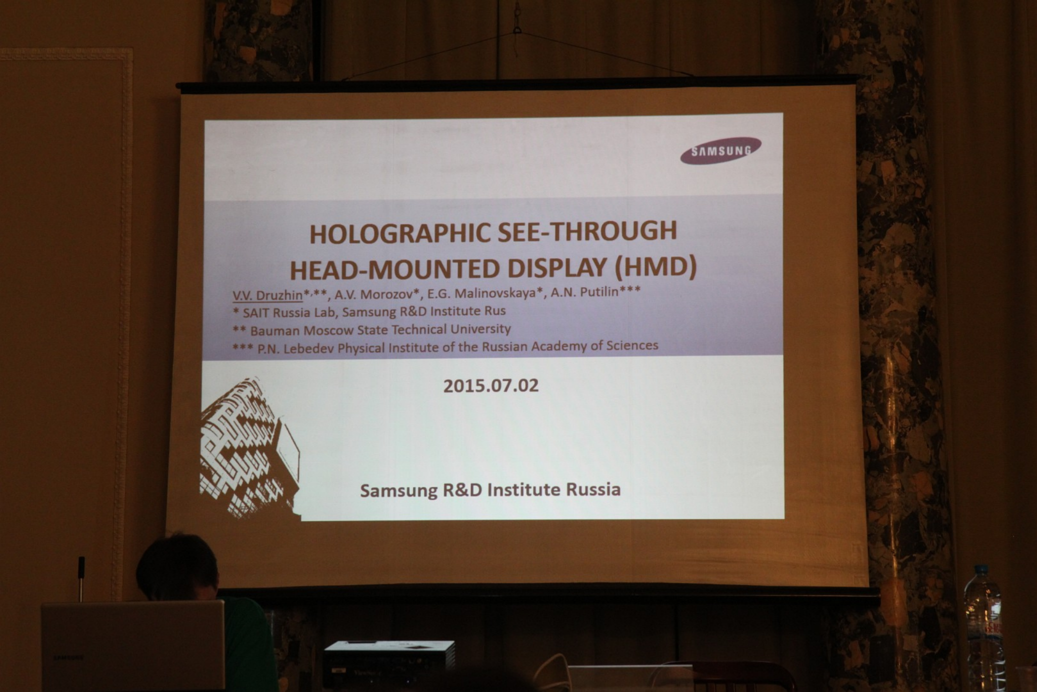

SAMSUNG
HOLOGRAPHIC SEE-THROUGH
HEAD-MOUNTED DISPLAY (HMD)
V.V. Druzhin*,**, A.V. Morozov*, E.G. Malinovskaya*, A.N. Putilin***
* SAIT Russia Lab, Samsung R&D Institute Rus
** Bauman Moscow State Technical University
*** P.N. Lebedev Physical Institute of the Russian Academy of Sciences
2015.07.02
Samsung R&D Institute Russia
САНКТ-ПЕТЕРБУРГ • ПУШКИН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HOLOGRAPHIC SEE-THROUGH
HEAD-MOUNTED DISPLAY (HMD)
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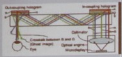
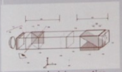
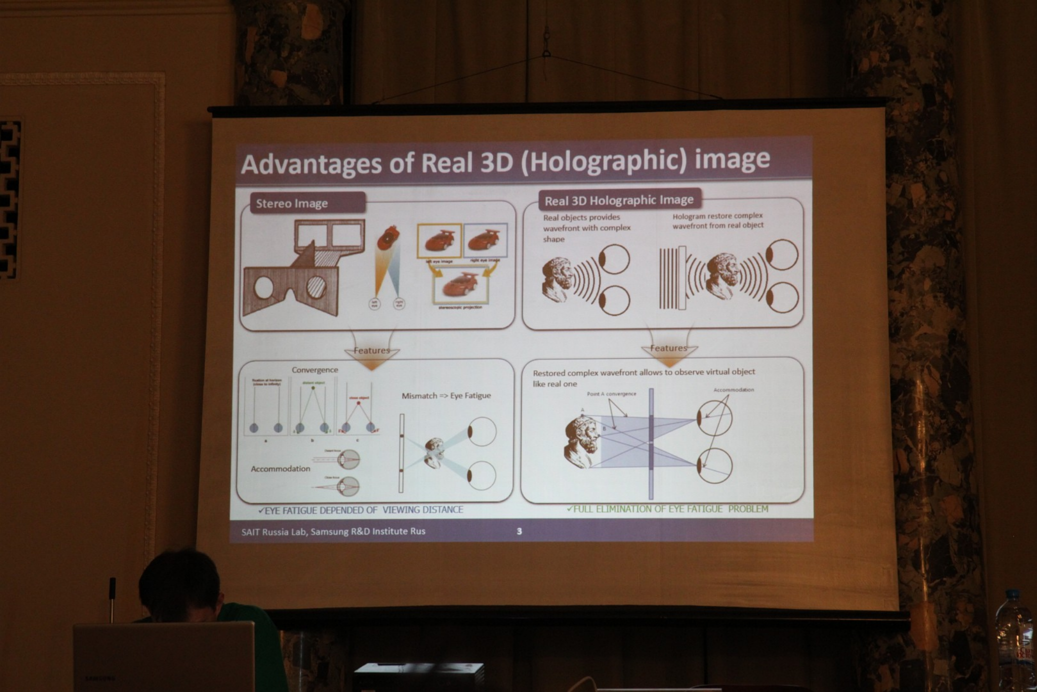
Wearable HMD

	Sony WGH Stereo Glasses	LumusOptical Engine Module OE-32	Fraunhofer IOF	Google glass
Optical System	 WGH based planar system	 Planar waveguides with see-through elements	 Free-form prism	 polarizing optics
Image Type	Stereo, 2D	Stereo, 2D	2D	2D
Display Type	 See-through	 See-through	 See-through	 See-through


Advantages of Real 3D (Holographic) image
Stereo Image
Real 3D Holographic Image
Real objects provides wavefront with complex shape
Hologram restore complex wavefront from real object
Features
Features
Convergence
Mismatch => Eye Fatigue
Accommodation
Restored complex wavefront allows to observe virtual object like real one
Point A convergence
Accommodation
✓EYE FATIGUE DEPENDED OF VIEWING DISTANCE
✓FULL ELIMINATION OF EYE FATIGUE PROBLEM
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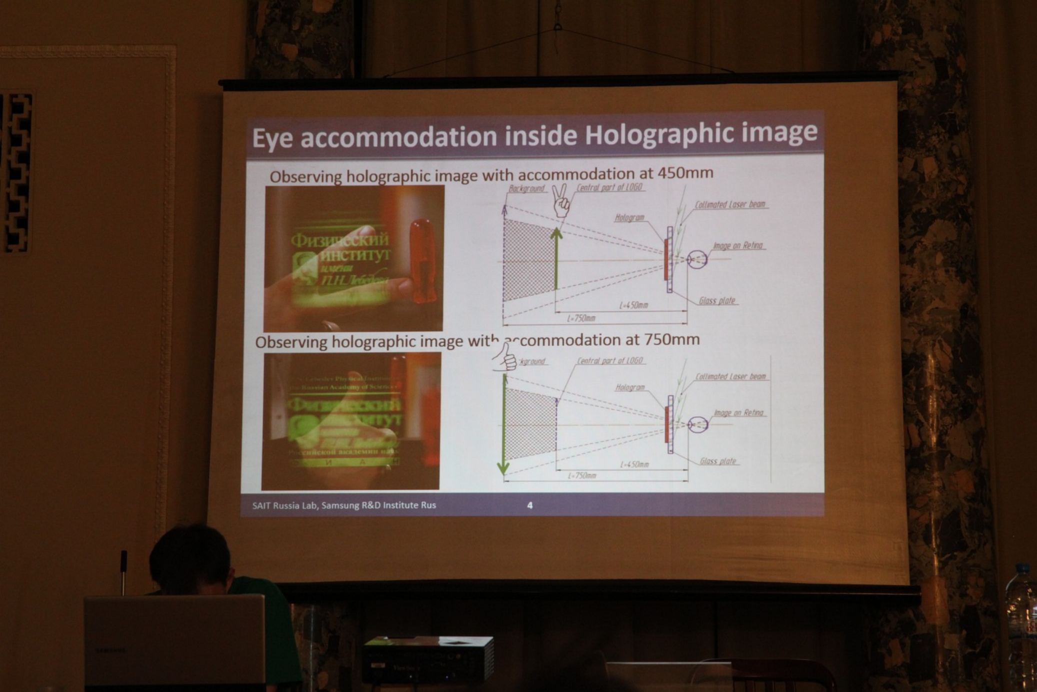
Eye accommodation inside Holographic image
Observing holographic image with accommodation at 450mm
Физический
институт
Background
Central part of LOGO
Collimated Laser beam
Hologram
Image on Retina
Glass plate
L=450mm
L=750mm
Observing holographic image wit
ccommodation at 750mm
Физический
институт
Central part of LOGO
Collimated Laser beam
Hologram
Image on Retina
Glass plate
L=450mm
L=750mm
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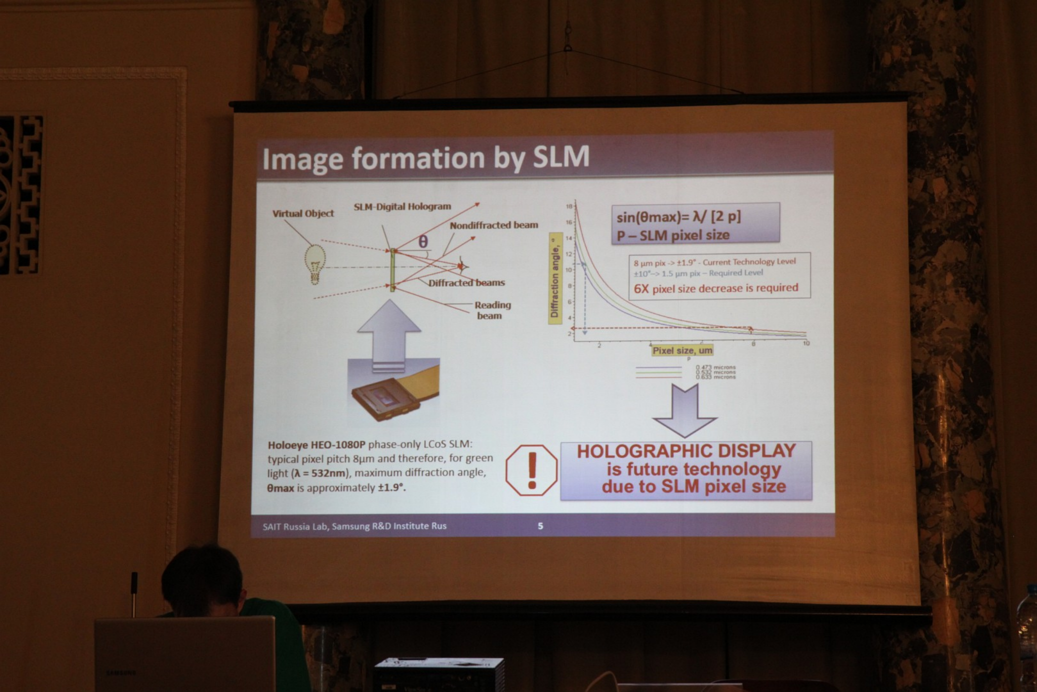

Image formation by SLM
Virtual Object
SLM-Digital Hologram
Nondiffracted beam
θ
Diffracted beams
Reading beam
sin(θmax)= λ/ [2 p]
P – SLM pixel size
8 µm pix -> ±1.9° - Current Technology Level
±10°–> 1.5 µm pix – Required Level
6X pixel size decrease is required
Diffraction angle, °
Pixel size, um
0.473 microns
0.532 microns
0.633 microns
Holoeye HEO-1080P phase-only LCoS SLM: typical pixel pitch 8µm and therefore, for green light (λ = 532nm), maximum diffraction angle, θmax is approximately ±1.9°.
HOLOGRAPHIC DISPLAY is future technology due to SLM pixel size
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Calculation of Viewing Angle

Phase SLM from HoloEye: LCoS PLUTO

Pixel pitch p = 8 µm
Wave-length λ=0,532 µm
Illumination angle i_x=60°, i_y=0°
Diffracted angle δ_x, δ_y

$$d = 2p$$

$$d(\sin i + \sin \delta) = \lambda \qquad (1)$$

$$2\theta = \delta + i \qquad (2)$$

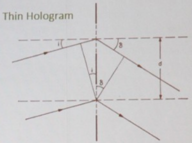
$$(1) \rightarrow \delta = arc\sin\left(\frac{\lambda}{d} - \sin i\right) \qquad (3)$$

$$(2,3) \rightarrow \theta = 0{,}5\{\delta - i\} = 0{,}5\left\{arc\sin\left(\frac{\lambda}{d} - \sin i\right) + i\right\}$$

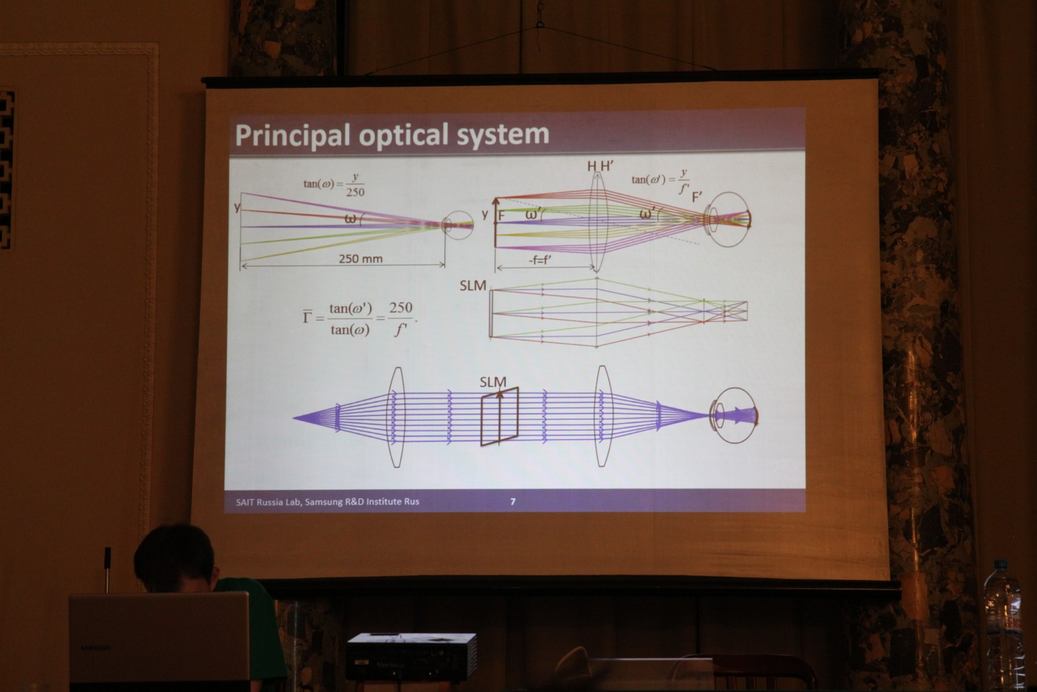
$$2\theta_x = 0{,}5\left\{arc\sin\left(\frac{0{,}532\mu m}{2 \cdot 8\mu m} - \sin 60°\right) + 60°\right\} = 3{,}6°$$

$$2\theta_y = 0{,}5\left\{arc\sin\left(\frac{0{,}532\mu m}{2 \cdot 8\mu m} - \sin 0°\right) + 0°\right\} = 1{,}9°$$

Thin Hologram



$2\theta_x = 3{,}6°$
$2\theta_y = 1{,}9°$
$2\theta_{diag} = 4{,}0°$


Principal optical system
tan(ω) = y/250
y
ω
250 mm
H H'
tan(ω') = y/f'
F'
y
F
ω'
ω'
-f=f'
SLM
Γ = tan(ω')/tan(ω) = 250/f'.
SLM
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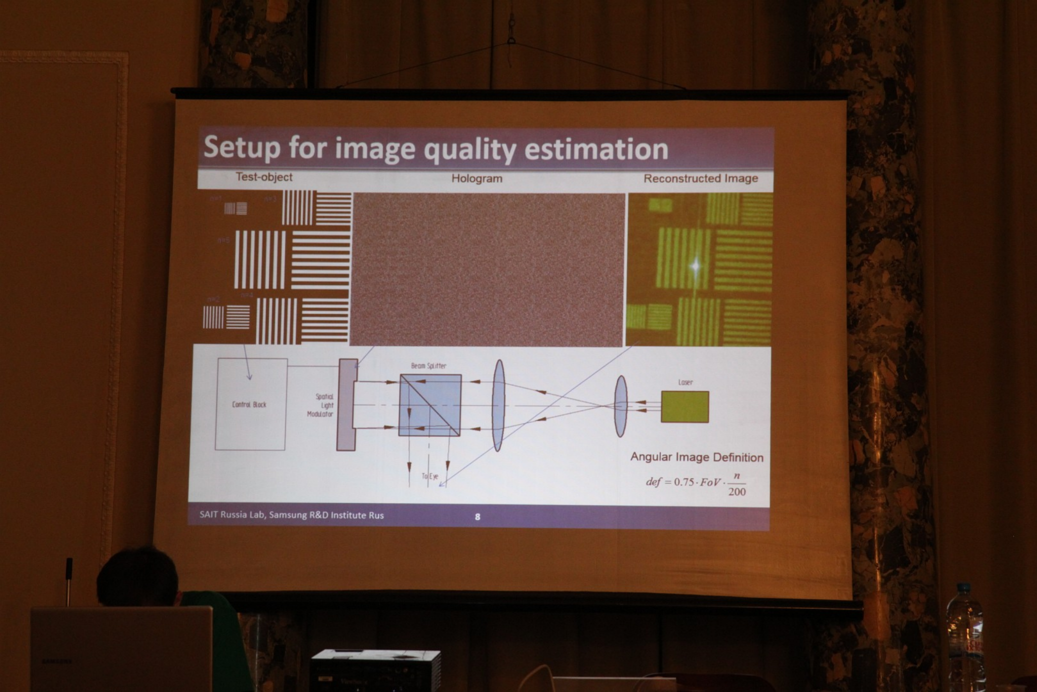
Setup for image quality estimation
Test-object
Hologram
Reconstructed Image
Beam Splitter
Laser
Control Block
Spatial Light Modulator
To Eye
Angular Image Definition
$def = 0.75 \cdot FoV \cdot \frac{n}{200}$
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Setup for image quality estimation
0°
45°
50°
60°
70°
FoV
Theoretical FoV 3.81° Experimental FoV 3.8°±0.2°
Theoretical FoV 5.16° Experimental FoV 5.0°±0.2°
Theoretical FoV 5.61° Experimental FoV 5.5°±0.2°
Theoretical FoV 6.91° Experimental FoV 7.1°±0.2°
Theoretical FoV 9.16° Experimental FoV 9.1°±0.2°
Image Quality, Angular Definition
1'
1'
1,3'
1,5'
5'
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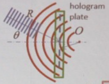
Operation Principles of Holographic optical Elements (HOE)

Object wave: $O = a_O \exp\left(-ik\frac{r^2}{2f}\right)$ Reference wave: $R = a_R \exp(-ik\sin(\theta)r)$

The interference of two waves is declare as: $I = (O+R)\cdot(O+R)^* = O\cdot O^* + R\cdot R^* + O\cdot R^* + O^*\cdot R$

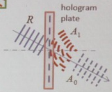
Recorded Hologram:

$$I_{recording} = a_O^2 + a_R^2 + a_O \exp\left(-ik\frac{r^2}{2f}\right)\cdot a_R \exp(ik\sin(\theta)r) + a_O \exp\left(ik\frac{r^2}{2f}\right)\cdot a_R \exp(-ik\sin(\theta)r)$$



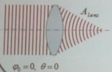
Reconstructed Hologram:

$$I_{reconstructed} = I_{recording}\cdot R = \underbrace{(a_O^2 + a_R^2)\cdot a_R \exp(-ik\sin(\theta)r)}_{A_0} + \underbrace{a_O \exp\left(-ik\frac{r^2}{2f}\right)\cdot a_R \exp(ik\sin(\theta)r)\cdot a_R \exp(-ik\sin(\theta)r)}_{A_1} + \dots$$



$$A_1 = a_O \exp\left(-ik\frac{r^2}{2f}\right)\cdot a_R \cdot a_R$$

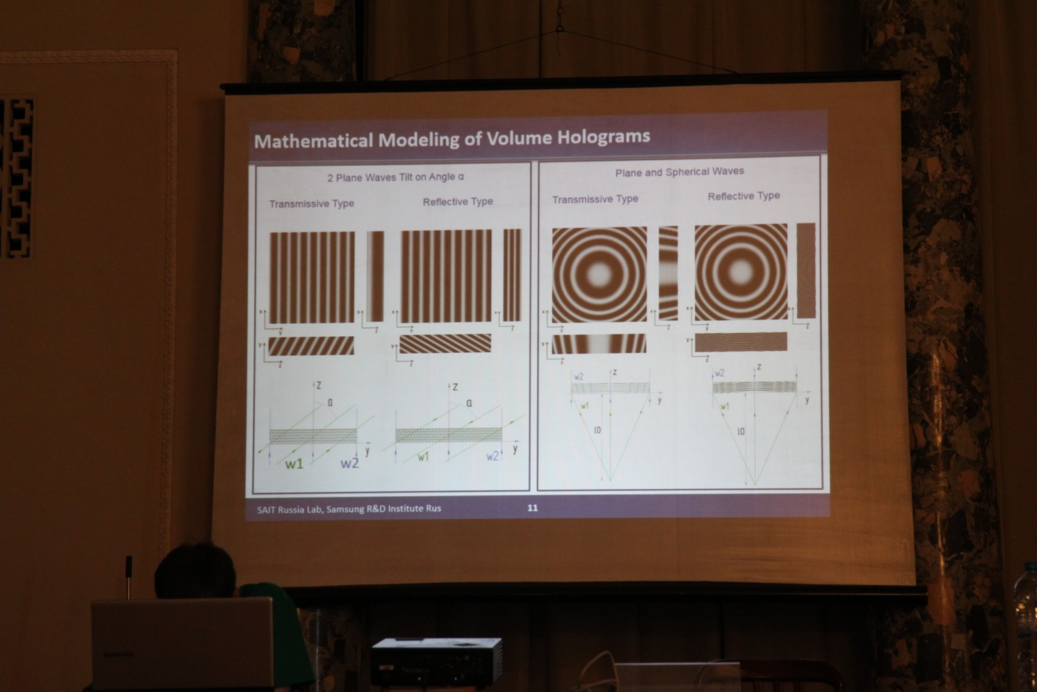
Conventional Lens:



$$A_{lens} = a_0 \exp\left(i\varphi_0 - ik\left(\frac{r^2}{2f}\right)\right)$$

$$A_1 = A_{lens}$$

$\varphi_0 = 0,\ \theta = 0$


Mathematical Modeling of Volume Holograms
2 Plane Waves Tilt on Angle α
Transmissive Type
Reflective Type
Plane and Spherical Waves
Transmissive Type
Reflective Type
w1
w2
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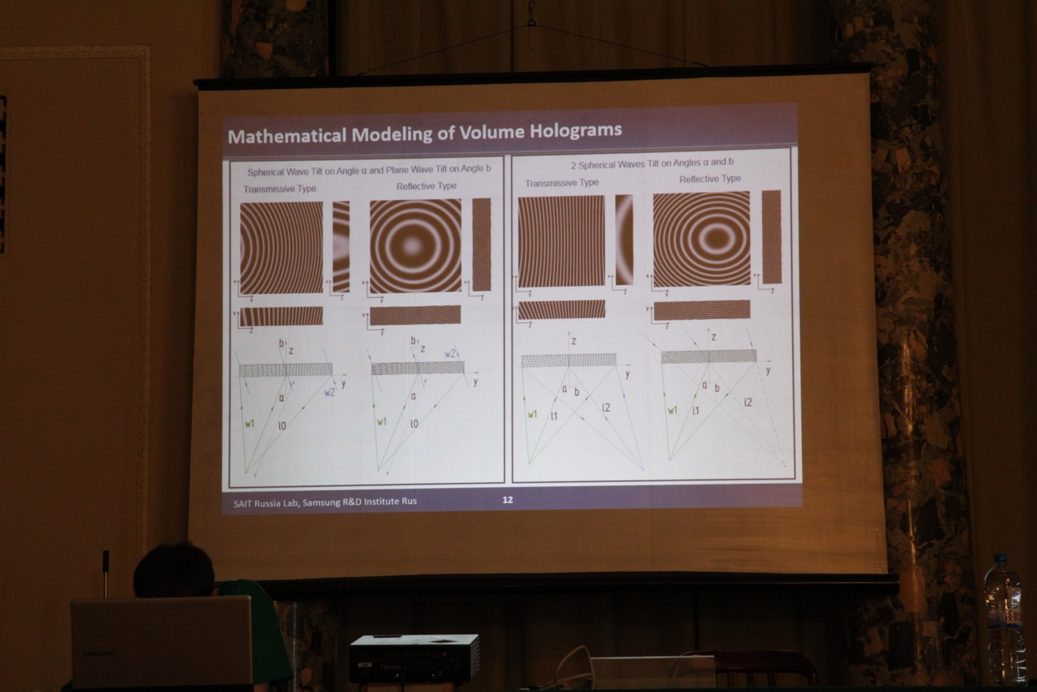
Mathematical Modeling of Volume Holograms
Spherical Wave Tilt on Angle α and Plane Wave Tilt on Angle b
Transmissive Type
Reflective Type
2 Spherical Waves Tilt on Angles α and b
Transmissive Type
Reflective Type
b
z
y
w1
w2
α
l0
l1
l2
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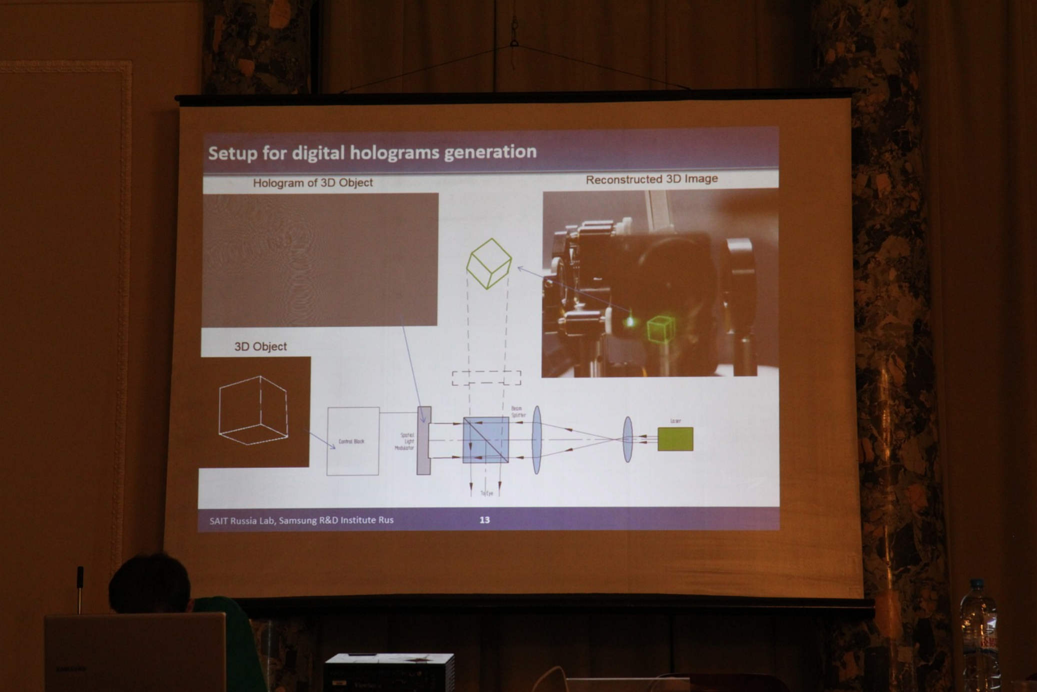
Setup for digital holograms generation
Hologram of 3D Object
Reconstructed 3D Image
3D Object
Control Block
Spatial Light Modulator
Beam Splitter
Laser
To Eye
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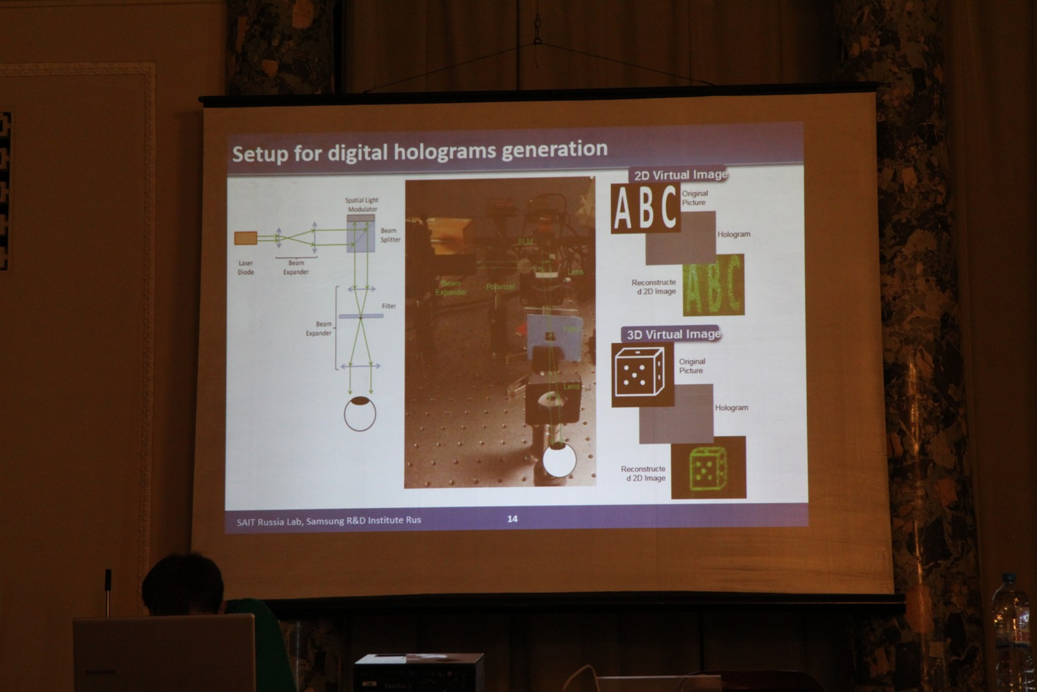
Setup for digital holograms generation
Spatial Light Modulator
Beam Splitter
Laser Diode
Beam Expander
Filter
Beam Expander
SLM
Lens
Beam Expander
Polarizer
Lens
2D Virtual Image
ABC
Original Picture
Hologram
Reconstructe d 2D Image
3D Virtual Image
Original Picture
Hologram
Reconstructe d 2D Image
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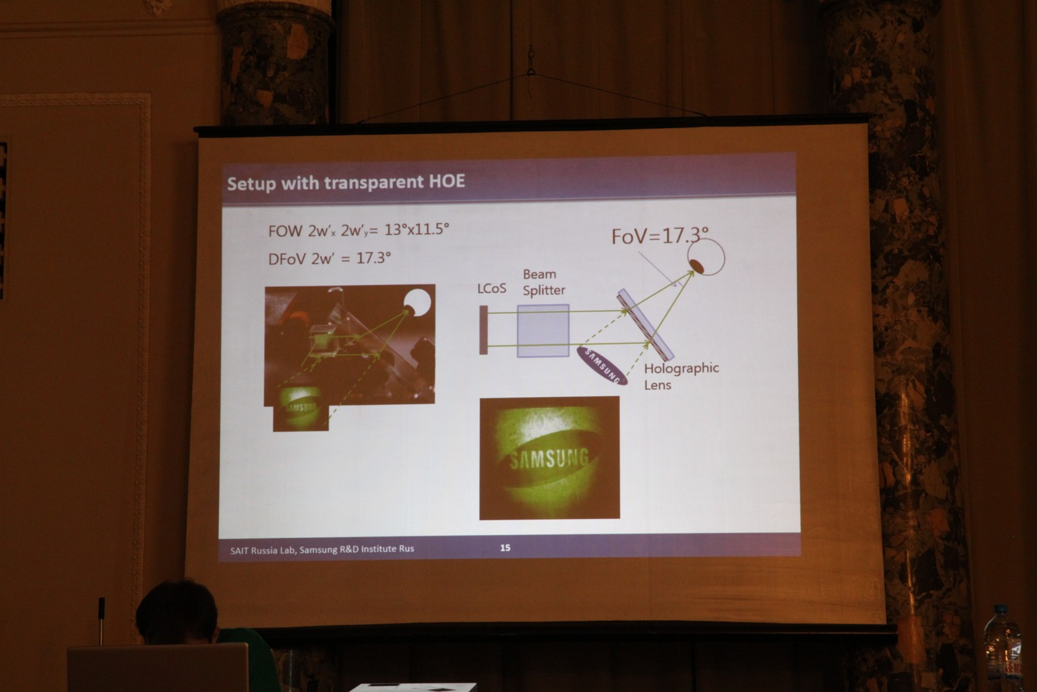
Setup with transparent HOE
FOW 2w'x 2w'y= 13°x11.5°
DFoV 2w' = 17.3°
FoV=17.3°
LCoS
Beam
Splitter
Holographic
Lens
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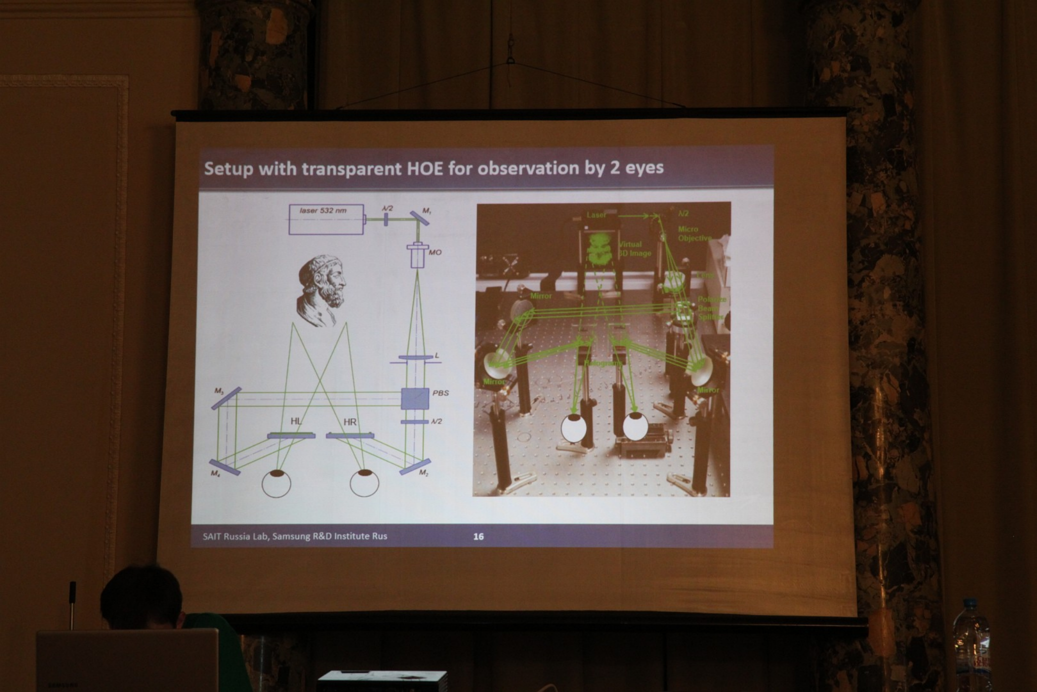
Setup with transparent HOE for observation by 2 eyes
laser 532 nm
λ/2
M1
MO
L
PBS
λ/2
M3
M4
M2
HL
HR
Laser
λ/2
Micro
Objective
Virtual
3D Image
Mirror
Mirror
Mirror
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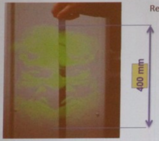
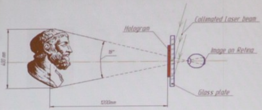
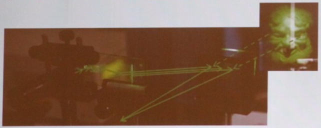
Setup with hologram illumination by lightguide

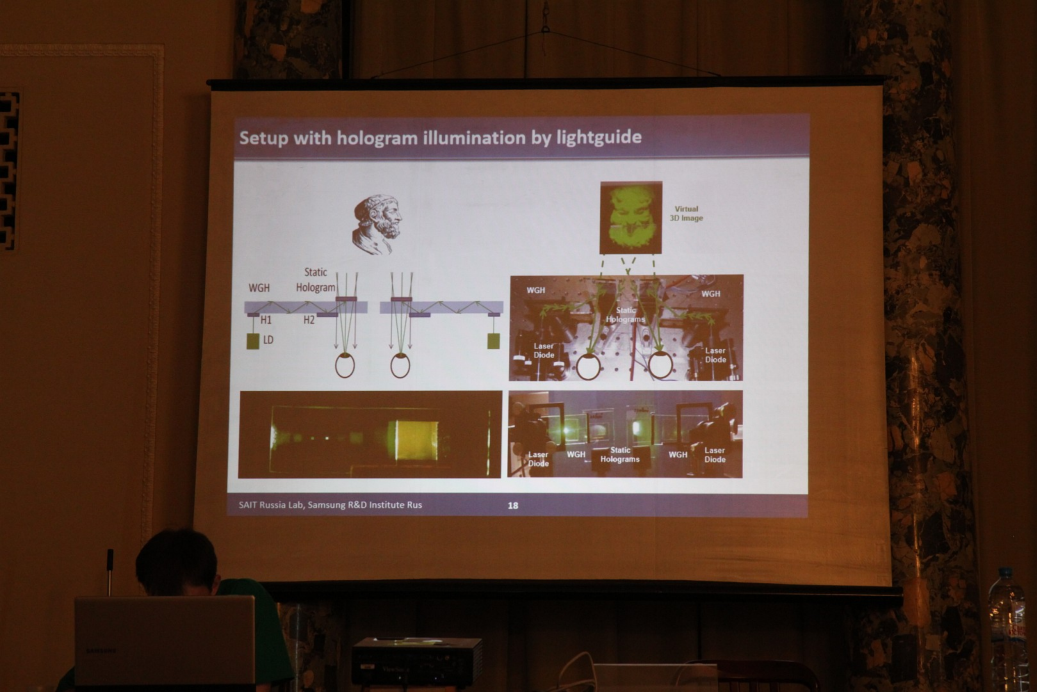


Reconstructed holographic virtual image with accommodation at 1200mm



Viewing angle of reconstructed virtual image is about 18°, linear field: 15″ at 1200 mm




Setup with hologram illumination by lightguide
Virtual
3D Image
Static
Hologram
WGH
H1
H2
LD
WGH
WGH
Static
Holograms
Laser
Diode
Laser
Diode
Laser
Diode
WGH
Static
Holograms
WGH
Laser
Diode
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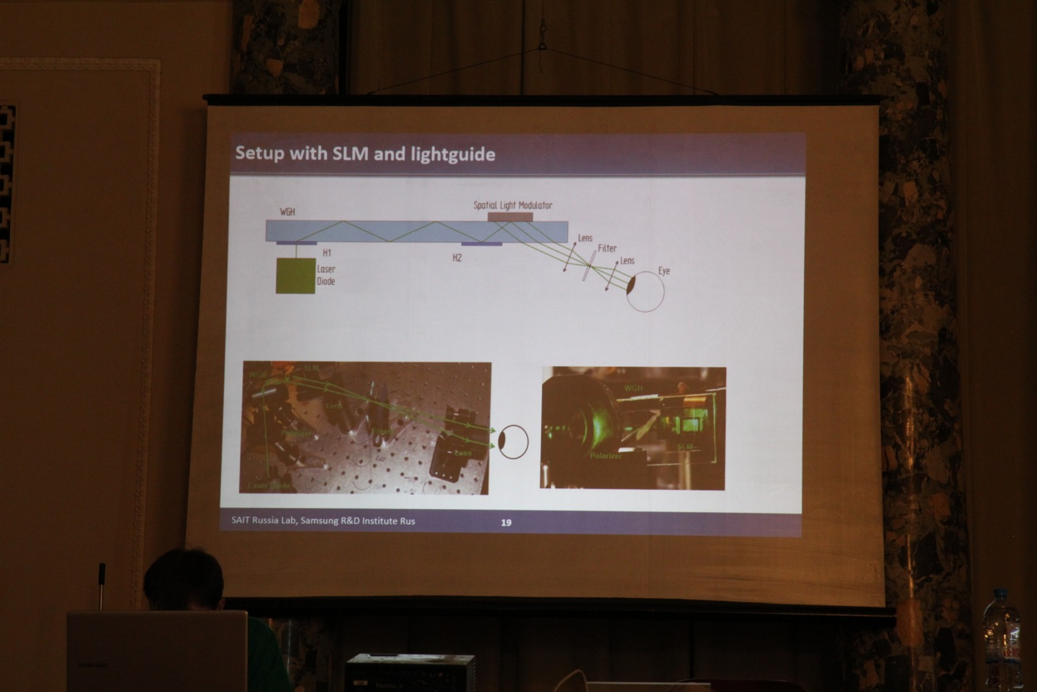
Setup with SLM and lightguide
Spatial Light Modulator
WGH
H1
H2
Laser
Diode
Lens
Filter
Lens
Eye
WGH
SLM
Lens
Polarizer
Filter
Lens
Laser Diode
WGH
Polarizer
SLM
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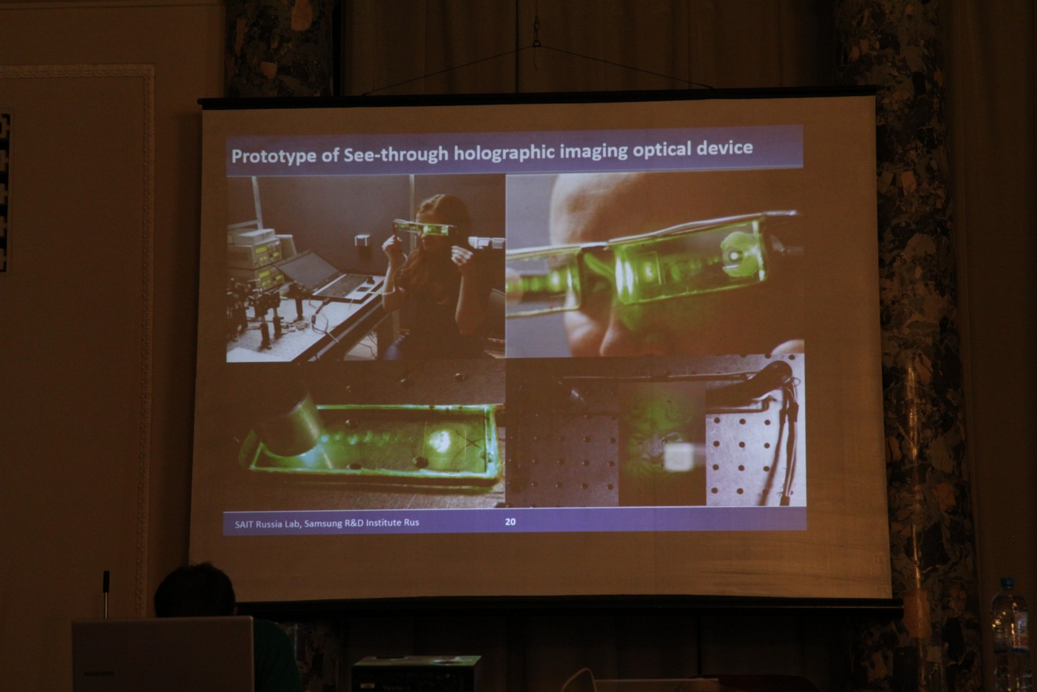
Prototype of See-through holographic imaging optical device
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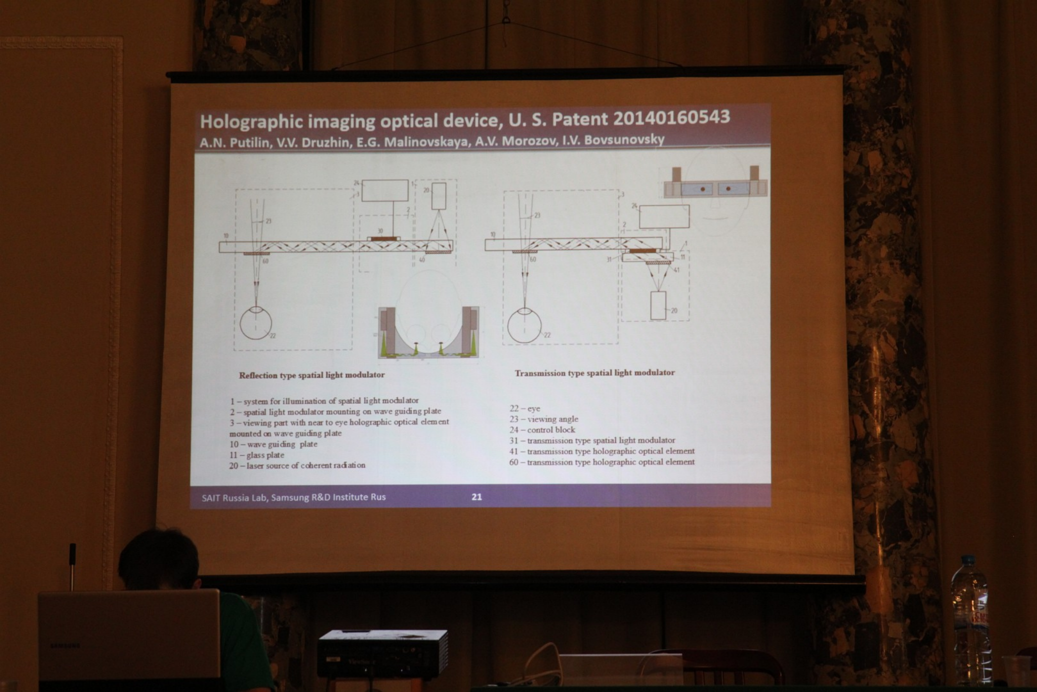
Holographic imaging optical device, U. S. Patent 20140160543
A.N. Putilin, V.V. Druzhin, E.G. Malinovskaya, A.V. Morozov, I.V. Bovsunovsky
Reflection type spatial light modulator
Transmission type spatial light modulator
1 – system for illumination of spatial light modulator
2 – spatial light modulator mounting on wave guiding plate
3 – viewing part with near to eye holographic optical element mounted on wave guiding plate
10 – wave guiding plate
11 – glass plate
20 – laser source of coherent radiation
22 – eye
23 – viewing angle
24 – control block
31 – transmission type spatial light modulator
41 – transmission type holographic optical element
60 – transmission type holographic optical element
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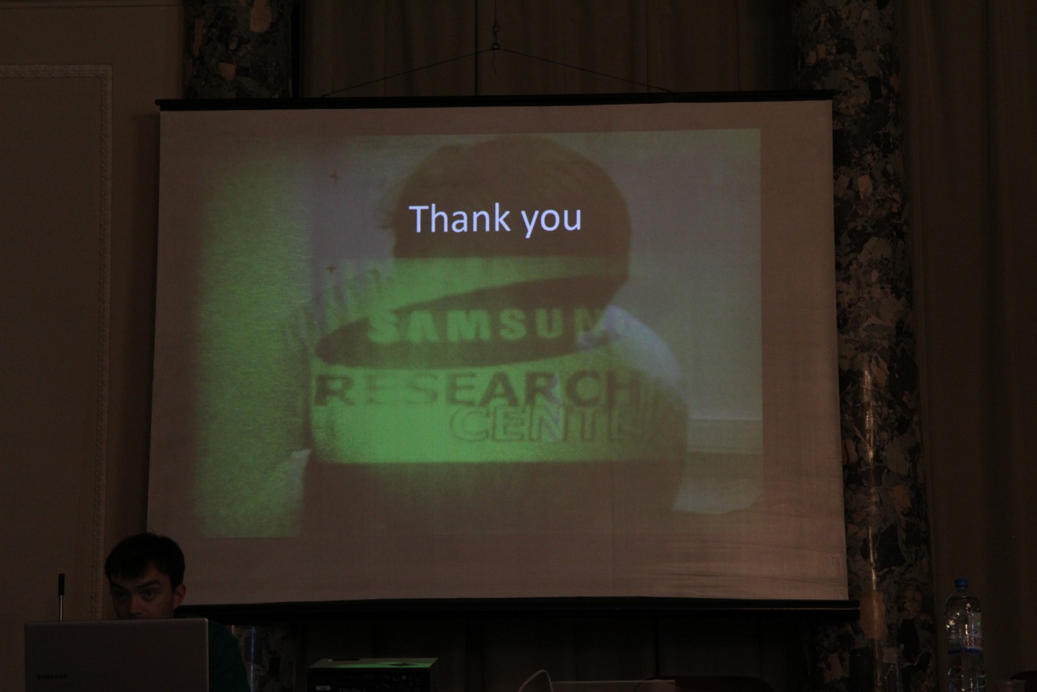
Thank you