

THE HINGED ASTROPHOTOGRAPHIC TRACKER

Building a Simple Mount to Track the Sky

In order to capture stunning views of the cosmos without trailing or blurry images you must track the sky to prevent the sky's apparent motion from ruining your images.

The sky's apparent motion doesn't move in a simple left to right motion. It rotates overhead in a large arc once per day. Stars appear to move around a fixed point in the sky, and your camera must move in that exact same motion in order to prevent the stars from becoming blurred during a photographic exposure. So let's look at that motion in detail:

-- First, the sky's motion is constant. The movement of the sky is a continuous rotation around a fixed point. Since the Earth rotates once per day, this means there is one full 360° rotation in 24 hours. This translates to **15° per hour** ($360/24=15$) or **1/4° per minute** ($360/24/60=.25$). This is called **SIDEREAL TIME**.

-- Second, the sky moves in a perfect circle around one single axis. This can be easily seen on long stationary photography, called Star trail photography:



-- Third, the motion is precisely centered on a fixed point in the sky, called the **CELESTIAL POLE**. For those who live above the equator, this point is very close to the North Star (Polaris) which makes it easy to locate. For those who live below the equator it is much more difficult to locate, as there are no bright stars right over the Southern celestial pole, but a good star chart can help you find this point. If you were living at the North or South Pole, this point would be straight overhead, while those at the equator would see it right on the horizon.

A camera platform capable of very long exposures of the night sky must track the sky at the exact **sidereal rate**, in a perfect **arc**, and aligned to the **celestial pole**. That's it. Sounds hard, but it isn't!

Introducing the Hinged Astrophotographic Tracker (HAT). This simple device will follow the sky at the correct angle, correct alignment, and at the correct speed to match the sky with such accuracy that you can use it to capture stunning views of the night sky.



The basic design of this mount was first designed by George Haig of Glasgow, Scotland in the April 1975 issue of Sky & Telescope. He called it the Scotch Mount, and it was capable of tracking the sky for up to 30 minutes with a 50mm lens without noticeable error. Over the years, the mount has become known as the Barn Door Tracker, since the hinge swings the two boards open like a barn door. The version detailed here is more accurate than the Scotch Mount but very easy and inexpensive to build. Let's break down the details:

- TRACKING RATE:

In order to move your camera at the correct rate to track the sky, we have to move it at the correct Sidereal Rate. As noted above, the sidereal rate is one revolution per 24 hours. This movement can be easy to accomplish! We can use a small gear to push our mount at the correct rate. Ideally, we would want a gear that rotates only once per day, but to try and turn such a gear accurately one revolution per 24 hours by hand is impossible. It is just too small of a movement. So we'll use a gear that spins much faster, and I will show you a way to accurately maintain a constant fixed rate.

If you had to spin a gear exactly 1440 times in one day, you may wonder how you could do that accurately. But if you rotate the gear one full turn every minute, that still translates to a rate of 60 revolutions per hour, or 1440 turns per day! Add a simple stop watch and a small mark on the object and anyone can move it accurately one revolution per minute. But it's even easier than that! If you turn the gear one quarter-turn every 15 seconds, this is still one full revolution per minute. So you only need to design our gear so that you simply maintain the average **sidereal rate** of 1 complete revolution every minute, even if you have to do it in 1/4 turn increments.

To move our tracking platform at the sidereal rate, we will use a threaded steel rod. Consider the rod to be a horizontal gear.



This is like a simple bolt, except much longer. In fact, you can buy these in lengths of a meter (3 feet) or more. Also, threaded rod comes in many diameters and different thread pitch. Choose the best quality rod you can, as the accuracy of your tracking will be influenced by any manufacturing defects in the rod. When completed, you will want your mount to move at the sidereal rate, based on the movement of this rod. Be sure you know the exact thread count (pitch) of your rod, so you can make any calculations needed.

So how do you get movement from just a rod? If you place a nut on the stationary rod and turn a nut at a constant rate, the nut moves up or down the rod at a constant rate. It is also true that if you turn the nut while keeping the nut stationary, the rod will move up or down. This is how we will make our mount move!

- TRACKING ARC:

Since the camera must move in an arc, consider a door swinging open about a hinge. A very nice arc can be accomplished with a simple hinge and two boards. A hinged board opens up in a sweeping arc, creating a perfect circle! Imagine the hinge is at the center of an imaginary clock, and so the attached board rotates around the center, which now becomes a giant hour hand on a 24-hour clock!



You may wonder how far you must move the board? Not far! Many of the very faintest objects in the sky, can be captured on film in only 30 minutes of exposure. The brighter objects need even less, and if you use a digital camera you need only a few minutes! But let's assume you want a long **½ hour exposure** - which is probably more than you will need for a fast (short focal ratio) lens.

Remember that Sidereal time is 15° per [u]1 HOUR[/u] and since you only need half of that amount of time, you only need 7.5° for 30 minutes. That's quite a short distance! Since we only want 30 minutes of exposure, that's just 7.5° . This is a very small portion of that 24-hour clock. If you use two pieces of wood only 11" long and you open it to the required 7.5° , then the distance they will travel is only about 1.5 inches. That's how short of a distance we are talking about!

- TRACKING ALIGNMENT:

In order for your camera platform to rotate correctly, you must make sure your hinge is pointed

exactly at the Celestial pole. This is a critical step that must be done with a very high degree of accuracy. As the board swivels around the hinge, it will now follow the perfect arc of the sky. Once aligned, all you have to do is move the mount in the same direction that the sky moves. In the Northern hemisphere that is counter clockwise around the celestial pole. In the Southern hemisphere it moves clockwise.

In the northern sky, you can locate the Celestial Pole by finding the bright star Polaris, the brightest star in the constellation Ursa Minor. To locate Polaris you can use two other common constellations to help guide you.



The drawing here shows how a line from Ursa Major ("Big Dipper") and Cassiopeia goes right through Polaris. Depending on your location, and the date and time, you may not see both Ursa Major and Cassiopeia at the same time, but you should be able to find Polaris using just one of those constellations and the chart here. Once you locate Polaris, note where in the sky it is, as it will not move from that spot as long as you do not travel too far away. Once you locate Polaris, you will be very close to the Celestial Pole.

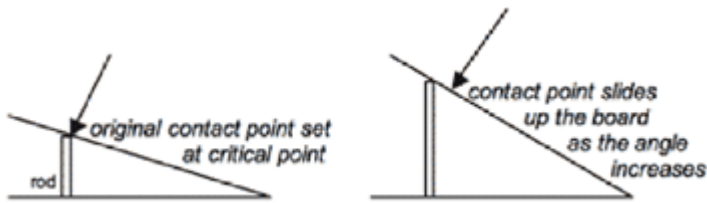
CONSTRUCTION DETAILS

The actual construction of the HAT is very simple. The first step is to take two pieces of wood and attach a hinge to create a movable platform that can swing open. You mount your camera on one board and secure the other to a solid tripod. The second step is to point the hinge axis very accurately at the Celestial Pole, which enables the camera to sweep in a perfect arc around the pole. The third step is to create a way to move the camera platform at the correct sidereal rate.

As stated above, the fine movement of our mount can be accomplished with a simple threaded rod. But there are a lot of things to consider when using a rod to push our hinged boards apart. The main issue is accuracy, because a straight, fixed rod, turning at a constant rate will not allow two hinged boards to swing open at a constant rate! Here's why:

-TANGENT ERROR

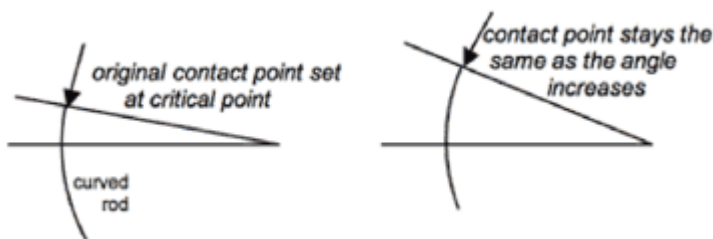
As the rod pushes the top board apart, the contact point where the rod hits the platform will not stay at the same place. As the separation angle of the two boards increase, the rod's contact point will slide up the platform, increasing the distance from the hinge.



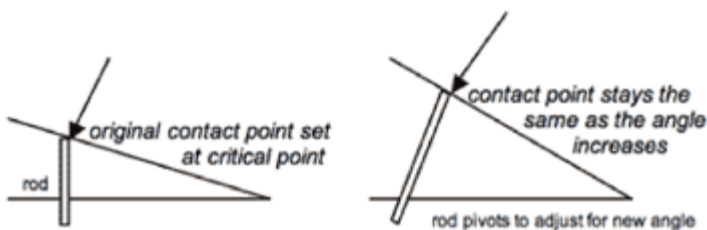
This new point of contact means that the platform will open more slowly as the contact point slides further up the board. Once the top board is 90° straight up, the rod will no longer make contact and the platform will fail to move at all! This is called Tangent Error.

To correct this tangent error one of three things can be done:

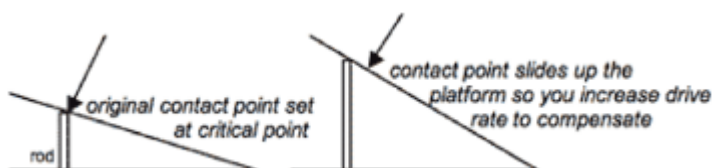
A. Curve the rod so it matches the radius of the contact point relative to the hinge. Since the rod is curved, it will always stay in contact with the same spot.



B. Allow the rod to tilt so that it remains in contact with the same spot on the top platform.



C: Adjust the speed at which the rod moves. If you increase the speed of the rod as the platform swings open, or decrease the speed as the platform swings closed, it will allow the mount to move at a constant rate.



You can also correct Tangent Error by building a rod drive mount that uses two or three moving arms

(boards). These are called a double arm or triple arm trackers.

This article only describes a simple single arm drive, and so the simplest way to solve this error is with a curved rod as illustrated in diagram "A" above.

- But how much of a curve is needed?
- How long of a rod?
- Where must it be mounted?

All these questions can be solved very easily if we consider that a curved threaded rod becomes a simple gear in our "clock" motor, and the threads can be considered teeth in our "gear"!

THE CLOCK GEAR DRIVE

We will need to know:

- The size of the gear (radius)
- How far from the hinge to place it

Since we already know the thread count of our rod (teeth in our gear) we can make a calculation to solve the above questions!

Consider: The Earth rotates once per 24 hours. Actually we need to be a little more accurate than that, since it rotates once per 23 hours 56 minutes. This equals a total of 1436 minutes. If we want to keep things simple, we want our gear to move at the rate of one tooth (thread) per minute, thus our gear will have **1436** teeth. But how big of a gear will it be? This depends on how fine our threads (or gear teeth) are on the threaded rod. Let's use a rod that has 20 threads per inch (very common in the USA). This means that for every inch of rod, there are 20 threads so that a nut will turn 20 times to cover that 1 inch. You can also say that our "gear" has twenty "teeth" per inch.

Gear Size

So.. if a gear has a total of 1436 teeth and there are 20 teeth per inch, then the gear must be 71.8 inches around (circumference). ($1436 / 20 = 71.8$)

This means that the gear's **diameter is 22.855 inches**. That's a very big gear.. and very accurate too!

Diameter = circumference / pi ($71.8 / 3.14 = 22.855$)

But remember, we fortunately only need a small portion of that gear! If the maximum duration of an exposure is 1 hour, then we only need 1/24th of our gear; which is about 3 inches ($71.8 / 24\text{hrs} = 2.99$). To give us some room to work, we will triple that, or a 9" piece of threaded rod.

So we now must bend our rod to match a **curve** with a 22.855 inch diameter.

Since a steel rod has spring to it, you should bend the rod around something with a diameter a lot smaller than 22 inches. You can use a tree or another round object with a large enough diameter that you can smoothly bend the rod around.



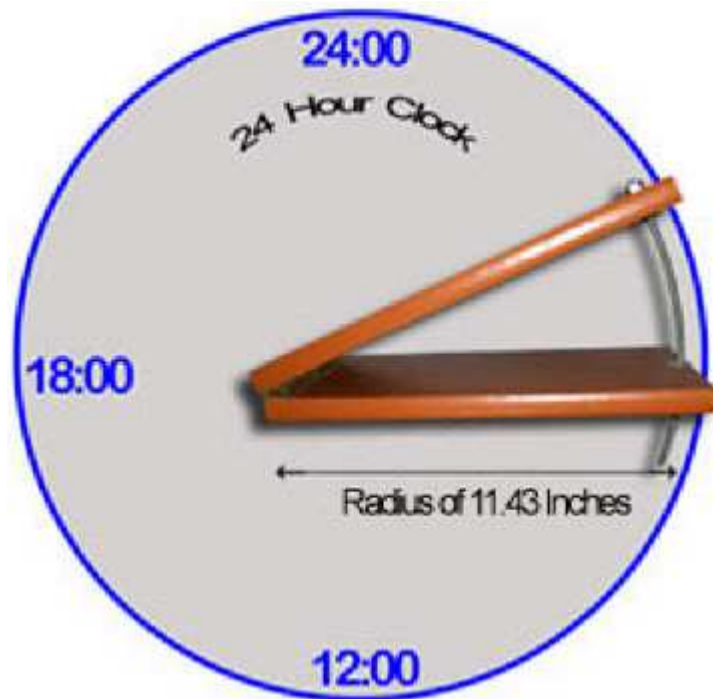
To make sure you get exactly the correct diameter, trace out an arc on a piece of large paper with a 22.855 diameter.

You do not need to complete a full circle; just a half circle will do nicely. Be very careful, and try to get as close to the correct arc as you can. Keep checking with the paper arc frequently. Any error here may show up on your photographs as a tracking error. **BE SURE NOT TO BEND ANY THREADS!** A tree works well as it is soft enough to prevent damage to the threads, but stiff enough to allow you to make the curve.

Now select the most accurate portion of the rod, and cut a 9" length to use on your mount.

- Gear Location?

The last question now is how far from the hinge do you place this curved rod, so it will open the platform at the correct speed? As I stated earlier, it is accurate to imagine this rod is part of a large clock gear, with the axis at the hinge.



Since we know the size of the gear (22.855" diameter) and you want to have the gear rotate about the hinge, our curved rod must be located exactly at the **radius**, or 11.43" from the hinge ($22.855/2$). Be sure you measure precisely from the hinge pivot pin.

The above photo shows the curved rod in place on our Barn Door Mount. It is bolted to the top, and runs through a hole in the bottom. Both holes are exactly located at the radius or exactly **11.43"** from the hinge.

The next step is to create an easy way to slide this curved rod up at the exact rate as the sky appears to move (the Sidereal rate of 15 degrees per hour). Since we made this "gear" with 1436 teeth to match the 1436 minutes in a day, the rod needs to push the platform up at the rate of 1 thread (tooth) per minute. If you place a nut on your threaded rod and turn it at the rate of one revolution per minute, the "gear" (rod) will move at the rate of 1 tooth (thread) per minute, exactly matching the sky!

If you attach a nut to a large disk, you will be able to turn it very easily. You can then draw some lines on the disk to allow you to keep track of its position and make it easier to maintain the accurate rate. You can cut a disk from plastic, or fashion one from an old CD disk as shown here. I glued a nut to the center of a CD disk.



Clock Gear Frequency

You need to turn the disk one full revolution per minute, but how frequently must you turn the disk? Can you simply rotate it quickly once, and then wait a full minute before doing it again? Or do you need to make tiny movements every second?

Well that depends on the focal length of your camera lens. If you are using a very short focal length lens you may simply turn the disk $\frac{1}{2}$ a turn every 30 seconds. But if you want to use a very long lens, like a 300mm telephoto lens, you must turn the disk every 5 seconds or you will capture some trailing between movements.

Here's why...

Consider a camera with no tracking movement at all. The higher the focal length of the camera lens, the faster it will detect any star movement from the Earth's rotation. Remember, this is how you are able to get the Star Trail photos.

The formula $1000 / FL * (\cos D) = EXP$ will give you the maximum length of time you can expose your film before star trails will become visible. FL = Focal Length of your camera lens, D = the declination of the area of sky you are pointing at (degrees), and EXP = the exposure time (seconds). The declination is how far from the celestial equator you are pointing at, where zero is at the equator and 90 is at the pole. The closer you point to the pole, the less star trailing you will record. To the right is a table showing how quickly your camera will show star movement based on varying lens focal lengths and declination. It shows the frequency to turn the drive to prevent star trails (minutes and seconds).

DEC	28mm	35mm	50mm	135mm	200mm
80	3m 25s	2m 44s	1m 55s	42s	28s
75	2m 17s	1m 50s	1m 17s	28s	19s
60	1m 11s	57s	40s	14s	10s
45	50s	40s	28s	10s	7s
30	41s	32s	23s	8s	5s
15	36s	29s	20s	7s	5s
0	35s	28s	20s	7s	5s

As you can see from this table, with a common 50mm lens you must move the mount at least every 20 seconds in order to prevent any star trailing from being recorded (if you are pointing the camera near the equator). However, if you are pointing near the pole, you can turn the drive nut once every minute! With this knowledge you can mark your spinning disk with even time-increments and use these marks to help maintain the correct tracking frequency.

Note: Be sure to use the correct frequency based on the fastest moving portion of your field of view, not just where you are pointing at. That is, you may be pointing at the pole which moves slowly, but using a wide angle lens that captures stars all the way down to 60 degrees. In this case, use the time calculated for 60 degrees. Now that we have a platform that will move at the correct arc as the sky, and a drive system that will move the mount at the exact rate as the sky's apparent movement, once it is accurately aligned to the Celestial Pole (as detailed below - see Polar Alignment)

To attach the camera, you can find lots of ways that will work. Just be sure you have the camera secured well, and that it can be rotated to any view of the sky. You can't move the mount once it's aligned!

In my example platform above, I attached the top of a cheap mini-tripod head that I had laying around. I simply cut the legs off, and then epoxied them to the wooden platform.

You can also make an easy do-it-yourself camera support with a 2" PVC compression coupler, a 2" wooden ball, and a 1" length of the same 1/4" threaded rod left over from the tracker! The coupler is cut and glued to the wooden platform, and the rod is inserted and glued into the wooden ball. You then want to add another ball inside, or a piece of plastic pipe that will hold the ball up so that the ball will move freely after the cap is added. To adjust the direction, you simply twist the cap on the PVC coupler and rotate the ball to the desired position. Tighten the cap and take your picture!



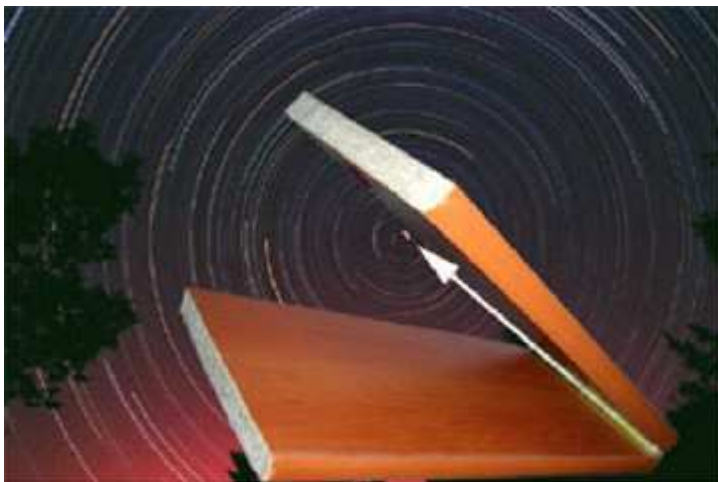
So now you have an accurate platform to track the sky at the exact rate, angle and arc! Drill a hole in the base, to mount on a stable camera tripod, or construct a home-made platform that will allow you to move the mount to the correct position. Standard camera tripods use a 1/4" 20 thread nut as an attachment bolt. You can simply drill a hole in your mount's base large enough to hold the nut flush with the bottom of the mount. Then glue it in place with epoxy. Be certain that the nut is very secure - you do not want to have it fall out and drop your camera!

- POLAR ALIGNMENT

The #1 cause of tracking error with this mount is poor alignment to the Celestial Pole. In order for your mount to compensate for the Earth's rotation, you need to make sure your tracker is precisely aligned with the celestial pole.

So how do you find the exact pole? Fortunately for those who live in the Northern Hemisphere, it is very close to the North Star - Polaris. Polaris is a fairly bright star that makes up the last star in the handle of the Little Dipper – Ursa Minor- as we discussed in the tracking alignment section above.

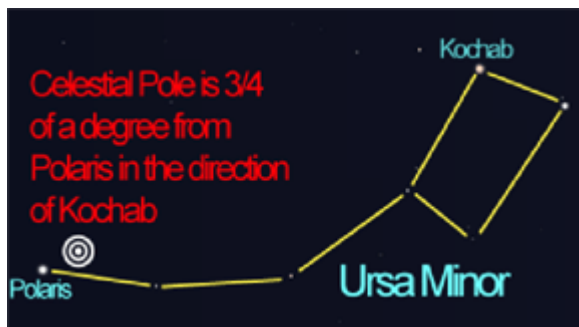
Once you locate Polaris, point the hinge axis directly at it.



This will put you very close to the Celestial Pole, but not close enough for our use. Now you must make one final adjustment to get the accuracy needed for long exposure astrophotography.

The North Celestial Pole is located $\frac{3}{4}$ of a degree away from Polaris, which is a very tiny amount. The full moon is $\frac{1}{2}$ a degree across, so you need to adjust your mount by slightly more than the diameter of the moon. But which way do you move the mount? This is also very easy!

The north Celestial Pole lies $\frac{3}{4}$ of a degree away from Polaris in the direction of the bright star Kochab, or Beta Ursa Minor.



You simply point the mount at Polaris, and then shift it slightly ($3/4$ of a degree) towards Kochab. Now you will be VERY closely aligned with the Celestial Pole, and your mount will track very accurately!

You can add a very small telescope (finder scope or gun scope) to help you locate the exact celestial pole to increase accuracy. The closer you get to perfect alignment with the pole, the longer you can expose before the trailing or blurring will occur.



In this photo I have attached a simple 6X finderscope from a commercial telescope to the top board. This allows you to get very accurate Polar Alignment vs. what you can get only using your eyes.

You should first look at the moon in order to learn what $3/4$ of a degree looks like. Remember, the moon is $1/2$ degree across, so once you see what $1/2$ a degree looks like, you can easily see what an additional $1/4$ of a degree would be.

To use a finderscope, it is absolutely essential that the finderscope is perfectly aligned with the HINGE . It will be much easier if you do this in daylight. First, secure the tracker on a tripod and then sight on a distant object in the finder, such as a telephone pole or church steeple, while looking through the finderscope, rotate the top board as far as you can. You should see the sighted object simply rotate in the field of view. If, however, the object swings out of view, then the finder must be carefully moved to improve the alignment. Keep repeating these steps until the object simply rotates around the center of the finder, and you will have it aligned perfectly with the hinge.

To keep cost down, many astrophotographers use a simple straw or small pipe to sight through. I have seen one tracker sight through the hinge itself, by removing the hinge pin during alignment!

Enjoy and Clear Skies to you!

PS: I would LOVE to see YOUR photos taken with this tool!