Design for Wireless-Powered Couplings in Satellite and Space Vehicles

Masts and panels used in solar paddle arrays for satellites are rigid structures. Paddle facing has limited degrees of freedom when optimizing received solar radiation. This article will discuss a means of inductive power coupling between mast segments which allows more degrees of freedom, both in pitch and rotation, to maximize solar energy input to the vehicle.

Published: 14 November 2022

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Power is a critical component of any satellite craft design. It can be argued it is the *most important* onboard system. While designs to improve power quantity and efficiency have been utilized over the years, at times unsuccessfully, it has yet to be seen a complete rethinking of the way in which these systems function.

Extendable masts are an attractive solution to increasing paddle area within the solar blanket. However, they can be problematic when heated differentially; when the solar paddle mast expands and the panel blanket contracts force is placed on the wired joints. The force is a potential source of failure, as witnessed in the ADEOS I and ADEOS II satellites.

Using inductive coupling between power joints rids the system of such a potential failure offering greater flexibility when designing onboard power for space craft and satellite vehicle systems.

Cartheur Research brings new innovations in the hope of improving performance and increasing the amount of power available for space activities.

Introduction

An intriguing proposition is the use of wireless power, more commonly known as inductive coupling, to act as a flexible joint between power connectors in energized circuits. Uses in very diverse environments allow coupling between disparate components and inhomogeneous connections. Greater freedom of design is expressed and a less rigid insistence on straight-line current delivery.

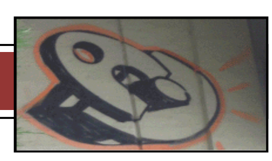
There are advantages to using wireless powered couplings. The most predominant is its ability to allow a larger ratio of error between electronic and mechanical components. In conventional circuitry, wires restrict what could be a more efficient and advantageous strategy when discovering by experience more optimal solutions to power problems.

Equally, there are disadvantages to using wireless powered couplings. While there is a loss of lengths of cabling, there is an addition of circuitry and the introduction of alternating currents at radio-frequencies. In intelligent designs, circuitry is kept to a minimum and energy is contained to power transistors. By proper foresight in the application where the circuits are to be used, the currents can be contained to the paths they conduct upon.

What should also be considered is the efficiency of the scheme. An excellent measure is the difference between energy input to a system compared to the energy extracted. While cabling has shown itself as a highly efficient means of transmitting currents, the direct current (DC) source of solar panel technologies over lengths and temperatures can drop significantly. Oscillating currents (AC) have proven time and time again their great advantage over DC designs. Wireless-powered schemes at stable radio-frequencies have demonstrated better efficiencies at gaps as large as twenty-five centimeters compared to those of cabled alternatives.

Highly energized circuits are necessary to satisfy power-hungry equipment. Large solar arrays can generate substantial amounts of power. Converting from DC to an oscillating scheme seems daunting but with the choice of a properly designed circuit using appropriate semiconductor technologies, conversion ratios are maintained between 90 and 95%.

Cartheur Research is taking a new approach in wireless power couplings which are reliable, high-powered, and robust designs. Our circuits can adapt to effects at the output frequency and stabilize energized sources to changing conditions.



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Theory of Operation

The wireless power system, in its simplest form, consists a transmission element and a receiving element. The transmission element contains an oscillator connected to a source of direct current (DC). The DC current is used to stimulate an antenna which propagates the electric force in its magnetic form across free-space. The receiving element is connected to a load and draws the current from the electromagnetic waves coalescing them into a wire.

A graphical model of the wireless power scheme is shown in Fig. 1.

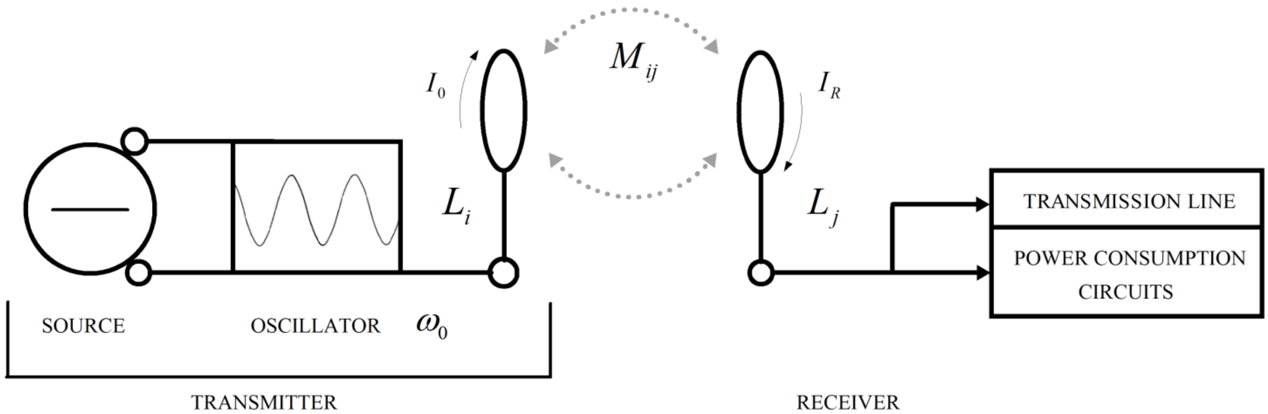

Fig. 1: Wireless Power Operational Design

A stabilized, frequency-free current is introduced to the oscillator, shown on the left side of Fig. 1, called the source. The source can be identified as any current-generating apparatus; for the purposes herein, this is a solar paddle array common in typical satellite deployments. The source is calibrated so that its output power, measured in watts, is regulated to be of the same tolerance as the amplifiers in the oscillator. The oscillator generates a sinusoidal wave of a particular frequency ω_0. The resonance frequency is determined by the properties of the transmission and receiving elements designated L_i and L_j respectively in tandem with a capacitor (not shown). When the values of the inductance L and capacitance C of the i^{th} and j^{th} elements are matched, the transmission and receiving elements form a closed resonant circuit at tension with a given mutual inductance M_{ij}. When a current I_0 is introduced into the transmission element, it is simultaneously observed as I_R flowing in the receiving element. The current, shown on the right side of Fig. 1, is now available to be utilized in other power consuming circuitry, transmission-line cabling, or to a second wireless power coupler. In the latter instance, when using wireless power couplers chained together, the oscillator element is not repeated; rather, added numbers of transmission and receiving elements project the currents across gaps, within a distance tolerance relative to the tension.

The design exhibited in Fig. 1 is generalized in the sense that it is replicated across inhomogeneous components. In the manner how a cabled system is intended in a design to transport currents, this system provides exactly the same service yet provides a dimensional flexibility to the mechanical components which rely on the transport or whose purpose is to delivery quantities of power. A particular modification to the use of cabling with this system is the insistence on transmission-line strength materials, designed specifically to allow the alternating current to continue at its manifest frequency.

Materials having higher relative permittivity support higher sensitivity because the electrical field strength is proportional to the relative permittivity, and inversely proportional to the thickness. The choice of material in the vacuum of space is a point of contention and its ability to transport alternating current valid. An oscillator driven in colder temperatures require more power to sustain them, hence, a sustained “skin” of energy aids in sustaining the circuits which manifest the energy field.

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Sample Application

Wireless coupling provides peak performance and unparalleled utility from drawing board to prototype to manufactured craft. It provides a unique and robust means to solve power distribution problems heretofore considered unsolvable. In consideration of the expected usage of the technology described in this article, for a new satellite craft, such as the ESA Galileo, with a paddle span of 13 meters and peak power of 1600 watts, the wireless power system is configurable to operate under these conditions.

An interesting proposal has been the invention of novel means to extend the paddle length and surface area of the solar blankets. This has been discussed at length in a paper[1] archived by NASA and ESA. The design was used in two Japanese satellites: ADEOS I, launched in August 1996 and ADEOS II, launched in December 2002. In the first instance, the solar array paddle failed due to differential heating when the craft adjusted its attitude to control its orbit. As a result of the maneuver, the solar panel received sunlight from the rear. This caused the solar paddle mast to expand and the panel blanket to contract, placing tension on a soldered joint on the paddle, which eventually severed the wired power connection. In the second instance, the solar panel simply failed. By using wired connections in these novel and useful advancements in solar array paddles, each satellite was only able to remain operational nine months.

In current schemes and in the attempt not to repeat the failures of the ADEOS I and II projects, a folding leaf solar array paddle—similar in the manner to opening a book—has been tried with success. Increase of the length of the solar paddle as well as increase of the surface area of the solar blanket allows more power to be utilized onboard the craft. While a good alternative, folding presents problems in fatigue to cabling and reduces the number of available blanket surfaces by two (one for each paddle arm). Clearly, it is more advantageous to maximize the amount of surface areas equating to maximum power given the current state-of-the-art. Additionally, the use of a solar-array driving mechanism (SADM) that connects the solar array paddles to the spacecraft and rotating them slowly so that the surface of the arrays can remain perpendicular to the Sun's rays at all times is more optimal.

One further improvement is the inclusion of a dimensional flexibility of solar paddle arrays in that paddle segments toward the end of the span can be made flexive.

A typical solar paddle array is shown in Fig. 2.

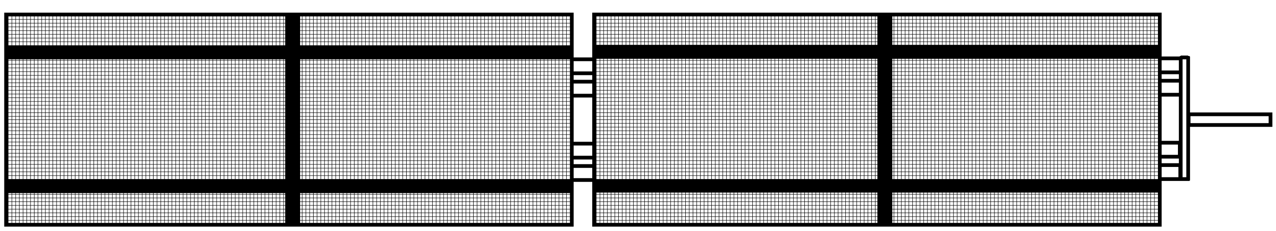

Fig. 2: Common Solar Paddle Array

Such a paddle array, contained in a launch vehicle by folding, provides a stable source of DC current to the satellite craft. Generally used in pairs, these arrays provide all the electricity to the onboard computing, transmission, and sensing systems by leveraging semiconductor technology which converts solar radiation into electrical current. The size and type of the semiconductor panels, shown as closely-packed squares in Fig. 2, determine the amount of current given the area of the panels and their orientation to the direction of solar radiation. For an optimal setting, the full value of current can be generated for the craft or vehicle using them by turning the panels if the solar radiation is less than desired. However, in most cases, only a partial current can be additionally delivered due to the array being limited to one or two degrees of freedom. Flexible mechanical structures have been explored, as previously mentioned, however, there are serious drawbacks. Altering the structure to use wireless powered couplings allows more degrees of freedom enhancing the ability of the craft to maximize its input current by aligning more succinctly with the incoming solar radiation.

[1] Kuramasu, et.al. "Development of Mechanism to Extend the Solar Array Paddle for the Advanced Earth Observing Satellite (ADEOS)", Sixth European Space Mechanisms & Tribology Symposium, Zurich, Switzerland, ESA SP-374, August 1995.

Modifying the common solar paddle array to leverage wireless power couplings is illustrated in Fig. 3.

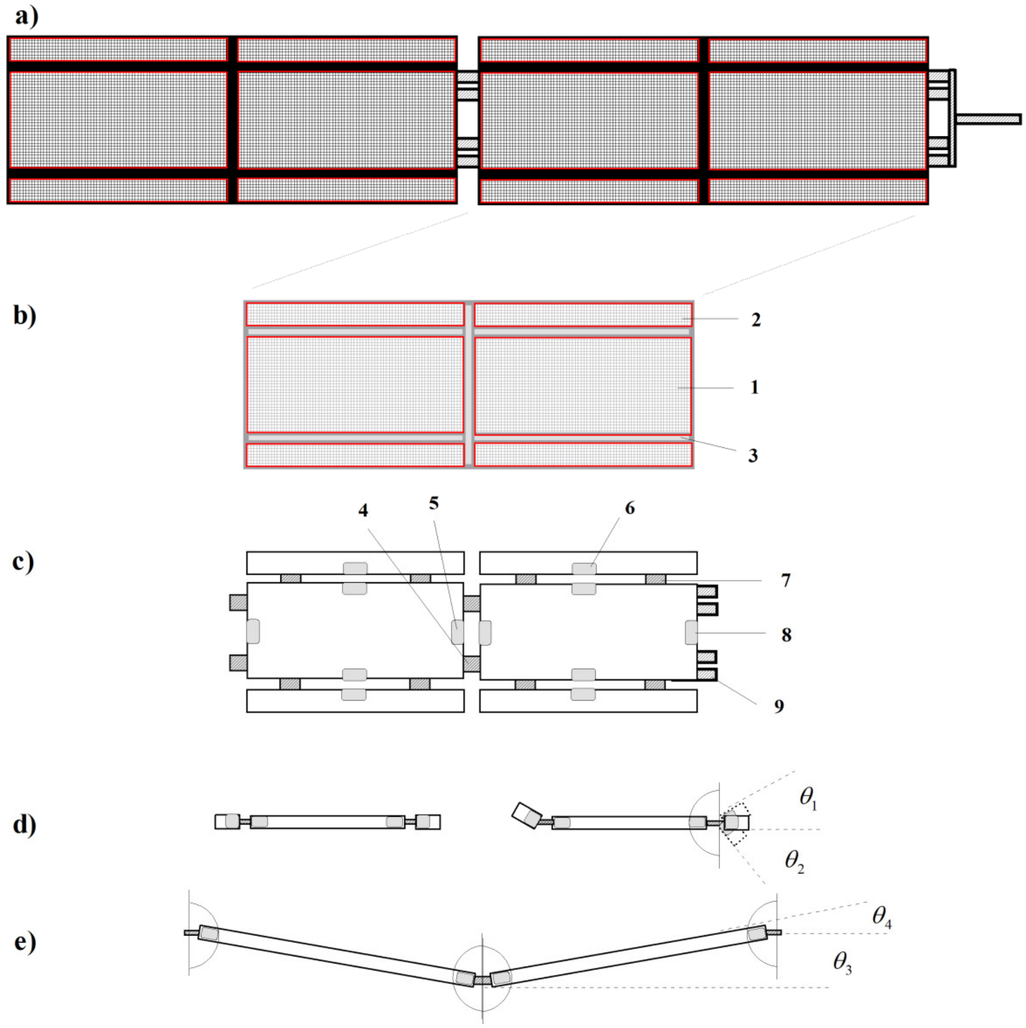

Fig. 3: Flexive Joints using Wireless-Power Couplings

The arrangement, shown in Fig. 3, consists of a set of views of the breakdown of a solar paddle array into flexive mechanical joints, denoted by shading, with wireless power couplings in their expected installation points.

Fig. 3a, following Fig. 2, shows a detail of the components of the solar paddle array for one arm of a satellite implementation. The structures inside the red boxes outline a solar panel used to convert solar energy into electrical current. A single conglomerate of a contiguous panel is shown in Fig. 3b consisting of a center sail **1** and outer sail **2** with flexion gaps **3** separating them. Fig. 3c illustrates what consists the connections nested inside the flexion gaps, consisting of a mechanical hinge joint **4** supporting the rotational mass of the center sail where the wireless power coupling **5** transmits the current in any position of axial flexion given by θ_3 of Fig. 3e. Similarly, the mechanical or electro-mechanical rotational joint **7** supporting the rotational mass of the outer sail where the wireless power coupling **6** transmits the current in any position of flexion given by θ_1 of Fig. 3d. The array, with the components already described, are connected with a mechanical or electro-mechanical rotational joint **9**, of more stiffness than the others so as to support the mass of the array, where the final wireless power coupling **8** transmits the total energy absorbed by the panels to the satellite craft. The power which is fed across the flexion gaps by the wireless power transmitters is intended to experience a minimum distortive impact, meaning where flexion in mechanical connections would not affect power being fed to the craft, in a typical manner, illustrated by the relationship between the array and the connection to the craft θ_3 and θ_4.

Frequency Selectivity and Sensitivity

As it is desirable to project currents at numerous frequencies, the wireless power system is configurable to utilize a range of frequencies. In approaching the problem of selectivity, it is worthwhile to understand which transmission frequency or frequencies are necessary given a particular transport problem. For single-instances, a “blanket” describing a contiguous field across the paddle is the model; for other instances, a pattern of frequencies where some concentrations of energy are greater than others given a particular gap ratio or folding across complex values of θ_n is more interesting. It is feasible at design time which strategy would be most successful.

Selectivity is a crucial consideration when sending a modulated wave over the power carrier signal. Some implementations require high sensitivity where sensors are mounted away from the central control across gaps to report solar intensity, temperature, or infrared readings. Some of these sensors could be designed to behave similarly to accelerometers reporting the exact angle θ_n for complex power optimization schemes. In order to satisfy such conditions, the wireless power couplings are modified to contain modulation circuitry only in the last case (during a chain) when decoding the signal for processing by the computer in the craft.

The energies in description emitted as a wireless transmission between couplings in the gaps has the same susceptibility to interference from the sun as the communications array in sun facing outages when thermal noise is at a maximum.

Conclusion

Currently, we are standing on the threshold of a bright future for humanity. We are becoming more heavily engaged on exploiting activities in space. As public interest and young people are more involved with creating this future, coupled with a longer lifespan, it is our responsibility now to understand how we can improve conditions for not only satellite craft, but also for manned craft, such as the International Space Station (ISS). It is only when we can maintain our presence consistently in space with comfortable, inhabitable dwellings can we plan the next phase of building ships in space designed for longer journeys within our solar system.

The design described in this paper can overcome these issues as it relies on the properties of the materials which consist the transmission and receiving elements and their subsequent properties at the given temperatures and pressures. At its apex, used to create larger and more elaborate arrays, distinctive in how a large, fabric-like surface can bend and contort to absorb maximum solar radiation. As such, it eliminates discussions of dangerous power enhancements as nuclear fission to fill the gap between required power, craft size, and craft complexity. It is the manner in which wireless power and its implications contribute to the understanding of tangible and realistic option in power generation and onboard environmental stability.

For brevity, this article has only described one sample application. There are numerous and varied ways in which wireless power can be leveraged in space activities and it is for the future to decide which research paths are most vital to realizing those new ambitions in space technology and research. It is only a function of the imagination which technologies are most interesting and helpful to support a new era of human activities in space.

Contact Cartheur Research for a project collaboration.

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