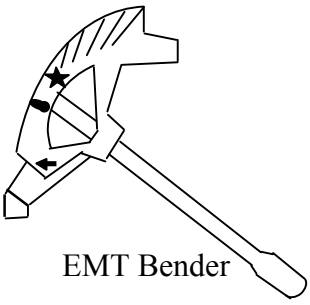
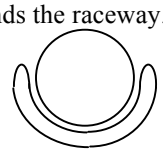
BENDING CONDUIT / TUBING USING HAND BENDERS



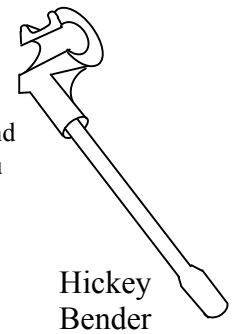
EMT Bender

The ability to bend conduit and tubing is a requirement for all electricians. This document will step the beginner through the five main bends that are used by electricians. The electrician must use caution when bending raceways to make sure that it maintains it's round shape throughout the bent portion of the raceway, in order to help prevent "jamming" when pulling the wires into it.(See NEC CH9 Table1 FPN2).

EMT is very easy to bend by hand. It is a thinwall galvanized metal tubing that is used mostly for interior construction. EMT benders are sweep benders or one-sweep, one piece benders. They have a curved track that the raceway follows as the electrician bends the raceway.



The raceway fits into a curved track or slot in the EMT bender which keeps the raceway from spreading out as it is bent. This keeps the raceway round in the bend and also keeps it from kinking.



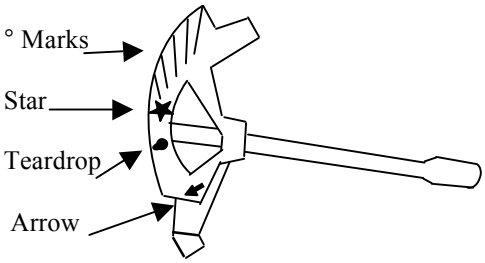
Hickey Bender

Rigid and IMC conduit are the hardest raceways to bend because they have a much thicker and harder wall. ½" and ¾" rigid or IMC can be bent by hand using a hickey (or segment bender). A hickey bender is used to bend conduit in small bends with short segments, for instance, in order to bend a 90° bend with this type of bender you would bend 9 each 10° bends with short gaps in between them. Another way to bend rigid or IMC conduit by hand is to use a full sweep bender for rigid or use an EMT bender. To use an EMT bender, the electrician would use a ¾" EMT bender for ½" rigid or IMC and for ¾" rigid or IMC, he would use a 1" EMT bender. The hickey bender is only used for Rigid or IMC. It would normally kink EMT tubing (except for very small bends) Large sizes of raceways can be bent with hydraulic benders or with mechanical benders, such as Chicago benders, that incorporate a ratcheting action.

PVC conduit can be bent with heat. Heat benders are used on big jobs, but for small jobs, 45° and 90° elbows can be purchased and glued together to complete the run if no heat benders are available. Also, an EMT bender can be used to bend small degree bends or "kicks" in PVC. Use an EMT bender to bend 30° kick in the PVC conduit by bending it to 60° and then the conduit will spring back to 30°. This will only work on ½" or ¾" PVC and only for small bends, but it is fast and pretty accurate.

This document will walk a beginning electrician through the steps to bend EMT tubing with a hand EMT tubing bender. These steps will produce consistent bends every time. Many electricians have developed their own technique for bending raceways and will skip many of the steps mentioned here. The less measuring that needs to be done, the faster the installation. However, when duplicate bends in raceways need to be run side by side, it is very difficult to produce matching runs without measuring. That is when an experienced electrician will still need to mark the raceway in a manner similar to what is illustrated in this document. When following this document, pay close attention to marking the raceway and which direction the bend is made from that mark. Marks are placed on the raceway in the same order that the bends are made. The first mark on the raceway is the first bend on the raceway. Using scrap raceways, practice each type of bend until you are good at it before moving on to the next type of bend. Practice makes perfect. You will never learn to bend raceways without doing it. The last page of this article has several tables needed to calculate the shrinkage or gain that the raceway will have when bending around corners. These values are especially useful when the raceway must be cut and threaded before it is bent.

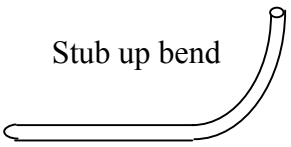
The EMT bender has degree marks on it for making precise 10°, 22 1/2°, 30°, 45° and 60° bends. There is not a 90° mark on the bender. This bend is made by bending the raceway until it looks like the raceway is bent to 90°. This will get easier with experience. The EMT bender also has several marks that are used to line up various types of bends. These are the arrow, the star and the teardrop. The teardrop (or the rim mark) is used for the center bend on 3 point saddles. The star is used on back to back bends. The arrow is used for all other bends covered in this manual.



Some of the terms used when bending raceway are defined as follows:

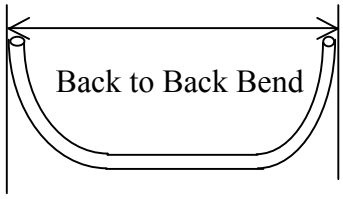
"Back to Back bend" - a 90° bend located a short distance away from a box, raceway fitting or another bend in the raceway.
"Box offset bend" - An offset bend that lifts the raceway up to the height of the opening of the box so that the raceway enters the box in a straight direction instead of a slight angle.
"Chicago Bender" - A ratcheting bender for larger raceway that usually is on wheels.
"Concentric bend" - multiple 90° bends around a corner running parallel to each other, that all have the same center.
"Dog Leg" - A mistake in bending when two bends in a raceway do not line up with each other.
"Foot" - The part on the bender that the electrician puts pressure with his foot to keep the raceway in the curved track of the bender.
"Gain" - The distance a raceway will shorten when it bends in a curve around a 90° corner instead of going all the way to the corner. The gain can be calculated by taking 43% of the radius of the bend. See table at the back of this handout.
"Jamming" - A problem that occurs when pulling wires around bends that have been lost their round shape. This happens when three equal size wires are pulled into the raceway and the ratio of the diameter of one wire to the raceway's inside diameter is between 1.8 and 3.2. The wires will lay side by side inside the bend and then get stuck when the raceway returns to its round shape.
"Kick" - A bend in the raceway, usually less than a 45° angle that changes the direction of the run.
"Kink" - The location where a raceway folded rather than bent smoothly while bending the raceway, usually from poor foot pressure.
"Offset bend" - Two equal but opposite bends in a raceway that allow the run to change to another plane.
"One Shot bender" - a bender that makes a complete bend in one step (not in segments).
"Rise" - The distance that a raceway will offset or stub up.
"Run" - A term used for a complete path of raceway or cable between two points, usually between boxes and/or panels.
"Segment bend" - A large bend formed by a series of smaller bends.
"Sled-Runner" - A 90° segment bend made with a hickey bender that is not made up of equal smaller bends.
"Springback" - The amount a raceway will straighten out after the pressure of bending is released.
"Stub-up bend" - A 90° bend in raceway that is located very near the end of the raceway.

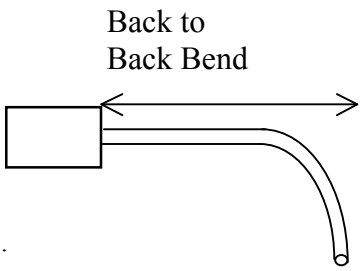
Introduction to the Bends taught in this Article



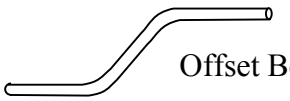
The first type of bend is the **stub up** bend. A stub up bend is used to bring a raceway from under the floor up to a receptacle box or into a panel or wireway. It is usually between 12" and 24" high. Most of the time on other types of bends, we can mark the exact distance we want for a bend directly on the raceway and place the bender on one of the marks and bend it. But, because the stub up bend is so close to the end of the raceway, the bender must be placed on the back side of the mark that is made on the raceway. The electrician will need to deduct 5" or 6" from the height to compensate for bending in the "wrong" direction. Deduct 5" for ½" EMT tubing. Deduct 6" for ¾" EMT tubing, etc.

The next type of bend is the **back to bac**k bend. A back to back bend is any bend that needs a 90° bend located a predetermined distance away. This is probably the most common type of bend. A mark is made on the raceway at the exact distance that is needed for the 90° bend.

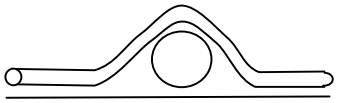


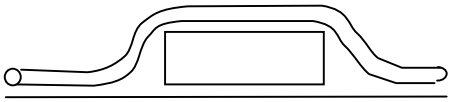


The third type of bend is the **offset** bend. This bend is made up of two equal degree bends that are bent in opposite directions. This bend can be used when the run of raceway is changing elevations. Both marks are placed on the raceway before any bending takes place. A **box offset** is a small offset bend (usually two 10° bends) that is used to lift a raceway from the surface up to the height of the knockout of the box it is entering. This allows the connector to enter the box on a straight angle.



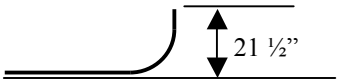
The fourth type of bend you will bend is the **3 point saddle**. This bend is used to jump over small obstructions 6" or less, such as an installed raceway that is running perpendicular to the raceway you are installing. This bend is made by bending the middle bend twice the degree of the other two bends. All three marks are placed on the raceway before any bending takes place.





The last type of bend described in this manual is the **four point saddle**. This bend is made up of two equal size offset bends bent in opposite directions. This bend is used to jump over larger blockages than a 3 point saddle can handle. All four marks are placed on the raceway before any bending takes place.

How to bend Stub Up Bends



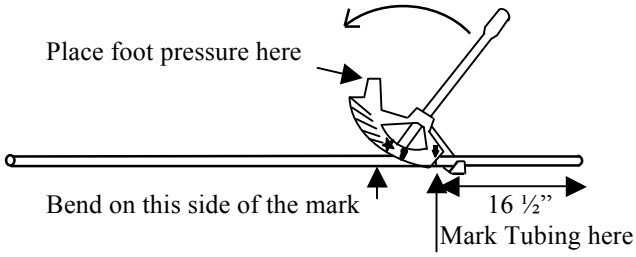
1. Determine the height of the offset.

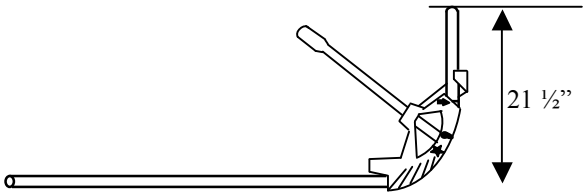
   For example: This stub up bend will stop at a height of 21 ½”.

2. Subtract 5” from the height for ½” EMT or 6” from the height for ¾” EMT.

   Using ½" EMT for example: 21½” - 5” = 16 ½”

3. Mark the tubing at the calculated distance and bend the tubing on the **arrow** and then bend the tubing up to a 90° angle using plenty of foot pressure as follows:



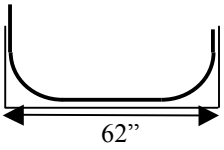


This should result in a stub up bend 21 ½” high. This bend is made on the opposite side of the mark from the measured end of the tubing. Stub up bends are usually short 90° bends. Because the bend is near the end of the raceway, it is not practical to bend the raceway on the same side of the mark as the end of the raceway. If we had placed the mark at exactly 21 ½” from the end, the result would be a stub up bend 26 ½” high. Therefore, we deleted 5” from the height on the ½” EMT tubing.

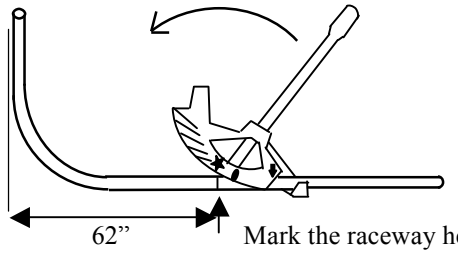
How to bend Back to Back Bends

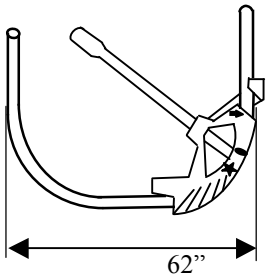
1. Determine the distance from the back side of one end of the ½” raceway to the back side of the other end.

   For example: This back to back bend will be 62” wide.



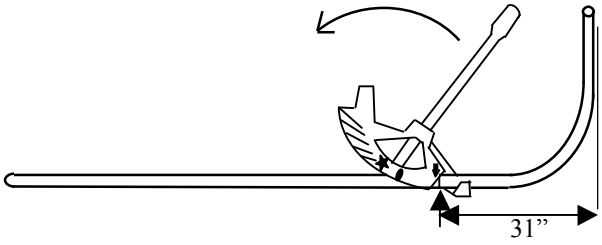
2. Mark the raceway at the calculated distance and then place the raceway on the **star** and then bend the raceway up to a 90° angle using plenty of foot pressure as follows:

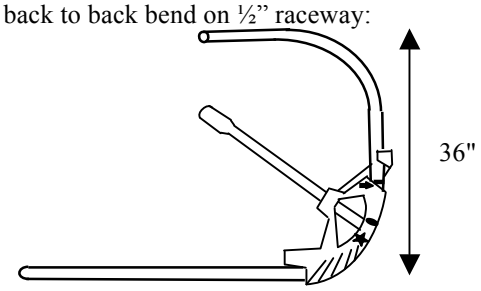




This should result in a back to back bend 62” wide. This bend is made on the **star** and in the direction of the measured end of the raceway. Because there was room to bend the raceway on that side of the mark, the bend could be placed on the **star**.

For **"short" back to back** bends, you can subtract 5” from the distance, mark the raceway and then bend the raceway on the **arrow** in the other direction from what is shown above. For instance for a 36” back to back bend on ½” raceway:

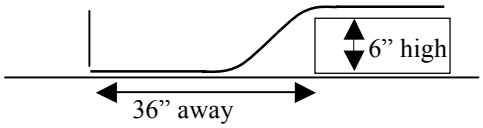




Mark the raceway here and use the arrow.

How to bend Offset Bends

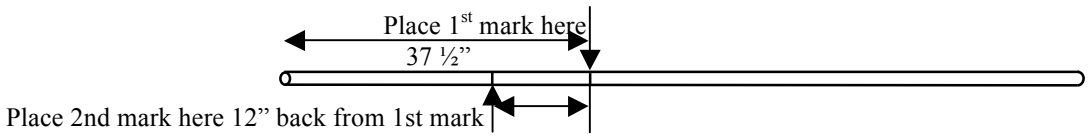
1. Determine the height of the offset and the distance from the end of the raceway.



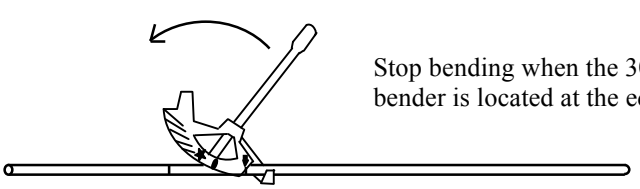
For example: This offset is 36" from the end of the raceway and 6" high

2. Determine the angle that will be used for the offset bends. Calculate the distance between bends and the shrinkage amount. Use the "offset bend" table. In this example we will use 30°angles, so the distance between bends is 12" and the shrinkage amount is 1 ½"

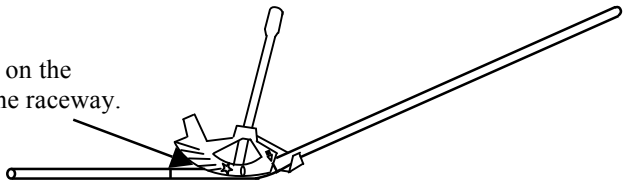
3. Place the first mark on the raceway a distance of 36" plus the shrinkage amount of 1 ½". This will be 37 ½" away from the end of the raceway.



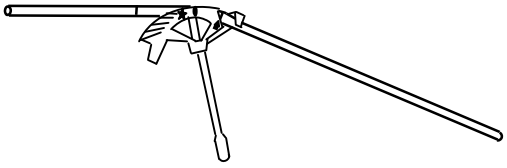
4. Place the second mark 12" back from the first Mark. Be sure to mark all the way around the raceway when placing marks on the raceway. Bend at the first mark placed on the raceway on the **arrow** in the direction shown to a 30° bend.

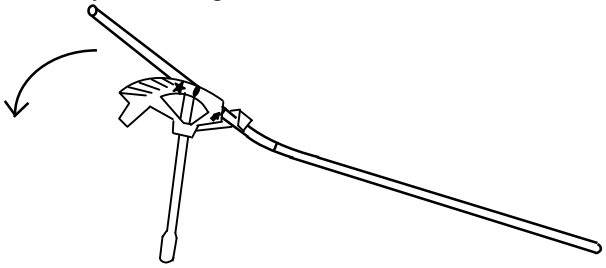


Stop bending when the 30° mark on the bender is located at the edge of the raceway.

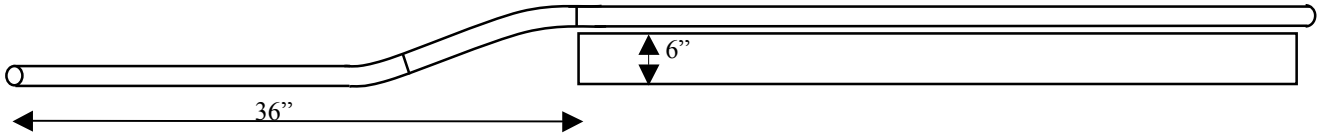


5. Leave the bender on the raceway and pick up both the raceway and the bender and stand the bender handle on the floor as shown. Then slide the bender back to the second mark and roll the raceway 180° and place the bender's **arrow** on the second mark.





6. Now place your hand and armpit on the raceway and bend another 30° angle on the raceway at the **arrow**. This should give you a 6" offset 36" away from the end of the raceway.

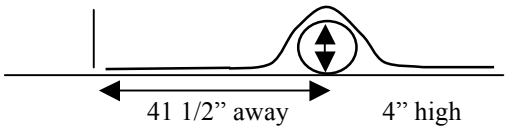


Note: This was done using 30° bends. 30° bends are easy to remember and calculate. The distance between bends is twice the offset depth and the shrinkage amount is ¼ the offset depth. Or you could say for the distance between bends you add 2" for each inch of offset rise and for the shrinkage amount you add ¼" for each inch of offset rise.

For example: To make an 8" offset you add 2" for the shrinkage amount and you need 16" between bends.

For other degree bends you will need to use the tables at the back of this handout to determine the shrinkage amount and the distance between bends.

How to bend Three Point Saddle Bends

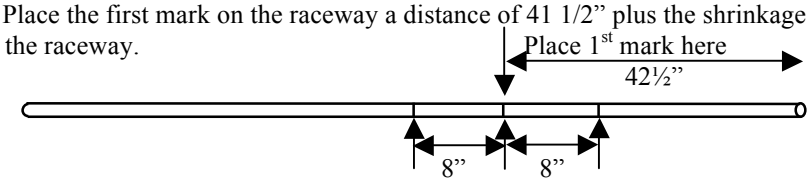


1. Determine the height of the Saddle and the distance from the end of the raceway. Note: measure to the centerline of the saddle.

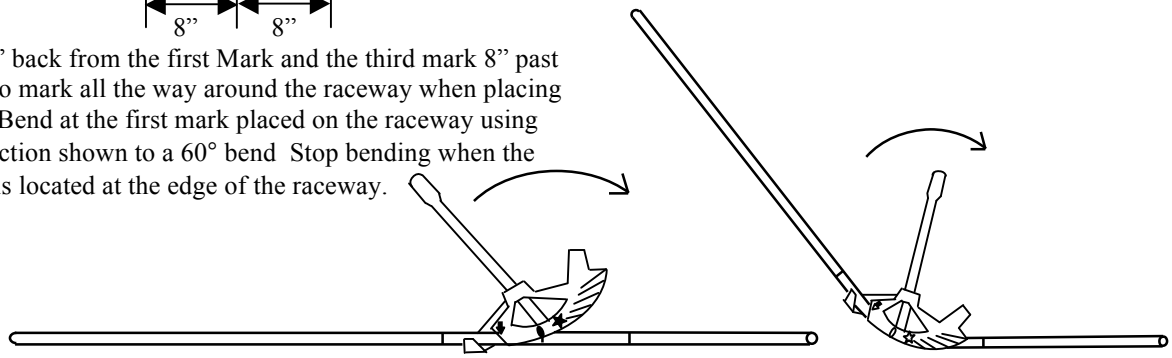
   For example: This offset is 41 1/2" from the end of the raceway and will clear an object 4" high

2. Determine the angle that will be used for the offset bends. The center bend angle will be twice the other angles. Calculate the distance between bends and the shrinkage amount. Use the provided table at the back of this document. In this example we will use a 60° center angle and two 30° outside angles, so the distance between bends is 8" and the shrinkage amount is 1"

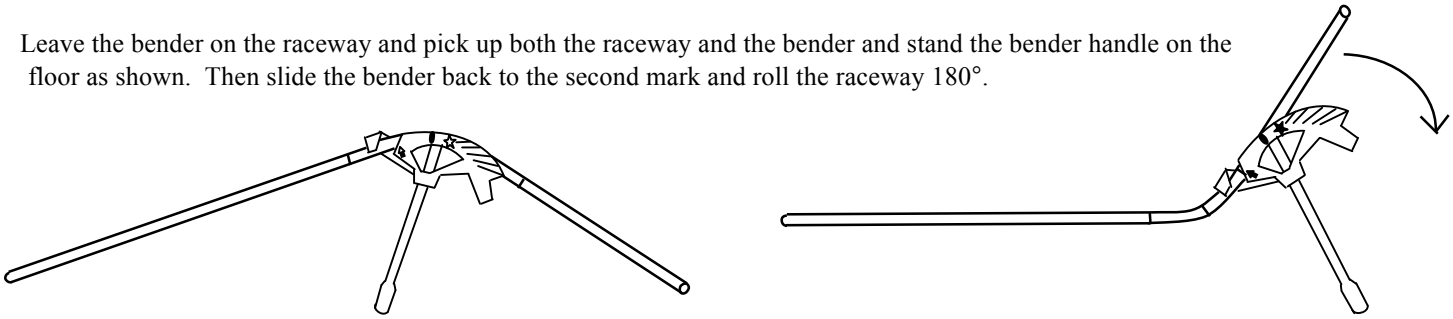
3. Place the first mark on the raceway a distance of 41 1/2" plus the shrinkage amount of 1". This will be 42 1/2" away from the end of the raceway.



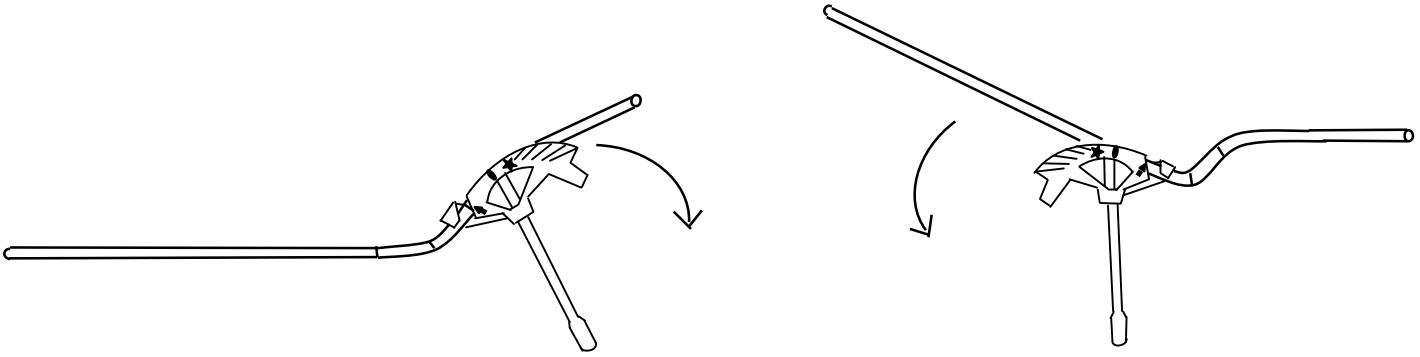
4. Place the second mark 8" back from the first Mark and the third mark 8" past the first Mark. Be sure to mark all the way around the raceway when placing marks on the raceway. Bend at the first mark placed on the raceway using the **tear drop** in the direction shown to a 60° bend Stop bending when the 60° mark on the bender is located at the edge of the raceway.



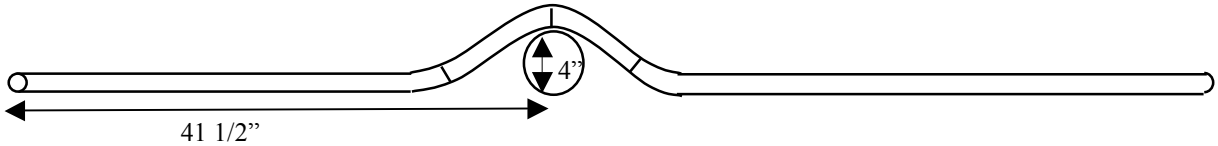
5. Leave the bender on the raceway and pick up both the raceway and the bender and stand the bender handle on the floor as shown. Then slide the bender back to the second mark and roll the raceway 180°.



6. Now place your hand and armpit on the raceway and bend a 30° angle on the raceway at the **arrow**. Next, take the bender off the raceway and turn the raceway in the opposite direction and place it back onto the bender on the last mark at the arrow.

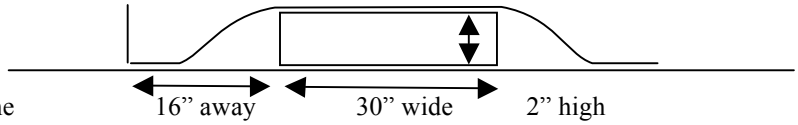


7. For the last bend, place your hand and armpit on the raceway and bend a 30° angle on the raceway at the **arrow**. This should give you a 4" high 3 point saddle 41 1/2" away from the end of the raceway.



Note: This was done using one 60° and two 30° bends. This combination is easy to remember and calculate. The distance between bends is twice the offset depth and the shrinkage amount is ¼ the offset depth. Or you could say for the distance between bends you add 2" for each inch of offset rise and for the shrinkage amount you add ¼" for each inch of offset rise.

How to bend Four Point Saddle Bends

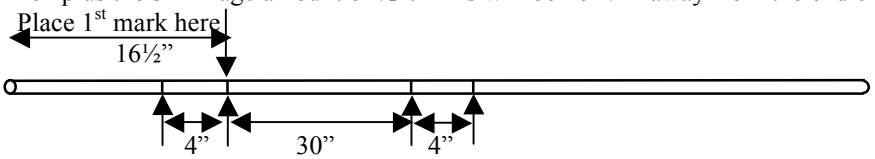


1. Determine the height and width of the Saddle and the distance from the end of the raceway.

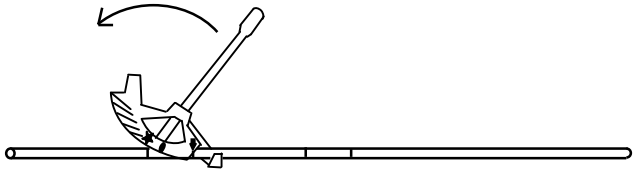
   For example: This offset is 16" from the end of the raceway and will clear an object 4" high and 30" wide

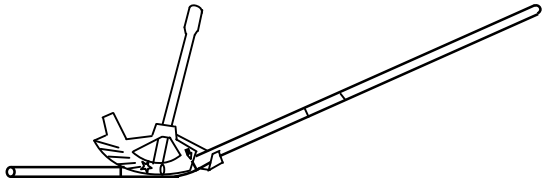
2. Determine the angle that will be used for the bends. These bends are the same as two offset bends with the width of the object between them. Calculate the distance between bends and the shrinkage amount. Use the provided table at the back of this document. In this example we will use all 30° angles, so the distance between bends is 4" and the shrinkage amount is ½" and the width of the offset is 30"

3. Place the first mark on the raceway a distance of 16" plus the shrinkage amount of ½". This will be 16 1/2" away from the end of the raceway.

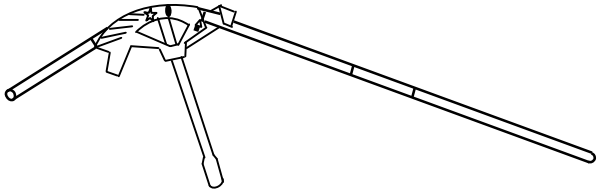


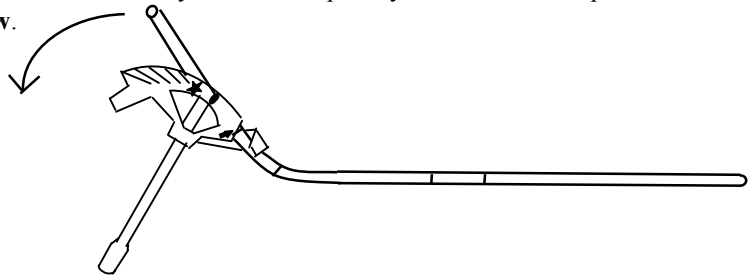
4. Place the second mark 4" back from the first Mark. Place the third mark 30" past the first Mark and the fourth mark 4" past the third mark. Be sure to mark all the way around the raceway when placing marks on the raceway. Bend at the first mark placed on the raceway on the **arrow** in the direction shown to a 30° bend Stop bending when the 30° mark on the bender is located at the edge of the raceway.



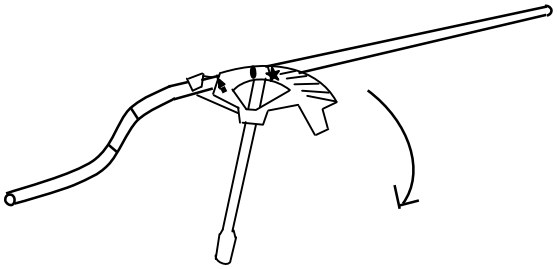


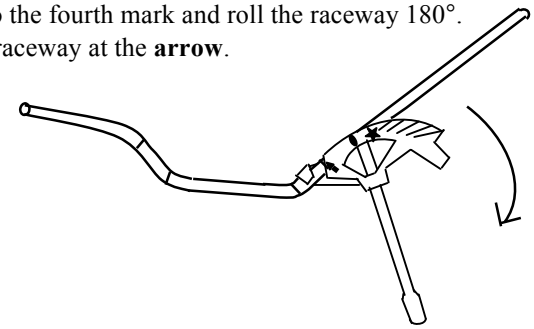
5. Leave the bender on the raceway and pick up both the raceway and the bender and stand the bender handle on the floor as shown. Then slide the bender back to the second mark and roll the raceway 180°. Now place your hand and armpit on the raceway and bend a 30° angle on the raceway at the **arrow**.



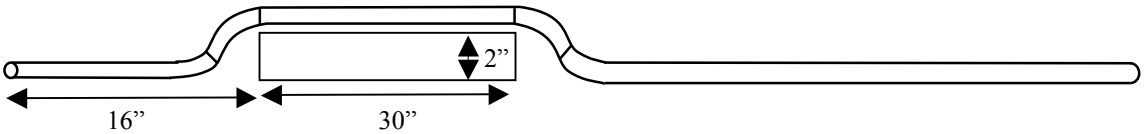


6. Next, take the bender off the raceway and turn the raceway in the opposite direction and place it on the bender on the third mark at the **arrow** and bend it to a 30° angle. Finally slide the bender back to the fourth mark and roll the raceway 180°. Now place your hand and armpit on the raceway and bend a 30° angle on the raceway at the **arrow**.





7. This should give you a 2" high and 30" wide 4 point saddle 16" away from the end of the raceway.



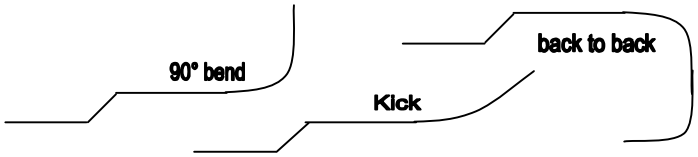
Note: This was done using 30° bends. This combination is easy to remember and calculate. The distance between bends is twice the offset depth and the shrinkage amount is ¼ the offset depth. Or you could say for the distance between bends you add 2" for each inch of offset rise and for the shrinkage amount you add ¼" for each inch of offset rise.

Determining the direction of multiple bends on one raceway:

Generally, the electrician will make all the measurements for the raceway and then mark and bend the first type of bend on the raceway. Then he will mark and bend the second type bend, then the third and fourth bends. Each type of bend may require several marks on the raceway. Whenever multiple bends are placed on the same raceway, it is very easy to create a dog leg. This is a condition where the multiple bends do not line up with each other (not all in the same plane). Take your time before you make the bend. Check the alignment in all directions and make sure the bender is placed on the correct side of the marks on the raceway.

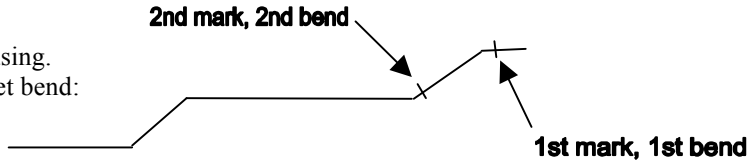
In all the examples in this handout, the raceway is marked at a point on the raceway where the bender's arrow, star or teardrop will be placed. In all of these types of examples, the marks are placed on the raceway in the order of the making the bends. The first mark on the raceway is where the first bend will take place. The second mark placed on the raceway is where the second bend will occur, and so on. You must learn first where to mark the raceway, second which direction to place the bender and third where to place the bender on the mark. After you learn these basic rules, then it becomes a matter of learning how much to bend the raceway to make the appropriate degree of bends. Also note, the only bend made with the tear drop mark on the bender was the middle bend of the three point saddle. The only bend made with the star was the back to back bend. All other bends used the star. Many bends can be made on the ground while the more complicated bends musts be made off the floor. Study the following examples to see which way to place the bender and which bends to make first:

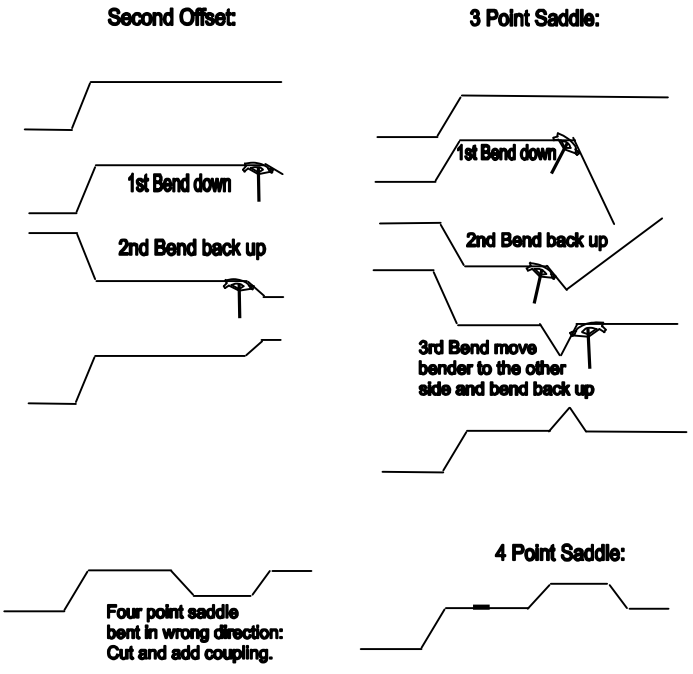
Note: In all of these examples, an offset bend was previously established on the raceway before the second type of bend was attempted.



Bending raceways can be a confusing task when first learned. Once an electrician learns to make single bends, it would seem that making two of them on one raceway would be easy. And it is, for 90°s, kicks and back to back bends, you just bend the raceway in the direction you want the bend to go. One bend and your done.

It is the multiple bends such as offsets and saddles that are so confusing. This example shows two marks placed onto a raceway with an offset bend:





Multiple bends require two to four steps each. Generally you will need to bend all these bends off the floor. They are confusing because most of these bends require the electrician to bend the first bend in the opposite direction of where it will end up. Bend the first bend down instead of up and then for your second bend, you slide the bender backwards and roll the pipe 180° s, without lifting it from the raceway to bend the first angle. This requires you to make your bends off the floor. This can be confusing. If you try to bend the second bend first, then you will unbend it when you try to bend the second bend. An easy way to know which way to first bend the pipe on offsets and saddle bends is to bend the first bend down into the surface you want to lift it up from. The second bend will lift the raceway back up. Most of these bends are bent upside down from the way they will wind up. Once you master which way to make the bends, you're on your way to becoming an expert bender.

Making multiple bends on the same raceway will get easier with experience. If your bend winds up in the wrong direction, then just cut the raceway in two and use a coupling to rotate and join the two pieces back together.

Practice is the only way to get better. Anything worth doing, is worth doing poorly the first time. It's time to quit reading and get to bending! After you have practiced awhile, then reread this article. You'll be surprised at how fast you can learn.

Calculating the length of the raceway before bending:

The last page of this document contains several tables. The "**Offset Shrinkage Table**" contains the formulas used to calculate all the dimensions in the "**3 Point Saddle Bend Chart**" and the "**Offset bend and 4 point saddle bend chart**". These charts will allow the user to calculate both the shrinkage amount that is associated with offset bends and the distance between marks on the raceway for the bends. The shrinkage amount is the extra length needed in the raceway to raise or lower the raceway to a different elevation. If you don't have a copy of the "3 Point Saddle Bend Chart" or the "Offset bend and 4 point saddle bend chart" on the job, just make a shirt pocket copy of the "Offset Shrinkage Table" and then round the remainder to the nearest 1/16th of an inch.

If only the "Offset Shrinkage Table" is used, then you can use a calculator to calculate the total number of inches and then multiply the remainder by 16 to find out how many 1/16ths of an inch to add to the distance. For example, to calculate the shrinkage amount and the distance between bends for a 6" offset bend using **10º bends**, make the following calculations:

Shrinkage amount: **1/16"** x 6 = 6/16" or **3/8**"

Distance between bends: **5.7588** x 6 = 34.5528"

Offset Shrinkage Table

Angle	Shrinkage of raceway per inch of rise	For distance between bends, multiply the offset depth by:
10º	1/16"	5.7588
22 1/2º	3/16"	2.613
30º	¼"	2
45º	3/8"	1.4142
60º	1/2"	1.1547

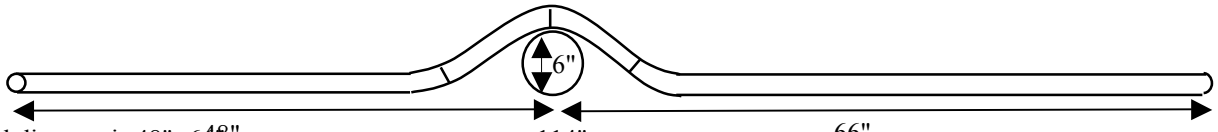
Then **.5528** * 8 = 4.4224 8ths (or 4/8's) for a total of **34 1/2**" between bends.
or **.5528** * 16 = 8.8448 16ths (or 9/16's) for a total of **34 9/16**" between bends.
or **.5528** * 32 = 17.6896 32nds (or 18/32's) for a total of **34 9/16**" between bends.

The "**Bender Gain**" table is use to measure the gain a rigid conduit makes when turning a 90º angle. Using both the "Offset shrinkage" table and the "Bender gain" table will allow the electrician to calculate the total length of a conduit before any bends are actually made in the conduit. This will allow the electrician to thread the conduit before making any bends in the conduit.

Bender Gain Table

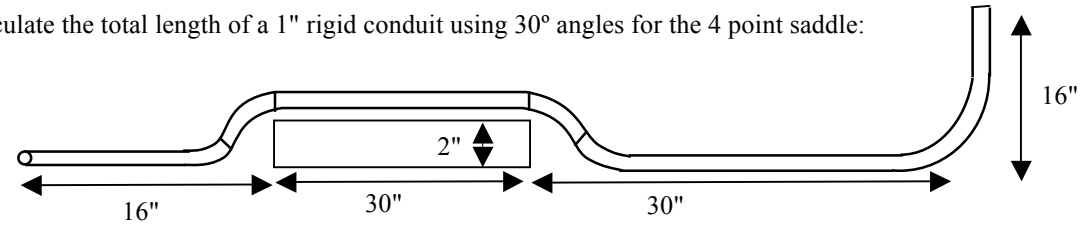
Rigid Conduit	NEC Radius	90º Gain
1/2"	4"	2 5/8"
3/4"	5"	3 1/4"
1"	6"	4"
1 1/4"	8"	5 5/8"

Example#1: Calculate the total length of a 1/2" rigid conduit using 60/30º angles for the 3 point saddle:



The total distance is 48"+66"= + 114"
The shrinkage amount for the first offset bend is : + 1 1/2"
The shrinkage amount for the second offset bend is: + 1 1/2"
Add 1/2" for threads inside of boxes on both ends: + 1 "
The total length of the conduit before bending is: 118"

Example#2: Calculate the total length of a 1" rigid conduit using 30º angles for the 4 point saddle:



The total distance is 16"+30"+30"+16"= + 92"
The shrinkage amount for the first offset bend is : + 8"
The shrinkage amount for the second offset bend is: + 8"
The gain amount for the 90º angle is : - 4"
Add 3/4" for threads inside of boxes on both ends: + 1 1/2"
The total length of the conduit before bending is: 105 1/2"

Conduit Bending charts

Offset Shrinkage Table		
Angle	**Shrinkage of raceway per inch of rise**	**For distance between bends, multiply the offset depth by:**
10º	1/16"	5.7588
22 1/2º	3/16"	2.613
30º	¼"	2
45º	3/8"	1.4142
60º	1/2"	1.1547

Bender Gain Table		
Rigid Conduit	**NEC Radius**	**90º Gain**
1/2"	4"	2 5/8"
3/4"	5"	3 1/4"
1"	6"	4"
1 1/4"	8"	5 5/8"

3 Point Saddle Bend Chart				
Degree of Bends	**One 45° Center Bend and two 22 ½ ° bends**		**One 60° Center Bend and two 30° bends**	
Obstruction Depth	Shrinkage Amount:	Distance between bends on both sides of center mark	Shrinkage Amount:	Distance between bends on both sides of center mark
1"	3/16"	2 1/2"	1/4"	2"
2"	3/8"	5"	1/2"	4"
3"	9/16"	7 1/2"	3/4"	6"
4"	3/4"	10"	1"	8"
5"	15/16"	12 1/2"	1 1/4"	10"
6"	1 1/8"	15"	1 1/2"	12"
For Each Additional inch Add:	3/16"	2 1/2"	1/4"	2"

Offset Bend and 4 point Saddle Bend Chart										
Degree of Bends	**10 º**		**22 1/2 º**		**30 º**		**45 º**		**60 º**	
Offset Depth	Shrink Amount	Distance Between Bends	Shrink Amount	Distance Between Bends	Shrink Amount	Distance Between Bends	Shrink Amount	Distance Between Bends	Shrink Amount	Distance Between Bends
1/2"	1/16	2 7/8	1/8	1 5/16	1/8	1	3/16	11/16	1/4	9/16
1 "	1/16	5 3/4	3/16	2 5/8	1/4	2	3/8	1 7/16	1/2	1 1/8
1 1/2"	1/8	8 5/8	5/16	3 15/16	3/8	3	9/16	2 1/8	3/4	1 3/4
2"	1/8	11 1/2	3/8	5 1/4	1/2	4	3/4	2 13/16	1	2 5/16
2 1/2"	3/16	14 3/8	1/2	6 9/16	5/8	5	15/16	3 9/16	1 1/4	2 7/8
3"	3/16	17 1/4	9/16	7 13/16	3/4	6	1 1/8	4 1/4	1 1/2	3 7/16
3 1/2"	1/2	20 1/8	11/16	9 1/8	7/8	7	1 5/16	4 15/16	1 3/4	4 1/6
4"	1/2	23 1/16	3/4	10 7/16	1	8	1 1/2	5 11/16	2	4 5/8
4 1/2"	5/16	25 15/16	7/8	11 3/4	1 1/8	9	1 11/16	6 3/8	2 1/4	5 3/16
5"	5/16	28 13/16	15/16	13 1/16	1 1/4	10	1 7/8	7 1/16	2 1/2	5 3/4
5 1/2"	3/8	31 11/16	1 1/16	14 3/8	1 3/8	11	2 1/16	7 3/4	2 3/4	6 3/8
6"	3/8	34 9/16	1 1/8	15 11/16	1 1/2	12	2 1/4	8 1/2	3	6 15/16
6 1/2"	7/16	37 7/16	1 1/4	17	1 5/8	13	2 7/16	9 3/16	3 1/4	7 1/2
7"	7/16	40 5/16	1 5/16	18 5/16	1 3/4	14	2 5/8	9 7/8	3 1/2	8 1/16
7 1/2"	1/2	43 3/16	1 7/16	19 5/8	1 7/8	15	2 13/16	10 5/8	3 3/4	8 11/16
8"	1/2	46 1/16	1 1/2	20 7/8	2	16	3	11 5/16	4	9 1/4
8 1/2"	9/16	48 15/16	1 5/8	22 3/16	2 1/8	17	3 3/16	12	4 1/4	9 13/16
9"	9/16	51 13/16	1 11/16	23 1/2	2 1/4	18	3 3/8	12 3/4	4 1/2	10 5/8
9 1/2"	5/8	54 11/16	1 13/16	24 13/16	2 3/8	19	3 9/16	13 7/16	4 3/4	11
10"	5/8	57 9/16	1 7/8	26 1/8	2 1/2	20	3 3/4	14 1/8	5	11 9/16
11"	11/16	63 3/8	2 1/16	28 3/4	2 3/4	22	4 1/8	15 9/16	5 1/2	12 11/16
12"	3/4	69 1/8	2 1/4	31 3/8	3	24	4 1/2	17	6	13 7/8
13"	13/16	74 7/8	2 7/16	34	3 1/4	26	4 7/8	18 3/8	6 1/2	15
14"	7/8	80 5/8	2 5/8	36 9/16	3 1/2	28	5 1/4	19 13/16	7	16 3/16
15"	15/16	86 3/8	2 13/16	39 3/16	3 3/4	30	5 5/8	21 3/16	7 1/2	17 5/16
16"	1	92 1/8	3	41 13/16	4	32	6	22 5/8	8	18 1/2
17"	1 1/16	97 7/8	3 3/16	44 7/16	4 1/4	34	6 3/8	24 1/16	8 1/2	19 5/8
18"	1 2/8	103 11/16	3 3/8	47 1/16	4 1/2	36	6 3/4	25 7/16	9	20 13/16
19"	1 3/16	109 7/16	3 9/16	49 5/8	4 3/4	38	7 1/8	26 7/8	9 1/2	21 15/16
20"	1 1/4	115 3/16	3 3/4	52 1/4	5	40	7 1/2	28 5/16	10	23 1/8
21"	1 5/16	120 15/16	3 15/16	54 7/8	5 1/4	42	7 7/8	29 11/16	10 1/2	24 1/4
22"	1 3/8	126 11/16	4 1/8	57 1/2	5 1/2	44	8 1/4	31 1/8	11	25 3/8
23"	1 7/16	132 7/16	4 5/16	60 1/8	5 3/4	46	8 5/8	32 1/2	11 1/2	26 9/16
24"	1 1/2	138 3/16	4 1/2	62 11/16	6	48	9	33 15/16	12	27 11/16
25"	1 9/16	144	4 11/16	65 5/16	6 1/2	50	9 3/8	35 3/8	12 1/2	28 7/8

Provided by Bill Bamford at Albany College