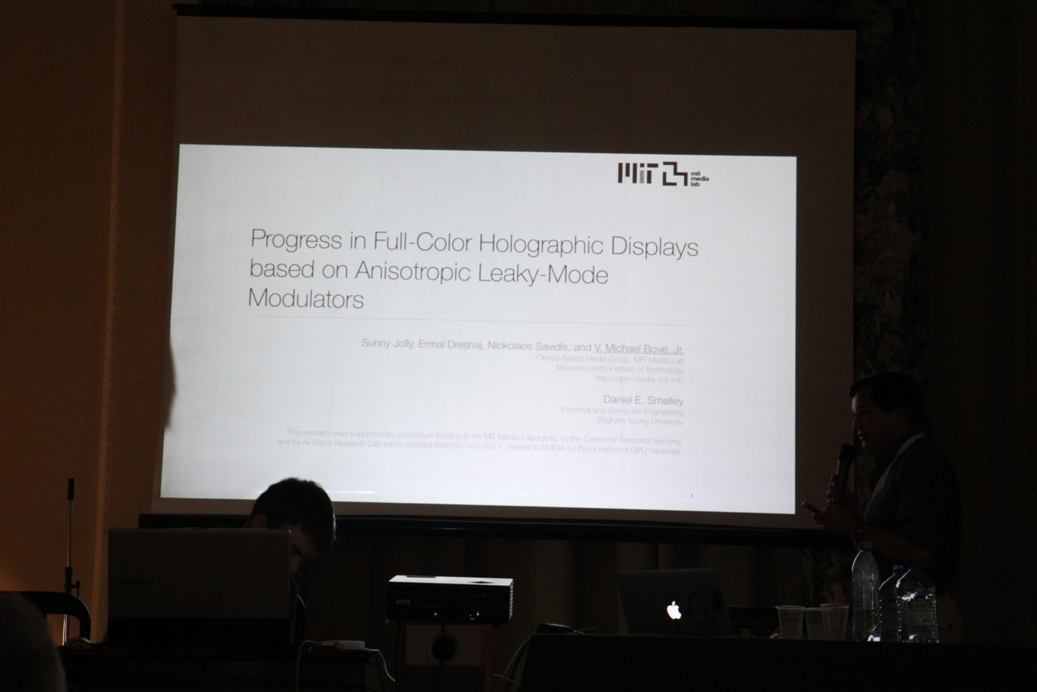
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Progress in Full-Color Holographic Displays based on Anisotropic Leaky-Mode Modulators
Sunny Jolly, Ermal Dreshaj, Nickolaos Savidis, and V. Michael Bove, Jr.
Object-Based Media Group, MIT Media Lab
Massachusetts Institute of Technology
http://obm.media.mit.edu
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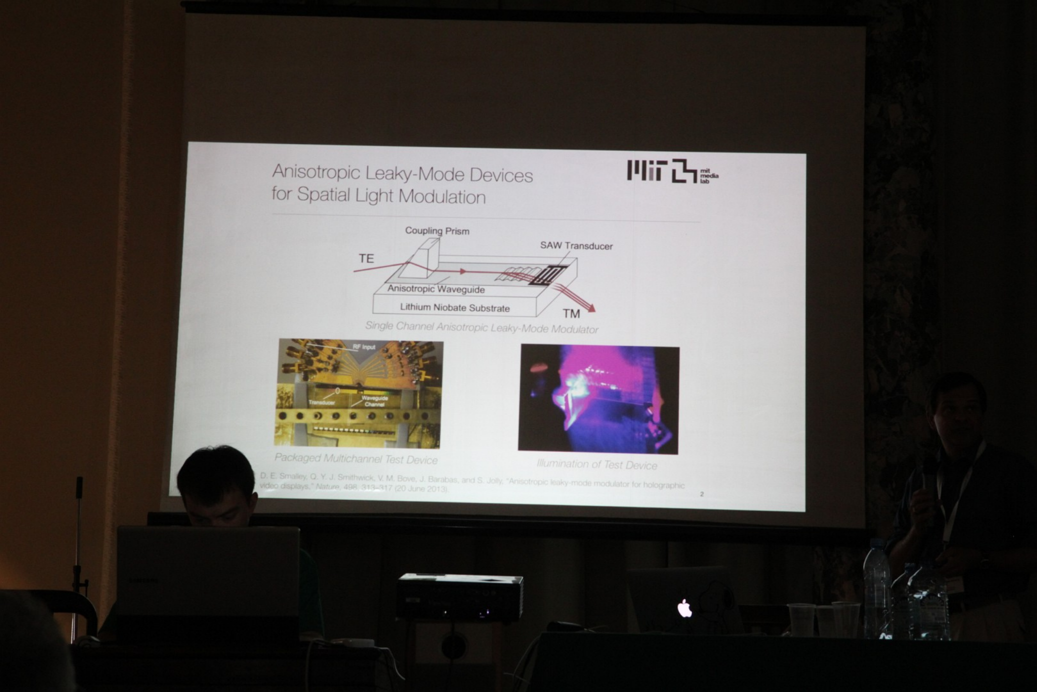
Electrical and Computer Engineering
Brigham Young University
This research was supported by consortium funding at the MIT Media Laboratory, by the Center for Terrestrial Sensing, and by Air Force Research Laboratory contract FA8650-14-C-6571. Thanks to NVIDIA for the donation of GPU hardware.
1


Anisotropic Leaky-Mode Devices
for Spatial Light Modulation
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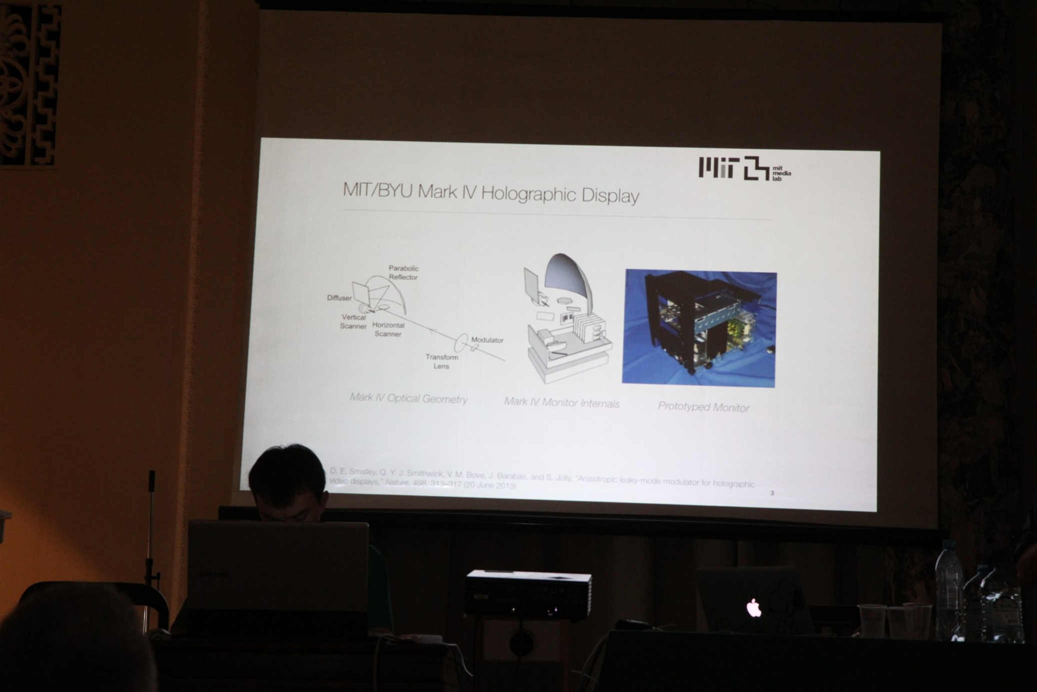
Coupling Prism
SAW Transducer
TE
Anisotropic Waveguide
Lithium Niobate Substrate
TM
Single Channel Anisotropic Leaky-Mode Modulator
RF Input
Transducer
Waveguide Channel
Packaged Multichannel Test Device
Illumination of Test Device
D. E. Smalley, Q. Y. J. Smithwick, V. M. Bove, J. Barabas, and S. Jolly, "Anisotropic leaky-mode modulator for holographic video displays," Nature, 498, 313–317 (20 June 2013).
2



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MIT/BYU Mark IV Holographic Display
Parabolic Reflector
Diffuser
Vertical Scanner
Horizontal Scanner
Modulator
Transform Lens
Mark IV Optical Geometry
Mark IV Monitor Internals
Prototyped Monitor
D. E. Smalley, Q. Y. J. Smithwick, V. M. Bove, J. Barabas, and S. Jolly, "Anisotropic leaky-mode modulator for holographic video displays," Nature, 498, 313–317 (20 June 2013).
3


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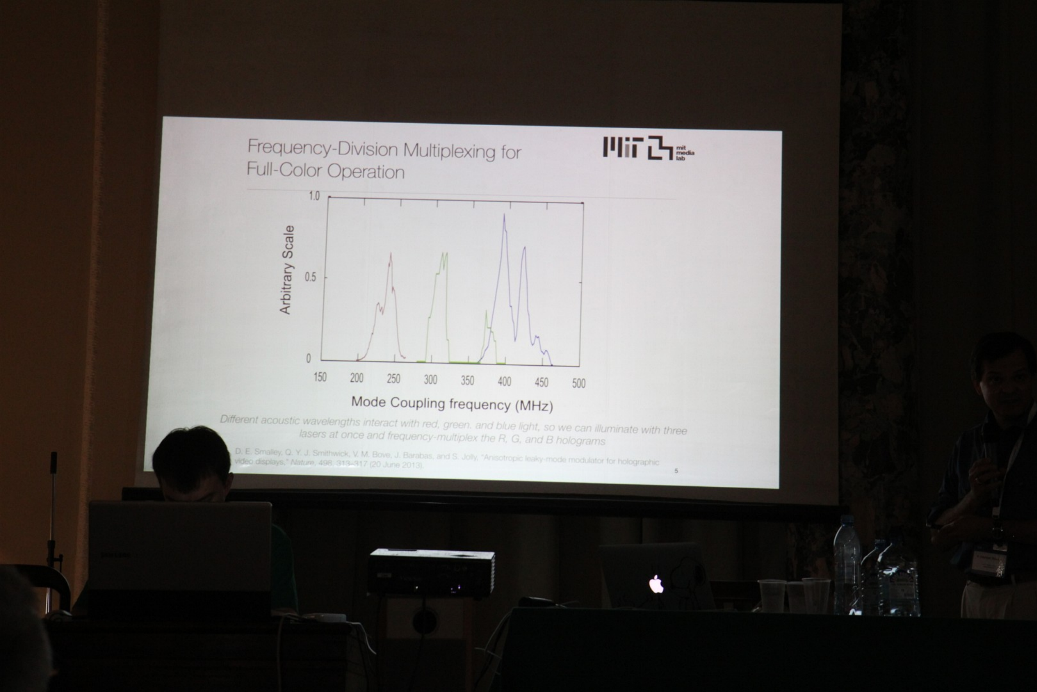
MIT/BYU Mark IV Holographic Display
D. E. Smalley, Q. Y. J. Smithwick, V. M. Bove, J. Barabas, and S. Jolly, "Anisotropic leaky-mode modulator for holographic video displays," Nature, 498, 313–317 (20 June 2013).
4


Frequency-Division Multiplexing for Full-Color Operation
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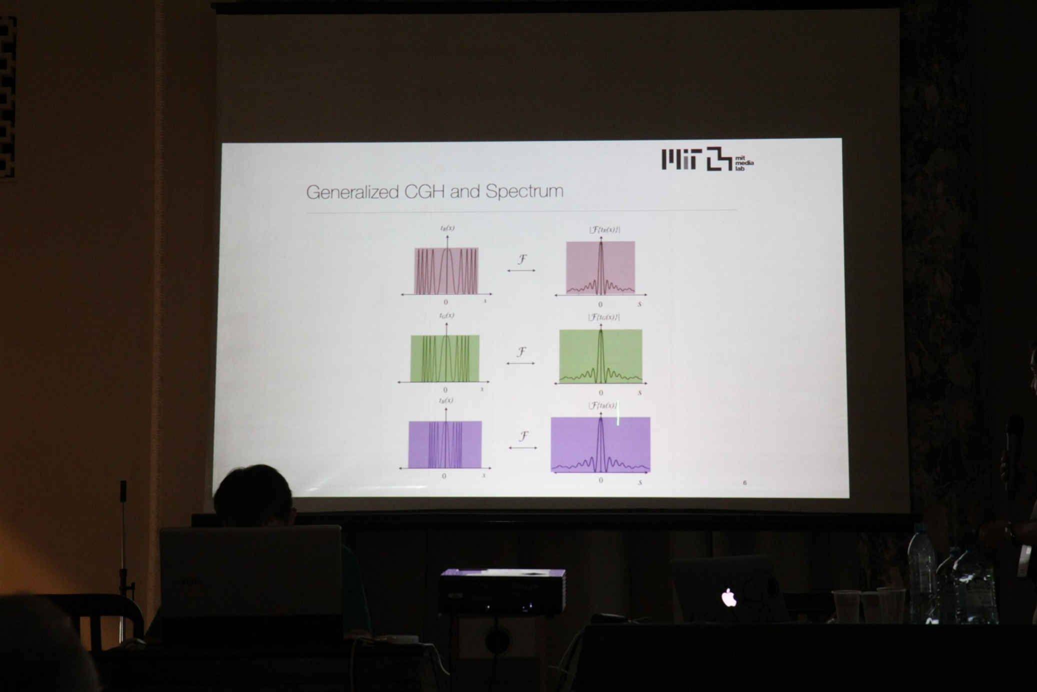
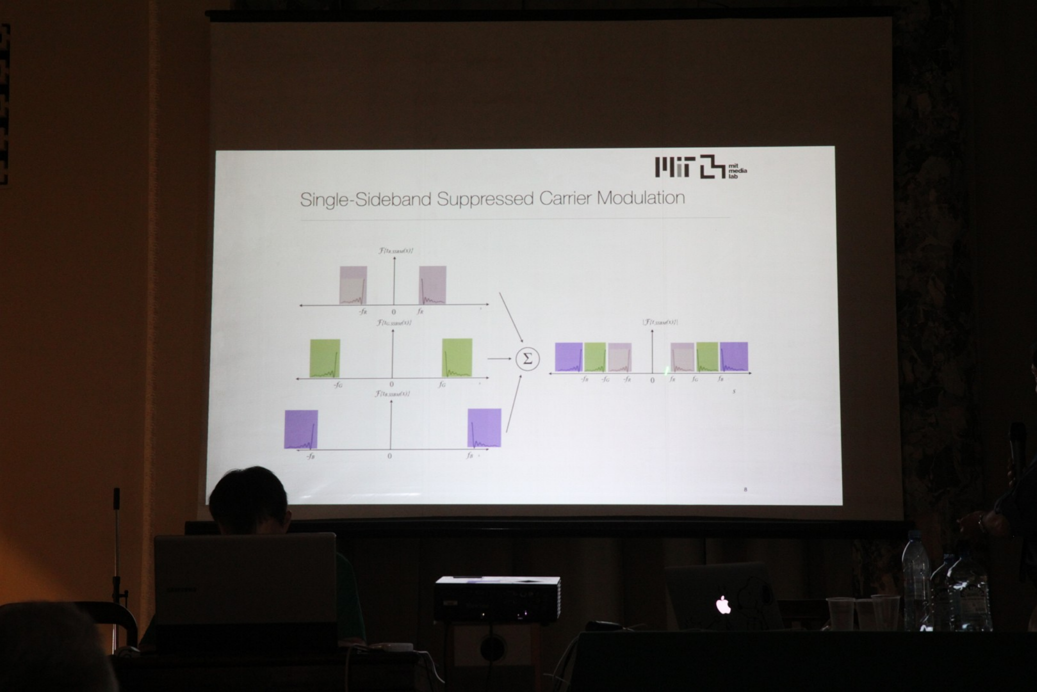
1.0
0.5
0
Arbitrary Scale
150
200
250
300
350
400
450
500
Mode Coupling frequency (MHz)
Different acoustic wavelengths interact with red, green. and blue light, so we can illuminate with three lasers at once and frequency-multiplex the R, G, and B holograms
D. E. Smalley, Q. Y. J. Smithwick, V. M. Bove, J. Barabas, and S. Jolly, "Anisotropic leaky-mode modulator for holographic video displays," Nature, 498, 313–317 (20 June 2013).
5


Generalized CGH and Spectrum
$t_R(x)$
$|\mathcal{F}\{t_R(x)\}|$
$\mathcal{F}$
0
x
0
s
$t_G(x)$
$|\mathcal{F}\{t_G(x)\}|$
$\mathcal{F}$
0
x
0
s
$t_B(x)$
$|\mathcal{F}\{t_B(x)\}|$
$\mathcal{F}$
0
x
0
s
6

mit media lab
Single-Sideband Suppressed Carrier Modulation
SSB
SSB
SSB
0
x


mit
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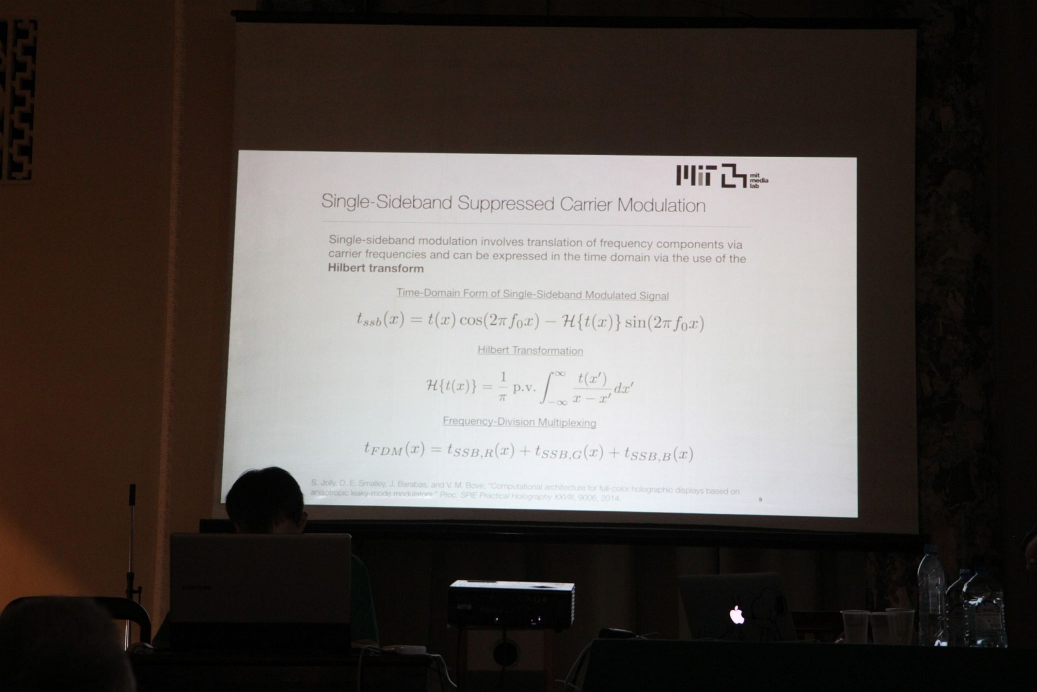
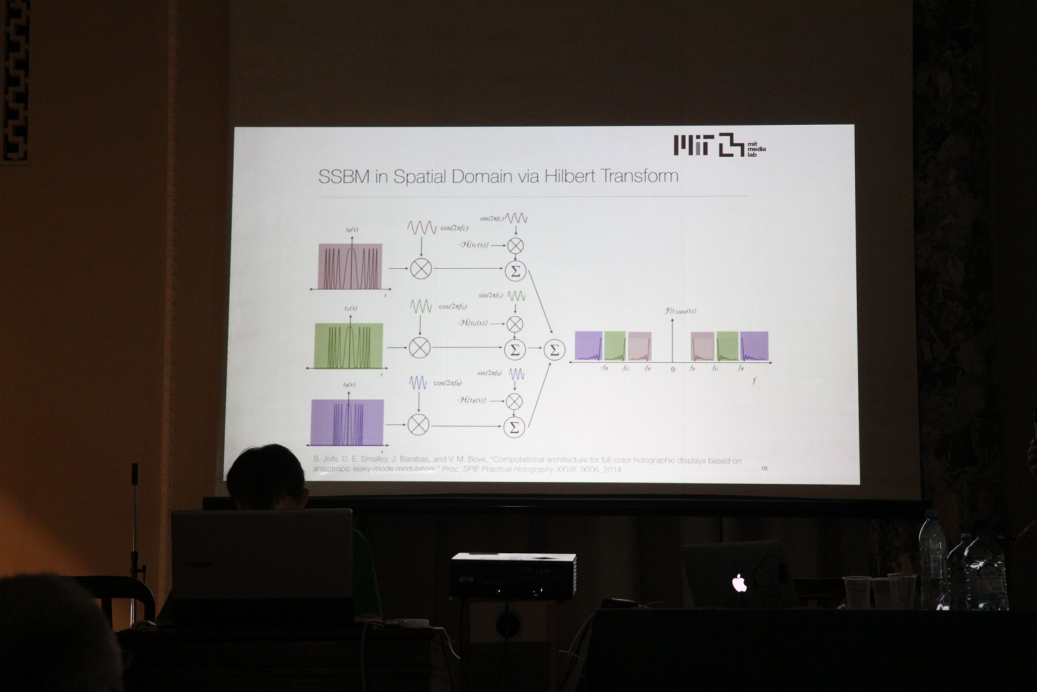
lab
Single-Sideband Suppressed Carrier Modulation
Σ
8


mit media lab
Single-Sideband Suppressed Carrier Modulation
Single-sideband modulation involves translation of frequency components via carrier frequencies and can be expressed in the time domain via the use of the **Hilbert transform**
Time-Domain Form of Single-Sideband Modulated Signal
$t_{ssb}(x) = t(x)\cos(2\pi f_0 x) - \mathcal{H}\{t(x)\}\sin(2\pi f_0 x)$
Hilbert Transformation
$\mathcal{H}\{t(x)\} = \frac{1}{\pi}\,\mathrm{p.v.}\int_{-\infty}^{\infty}\frac{t(x')}{x - x'}dx'$
Frequency-Division Multiplexing
$t_{FDM}(x) = t_{SSB,R}(x) + t_{SSB,G}(x) + t_{SSB,B}(x)$
S. Jolly, D. E. Smalley, J. Barabas, and V. M. Bove, "Computational architecture for full-color holographic displays based on anisotropic leaky-mode modulators," *Proc. SPIE Practical Holography XXVIII*, 9006, 2014.
9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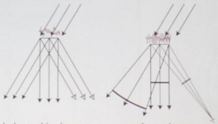
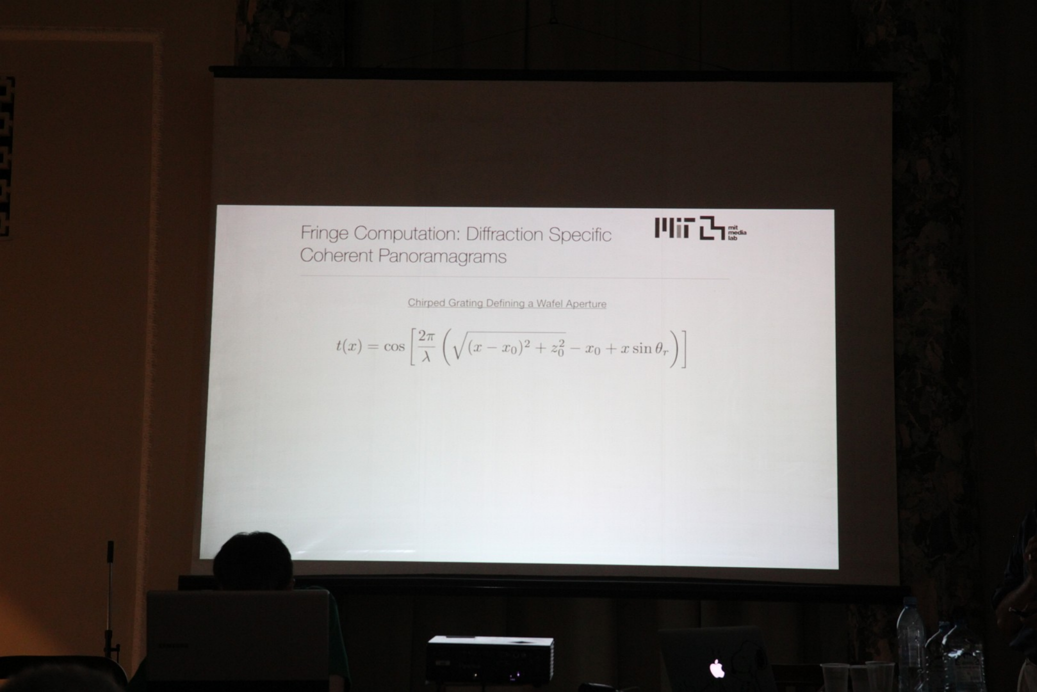
SSBM in Spatial Domain via Hilbert Transform
cos(2πf_C)
sin(2πf_C)
cos(2πf_G)
sin(2πf_G)
cos(2πf_B)
sin(2πf_B)
Σ
0
f
S. Jolly, D. E. Smalley, J. Barabas, and V. M. Bove, "Computational architecture for full-color holographic displays based on anisotropic leaky-mode modulators," Proc. SPIE Practical Holography XXVIII, 9006, 2014.
10

# Fringe Computation: Diffraction Specific Coherent Panoramagrams

- The DSC Panoramagram is a diffraction-specific approach to real-time holographic stereogram generation that provides correct visual accommodation cues and smooth motion parallax
- Wafel approach allows for controllable intensities at desired directions (wavefront control) rather than the approximation of wavefront control via plane wave superposition
- Needs a relatively small number of views (1/2 to 2 per degree of view angle) to provide smooth motion parallax
- Requires a depth map for the image data
- Converges to Fresnel hologram in the limit of large number of views




Q. Y. J. Smithwick, J. Barabas, D. Smalley, and V. M. Bove, Jr., "Interactive Holographic Stereograms with Accommodation Cues," *Proc. SPIE Practical Holography XXIV: Materials and Applications*, **7619**, 761903 (2010).


Fringe Computation: Diffraction Specific Coherent Panoramagrams
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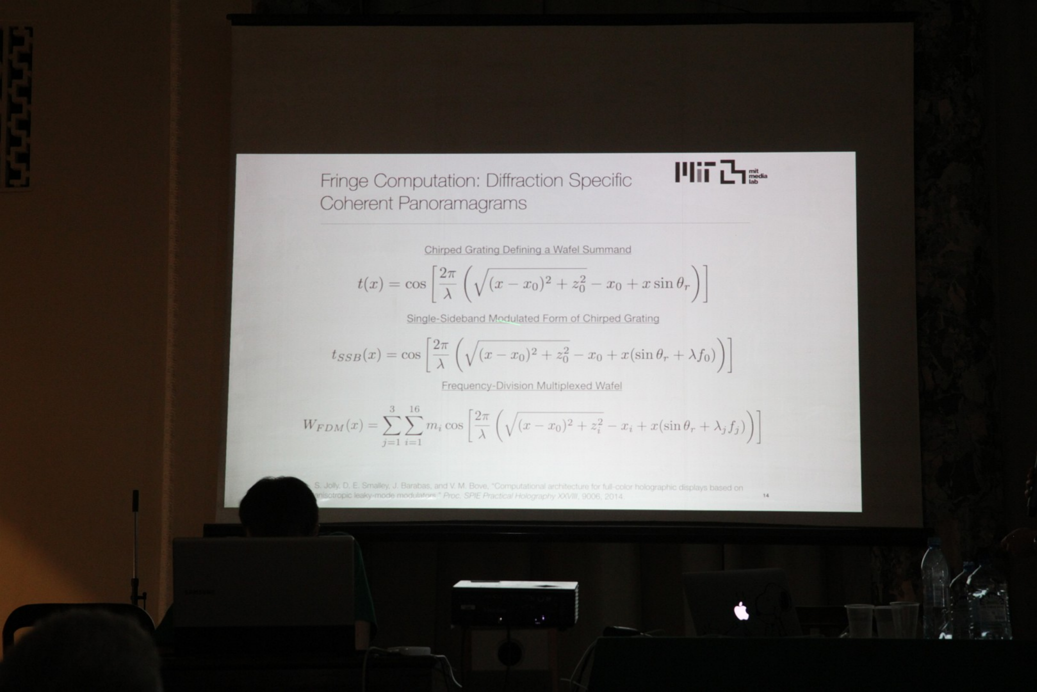
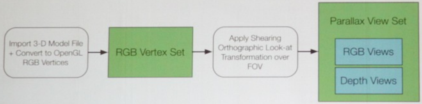
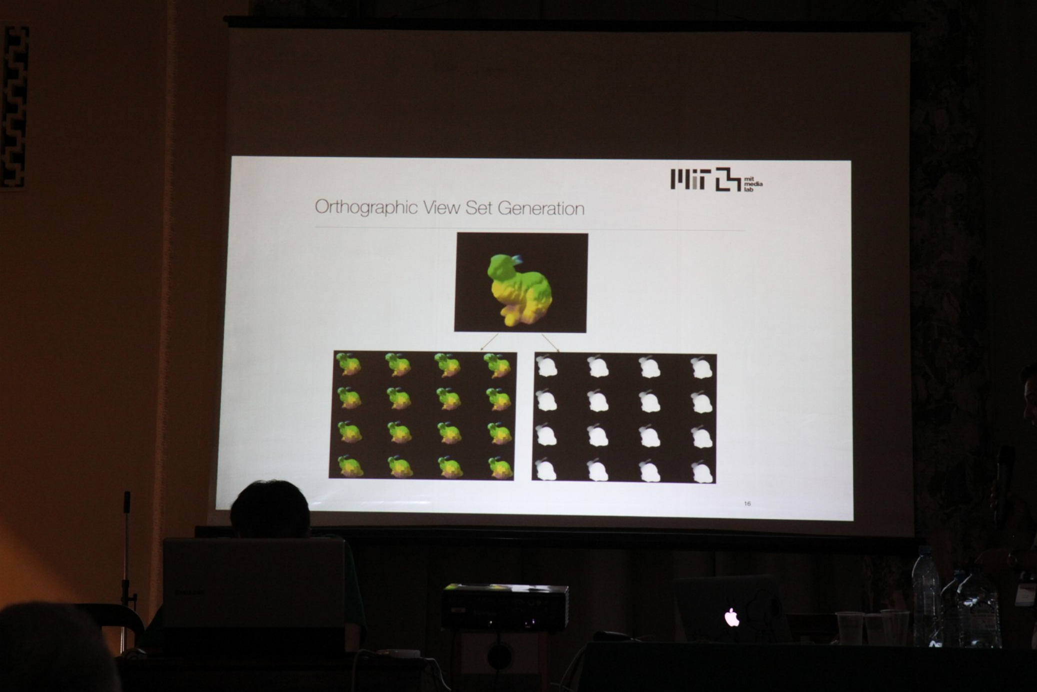
Chirped Grating Defining a Wafel Aperture
$t(x) = \cos\left[\frac{2\pi}{\lambda}\left(\sqrt{(x-x_0)^2+z_0^2} - x_0 + x\sin\theta_r\right)\right]$


Fringe Computation: Diffraction Specific Coherent Panoramagrams
mit media lab
Chirped Grating Defining a Wafel Summand
$t(x) = \cos\left[\frac{2\pi}{\lambda}\left(\sqrt{(x-x_0)^2+z_0^2} - x_0 + x\sin\theta_r\right)\right]$
Single-Sideband Modulated Form of Chirped Grating
$t_{SSB}(x) = \cos\left[\frac{2\pi}{\lambda}\left(\sqrt{(x-x_0)^2+z_0^2} - x_0 + x(\sin\theta_r + \lambda f_0)\right)\right]$
Frequency-Division Multiplexed Wafel
$W_{FDM}(x) = \sum_{j=1}^{3}\sum_{i=1}^{16} m_i \cos\left[\frac{2\pi}{\lambda}\left(\sqrt{(x-x_0)^2+z_i^2} - x_i + x(\sin\theta_r + \lambda_j f_j)\right)\right]$
S. Jolly, D. E. Smalley, J. Barabas, and V. M. Bove, "Computational architecture for full-color holographic displays based on anisotropic leaky-mode modulators," Proc. SPIE Practical Holography XXVIII, 9006, 2014.
14

# Orthographic View Set Generation




*RGB + Depth Orthographic View Generation from 3-D Model Input*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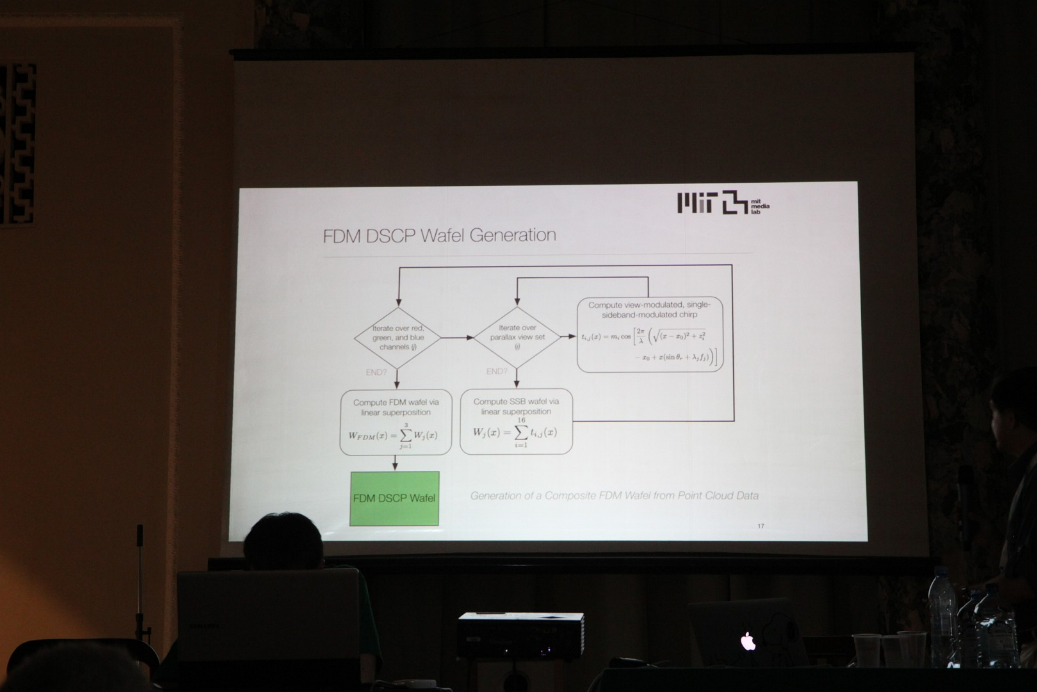
Orthographic View Set Generation
16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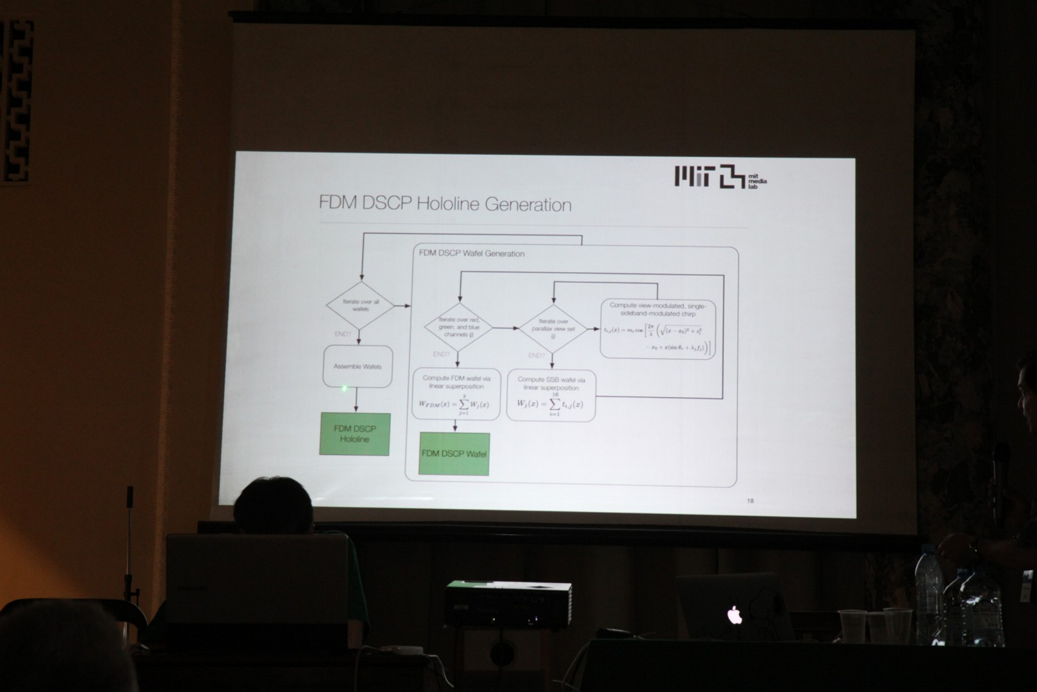
FDM DSCP Wafel Generation
Iterate over red, green, and blue channels (j)
Iterate over parallax view set (i)
Compute view-modulated, single-sideband-modulated chirp
$t_{i,j}(x) = m_i \cos\left[\frac{2\pi}{\lambda}\left(\sqrt{(x-x_0)^2 + z_i^2} - x_0 + x(\sin\theta_r + \lambda_j f_j)\right)\right]$
END?
END?
Compute FDM wafel via linear superposition
$W_{FDM}(x) = \sum_{j=1}^{3} W_j(x)$
Compute SSB wafel via linear superposition
$W_j(x) = \sum_{i=1}^{16} t_{i,j}(x)$
FDM DSCP Wafel
Generation of a Composite FDM Wafel from Point Cloud Data
17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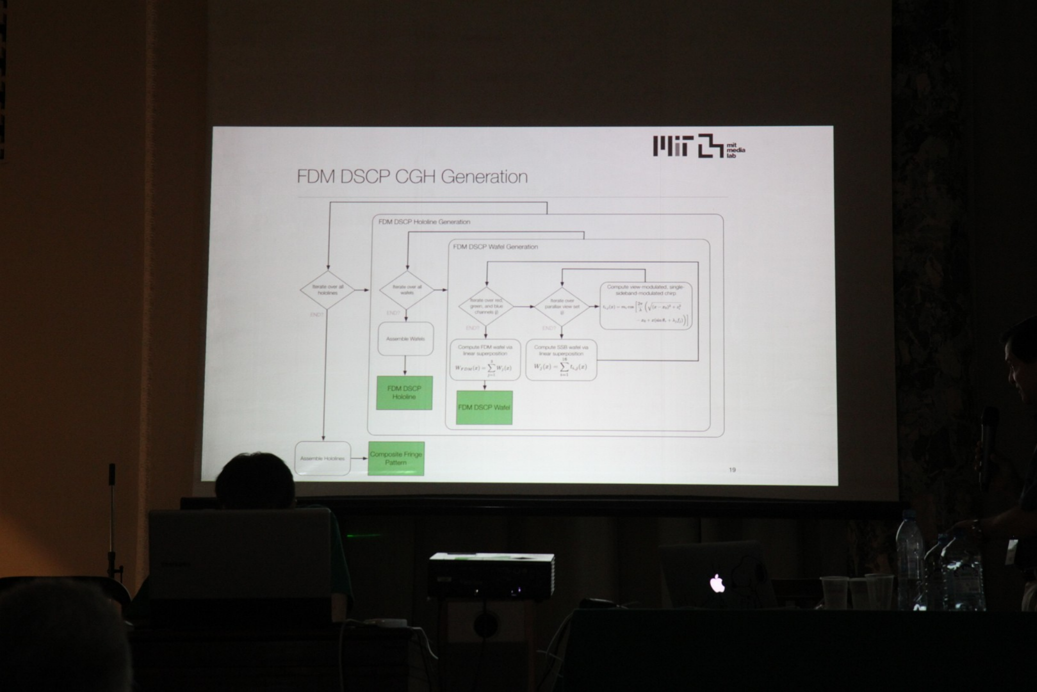
FDM DSCP Hololine Generation
FDM DSCP Wafel Generation
Iterate over all wafels
END?
Assemble Wafels
FDM DSCP Hololine
Iterate over red, green, and blue channels (j)
END?
Compute FDM wafel via linear superposition
$W_{FDM}(x) = \sum_{j=1}^{3} W_j(x)$
FDM DSCP Wafel
Iterate over parallax view set (i)
END?
Compute SSB wafel via linear superposition
$W_j(x) = \sum_{i=1}^{16} t_{i,j}(x)$
Compute view-modulated, single-sideband-modulated chirp
$t_{i,j}(x) = m_i \cos\left[\frac{2\pi}{\lambda}\left(\sqrt{(x-x_0)^2+z_i^2} - x_0 + x(\sin\theta_r + \lambda_j f_j)\right)\right]$
18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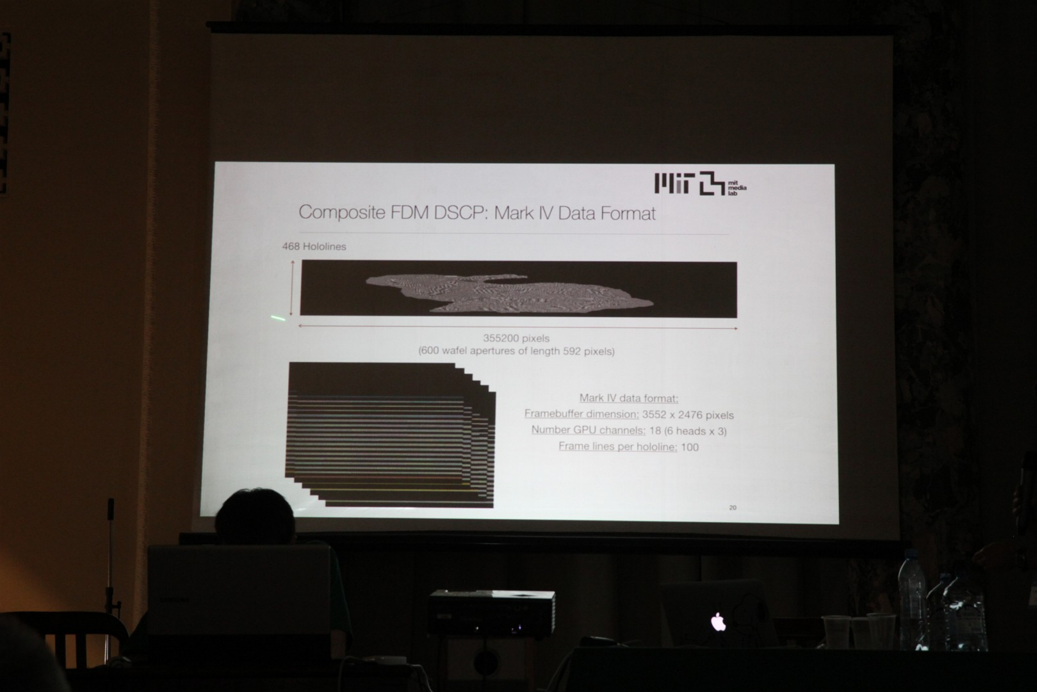
FDM DSCP CGH Generation
FDM DSCP Hololine Generation
FDM DSCP Wafel Generation
Iterate over all hololines
END?
Iterate over all wafels
END?
Iterate over red, green, and blue channels (j)
END?
Iterate over parallax view set (i)
END?
Compute view-modulated, single-sideband-modulated chirp
Assemble Wafels
Compute FDM wafel via linear superposition
$W_{FDM}(x) = \sum_{j=1}^{3} W_j(x)$
Compute SSB wafel via linear superposition
$W_j(x) = \sum_{i=1}^{16} t_{i,j}(x)$
FDM DSCP Hololine
FDM DSCP Wafel
Assemble Hololines
Composite Fringe Pattern
19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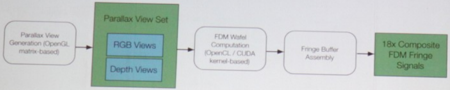
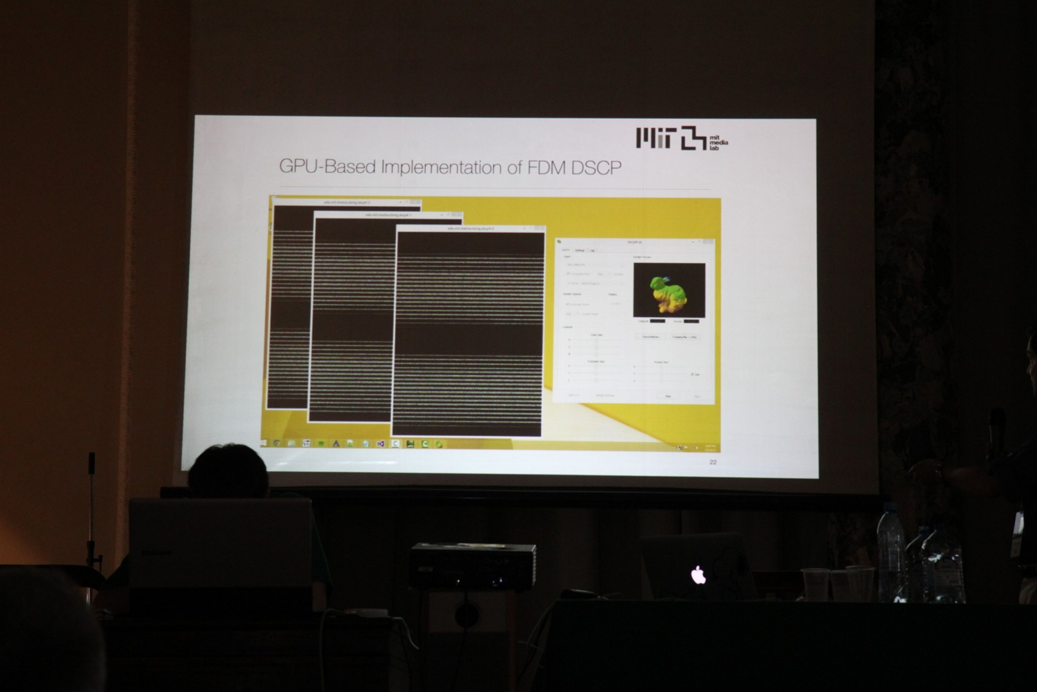
Composite FDM DSCP: Mark IV Data Format
468 Hololines
355200 pixels
(600 wafel apertures of length 592 pixels)
Mark IV data format:
Framebuffer dimension: 3552 x 2476 pixels
Number GPU channels: 18 (6 heads x 3)
Frame lines per hololine: 100
20

# GPU-Based Implementation of FDM DSCP




| Computational System | |
|---|---|
| GPUs | 3x NVIDIA Quadro K6000 |
| Total Number of Wafels | 600 x 468 = 280800 |
| Frame Rate (OpenCL Kernel) | 26 fps |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GPU-Based Implementation of FDM DSCP
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# Summary and Future Work

- We have presented algorithms and real-time implementations of fringe signal generation schemes appropriate for driving MIT/BYU Mark IV display systems in full-color
- Parallel schemes for GPU-based FDM DSCP wafel generation in OpenCL and CUDA demonstrated to achieve high frame rates
- Real-time display of live video DSCPs in full color (from a rangefinding camera) to be demonstrated later this year