Pitched Roof Mounting

by Rebekah Hren

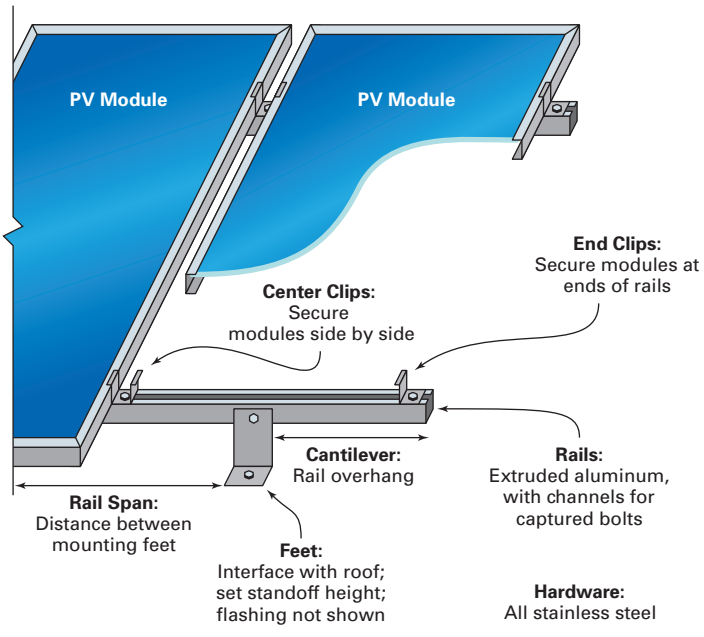
One of the many beautiful things about photovoltaic technology is the ability to transform underutilized space—the residential roof—into a clean, renewable, local power production plant. Today's roof-mounting systems can make installations faster and more streamlined than before.

Courtesy www.ironridge.com

Whether because of limited ground space, better solar access with less shading from structures and trees, or lower installed cost, roofs are the default location for residential solar-electric systems. While the vagaries of residential construction lead to roofs of myriad shapes and sizes, most roofs are designed with a pitch (slope). For the PV system and installer, the pitch is important for ease of installation and for system efficiency, since modules produce greater power the more perpendicular they are to the sun's rays.

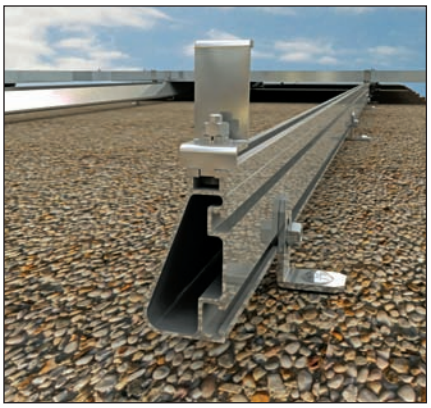
Manufacturers' mounting systems for pitched roofs tend to follow a top-down rail mounting scheme. Aluminum or stainless steel L-feet or standoff posts, usually lag-bolted into a rafter, support an aluminum rail at regular intervals. Two rails run under each row of PV modules, and the modules are secured to the rail by means of top-mounted clips. These are bolted down to the rail between modules, with one clip connecting the sides of two adjacent modules.

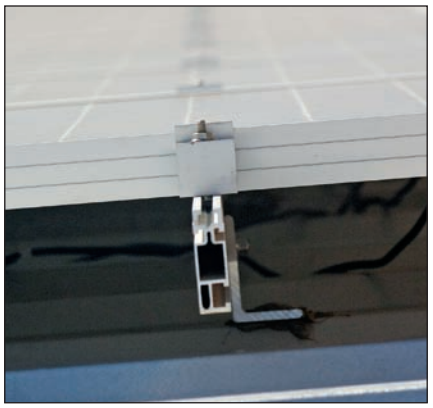
Typical Top-Down PV Mount



Parts & Pieces: Feet

Mount feet come in many varieties, and this is one of the places where great innovation has been happening in the industry. Examples include Quick Mount PV's Composition Mount, Thompson Technology's Flat Jack, and Direct Power & Water's


Courtesy www.ironridge.com


Courtesy www.unirac.com


Courtesy www.conergy.us

Almost all residential PV racks are "top-down," meaning modules are easily installed from above. Typical examples (from L to R): IronRidge, Unirac, and Conergy. All show foot, rail, and clip.

(DP&W) Easy Feet. The mount you choose to hold your rail depends on a few factors: roof type, climate characteristics, price, and personal preference.

L-feet are lag-screwed to rafters through the existing roofing layers and depend solely on sealant to remain watertight during the life of the roof. PV mounting manufacturers don't recommend a brand of sealant, but refer you to roofing manufacturers. While they are the fastest, least-expensive footing option, L-foot installations may void roof warranties when not flashed (see "Protecting the Roof with Flashing" sidebar). Some types of sealant are designed to work only with certain roofing materials—and will not work properly with others. Leaking mount feet may cause damage to the underlying roof structure, which could lead to mold problems and, in some cases, litigation. When in doubt, consult a professional roofer.

Direct Power & Water's Easy Feet are designed to hold to roof sheathing when rafters aren't available.


Courtesy www.directpower.com

Flashed standoffs resist water infiltration more reliably than a sealed L-foot. Standoffs, or stanchions, are specialized bolts or posts with a solid base that is lag-screwed into the roof rafters. They are the best choice when working with a new roof installation where the decking is exposed and accessible. Roofers can flash around them just like any other vent pipe or duct as the roofing material is installed. Standoffs can also be retrofitted onto an existing roof, although this is a slightly more time-consuming process than using L-feet. Some newer standoffs, such as the Flat Jack and Quick Mount PV's Composition Mount, come with flashing integrated into the mount, and can be slid under existing asphalt shingles, shakes, and tiles. Other standoffs rely on roofing industry standards like Oatey flashings, which slide over the standoff post.

Top-down technology and extruded rails make attaching feet, module clips, and even combiner boxes quick and easy.


Courtesy www.directpower.com

Protecting the Roof with Flashing

Flashing is commonly used around plumbing vents, chimneys, and other roofing joints to keep water from entering and damaging the roof structure. In PV installations, it's also used around roofing penetrations.

On composition roofs, a thin, rectangular piece of metal is typically used. One half is pushed up under a shingle, while the other half overlaps the shingle in the row beneath. For mounting standoffs, the metal sheet has a plastic collar, which fits tightly around the standoff, preventing water entry. Oatey is a manufacturer of flashings commonly used with various PV mounts.

Flashing metal roofs poses more challenges, as the roof metal must be uninstalled, cut, and then refit to allow for an overlap around the hole where the square of flashing can be inserted. Metal roofing specialists do offer flashings that don't require an overlap but instead use sealant to secure the flashing to the metal roof. In these cases, watertightness relies solely on sealant for the life of the system.

Courtesy www.directpower.com

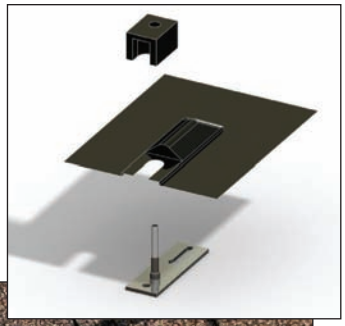
Oatey flashings provide a watertight seal for the mounting post.

With the exception of only a few products on the market, rail supports attach to rafters with stainless-steel lag screws. The screws must be sized based on uplift point loads and wood strength charts like those provided by the American Wood Council (see Access). Racking manufacturers should provide engineering recommendations. Exceptions to lagging into a rafter include the Easy Feet and SunPower's Smart Mount. Easy Feet come with butyl mastic backing and are held down with five screws, which are secured through the roofing material into the decking or sheathing. These are good options in cases where the rafters are inaccessible (as with standing-seam metal roofs, when rafters are inaccessibly located under a V), or when retrofitting a structural insulated panel (SIP) roof, which has no rafters. Note that Easy Feet depend on structurally sound roof decking and should not be used on roofs with compromised decking.

Parts & Pieces: Rails

Nearly every rail on the market is made of extruded aluminum. In the extrusion process, hot aluminum is pushed through a

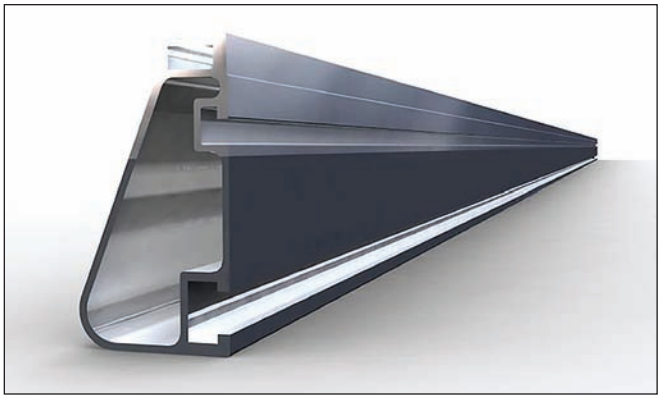
Thompson Technology's Flat Jack mounting foot uses integrated flashing that slides up under shingles.



Courtesy www.thompsontec.com

Quick Mount PV's Composition Mount is also self-flashed. Shown (below) on a cedar shake roof.

Courtesy www.quickmountpv.com



Courtesy www.ironridge.com

Extruded aluminum rail is the backbone of a PV mount.

die to create the desired profile. Many manufacturers use anodizing, which creates a hard, nonreactive surface film to improve corrosion- and wear-resistance. Generally, an anodized rail retains its silver color , though other anodized rail colors (such as bronze for SunEarth's CompRail system) may be available. The other commonly available rail color is black, which usually means a protective powder coating has been applied. Powder coating is a dry coating that's cured under heat to form a "skin." It can create a hard finish tougher than conventional paint.

Some manufacturers sell both light and heavy rail. Heavy rail is thicker and stronger, and can span longer distances between supports and carry heavier loads. Light rail is considered adequate for the majority of residential pitched roofs. Rail can typically be ordered in lengths up to 27 feet, and splice kits are used to tie lengths together. Rail can run horizontally or vertically on a roof.

Spacing of rail supports, referred to as "rail span" or "foot spacing," depends upon rafter spacing (commonly 16 or 24 inches on center), manufacturer's recommendations, and loading estimates, such as dead load, wind load, and snow load (see "Dealing with the Forces of Nature," at right). Each manufacturer has its own recommendations for maximum recommended rail span wind speeds—some to 90 mph, some to 125 mph. Typically, rail span will vary between 48 and 96 inches when using light rail.

Dealing with the Forces of Nature

Loads from wind, snow, and the combined weight of the system components impact rail span and spacing and rail gauge, as well as roof design limits. If the mounting system isn't sized accordingly, strong winds can put additional uplift strain on your modules and mounts, causing damage to the system and roof structure. Similarly, the additional weight of snow on top of the modules can compromise a roof's integrity. If you're retrofitting a system to an existing roof, you'll need to consult with an engineer to make sure your roof is beefy enough to withstand the added array weight (the roof's "dead" load) and wind load. Similarly, if you're building a new house, you'll need to design the roof accordingly to accept the increased loads of the system.

Wind load (uplift and downlift pressure). Three factors are used to find down-force and uplift from wind pressure:

- Basic wind speed—found by consulting local wind maps or building code officials
- Effective wind area—the total continuous area of modules
- Roof zone—which section of a roof is utilized, whether interior, end, or corner.

These factors come together in an engineering formula or table that specifies down-force and uplift pressure in pounds per square foot according to the input factors. This pressure will then need to be adjusted for other factors, including topography (whether the building is in an urban area or windswept plain), height exposure category (based on building height), and importance factor (such as whether the building is a residence or hospital, for instance, and whether the building is in a hurricane region).

Snow load is the weight of the heaviest snow likely to occur in an area, calculated in pounds per square foot. Data is typically available from local building officials and code books.

Dead load is the additive weight of modules, and rail and racking components, calculated in pounds per square foot.

No Penetrations, No Problem

Metal Roof Innovations Ltd.'s S5! clamps don't require any roof penetrations, nor do they penetrate the seam of the roof, but clamp on by means of stainless steel setscrews. The clamps can be mounted from the side of the seam or from the top, and are available with various set-screw hole configurations and clamp profiles to suit variations in standing seams. Depending on the thickness of the metal, tightening specs vary for the setscrews: 115 inch-pounds (for 24-gauge metals) or 150 inch-pounds (for 22-gauge steel). Some S5! installations don't need rail, as the module frames are supported by the top platform of the S5! clamps, and mid- and/or end-clips are bolted directly to the clamp. Other installations use the S5! clamps to mount standard rails.

Courtesy www.s-5.com

S5! clamps are made for various standing-seam metal roofing, and can be used to mount rails or PV modules directly, as shown.

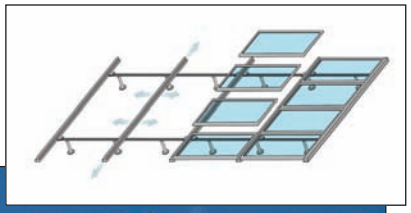
Another facet of rail span is the cantilever or rail overhang—the distance between the rail end and the first support. Manufacturer's instructions will vary: For example, Unirac recommends no more than 25% of module width as an acceptable overhang. DP&W's Power Rail allows an overhang of 32 inches for 125 mph wind load and 36 inches for 90 mph wind load. Of course, the spans and cantilever can be greater for heavy rail. Be sure to follow manufacturer's recommendations.

Parts & Pieces: Clips & Bolts

Clips secure the modules to the rail. Two types of clips are used in top-down mounting: **mid-clips**, which fit between modules, and **end-clips,** for the outside edge of the end modules. Clips are either aluminum or stainless steel, and may be powder-coated or anodized. Because modules come in a variety of thicknesses, the clip height must match the module frame height.

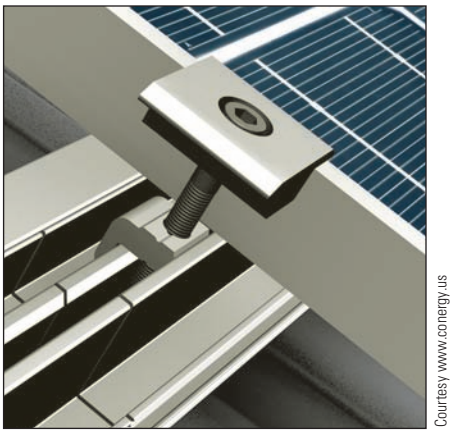
Clips are attached to rails with stainless steel bolts and nuts. There are a few basic styles, some with bolt heads that are secured (captive) within the rail. One, such as DP&W offers, uses an oval head bolt that must be slid into position from one end of the rail. (Watch out for rail splices, which can stop your bolt!) Another, such as used with Unirac's SolarMount, uses a T-head bolt, which can be placed in the rail at the appropriate spot, and then twisted to grip the inside of the rail. Care must be taken to make sure it engages properly. There are other approaches as well, such as Conergy's mounting system, which uses specialized nuts ("Quickstones") that can be slid down the channel and into position.

A few systems (such as SunEarth's CompRail and Unirac's SunFrame) forego mid- and end-clips. Instead, two rows of modules share a single, central rail between them. The modules sit on a shelf on either side of the rail, then are secured with a cap that bolts into the rail.



SunEarth's CompRail uses full-length channels instead of clips.

Courtesy www.sunearthinc.com (2)



Though styles vary, almost all top-down systems feature stainless-steel captured bolts or nuts, and module clips.

Courtesy www.conergy.us

Beyond Composition Roofs

PV mounts for tile or wood shakes are available from Quick Mount PV and Professional Solar Products. Quick Mount PV's mounts for curved or flat tile replace the tile itself, integrating the tile-shaped flashing and aluminum standoff into one bolt-together unit. The mount is attached to the decking with four $^1/_4$-inch-diameter lag screws. Professional Solar Products's Tile Trac takes a different approach by drilling, bolting, and sealing through the crown of the existing tile to the decking. The Tile Trac system lag-screws a metal track into the rafter, with a long bolt or standoff running up and through the crown of the sealed tile to hold the rail.

For installations on new seamless metal roofs, flashed standoffs can be used. However, retrofitting standoffs onto an existing roof is more challenging. On these roofs, securing a lag screw for an L-foot into a rafter can be difficult or impossible, as a raised metal V often lands over the rafter line and should not be squashed down by a mount. There are two possible solutions: adding spacers or sisters between the rafters to screw into or using a mount, such as DP&W's Easy Feet, screwed into the existing sheathing. Spacers are boards in an attic nailed between and perpendicular to two rafters, and held tightly against the roof decking's underside to provide a secure attachment point from above the roof. A sistered board is nailed against a rafter to extend the rafter's width.

The rare metal shingle roof or raised profile (shingle-appearance) metal roof should be approached with caution. Regular flashing might work with some smaller metal shingles, but others are in large sheets that resist attempts at flashing. L-feet won't usually work with this type of metal roof either, as the profile will get crimped. The best solutions are to mount standoffs and flashing during initial roofing or, for a retrofit, to remove the metal and reinstall after standoffs are placed.

Other Considerations

Adjustable Array Angle. Using adjustable legs beneath the rail to optimize the tilt of a roof-mounted array is becoming less common, since the production gained is moderate (usually 1% to 5% for fixed-tilt arrays), and most homeowners

don't want to climb on the roof to make adjustments. Tilting an array can create a number of difficulties, including more complex wind loading, more hardware needed, more difficult installation, and a perceived lack of aesthetics. Using the National Renewable Energy Laboratory's PVWatts calculator (see Access) to model power production at different tilt angles can be a useful cost–benefit analysis tool (see "PV Performance at Different Pitches," below).

What is easily configurable in flush-mounted roof arrays on rails is the height of the modules above the roof. L-feet and standoffs can be purchased in varying heights. The taller the standoffs, the more airflow beneath the modules, which results in cooler modules and more power output. On the minus side, the farther an array is from the roof, the more it will stand out.

Grounding. Rail and modules must be grounded using UL- or ETL-listed equipment. Wiley Electronics' WEEB (washer, electrical equipment bond) and Unirac's grounding clips are listed to meet UL Standard 467. These clips lay in the rail between module corners, and are faster and less expensive to install than the old standby: the Ilsco lay-in lug. The Ilsco lug is made of tin-plated solid copper, with a stainless steel screw to hold the wire. It screws into the dedicated ground spot on the module frame, and requires a solid copper wire run from lug to lug. (For more on grounding, see *Code Corner* in *HP128* and *Independent Power Providers* in *HP121*.)

Courtesy www.quickmountpv.com

Quick Mount PV's Tile Mount is sized to replace an existing roof tile.

Pitched Roof Performance

Along with the growth in the solar industry have come many advances in PV installation methods. Manufacturers and engineers are trailblazing options that make installations more durable, dependable, and cost-effective. To uphold our part of the bargain as end users, we must install components correctly, and use them only for the jobs they are meant to do. Being part of a vibrant, burgeoning industry means taking responsibility to continually learn on the job and being flexible enough to adapt to improvements in methods when they come our way.

PV Performance at Different Pitches

How much impact does tilt have on a fixed grid-tied array? In Raleigh, North Carolina, on a roof with slope of 25° (a roof pitch between 5:12 and 6:12), a flush-mounted 3 kW array will produce about 3,916 kWh per year. The same size array tilted close to latitude (in this case, 35.9°) would produce about 3,937 kWh per year—a production difference of 21 kWh. Of course, if the array tilt was adjusted throughout the year, the production numbers would increase.

For example, a monthly adjustment to each month's optimum angle would result in 4,139 kWh per year. A quarterly adjustment to optimum tilt would result in 4,127 kWh per year, a 4.8% increase over the fixed-tilt array. Generally, only off-gridders who need to squeeze every winter watt-hour out of their systems are willing to go to these lengths, which can add up to 10% to their system's winter production.

	Array Tilt = 35.9° (Latitude)			Array Tilt = 25.0° (Roof Pitch)		
Month	Avg. Solar Radiation (kWh/m² /Day)	AC Energy (kWh)	Value ($)	Avg. Solar Radiation (kWh/m² /Day)	AC Energy (kWh)	Value ($)
January	3.73	265	$22.53	3.43	243	$20.66
February	4.66	298	25.33	4.40	281	23.89
March	5.38	368	31.28	5.28	362	30.77
April	5.77	372	31.62	5.89	381	32.38
May	5.55	357	30.34	5.83	376	31.96
June	5.77	354	30.09	6.15	378	32.13
July	5.54	352	29.92	5.86	373	31.71
August	5.58	353	30.00	5.77	365	31.03
September	5.35	333	28.30	5.34	333	28.30
October	5.33	354	30.09	5.07	338	28.73
November	4.34	287	24.39	4.01	265	22.53
December	3.51	245	20.82	3.19	222	18.87
Annual Total	5.04	3,937	$334.64	5.02	3,916	$332.86

Source: PVWatts for Raleigh, NC, 3 kW array (www.nrel.gov/rredc/pvwatts/)

Pitched Roof Mount Checklist

- ☐ Inspect roof and, if necessary, replace it prior to installation
- ☐ Use stainless steel and/or aluminum hardware (rails, supports, clips, etc.)
- ☐ Use flashing and/or appropriate sealing for every roof penetration
- ☐ If necessary, reinforce roof with spacers or sistered rafters
- ☐ Use stainless steel lag screws with sufficient rafter penetration for loading specifications
- ☐ Make sure rail supports (standoffs, L-feet, or S5! clamps) are appropriately spaced for all loading considerations
- ☐ Choose rail and module clip color to match module frames
- ☐ Make sure rail and modules are properly grounded (Wiley WEEB, Unirac UGC-1, or Ilsco lay-in)
- ☐ Make sure that all mid-clips and end-clips are tight and square, and the appropriate height for the module frame

Access

Rebekah Hren (rebekah@honeyelectricsolar.com) is a licensed electrician in North Carolina. She designs and installs PV systems with Honey Electric Solar Inc. teaches PV design and installation courses for Solar Energy International, and is coauthor of *The Carbon-Free Home: 36 Remodeling Projects to Help Kick the Fossil-Fuel Habit* (Chelsea Green, 2008).

Roof-Mounting System Manufacturers:

Conergy • www.conergy.us
Direct Power & Water • www.directpower.com
IronRidge • www.ironridge.com
Metal Roof Innovations Ltd. • www.s-5.com • Standing-seam roofs only
Professional Solar Products • www.prosolar.com
Quick Mount PV • www.quickmountpv.com • Flashed mounting anchors only
Shuco • www.schuco-usa.com
Solar Racks • www.solar-racks.com
SunEarth Inc. • www.sunearthinc.com • Compression-style rail only
Thompson Technology Industries • www.thompsontec.com
Unirac • www.unirac.com

Module-Specific Mounting Systems:

Sharp • www.sharpsolaritson.com
SunPower Corp. • www.sunpowercorp.com

Other Resources:

American Wood Council • www.awc.org • Wood-strength tables
PVWatts • www.nrel.gov/rredc/pvwatts/