Practical Plastic Optics

Practical Optics Seminar
September 6, 2006

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Overview

- Plastic Optics?
- Optical plastics
- Basics of injection molding
- Design guidelines
- Tolerances
- Coatings
- Design Examples
- Optomechanical design
- Prototyping
- Testing
- References

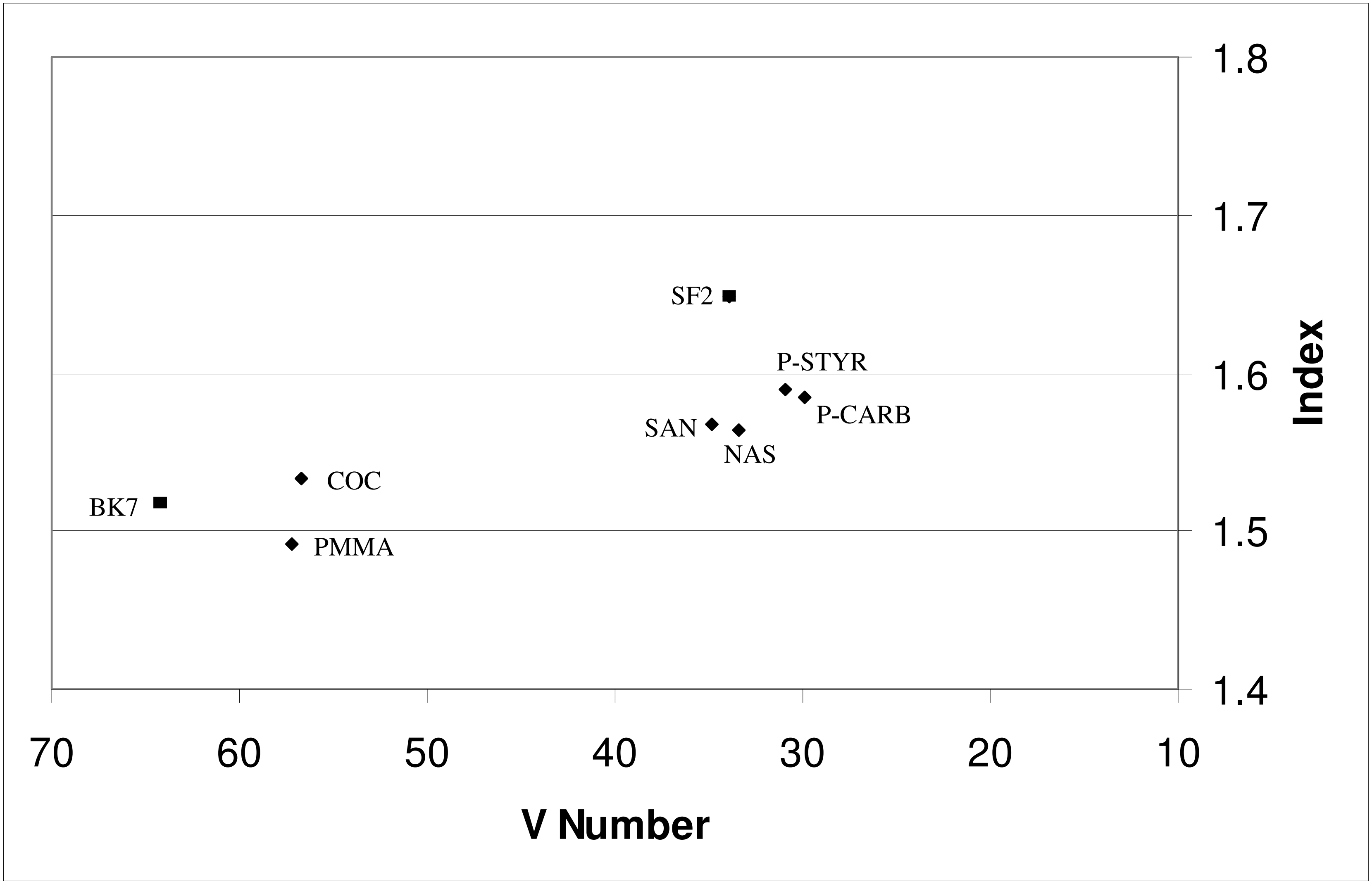
Plastic Optics - Potential Advantages

- Cost
- Production volume – can make large quantities with high quality and repeatability
- Integral features – can have mounting features or multifunction parts
- Reduced weight
- Aspheric and diffractive surfaces

Plastic Optics - Potential Disadvantages

- Lower service temperature than glass
- Higher dn/dt and CTE
- Environmental susceptibility
- Birefringence
- Limited material selection

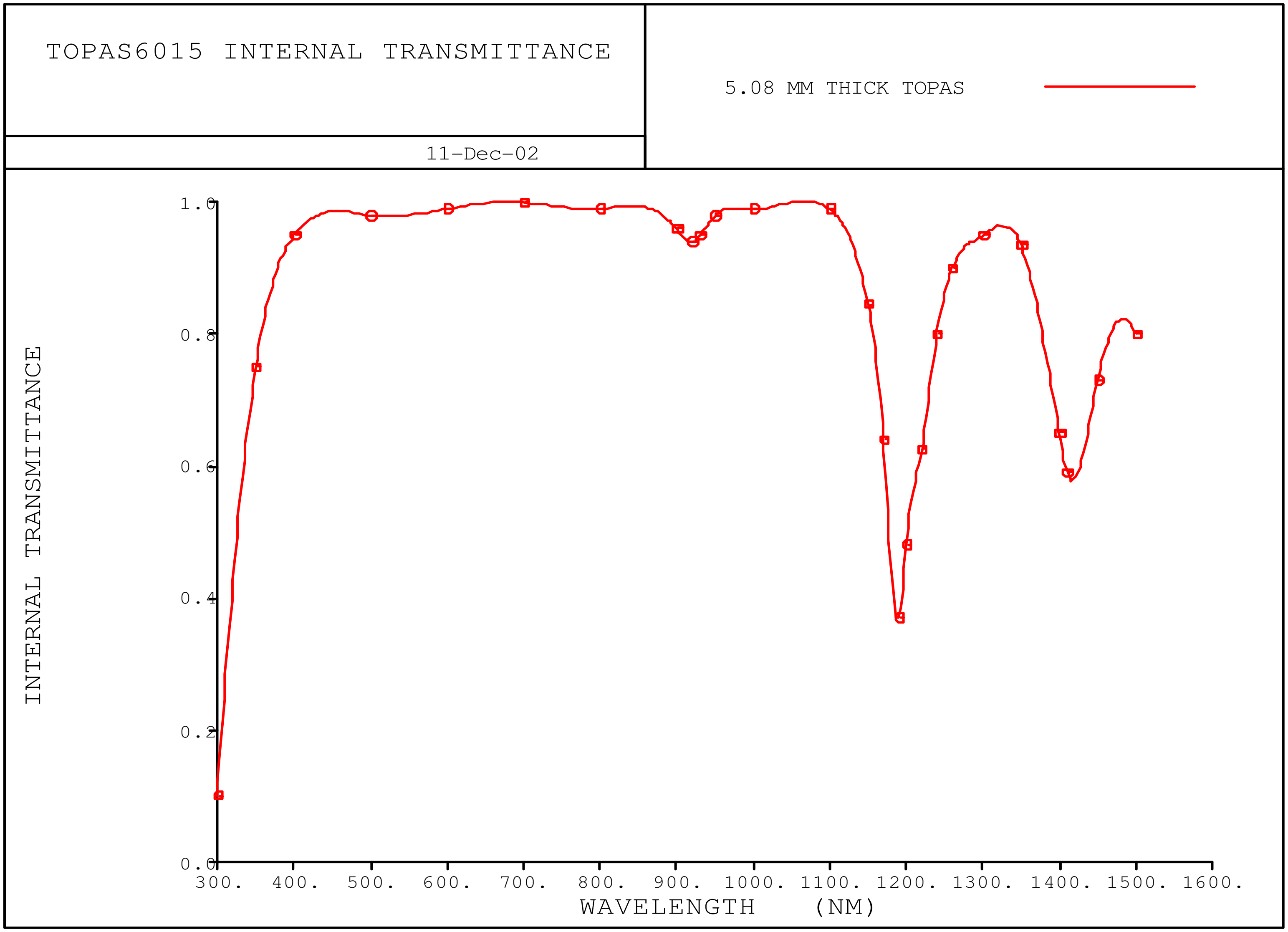
Glass/Plastic Map



Properties of Optical Polymers

Material	PMMA	P-STYR	P-CARB	SAN	NAS	COC
Typ Mfg	AtoHaas	Monsanto	GE	Mon	Richardson	Topas
'Glass Code'	492.572	590.309	585.299	567.348	564.334	533.567
Spec Grav	1.18	1.05	1.25	1.07	1.09	1.02
Serv Temp (C)	85	75	120	80	80	150
Exp Coeff *	60	50	68	50	58	60
dn/dt *	-105	-140	-107	-110	-115	-101
Birefringence **	4	10	7	5	5	2
% H_2O absorp †	0.30	0.10	0.20	0.28	0.15	0.01
Trans (vis avg) ‡	0.92	0.90	0.88	0.90	0.90	0.92
Haze (%) ‡	2.0	3.0	2.0	1.5	1.5	1.0
Rel Cost	$$	$	$$$	$$	$$	$$$$
Attributes						
SPDT	EXCEL	FAIR	POOR	EXCEL	EXCEL	GOOD
COATING	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD

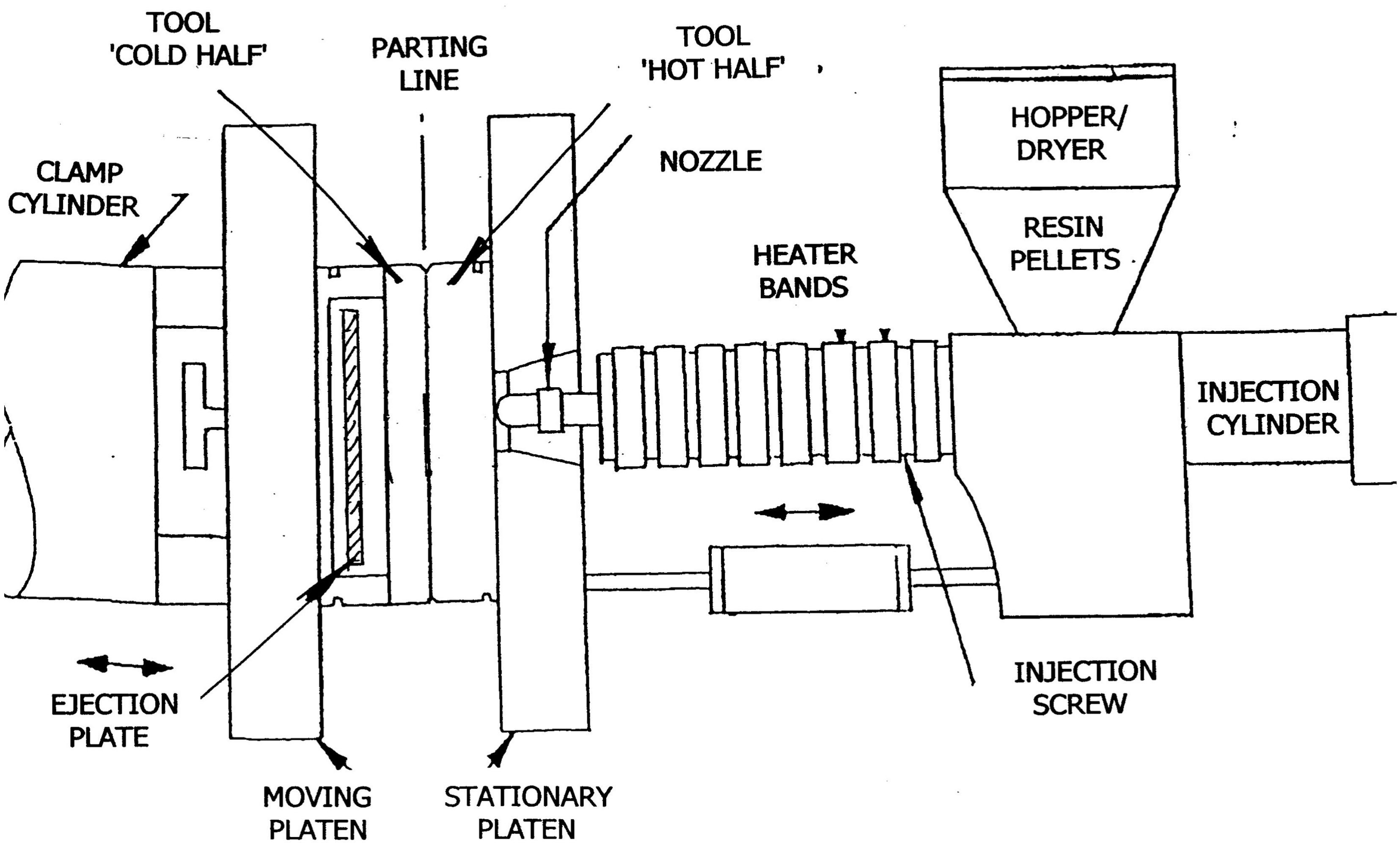
- * X10^{-6} C   ** Relative 0 to 10   † 24 hr immersion   ‡ 3mm thk


TOPAS6015 INTERNAL TRANSMITTANCE
11-Dec-02
5.08 MM THICK TOPAS
INTERNAL TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0.0
300. 400. 500. 600. 700. 800. 900. 1000. 1100. 1200. 1300. 1400. 1500. 1600.
WAVELENGTH (NM)

Manufacturing Methods

- Casting
- Embossing
- Machining
- Injection molding

Schematic of Injection Molding Machine



Production Volumes

- Simple math, with scaling assumptions
- 30 days = 43200 minutes
- Number of cavities = 8
- Up time percentage = 90%
- Cycle time = 1.5 minutes
- Monthly volume = 207,360 parts

Injection Molding Design Guidelines

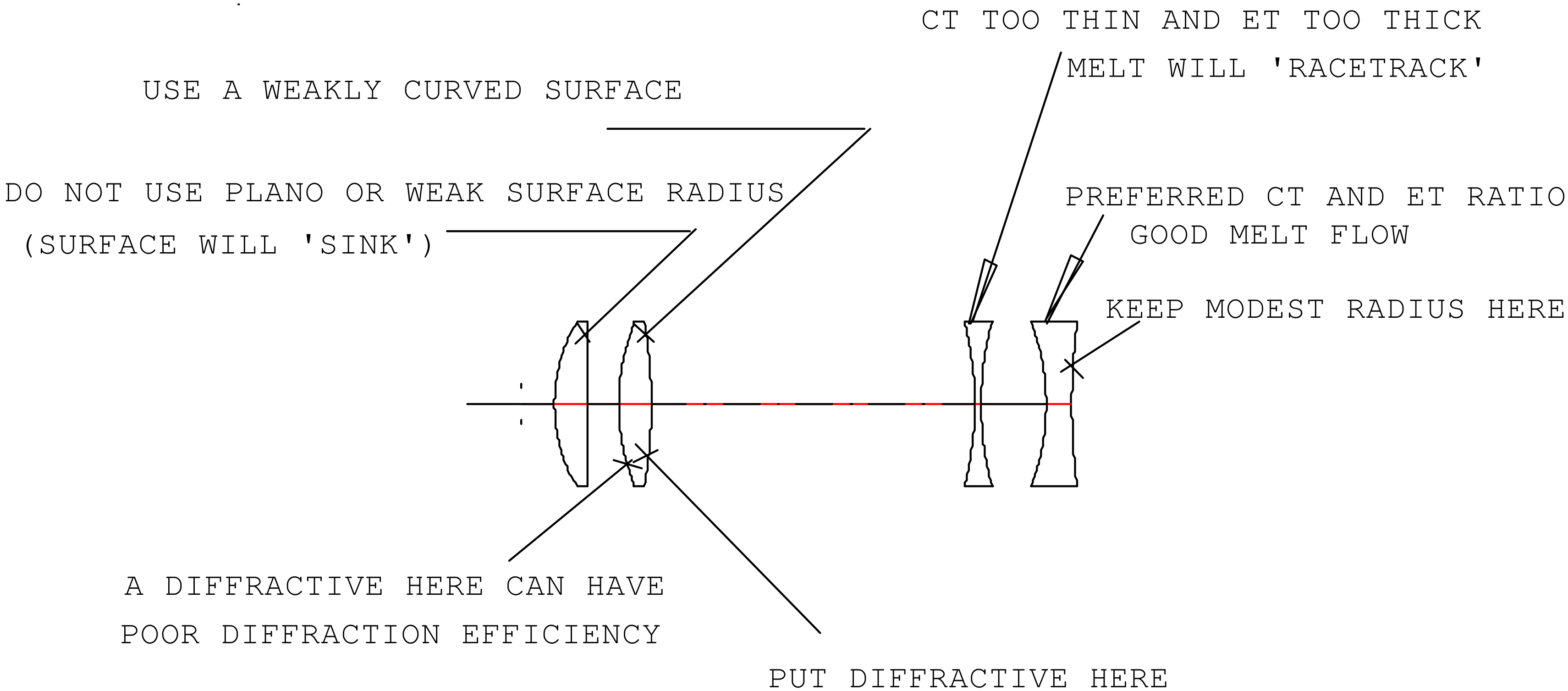
- If possible:
  - Avoid plano and weakly curved surfaces
    - Try moderate radius < 50 mm
  - Avoid strong biconcave elements
    - Maintain adequate center thickness for proper flow
  - Maintain adequate edge thickness for injection
    - Allows proper flow, avoid jetting
  - Reduce unnecessary thickness

Design Guidelines (cont.)

- If possible:
  - Have at least 1 mm outside clear aperture
    - Leaves room for edge break
  - Place diffractives on relatively weak power surfaces
    - Keep eye on minimum step size
    - Minimize angle variation
    - Look at effect of other diffractive orders

Design Guidelines (cont.)

- If possible:
  - Minimize aspheric terms, eliminate unnecessary aspheres
  - Think about stray light during design
  - Think about opto-mechanical design
  - Consider coatings/filter placement during design
  - Round corners on square/rectangular parts



THE TWO LENSES ON THE LEFT HAVE SAME POWER

THE TWO LENSES ON THE RIGHT HAVE SAME POWER

Injection Molded Plastic Tolerances

	Commercial	Precision	State-of-the-Art
Radius	± 5%	± 2%	± 0.5%
EFL	± 5%	± 2%	± 1.0%
Thickness (mm)	±0.13	±0.05	±0.020
Diameter (mm)	±0.13	±0.05	±0.020
Surface Figure	<10f (5λ)	<6f (3λ)	<2f (1λ)
Surface Irreg	< 5f (2.5λ)	<3f (1.5λ)	<1f (0.5λ)
Surface RMS err	<100A	<50A	<20A
Surface S/D qual	80/50	60/40	40/20
Wedge (TIR)	<0.025 mm	<0.015 mm	<0.010 mm
Radial Displ	<0.100 mm	<0.050 mm	<0.020 mm
Aspect Ratio *	<8:1	<6:1	<4:1
Repeatability**	<2%	<1%	<0.5%
DOE depth	---	±0.25 um	±0.10 um
DOE min groove	---	25 um	10 um

*diameter/thickness ratio **part to part in one cavity

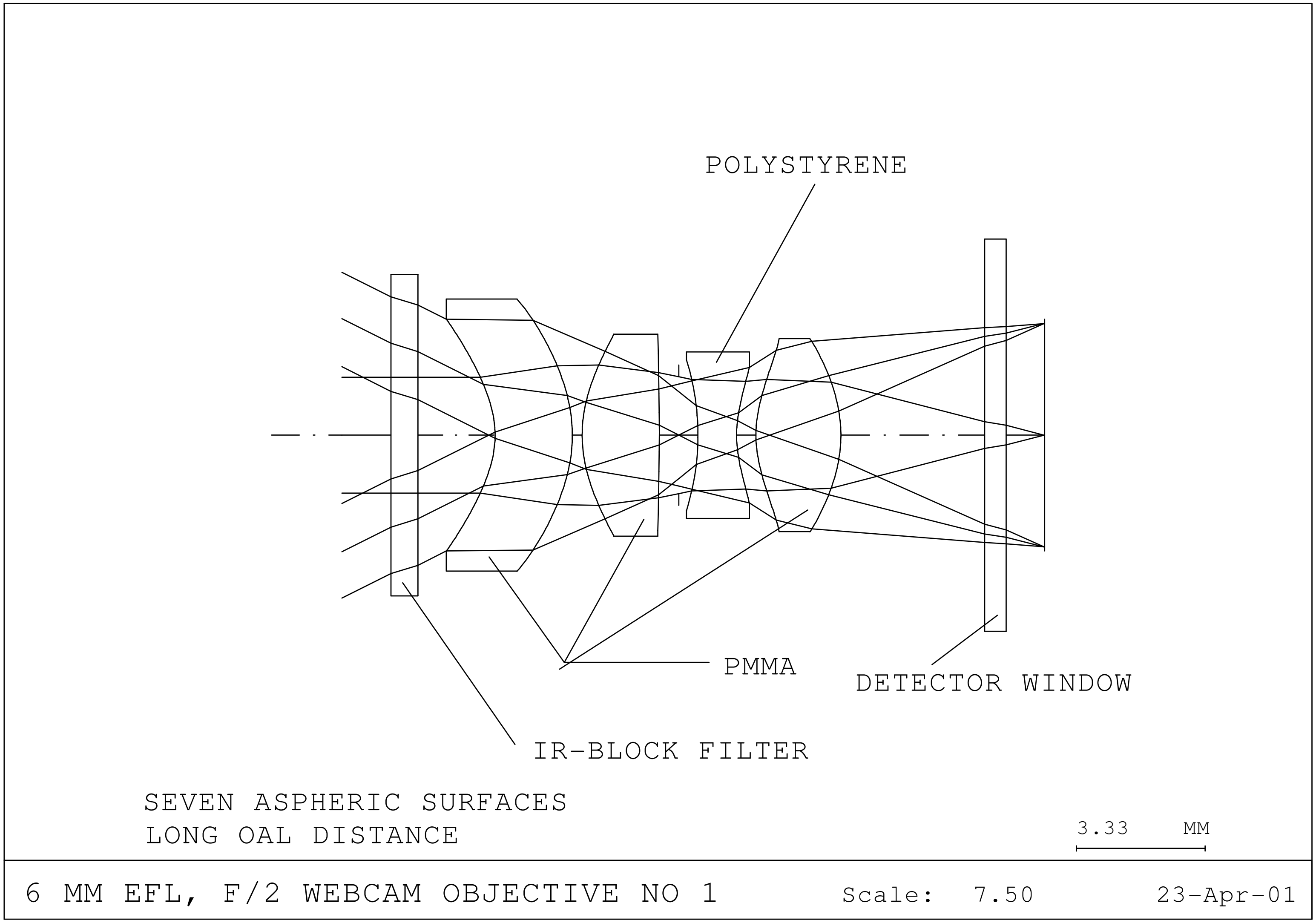
- NOTES: Above tolerances are for 10 to 25 mm diameter elements. Surface figure and irregularity expressed in fringes (waves) per inch of diameter.

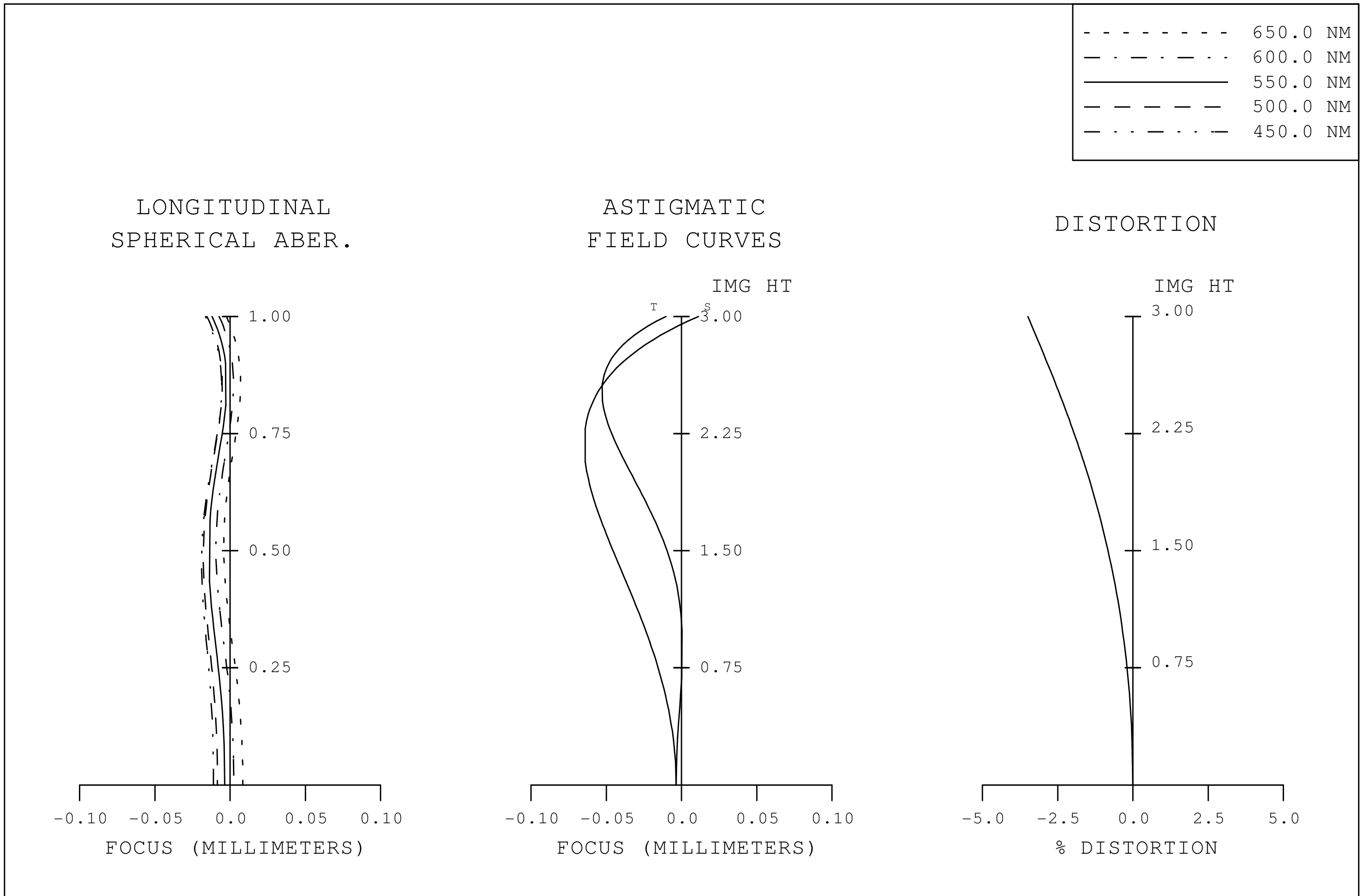
Coatings

- AR coatings
  - More elements, more reflection loss
  - Typically use multilayer for broadband
  - Most materials can be coated
  - Coatings continue to improve
  - Usually best to have coated at same place that is molding

Plastic Optics Designs

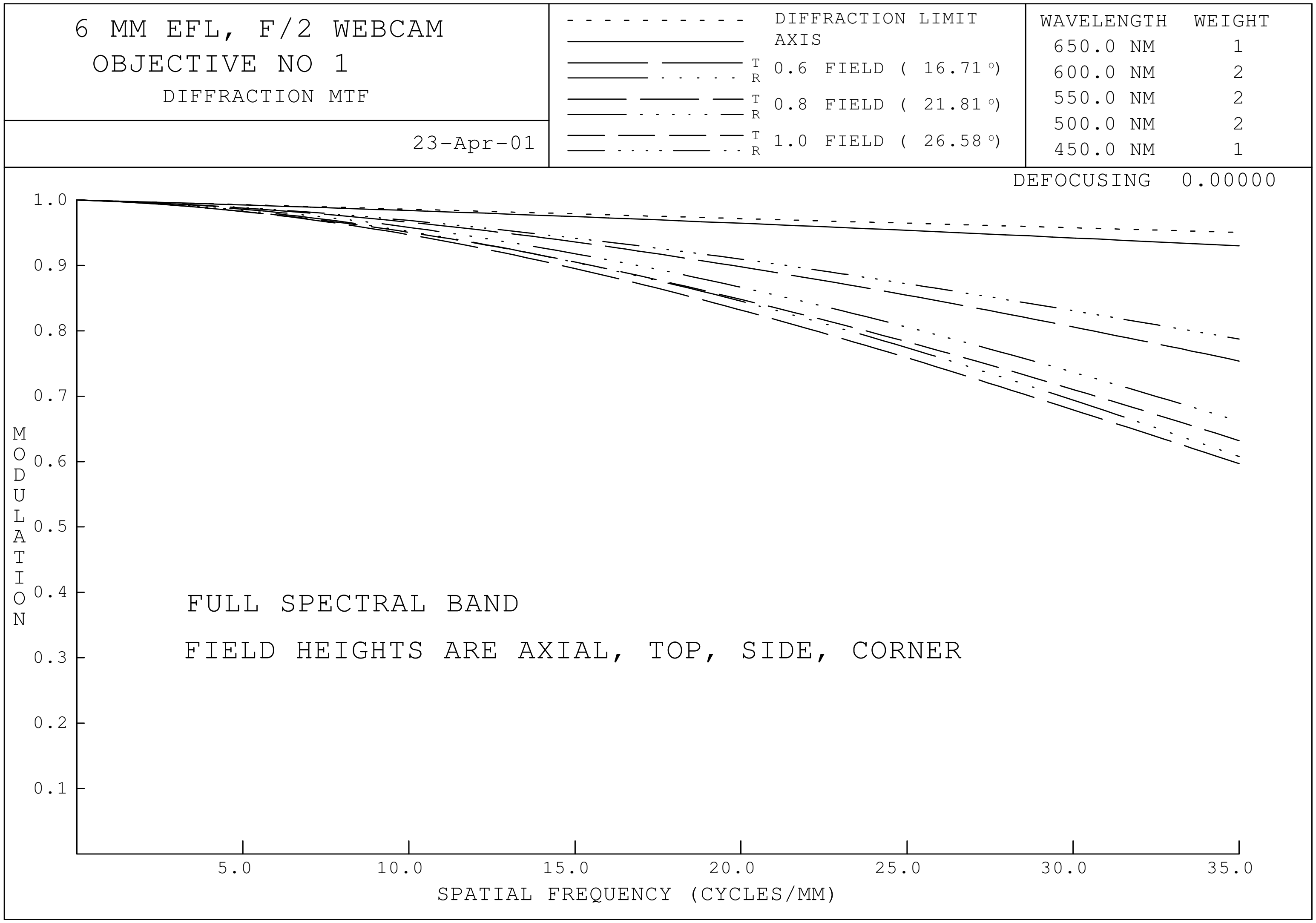
- Often highly constrained
- Tradeoffs
  - Cost
  - Performance
  - Manufacturability/yield
  - Height/weight/volume
  - Specific optical characteristics
    - Chief ray angle
    - Distortion
    - Flare

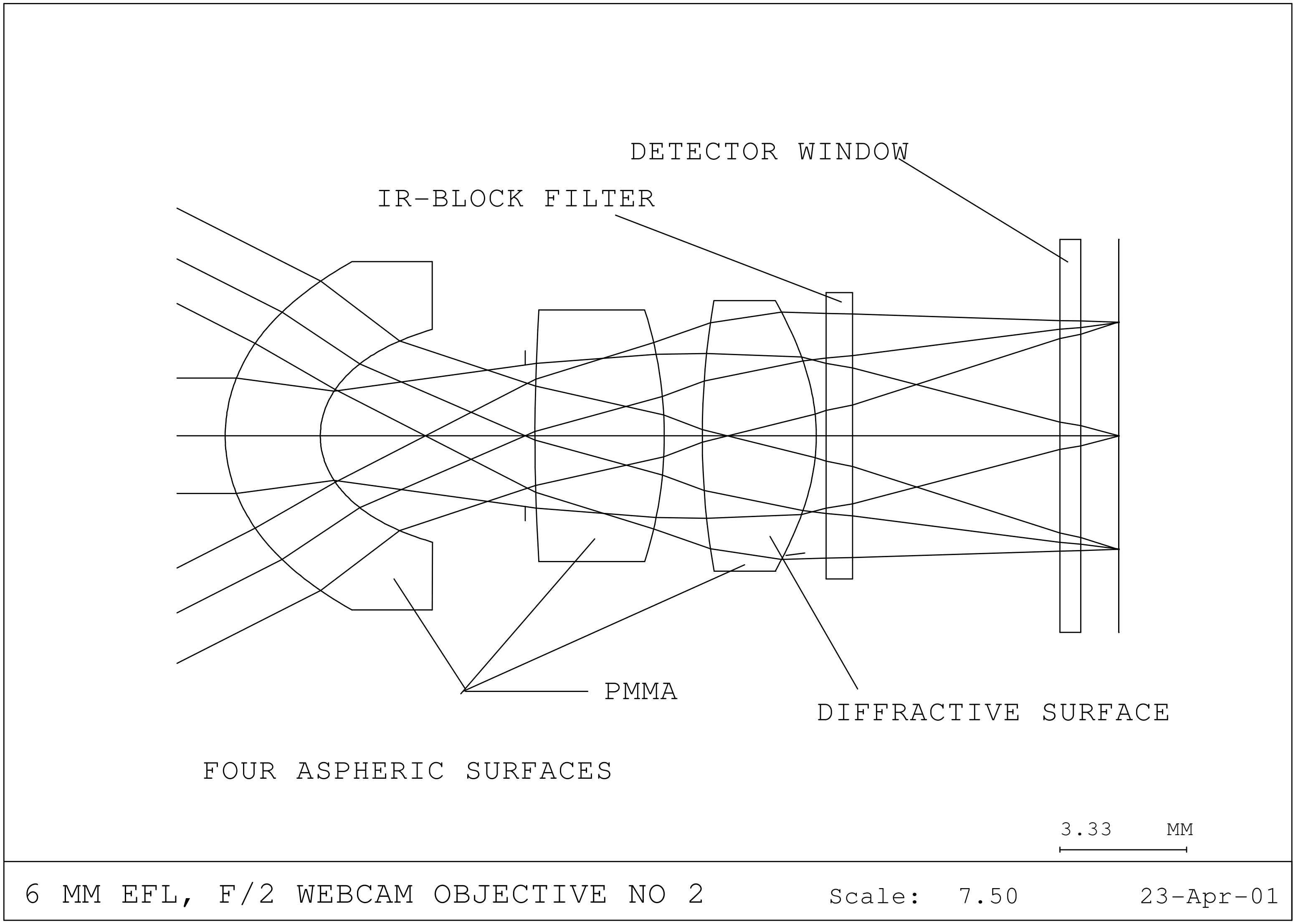

POLYSTYRENE
PMMA
DETECTOR WINDOW
IR–BLOCK FILTER
SEVEN ASPHERIC SURFACES
LONG OAL DISTANCE
3.33 MM
6 MM EFL, F/2 WEBCAM OBJECTIVE NO 1
Scale: 7.50
23-Apr-01

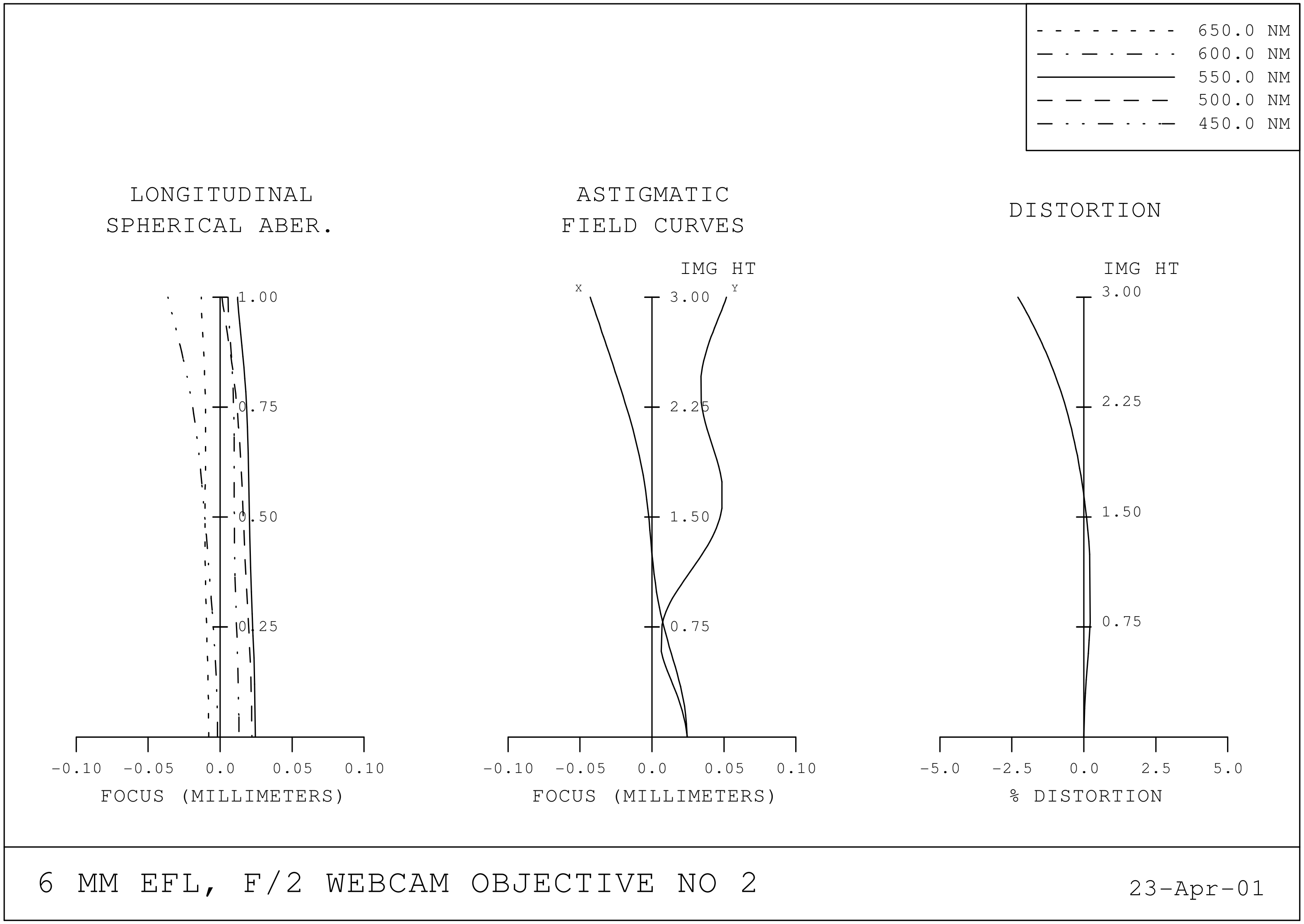


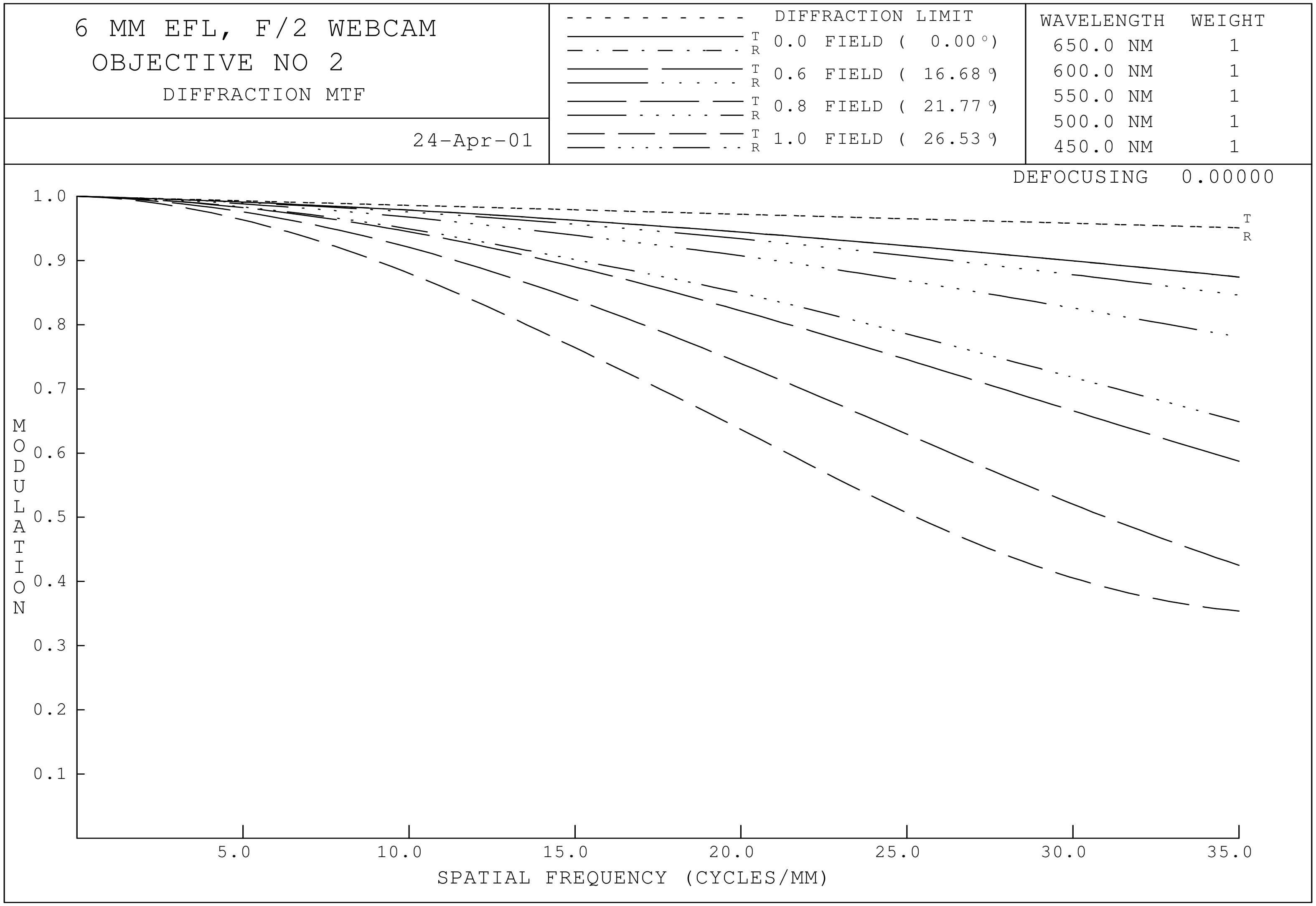
6 MM EFL, F/2 WEBCAM OBJECTIVE NO 1

23-Apr-01

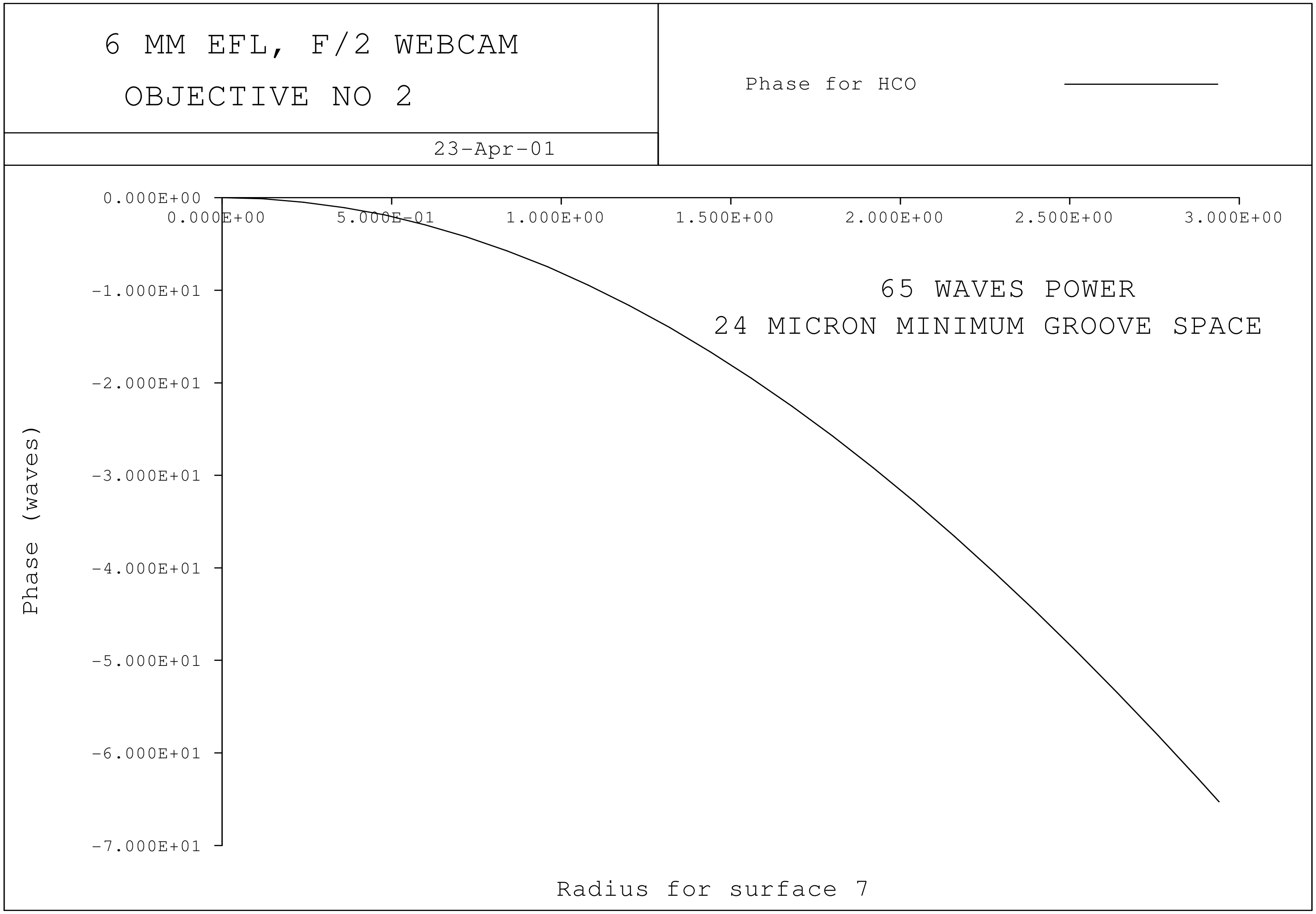

6 MM EFL, F/2 WEBCAM
OBJECTIVE NO 1
DIFFRACTION MTF
23-Apr-01
DIFFRACTION LIMIT
AXIS
T R 0.6 FIELD (16.71°)
T R 0.8 FIELD (21.81°)
T R 1.0 FIELD (26.58°)
WAVELENGTH WEIGHT
650.0 NM 1
600.0 NM 2
550.0 NM 2
500.0 NM 2
450.0 NM 1
DEFOCUSING 0.00000
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
MODULATION
FULL SPECTRAL BAND
FIELD HEIGHTS ARE AXIAL, TOP, SIDE, CORNER
5.0
10.0
15.0
20.0
25.0
30.0
35.0
SPATIAL FREQUENCY (CYCLES/MM)

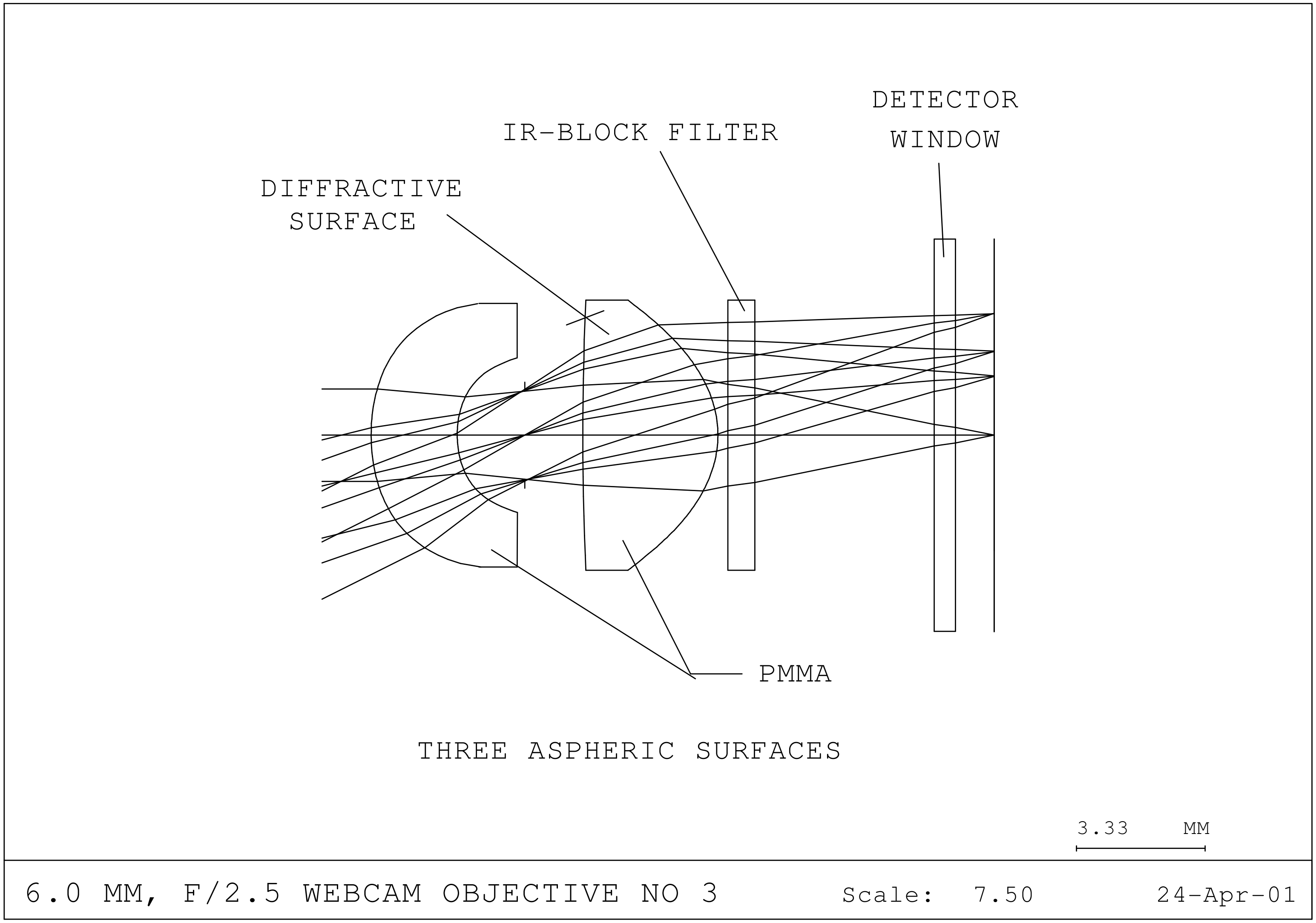

DETECTOR WINDOW
IR-BLOCK FILTER
PMMA
DIFFRACTIVE SURFACE
FOUR ASPHERIC SURFACES
3.33 MM
6 MM EFL, F/2 WEBCAM OBJECTIVE NO 2
Scale: 7.50
23-Apr-01

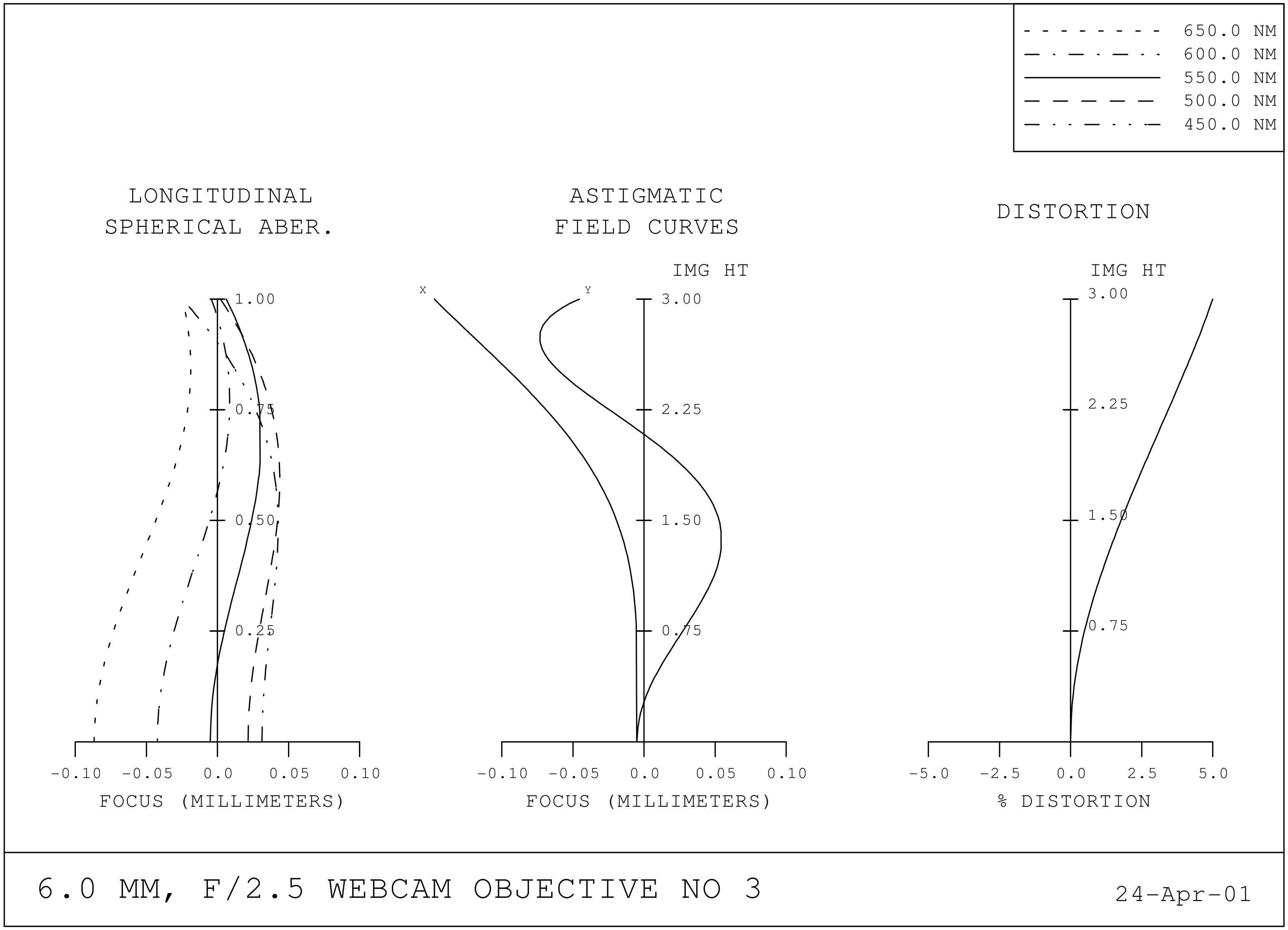

650.0 NM
600.0 NM
550.0 NM
500.0 NM
450.0 NM
LONGITUDINAL SPHERICAL ABER.
1.00
0.75
0.50
0.25
-0.10 -0.05 0.0 0.05 0.10
FOCUS (MILLIMETERS)
ASTIGMATIC FIELD CURVES
IMG HT
X
Y
3.00
2.25
1.50
0.75
-0.10 -0.05 0.0 0.05 0.10
FOCUS (MILLIMETERS)
DISTORTION
IMG HT
3.00
2.25
1.50
0.75
-5.0 -2.5 0.0 2.5 5.0
% DISTORTION
6 MM EFL, F/2 WEBCAM OBJECTIVE NO 2
23-Apr-01



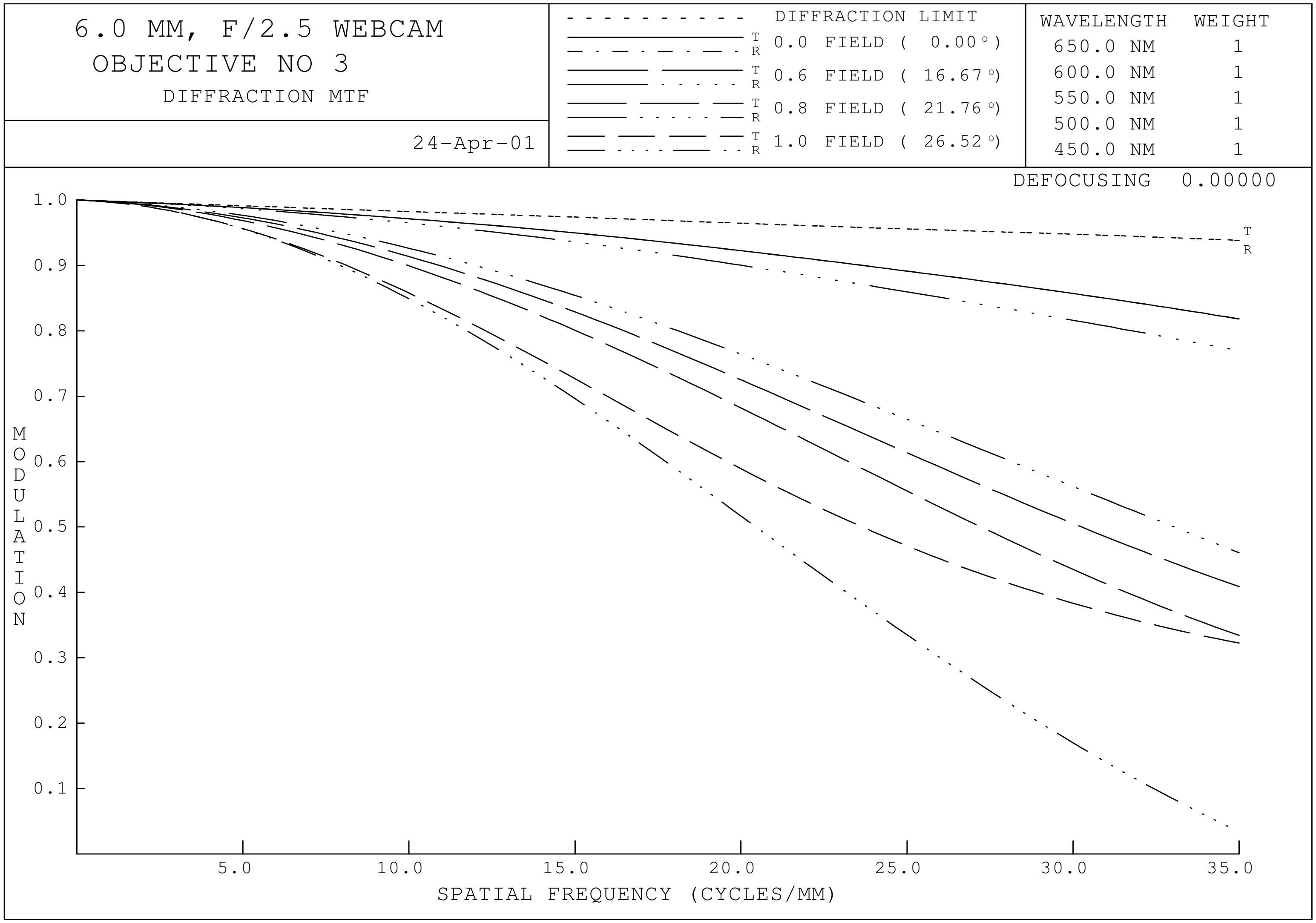
6 MM EFL, F/2 WEBCAM
OBJECTIVE NO 2
DIFFRACTION MTF
24-Apr-01
DIFFRACTION LIMIT
T R 0.0 FIELD (0.00 °)
T R 0.6 FIELD (16.68 °)
T R 0.8 FIELD (21.77 °)
T R 1.0 FIELD (26.53 °)
WAVELENGTH WEIGHT
650.0 NM 1
600.0 NM 1
550.0 NM 1
500.0 NM 1
450.0 NM 1
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
5.0
10.0
15.0
20.0
25.0
30.0
35.0
SPATIAL FREQUENCY (CYCLES/MM)


6 MM EFL, F/2 WEBCAM
OBJECTIVE NO 2
23-Apr-01
Phase for HCO
0.000E+00
-1.000E+01
-2.000E+01
-3.000E+01
-4.000E+01
-5.000E+01
-6.000E+01
-7.000E+01
0.000E+00
5.000E-01
1.000E+00
1.500E+00
2.000E+00
2.500E+00
3.000E+00
65 WAVES POWER
24 MICRON MINIMUM GROOVE SPACE
Phase (waves)
Radius for surface 7

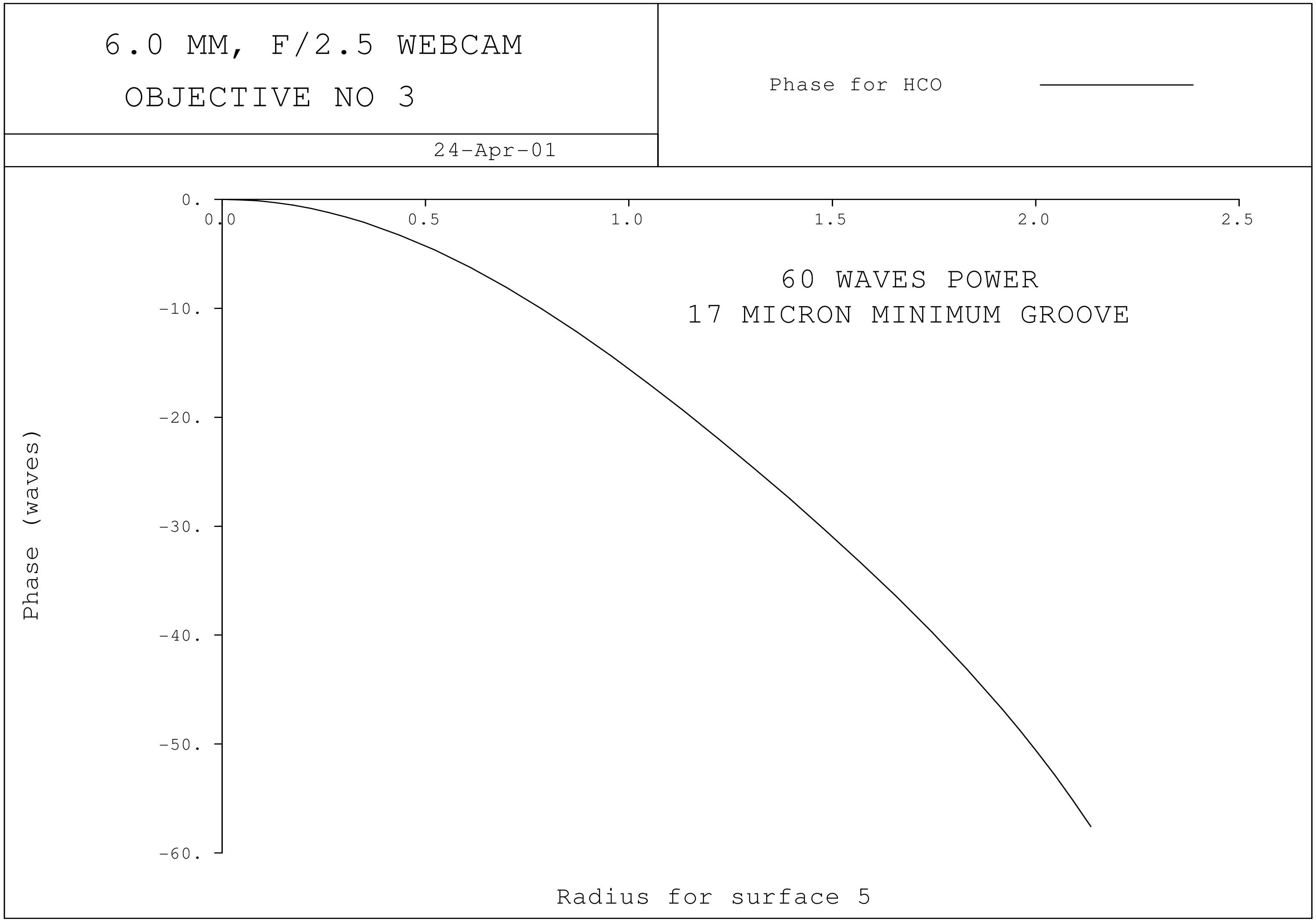

DETECTOR
WINDOW
IR-BLOCK FILTER
DIFFRACTIVE
SURFACE
PMMA
THREE ASPHERIC SURFACES
3.33 MM
6.0 MM, F/2.5 WEBCAM OBJECTIVE NO 3
Scale: 7.50
24-Apr-01



650.0 NM
600.0 NM
550.0 NM
500.0 NM
450.0 NM
LONGITUDINAL
SPHERICAL ABER.
ASTIGMATIC
FIELD CURVES
DISTORTION
IMG HT
IMG HT
1.00
0.75
0.50
0.25
X
Y
3.00
2.25
1.50
0.75
3.00
2.25
1.50
0.75
-0.10 -0.05 0.0 0.05 0.10
FOCUS (MILLIMETERS)
-0.10 -0.05 0.0 0.05 0.10
FOCUS (MILLIMETERS)
-5.0 -2.5 0.0 2.5 5.0
% DISTORTION
6.0 MM, F/2.5 WEBCAM OBJECTIVE NO 3
24-Apr-01



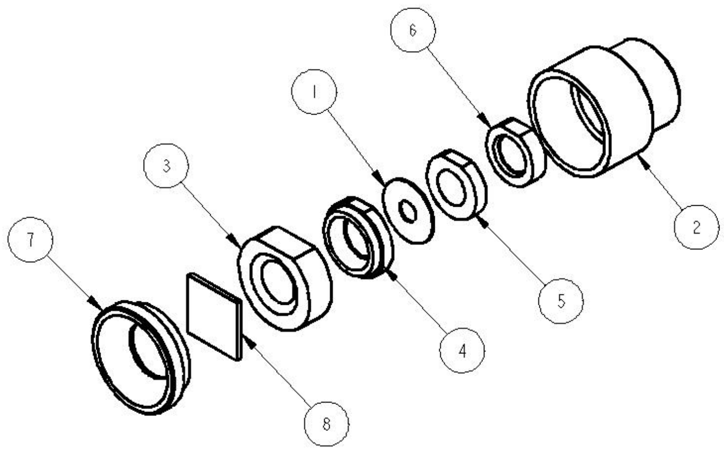
6.0 MM, F/2.5 WEBCAM
OBJECTIVE NO 3
DIFFRACTION MTF
24-Apr-01
DIFFRACTION LIMIT
T R 0.0 FIELD (0.00°)
T R 0.6 FIELD (16.67°)
T R 0.8 FIELD (21.76°)
T R 1.0 FIELD (26.52°)
WAVELENGTH WEIGHT
650.0 NM 1
600.0 NM 1
550.0 NM 1
500.0 NM 1
450.0 NM 1
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
5.0
10.0
15.0
20.0
25.0
30.0
35.0
SPATIAL FREQUENCY (CYCLES/MM)
T
R

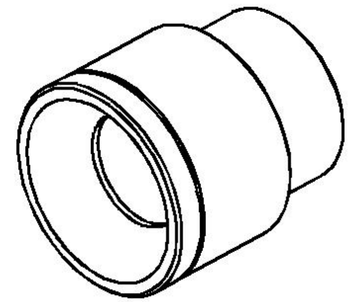

6.0 MM, F/2.5 WEBCAM
OBJECTIVE NO 3
24-Apr-01
Phase for HCO
60 WAVES POWER
17 MICRON MINIMUM GROOVE
Phase (waves)
Radius for surface 5
0.
-10.
-20.
-30.
-40.
-50.
-60.
0.0
0.5
1.0
1.5
2.0
2.5

DWG NO	SH	REV
WEBCAM	1	00

REVISION HISTORY

REV	DESCRIPTION	DATE	APPROVED





SCALE 4.000

ITEM	QTY	PART NUMBER	DESCRIPTION
8	1	IR_WINDOW	WINDOW, IR, WEBCAM
7	1	RETAINER	RETAINER, WEBCAM
6	1	LENS_4	LENS, #3, WEBCAM
5	1	LENS_3	LENS, #3, WEBCAM
4	1	LENS_2	LENS, #2, WEBCAM
3	1	LENS_1	LENS, #1, WEBCAM
2	1	BARREL	BARREL, WEBCAM
1	1	APERT	APERTURE, WEBCAM

ASSEMBLY BOM

DIMENSIONS :
MILLIMETERS [INCHES]

TOLERANCES
(EXCEPT AS NOTED)
.X ± .25 [.010]
.XX ± .12 [.005]
.XXX ± .010 [.0004]
ANG ± 0°30'

THIRD ANGLE PROJECTION

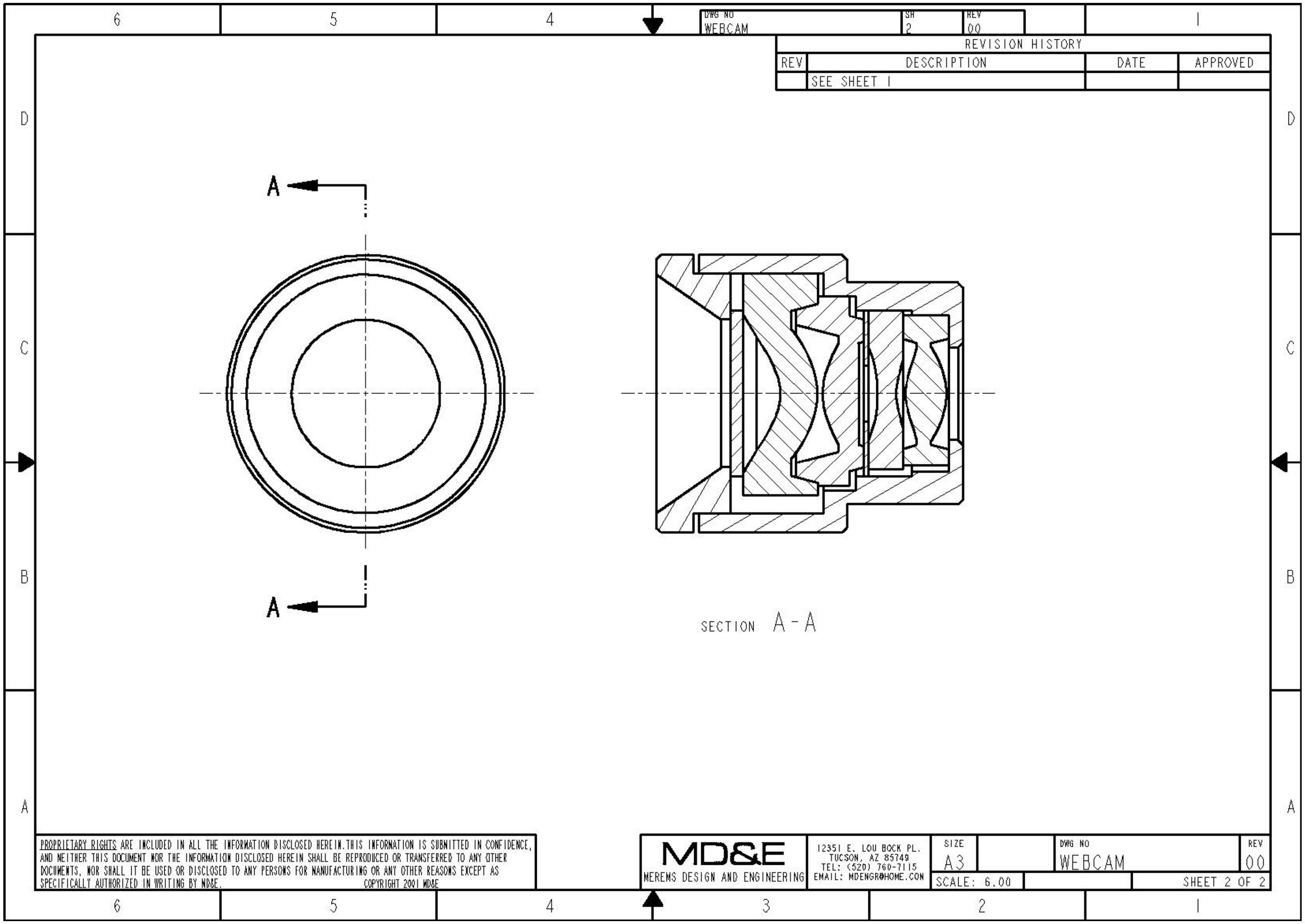
MD&E
MEREMS DESIGN AND ENGINEERING

12351 E. LOU BOCK PL.
TUCSON, AZ 85749
TEL : (520)-760-7115
EMAIL: MDENGR@HOME.COM

ASS'Y, LENS, WEBCAM

SIZE		DWG NO	REV
A3		WEBCAM	00
SCALE: 2.00		SHEET 1 OF 2	

MATERIAL: LISTED
FINISH: N/A
DRAWN BY: P. MEREMS


DWG NO WEBCAM
SH 2
REV 00
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
A
A
SECTION A-A
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EMAIL: MDENGR@HOME.COM
SIZE A3
DWG NO WEBCAM
REV 00
SCALE: 6.00
SHEET 2 OF 2

DWG NO LENS_4 | SH 1 | REV 00

	RADIUS	RAD ERR/ASPH ERR/CYL ERR	CA DIAMETER	CT
S1	ASPHERE	±1.0% / 5F / 2F	5.00	2.194±.050
S2	ASPHERE	±1.0% / 5F / 2F	5.00	

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED

NOTES: UNLESS OTHERWISE SPECIFIED

$\boxed{18}$ GATE LOCATION

17 CAVITY ID: SEQUENTIAL PROTRUDING FEATURES

$\boxed{16}$ FILLET RADIUS: .05 MAX.

$\boxed{15}$ DRAFT PERMITTED WITHIN SPECIFIED TOLERANCE.

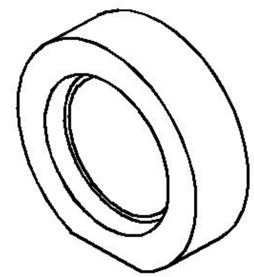
14. PART DATA BASE TAKES PRECEDENCE OVER DRAWING.
13. THIS ELEMENT IS AN INJECTION-MOLDED COMPONENT USED IN AN OBJECTIVE ASSEMBLY. DIMENSIONS FOR RADIUS, CA, & CT ARE MM. PWR/IRR TOLERANCES ARE FRINGES AT 633NM.
12. $\boxed{OA1}$ IS THE THEORETICAL OPTIC AXIS OF THE FIRST OPTIC SURFACE.
11. $\boxed{OA2}$ IS THE THEORETICAL OPTIC AXIS OF THE SECOND OPTIC SURFACE.
10. DRAFT ON O.D. OF PART IS 1/2°
9. USE OF MOLD RELEASE IS NOT PERMITTED.

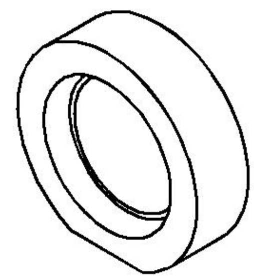
$\boxed{8}$ GATE VESTIGE NOT TO EXCEED PART O.D..

7. MATERIAL: OPTICAL GRADE ATOHAAS PLEXIGLAS V825-100 OR EQUIVALENT. Nd=1.4918 +/- 0.001)V(F-C)=57.2 +/- 0.1
6. SURFACE FINISH (EXCLUDES OPTICAL SURFACES): SPI #C-3
5. S1 HAS AN ASPHERIC PROFILE GIVEN BY: $Z(H)=\dfrac{CV*H^2}{1+[1-(1+K)*CV^2*H^2]^{0.5}}+A*H^4+B*H^6+C*H^8$

   WHERE: H= RADIAL DISTANCE FROM S1 VERTEX IN MM
   CV=1/R, K= -7.068500, A=0.00000, B=0.00000, C=0.00000, R=7.00126MM
4. S2 HAS AN ASPHERIC PROFILE GIVEN BY: $Z(H)=\dfrac{CV*H^2}{1+[1-(1+K)*CV^2*H^2]^{0.5}}+A*H^4+B*H^6+C*H^8$

   WHERE: H= RADIAL DISTANCE FROM S2 VERTEX IN MM
   CV=1/R, K= -1.747370, A=0.00000, B=0.00000, C=0.00000, R=-4.74184MM
3. S1 AND S2 SURFACE FINISH <90 ANGSTROM RMS ROUGHNESS AND 60-40 OR EQUIVALENT OPTICAL QUALITY.
2. FEATURES IDENTIFIED AS ℄ ARE CRITICAL CHARACTERISTICS.
1. FEATURES IDENTIFIED AS Ⓢ ARE SPC ITEMS.





MATERIAL: SEE NOTES
FINISH: SEE NOTES
DRAWN BY: P.MEREMS

DIMENSIONS : MILLIMETERS [INCHES]
TOLERANCES (EXCEPT AS NOTED)
.X ± .25 [.010]
.XX ± .12 [.005]
.XXX ± .010 [.0004]
ANG ± 0°30'
THIRD ANGLE PROJECTION

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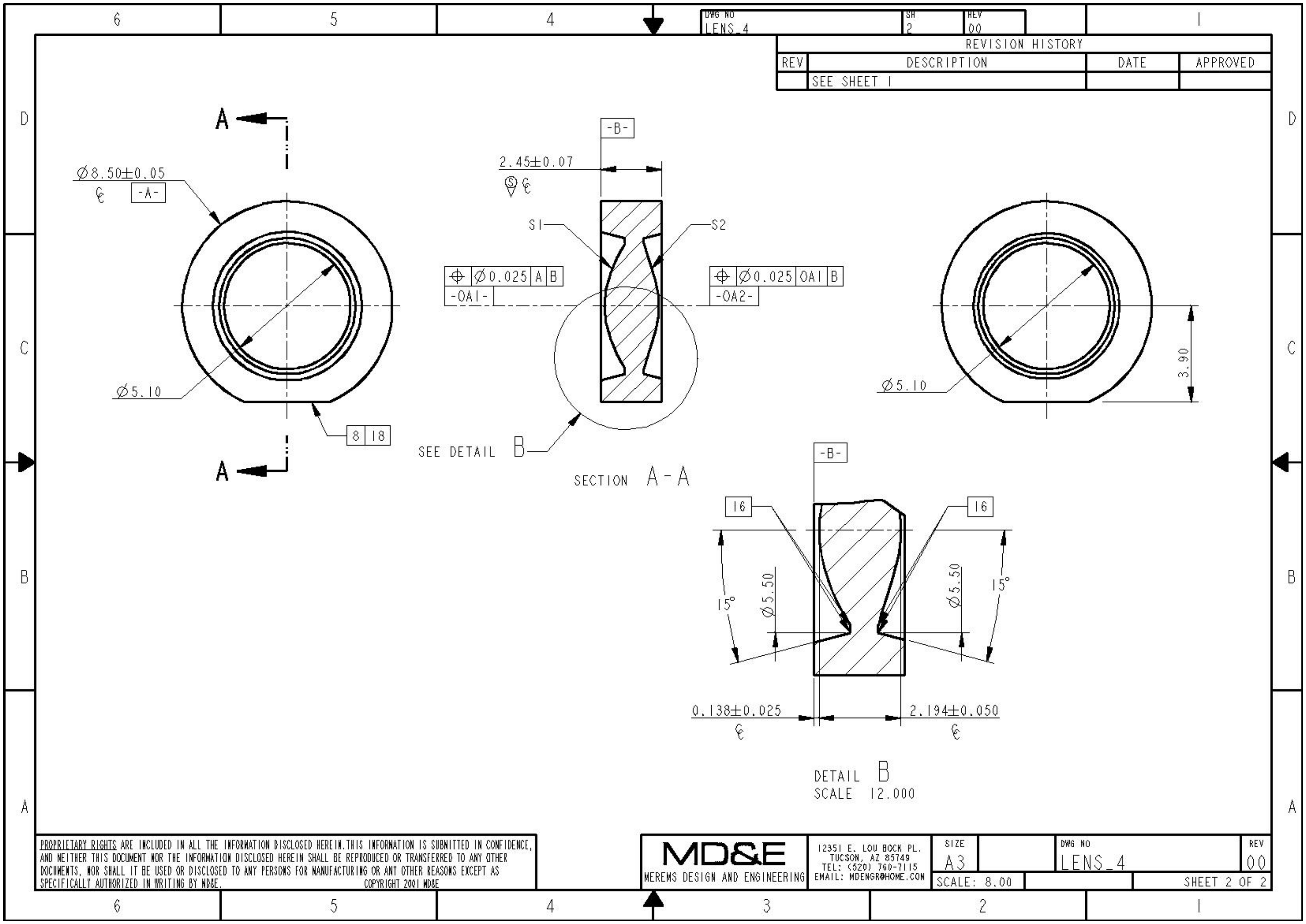
TEL : (520)-760-7115
EMAIL: MDENGR@HOME.COM

LENS, #3, WEBCAM

SIZE A3 | DWG NO LENS_4 | REV 00
SCALE: 8.00 | SHEET 1 OF 2


DWG NO LENS_4
SH 2
REV 00
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
SEE SHEET 1
Ø8.50±0.05
-A-
Ø5.10
8 18
A
A
-B-
2.45±0.07
S1
S2
Ø0.025 A B
-OA1-
Ø0.025 OA1 B
-OA2-
SEE DETAIL B
SECTION A-A
Ø5.10
3.90
-B-
16
16
15°
Ø5.50
Ø5.50
15°
0.138±0.025
2.194±0.050
DETAIL B
SCALE 12.000
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EMAIL: MDENGR@HOME.COM
SIZE A3
DWG NO LENS_4
REV 00
SCALE: 8.00
SHEET 2 OF 2

Prototyping

- Due to cost and time for production molds, typically prototype design first
- Methods
  - Diamond Turning
  - “Stock” Molds
  - Single Cavity Mold

Common Testing

- Surfaces – Profiler or interferometer (may require null lens)
- Mechanical – CMM, indicators, etc.
- System – MTF bench, resolution test
- Stray light – Collimator, light bulb, sun

References

- Handbook of Plastic Optics – Baumer (Ed.), published by Wiley
- Handbook of Plastic Optics – USPL
- OSA Handbook of Optics – Vol. 2, Chapter by Lytle