

## DX or APS-C Format DSLR Camera

A medium-format digital single lens reflex (DSLR) is to be designed using an image sensor in the DX or APS-C format. The sensor size is 24 x 16 mm.

a) The first task is to specify the focal length of the camera objective. The field of view for distant objects should be equivalent to a 35 mm film based camera with a 38 mm focal length lens. The 35 mm film format is 24 x 36 mm.

b) The next task is to determine the lens focus positions needed to cover a range of object positions from infinity to 500 mm. The camera lens will operate at  $f/4$ .

One criteria for good image focus is that the blur diameter due to defocus matches the pixel width on the sensor. For this problem, diffraction and aberrations are to be ignored. (Note that this criterion is very conservative, and significantly more blur may still produce good images.)

The pixels on the image sensor are 10.0 x 10.0  $\mu\text{m}$ .

The first focus zone extends from infinity to its  $L_{\text{NEAR}}$ . The next zone starts at this position as  $L_{\text{FAR}}$  and continues to a new  $L_{\text{NEAR}}$ . The zones continue until the entire object range is covered. At each zone, give the required sensor location relative to the rear focal point of the lens. These values actually provide the amount of lens motion that is required to go from zone to zone (as the lens is actually moved, not the sensor).

This problem is best done by setting up a spread sheet. This also allows the various parameters to be varied to investigate system changes:

How does the number of required zones vary with

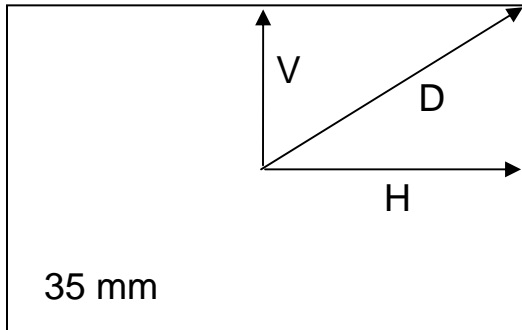
Focal length?

Blur?

F/#?

Solution:

a) Required FOV – based upon 35 mm format with a 38 mm lens. Can use either the Horizontal, Vertical or Diagonal dimensions:



V: 12 mm  
H: 18 mm  
D: 21.6 mm

Chief Ray Angles:

$$\bar{u}_V = \frac{12mm}{38mm} = .316$$

$$HFOV_V = \tan^{-1}(\bar{u}_V) = 17.5 \text{ deg}$$

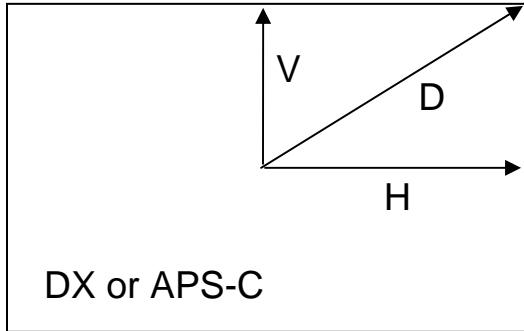
$$\bar{u}_H = \frac{18mm}{38mm} = .474$$

$$HFOV_H = \tan^{-1}(\bar{u}_H) = 25.3 \text{ deg}$$

$$\bar{u}_D = \frac{21.6mm}{38mm} = .569$$

$$HFOV_D = \tan^{-1}(\bar{u}_D) = 29.7 \text{ deg}$$

To determine the DX format focal length, these FOV's from the 35 mm system must be matched. Since the dimensions of the DX sensor are in the same ratio, any of the dimensions can be used to determine the focal length.



V: 8 mm  
H: 12 mm  
D: 14.4 mm

Using the Vertical dimension:

$$\bar{u}_V = .316 = \frac{8mm}{f}$$

$$f = 25.3mm$$

b) The focus zones are determined by using the equations for Depth of Field:

$$L_{FAR} \approx \frac{L_0 f D}{f D + L_0 B'}$$

$$L_{NEAR} \approx \frac{L_0 f D}{f D - L_0 B'}$$

and solving for  $L_0$  in terms of  $L_{FAR}$ :

$$L_0 \approx \frac{L_{FAR} f D}{f D - L_{FAR} B'}$$

$$f / 4 \rightarrow f / D = 4 \quad D = 6.33mm$$

$$B' = 10.0 \mu m = 0.010mm$$

For the most distant zone or zone 1,  $L_{\text{FAR}}$  is infinity.  $L_0$  and  $L_{\text{NEAR}}$  are then determined. The image plane for the sensor is found by imaging  $L_0$ :

$$\frac{1}{L'_0} = \frac{1}{L_0} + \frac{1}{f} \quad f = 25.3\text{mm}$$

The following spreadsheet provides the results:

Zone	L FAR	L 0	L NEAR	Image Plane	Focus Shift
1	1E+20	-16014.90	-8007.45	25.34	0.040
2	-8007.45	-5338.30	-4003.73	25.42	0.120
3	-4003.73	-3202.98	-2669.15	25.50	0.201
4	-2669.15	-2287.84	-2001.86	25.58	0.283
5	-2001.86	-1779.43	-1601.49	25.66	0.365
6	-1601.49	-1455.90	-1334.58	25.75	0.447
7	-1334.58	-1231.92	-1143.92	25.83	0.530
8	-1143.92	-1067.66	-1000.93	25.91	0.614
9	-1000.93	-942.05	-889.72	26.00	0.698
10	-889.72	-842.89	-800.75	26.08	0.783
11	-800.75	-762.61	-727.95	26.17	0.868
12	-727.95	-696.30	-667.29	26.25	0.954
13	-667.29	-640.60	-615.96	26.34	1.040
14	-615.96	-593.14	-571.96	26.43	1.127
15	-571.96	-552.24	-533.83	26.51	1.215
<b>16</b>	<b>-533.83</b>	<b>-516.61</b>	<b>-500.47</b>	<b>26.60</b>	<b>1.303</b>
17	-500.47	-485.30	-471.03	26.69	1.392
18	-471.03	-457.57	-444.86	26.78	1.481
19	-444.86	-432.84	-421.44	26.87	1.571
20	-421.44	-410.64	-400.37	26.96	1.661
21	-400.37	-390.61	-381.31	27.05	1.752
22	-381.31	-372.44	-363.98	27.14	1.844
23	-363.98	-355.89	-348.15	27.24	1.936
24	-348.15	-340.74	-333.64	27.33	2.029
25	-333.64	-326.83	-320.30	27.42	2.123

16 zones are required to image objects as close as 500 mm.

$L_0$  for the distant zone is the hyperfocal focus position of the system.

The lens position must shift by about 1.3 mm for the full range of object positions (infinity through 500 mm).

Note that the detector position must always be outside the rear focal point of the lens.

Note also that the focus zones get small for close object positions.

Using the spreadsheet:

If the focal length is decreased – fewer zones are required.

If the required blur is decreased (higher quality image) – more zones are required.

If a faster lens is used ( $D$  is increased) – more zones are required.