MedCrave
Step into the World of Research
Aeronautics and Aerospace Open Access Journal

Research Article

Open Access

Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's

Volume 8 Issue 2 - 2024

Shawn P Boike,[1] Dr. David Hyland[2]

[1]American Industrial Consultants & Insta-Grid's SMF Huntington Beach, USA

[2]Department of Aerospace Engineering, Texas A&M University, USA

Correspondence: Shawn P Boike, American Industrial Consultants & Insta-Grid's SMF Huntington Beach, California 92649/USA, Tel 5623389911, Email spboik@gmail.com

Received: April 29, 2024 | **Published:** May 23, 2024

Abstract

Solar-Microwave Fabric (SMF) is a mass-produced, thin, flexible membrane upon which is imprinted various combinations of solar cells, microwave patch antennas, and analog control devices. This is for applications such as solar power collection, power transmission, communication, and defense. It can be folded into a compact volume for transport and then unfurled for its operation. In its most sophisticated form, the SMF features the full complement of printed devices: solar cells, patch antennas, transceivers, and retro-directive phased array capability. This most mature capability can be applied to the Power-Star in section 1.6 (Figure 46) space solar power satellite, and to ground installations for combined solar power and air defense. The SMF has various modes of operation of, Solar Power Collection, Communications, Distribution & Defensive systems. Ultimately the Power/Comm/Defense has one side printed as an "active" mode of power transmission whereby radiation is broadcast to a non-cooperative target and the return from the target is used as the beacon for the direction of a high-power density beam with focusing (vaporization). This could be applied for both ground-based power collection and air/space defense. World's 1st exposure to: US Patent 11,251,658, Japan Patent 6,987,935.

Keywords: solar, microwave, fabrics, composites

Introduction

The very new and rapidly advancing in 3D printed aka additive manufacturing (Multi-Layer Manufacturing MLM) makes new materials and applications. Printed microwave antennas are also well known and are being advanced at a rapid rate for numerous communication applications. Solar-Microwave Fabric combines these two components on the surface of the same flexible substrate.

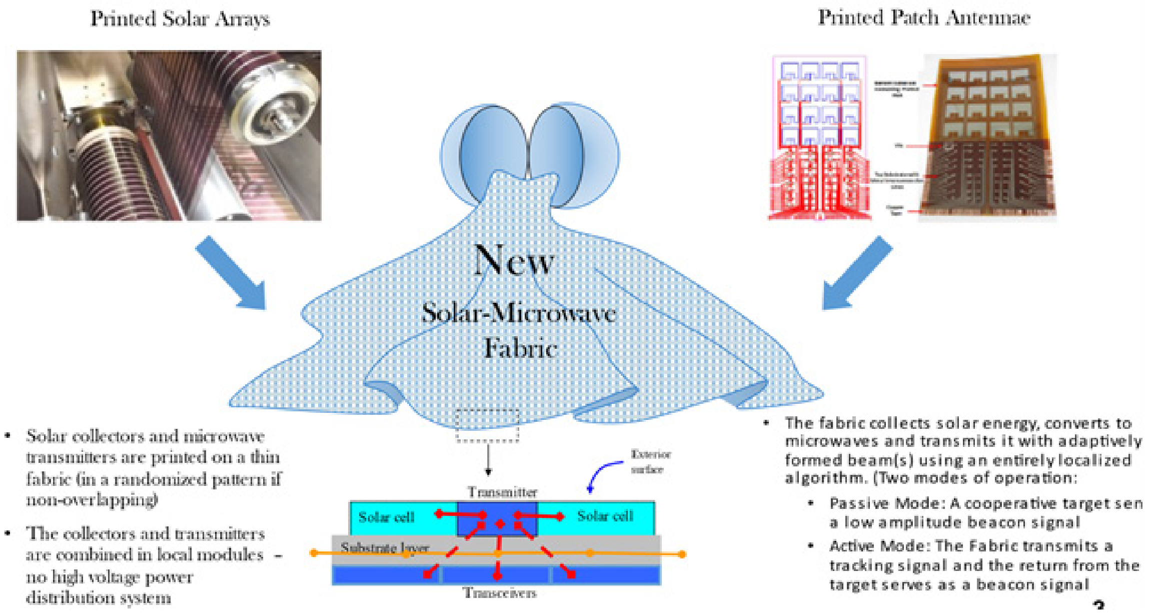
The lower part of Figure 1 illustrates a typical cross-section. The solar cells and patch antennas are interspersed (without overlapping) with a randomized tessellation to eliminate grating lobes. This pattern is printed on what becomes the exterior surface of the substrate sheet or "skin." In the full system, there may also be an array composed solely of microwave transceivers (dual transmitters and receivers) printed on the opposite surface (due to becoming the interior surface of the sphere). Patch antennas on the exterior surface draw power from the immediately adjacent solar cells (a few centimeters distance) or from the interior transceivers, through the thickness of the skin. Details of power transfer are described in the Intra-Satellite Power Distribution section 1.6 (figure 1.6) sub-section below. Besides the short power leads there is a grid of conducting wires for electrical ground and for rigidizing the sphere prior to evacuation. In this section we discuss printed solar cells, printed microwave antennas and choice of substrate material.

Solar-Microwave Fabric (SMF) is a mass-produced thin, flexible membrane upon which is imprinted various combinations of solar cells, microwave patch antennas, and analog control devices, for applications such as solar power collection, power transmission, and communication. This is designed such that it can be folded into a compact volume for transport and then unfurled for its operation.

In its most sophisticated form, the SMF is illustrated in Figure 1, and features the full complement of printed devices: solar cells, patch antennas, transceivers, and retro-directive phased array capability. Recently invented and patented February 15, 2022, by Dr. David Hyland.

This most mature capability can be applied to the Power Star space solar power satellite, and to ground installations for combined solar power and air defense, as will be discussed below. Overall, the SMF has 4 following embodiments and modes of operation, listed in order of complexity.

1) Printed Solar Cells aka Solar Power Collector – Solar cells printed on flexible fabric, with appropriate power distribution subsystem.
2) Printed Microwave Antennas aka Solar Power plus Communication – Item (1) with the addition of microwave patch antennas for communication.
3) Dual Sided Microwave Antennas aka Power/Communication/Transmission – Item (2) with the addition of microwave transceivers on both sides of the flexible substrate, and retro-directive phased array capability for power transmission to a distant collection station, using a microwave beacon at the collection point (example shown in Figure 1). This is the embodiment of the Power-Star Satellite. Use of a beacon constitutes the passive mode of beam direction and shaping.
4) Power/Comm/Defense – Item (3) with only one side printed and with the addition of an "active" mode of power transmission whereby radiation is broadcast to a non-cooperative target and the return from the target is used as the beacon for direction of a high-power density beam. This could be applied for both ground-based power collection and air/space defense (example shown in Figure 1).



- Solar collectors and microwave transmitters are printed on a thin fabric (in a randomized pattern if non-overlapping)
- The collectors and transmitters are combined in local modules – no high voltage power distribution system

- The fabric collects solar energy, converts to microwaves and transmits it with adaptively formed beam(s) using an entirely localized algorithm. (Two modes of operation:
    - Passive Mode: A cooperative target sen a low amplitude beacon signal
    - Active Mode: The Fabric transmits a tracking signal and the return from the target serves as a beacon signal

Figure 1 Solar microwave fabric in its most sophisticated embodiment.

Detailed explanation of Introduction section is broken into these 6 sub-categories:

1.1 Printed Solar Cells (aka Solar Power Collector)

1.2 Printed Microwave Antennas aka Solar Power Plus Communication

1.3 Power/Comm/Transmission, Dual Sided Microwave Antennas

1.4 Substrate Materials

1.5 Solar Microwave Fabric Applications

1.6 Energy From Space; The Future of SMF in Power-Star

We now discuss each of these embodiments:

Printed solar cells (aka solar power collector)

Large scale production of inexpensive solar arrays is well underway. Presently, there is a range of solar cell printing technologies, where rapid manufacturability is traded off against cell efficiency. A notable example is that reported in Reference.[1] The Victorian Organic Solar Cell Consortium has demonstrated the capability to produce printed solar arrays at speeds of up to ten meters per minute, or one cell every two seconds. Up to 30cm wide, these cells produce 10-15 to be 100-150 watts of power per square meter per square meter under maximum ground insulation. Substrates include paper-thin flexible plastics, fabrics/composites, metals, and matrixed variations. As illustrated in Figure 2, the cells combine various organic materials to capture power from various parts of the solar spectrum (ref as we see in the 400-700 nm frequencies).

In comparison, MIT solar cells[2] use an ink-jet process to print cells on paper or fabric. Efficiency for most designs is presently 1% to 2%. However, 22% is a near-term goal for large scale manufacturing. More advanced laboratory investigations[3] have demonstrated 50m GalnP/GalnAs/Ge triple junction solar cells with an average conversion efficiency of 28%. It is quite reasonable to anticipate 22% for large-scale manufacture in the future. As a baseline we can say that a minimum of 22% efficiency with rapid fabrication ability is the baseline capability for SMF.

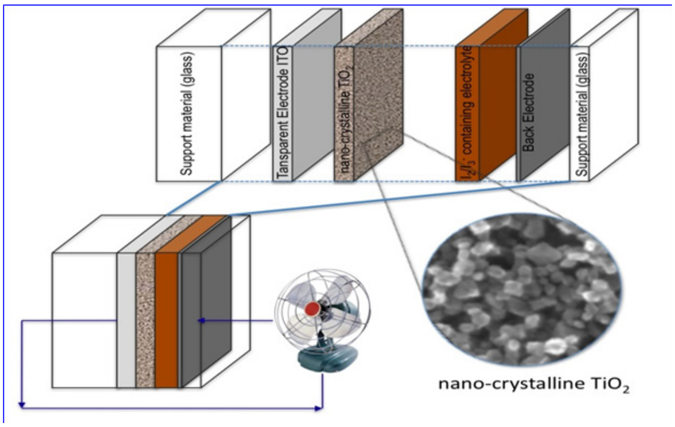


Figure 2 Composition of the Victorian organic solar cell consortium.

In summary, technology to print solar cells on a wide variety of flexible materials presently exists. However, existing art anticipates the installation of such solar arrays on permanent, stationary structures. Existing art does not include flexible solar arrays that can be compactly folded in a small volume for transport to hard-to-access areas, with a corresponding ability to be easily unfolded for use at such locations.

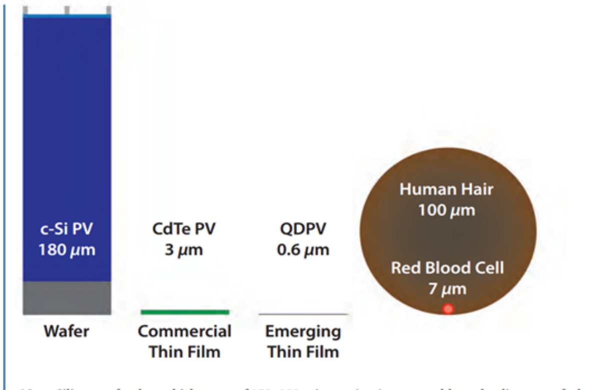
We must develop the world's best-known 3D printed Solar Cell Technology and integrate into a roll-to-roll process. Efficiency and much thinner solar cells than standard wafers this plays its role in optimal SWAP-C Size, weight, and power also cost commercially used as referenced in Figure 3.

Weight savings along with efficiency improvements >20% are being developed by many companies & countries, it is like finding the Holy Grail of power to weight "Best Solar Cell Material".

We need to develop the best-known technology for printed flexible solar cells onto various substrate layers/media/fabric. Further explanation is explained below, first you must understand the solar cell state of the technologies "Best known & proven Efficiencies."

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J*. 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

Looking at the National Renewable Energy Laboratory (NREL) charted confirmed efficiency and the applied technology used to achieve them. Solar cells in Figure 4 typically convert not more than 20 percent of incoming energy into electricity, in part because they capture only certain wavelengths of light.



Note: Silicon wafers have thicknesses of 150–180 microns (µm), comparable to the diameter of a human hair. Relatively thick wafers are required since silicon does not absorb light strongly. Alternative materials such as CdTe, CIGS, and quantum dots (QD) are much better absorbers, allowing thin-film PV active layers to be as thin as 0.1–10 µm. Thin active layers save material and enable the production of flexible and lightweight cells when appropriate substrates are used. Layer thicknesses are shown to scale.

Figure 3 Solar cell thicknesses by technology classification.

Figure 4 Example- printed (flexible) solar cell.

Researchers at Germany's Fraunhofer Institute for Solar Energy Systems have developed a solar cell that converts 46.0 percent a record at the time. It consists of a lens that concentrates sunlight onto four stacked subcells, each designed to absorb a distinct portion of the spectrum (Figure 5).

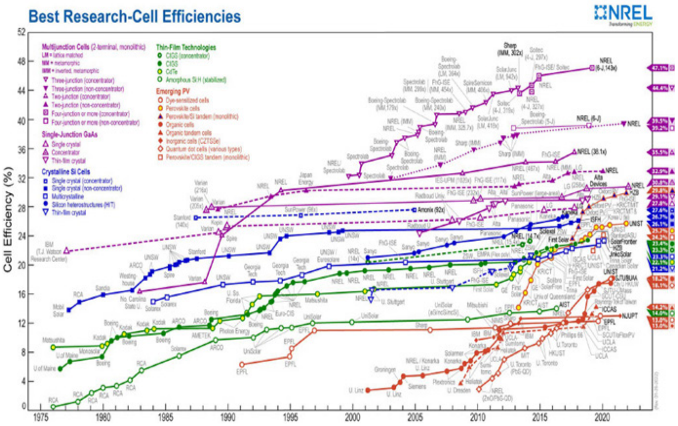


Figure 5 Solar cell (photovoltaic) efficiencies.

The German team estimates it will take them another two to three years to scale up the 5.2-millimeter prototype for use in solar-power plants.

1. Sunlight passes through a multifaceted lens known as a Fresnel. The lens focuses direct sunlight, delivering the power equivalent of 297 suns to the solar cell below (example shown in Figure 6).
2. The first subcell, made from gallium indium phosphide, captures photons from the shortest wavelengths of light. The subcell(s) beneath it contain elements capable of capturing progressively longer wavelengths.
3. Each subcell consists of several semiconductor layers, which create an electric field. As photons enter, they excite electrons, freeing them from the subcell.
4. Once the freed electrons reach the top of the stack, a metal contact funnels them toward an output terminal as a direct current.

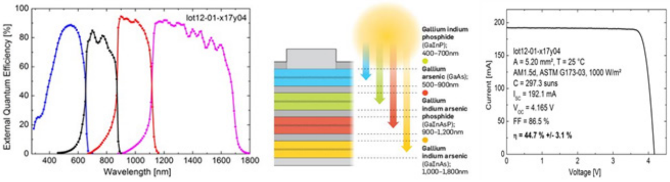


Figure 6 Solar cell best new technology (like 297 suns).

Roll to Roll Processing will be used for an intelligent fully automated manufacturing system. The R2R process will be used for: our printed electronics, Solar Cells, and Microwave Patch Antennas.

To provide understanding on the basics as shown in Figure 7–9, the three essential steps of R2R manufacturing are deposition, patterning, and packaging. Following the bottom contact TFT device structure shown in Figure 8, a transparent conducting oxide film is deposited on top of the flexible substrate to act as the gate electrode for the TFT. Indium Tin Oxide (ITO) is the current industry favorite due to its superior environmental stability, low electrical resistivity (1 to 3 x 10-4 Ω-cm) and high transparency to visible light (>90% at a film thickness of 6 to 100 nm). 17 In the interest of space, deposition methods will not be discussed in this review. In subsequent patterning steps, a thin insulating dielectric film of SiO2 and the metallic source and drain electrodes are produced before printing the organic semiconductor layer. Rather than conventional photolithography methods, soft lithography methods, laser ablation, and inkjet printing methods seem like promising technologies for large area flexible displays. Finally, the devices must be packaged in a barrier layer to prevent oxygen and moisture contamination of the organic semiconductor layers.

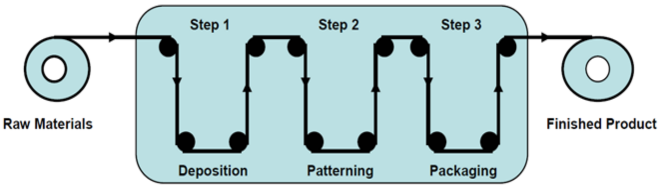


Figure 7 Roll to roll process flow (simplified).

Figure 8 Example of solar cell roll to roll process (ref: riso labs).

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196

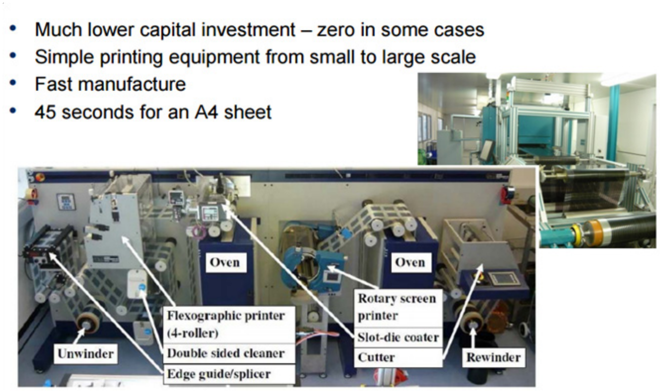


Figure 9 Example 2 of solar cell roll to roll process with 3D printing & Coating.

3D Printing Solar Cells Roll To Roll Processing for our processing; 1) Starts with the (Raw Material) substrate layer or media. Our Roll-to-Roll processing will be developed & perfected during the initial R&D Phase, all the Best materials & processes will be studied & developed providing 3 of the Best options for all 3 different product lines.

There is multiple cross section being investigated and evaluated for "Best Performance" per application along with the optimal design & "Best Producibility" techniques (Figure 10).

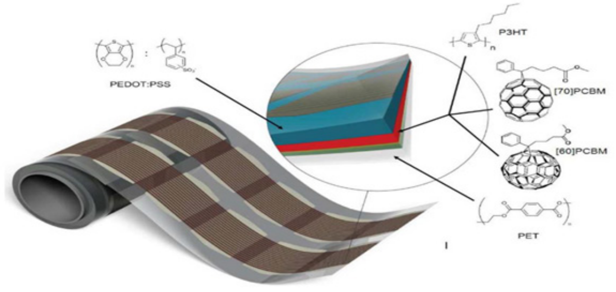


Figure 10 Example of how (materials) solar cell roll to roll is manufactured.

Figure 11 is a simplified view of another cross section to perform antenna activity on an Eco style design with Mylar media.

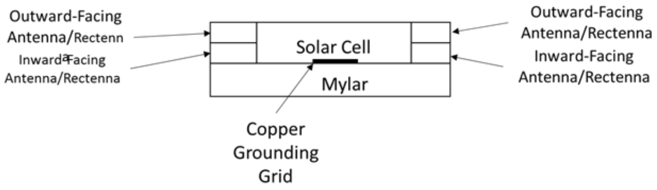


Figure 11 Example of proposed structural cross section.

Printed microwave antennas aka solar power plus communication

This embodiment combines printed solar cells powering printed microwave antennas: both printed on the same flexible sheets. The patch antennas in this case provide communication capabilities, including relay communication facilities on the ground or in space.

Printed microwave antennas are presently well known and are being advanced at a rapid rate for numerous communication applications. If the solar cells and patch antennas are interspersed without overlapping, they would be arranged with a randomized tessellation to eliminate grating lobes. Alternately, it is possible to have both components printed to occupy the same surface area on the sheets. In the full system, there may also be an array composed solely of microwave transceivers (dual transmitters and receivers) printed on the opposite surface (due to becoming the interior surface of the sphere).

Antennas can be inkjet printed or produced with photolithography techniques onto many flexible materials, including cotton-polyester, and light-weight cotton clothing for athletes,[4] and garments[5] with capability for off-body communication for emergency responders. Studies have also verified a limited degree of flexibility for these patch antennas.[6–8] Multiple printing layers can be used to increase efficiency. Inkjet-printed phased array antennas integrating several patch antennas have also been studied.[9] Finally, the printing of optically transparent patch antennas (mesh design) directly onto printed solar cells has been proposed.[10] This means that the entire surface of the flexible sheets can be occupied by both the solar cells and the antennas with complete overlap.

As illustrated in Figure 12, a microwave patch antenna consists of a metal "patch" mounted on a grounded, dielectric substrate.

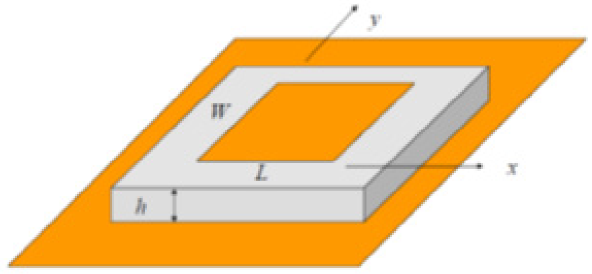


Figure 12 The basic configuration of a microwave patch antenna.

The dielectric provides a resonant cavity to amplify the transmitted signal. Since L is the resonant dimension, we must have:

$$L = \lambda/2 \tag{1}$$

Where λ is the operating wavelength. W is usually chosen as $1.5L$ to get higher bandwidth, but we shall assume here. The practical printing resolution is 15 microns and is quite sufficient to satisfy Equation (1) to sufficient accuracy. Table 1 shows a survey of performance statistics for existing patch antennas.[11] Efficiencies of up to 79% are presently attainable.

Table 1 Performance characteristics of various printed patch antennas

Substrate Height in mm BW = Bandwidth	**Etched patch on FR45 substrate**	**Inkjet Patch (two layers of ink) glued on FR45 substrate**	**Inkjet Patch (one layer of ink) on felt**	**Inkjet Patch (two layers of ink) on felt**
Patch size(mm)	37.4 x 28.1	37.4 x 28.1	47.7 x 36.9	47.7 x 36.9
Substrate height	1.6	1.6	1.9	1.9
Frequency (GHz)	2.378	2.48	2.405	2.505
S11 (dB)	-13.39	-14.89	-10.05	-9.95
10 dB BW (MHz)	22.5	24.5	17.5	N/A
Directivity (dBi)	7.39	7.55	8.38	8.72
Gain (dBi)	6.37	5.09	4.02	5.98
Efficiency (%)	79	57	37	53

Patch Antenna design & 3D printing; The key innovations essential to the system include: (1) high efficiency dual polarized rectenna and array; (2) EMI noise reduction techniques, (3) failure and thermal analysis (4), device technology study for high frequency rectennas and (5) the bus-bar design for DC output power Figure 13.

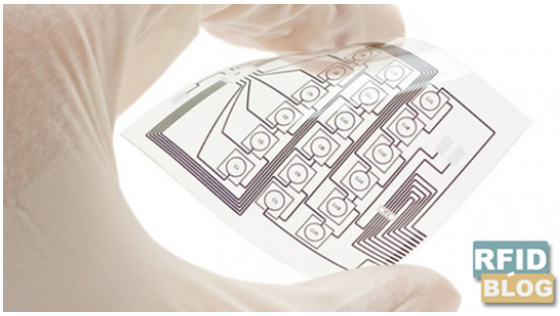


Figure 13 Example- printed (flexible) patch antenna.

High power transmitter sources such as high power tubes or quasi-optical power combiner in which a large number of low power devices combine their output powers quasi-optically in the free space can convert available electrical energy (solar, nuclear, hydro, etc.) into an electromagnetic wave (microwave, millimeter-wave, laser), transmitting via an antenna, and the receiving the energy at a remote point, and converting back into a usable format (DC, 60 Hz, etc.). The rectenna (rectifier + antenna) that converts the received microwave power into DC power can be developed using printed antenna elements integrated with the solid-state devices such as Schottky devices. Benefits of printed Patch Antennas:

Figure 14 can be sewn &/or using an inkjet type printer for patch antennas printing in R2R process:

1. Allows printing on any shape, including "beach ball" strips
2. Allows experimenting with number of layers for effectiveness and flexibility
3. Allows experimenting with printed material (i.e., gold, silver)
4. Currently the Technology Readiness Level is (TRL): 4
5. Currently has not been tested in a relevant environment.
6. Mass production has not yet been attempted.
7. Estimated cost: TBD, we will perform a confirmed manufacturing matrix for comparability & applications.
8. Up to 79% efficiency on FR45 resin.

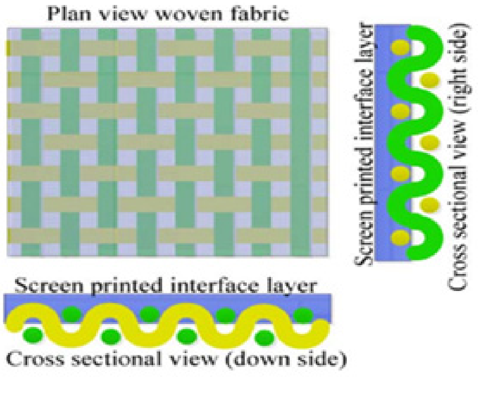


Figure 14 Example woven conductive materials for patch antenna & electronics.

We will run strip through solar cells printer first, then onto patch antenna printer.

In summary, technology to print solar cells and patch antennas on a wide variety of flexible materials presently exists. However, existing art does not include flexible fabric with solar arrays fully integrated with patch antennas that provides its own power to high gain communication capability and can be compactly folded in a small volume for transport to hard-to-access areas, with a corresponding ability to be easily unfolded for use at such locations.

Power/communication/transmission

This embodiment is Item 2 described above with the addition of microwave transceivers to the obverse side of the flexible substrate, and retro-directive phased array capability for power transmission to a distant collection station. The principal application is the Power Star satellite concept. The external side of the Power Star balloon skin is equipped with both solar cells and patch antennas, as in Item 2, except that the antennas cover the surface as fully as possible. If the antennas are printed so that they do not overlap the solar cells, the antenna placement is randomized to avoid grating lobes. Alternately, transparent patch antennas can be printed directly upon the solar cells so that both components simultaneously occupy the entire surface area, as discussed above. The "obverse" side of the flexible substrate corresponds to the internal side of the Power Star skin and is fully populated with microwave transceivers (dual transmitters and receivers). The role of these devices is to transfer power across the Power Star, as will be explained below. The operating frequency of these transceivers may be different from that of the external surface antennas. A higher frequency may be used for the internal transceivers to reduce diffraction effects.

Regarding the substrate material, although solar cells and patch antennas have been printed on a wide variety of materials, one may consider two materials that have the closest connection to Echo satellite technology[12–14] which is the basis for the packaging and deployment of the Power Star satellite. The foremost, and the one with the most heritage, is Mylar, a polyester film made from resin Polyethylene Terephthalate (PET). This material retains its full mechanical capabilities at temperatures ranging from -70 C to 150 0C. Its melting point is 254 0C. Its volumetric density is 1390 kg/m3. An attractive alternative is Kapton, an organic polymeric material that effectively does not melt or burn and functions well at temperatures ranging from -269 C to 400 0C. At 1420 kg/m3, its volumetric density is slightly larger than that of Mylar. Continuing studies are underway to explore print-compatible materials with adequate tear resistance and minimum density.

The retro-directive phased array capability is needed for power transmission to a distant collection station (rectifying antenna). In the Power Star concept, a low amplitude microwave beacon is located at each power reception station. An analog processor resident in each patch antenna receives the beacon radiation at its location, then conjugates its phase, amplifies it, and transmits it. Basic principles of electromagnetic wave propagation ensure that the total signal forms a concentrated beam centered on the location of each beacon. Retro directive phased arrays have been understood for some time, and the technology for implementation is well developed[15,16] The present embodiment uses a high efficiency analog circuit that avoids the sensitivity to cosmic radiation inherent in digital circuitry.

A diagram of the cross-section of the Power/Communication\ transmission embodiment is shown in Figure 15. In one embodiment, (Figure 15 (a)), the printed solar cells are positioned on the surface to not overlap with the patch antennas. The pattern is randomized to prevent grating lobes. Each external surface transmitter is powered either by the adjacent solar cells, if it is in sunlight, or by the transceivers proximate to the transmitter on the inner surface, through the thickness of the substrate layer, in the case where the transmitter is in shadow. A second embodiment, (Figure 15(b)) would have optically transparent microwave patch antennas (possibly a mesh design) printed directly on the solar cells, so the total area of the fabric collects solar energy. Analysis of the Power Star shows that this arrangement would boost the power delivered to the ground by a factor of four.

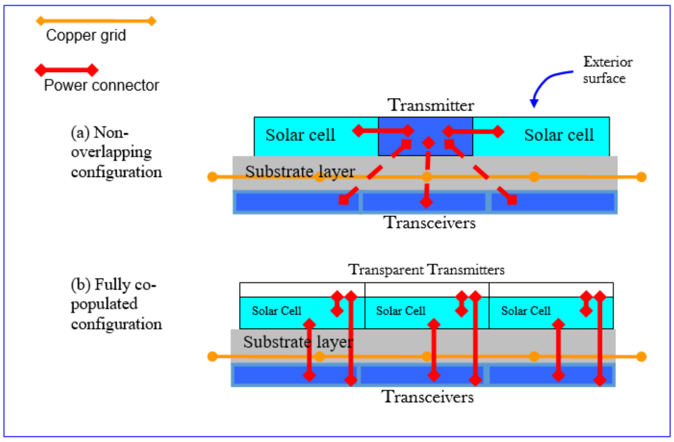
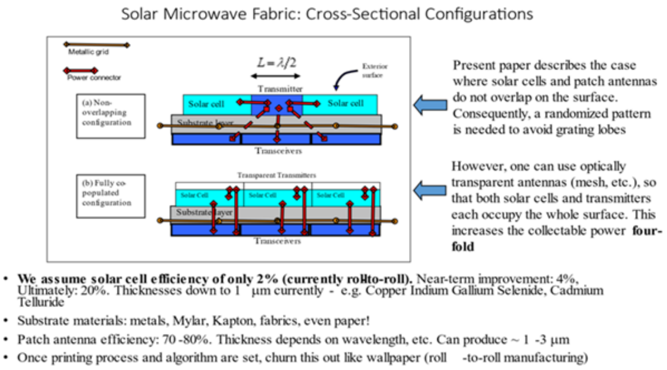


Figure 15A Cross-sections of the power/communication\transmission embodiment.


Solar Microwave Fabric: Cross-Sectional Configurations

Present paper describes the case where solar cells and patch antennas do not overlap on the surface. Consequently, a randomized pattern is needed to avoid grating lobes

However, one can use optically transparent antennas (mesh, etc.), so that both solar cells and transmitters each occupy the whole surface. This increases the collectable power **four-fold**

- **We assume solar cell efficiency of only 2% (currently roll-to-roll).** Near-term improvement: 4%, Ultimately: 20%. Thicknesses down to 1 µm currently - e.g. Copper Indium Gallium Selenide, Cadmium Telluride
- Substrate materials: metals, Mylar, Kapton, fabrics, even paper!
- Patch antenna efficiency: 70 -80%. Thickness depends on wavelength, etc. Can produce ~ 1 -3 µm
- Once printing process and algorithm are set, churn this out like wallpaper (roll -to-roll manufacturing)

Figure 15B Repetition of Figure 15 with notes (cross-sections of the power/communication\transmission embodiment).

Each microwave transmitter is equipped with an analog circuit that conjugates the phase of the beacon signal that marks the location of a reception station, then amplifies the signal and re-transmits it. In other words, if the beacon radiation received by any one patch antenna is $V_B\cos(\omega_B t+\theta_B)$, then the transmitter, with its retro directive circuit will emit an amplified signal proportional to $\cos(\omega_B t-\theta_B)$. Electromagnetic theory shows that with every transmitter so equipped, the skin of the fabric can direct a concentrated beam at the beacon without a priori knowledge of the beacon location or the surface geometry of the fabric. The most efficient way to accomplish phase conjugation at each individual transmitter is using a heterodyne technique. The transmitter is connected to a mixer that is pumped with a local oscillator, (LO), signal that has double the frequency of the beacon signal. This is illustrated in Figure 16 Let the LO signal be denoted by $V_{LO}\cos(\omega_{LO}t)$, then the mixing product, V_M, is:

$$\begin{aligned}V_M &= V_B\cos(\omega_B t+\theta_B)V_{LO}\cos(\omega_{LO}t)\\ &= \frac{1}{2}V_BV_{LO}\left[\cos\left((\omega_{LO}-\omega_B)t-\theta_B\right)+\cos\left((\omega_{LO}+\omega_B)t+\theta_B\right)\right]\end{aligned} \tag{2}$$

Since the LO frequency is twice the beacon frequency, we have:

$$V_M = \frac{1}{2}V_BV_{LO}\left[\cos(\omega_B t-\theta_B)+\cos(3\omega_B t+\theta_B)\right] \tag{3}$$

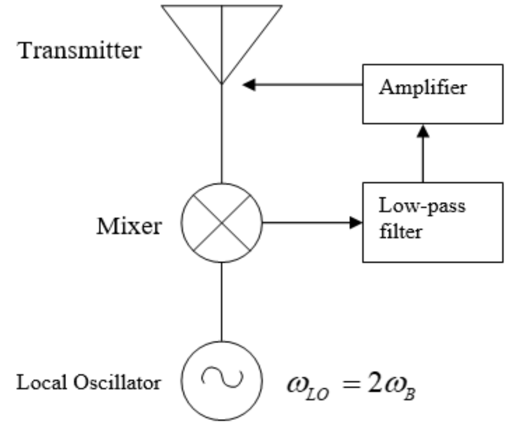


Figure 16 Diagram of the phase conjugation circuit.

Note that the first term above has the same frequency as the beacon signal, but has conjugate phase, as desired. The frequency of the second term is so large compared with the beacon frequency that it can be readily filtered and suppressed. For the same reason, any LO leakage can be filtered. Another signal that must be suppressed is the beacon signal that leaks directly into the output of the phase conjugator. In general, balanced mixer topologies can be used to eliminate this leakage signal. The phase conjugation process can be generalized to the case wherein the beacon and transmitted output signal do not have the same frequencies.

One of the underlying assumptions of the above discussion is that all the local oscillators that drive the transmitter elements are in phase, because the beacon phase measurement is only relative to the LO phase. In most applications this is satisfied by having each transmitter in the phased array driven by the same local oscillator. The size of the Power Star is likely to make direct wire transmission of one LO signal to all the patch antennas impractical. An alternative realization would use wireless transmission from one LO to all transmission elements. If the transmitted signal is first band-pass filtered to suppress all but the $2\omega_B$, this is practicable. Another realization would entail signal processing in each patch antenna that by emergent behavior synchronizes its LO phase with its neighbors.

The phase synchronization works by means of deliberate LO signal leakage combined with an analog phase locked loop (APLL) in each transmitter element. First, as shown in Figure 6, the LO of transmitter $k\,(k=1,\ldots,N)$ is embedded within the APLL, whose output is a signal of the form $V_{LO\,k}\cos\left(2\omega_B t+\varphi_{LO\,k}\right)$. This signal is not only input to the mixer, it is passed through a band-pass filter centered at (to suppress the ω_B and $3\omega_B$ signals) and fed into the antenna as a low amplitude signal for transmission (as end-fire leakage) to neighboring antennas. Likewise, there will be a leakage signal component at $2\omega_B$ mixed in with the received signal due to all the neighboring transmitters. The received signal is passed through a band-pass filter centered at $2\omega_B$, to form signal L_k, which serves as the reference input to the APPL. This signal has the form:

$$\begin{aligned}L_k &= \sum_{\substack{m=1,\\ m\neq k}}^{N}\beta_{mk}V_{LO\,m}\cos\left(2\omega_B t+\varphi_{LO\,m}\right)\\ \beta_{mk} &= \beta_{km}\text{, real and positive }\forall\ k,m=1,\ldots,N\end{aligned} \tag{4}$$

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

The factors β_{mk} represent transmission coefficients from a neighboring antenna to antenna k. Since there is reciprocity between reception and transmission, $\beta_{mk} = \beta_{km}$.

A detailed diagram of the APPL & LO block in Figure 17 is shown in Figure 18. The filtered leakage signal, L_k, forms the reference input. An analog phase detector consisting of a mixer and filter combines L_k and the negative feedback signal to produce a signal proportional to the sum of the phase differences between transmitter k and the neighboring transmitters. This signal is then low-pass filtered to produce an output denoted here by x_k. The voltage-controlled oscillator, centered at $2\omega_B$, causes a rate of change of $\varphi_{LO\,k}$ proportional to $g_v C x_k$ (taking account of the negative feedback).

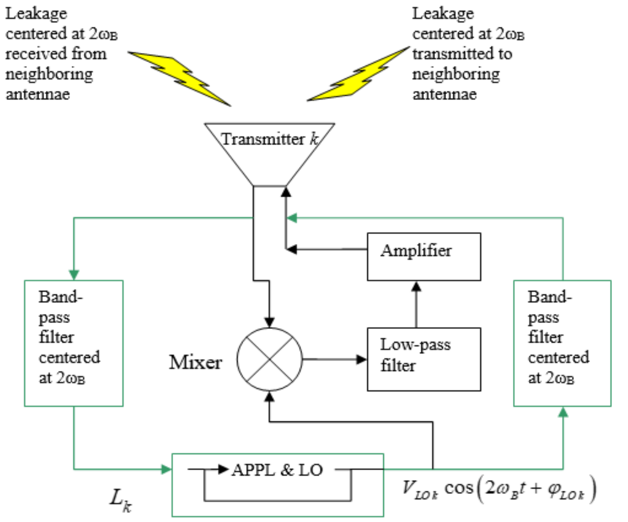


Figure 17 Modifications (shown in green) of the transmitter/phase conjugation circuit to synchronize LO phase.

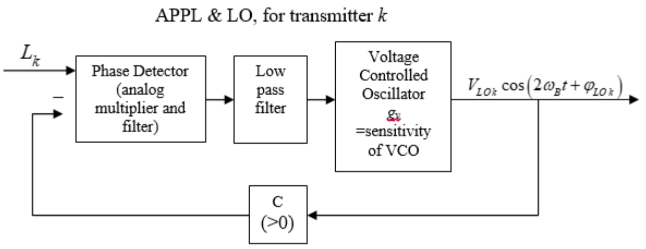


Figure 18 Detail of the APPL & LO device.

At this point we can construct a phase-domain model of the entire LO phasing system.[17–19] The phase detector characteristics produce the output $\frac{1}{2}\sum_{\substack{m=1,\\ m\neq k}}^{N} \beta_{mk} V_{LO\,m} V_{LO\,k} \sin\left(\varphi_{LO\,k} - \varphi_{LO\,m}\right)$. To illustrate results with the simplest example, let the low-pass filter be a simple RC circuit with time constant τ. Then the filter output is determined by:

$$\dot{x}_k = -\frac{1}{\tau}x_k + \frac{1}{2\tau}\sum_{\substack{m=1,\\ m\neq k}}^{N} \beta_{mk} V_{LO\,m} V_{LO\,k} \sin\left(\varphi_{LO\,k} - \varphi_{LO\,m}\right) \tag{5}$$

And the action of the VCO and its feedback path can be expressed as:

$$\dot{\varphi}_{LO\,k} = -g_v C x_k \tag{6}$$

For purposes of analysis, let us drop the "LO" subscript on the phases; then solve (6) for and substitute the result into (5). This produces the following system of equations modeling all the transmitter phases:

$$\ddot{\varphi}_k + \frac{1}{\tau}\dot{\varphi}_k + \sum_{\substack{m=1,\\ m\neq k}}^{N} \gamma_{mk} \sin\left(\varphi_k - \varphi_m\right) = 0$$

$$k, m = 1, \ldots, N \tag{7.a,b}$$

$$\gamma_{mk} = \frac{g_v C}{2\tau}\beta_{mk} V_{LO\,m} V_{LO\,k} \;\left(\gamma_{mk} = \gamma_{km}\right)$$

The main features of the LO phase dynamics can be illustrated by consideration of just two neighboring transmitters. The dynamical equations, (7.a) can be written:

$$\begin{aligned} &\ddot{\varphi}_1 + \frac{1}{\tau}\dot{\varphi}_1 + \gamma_{12}\sin\left(\varphi_1 - \varphi_2\right) = 0 \\ &\ddot{\varphi}_2 + \frac{1}{\tau}\dot{\varphi}_2 + \gamma_{12}\sin\left(\varphi_2 - \varphi_1\right) = 0 \end{aligned} \tag{8.a,b}$$

If we sum the above equations and note that both transmitter VCOs are centered on $2\omega_B$, we can deduce that the sum of the phases is a constant equal to its initial value. A more important effect is concerned with the phase difference. Subtracting (8.a) from (8.b) and defining $\psi = \varphi_2 - \varphi_1$, we get:

$$\ddot{\psi} + \frac{1}{\tau}\dot{\psi} + 2\gamma_{12}\sin\psi = 0 \tag{9}$$

This is the equation of motion of a damped pendulum. As is well known, the equilibrium point $\psi = 0$ is globally asymptotically stable. Thus, from some initial value, the frequency difference converges to zero.

Entirely similar characteristics can be shown for the complete system, (7).

In summary: If each transmitter "leaks" its local oscillator signal to produce "cross-talk" among its neighbors, and the cross-talk is used as the reference for a phase-locked loop as described here, the phases of all the transmitter element's local oscillators will become synchronized in the course of time, regardless of their initial values. With synchronized LO phases, the phase-conjugated signals of the patch antennas will, indeed, be correct.

Moving to another topic, in the application of the fabric to the Power Star, since the directions of the sun and the beacons are not coincident, a mechanism for distributing power within the satellite is needed. Figure 19 shows the geometry of irradiation from the sun and the beacons, where we assume that the angular separation of beacons is small so that a single, representative beacon direction may be considered. The quantity φ is the angle between the sun direction and the beacon direction. Recall that the interior surface of the sphere is coated with transceivers operating at a higher frequency (to reduce diffraction effects). These transceivers are to be oriented so that the resonant axes of each diametrically opposite pair are parallel.

As illustrated in Figure 19, the surface of the sphere is divided into four sectors: The sector exposed to both sunlight and beacon radiation (denoted by S, B); that receiving beacon radiation but no sunlight ($\tilde{S}, B$); that exposed to sunlight but not beacon ($S, \tilde{B}$), and the region where neither sun nor beacon are visible ($\tilde{S}, \tilde{B}$). Clearly, sectors ($\tilde{S}, B$), and ($S, \tilde{B}$) are mirror images, such that each point

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

on $(\tilde{S}, B)$ has a diametrically opposite point on $(S, \tilde{B})$, and vice-versa. The same remark pertains to (S, B), and $(\tilde{S}, \tilde{B})$. The sector where a particular transmitter and its adjacent solar cells are located is indicated by their output signals. Given this information, the power supply algorithm is indicated in Table 2. Note that no processing is needed for this algorithm. In essence, the transmitters that need to be active because they receive a beacon signal are powered by either the proximate solar cells or by the proximate internal transceivers, whichever is producing power. No beacon signal means the transmitter is blocked. Each transmitting antenna draws power from the solar cells in its immediate vicinity (within a few centimeters), or through the thickness of the skin. Each transmitter receives just a few Watts, so there are no high voltages or large wires. This localized architecture means robustness against partial damage.

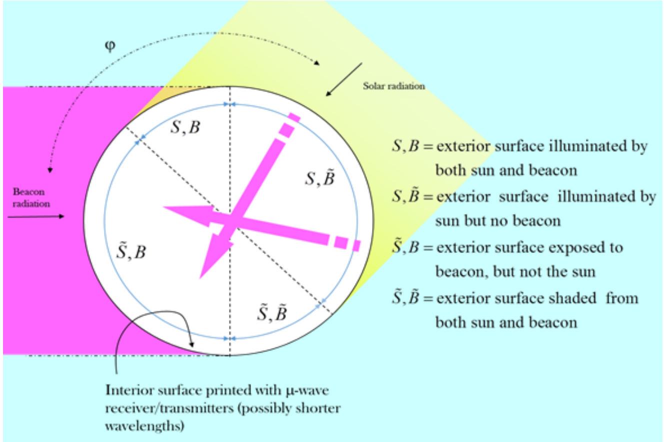


Figure 19 Geometry of the power distribution system. Angle ϕ denotes the angle between the directions to the sun and a beacon.

Table 2 Power transfer algorithm

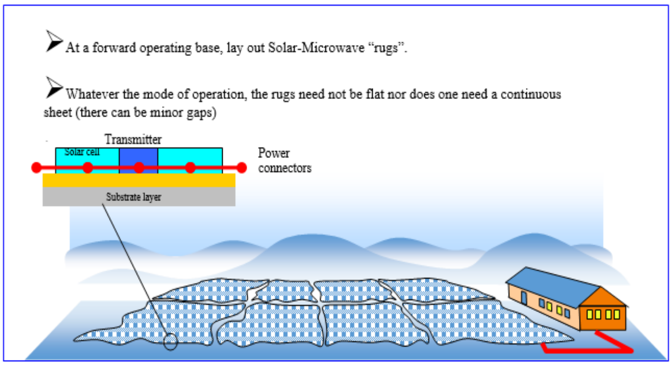
Sector	Power Transfer
(S, B)	External surface transmitter draws power from the adjacent solar cells
$(S, \tilde{B})$	Solar cells transfer power through the skin to their immediate proximate internal surface transceivers. The internal transceivers emit power beams through the center of the sphere to fall on the internal transceivers in sector $(\tilde{S}, B)$.
$(\tilde{S}, B)$	Internal transceivers transfer received power through the skin to their immediately proximate external surface transmitters
$(\tilde{S}, \tilde{B})$	No action taken.

In summary, while separate components such as printed solar arrays and patch antennas and retrodirective circuits have been have been demonstrated at some level (which argues for the feasibility of the invention described here), the concept of combining these elements in a unified, integrated system that can be folded into a small volume for launch, then deployed automatically for space operation without need for complex structures or on-orbit construction is a new contribution to the state-of-the-art.

Power/comm/defense

This embodiment is the item described above, but with the internal transceivers omitted and with the addition of an "active" mode of power transmission whereby radiation is broadcast to a non-cooperative target and the return from the target is used as the beacon for direction of a high-power density beam.

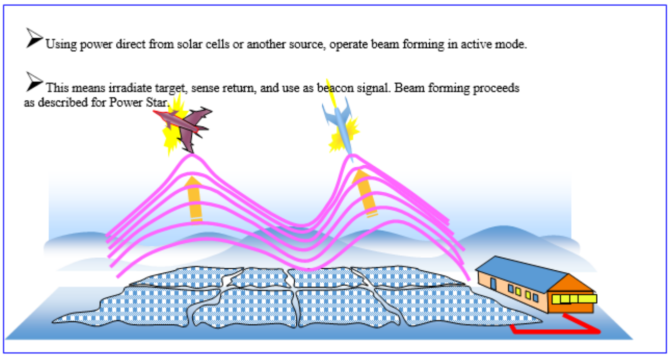
In the power gathering mode, the Power/Com/Defense embodiment simply uses the printed solar array elements. As pictured in Figure 20, a compactly folded rug of fabric is brought to a forward military base, a developing world location or similarly difficult to access location and is then unfolded, and spread over the ground. Once deployed, it provides solar power using printed solar cells and a conventional power management and distribution system.


➢ At a forward operating base, lay out Solar-Microwave "rugs".

➢ Whatever the mode of operation, the rugs need not be flat nor does one need a continuous sheet (there can be minor gaps)

Figure 20 Power/com/defense embodiment in power collection mode.

Besides providing power, this embodiment can be run in "active" retro directive mode to provide self-defense against airborne attack, as pictured in Figure 21. The patch antennas are energized to transmit a broad directivity radiation pattern, and radiation return from intruding air vehicles is used as the beacon for retro directive beam transmission. Note that a first revenue unit Power Star at geostationary orbit will generate safe, low energy density radiation on the ground.


➢ Using power direct from solar cells or another source, operate beam forming in active mode.

➢ This means irradiate target, sense return, and use as beacon signal. Beam forming proceeds as described for Power Star.

Figure 21 Power/com/defense embodiment in defense mode.

Decrease the transmission energy to less than 100km, however, and the power density is enormous. A Power/Comm/Defense rug could easily be designed to disable an aircraft or rocket at some tens of kilometers distance.[20]

The addition of the active mode of retro directive beam control makes this embodiment an original contribution to the state-of-the-art – both for power collection in remote places and as a method for aircraft and missile defense. As shown in Figure 20 & 21.

Dynamic asymptotic system

Here we show that the dynamical system, (7), is globally asymptotically stable. To reprise, for $k, m = 1, \ldots, N$:

$$\begin{aligned} &\ddot{\varphi}_k + \frac{1}{\tau}\dot{\varphi}_k + \sum_{m=1}^{N} \gamma_{mk} \sin\left(\varphi_k - \varphi_m\right) = 0 \\ &\gamma_{mk} = \gamma_{km} > 0 \\ &\varphi_k\left(0\right) = \varphi_{k0}, \\ &\dot{\varphi}_k\left(0\right) = 0 \end{aligned} \tag{A-1.a-d}$$

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196

Initial conditions (A-1.d) arise because the VCOs are centered on $2\omega_B$, and in particular, when the feedback mechanism is first turned on, there is no drift in the phases. Otherwise, there are no restrictions on the initial phase values.

First note that if we sum (A-1.a) over all k, we get $\left(\frac{d^2}{dt^2}+\frac{1}{\tau}\frac{d}{dt}\right)\sum_{k=1}^{N}\varphi_k=0$. Integrating this from 0 to t produces:

$$\frac{d}{dt}\sum_{k=1}^{N}\varphi_k\left(t\right)=\frac{1}{\tau}\sum_{k=1}^{N}\left(\varphi_k\left(t\right)-\varphi_{k0}\right)-\sum_{k=1}^{N}\dot{\varphi}_k\left(0\right) \quad \text{(A-2)}$$

In view of the initial conditions (A-1.c,d), this implies:

$$\sum_{k=1}^{N}\varphi_k\left(t\right)=\sum_{k=1}^{N}\varphi_{k0},\;\; t\in\left[0,\infty\right) \quad \text{(A-3)}$$

Thus, the trajectories in the system state space are confined to a hyper plane. Let us center the state on this hyper plane by defining:

$$\chi_k\left(t\right)=\varphi_k\left(t\right)-\frac{1}{N}\sum_{m=1}^{N}\varphi_{m0},\;\; t\in\left[0,\infty\right) \quad \text{(A-4)}$$

The hyper plane thus becomes $\sum_{k=1}^{N}\chi_k\left(t\right)=0$, and (A-1.a) retains its form, i.e.:

$$\begin{aligned}&\ddot{\chi}_k+\frac{1}{\tau}\dot{\chi}_k+\sum_{m=1}^{N}\gamma_{mk}\sin\left(\chi_k-\chi_m\right)=0\\&\chi_k\left(0\right)=\varphi_{k0}-\frac{1}{N}\sum_{m=1}^{N}\varphi_{m0},\\&\dot{\chi}_k\left(0\right)=0\end{aligned} \quad \text{(A-5.a-c)}$$

With definition (A-4), the equilibrium point is now at the origin of the statespace.

Now we attempt to form a Lyapunov function and its derivative by multiplying (A-5.a) by $\dot{\chi}_k\left(t\right)$ and summing over all k. After this multiplication and summation, we have:

$$\sum_{k=1}^{N}\dot{\chi}_k\ddot{\chi}_k+\sum_{k=1}^{N}\sum_{m=1}^{N}\gamma_{mk}\dot{\chi}_k\sin\left(\chi_k-\chi_m\right)=-\frac{1}{\tau}\sum_{k=1}^{N}\dot{\chi}_k^2 \quad \text{(A-6)}$$

Using (A-1.b) and after much algebra, we find that the second term on the right in the above relation is given by:

$$\sum_{k=1}^{N}\sum_{m=1}^{N}\gamma_{mk}\dot{\chi}_k\sin\left(\chi_k-\chi_m\right)=\tfrac{1}{4}\sum_{k=1}^{N}\sum_{m=1}^{N}\gamma_{mk}\frac{d}{dt}\left[1-\cos\left(\chi_k-\chi_m\right)\right] \quad \text{(A-7)}$$

Substituting this into (A-6), and noting that $\sum_{k=1}^{N}\dot{\chi}_k\ddot{\chi}_k=\frac{d}{dt}\sum_{k=1}^{N}\tfrac{1}{2}\dot{\chi}_k^2$ we obtain:

$$\frac{d}{dt}\left\{\sum_{k=1}^{N}\left[\tfrac{1}{2}\dot{\chi}_k^2+\tfrac{1}{4}\sum_{m=1}^{N}\gamma_{mk}\left(1-\cos\left(\chi_k-\chi_m\right)\right)\right]\right\}=-\frac{1}{\tau}\sum_{k=1}^{N}\dot{\chi}_k^2 \quad \text{(A-8)}$$

The term in braces, {.}, is our candidate Lyapunov function. This is positive definite and decrescent (see Hahn, [20] for definitions), but its derivative, given by the right-hand side, is nonpositive, rather than negative definite (which would suffice for asymptotic stability). However, in the domain where the derivative is zero, namely $\left\{\dot{\chi}_k=0,\,\forall k=1,\ldots,N\right\}$, there lies no complete half–trajectory 0f (A-5). Indeed, if the system is initially in the domain $\left\{\dot{\chi}_k=0,\,\forall k=1,\ldots,N\right\}$ a series expansion of (A5-a) shows that trajectories immediately leave the domain unless the initial state is at the origin as well. In summary, positive definiteness, and decrescence of the trial Lyapunov function; non-positivity of its derivative; and the non-existence of a complete half trajectory in the domain of zero derivative are sufficient conditions for the asymptotic stability of (A-5).[21,22] Obviously, these properties are global. Hence for all initial values:

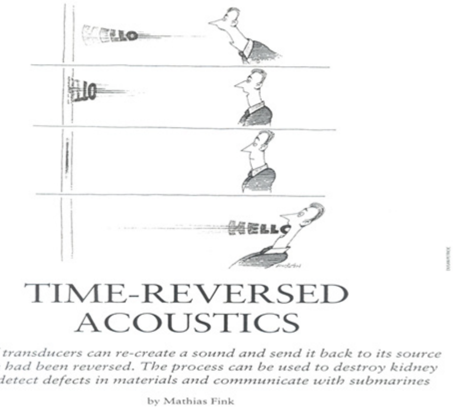
$$\chi_k\left(t\right)=\varphi_k\left(t\right)-\frac{1}{N}\sum_{m=1}^{N}\varphi_{m0}\xrightarrow[t\to\infty]{}0 \quad \text{(A-9)}$$

Thus, all the LO phases converge to the same value.

Focusing/ retro-directive MW transmission

The Space Solar Team at the 2014 National Space Society (NSS) International Space Development Conference in Los Angeles they agreed to frequency was 5.8 GHz. This is the same as most people's home cordless phone system uses, after more definitive research the best is ½ that @ 2.45 GHz. Brown published the first paper proposing microwave energy for power transmission, and in 1964 he demonstrated a microwave-powered model helicopter that received all the power needed for flight from a microwave beam at 2.45 GHz from the range of 2.4GHz–2.5 GHz frequency band which is reserved 101 for Industrial, Scientific, and Medical (ISM) applications. Experiments in power transmission without wires in the range of tens of kilowatts have been performed at Goldstone in California in 1975 and at Grand Bassin on Reunion Island in 1997.

Retro-Directive Rectenna principal technologies explained: Understanding Fundamental Power Shaping Concept (Figure 22).



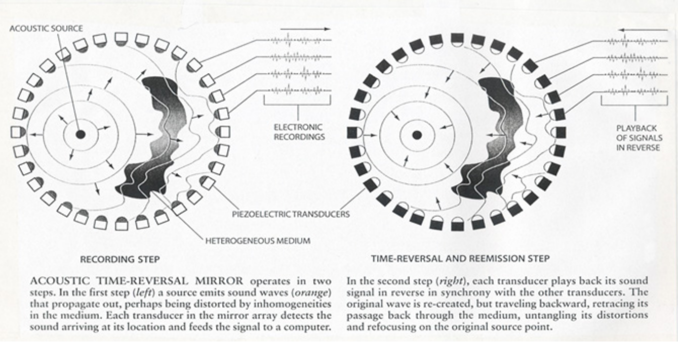
TIME-REVERSED
ACOUSTICS

Arrays of transducers can re-create a sound and send it back to its source as if time had been reversed. The process can be used to destroy kidney stones, detect defects in materials and communicate with submarines

by Mathias Fink

Figure 22 Example– power shaping.

The very same time-reversal principle has been applied to acoustics. See Scientific American, November 1999 (Figure 23).



ACOUSTIC TIME-REVERSAL MIRROR operates in two steps. In the first step (*left*) a source emits sound waves (*orange*) that propagate out, perhaps being distorted by inhomogeneities in the medium. Each transducer in the mirror array detects the sound arriving at its location and feeds the signal to a computer.

In the second step (*right*), each transducer plays back its sound signal in reverse in synchrony with the other transducers. The original wave is re-created, but traveling backward, retracing its passage back through the medium, untangling its distortions and refocusing on the original source point.

Figure 23 Example– the acoustic time-reversal mirror.

The collectenna TM (like Rectenna) operations are simultaneous. But we illustrate one step at a time. The next chart Figure 24 shows a simulation of a flat phased array receiving radiation from two beacons on the ground.

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

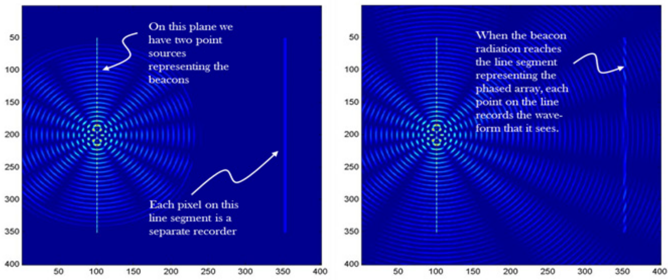


Figure 24 Example– flat phased array receiving radiation from two ground beacons.

Recording the beacon signals, then amplifying them and playing them back in reverse time occur concurrently. To simplify the explanation, we illustrate these steps separately. First, consider the beacon propagation (Figure 25).

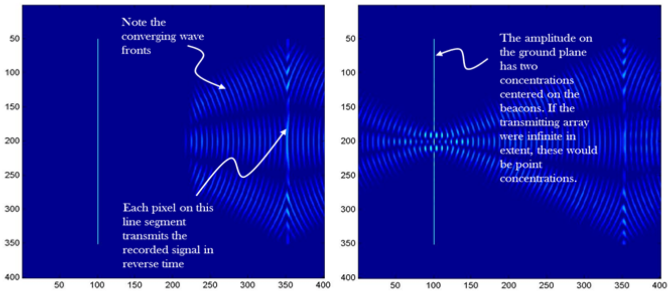


Figure 25 Example– Plotted phase array beacon transmission.

Now turn off the beacon and let each pixel on the line segment re-transmit the waveform it recorded - but in reverse time. The phased array surface does not have to be planar as shown here for clarity. In fact, the Power Star is a sphere. Beam shaping & power transmission for Power-Star as a sphere pattern explanation show in Figure 26.

Remember in 3D; the phased array does not have to be flat!

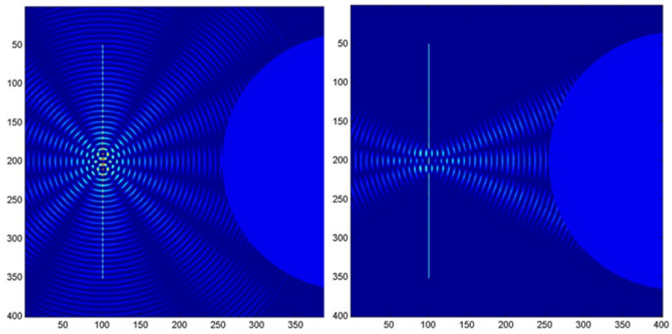


Figure 26 Example– power-star power transmissions in 3D.

Beam Shaping Algorithm – Summary:

1. Each patch antenna (a transmitter/receiver) senses the beam(s) radiation at its location.
2. It processes this information and transmits a greatly amplified signal in reverse time.
3. Control of each patch antenna is purely local. No global, large-scale algorithm is needed.
4. The patches act independently – the resulting transmission pattern is an emergent phenomenon.
5. Even if the Power-Star surface is distorted or damaged, the beam shaping algorithm will perform at some level.

Each antenna transmits only if the beacon(s) radiation is received.

Each transmitting antenna draws power from: Solar cells in its immediate vicinity (within a few centimeters), or through the thickness of the "skin" from receivers on the inner surface of the skin.

Power distribution to each antenna is local – there is no need for a complex power management system. Strictly local architecture means robustness against partial damage!

The steps for how power is generated and transferred to the rectenna beacons are shown in Figure 27. The photovoltaic cells absorb sunlight or solar energy and convert it directly into electricity. The microwave transmitters within sector 1.) draw the electricity generated from the adjacent photovoltaic cells using the power connectors that link the microwave transmitters to nearby photovoltaic cells. At electricity generated by the photovoltaic cells in sector 2.) is transferred through the substrate to immediately proximate internal surface layer transceivers. This transfer is done via the power connectors that indirectly or directly link the photovoltaic cells to the transceivers. The transceivers in sector 2.) emit electrical power beams through the center of the sphere towards sector 3.) at so that the electrical power beams can be received by the transceivers in sector 3.). At microwave transmitters in sector 3.) draw the received electrical power through the thickness of the substrate layer from the proximate transceivers in the inner surface layer. This drawing of power is performed via the power connectors that directly link the transceivers to the microwave transmitters. Each transmitter receives just a few watts so there are no high voltages or large wires. This localized architecture means robustness against partial damage. Each microwave transmitter is equipped with a retro-directive circuit that conjugates the phase of the beacon signal that it receives from the rectenna beacon, then amplifies the signal and re-transmits it. Thus, the microwave transmitter, with its retro-directive circuit, emits an amplified signal proportional to the beacon radiation received by any one patch antenna. The solar-microwave fabric of the solar power collection balloon directs a concentrated signal at the rectenna beacon without a priori knowledge of the rectenna beacon's location or the surface geometry of the solar-microwave fabric. One way to accomplish the phase conjugation of the 7 rectenna beacon signal at each individual transmitter is the heterodyne technique. The heterodyne technique achieves phase conjugation with only analog hardware, relatively simple circuitry, no digital processing, and lots of resistance to the space radiation environment. Using this technique, the transmitter is connected to a mixer that is pumped with a local oscillator signal that has double the frequency of the beacon signal. The heterodyne technique therefore allows for no digital processing and resistance to the space radiation environment.

The patch antenna elements of the phased array can be equally spaced or arbitrarily located or on a different layer of the solar-microwave fabric. By changing the local oscillator frequency, the re-radiated signal can be frequency modulated. In an alternative embodiment of the invention, a single microwave transmitter transmits a signal to all other microwave transmitters. The other microwave transmitters have a local oscillator embedded in an analog phase-locked loop that uses this signal as a reference signal. The reference signal is fed to a phase detector comprised of an analog multiplier and filter. The low-pass filtered output is input to a voltage-controlled

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J*. 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196

oscillator. The output from the voltage-controlled oscillator is, in turn, fed back in a negative feedback loop to the phase detector with some gain. The reference signal from the synchronizing microwave transmitter may be fed into a phase detector consisting of an analog multiplier and filter. The low-pass filtered output is input to a voltage-controlled oscillator, and its output is, in turn, fed back in a negative feedback loop to the phase detector with some gain.

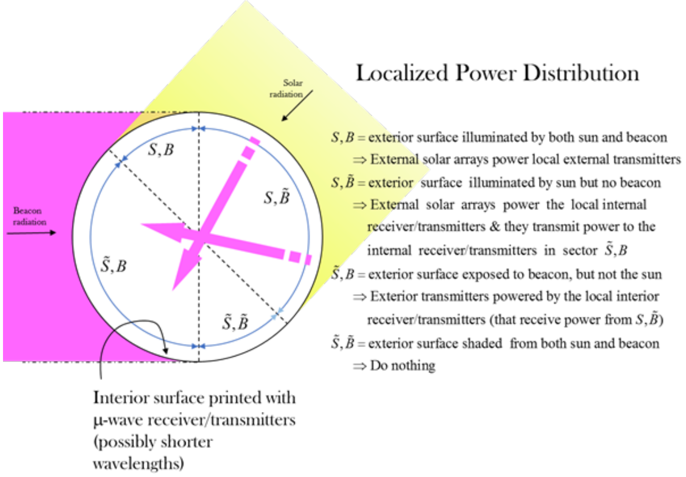


Figure 27 Power-star power transmission principals.

Reliance on a single transmitter to synchronize all the local oscillators might bear the risk of a single point of failure. Accordingly, in another embodiment of the invention, building in synchronization into each transmitter circuit and not having a special reference unit is preferred. In this embodiment, crosstalk is provided at a specific frequency such as 2□B and the crosstalk becomes the reference signal for the analog phase-locked loop. In yet another embodiment of the invention, the local oscillator is replaced by the analog phase-locked loop.

The output of the analog phase-locked loop is input to a bandpass filter centered at frequency. The low amplitude filter output is then added to the phase conjugated signal at frequency, which is broadcast by the microwave transmitter. The slight crosstalk that is inevitable for the patch antenna results in neighboring antennae receiving the leaked signal. Likewise, due to crosstalk, antenna k receives the 2□B signals broadcast by other patch antennas. This received signal is passed through a bandpass filter centered at frequency to suppress all other frequency content, the output of which serves as the reference signal, Lk, for the analog phase-locked loop. When several microwave transmitters are placed near to one another, withing a short time their local oscillators will all synchronize. Thus, the phase conjugated signals will be locked to a common time reference. In other words, when several transmitters are placed near one another, within a short time their local oscillators will all synchronize. Thus, by means of this highly decentralized mechanism, the phase conjugated signals will be locked to a common time reference. In an alternative embodiment of the invention, the microwave transmitter has a microprocessor that records the beacon radiation received from the rectenna beacon, records the radiation wave form, and concurrently emits a return signal in reverse time. In this embodiment, radiation commences with a widening interference pattern, then each microwave transmitter on the circumference of the sphere records the time signal of the field amplitude measured at its location, and transmits a signal recorded in reverse time. The resulting transmitted signal sent to the rectenna beacons has concentrated spots of intensity centered at the rectenna beacon locations. These spots represent point spread function distributions and are broader than the beacons. The broader width of the ground plane spots is proportional to the overall size of the solar power collection balloon. Despite the usual assumption that phased arrays are planar, the accuracy with which a desired ground distribution is duplicated is mostly dependent on size, not on shape (Figure 28).

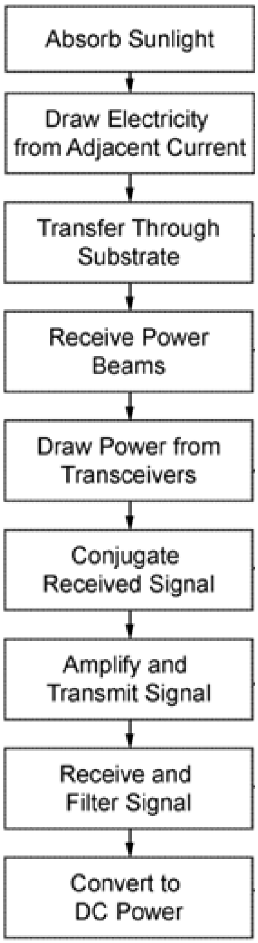


Figure 28 Flow chart.

Substrate materials

Although solar cells and patch antennas have been printed on a wide variety of materials, we have focused on two materials that have the closest connection to Echo satellite technology. The foremost, and the one with the most heritage, is Mylar, a polyester film made from resin Polyethylene Terephthalate (PET). This material keeps its full mechanical capabilities at temperatures ranging from -70 C to 150 0C. Its melting point is 254 0C. Its volumetric density is 1390 kg/m3. An attractive alternative is Kapton, an organic polymeric material that effectively does not melt or burn and functions well at temperatures ranging from -269 C to 400 0C. At 1420 kg/m3, its volumetric density is slightly larger than that of Mylar. Continuing studies will explore print-compatible materials with adequate tear resistance and minimum density.

Although solar cells and patch antennas have been printed on a wide variety of materials, we have focused on two materials that have the closest connection to Echo satellite technology. The foremost, and the one with the most heritage, is Mylar, a polyester film made from resin Polyethylene Terephthalate (PET). This material retains its full mechanical capabilities at temperatures ranging from -70 C to 150

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196

0C. Its melting point is 254 0C. Its volumetric density is 1390 kg/m3. An attractive alternative is Kapton, an organic polymeric material that effectively does not melt or burn and functions well at temperatures ranging from -269 C to 400 0C. At 1420 kg/m3, its volumetric density is slightly larger than that of Mylar. Continuing studies will explore print-compatible materials with adequate tear resistance and minimum density.

Substrate Layer as shown in Figures 20&21 could be made from a multitude of materials from common Kapton (Figure 27), Mylar, Composites; Carbon, Kevlar & Dyneema all commercially available on rolls. We are looking at customizing to (3D) 3 dimensionally sewn Hybrid composites with Kevlar, Carbon, Dyneema fiber with conductive threads. The simple industrial materials which can be purchased in roll form shall be done this way such as the Kapton, Mylar or similar electrical sheets which do not need integral fibers or composite strengthening (Figure 29).

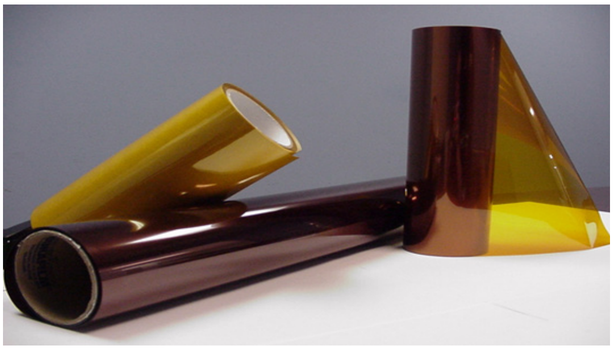


Figure 29 Kapton– polyimide.

The electrical production industry commonly uses Kapton which has such Properties as:

1. Organic Polymeric material
2. Comes in films of types: HN, VN, FN
3. Does not melt or burn
4. Functions at temperatures ranging from -269 C to 400 C
5. Excellent chemical resistance

Kapton has its advantages in high temperature, roll form film available & very good chemical resistance. This can easily be adapted to our roll-to-roll mass production system. It does not stretch well and can be formed into a huge Power-Star Satellite. Kapton has its advantages in high temperature applications & transparency to microwave.

NASA's original Echo Satellite was made from Mylar. Here are some basic properties of Mylar which may be used for the right applications ref. Figure 30 & 31.

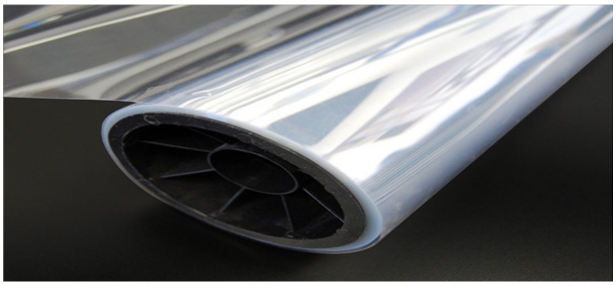
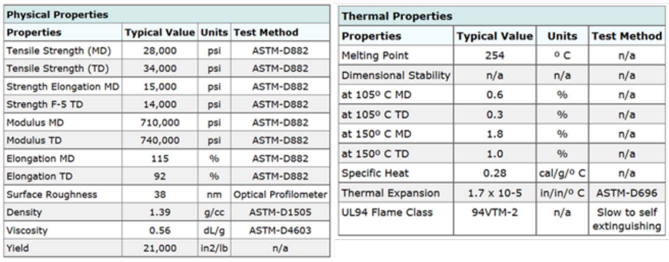


Figure 30 Mylar –BOPET.



Physical Properties			
Properties	**Typical Value**	**Units**	**Test Method**
Tensile Strength (MD)	28,000	psi	ASTM-D882
Tensile Strength (TD)	34,000	psi	ASTM-D882
Strength Elongation MD	15,000	psi	ASTM-D882
Strength F-5 TD	14,000	psi	ASTM-D882
Modulus MD	710,000	psi	ASTM-D882
Modulus TD	740,000	psi	ASTM-D882
Elongation MD	115	%	ASTM-D882
Elongation TD	92	%	ASTM-D882
Surface Roughness	38	nm	Optical Profilometer
Density	1.39	g/cc	ASTM-D1505
Viscosity	0.56	dL/g	ASTM-D4603
Yield	21,000	in2/lb	n/a

Thermal Properties			
Properties	**Typical Value**	**Units**	**Test Method**
Melting Point	254	º C	n/a
Dimensional Stability	n/a	n/a	n/a
at 105º C MD	0.6	%	n/a
at 105º C TD	0.3	%	n/a
at 150º C MD	1.8	%	n/a
at 150º C TD	1.0	%	n/a
Specific Heat	0.28	cal/g/º C	n/a
Thermal Expansion	1.7 x 10-5	in/in/º C	ASTM-D696
UL94 Flame Class	94VTM-2	n/a	Slow to self extinguishing

Figure 31 Mylar physical & thermal properties.

Since NASA's Echo production used Mylar which has such noted Properties:

1. Polyester Film made from resin Polyethylene Terephthalate (PET)
2. Functions at temperature ranging from -70 C to 150 C or -250 C to 200 C when physical requirements are not demanding

Every application will require Formal Trade Studies to provide insight into deciding the correct material per its environment & use. This is a standard substrate layer for understanding. A more advanced composite fabric system has been used in Aerospace & Defense applications usually as the composites themselves with an epoxy resin system to stiffen & shape the material into the vehicles required mild line surfaces. Sometimes we have co cured a scrim cloth which is like a screen that is conductive to create the faraday cage to protect the inside from any outside events like Electro-Magnetic Pulse, Nuclear Events or on the Apache helicopter it was used to protect the avionic packages from microwave interference from then new cellular or mobile phones (more like bricks). Plans made for developing at least three different fabrics; Kevlar, Carbon and Dyneema in Figures 32&33.

Figure 32 Kevlar fabric roll.

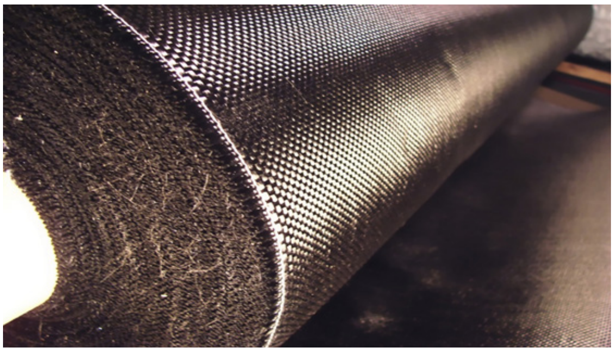


Figure 33 Carbon fabric roll.

Kevlar Fabric: Benefits overall are Microwave Transparency, Fireproof & Bulletproof. The tensile modulus and strength of Kevlar 29 is comparable to that of glass (S or E), yet its density is almost half

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

that of glass. Thus, to a first approximation, Kevlar can be substituted for glass where lighter weight is desired. Kevlar 49 or 149 can cut the weight even further if the higher strength is accounted for. Kevlar's weight savings does come at a price: Kevlar is significantly more expensive than glass.

Kevlar has other advantages besides weight and strength. Like graphite, it has a slightly negative axial coefficient of thermal expansion, which means Kevlar laminates can be made thermally stable. Unlike graphite, Kevlar is very resistant to impact and abrasion damage. It can be used as a protective layer on graphite laminates. Kevlar can also be mixed with graphite in hybrid fabrics to provide damage resistance, increased ultimate strains, and to prevent catastrophic failure modes.

Carbon Fabric: Benefits In the case of carbon fiber, things can be advantageous:

1. Great Thermal Properties (stability, and conductivity) are better than steel.
2. High Tensile and compression strength
3. Great Thermal endurance (particularly at cold temperatures)
4. Moisture absorption resistance
5. Good Electrical conductivity
6. Great Chemical resistance

Advantages: Carbon is stiffer and stronger though some specialized high-strength glass like S2 glass, are almost comparable in strength on a volume basis. Carbon is also lighter for the same volume of material. Carbon composite parts therefore tend to be much lighter than glass composite parts. Given that the cost-effective route seems to have been beaten to death, making a more robust system capable of handling more stress and fatigue than the "tired and true" fiberglass, Mylar or Kapton methods ever could.

Disadvantages Glass stretches more before it breaks, so it is more useful for flexible applications, like skis and snowboards, and helicopter blades. This ability to stretch also makes glass better suited for really high impact damage, like ballistics (bullets hitting your glass or carbon part, though presumably not your snowboard). Carbon fiber is roughly 8X-15X more expensive than glass per weight. Carbon fiber is conductive (useful or not depending on application), electrically and thermally, glass is not. Carbon fiber does not change size much with temperature. Glass does about as much as steel, when in a composite form.

It means that the weight savings will justify the additional cost. But good luck finding that number out. The auto designers have some idea what it is, for example, maybe it's \$20-\$30/lb. of weight saved, but most aerospace & automotive manufacturers don't even know the real cost of their existing parts, (total cost, including all the allocated overhead, etc.) so it's difficult to make a good comparison and figure out when it's possible to make such changes.

Dyneema Fabric: Benefits is the strongest and most durable fiber in the world (Figure 34).

As a fabric, it offers game-changing properties for the sports and lifestyle, life protection, and workwear industries.

1. 30% lighter than nylon/ polyester
2. 45% lighter than aramid
3. 15 times stronger than steel

Figure 34 Dyneema fabric rolls.

Flexible composite fabrics take strength and durability to new highs. Dyneema® Composite Fabrics dramatically increase tear, puncture, and abrasion performance dramatically compared with 500D nylon, while cutting weight and reducing bulk.

Dyneema can also be tailored and optimized for strength, stretch, and weight, and for thickness overall and at specific points or along predetermined load paths. The customizable properties of these flexible composite fabrics allow them to be used in numerous applications and industries, ranging from outdoor sports equipment to emergency medical products. We have just shown and explained the basics of these standard materials on rolls we nickname media.

Solar microwave fabric applications

The solar microwave fabric can provide solar power directly to other devices or can be used to collect power for communications. It can also transmit power to other distant locations. The "skin" structural media of the SMF can be made of a variety of materials, including Mylar, Kapton, Kevlar, many hybrid composites, metallic sheets, paper, and woven fabrics. For any given application, once the printing "algorithm" is set, the SFM can be churned out in mass quantity, like wallpaper & fabrics.

Current technology provides laboratory-scale samples of separately printed solar cells and patch antennas, larger scale printing of low-efficiency solar cells, and very small samples of non-integrated combinations.

The SMF product is unique in that solar power collection, wireless power transmission and communication capabilities are integrated into large thin, light-weight sheets that can be made into "rugs" or other shapes and folded into compact packages for transport to needed locations.

Longer term, in large scale solar power collection, there may be a market for space solar power (SSP). This means collecting solar power by a satellite (usually in geostationary orbit, where it hovers over one location), and beaming it in the form of microwave radiation (to which the atmosphere is mostly transparent) to a ground station where it is converted into AC current. The ground station would consist of arrays of rectifying antennas ("rectennas") that can be mounted on the ground without interfering with sunlight or alternate land use. There are some strong motivations for SSP. For example, taking account of 24/7 operation and the absence of weather and atmospheric attenuation of sunlight, SSP can average almost ten times the efficiency of ground-based solar farms. The big obstacle is the cost of an initial "First Revenue System" (FRS), that would be large enough (at least 50 MW) to prove the technology and turn a profit. All (except one) SSP satellite designs involve gigantic, complicated structures, with many (sometimes thousands) of moving parts, requiring hundreds of launches and on-orbit construction, usually invoking nonexistent robotics and other technologies.

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J*. 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

In contrast is the Power-Star™ design. Take sheets of SMF having both solar cells and transparent microwave patch antennas with retro directive phased array capability, and assemble a large balloon, using the old Echo satellite technology. As in Echo satellites I and II, fold the balloon into a small spherical container, and launch it into geostationary orbit. Once there, the container opens, and a powder coating the interior surface sublimates, thereby inflating the balloon. Assuming only 20% solar cell efficiency, Power-Star™ can collect 90 to 150MW of power. When stowed for launch, Power-Star™ can be accommodated by four existing launch vehicles. Also considering the largest and growing Space-X platforms. Therefore, SMF makes a First Revenue System (FRS) possible (and affordable) in one launch. Power-Star™ features the simplest possible structure, no moving parts, no on-orbit robotic construction and safe, automatic, and robust operation. Further details are discussed in Section […].

Once proven by an FRS, Power-Star™ can be used to beam power to hard-to-access places, industrial parks, and even individual buildings with rectennas installed on building roofs or over parking lots. New markets created by SMF are only limited by one's imagination, in this category, we might include SSP systems just described. However, we draw attention to near-term applications that are enabled by SMF and not anticipated before the invention of SMF.

Self –powered cell phone towers

All cell towers rely on external power and are disabled in a blackout. SMF (plus battery storage) provides a cheap, independent power source. Quantities of lightweight can be wrapped around the framework of the cell tower to prevent power interruption (Figure 35).

Figure 35 Cross-section of solar cells with transmission/antennas side by side.

Once these Cell towers are wrapped with SMF it would be self-powered & protected from lightning strikes & bad weather disturbance.

Advanced habitation technology

By "habitation technology" we refer to an integrated, portable system of systems that enables a small group of people to generate most or all their consumables. SMF can provide a substantial component of such systems shown previously in Figure 20.

Power, communications, and self-defense capabilities can be provided inexpensively to people wishing to live more independently as shown in Figure 21.

Self-Powered tents

SFM can be embodied in rugged, flexible, and waterproof fabrics. Under current technology stiff, bulky solar arrays must be wired to tent fabric to be used, and then unwired to fold the tent (Figure 36).

Figure 36 Self powered tents with satellite communication.

On the other hand, a flexible SMF tent is both a shelter and the power source and can be simply folded and unfolded.

Bimini tops and convertible tops

Like the above, stiff, bulky solar arrays must be wired to the Bimini fabric to be used, and then unwired to fold the Bimini (Figure 37).

Figure 37 Should be a powered Bimini tent & awning.

No such complications arise with SMF Bimini tops. SMF solar powered convertible tops are both convenient and save battery life and improve mileage.

Powered clothing

SMFTM fabric with solar cells can be manufactured using wearable fabric. This means that a person's coat can be used to recharge electronic devices such as smart phones, watches, etc (Figure 38).

Figure 38 Powered clothing illuminated.

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196

Point-to-point communication clothing

SMF clothing having both solar cells and patched antenna phased arrays would not only power personal electronics but could be used for point-to-point communication. The communications signal would be amplified and the retro directive phased array capability used to transmit a tight beam to the near vicinity of the receiving person (Figure 39).

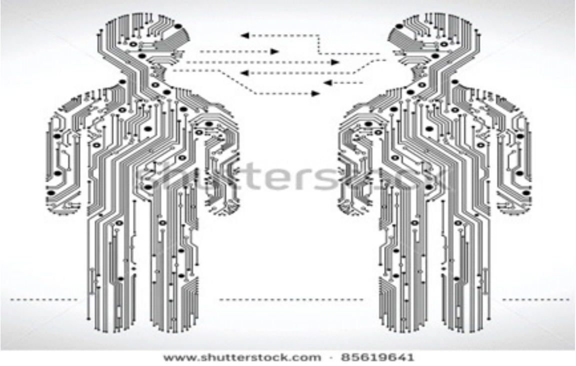


Figure 39 Point to point contact.

This would be very useful to emergency first-responders, where disaster emergency conditions require high fidelity communications independent of existing networks.

Clothing with tactile messaging/touch devices (beam me! or the "intimate touch")

This is point-to-point communication clothing with the object of promoting the confidentiality of personal communications. In addition, the microwave signal could be used to energize devices that provide tactile stimulation through the recipient's clothing as a way of announcing a call. "Beam Me!" could go viral.

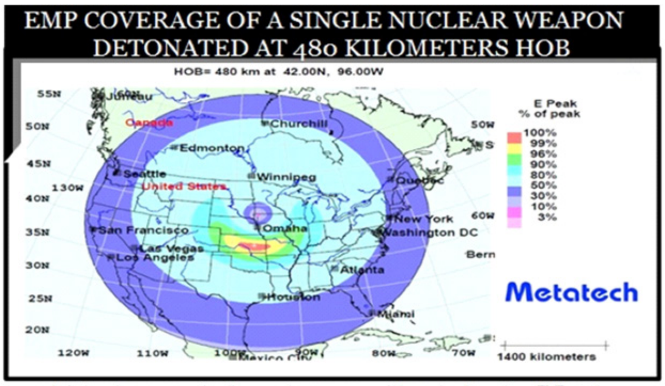
Figure 40 is used to illustrate separate localized areas for activation on clothing here it is a shirt, Tactile messaging would not have to have any illumination to it but could just be the vibratory pads use for physical therapy or muscle relaxation systems, also used on Abs electronic stimulating machines to harden up muscles not easy to get to or work on without many hours.

Figure 40 Example of tactile messaging.

Protecta-grid nuclear hardening & bullet-proofing US

Protecta-Grid, Solar-Nuclear Hardened Fabric; to be used to harden/protect the electrical grid system, from Electro-Magnetic Pulse (EMP) or upper atmosphere nuclear explosion, Solar Flares and prevent disaster from penetration of EMP strong enough to wipe out our electrical grid system & important infrastructures. This Hybrid Solar-Nuclear Hardened Fabric; is manufactured is large rolls like the SMF Fabrics with the added matrixed composites woven with conductive Faraday cage sewn in & built-in power supply. Enable to provide small arms protection we add the necessary materials (i.e., Kevlar, S2, Dyneema, Graphite, etc.) along with conductive strands which produce the faraday cage to protect everything it surrounds. We will also provide built in LED Lighting if desired for illumination for maintenance or protection of the environment at war time.

According to Frank Gaffney, a spokesperson for the Center for Security Policy, within a year of an attack "nine out of 10 Americans would be dead, because we can't support a population of the present size in urban centers and the like without electricity." If that sounds a little high, consider Former CIA Bureau Chief Claire Lopez is also warning that "Within one year, it is estimated that 9 out of 10 of all Americans would be dead (Figure 41)."



A single nuclear weapon – virtually any nuclear weapon – could be employed to make an EMP attack against unhardened civilian critical infrastructures across the entire contiguous United States. (Source: Courtesy Dr. William Radasky, President, Metatech.)

Figure 41 Example of 1 nuclear weapon over the USA affect.

Protecta-Grid will protect all Protecta-Grid will be a tarp like material with self-energized faraday cage for nuclear hardening at frequencies known in classified circles. This will be not only a self-energized power source with Lithium polymer (or better) pack snapped onto the tarps but the underlying surface of the Tarp. This is in high demand for our troops & National Security in the US Dept. of: White House driven to the DOD, NSA, DHS, DOE. This will also have sectional high output LEDs to light up everything in the grid system at all times of day or night. Continuously protecting the grid system should hick-ups happen the system can support independently all emergency systems such as: Police, Fire Dept., Hospitals & life dependent places and means (like retirement homes). We want to call it Hallow but a Movie took that name (Figure 42).

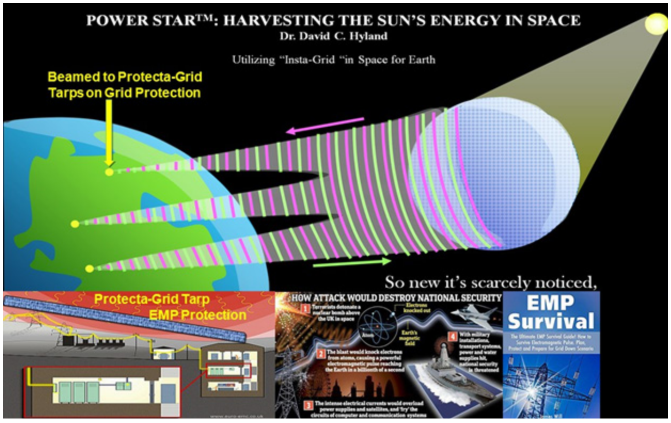


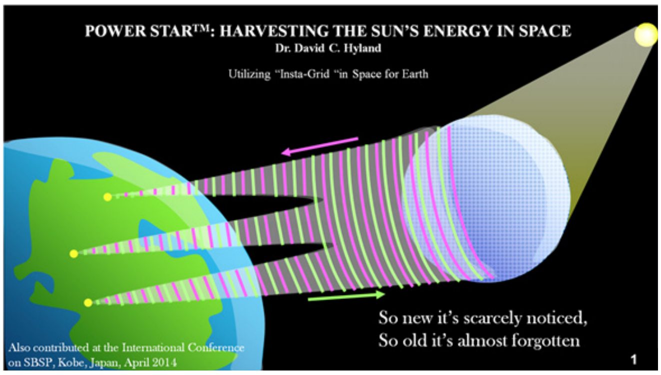
Figure 42 Example EMP protection, transmit & receive energy.

We could wrap fuel tankers with (bullet absorbing material) this to make them bullet-proof & Nuclear Hardened their skin could become Electro-Magnetic Armor. The Greatest thing about Protecta-Grid is once it is in place, after we place Power-Star satellites into Space they have focal points to send energy safely to with accuracies never seen before. Thus, allowing America to always have a plan B for energy & communications.

Energy from space; the future SMF in power-star

A solar power system consists of a space segment that collects solar energy, converts the energy into radiation (typically in a wavelength band to which the atmosphere is mostly transparent), then transmits the radiation to a ground facility that converts the radiation into electrical power. Power-Star is the breakthrough solution for the space segment. Take mass- produced SMF, and form it into balloon satellites, as in the Echo satellites (see below). Compactly folded for launch, it is automatically inflated on-orbit to provide enough power for a first-revenue system. Dozens of launches of complex structures with many moving parts requiring robotic in-space construction are all unnecessary. One launch = one system."

Space Solar Power to be known as: Energy from Space Program aka, refers to the concept of a space system that collects solar power via photovoltaic & mirrors then transmits it to ground collection stations using visible or microwave radiation. This has recently been invented and patented by Dr. David Hyland & Art Dula patent. System and Method for Collection and Distribution of Space Based Solar Power aka Power-Star. This is an awarded patent US Patent 10,666,092 issued 5/26/2020, and Japanese Patent 6,746,573 issued 8/7/2020 (Figure 43).



POWER STAR^{TM}: HARVESTING THE SUN'S ENERGY IN SPACE
Dr. David C. Hyland
Utilizing "Insta-Grid "in Space for Earth

So new it's scarcely noticed,
So old it's almost forgotten

Also contributed at the International Conference on SBSP, Kobe, Japan, April 2014

1

Figure 43 Overview of energy from space called power-star.

Building the Space Solar Power Transmission Systems with >300+ Smaller Satellites with morphing mirrors can produce over 25 Terawatts and power most of the World for many decades & centuries. In addition, we can beam down the power via lasers and create efficient, affordable desalination salt water to places worldwide. We can also start to control/tame weather by overlapping beams/rays and even some known frequencies causing convection and using upper currents to move it to rain where there are droughts including eliminating tornadoes & bad hurricanes. We can also make Space Death rays for vaporizing threats from space (like Reagan's Star Wars), also vaporize those threats which cannot be captured (space debris), additionally send a beam out to our Mars or outer planetary transport. Understand the future does not have to be like the past and demanding to make the Future better - like our Race to Space and the moon. In this pursuit of one's destiny is limitless.

NASA's Echo shown in Figure 44 was America's response to Russia's sputnik the World's 1st space Satellite. The Echo was produced from Mylar as explained above ref. Figure 30. The Advantages NASA had over the Russian Sputnik is cover & capability due in large to its size or square foot area and launching as a compressed small, packaged unit (Figure 45&46).

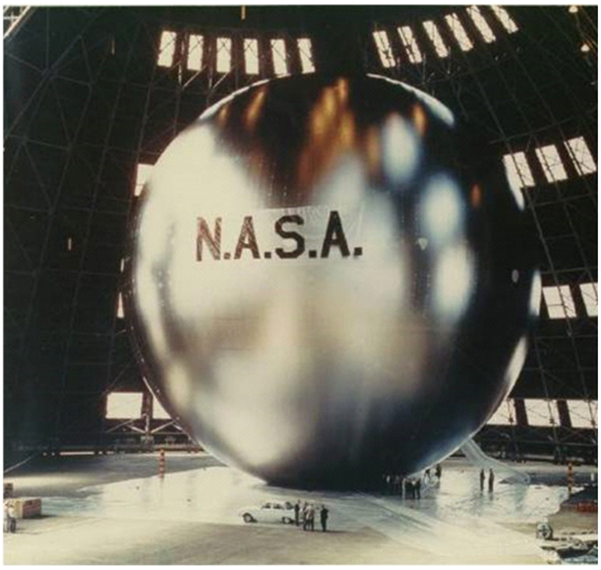


Figure 44 NASA's 1st Satellite echo in response to Sputnik.

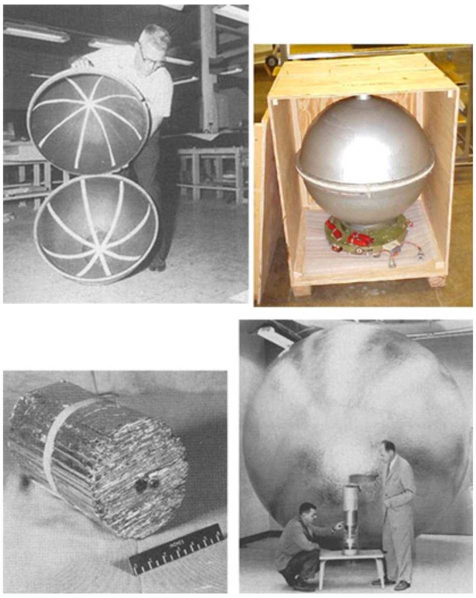


Figure 45 Echo packaging for launch.

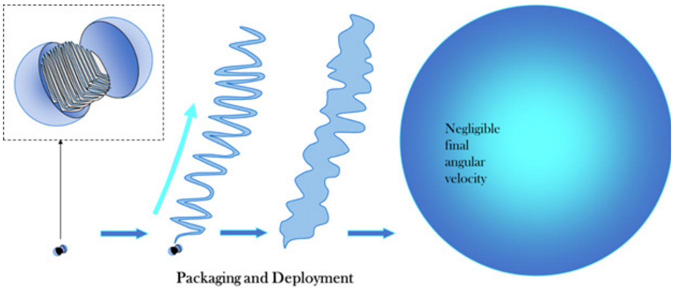


Figure 46 Packaging post launch in space expansion.

Power-Star's packaging would be like that used for NASA's Echo some 50+ years ago. FYI - Echo II inflation mechanism is similar to that we use in today's automotive life-saving air-bags.

The Powers-Star will use similar inflation mechanism as used on NASA's Echo II here is an overview explanation in Figure 47;

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

Balloon will be inflated by the sublimation of a powder upon exposure to the heat of sunlight.

1. This gas will inflate pillows, which will begin the deployment process and prevent the gas from getting trapped in pockets.
2. Once the pillows inflate, they will vent gas through perforations in the surface of the pillow, inflating the rest of the satellite.
3. The copper grounding grid will be designed to yield at a certain pressure, providing stability to the satellite's shape.
4. One of the pillows will be designed to rupture the outer surface of the balloon after deployment, allowing the Power-Star to release excess gas once the copper grid has just begun to yield.

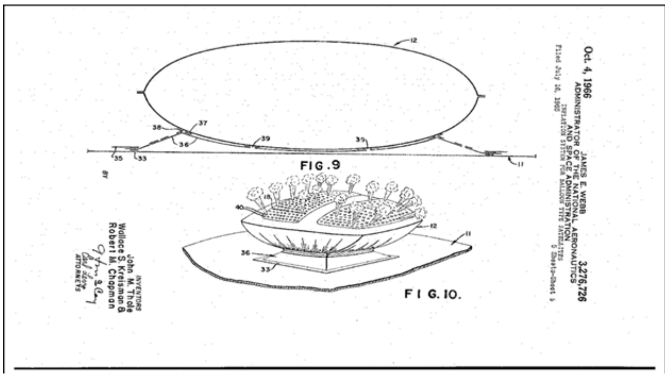


Figure 47 NASA's inflation mechanism for in space expansion (ref. - patent).

The exterior surface of the sphere is printed with solar cells and microwave transmitters (Figure 47, lower right), where the placement of transmitters is somewhat randomized to prevent grating lobes (see below). There are power connectors between each transmitter and a subset of the immediately adjoining solar cells (Figure 48, top, center, red lines in the cross-section). Beneath the exterior coating is the substrate layer (gray band in the Figure) with an embedded copper grid (orange lines in the Figure) for electrical ground and rigidification. The interior surface of the substrate is coated solely with transceivers (transmitter/receivers, blue layer on the bottom of the cross-section). There are power connections through the thickness of the skin from the internal transceivers and the immediately proximate external transmitters. Power connections in the skin are very short (a few centimeters) and the power collection and transmission devices are on a microscopic scale, such that we anticipate an eventual halving of the Echo skin thickness to $\sim 6\mu m$ (microns).

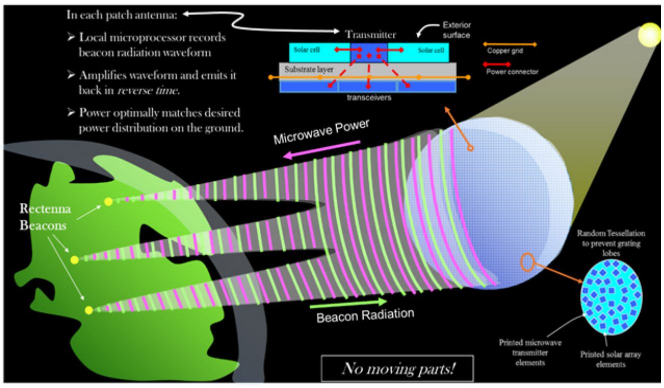
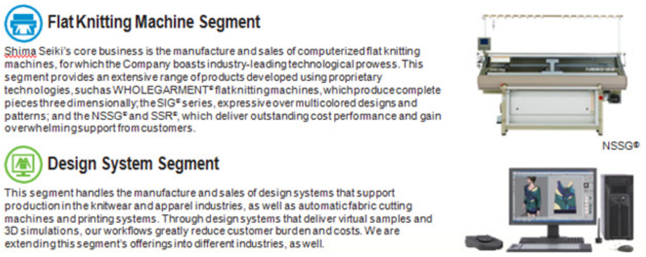


Figure 48 Overall, power-star operation once deployed.

Power is received at several locations on the ground by arrays of rectifying antennas (rectennas). At the location of each rectenna, a low-power microwave beacon is placed. At each patch antenna a local microprocessor records the beacon radiation that the patch receives; records the radiation wave form; amplifies the waveform and emits it back in reverse time (or, equivalently with conjugate phase). As will be elaborated below, this completely decentralized transmitter control scheme produces transmitted radiation that, given the size and shape of the Power-Star, optimally matches desired power distribution on the ground. Note that the system can absorb power from the sun and transmit power in any other direction without the need for slewing or mechanical motions. The system works with electrons and photons and has no moving parts.

Materials processing

We will be mass producing the Solar-Fabric with greater than >20% efficiency. This is to be produced at $1 dollar per KW and objectively supply energy as clean new source at less than 7 cents per Kilowatt per Hour (KWHr.). Much less than today's market price in the USA and ¼ that of Europe's. The tangible structural fabric will be automated using an advanced Shima Seiki's CAD/CAM system explained below (Figure 49).



Flat Knitting Machine Segment

Shima Seiki's core business is the manufacture and sales of computerized flat knitting machines, for which the Company boasts industry-leading technological prowess. This segment provides an extensive range of products developed using proprietary technologies, such as WHOLEGARMENT® flat knitting machines, which produce complete pieces three dimensionally; the SIG® series, expressive over multicolored designs and patterns; and the NSSG® and SSR®, which deliver outstanding cost performance and gain overwhelming support from customers.

NSSG®

Design System Segment

This segment handles the manufacture and sales of design systems that support production in the knitwear and apparel industries, as well as automatic fabric cutting machines and printing systems. Through design systems that deliver virtual samples and 3D simulations, our workflows greatly reduce customer burden and costs. We are extending this segment's offerings into different industries, as well.

Figure 49 Materials custom knitting machine.

After industrial review of knitting & sewing machines out there, one company has innovated better techniques for producing full 3D products (usually garment industry into Aerospace). Shima Seiki developed WHOLEGARMENT® flat knitting machines, which in their originality had an impact on the knitwear industry judged comparable to the advances of the Industrial Revolution. The high quality and superior cost performance of the Shima Seiki have become bywords among customers throughout the world, in advanced nations and emerging markets alike. Through its continued development of ingenious products and proposal of its Total Fashion System with the design system at its core, continues shaping the clothing culture and contributing to the development of many industries well into the future.

Future Focus and building the Power-Star (Space Solar Power Transmission) Systems with >300+ Smaller Satellites can produce over 15 Terawatts and power most of the World for many decades & centuries.

Once SMF then Power-Star is developed, we can beam down the power via lasers and create efficient, affordable desalination salt water to places worldwide. We can also start to control/tame weather by overlapping beams/rays and even some known frequencies causing convection and using upper currents to move it to rain where there are droughts including eliminating tornadoes & bad hurricanes (Figure 50).

We can also make Space Death rays for vaporizing threats from space (like Reagan's Star Wars), also vaporize those threats (asteroids, missiles, aircraft) which cannot be captured (space debris), additionally send a beam out (tracker beams) to our Mars or outer planetary transport vehicles.

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196

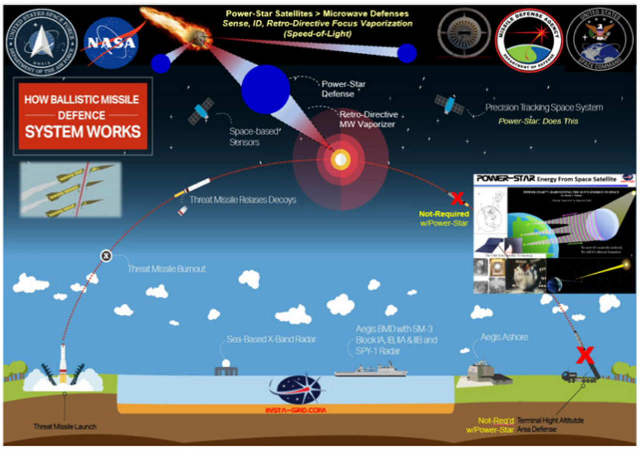


Figure 50 Power-star for space & missile defense.

High Powered Microwave HPM technology will continue to advance, creating more opportunities to place these systems on different platforms, new and old. Having more platforms and options will help to legitimize the technology for operational units. Currently, AFRL and industry partners create these systems to demonstrate their potential and feasibility of the technology. Once these systems become more readily available, more training can occur. Having access to these systems at the operational level will provide an opportunity to showcase their capability and get the required buy-in so they can deploy in future conflicts.[23]

Experimentation

Here are two qualitative and quantitative experiment is data, knowledge, and current technology assessment. The cost and schedule limitations are currently limited, requiring many Technical Trade studies, much detailed engineering, designs, and materials processes to be studied. Unquestionably many experimental formal trade studies & lab experimentations, tests along with verify & validate and find various benefits vs. limitations.

Technology risk review

SMF Technology Review Level Assessment, we start at itemizing the technologies which are used in the making of Solar Microwave Fabric at a basic good example level. This qualitative and quantitative experiment is not to be confused with Space flight readiness for SFM making of Power-Star Satellites. This is the logical and scientific way to start on this "Leap Frog" technology (Figure 51).

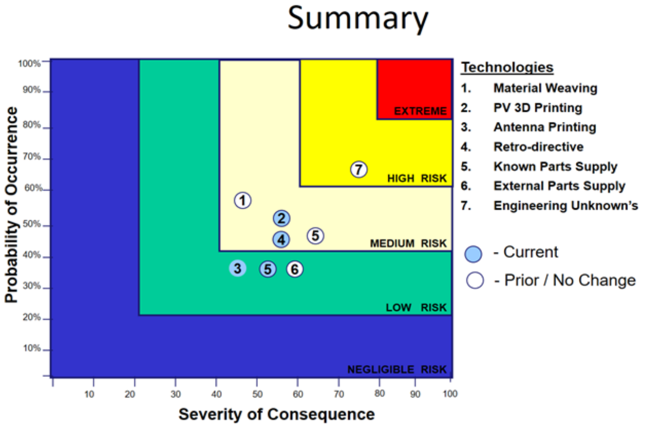


Figure 51 Solar microwave fabric risk assessment.

We reviewed each technology independently as a list in the side bar of 7 various known technologies listed. Risk assessment involves the calculation of the magnitude of potential consequences (levels of impacts) and the likelihood (levels of probability) of these consequences to occur, Risk = Consequence x Occurrence (likelihood). The higher the number, the greater the Severity, Probability or Exposure. Severity: Scored 10 to 100. This number describes the potential loss or consequence, or a mishap should something go wrong, the results are likely to be found in the following areas: Property damage or loss, Mission degradation, Reduced morale, Adverse publicity, Administrative and/or disciplinary actions 10=none or slight 25=Minimal 50=Significant 75=Major 100=Catastrophic Probability: Scored 1 to 100. The amount of time, number of cycles, number of people and resources (equipment) involved. 10=None or below average 25=Average 50=Above average 75=Great Compute the value of Risk. Values Risk Level Action 80-100 Very High Discontinue, STOP 60-79 High Immediate Correction, 40-59 Substantial Correction Required, 20-39 Possible Attention Needed, 1-19 Slight Possibly Acceptable Compute the Risk Value for each hazard identified. Focus attention from highest values assessment of Severity, which is typically based on qualitative criteria used to describe, property or the Risk of Probability vs Severity of Consequence due to each independent impact to success vs failure. The higher the percentage number the more risk of risk concern, the lower the number the lower the risk.

Material Weaving: technologies to perform this unique weaving and weaving patterns for the substrate which is the main body material for the SMF. Shima Seiki has been proven incredibly effective in unique patterning based on their uniquely design sewing needles/hooks. This can be seen in their ability to sew up a suit with the sleeves, pockets, etc. all in one, not flat then sewn to make them. Medium Risk; rating of Probability 58% and Severity 45%, TRL 5.

Photo-Voltaic (PV) 3D Printing: A Formal Materials Trade Study must be performed to determine the Best Suited PV 3D printed System at the time prior to Proof Of Concept (POC) design & build. It is strongly recommended that the material environment and application to be determined prior to POC and it should be market driven. If it is for National Defense and the Space Satellites as described in Power-Star example then all harsh unique concerns can help influence a better design for POC and all its testing in accordance to rule & guidelines in DoD & NASA satellites, Medium Risk; rating of Probability 52% and Severity 55%, TRL 4 & higher.

Antenna/Rectenna Printing: technology is already in mass production in industry and getting even broader & larger as materials and processes evolve. As described above we use best known existing systems for this assessment, knowing better and more efficient materials will soon be available. Antenna Printing has a Low-Risk rating of Probability 37% and Severity 45%, TRL 4 & higher.

Retro-Directive: MW Transmission, Cal Tech, Pasadena has recently successfully created the proof of concept for microwave transmission of Solar Energy delivery. This is considered Medium Risk because distance is so large and difficult to achieve through atmospheres. High Risk; rating of Probability 37% and Severity 55%.

Known Parts Supplies/Customized Components) was a medium risk due to little known suppliers in 3D printed electronic circuitry & parts, recently more suppliers developing and using to make customized parts making this currently Low Risk; rating of Probability 37% and Severity 53%, TRL 5.

External Parts Supply/Altered Commercial Off The Shelf (COTS) is Low Risk; rating of Probability 37% and Severity 59%, TRL 4

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

Engineering Unknowns Integration, Symbiotic Functionality is High Risk: rating of Probability 37% and Severity 59%, TRL 2

In Aerospace & Defense Technology Readiness Level started by NASA is the best way to itemize & analyze the various detailed technologies. The TRL describes the state of a given technology and provides a baseline from which maturity is gauged and advancement defined. As a set of metrics, TRLs enable the standardized assessment of the maturity of a particular technology and the consistent comparison of the maturity between different types of technology in the context of a specific application, implementation, and operational environment.[24]

Progression of TRLs

We have every intention to do this with USAF for Power-Star development as soon as possible. TRL measures the progression of new technology from concept to use in an operational flight mission. The new technology conception occurs starting at TRL 1 through TRL 3. Development and demonstration occur between TRLs 4 through TRL 6. Once TRL 6 is demonstrated, the risk associated with the new technology is roughly equivalent to the risk of a new design that employs standard engineering practice and is bounded by previously implemented ground-based systems. NASA practice recommends technology demonstrates TRL 6 prior to the Preliminary Design Review (PDR) (Figure 52).

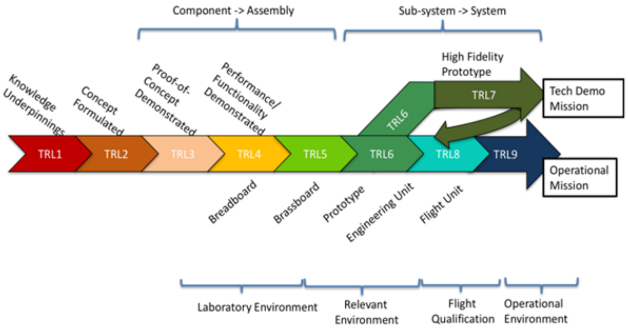


Figure 52 Two paths to flight.

The most common path progresses from TRL 1 to TRL 2 is writing this paper explain our methodology to get to proof of concept & demonstration. TRLs range from 1- Basic Technology Research to 9- Systems Test, Launch, and Operations. Typically, a TRL of 6 (technology demonstrated in a relevant environment) or higher is required for a technology to be integrated into a flight system.

Solar Microwave Fabric is only TRL 2 all its components/ sub-systems are TRL 4 or higher, no known Proof Of Concept or Demonstrator exists yet. It was recently invented & patented by Dr. David Hyland & Art Dula from Texas.

Terminology

The first step in developing a uniform TRL assessment is to define terms. It is crucial to develop and use a consistent set of definitions over the course of the program/project.

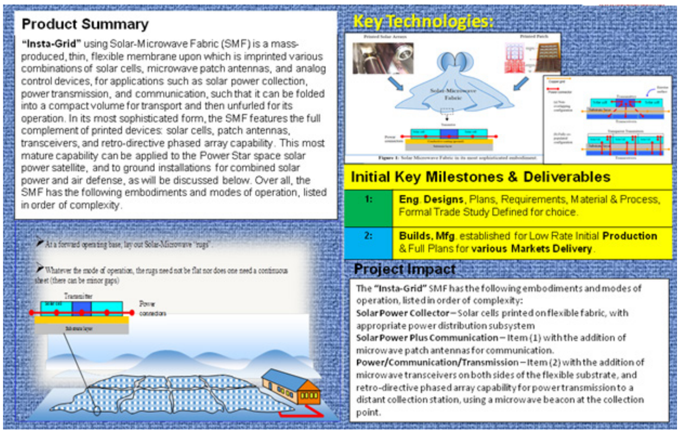
Hardware levels

Proof of Concept: Analytical and experimental demonstration of hardware/software concepts that may or may not be incorporated into subsequent development and/or operational units.

Breadboard: A low fidelity unit that demonstrates function only, without respect to form or fit. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.

Brassboard: A medium fidelity functional unit that typically tries to make use of as much of the final product as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects but is structured to be able to operate in simulated operational environments to assess performance of critical functions.

Prototype Unit: The prototype unit demonstrates form and function at a scale deemed to be representative of the final product operating in its operational environment. A subscale test article provides fidelity sufficient to permit validation of analytical models capable of predicting the behavior of full-scale systems in an operational environment. This would be the minimum to do with World Class R & D on this and produce a good Proof Of Concept (Figure 53).



Product Summary

"Insta-Grid" using Solar-Microwave Fabric (SMF) is a mass-produced, thin, flexible membrane upon which is imprinted various combinations of solar cells, microwave patch antennas, and analog control devices, for applications such as solar power collection, power transmission, and communication, such that it can be folded into a compact volume for transport and then unfurled for its operation. In its most sophisticated form, the SMF features the full complement of printed devices: solar cells, patch antennas, transceivers, and retro-directive phased array capability. This most mature capability can be applied to the Power Star space solar power satellite, and to ground installations for combined solar power and air defense, as will be discussed below. Over all, the SMF has the following embodiments and modes of operation, listed in order of complexity.

➤ At a forward operating base, lay out Solar-Microwave "rugs".

➤ Whatever the mode of operation, the rugs need not be flat nor does one need a continuous sheet (there can be minor gaps)

Key Technologies:

Initial Key Milestones & Deliverables

1:	**Eng. Designs**, Plans, Requirements, Material & Process, Formal Trade Study Defined for choice.
2:	**Builds, Mfg.** established for Low Rate Initial **Production** & Full Plans for **various Markets Delivery**.

Project Impact

The **"Insta-Grid"** SMF has the following embodiments and modes of operation, listed in order of complexity:
Solar Power Collector—Solar cells printed on flexible fabric, with appropriate power distribution subsystem
Solar Power Plus Communication—Item (1) with the addition of microwave patch antennas for communication.
Power/Communication/Transmission—Item (2) with the addition of microwave transceivers on both sides of the flexible substrate, and retro-directive phased array capability for power transmission to a distant collection station, using a microwave beacon at the collection point.

Figure 53 Proof of concept model.

The next effort is to perform all studies required prior to Buy, Build and Test a Proof of Concept. Already have large amounts of solar-fabric, need to: perform rectenna design & simulations. #D Print Rectenna attaches it to solar fabric and tests it.

Results

SMF is a technological reality scientifically and the formulation of how to get there is started as a great baseline to progress into the next steps for evolution into everyday products. Printing of solar cells (PV) in a roll-to-roll process already exists and so does 3D printing of patch antennas. Each substrate material has beneficial characteristics which should be studied & traded for the Best results for each application. Space Solar Power is now becoming more of a reality after well over 50 years since the concept was considered by Peter Glaser in 1968, along with the first satellite patented in 1973. Currently Cal-Tech and the US Air Force are making progress in this and demonstrators in space are continuing to make progress.[25–27] These systems are going to address wireless energy transmission which started at the beginning of the Space Force in 2019.

Wireless energy transmission

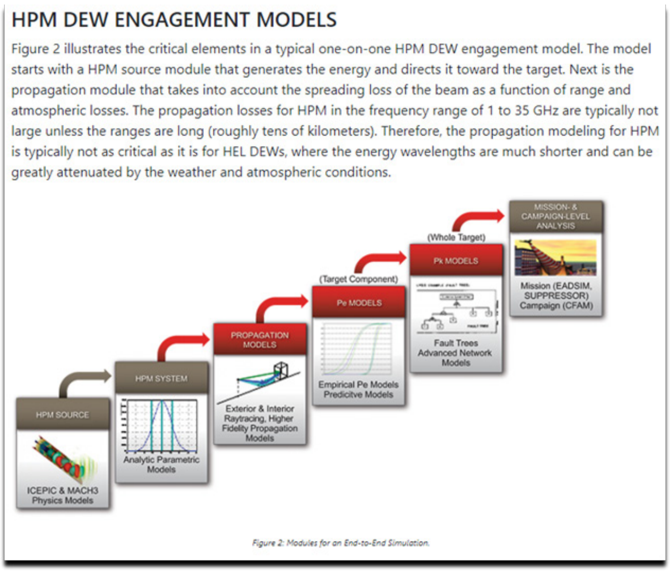
Wireless transmission technologies required to make this happen are still in their infancy, but such a method of power delivery could prove to be extremely promising. Beyond that, scientists will have to test sending the energy back to Earth. The panels would know precisely where to send the microwaves and not accidentally fire it at the wrong target using a technique called "retro-directive beam control." This sends a pilot signal up from the destination antenna on Earth to the panels in space.[26] The near future holds many answers

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196

to many technical hurdles and difficulties, none of them have a SMF concept which would be lighter and more powerful than any prior to our first launch.

Required detailed investigation

Everything in developing SMF must be digital and as the Power-Star HPM-DEW satellite(s) many models must be created and analyzed. This is necessary for capturing knowledge, data & decision-making criteria. These models help creating the various Operational Requirements Documents needed for a complete celestial bodies we nickname "Angel Sats" which provides the US Space Force aka "Guardians" revolutionary new weaponry along with profitable energy delivery systems. These models are represented by the e example shown but not limited to in Figure 54.



HPM DEW ENGAGEMENT MODELS

Figure 2 illustrates the critical elements in a typical one-on-one HPM DEW engagement model. The model starts with a HPM source module that generates the energy and directs it toward the target. Next is the propagation module that takes into account the spreading loss of the beam as a function of range and atmospheric losses. The propagation losses for HPM in the frequency range of 1 to 35 GHz are typically not large unless the ranges are long (roughly tens of kilometers). Therefore, the propagation modeling for HPM is typically not as critical as it is for HEL DEWs, where the energy wavelengths are much shorter and can be greatly attenuated by the weather and atmospheric conditions.

Figure 2: Modules for an End-to-End Simulation.

Figure 54 HPM-DEW models, studies to be performed.

This Figure 54 shows the various engineering activities that must proceed for certain applications, formal trade studies and creation of an Operational Requirements Documents (ORD). Once the ORD for each system and its application where used is formulated digitally. Afterwards the details needed for Requests For Information (RFI) and onto Request For Proposals may be generated logically. This entire process shall be performed digitally allowing continuous improvements throughout the development of the process.

Required detailed investigation

Once the ORD(s) have been generated, engineering can use the optimal Model Based Systems Engineering (MBSE) processes and tools to successfully develop the system, which feeds into the System Of Systems (Figure 55).

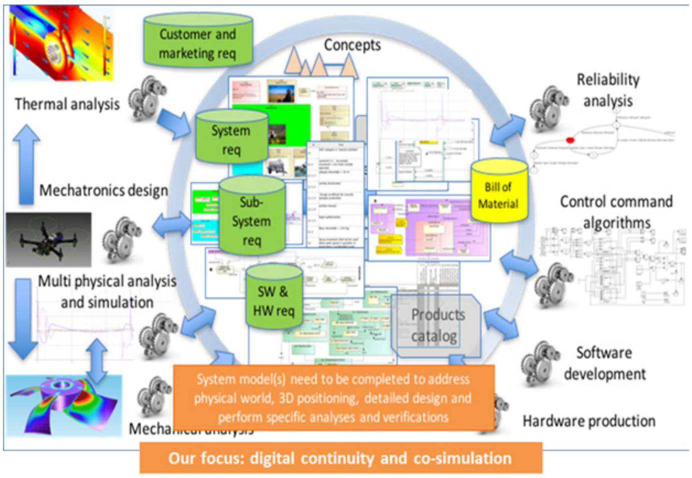


Figure 55 Engineering models, analysis & development to be performed.

This chart shows the systems engineering activity that must proceed certain application trade studies and Operational Requirements documentation. Every part of software and hardware engineering development shall be performed digitally, coordination, verification and validation also electronically providing value driven databases for continuous improvement and expansion.

Conclusion

Solar Microwave Fabric is the way of the Future, especially for producing and transmitting energy all around the World. You would not need a grid system or power plants to deliver your energy. Just lay down the SMF on a roof top or the ground to provide your energy & defense needs. This is categorized as a Directed Energy Weapon with High Powered Microwave and lots of it enough to vaporize all threats.

SFM for directed energy weapon as a high-powered microwave (HPM)

HPM technology,[23] while not new, is a revolutionary technology that will provide the US unique capabilities. HPMs are the type of technology that the US will need to maintain its competitive advantage of its adversaries. This technology has been in a perpetual state of evolution and has seen significant advances in capability. HPM weapons come in two types, continuous-wave and pulsed-wave, and each provides unique capabilities. This study focused on how the US could take pulsed-wave HPMs from the laboratory setting and operationalizing them to prepare for tomorrow's fight. Employing these types of weapons systems will require some 18 changes to how intelligence professionals support the platforms to how the US conducts targeting. This study proposes that HPMs can be used to strike counter value targets that will affect the adversaries' decision calculus. Having the ability to hold these types of targets at risk or conducting strikes against them provides the US with a new tool to coerce potential adversaries. HPM weapon systems should not replace any weapon or electronic warfare system. These systems provide alternative options for when and if the US decides it needs to use the military instrument of power.[23]

The basic design concept of a space-based solar power system in the 1970s was inefficient, difficult to launch, had no automation and received negative feedback from the National Research Council (NRC) and the Congressional Office of Technology Assessment (OTA). We have increased solar power generation efficiency, increased efficiency in wireless power transmission, created easier launch capabilities and have a more retractable design that does not require any astronauts or space factories, as the 1970s version did. Mankins made the point that "you don't need hundreds of billions of dollars to see if these new systems are economically viable."[25]

Scientists working for the Pentagon have successfully tested a solar panel the size of a pizza box in space, designed as a prototype for a future system to send electricity from space back to any point on Earth shown in Figure 56. A Photovoltaic Radiofrequency Antenna Module (PRAM) was first launched in May 2020, attached to the Pentagon's X-37B unmanned drone, to harness light from the sun to convert to electricity.[26]

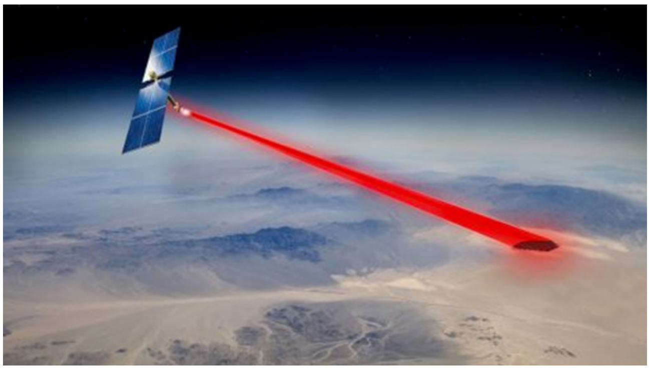


Figure 56 Concept of a space-based solar power system beaming to installations.

The above Figure 57 shows the PRAM sits outside the thermal vacuum chamber during testing at the US Naval Research Laboratory in Washington, DC. The panel is designed to make best use of the light in space, which does not pass through the atmosphere, and so retains the energy of blue waves, making it more powerful than the sunlight that reaches Earth. Blue light diffuses on entry into the atmosphere, which is why the sky appears blue. "We're getting a ton of extra sunlight in space just because of that," said Paul Jaffe, a co-developer of the project. An experiments show that the 12x12-inch panel can produce about 10 watts of energy for transmission, That's about enough to power a tablet computer. This is to prove the legitimacy of wireless energy transmission from space.

Figure 57 The photovoltaic direct current to radio frequency antenna module (PRAM).

China gets in on space solar power

China: says aside from sending clean energy to Earth, the power plant could also feasibly power missions deeper and farther into space, if the beam is precise enough to target any ships that are rocketing away to explore the cosmos.[27]

The future of SMF

In Conclusion, this Solar Microwave Fabric is the Right Technology at the Right Time! With the World pushing for more cleaner renewable energy and making Earth and Space our avenues for access to the sun's power in photons which SMF will harness and transmit energy wirelessly. Details have been unveiled for Defense and Threat elimination to be ventured into consciously and be warned any other Country could develop this and make all others slaves. By creating and controlling the energy and electronics of any system in existence on Earth or Space. The benefits highly outweigh any disadvantage because a Space Force (Guardian's) Power-Star celestial system (Angels) with EMP Protecta-Grid tarps on existing power stations can provide power 24-7 any place on earth. More importantly this Guardian's Angel can prevent ALL Future Nuclear Wars and any threats and transgressions in Space or on Earth at the speed of light preventing them from destroying the USA and the World.

Knowing where nuclear missiles & warhead are is only a start with fast launch time of less than ½ hour delivery system to destroy the US or our allies.[28] Figure 58 shows the ICBMs Silos in Russia which must be destroyed to prevent nuclear war (shown by nuclear subs attacking. Like US, Russia has other delivery systems for nuclear war such as their, naval, submarines, and aerial bombers. This is the beginning of a whole new warfare or the defensive system which can overcome (stop & destroy) all (nuclear) weapon delivery systems. Making the submarine and bomber attacks to be the second line of defense because they are so slow in comparison.

Figure 58 Russian nuclear arms.

Whoever Dominates the World in Solar Microwave Fabric will dominate the World of Energy and Defense. This should be considered a National Defense Critical Material and Strategic Defense Initiative. Since the Power-Star makes energy & transmit it will turn the Space Force into a World Profit Center in the largest costly product necessary for health is Energy.

Discussion

The results of this study, opens new product applications to be created for adding photovoltaic, converter and patch antenna(s) to many external surfaces for energy creation and transmission. We propose aerospace vehicles apply this SMF to aircraft thus the need for Auxilary Power Units (APUs) maybe eliminated making airports less polluting jet fuels and noises while sitting idle on the tarmac. This technique adds in flight re-energizing upon the addition of Space Power-Star Satellites made from the same materials are added to our orbits.

Acknowledgments

None.

Conflicts of interest

The authors declare that there is no conflict of interest.

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J.* 2024;8(2):87‒108. DOI: 10.15406/aaoaj.2024.08.00196

References

1. Newsroom.
2. Chandler DL. While you're up, print me a solar cell. MIT News Office; 2012.
3. Law DC, Edmondson KM, Siddiqi N, et al. Lightweight, flexible, high-efficiency iii-v multijunction cells. Space Cells and Radiation effects, Conference Record of the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion; Waikoloa, HI: 2006;2:1879–1882.
4. Galehdar A, Thiel DV. Flexible, light-weight antenna at 2.4 GHz for athletic clothing. 2007.
5. Scarpello ML, Vallozzi L, Rogier H, et al. High-gain textile antenna array system for off-body communication. *International Journal of Antennas and Propagation*. 2012.
6. Osman MAR, Rahim MKA, Samsuri NA, et al. Textile UWB antenna bending and wet performances. *International Journal of Antennas and Propagation*. 2012.
7. Mantash M, Tarot AC, Collardey S, et al. Investigation of flexible textile antennas and AMC reflectors. *International Journal of Antennas and Propagation*. 2012.
8. Boeykens F, Vallozzi L, Rogier H. Cylindrical bending of deformable textile rectangular patch antennas. *International Journal of Antennas and Propagation*. 2012.
9. Subbaraman H, Pham DT, Xu X, et al. Inkjet-printed, two-dimensional phased-array antenna on a flexible substrate. *IEEE Antennas and Wireless Propagation Letters*. 2013;12:170–173.
10. Yasin T. Transparent antennas for solar cell integration. Doctoral Dissertation in the Department of Electrical Engineering; Utah: State University; 2013.
11. William GW, Alford C, Li Y, et al. Inkjet-printed Microstrip patch antennas realized on textile for wearable applications. 2014.
12. NASA. Echo 1, 1A, 2 Quicklook. Mission and Spacecraft Library; 2010.
13. Jones HM, Shapiro II, Zadunaisky PE. Solar radiation pressure effects, gas leakage rates, and air densities inferred from the orbit of echo I. In HC Van De Hulst, C De Jager, AF, Editors. Space Research II, Proceedings of the Second International Space Science Symposium; Florence: 1961.
14. Echo II satelloon inflation. 1964.
15. Guo YC, Shi XW, Chen L. Retrodirective array technology. *Progress in Electromagnetics Research B*. 2088;5:153–167.
16. Chen L, Guo YC, Shi XW, et al. Overview of the phase conjugation techniques of the retrodirective array. *International Journal of Antennas and Propagation*. 2010.
17. Leonov GA, Kuznetsov NV, Yuldashev MV, et al. Computation of phase detector characteristics in synchronization systems. *Doklady Mathematics*. 2011;84(1):586–590.
18. Kuznetsov NV, Leonov GA, Yuldashev MV, et al. Analytical methods for computation of phase-detector characteristics and PLL design. International Symposium on Signals, Circuits and Systems, Proceedings; 2011;7–10.
19. Viterbi AJ. Principles of coherent communication. McGraw-Hill; New York: 1966.
20. Hahn W. Theory and application of Liapunov's direct method. Prentice-Hall; Englewood Cliffs, NJ: 1963.
21. Krasovskii NN. Theorems on stability of motions determined by a system of two equations. PMM 16. 1962;547–554.
22. Tuzov AP. Stability questions for a certain regulating system. Vestnik Leningradsk Univ Ser mat fiz. 1955;10(22):43–70.
23. McGonegal MJ. USAF, high power microwave weapons: disruptive technology for the future. ACTS 2.0 Research Task Force. Air Command and Staff College; Maxwell Air Force Base, AL Spring: 2020.
24. NASA. TRA Technology Readiness Assessment Best Practices Guide. TRL SP-20205003605.
25. Denise Adams. Mankins returns to NASA with a space-based solar powered solution. NASA Researcher News; 2008.
26. Nick Paton Walsh. A solar panel in space is collecting energy that could one day be beamed to anywhere on Earth. AD11074999 CNN; 2021.
27. Dan Robitzski. China is building a solar power station in space, this would take solar power to a whole new level. Futurism. 2019.
28. Modern Muscle. What's America's Russian nuclear war plan? 2023.

Citation: Boike SP, Hyland D. Solar microwave fabric paper on the key technology for making our future satellite and skin surfaces for aircraft, eliminating APU's. *Aeron Aero Open Access J*. 2024;8(2):87–108. DOI: 10.15406/aaoaj.2024.08.00196