Optics of Near to Eye Displays (NEDs)

Introduction

Categories of optical design forms
- Performance
- Imitations
- Optical design tradeoffs

Latest developments
- Google “project glass”
- Apple
- Microsoft

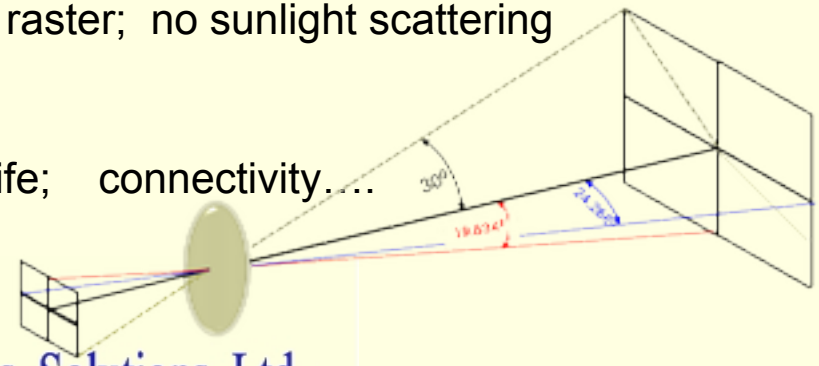
Summary

Dave Kessler, Oasis 2013
Tel Aviv, February 19, 2013

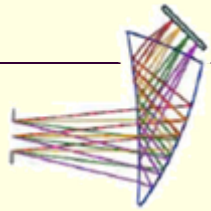
What does everyone want?

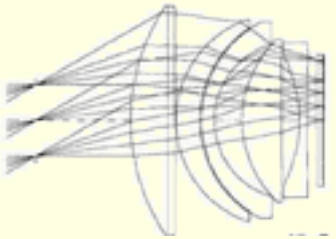
Oakley Thump = Sunglasses+MP3

"Oakley look" .	i.e., thin & small optics
Augmented imaging	preferably an optical see-through channel
Low cost	& small image generators (OLED, LCOS, …)
Wide field of view	30^0 deg to 110^0 full diagonal field
Large eye box	~10 mm diameter, for eye ball movement + loose alignment
Large eye relief	> 20 mm, for lash clearance and prescription glasses
High resolution	~ SXGA (1280 x 1024) or higher
Low distortion	< 2%
Bright	hundreds of Cd/m^2
Artifact free;	no "dirty windows" ; no raster; no sunlight scattering
Low weight	
Other:	eye tracking; battery life; connectivity….

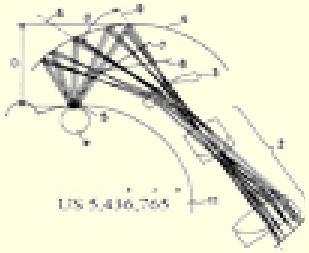


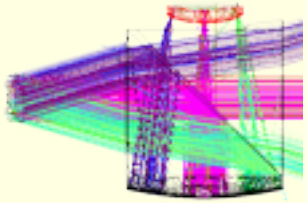
NEDs: categories of optical design forms



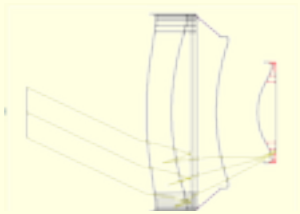


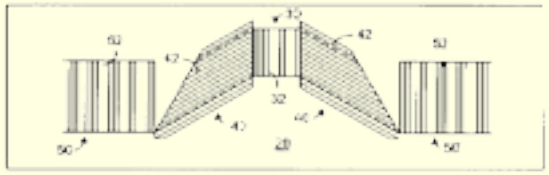
- Magnifiers i.e. eye piece + image generator
- Relay based NEDs
- Monocentric system





- “Pancake” designs : on axis folded by polarization means
- Pupil splitting :
- Segmented (or tiled) NEDs:





- Other: Foveated; Fiber scanning; Retina scanners; etc.

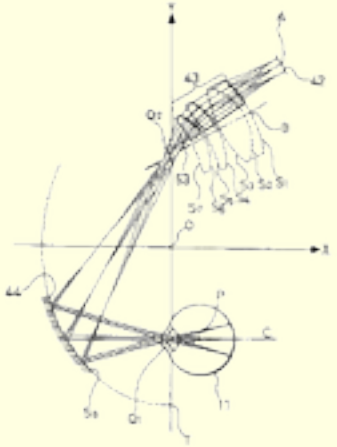
A good start though a bit dated:

Head-Worn Displays: A Review

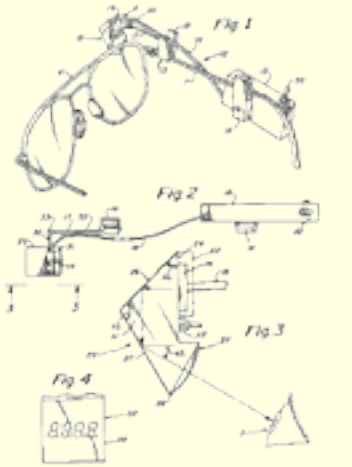
Ozan Cakmakci and Jannick Rolland, *Member, IEEE*

" J. Display Technol. 2, 199-216 (2006).

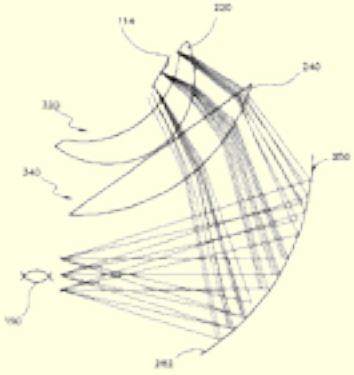
A 2006 review of NEDs . Categorization by low field, (<40^0), mid field (40^0 -60^0) and large field.



Iba. Image Observation Device.
US 5,384,654
Jan. 24, 1995
(m)



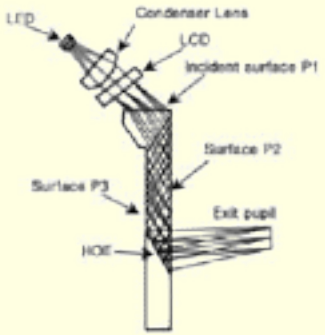
Kubik. Headwear-mounted Periscopic Display Device.
US 4,753,514
Jun. 28, 1988
(n)



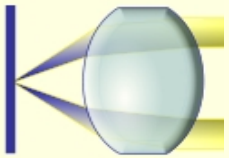
Ferrin. Headgear Display System Using Off-axis Image Sources.
US 5,576,887
Nov. 19, 1996
(o)

Lippert. Visor Display with Fiber Optic Faceplate Correction.
US 5,309,169
May 3, 1994
(p)

Lacroix. Device for the Display of Simulated Images for Helmets.
US 5,184,250
Feb. 2, 1993
(r)

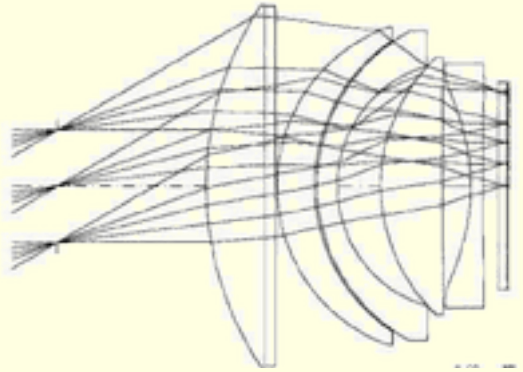


Kasai. A Forgettable Near-Eye Display.
ISWC 2000.
(s)

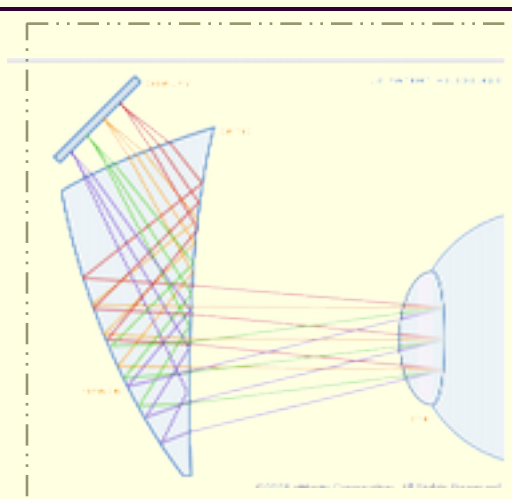


Magnifiers = image source+ an eyepiece

NON See-Through

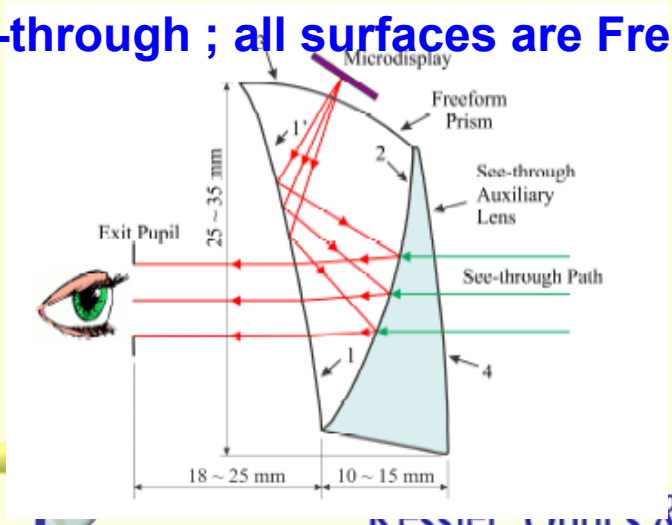


Traditional eyepiece



Compact off axis eyepiece , using FFSs

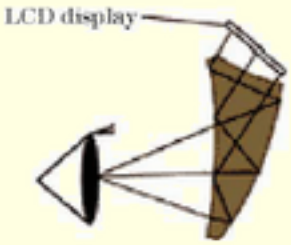
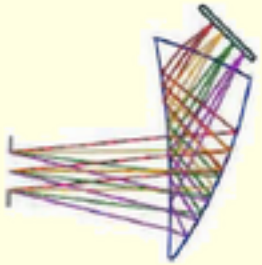
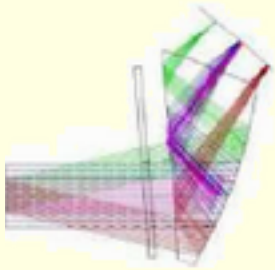
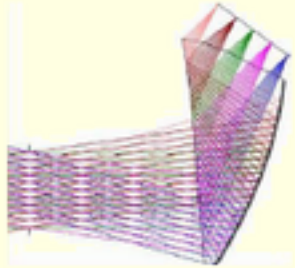
See-through ; all surfaces are Free Form Surfaces (FFS)



See through accomplished with an optical compensator

Resolution ~ SVGA (800 x 600)

Design tradeoffs

	Eye-Trek FMD 220	Z800 3dvisor	ProView SL40	Dewen/Hua design
Module view				
Full diagonal FOV	37	39.5	40	53.5
Eye relief (mm)	23	27	30	18.25
Exit pupil diameter	4	4	5	8
Effective focal leng	21	22	20.6	15
Diagonal image siz	0.55	0.61	0.59	0.61
f/#	5.25	5.5	4.1	1.875

(Field of View) = (Diagonal image generator) / EFF

(Exit Pupil) = EFF / (F#)

(Eye Relief) ∝ EFF

Cost and optics size push device diagonal down.

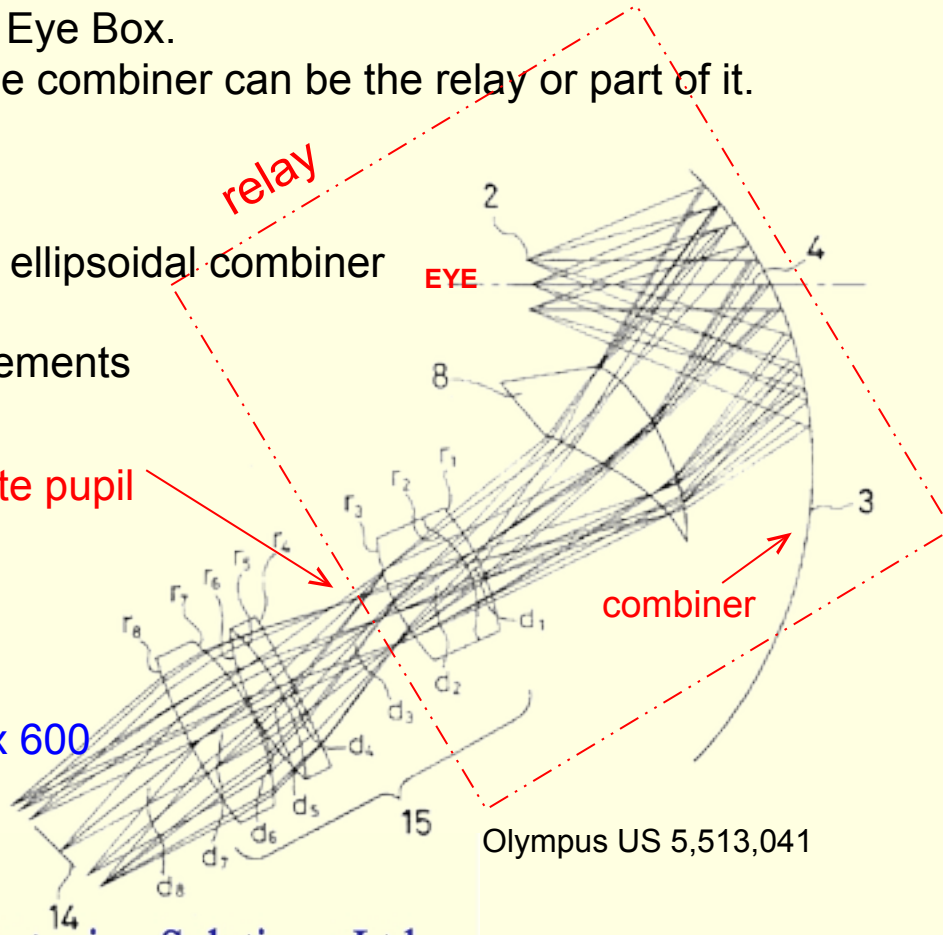
FOV now needs shorter EFF. This means faster optics (low F#) which are harder to correct and shorter Eye Relief.

Dewen Cheng, Hong Hua, et al.,"Design of an Optical See Through Head Mounted Display…..Applied Optics, Vol. 48, No 14 (2009)

Relay based NEDs

A relay provides :
* magnified LOCS or OLED
* longer system EFF
* larger FOV
* larger Eye Relief and Eye Box.
* easier packaging ; the combiner can be the relay or part of it.

Drawbacks:
* off axis pupil relay has to compensate for ellipsoidal combiner
* system size
* complexity -non rotationally symmetric elements

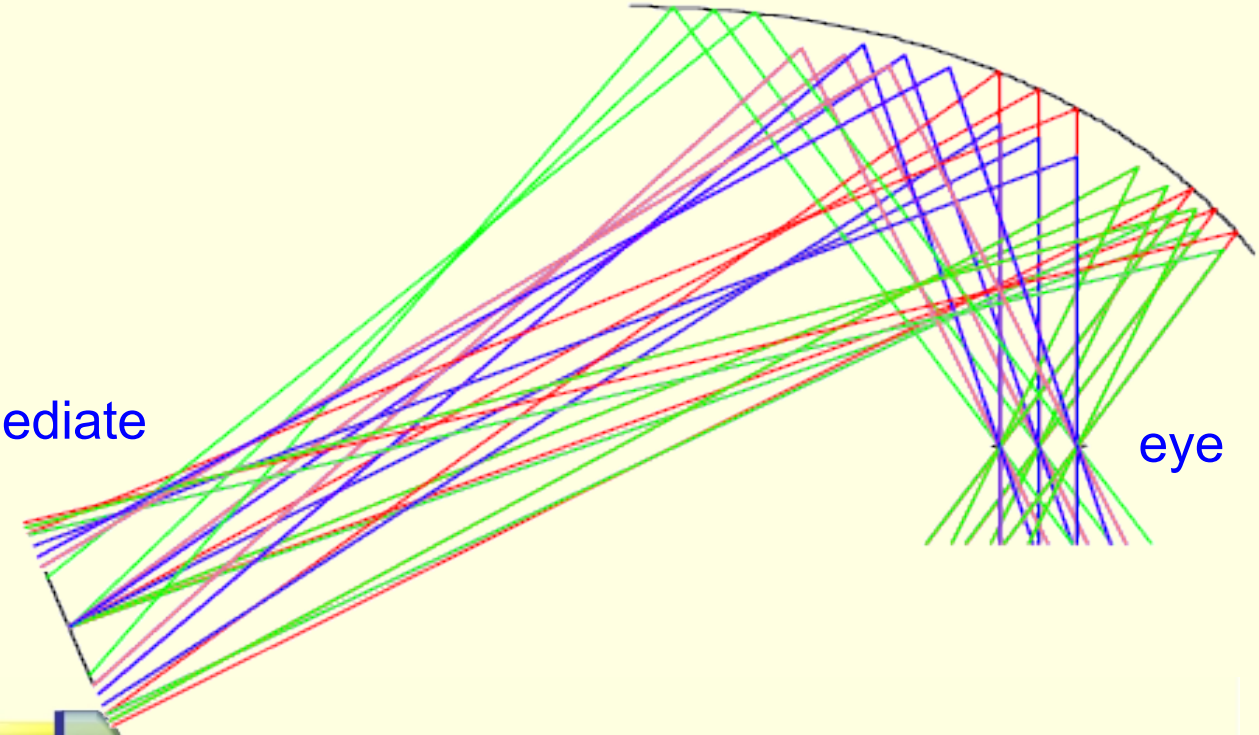


1996 patent
Eye box 8 mm
Resolution ~800 x 600
FOV 45^0x 34^0

Olympus US 5,513,041

The core of the design difficulty

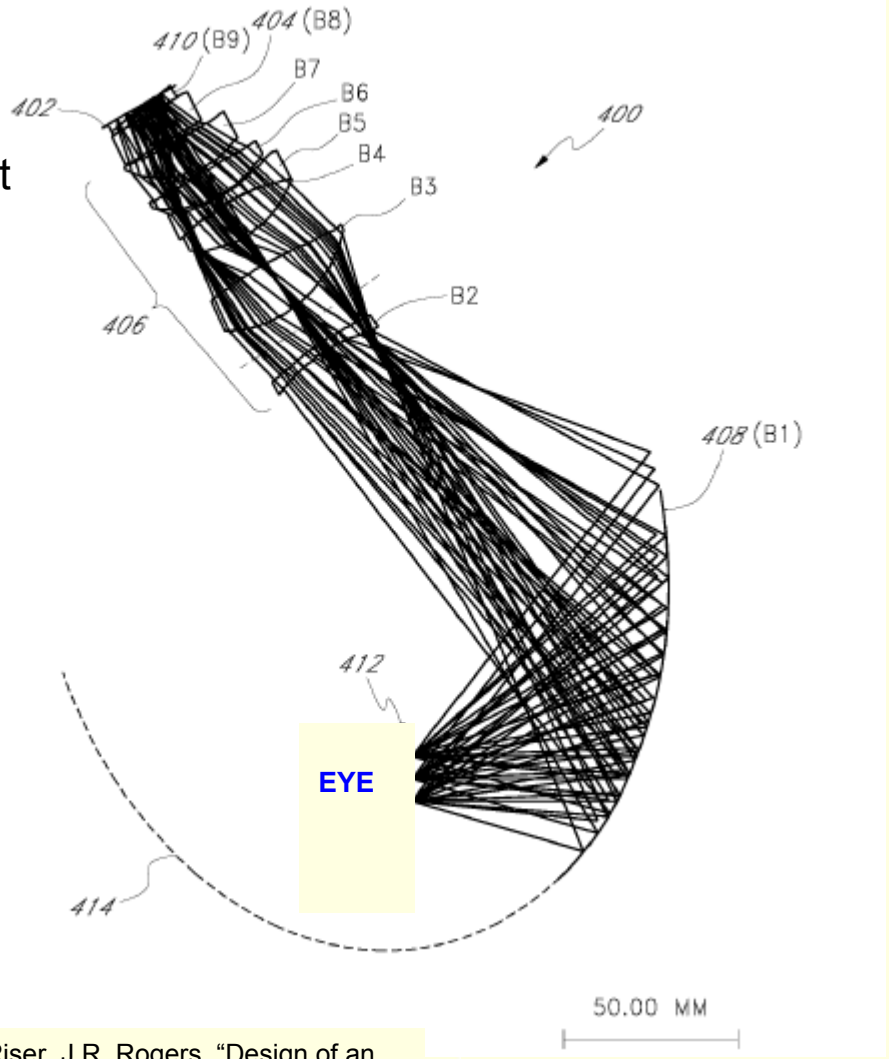
The powered combiner such an ellipsoid can easily relay the **pupils centers** when their centers are at the ellipsoid foci. However, it cannot by itself **maintain the beam collimation** at its power changes over the field and the large off axis aberrations have to be corrected by the remaining optics.



Pilot training HMD using symmetrical elements

The designs are based on the “Nodal Theory” by Thompson and Shack which shows that the aberrations of the tilted combiner can be compensated by a system using tilted symmetrical components which does not result in new aberrations , but just adds new field dependencies.

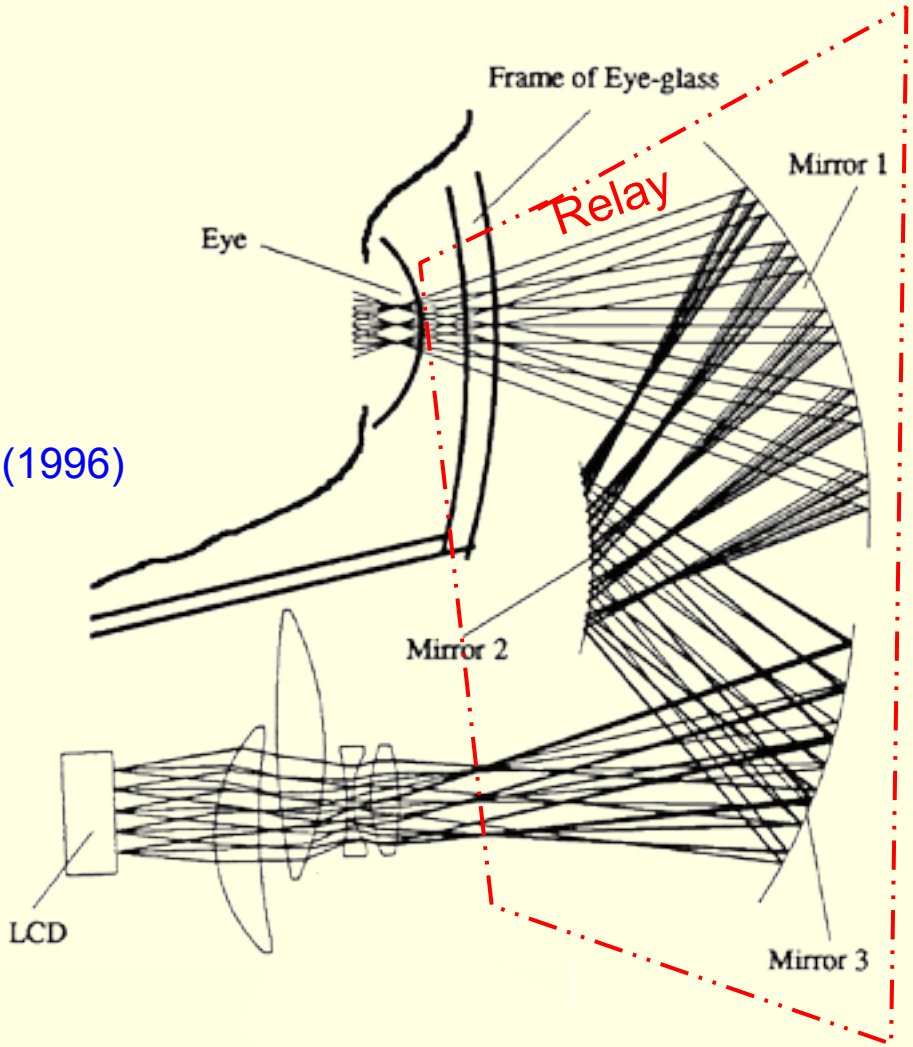
Eye Relief > 50 mm
Eye Box 15 mm
FOV 65 deg H, 60 deg V
SXGA



A. Sisodia, A. Riser, J.R. Rogers “Design of an Advanced Helmet Mounted Display “ Proc. SPIE Vol. 5801 (2005)

Using the 1:1 Offner relay

50^0 diagonal
Large Eye Relief
0.7” LCD
VGA
Hiroshi et al, Canon
Proc. SPIE Vol 2653 “Off Axial HMS…”(1996)



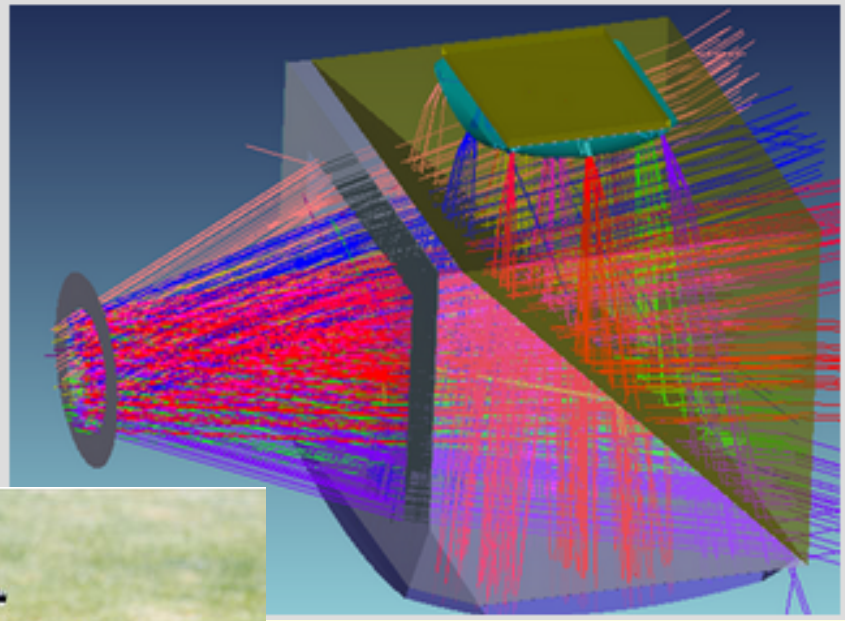
Monocentric, i.e. highly symmetrical designs

Higher degree of symmetry reduces the off axis aberrations

SXGA
10 mm Eye Box
23mm Eye Relief
0.78” OLED
140 grams per eye

50 Degree See Through

50 degree diagonal see through eyewear using eMagin OLED devices.

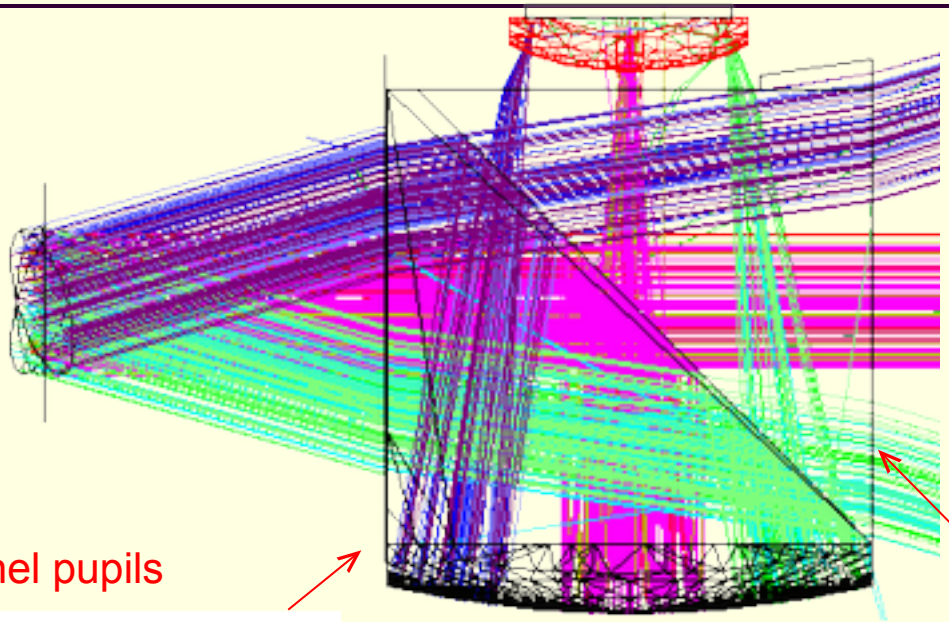


“Bird’s bath “
configuration

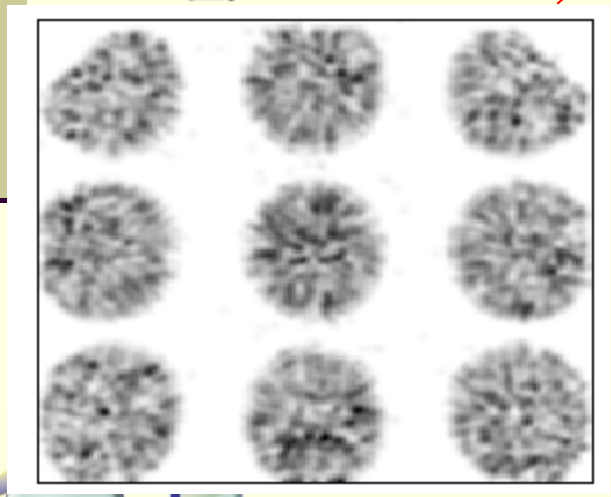
http://www.nvisinc.com/configurator.php?product=66&type=hmd

Kessler and Bablani , USA 8094377, assigned to NVIS.

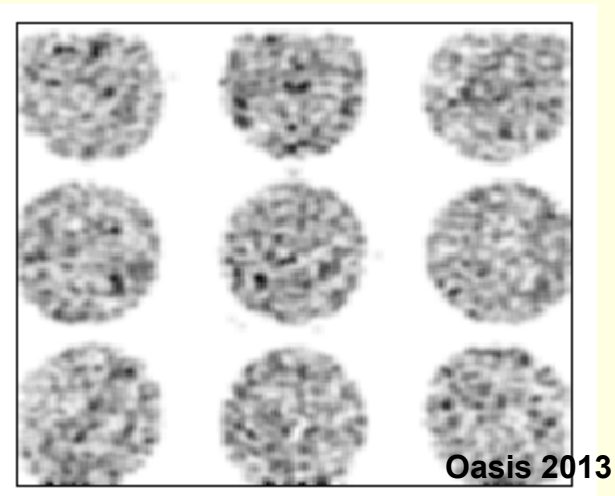
Non Sequential analysis to verify sequential design



OLED channel pupils



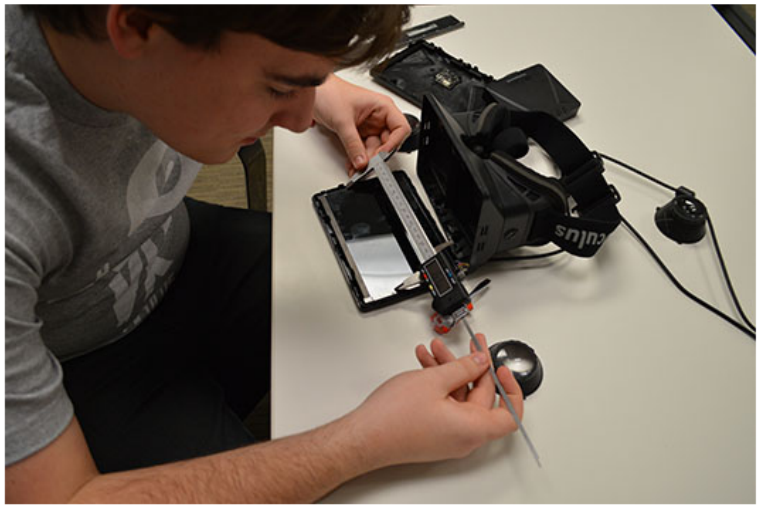
See-through pupils at exit prism



OCULUS RIFT

OCULUS RIFT

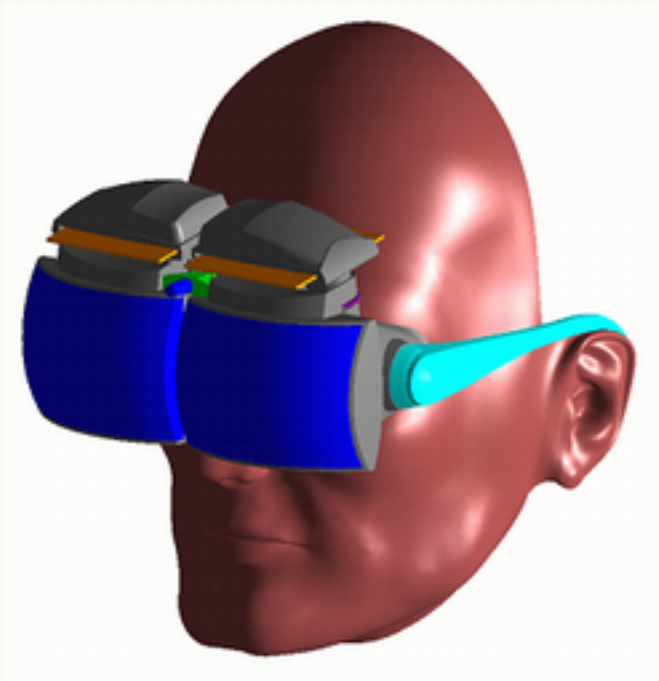
Oculus Rift, by Palmer Luckey
http://www.oculusvr.com/
110 deg diagonal - (65^0 per eye with 30^0 overlap?
Gaming, eye tracking , low cost?
Small eye relief- no prescription glasses
Using two “classical magnifiers” , like LEEP optics? http://www.gc
US4406532

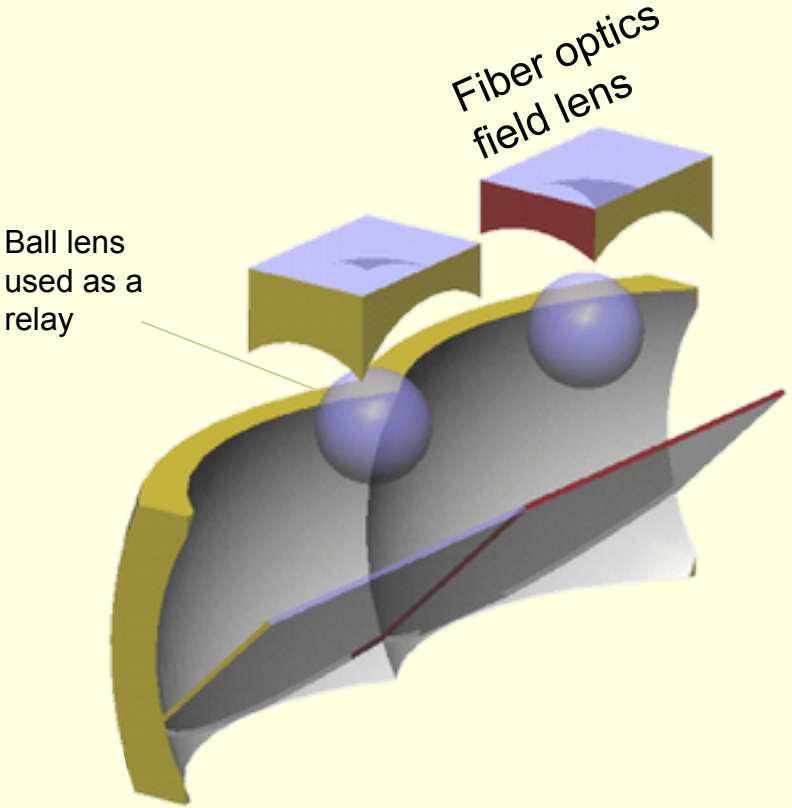


Ball lens ,concentric, design- R&D

Ball Lens Design

90 degree horizontal field of view, OLED based, 15 mm pupils.



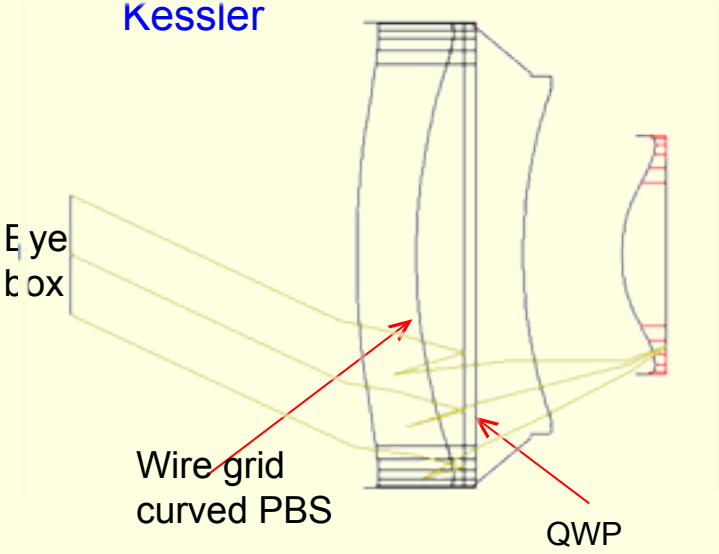


Very high FOV
Eye relief reduced by the splitter
Small, compact
An incomplete Kodak project

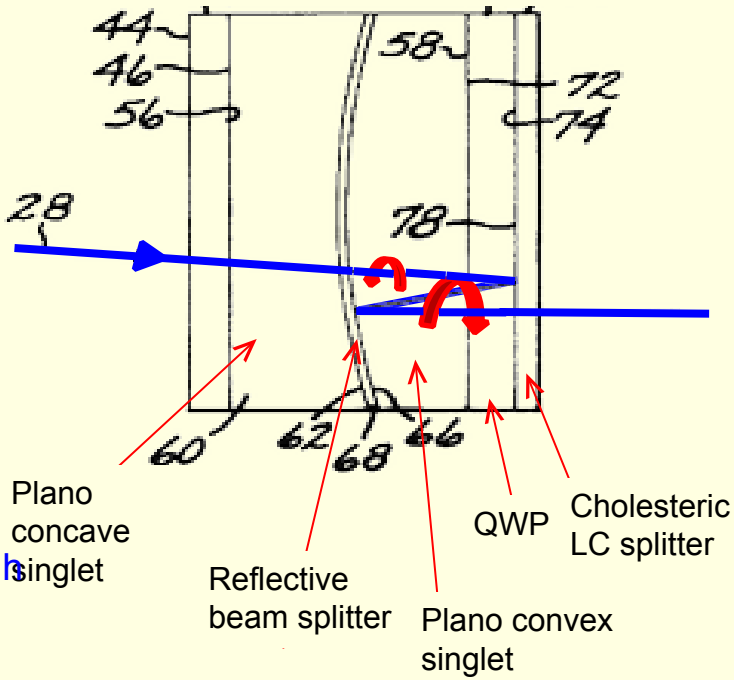
“Pancake “ NED designs

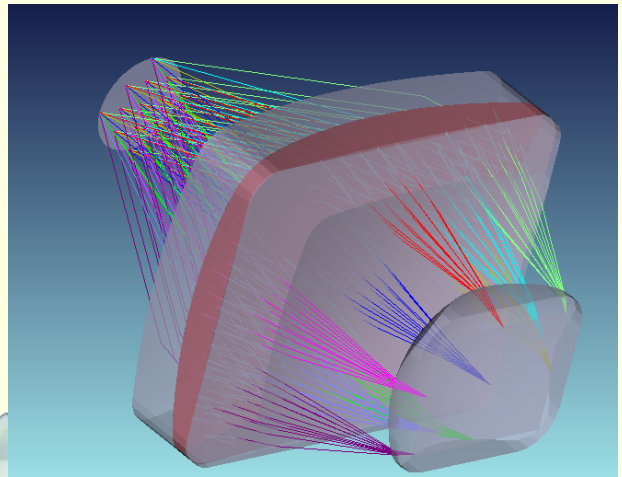
On axis designs folded by polarization means

Kessler



Raytheon US
6,563,638B2



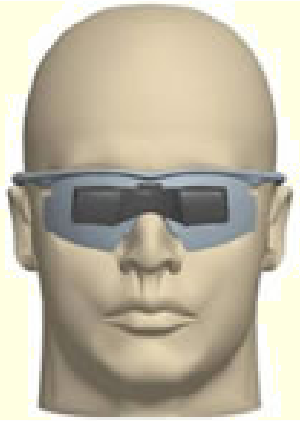


Usually not a see through
SXGA
60^0 FOV
10mm Eye box
24 mm Eye Relief

Main problem : efficiency ~ 6%

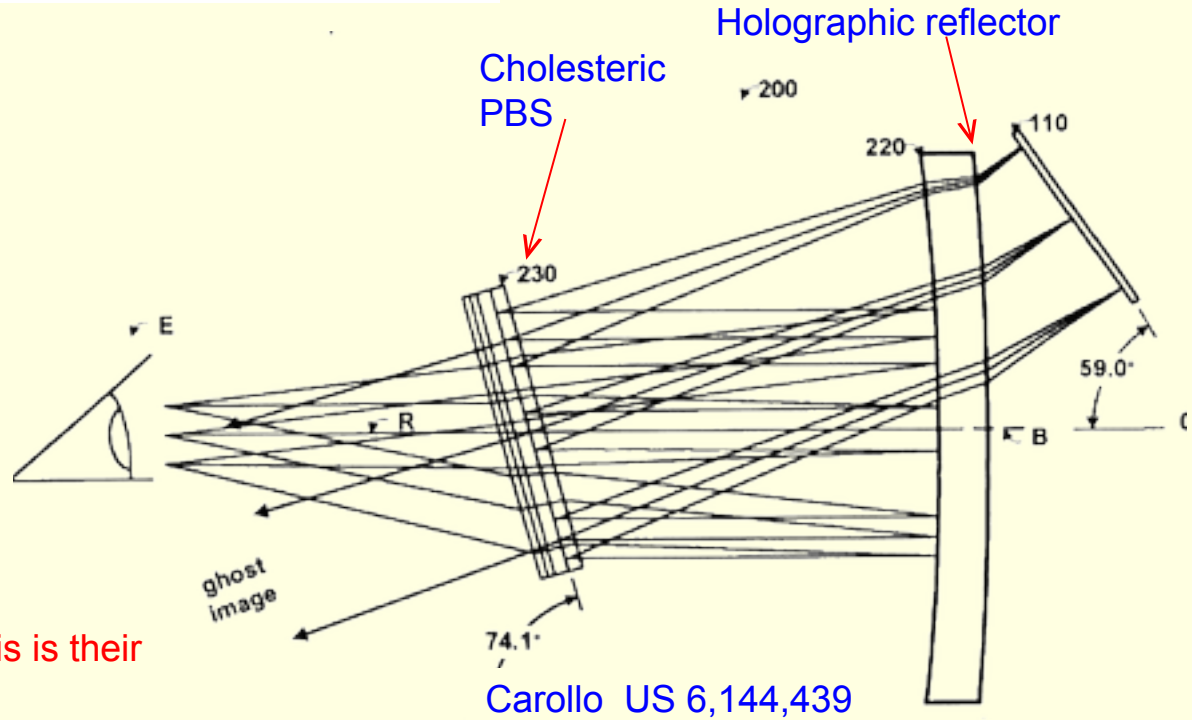
www.Intevac.com

Higher efficiency pancakes



I-PORT Binocular 60

- 60° diagonal field of view (FOV)
- In-Line Reflective Optical Collimator
- Full Color SXGA



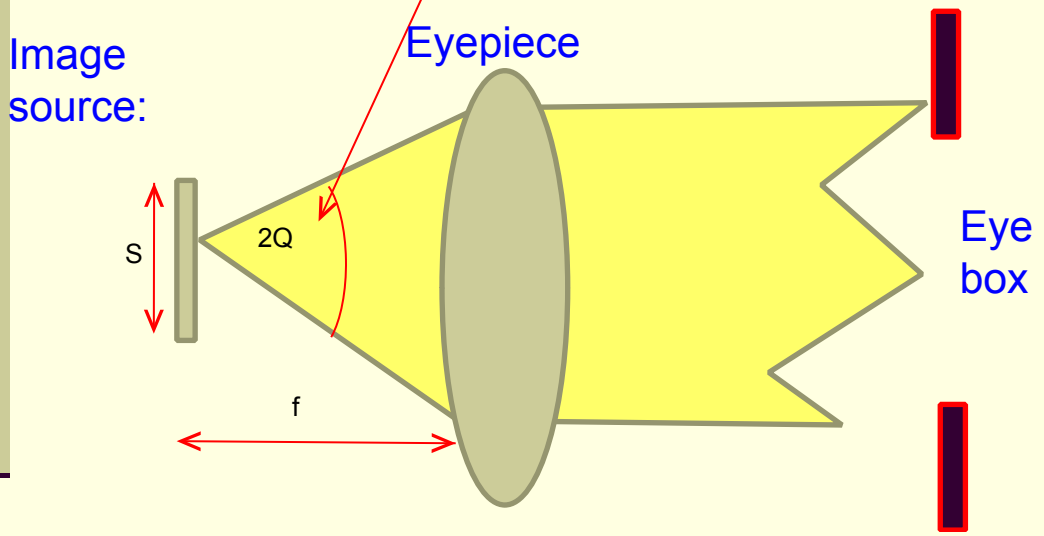
I assume this is their design

Carollo US 6,144,439

Pupil splitting designs
(also: pupil expanders and dilated optics)

We want an optical system to project into the eye with :

* Low F/number (= high Numerical Aperture) for efficiency
* large eye box
* Short focal length for large field and small optics



NA = sin(q)
(Eye Box) = 2*f * NA
FOV = S / f

However , short focal length means small eye box, so we use a short focal length and get a small exit pupil and then expand it by replication to fill the eye box.

Conservation laws and invariants

Etendue = A W

- A = area
- W = projected solid angle = $p * (NA)^2$

Also: P = B*A*W ,

where P = power ,in lumens or Watts

B = luminance in Cd/m^2 or Nits

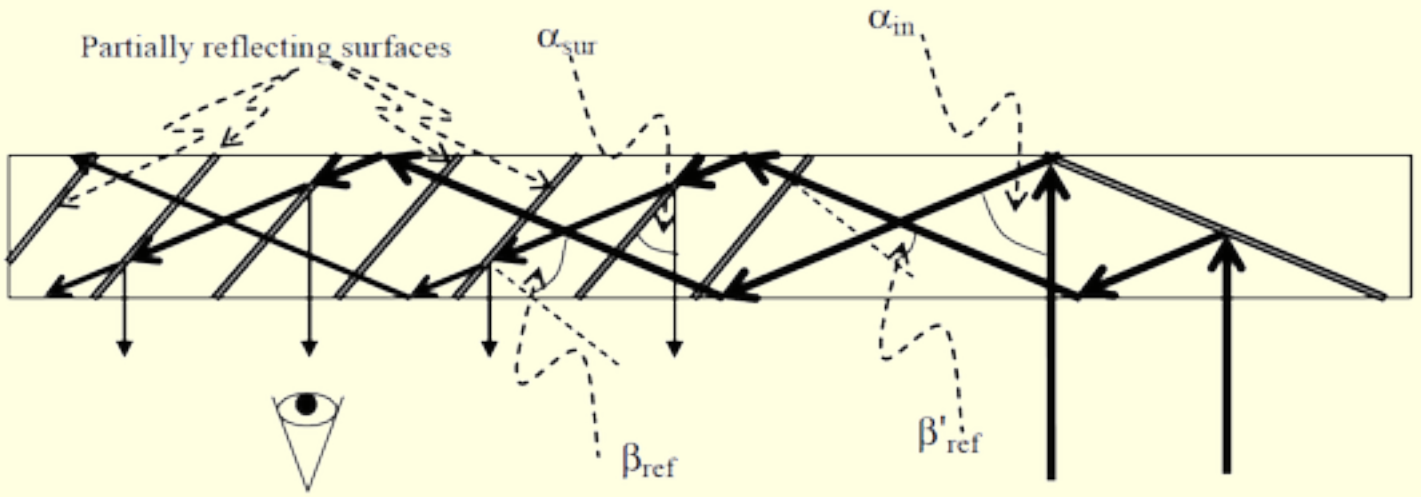
The three conversion laws (when there is no pupil expansion or diffusion)

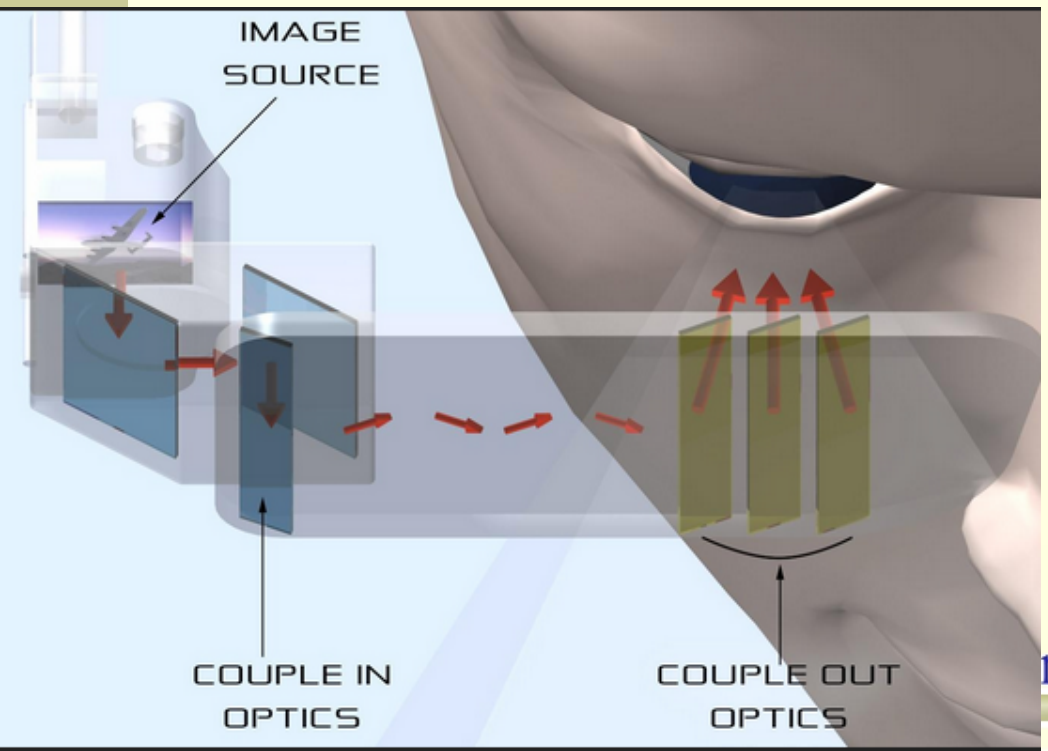
P' = P	energy conservation
A' W' = A W	Etendue invariance,
B' = B	Brightness theorem

When we diffuse at the image or expand the pupil:

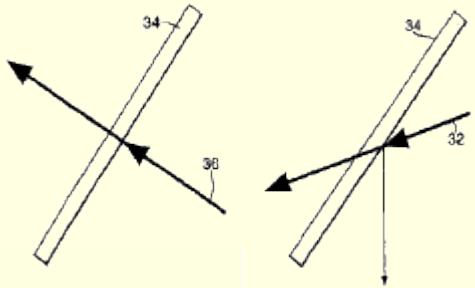
P' = P	energy conservation
A' W' > A W	Etendue is increased
A' > A	for pupil splitting
W' > W	diffusion at an intermediate image
B' < B	Brightness decreased

LUMUS one dimensional Light-guide Optical Element (LOE)



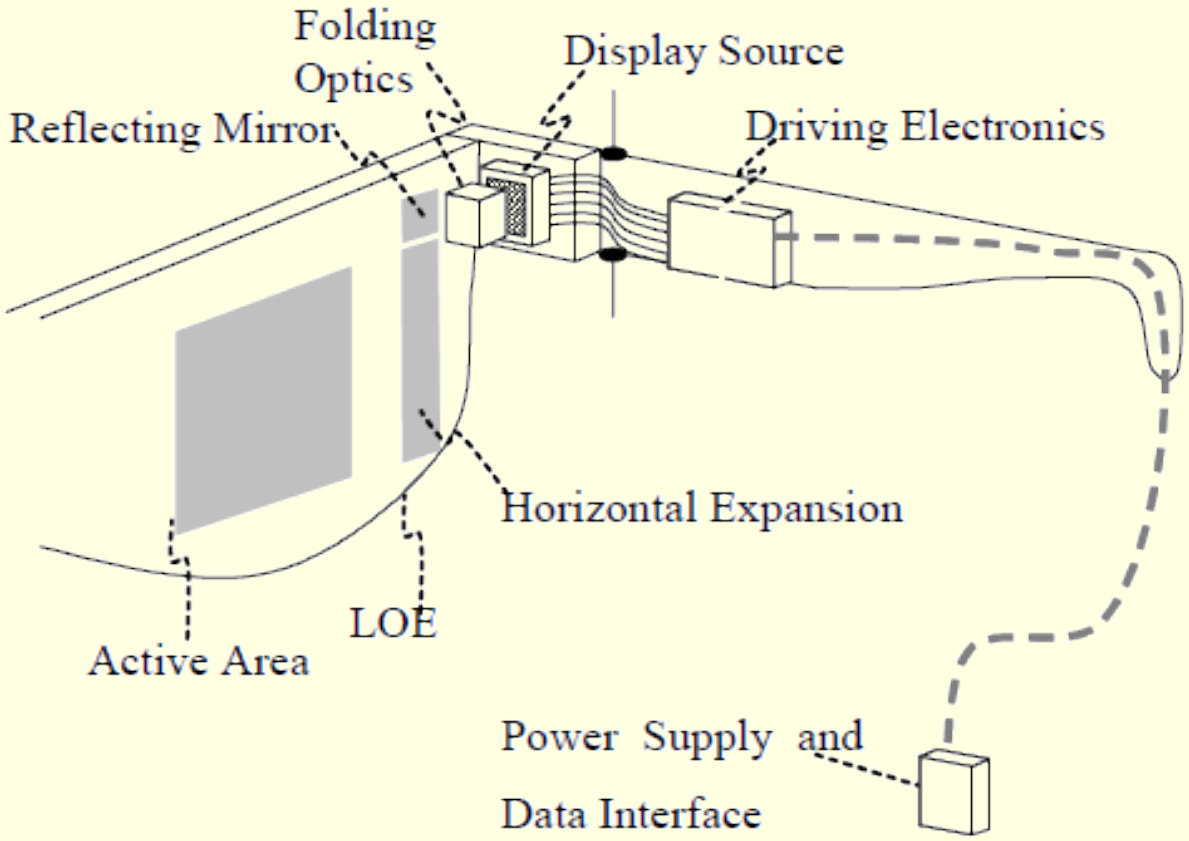


inventor: Yacov Amitai



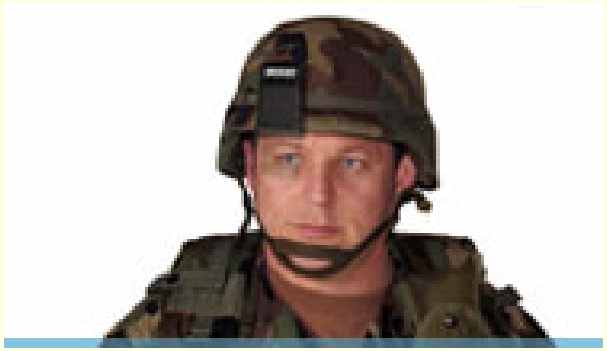
nics Solutions, Ltd.
www.kessleroptics.com

Lumus 2 dimensional pupil expansion



Lumus Professional

1280 x 720 pixels
FOV 40^0
Eye Box 10 x 8 mm
Eye relief 22 mm
Weight 26 g



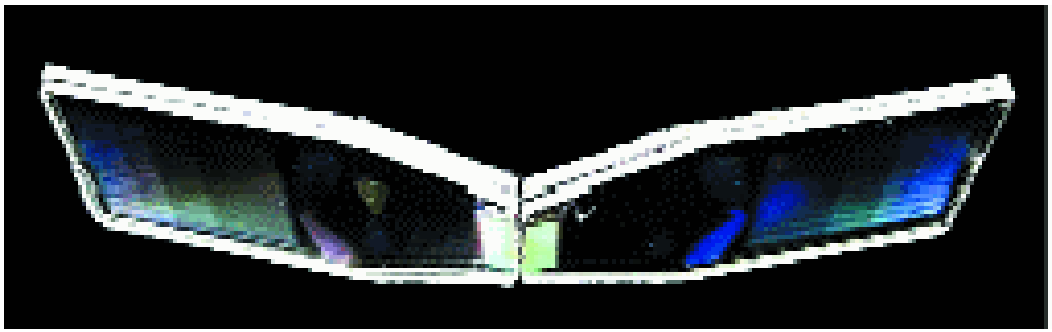
800 600pixels
FOV 32^0
Eye Box 10 x 10 mm
Eye relief 23 mm
Weight 70 g

Nokia- holographic pupil slitting US2006/0126182A1,

Near-to-eye display with diffractive exit pupil expander having chevron design

Tapani Levola ***(SID Member)***
Viljakaisa Aaltonen

Nokia *Research Center*



This technology has been around for quite some time

The basic Nokia waveguide

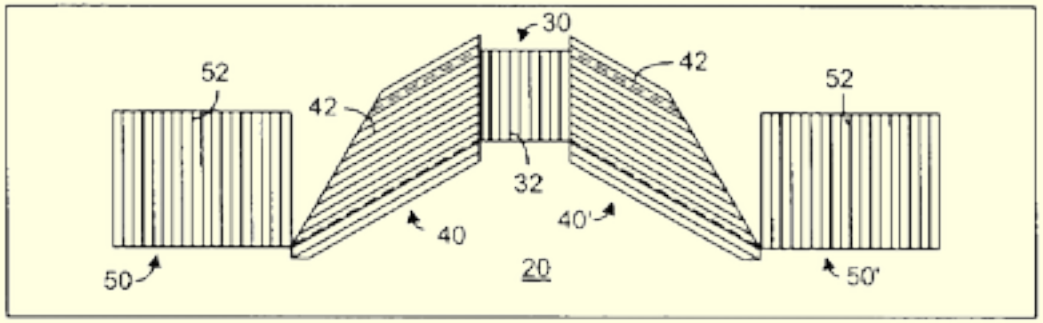
(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0126182 A1**

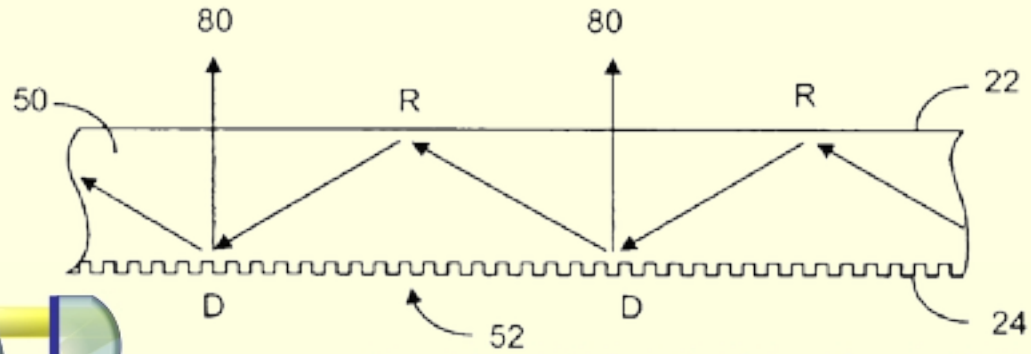
Levola (43) **Pub. Date: Jun. 15, 2006**

(54) **GENERAL DIFFRACTIVE OPTICS METHOD FOR EXPANDING AN EXIT PUPIL**

Publication Classification



Problem: limited FOV since this is basically a Bragg reflector obeying the Bragg condition



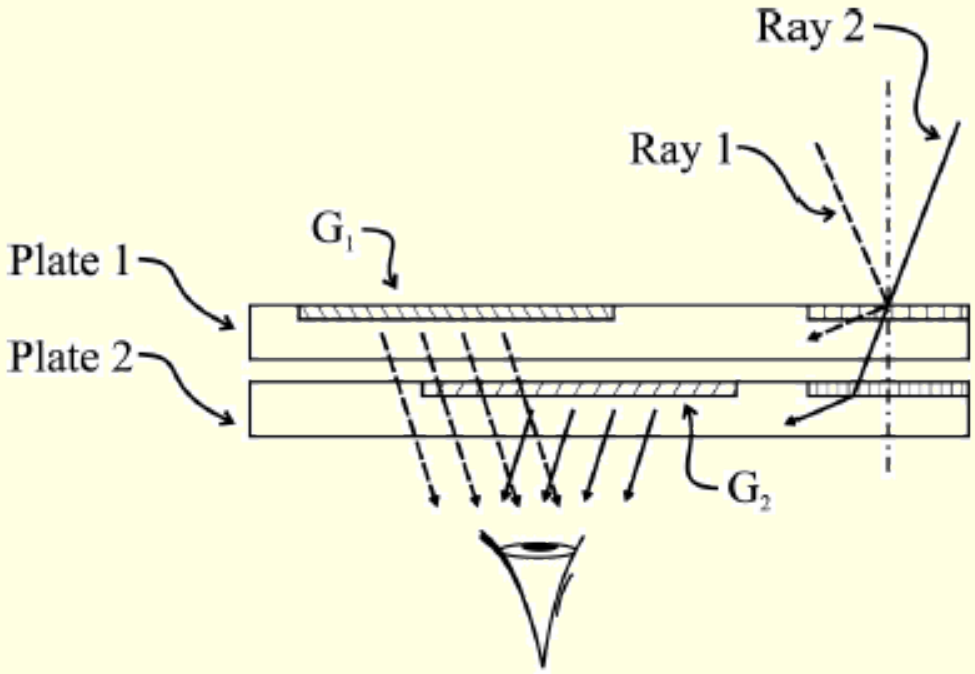
Nokia large FOV waveguide

(and later non-Nokia IP and papers)

Diffractive exit-pupil expander with a large field of view

Pasi Saarikko

Nokia Research Center, Itämerenkatu 11-13, 00180 Helsinki, Finland



Proc. of SPIE Vol. 7001 700105-6 2008

Vuzix IP

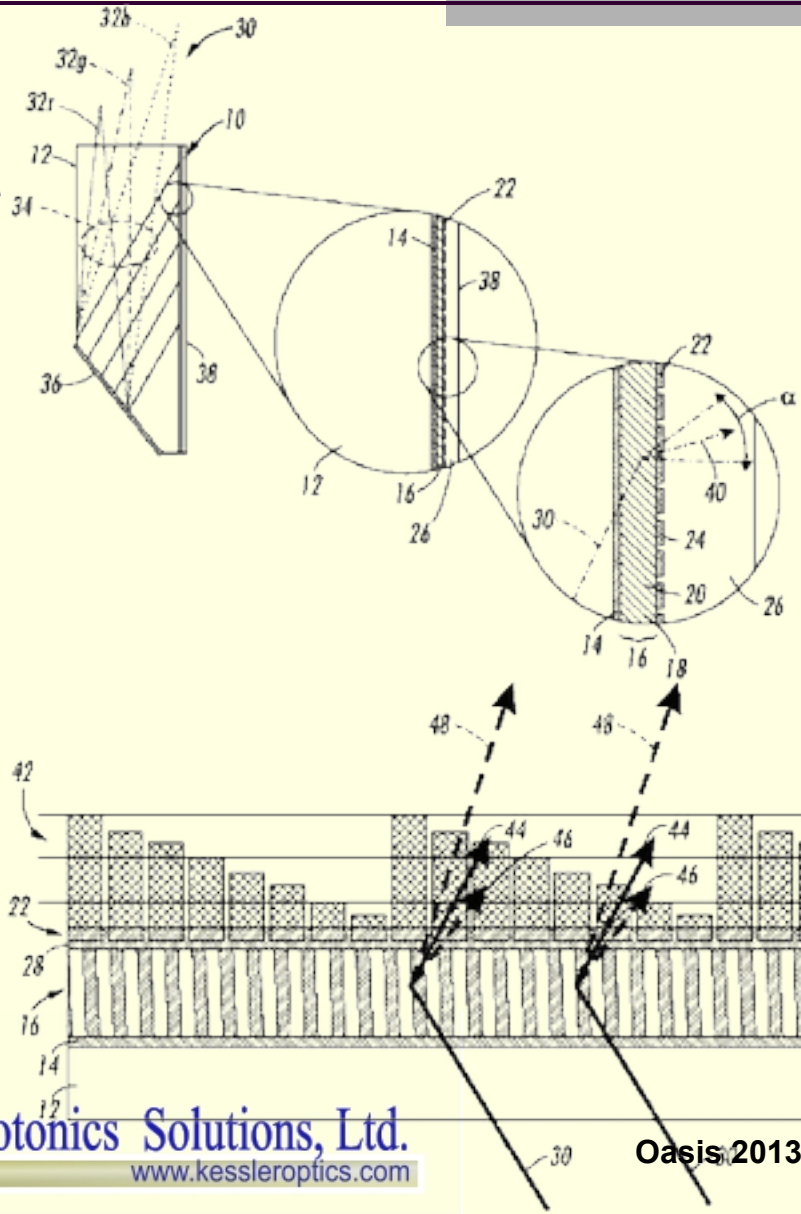
Dynamic waveguide

(10) Patent No.: US 8,014,050 B2
(45) Date of Patent: Sep. 6, 2011

(12) **United States Patent**
McGrew

(54) **AGILE HOLOGRAPHIC OPTICAL PHASED ARRAY DEVICE AND APPLICATIONS**

(75) Inventor: **Stephen Paul McGrew**, Spokane, WA (US)



LC shutter , 2 microns thick, using dielectric vanes at about 10 degrees, with 250nm pitch and addressable electrodes at 400 nm pitch and 100nm spacing

A concept were an addressable pupil control is being considered as a way to uniformize the pupil, increase efficiency by not extracting light from unviewed pupil locations.
Also will help in controlling ambient

Has not been demonstrated yet.
Not clear what level of modeling has been done. Work in progress.

Microvision

Laser scanning + pupil splitting

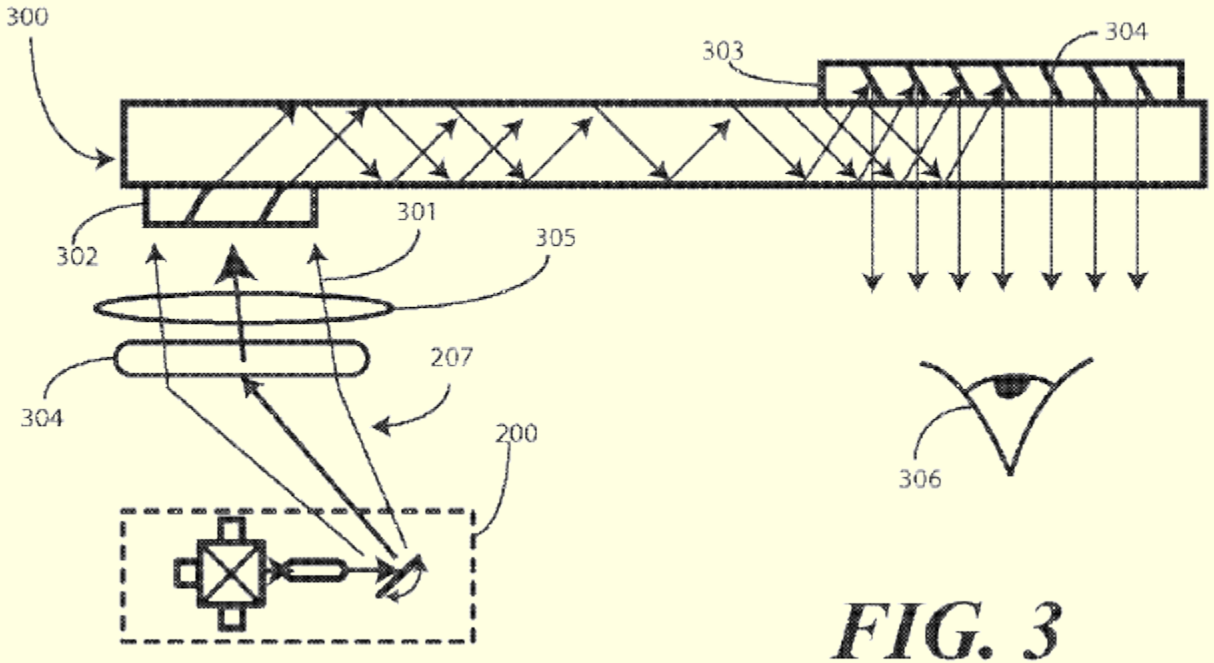


FIG. 3

US2012 20257282A1

Other NEDs :

INNOVEGA
Visualizing the digital world

Contact lens with a lenslet

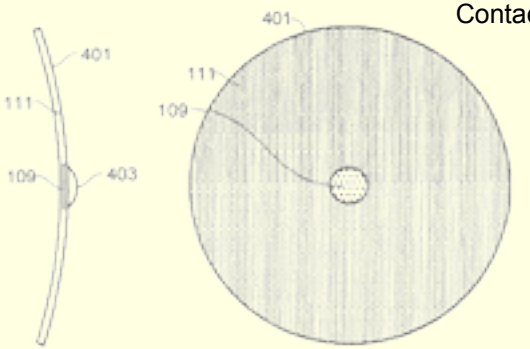
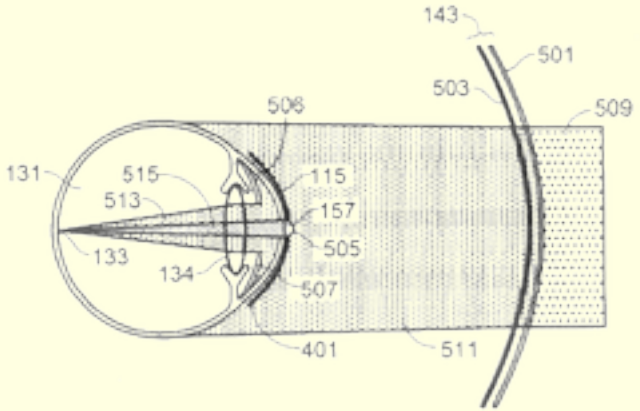


Fig. 4B Fig. 4A

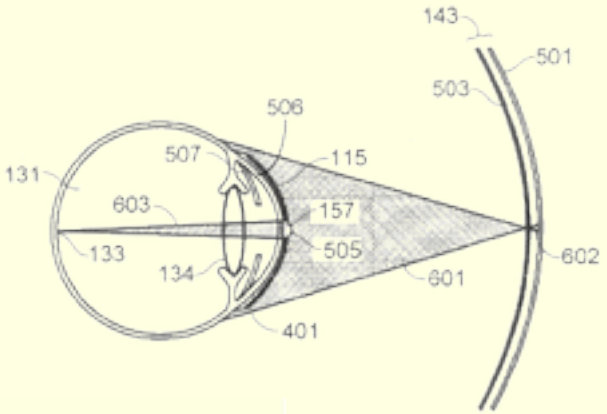


Curved OLED

Fig. 5

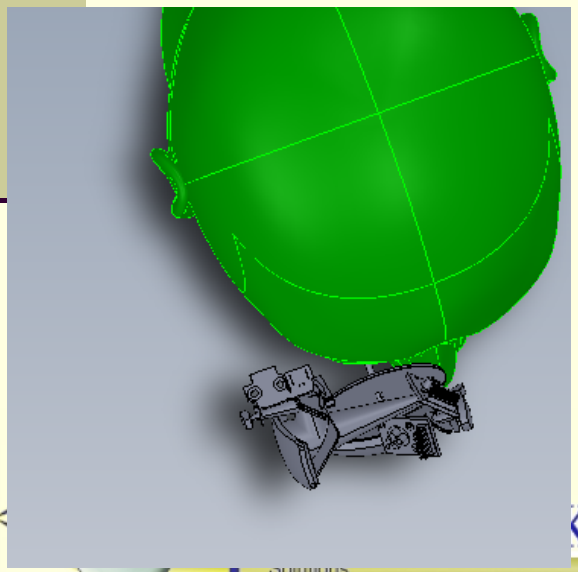
NICE IDEA though contacts are needed, WILL IT WORK?

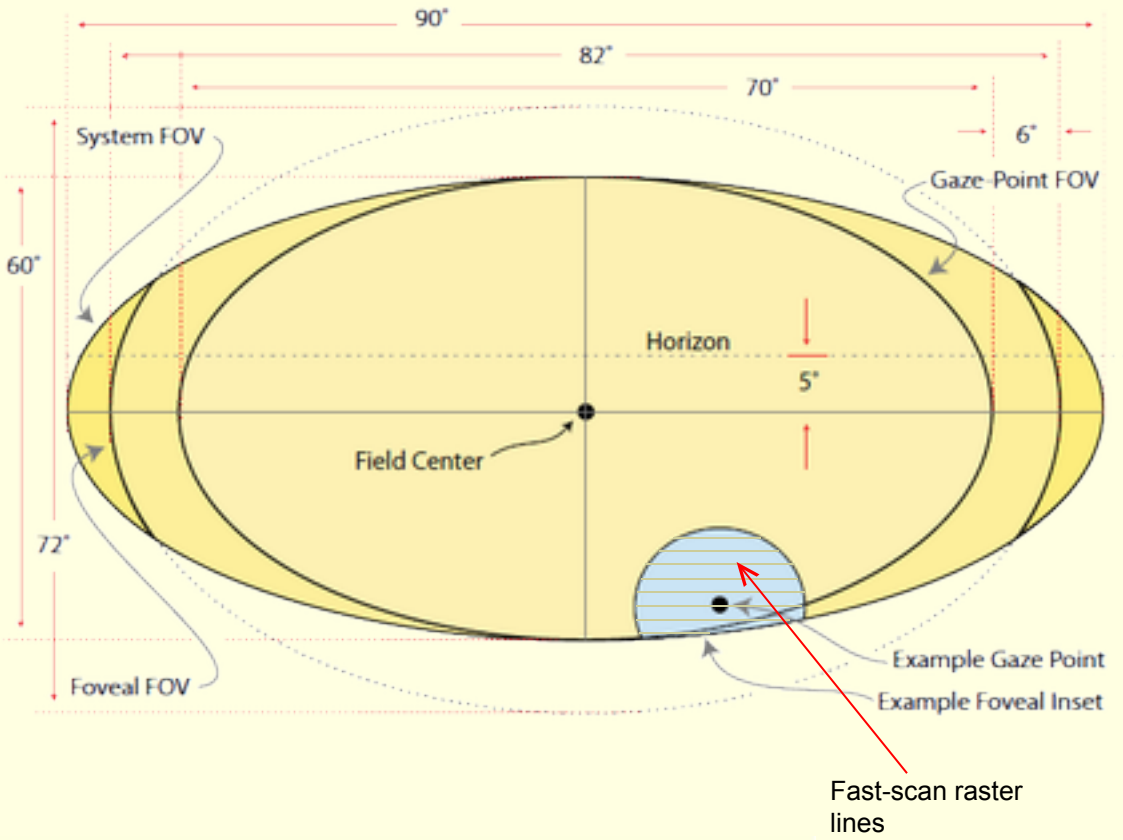
Us 8,142,016



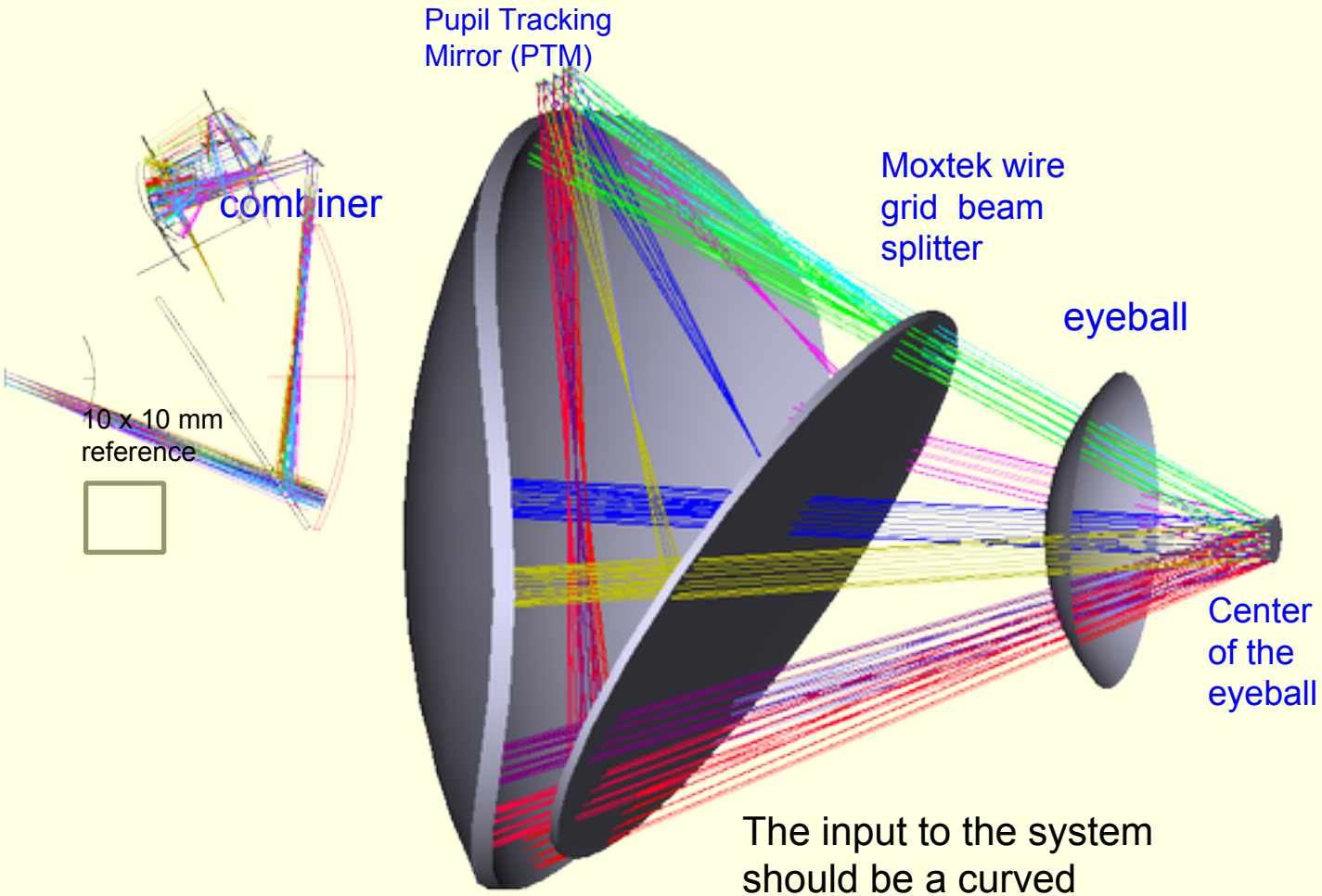
FOVEATED NEDs
Spectoccular, a laser scanning foveated system

The idea is to provide high resolution only in a small field, about 12^0, about the tracked gaze direction but this sub field is steerable within a much larger field of about 80^0 x 60^0 degrees per eye.





Main optical module



The input to the system should be a curved object about the PTM

Segmented or tiled NEDs

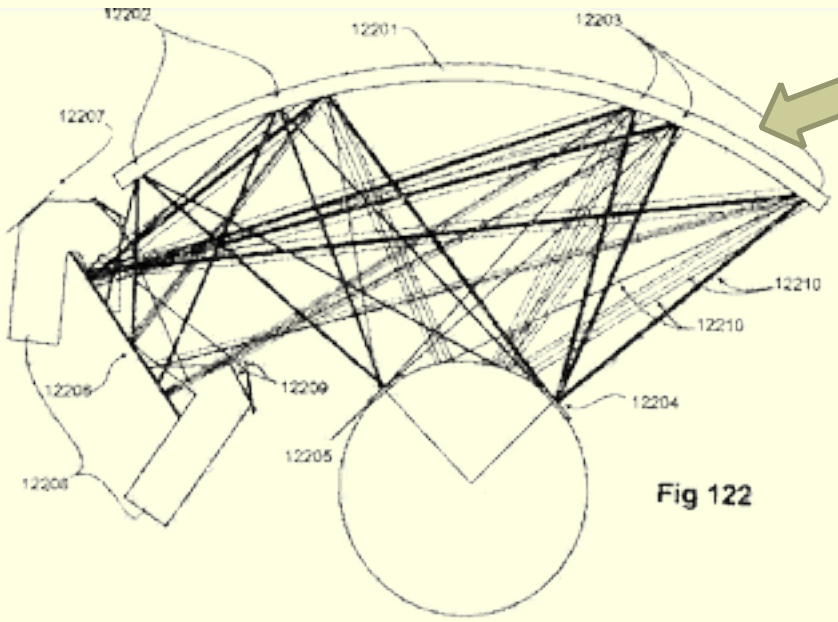


Fig 122

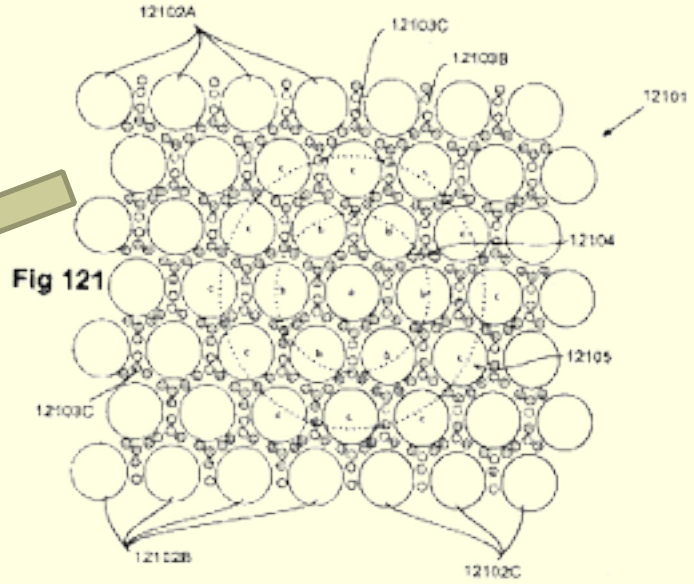


Fig 121

Patches of different size holograms dispersed over the combiner and interact with an array of laser beams.

High potential for sunlight “dirty window” scattering

Chaum et.al US20120/0149073A
100 pages, 300 figures, 85 claims

Google glass

Google “project glass”

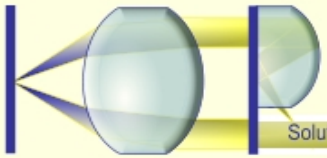
The Video clip is impressive

The optics: So far- not impressive…
small FOV only 15 degrees
not a real see through.

Design: traditional “bird’s bath” design

Augmented Reality in a Contact Lens

Dr. Parviz, Google’s, futuristic solutions?



Kessler Opt

Solutions

Microsoft- what are they up to?

Microsoft has now on staff now both **Pasi Saarikko, the NED holography expert (originally from Nokia)**

And: Andrew Travis- the inventor of the "wedge optics"

Another form of pupil splitting

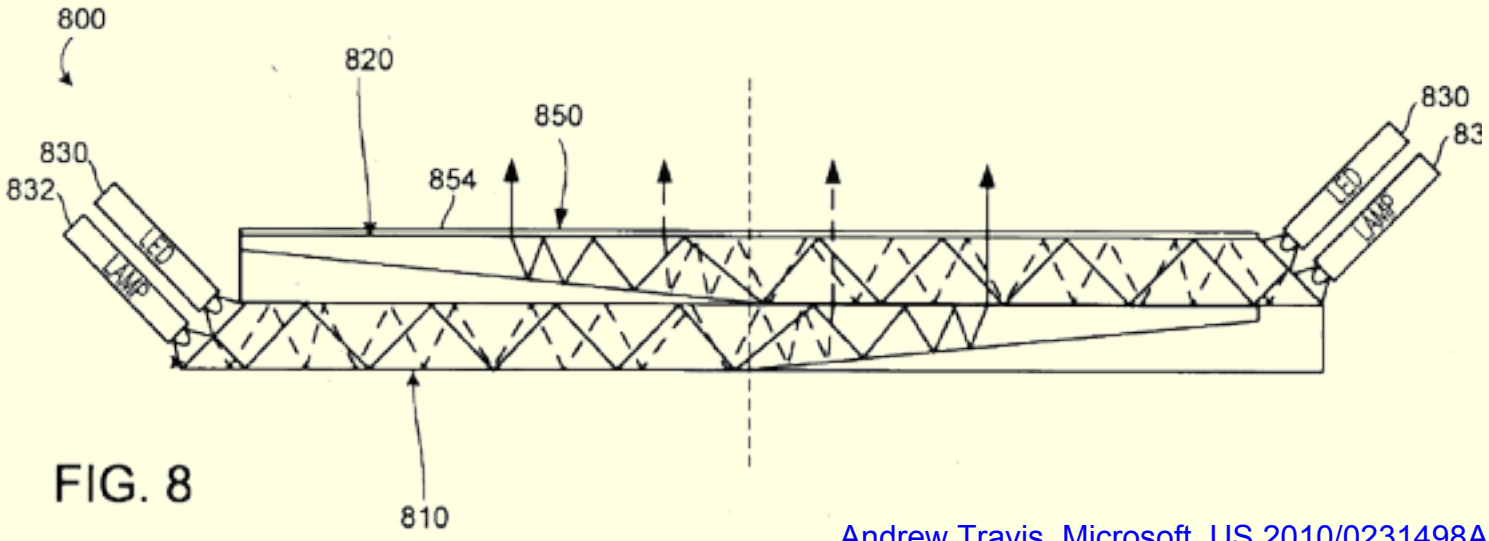


FIG. 8

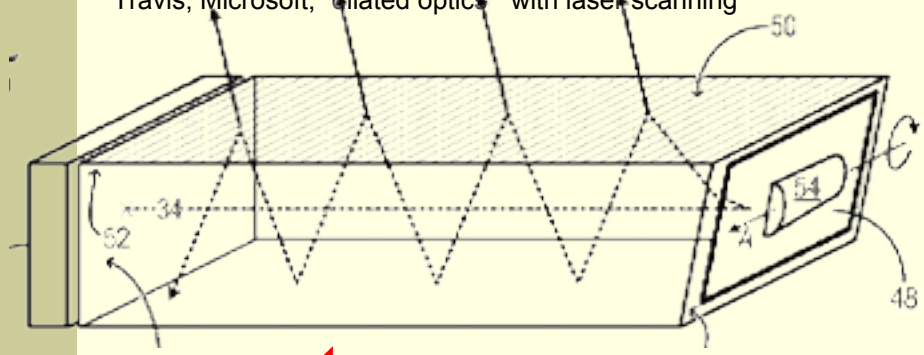
Andrew Travis, Microsoft, US 2010/0231498A1

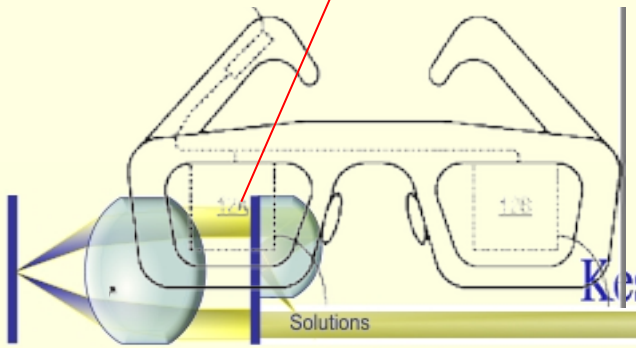
Microsoft Andrew Travis,

Other Travis solutions

US20120062850A1

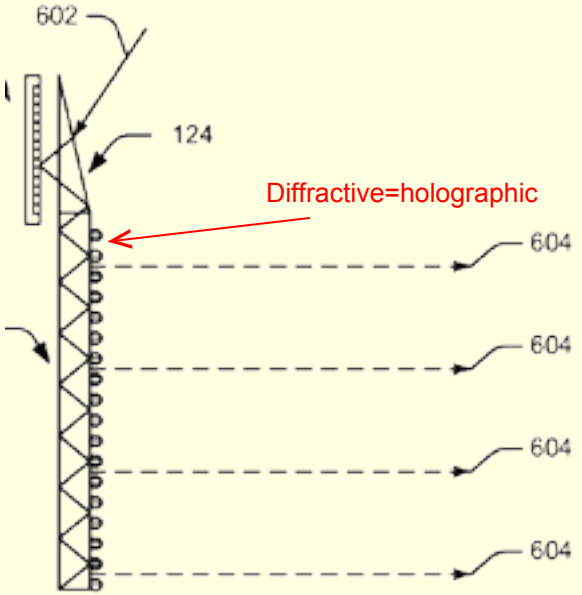
Travis, Microsoft, “dilated optics” with laser scanning





US20130021392A1

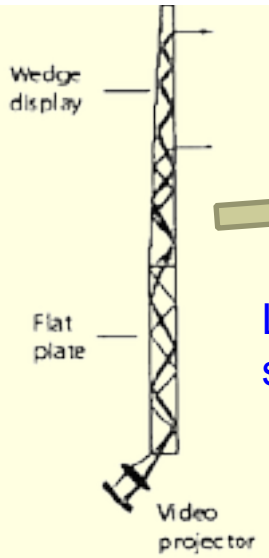
Wide FOV virtual projector



Does Pasi have to do with the holographic part?

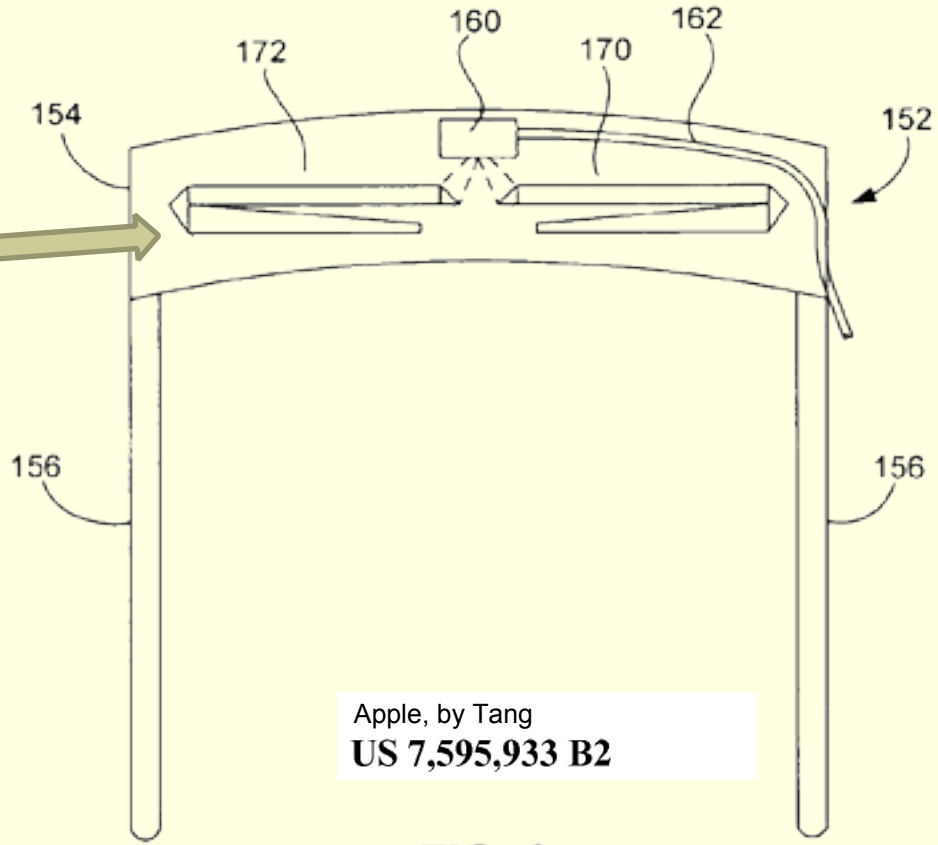
Apple- what are they up to?

Apple, by Tang
US 8,212,859 B2



?

Looks like a Travis solution?



Apple, by Tang
US 7,595,933 B2

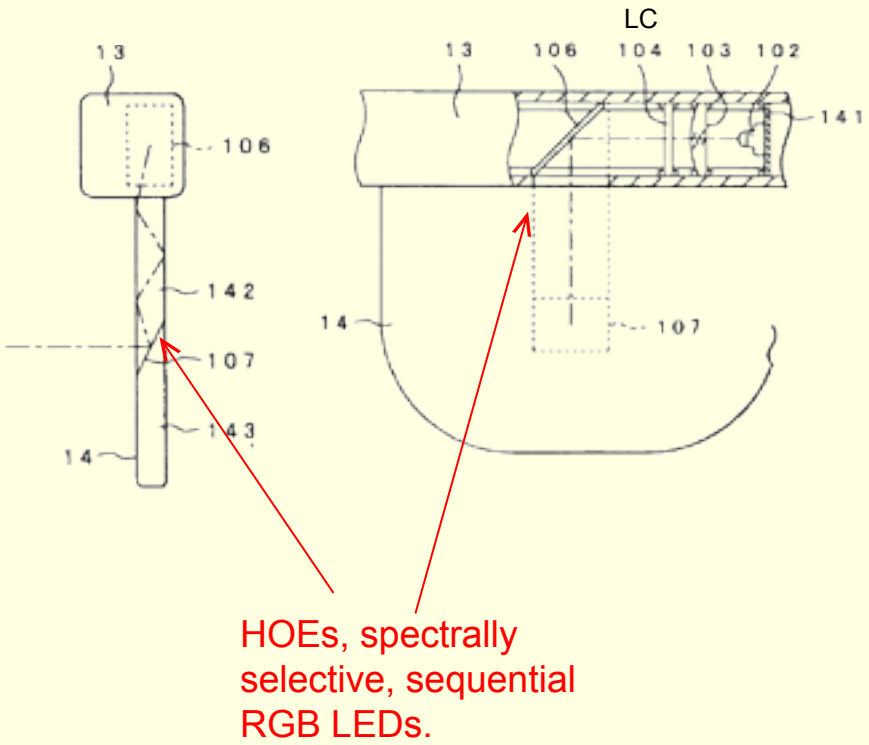
FIG. 6

Oakley Airway ski goggles, sold by Apple connected to the Iphone,14 deg diagonal full field

Looks like th
used thou

Olympus Meg.4

320x 240 QVGA
30 grams
Bluetooth



Small FOV
Low end design
Good form factor

US7,199,932 142 and 106 are HOEs reflecting narrow spectral bandwidth RGB LED .

Digilens, SBG labs

http://www.digilens.com/Head_Mounted_Display.html

98 patents by
Popovich
Great ideas
Controlled brag

Is there a product?

In conclusion:

*The Near to Eye Displays area is currently energetic and evolving quickly.

* Optical see-through is often requested.

* While Free Form Surfaces are more frequently employed, striving for higher degree of symmetry usually pays off in terms of performance and complexity

* Major league companies are actively looking for NEDs solutions.

* Stayed tuned….