Section 12
Zoom/Multi-configuration Systems

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What Is the Zoom Feature in CODE V?

- The zoom feature in CODE V allows you to setup, design, and analyze systems which are not completely described by a single lens configuration
- It allows you to have multiple configurations of your lens, in which one or more parameters are changed in different configurations
  - Spacings (classical zoom lens)
  - Changes in surface parameters (radii, thicknesses, materials, special surface parameters, etc.)
  - Specification data (fields, EPD, etc.)
- We have traditionally called this feature a zoom feature, although multi-configuration would be a better description

Typical Uses of the Zoom Feature

- Conventional zoom lenses (variable focus lenses)
- Multiple conjugate optimization (e.g., macro lenses)
- Flip-in / flip-out lens attachments or alternate elements
- Spectrally divided systems
- Scanning systems
- Multiple eye positions in display systems (e.g., HUDs)

Zoom Features

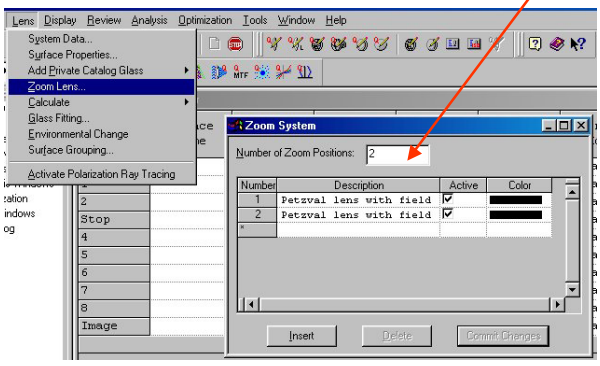
- With few exceptions, any lens data can be "zoomed"
- Up to 21 zoom positions allowed
- Simultaneous optimization over all zoom positions
- Analysis performed for all zoom positions
  - Specific zoom positions can be turned off (analysis not performed for those positions)

How to Zoom a Lens

- First, specify how many zoom positions you want
- Next, zoom each specific parameter which changes between zoom positions
  - This includes surface data (spacings, tilt angles, etc.)
  - This also includes specification data (fields, wavelength weights, etc.)
- Surface parameters which are zoomed also have zoomed control codes for whether they are frozen or variable in each zoom position

Setting Up a Zoom Lens

- Select **Lens > Zoom Lens** or click on the zoom icon



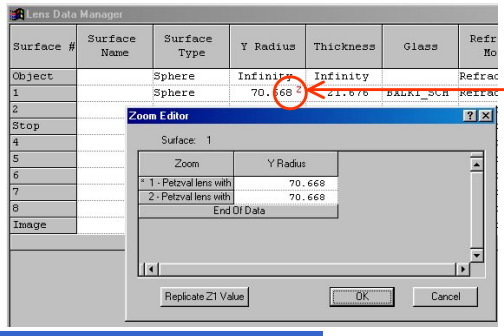
- Review the data with **Display > List Lens Data > Zoom Data**

Setting Up a Zoom Lens (Commands)

- Use the **ZOO** command and enter the number of desired positions
  `ZOO 3`
- You only need to give the **ZOO** command once
  - If you give it again with fewer positions, the higher positions are dropped
  - If you give it again with more positions, the highest position is replicated
- You can query the number of zoom positions
  `ZOO ?`

Zooming a Parameter

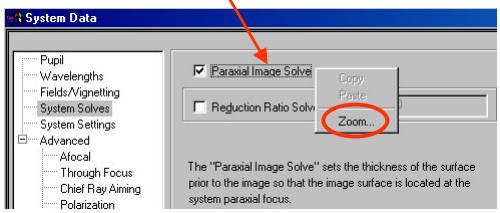
- Select the parameter to be zoomed (surface data or specification data)
- Right click and select **Zoom** from shortcut menu to open Zoom editor dialog box
- Enter value for the parameter in each zoom position.



A small "z" will appear next to the parameter

Zooming the PIM Solve

- Use **Lens > System data** to open window
- Select **System Solves** from navigation tree
- Right click on **Paraxial Image Solve** and select **Zoom**



Zooming a Parameter (Commands)

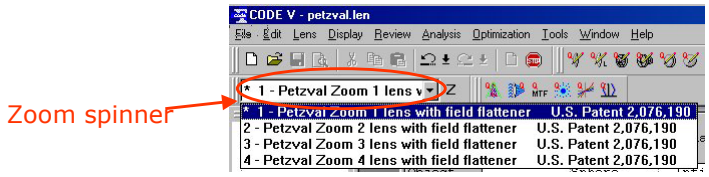
- Use the **ZOO** command with the parameter and the desired values for each zoom position
  ```
  ZOO THI S3 8.2 10.5 12.3
  ```
- If you do not enter the values, the parameter is defined as a zoomed parameter, but the values are the same in all zoom positions
  ```
  ZOO THI S6
  ```
- If you only enter one value, it is used for all zoom positions
  ```
  ZOO THI S8 10.0
  ```

Zooming a Parameter (cont.)

- Control codes (0 = variable, 100 = frozen) are automatically zoomed with the parameter
  - The previous **ZOO** commands also zoom the **THC** (thickness control code) settings
  - You can couple zoomed variables, but only to other zoomed variables of the same type
- Zoom the **PIM** solve with
  ZOO PIM

The Zoom Spinner

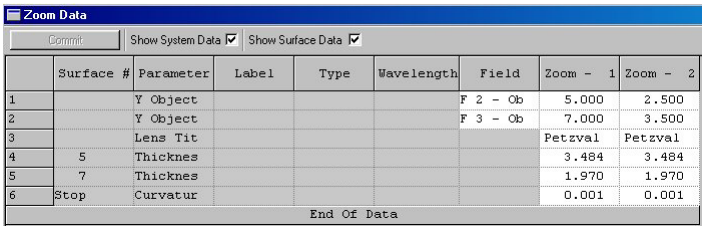
- Zoom spinner lets you select what zoom position is used for data display



- LDM spreadsheet, Surface Properties dialog box, System Data dialog box, etc., display data values for the zoom position listed in the zoom spinner

Reviewing Zoom Data

- Select **Review > Zoom Data**



	Surface #	Parameter	Label	Type	Wavelength	Field	Zoom - 1	Zoom - 2
1		Y Object				F 2 - Ob	5.000	2.500
2		Y Object				F 3 - Ob	7.000	3.500
3		Lens Tit					Petzval	Petzval
4	5	Thicknes					3.484	3.484
5	7	Thicknes					1.970	1.970
6	Stop	Curvatur					0.001	0.001

End Of Data

- Both system and surface data can be displayed

Reviewing Zoom Data (Commands)

- Review zoom data with **ZLI** command (zoom list)

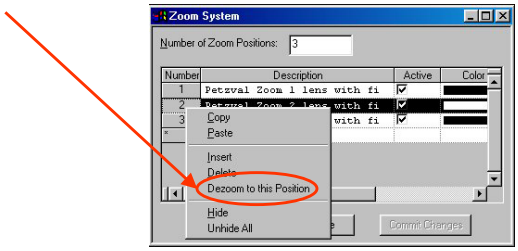
```
CODE V> ZLI SA

ZOOM DATA
                    POS 1        POS 2        POS 3

   PIM                YES          YES          YES
    THI S11       30.97100      8.22300      1.91000
   THC S11             0            0          100
   THI S13        1.72400      5.32200      1.78500
   THC S13           100            0          100
   THI S25       15.35958     15.34731     15.34947
   THC S25          100 *        100 *        100 *
   THI S26       -0.03200      0.02600     -0.01900
   THC S26             0            0            0

* GENERATED BY A SOLVE - VALUE WILL CHANGE TO
   SATISFY THE SOLVE
```

Modifying Zoom Data (Commands)

- Do not use the **ZOO** command again (not necessary)
- Enter the parameter with the new data for each zoom position
  ```
  THI S6 7.5 8.3 10.2
  ```
- **No** (or **N**) can be used to not change data for a particular zoom position
  ```
  THI S6 8.5 N 10.5
  ```
- You can also use zoom qualifiers to limit the change to certain zoom positions
  ```
  THI S6 Z3 12.3
  THI S6 Z2..3 10.4 12.5
  THI S6 Z2..3 10.4
  ```


Dezooming the Lens

- The lens can be dezoomed to a specified zoom position
  - Select **Lens > Zoom Lens** and either:
    - delete the zoom positions you don't want *or*
    - highlight the position you do want, right click and select **Dezoom to this Position**



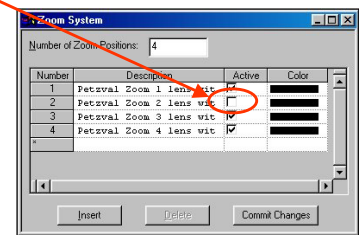
  - Results in a single configuration lens
  - Command is **DEZ** (e.g., `DEZ 3`)

Dezooming a Parameter

- A single parameter can also be dezoomed (made a non-zoomed parameter)
  - Select the cell of the parameter to dezoom
  - Right click and choose **Dezoom** from the shortcut menu
  - Command is **DEZ** (e.g., `DEZ THI S6`)

Control of Zoom Positions

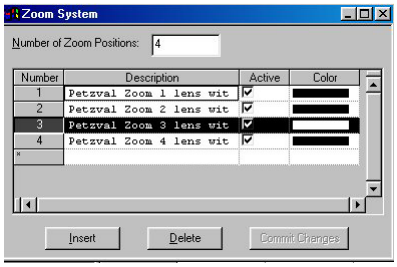
- Each zoom position is by default enabled
  - Options operate on all zoom positions
- Selected zoom positions can be disabled (turned off) with by unchecking the **Active** box in the Zoom System dialog (**Lens > Zoom Lens**)



  - Command is **POS Zk|Zi..j [ONL] Yes|No** (e.g., `POS Y N Y`)
- Optimization always operates on all zoom positions, regardless of the Active positions settings

Inserting and Deleting Zoom Positions

- Click **Lens > Zoom Lens** and select a zoom position
  - **Insert** button inserts a new zoom position before the selected position, with the data of the previous zoom position
  - **Delete** button deletes the current zoom position



Inserting, Deleting, and Copying Zoom Positions (Commands)

- Zoom positions can be inserted with **INS Zk | Zi..j**
  - Higher numbered zoom positions are pushed up in number
  - Inserted zoom positions have the zoom data as the next lower numbered zoom position
    - For example, **INS Z3** will insert a new zoom position with the same data as zoom position 2
- Zoom positions can be deleted with **DEL ZK | Zi..j**
  - Higher numbered zoom positions are dropped down in number
- The data from one zoom position can be copied to another zoom position with **COP Zi Zj**

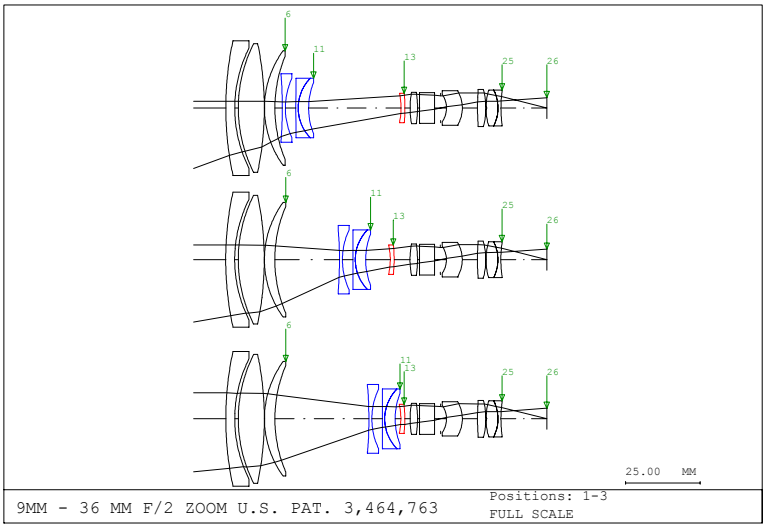
Zoom Example - Classic Zoom Lens

- Three position zoom lens
  - 3.8 X zoom lens
  - Overall length is constant, and back focal length is constant
- Zoom data input (lens data not shown):

```
ZOO 3
ZOO THI S6      2.5      21.65     31.5
ZOO THI S11    30.971     8.223     1.91
ZOO THI S13     1.724     5.322     1.785
ZOO PIM           Y         Y         Y
ZOO THI SI
```

data for zoom 1 | data for zoom 2 | data for zoom 3

Zoom Lens Example (cont.)

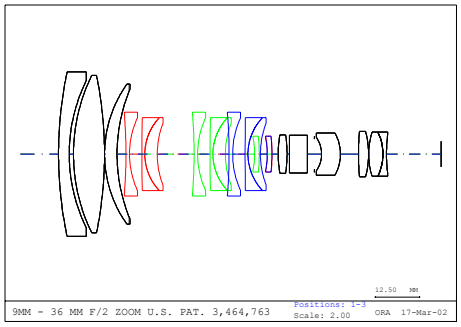


VIEW Commands for Zoom Example

```
VIE                  ! enter the VIEW option
RET Y Y N            ! used to overlay zoom positions
OFS Z1 0  2.1        ! offset zoom 1 up by 2.1 inches
OFS Z3 0 -2.1        ! offset zoom 3 down by 2.1 inches
SF 1                 ! scale factor (full scale)
NBR SUR S6 GRE       ! number surface 6 (in green)
NBR SUR S11 GRE      ! number surface 11
NBR SUR S13 GRE      ! number surface 13
NBR SUR SI-1 GRE     ! number the PIM surface
NBR SUR SI GRE       ! number the image surface
RFR N                ! don't draw the reference rays
RSI F1 0 1           ! draw on-axis upper marginal ray
RSI F3 0 0           ! draw full field chief ray
LNS S7..10  BLU      ! draw first moving group in blue
LNS S12..13 RED      ! draw second moving group in red
GO                   ! execute the option
```


Alternate VIEW Commands for Zoom Example

```
!Colors for zoom positions
CLS ZOO RED GRE BLU
VIEW
!Put 3 zooms on 1 pg
RET Y Y N
!Overlay zooms at S1
OFS OVE S1
!Scale factor =2
SF 2
!Don't draw ref. rays
RFR N
!Draw surfs 1 to 6 and
LNS S1..6 BLA
!14 to image in black
LNS S14..I BLA
GO
```



Using Zoom in Optimization

- In the previous example, we want the overall length to vary, yet be the same in all zoom positions
  - We want to do the same for the back focal length
- This is done in Optimization by using user-defined constraints

```
AUTO

! constrain overall lengths to be equal
@DELTA_OAL_2_1 == (OAL S1..I-1 Z2) - (OAL S1..I-1 Z1)
@DELTA_OAL_2_1 = 0
@DELTA_OAL_3_1 == (OAL S1..I-1 Z3) - (OAL S1..I-1 Z1)
@DELTA_OAL_3_1 = 0

! constrain image distances to be equal
@DELTA_IMD_2_1 == (IMD Z2) - (IMD Z1)
@DELTA_IMD_2_1 = 0
@DELTA_IMD_3_1 == (IMD Z3) - (IMD Z1)
@DELTA_IMD_3_1 = 0
```


More on Zoom and Optimization

- Some optimization parameters can be different across zoom positions, e.g.:
  - Aperture weighting (**WTA**)
  - Pupil grid for MTF optimization (**DEL**)
- Other optimization parameters are always the same across zoom positions, e.g.:
  - Run-time controls: Maximum/minimum # of cycles (**MXC**, **MNC**), improvement fraction (**IMP**)
  - Error function content (wavefront or ray **WFR Y|N**), type (**ERR**)

Still More on Zoom and Optimization

- General constraints work for all zoom positions simultaneously
  - These include min/max element, edge, and air thicknesses (**MXT**, **MNT**, **MNE**, **MNA**, **MAE**)
  - Remember that a center or edge thickness constraint (**CT** or **ET**) on a surface deactivates ALL the general constraints for ALL zoom positions for that surface
- Specific constraints act on a specific zoom position only
  - If a zoom position is not specified, zoom position 1 is assumed; Z1 is default entry in zoom dialog box

```
EFL = 100      ⇒      EFL Z1 = 100
```


Zooming Field Weights

- Default: the same field weights are applied across zoom positions

	Zoom Position		
Field	1	2	3
1	1.0	1.0	1.0
2	0.875	0.875	0.875
3	0.5	0.5	0.5

- You can enter field weights in either direction

```
WTF F1 1.0 0.9 0.9       !wt for field 1 for all zooms
WTF Z1 1.0 0.9 0.8       !wt for each field for zoom 1
```

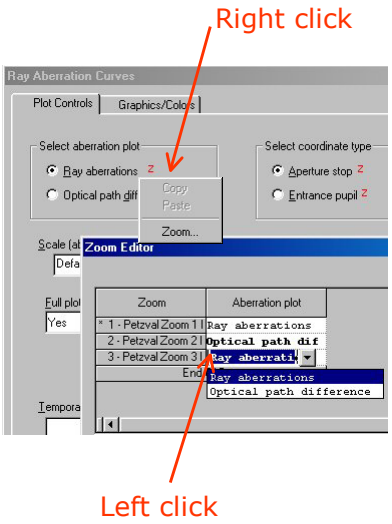
  - This is true for the **WTX** and **WTY** components of **WTF**
- The same is also true for wavelength weighting

```
WTW W1 2 4 2       !wt for wavelength 1 for all zooms
WTW Z1 1 2 1       !wt on wavelengths for zoom 1
```

- For option parameters which are zoomable, enter data in separate fields

Zoom Features in Other Options

- Some option parameters can have different values in each zoom position
  - Right click to zoom the parameter and open zoom editor.
  - Left click in data cell to see drop-down menus of options.
- Enter a value for each parameter



Zoom Features in Other Options (Commands)

- Some option parameters can have different values in each zoom position
  - These are indicated with ....z in syntax listings

```
MFR max_lines_per_mm....z
```

- Enter a value for each parameter

```
MFR 100 50 100
PLO FRE Y N Y
```

  - If only one value is entered, it is assumed to apply to all zoom positions
- A zoom qualifier can be used to specify a given zoom position
  - Only way to enter zoomed titles in commands

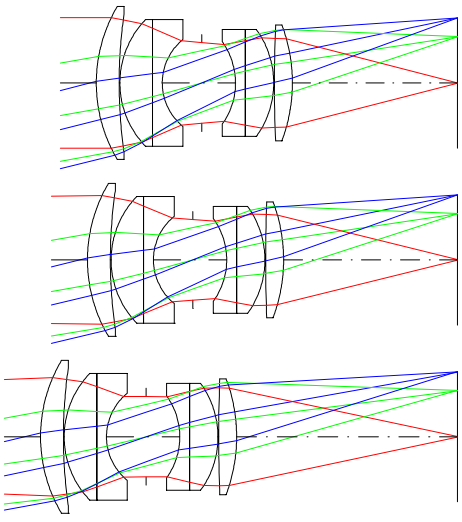
```
TIT Z1 "First Zoom Position"
```

Zoom Example: Multiple Conjugate Optimization

- Most fixed focal length camera lenses are designed to focus from infinity down to some close distance
- In this case, the lens as a whole does not change, only its conjugate distances (object and image distances)
- The image height stays the same (fixed film format)
  - This can be done with image height field specification
  - The object size will change with object distance
- When setting up this type of lens, the object distance can be zoomed as fixed values, or by its reduction ratios (solves for object distance)
- The paraxial image distance (**PIM**) should also be zoomed, as should the defocusing term
- When optimizing, the EFL only needs to be controlled for the infinite conjugate zoom position

Multiple Conjugate Example

```
RES CV_LENS:DBGAUSS
YIM 0 (YIM F2) (YIM F3)

ZOOM 3
ZOO THI S0 1E13 3000 500
ZOO PIM
ZOO THI SI

AUTO
EFL Z1 = 50.0
etc.
```

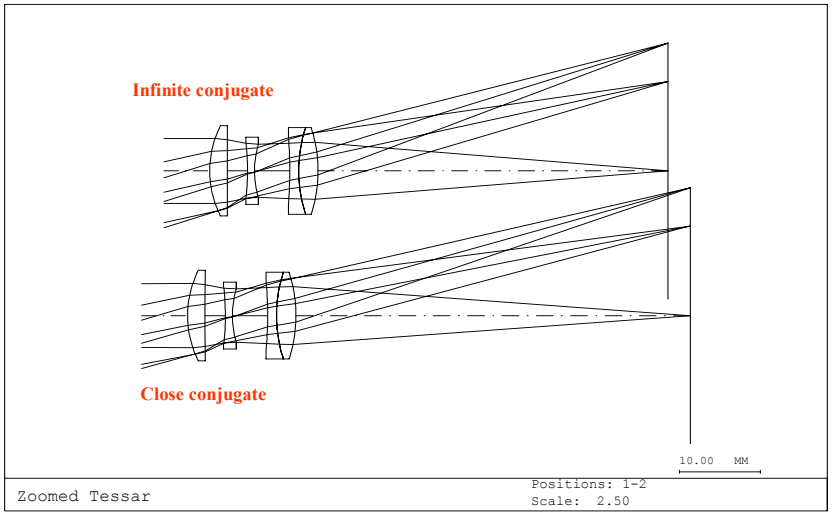


Workshop 15
Multiple Conjugate Zoom Lens

1. Using the final optimized Tessar that you saved, set up a two position zoom lens. The two positions will be for imaging an object at infinity and at 500 mm (typical focus range for a 35 mm camera lens). The lens will shift as a whole (as it does in camera lenses), only requiring refocusing for each zoom position.

   Redefine the field specification to image heights (use 0, 12.6, and 18.0), and zoom the object distance, the paraxial image distance (**PIM**), and the defocus term (**THI SI**).
2. Since the lens is already optimized for infinite object distance, freeze the lens, and only optimize on the defocus term for zoom position 2. Compare the lens performance of the second zoom position with the first, using **Analysis > Diagnositcs > Ray Aberration Curves** and **Analysis > Diffraction > Wavefront Analysis**

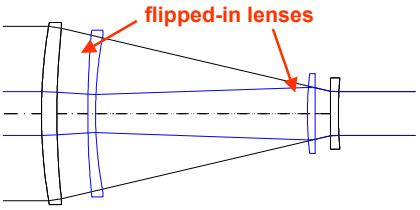
Workshop 15
Multiple Conjugate Zoom Lens (cont.)



Zoom Example: Flip-in Lenses

- In many lenses, a set of lenses is designed to flip-in, for example to cause a magnification change in an afocal telescope
- Easiest way is to zoom the glasses to air

```
ZOO 2
ZOO EPD 100 25
ZOO YAN F2 2 8
ZOO STO S1 SI-1
ZOO GLA S3 AIR GERMLW
ZOO GLA S5 AIR GERMLW
```



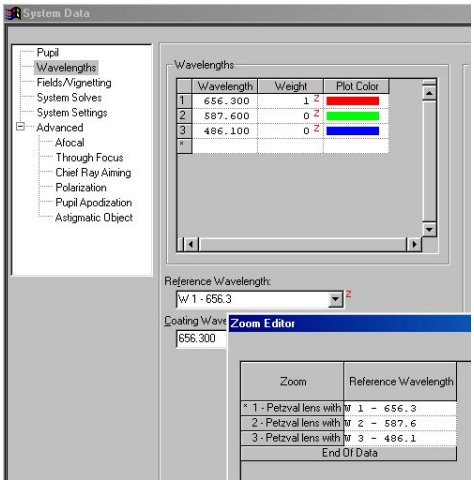
- Other methods can be used
  - For example, for the flip-in lenses, zoom the curvatures to flat and the thicknesses to zero

Zoom Example: Spectrometer

- Default in AUTO is to optimize to smallest spot, including all wavelengths
- This is not wanted in a spectrometer
  - Want a separate small spot for each wavelength, centered on each wavelength's chief ray
- This can be done by zooming the reference wavelength and the wavelength weights so each zoom position corresponds to only one wavelength
- Other zoomed parameters may be needed, also
  - Such as in systems with spectrally dividing beamsplitter, there will be different lenses in each zoom position after the beamsplitter

Zoom Ex.: Spectrometer (cont.)

Select **Lens > System Data** and right click to zoom parameters



Or at command prompt enter:

```
ZOO 3
ZOO REF     1 2 3
ZOO WTW W1  1 0 0
ZOO WTW W2  0 1 0
ZOO WTW W3  0 0 1
```


Zoom Example: Scanning Systems

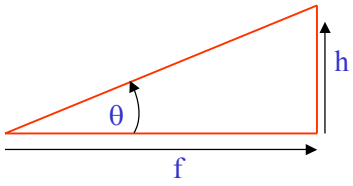
- Scanning systems are a common use of the zoom feature in CODE V
- Typical zooming parameters include tilt angles, and field angles
- Two types of scanning systems
  - Fixed input beam
    - Output beam scans
    - For example, laser scanners
  - Fixed output beam
    - Field angles change
    - For example, infrared scanning systems

Zoom Example: Laser Scanner

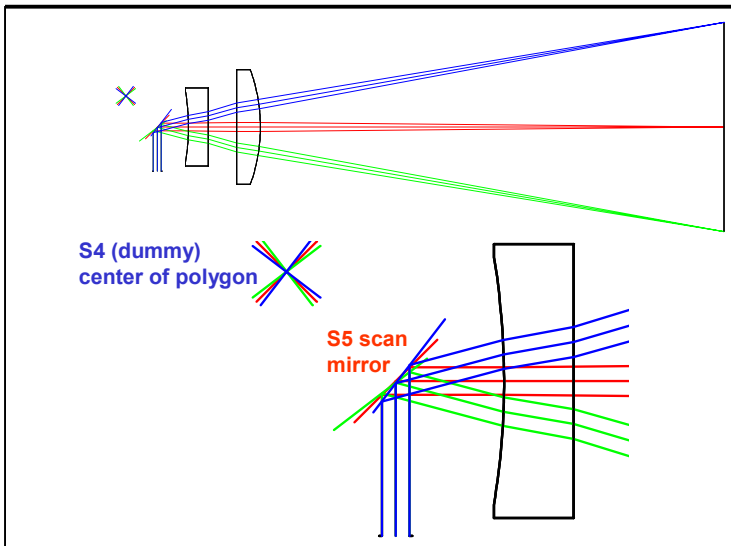
- Laser scanners usually have a fixed input beam and a rotating polygon mirror to cause the scanning
- This can be modeled simply with different field angles
- It is modeled more correctly by a pivoting mirror
  - The best model has the mirror pivot point at the center of the polygon mirror
  - This usually takes extra dummy surfaces to set up properly

Laser Scanner Example (cont.)

- Laser scanners are usually optimized for an f-theta distortion condition
  - Provides constant motion across the image plane with constant scan angle of the polygon mirror
    - Normal distortion: $h = f \tan\theta$; leads to $dh/dt = f \sec^2\theta \, d\theta/dt$
    - f-theta distortion: $h = f\theta$; leads to $dh/dt = f \, d\theta/dt = f\omega$



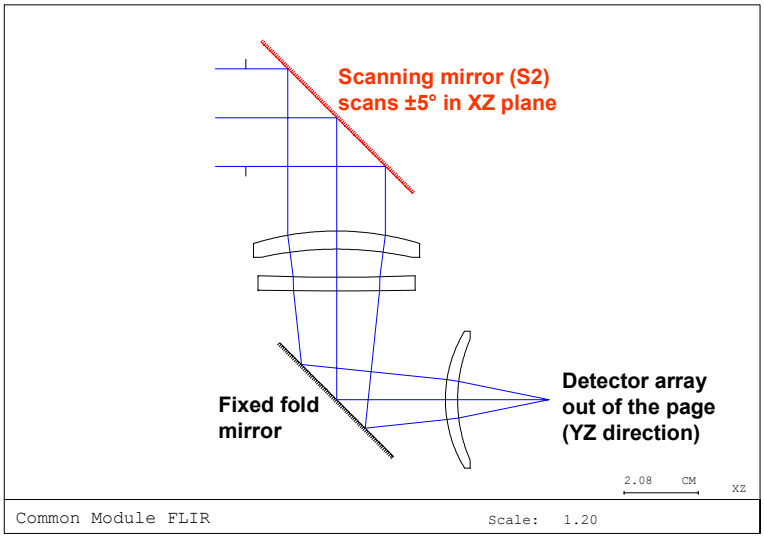
Laser Scanning Example Layouts



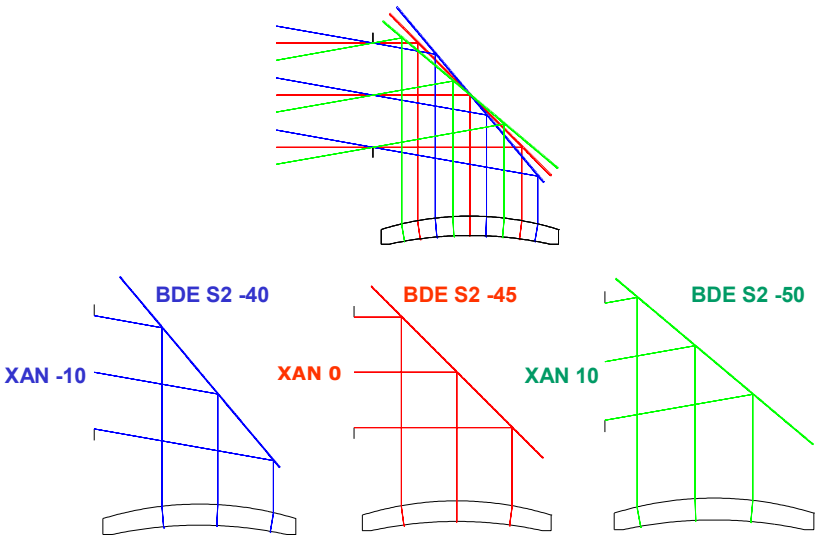
Laser Scanning Example Setup

```
S1 0 10; STOP
S2 0 0                !dummy for return reference
S3 0 10               !tilt and translate to
  ADE 45              !polygon center
S4 0 -10              !center of 10-sided polygon
  ADE 0               !rotation angle of polygon(zoom)
S5 0 0 REFL           !polygon reflecting surface
  REX 2               !set apertures
  REY (THI S3)*TANF(18/57.295)
S6 0 0
  RET S2              !return to coordinates of s2
S7 0 -7
  ADE 90              !fixed tilt to rotate axis 90°
…                     !rest of lens data
ZOO ADE S4 0 -7.5 7.5
```

Infrared Scanning System



Scanning Method



Zoom Data Input for IR Scanner

```
ZOO 3
ZOO BDE S2 -45 -40 -50
ZOO XAN F1   0 -10  10
ZOO XAN F2   0 -10  10
ZOO XAN F3   0 -10  10
```