Video cameras that are installed to record activities in classrooms can be positioned anyplace there is a place to mount them. Some may be mounted on the ceiling, some on the wall, others on a ledge or a column. Some are centered in the room, some are on the right, others are on the left. Some may be closer than others to the front of the room. Viewing lecture capture recordings made in various classrooms is an inconsistent viewing experience for students, and in many instances the images necessary for viewing and comprehending information on a room's white board (often the focus of many classes) may be framed loosely, obstructed, or may keystone to the point where the legibility and readability breaks down.

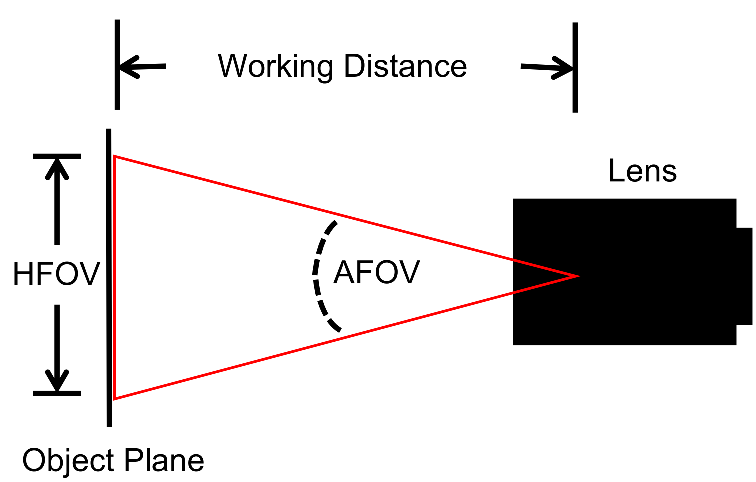
It is preferred that cameras be mounted consistently in all rooms to allow for two advantages. The first is to position a camera so the information on the white board becomes the primary focus of the recording and easily can be seen and comprehended when the recordings are viewed. Second, consistent camera positioning creates a common viewing experience across all rooms where lectures are captured - adding to the overall production value of lecture capturing.

Academic Technology Services has addressed the positioning of cameras in the classrooms by developing an application that will calculate the optimum position for video cameras which will allow for adequate framing that best captures white board activity.

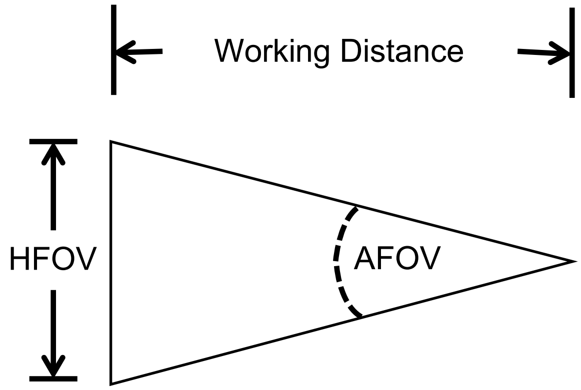
ATS started with the question, how far back should a camera be placed to capture a given width (defined whiteboard space) for a particular camera lens' field of view?

The calculations are based on two triangles. The first measures the distance between the camera and the white board (working distance) and the second measures how high the camera should be positioned in the room.

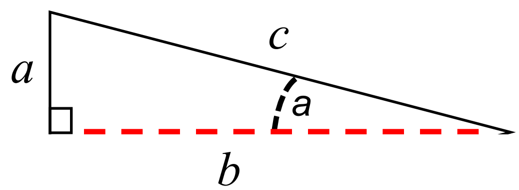
In the figure below HFOV represents the horizontal field of view which is the width to be captured. The red triangle represents the actual field of view, that is, the angle of view seen by the lens. Light coming into the lens is in the shape of a cone, but in two dimensions becomes a triangle. Using both the HFOV and the AFOV (actual field of view) as represented by this triangle one can calculate the working distance – the distance between the white board (object plane) and the camera lens.



To find the working distance, the isosceles triangle created by the lens field of view …



… must be converted into a right triangle by dissecting it into two halves. The line of dissection represents the working distance (side b below).



To find the working distance, we can apply a simple formula where the tangent of angle a equals the opposite side (a) divided by the adjacent side (b). It is important to remember that these two dimensions represent half of the original HFOV and AFOV –

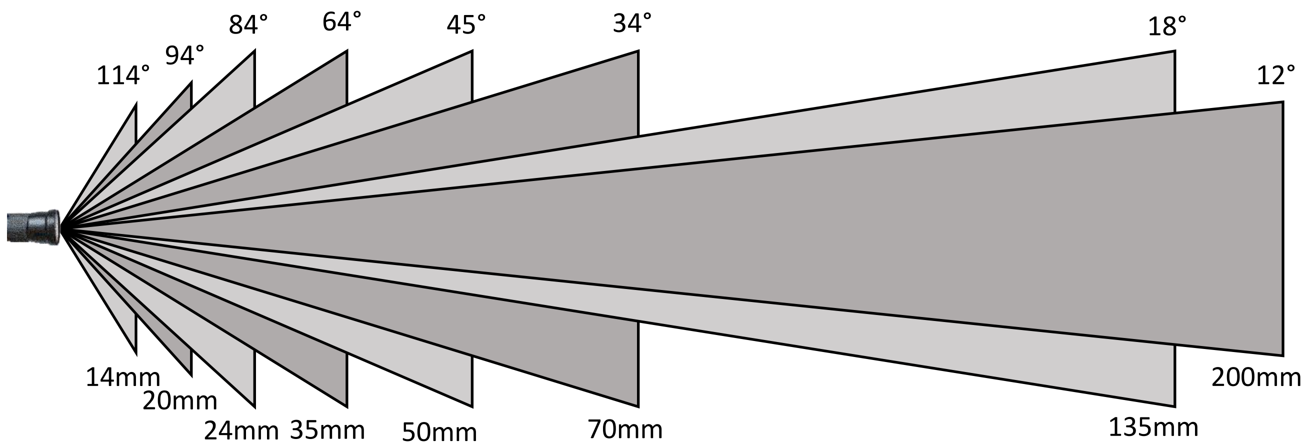
$$\text{tangent } a = \frac{\text{opposite leg } a}{\text{adjacent leg } b}$$

The equation can be transposed to solve for side b, the distance we want to determine, where –

$$b = \frac{a}{\tan(a)}$$

It is important to remember that the critical variable in this equation is the focal length of the lens – that is, the actual field of view (AFOV). Wide lenses have very wide fields of view while long lenses have narrow fields of view.

In the following chart, one can see that a 50mm lens, for example, has a field of view of 45 degrees while a 200mm lens has a narrower field of view of only 12 degrees. Fields of view are important when the tangent of half of the horizontal field of view needs to be determined as a variable in the equation.



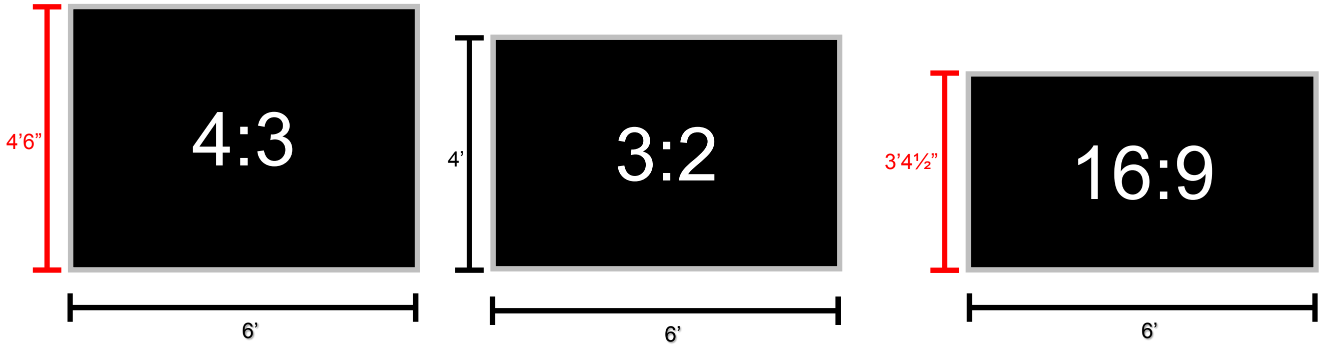
The fields of view for all lens focal lengths ranging from 10mm to 200mm are factored into the camera application. Fields of view are calculated for all focal lengths ranging in one-degree increments and are referenced when the focal length is entered into the application along with the corresponding tangent for one half of the angle of each field of view. The width of the field of view is important to determine the defined width of the horizontal field of view that is desired.

If a camera is equipped with a zoom lens with a range of focal lengths the question arises, which field of view should be used. The widest? The narrowest? Somewhere in between? The application has been designed to calculate the midpoint between the widest and the narrowest field of view.

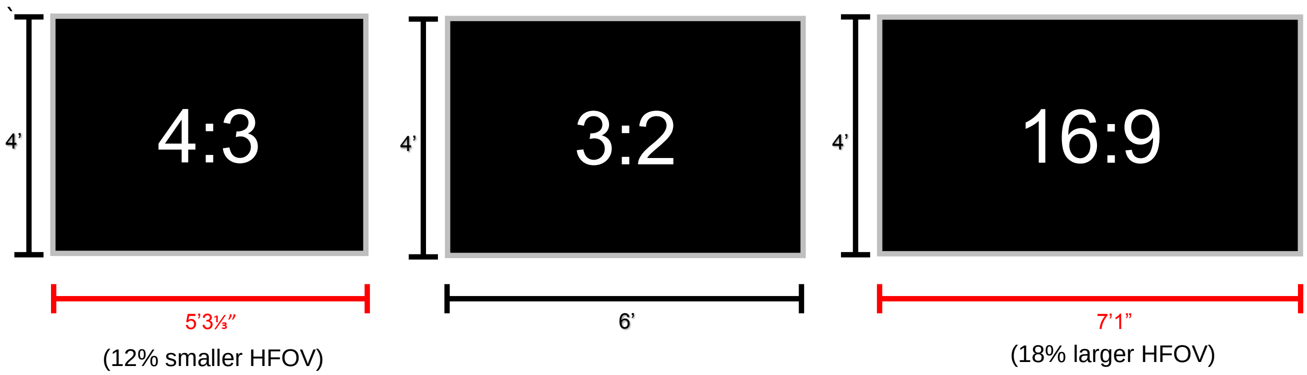
Using the midpoint as the calculation reference allows some latitude in shot framing. Although designed primarily to frame a desired area of a white board, there may be times when the camera needs to be zoomed in to capture small writing or detailed drawings, or when the camera needs to zoom in to other pre-set shots such as an instructor at the classroom podium. Conversely, not all activity in the classroom happens on the white board or at the instructor's podium so there is latitude to zoom out to include such classroom activities as demonstrations, panel discussions, and student presentations.

Calculating the camera distance using the midpoint of the zoom range also allows for 'wiggle room' should the calculated position be compromised by obstructions in the room such as projectors, HVAC ducts, and lights. The camera can be moved forward or backwards and the framing can be adjusted by zooming slightly to accomplish the desired HFOV.

Such leeway also is important to adjust for a video's aspect ratio. This app is set up to calculate a desired width. It is based on digital cameras where the aspect ratio is 3:2, so the camera, if recording a six-foot width, would 'see' an image that is four feet high. The previously common 4:3 aspect ratio yields a higher image where a six-foot wide image would produce an image that is 4 feet, six inches high. Modern 16:9 formats are not as high – a six-foot wide image would yield three feet, four and a half inches in height. Since the app is set up to capture a certain width, it should work for any aspect ratio where that width is desired.

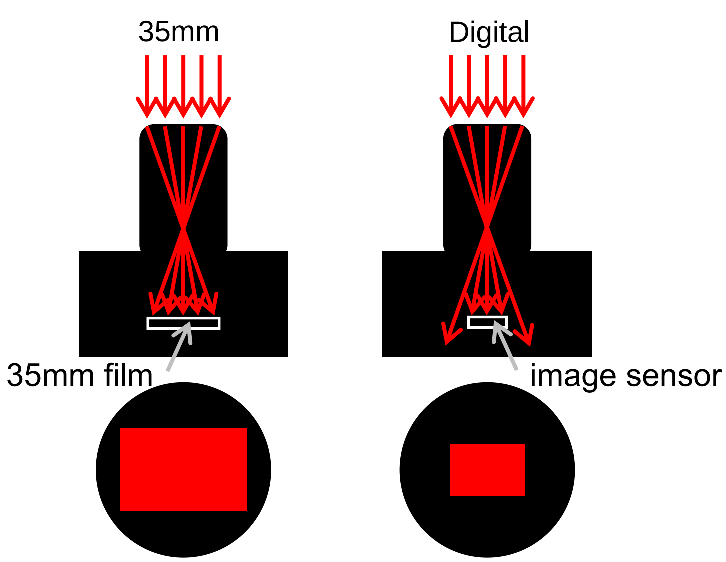


If height is more important than width, the calculation for a 4:3 image should be reduced by 12% while the height for a 16:9 image should be increased by 18%, attainable by zooming the lens in or out slightly.



Using the midpoints of the zoom ranges on two of our video cameras, we went into the classrooms to test the calculations of the camera distances necessary for various horizontal fields of view. However, every test resulted in a finding contrary to what was expected. Each attempt gave us framed shots that were much closer than anticipated. After a thorough check of the equations and camera settings, and noting that they were accurate, we eventually discovered the reason why the shots appeared closer.

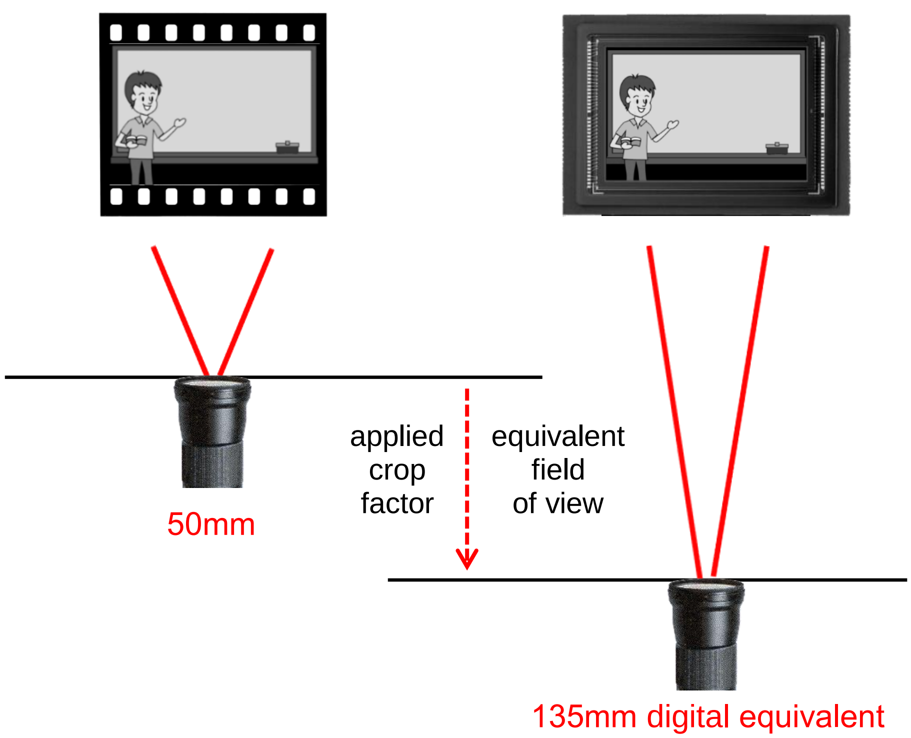
We are conditioned to seeing images that are based on nearly seventy years of 35mm photography. Lenses work the same whether using a 35mm camera or a newer digital camera. A 35mm frame is 36mm wide by 24mm high. Unless using a full frame digital camera, the electronic image sensor in a digital camera is smaller than a 35mm frame, thus capturing a smaller sample of the light coming in through the lens. Consequently, the smaller captured image area makes it appear that the camera is closer to the subject even though it is not.



To correct the proximity problem, we need to apply a crop factor to our original field of view to arrive at an *adjusted* field of view. The adjusted field of view then would simulate a tighter, comparable lens setting that would allow the calculations to work accurately.

The crop factor is the ratio of the digital sensor to 35mm. Multiplying the lens focal length setting by the crop factor will result in an equivalent focal length relative to 35mm film.

As an example, we will use a lens that is set to a 50mm focal length. We will use a digital image sensor that is 13.2mm wide. To arrive at the crop factor, we must divide the original width of a 35mm film frame (36mm) by the sensor width (13.2mm) which results in 2.72. Rounding off to one decimal point will give us a crop factor of 2.7 which will be used to multiply the original focal length (50mm) by. Multiplying 50mm by 2.7mm results in a product of 135mm. So, for calculation purposes our adjusted field of view (focal length) would be 135mm. Using this equivalent FOV calculates a position farther back from the video target, but also results in the desired horizontal field of view.



The diagram below represents popular digital image sensor sizes found in many of today's cameras. If a sensor is, or is nearly the same size as a 35mm frame, the camera is referred to as a full frame camera since the image it collects is equivalent to the image size of 35mm film. However, most cameras used in classrooms have sensors that fall on the right side of the chart – that is, they are much smaller than 35mm film. The crop factors of each are important variables in calculating a camera's distance.

Common Sensor Sizes

35mm Film	Full Frame	APS-H	APS-C	4/3	1"	1/1.63	1/2.3"	1/3.2"
36 x 24mm	36 x 23.9mm	27.9 x 18.6mm	23.6 x 15.8mm	17.3 x 13mm	13.2 x 8mm	8.38 x 5.59mm	6.16 x 4.62mm	4.54 x 3.42mm
Crop Factor:	1.0	1.29	1.52	2.0	2.7	4.3	5.62	7.61

Because of the importance of the sensor size and its associated crop factor, we learned not to rely too much on manufacturers' sensor labels. In the chart above, where each column is titled with a common manufacturer sensor description, note that the 1" sensor is only 13.2mm wide. However, 1 inch is equal to 25.4mm. We noticed this discrepancy and found the reason for it in an online article titled, *The Myth of the 1" Sensor – Is it Fraud or a Felony?* by Ken Rockwell. (http://kenrockwell.com/tech/one-inch-sensor.htm).

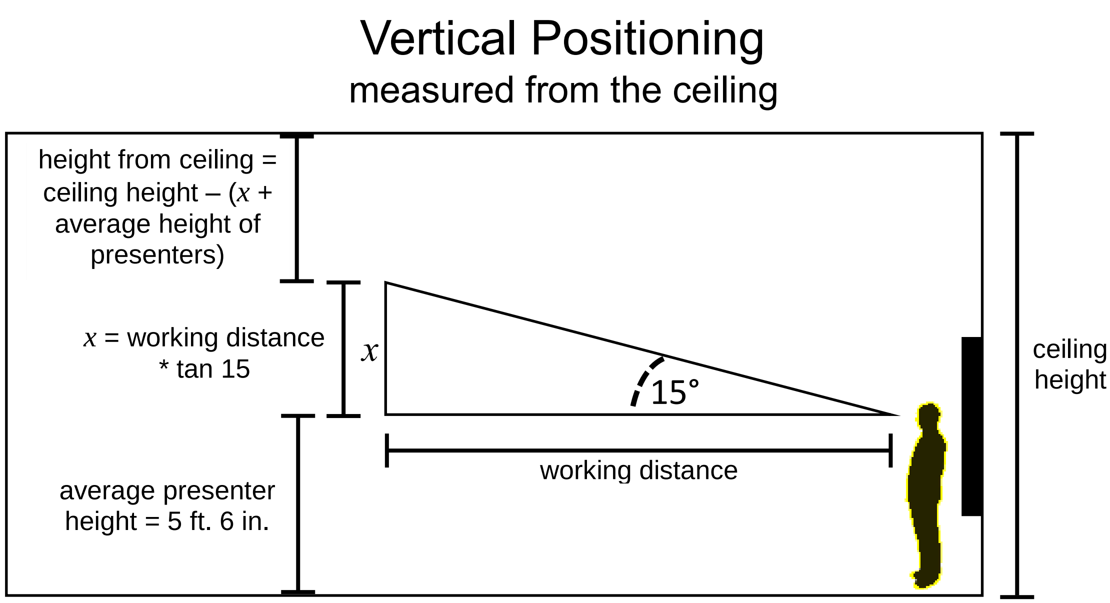
Rockwell says that when vacuum tubes earlier were used in video cameras the tubes were measured by their outside diameters. The sensor inside the tube was smaller. So, a tube with a 1-inch diameter had an image sensor inside that was of smaller size. Rockwell claims that digital camera makers use this technique to try to make their tiny sensors seem bigger than they are. In other words, he says, "the only thing one inch about a 'one-inch sensor' is that a vacuum tube 50 years ago would have had an outside diameter of about an inch if it had an image pick-up area about the same size as the (so called) 'one-inch sensor' today."

We learned not to rely on marketing descriptions, rather always to look at the specifications in the camera manual or online to get an accurate horizontal measurement of the image sensor.

This is how the application works to determine the distance that a camera should be placed to capture a specific image width. As an example, we will assume that our camera has a zoom lens with a range from 35mm to 80mm. Our camera has a sensor width of 13.2mm. We want to capture a 6-foot width of a white board. Using the equation above, where our working distance is side b of the right triangle, we can calculate that the working distance is equal to one half of our desired horizontal field of view (3 feet) divided by the tangent of one half of our focal length field of view. We need to determine the midpoint of our zoom range which is 57mm. Our sensor's crop factor would be 36mm divided by 13.2mm which results as 2.7. So, our equivalent focal length is 57mm x 2.7 crop factor which results in 154mm. The actual field of view of a 154mm lens is 16 degrees, but we must remember to divide that in half since we are calculating the side of a right triangle that is one half of the original actual field of view. The result is a field of view that is 8 degrees. The tangent of an 8-degree angle is 0.140. We now have the values needed to complete the equation.

The working distance is equal to 3 (one half of the desired horizontal field of view) divided by 0.140 (the tangent of the 8-degree equivalent field of view). b = 3/0.140 = 21.4285. So, we will place our camera 21.4 feet back from the white board to capture a 6-foot width with our zoom lens set at its halfway point, allowing us the option to zoom in or out as necessary to make adjustments, to accommodate other pre-set shots, or for other framing possibilities.

At this point, our calculations are half complete. We still must determine how high the camera should be placed in the room. Video cameras normally are elevated between 15 and 20 degrees. We chose 15 degrees to minimize looking down too much on the presenter, and to decrease the effects of vertical keystoning. Now that we know the camera distance to the subject, and know that it should be elevated 15 degrees, we can determine how high the camera should be positioned in the room using the same equation we used already, but this time calculating the length of x (which above represented the horizontal field of view).



We already know the working distance from our earlier example calculation. The app will use this distance value in the height calculation automatically. The 15-degree angle remains a constant. The tangent of a 15-degree angle is 0.2679, so this becomes a constant in the equation. To solve for side x, we multiply the working distance by the tangent, 0.2679. The result is 5.76, or 5 feet 9 inches.

To determine how far down from the ceiling the camera should be placed we must know the ceiling height since we want to measure from the ceiling down. We cannot measure from the floor up because in some rooms the floors are not level, rather they are sloped or tiered, and there may be no level base to measure up from. Therefore, it is important to know the ceiling height of the room.

Notice in the diagram that the triangle is placed 5 feet 6 inches above the floor. On average, presenters are 5’6” tall. (5’4” for women and 5’9” for men according to Wikipedia.) We want our camera to point 15 degrees down on the heads and shoulders of the presenters so we set our target point at 5’6” above the floor - the approximate average speaker height.

The last step in the calculation – the ceiling height of the room minus the x height of the 15-degree triangle minus 5 feet 6 inches – determines how far from the ceiling the camera should be placed.

Continuing with our example we can use the same formula we used to determine the working distance to calculate the length of side x –

$$tan\ a = \frac{opposite\ leg\ (x)}{adjacent\ leg\ (b)}$$

To solve for side x, we can transpose the formula to –

$$x = side\ b\ *\ tan\ (15°)$$

We already know the value of side b – that is the working distance that was calculated previously, and the 15-degree angle never changes so the tangent of that angle, 0.2679, becomes a constant in the equation.

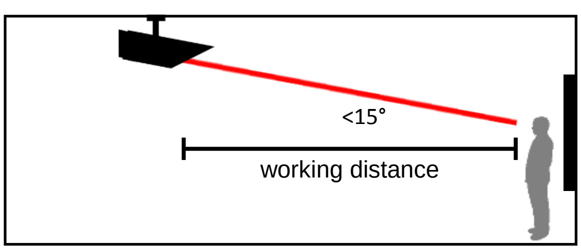
In our example, we calculated the working distance (side b) to be 21.4 feet. So, multiplying 21.4 by the tangent value of the 15-degree angle, 0.2679, we find the value of x to be 5.73 (5.75 rounded off).

To determine the distance the camera should be hung below the ceiling, we will take the ceiling height, which is 12 ft. in our example, and subtract the value of x as well as the average height of a presenter.

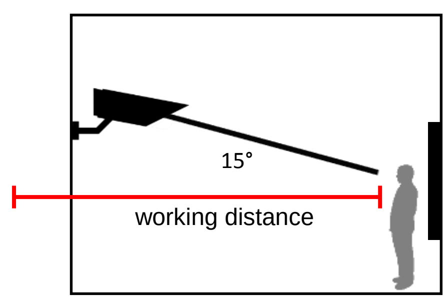
12 ft. minus 5.75 ft. minus 5.5 ft. equals .75 ft. Our camera will be placed three fourths of a foot, or 9 inches, below the ceiling.

Note that if the position below the ceiling is calculated as a negative number, the ceiling height is too low to support a 15-degree angle at the calculated working distance. In such cases we recommend using the working distance, but mounting the camera as close to ceiling height as possible to maintain as much camera elevation as possible.

Note, too, that in smaller rooms, the calculated working distance may extend beyond the back wall of the room. If so, mount the camera on the rear wall at a 15-degree angle above the presenter.



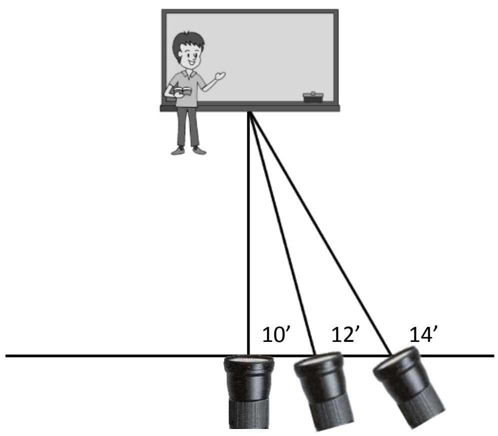
Low ceiling: camera mounted at ceiling height <15°



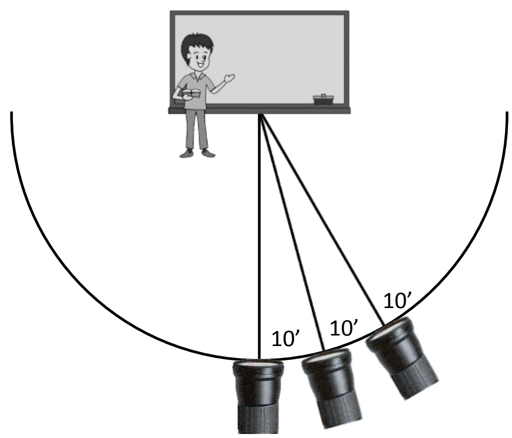
Room shorter than working distance: camera mounted on rear wall at 15° angle.

One thing to be mindful of (that is not calculated in the camera positioning application) is where to place a camera laterally in a room. Placing a camera in the center of a room perpendicular to the front may cause problems by obstructing what is being written on a white board behind the presenter. Problems may arise, too, from other fixtures centered in the ceiling, such as video projectors. From a production standpoint framing a shot straight behind the back of a presenter's head is less appealing than an over the shoulder shot. Our recommendation is to move the camera about 15-degrees right or left of center. Since most presenters are right-handed, moving the camera to the right of center would be beneficial in most situations in order to see what's being written on a white board in front of a presenter's shoulder. If budget will allow, a second camera positioned left of center would benefit left-handed presenters.

Be careful not to move the camera left or right laterally. That will increase the distance between the camera and the target. Move the camera on an arc to maintain the calculated viewing distance. However, don't move it too far to avoid extreme keystoning.



Moving the camera laterally will increase the viewing distance.



Moving the camera along an arc maintains the proper viewing distance.

Step by step, this is how the camera positioning application was constructed and operates, using the example given previously.

Our camera has a zoom lens that ranges from 35mm to 80mm; we have a digital image sensor labeled one-inch; we will capture a six-foot width of our white board; and the ceiling in our room is 12 feet high.

We must determine the field of view of the midpoint of our zoom lens. Using the midpoint will allow us to adjust our camera framing for tighter or looser shots, or for other camera presets such as framing the instructors' podium.

The first step in the application is to enter the widest field of view of our lens, 35. Then we enter the narrowest field of view, 80. The application will determine the range between the two numbers which is 45. By dividing 45 by 2 (22.5) and adding that value to the widest field of view, 35, the midpoint for our lens is 57.5mm.

We must be sure that our digital sensor width is accurate. Although our sensor in this example is one-inch we check our camera specifications and determine that the actual width of a one-inch sensor is 13.2mm.

The next step in the application is to enter 13.2 as our sensor size. The application will divide 36, the size of a 35mm frame, by 13.2 and calculate a crop factor of 2.7.

The application will multiply our midpoint field of view, 57.5 by the crop factor, 2.7, and deliver an adjusted field of view of 154mm.

The application then will ask us to enter 154 into the next step. Using a comparison chart, it returns the actual field of view of a 154mm lens which is 16 degrees.

Since our equation works with a right triangle, we need to split the isosceles triangle of the adjusted field of view in half. The application will divide 16 degrees by 2, and will divide our desired white board width (horizontal field of view – 6 ft.) by 2 and apply those values to the equation 'working distance = horizontal field of view divided by the tangent of the angle of the actual field of view'. In this instance, the working distance is equal to 3 divided by 0.140 and results in a determined working distance of 21.4285 feet, rounded off to 21.4 feet.

The next step is to enter the ceiling height in feet in the room where the camera will be mounted. The application already has determined the working distance, and will use that value to determine the length of the opposite side of a 15-degree right triangle. The equation used is the same one we used earlier, but this time solving for a different side of the triangle. The 15-degree triangle is constant so the tangent of 15-degrees, 0.2679, is programmed into the app and does not change. This will determine the value of x as illustrated in the diagram above, which will be subtracted from the ceiling height.

Transposed, the equation is 'x equals working distance x tan 15' so 'x = 21.5 x 0.2679 = 5.76.' Rounded off the length of side x is 5.75 feet.

The calculation now subtracts the x value from the ceiling height, and subtracts the average presenter height of 5.5 ft., and results in 12 - 5.75 - 5.5 = 0.75. Our camera should be hung 0.75 feet, or 9 inches, below the ceiling.

Calculation process beginning to end –

user is instructed to "Enter the smallest focal length (mm)"

user enters a value (35)

app registers value (35) in a field

user is instructed to "Enter the largest focal length (mm)"

user enters a value (80)

app registers value (80) in a field

app determines the midpoint between the smallest and the largest focal length

app subtracts the smaller value from the larger value to determine a range

(80–35)

app returns a value

(45)

app divides the returned value by 2

(45/2)

app adds that value to the value in the smallest value field above

(35+22.5)

app returns this value as the midpoint of the zoom range

(57.5)

user is instructed to "Enter sensor size (mm)"

user enters a value (13.2)

app registers a value (13.2) in a field

app calculates crop factor by dividing 36 by previous field

(36/13.2)

(2.7)

app multiplies zoom range midpoint by crop factor

(57.5 x 2.7)

app returns value as equivalent focal length

(154)

user instructed to enter "Horizontal Field of View (in feet)"

user enters a value (6)

user instructed to "Select Equivalent Focal Length (as determined above)"

user selects (154) from dropdown list

app substitutes equivalent field of view with tangent of one half of the field of view

app registers value

(0.140)

app calculates one half of the horizontal field of view

value from earlier field / 2

(6/2)

(3)

app calculates working distance

(3/0.0140)

(21.5)

User instructed to "Enter the height of the ceiling in feet"

user enters a value (12)

app calculates x value of height triangle

app uses value determined above for working distance

app multiplies working distance by tangent of 15-degree angle

(21.5x0.2679)

(5.75)

app subtracts x value and constant 5.5 from entered ceiling height value

(12 – 5.75 – 5.5)

app returns result as distance from ceiling in feet

(0.75)

The app returns the value **21.5** as the working distance in feet, and **0.75** as the distance from the ceiling in feet.