Optical Versus Passthrough Mixed Reality

By Karl M. Guttag

KGOnTech LLC Blog (www.kguttag.com)

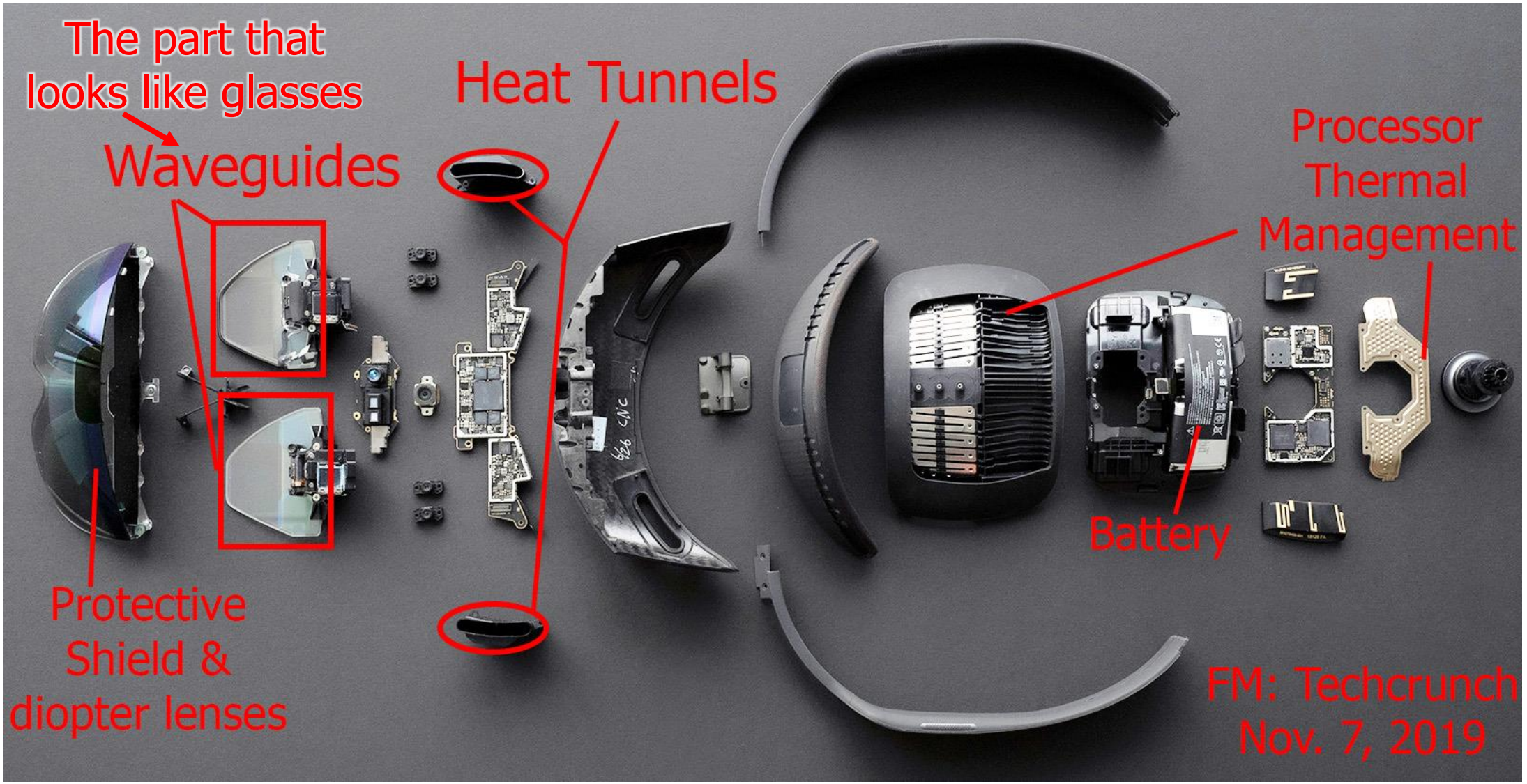
Start with Ray Ban but end Up with Hololens

Hololens 2 Video Feed Image

Hololens 2 Through Optics

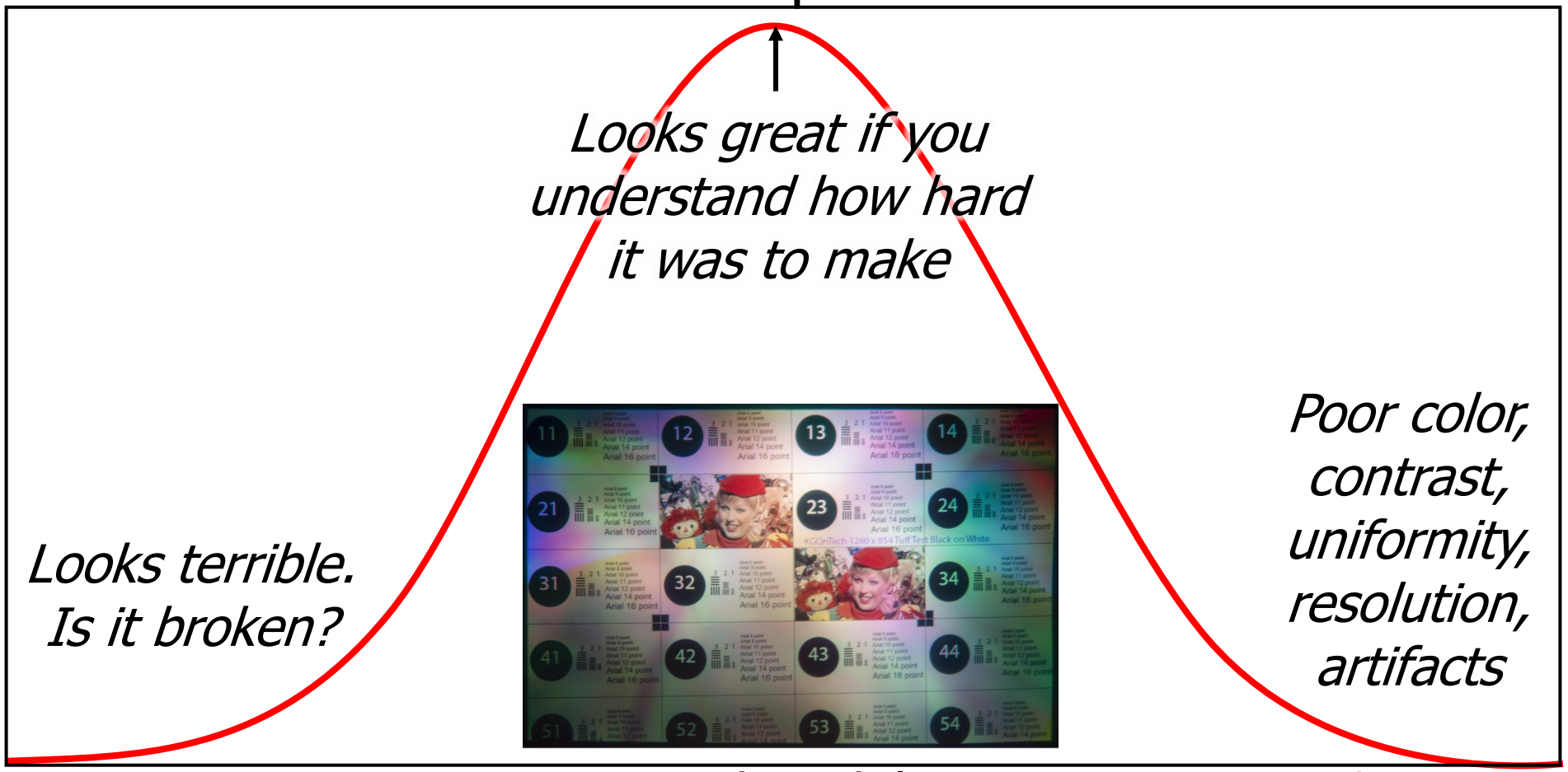
Expectations are out of line with what is possible, no less practical

Hololens 2


The part that looks like glasses
Waveguides
Heat Tunnels
Processor Thermal Management
Battery
Protective Shield & diopter lenses
FM: Techcrunch Nov. 7, 2019

A Consumer, Technophile, and Scientist Look at the Same Image

Consumer vs Technophile Saddle Curve



Consumer | Technophile | Scientist

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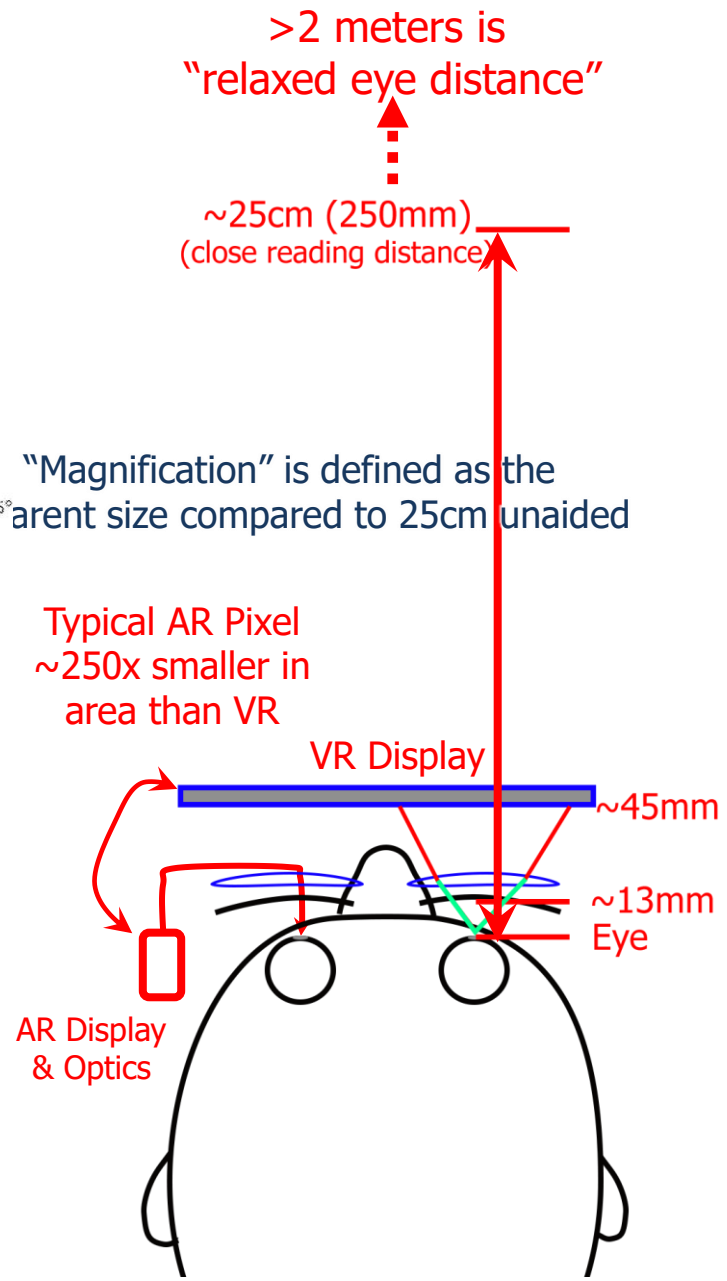
Why is Optical AR So Hard?

- The wavelengths of visible light is fixed
  - **Typical AR display pixel >10x smaller linearly than VR**
  - Diffraction becomes exponentially more of a factor
- Blocking incoming light is crude and inaccurate
- The display can't be in the "right place" (unlike VR)
- Large FOV requires large final optics
- Everything must be small, light, and low powered
- **Anything that "Combines" the real world and virtual image <u>hurts both</u>**

Magic Leap 2
patent application



MR Major Design Challenges "Checklist"

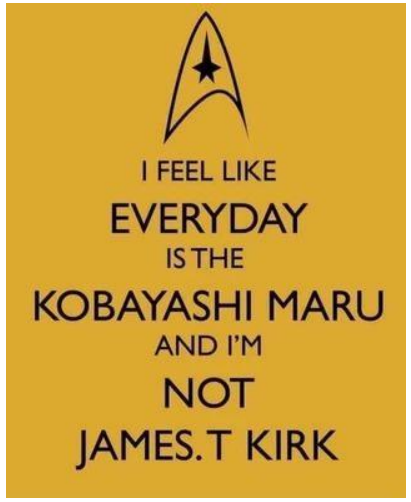
1. Cost
2. Transparency
3. Distortion and visual artifacts
4. Eye relief [Enough for Glasses?]
5. Blocking vision both forward & periphery (safety)
6. Field of View (FOV)
7. Resolution [Angular and number of pixels]
8. Eye box size [Makes seeing/finding image easier]
9. Brightness **to the eye**
10. Contrast ["black" and "picture frame"]
11. Uniformity & color quality
12. Vergence-Accommodation Conflict (VAC)
    - Most MR focus at ~2m, the hands are at ~0.5m
13. Size, weight & form-factor
14. Eye protection
15. IPD (interpupillary distance)
16. Variability in head and face shapes
17. Power/efficiency [battery size/weight & **heat**]
18. "Situational awareness" [**safety**]
19. Social issues
    - Privacy, ugly, seeing eyes, glowing eyes, etc.
20. Computing & Comm. (**power, size, & weight**)
21. Portability (**wear all day or fit in pocket)**
22. Vision Correction
23. **Various issues with human visual perception**
    - "Doesn't work right"

Often Improving One Aspect Has Negative Effects on Others –> **N-Dimensional Chess**

Requirements Forcing Design Spirals

- **IF** >50° FOV, SLAM, Hand Tracking
  - Beyond glasses form factor (helmet or goggles)
- **IF** Glasses form factor
  - FOV<30°, **front heavy**, limited battery, limited functionality
  - Limited/no SLAM, hand tracking, etc.
  - Custom lenses/waveguides for prescriptions
  - Limited battery life
  - Heat dissipation can be a massive problem
- **IF** Eye Relief < ~23mm
  - Can't support normal glasses and headset becomes non-interchangeable (limits market)
- **IF** Helmet or Goggles (full rap around) form factor
  - A problem with large hairstyles
- **IF** Birdbath design with OLED or LCD
  - >30% transparency, low efficiency, limited brightness (at least for now)
  - Front-heavy and thick
- Outdoor Use requires >2,000 Nits
- **What about** VAC?
  - Everyone talks about but very few even try to solve and those that have (Magic Leap 1) failed
  - How good?, lag issues?

Can't Win,
Can't Draw,
Must Play



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Pro and Cons of Passthrough AR

Pros of Passthrough MR

- Better virtual image quality (contrast/black)
- **Hard-edge (pixel level) occlusion** becomes trivial
  - Impossible with Optical AR, Soft-edge occlusion is very soft
  - Does not compete with ambient light (power savings too)
- Simpler and less expensive optics

Cons Of Passthrough MR

- **Fixed focus of the real world** (with practical technology)
- Orders of magnitude less **dynamic range** than the real-world
- Lower resolution than the real world
- Motion to Photon delay
- Imperfect alignment (both 2-D and 3-D) of camera to the eye
  - Thinner optics (ala Lynx or pancake) helps but does not solve
  - Issues with motor skills and/or safety
- Non-display vision blocked
- Social issues of blocking person
- **Massive potential safety issues**
  - Must be in a "safe" location

What is Hard with Optical AR is Easy with Passthrough AR & Vice Versa
I see very little overlap in the application spaces

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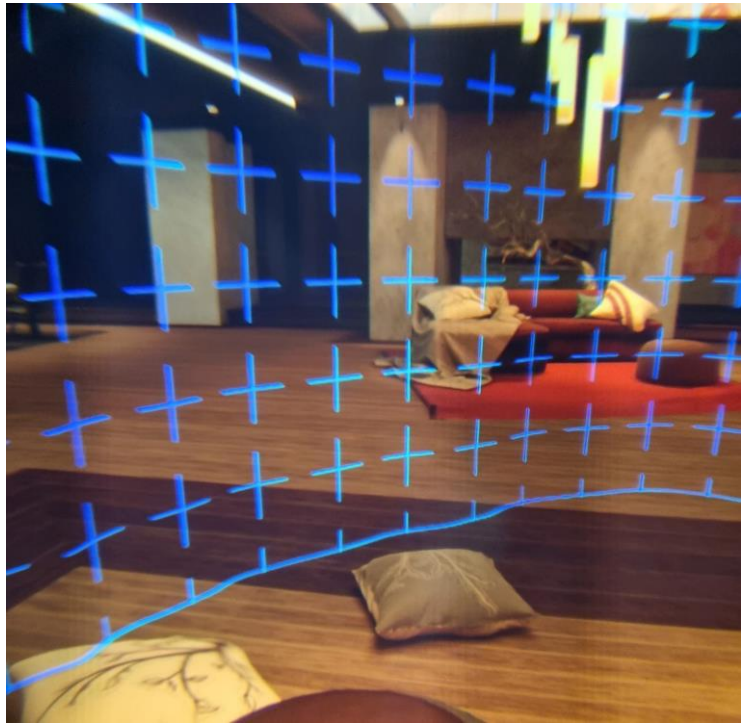
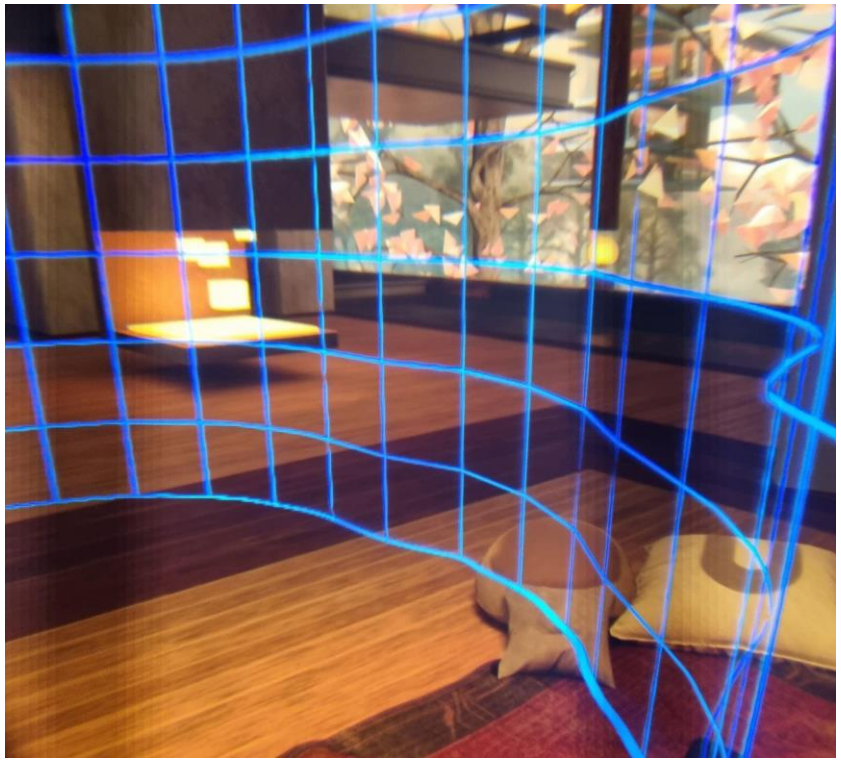
Personal VR Boundary

No virtual boundary is small enough to keep you safe or large enough to not be annoying





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Little Overlap in Requirements and Application

Optical MR

- Seeing real world is top priority
  - No lag
  - High dynamic range
  - Infinite number of focus distances
  - 100% accuracy in size, location, depth
    - Especially a person's hands
- Peripheral vision is important
- Often "hands free"
  - Gesture recognition is **NOT** "hands free"
- Movement in the real world
  - Could be used outside
- Sometimes worried about social issues
  - Looks, eyes, recording
- Occlusion is difficult and inaccurate

Passthrough MR

- Seeing the virtual world is top priority
  - High image quality with high contrast
- Immersion with extremely wide FOV
- Usually with controllers in the hands
- Peripheral vision is gone
- Must be in a "safe" location
- Ignores social issues with wearing headset

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What is the Problem Are You Solving?

- Immersive Video Games
  - Very large FOV (>100 degrees); Good contrast and high dynamic range
- Movie and TV watching (Media Player)
  - Medium FOV (35-50 degrees); Mid to high PPD (>40 PPD); Great contrast/blacks
- All day wearable (at best, data snacking is possible)
  - Transparency, **very light weight & small**, stylish, no forward projection
  - Complex issue for prescription correction (must be inexpensive and integrated)
- Enterprise non-office (ex. warehouse, factory, delivery)
  - Transparency, small FOV (10°-30°), light weight, rugged
- Enterprise (Office Worker)
  - Typically, Medium FOV (but varies with application)
  - Monitor replacement (**Does not work well!**)
  - Visualization (small market), Avatar Conferencing (seriously?)
- Military (deployed, as opposed to training)
  - High PPD and wide FOV, very transparent & not interfering with other equipment, highly rugged, no front projection, high brightness (>7,000 nits even with dimming), fast transition for any dimming & non-polarizing

Ice bucket type challenges
"I replaced my monitor for 2 weeks with VR"

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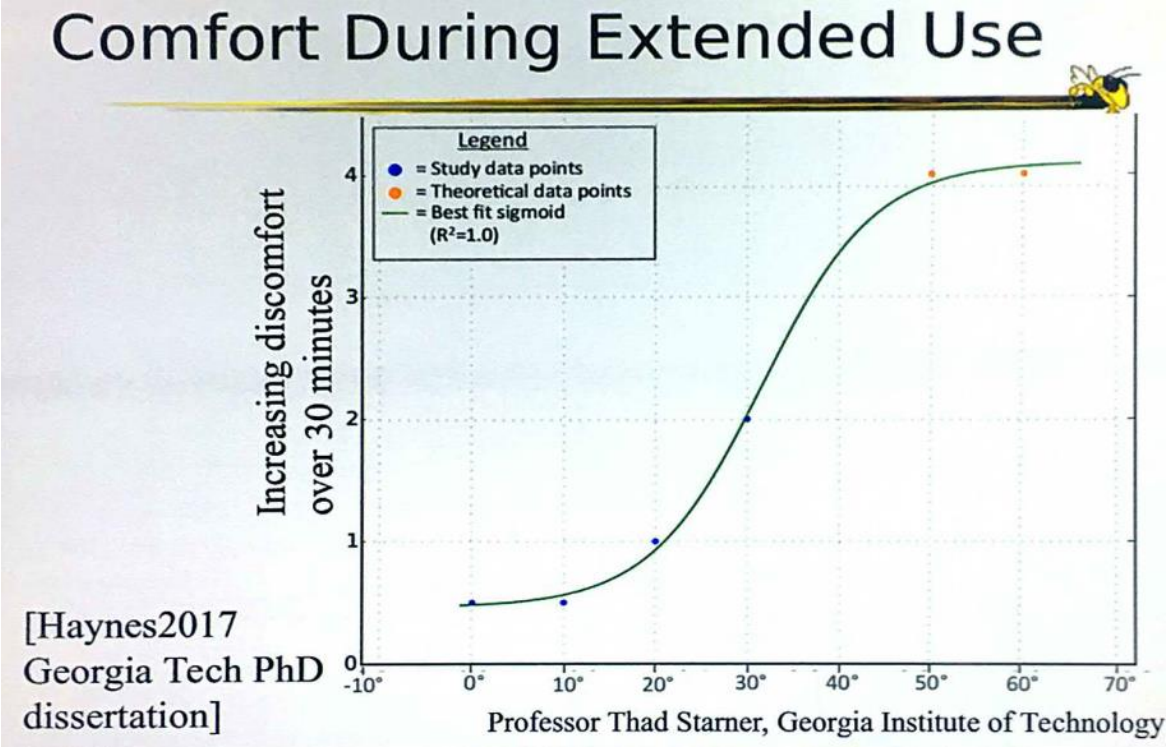
Some Wide FOV Data Points



How Much FOV is Enough?

KG Warning: Thad picked and chose some data points

6.4	video iPod (4th Gen nano) held landscape
6.6	typical newspaper column of text
7.1	Time magazine text column
9.2	**iPhone 6 held at normal viewing distance (portrait)**
12	Glass v1
15	iPad mini 2 (2017)
23	Apple iPad Air 2 (2017)
30	SMPTE recommendation for optimal viewing of HDTV
30	Max FOV recommended by ophthalmologists
30	typical range of motion of eyes before user moves head
34	Laptop 12.5" screen (11" horizontal) viewed at 18"
35	THX minimum for "most immersive cinematic experience"
55	IMAX theater minimum (max 115)

(all #s are horizontal FOV, in degrees)

Recommended Theater Viewing is around 45-degrees

Professor Thad Starner, Georgia Institute of Technology

Since VR took off first and it was easy to support wide FOV but at low PPD, it has driven unrealistic expectations for AR devices and PPD is often ignored

Optimum Movie Image Problem

- 45-Degrees would be an "optimum movie theater experience"
- But there is a drive for >>45-Degrees
- Immersion drives video games
- If the display was exactly 45 Degrees what do you do?
  1. Move image with the head – does not "work right"
  2. Keep image stationary and cut it off – annoying/distracting
  3. Shrink image – loose movie theater effect and by how much
  4. Make a much bigger FOV – expensive with image quality impact and extra power consumption

-> Similar issues exist for the Optimum computer monitor

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Computer Monitor MR Simulation

- Need >40ppd to have text readable without requiring too much eye movement for readable text
  - Typical VR headset has 15 to 22 ppd
- How do you support a wide monitor with >40ppd?
  - Need lots of pixels and a very wide FOV
    - Expensive, power consumption, image quality typically degrades with wide FOV
  - See optimum movie image issues in prior slide

-> And then you have a myriad of other visual human factor problems

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AR and VR Have Different Major Issues

Optical AR (Glasses Form Factor)

- Real world has infinite focus distances simultaneously
- Highly transparent to the real world and the **real world "works correctly"**
- Peripheral vision very important (safety)
- Brightness for outdoor use >2,000 nits
- Full hard-edge occlusion is **impossible** due to inability to focus the incoming light
  - Soft edge occlusion affects thousands pixels
- Prescription correction complicated by needing to address the real and virtual view
- Wide FOV is very difficult and with compromises
- Requires very small pixels (often >3 microns)
- IPD supported with large eye box or custom

Passthrough VR

- VR typically has a single focus (at a time)
  - Might mitigate with eye tracking and variable focus
  - **Visual system can tell the real world is not right**
- Invariably blocks much of peripheral vision
  - User must be in a "safe" location (too dangerous)
  - Use in a factory unlikely
  - Outdoor use unlikely
- Typically, ~100 nits to the eye
- Hard edge occlusion is trivial
- Still must deal with camera to eye parallax
- Wide FOV is relatively easy
- Can use mid-range pixels (10 to 30 microns)
- Mechanically adjusted IPD (or custom)

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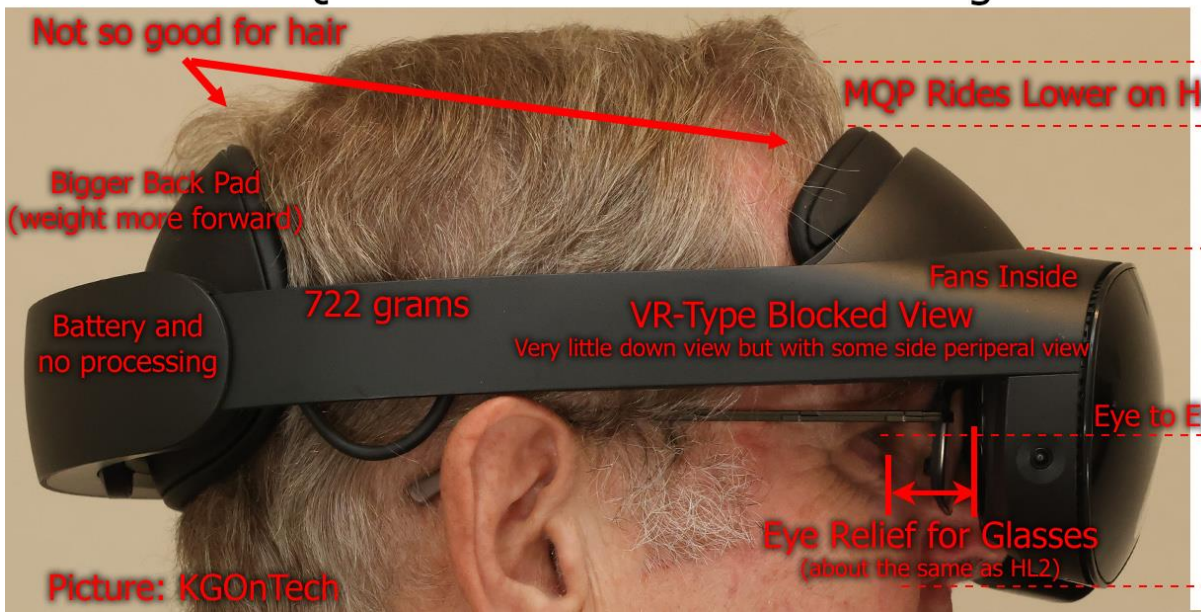
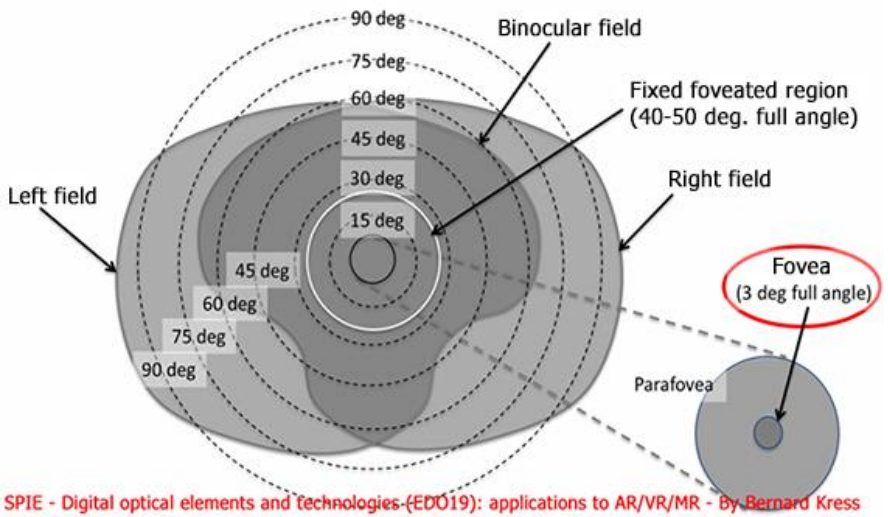
Passthrough & Optical MR Looking More Alike

Meta Quest Pro VR with AR Passthrough



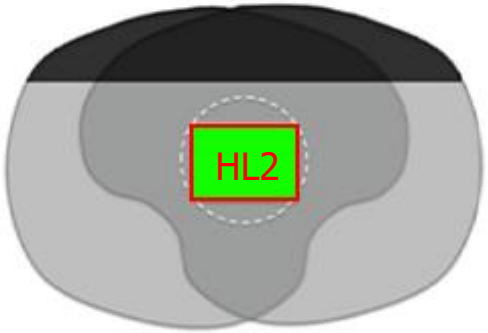
Hololens 2 Optical MR



Meta Quest Pro

Not much see through
106 x 96 deg. display FOV

Hololens 2



220 deg see through
52 deg display D-FOV

BOE New 4K by 4K Micro-OLED (SID 2023)

- Display Size – 1.3 inches
- Resolution – 3552 x 3840
- Pixel Pitch ~6.5 microns (Meta Q.P. LCD ~20 microns or ~3x)
- Refresh rate – 90hz
- Brightness – "up to 5,000 nits" (likely using micro-lens-array)
  - Can it sustain without burn-in?
- Some dead pixels ("so long as they are black")
- Power consumption – Video <4W, Gaming <7W (Yikes!)
- Duty cycle ?

Source: www.youtube.com/watch?v=_dzkJfvQ9i8&t=181s

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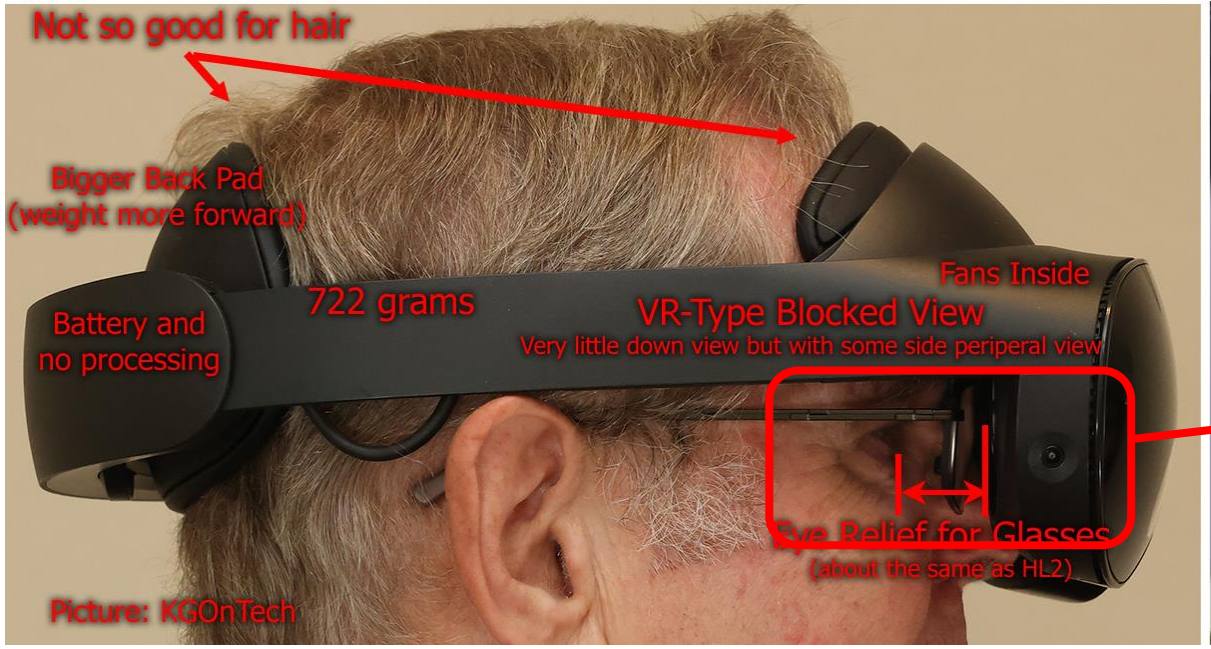
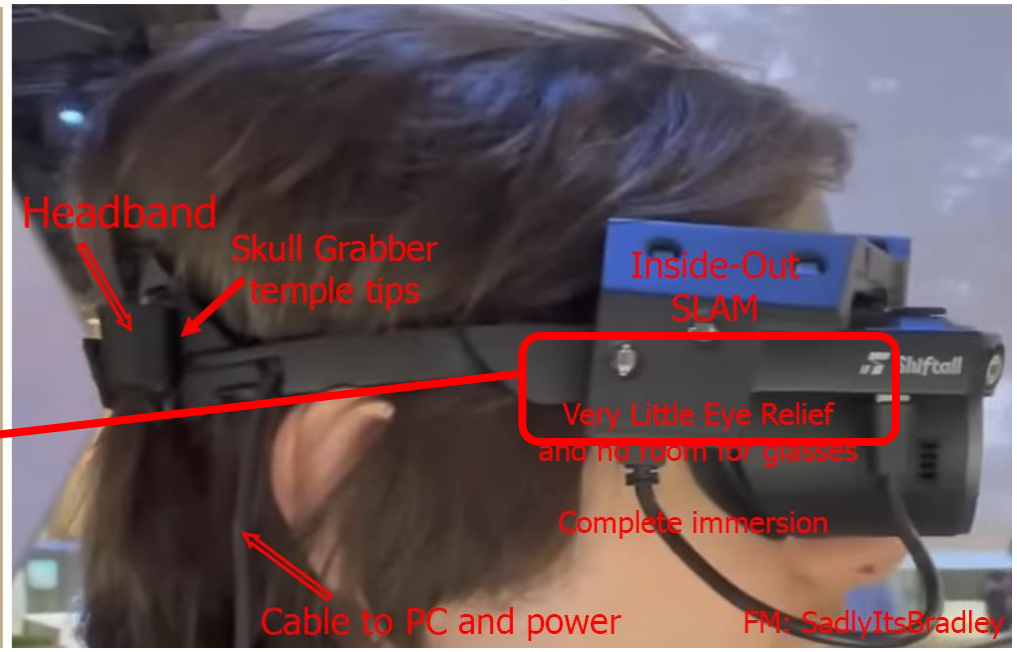
Eye Relief: Quest Pro (with larger LCD pixels) Compared to Panasonic Shiftall (with smaller µOLED pixels)

Meta Quest Pro with Small, but Non-Micro, LCD and Pancake Optics



Panasonic with MicroDisplay and Pancake Optics



- Smaller microdisplay supports smaller headset, but requires more magnification
  - For similar optics complexity and FOV, it tends to move display and optics closer to the eye
  - May force prescription inserts vs. using glasses
- Apple appears to be using Sony µOLED microdisplays and requires prescription inserts
  - Like Panasonic

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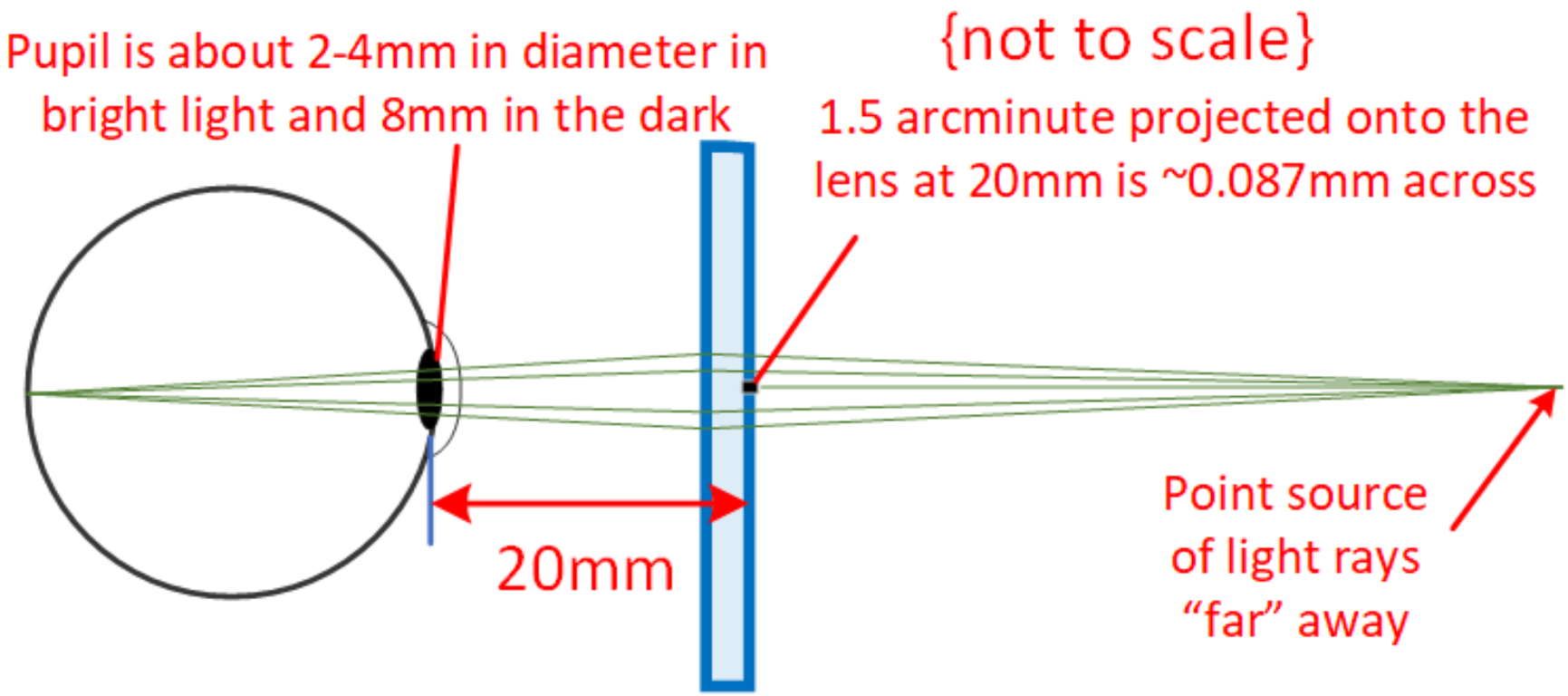
Optical "Soft Edge" Occlusion



Area of a 4mm Pupil = $(2mm)^2 \times \pi$ = ~ $12.566mm^2$

1.5 arcminutes @ 20mm = ~0.0087mm or $0.00007615mm^2$ in area

A 1.5 arcminute dot on the lens would blocks ~1/165,000 of the light from ~165,000 pixels

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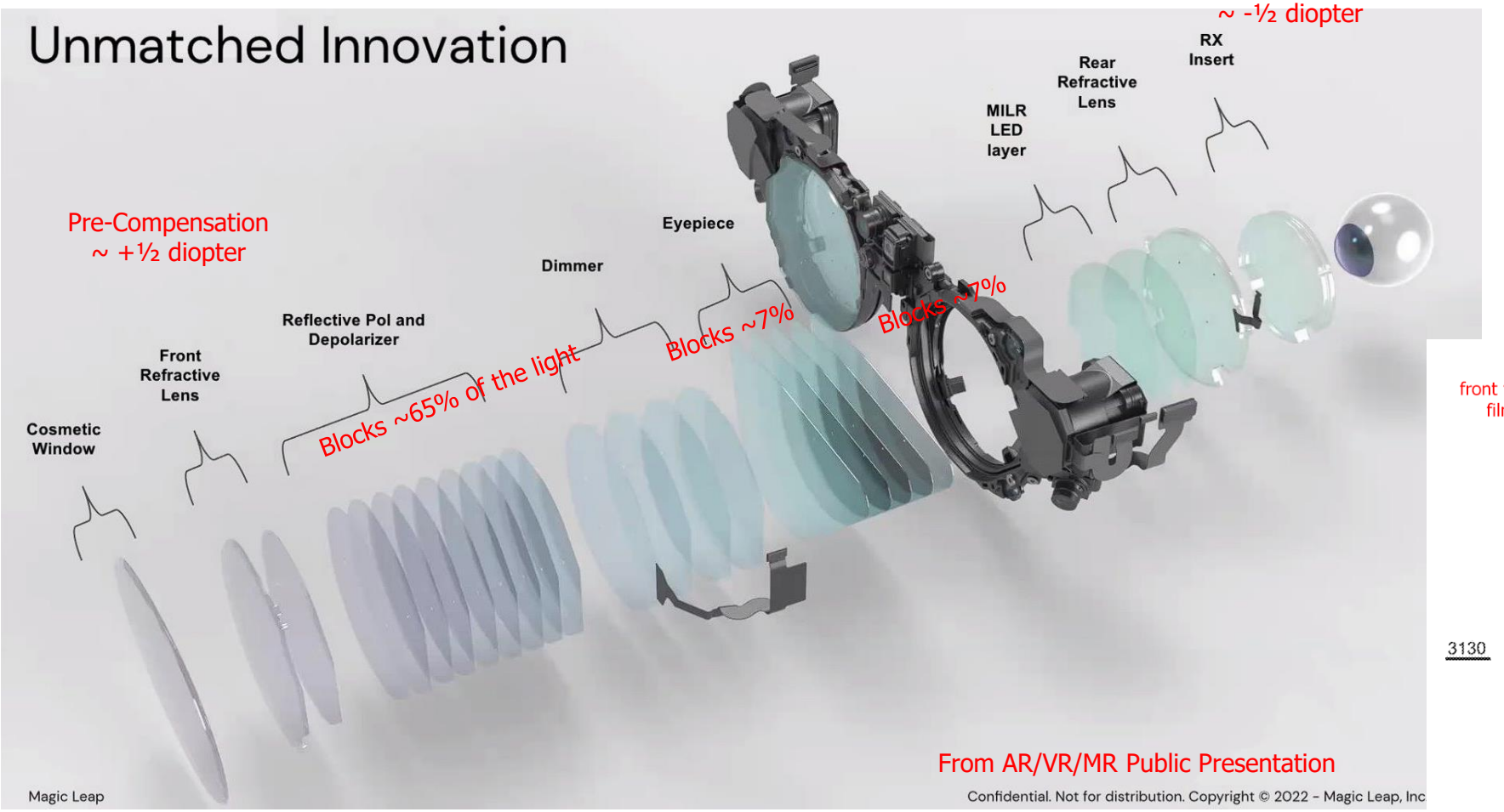
Magic Leap 2 – Many Optical Layers



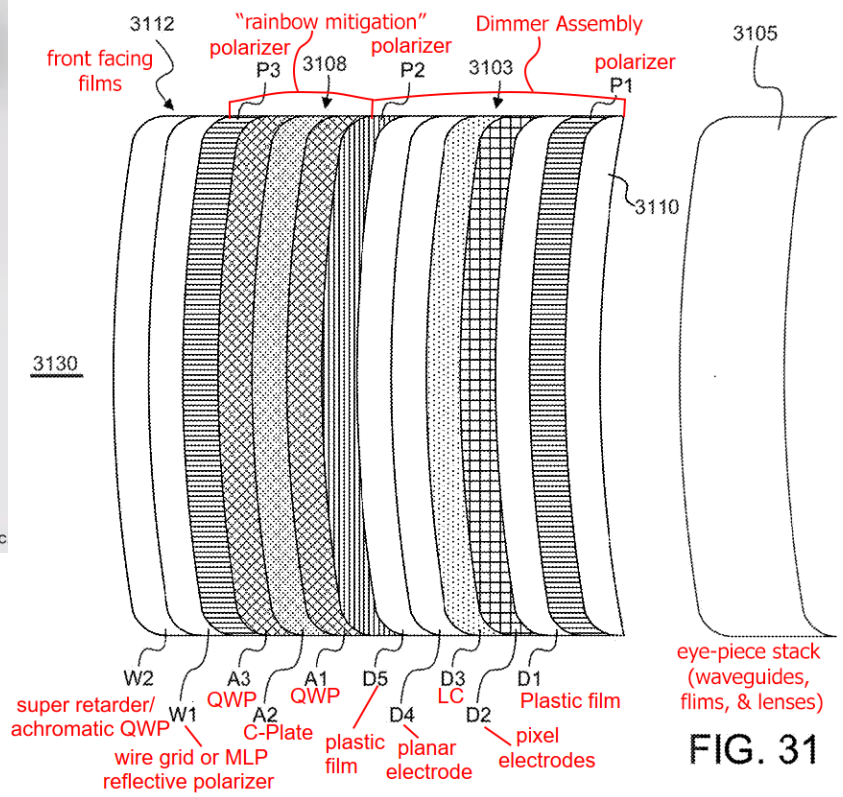
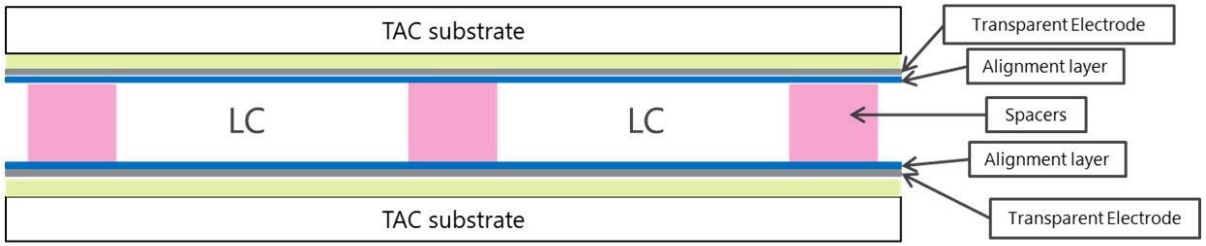
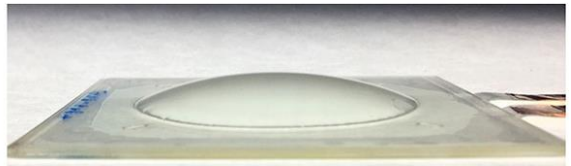


FIG. 31

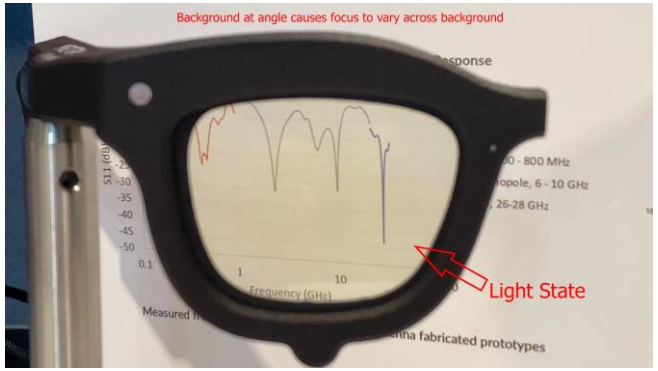
Non-Polarized Electronic Dimming

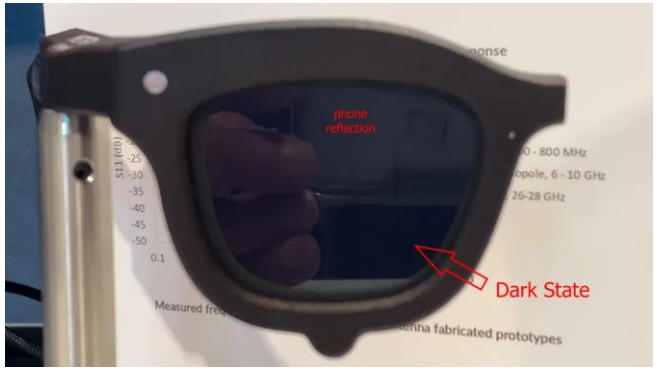
Flexenable





Meta Materials





Suzhou BearSunny Technologies Inc

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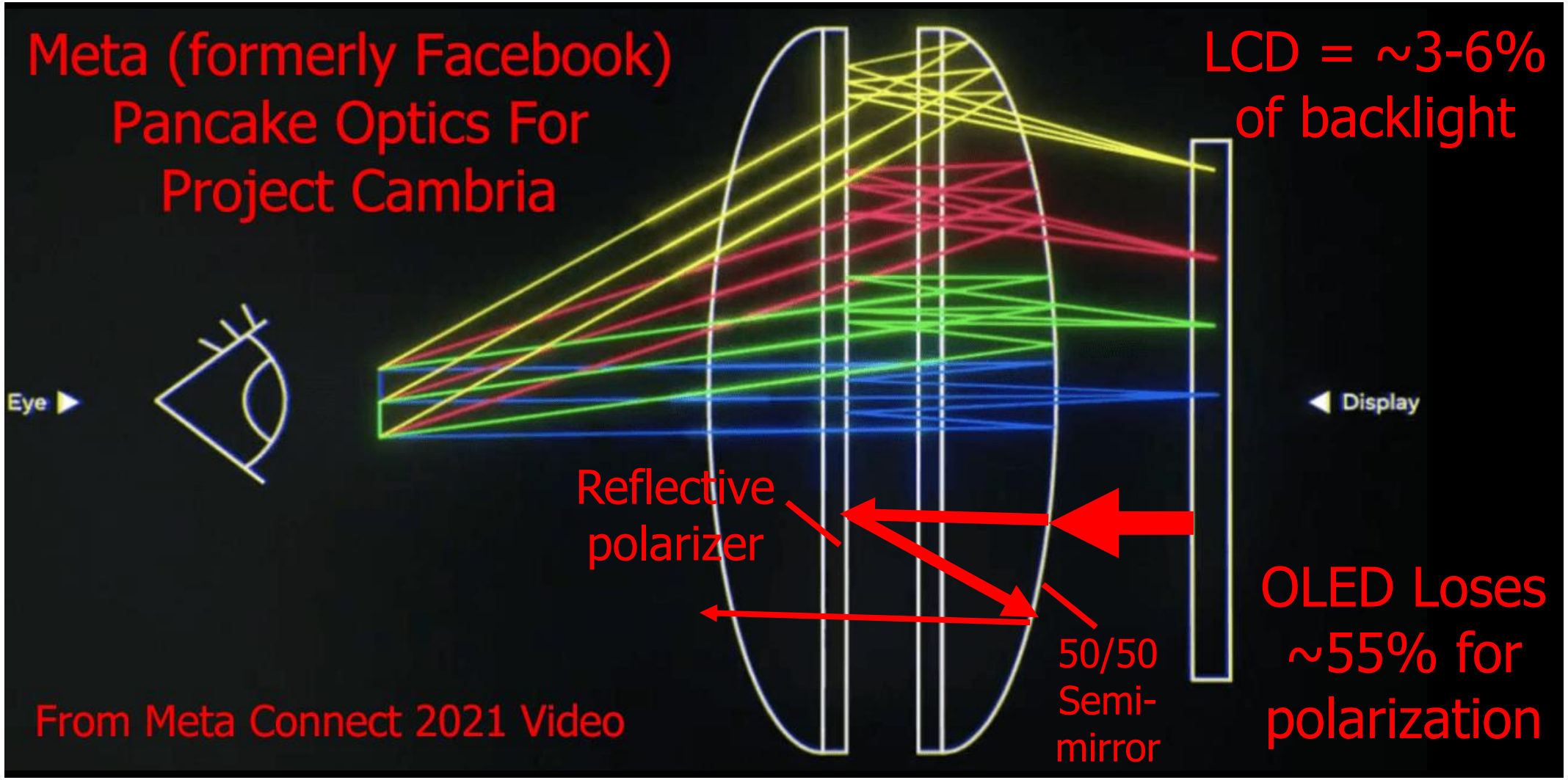
Pancake Optics are Inefficient



OLED nominal throughput ~= 0.5x0.5x0.45 = ~11%

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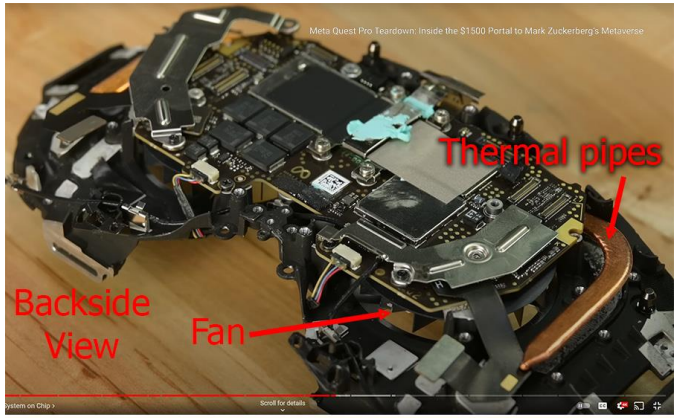
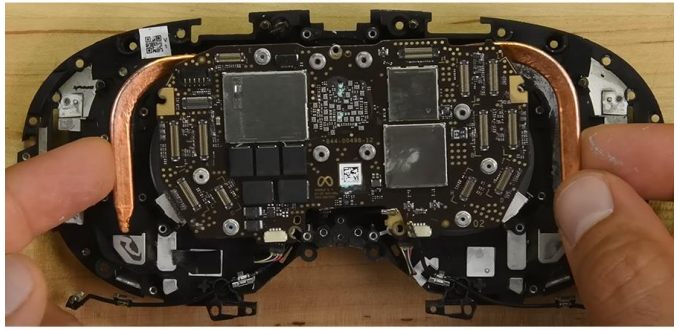
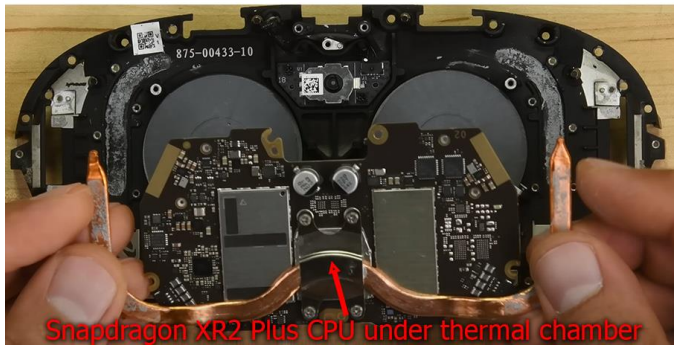
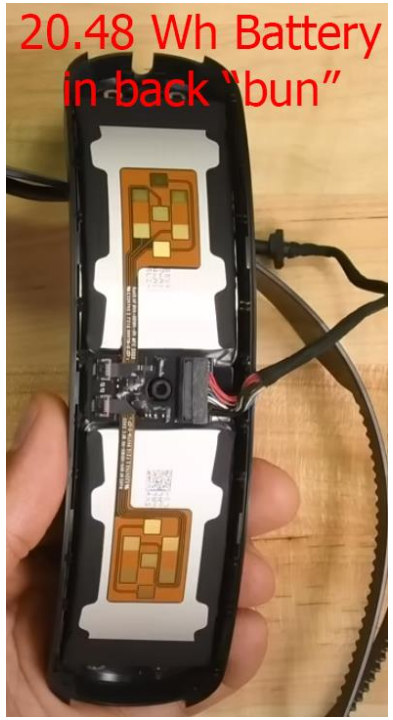
Meta Quest Pro Thermal Management









Amateurs worry about battery life
Pros worry about thermal management

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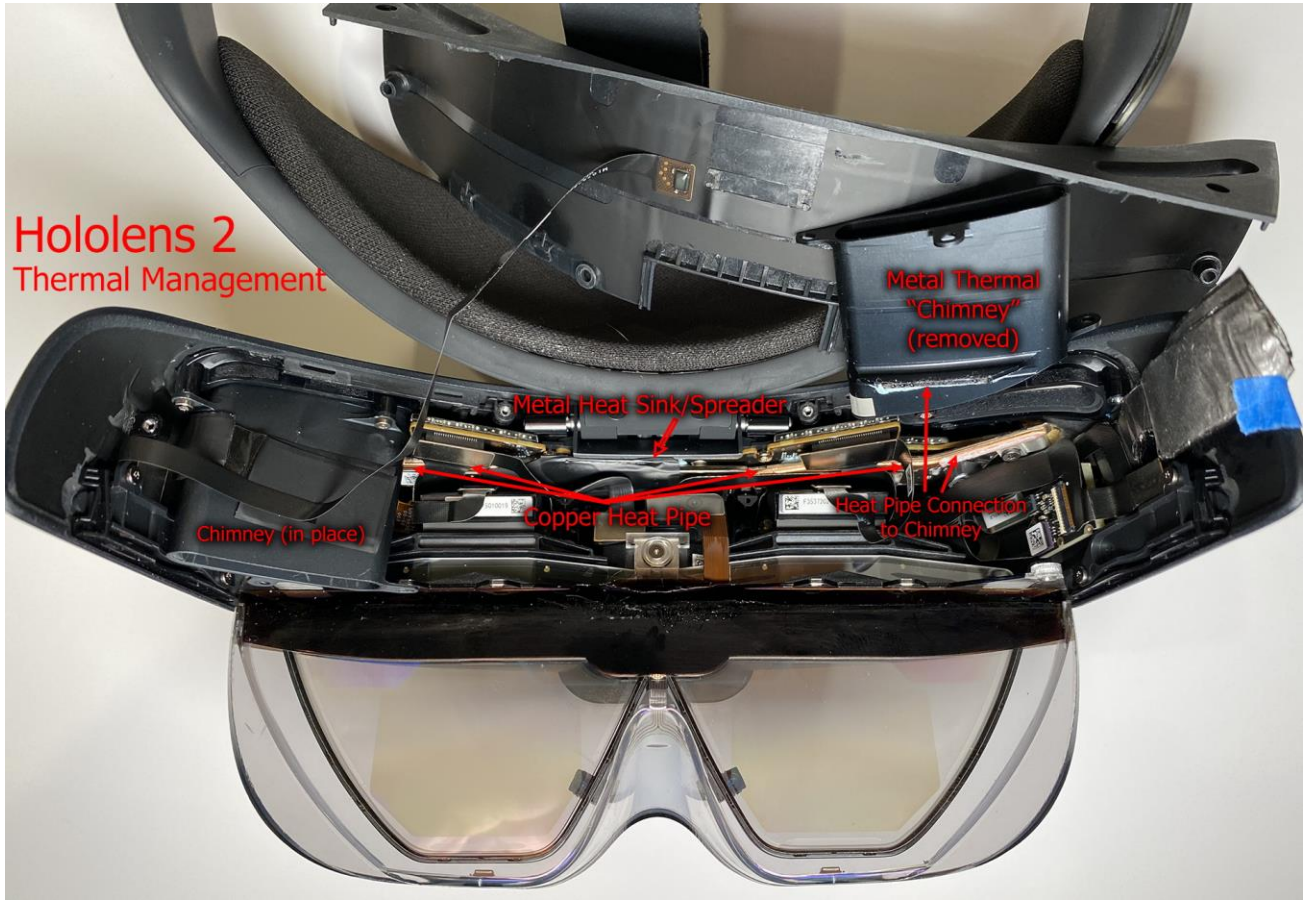
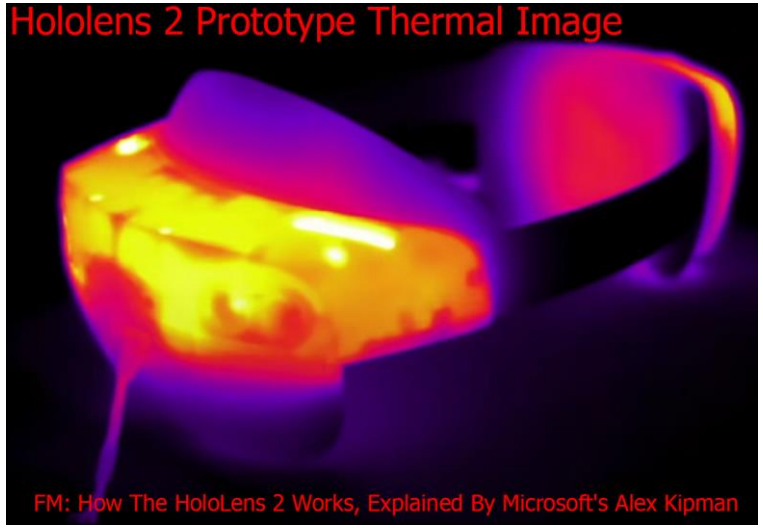
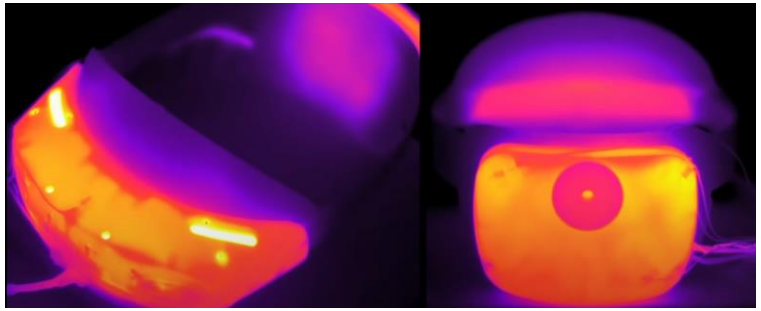
Hololens 2 Thermal Management







Where would all this go in a "glasses" form factor?
Part of why "start with Ray-Ban, end up with Hololens"

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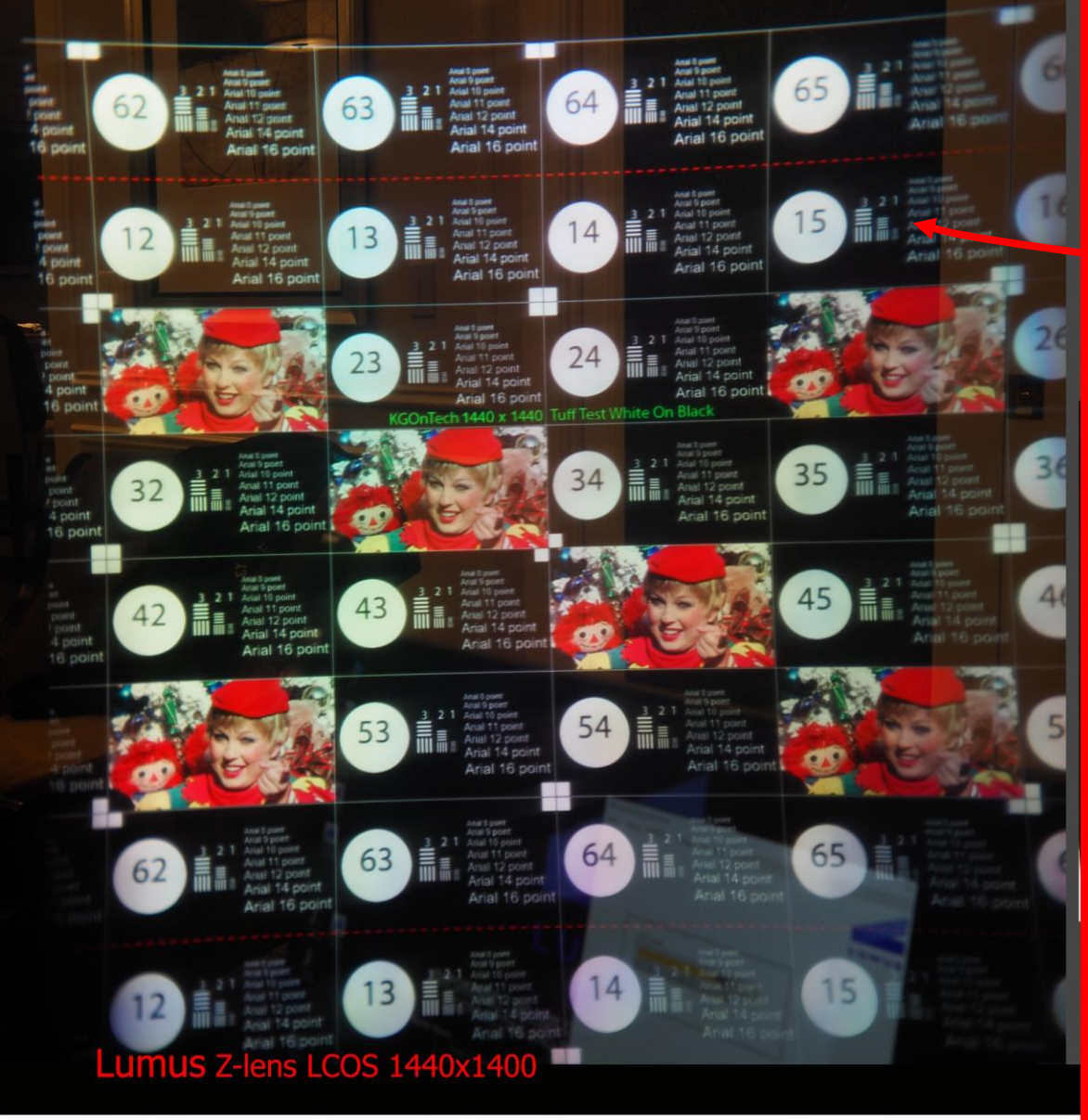
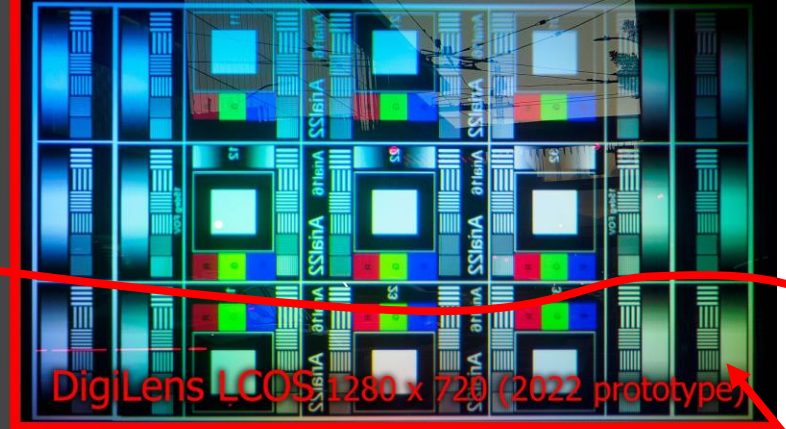
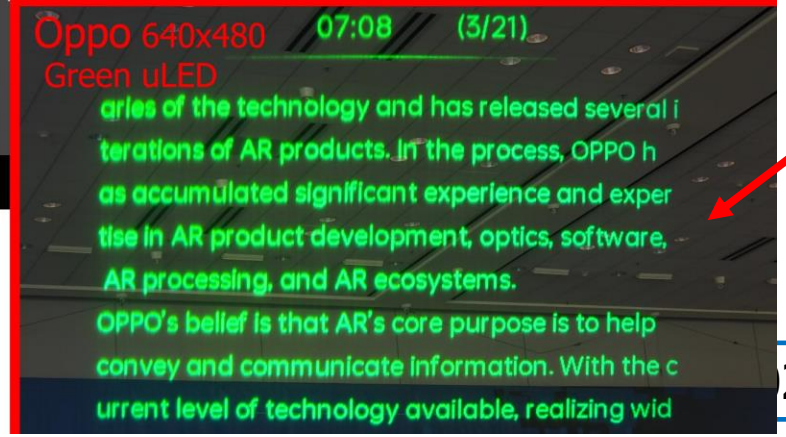
Recent AR Glasses







All pictures were taken with same camera and fixed 17mm lens with no scalling (all 100% crops).

Demonstrating relative FOV, Resolution, and Color

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The Human Visual System Senses a Problem (not all of which are consciously visible)

- Temporal artifacts
  - Saccades – mixture of fast and slow eye movement with blanking
  - Normal eye movement and fixation – eye tracking
  - Often cause "flash" artifacts
  - Judder – frame rate and display duration/blanking issues
  - Sensitively varies dramatically between people
- Motion-to-photon lag
- Focus is always wrong – real world has infinite focus all the time
  - Not just VAC, but the world does not behave right
  - Improving it hurts motion-to-photon lag
- Perspective does not work right
  - Things farther away move slower when the eyes move

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Importance of Centering Camera with Passthrough AR

"The camera was situated close to one eye, but it didn't have quite the same viewpoint. The slight misalignment seemed unimportant at the time, but it produced some strange and unpleasant result. And those troubling effects persisted long after I took the gear off. That's because my brain had adjusted to an unnatural view, so it took a while to readjust to normal vision. "

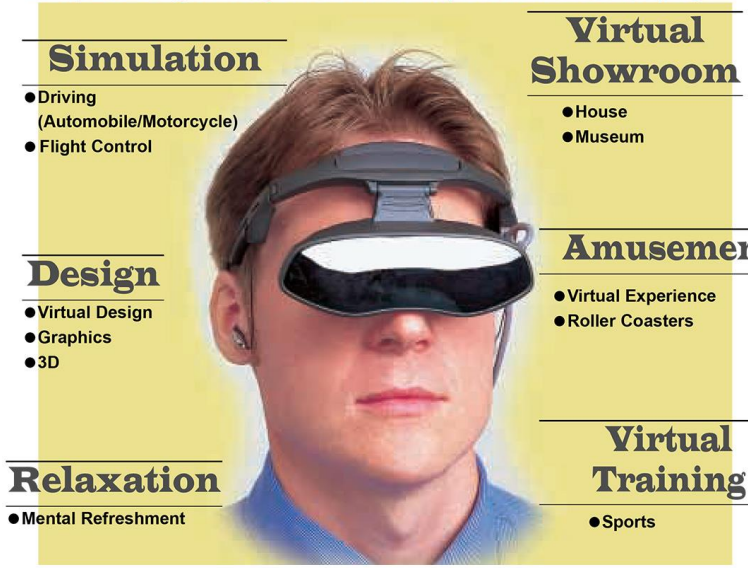
Steve Mann, March 2013, IEEE Spectrum "What I've learned from 35 years of wearing computerized eyewear".

Why Didn't Head Worn TV/Monitors Take Off?

Sony Glasstron 1998

SONY PLM-S700

High resolution with 1.55 million dot LCD for Professional use
Compact & light weight headmount personal LCD Display



Up to 6 hours with optionaliOn battery

Personal LCD Display

- ***SVGA/VGA input capability***
- ***0.7-inch, 1.55 milion dot LCD***
- ***Simulates dynamic 30-inch screen as viewed at 1.2 m*** (or 50-inch at 2M)
- ***Light (Head=120 g) weight highly durable using magnesium alloy***
- ***See-through mode, using LCD shutters***

Olympus Eye-Trek 2000

Key functions	Viewing angle	37.5 degrees horizontal, 21.7 degrees vertical. Equiv.to a standard 62-inch screen at a distance of 2m
	No. of pixels	0.7-inch TFT liquid crystal delta array of 240,000 pixels x 2
	Video signal format	AV video signal (NTSC Japanese and U.S. standard formats) Built-in stereo earphones
	Image adjustment functions	Contrast, Brightness, Color Balance, Color Depth
	Audio adjustment functions	SRS HEADPHONE, Low/High Frequency Adjustment
Weight:		Display unit: Approx. 95g Control unit: Approx. 38 g (excluding battery)

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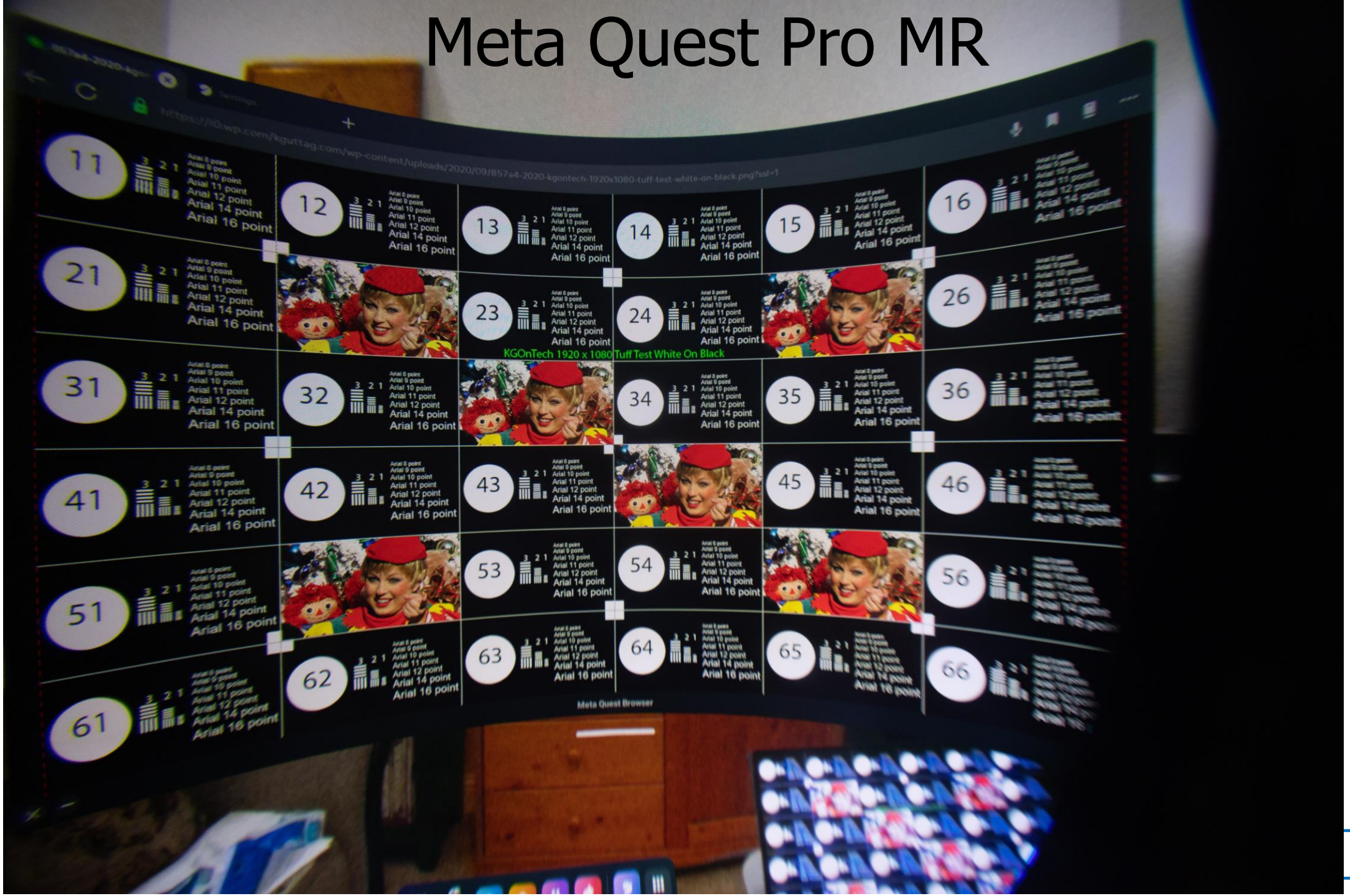
Meta Quest Pro MR

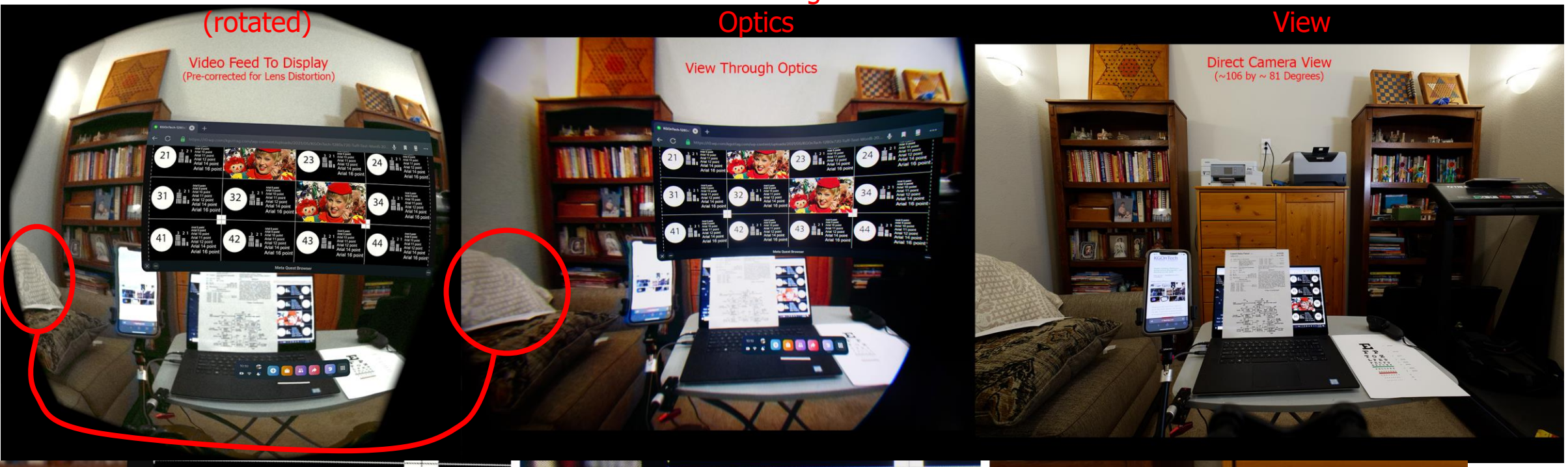


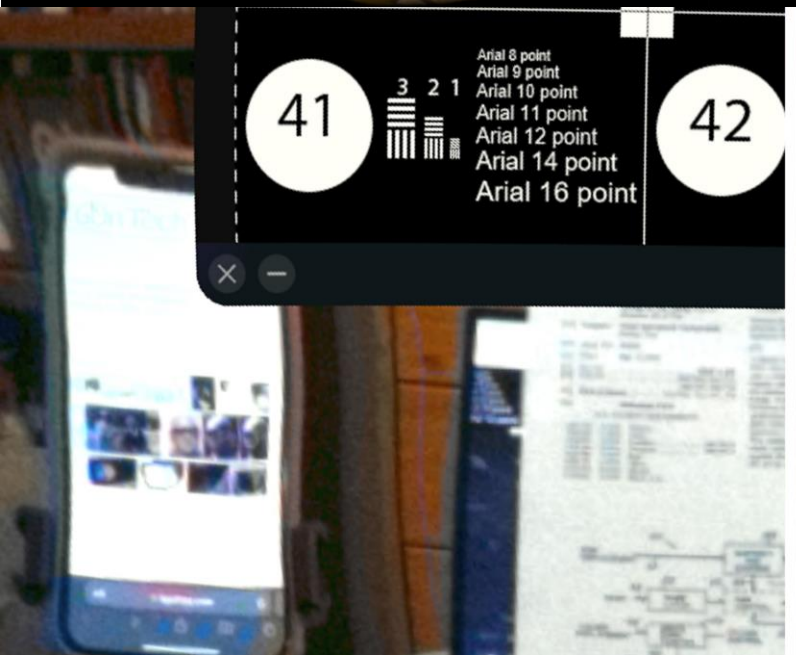
Meta Quest Pro

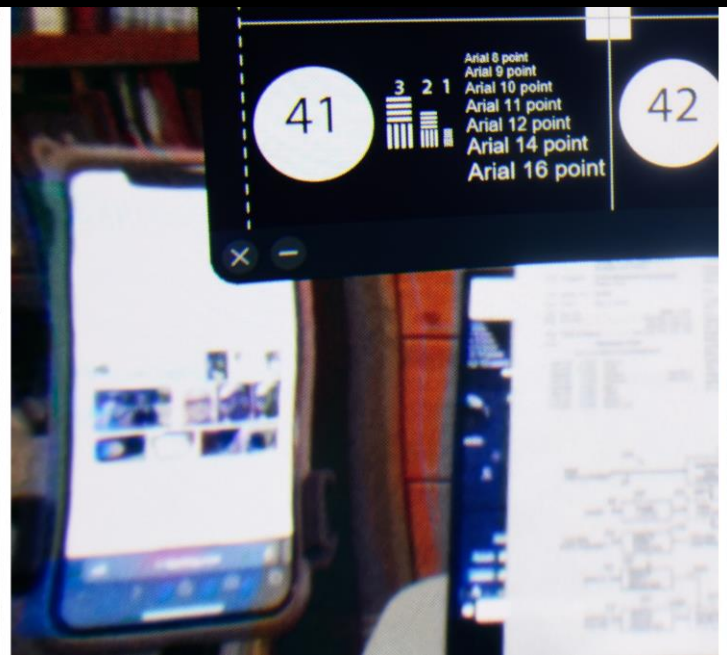
Video Feed with Pre-Correction (rotated)

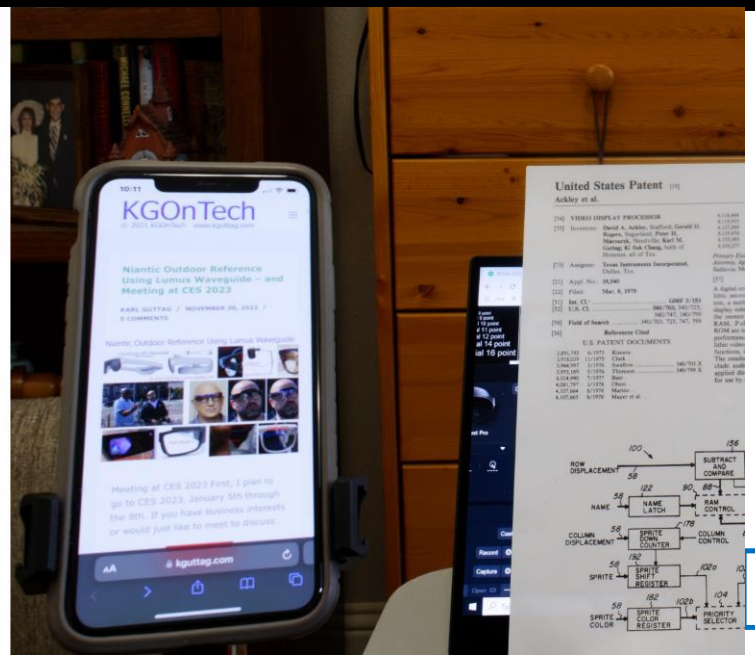
View through Optics

Direct Camera View





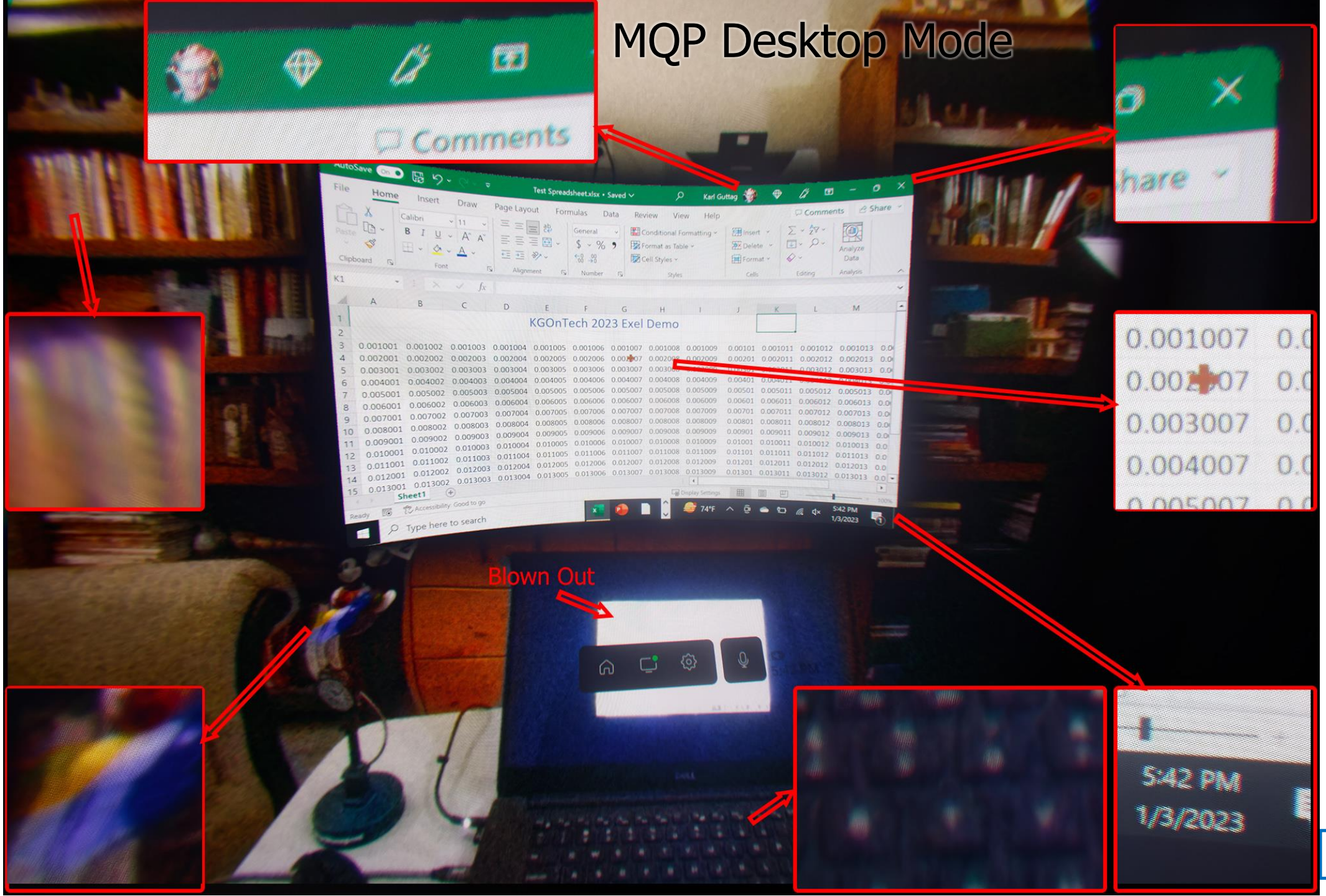




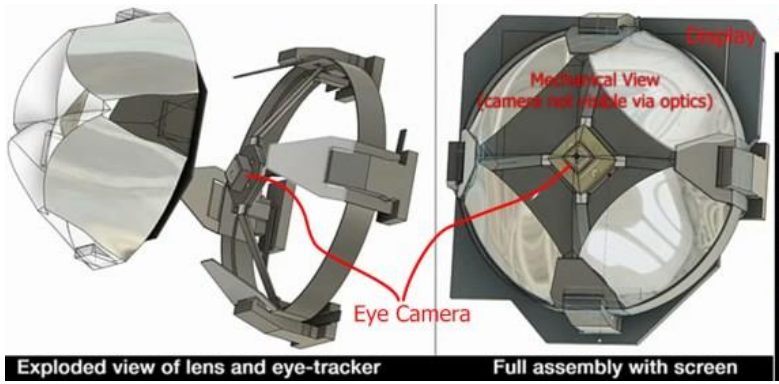
MQP

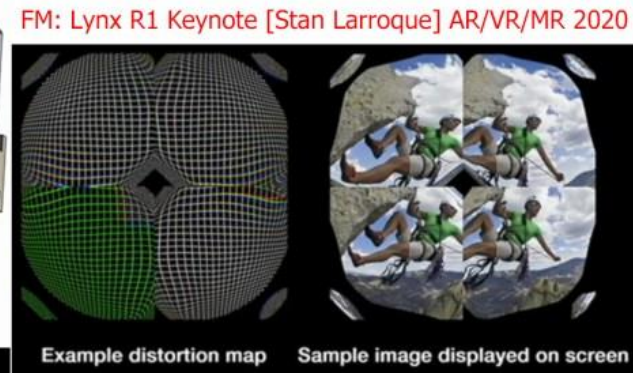
Snellen eye chart scaled 1/3 from 2m (1/3 of 6m)

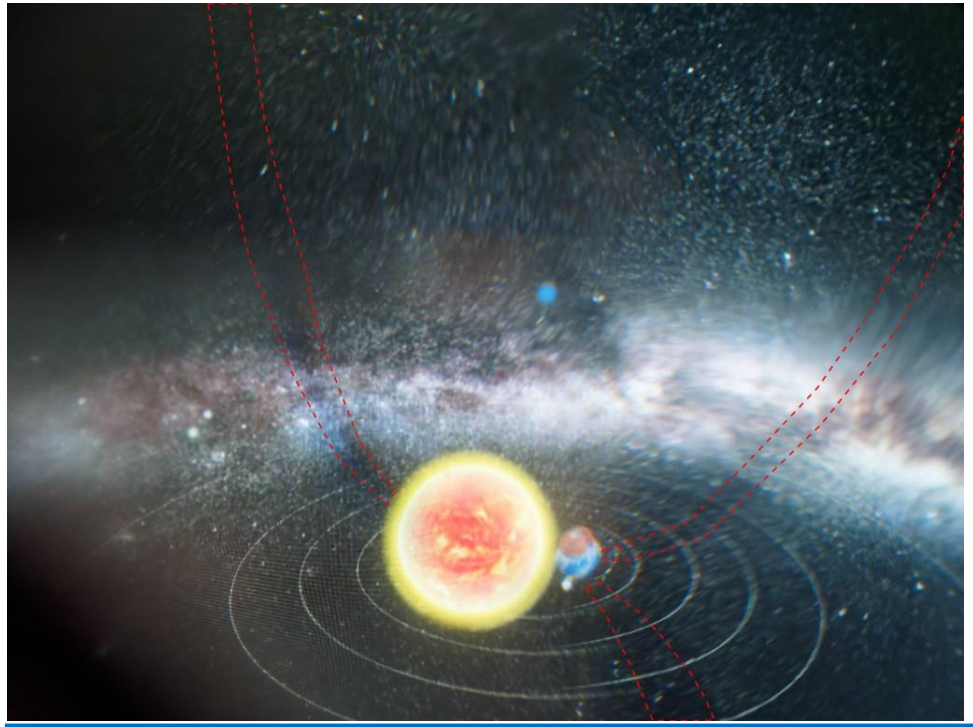
MQP Desktop Mode



Lynx Pass-Through AR with "Thin" Display







Apple (as Rumored by Gurman and Kuo) Will it be a sugar rush or go the distance?

- Kuo - "goal is to replace the iPhone with AR in 10 years"
  - Not possible – too many massive unsolved problems
- Apple does not appear to know the application
  - They are hoping developers will tell them (really?)
- Apple's technologist reluctant, but management is insistent
  - (really?) "Kicked out of the LAB by Management" – Management's put up or shut down of R&D - If true, almost always a disaster
- Separate compute module connected by cable (Yikes!)
  - Snag and/or disconnect hazard (reportedly magnetic)
- ~2x the linear resolution of the MQP or ~44 PPD
  - Not quite "retinal" 60 PPD, but close
- Talk of "**prescription inserts**") suggest small eye relief
  - Result of smaller pixels of a Sony Micro-OLED
- Expect high resolution cameras for passthrough
  - Will they adjust for the camera to eye misalignment?
  - Still single focus & occasional focus lag
- Likely will not solve vergence-accommodation conflict
- Variable AR/VR transparency
  - Useful, but does not solve all the safety issues
- Aimed at "pro" uses with limited battery life
  - Aimed at "Gamming, Media, and Communication"
- Expect sensors everywhere with lots of processing/AI
  - Hands, eyes, SLAM, world tracking (map/building data)
- Not "flip up"

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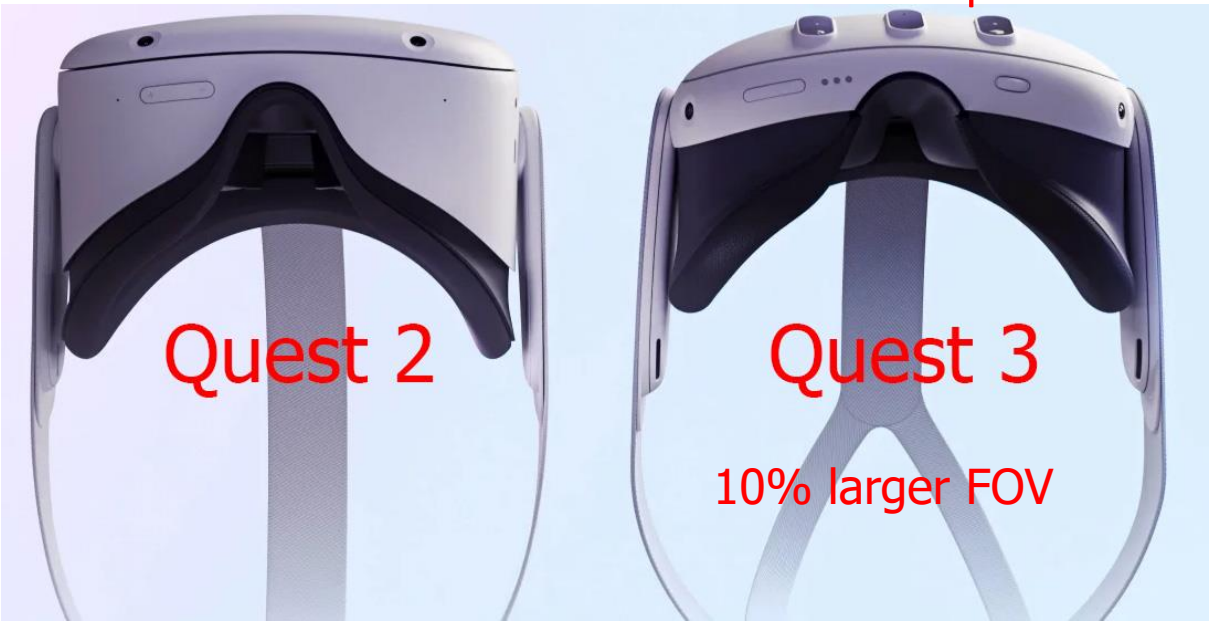
Quest 3 Announced (probably not a coincidence)

Two Full Color Cameras
Two IR cameras
Depth sensor in middle

Pancake Optics



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Apple Pro vs Meta Quest Pro

- I expect they will fix the obvious stuff
  - 4K x 4X displays with about 40 pixels/degree
    - But still not a computer monitor replacement
  - High res. color camera per eye for vastly better AR passthrough
  - Variable passthrough (no sure how important this will be)
  - Better tracking with may more cameras
  - More dynamic range (camera and display)
  - Long wearing comfort (issues with Meta Quest Pro)
- Some things expected to be worse
  - Not enough eye relief for glasses – requiring prescription inserts
  - Cost
- Many more cameras and sensors
- Will they address VAC and if so, how well will it work?

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Spending ~Billions Per Year Club

- Meta
  - Over 10,000 very smart people spending $12Billion/year
  - "In MR, if you can dream of it, Meta as tried it" – Karl Guttag
- Apple
  - Passthrough MR using Sony 4K/eye Micro-OLEDs"
- Microsoft – Retreated to the existing market of "enterprise"
- Snap – Seems to be trying to protect its supply chain
- Samsung – Microsoft deal and other investments
- Meta, Apple, and Snap are have "bought" one or more MicroLED companies
- All the big companies have invested heavily in waveguide technology

If all MR took was money and smart people, it would be here already
Apple, Meta, etc. can't buy different physics

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The End

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