The Rafter Square

Laying out a roof with this basic tool and a new generation of accessories

by Jud Peake

Few carpenters would neglect to include a steel square when packing their toolboxes for a job. Yet, when pressed, quite a few good builders will abashedly admit that they generally use the square just for scribing a cut-off line on stock too large for their combination square. The steel square can serve a variety of functions, from stairbuilding to making simple checks for right angles, but it's especially useful for laying out rafters and other roof-frame members. With a little instruction, anyone can lay out cuts for common rafters, valleys, hips, jacks and gable ends. This doesn't require a knowledge of trigonometry, just a simple understanding of the geometry involved.

The rafter square—This versatile tool consists of two parts—the body, or blade, and the tongue (drawing, facing page). These two meet at the heel. The body is 24 in. long and 2 in. wide, and usually represents the level line, or run, in laying out rafters. Plumb, or rise, is represented by the tongue, which is 16 in. long and 1½ in. wide. The face and back of the square are usually imprinted with edge scales and math tables. The latter distinguish a rafter square from a framing square.

Squares are made of steel, usually painted black, or aluminum. Aluminum squares are typically more expensive, but lighter and less liable to bring second-degree burns to your palms on hot summer days. The best squares have their numbers stamped deeply into the metal rather than painted on. Most of them come with instruction books that are a handy toolbox reference.

The use of the rafter square is based on the geometry of right triangles. All right triangles have a 90° angle, which can be used to describe the intersection of a plumb and level line—the intersection of the tongue and the body of a framing square. Right triangles also share another quality: when the rise and run of a right triangle are increased proportionally, the hypotenuse lengthens proportionally, too, although its slope or pitch remains constant. A stair with a rise of 6$^{11}/_{16}$ in. and a 10-in. tread has the same pitch as an 8-in-12 roof because the proportion between rise and run for each of them is the same. Since rafters are nothing more than the sloping side of the triangle, the rafter square acts as an infinitely expanding intersection of plumb and level, allowing you to use the rafter stock as the hypotenuse. More information on how the proportional nature of the rafter square can come in handy will be presented later.

A useful quality of right triangles, discovered by Pythagoras, is that the sum of the square of the sides equals the square of the hypotenuse ($a^2 + b^2 = c^2$). To the roof framer this means that if the rise and run are known, then the length of the rafter can be easily calculated. (The glossary on p. 63 defines common roofing terms.)

Scales and tables—On the face side of the square, the side with the maker's stamp on it, inches are broken into eighths and sixteenths. On the back, the outside edge of both the body and the tongue shows twelfths of an inch. This is useful for scaling inches to feet. The inside edge of the tongue is laid out in tenths, and the face of the heel usually has a hundredths scale. By holding your tape measure against these last two scales, you can easily convert back and forth from decimal inches to sixteenths.

Different manufacturers of squares give slightly different information in the tables on the face of the square. Usually, the first line gives in decimal inches the lengths of common rafters per foot of run; the second line does the same for regular hip and valley rafters. These figures are listed in the tables by their unit rise. Units of run are always 12 in. The inch markings on the outside face of the body double as unit-rise headings under which unit rafter lengths can be found. None of the tables that give rafter lengths makes allowance for the thickness of the framing members that they butt. This allowance, referred to as reduction or shortening, is a factor I'll talk about later.

The next two lines in the tables give the actual difference in the lengths of jack rafters in inches and fractions. The first of these lines gives the common difference for jacks on 16-in. centers, and the second line for those on 24-in. centers. Most squares then show two lines of side cuts for hips, valleys and their jacks. Some squares have a seventh line, which gives the angle at which sheathing should be cut where it meets hips and valleys.

Unit measurement—The square can be used in two ways to determine the length of rafters. The first method is unit measurement. As shown in the drawing, top of facing page, this technique uses the proportional qualities of the right triangle, and expresses rise and run as a ratio. For common rafters, unit run is always 12 in., and the unit rise is the rise per foot of run. The pitch triangle seen in most plans is a representation of unit measurement; so are the rafter tables on the square. For example, if you need the unit length of a common rafter on a 4-in-12 roof, look in the first line of the tables, length of common rafters per foot of run, under the 4-in. mark, the unit rise, on the outside of the body. The number given is 12 65. This means that for every foot of run with a rise of 4 in., the rafter will have to be 12.65 in. long. Check this figure by measuring diagonally with your tape between the 4 and the 12 on the square. You should get slightly more than 12⅝ in., or 12.65 in. The drawing, right, shows how holding the rise and run of the square determines the unit length of the hypotenuse, which, for the purposes of framing a roof, is the edge of a rafter.

Once you have found the unit length of the rafter in the tables for a given rise and run, multiply this figure by the actual run (usually half the width of the building) to get the theoretical, or unadjusted, length. This measurement begins with a plumb cut at the top of the rafter and ends with the plumb cut of the bird's mouth, the 90° cutout where the rafter sits on the top plate of the exterior wall. You will have to add the length of the rafter tail, and subtract half the thickness of the ridgeboard.

Stepping off—The second method for finding an unadjusted rafter length is called stepping off. To step off, lay the square on the rafter with the tongue and body reading the pitch, and repeat this procedure as many times as there are feet in the total run (drawing, bottom of facing page). For example, if the actual run of a rafter on a 4-in-12 roof were 13 ft., you would have to mark the rafter 13 consecutive times to lay out the length of the body of the rafter. You would do this by setting the square on the rafter stock, crown side away from you, so that the heel of the square is toward you and the tongue is on your right. Align the 4-in. mark on the outside of the tongue, representing the rise, and the 12-in. mark on the body, representing the run, on the edge of the rafter. Now scribe a line on the outside of the body at the edge of the rafter, and slide the square along until the outside of the tongue, held on the edge of the rafter at the 4-in. mark, lines up with the scribed line, and scribe again.

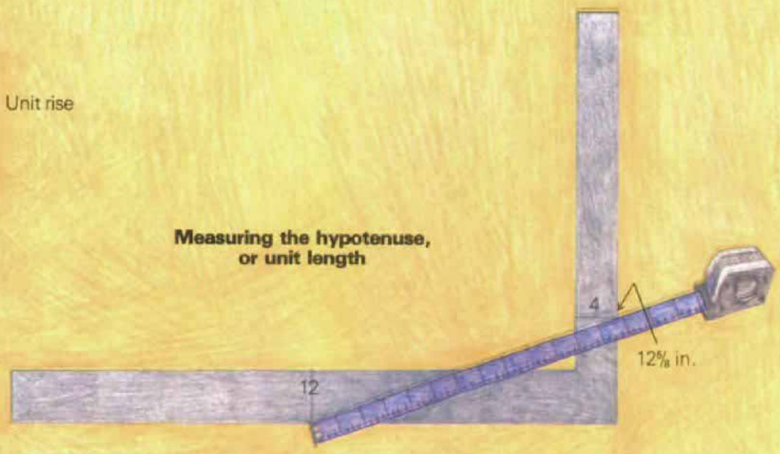
Move the square and scribe in the same attitude twelve times from the original position. The plumb cut of the bird's mouth will intersect

Illustrations: Frances Boynton

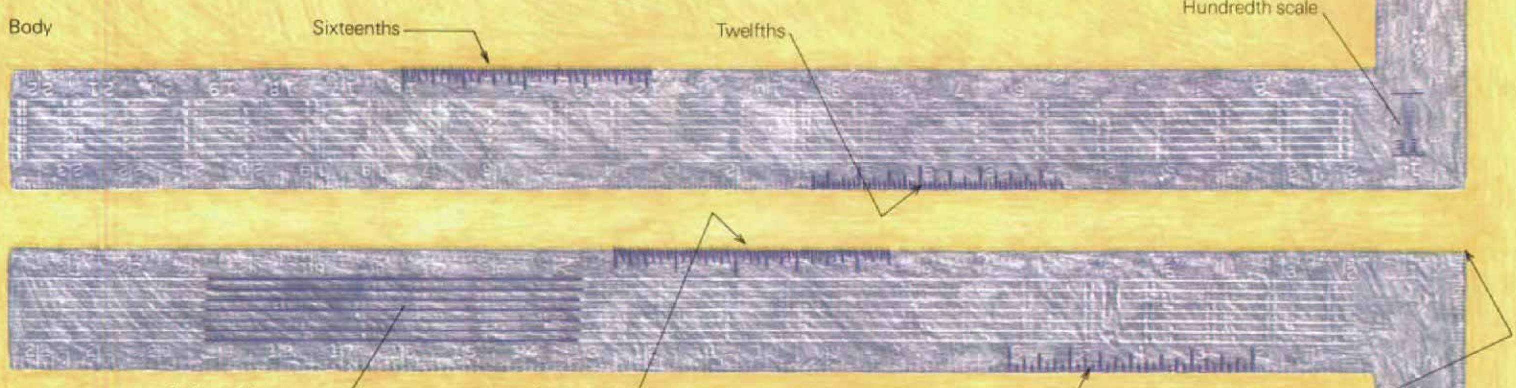
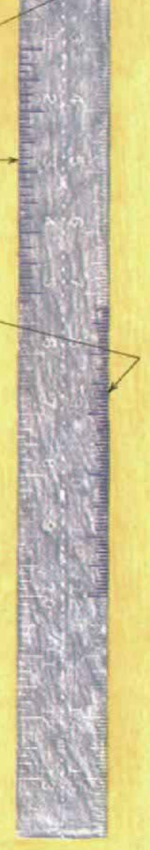
Unit measurement

To figure rafter length by this method, first find the unit length (hypotenuse) in the tables for the given rise and run. Then multiply this number by the total run. Unit length × total run = unadjusted rafter length.

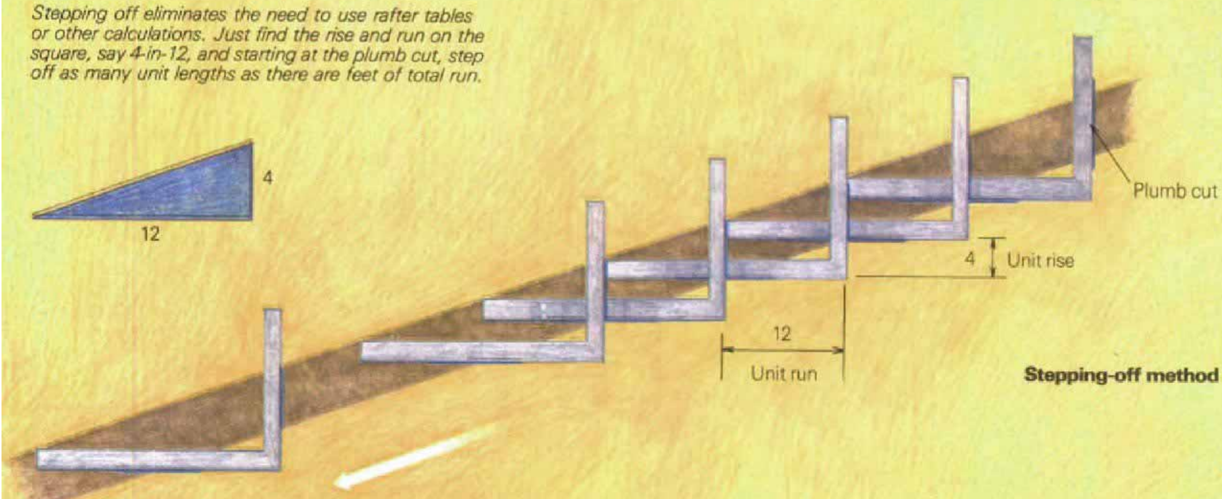
Measuring the hypotenuse, or unit length



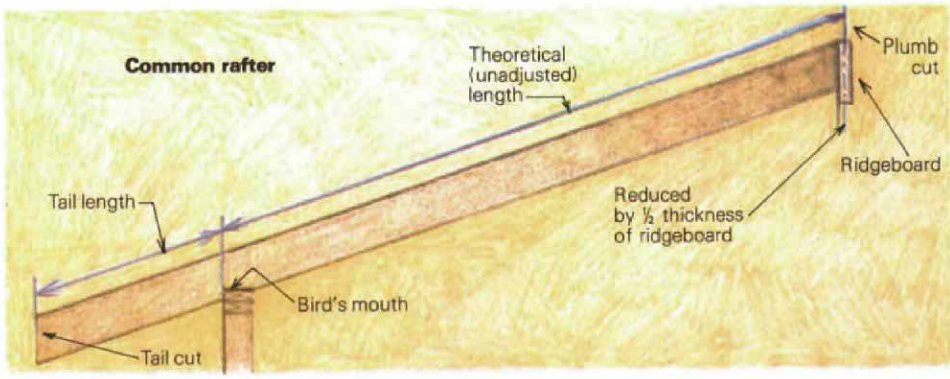
The rafter square

Stepping off eliminates the need to use rafter tables or other calculations. Just find the rise and run on the square, say 4-in-12, and starting at the plumb cut, step off as many unit lengths as there are feet of total run.



Stepping-off method

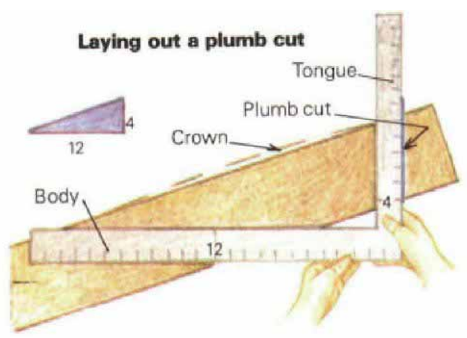


the edge of the rafter at the thirteenth scribed line. This is the unadjusted, or theoretical, length of the rafter. Stepping off won't tell you its length in inches and feet. You'll have to measure it later.

When the run is not in whole feet, the remaining inches are measured along the level line of the body. This mark is brought back to the edge of the rafter by lining up the tongue with this mark and scribing a plumb line, while still holding the rise and run on the square along the edge of the material. The stepping-off method also requires reduction. As with unit measurement, you'll have to subtract half the thickness of the ridge, and add the length of any overhang. Stepping off must be done carefully because of the danger of accumulated error. It also doesn't give you the precise length of rafter stock at the outset.

Laying out a common rafter—The object of all of these tedious calculations is to cut a rafter pattern, which can then be used to lay out the remainder of the roof without any further headscratching. If you think of a rafter pattern as the only obstacle between you and the goal of calculating an entire roof plane, it will lighten the burden a little.

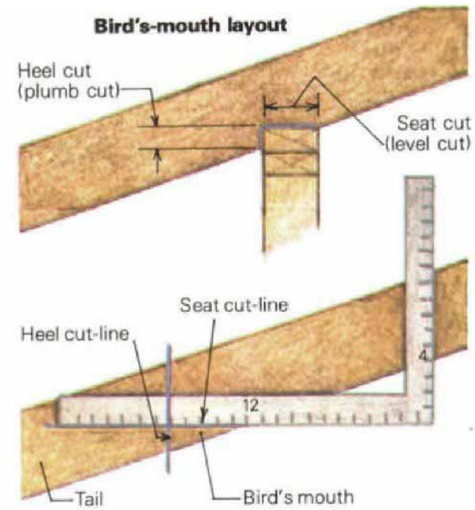
The first task is to lay out the plumb (top) cut of the rafter, as shown above. This cut will rest against the ridgeboard when installed. Lay it out by setting the square on the rafter stock just as you would for stepping off. Align the inch



marks that correspond with rise and run on the outside of the tongue and body on the side of the stock nearest you (drawing, above). Remember to use the tongue for the unit rise, and the body for the unit run. Set your pencil against the outside of the tongue and draw the plumb line. This line represents the very center of the span, as if the rafters from each side were butting together without a ridgeboard. Because this line doesn't take the ridgeboard into account, you must measure along the body of the square (a level line) half the thickness of the ridgeboard and draw a new line parallel to the original plumb line for the actual cut. For a 2x ridgeboard, you would measure ¾ in. perpendicular to the plumb line—not along the edge of the rafter—to get the shortening line.

Determine the unadjusted length of the rafter either by stepping off or by unit measurement. Measure from the plumb line (not the reduced cut-line) to the plumb line of the bird's mouth, known as the heel cut. This is the part of the bird's mouth that hooks over the outside of the wall (drawing, below).

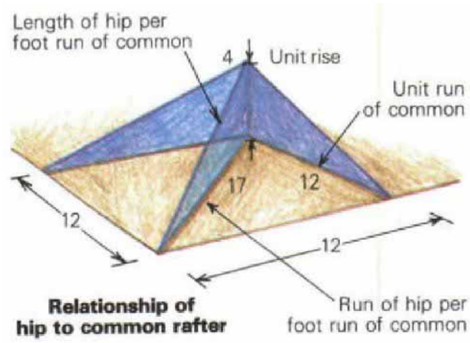
To lay out the bird's mouth, make a mark 1½ in. up from the bottom of the heel cut. Begin measuring from the rafter edge nearest



you. Now slide the square, still holding it at the correct rise and run, along the rafter toward the top plumb cut. When the body of the square intersects the 1½-in. mark on the heel cut, scribe along the body from the 1½-in. mark across to the edge of the rafter. This is a level mark; the heel (plumb) cut and the seat (level) cut make the bird's mouth. The 1½-in. depth of the bird's mouth is arbitrary, but it shouldn't be cut so deep that it weakens the rafter tails. The depth of this cut doesn't affect the roof's slope, but does affect the absolute height of the ridge. If you deepen the seat cut by 1 in. the ridge will be lowered by 1 in. This usually doesn't matter unless you already have high walls, purlins or a ridge beam in place.

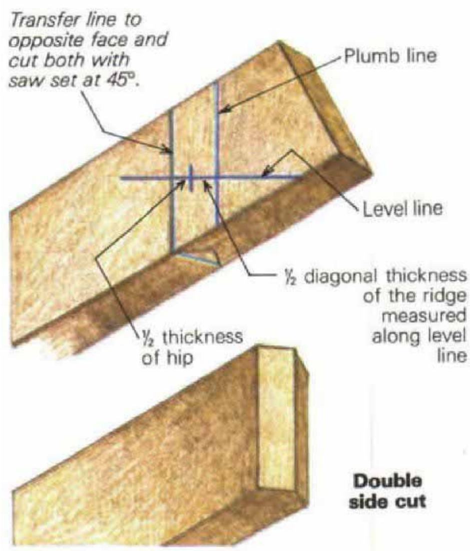
You can now add the length of the tail, or overhang. Beginning with the heel cut of the bird's mouth, measure down along the rafter (or step it off) and mark the tail cut. Standard tails can be cut square (perpendicular to the line of the rafter), cut level or cut plumb.

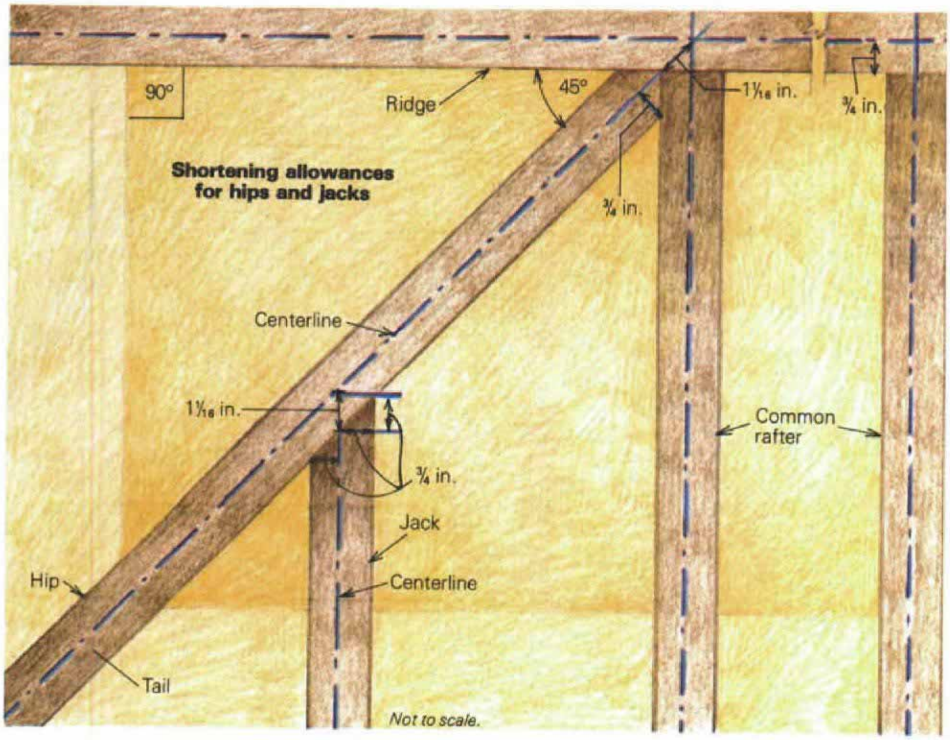
Laying out a regular hip or valley—Hips and valleys are different from common rafters because they take a diagonal path across the building. The run of regular hips and valleys angles across the plan at 45°, completing an isosceles right triangle with the run of the last common rafter and the top plate. This means that the run is longer than that of the common rafter, although the rise remains the same. The drawing below shows the relationship of the run of common rafters and hips. By applying the Pythagorean theorem, or by measuring diagonally between the 12-in. marks on the square, the unit run of the hip figures out to be about 17 in. for every 12 in. of common run. This means that each time you would use the

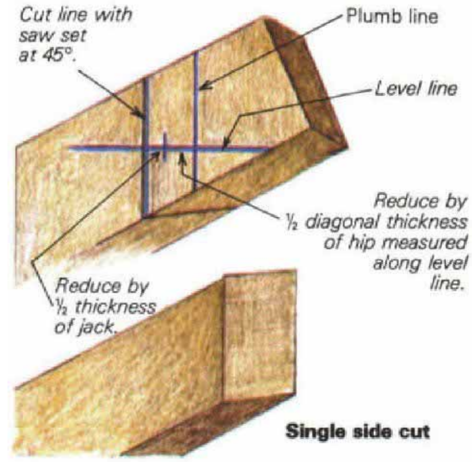


12-in. mark on the body of your square to find the cuts and lengths of common rafters, you use the 17-in. mark to work with hips and valleys. However, you still use the same rise figure and, in stepping off, take the same number of steps as you would with a common.

The adjustments for hip and valley rafters are more complicated than they are for commons. Because a hip intersects both the ridge and the common rafter at the top, each side requires a vertical 45° bevel to form the plumb cut. This is known as a double cheek or double side cut. The drawing below shows the reductions that







are necessary for double side cuts. With the common rafters we deduct one-half the ridge thickness, measured level, on the side of the rafter. With a hip we have to deduct one-half the diagonal measure of the ridge thickness and again lay this out level on the side of the rafter. To move to the side of the rafter, you have to deduct another $\frac{3}{4}$ in. (for a 2x hip), again measured level, to account for the difference between the long point of the double bevel at the center of the hip and the short point on the side, as shown above.

These cuts can be made easily and accurately with a circular saw set at 45° because at any pitch, regular hips and valleys intersect common rafters at 45°. If you draw the correct double side cut on the top edge of the rafter, it won't appear as a 45° angle because the edge of the rafter is not a level line when installed. However, for a good fit using a circular saw on regular hips and valleys, the only mark you'll need is the plumb line.

In the tables, determine the lengths of regular hips and valleys the same way you find them for commons. Just make sure to look under the heading "length of hips and valley per foot of run." The bird's mouths are also similar except you have to use the 17-in. mark on the body for the level line, and the depth of the heel cut will be different. Hip and valley rafters are usually of wider stock than commons; so to make sure the tails are level, hip and valley bird's mouths have to be deeper, leaving the same amount of uncut rafter above them as you did on the commons. After adding length for the overhang you can lay out and cut the tail. If you are planning on a surrounding fascia, the tail cut has to be a double side cut.

The rafter tail is a good place to practice stepping off inches. For an example, assume that a 4-in-12 roof requires a 1-ft. $6\frac{1}{2}$in. tail. Step off the first foot of run as you did with the common, except with the hip, use 4 and 17. Draw a level line. Just as 17 (the diagonal measure of 12 and 12) gives you the first foot of run, the diagonal measure of $6\frac{1}{2}$ and $6\frac{1}{2}$ will give you the remainder of the run. Stretching a tape measure between these marks on the square gives a measurement of $9\frac{3}{16}$ in. Measure along the level line on the rafter tail $9\frac{3}{16}$ in., and the overhang will be correct.

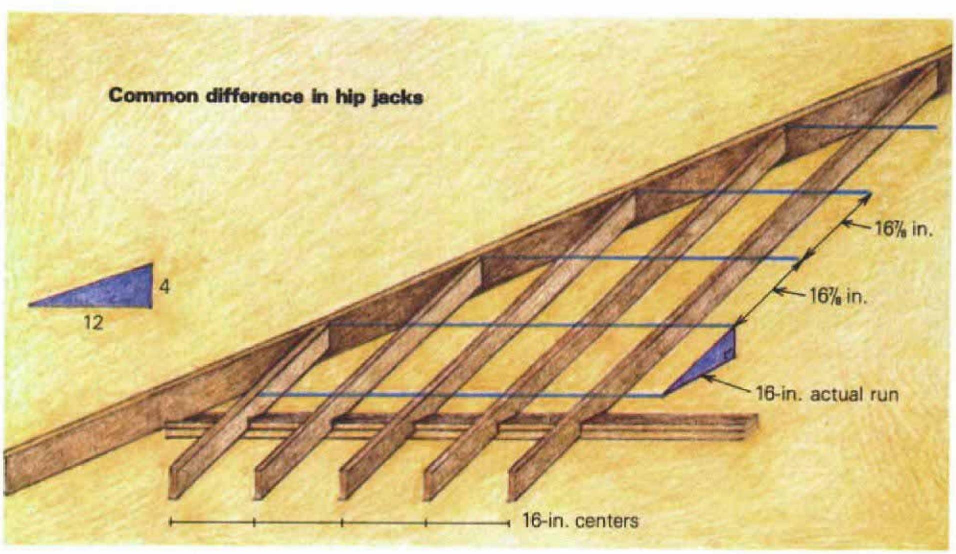
Laying out a jack—A jack rafter is a common rafter that intersects a hip or valley before it reaches the ridge or plate. The only way that it differs from a common is its length and the bevel of its plumb cut. This is a single side cut, and in 2x material I make it with a circular saw set at 45°.

Once you have established the plumb line on the jack rafter, make the hip or valley reduction (one-half the diagonal thickness) along a level line as shown in the illustration, above right. With a 2x hip or valley, this measures $1\frac{1}{16}$ in. To reach the short point of the side cut, make a further reduction along the level line for one-half the thickness of the jack itself. This measures $\frac{3}{4}$ in. The jack reduction is necessary because you are laying out the side cut on the side of the rafter, rather than on the centerline of the top edge.

As with hip or valley rafters, using a saw with a shoe that pivots allows you to cut any regular hip or valley jack correctly by following the reduced plumb line with the saw set at 45°.

Big beams require the angle of the side cut to be laid out on the top edge of the rafter because a circular saw won't handle the depth of cut. Use a rafter book or the rafter tables for the coordinates on the square. If two figures appear under each rise, find the first figure on the body of the square, and set it on the edge of the rafter stock. Next find the second number on the tongue and place it on the same edge of the rafter. Check instructions for your square or book for which leg of the square to scribe against. If there is only one figure listed, then use it on the body, use 12 on the tongue, and make your mark along the tongue.

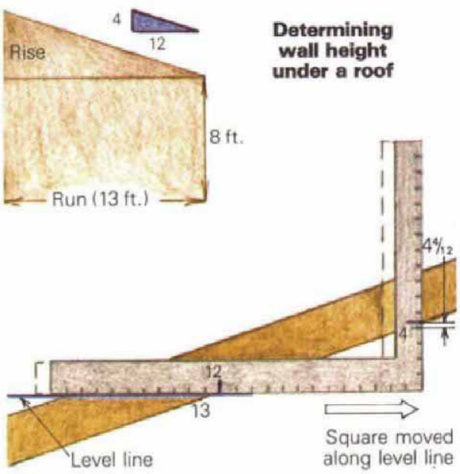
Once you have determined the length of the first jack, the rest are merely multiples. This is called the common difference, and can be seen in the framing diagram (drawing, below). Find



the appropriate table on your square (16-in. spacing or 24-in. spacing) and look up the pitch of your roof. The figure you see listed is the length of the first jack, excluding the length of the tail, and also the increase in the length of each subsequent jack.

Notice that the relationship that regular hips and valleys have with common rafters and plates is the same one that exists between jacks and their hip or valley rafter. This is an isosceles right triangle in plan, and means that the actual run of the first jack will be the same as its spacing. If the first jack is 16 in. away from the seat cut of the hip, it will have an actual run of 16 in.; if it's 24 in. along the plate, the actual run will be 24 in. This is an actual run, not a unit run.

Solving proportion problems—With a rafter square, you can easily determine the wall height under a shed roof. For example, if a 4-in-12 roof is supported by an 8-ft. wall on the low side, then what is the height of the supporting wall 13 ft. away on the high side? Use the twelfths scale. Lay the 4-in. mark of the tongue and the 12-in. mark of the body on a straightedge, as shown below. Draw a line against the



body representing a level line. Then move the square along this line until 13, representing the actual run, lines up with the edge of the material. The answer, **4 4/12**, reads on the tongue of the square where it first comes in contact with the wood. This figure (4 ft. 4 in., when multiplied from unit dimensions to actual dimensions) represents the rise of the wall above the established 8-ft. mark. The height of the other wall is then 12 ft. 4 in.

Determining the length of gable-end studs is another proportion problem, and can be solved in the same way as determining wall heights under a roof. Like jack rafters, the length of the first gable stud is equal to the difference in the lengths of the other studs. The length of the first stud can be determined by the proportional method, with a calculator, or by measurement. To use the square, follow the directions for finding wall heights. In this case the spacing of your studs, typically 16 in. or 24 in., is the actual run. □

Jud Peake is a carpenter and contractor in Oakland Calif.

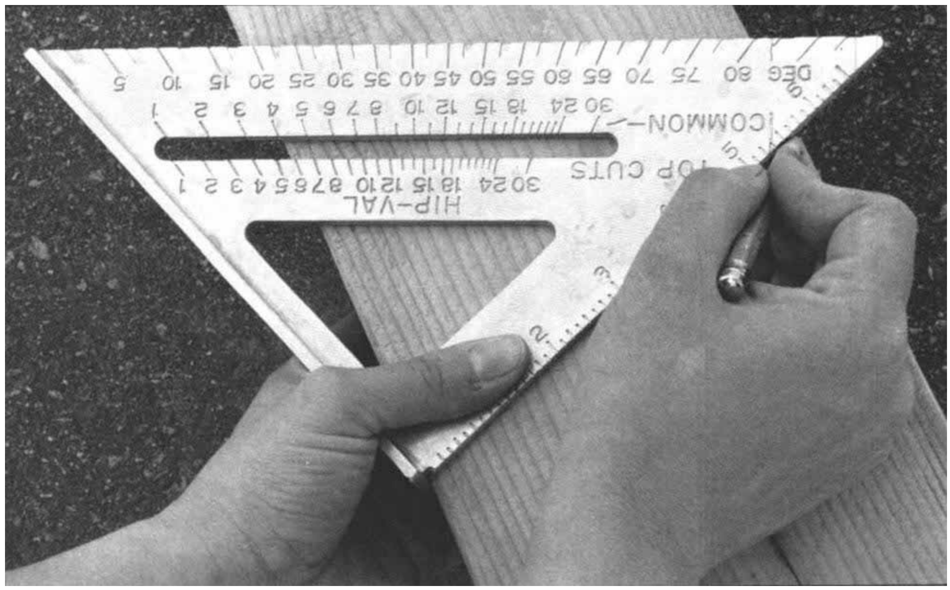
Other tools that help

The rafter square is still king. Despite challenges from quite a number of patented devices, few roofs get framed without the use of a rafter square. It remains the best choice because of its accuracy, durability and variety of necessary data. Still, there are several other useful tools that can simplify the job. Most of these are used in conjunction with a rafter square.

Rafter books. These guides give listings of rafter lengths for common, hip, valley and jack rafters referenced by span, and are typically organized by pitch from ½-in-12 to 24-in-12. The pitch angle is given, as well as the corresponding layout numbers on the steel square for all cuts and bevels. Although quick and accurate, these guides will leave you in the dark if you're working on an irregular or polygonal roof. One widely used rafter book is *The Full Length Roof Framer* (A.F. Riechers, Box 405, Palo Alto, Calif. 94302). It lists 48 different pitches and includes the cuts and bevels for gable and cornice moldings. It is pocket size, bound, and sells for about $6.

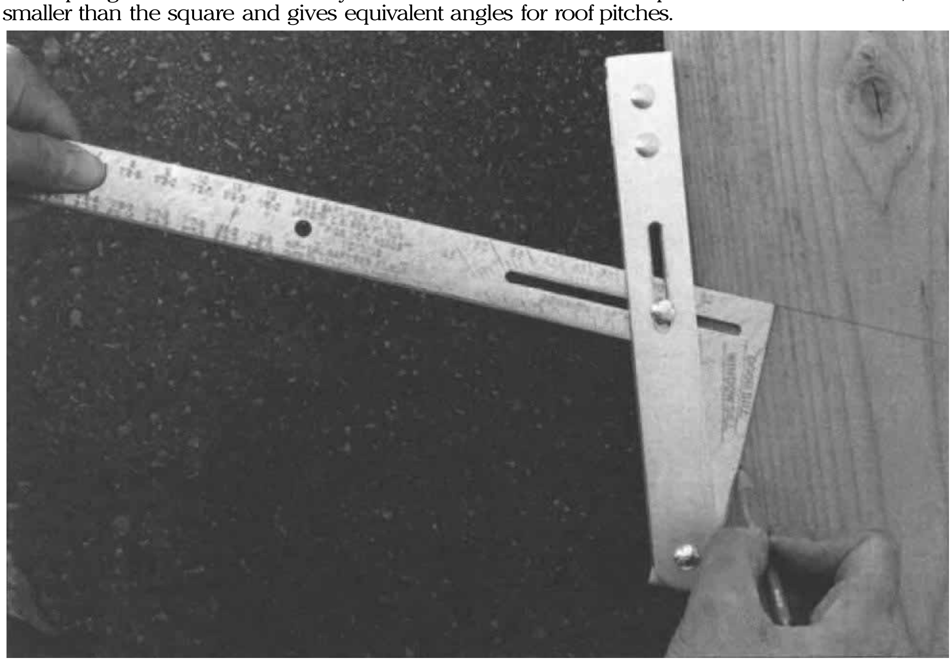
Squangle (Mayes Bros. Tool Mfg. Co., Box 1018, Johnson City, Tenn. 37601). This device is small enough to fit into your nail bag and can be used with one hand. It has some limited rafter tables on its tongue, although it's best used with a rafter book or the rafter tables on a square. Unlike a square, the Squangle can convert a unit rise and run into degrees. But once the tool is dropped from a roof, it may not work accurately. It sells for about $9.

Speed Square (The Swanson Tool Co., Box 434, Oak Lawn, Ill., 60453). This tool is also small enough to be carried on your tool belt. It comes with an instruction book and extensive, full-length rafter tables. A solid



The Speed Square is an aluminum casting small enough to fit into nailbags. Angles in degrees are given on the face of the tool, and it comes with an instruction book and rafter tables.

The Squangle is one of the relatively new tools based on the rafter square. It has limited tables, but is smaller than the square and gives equivalent angles for roof pitches.



aluminum casting, the Speed Square won't bend or break, but because of its sharp points, you wouldn't want it hanging from your belt if you lost your balance and took a fall. Angles in degrees are also given on the face. It takes two hands to use it, and costs $8.35.

Two other squares that are nearly identical to the Speed Square are the Carpenter Handy Square for $7.49 (Macklanburg-Duncan Co., Box 25188, Oklahoma City, Okla. 73125), and the Angle Square at $7.67 (Johnson Level and *Tool* Mfg. Co., 2072 North Commerce St., Milwaukee, Wis. 53212).

Stair-gauge fixtures. These really help if you use the framing square. They are purchased in pairs, usually made of milled brass, and cost about $8. You fix them to the square by tightening a setscrew on each one. Attach these stops at the points on the square that define the pitch you are using (such as 4 and 12), and you can repeatedly set the square accurately on the rafter stock without having to read the numbers each time. If you are careful when you attach them to the square, they will improve your accuracy greatly, particularly if you are using the stepping-off method. As the name says, they are also very helpful in laying out stair stringers.

Layout tee. This is a roof-framing aid that you make on the job site. Tees are patterns, or templates, of the tail and bird's mouth, or the ridge cut of a rafter that is used to transfer the layout onto rafter stock. They are made of a short length of rafter with a 1x4 nailed to the edge as a fence to reference the tee to the rafter being marked.

Pitch board. This is simply a piece of plywood cut in the shape of a right triangle defined by the rise and run of the roof to be framed. It is used for stepping off rafters in the same manner as a framing square. It can also help mark cuts for gable-end studs and bird's mouths.

Calculator. One of the items you are likely to find in the toolbox of a canny roof framer these days is an extra battery. With the advent of the $10 pocket calculator, the framing square has a new companion. Because roof-framing calculations are based largely on the Pythagorean theorem, any calculator with a square-root key will do. Using a calculator is more accurate and less tedious than reading the tables on a framing square because you are able to deal directly with the equation and the variables involved.

It's important to decide what units you are using—inches, feet or decimal inches/feet—and remain consistent throughout the calculation. I find it easiest to enter measurements and take the answers in inches to save conversion steps, which are a common source of error. I use my calculator to determine pitch angles, rafter lengths, common difference in jacks, gable-end stud heights and other proportional problems, as explained below. —*Jud Peake*

Using a pocket calculator

Proportion. This is a useful calculation in determining wall heights as in the example given (drawing facing page) using the framing square. This is a matter of converting a unit rise and run to an actual rise given an actual run. My calculator uses the algebraic operating system, so your keystrokes may be different but the logic goes like this:

$$\text{If } \frac{\text{unit rise}}{\text{unit run}} = \frac{\text{actual rise}}{\text{actual run}},$$

$$\text{then actual rise} = \frac{\text{unit rise}}{\text{unit run}} \times \text{actual run}$$

To find the actual rise of a 4-in-12 roof over a 13-ft run:

$$\frac{4}{12} = \frac{\text{actual rise}}{13\text{ ft}}, \text{ and actual rise} = \frac{4}{12} \times 13\text{ ft}$$

This answer is in feet. On the calculator the keystrokes are:

rise [÷] run [×] actual run (ft.) [=] actual rise (ft.)

Difference in the lengths of gable studs. The unadjusted length of the first gable stud is also the difference in the lengths of the gable studs. This is just another proportion problem:

$$\frac{\text{difference in length of studs}}{\text{spacing of stud centers}} = \frac{\text{rise}}{\text{run}}$$

The keystrokes are:

rise [÷] run [×] spacing (in.) [=] difference in length (in.)

The formula is simplified for common stud centers. For studs 24 in. o.c.,

$$\text{difference in length of studs} = 2 \times \text{unit rise}$$

For 16-in. centers,

$$\text{difference in length of studs} = 1.333 \times \text{unit rise}$$

Lengths of common rafters. These are given in a general way by the Pythagorean theorem:

$$\text{length of common} = \sqrt{\text{rise}^2 + \text{run}^2}$$

However, you need to be clear about which units of measure you are using. If you use the actual rise and run in feet, the answer will be the actual length of the common, expressed in feet. If you use the unit rise and run, the answer will be the unit length of the rafter. This is a length in inches for every 12 inches of run. The simplest formula uses the unit rise and run:

$$\text{length of common rafter (in.)} = \sqrt{\text{rise}^2 + 144} \times \text{actual run (ft.)}$$

The keystrokes are:

rise [x²] [+] 144 [=] [√] [×] actual run (ft.) [=] length of common (in.)

This answer doesn't account for the thickness of the ridge. There is less chance of error if you make this allowance during the layout of the rafter.

Lengths of regular hips and valleys. Once you determine the run, you can find the length of a hip or valley. Because the run of a regular hip or valley is the diagonal of a square whose sides are runs of the common rafters, the run is the square root of twice the square of the common run:

$$\text{Run of hip} = \sqrt{2 \times \text{run of common}^2} \text{ and}$$

$$\text{length of hip} = \sqrt{\text{run of hip}^2 + \text{rise}^2}$$

$$= \sqrt{2 \times \text{run of common}^2 + \text{rise}^2}$$

Or you can use unit rise, unit run, and the run of the common rafter:

$$\text{hip length} = \sqrt{2\times \text{unit run}^2 + \text{unit rise}^2} \times \text{actual run of common}$$

Since the unit run is always 12, this becomes:

$$\text{length of hip} = \sqrt{288 + \text{unit rise}^2} \times \text{actual run of common}$$

The square root of 288 is $16^{31}/_{32}$, or almost 17, the same 17 that you use on the framing square for the run. The keystrokes for finding a regular hip or valley length with a calculator are:

rise [x²] [+] 288 [=] [√] [×] actual run (ft.) [=] unadjusted hip length (in.)

Again, it's useful to make the ridge reduction on the actual rafter. This time, though, the ridge thickness is a diagonal measure:

$$\frac{\text{ridge thickness in inches}}{2} \times \sqrt{2} = \text{diagonal of } \tfrac{1}{2} \text{ ridge thickness}$$

In an isosceles right triangle, the square root of 2 multiplied by the side equals the hypotenuse.

Difference in the lengths of hip and valley jacks. The first jack has an actual run equal to the spacing of the jacks. The length of this jack, unadjusted, will be equal to the difference in the lengths of the jacks:

$$\text{difference in length of jacks (in.)} = \sqrt{\left(\frac{\text{rise}}{\text{run}} \times \text{spacing}\right)^2 + \text{spacing}^2}$$

For jacks 16 in. o.c.:

$$\text{difference} = \sqrt{(\text{rise} \times 1.333)^2 + 16^2}$$

For jacks 24 in. o.c.:

$$\text{difference} = \sqrt{(\text{rise} \times 2)^2 + 24^2}$$

To adjust for thickness on the long point side, deduct the following:

$$\text{thickness of hip} \times \sqrt{2} - \frac{\text{thickness of jack}}{2}$$

Bevels and angles. Plumb, level and bevel cuts can be converted to degrees if your calculator has trig functions. The keystrokes are:

for angle A, rise [÷] run [=] [TAN⁻¹]
for angle B, run [÷] rise [=] [TAN⁻¹]