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APPLICATION NUMBER: 62/745,188

FILING DATE: *October 12, 2018*

RELATED PCT APPLICATION NUMBER: *PCT/US19/49275*

THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS CONVENTION, IS *US62/745,188*



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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA16
		Application Number	
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

Secrecy Order 37 CFR 5.2:

☐	Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)
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Inventor Information:

Inventor 1				
Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Jack		West	
Residence Information (Select One) ☒ US Residency ☐ Non US Residency ☐ Active US Military Service				
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All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the Add button. Add				

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA16
		Application Number	
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods		

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence information of this application.**

Customer Number	157339		
Email Address		Add Email	Remove Email

Application Information:

Title of the Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods		
Attorney Docket Number	PPA16	Small Entity Status Claimed	☐
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	6	Suggested Figure for Publication (if any)	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	☒ Customer Number	☐ US Patent Practitioner	☐ Limited Recognition (37 CFR 11.9)
Customer Number	157339		

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA16	
		Application Number		
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods			

Prefix	Given Name	Middle Name	Family Name	Suffix	Remove
Registration Number					

Prefix	Given Name	Middle Name	Family Name	Suffix	Remove
Registration Number					

Additional Representative Information blocks may be generated within this form by selecting the **Add** button.

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Application Number	Country ⁱ	Filing Date (YYYY-MM-DD)	Access Code ⁱ (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA16
		Application Number	
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods		

This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.



NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	PPA16
	Application Number	
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA16
		Application Number	
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods		

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

[Clear](#)

☐ Assignee ☐ Legal Representative under 35 U.S.C. 117 ☐ Joint Inventor

☒ Person to whom the inventor is obligated to assign. ☐ Person who shows sufficient proprietary interest

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name Ojjo, Inc.

Mailing Address Information For Applicant:

Address 1	47 Mark Drive		
Address 2			
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Country ¹	US	Postal Code	94903
Phone Number	415-786-4685	Fax Number	
Email Address	pmancini@ojjo.com		

Additional Applicant Data may be generated within this form by selecting the Add button.

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA16
		Application Number	
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods		

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Assignee 1				
Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.				
If the Assignee or Non-Applicant Assignee is an Organization check here. ☐				
Prefix	Given Name	Middle Name	Family Name	Suffix
Mailing Address Information For Assignee including Non-Applicant Assignee:				
Address 1				
Address 2				
City		State/Province		
Country i		Postal Code		
Phone Number		Fax Number		
Email Address				
Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.				

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	PPA16
		Application Number	
Title of Invention	Optimized A-frame foundations for axial solar arrays and related systems and methods		

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Phillip D. Mancini/			Date (YYYY-MM-DD)	
First Name	Phillip	Last Name	Mancini	Registration Number	46743
Additional Signature may be generated within this form by selecting the Add button.					

FIG. 1A

ADA-14

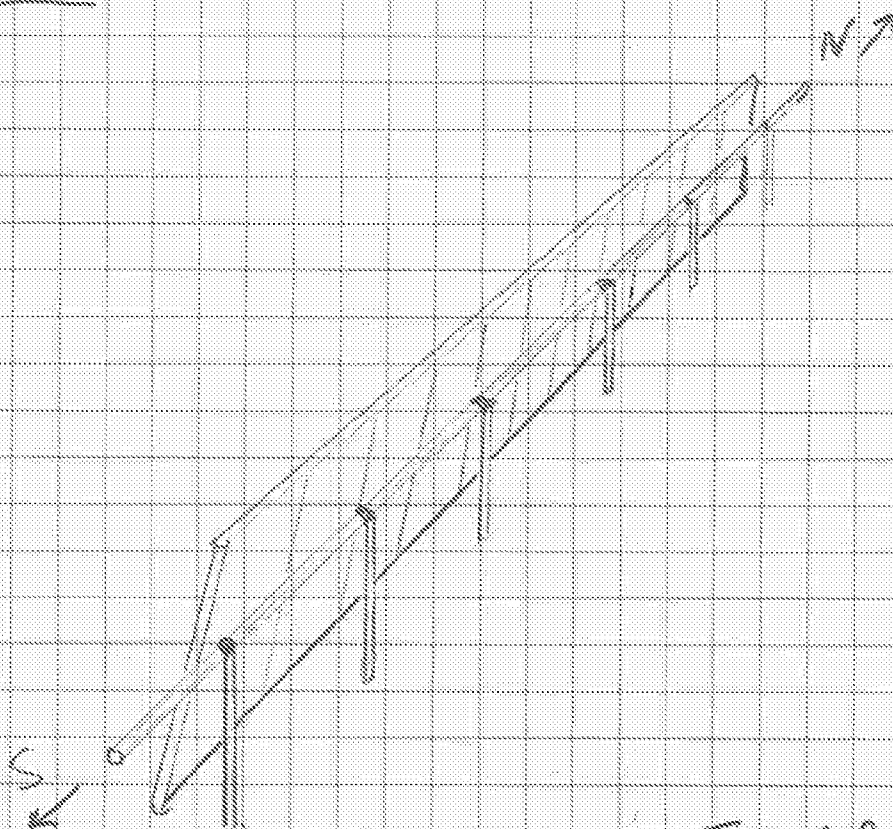


FIG. 1B

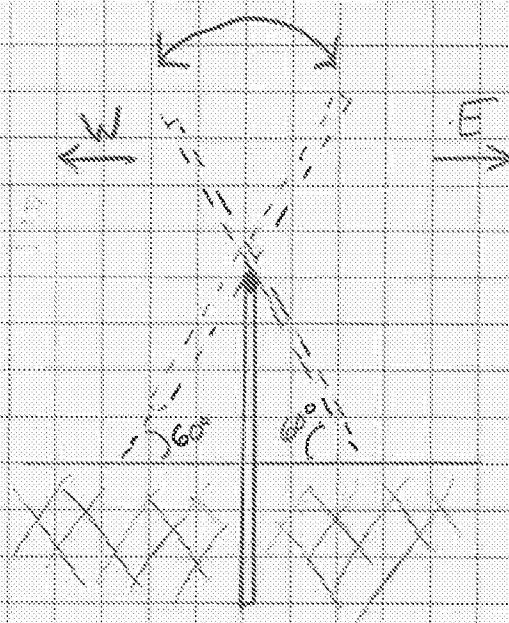


FIG. 2A

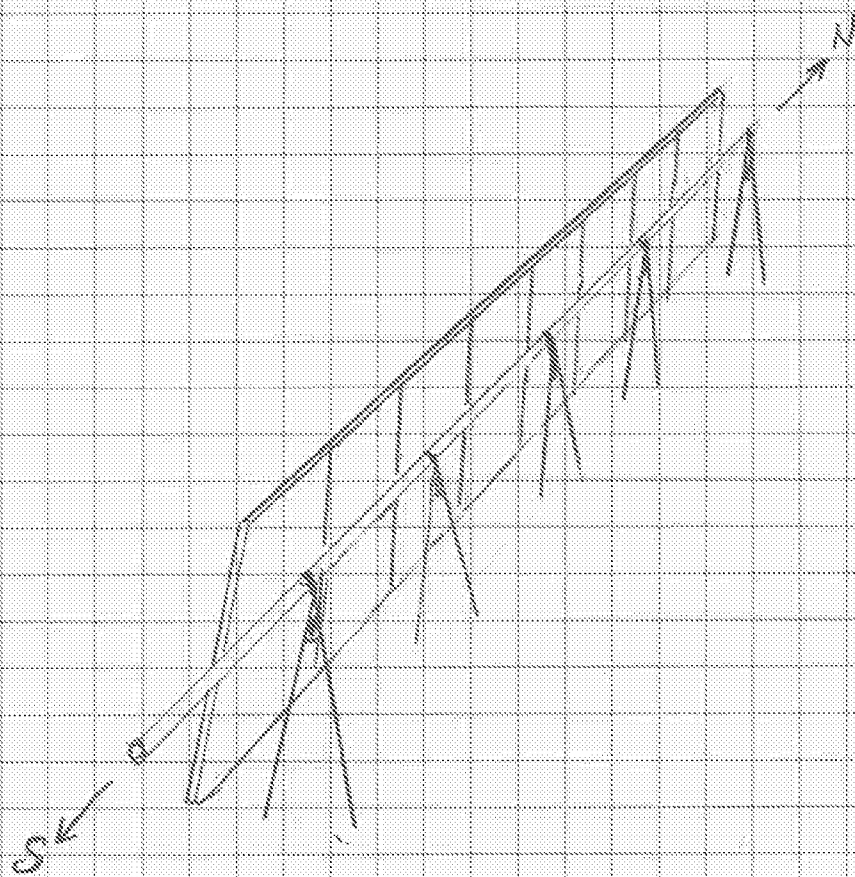


FIG. 2B

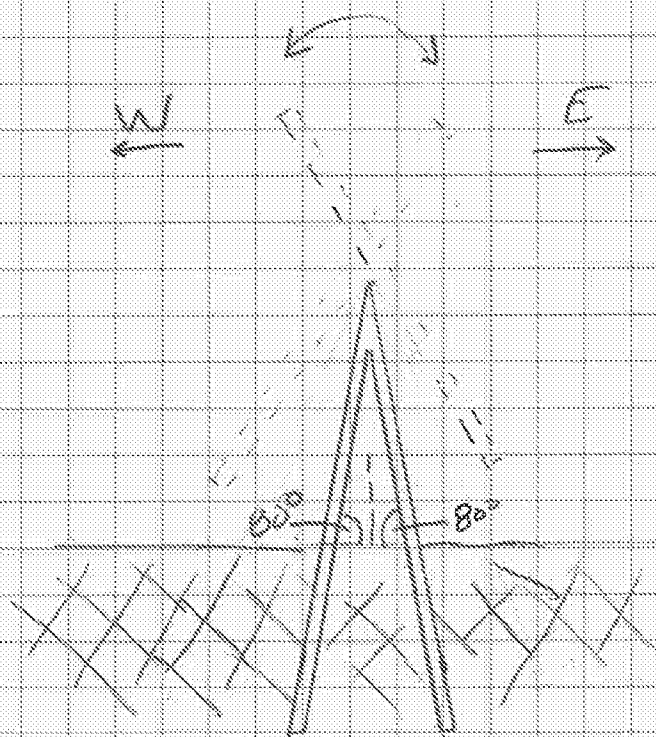
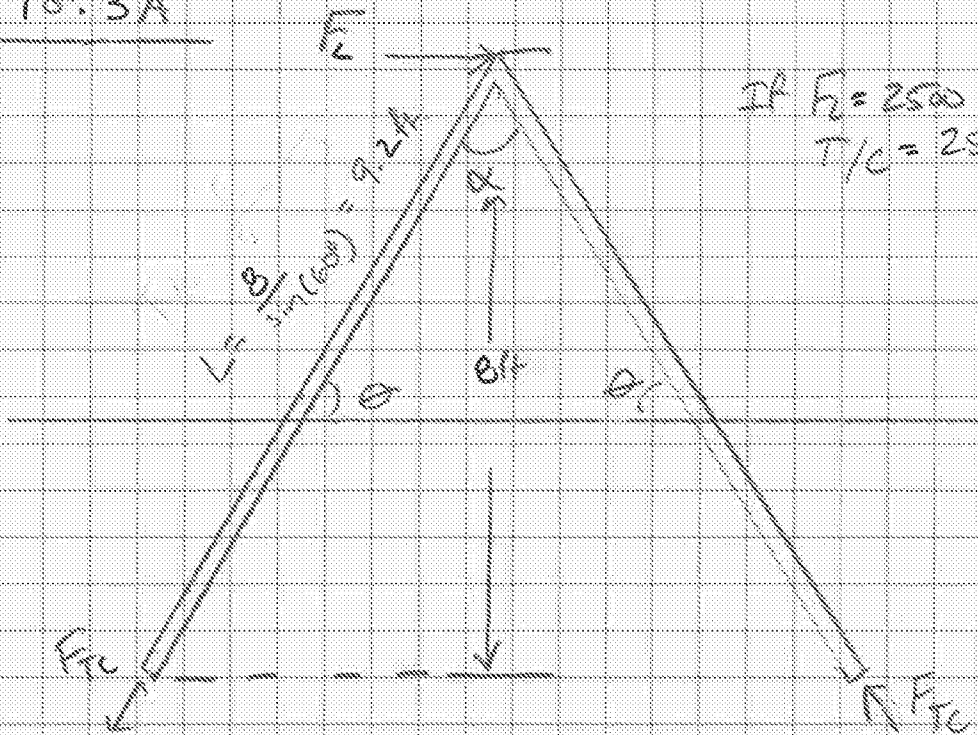
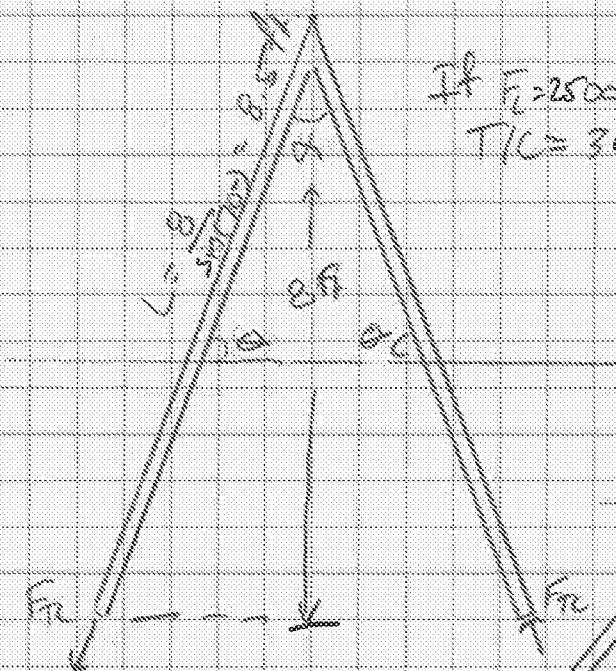


FIG. 3A



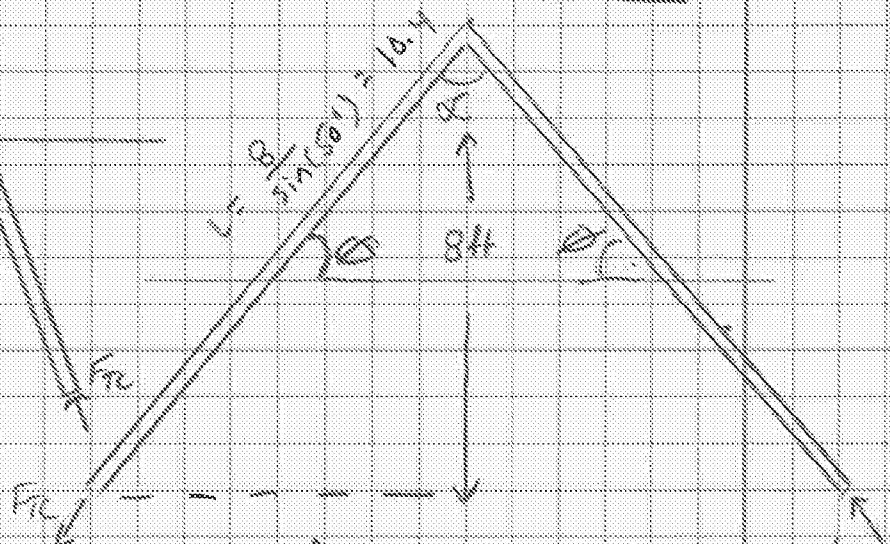
If $F_2 = 2500$, $\theta = 60^\circ$, $\alpha = 60^\circ$
 $T/C = 2500 \text{ lbs}$

FIG. 3B



If $F_2 = 2500$, $\theta = 70^\circ$, $\alpha = 40^\circ$
 $T/C = 3655 \text{ lbs}$

FIG. 3C



If $F_2 = 2500$, $\theta = 50^\circ$, $\alpha = 80^\circ$
 $T/C = 1945 \text{ lbs}$

FIG 4

2500 pound lateral force

Pile Angle (°)	Top Angle (°)	T/C Force (pounds)
5°	170°	1255
10°	160°	1269
15°	150°	1294
20°	140°	1330
25°	130°	1379
30°	120°	1443
35°	110°	1526
40°	100°	1632
45°	90°	1768
50°	80°	1945
55°	70°	2179
60°	60°	2500
65°	50°	2958
70°	40°	3655
75°	30°	4830
80°	20°	7198
85°	10°	14342

Pile Angle	Top Angle	Force
70°	40°	3655
70.5°	39°	3745
71°	38°	3839
71.5°	37°	3939
72	36°	4045
72.5	35°	4157
73	34°	4275

Tension and Compression
vs. Pile Angle

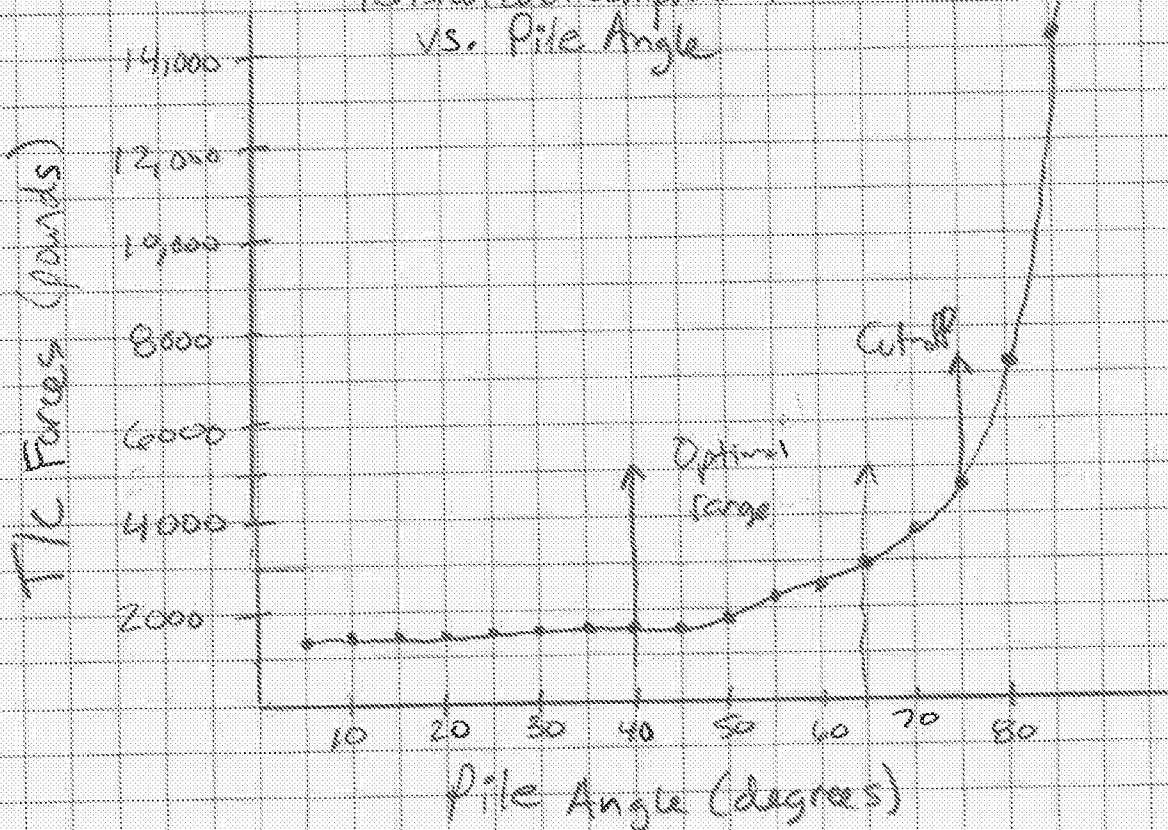


Fig. 5

(1) Pile Angle	(2) Top Angle	Pile Length (ft)
5°	170°	51.8
10°	160°	46.1
15°	150°	30.9
20°	140°	23.4
25°	130°	18.9
30°	120°	16.0
35°	110°	13.9
40°	100°	12.4
45°	90°	11.3
50°	80°	10.4
55°	70°	9.8
60°	60°	9.2
65°	50°	8.8
70°	40°	8.5
75°	30°	8.3
80°	20°	8.1
85°	10°	8.0

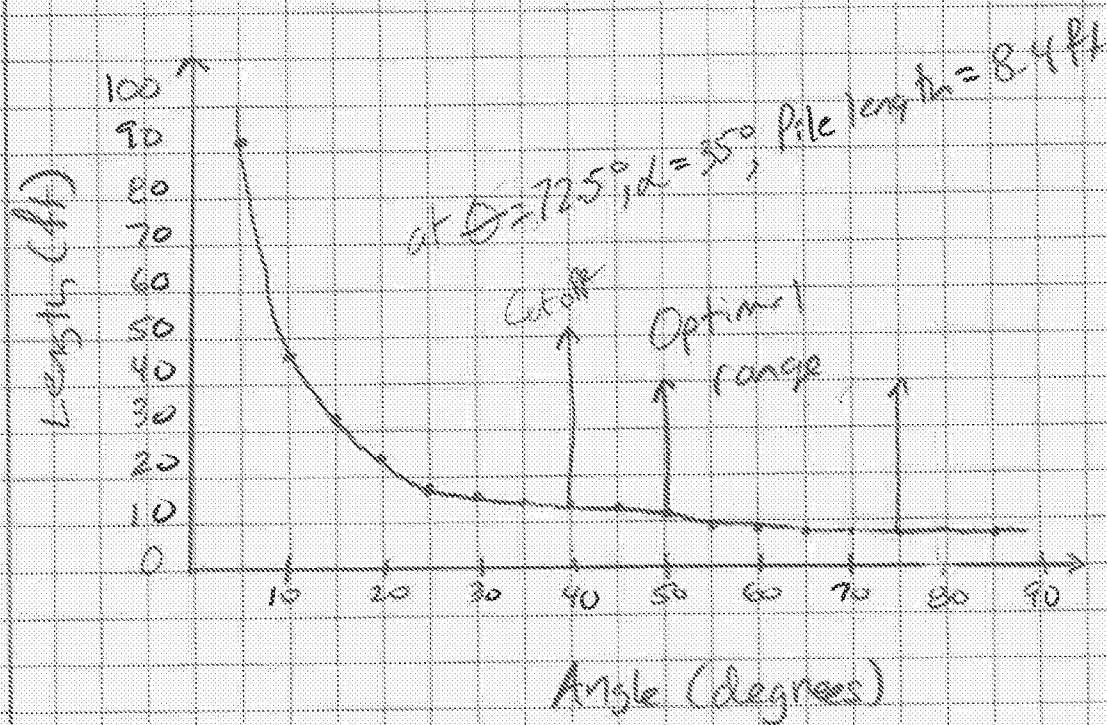


FIG. 6A

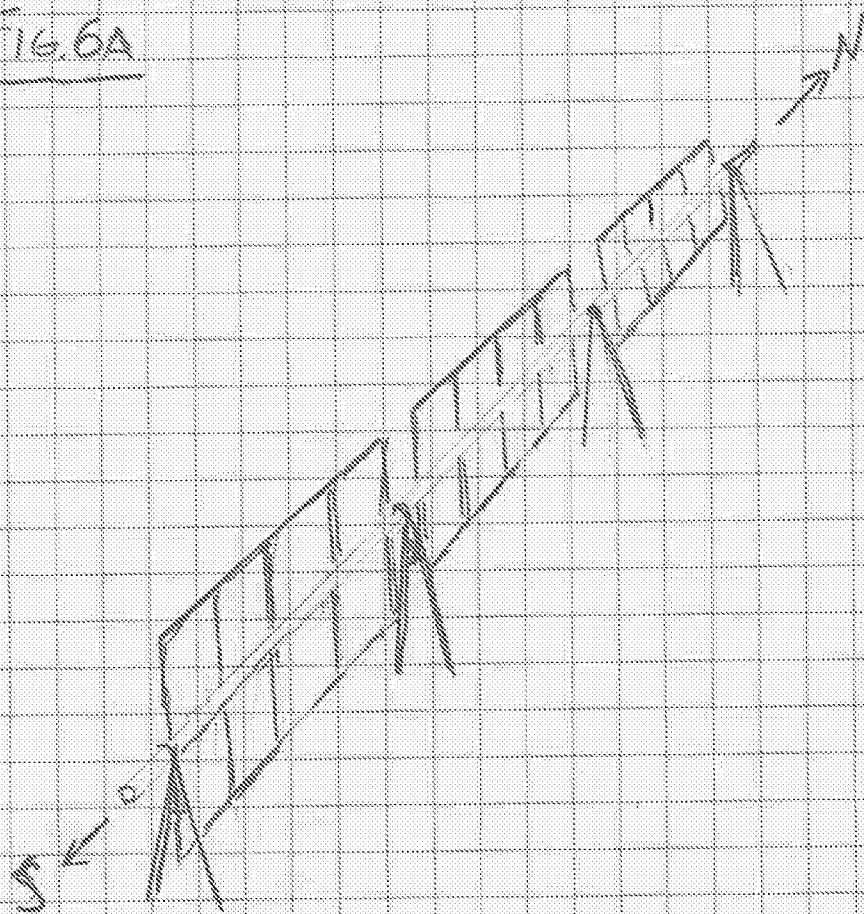
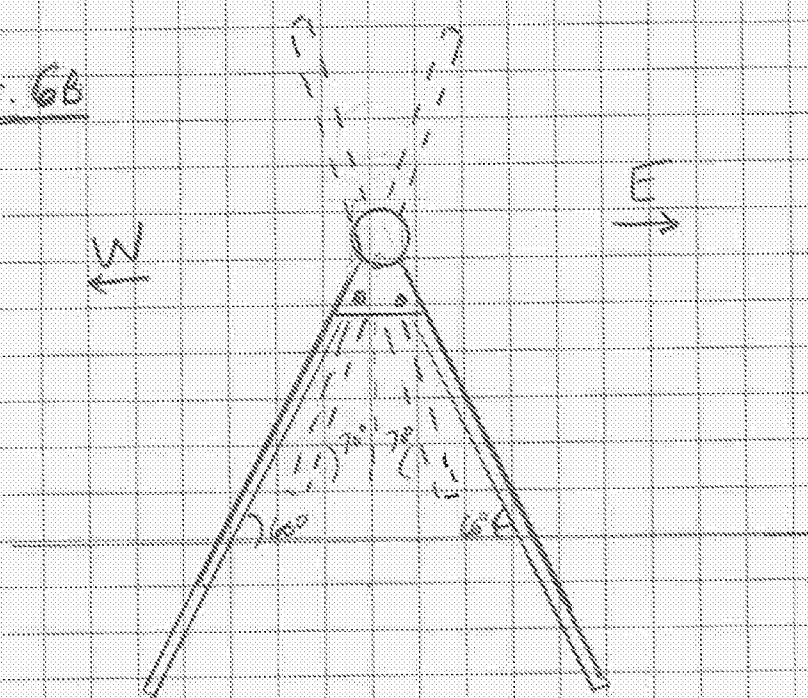


FIG. 6B



Electronic Acknowledgement Receipt

EFS ID:	34001391
Application Number:	62745188
International Application Number:	
Confirmation Number:	6810
Title of Invention:	Optimized A-frame foundations for axial solar arrays and related systems and methods
First Named Inventor/Applicant Name:	Jack West
Customer Number:	157339
Filer:	Phillip Dominick Mancini
Filer Authorized By:	
Attorney Docket Number:	PPA16
Receipt Date:	12-OCT-2018
Filing Date:	
Time Stamp:	18:57:18
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	\$ 140
RAM confirmation Number	101518INTEFSW18582201
Deposit Account	
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	WebADS.pdf	127209	no	8
			5a4e815797d0ed8e59d6afe5096b135bbe774324		
Warnings:					
Information:					
2	Specification	PPA16.pdf	156922	no	12
			4cda005c06be81076d402b06010efef8de40c01		
Warnings:					
Information:					
3	Drawings-other than black and white line drawings	PPA16DWGS.pdf	996458	no	6
			1238ab8d759ce8903b088e9b02661c10be631e44		
Warnings:					
Information:					
4	Fee Worksheet (SB06)	fee-info.pdf	29796	no	2
			7a1a2791a2a6b016a1155e56273959eabef72a66		
Warnings:					
Information:					
Total Files Size (in bytes):			1310385		

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

OPTIMIZED A-FRAME FOUNDATIONS FOR AXIAL SOLAR ARRAYS AND RELATED SYSTEMS AND METHODS

BACKGROUND

- [001] Solar energy is one of the world's largest source of untapped energy. At sea level, the usable energy density is approximately 250 watts per square meter. Using a two-dimensional model to approximate the earth, $250\text{watts/square meter} \times \pi \times 6,371,000\text{ meters}^2$ yields about 32,000 terra (trillion) watts of energy that strikes the earth at any moment. Given that the sun will continue to supply this energy for billions of more years, the survival of human life will ultimately depend on harnessing this essentially unlimited, clean energy source.
- [002] As in any industry, achieving scale is critical to maximizing the competitiveness of solar relative to other energy sources. This economic reality militates in favor of large-scale (multi-megawatt to multi-gigawatt) solar power plants over residential solar, although there is room for both modalities in the market place. Large-scale solar power plants are predominantly configured as either fixed-tilt or single-axis tracker arrays. Fixed-tilt arrays are arranged as East-West oriented rows of panels tilted South at an angle dictated by the latitude of the array site. By contrast, single axis trackers are rows of solar panels arranged on a rotating North-South axis called a torque tube that sweeps through an East to West rotation through the course of the day, following the sun's progression through the sky. For purposes of this disclosure, both fixed-tilt and single axis trackers will be referred to collectively as axial solar arrays.
- [003] Many large-scale solar projects are funded with so-called power purchase agreements (PPAs), whereby a customer agrees to purchase the power generated by the array at a predetermined megawatt hour rate (e.g., \$25-35 per megawatt hour at today's prevailing rates). Knowing the lifetime of the array (e.g., 35-40 years), a bank or other investor will be comfortable financing such a project given the predictable stream of revenue the array will generate over its lifetime.
- [004] Excluding land acquisitions costs, overall project costs typically include site preparation (road building, leveling, grid and water connections etc.), foundation piers, tracker

hardware or fixed-tilt hardware, photovoltaics, inverters and electrical (conduit, wiring, trenching, etc.). Inherent in all of these are also labor costs. At today's prevailing rates, this totals about \$1 per watt of energy. So, building a 100-megawatt solar power plant today would cost approximately \$100,000,000 dollars.

- [005] Many of these system component costs have dropped over the past few years, including solar panels and solar mounting hardware, however, one area that has been mostly overlooked is the cost associated with foundation piers. These structures physically couple solar trackers or fixed-tilt solar arrays to the earth. Typically, after the site has been prepped, a grid of H-piles or other structures are driven into the ground at regular intervals and other components are subsequently attached to those piles. In a conventional, large-scale single-axis tracker array, these piers will typically represent 5-7 percent of the cost of installing an array. Despite this relatively small share of the total array cost, any savings in steel and labor associated with foundation piers will amount to a significant amount of money over a multi-gigawatt portfolio of solar power plant projects. This is particularly true in the solar power plant business because many of these deals are locked in years before the installation costs are incurred. Therefore, the savings will be in addition to profits already factored in the calculations that supported the PPA. Reducing steel and associated labor costs used in foundation piers is the object of this application.

DESCRIPTION

- [006] FIG. 1 shows a conventional single-axis tracker array built on H-piles. In such an array, a row of H-piles are driven into the ground, typically with a pile driver, along an imaginary North – South line. Then, support brackets are attached to the above-ground end of each H-pile so that torque tube bearing, motors, combiner boxes and other equipment may be subsequently installed. The panels are attached to the torque tube so that when it rotates about its bearings, the panels will sweep through a range of orientations from East-facing to West-facing to track the sun's movement through the sky each day. One advantage of this single-pile design is that interference between the vertical H-pile supports and the panels on the torque tube is essentially minimized. In most cases,

when vertical H-piles are used, the torque tube can be rotated to any angle below 90 degrees without running into the piles. In current single-axis trackers, the torque tube can typically rotate the modules as steep as 60 to 65 degrees although that may increase with time. This is shown, for example, FIG. 1B where the panels can rotate all to 60 degrees.

- [007] A-frame type foundations provide several advantages over the conventional H-piles used today's single-axis tracker and fixed -tilt solar arrays. One advantage is that they take the pile out of bending and instead put the legs of the A-frame in tension and compression when exposed to lateral forces. Conventional H-piles are not particularly good at resisting bending, so as a result, relatively large, heavy and expensive H-beams must be used to achieve the requisite resistance to lateral loads in a single-axis tracker. By contrast, far less steel is needed when only resisting the axial forces of compression and tension. This allows the gauge of the steel in an A-frame to be significantly reduced relative to H-piles for axial solar arrays and may also reduce the required driving depth.
- [008] Despite these advantages, even within the A-frame paradigm, there is room for improvement because the specific angles of the members making up the frame will dramatically and non-linearly impact performance. Also, depending on the angle used, switching to an A-frame style foundation may create interference issues between the modules and the piles at steep angles. Accordingly, various embodiments of the invention seek to provide an optimized A-frame foundation for axial solar arrays that does not create interference with modules attached to the torque tube.
- [009] FIGS. 2A and 2B show a single-axis tracker array that is uses A-frame type foundations in place of conventional H-piles. As seen in FIG. 2B, these A-frames are composed of a pair of adjacent arms installed in the ground at reciprocal angles to one another with respect to grade. In this example, the arms are each oriented at 80 degrees with respect to grade. This relatively steep angle provides good clearance for the panels on the torque tube to rotate through their full range of motion with clearance for bending and manufacturing tolerances, however, as discussed in greater detail herein, such a sharp angle makes the arms of the A-frame resist very high forces relative to a lower angle in

response to the same lateral load. To counteract this, heavier gauge material may have to be used and/or the piles may have to be driven to greater depths, reducing or even eliminating the advantages of the A-frame relative to conventional H-piles.

- [010] Turning to FIGS. 3A – 3C, these figures explain how the selection of angles or range of angles optimizes the forces on the A-frame and material usage in an axial solar array. Wind striking the surface of modules attached to the torque tube imparts a lateral load on the system, labeled F_L in FIG. 3A. If we assume that the magnitude of that lateral load is 2500 pounds, resisting that force (i.e., the legs of the A-frame holding fast) requires that the sum of forces in the X direction equal zero. When summing the forces in this system, in equilibrium, the lateral load F_L (2500 pounds) must be countered by the X-component of the compression/tension force F_{CT} . That is, the X-component must also be equal to 2500 pounds. For the X-components of these forces to sum to 2500 pounds, the magnitude of the axial forces on the left and right A-frame members will vary significantly as the angle Θ varies because the X-component of F_C and F_T are proportional to the cosine of Θ . For a given angle Θ , the X-components are equal to $2 \cdot \cos(\Theta)$. As seen in FIG. 3A, this results in a tension/compression force of 2500 pounds on each A-frame member. This is derived from the equation:

$$F_{TC} = \frac{2}{F_L(\cos(\Theta))}$$

where F_L is assumed to be 2500 and Θ is equal to 60 degrees. If the angle Θ is increased to 70 degrees, this force jumps up to 3655 pounds, as seen in FIG. 3B. Likewise, if the angle Θ is reduced to 50 degrees, as in FIG. 3C, F_{TC} drops to 1945 pounds. Using a relatively steep angle such as 80 degrees as shown in FIGS. 2A and 2B drives F_{TC} up to a staggering 7198 pounds for the same lateral force F_L of 2500 pounds. Therefore, angles under 80 degrees are preferred or else the foundation piles have to made much stronger than they would at lesser angles, for example 75 degrees, 72.5 degrees or lower.

- [011] Regarding material usage, continuing to look at FIGS. 3A – 3C, if we could assume that the desired A-frame height (vertical height from apex of A-frame to the imaginary horizontal line connecting underground base of the two legs) was 8 feet, then

decreasing the angle will require a longer leg length. In 3A, with Θ equal to 60 degrees, each leg must be 9.2 feet in length. This is derived from the equation:

$$L = \frac{8}{\sin(\Theta)}$$

where 8 feet is the desired height and $\Theta = 60$ degrees. In 3B, the length drops to 8.5 feet while in 3C it expands to 10.4 feet. Therefore, there is a material trade-off from relatively less to relatively more as the angle Θ decreases. This trade-off, however, does not tell the whole story because as Θ decreases F_{TC} also decreases. This means that if 8 feet is considered a constraint, the diameter of the legs of the A-frame will have to increase as Θ increases so that skin friction will enable them to counteract the axial tension and compression force F_{TC} to keep the system in equilibrium. Going back to FIG. 2 where Θ was 80 degrees, due to the relatively high value of F_{TC} , the legs will have to be relatively larger in diameter as compared to an A-frame with a lower Θ , or the legs will have to be embedded deeper into the ground, or both, resulting in relatively more material usage and potentially more effort to drive the A-frame legs into the ground.

- [012] Referring now to FIG. 4, this figure is a table showing the correlation between the angle Θ of the legs of the A-frame with respect to grade and the magnitude of F_{TC} . The figure is broken into two parts: a table of data at the top and a corresponding graph below. The first column of the table is the pile angle, that is the angle Θ shown, for example, in FIGS. 3A – 3C. Here Θ ranges from a minimum of 5 degrees to a maximum of 85 degrees. The second column is the top angle α made by the free ends of each A-frame leg when they are joined at the apex. This is equivalent to $180-2*\Theta$, so as Θ varies in 5-degree increments, α will vary by 10 degrees. The third column of the table at the top of FIG. 4 is the tension and compression force F_{TC} . At the minimum, where $\Theta = 5$ degrees, and $\alpha = 170$ degrees, the force $F_{TC} = 1255$ pounds, just barely more than $\frac{1}{2}$ of lateral force F_L . At the maximum, where $\Theta = 85$ degrees, and $\alpha = 10$ degrees, the force F_{TC} jumps up to 14,342 pounds – nearly a six-fold increase over F_L .
- [013] The values from the table are shown graphically in the graph at the bottom of FIG. 4. As seen clearly in this graph, F_{TC} increases slowly at first up until approximately 72.5 degrees, where the $F_{TC} = 4157$, and then exponentially after to that going up to infinity

as Θ approaches 90 degrees, where it essentially becomes an H-pile. This graph shows that there is a preferred range of Θ from 40 degrees up to approximately 72.5 degrees where for a F_L of 2500 pounds, F_{TC} ranges from 1632 pounds to 4157 pounds. This corresponds to respective values of top angle α ranging from 100 degrees down to 35 degrees. For angles of Θ below 35 degrees, F_{TC} continues to go down marginally, but as discussed in greater detail in the context of FIG. 5, these gains are offset by rapidly increasing material length requirements and therefore the upper end of Θ is controlling from a force optimization perspective. The optimal range shown in FIG. 4 is for a value of Θ between 50 degrees and 65 degrees where F_{TC} ranges from 1632 pounds to 2958 pounds. This correlates to a top angle α ranging from 80 down to 50 degrees respectively.

- [014] Turning now to FIG. 5, this figure is another table that shows the pile length (i.e., length of each A-frame leg member) for a given height of the A-frame, which in this example is set to 8 feet. The first column of the table on FIG. 5 is the pile angle Θ , again ranging from a minimum of 5 degrees to a maximum of 85 degrees in five-degree increments. Top angle α formed when the two legs are joined above ground has a corresponding range of 170 degrees down to 10 degrees in 10-degree increments. The cut-off here is at about 40 degrees for Θ where the pile length starts to increase exponentially for every 5-degree reduction in Θ . Of course, as Θ continues to increase, the pile length will eventually approach 8 feet, however, as seen in FIG. 4, this results in an F_{TC} approaching infinity. Therefore, the lower end of Θ rather than the upper end of Θ is determinative from a material optimization perspective.
- [015] Taken together, the information in FIGS. 4 and 5 show that there is an optimal range for Θ that balances minimizing F_{TC} against minimizing material usage. The preferred range is for a value of Θ between 40 degrees and 72.5 degrees, while the optimal range is between 50 degrees and 65 degrees. This corresponds to preferred range for α between 100 degrees and 35 degrees and optimally between 80 degrees and 50 degrees.

- [016] Referring now to FIGS 6A and 6B, these figures show a single-axis tracker array and an A-frame foundation for a single-axis tracker array or other axial solar array according to various embodiments of the invention. As discussed above in the context of FIGS. 1 and 2, one potential disadvantage of an A-frame type foundation over a conventional H-pile is that as the torque tube rotates the panels into steep angles (greater than 50 degrees), the panels may run into the legs of the A-frames, depending on the angle they are set at. This could require using a steeper angle for the A-frame (a sub-optimal solution due to the relatively large value of F_{TC}) or limiting the range of motion for the tracker – also sub-optimal because it eliminates the harvesting of so-called “shoulder power” obtained at the beginning of and at the end of each day when the sun is rising from or setting towards the horizon. Tracker manufacturers specifically design their systems to harvest this shoulder power so eliminating the motion of the tracker with the foundation piles is impractical from a business perspective.
- [017] Accordingly, one way to overcome this interference is to introduce a space at each point on the torque tube above one of the A-frame foundations (e.g., at the torque tube bearing locations). In this way, the torque tube can rotate through a full range of angles (up to and including perpendicular to grade) and is limited only the length of slack wire interconnecting the modules. As seen, in 6B, with a 60-degree angle for the legs of the A-frame (e.g., the angle Θ) corresponding to a 60-degree top angle (e.g., the angle α), the torque tube can rotate the panels all the way to 70 degrees or even steeper.
- [018] It should be appreciated that the embodiments described and claimed herein are exemplary only. Those of ordinary skill in the art will appreciate modifications and substitutions that retain the spirit and scope of the invention.

CLAIM SET 1:

1. A tracker array comprising:
 - a torque tube oriented along a North – South axis;
 - a plurality of photovoltaic modules attached to the torque tube; and
 - a plurality of A-frame foundation piles supporting the torque tube along its length, each A-frame foundation pile comprising a pair of elongated legs installed partially underground at reciprocal angles to one another and joined together above ground to form a rigid A-frame structure, wherein the torque tube is operable to rotate the attached plurality of photovoltaic modules through a range of motion from an East-facing orientation to a West-facing orientation, wherein each leg of each A-frame foundation pile is oriented at an angle ranging from 40 degrees to 72.5 degrees with respect to grade and are joined together to form a top angle ranging between 100 and 35 degrees.
2. The tracker array according to claim 1, wherein each leg of each A-frame foundation pile is oriented at an angle ranging from 50 degrees to 65 degrees with respect to grade and are joined together to form a top angle ranging from 80 degrees to 50 degrees.
3. The tracker array according to claim 1, further comprising a gap between adjacent photovoltaic piles at each point on the torque tube supported by an A-frame foundation pile enabling the plurality of photovoltaic modules to rotate to a steeper angle than an angle of the leg of each A-frame foundation pile without interference.
4. The tracker array according to claim 3, wherein the steeper angle is at least 60 degrees.
5. The tracker array according to claim 3, wherein the steeper angle is at least 65 degrees.
6. A foundation for an axial solar array comprising:
 - a first support member partially submerged in supporting soil at a first angle;
 - a second support member, adjacent the first support member, the second support member partially submerged in the supporting soil at a second angle, wherein the first angle and the second angle are reciprocal to one another and are in a range of 40 degrees to 72.5 degrees with respect to grade; and

a connecting portion, joining above-ground ends of the first and second adjacent support members at an angle in a range from 100 degrees to 35 degrees to form an A-frame foundation, the connecting portion comprising a mounting surface for attaching additional axial solar array components.

7. The foundation according to claim 6, wherein the first angle and second angle are in a range of 50 to 65 degrees with respect to grade and are joined together by the connecting portion to form an angle in a range of 80 degrees and 50 degrees.
8. The tracker array according to claim 6, further comprising a gap between adjacent photovoltaic modules at each point on the torque tube supported by an A-frame foundation enabling the torque tube to rotate the plurality of photovoltaic modules to a steeper angle than an angle of the support members of each A-frame foundation without interference.
9. A foundation for an axial solar array comprising:
 - a first support member partially submerged in supporting soil at a first angle with respect to a grade of the supporting soil;
 - a second support member, adjacent the first support member, the second support member partially submerged in the supporting soil at a second angle with respect to grade, wherein the first angle and the second angle are reciprocal to one another and are in a range from 40 to 72.5 degrees; and
 - a connecting portion, joining above-ground ends of the first and second adjacent support members at an angle between 100 degrees and 35 degrees to form an A-frame foundation, the connecting portion comprising a mounting surface for attaching additional axial solar array components.
10. The foundation according to claim 9, wherein the first and second angles are in a range from 50 to 65 degrees.
11. The foundation according to claim 9, wherein the connecting portion joins the above-ground ends for the first and second adjacent support members together to form an angle ranging from 50 degrees to 80 degrees.
12. A single-axis solar tracker array comprising:

- a torque tube oriented along a North – South axis;
 - a plurality of photovoltaic modules mounted to the torque tube;
 - a plurality of A-frame foundation piers supporting the torque tube above ground, the A-frame foundation piers each comprising a pair of elongated leg members driven into the ground adjacent one other at reciprocal angles to one another with their above-ground ends joined with a connecting portion to form an A-frame foundation supporting the torque tube, wherein the connecting portion joins the above-ground ends of the adjacent legs to form an angle in a range of 100 degrees to 35 degrees.
13. The single-axis tracker according to claim 12, wherein the connecting portion joins the above-ground ends to form an angle in a range of 80 degrees to 50 degrees.
14. The single-axis tracker according to claim 12, further comprising a gap along the torque tube between adjacent photovoltaic modules at each point where the torque tube is supported by one of the A-frame foundation piers so that the torque tube may rotate the photovoltaic modules between an East-facing orientation and a West-facing orientation at angles steeper than the elongated leg members making up each A-frame foundation pier without interference.
15. A ground mounted fixed-tilt solar array comprising:
- a first plurality of interconnected above-ground support members defining one row of the array and oriented in an East to West orientation;
 - a plurality of photovoltaic modules attached to the first plurality of interconnected above-ground support members at a common angle with respect to grade; and
 - a second plurality of ground-based support members connected to and supporting the first plurality of interconnected above-ground support members, wherein each of the second plurality of ground-based support members comprises a pair of adjacent arms partially driven into supporting ground at reciprocal angles to one another in a range from 40 degrees to 72.5 degrees with respect to grade, with their above-ground ends joined together with a connecting portion to make an angle in a range of 100 to 35 degrees.

16. The fixed-tilt solar array according to claim 15, wherein the above ground-ends are joined together with a connecting portion to make an angle in a range of 80 degrees to 50 degrees.
17. A method of installing a foundation pier for an axial solar array comprising:
 - installing a pair of adjacent support piles into supporting ground at reciprocal angles to one another so that they are partially buried below ground;
 - connecting a free end of each adjacent support pile together to form an A-frame structure with a connecting portion; and
 - attaching an axial solar array support member to the connecting portion, where connecting a free end of each adjacent support pile together to form an A-frame structure comprises connecting them to form an angle between 100 degrees and 35 degrees.
18. The method according to claim 17, further comprising connecting a free end of each adjacent support pile together to form an angle in a range of 80 degrees to 50 degrees.
19. A tracker array comprising:
 - a torque tube oriented along a North – South axis;
 - a plurality of photovoltaic modules attached to the torque tube and operable to rotate with the torque tube from an Eastward-facing direction to a Westward facing direction; and
 - a plurality of A-frame supports oriented in a row under the torque tube and supporting the torque tube above ground, wherein each A-frame support comprises a pair of adjacent support piles partially installed below ground at reciprocal angles to one another and joined above ground with a connecting portion to form an angle ranging from 100 to 35 degrees.
20. The tracker array according to claim 19, wherein the pair of adjacent support piles of each A-frame support is joined above ground with the connecting portion to form an angle ranging from 80 to 50 degrees.
21. The tracker array according to claim 19, further comprising a gap between adjacent modules on the torque tube at a location above each A-frame support, the gap allowing

the torque tube to rotate the plurality of photovoltaic modules through a range of angles steeper than an angle of the adjacent support piles without interference.