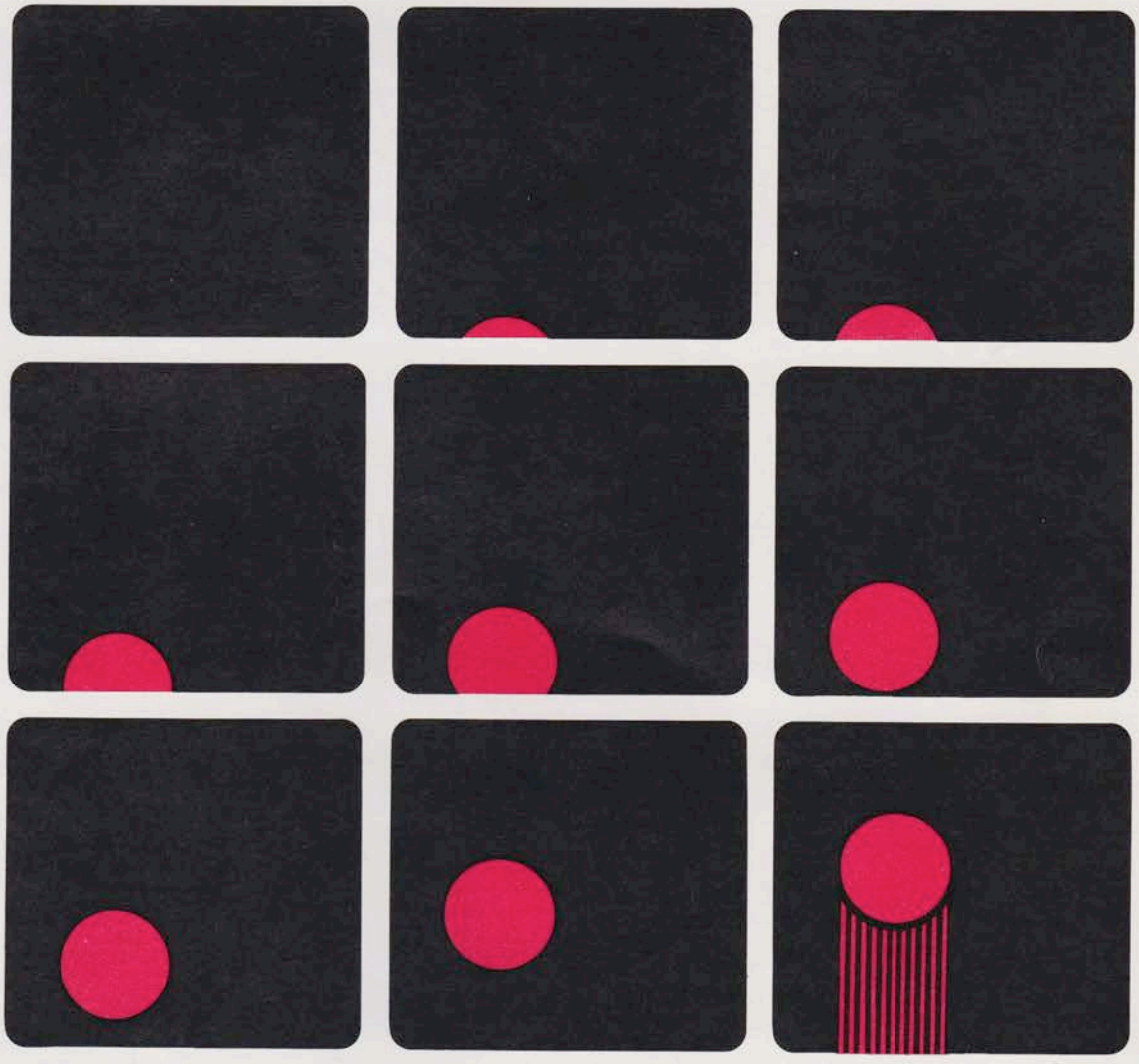
Building Blocks for Solar Electricity

Solarex® Corporation



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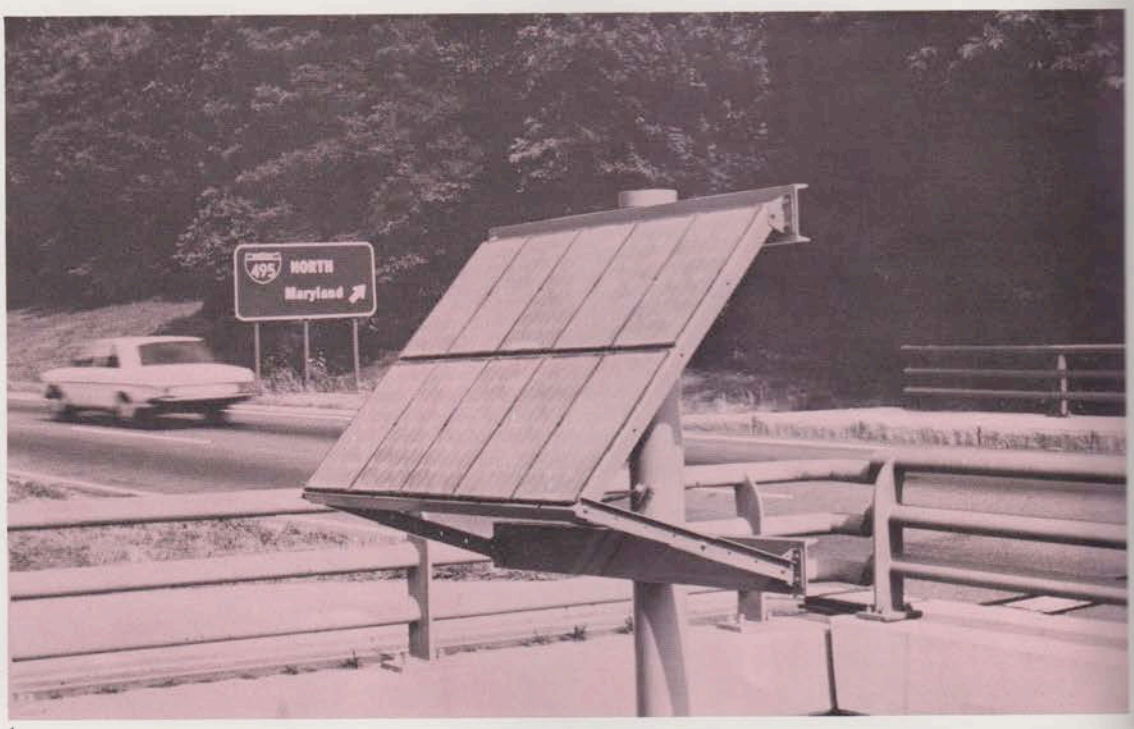
Solarex is the leading manufacturer of the most efficient and economical photovoltaic systems and their component building blocks for the direct conversion of light into electricity. Starting with a single silicon solar cell and climaxing with solar electric generator systems, Solarex can tailor building blocks to suit a variety of needs.

Solar electric systems are most effective in providing continuous power where commercial power is unavailable, too costly, or unreliable. Solar cells are applied in many ways to furnish power, including:

- Radio and microwave repeaters
- Telemetry platforms
- Navigation aids
- Cathodic protection
- Consumer products
- Lighting
- Irrigation
- Railroad signals
- Environmental sensors
- Remote buildings

Solarex presents a unique solar building block concept, its components, and outstanding features as compared to other electrical power sources. A suggested formula is provided for estimating the number of solar panels required for a specific application. Mounting procedure and hardware are also thoroughly discussed.

1. A solar array providing impressed current for cathodic protection of a highway bridge deck. This Solarex array delivers approximately 90W (peak). Lexan covers are used for each of the individual solar panel modules for protection against vandalism.
2. 260W (peak) Solarex solar electric generator powers a marker beacon for an airport in Kenai, Alaska for the FAA.
3. Solarex 460W (peak) solar electric system powering microwave and VHF repeaters in the Mojave Desert for the California Highway Patrol.



1.


2


3.

The basic building block of a solar electric system is the solar cell, a semi-conductor device that converts light energy directly into electrical energy. The amount of electrical power delivered by solar cells depends on their size and efficiency. Solarex silicon solar cells are the largest, the most efficient and the most economical in use today. A patented chevron current collecting pattern is characteristic of Solarex solar cells.

Solarex silicon solar cells are made by doping pure, cylindrical silicon crystals with other chemical elements. When phosphorus is added during the growth of the crystal, the silicon develops negative (n) charge carriers (electrons). When boron is added, positive (p) charge carriers (holes) appear. The crystal cylinders are then sliced into wafers. High temperature diffusion of phosphorus into a boron doped silicon creates an n-type to p-type junction and a built-in field.

When the diffused silicon slice is illuminated, incoming units of light energy (photons) are absorbed by the electrons within the silicon wafer. This creates negative charges which are attracted to the n-type silicon, and positive charges, which are attracted to the p-type. A photocurrent flows, voltage develops, and electricity is produced. Thus, a power source is created—a photovoltaic generator or a solar cell.

All solar cells, when exposed to light, produce about the same voltage (approximately 0.5V). However, the amount of current varies with the light intensity and the surface area of the solar cell. The solar cells are responsive to a broad range of light energy in the spectrum from the ultra-violet, through the visible, to the infrared. Therefore, they produce energy whenever there is light, even on heavily overcast days or in ordinary room light (tungsten or fluorescent).

Temperature also affects solar cell output. Using a temperature of 25°C ± 3°C as a standard test condition, the output voltage of each cell varies inversely with temperature about 2mV/°C. Power output follows the voltage characteristics but changes only about 0.3 percent/°C because of the compensating effect of current which varies directly with temperature.

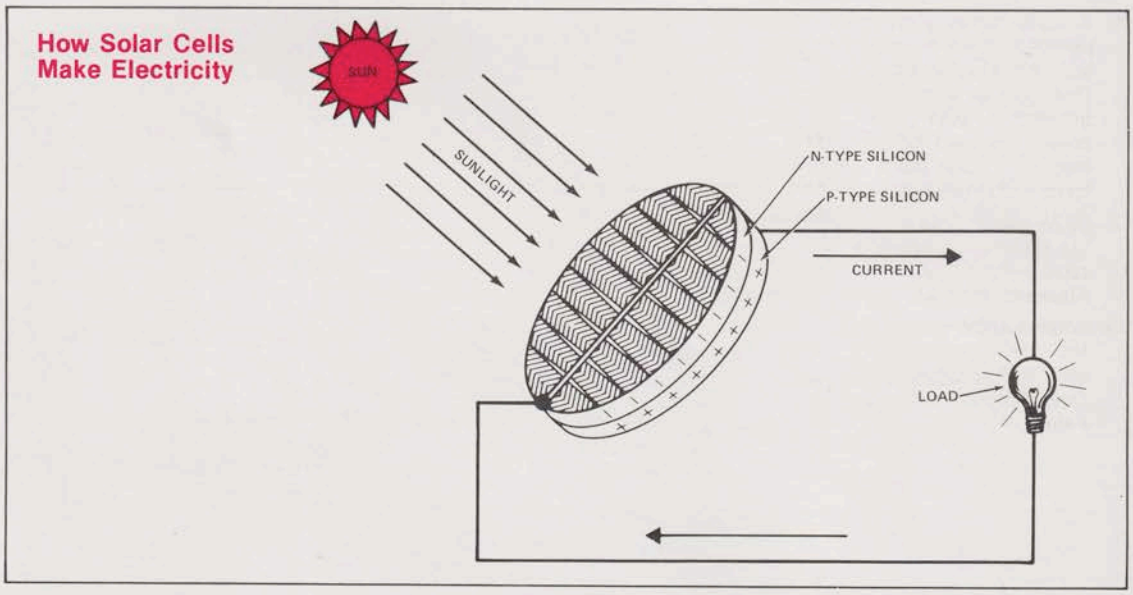
Solarex Solar Cell Features:

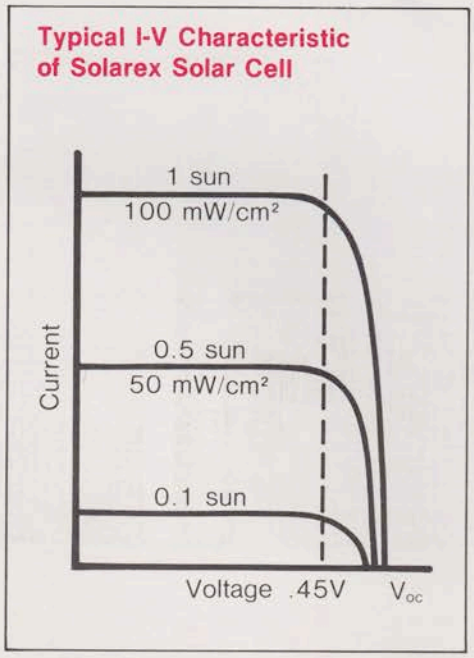
- Unique corrosion resistant Trimet™ contacts (electrodes)
- Tantalum oxide anti-reflection coating
- Redundant contact pattern for high conversion efficiency and high reliability
- Back surface field for increased efficiency

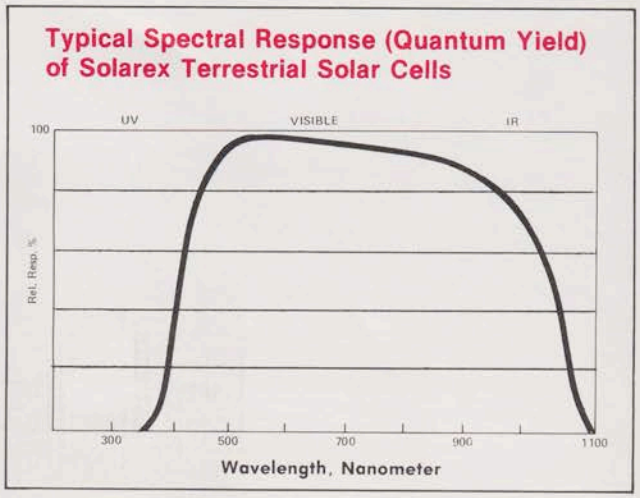
Note: More literature on Solarex solar cells available.

Solar Cells

4. How solar cells make electricity; Typical I-V Characteristics of Solarex Solar Cells; Typical Spectral Response (Quantum Yield) of Solarex Solar Cells.







The unique Solarex solar electric panel is called a Unipanel®. Since a typical silicon solar cell delivers peak power in full sunlight* at about 0.45 Volts (V), numerous solar cells are interconnected to achieve a particular operating voltage and peak Watt (W) output. For example, the charging of a 12V lead-acid battery requires at least 30 cells connected in series. For such applications Solarex typically uses 32 or 36 cell Unipanels. The extra margin is provided to allow for system losses, high temperature operation, low light levels, etc. The size of the individual cells in the panel determines the current. For example, the Solarex type 4200 Unipanel consists of 36 3" diameter silicon cells and delivers 20 Watts (peak). The Type 1480 Unipanel consists of 36 half sections of the same solar cell, has one half the area of the type 4200 Unipanel and delivers in excess of 9 Watts (peak).

A Solarex Unipanel consists of the interconnected cells, generally mounted on a fiberglass board and fully encapsulated in clear, stabilized, silicone rubber. These durable materials provide a sealed, highly transparent, weather resistant package to protect the solar cells' metal electrodes and all inter-connections from corrosion. Cells normally have electrodes made of metal which may be subject to corrosion. However, Solarex has developed a metallization which makes the contacts totally resistant to moisture and corrosion. Even the external connecting wires are typically Teflon (Reg. DuPont™) insulated.

For special environmental conditions, the Unipanel surface may include tough, transparent cover materials such as Lexan (Reg. General Electric™) or Plexiglas (Reg. Rohm & Haas™). Tempered glass covers are also available.

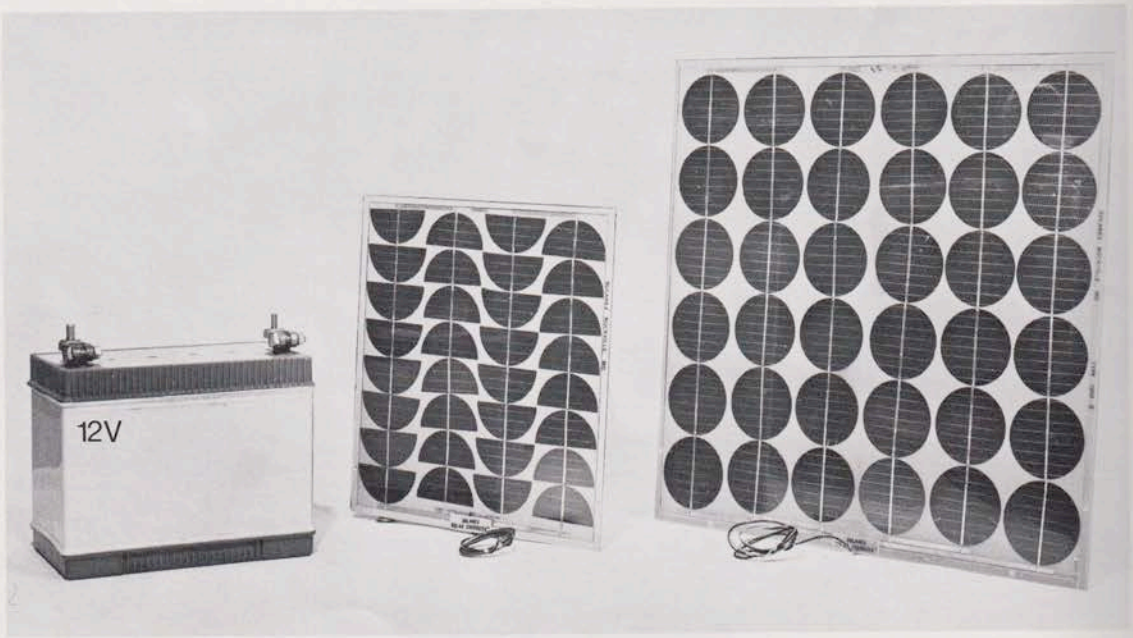
Solarex Solar Panel Features:

- Fiberglass board specially selected and tested
- Silicon rubber encapsulant specially formulated by Solarex
- Stress-relieved cell interconnects
- Field and environmental tested for construction and performance
- Extensive in-house quality control throughout panel manufacture

*100mW/ cm² at 25°C±3°C

Solar Panels

5. The charging of a 12V lead-acid battery requires at least 30 solar cells connected in series. Solarex typically uses 32 or 36 cells. The Type 4200 Unipanel consists of 36 3" diameter round cells and delivers 20 Watts (peak). The Type 1480 Unipanel consists of 36 half sections of the same solar cell and delivers in excess of 9 Watts (peak).



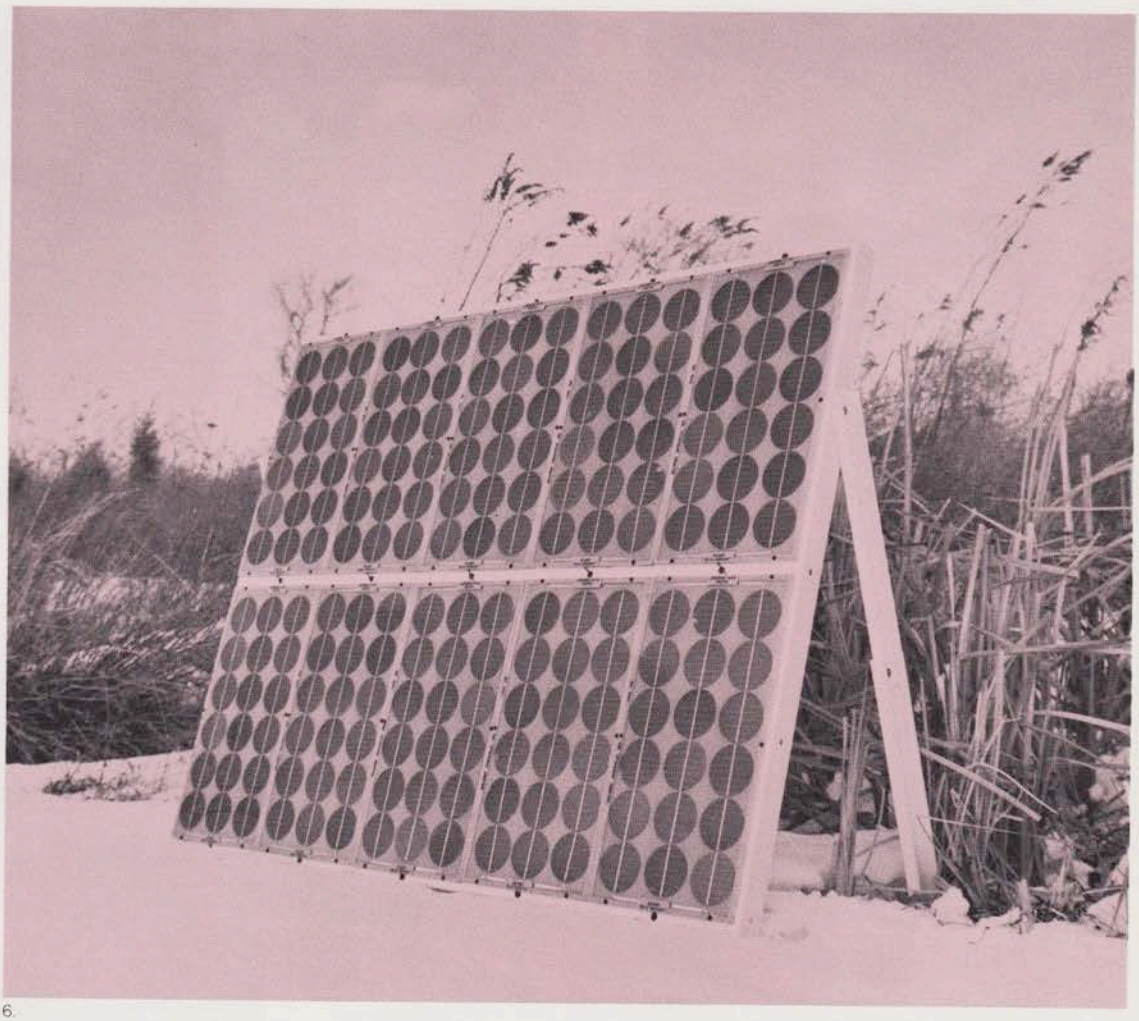
5.

If a desired peak power output at a particular voltage and current cannot be attained by a Unipanel, then a number of Unipanels must be interconnected in a particular series-parallel combination to form a Solarex solar array. Array power output may be changed by increasing or decreasing the number of Unipanels and/or altering the Unipanel interconnections.

The Unipanels that comprise a solar array are mounted on a rigid frame by means of non-metallic fasteners or silicone rubber. Anodized aluminum frames with enamel painted surfaces are generally used for maximum resistance to corrosion, high strength-to-weight ratio, and reasonable cost. Solarex provides bird wires and lightning arrestors for solar arrays when required.

Solar Arrays

6. 100W (peak) Solar array consisting of ten Type 785 Unipanels.



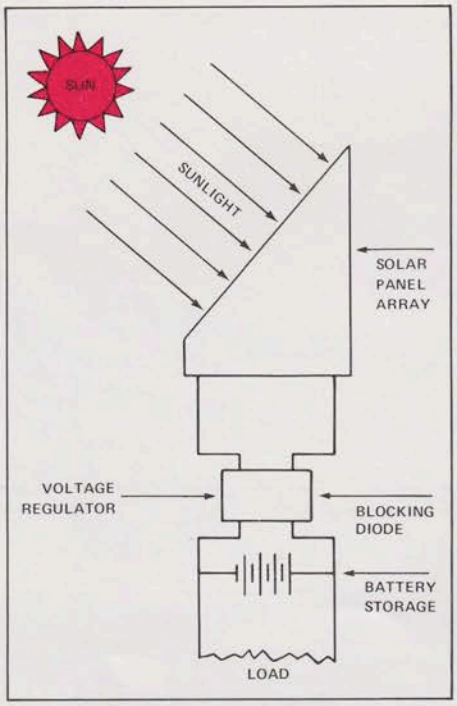
6.

Solar electric generators, developed by Solarex, contain enough panels wired together in series to provide the required output voltage and enough in parallel to provide the required current. Solar electric generators are reliable and totally independent power sources. The generators include solar panel arrays, electrical storage, and associated power conditioning circuitry, e.g., voltage regulators. Electricity is produced by the solar panel array, stored usually in rechargeable batteries, and supplied to a load on demand.

Unique to Solarex is a special power conditioner called the Powermizer™, specifically developed for solar electric generators. The Powermizer is designed to prevent overcharging of storage batteries after having reached full charge. At the same time the Powermizer conserves solar electric power during the charging process and prevents discharge of the batteries during periods of darkness.

Solar Electric Generator Systems

7. Solar Electricity is produced by the solar panel array, stored in rechargeable batteries, and supplied to a load on demand.
8. 70W (peak) Solarex system powering a mountaintop repeater for the Arizona Department of Public Safety near Phoenix.



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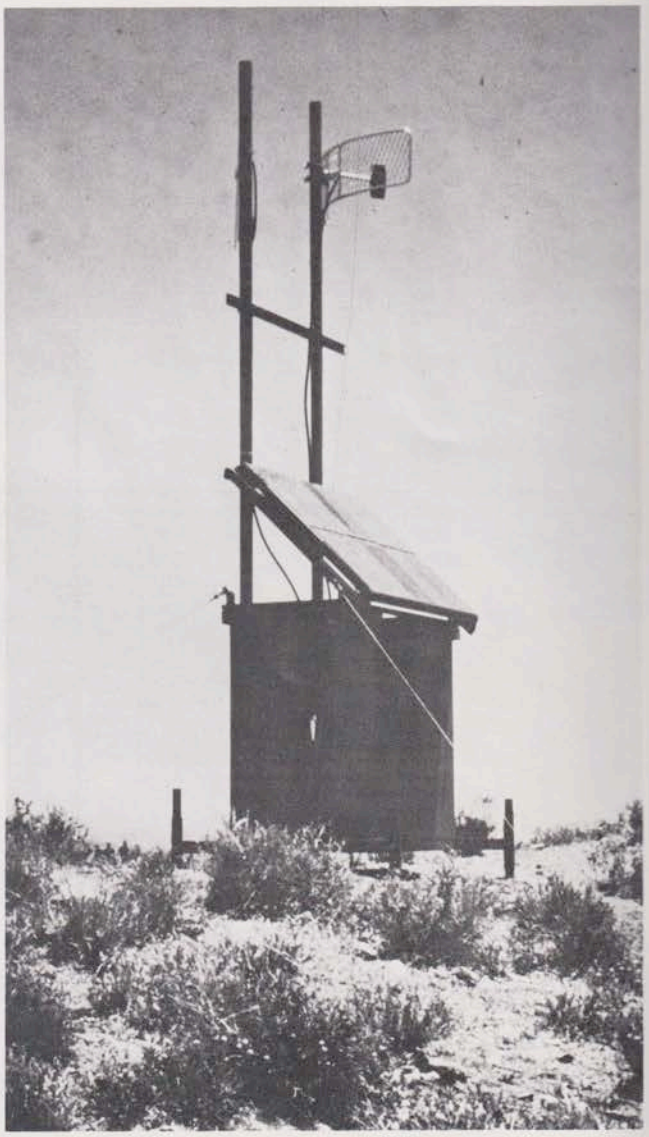
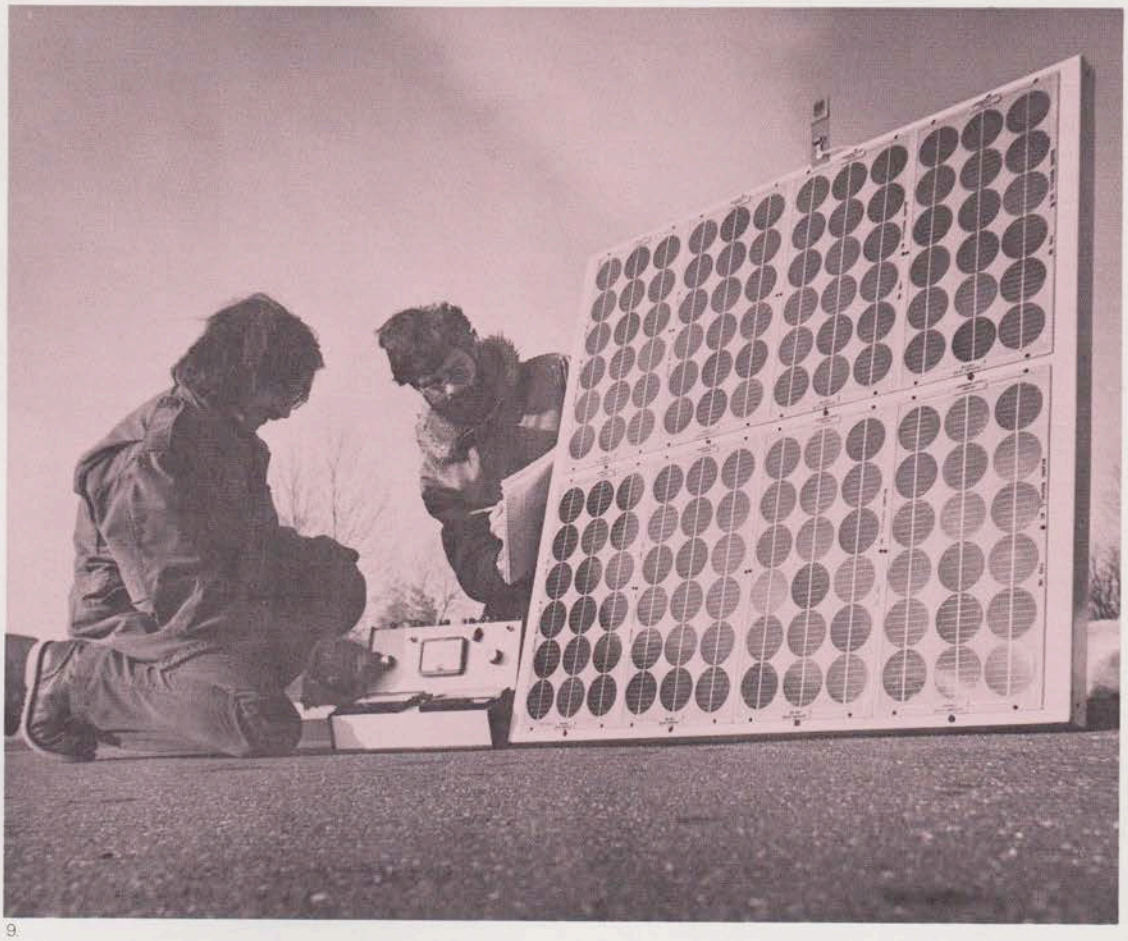

8.

- Modular—Capable of upgrading on site to increase or change the power output of the array by adding Unipanels and/or altering the interconnection of the array.
- Lightweight Panel Construction—Over 4W/lb.
- High Panel Packing Density—Over 6W/sq. ft.
- Maximum Weatherability—All solar panels are manufactured to exceed Jet Propulsion Laboratory environmental test specifications (−40° to + 90°C and 90% humidity @ + 70°).
- High Wind Loading Toleration—Arrays capable of withstanding in excess of 150 knot wind.
- Maintenance-Free—No moving parts, self-cleaning.
- Economical—Low life cycle cost.
- Pollution-Free—No fuel required.
- Quiet—Minimizes detection.
- Safe—Not hazardous to man or wildlife; no electric shock potential, no combustible vapors, no hot surfaces or burners. Can be short circuited or open circuited without danger.

Outstanding Features of Solarex Building Blocks

9. All Solarex arrays are tested prior to shipment as is being done with this 80W (peak) array. Note calibration solar cell at top of array used to reference measurements to full sun conditions (100mW/cm²).



9.

Although the amount of available daily sunshine varies with environmental factors such as geographical location (latitude), local weather, and the season, it is still possible to estimate the number of solar panels required for a specific application.

Solarex has developed a handy tool for determining "peak sun hours" per day (as shown on the solar radiation map) by converting Langleys* to sun hours using its computer program for systems design. An optimum tilt for year round operation for an average U.S. location was also used (a tilt facing due South of 45°), and it was assumed that the panel was not shaded at anytime. Therefore, some adjustments in sun hours given may have to be made to fit local site conditions.

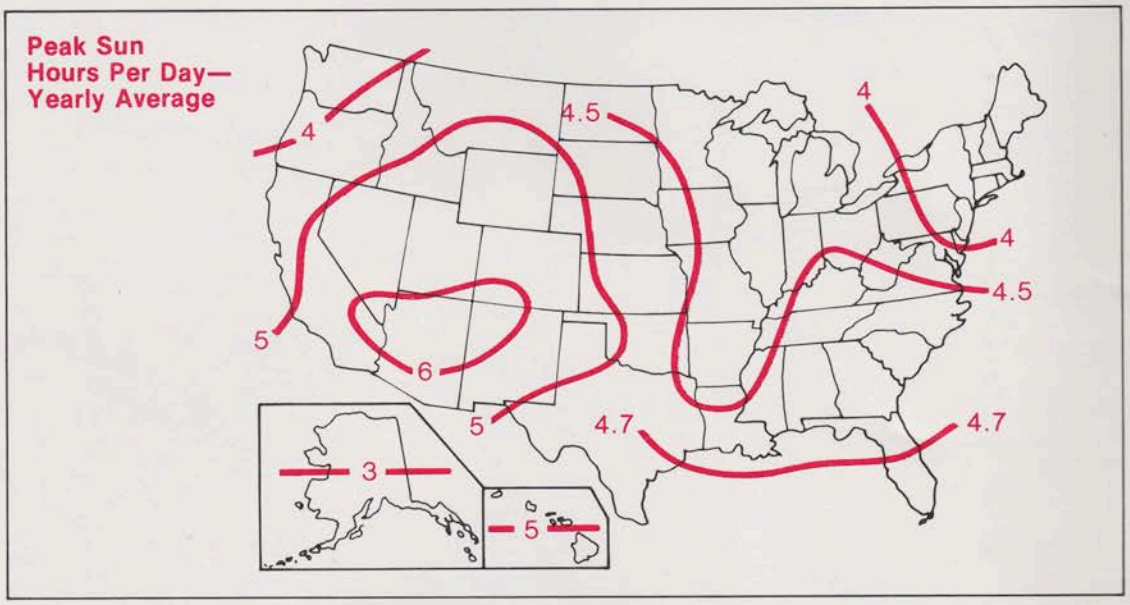
To estimate the number of panels needed for a specific application, the following equations are suggested:

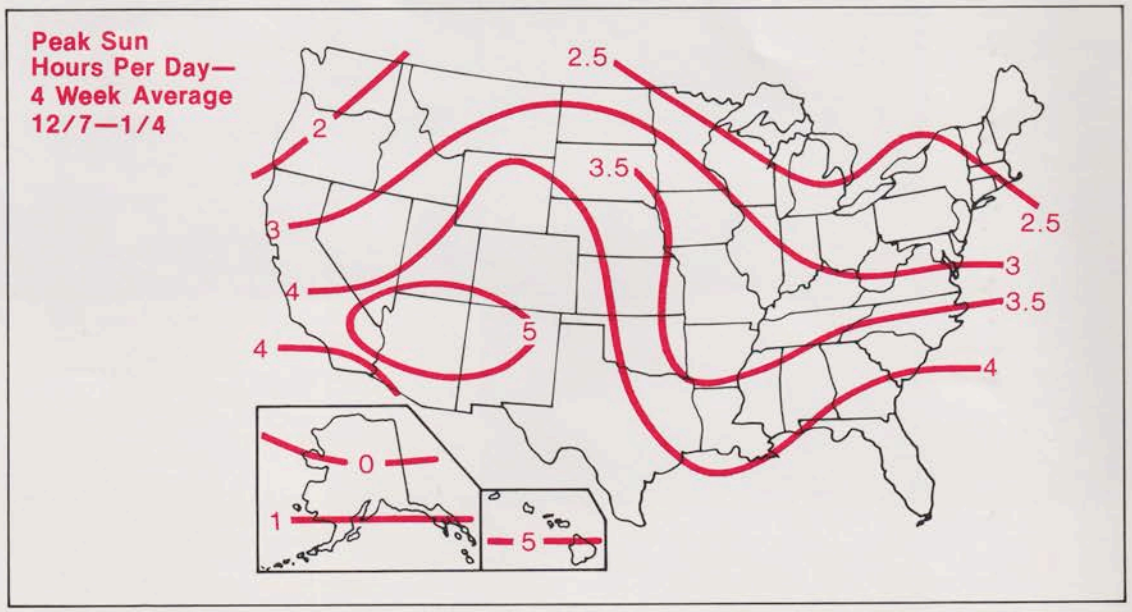
$$\frac{\text{Average Daily Load in } \textbf{AMPERE HOURS} \text{ (Ah) at Nominal Operating Voltage } \textbf{+ 20\%} \text{ for System Losses}}{\text{Peak Sun } \textbf{HOURS} \text{ Available at Site}} = \text{Total System Output Required in } \textbf{AMPERES} \text{ (A)}$$

*1 Langley = 1 Gram calorie/centimeter² = 11.62 Watt Hours/meter² (optional conversion)

Estimating Solarex System Size

10. Solarex solar radiation map shows variations in yearly average peak sun hours per day for locations throughout the U.S. (45° panel tilt; no shade)





Then, choosing a solar panel of the proper voltage from the specifications given, the number of panels needed can be obtained as follows:

$$\frac{\text{Total Solar System Output in A Required}}{\text{Current A Output of Panel}} = \text{Number of Panels Needed}$$

For example, to power a radio repeater for a communications link in Kansas City, Missouri for 24 hours of continuous operation and with an average load of 2A at 12VDC nominal battery voltage, 10 Type 4200 Unipanels wired in parallel are needed. This determination was made by substituting in the previously given equations:

$$\frac{2A \times 24 \text{ Hours} + 20\%}{4.5 \text{ Peak Sun Hours}} = 12.8A \text{ Total Solar System Output Required}$$

Selecting the Type 4200 panel*, for example, with an output of 1.3A @ 14Vnom., the number is:

$$\frac{12.8A \text{ (Solar System Output Required)}}{1.3A \text{ (Type 4200)}} = 9.8 \text{ or } 10 \text{ Panels}$$

A computer-aided analysis technique, developed by Solarex accurately predicts performance of proposed solar electric generator systems for every month of the year. Trade-offs in the system are computed, between the sizes of panel arrays and storage batteries. With this data in hand, choices are made for array size and storage capacity for a specific application.

*In a system using 12V batteries and charge control circuitry, Solarex recommends 14V panels for optimum performance.

11. A computer-aided analysis technique, developed by Solarex, permits predicting performance of proposed solar electric generator systems.

```
     SOLAR ELECTRIC SYSTEM DESIGN


MADE FOR:  TVA  LOC.: KINGSTON, TN.
DATE: NOV. 1976

LATITUDE:  36 DEGREES

MEASURED LANGLEYS:
    JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
    180 250 340 450 515 560 530 480 420 340 225 170

MONTHLY LOAD (WATT-HRS) :    TIMES:     300.000

    100 100 100 100 100 100 100 100 100 100 100 100

        RECOMMENDED SYSTEM:
        -------------------

TILT ANGLE:  45 DEGREES

SOLAR ARRAY VOLTAGE:      12.00

PEAK CURRENT (AT 100MV/SQ.CM):      31.67 AMPERES

PEAK WATTS (AT 100MV/SQ.CM):     380.00 WATTS

BATTERY SIZE:   1875.00 AMP-HRS   FOR CLIMATE CODE: NORM
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   SOLAREX

 SOLAR ELECTRIC SYSTEM ANALYSIS
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MADE FOR:  TVA  LOC.: KINGSTON, TN.
DATE: NOV. 1976

LATITUDE:  36  DEGREES
MOUNTING ANGLE: 45  DEGREES

MEASURED LANGLEYS:
    JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

    180 250 340 450 515 560 530 480 420 340 225 170

CORRECTED LANGLEYS:

    15  15  15  15  15  15  15  15  15  15  15  15  21  21
    JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JUN DEC
    265 316 360 405 410 420 407 410 419 403 316 261 413 265

EQUIVALENT SUN HRS.

 JAN 15   FEB 15   MAR 15   APR 15   MAY 15   JUN 15   JUN 21
   3.08     3.67     4.19     4.71     4.77     4.88     4.80

 JUL 15   AUG 15   SEP 15   OCT 15   NOV 15   DEC 15   DEC 21
   4.73     4.77     4.87     4.69     3.67     3.03     3.08

SUN INPUT:  60. % DIR    40. % DIFF
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 BATTERY AND SOLAR ARRAY TRADEOFF

ARRAY                BATTERY SIZE (W-HOURS)
PEAK          6480.0   12960.0   19440.0   25920.0   32400.0
WATTS           :         :         :         :         :
   500.00
   492.00
   484.00
   476.00
   468.00
   460.00
   452.00
   444.00
   436.00 II
   428.00   III
   420.00     II
   412.00       II
   404.00         III
   396.00           II
   388.00             III
   380.00               II
   372.00                 IIII
   364.00                     IIIII
   356.00                          IIIII
   348.00                               IIIIII
   340.00                                    IIIII
   332.00                                         IIIII
   324.00
   316.00
   308.00
              :         :         :         :         :
          6480.0   12960.0   19440.0   25920.0   32400.0
                 BATTERY SIZE (W-HOURS)


X AXIS - BATTERY SIZE
FULL SCALE=
   2700.00 AMP-HRS AT      12.00 VOLTS =  32400.00 WATT-HRS
ZERO OFFSET =        0.0  WATT-HRS

Y AXIS - MINIMUM PANEL SIZE FOR WHICH BATTERY
DOES NOT DISCHARGE BELOW  25 % FULL CHARGE
FULL SCALE =      500.00 WATTS
ZERO OFFSET =     300.00 WATTS

 1 -  45 DEGREES TILT
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STORAGE BUDGET FOR 25 MONTHS

SOLAR ARRAY SIZE:   380.000 WATTS

BATTERY SIZE:
   1875.00AMP-HRS AT     12.00 VOLTS =   22500.00 WATT-HRS

      EQUIV.    STORAGE    MONTHLY      POWER       STORAGE
MONTH  SUN       START      LOAD      PRODUCED       END
     (HRS/D) (WATT-HRS)  (WATT-HRS)  (WATT-HRS)  (WATT-HRS)
 JUL   4.74   22500.00    32400.00    54017.30    22500.00*
 AUG   4.77   22500.00    32400.00    54392.41    22500.00*
 SEP   4.88   22500.00    32400.00    55621.66    22500.00*
 OCT   4.69   22500.00    32400.00    53434.19    22500.00*
 NOV   3.68   22500.00    32400.00    41923.80    22500.00*
 DEC   3.04   22500.00    32400.00    34696.21    17856.96
 JAN   3.09   17856.96    32400.00    35212.30    13626.80
 FEB   3.68   13626.80    32400.00    41902.12    14748.49
 MAR   4.20   14748.49    32400.00    47842.21    20622.26
 APR   4.71   20622.26    32400.00    53698.37    22500.00*
 MAY   4.78   22500.00    32400.00    54447.08    22500.00*
 JUN   4.89   22500.00    32400.00    55779.23    22500.00*
 JUL   4.74   22500.00    32400.00    54017.30    22500.00*
 AUG   4.77   22500.00    32400.00    54392.41    22500.00*
 SEP   4.88   22500.00    32400.00    55621.66    22500.00*
 OCT   4.69   22500.00    32400.00    53434.19    22500.00*
 NOV   3.68   22500.00    32400.00    41923.80    22500.00*
 DEC   3.04   22500.00    32400.00    34696.21    17856.96
 JAN   3.09   17856.96    32400.00    35212.30    13626.80
 FEB   3.68   13626.80    32400.00    41902.12    14748.49
 MAR   4.20   14748.49    32400.00    47842.21    20622.26
 APR   4.71   20622.26    32400.00    53698.37    22500.00*
 MAY   4.78   22500.00    32400.00    54447.08    22500.00*
 JUN   4.89   22500.00    32400.00    55779.23    22500.00*
 JUL   4.74   22500.00    32400.00    54017.30    22500.00*

* REGULATOR REQUIRED

    60. % DIR    40. % DIFF

    0.80 EFF
```

11.

All Solarex Unipanels are designed to be easily mounted individually or in arrays by the customer on site on his choice of frame or structural member by means of non-metallic fasteners, silicone rubber or other equivalent adhesives. However, since factory mounting of Unipanels is generally recommended and desired, Solarex offers specially designed hardware of the following configurations.

- Single Panel—Type **HP**

  Single panels are securely mounted on an enamel painted anodized aluminum frame complete with charge control circuitry and ready for installation. They are lightweight and may be pole or flat mounted by means of a universal tilt-angle bracket assembly. Included on the reverse side of the frame is a low power charge control circuit enclosed in a sealed junction box.
- Double Panel—Type **HHP**

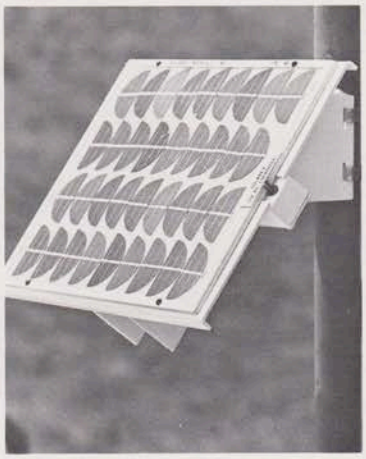
  Same as above, but designed to accommodate two solar panels.
- Arrays

  When multiple solar panels are interconnected to form an array for a solar electric generator, they are secured with plastic screws and silicone rubber onto large, enamel painted, anodized aluminum frames that have adjustable length leg assemblies and pivotal foot plates which allow the tilt angle to be varied. The legs and foot plates are adaptable for mounting on a structural member or directly on the ground. The solar panels are wired to sealed junction boxes attached on the reverse side of the frames.

Typically, not more than ten full size Unipanels (e.g. Type 785), are mounted on a single frame, so as to minimize handling difficulties. For every large solar electric generator, multiple array frames may be attached together.

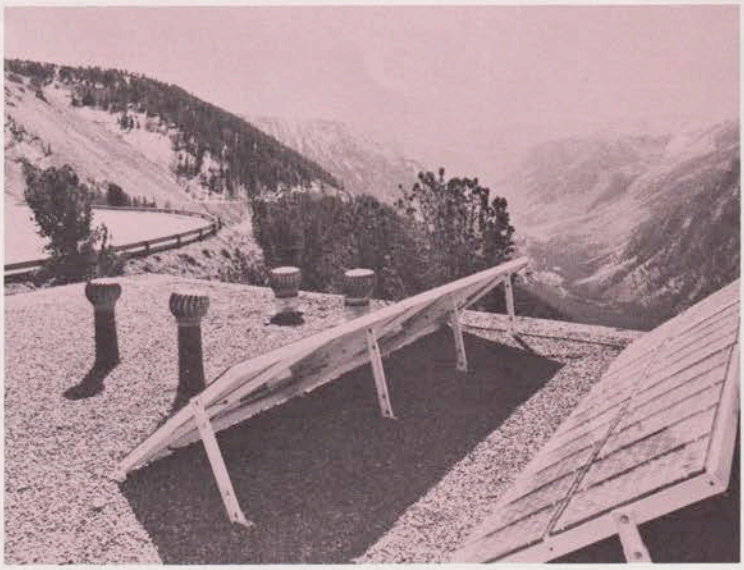
Mounting Hardware

12. Pole mounting may be accomplished by using stainless steel adjustable clamps (straps) that fit through slots in the bracket. The unit may also be screwed or bolted to a flat surface. Adjustment of the tilt angle between the mounting bracket and the frame is accomplished with a stainless steel bolt, nut and lock-washer combination.
13. Solarex solar arrays are well adapted for rooftop installation as shown by this 360W (peak) system located in Custer National Forest, Montana.



12A.

12B.



13.

The foregoing represents a summary of Solarex's present capabilities brought about through its advanced research and development efforts in the field of terrestrial solar cells, panels and systems. Research and development accomplishments have made it possible for Solarex to become the world's leading producer of silicon photovoltaics through such developments as the largest, most efficient silicon solar cells, concentrator cells up to 100x, "semi-crystalline" solar cells, ultra-thin solar cells, and high packing density solar panels.

As research and development efforts at Solarex continue to improve efficiency and reduce the cost of solar cells, photovoltaics for the conversion of light energy into electrical energy will become a rooftop reality by the 1980's.

- Test Parameters

The data provided for Solarex solar panels are measured at 100mW/cm² at 25°C ± 3°C. This is determined by a calibrated pyranometer such as Eppley, Model 8-48, calibrated against a primary standard group of Angstrom Pyrheliometers reproducing the International Pyrheliometric Scale.

Note: All Solarex UNIPANELS are available with or without blocking diodes. When ordering with built-in blocking diodes, add suffix "D" after Unipanel number (e.g. 280D).

The Solarex Unipanels listed below summarize the standard types. However, Solarex will design other solar panels specially suited to customer specifications and applications.

Complete system designs for various applications are now available. Contact Solarex Corporation Marketing Department for additional technical details and pricing information.

Unipanel Specifications

Type	Volts (nom.)	Volts (o.c.)	+Watts (peak)	Amps @ Nominal Voltage	*Ah/week	*Wh/week	Size Inches
435	14	20	4.5	0.30	9.0	135	10×12
1480			9.0	0.60	18.0	270	12⅞×15¾
480			9.5	0.65	20.0	285	14⅞×15½
4200			20.0	1.3	40.0	600	20×20
4300			36.0	2.1	63.0	1080	26×26½
220	12	18	2.0	0.15	4.5	60	7×8½
230			4.0	0.30	9.0	120	10×11
1270			8.0	0.60	18.0	240	12⅞×14
280			9.0	0.65	20.0	270	10½×20
735	7	10	4.5	0.6	18.0	135	10×12
785			10.0	1.3	40.0	300	10½×20
7150			18.0	2.1	63.0	540	14×26½
615	6	9	2.0	0.30	9.0	60	5½×11
460	4	6.6	6.5	1.3	40.0	195	7½×20
**9200J	16	23	23	1.3	40.0	690	22⅞×22⅞

+Typical Output at the Maximum Power Point in Full Sun (100mW/cm²) at 25 C±3 C

*Typical Output Based on U.S. Average Insolation

**Unipanel includes integral anodized aluminum mounting frame with UL approved weatherproof junction box.

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