IAC-18-C3.1.11

Development of an RFID System for SPS-ALPHA

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Abstract

The SPS-ALPHA Space Solar architecture appears promising as a possible future sustainable energy means. One major challenge presented is the large size and complexity of the systems to be built. These systems will likely be assembled in space at least semi-autonomously by robots that would need to understand what each component of the structure is and how it should be connected with the others. In this paper, we will propose a system for identifying each component for the development of the structure in space. The system involves utilizing unique codes that are embedded in the systems of every part of the structure that tell what part it is, where it belongs in the overall completed structure, and which components neighbor it. This system involves using passive RFID tags located in the body of each part to be assembled. During the build period, if a robot detects it is in close proximity to a part, it can send out a signal that activates the RFID technology in the part and obtain its identifying code. RFID technology is low-cost and can serve as a verification that the robot has obtained the correct component. This system will make the process of assembling the SPS-ALPHA structure in space one that is orderly instead of chaotic, and ultimately feasible.

Keywords: Space Solar, RFID

1. Introduction

With the global increase in energy dependency, alternatives to conventional fossil fuel energy generation have become increasingly important. About 66 percent of the world's energy needs are met by burning fossil fuels [1]. Among the alternatives are efforts to harness solar power. Solar power allows for the generation of energy with the use of energy from the sun. This method reduces environmental pollution by reducing the creation of harmful greenhouse gases that are produced during conventional energy production [2]. The production of solar energy is also sustainable and will soon be economically competitive as fossil fuels deplete and PV cells become more efficient.

Among the many efforts for solar power generation, space solar presents a vital opportunity for the creation of a sustainable, green power source. Existing solar power generation methods are capable of producing electricity, but face limitations in doing so due to intermittent sunlight [2]. Space solar energy generation is capable of reducing these negative effects. Space solar systems usually consist of a photovoltaic array that collects solar power and then wirelessly transmits it to the Earth. By collecting solar energy in geostationary earth orbit, these systems are able to avoid losses in sunlight power intensity [3]. Systems in space can experience large and constant solar flux that is up to 5 times higher than the average flux on the earth's surface [4].

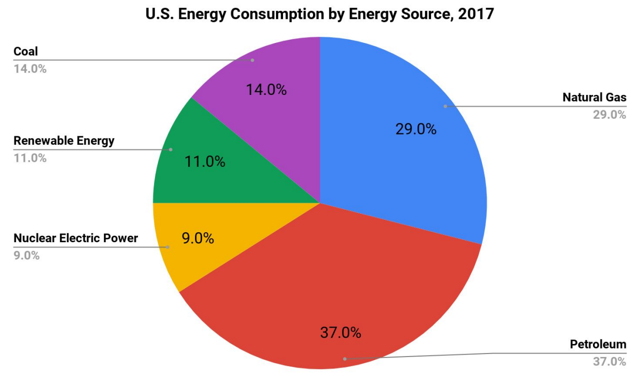


Fig 1. U.S. Energy Consumption by Energy Source, 2017 [1]

The SPS-ALPHA (Solar Power Satellite by means of Arbitrarily Large Phased Array) system as described by John C. Mankins proposes a method of collecting sunlight in space for energy generation [3]. It consists of an assembly of thin-film mirrors that redirects the sun's energy to a large photovoltaic array that converts the energy into electrical power. The resulting electrical power is then beamed from geostationary earth orbit down to earth's surface by means of radio-frequency transmitters capable of sending it at a precise phase [3]. The energy would then be converted and distributed to consumers [3].

In order to create an in-orbit array with the potential to absorb enough sunlight to generate a reasonable amount of energy, it is important that the array is large. Because of this, it is clear that the SPS-ALPHA system in space will have thousands of components.

The question then becomes: "How will this array be assembled?" There are multiple approaches that can be considered regarding this. Due to the complexity and size of the array, it is very likely that the most cost-effective method will involve multiple launches of the components and extensive in-orbit assembly [3]. One method could involve the use of port confirmation. If each part in the array were to have a port that was capable of transmitting information regarding what it was and it exact final destination in the array's architecture, an autonomous robot could potentially survey each part, find the port, and then know exactly where it belongs in the structure. Although this idea seems like it could be feasible, it soon loses feasibility when considering the increased costs and potential design changes that the entire system would experience in order to install said port on every component. Also, this method would require increased physical interaction that can increase the risk of component collision and damage and multiply assembly time.

Another method to be considered involves the use of bar codes. Each component in the system could be assigned a unique id represented in a bar code. During the assembly process, each component's code could be scanned, enabling autonomous systems to identify the part. This idea seems possible as well because of the idea that barcodes could withstand harsh conditions and still function properly, but it loses its appeal when considering that barcodes hold limited data, and cannot be changed once deployed. This method could potentially be used to support another assembly method.

One more method that could make in-space assembly feasible involves the implementation of a radio frequency identification, or RFID system. In this system, RFID tags embedded in system components would be used to store and send information on the component's specifications and final location in the overall structure.

In this paper, a system for using RFID technology will be specified. This system will allow for a more orderly in-space assembly process for the SPS-ALPHA architecture and easier navigation and maintenance of the satellite once it is constructed.

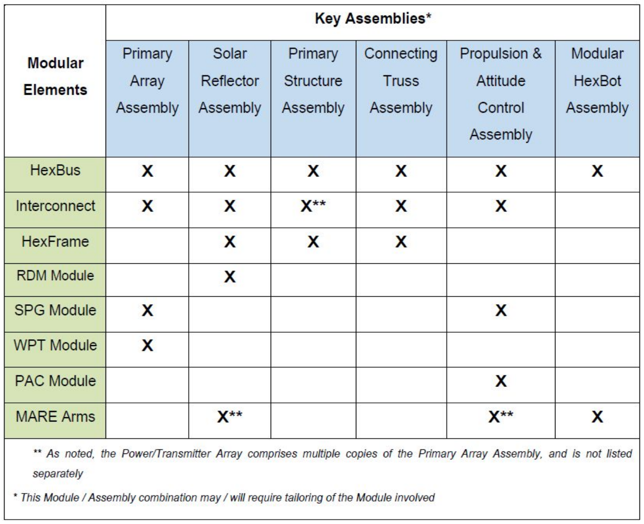
2. Part Identification System

The SPS-ALPHA concept consists of thousands of replicas of each module. The eight modules used are the HexBus, the HexFrame, the Interconnect, the Solar Power Generation (SPG) module, the Wireless Power Transmitter (WPT) module, the Reflector Deployment Module (RDM), the Propulsion and Altitude Control (PAC) module, and the Modular Autonomous Robotic Equipment (MARE) arms [3].

Fig 2. Modular Autonomous Robotic Effectors (MARE) [3]

Autonomous robotic structures will most likely be employed to complete the in-space development of the SPS-ALPHA system. Modules capable of doing so are the Modular Autonomous Robotic Effectors (MARE) as defined by Mankins [3]. These systems are capable of communicating with the HexBus and other modules in the SPS-ALPHA assembly. These systems will be un-tethered to the rest of the system and will have interface fixtures on both ends (Fig. 2), which make them effective for the construction and upkeep of the satellite [3].

In order for there to be successful assembly and maintenance of these components it is necessary for there to be an identification system that provides part identification, location history, and damage history. This allows the MARE system to identify parts and know the location of the part with in the SPS-ALPHA satellite and determine the likelihood of a failure occurring. The SPS-ALPHA architecture has eight different modules and six key assemblies [3]. This can be seen in Table 1 below. In order to represent the 8 modules present on the vertical axis, at least 3 bits of data is required. Likewise, in order to represent the 6 assemblies that construct the satellite, another 3 bits of data is required. One byte each is alloted for module and assembly identification. In order to provide distinction between parts, 4 byte wide unique ID field is added. This would allow for 10^{18} different values to be used in creating distinction between each module.



Modular Elements	**Key Assemblies***					
	Primary Array Assembly	Solar Reflector Assembly	Primary Structure Assembly	Connecting Truss Assembly	Propulsion & Attitude Control Assembly	Modular HexBot Assembly
HexBus	X	X	X	X	X	X
Interconnect	X	X	X**	X	X	
HexFrame		X	X	X		
RDM Module		X				
SPG Module	X				X	
WPT Module	X					
PAC Module					X	
MARE Arms		X**			X**	X

*** As noted, the Power/Transmitter Array comprises multiple copies of the Primary Array Assembly, and is not listed separately*

** This Module / Assembly combination may / will require tailoring of the Module involved*

Table 1. Crosswalk between SPS-ALPHA Modules and Assemblies [3].

In order for the autonomous systems to know where each module is in reference to the satellite, it is proposed that location fields be used. Location fields will map out the space of the entire structure into a coordinate system relative to one point. The data structure of the part identification system enables each component to include the precise location of the part. A proposed breakdown of the part identification system structure can be seen in Table 2. The first two bytes of the part identification would be used to identify the specific module and assembly that the component is from. The following 4 bytes would contain a unique ID field that would be used to differentiate between duplicates of the same module. The next 12 bytes would provide the exact X-axis, Y-axis, and Z-axis positions of where the part is in reference to the location field mapping the entire system. This allows for the mapping of 4294 km with a resolution of 1 mm.

Width in Bytes:	**128**	**874**	**4**	**4**	**4**	**4**	**1**	**1**
	Parity	Operations Log	Z Pos	Y Pos	X Pos	Unique ID Field	Assembly Field	Module Field

Table 2. Breakdown of Part Identification System Data Structure

The remaining 874 bytes of the part identification structure would hold an operations log. This log would catalog specific information about the part and could potentially be rewritten by autonomous systems to log the history of its activity and updates on its status.

In the operations log every entry has the MARE ID, Time, Damage Assessment, and Health fields. The MARE ID stores the Unique ID of the MARE arm which analyzed the part. The Time field is 4 bytes wide and it holds the time on earth when a MARE arm analyzed the module. It stores year, month, date, hour, and minute. The Damage Assessment field stores a rating from 1 to 50. A rating of 50 means critical damage has occurred and a 1 corresponds to minor and easily fixable damage. The Health field stores the health of the module after it had been analyzed. Each entry takes up 14 bytes so the memory is capable of holding 70 entries.

Width in Bytes:	**8**	**4**	**1**	**1**
	MARE ID	Time	Damage	Health

Table 3. Structure of the entries in the Operations log

Width in Bits:	**12**	**4**	**5**	**5**	**6**
	Year	Month	Date	Hour	Minute

Table 4. Structure of the Time field in Table 3.

For example, a segment of a hex bus used in the structure could have data in its operations log indicating that it was last interacted with 5 hours ago and that it has minor damage but should still be functional. Information like this would be vital for autonomous interactions during the repair process. The MARE arms will be able to access some information about the part’s history when deciding if a part is repairable. This will reduce the likelihood of an unusable part being utilized.

3. Passive RFID Circuits

Passive RFID consists of a reader and and a tag [5]. The RFID tag consists of an an antenna and an integrated circuit capable of storing data. When the reader emits a modulated RF signal to the tag, the tag’s circuit receives power through the antenna and responds by varying its input impedance so that it modulates the backscattered signal [6]. This results in the reader receiving data from the tag although the tag does not have an independent power source. Data can be written to the tag by the reader as well using this method.

Passive RFID technology has many uses in industries such as retail, logistics, and even healthcare [6]. Passive RFID is an attractive choice because it has been found to withstand harsh conditions such as gamma ray irradiation and low temperatures [7]. These characteristics are ideal for harsh in-space conditions. RFID tags to be used in the SPS-ALPHA system would need to be designed and tested to operate well in the space radiation environment for a long period of time. The RFID tag data structure would include additional bits to detect and correct possible data errors due to radiation.

Passive RFID is also attractive because it is relatively cheap to implement [8]. Depending on the communication range and frequency of operation, most passive RFID tags can cost less than $1. For an SPS-ALPHA system of thousands of components, it is vital that the part identification system is cost-effective.

4. Error Correction

To detect data errors that can occur, the data structure could employ a Reed-Solomon RS(255,223) error correction code. The RS(255,223) uses a 255 symbol long codeword which consists of 223 symbols of data and 32 symbols of parity [9]. Each symbol is 8 bits wide. We divide the memory of the RFID into 4 codewords which uses up 1020 of the available 1024 bytes.

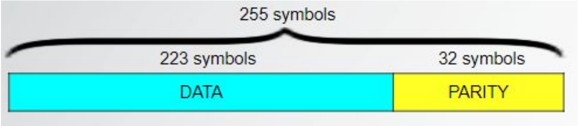


Fig 3. Reed-Solomon RS(255,223) codeword [9]

This code can correct errors in up to 16 symbols located anywhere in the memory [9]. This means that if an error occurs in such a way that all the bit flips are distributed within a set of 16 symbols then the errors can be corrected. If the bit flips are distributed across more than 16 symbols then they cannot be corrected.

5. RFID Theory of Operation

Assembling the SPS-ALPHA system could be done using RFID in the following method. Each module would have an RFID tag with its module and Unique ID fields filled in and the rest empty. When the building sequence is initiated, the MARE arm will locate the needed module and place it where needed. Then it will fill in the Assembly, X, Y, and Z fields of the RFID tag. Once a part is placed, the RFID tag will store data on the part's history. This includes information such as damage occurring to the part or if the part has ever been moved. A moving of a module will be signified by the damage being zero in the operations log. The location fields saved in the part ID structure of the RFID tags can also allow the the tags to be used as reference points on an internal map of the satellite [10].

When enabled, the autonomous MARE arms would approach the part and use a reader/writer to emit a signal at a designated frequency. This signal would provide enough power to activate the RFID tag embedded in the component. Upon activation, the RFID tag would emit a return signal with the data described above. The wireless receivers aboard the autonomous MARE arms would then receive the return signal and decode it using a Reed-Solomon decoder. The MARE arm can also use the reader/writer to write onto the memory of the RFID tag using the following steps. It would read the data from the RFID tag, decode it using RS(255,223) decoder, edit the data, encode it using RS(255,223) and write it onto the RFID tag's memory.

Fig 4. RFID memory write sequence [9]

5. Conclusion

The RFID system proposed in this paper would make the in-space assembly process for the SPS-ALPHA architecture. Embedded RFID tags in each component would allow systems constructing the solar power satellite to obtain comprehensive part information conveniently. The proposed part identification system would ensure that autonomous systems knew exactly which part they are interacting with and where exactly in the system it should be. This system will ultimately improve the SPS-ALPHA assembly, maintenance, and repair processes.

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