Formulas Review for NABCEP PVI Exam

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Some Need-To-Know Formulas

- **System Sizing Calculations**
- **Determine Attachment Points Required**
- **Lag Bolt Calculation**
- **Determining Max. and Min. System Voltages**
- Part 2, TBA:
- Voltage Drop Calculations
- Max. Circuit Current Calculations
- Conductor and OCPD Sizing

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System Sizing

- Based on available budget
- Based on area available [ft^2 or m^2]
- Based on required energy offset

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Residential
Budget Ba$ed Example:

- How much cash do you have stashed?
- $12,000 bucks.
- Ok, then… at 6$/ Watt*:
  - $12,000 ÷ 6$ = 2,000 Watts or a 2kW DC System
  - Keep it real- consider conversion losses for actual production:
  - 2,000 W DC x .77 = 1,540W AC
  - 1.54 kW AC production
- * US Solar Market Insight Report Q1 2012.
- Prices vary depending on location in the world! Example- *much cheaper* on Europe and Mexico.

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Commercial

Budget Ba$ed Example:

- How much can you invest?
- $150,000.00
- $150,000 ÷ $4.63/W* = 32,397 Watts or 32.4kW DC system
- 32.4 kW DC x .77 = 25kW AC actual production
- $150,000 x 30% Federal Tax Credit = $45,000
- Cost after applying tax credit = $105,000
- * US Solar Market Insight Report Q1 2012.
- Prices vary depending on location in the world! Example- *much cheaper* on Europe and Mexico.

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P[kW]

A[m²] | η

Area Based Calculations

215W module
1.26084m²
η = .215 ÷ 1.26084 = 17.1%

- **STC: 1000w/m ², 25° C, 1.5 Air Mass**
  - Estimate: at 10% η = 100w/m²
  - Estimate at 15% η = 150w/m²
- **For an individual module, efficiency can be determined with a simple formula [η = kW ÷ m²] but area required is a whole separate game.**
- **Consider module size and available non shaded area**
  - Fire codes - safety of fire fighters
  - Maintenance considerations
  - Wind loads on eaves
  - Roof supports
  - clamps

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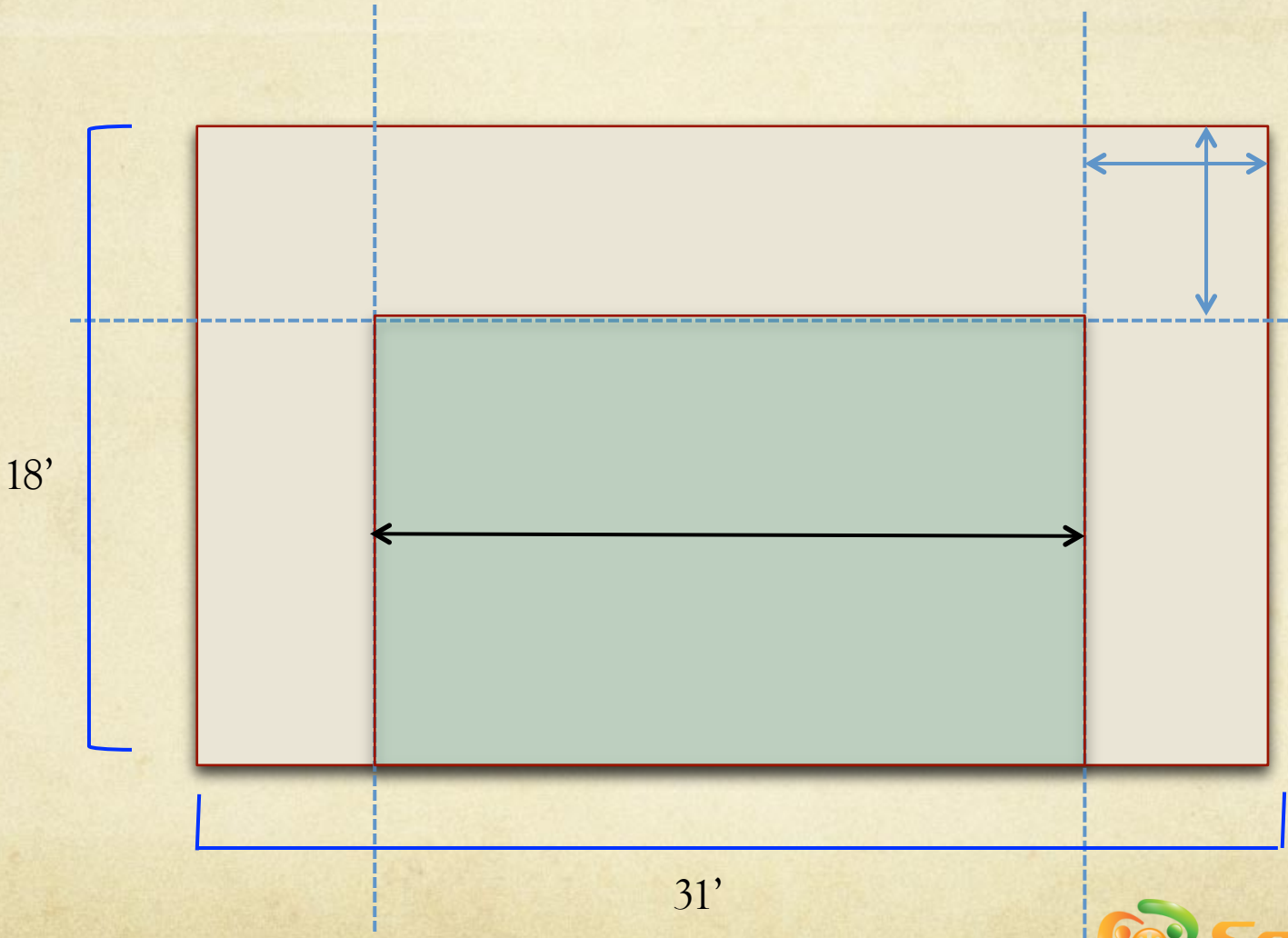
Area Based Calculations



Suggestion not requirement: 3' at ridges & eaves for access...

Subtracted from original area- leaves us an actual 15' x 25'

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Area Based Calculations

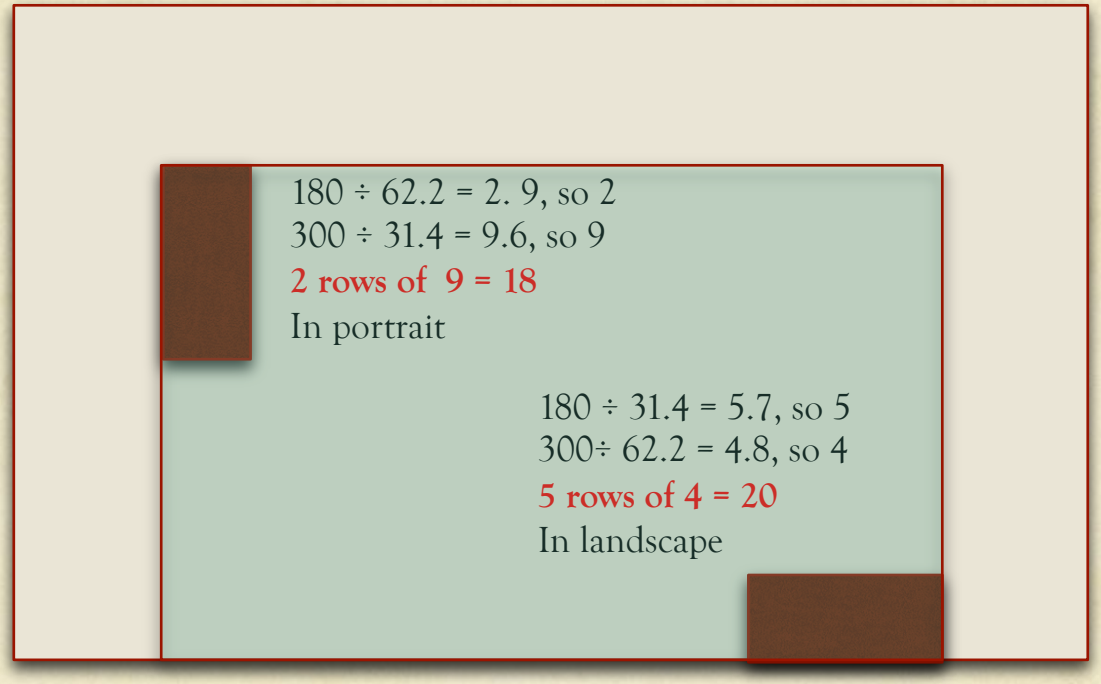
Module dim.:
62.2” x 31.4”

Roof is 18’ x 31’

Usable area is:
15’ x 25’

In inches, that’s:
180” x 300”

Try it both ways..



Consider that there will be 1” between for mid clamps and 2” at each end for end clamps.

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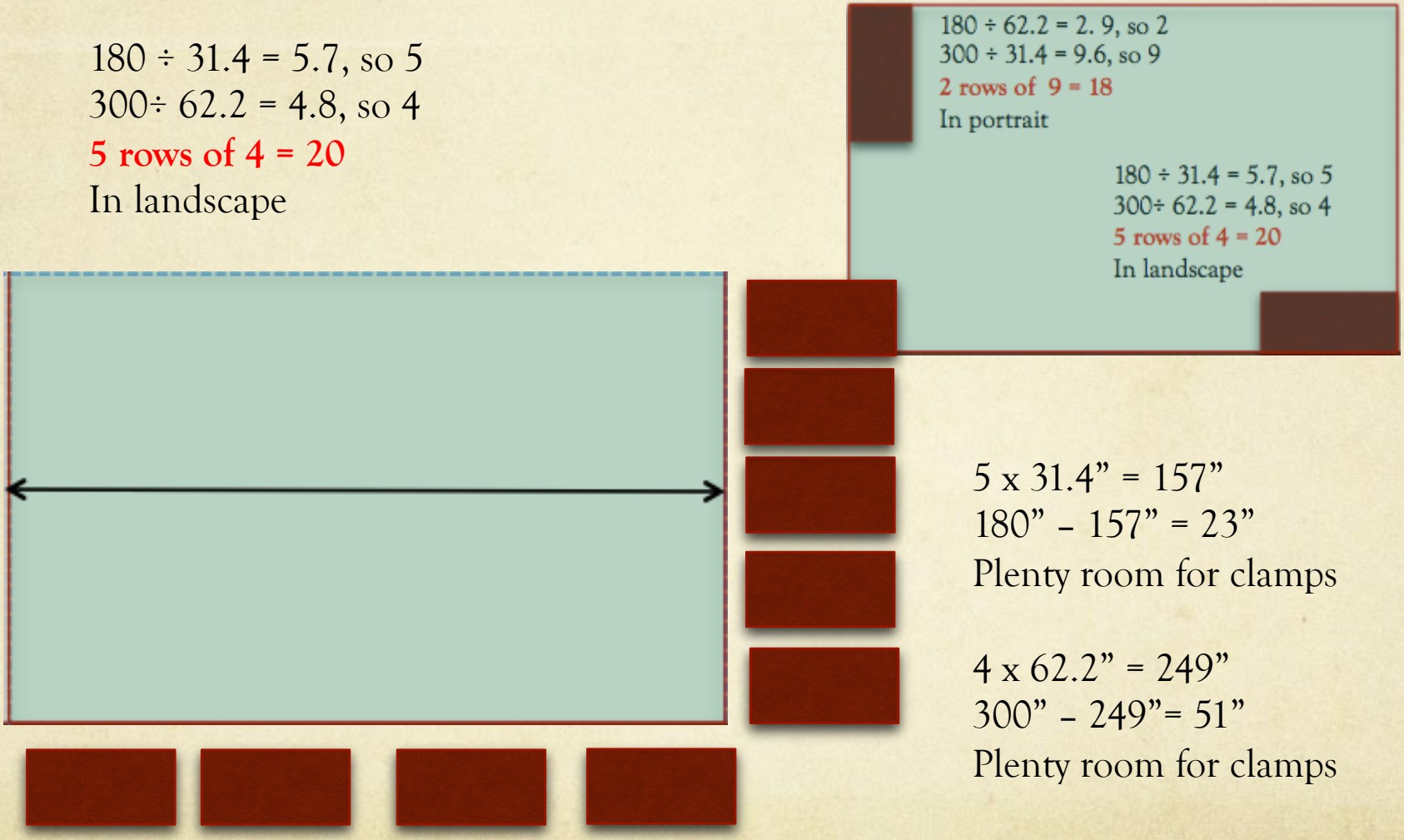
Area Based Calculations

180 ÷ 31.4 = 5.7, so 5
300÷ 62.2 = 4.8, so 4
5 rows of 4 = 20
In landscape



5 x 31.4” = 157”
180” – 157” = 23”
Plenty room for clamps

4 x 62.2” = 249”
300” – 249”= 51”
Plenty room for clamps

Area based system sizing

"coctail napkin" average sounds good, but unrealistic

- I have an area that is 15' x 25'. What size system can I fit in that space using 215 watt modules with an efficiency of 17%?
- We could also say:
- 17% of 1000w/m^2 = 170w/m^2
- 15' x 25' = 375'... x .093 to convert ft^2 to m^2 = 34.88m^2
- With 34.88m^2:
  - 34.88m^2 x 170w/m^2 = 5929 watts or 5. 9kW
- **BEWARE - this is not accurate! It is only a rough estimate.**
- **5 rows of 4 will fit [20 modules]**
- **215W X 20 = 4300 watts or 4.3kW, If they all fit. 1.6kW less!**

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Area based system sizing:

- What efficiency is required to achieve 7.2kW AC from a $56m^2$ **array**?
- $P = A \times \eta$
- 7.2 kW AC ÷ .77 = 9.35 kW DC
- 9.35 kW AC = $56m^2 \times [\eta]$
- Divide both sides by 56:
- $.1669 = \eta$
- 17% η is required – This is only surface area of *array*

How much Power do you need?

- I'd like a 5kW DC system. I live in Austin.
- Ok, well… it'll cost:
- 5,000 W x $6 = $30,000
- Holy Cow!
- BUT: Austin rebate: $2.00/W x CEC Inverter Efficiency, say 90%. So that's minus 9,000… and then there's a 30% tax credit on the remaining 21,000. Subtract another $6300, so that's actually 14,700! So… that's really $2.94/watt cost! ☺
- Nice!

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How much Energy do you use/*need*?

- Well… my bill says my electricity usage is 1100 kWh AC for this month. That's… $106.70 in Austin at $.097/kWh
- To offset 50% of my bill, how big would my system need to be?
- 1100kWh ÷ 2 = 550kWh AC, or 550,000 Wh AC per month…
- Whoa.
- Yeah- 550,000 Wh AC. Maybe you should change some light bulbs first? Maybe turn the Air Conditioning down?
- Here we go…

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How much Energy do you use/*need*?

- 1100kWh AC÷ 2 = 550kWh, or 550,000 Wh AC/month…
- 550kWh AC ÷ 30 = 18.3 kWh AC/day
- 18.3kWh AC ÷ 5.3 peak sun hours/day =3.45kW AC
- Don't forget to keep it real- conversion losses.
  - 3.45kW AC ÷ .77 = 4.48kW DC

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Tips:

- Remember if you are determining a larger # from a smaller one you divide:
  - Ex.: What size system will you need to produce 4kW AC?
  - 4kW AC ÷ .77 = 5.3kW DC
- Vice Versa:
  - Ex. What is the actual AC production of a 5kW after conversion losses?
  - 5.3 kW DC x .77 = 4.08kW AC
- What are you being asked, and does your answer make sense?

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Exam Tips:

- Slow down:
- Don't forget the decimal.
- Consider what's being asked:
  - Production vs. size [before or after the .77]
  - Are you figuring 50% of something or the whole?
  - Are you determining kWh for the year or the day?
  - Etc.
- **Read the question closely and look at what it's asking.**

Array Attachment Points:

How Many?

- Example standards *per manufacturer*:
  - No less than 48” between modules
  - No more than 24” from ends of rails
  - 1” between modules for mid-clamps
  - 2” at the end for end-clamps
- How big is the module?
- How many will there be?

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Array Attachment Points:

How Many?

✧ Make sure to use the right dimensions [module with frame].

Mechanical Specifications

Internal Bypass Diodes	3 Bypass Diodes
Module Area	13.56 Ft^2 (1.26m^2)
Weight	35.3 Lbs. (16kg)
Dimensions LxWxH	62.2x31.4x1.8 in. (1580x798x46 mm)
Cable Length +Male/-Female	40.55/34.6 in. (1030/880 mm)
Cable Size / Connector Type	No. 12 AWG / MC4™ Locking Connectors
Static Wind / Snow Load	60PSF (2880Pa) / 39PSF (1867Pa)
Pallet Dimensions LxWxH	63.2x32x72.8 in. (1607x815x1850 mm)
Quantity per Pallet / Pallet Weight	34 pcs./1234.5 Lbs (560 kg)
Quantity per 53' Trailer	952 pcs.

Yes

No

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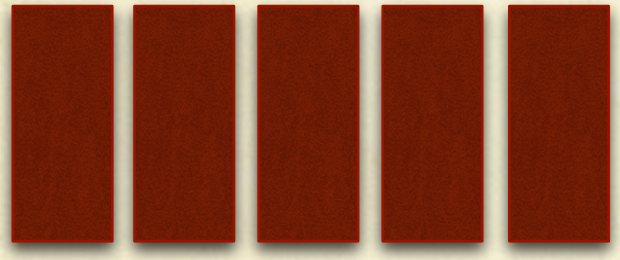
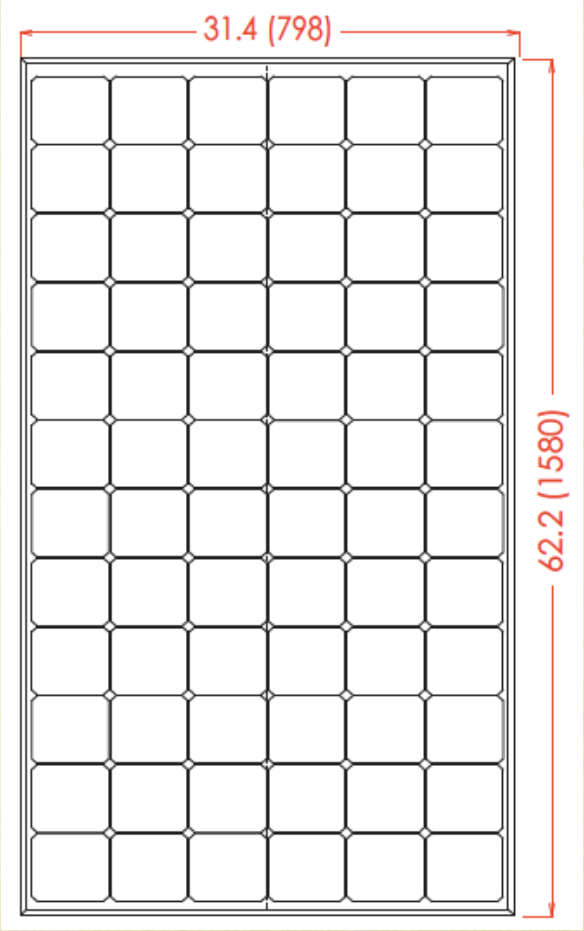
Array Attachment Points:

How Many?

- 31.4” x 62.2”
- 5 modules ran in portrait mode.



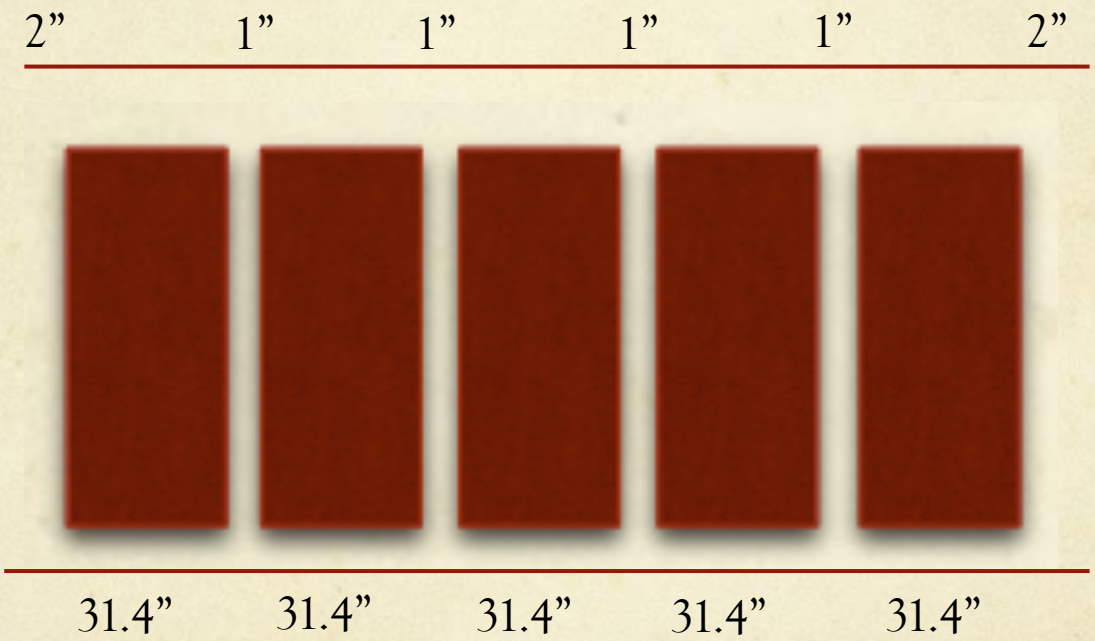


✧ How many attachment points will be needed ?

Array Attachment Points:

How Many?

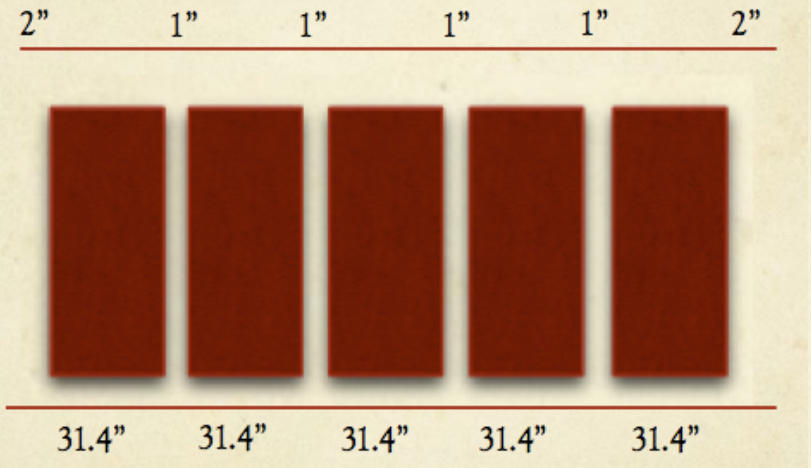
- Draw it out:



Array Attachment Points:

How Many?

- Add it up:

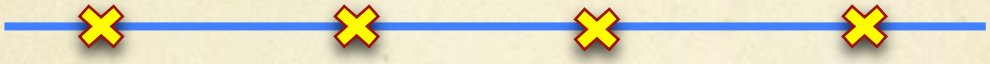


- 2” + 4” +2” + [31.4” x 5] = 165” total length to support

Array Attachment Points:

How Many?

- = 165” total length to support
- 48”> between & 24”> at ends

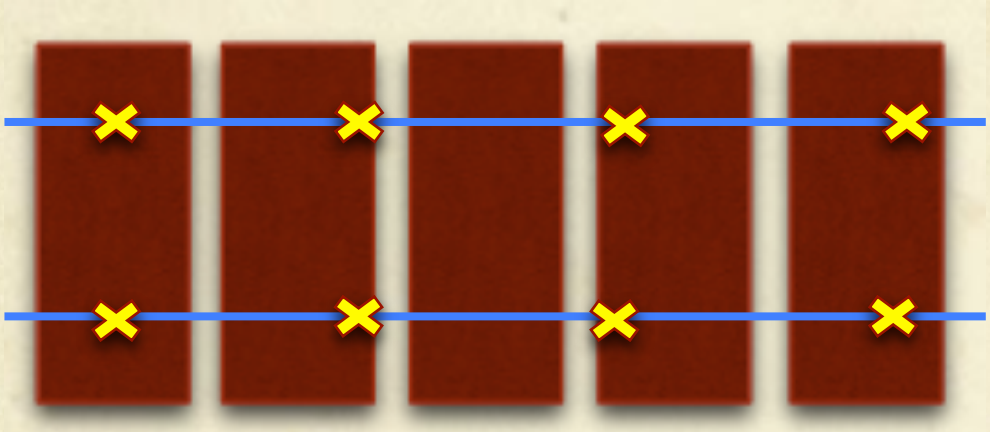


- 165” – 24” – 24” = 117”
- 117” – 48” = 69”
- 69” – 48” = 21”
- So- 4 per rail.
- Draw it out to double check…

Array Attachment Points:

How Many?

- Draw it out and double check the math:

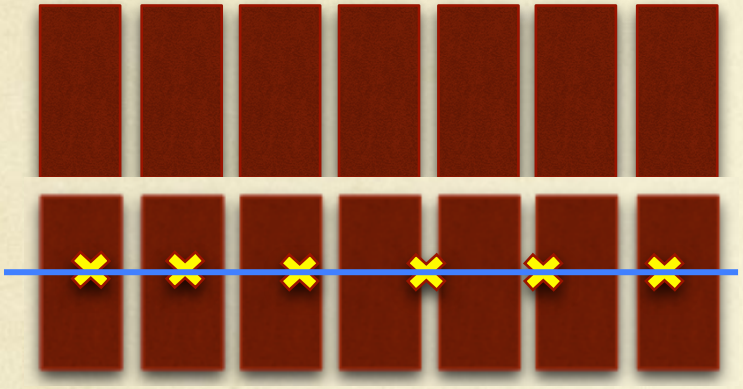


- [165” – 48”] ÷ 3 spaces between attachments
  - 117” ÷ 3 = 39” between – OK!
- So- with 2 rails - that is 8 attachments total.

Array Attachment Points:

How Many?

- One more…



Check the math:
207” ÷ 5 = 41.4” between – OK!

Module Dimensions: 35” x 65”
2 rows of 7
7 x 35” = 245”

245” + 6” mid-clamps + 4” end-clamps = 255” of modules plus all clamps

255” – 24” – 24” = 207”
207” – 48” = 159”
159” – 48” = 111”
111” – 48” = 63”
63” – 48” = 15”

So 6 per rail, total of **24**.

W/ numbers only:

- 2 rows of 7
- 7 x 35” = 245”
- 2 end-clamps (allow 2” each), 6 mid-clamps (1”) = +10”
- 255” – 24” – 24” = 207”
- With 7 attach./rail [6 spaces in between]: 207” ÷ 6 = 34.5”
- **With 6 attach./rail [5 spaces]: 207” ÷ 5 = 41.4”**
- With 5 attach./rail [4 spaces]: 207” ÷ 4 = 51.75”
- So- total of 6 *per rail, 4 rails = grand total of 24*

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Lag Screw Calculations

- Wind load?
- Wood type/pull strength [AWL- allowable withdrawal load]?
  - *The figures should be given to you, but if you want to learn them they can be found online or in Photovoltaic Systems 2010 by Dunlop page 274.
- Roof thickness?
- # Mounting Feet/Attachments?
- Array area?

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Lag Screw Calculations

- Formula:
- [{[WL x Area x Qty.] ÷ #attachments} ÷ AWL} + RT] = TL
- Wind load in psf. x area of one module in ft.^{2} = lb/each
- Lb. Each x # of modules = total weight
- Total weight ÷ # attachment feet = load for each Lag Screw
- Lag Screw Load ÷ allowable withdrawal of screw = length
- Add RT or "roof thickness" to get total length

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Lag Screw Calculations

Example:

- 5/16 bolt in Southern Yellow Pine = allowable withdrawal load of 332 lb/in^2.
- Array will be 10 modules that are 12.5 ft^2.
- Wind Load is 25psf.
- There are 8 attachments.
- Roof [including mtg. attachment] is average, 1" thick.
- [{[WL x A x Qty.] ÷ #attachments} ÷ AWL] + RT = TL

Lag Screw Calculations

Example:

- [{[WL x A x Qty.] ÷ #attachments} ÷ AWL] + RT = TL
- [{[25 x 12.5 x 10} ÷ 8} ÷ 332] + 1” = TL
- [3125lb ÷ 8 attachments] ÷ 332lb/in^2] +1” = TL
- [390.62 ÷ 332] + 1” = TL
- **1.18” + 1” = 2.18” or 2 1/4 inches Lag Screw needed**

Lag Screw Calculations

Example:

- 7/16 lag screw in white spruce [AWL = 292lb/in^2], 6 attachments
- 30psf wind load, 6 modules that are 11ft^2
- 30psf x 6 mod. X 11ft^2 = 1, 980 lb.
- 1980 lb. ÷ 6 attachments = 330 lbs. per attachment
- 330 lbs./attachment ÷ 292 AWL = 1.13”
- 1.13” + 1” = 2.13”,
- **Closest size you’ll be able to buy = 2 ¼” lag screw**

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Lag Screw Calculations

- NOTE:
  - The pilot hole that is drilled for a lag screw should be:
  - 60 – 75% of the screw nominal shank diameter
    - 2010 Photovoltaic Systems by Dunlop
  - 67 - 80% of the screw nominal shank diameter
    - NABCEP 2011 IRG
  - Larger pilot holes for harder woods, smaller ones for softer woods
- 5/16" diameter – what is **75**%?
- 5 ÷ 16 = .3125…x.75 = .234 or ¼"
- Or, 5 x .75 = 3.75… so 3.75/16 or…4/16 roughly [= 1/4]

System Voltages

Max. and Min.

- Safety: You must determine the *maximum* voltage the system will produce for the ambient temperature for the design location- a SAFETY precaution.
  - **Use low temp. and Voc**
- Performance: You must determine the *minimum* voltage the system will produce to make sure that it operates within the inverter's required range – a PERFORMANCE issue.
  - **Use high temp. and Vmp**

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System Voltages

Max. and Min.

- There are 2 ways to do this calculation- know both.
- NEC Code 2011 states you must use manufacturers specifications. This means if a temperature coefficient is given, you must do the long equation.
- NEC Code 2011 also provides you with predetermined correction factors based on ambient temperatures. Know these, where they are in the code book, and how to use them.

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System Voltages

Max. and Min.

- Table 690.7 for Low Temp. Correction Factors

Table 690.7 Voltage Correction Factors for Crystalline and Multicrystalline Silicon Modules

Correction Factors for Ambient Temperatures Below 25°C (77°F). (Multiply the rated open circuit voltage by the appropriate correction factor shown below.)

Ambient Temperature (°C)	Factor	Ambient Temperature (°F)
24 to 20	1.02	76 to 68
19 to 15	1.04	67 to 59
14 to 10	1.06	58 to 50
9 to 5	1.08	49 to 41
4 to 0	1.10	40 to 32
-1 to -5	1.12	31 to 23
-6 to -10	1.14	22 to 14
-11 to -15	1.16	13 to 5
-16 to -20	1.18	4 to -4
-21 to -25	1.20	-5 to -13
-26 to -30	1.21	-14 to -22
-31 to -35	1.23	-23 to -31
-36 to -40	1.25	-32 to -40

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Say What?

Method 1 —

Module Manufacturer's Temperature Correction Factor—Percentage Method

Temperature Coefficient for $V_{OC} = \alpha V_{OC} = -0.37\%/°C = -0.0037/°C$

Temperature Correction Factor $= 1 + \alpha V_{OC}(\%) \times (Temp_{LOW} - Temp_{RATING})$

$= 1 + (-0.0037/°C) \times (-12°C - 25°C)$

$= 1 + 0.0962 = 1.1369$

$V_{MAX} = 37.3V \times 14 \times 1.1369 = 593.7$ *Volts< 600 Volts (compliant for a* $600V_{MAX}$ *inverter)*

Method 2 —

Module Manufacturer's Temperature Correction Factor—Voltage Method

Temperature Coefficient for $V_{OC} = \alpha V_{OC} = 137mV/°C = 0.137\ V/°C$

Temperature Correction Factor $= 1 + [\alpha V_{OC}(V) \times (Temp_{LOW} - Temp_{RATED}) \div VOC]$

$= 1 + [0.137\ V/°C \times (-12°C - 25°C) \div 37.3V]$

$= 1 + [5.069V \div 37.3V] = 1.1359$

$V_{MAX} = 37.3V \times 14 \times 1.1359 = 593$ *Volts < 600Volts (compliant for a* $600V_{MAX}$ *inverter)*

Method 3 —

Table 690.7 Temperature Correction Factor

From row for ambient temperature = -11°C to -15°C → 1.16

$V_{MAX} = 37.3V \times 14 \times 1.16 = 605.8$ Volts > *600Volts (this is less accurate and yields a value that exceeds the allowable* $600V_{MAX}$ *for the inverter)*

NEC 2011 PVI Installer Resource Guide

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System Voltages

Maximum ★

Model	HIT Power 215N or HIP-215NKHA6
Rated Power (Pmax)[1]	215 W
Maximum Power Voltage (Vpm)	42.0 V
Maximum Power Current (Ipm)	5.13 A
Open Circuit Voltage (Voc)	51.6 V ★
Short Circuit Current (Isc)	5.61 A
Temperature Coefficient (Pmax)	-0.336%/ °C
Temperature Coefficient (Voc)	-0.143 V/ °C

Performance

Safety

V/°C

- Voc is 51.6V
- Voc Temp. Coeff. Is -.143V/°C

SVA: Series Volts add
PAA: Parallel amps add
"SVA-PAA"

System Voltages

Maximum

- Voc = 51.6V
- Temp. LOW = -25 °C, corr. Factor of 1.2 [Table 690.7]
-21 to -25	1.20	-5 to -13
- 9 modules in series [SVA- series - volts - add]
- Vmax = Voc x # in series x Corr. Factor
- Vmax = 51.6 x 9 x 1.2 = 557.28
- 557.28V < 600V so OK
- Vmax = 51.6 x 10 x 1.2 = 619.2V- 10 is NOT OK

System Voltages

Maximum

- Voc = 51.6
- Temp. Low = -25 °C
- T Coeff. : -0.143V/°C
- {Voc + {[Low T°C – 25 STC] x -.143V/°C}} x 10
- {51.6 V + {[-25 – 25] x -.143 V/°C}} x 10
- {51.6 V + 7.15 V} x 10 = 587.5 !!! So, 10 *is* o.k.!
- ? Remember range on 690.7 was -21 to -25 .... Hmf!

System Voltages
Minimum

- Vmp is 42V
- Temp. High is 37°C for Dallas, TX
- -.336%/°C = Coeff. of Pmax
- -.143V/°C = Coeff. Of Voc

Model	HIT Power 215N or HIP-215NKHA6
Rated Power (Pmax)[1]	215 W
Maximum Power Voltage (Vpm)	42.0 V
Maximum Power Current (Ipm)	5.13 A
Open Circuit Voltage (Voc)	51.6 V
Short Circuit Current (Isc)	5.61 A
Temperature Coefficient (Pmax)	-0.336%/ °C
Temperature Coefficient (Voc)	-0.143 V/ °C

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System Voltages

Minimum

- Determine cell temp. @ site's high ambient temp. by adding T rise coefficient [the change in cell temp. due to irradiance]*:
  - Ambient high is 37°C.
  - 37°C + 30°C = 67°C
- Calculate difference between high cell temp and STC:
  - 67°C – 25°C = 42°C
- Find change in Vmp with T Coeff.:
  - 42°C x -.143 = -6.006V
- Adjust module Vmp and multiply by # in series:
  - 42V + -6.006V = 36V
  - 36V x 10 = 336V
- Inverter must work within the range of 336V and 587V

***Justine Sanchez- Home Power #128**
*Jeff Gilbert- Verify System Design- SolarMOOC

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System Voltages

Minimum

- $V_{corr} = Vmp + [Vmp \times \{C_v \times [T_{cell} - T_{STC}]\}]$
- 42Vmp + [42 x {-.336%/°C x [37 + 30 – 25]}]

  Ambient High T°C

  T-Rise Coeff.

- 42Vmp + [42Vmp x {-.00336 x 42°C]
- 42Vmp + [42Vmp x -.1411]
- 42Vmp + -5.93
- 36.07V per module actual V in hot temp.
- Min. DC voltage is 220V:
- 220 ÷ 36.07 = 6.09 so 7 mod. Min., six might be ok- design decision

*Justine Sanchez- Home Power #128

***Jeff Gilbert- Verify System Design- SolarMOOC**

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System Voltages

Minimum

- Min Start Voltage is 175V/220V so OK

Technical data	Sunny Boy 2000HF-US	
	208 V AC	240 V AC
Input (DC)		
Max. recommended PV power (@ module STC)	2500 W	
Max. DC power (@ cos φ = 1)	2200 W	
Max. DC voltage	600 V	
DC nominal voltage	480 V	
MPP voltage range	175 – 480 V	
Min. DC voltage / start voltage	175 V / 220 V	

Resources to Review

- SolPowerPeople Webinar Schedule- see who's coming up and access an organized list of past lecturers/lecturers from current time SolarMOOC back to last March NABCEP Prep. beginnings

- Understanding the Cal Fire PV Installation Guide- Bill Brooks – illustrations and explanations about suggested array access

- **Home Power #128** Back Page Basics- PV Array Temperature Impact Calculations, by Justine Sanchez [contact HomePower for a copy!]

- Sizing Batteryless Grid-Tied PV Arrays, by Justine Sanchez

- SolarMOOC Lectures:
  - **Jeff Gilbert** – Verifying System Design- Max and Min Voltages covered thoroughly
  - Mike Holt- Installing Electrical Components- conductor and OCPD sizing
  - Johan Alfsen – Installing Mechanical Components- best mounting practices
  - Dr. Jeffery Lee Johnson- Electrical Installation of a PV System- designing for voltages, electrical installation methods, more

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Thank you!

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My blog: abundancesolar.com

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More explanations...

- SolPowerPeople Newsletter Archive:
  - http://solpowerpeople.com/solarmooc-newsletter-archive/
  - Mike Holt - Verifying System Design [wire/OCPD sizing]:
    - http://info.solpowerpeople.com/solarmooc-newsletter/bid/110191/SolPowerPeople-SolarMOOC-Newsletter-Day-4
  - Johan Alfsen - Installing Mechanical Components:
    - http://info.solpowerpeople.com/solarmooc-newsletter/bid/115242/SolarMOOC-Newsletter-Day-14
  - Janet Hughes – Installing Electrical Components:
    - http://info.solpowerpeople.com/solarmooc-newsletter/bid/112926/SolarMOOC-Newsletter-Day-11
  - Jeff Gilbert – Verifying System Design [String Sizing & Voltage Max/Min]:
    - http://info.solpowerpeople.com/solarmooc-newsletter/bid/139048/Verifying-System-Design-with-Jeff-Gilbert-SolarMOOC-Newsletter