350-464 SR
OR 3,588,228
SEARCH ROOM

United State. [11] 3,588,228

[72] Inventors **Janusz S. Wilczynski**
Ossining; Raymond E. Tibbetts, Mahopac, both of N.Y.

[21] Appl. No. **857,270**
[22] Filed **Aug. 15, 1969**
[45] Patented **June 28, 1971**
[73] Assignee **International Business Machines Corporation**
Armonk, N.Y.
Continuation-in-part of application Ser. No. 600,158, Dec. 8, 1966, now abandoned.

[54] **VARIABLE REDUCTION LENS SYSTEM**
2 Claims, 28 Drawing Figs.

[52] **U.S. Cl.** **350/215,** 350/183
[51] **Int. Cl.** **G02b 9/62,** G02b 15/06
[50] **Field of Search** 350/183, 215

[56] **References Cited**
UNITED STATES PATENTS

2,701,982	2/1955	Angenieux	350/215
2,837,009	6/1958	Tronnier	350/215X

FOREIGN PATENTS

204,799	1/1959	Austria	350/215

Primary Examiner—David Schonberg
Assistant Examiner—Paul A. Sacher
Attorneys—Hanifin and Jancin and John J. Goodwin

ABSTRACT: The present invention relates to optical lens systems and more particularly to a lens system having variable magnification and constant high correction. The lens system consists of eight lens elements and changes in reduction are produced by varying the shape of one lens element and changing one airspace while the remaining lens elements and air spaces remain constant.

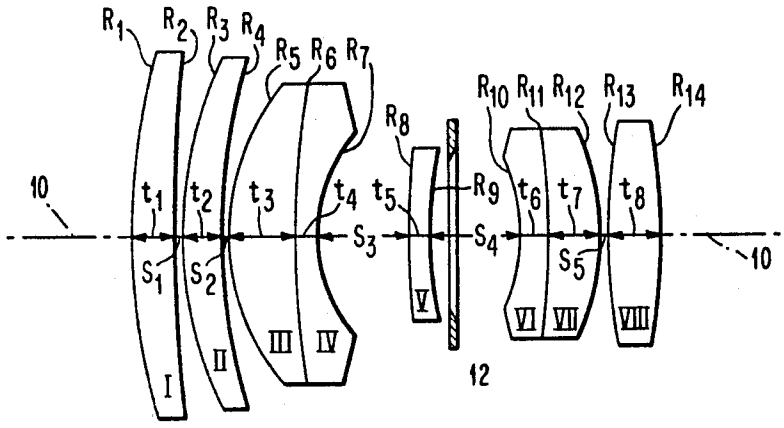


FIG. 1

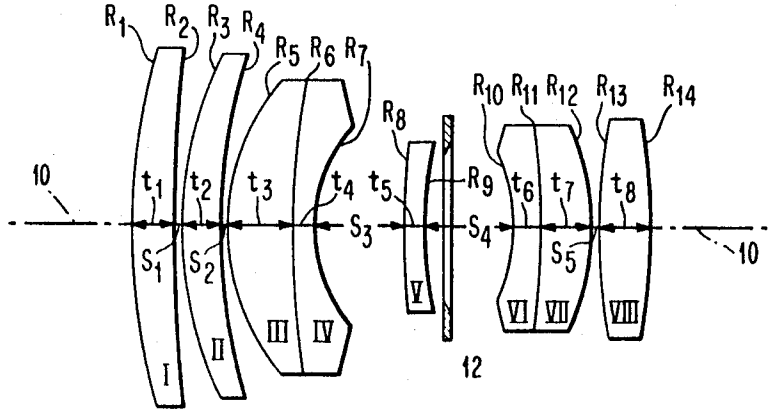


FIG. 2

F/3	REDUCTION = 20X			
LENS	RADIUS	THICKNESS (t) OR AIRSPACE (S)	N_D	V
I	R_1 = +0.9840 F R_2 = +3.8081 F	t_1 = .0691 F S_1 = .0044 F	1.69089	54.80
II	R_3 = +0.6089 F R_4 = +0.8903 F	t_2 = .0616 F S_2 = .0044 F	1.69089	54.80
III	R_5 = +0.3461 F R_6 = +2.4406 F R_7 = +0.2320 F	t_3 = .0995 F t_4 = .0352 F S_3 = .1329 F	1.69089	54.80
IV			1.64752	33.80
V	R_8 = +1.6228 F R_9 = +0.6295 F	t_5 = .0299 F S_4 = .1294 F	1.64752	33.80
VI	R_{10} = -0.2813 F R_{11} = -2.3989 F R_{12} = -0.3923 F	t_6 = .0396 F t_7 = .0804 F S_5 = .0044 F	1.60328	38.02
VII			1.69089	54.80
VIII	R_{13} = +1.3630 F R_{14} = -0.8977 F	t_8 = .0792 F	1.69089	54.80

INVENTORS
JANUSZ S. WILCZYNSKI
RAYMOND E. TIBBETTS
BY John J. Goodwin
ATTORNEY

$\delta\ell' = -.049$ MILLIMETERS
$\lambda = 5461$ ANGSTROMS

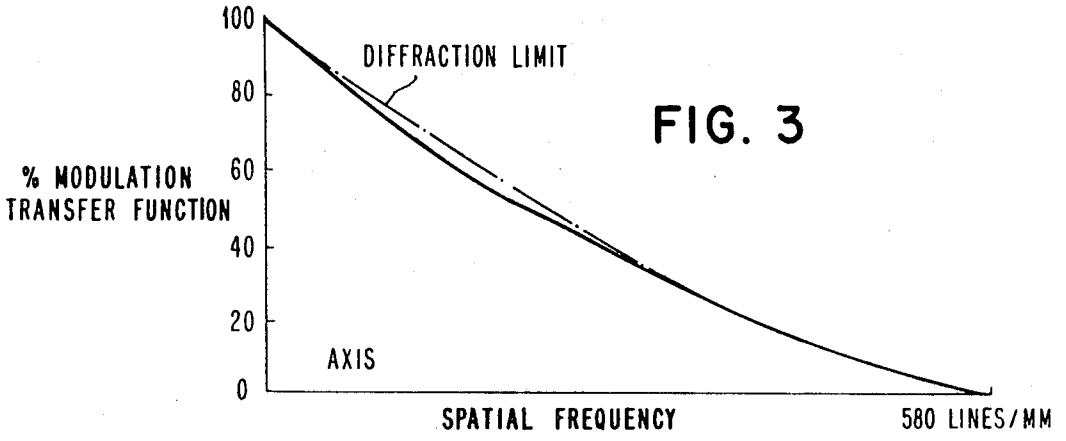


FIG. 3

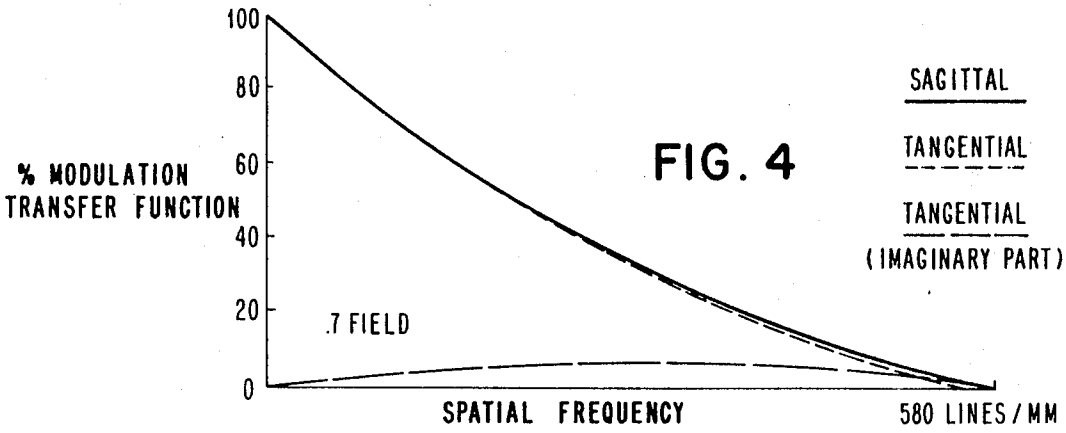


FIG. 4

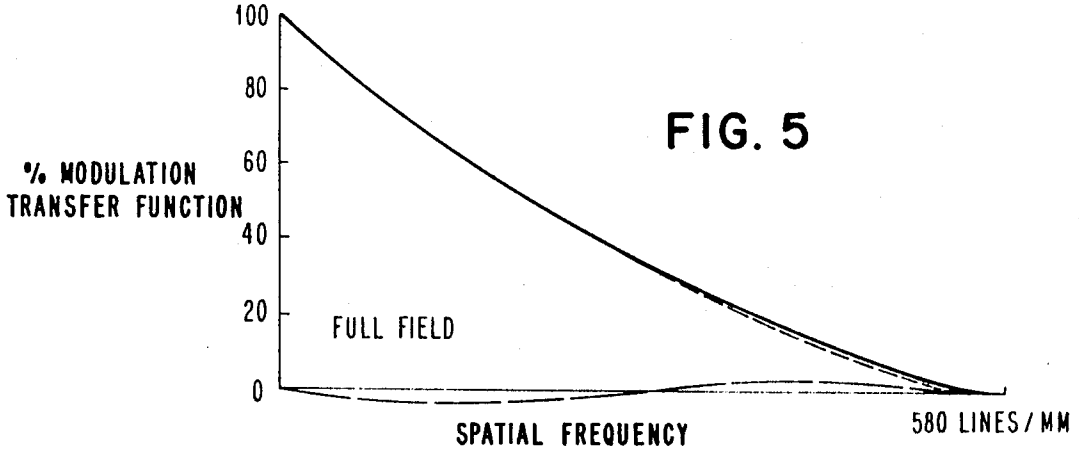


FIG. 5

$\delta\ell' = -.044$ MILLIMETERS

$\lambda = 5461$ ANGSTROMS

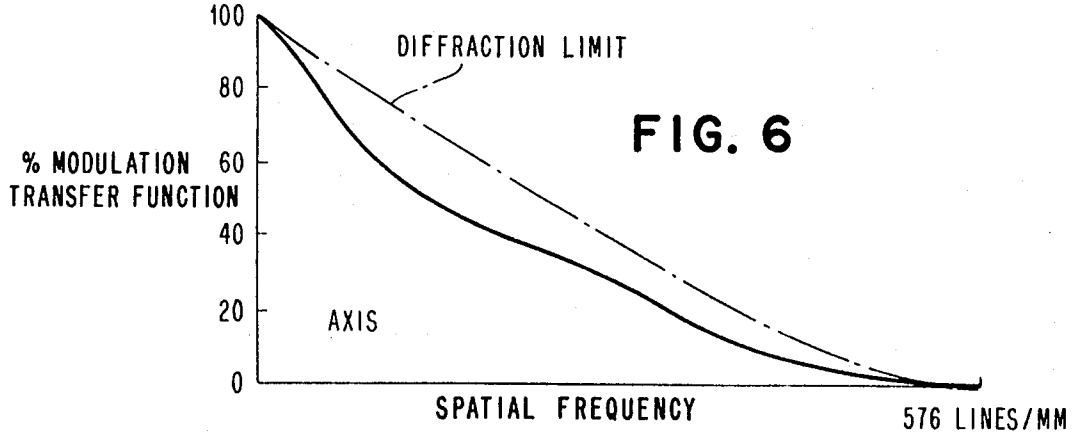


FIG. 6

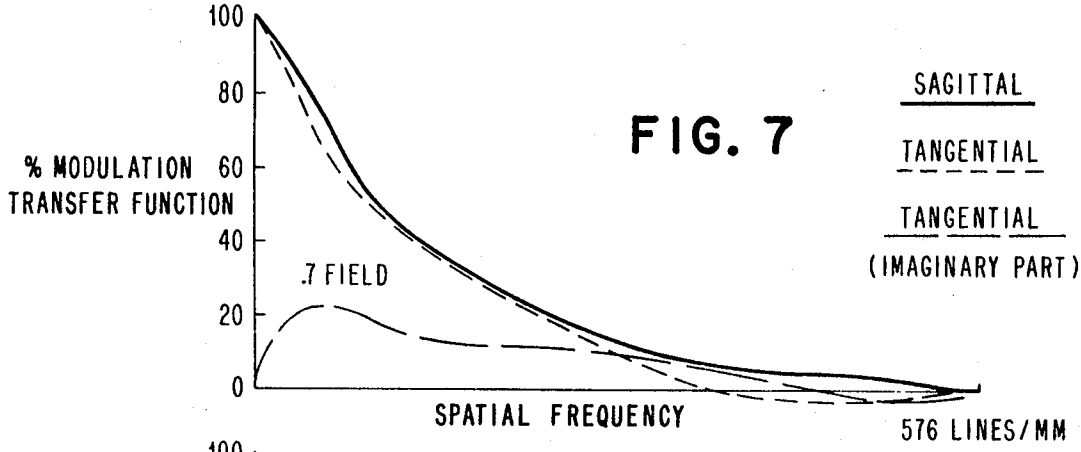


FIG. 7

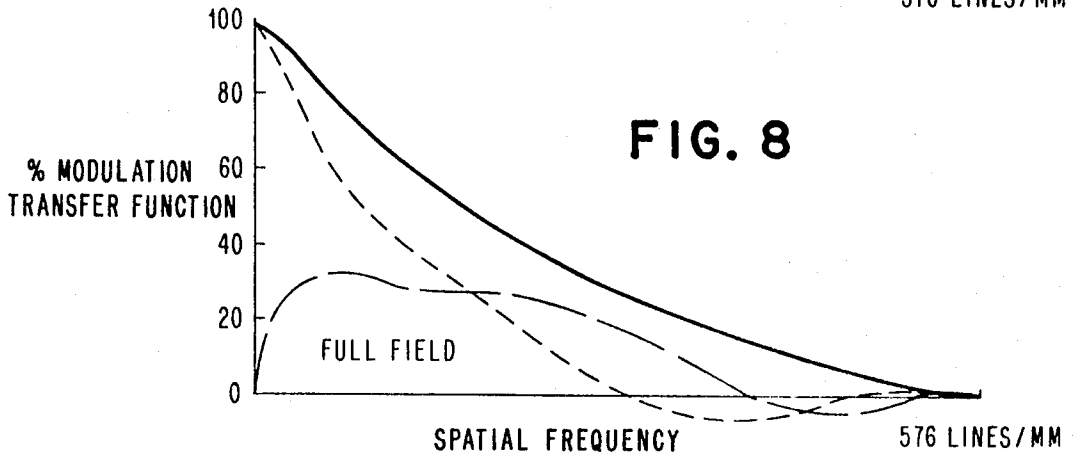


FIG. 8

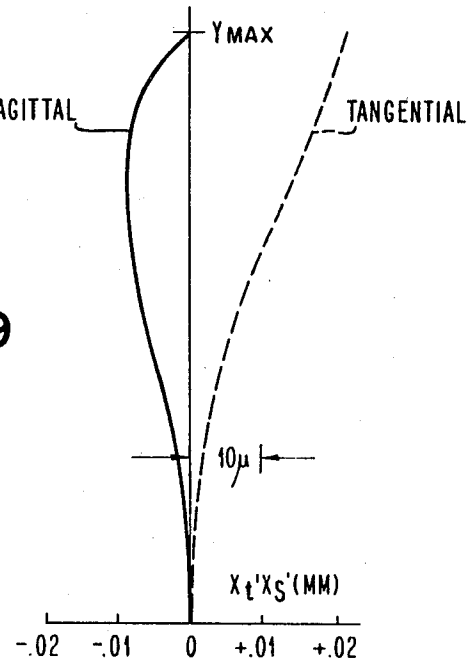

YMAX
SAGITTAL
TANGENTIAL
10μ
Xt'Xs'(MM)
-.02
-.01
0
+.01
+.02

FIG. 9

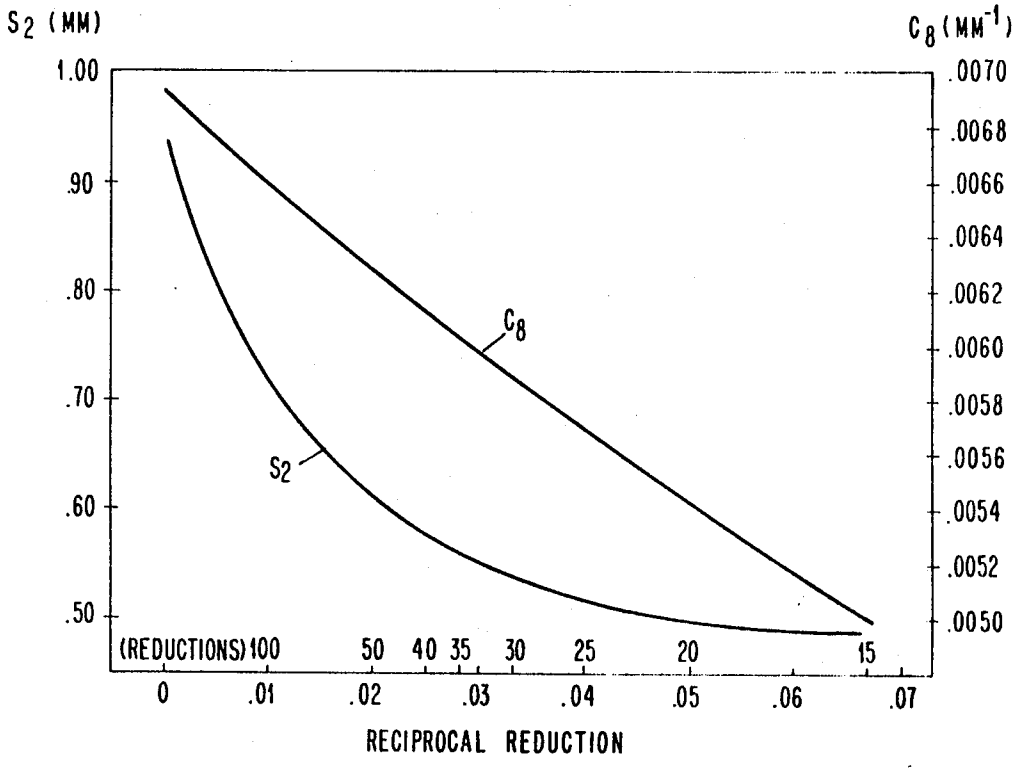
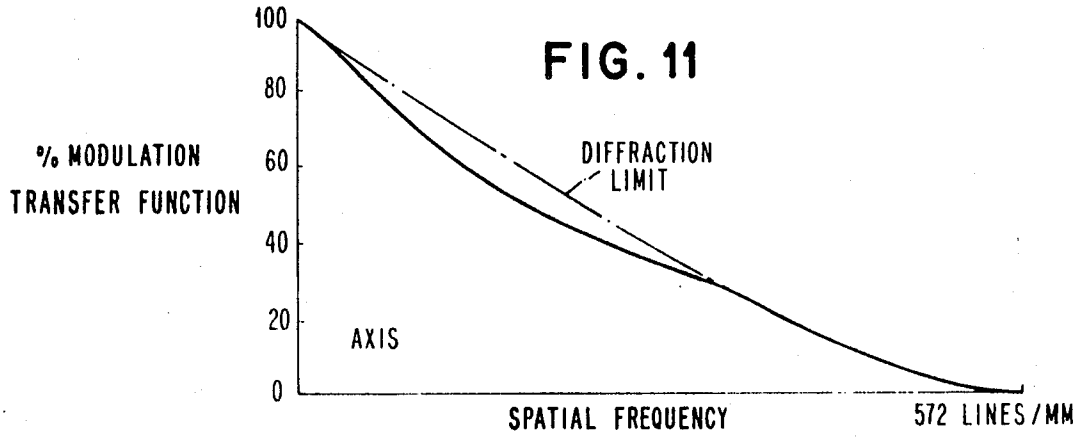
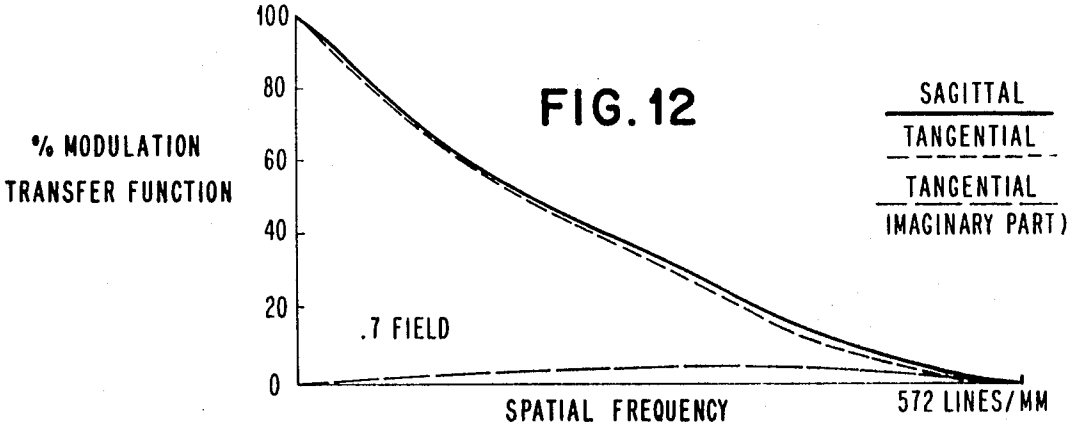
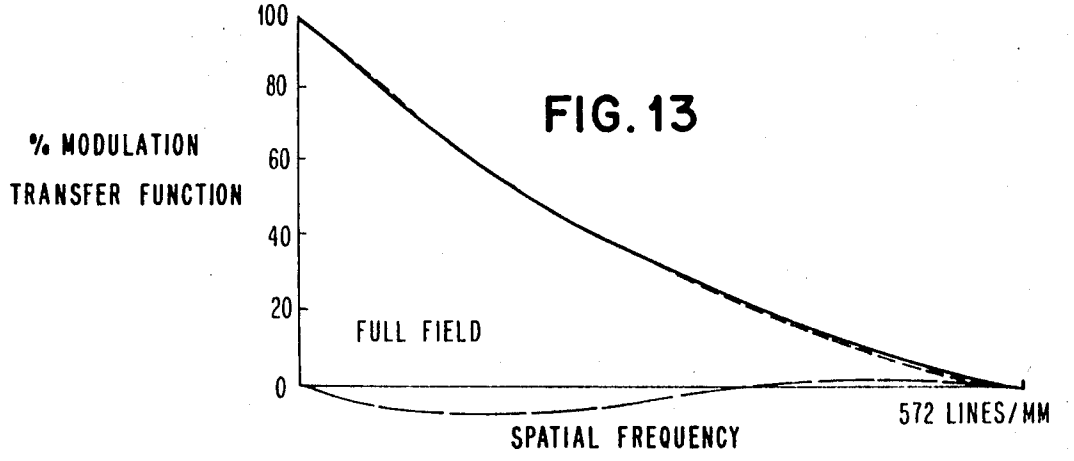

S2 (MM)
C8 (MM-1)
1.00
.90
.80
.70
.60
.50
.0070
.0068
.0066
.0064
.0062
.0060
.0058
.0056
.0054
.0052
.0050
C8
S2
(REDUCTIONS) 100
50
40
35
30
25
20
15
0
.01
.02
.03
.04
.05
.06
.07
RECIPROCAL REDUCTION

FIG. 10

$\delta\ell' = -.059$ MILLIMETERS
λ = 5461 ANGSTROMS







$\delta\ell' = -.040$ MILLIMETERS
λ = 5461 ANGSTROMS

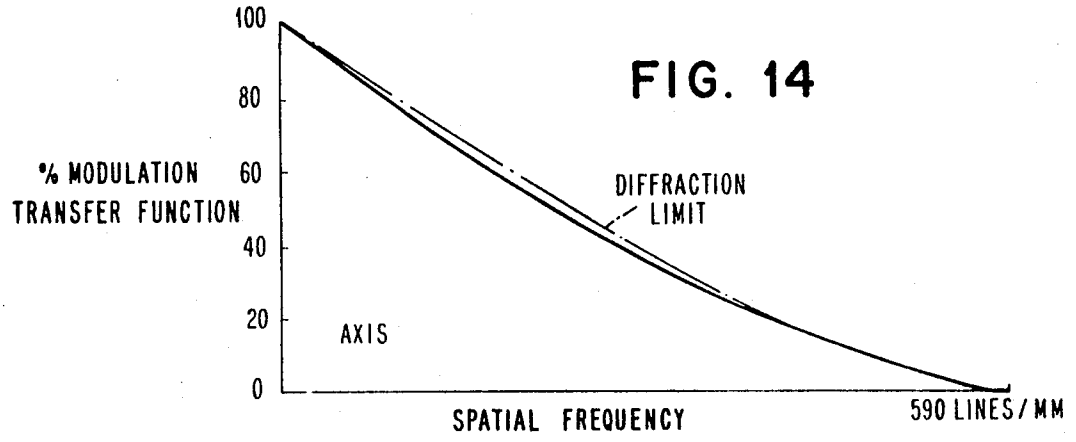


FIG. 14

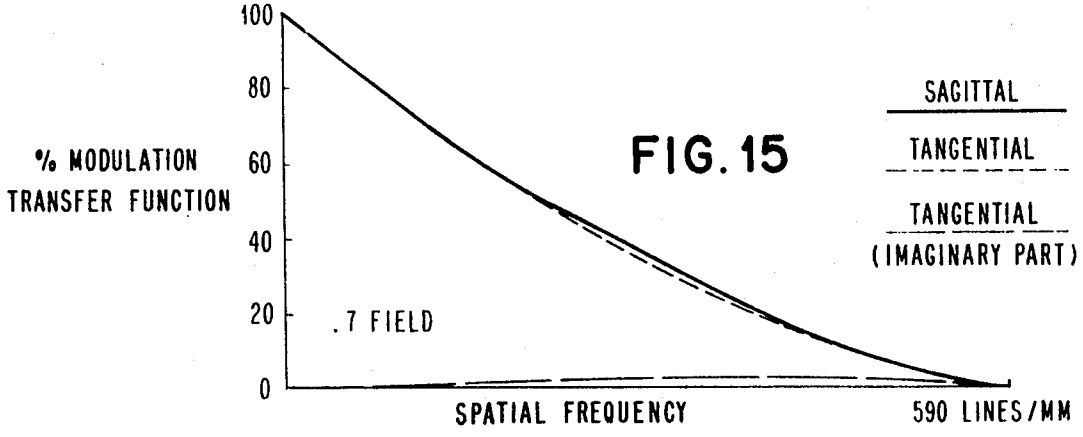


FIG. 15

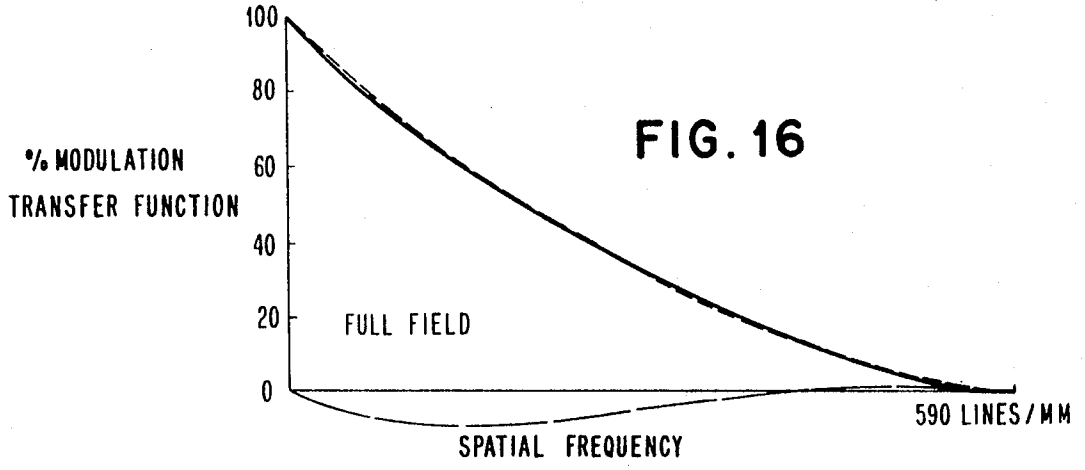


FIG. 16

$\delta\ell'$ = −.034 MILLIMETERS
λ = 5461 ANGSTROMS

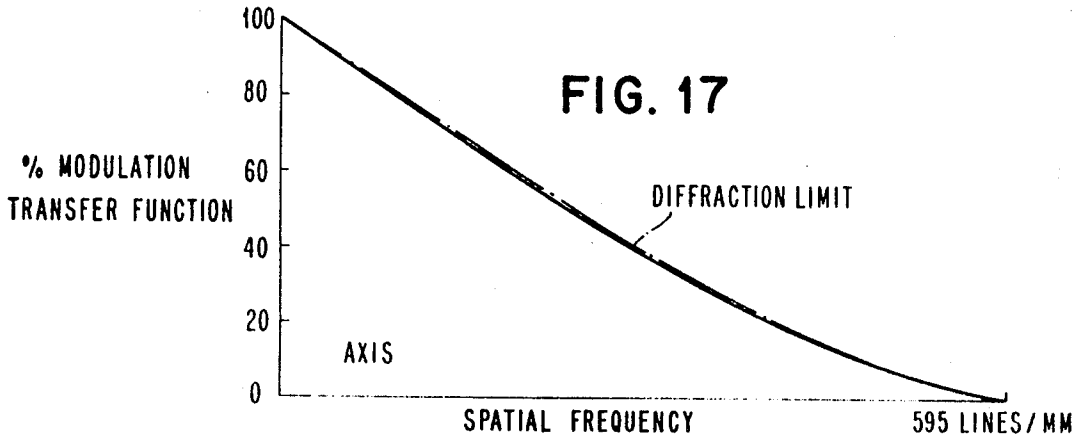


FIG. 17

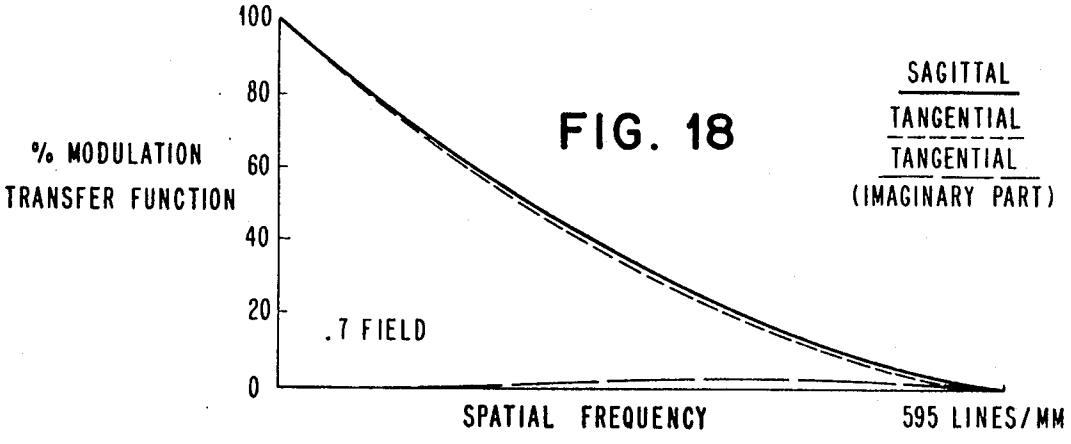


FIG. 18

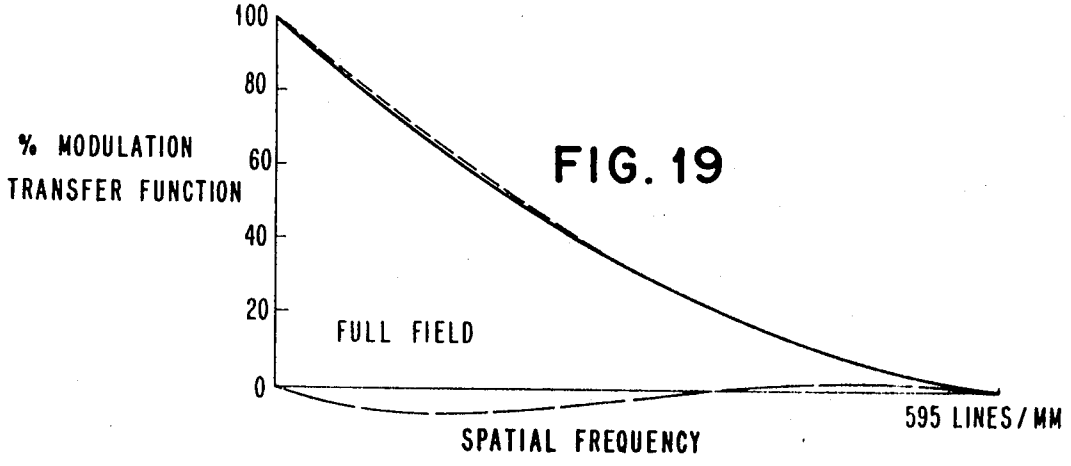


FIG. 19

$\delta\ell' = -.031$ MILLIMETERS
$\lambda = 5461$ ANGSTROMS

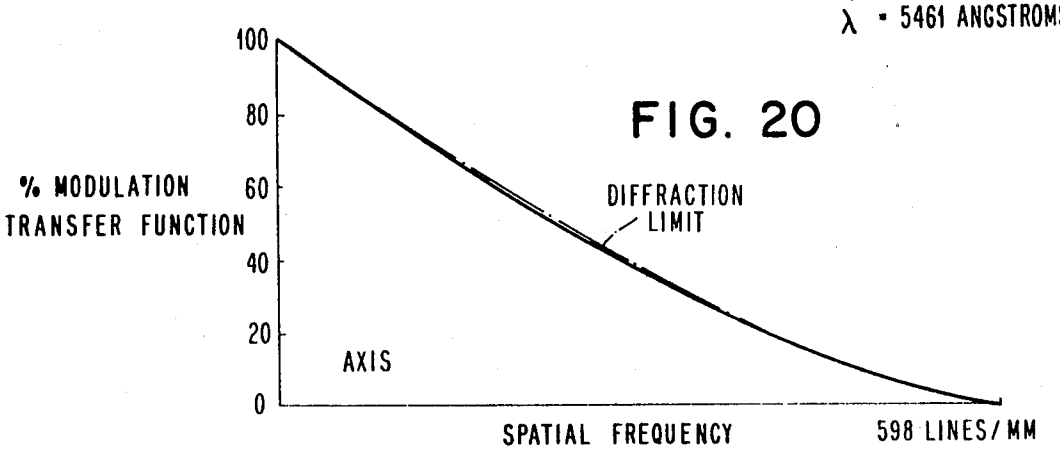


FIG. 20

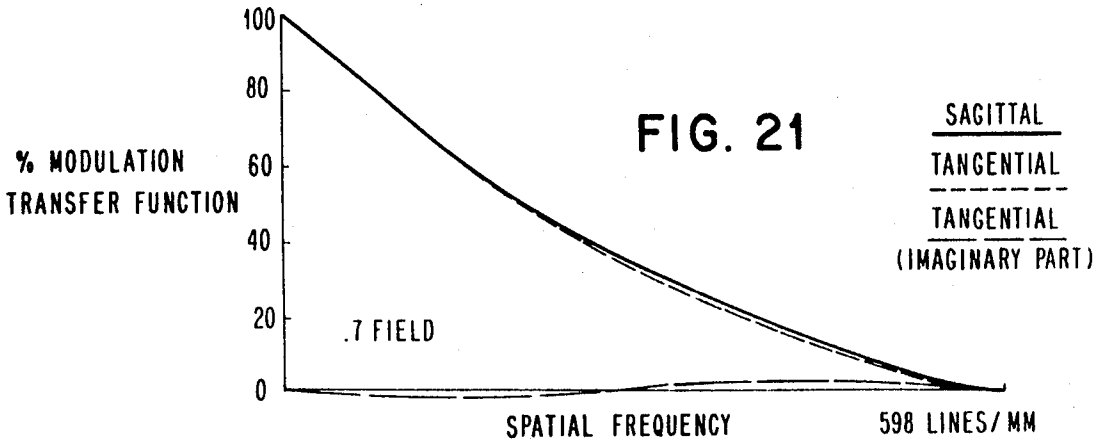


FIG. 21

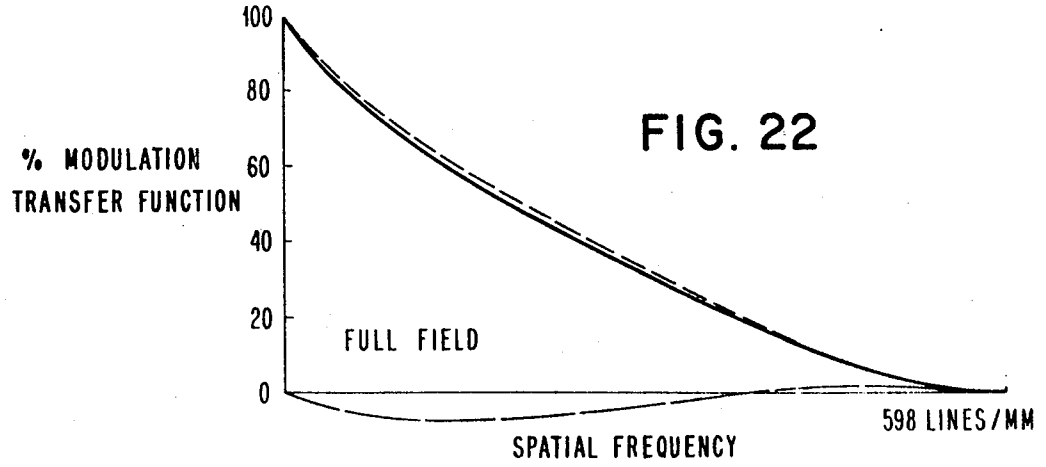


FIG. 22

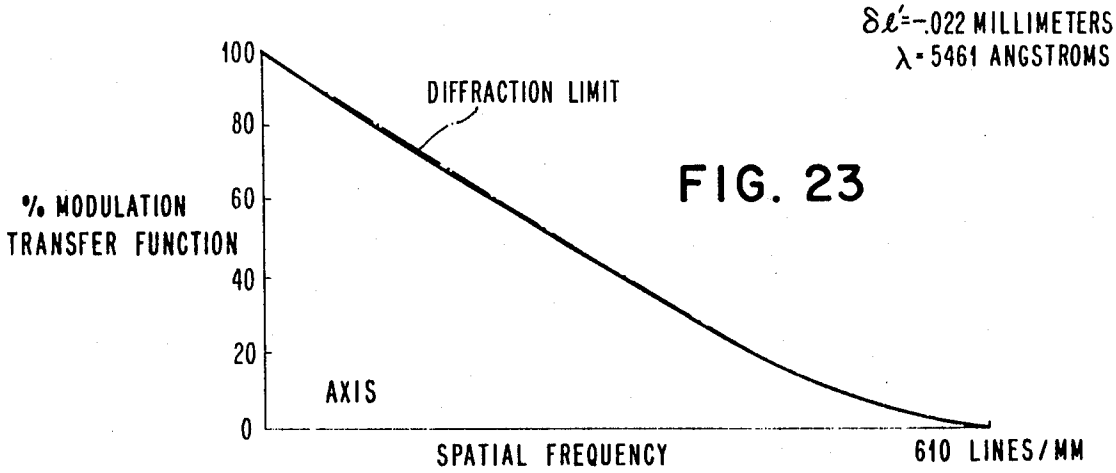


FIG. 23

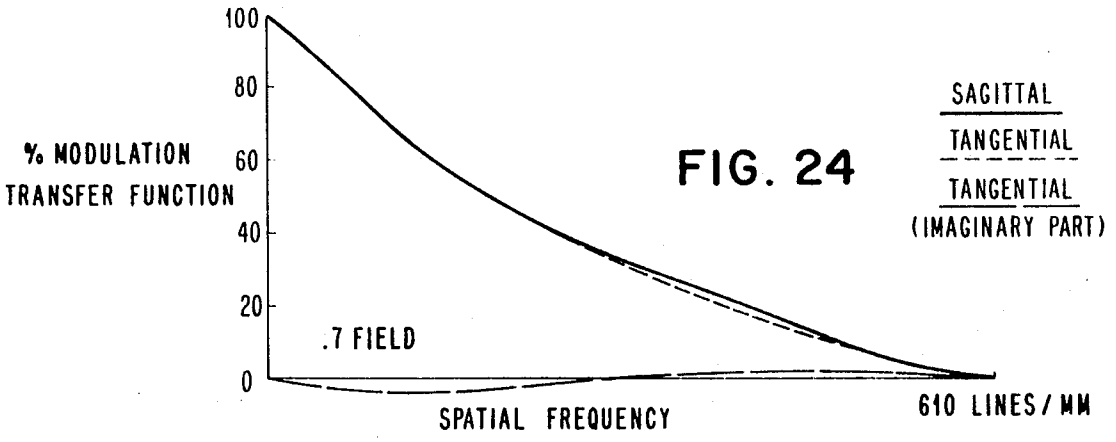


FIG. 24

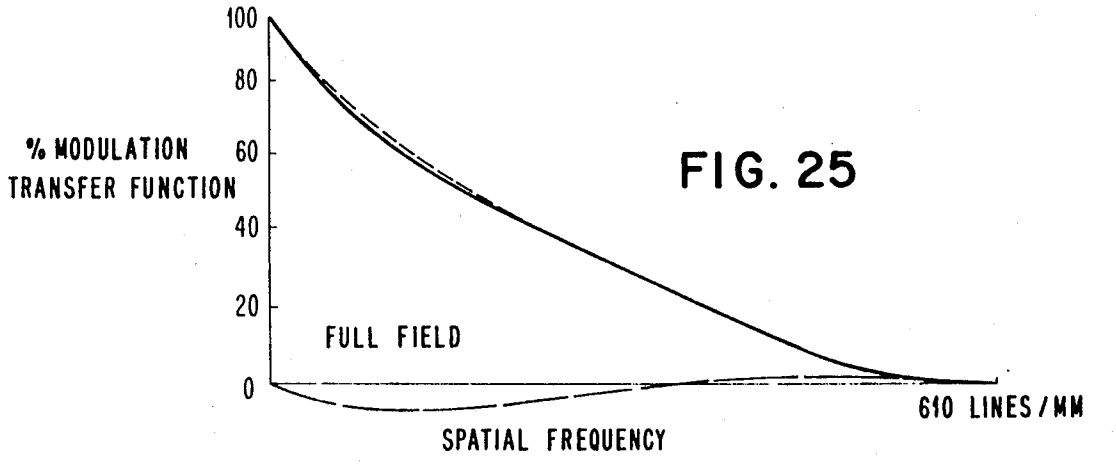


FIG. 25

FIG. 26

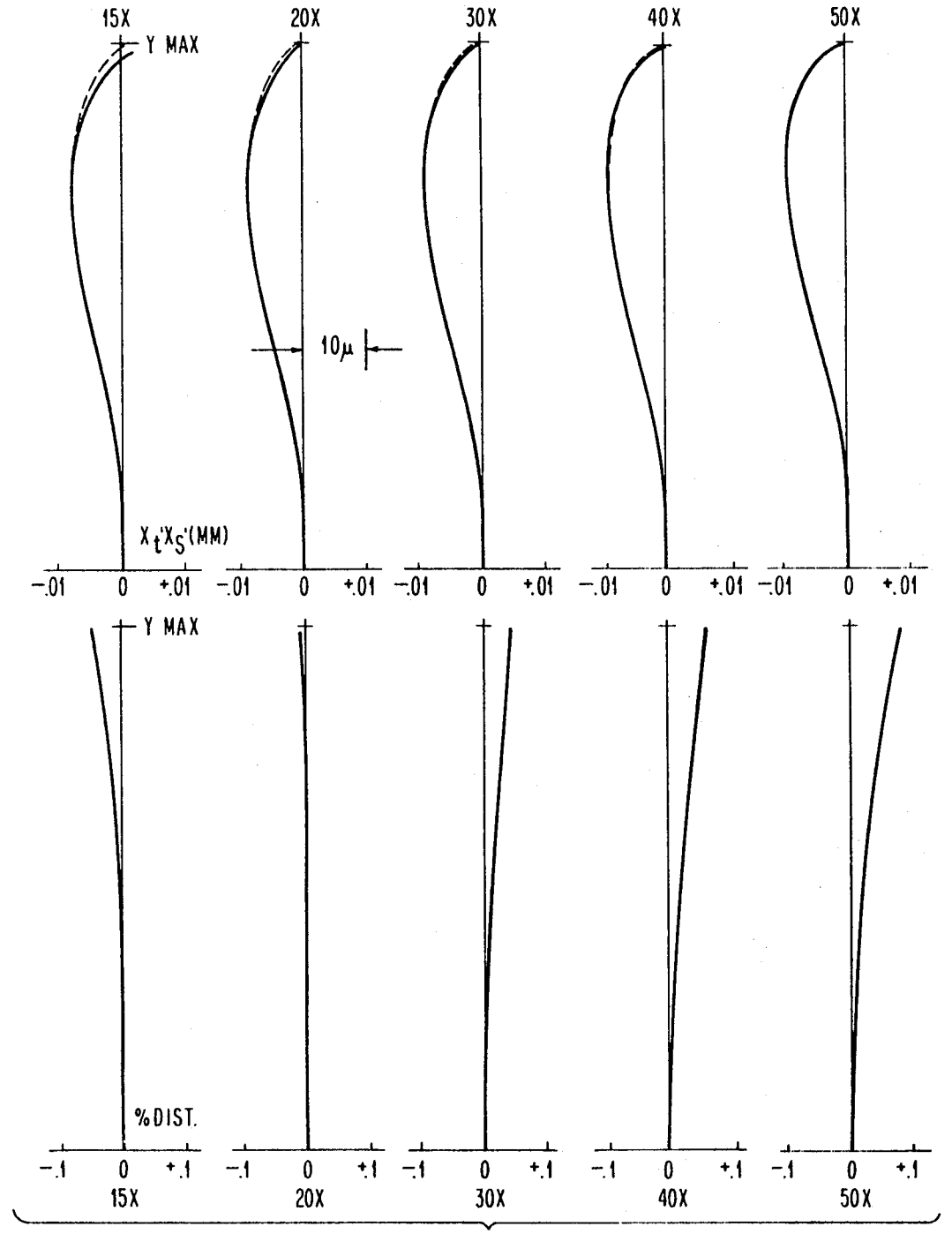
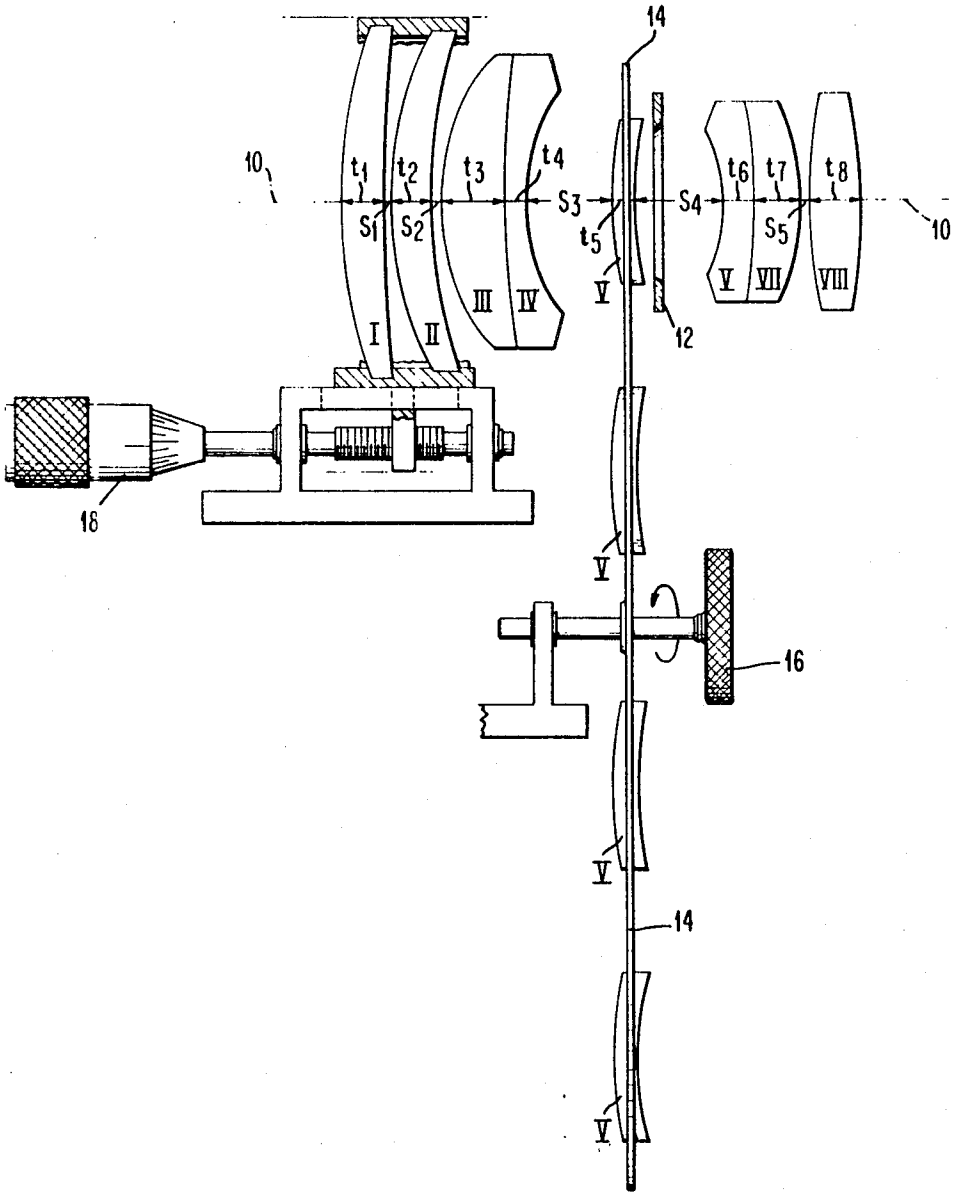

15X
20X
30X
40X
50X
Y MAX
10μ
X_t'X_S'(MM)
-.01
0
+.01
Y MAX
%DIST.
-.1
0
+.1
15X
20X
30X
40X
50X

FIG. 27

FIG. 28


14
10
t1
t2
t3
t4
S1
S2
S3
S4
t5
t6
t7
t8
S5
10
I
II
III
IV
V
V
VII
VIII
12
16
V
16
V
14
V

VARIABLE REDUCTION LENS SYSTEM

This application is a continuation-in-part of copending parent U.S. Pat. application, Ser. No. 600,158 filed Dec. 8, 1966, now abandoned.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention is in the field of optics and more particularly relates to a lens group including lens elements.

SUMMARY OF THE INVENTION

It is well known that a given lens exceedingly well corrected at one working magnification will exhibit very poor performance at a different magnification (or reduction). In the production of miniature integrated circuits, by optical means, or in microfilming, the mask or document is reduced the desired amount by the lens producing the circuit or copy on some type of photoreceptive surface. If it is necessary to change this reduction by some desired amount, say from 20× to 17×, the same lens cannot be used at the new reduction and yet yield the usual high quality results, the two most offending aberrations being coma and astigmatism. For optimum results, a new lens especially corrected for the new reduction must be designed and employed. Versatility together with high performance is therefore generally unattainable with one lens.

An object of the present invention is to provide a versatile lens system which may be used over a relatively large range of reductions with no appreciable loss in image quality.

Another object of the present invention is to provide a lens system wherein changes in reduction with constant high image quality may be accomplished with two simple adjustments.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is an optical diagram of a variable reduction lens system constructed according to the present invention.

FIG. 2 shows a chart of the constructional data for the lens system of FIG. 1.

FIGS. 3, 4 and 5 show curves of the modulation transfer function of the lens system of FIG. 1 calculated for a reduction value of 20× at the optical axis, at 0.7 field, and at full field, respectively.

FIGS. 6, 7 and 8 show curves of the modulation transfer function of the lens system of FIG. 1 calculated for a reduction value of 17× at the optical axis, at 0.7 field, and at full field, respectively, when said lens is not modified according to the present invention.

FIG. 9 is a curve of the astigmatism of the lens of FIG. 1 for a reduction of 17× when not modified according to the present invention.

FIG. 10 is a curve of one airspace an one reciprocal radius of curvature of the lens system of FIG. 1 plotted as functions of reciprocal reduction.

FIGS. 11, 12 and 13 are curves of the modulation transfer function of the lens system of FIG. 1 calculated at the optical axis, 0.7 field, and full field, respectively, for a reduction of 15×.

FIGS. 14, 15 and 16 are similar modulation transfer function curves for a reduction of 30×.

FIGS. 17, 18 and 19 are similar modulation transfer function curves for a reduction of 40×.

FIGS. 20, 21 and 22 are similar modulation transfer function curves for a reduction of 50×.

FIGS. 23, 24 and 25 are similar modulation transfer function curves of an object at infinity.

FIG. 26 shows curves of the astigmatism for the lens of the present invention for reductions of 15×, 20×, 30×, 40× and 50×.

FIG. 27 shows curves of the distortion for the lens of the present invention for reductions of 15×, 20×, 30×, 40×, and 50×.

FIG. 28 is a schematic drawing of an adjustable reduction camera including the lens system of the present invention.

Referring to FIG. 1 an embodiment of a variable reduction lens is shown including eight lens elements designated as elements I, II, III, IV, V, VI, VII and VIII. Lens elements I and II are meniscus singlet lenses, lens elements III and IV are cemented together to form a meniscus doublet lens element V is a negative meniscus singlet lens; lens elements VI and VII are cemented together to form a meniscus doublet lens, and lens element VIII is a biconvex lens. The lenses are optically aligned on axis 10, and a diaphragm 12 is provided between lens elements V and VI.

At 5461 Angstroms, the lens system of FIG. 1 has an effective focal length of 113.62 millimeters, a back focal length of 59.26 millimeters, and a front focal length of 46.78 millimeters designed for a reduction of 20×.

The following table sets forth the constructional data for an embodiment of the present invention.

Lens	Radius	Thickness (t) or airspace (s)	N_D	V
	R_1=+0.9840F			
I	R_2=+3.8081F	t_1=.0691F	1.69089	54.80
		S_1=.0044F		
	R_3=+0.6089F			
II	R_4=+0.8903F	t_2=.0616F	1.69089	54.80
		S_2=.0044F		
	R_5=+0.3461F			
III	R_6=+2.4406F	t_3=.0995F	1.69089	54.80
IV	R_7=+0.2320F	t_4=.0352F	1.64752	33.80
		S_3=.1329F		
	R_8=+1.6228F			
V	R_9=+0.6295F	t_5=.0299F	1.64752	33.80
		S_4=.1294F		
	R_{10}=−0.2813F			
VI	R_{11}=−2.3989F	t_6=.0396F	1.60328	38.02
VII	R_{12}=−0.3923F	t_7=.0804F	1.69089	54.80
		S_5=.0044F		
	R_{13}=+1.3630F			
VIII	R_{14}=−0.8977F	t_8=.0792F	1.69089	54.80

wherein R_1 through R_{14} represent the radii of curvature of the associated individual lens elements; t_1 through t_8 represent the axial thicknesses of the associated lens elements; S_1 through S_5 represent the axial spacing between the associated lens elements; N_D represents the refractive index and V represents the Abbe number of each lens element.

The following Table I of mathematical statements lists the range of constructional data of the lens system of FIG. 1.

TABLE I

$.92F<+R_1<1.04F$	$.066F<t_1<.072F$
$3.60F<+R_2<4.00F$	$.003F<S_1<.005F$
$.58F<+R_3<.63F$	$.060F<t_2<.063F$
$.84F<+R_4<.94F$	$.003F<S_2<.005F$
$.32F<+R_5<.38F$	$.098F<t_3<.102F$
$2.35F<+R_6<2.53F$	$.033F<t_4<.037F$
$.22F<+R_7<.24F$	$.130F<S_3<.136F$
$1.53F<+R_8<1.71F$	$.027F<t_5<.033F$
$.60F<+R_9<.66F$	$.125F<S_4<.133F$
$.26F<-R_{10}<.30F$	$.037F<t_6<.042F$
$2.30F<-R_{11}<2.50F$	$.078F<t_7<.082F$
$.37F<-R_{12}<.41F$	$.003F<S_5<.005F$
$1.26F<+R_{13}<1.45F$	$.076F<t_8<.082F$
$.85F<-R_{14}<.94F$	

R_1 through R_{14} represents the respective radii of the lenses as designated in FIG. 1, t_1 through t_8 represents the respective thickness of the lenses along axis 10, S_1 through S_5 represents the airspaces between the respective lenses along the axis 10, all set forth as functions of the effective focal length F (113.62 millimeters). The fixed diaphragm of 20.8 millimeters diameter at $f/3$ is located 3.7 millimeters to the right of lens element V.

FIGS. 3, 4 and 5 are curves of the modulation transfer function of the lens system of FIG. 1 calculated at the axis 10, at

0.7 field, and at full field, respectively. The calculations were done at λ of 5461 Angstroms and F=113.62 millimeters covering a linear field of ± 16 millimeters reduced from ± 320 millimeters.

The uniform high correction is illustrated in FIGS. 3, 4 and 5 by the slight departure of all curves from the diffraction limit. The magnitude of the imaginary part of the tangential fan is quite small and its reversal of sign denotes a balance of the residual coma. On the other hand when the lens system of FIG. 1 is used at a reduction of 17×, the modulation transfer function curves calculated at this new reduction shown in FIGS. 6, 7 and 8 readily show how the lens performance drops when the lens is not used at its designed reduction. The imaginary part of the tangential fan is extremely large, causing the lens to be useless at even this small change in reduction. The astigmatism at 17× reduction as shown in FIG. 9 is also far too large to yield acceptable performance. The maximum value of Y in FIG. 9 (and FIGS. 26 and 27) is 16.0 millimeters.

The present invention is directed to the manner in which the lens system of FIG. 1 can be slightly modified so as to provide a lens arrangement which can be used over a wide range of reductions while still maintaining the same high correction at each reduction. It has been found that by adjusting merely the shape associated with just one lens element (element V) of FIG. 1 such a lens system is obtainable rather than the usual requirement of redesigning an entire new lens system for each reduction. Thus the seven lens elements and their spacings (lens elements I through IV and VI through VIII) with the exception of spacing S_2 remain the same over a wide range of reductions. Furthermore, the adjustment of lens element V is in accordance with a given procedure as follows.

When the reduction of a lens system is changed form the initial design value, the main cause of the poor performance of the lens system is due to two aberrations; coma and astigmatism. In the present invention the coma and astigmatism aberrations can be rebalanced by changing only two parameters, the coma being rebalanced by changing the shape of element V and the astigmatism being rebalanced by changing airspace S .

Considering first coma correction, since element V is relatively thin and close to the diaphragm of the system, its astigmatic contribution is mainly a function of the lens power and almost independent of its shape. Also, since the nominal shape of lens element V is such that the lens is working at close to minimum deviation for the axial bundle, the spherical aberration changes slowly as a function of bending. The Seidel coma contribution of lens element V, however, changes rapidly with bending, and since the higher order comatic aberrations of the entire lens system change slowly at different reductions, bending lens element V as a function of reduction thus balances all orders of coma with very small zonal residuals.

The modulation transfer function curves of the lens system of FIG. 1 at a reduction of 20× is shown in FIGS. 3, 4 and 5. The modulation transfer function curves for the lens system with element V adjusted at a reduction of 15× is shown in FIGS. 11, 12 and 13. A comparison of the curves at the two reductions illustrates at both reductions the imaginary parts of the tangential fans are quite small. The correction can be appreciated by contrasting the curves of FIGS. 11, 12 and 13 at a reduction of 15× with those of FIGS. 6, 7 and 8 for the unmodified lens system at a reduction of 17×. The total curvature of lens element V of FIG. 1 is represented by the expression $C=C_8-C_9$

$$C=1/R_8-1/R_9$$

$$C=-0.0085566\ (\text{millimeters}^{-1})$$

Thus, when the curvature C_8 (i.e., $1/R_8$) is properly specified for a desired reduction power the curvature C_9 (i.e., $1/R_9$) may be calculated.

Referring to FIG. 10, the proper value of C_8 is plotted as a function of the reduction powers and reciprocal of the reduction powers. Presume that the lens system of FIG. 1 is desired to be used at a reduction of 30×. In FIG. 10, an abscissa of 30× (or reciprocal reduction 0.033) for curvature C_8 has an ordinate of 0.00586 millimeters^{-1}. Since $R_8=1/C_8$, the radius R_8 for the lens element V at 30× is 1/00586 millimeters^{-1} which for an effective focal length F of 113.62 millimeters is $R_8=1.5019F$.

Also since $C=1/R_8$EA$/R_9$ and $C=-0.0085566$, then $1/R_9 0.0085566=0.00586=0144166$ millimeters^{-1} which for F of 113.62 millimeters is 0.6105 F. In like manner the values of R_8 and R_9 can be calculated for any reduction power thereby specifying the curvature of lens element V.

To rebalance the astigmatism aberration the airspace S_2 is changed. Referring again to FIG. 10, the airspace S_2 is plotted as a function of the reduction power and its reciprocal.

For a reduction of 30× the abscissa of curve S_2 has an ordinate 0.533 millimeters which means $S_2=0.533$ millimeters or 0.00469 F where F is 113.62 millimeters.

Using the curves of FIG. 10 the constructional data for the shape of lens element V and airspace S_2 can be determined for each reduction. The following table lists the values of S_2 and $1/R_8$ for various reductions.

	S_2, millimeters	$1/R_8$, millimeters^{-1}
Reduction:		
15×	.490	.004988
20×	.500	.0054237
30×	.533	.00586
40×	.576	.006108
50×	.616	.006255
Object at infinity	.930	.00962

It is to be particularly noted that lens elements I, II, III, IV, VI, VII and VIII and airspaces S_1, S_3, S_4, and S_5 of the embodiment were not changed. To illustrate that the lens system has constant high correction at the various reductions, the modulation transfer function curves were plotted for the lens system at the different reductions. FIGS. 11, 12 and 13 show the curves for a reduction of 15×, FIGS. 14, 15 and 16 show the curves for a reduction of 30×, FIGS. 17, 18 and 19 show the curves for a reduction of 40×, FIGS. 20, 21 and 22 show the curves for a reduction of 50×, and FIGS. 23, 24 and 25 show the curves for an object at infinity. The limiting case of object at infinity is provided to demonstrate the scope of the lens of the present invention. All curves denote extremely high performance over this range, with the residual coma quite small in magnitude and again of a balanced state. The astigmatism is also quite small (as shown in FIG. 26) and the distortion in no case exceeds 0.1 percent (as shown in FIG. 27). The reduction for the astigmatism curves and the distortion curves are set forth in FIGS. 26 and 27. The calculations for all reductions were done at F=113.62 millimeters covering a linear image field of ± 16 millimeters.

Other embodiments of lens systems in accordance with the present invention may be selected from the ranges previously set forth in Table I. The other embodiments will have the same extremely high resolution over a relatively small field as set forth for the embodiment of FIG. 1. In particular, five additional embodiments of lens systems for reductions of 20× will be hereinafter set forth as embodiments two through six. The embodiments have different constructional data than that of FIG. 1 and particular parameters have been selected to be at or beyond the limits of the ranges previously set forth in Table I. After specifying the six additional embodiments, the modulation transfer functions of the embodiments at axis, at 0.7 field filed and at full field will be set forth in Table II and compared in tabular form with the modulation transfer functions of the embodiment of FIG. 1 illustrated in FIGS. 3, 4 and 5. The modulation transfer functions of embodiments two through six cannot be compared graphically with those shown in FIGS. 7, 8 and 9 because the scale used would not show any distinction. This in itself is an indication that all six embodiments provide the same high resolution as will other embodi-

ments of the invention with the ranges set forth in Table I and will illustrate to one skilled in the art that lens systems in accordance with the present invention can be selected from the ranges of Table I.

Second Embodiment

Radii	S	t
R_1=−.9230F R_2=−3.2575F R_3=−.6140F R_4=−.9058F R_5=−.3489F R_6=+2.5536F R_7=+.2323F R_8=+1.6432F R_9=+.6323F R_{10}=−.2894F R_{11}=−2.3435F R_{12}=−.3912F R_{13}=+1.3630F R_{14}=−.8956F	S_1=.0044F S_2=.0044F S_3=.1329F S_4=.1294F S_5=.0044F	t_1=.0691F t_2=.0616F t_3=.0995F t_4=.0352F t_5=.0299F t_6=.0396F t_7=.0804F t_8=.0792F

R_2 is changed and is below the range $3.60F < +R_2 < 4.00F$

Third Embodiment

Radii	S	t
R_1=+0.9863F R_2=+3.8091F R_3=+0.6083F R_4=+0.8915F R_5=+0.3463F R_6=+2.4617F R_7=+0.2319F R_8=+1.6317F R_9=+0.6306F R_{10}=−0.2807F R_{11}=−2.3636F R_{12}=−0.3914F R_{13}=+1.3636F R_{14}=−0.8949F	S_1=.0044F S_2=.0044F S_3=.1329F S_4=.1294F S_5=.0044F	t_1=.0725F t_2=.0616F t_3=.0995F t_4=.0352F t_5=.0299F t_6=.0396F t_7=.0804F t_8=.0792F

t_1 is changed and is above the range $0.66F < t < 0.72F$

FOURTH EMBODIMENT

Radii	S	t
R_1=+1.0011F R_2=+4.1337F R_3=+0.5801F R_4=+0.8393F R_5=+0.3505F R_6=+2.6148F R_7=+0.2327F R_8=+1.6362F R_9=+0.6318F R_{10}=−0.2816F R_{11}=−2.3809F R_{12}=−0.3923F R_{13}=+1.3613F R_{14}=−0.8970F	S_1=.044F S_2=.0044F S_3=.1329F S_4=.1294F S_5=.0044F	t_1=.0691F t_2=.0616F t_3=.0995F t_4=.0352F t_5=.0299F t_6=.0396F t_7=.0804F t_8=.0792F

R_2 is changed above upper limits and R_3 and R_4 are at their respective lower limits.

FIFTH EMBODIMENT

Radii	S	t
R_1=+0.9805F R_2=+3.7819F R_3=+0.6077F R_4=+0.8932F R_5=+0.3469F R_6=+2.4710F R_7=+0.2319F R_8=+1.6039F R_9=+0.6268F R_{10}=−0.2831F R_{11}=−2.6044F R_{12}=−0.3953F R_{13}=+1.3564F R_{14}=−0.9054F	S_1=.0044F S_2=.0044F S_3=.1329F S_4=.0044F S_5=.0044F	t_1=.0691F t_2=.0616F t_3=.0995F t_4=.0352F t_5=.0299F t_6=.0417F t_7=.0804F t_8=.0792F

R_{12} is changed to beyond upper range. t_6 changed to its upper limit.

SIXTH EMBODIMENT

Radii	S,t
R_1=+1.0520F R_2=+4.1991F R_3=+0.6165F R_4=+0.9390F R_5=+0.3387F R_6=+2.4598F R_7=+0.2272F R_8=+1.5958F R_9=+0.6227F R_{10}=−0.2860F R_{11}=−1.9427F R_{12}=−0.4025F R_{13}=+1.3535F R_{14}=−0.8821F	t_1=.0689F S_1=.0044F t_2=.0616F S_2=.0044F t_3=.0992F t_4=.0351F S_3=.1326F t_5=.0299F S_4=.1317F t_6=.0396F t_7=.0803F S_5=.0044F t_8=.0790F

R_1, R_2 and R_4 are changed to at or above upper range. R_{11} is changed to below range.

TABLE II

Embodiment	Percent of Limiting Preg.	Percent MTF .7 Field Axis	.7 Field Sag	.7 Field Tan	Full Field Sag	Full Field Tan
First	25	62.3	61.4	60.4	62.8	62.6
	50	37.9	34.6	33.5	34.3	34.5
	75	15.4	12.7	10.4	12.8	12.2
Second	25	62.1	60.6	59.6	63.3	61.9
	50	37.5	34.1	33.4	35.1	33.7
	75	14.8	12.7	11.0	13.2	12.3
Third	25	61.6	61.4	60.0	63.2	62.9
	50	37.1	34.8	33.7	34.9	34.5
	75	14.8	12.7	10.8	13.0	12.0
Fourth	25	61.6	60.0	59.2	63.4	62.0
	50	37.5	33.8	33.4	35.1	34.4
	75	14.4	12.5	10.8	13.3	12.0
Fifth	25	61.4	62.0	61.1	62.8	61.3
	50	36.9	35.4	35.0	34.3	32.9
	75	14.8	13.0	11.6	13.0	12.3
Sixth	25	61.3	60.9	59.4	63.9	62.5
	50	37.3	34.7	33.7	35.2	34.8
	75	14.4	12.9	10.6	13.2	12.8

The lens system of the present invention is extremely versatile, being capable of replacing an almost infinite number of conventional fixed design reduction lenses. In operation, the lens system may be embodied in a camera. Referring to FIG. 28, a schematic drawing of the mechanical elements of such camera are shown. In FIG. 28 in lens elements I, II, III, IV, VI, VII and VIII and their spacing (with the exception of S_2) are identical to those shown in FIG. 1 and as described in FIG. 2. A turret A is provided which contains a plurality of different lens elements V, each one designed for a different reduction power as previously described. A selected lens element V for a desired reduction is introduced into the lens system by rotation of the turret 14 by handle 16. For each of the lens elements V a corresponding airspace S_2 distance must be established. This is accomplished by a lead screw arrangement 18 which moves lens elements I and II in unison toward or away from lens element III so that a desired distance S_2 may be established while the remaining airspaces of the lens system remain constant. It should be noted that lens element V is also the least expensive lens element.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

We claim:

1. A variable reduction lens system comprising first, second, third, fourth, fifth, sixth, seventh and eighth optically aligned lens elements wherein said first and second lens elements are meniscus singlet lenses, said third and fourth lens elements are meniscus singlet lenses cemented together to form a meniscus doublet, said fifth lens element is a negative meniscus singlet lens, said sixth and seventh lens elements are meniscus singlet

lenses cemented together to form a meniscus doublet, and said eighth lens element is a biconvex lens,

and wherein said first lens element has radii of curvature R_1 and R_2 and thickness t_1, said second lens element has radii of curvature R_3 and R_4 and thickness t_1, said third lens element has radii of curvature R_5 and R_6 and thickness t_2, said fourth lens element has radii of curvature R_6 and R_7 and thickness t_4, said sixth lens element has radii of curvature R_{10} and R_{11} and thickness t_6, said seventh lens element has radii R_{11} and R_{12} and thickness t_7 and said eighth lens element has radii R_{13} and R_{14} and thickness t_8,

wherein said first and second lens elements are axially separated by a distance S_1, said fourth and fifth lens elements are separated by an axial distance S_3, said fifth and sixth lens elements are separated by an axial distance S_4, and said seventh and eighth lens elements are separated by an axial distance S_5,

wherein said radii, thicknesses and spacings are within limits as follows where F is the effective focal length of the lens group:

$.92F<+R_1<1.04F$	$.066F<t_1<.072F$
$3.60<+R_1<4.00F$	$.003F<S_1<.005F$
$.58F<+R_3<.63F$	$.060F<t_2<.063F$
$.84F<+R_4<.94F$	$.095F<t_3<.102F$
$.32F<+R_5.38F$	$.033F<t_4<.037F$
$2.35F<+R_6<2.53F$	$.130F<S_3<.136F$
$.22F<+R_7<.24F$	$.027F<t_5<.033F$
$.26F<-R_{10}<.30F$	$.125F<S_4<.133F$
$2.30F<-R_{11}<2.50F$	$.037F<t_6<.042F$
$.37F<-R_{12}<.41F$	$.078F<t_7<.082F$
$1.26F<+R_{13}<1.45F$	$.003F<S_5<.005F$
$.85F<-R_{14}<.93F$	$.076F<t_8<.082F$

wherein said fifth lens element has radii of curvature R_8 and R_9 having values which are a function of the reduction power of said lens system,

and wherein said second and third lens elements are axially separated by a distance S_2 having a value which is a function of the reduction power of said lens group.

2. A variable reduction lens system according to claim 1 having numerical data substantially as follows:

Lens	Radius	Thickness (t) or airspace (s)	N_D	V
I	$R_1=+0.9840F$	$t_1=.0691F$	1.69089	54.80
	$R_2=+3.8081F$	$S_1=.0044F$		
II	$R_3=+0.6089F$	$t_2=.0616F$	1.69089	54.80
	$R_4=+0.8903F$	$S_2=.0044F$		
III	$R_5=+0.3461F$	$t_3=.0995F$	1.69089	54.80
IV	$R_6=+2.4406F$	$t_4=.0352F$	1.64752	33.80
	$R_7=+0.2320F$	$S_3=.1329F$		
V	$R_8=+1.6228F$	$t_5=.0299F$	1.64752	33.80
	$R_9=+0.6295F$	$S_4=.1294F$		
VI	$R_{10}=-0.2813F$	$t_6=.0396F$	1.60328	38.02
VII	$R_{11}=-2.3989F$	$t_7=.0804F$	1.69089	54.80
	$R_{12}=-0.3923F$	$S_5=.0044F$		
VIII	$R_{13}=+1.3630F$	$t_8=.0792F$	1.69089	54.80
	$R_{14}=-0.8977F$			

wherein R_1 through R_{14} represent the radii of curvature of the associated individual lens elements,

t_1 through t_8 represent the axial thicknesses of the associated lens elements,

S_1 through S_5 represent the axial spacing between the associated lens elements, N_D represents the refractive index and V represents the Abbe number of each lens element.

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,588,228 Dated June 28, 1971

Inventor(s) Janusz S. Wilczynski; Raymond E. Tibbetts

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Patent:

Section 3, line 40 "S" should be --S_2--

In the Application:

Page 7, line 20 States "S_2".

CLAIMS

In the Patent:

Section 7, line 5 "thickness t_1" should be --thickness t_2--

In the Application:

Amendment A, page 5, line 13 states "thickness t_2".

In the Patent:

Section 7, line 6 "thickness t_2" should be --thickness t_3--

In the Application:

Amendment A, page 5, line 15 states "thickness t_3".

Signed and sealed this 27th day of June 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents