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OR 3,953,111

United States Patent [19]

Fisher et al.

[11] 3,953,111

[45] Apr. 27, 1976

[54] NON-LINEAR LENS

[75] Inventors: **Ralph W. Fisher**, St. Charles; **George Licis**, Manchester; **Wayne W. Schurter**, Bridgeton, all of Mo.

[73] Assignee: **McDonnell Douglas Corporation**, St. Louis, Mo.

[22] Filed: **Nov. 4, 1974**

[21] Appl. No.: **520,487**

[52] **U.S. Cl.** **350/189**; 350/181
[51] **Int. Cl.²** **B29D 13/18; G02B 13/08**
[58] **Field of Search** 350/189, 192, 198, 175, 350/181

[56] **References Cited**

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Primary Examiner—John K. Corbin
Assistant Examiner—Conrad Clark
Attorney, Agent, or Firm—Graveley, Lieder & Woodruff

[57] **ABSTRACT**

A non-linear lens possesses distortion characteristics which are such that objects along the optical axis of the lens occupy disproportionately large areas of the image cast by the lens, whereas objects near the periphery of the field of view occupy a disproportionately small area of the image. The distortion characteristics approximate the formula $H = \sin^{1/3} \theta$ where H is height measured from the optical axis and θ is the angle measured from the optical axis. The image cast by the lens falls on the vidicon of a television camera where it is scanned and transmitted to a projector. Since the lens enlarges objects in the vicinity of the optical axis, those objects are transmitted with much greater detail than objects in the peripheral region of the view. The transmitted image is reproduced at a projector and the reproduced image is rectified through another lens having identical distortion characteristics. This lens casts the rectified image on a spherical screen. The final image which appears on the screen possesses a high degree of acuity in the region of the optical axis and substantially less acuity in peripheral regions. The resolution throughout the entire field of the reproduced image corresponds quite closely to the resolution characteristics of the human eye.

10 Claims, 7 Drawing Figures

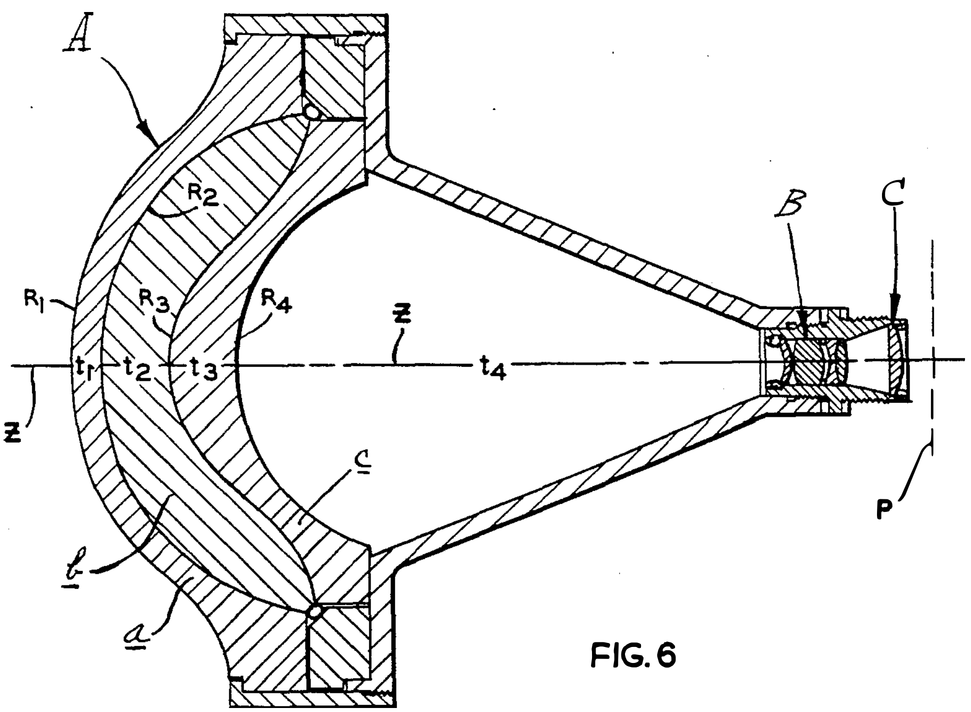

FIG. 6

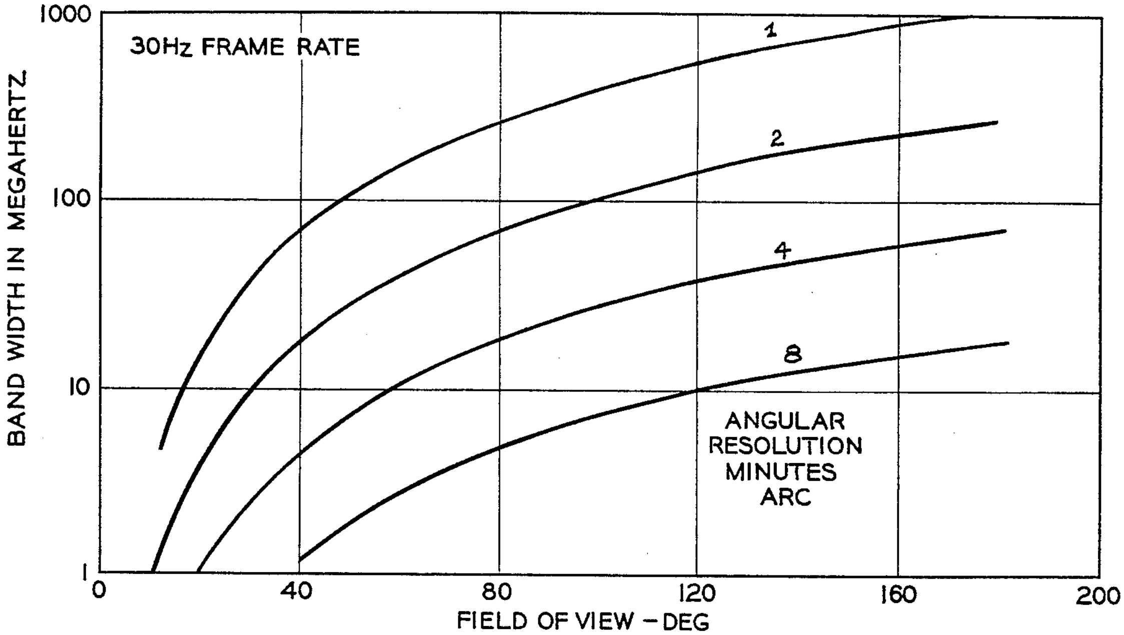

FIG. 1

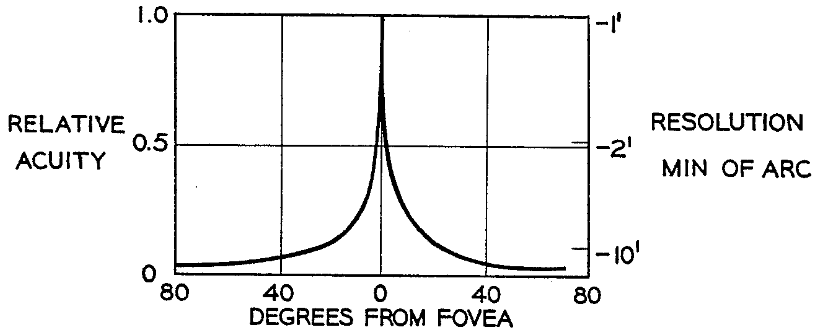

FIG. 2

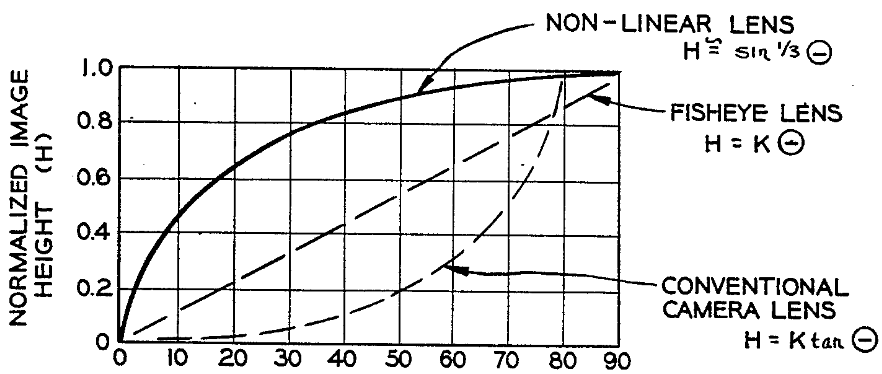

FIG. 3

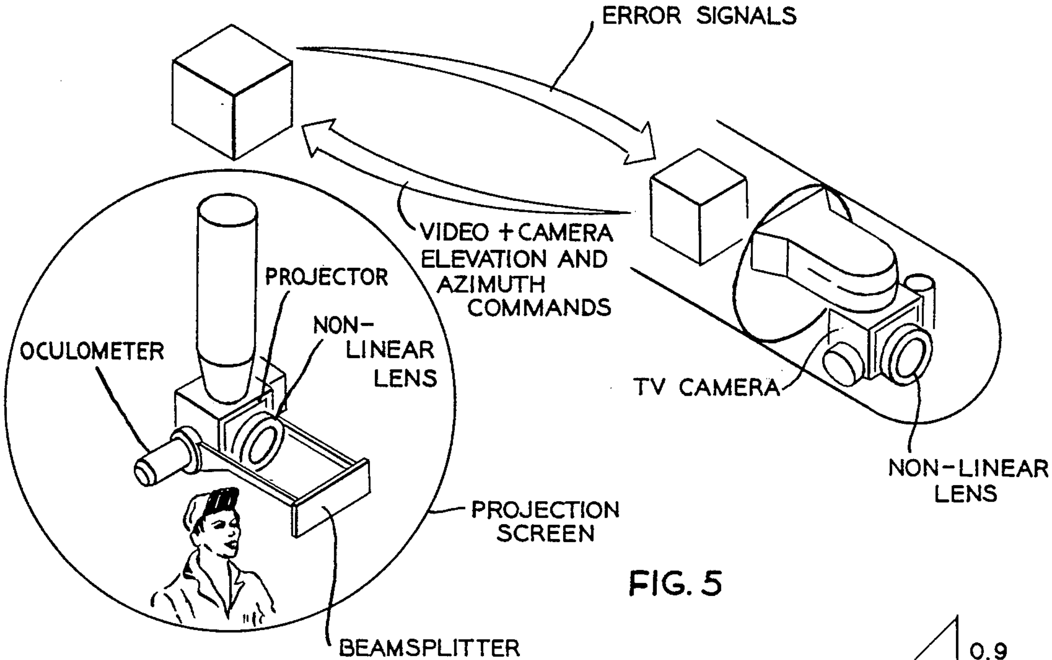
ERROR SIGNALS
VIDEO + CAMERA ELEVATION AND AZIMUTH COMMANDS
PROJECTOR
NON-LINEAR LENS
OCULOMETER
TV CAMERA
NON-LINEAR LENS
PROJECTION SCREEN
BEAMSPLITTER

FIG. 5

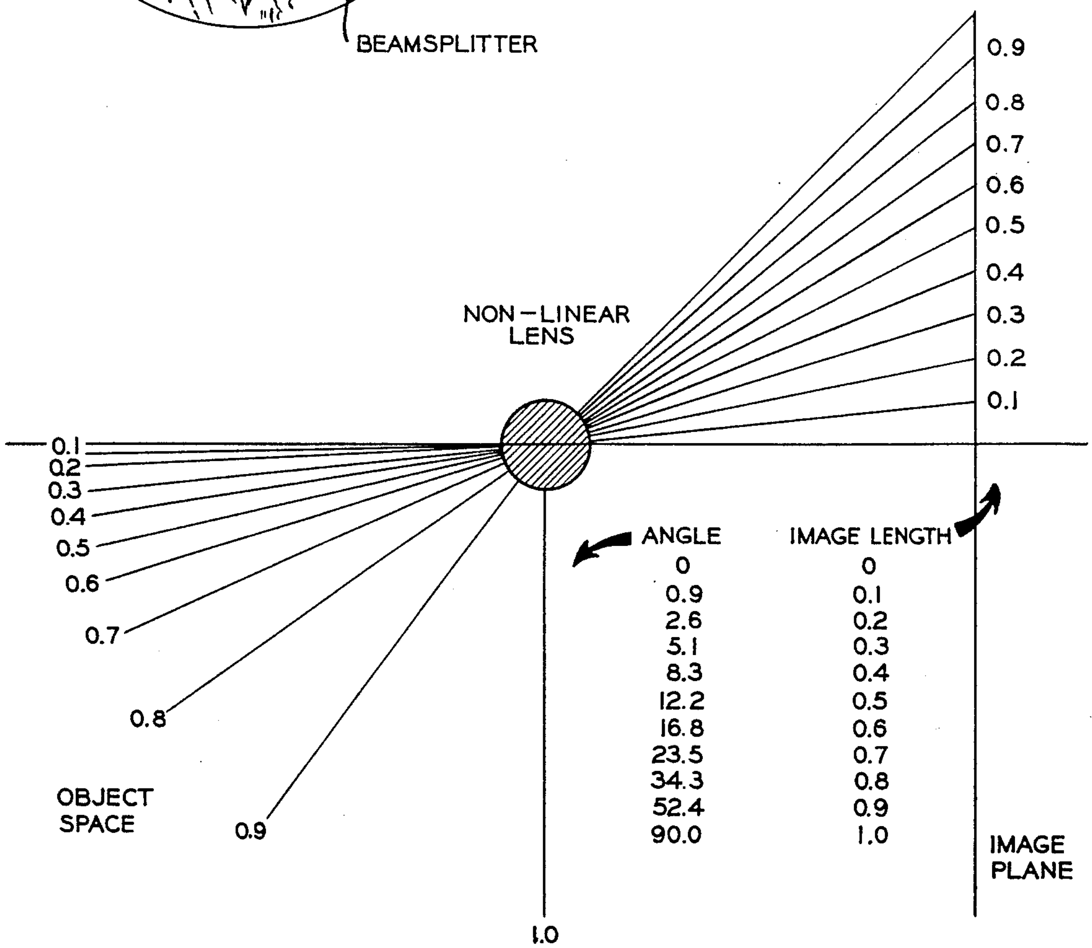
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
NON-LINEAR LENS
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
OBJECT SPACE
1.0
ANGLE
0
0.9
2.6
5.1
8.3
12.2
16.8
23.5
34.3
52.4
90.0
IMAGE LENGTH
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
IMAGE PLANE

FIG. 4

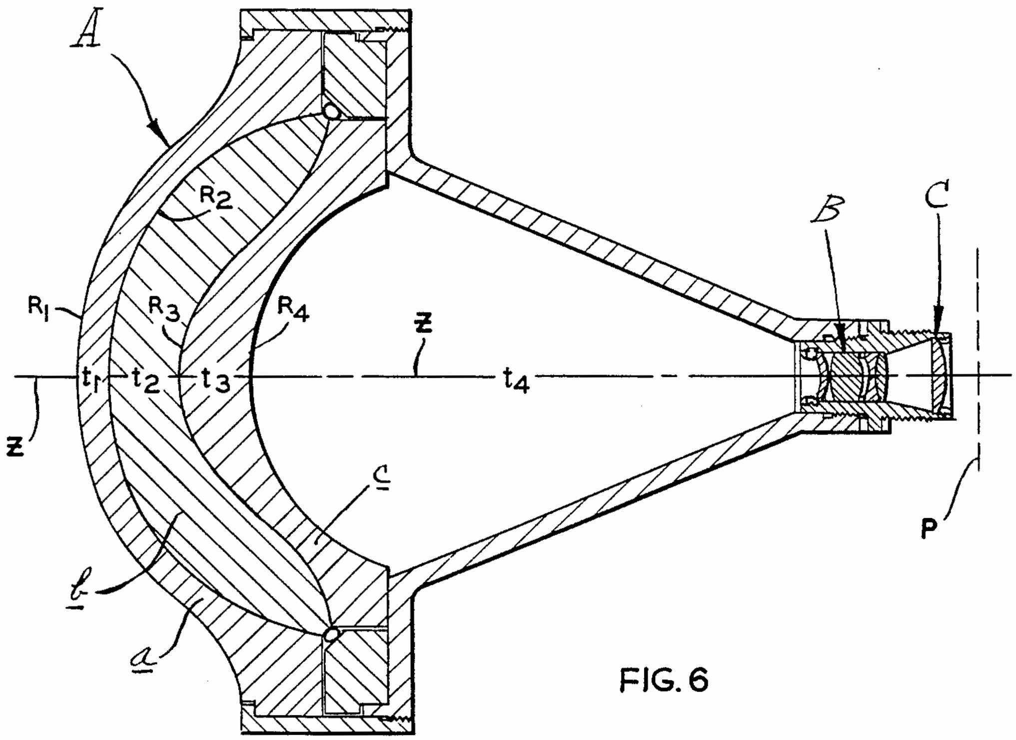
A
B
C
R1
R2
R3
R4
t1
t2
t3
t4
Z
Z
c
b
a
P

FIG. 6

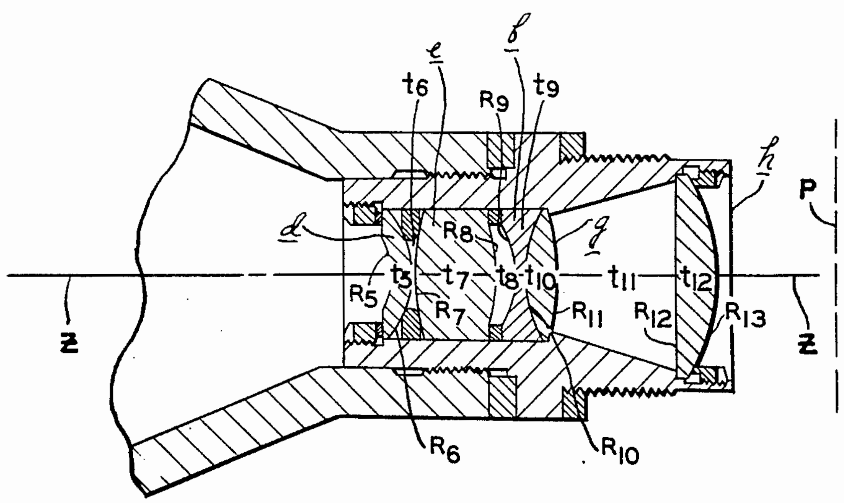
e
f
t6
R9
t9
h
P
d
R8
g
t5
t7
t8
t10
t11
t12
R5
R7
R11
R12
R13
Z
Z
R6
R10

FIG. 7

NON-LINEAR LENS

The Government has rights in this invention pursuant to Contract Number N00014-73-C-0154 awarded by the Department of the Navy.

BACKGROUND OF THE INVENTION

The present invention relates in general to lenses and more particularly to a lens having non-linear distortion characteristics.

The typical remote viewing system utilizes a television camera at the remote location, some type of projector at the observer location, and a television transmitting system linking the two. These viewing systems fall far short of duplicating the visual characteristis of the human eye in that they have extremely limited fields of view or else poor resolution in a large field of view.

In particular, for any fixed angular resolution (measured in minutes of arc) and frame rate (usually 30 Hz or frames/sec.) a definite relationship exists between field of view and bandwidth for transmitting that field of view. For example, commercial television, which utilizes a 525 line raster traced 30 times per second, operates on a bandwidth of 3.93 MHz. To match the resolution of the human eye, which is one minute of arc along its foveal or optical axis, the field of view for commercial television must be restricted to less than 10° (see FIG. **1**). On the other hand, if the field of view is increased to about 180°, which is the field of view for the human eye, the bandwidth must be increased to 1000 Mhz to maintain one minute of arc resolution over the entire field. This demands a raster of 10,000 lines and is far in excess of the capabilities of current television systems.

Indeed, the most advanced television currently available utilizes an 875 line system and requires a bandwidth of 10.9 Mhz. This provides a field of view of about 20° with one minute arc resolution throughout the entire field, which is far less than the 180° field of view possessed by the human eye.

From the foregoing, it is clear that present television viewing systems present a dilemma. If the field of view is sufficient to encompass all possible locations of interest, resolution is so low that detection or clear observation is impossible. On the other hand, if the resolution is adequate to insure that the objects will be seen clearly, the field of view is quite limited and many objects of interest are located outside of the field of view.

In a sense the human eye provides a solution for the foregoing dilemma. The human eye possesses high optical acuity along and in the vicinity of its foveal or optical axis, but the acuity diminishes outwardly therefrom. In other words, the eye distinguishes fine detail directly in front of it, but not to the sides. This characteristic is not derived from the shape of the eye lens, but instead results from the fact that most of the optical fibers for the eye are concentrated in the vicinity of the optical axis. Hence, only along the optical axis does the eye possess one minute of arc resolution. The resolution becomes progressively less toward the periphery of the field of vision (see FIG. **2**). Nevertheless, the resolution in the peripheral area is sufficient to detect the presence of many objects in that area as well as much movement in that area. Of course, when the eye detects anything of interest in the peripheral areas, the head or eye is immediately moved to bring the foveal axis to the thing of interest and thereby provide a clearer image of it.

SUMMARY OF THE INVENTION

One of the principal objects of the present invention is to provide a lens having non-linear distortion characteristics which are such that objects located along and near the optical axis of the lens occupy a disproportionately large area of the image produced by the lens. Another object is to provide a lens of the type stated which closely approximates the resolution characteristics of the human eye over a wide field of view. A further object is to provide a lens of the type stated which is ideally suited for use in remote viewing systems in that it provides a wide field of view with maximum acuity along the optical axis. These and other objects and advantages will become apparent hereinafter.

The present invention is embodied in a lens which distorts a field of view such that objects in the vicinity of the optical axis occupy a disproportionately large area of the image cast by the lens and objects in the peripheral region of the field of view occupy a disproportionately small area of the image. The invention also consists in the parts and in the arrangements and combinations of parts hereinafter described and claimed.

DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which form part of the specification and wherein like numerals and letters refer to like parts wherever they occur:

FIG. **1** is a graph showing the relationship between field of view, angular resolution, and bandwidth for transmitting a picture of a remote location by television;

FIG. **2** is a graph showing relative acuity of the human eye throughout the field of view for the eye;

FIG. **3** is a graph showing the distortion characteristics of the lens of the present invention in terms of normalized image height and field of view and comparing such distortion characteristics with the distortion characteristics of a fisheye lens and a conventional camera lens;

FIG. **4** is a graphic representation of the non-linear distortion characteristics and showing how equal increments on the image plane correspond to unequal increments in the field of view;

FIG. **5** is a schematic perspective view of the remote viewing system in which the non-linear lens may be utilized;

FIG. **6** is a sectional view of the non-linear lens; and

FIG. **7** is an enlarged sectional view of the second and third lens groupings for the non-linear lens.

DETAILED DESCRIPTION

The lens of the present invention (FIGS. **6** and **7**) provides non-linear image distortion characteristics over an extremely wide field of view which approaches 160°. This is in contrast to so-called fisheye lenses which provide linear distortion characteristics. In paticular, with a linear or fisheye lens the image height is directly proportional to the field angle (FIG. **3**). The relationship is defined by the formula $H=K\theta$ where H is the image height from the optical axis, K is a constant, and θ is the angle measured from the optical axis. Thus, with a linear lens an object occupying twice the angle as another object, when measured from the optical axis, will cast an image twice as high as the other

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