What is an axicon?

and
What can they do for us …

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OUTLINE

- Original axicon definition
- Axicon application to presbyopia
  - Quartic axicons
  - Optimized axicons for a fixed pupil radius
  - Optimized "axicons" for pupil dynamics
- Conclusions
- Future work

What is an axicon?

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA VOLUME 44, NUMBER 8 AUGUST, 1954

The Axicon: A New Type of Optical Element **1954**

JOHN H. MCLEOD
Eastman Kodak Company, Hawk-Eye Works, Rochester, New York
(Received September 10, 1953)

A search for a universal-focus lens has led to a new class of optical elements. These are called axicons. There are many different kinds of axicons but probably the most important one is a glass cone. It may be either transmitting or reflecting. Axicons form a continuous straight line of images from small sources. One application is in a telescope. The usual spherical objective is replaced by a cone. This axicon telescope is in focus for targets from a foot or so to infinity without the necessity of moving any parts. It can be used to view simultaneously two or more small sources placed along the line of sight. If a source of light is suitably added to the telescope it becomes an autocollimator. Like ordinary autocollimators it can be used to determine the perpendicularity of a mirror. In addition, it can simultaneously act as a telescope for a point target which may be an illuminated pinhole in the mirror. The axicon autocollimator is also a projector which projects a straight line of images into space.

INTRODUCTION

THE word axicon has been coined to cover a type of optics. All axicons are figures of revolution. An axicon has the property that a point source on its axis of revolution is imaged to a range of points along its axis. Axicons do not, therefore, have a definite focal length. The name axicon means axis image. Axicons form images only of small bright sources like lamp filaments or brightly illuminated pinholes.

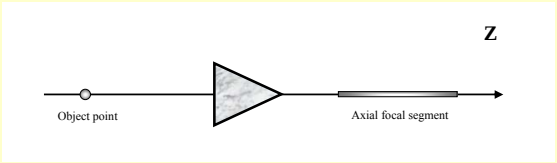
EXPERIMENTAL

The first attempt to construct an axicon was simply to make a narrow circular opening in an opaque disk and use the interference pattern produced by it, see Fig.

What is an axicon?

An axicon has the property that a point source on its axis of revolution is imaged to a range of points along its axis. Axicons do not, therefore, have a definite focal length. The name axicon means axis image. Axicons

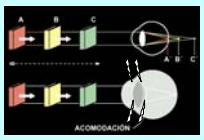
J.H. McLeod. en, *The axicon: A new type of optical element*, J. Opt. Soc. Am., **44**, 1954, pp. 592-597.



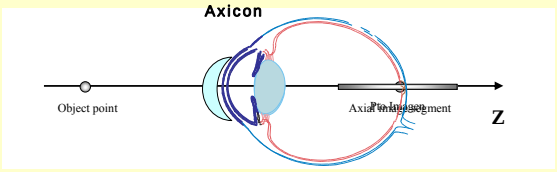
But ….

What can axicons do for us ??

Compensation of accomodation deficiency



How can axicons compensate accomodative deficiencies?

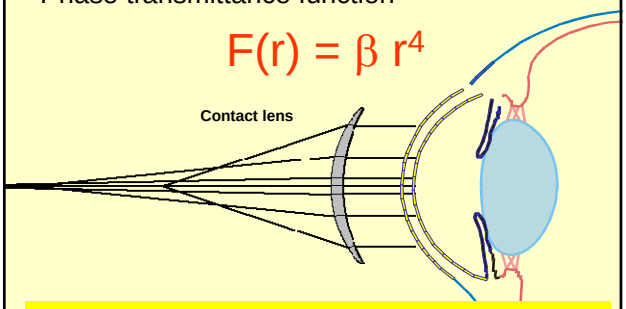


DUE TO THEIR FOCAL SEGMENT PROPERTY, AXICONS ARE ELEMENTS WITH A VERY VERY LARGE DEPTH OF FOCUS

QUARTIC AXICON

Phase transmittance function

$$F(r) = \beta\, r^4$$



Increase the spherical aberration in an optimal way

ORIGINAL ARTICLE

Presbyopia Compensation with a Quartic Axicon

JORGE ARES, OD, MSc, RAMÓN FLORES, PhD, SALVADOR BARA, PhD, and ZBIGNIEW JAROSZEWICZ, PhD

Área de Óptica, Departamento de Física Aplicada (JA, RF, SB), Universidade de Santiago de Compostela, Compostela, Galicia, Spain, Institute of Applied Optics (ZJ), Warsaw, Poland, and National Institute of Telecommunications (ZJ), Warsaw, Poland

ABSTRACT: *Purpose.* The purpose of this study was to evaluate the performance of quartic axicons for presbyopia compensation. The working principle relies on profiting the high depth of focus of the axicons to supplement the reduced accommodation amplitude of presbyopes. *Methods.* We present the design equations of a particular kind of axicon to compensate a general presbyopia condition using simultaneous vision. A rotationally symmetric polynomial of fourth-order, corresponding to the well-known Seidel spherical aberration term, was chosen as its refractive profile. To validate its performance, we computed the retinal images with Stiles-Crawford apodization for a presbyopic eye compensated with this quartic axicon and compared them with those obtained without compensation or with other available solutions based on the simultaneous vision principle. *Results.* The quartic axicon provides an important improvement of the image quality for intermediate distance vision in comparison with conventional bifocal and trifocal solutions. The image quality, however, is still not optimum for all distances. *Conclusions.* The results show the usefulness of the proposed approach and point out the need for developing further adapted optimizations. (Optom Vis Sci 2005;82:1071–1078)

Key Words: presbyopia correction, ophthalmic optics and lenses, geometric optics, visual optics, refractive error

1040-5488/05/8212-1071/0 VOL. 82, NO. 12, PP. 1071–1078
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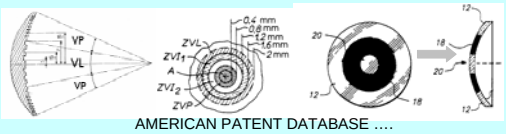
IS THE OPTICAL QUALITY OF THE AXICONS BETTER THAN THE OTHER PRESENT COMPENSATIONS?

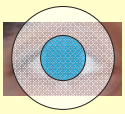


AMERICAN PATENT DATABASE ....

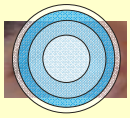
Retinal image calculation

Addition=1.5 D

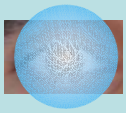
OTHER POPULAR PRESBYOPIA COMPENSATION



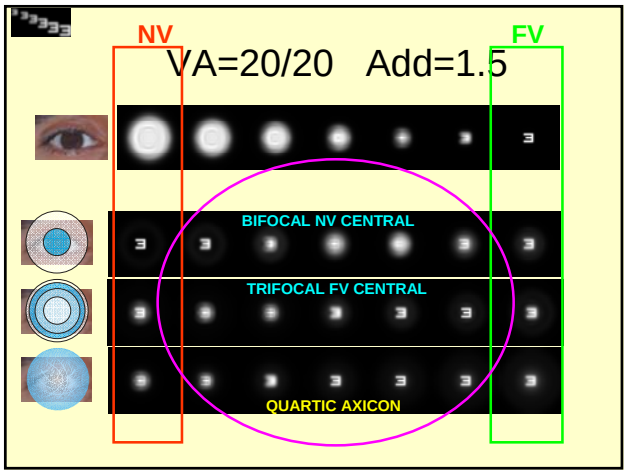
NEAR CENTER BIZONAL LENS



DISTANCE CENTER TRIZONAL LENS



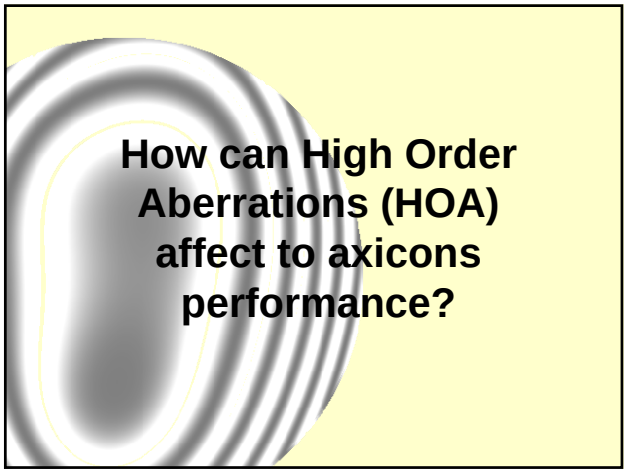
QUARTIC AXICON

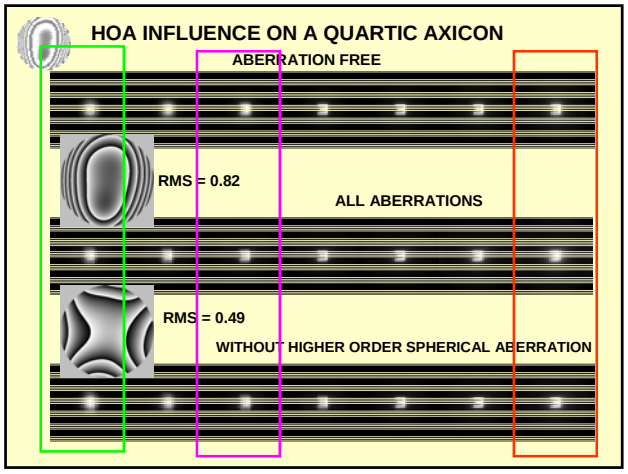


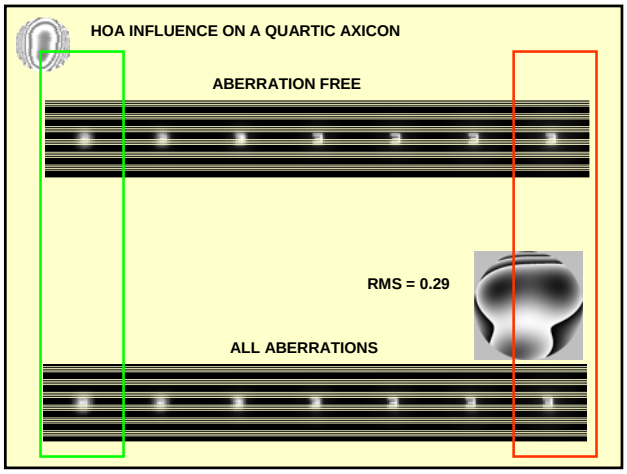
For a fixed pupil radius

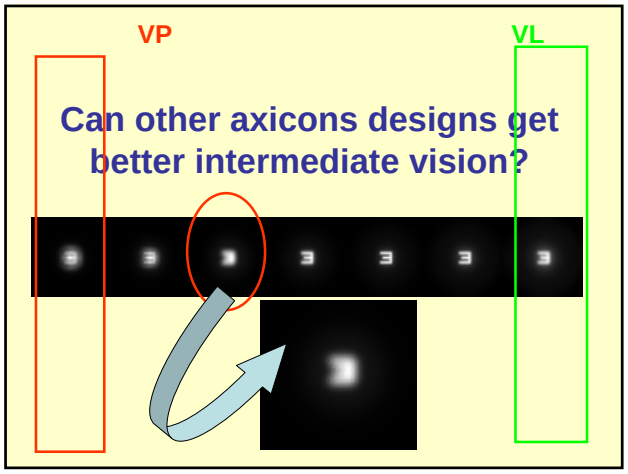
In global the vision quality of the axicon are clearly better than the BiZonal lenses

And slightly better than the Trizonal lenses

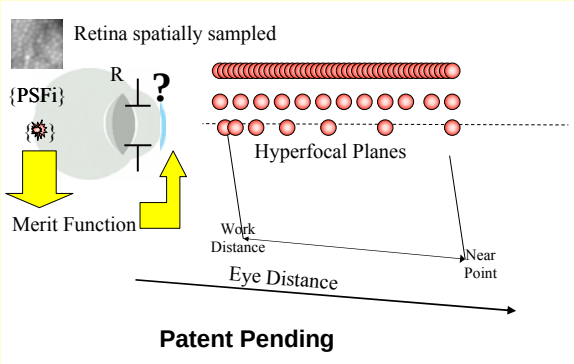






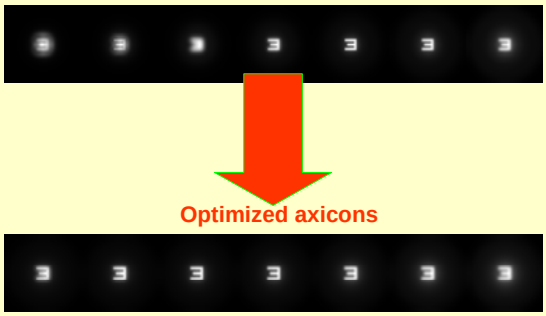


Optimization strategy



Patent Pending

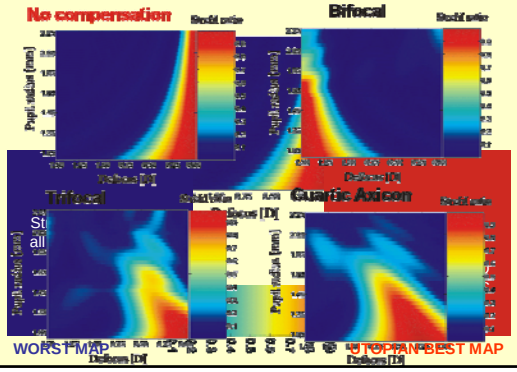
FAR-Intermediate-NEAR vision optimization for a PUPIL RADIUS



Patent pending

What is the quartic axicon performance when pupil size is changing?

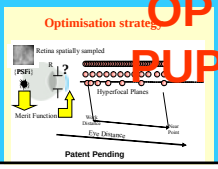
STREHL RATIO MAPS



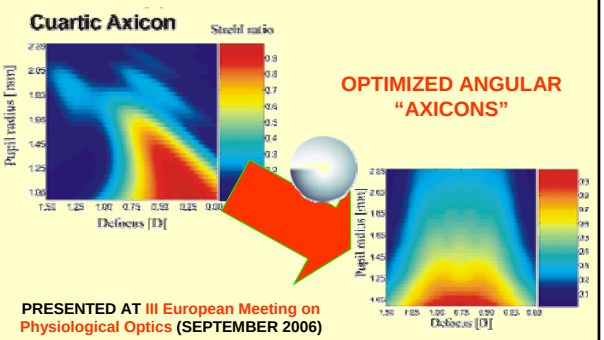
The quartic Axicon is much more stable than the bizonal lens with pupil dynamics and slightly better than Trizonal lens

AXICONS ARE NOT CONSTRAINED TO ANY PARTICULAR FORM SO …

CAN ALSO BE OPTIMIZED FOR PUPIL DYNAMICS



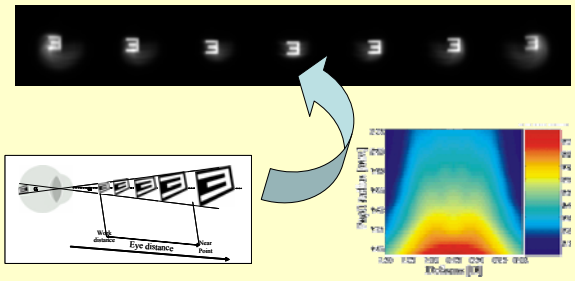
PRELIMINARY RESULTS



PRESENTED AT III European Meeting on Physiological Optics (SEPTEMBER 2006)

OPTIMIZED ANGULAR "AXICONS" RETINAL SIMULATIONS

Insensitive to pupil changes

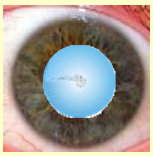


Conclusions

- Axicons can be good solutions to compensate presbyopia and other accomodative deficiencies.
- The quartic axicon is a simple and spatially continuous example. It works much better than concentric bizonal lenses and slightly better than concentric trizonal lenses.
- Spherical aberration is not always bad, it can be good if we introduce it in the correct dose.
- Axicons are not constrained to any particular form, as a consequence, they can be completely customized to work in an optimal way for very different pupil and vision ranges.

FUTURE WORK

- **Axicons have very good image quality but, Will they be a comfortable compensation for the human perception??**



WE THINK SO BUT …

- **LAB trials with different optimized designs are being tested….**

Thanks for you attention

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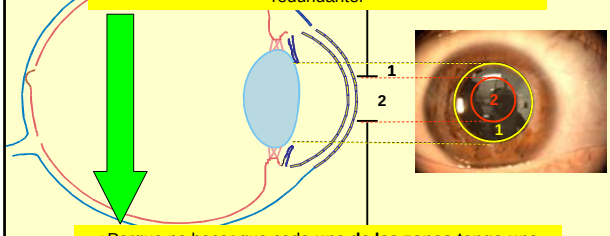
This work was suppported by Ministerio de Educación y Ciencia en el marco del Plan Nacional I+D+I, FIS 2005-0502-C03-02 y el FEDER

Compensación mediante visión simultánea

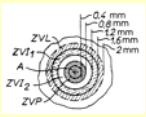
Las **zonas 1 y 2 son empleadas para realizar la misma función refractiva** ... La información que dan puede ser redundante.



¿Porque no hacer que cada **una de las zonas tenga una función diferente** ?

¿Cómo conseguir que cada una de las diferentes zonas no distorsionen las funciones de las demás?

Cuando formemos imagen de un objeto que está situado a una distancia determinada, la imagen que proporcionan las otras zonas del mismo objeto han de estar suficientemente desenfocadas.



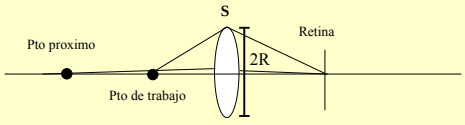
SOLUCIÓN: Axicones

¿Qué es un axicón?

- AXICONES DIRECTOS E INVERSOS

Fórmulas de diseño

Axicón de tipo inverso de fase cuártica



$t(r)=\exp(-ik\varphi(r))$, *dónde* $\varphi(r) = \varphi(r)_{Ojo} + \varphi(r)_{Axicón} = r^2/(2\ f_{PtoProx})+\beta r^4$

$d\varphi/dr \approx -r/z(r)$ $\quad \beta=(1/f_{PtoTrab}-1/f_{PtoProx})/(4R^2)$ $\quad 1/z(r)=1/f_{PtoProx}+4\beta r^2$

Adición

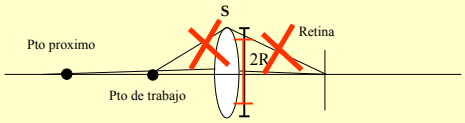
Radio de la pupila

Axicón cuártico $F(r) = \beta\ r^4$

El axicón cuártico es capaz de compensar un defecto acomodativo de 1.5 D aumentando la profundidad de foco del sistema visual

Fórmulas de diseño

Axicón de tipo inverso de fase cuártica



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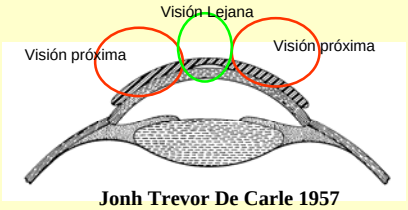
Adición

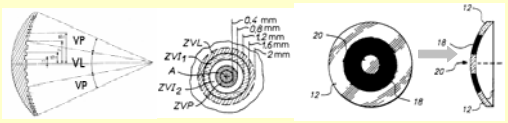
Radio de la pupila

Axicón cuártico $\quad F(r) = \beta\, r^4$

Compensación mediante visión simultánea



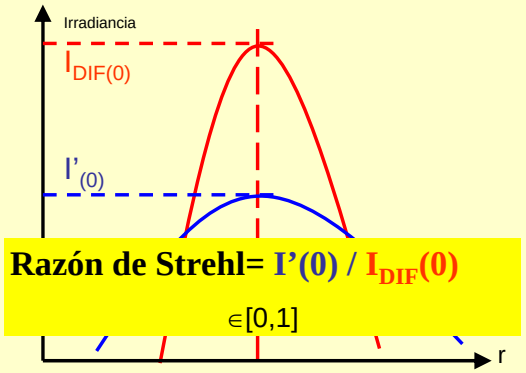
Jonh Trevor De Carle 1957



Compensación de la presbicie con un axicón cuártico

- Introducción
  - Compensación de presbicie mediante visión simultánea. Motivación.
  - ¿Qué es un axicón cuártico?
- Diseño de un axicon cuártico
- Simulación de la calidad de imagen retiniana
- Otros axicones interesantes
- Conclusiones
- Perspectivas de futuro

Definición de Razón de Strehl



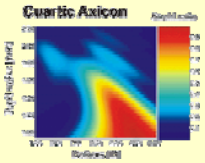
Razón de Strehl= $I'(0) / I_{DIF}(0)$

$\in[0,1]$

Posibles mejoras

- Inestabilidad en la calidad de imagen para distintos desenfoques.

- Inestabilidad frente a cambios en el tamaño pupilar.



Perspectivas futuras

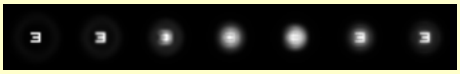
Perspectivas futuras

Todavía restan preguntas por responder …

¿Cuál es el papel que jugará la acomodación residual ante el tipo de imágenes que proporciona un elemento que compensa la presbicie mediante visión simultánea?

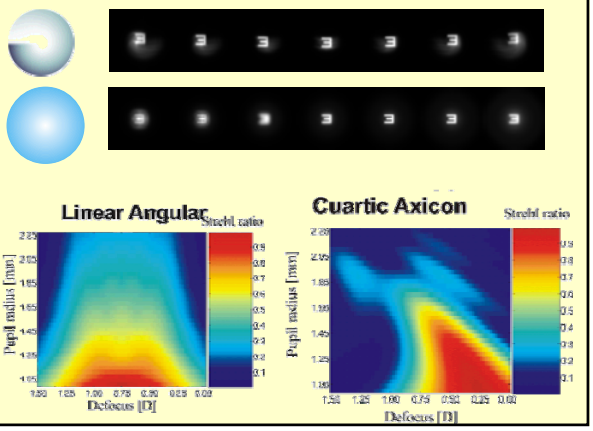
… y las adaptacionesperceptivas al desenfoque?

Compensación de la presbicie con un axicón cuártico

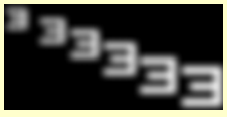


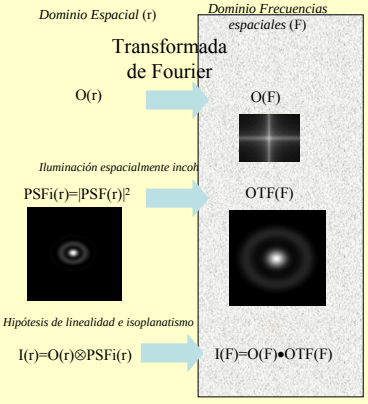
[1] J. Ares, R. Flores, S. Bara, Z. Jaroszewicz, Optometry & Vision Science. 82(12):1071-1078, December 2005.

[2] A. Kolodziejczyk, S. Bara, Z. Jaroszewicz, and M. Sypek, "The light sword optical element—a new diffraction structure with extended depth of focus," J. Mod. Opt. 37, 1283–1286 (1990).

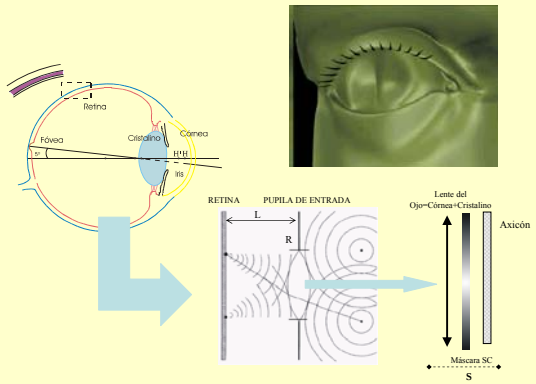


Simulación de formación de Imagen



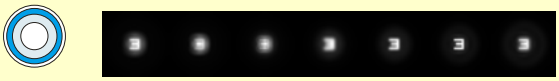


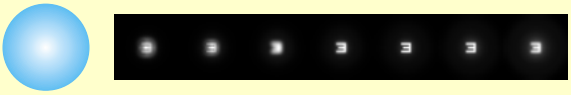
Modelo de ojo reducido



- Diapo de De Carle

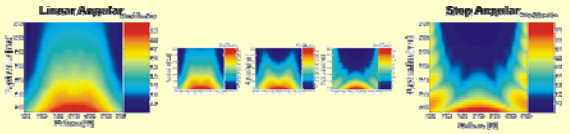
Compensación de la presbicie con un axicón cuártico





Compensación de la presbicie con un axicón cuártico

- Segunda generación de axicones cuárticos
- Elementos con simetría de revolución.
- Interacción de la acomodación con elementos



Del griego αξών (axón) + εικών(eikón)
eje imágen

"Elemento óptico con simetría de revolución que transforma un punto objeto axial en un conjunto continuo de puntos imagen a lo largo del eje."

J.H. McLeod. en, *The axicon: A new type of optical element*, J. Opt. Soc. Am., 44, 1954, pp. 592-597.