Wroten, GRC - DPEO |

## *II. TEST NOTES*

II.1 The purpose of this test was to characterize the radiated electric field emissions from the photovoltaic power trailer. The test was conducted in an open air test site rather than in a shielded test chamber so the trailer could make use of sunlight for power generation. The test site selected was adjacent to the building that housed EMI lab for ease in trailer and test equipment logistics and standard power access. The open air test site was prone to high ambient levels of RF due to standard broadcast transmitters, weather radar, airport operations, and other large city (Cleveland, OH) expected RF activity. The ambient field, therefore, will have the tendency to mask low to moderate levels of emissions that could come from the equipment under test (EUT).

II.2 The power system was operated in several turn-on stages in order to isolate any particular system portion emission. Ambient readings and four operational modes were selected for measurement and are identified below:

(1) Ambient – all EUT turned off but positioned like other modes.
(2) Solar panels open and illuminated by sunlight, all other equipment off
(3) Add the solar panel system regulator turned on, battery charger powered with batteries on trickle charge
(4) Add inverter turned on with minimal load (power analyzer, data logger, and Laptop)
(5) Add battery heavy charge load and 250 W lamp load.

II.3 The sunlight was plentiful making the weather environment hot (75 to 95 °F) and humid (70%RH – 37%RH). The EUT and test equipment tolerated the hot condition. However, mention must be made that the temperature gradient and sustained high level could affect test data to some smaller degree. The instrumentation noise floor was seen to shift slightly over the duration of the test.

II.4 During Power System Trailer operations, several markers were recorded. The charger output was 52 VDC or higher delivering between 8.1 to 9.1 A in the test's highest load condition. The charger feeds the batteries and the inverter in parallel so all load current (and power) passes through the charger. The inverter output was between 225 to 227 V AC (60 Hz 1Φ) at this time The power quality analyzer connected to the inverter recorded 1.2 percent voltage harmonic distortion, and 2.8 percent current harmonic distortion during high load conditions.

II.5 All plots where the Power System Trailer was in some state of activity were compared to the ambient plots (background). This was done to determine if there was any radiated electric field that the Trailer produced above the ambient levels. Each plot was expanded sufficiently (with a tool inside the generating software package) to judge any apparent frequencies that the trailer generated. Many background and trailer peaks were right on top of each other as viewed in this report's graphics. Expansion allowed the necessary discrimination. Judgment criteria included:

(1) Only peaks >10 dB above the noise floor were examined
(2) Peaks that were slightly off background frequencies but within a tight grouping of associated background peaks were ignored

II.6 After reviewing all plots against their background counterparts, the following conclusions were reached:
(1) There were numerous peaks seen in the trailer active plots that were not seen in the background plots. A short table was generated and placed immediately after each plot to show those frequencies.
(2) A comparison was made of each of these tables for frequencies that were common to 3 or more different scans (plots). The table below shows these common plot frequencies.

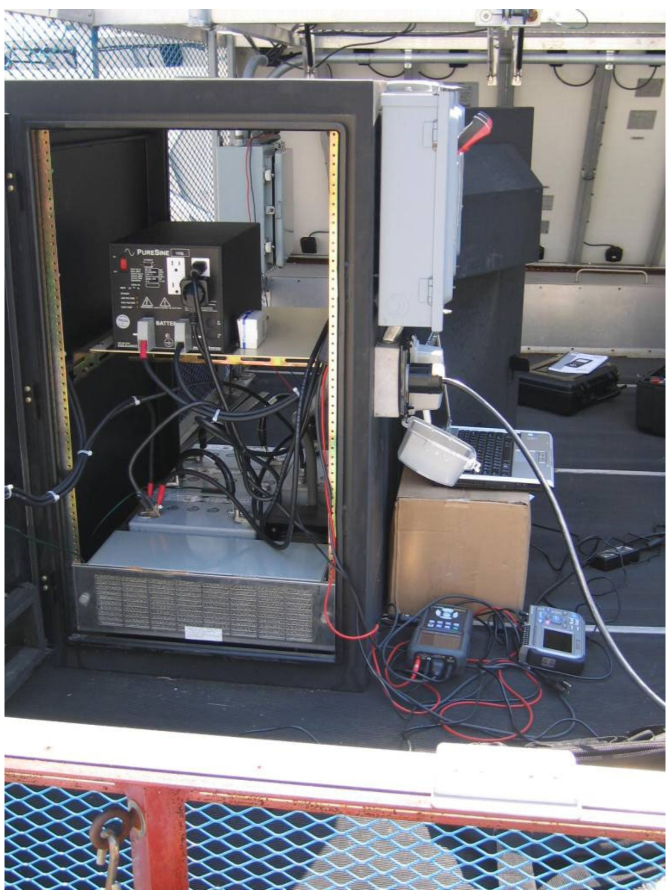
| Common frequency (MHz) | Number of plots appearing in | Comment |
|---|---|---|
| 0.0385 (Fundamental) | 5 | See note II.6(3) below |
| 0.077 (2nd Harmonic) | 5 | |
| 0.115 (3rd Harmonic) | 5 | |
| 0.500 (13th Harmonic) | 5 | |
| 1.65 (43rd Harmonic) | 5 | |
| 29.990 (779th Harmonic) | 5 | |
| 15.22 | 4 | These 4 frequencies are within FCC approved broadcast bands and was likely their source. |
| 15.37 | 3 | |
| 15.75 | 3 | |
| 18.93 | 4 | |

The first 6 frequencies listed in the table above appeared in all the scan cases where the Power System Trailer's inverter was active. The fundamental frequency of 38.5 kHz is likely generated from a DC to DC converter used in the inverter. A sampling of the harmonics is presented above to show the radiation was measured well up in frequency. The measurement receiver's input filter bandwidth was changed to 100 kHz when the scan went above 30 MHz. At this point the measurement equipment band width could no longer resolve the harmonics. The harmonic energy returned to within 10 dB of the noise floor at about 35 MHz.

## *III. GENERAL PHOTOGRAPHS*

Power System Trailer With Photovoltaic Panels Deployed.

Power System Trailer Side View.



Power System Trailer Bed View With Equipment Cabinet Panels Open.

Power System Trailer Side View With EMI Measurement Equipment on Cart.

Load Lamp Assembly With Distant Power System Trailer.

Load Lamps, Transformer, and Load Cable Spool Close-Up View.

## *IV. TEST EQUIPMENT CALIBRATIONS*

| Instrument | Manufacturer model # (s/n) | Test type | Cal. due | Calibration source |
|---|---|---|---|---|
| Antenna, Small horn | EMCO 3115 (3558) | RE02p2 | 4 Aug 07 | Liberty Labs Inc |
| Antenna, Wideband Active | ARA SAS-2A/M | RE02p1 | 21 Aug 07 | Antenna Research |
| EMI Receiver | Rhode & Schwarz ESI26 | RE01p1/p2 | 21 Dec 07 | World Cal. Inc. |

## *V. TEST DATA AND PHOTOGRAPHS*

### V.1 Ambient Background Measurements

(Data begins next page)

## NASA Glenn Research Center

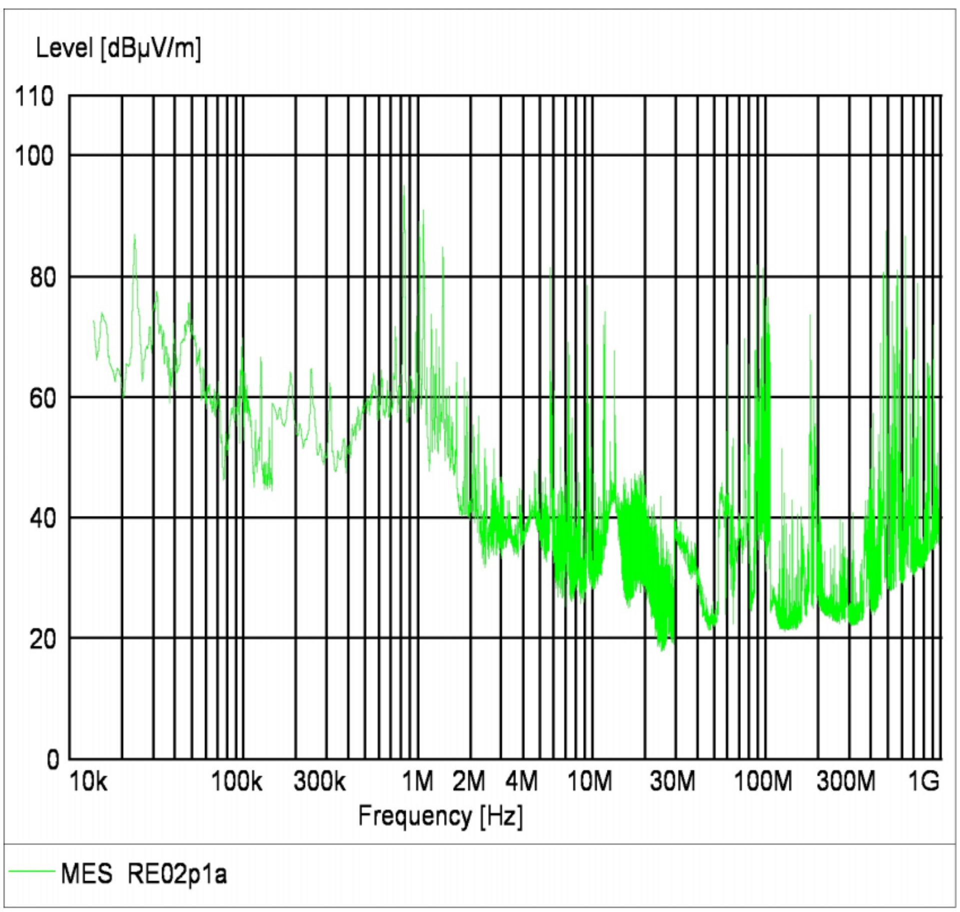
## EMI Laboratory

| | |
|---|---|
| EUT: | Launch Vehicle Power Trailer |
| EUT Engineer(s): | Sam Hussey, Anthony Colozza, Ian Jakupca |
| Test Engineer(s): | Mike Herlacher, Gary Wroten |
| Operating Condition: | 9:30A, 1 Aug 2007, 75F, 70%RH |
| Test Site: | Open air test site between Bldgs 334 & 332 |
| Test Spec/Plan: | Radiated Emissions Verbal Plan |
| Comment: | Antenna at rear, Vertical polarity, Background |
| | Trace: GRN - Trailer closed, All off |

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |



## NASA Glenn Research Center

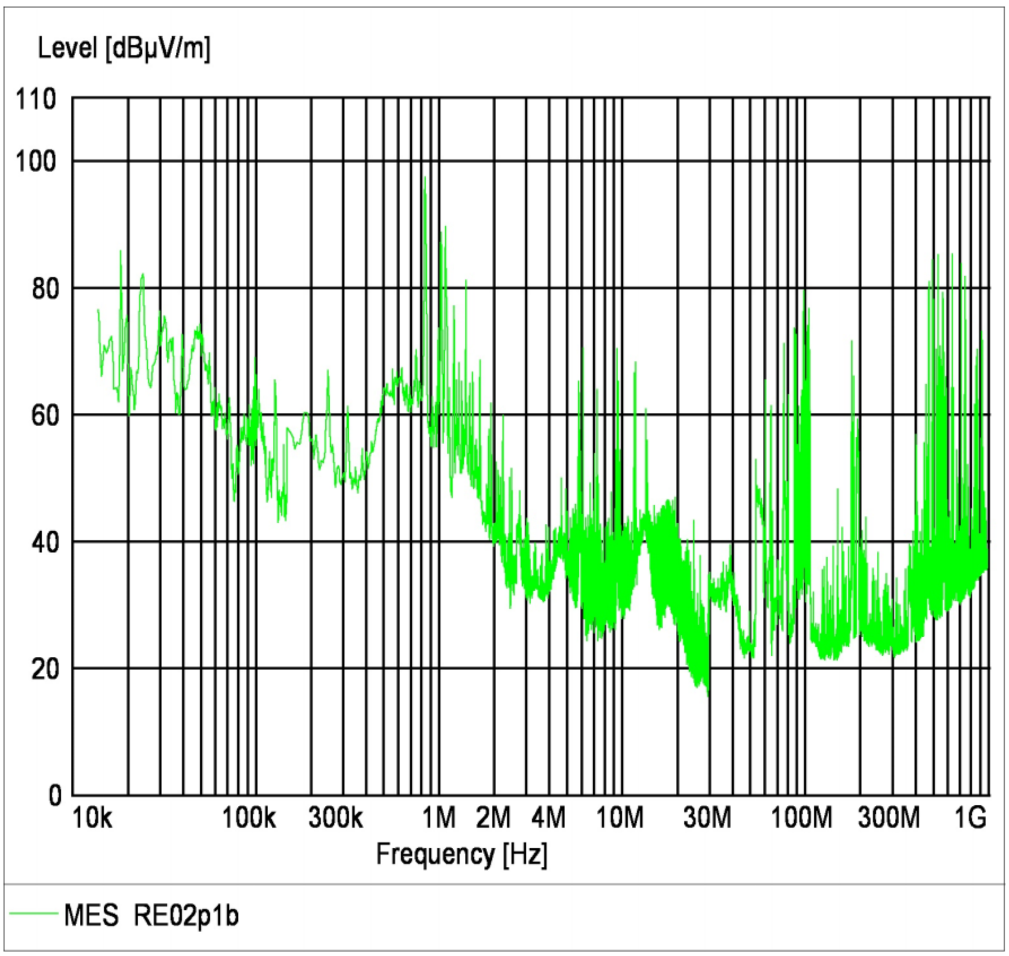
## EMI Laboratory

| | |
|---|---|
| EUT: | Launch Vehicle Power Trailer |
| EUT Engineer(s): | Sam Hussey, Anthony Colozza, Ian Jakupca |
| Test Engineer(s): | Mike Herlacher, Gary Wroten |
| Operating Condition: | 8:43A, 1 Aug 2007, 75F, 70%RH |
| Test Site: | Open air test site between Bldgs 334 & 332 |
| Test Spec/Plan: | Radiated Emissions Verbal Plan |
| Comment: | Antenna at left, Vertical polarity, Background<br>Trace: GRN - Trailer closed, All off |

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| **Start Frequency** | **Stop Frequency** | **Step Width** | **Detector** | **Meas. Time** | **IF Bandw.** | **Transducer** |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |



## NASA Glenn Research Center

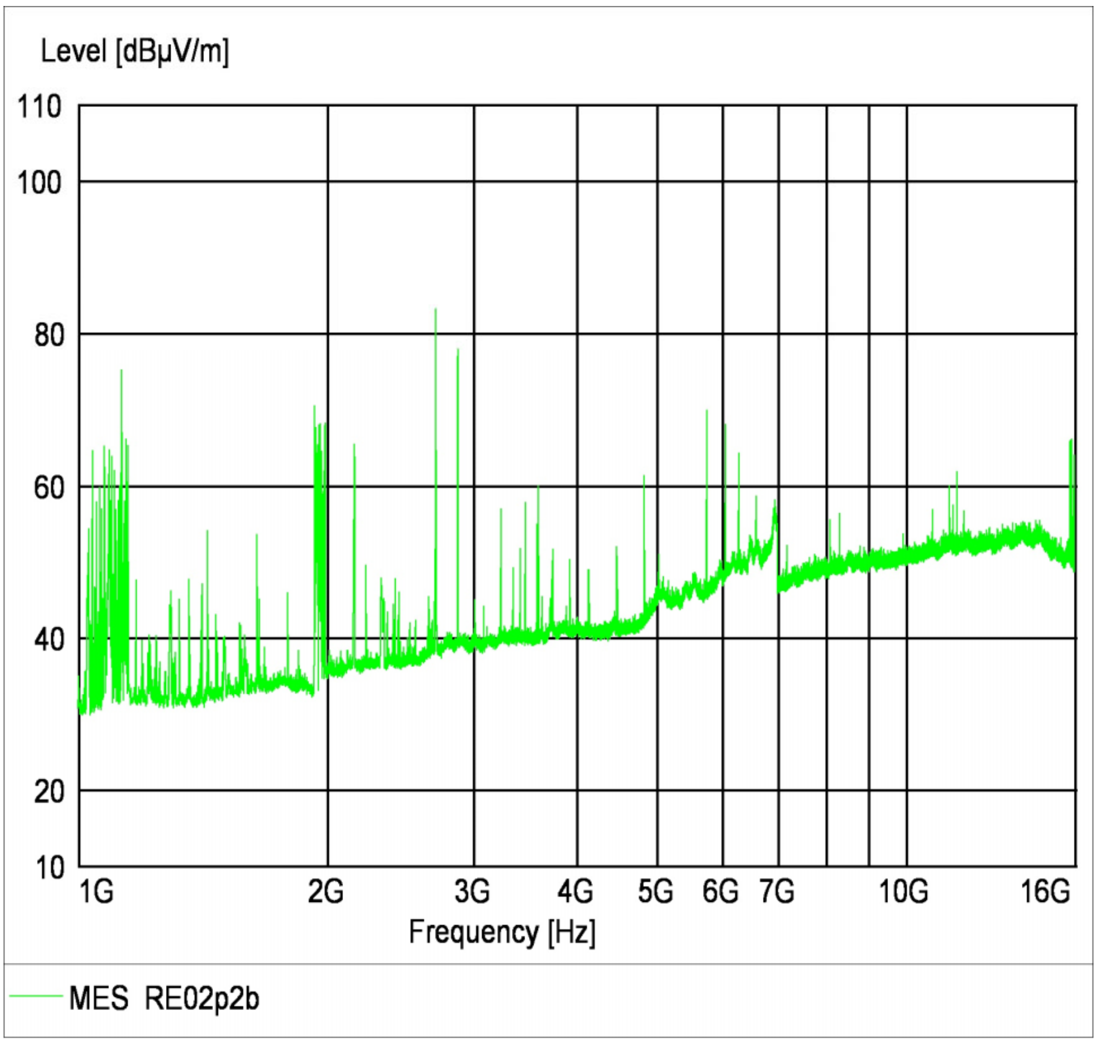
## EMI Laboratory

| | |
|---|---|
| EUT: | Launch Vehicle Power Trailer |
| EUT Engineer(s): | Anthony Colozza |
| Test Engineer(s): | Mike Herlacher |
| Operating Condition: | 9:16A, 1 Aug 2007, 82F, 61%RH |
| Test Site: | Open air test site between Bldgs 334 & 332 |
| Test Spec/Plan: | Radiated Emissions Verbal Plan |
| Comment: | Antenna at rear, Vertical polarity, Background<br>Trace: GRN - Trailer closed, All off |

## SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |



## NASA Glenn Research Center

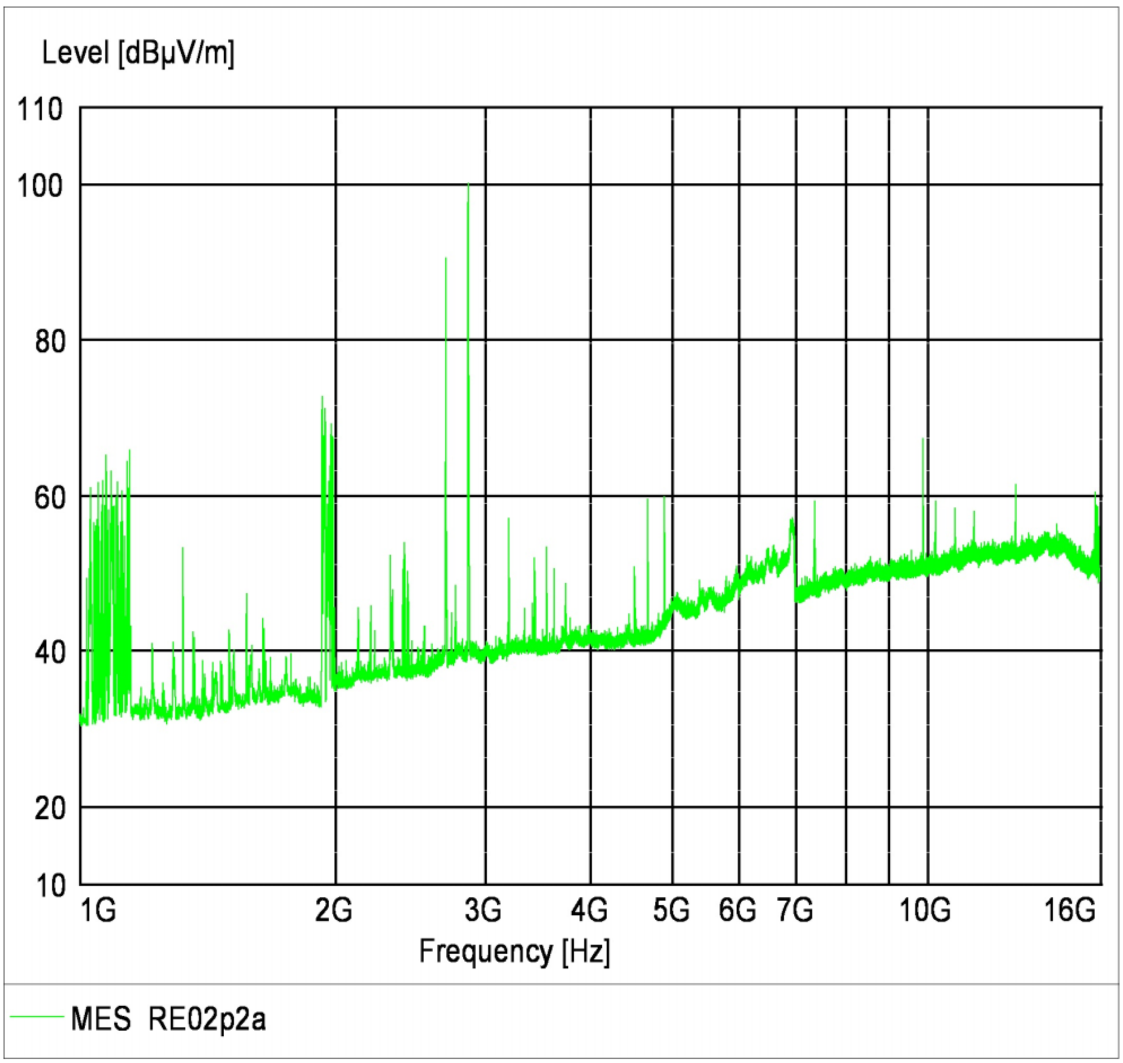
## EMI Laboratory

| | |
|---|---|
| EUT: | Launch Vehicle Power Trailer |
| EUT Engineer(s): | Anthony Colozza |
| Test Engineer(s): | Mike Herlacher |
| Operating Condition: | 9:01A, 1 Aug 2007, 75F, 70%RH |
| Test Site: | Open air test site between Bldgs 334 & 332 |
| Test Spec/Plan: | Radiated Emissions Verbal Plan |
| Comment: | Antenna at left, Vertical polarity, Background |
| | Trace: GRN - Trailer closed, All off |

## SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| **Start Frequency** | **Stop Frequency** | **Step Width** | **Detector** | **Meas. Time** | **IF Bandw.** | **Transducer** |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |



V.2 Photo-Cells Illuminated Only

## NASA Glenn Research Center

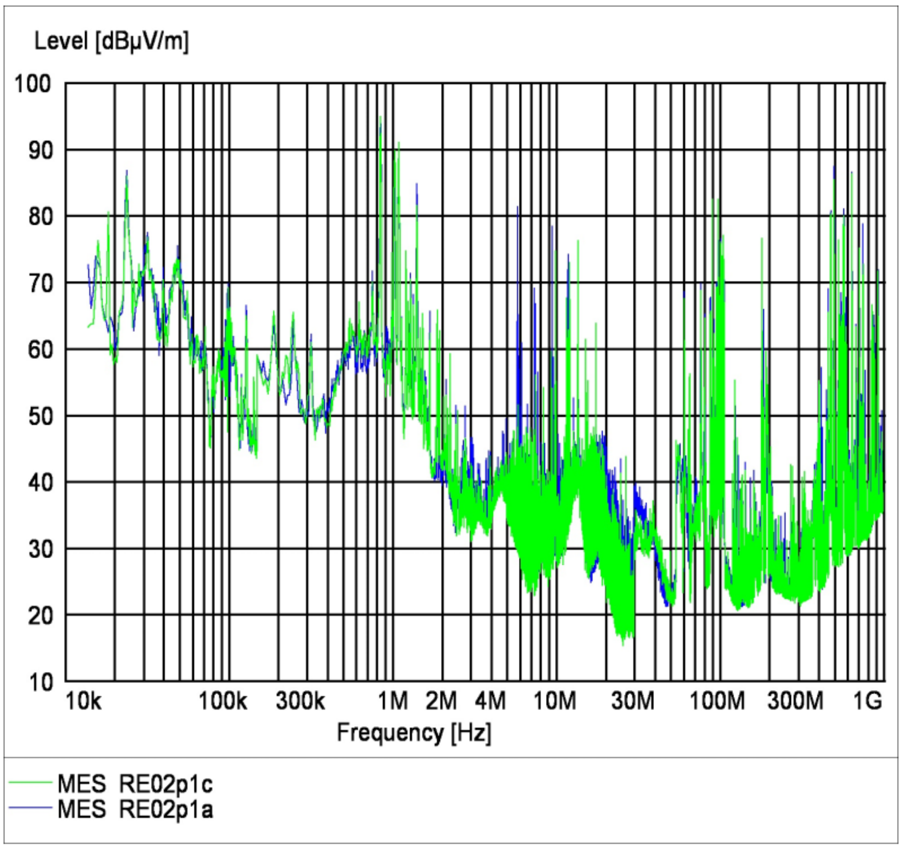
## EMI Laboratory

```
EUT:                    Photovoltaic Power Trailer
EUT Engineer(s):        Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):       Mike Herlacher, Gary Wroten
Operating Condition:    10:09A, 1 Aug 2007, 91F, 48%RH
Test Site:              Open air test site between Bldgs 334 & 332
Test Spec/Plan:         Radiated Emissions Verbal Plan
Comment:                Antenna at rear, Vertical polarity
                        Traces: GRN - Photo-cells open
                                BLU - Background
```

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |



**Frequencies seen in current mode (RE02p1c) and not in background (RE02p1a)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 15.22 | 21 |
| 15.37 | 14 |
| 15.75 | 16 |
| 17.60 | 23 |
| 27.02 | 17 |

Radiated Electric Field Low Band, Antenna at Rear.

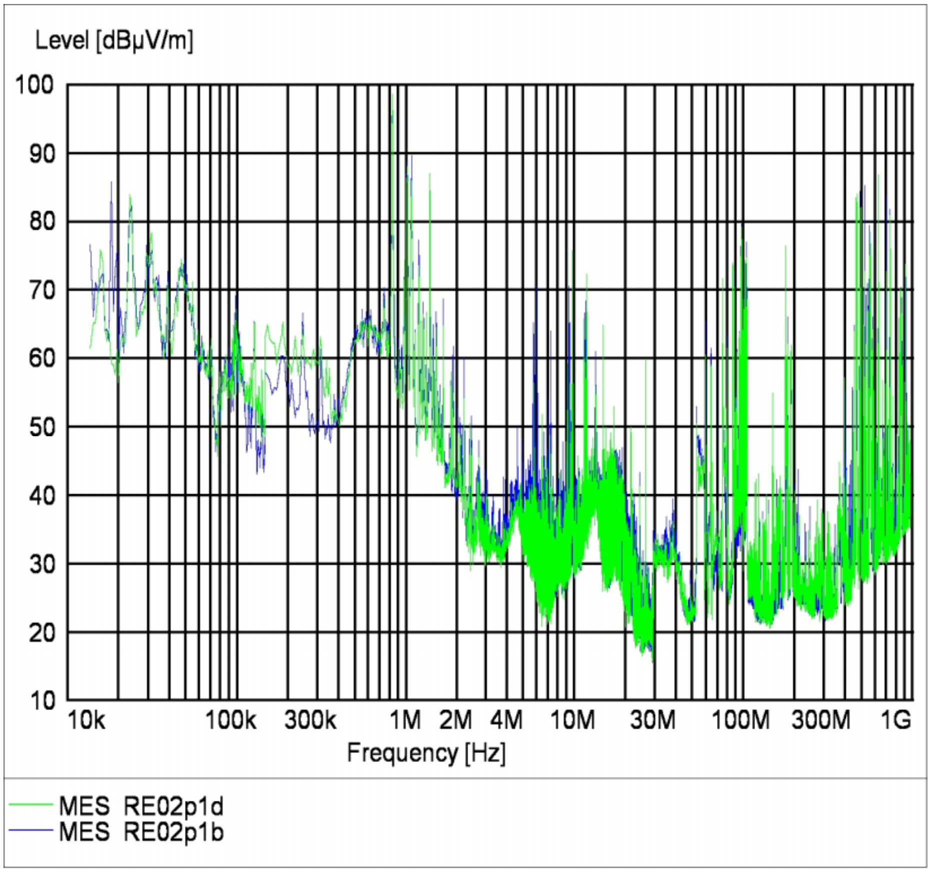
## NASA Glenn Research Center

## EMI Laboratory

```
EUT:                   Photovoltaic Power Trailer
EUT Engineer(s):       Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):      Mike Herlacher, Gary Wroten
Operating Condition: 10:21A, 1 Aug 2007, 91F, 44%RH
Test Site:             Open air test site between Bldgs 334 & 332
Test Spec/Plan:        Radiated Emissions Verbal Plan
Comment:               Antenna at left, Vertical polarity
                       Traces: GRN - Photo-cells open
                               BLU - Background
```

# SCAN TABLE: "30237 RE02p1"

| *Short Description:* | | | *30237 RE02p1* | | *In2DC* | |
|---|---|---|---|---|---|---|
| **Start Frequency** | **Stop Frequency** | **Step Width** | **Detector** | **Meas. Time** | **IF Bandw.** | **Transducer** |
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |




**Frequencies seen in current mode (RE02p1d) and not in background (RE02p1b)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 15.22 | 24 |

Radiated Electric Field Low Band, Antenna at Left.

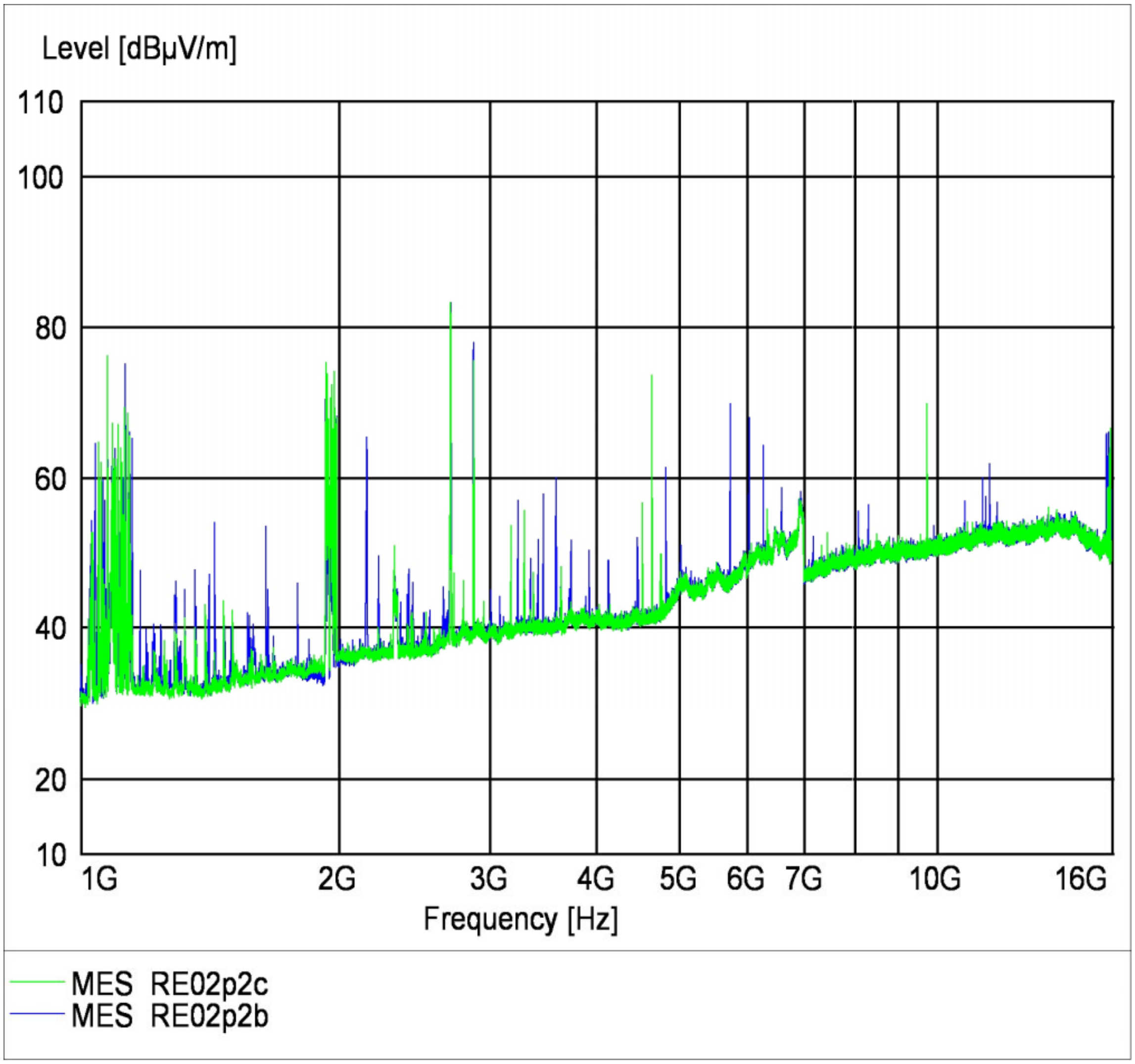
# NASA Glenn Research Center

# EMI Laboratory

```
EUT:                   Photovoltaic Power Trailer
EUT Engineer(s):       Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):      Mike Herlacher, Gary Wroten
Operating Condition: 9:37A, 1 Aug 2007, 86F, 55%RH
Test Site:             Open air test site between Bldgs 334 & 332
Test Spec/Plan:        Radiated Emissions Verbal Plan
Comment:               Antenna at rear, Vertical polarity
                       Traces: GRN – Photo-cells open
                               BLU - Background
```

## SCAN TABLE: "30237 RE02p2"

| *Short Description:* | | | *30237 RE02p2* | | *In1DC* | |
|---|---|---|---|---|---|---|
| **Start Frequency** | **Stop Frequency** | **Step Width** | **Detector** | **Meas. Time** | **IF Bandw.** | **Transducer** |
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |




**Frequencies seen in current mode (RE02p2c) and not in background (RE02p2b)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 4.656 | 31 |
| 9.740 | 19 |

Radiated Electric Field High Band, Antenna at Rear.

# NASA Glenn Research Center

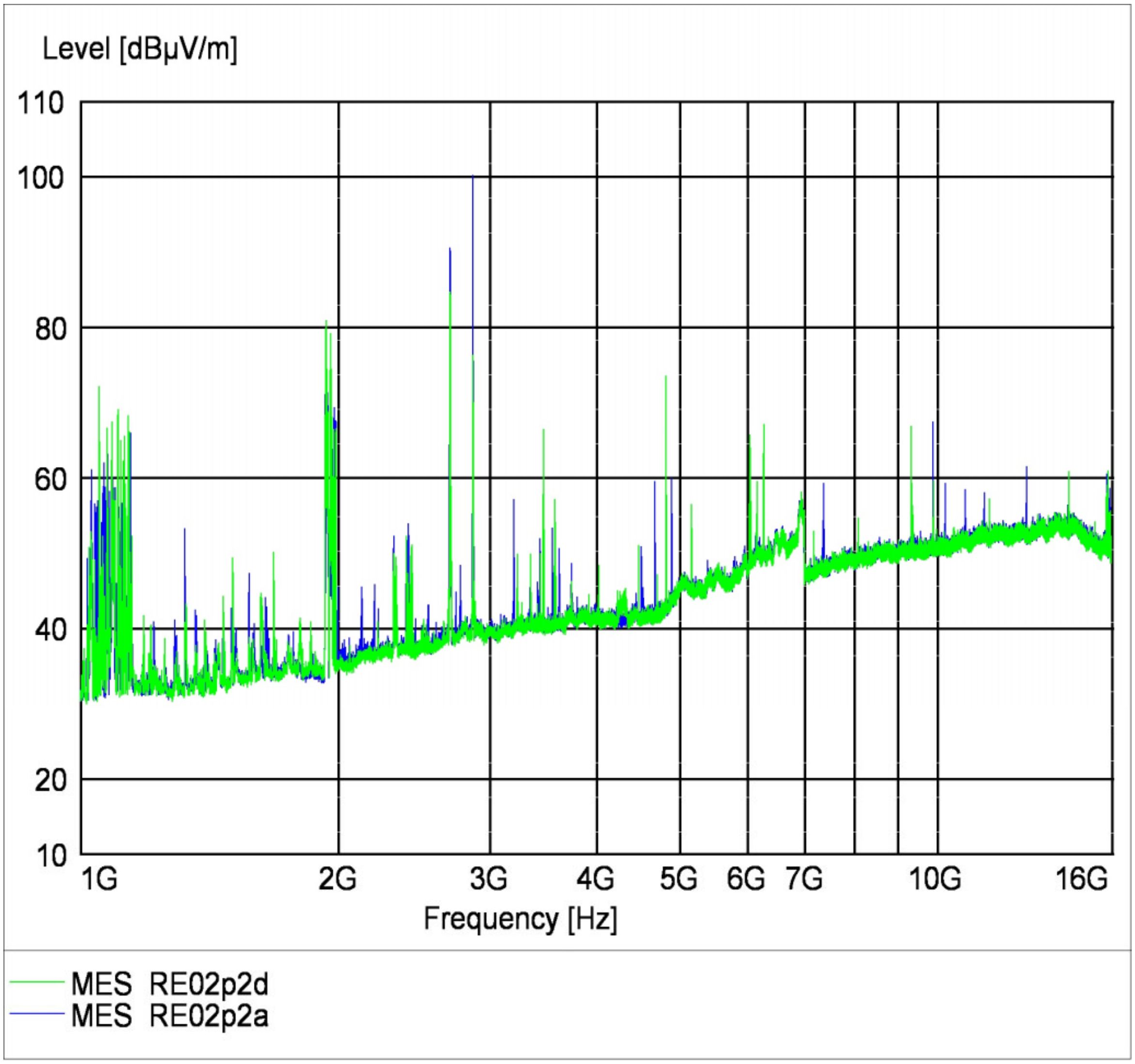
## EMI Laboratory

| | |
|---|---|
| EUT: | Photovoltaic Power Trailer |
| EUT Engineer(s): | Sam Hussey, Anthony Colozza, Ian Jakupca |
| Test Engineer(s): | Mike Herlacher, Gary Wroten |
| Operating Condition: | 9:51A, 1 Aug 2007, 88F, 53%RH |
| Test Site: | Open air test site between Bldgs 334 & 332 |
| Test Spec/Plan: | Radiated Emissions Verbal Plan |
| Comment: | Antenna at left, Vertical polarity |
| | Traces: GRN – Photo-cells open |
| | BLU - Background |

## SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |




**Frequencies seen in current mode (RE02p2d) and not in background (RE02p2a)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 3.407 | 17 |
| 3.475 | 26 |
| 4.833 | 30 |
| 5.174 | 12 |
| 6.055 | 17 |
| 6.061 | 15 |
| 6.284 | 13 |
| 6.290 | 18 |
| 9.340 | 17 |

Radiated Electric Field High Band, Antenna at Left.

### V.3 Photo-Cells and Regulator Active

## NASA Glenn Research Center

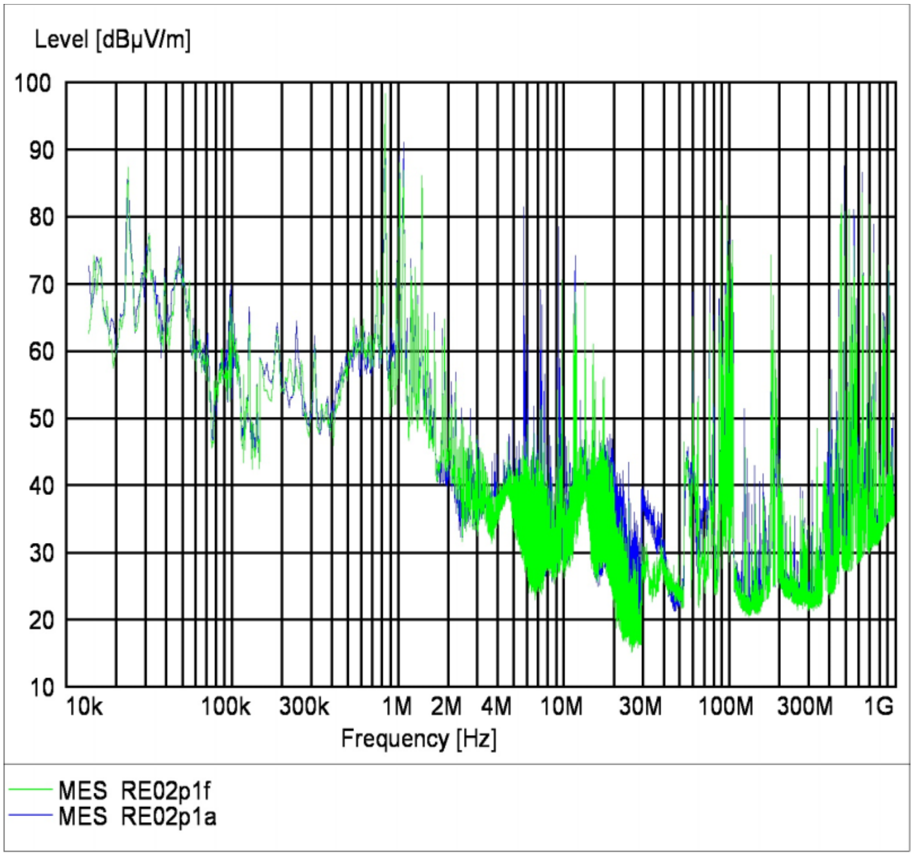
## EMI Laboratory

```
EUT:                 Photovoltaic Power Trailer
EUT Engineer(s):     Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):    Mike Herlacher, Gary Wroten
Operating Condition: 10:46A, 1 Aug 2007, 93F, 41%RH
Test Site:           Open air test site between Bldgs 334 & 332
Test Spec/Plan:      Radiated Emissions Verbal Plan
Comment:             Antenna at rear, Vertical polarity
                     Traces: GRN – Photo-cells open, Regulator active
                             BLU - Background
```

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MH | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |




**Frequencies seen in current mode (RE02p1f) and not in background (RE02p1a)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 15.22 | 16 |
| 15.37 | |
| 15.74 | |
| 17.63 | 14 |
| 17.87 | |
| 345.1 | 16 |

## NASA Glenn Research Center

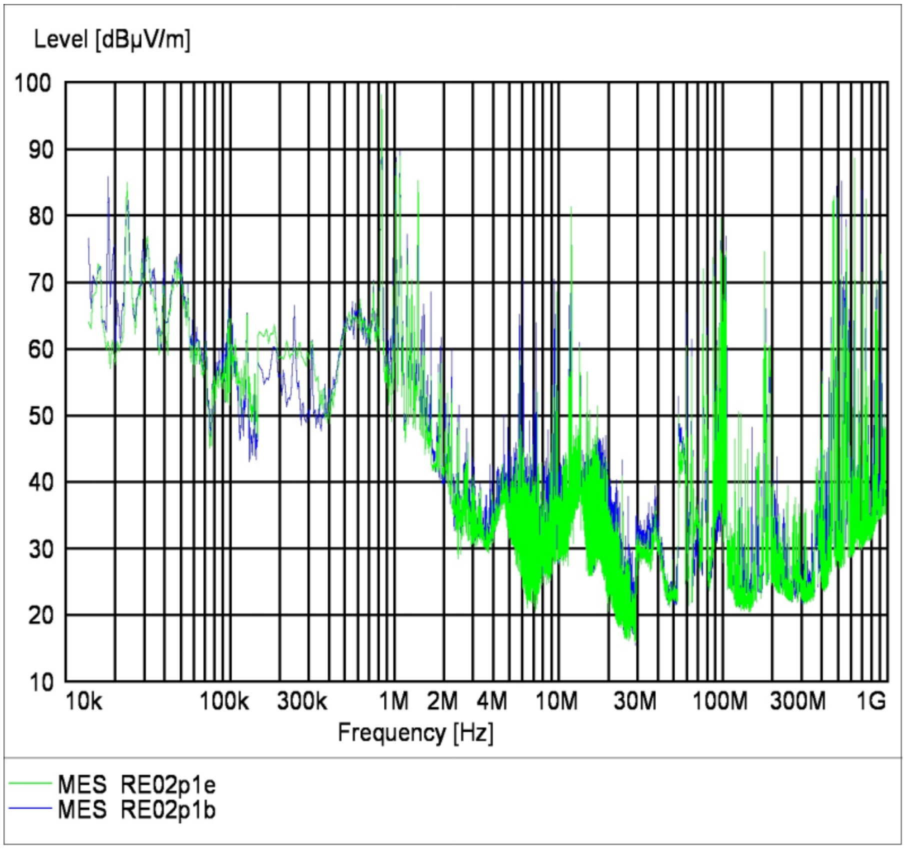
## EMI Laboratory

```
EUT:                    Photovoltaic Power Trailer
EUT Engineer(s):        Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):       Mike Herlacher, Gary Wroten
Operating Condition:    10:33A, 1 Aug 2007, 91F, 40%RH
Test Site:              Open air test site between Bldgs 334 & 332
Test Spec/Plan:         Radiated Emissions Verbal Plan
Comment:                Antenna at left, Vertical polarity
                        Traces: GRN – Photo-cells open, Regulator active
                                BLU - Background
```

# SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |




**Frequencies seen in current mode (RE02p1e) and not in background (RE02p1b)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 15.22 | 16 |

## NASA Glenn Research Center

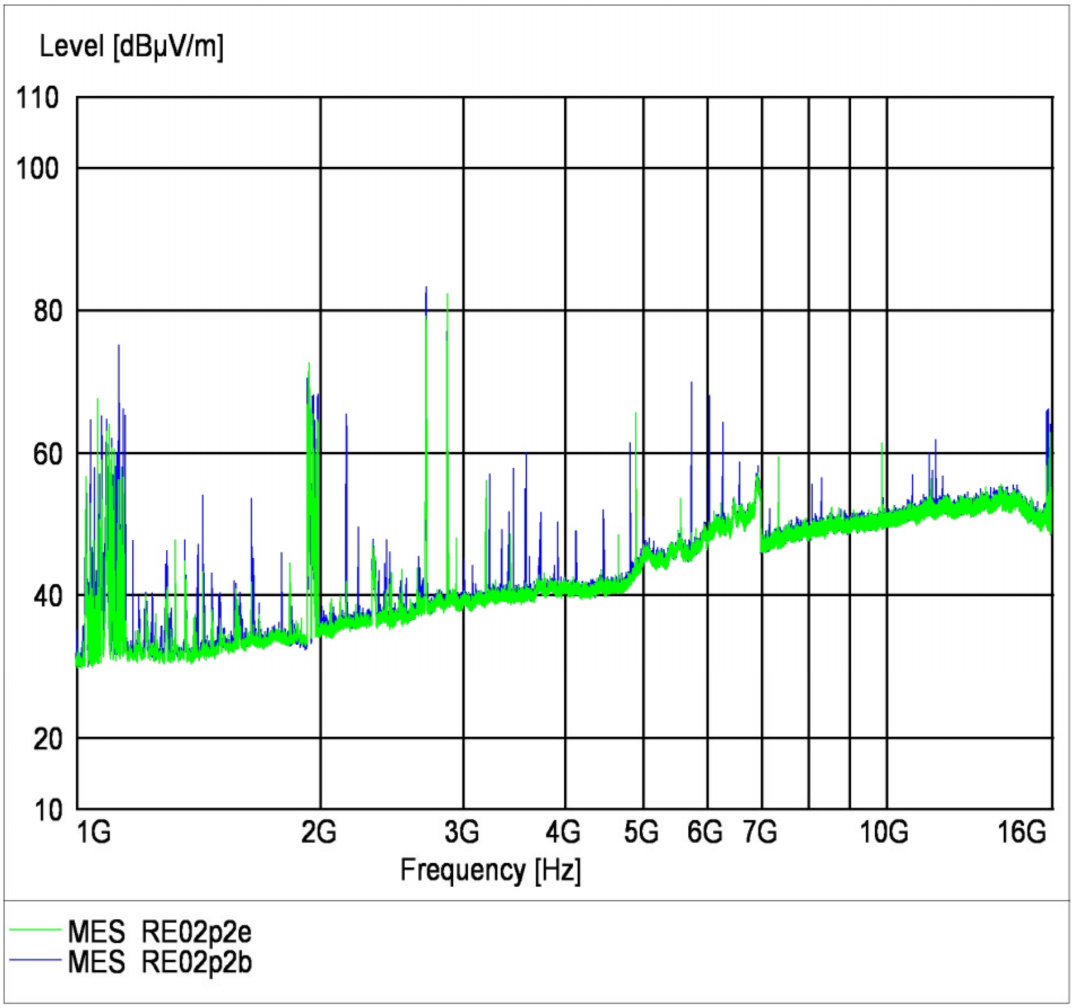
## EMI Laboratory

| | |
|---|---|
| EUT: | Photovoltaic Power Trailer |
| EUT Engineer(s): | Sam Hussey, Anthony Colozza, Ian Jakupca |
| Test Engineer(s): | Mike Herlacher, Gary Wroten |
| Operating Condition: | 11:02A, 1 Aug 2007, 93F, 41%RH |
| Test Site: | Open air test site between Bldgs 334 & 332 |
| Test Spec/Plan: | Radiated Emissions Verbal Plan |
| Comment: | Antenna at rear, Vertical polarity |
| | Traces: GRN – Photo-cells open, Regulator active |
| | BLU - Background |

## SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |



**Frequencies seen in current mode (RE02p2e) and not in background (RE02p2b)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 3.211 | 16 |
| 4.910 | 23 |
| 7.375 | 12 |
| 9.891 | 11 |

## NASA Glenn Research Center

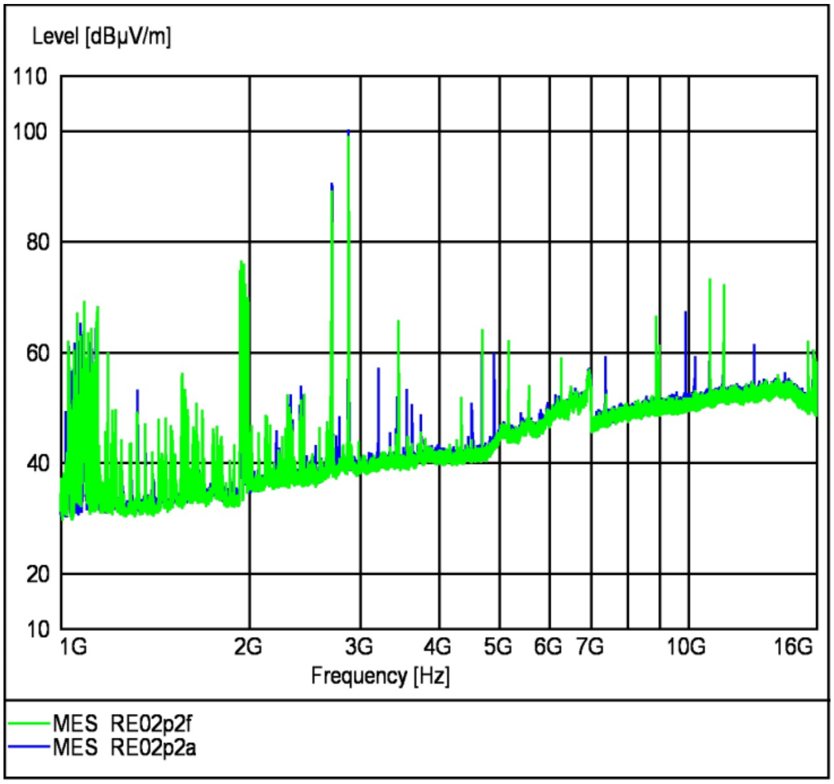
## EMI Laboratory

```
EUT:                   Photovoltaic Power Trailer
EUT Engineer(s):       Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):      Mike Herlacher, Gary Wroten
Operating Condition: 11:17A, 1 Aug 2007, 91F, 38%RH
Test Site:             Open air test site between Bldgs 334 & 332
Test Spec/Plan:        Radiated Emissions Verbal Plan
Comment:               Antenna at left, Vertical polarity
                       Traces: GRN – Photo-cells open, Regulator active
                               BLU - Background
```

## SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |




**Frequencies seen in current mode (RE02p2f) and not in background (RE02p2a)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 1.189 | 28 |
| 5.172 | 18 |
| 8.881 | 17 |

V.4 Photo-Cells, Regulator, Inverter, and Low Load Active

## NASA Glenn Research Center

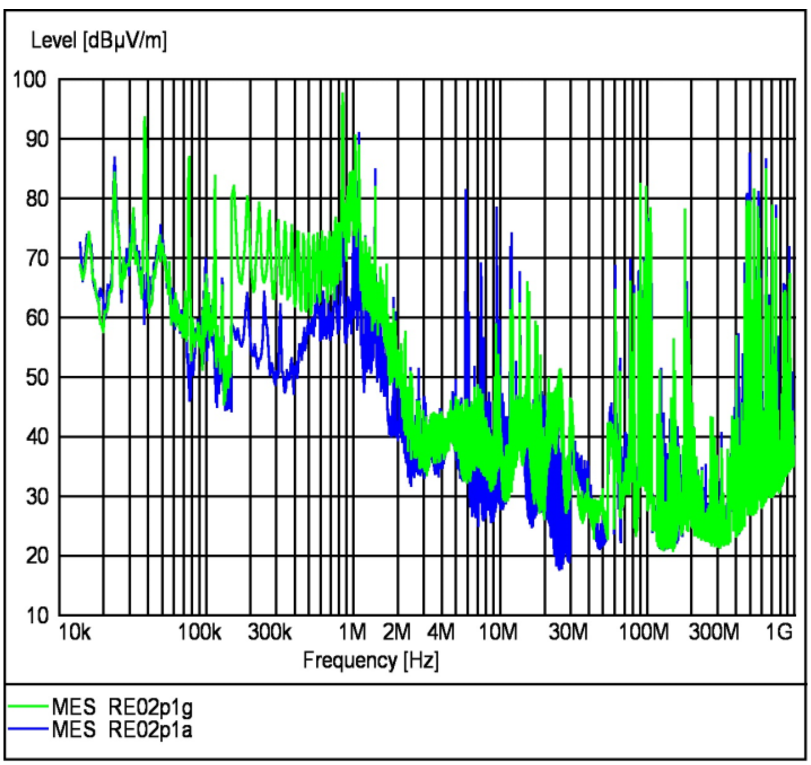
## EMI Laboratory

```
EUT:                     Photovoltaic Power Trailer
EUT Engineer(s):         Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):        Mike Herlacher, Gary Wroten
Operating Condition:     12:15P, 1 Aug 2007, 93F, 33%RH
Test Site:               Open air test site between Bldgs 334 & 332
Test Spec/Plan:          Radiated Emissions Verbal Plan
Comment:                 Antenna at rear, Vertical polarity
                         Traces: GRN – Photo-cells open, Regulator & Inverter
active,
                                 Low load
                         BLU - Background
```

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |



**Frequencies seen in current mode (RE02p1g) and not in background (RE02p1a)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 0.0385 (Fundamental) | 28 |
| 0.077 (2nd Harmonic) | 24 |
| 0.115 (3rd Harmonic) | 20 |
| 0.500 (13th Harmonic) | 17 |
| 1.65 (43rd Harmonic) | 8 |
| 29.990 (779th Harmonic) | 6 |
| 15.37 | 18 |
| 15.82 | |
| 17.48 | 17 |
| 17.87 | |
| 18.93 | |

# NASA Glenn Research Center

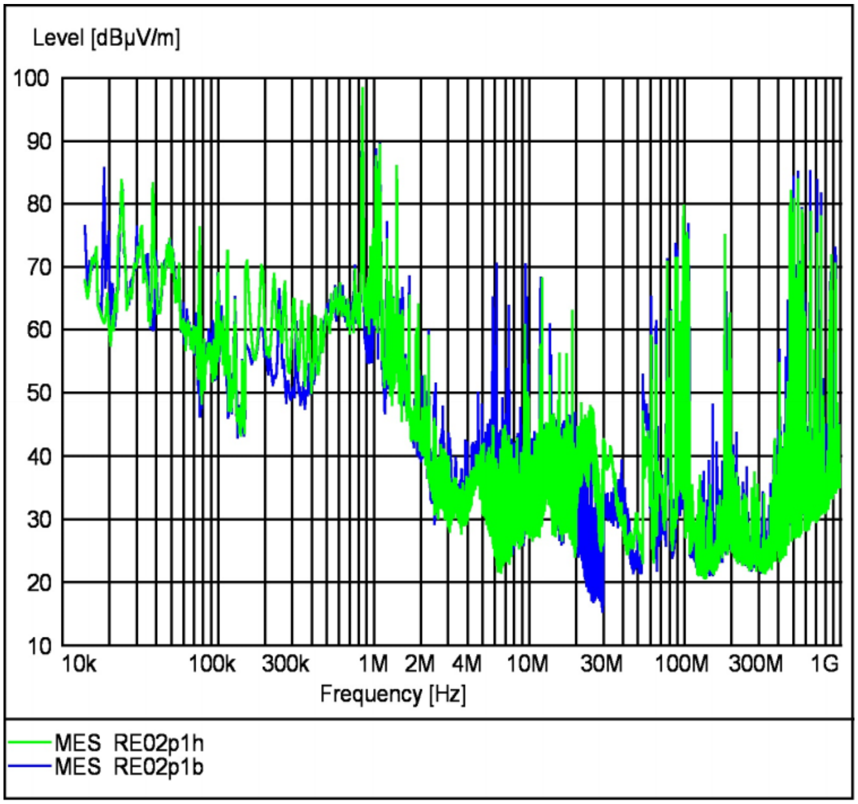
# EMI Laboratory

```
EUT:                    Photovoltaic Power Trailer
EUT Engineer(s):        Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):       Mike Herlacher, Gary Wroten
Operating Condition:    12:28P, 1 Aug 2007, 95F, 34%RH
Test Site:              Open air test site between Bldgs 334 & 332
Test Spec/Plan:         Radiated Emissions Verbal Plan
Comment:                Antenna at left, Vertical polarity
                        Traces: GRN – Photo-cells open, Regulator & Inverter
active,
                               Low load
                        BLU - Background
```

# SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |




**Frequencies seen in current mode (RE02p1h) and not in background (RE02p1b)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 0.0385 (Fundamental) | 18 |
| 0.077 (2nd Harmonic) | 19 |
| 15.77 | 16 |
| 17.48 | 13 |
| 18.93 | 20 |

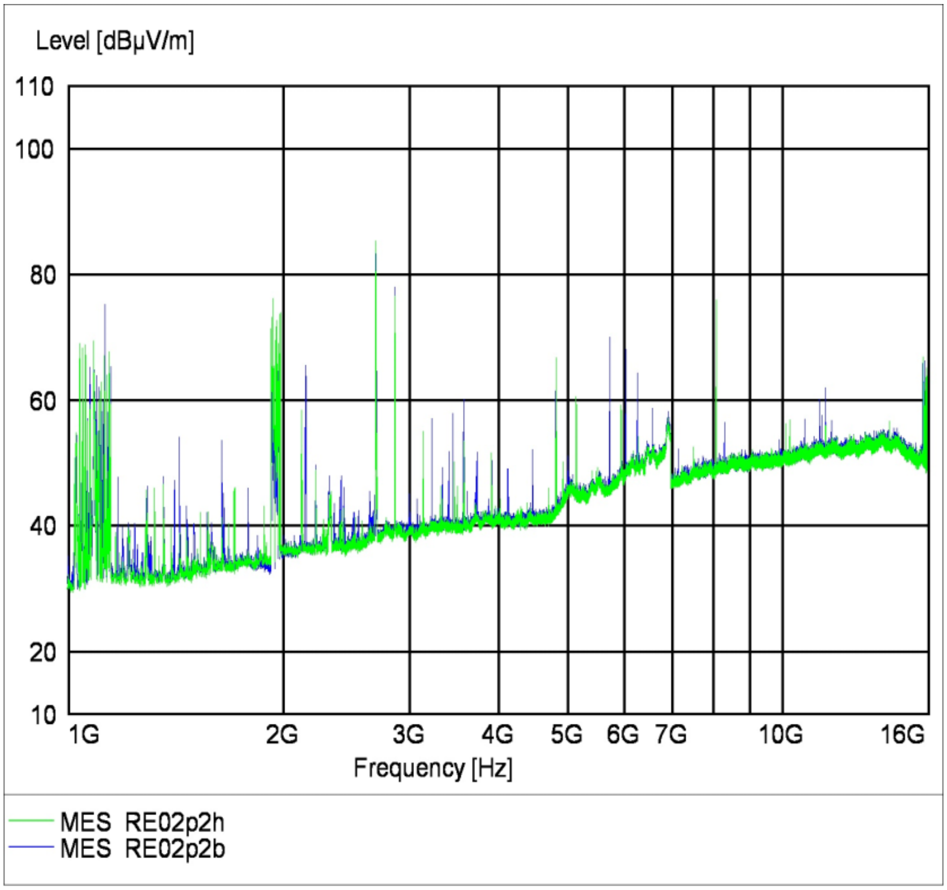
## NASA Glenn Research Center

## EMI Laboratory

EUT: Photovoltaic Power Trailer
EUT Engineer(s): Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s): Mike Herlacher, Gary Wroten
Operating Condition: 12:02P, 1 Aug 2007, 93F, 37%RH
Test Site: Open air test site between Bldgs 334 & 332
Test Spec/Plan: Radiated Emissions Verbal Plan
Comment: Antenna at rear, Vertical polarity
Traces: GRN – Photo-cells open, Regulator & Inverter active,
Low load
BLU - Background

# SCAN TABLE: "30237 RE02p2"

| *Short Description:* | | | *30237 RE02p2* | | *In1DC* | |
|---|---|---|---|---|---|---|
| **Start Frequency** | **Stop Frequency** | **Step Width** | **Detector** | **Meas. Time** | **IF Bandw.** | **Transducer** |
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |




**Frequencies seen in current mode (RE02p2h) and not in background (RE02p2b)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 3.156 | 14 |
| 5.159 | 16 |
| 8.109 | 26 |

## NASA Glenn Research Center

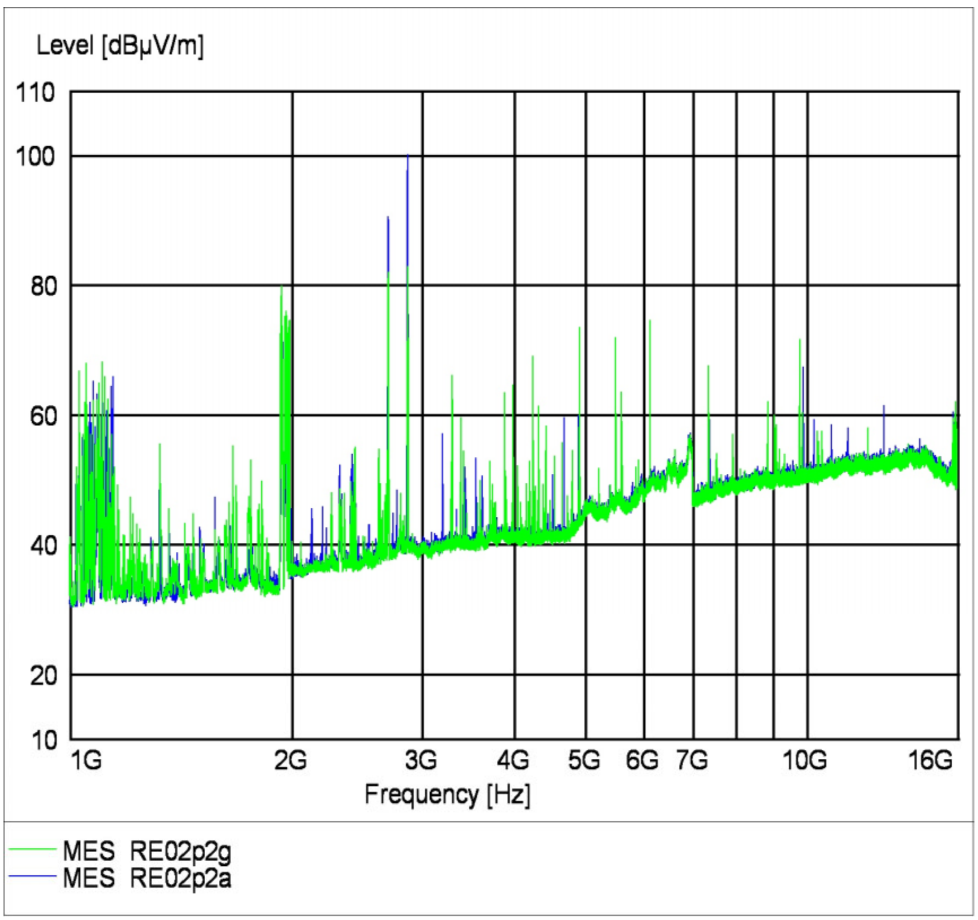
## EMI Laboratory

| | |
|---|---|
| EUT: | Photovoltaic Power Trailer |
| EUT Engineer(s): | Sam Hussey, Anthony Colozza, Ian Jakupca |
| Test Engineer(s): | Mike Herlacher, Gary Wroten |
| Operating Condition: | 11:47A, 1 Aug 2007, 93F, 37%RH |
| Test Site: | Open air test site between Bldgs 334 & 332 |
| Test Spec/Plan: | Radiated Emissions Verbal Plan |
| Comment: | Antenna at left, Vertical polarity |
| | Traces: GRN – Photo-cells open, Regulator & Inverter active, Low load |
| | BLU - Background |

## SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |



**Frequencies seen in current mode (RE02p2g) and not in background (RE02p2a)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 2.628 | 17 |
| 3.302 | 26 |
| 3.398 | 20 |
| 3.897 | 23 |
| 3.994 | 24 |
| 4.248 | 28 |
| 4.332 | 21 |
| 4.432 | 17 |
| 5.501 | 25 |
| 5.608 | 17 |
| 6.125 | 26 |

## V.5 All Trailer Equipment on With Lamp Loading

## NASA Glenn Research Center

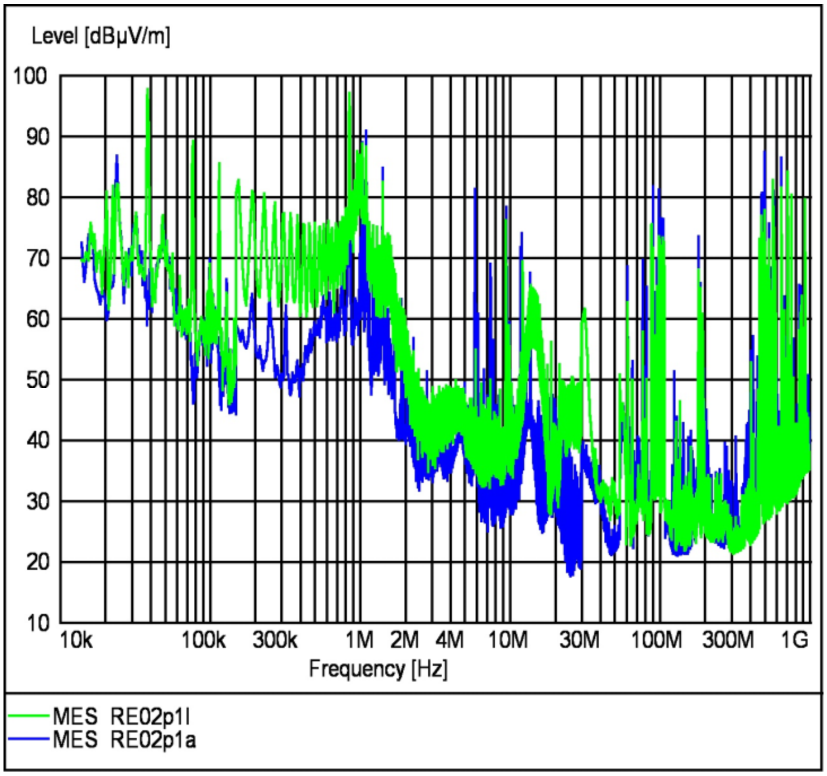
## EMI Laboratory

```
EUT:                    Photovoltaic Power Trailer
EUT Engineer(s):        Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):       Mike Herlacher, Gary Wroten
Operating Condition:    3:58P, 1 Aug 2007, 93F, 37%RH
Test Site:              Open air test site between Bldgs 334 & 332
Test Spec/Plan:         Radiated Emissions Verbal Plan
Comment:                Antenna at rear, Vertical polarity
                        Traces: GRN – Photo-cells open, Regulator & Inverter
active,
                                Heavy load, Charger out = 8.9A
                             BLU - Background
```

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |




**Frequencies seen in current mode (RE02p1l) and not in background (RE02p1a)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 0.0385 (F) | 30 |
| 0.077 (2) | 36 |
| 0.115 (3) | 30 |
| 18.93 | 14 |
| 21.52 | 14 |

## NASA Glenn Research Center

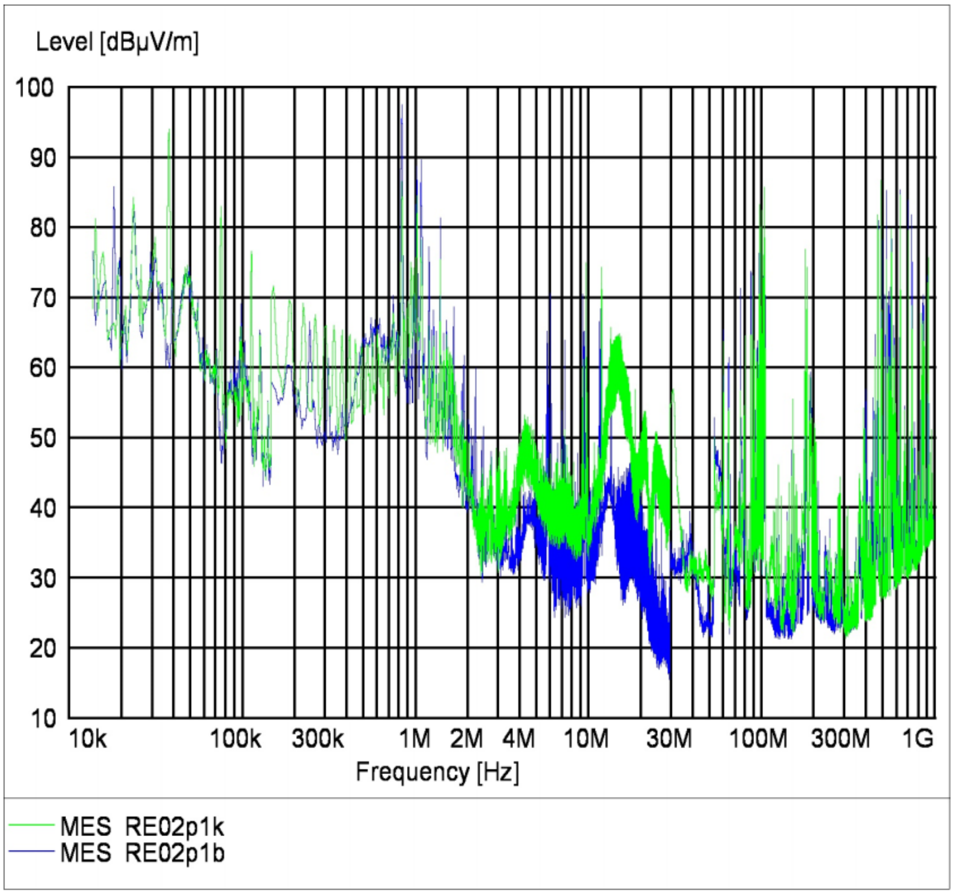
## EMI Laboratory

EUT: Photovoltaic Power Trailer
EUT Engineer(s): Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s): Mike Herlacher, Gary Wroten
Operating Condition: 3:44P, 1 Aug 2007, 93F, 40%RH
Test Site: Open air test site between Bldgs 334 & 332
Test Spec/Plan: Radiated Emissions Verbal Plan
Comment: Antenna at left, Vertical polarity
Traces: GRN – Photo-cells open, Regulator & Inverter active,
Heavy load, Charger out = 8.9A
BLU - Background

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |




**Frequencies seen in current mode (RE02p1k) and not in background (RE02p1b)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 0.0385 (F) | 25 |
| 0.077 (2) | 25 |
| 0.115 (3) | 19 |
| 18.93 | 16 |

## NASA Glenn Research Center

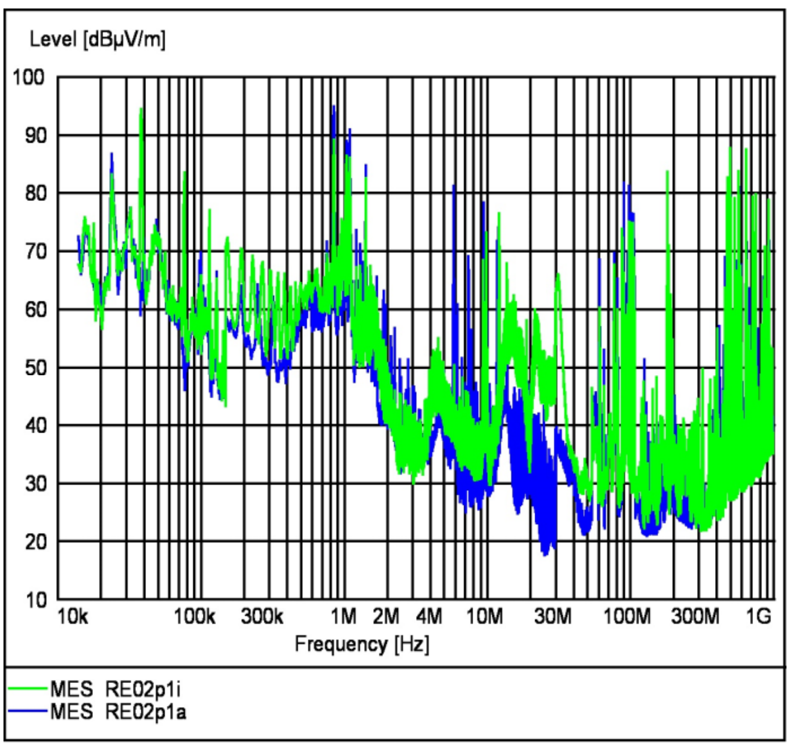
## EMI Laboratory

EUT: Photovoltaic Power Trailer
EUT Engineer(s): Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s): Mike Herlacher, Gary Wroten
Operating Condition: 3:10P, 1 Aug 2007, 95F, 38%RH
Test Site: Open air test site between Bldgs 334 & 332
Test Spec/Plan: Radiated Emissions Verbal Plan
Comment: Antenna at right, Vertical polarity
Traces: GRN – Photo-cells open, Regulator & Inverter active,
Heavy load, Charger out = 9.1A
BLU - Background

## SCAN TABLE: "30237 RE02p1"

*Short Description:* *30237 RE02p1* *In2DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 14.0 kHz | 150.0 kHz | 500.0 Hz | MaxPeak | 20.0 ms | 1 kHz | AA SAS-2A/M (1052) |
| 150.0 kHz | 30.0 MHz | 5.0 kHz | MaxPeak | 20.0 ms | 10 kHz | AA SAS-2A/M (1052) |
| 30.0 MHz | 1.0 GHz | 50.0 kHz | MaxPeak | 20.0 ms | 100 kHz | AA SAS-2A/M (1052) |



**Frequencies seen in current mode (RE02p1i) and not in background (RE02p1a)**

| Frequency (MHz) | Level above noise floor (dB) |
|---|---|
| 0.0385 (F) | 27 |
| 0.077 (2) | 26 |
| 0.115 (3) | 20 |

Radiated Electric Field Emissions Low Band, Antenna at Right Side.

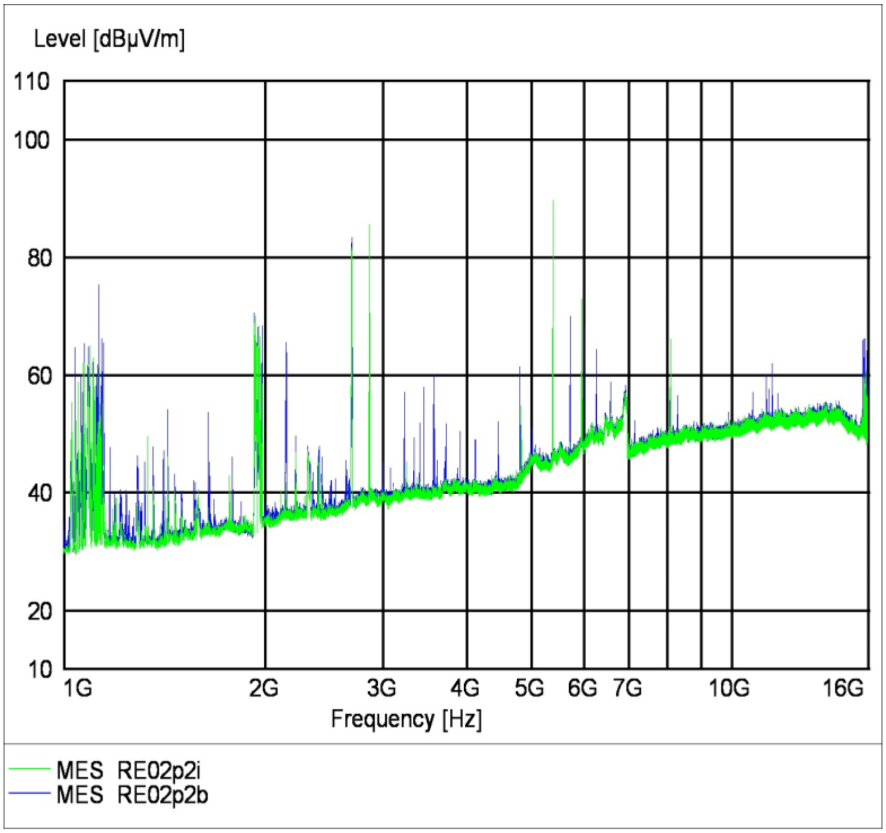
## NASA Glenn Research Center

## EMI Laboratory

```
EUT:                    Photovoltaic Power Trailer
EUT Engineer(s):        Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):       Mike Herlacher, Gary Wroten
Operating Condition:    4:14P, 1 Aug 2007, 93F, 39%RH
Test Site:              Open air test site between Bldgs 334 & 332
Test Spec/Plan:         Radiated Emissions Verbal Plan
Comment:                Antenna at rear, Vertical polarity
                        Traces: GRN – Photo-cells open, Regulator & Inverter
active,
                                Heavy load, Charger out = 8.5A
                              BLU - Background
```

# SCAN TABLE: "30237 RE02p2"

| *Short Description:* | | *30237 RE02p2* | | | *In1DC* | |
|---|---|---|---|---|---|---|
| **Start Frequency** | **Stop Frequency** | **Step Width** | **Detector** | **Meas. Time** | **IF Bandw.** | **Transducer** |
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |




**Frequencies seen in current mode (RE02p2i) and not in background (RE02p2b)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 5.411 | 44 |
| 5.984 | 24 |
| 8.127 | 15 |

## NASA Glenn Research Center

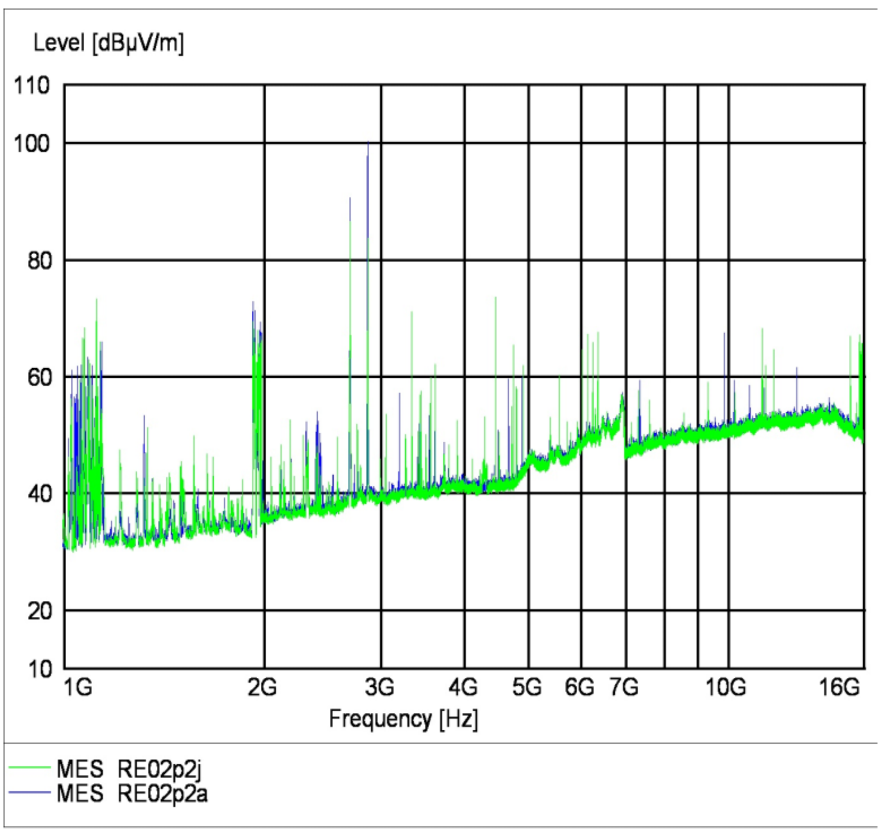
## EMI Laboratory

```
EUT:                    Photovoltaic Power Trailer
EUT Engineer(s):        Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):       Mike Herlacher, Gary Wroten
Operating Condition:    4:28P, 1 Aug 2007, 95F, 37%RH
Test Site:              Open air test site between Bldgs 334 & 332
Test Spec/Plan:         Radiated Emissions Verbal Plan
Comment:                Antenna at left, Vertical polarity
                        Traces: GRN – Photo-cells open, Regulator & Inverter
active,
                                High load, Charger out = 8.5A
                                BLU - Background
```

## SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| Start Frequency | Stop Frequency | Step Width | Detector | Meas. Time | IF Bandw. | Transducer |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |



**Frequencies seen in current mode (RE02p2j) and not in background (RE02p2a)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 4.477 | 32 |
| 6.050 | 17 |
| 6.164 | 18 |
| 6.278 | 16 |
| 6.395 | 18 |
| 11.297 | 16 |
| 11.755 | 12 |
| 15.302 | 16 |

# NASA Glenn Research Center

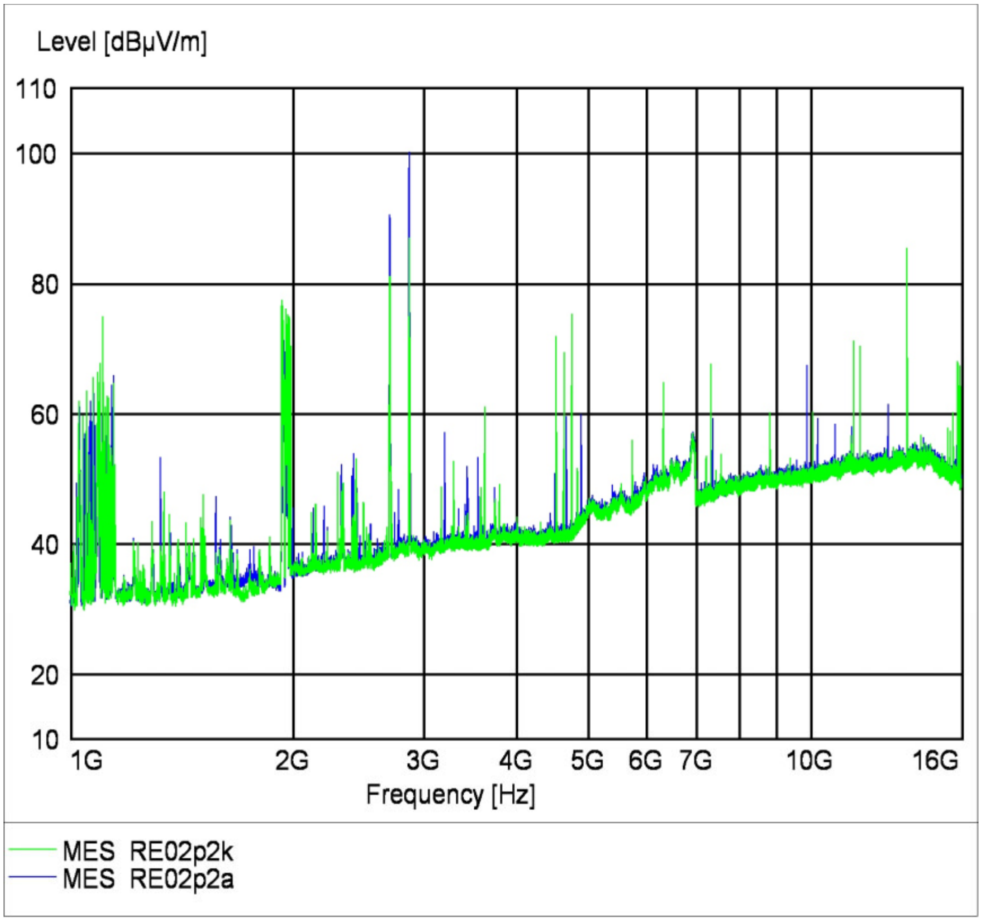
# EMI Laboratory

```
EUT:                     Photovoltaic Power Trailer
EUT Engineer(s):         Sam Hussey, Anthony Colozza, Ian Jakupca
Test Engineer(s):        Mike Herlacher, Gary Wroten
Operating Condition:     4:43P, 1 Aug 2007, 93F, 35%RH
Test Site:               Open air test site between Bldgs 334 & 332
Test Spec/Plan:          Radiated Emissions Verbal Plan
Comment:                 Antenna at right, Vertical polarity
                         Traces: GRN – Photo-cells open, Regulator & Inverter
active,
                                    High load, Charger out = 8.1A
                              BLU - Background
```

# SCAN TABLE: "30237 RE02p2"

*Short Description:* *30237 RE02p2* *In1DC*

| **Start Frequency** | **Stop Frequency** | **Step Width** | **Detector** | **Meas. Time** | **IF Bandw.** | **Transducer** |
|---|---|---|---|---|---|---|
| 1.0 GHz | 16.0 GHz | 500.0 kHz | MaxPeak | 20.0 ms | 1 MHz | PA 3115 (3558) |




**Frequencies seen in current mode (RE02p2k) and not in background (RE02p2a)**

| Frequency (GHz) | Level above noise floor (dB) |
|---|---|
| 6.339 | 16 |
| 11.467 | 19 |
| 11.696 | 17 |
| 13.527 | 33 |

Radiated Electric Field Emissions High Band, Antenna at Right Side.

| **REPORT DOCUMENTATION PAGE** | | | | | | *Form Approved* *OMB No. 0704-0188* |
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**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

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**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
A stand alone, mobile photovoltaic power system along with a cable deployment system was designed and constructed to take part in the Desert Research And Technology Studies (RATS) lunar surface human interaction evaluation program at Cinder Lake, Arizona. The power system consisted of a photovoltaic array/battery system. It is capable of providing 1 kW of electrical power. The system outputs were 48 V DC, 110 V AC, and 220 V AC. A cable reel with 200 m of power cable was used to provide power from the trailer to a remote location. The cable reel was installed on a small trailer. The reel was powered to provide low to no tension deployment of the cable. The cable was connected to the 220 V AC output of the power system trailer. The power was then converted back to 110 V AC on the cable deployment trailer for use at the remote site. The Scout lunar rover demonstration vehicle was used to tow the cable trailer and deploy the power cable. This deployment was performed under a number of operational scenarios, manned operation, remote operation and tele-robotically. Once deployed, the cable was used to provide power, from the power system trailer, to run various operational tasks at the remote location.

**15. SUBJECT TERMS**
Photovoltaic conversion; Power distribution

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON** |
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