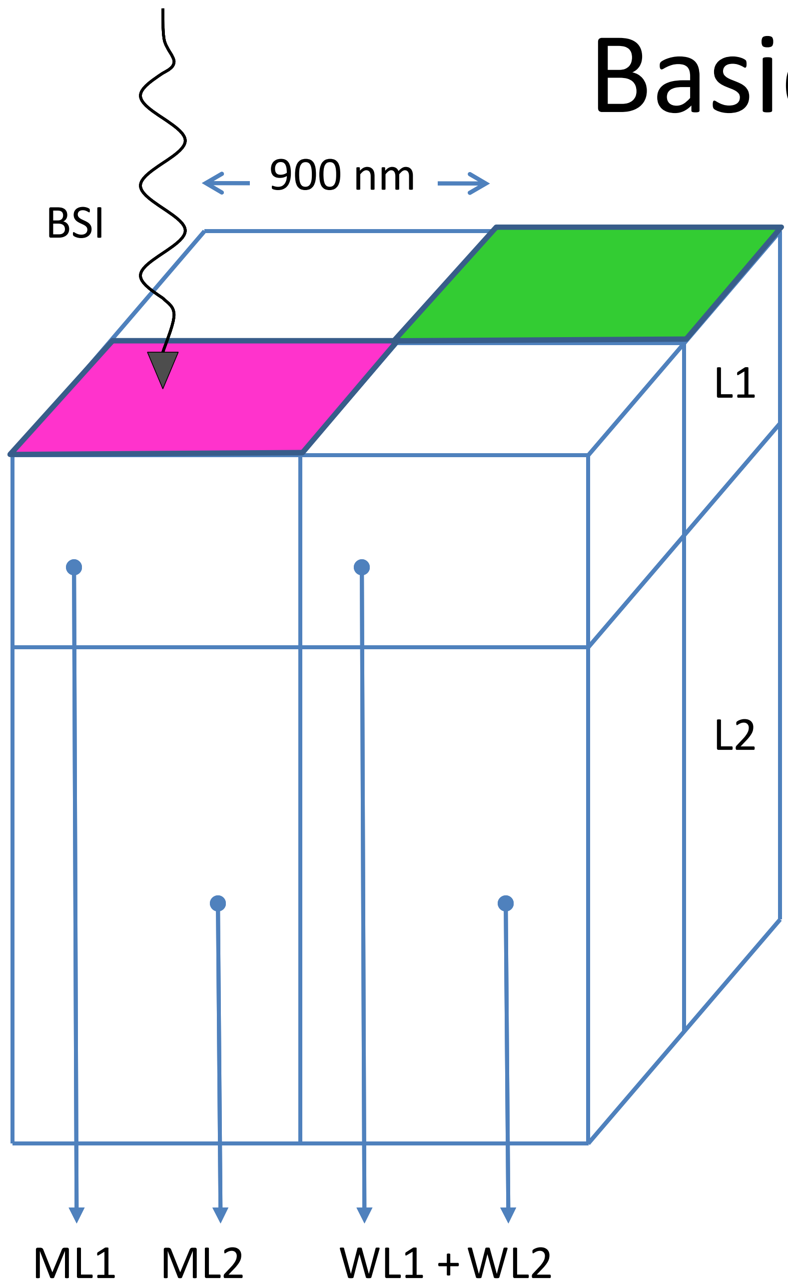
Two-Layer Photodetectors for YSNR10 Improvement in Submicron Pixels

Eric R. Fossum
Samsung Semiconductor R&D Center
Thayer School of Engineering at Dartmouth

2011 International Image Sensor Workshop, June 8-11 2011, Hokkaido, Japan

Basic Idea



- 2x2 kernel
- GWMW CFA
- Each pixel has two outputs, L1 and L2.
- 8 outputs for 2x2 kernel
- Some outputs can be summed, e.g. WL1+WL2
- Use 4 to 8 inputs to CCM to generate RGB

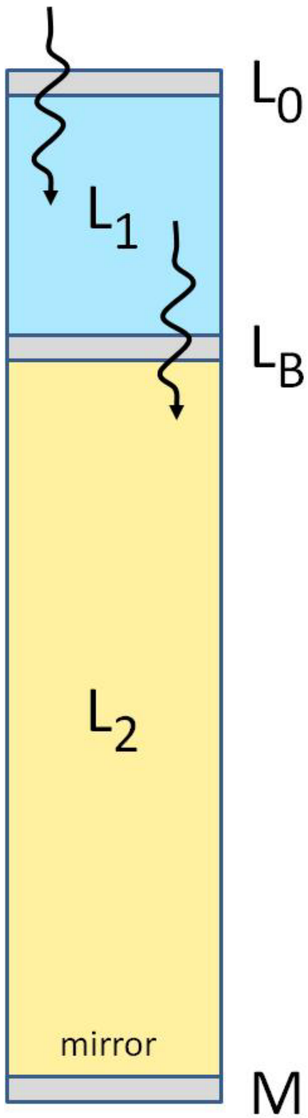
Motivation

- Luminance YSNR10 lux value limited by shot noise in submicron pixels.
- Want to use all available photons without compromising color (too much).
- RGBW single-layer pixels are well understood so looking for unconventional approaches.
- More color information from smaller kernel will improve color resolution

Summary of Results

- YSNR10 can be improved, but not by a large amount
- Color quality might be ok, but not as good as RGBG, or RGBW
- Need a simple way to readout two layers. Additional fabrication complexity can reduce appeal of using two-layers.
- Not recommended at this time.

Two Layer Structure



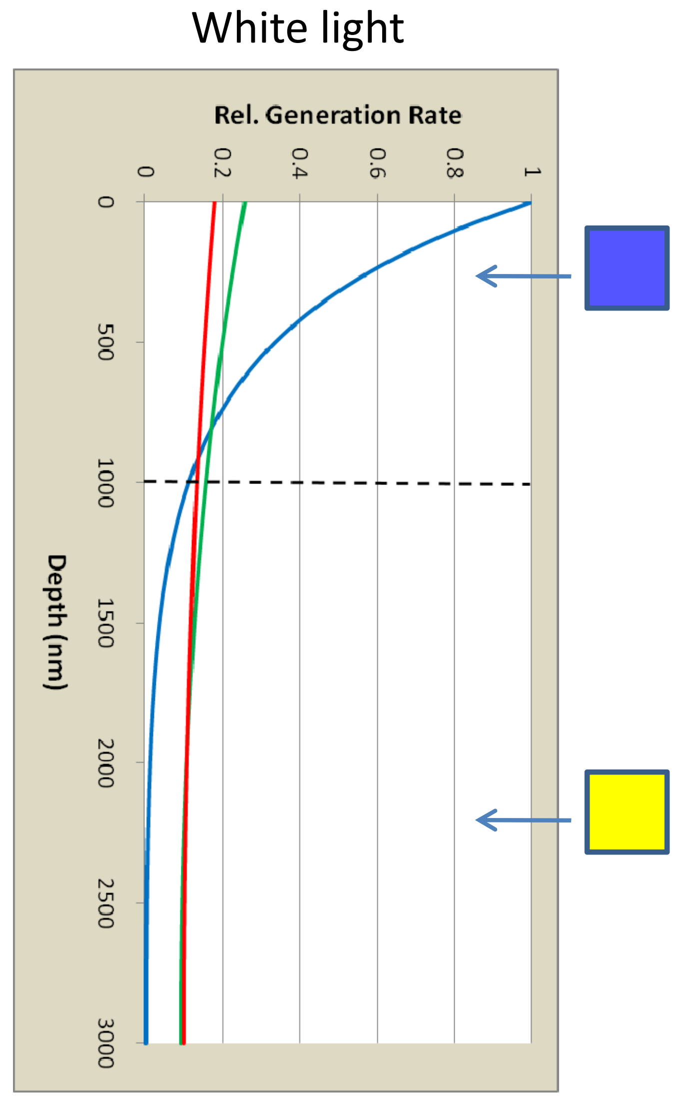
Dead layer 20 nm

"Blue" layer
1000 nm

Barrier layer

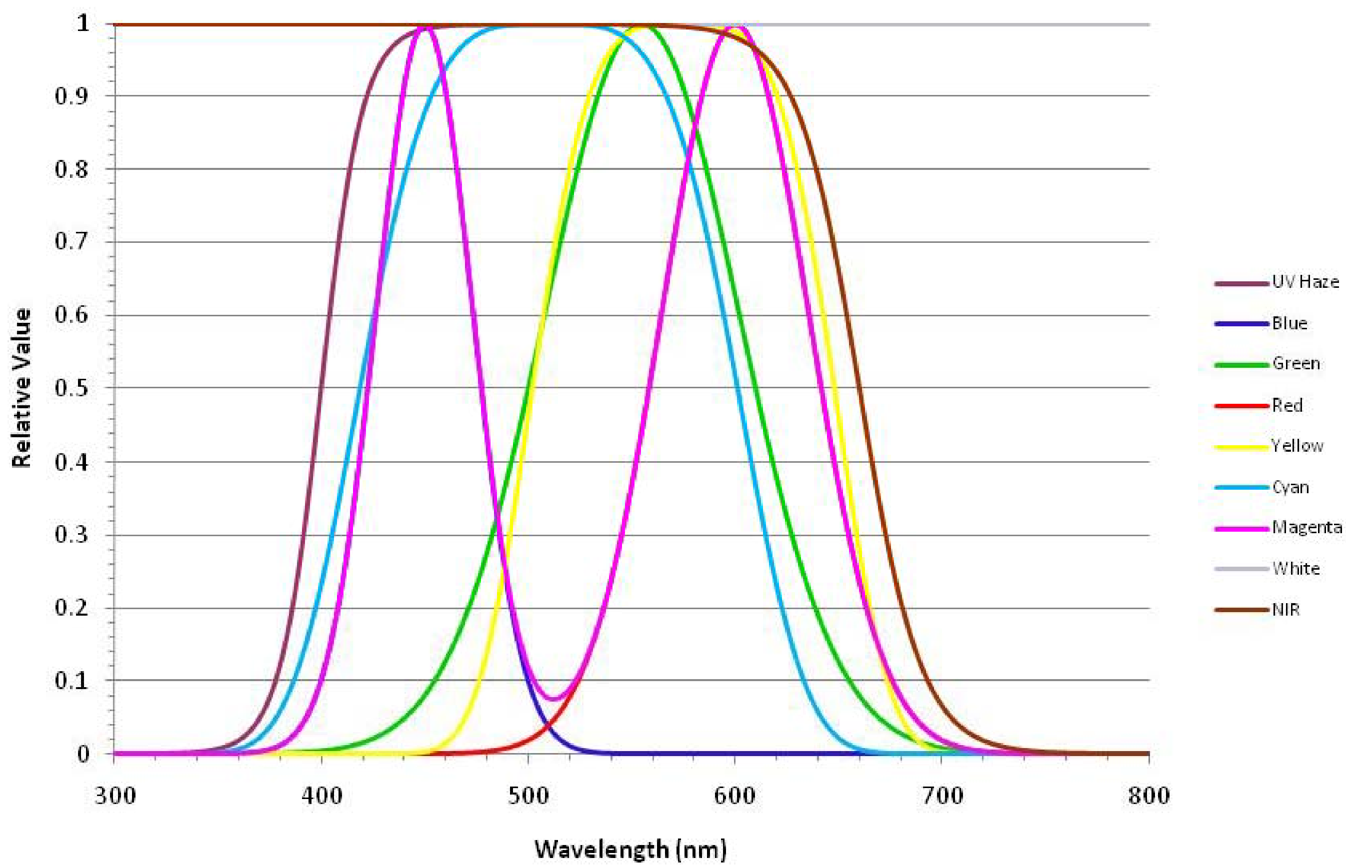
"Yellow" layer
~2000x2 nm

Mirror layer

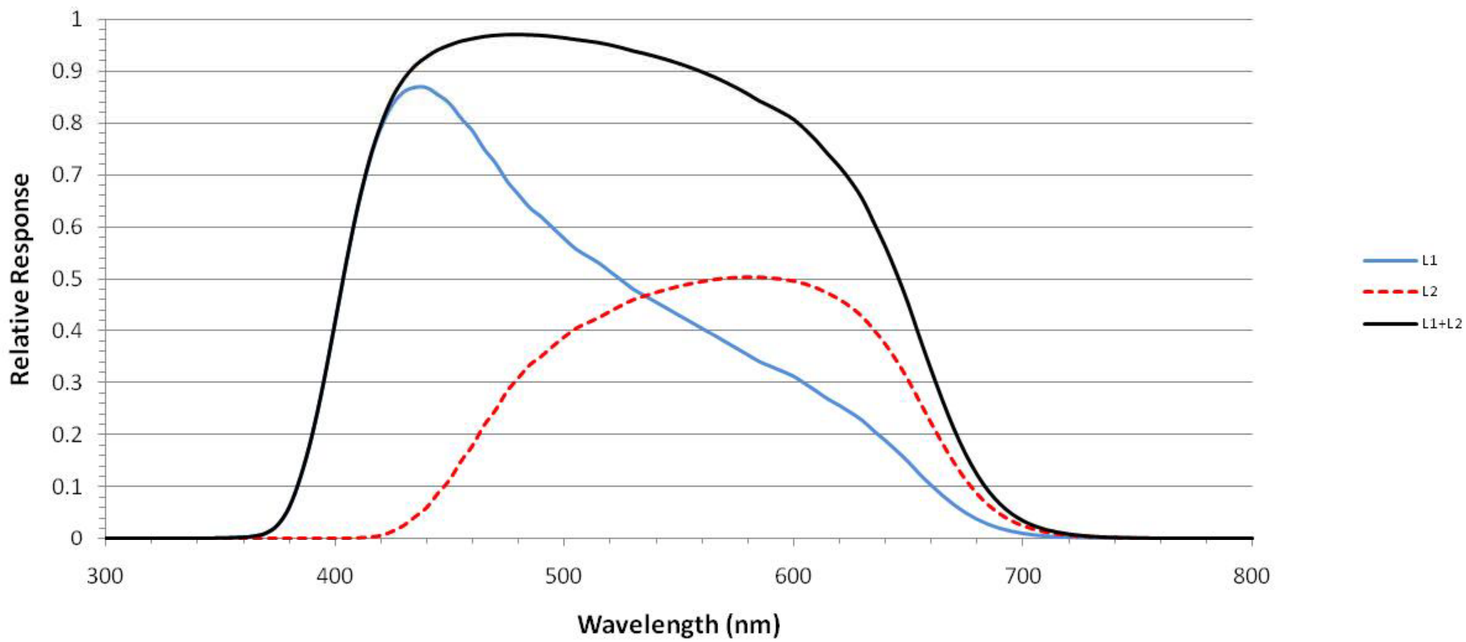


Filter Responses

(use of actual filter data does not affect general results)



Two-Layer Response
(no CFA, just UV/NIR)



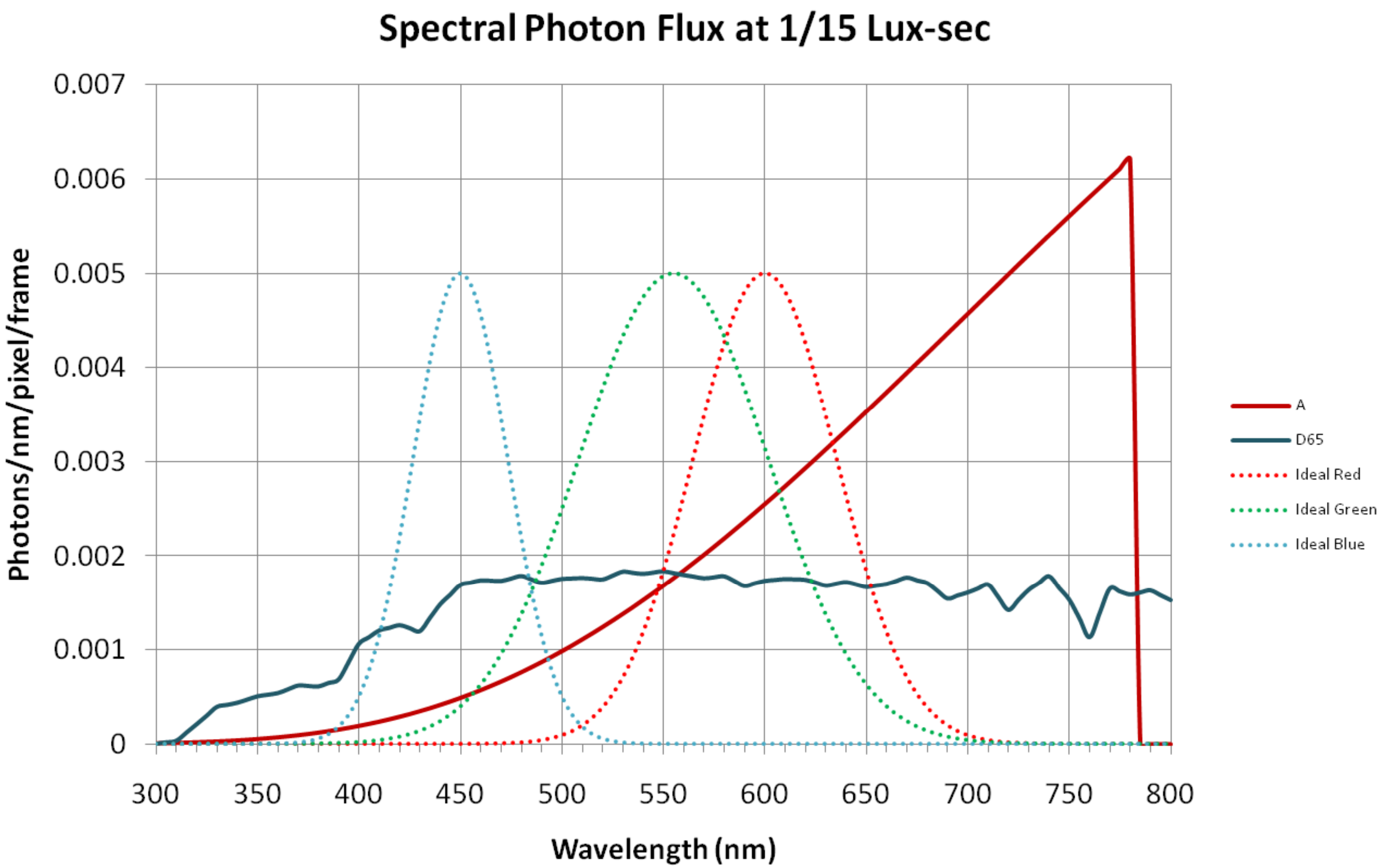
Primary Model Parameter Values

Table I. Parameter values.

Parameter	Value
L_0 thickness	20 nm
L_1 thickness	1000 nm
L_B thickness (optical)	0 nm
L_2 thickness (effective)	6000 nm
Scene illuminant	CIE A (2856K)
Scene reflectivity	18%
Lens F-number	2.8
Total trans. from lens to Si	55%
Pixel pitch	900 nm
BSI eff. fill factor	90%
Carrier collection efficiency	100%
Integration time	67 msec (15 fps)
Ideal red center/halfwidth	600/50 nm
Ideal green center/halfwidth	555/66 nm
Ideal blue center/halfwidth	450/33 nm

← 3500 nm

Photons In

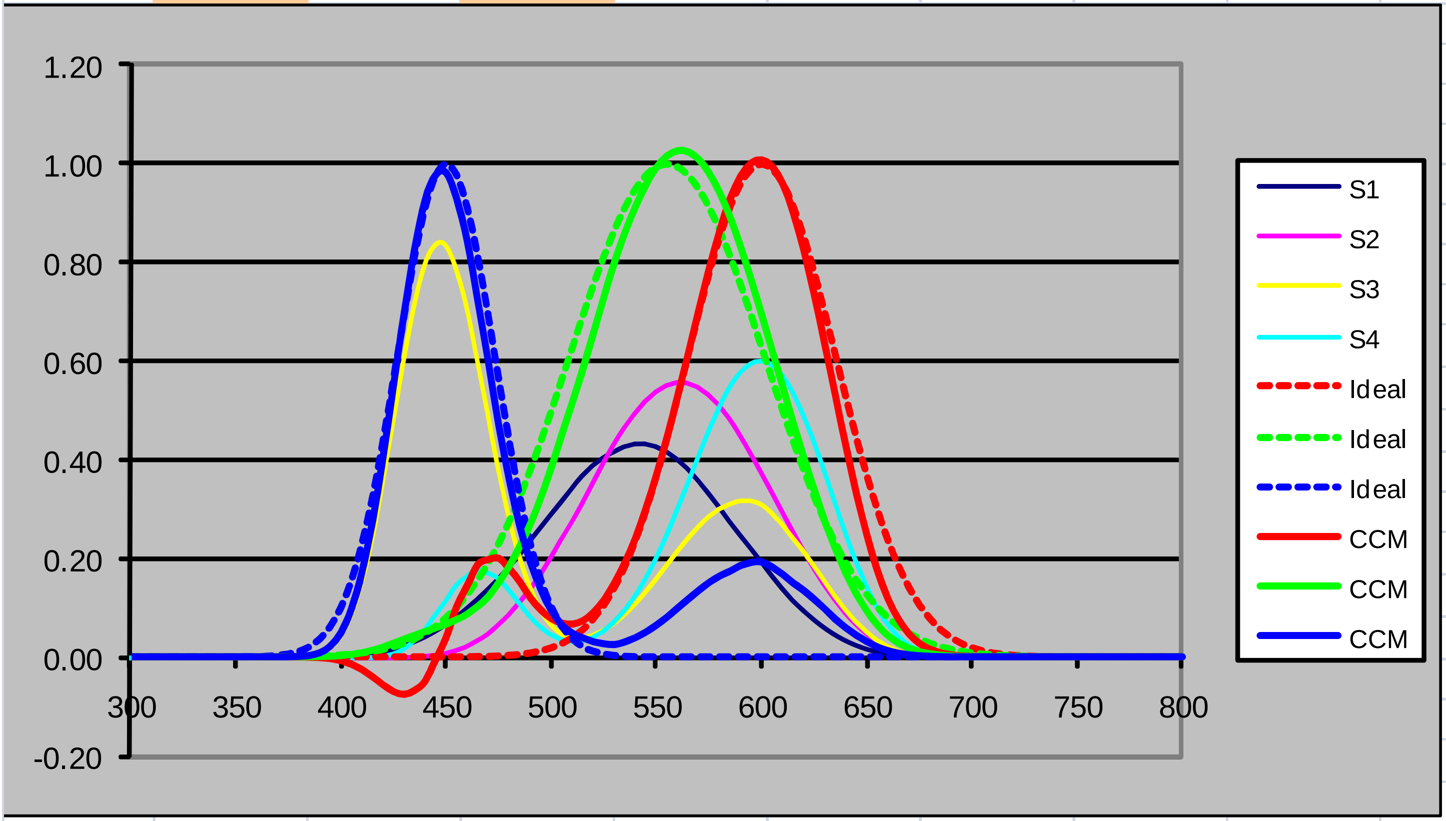

Spectral Photon Flux at 1/15 Lux-sec
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Photons/nm/pixel/frame
300
350
400
450
500
550
600
650
700
750
800
Wavelength (nm)
A
D65
Ideal Red
Ideal Green
Ideal Blue

Readout

- Modeled two possibilities:
  - L1 is kTC noise limited (23 e- rms), L2 is CDS and low noise (1.8 e rms)
  - L1 and L2 are each CDS and low noise (1.8 e- rms)
- Implementation possibilities
  - Vertical Charge Transport (VCT) uses higher voltages and similar to CCD vertical shutter.
  - Via hole drilled to L1 for 3T-type readout
  - Vertical transfer gate to readout L1
- YSNR results competitive only for CDS on both layers.
  - Had hoped L1 layer blue-response noise would have low impact on Y= rR + gG + bB if b small.

Example: G2M2

CCM	S1	S2	S3	S4	S5	S6
R	-0.110701	0.204362	-0.171761	1.673906		
G	0.093151	1.76161	0.054178	-0.007151		
B	0.443091	-0.54054	1.150673	-0.083358		
Total Error	1	YSNR	4.09			

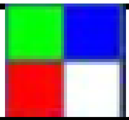
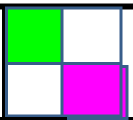


Results

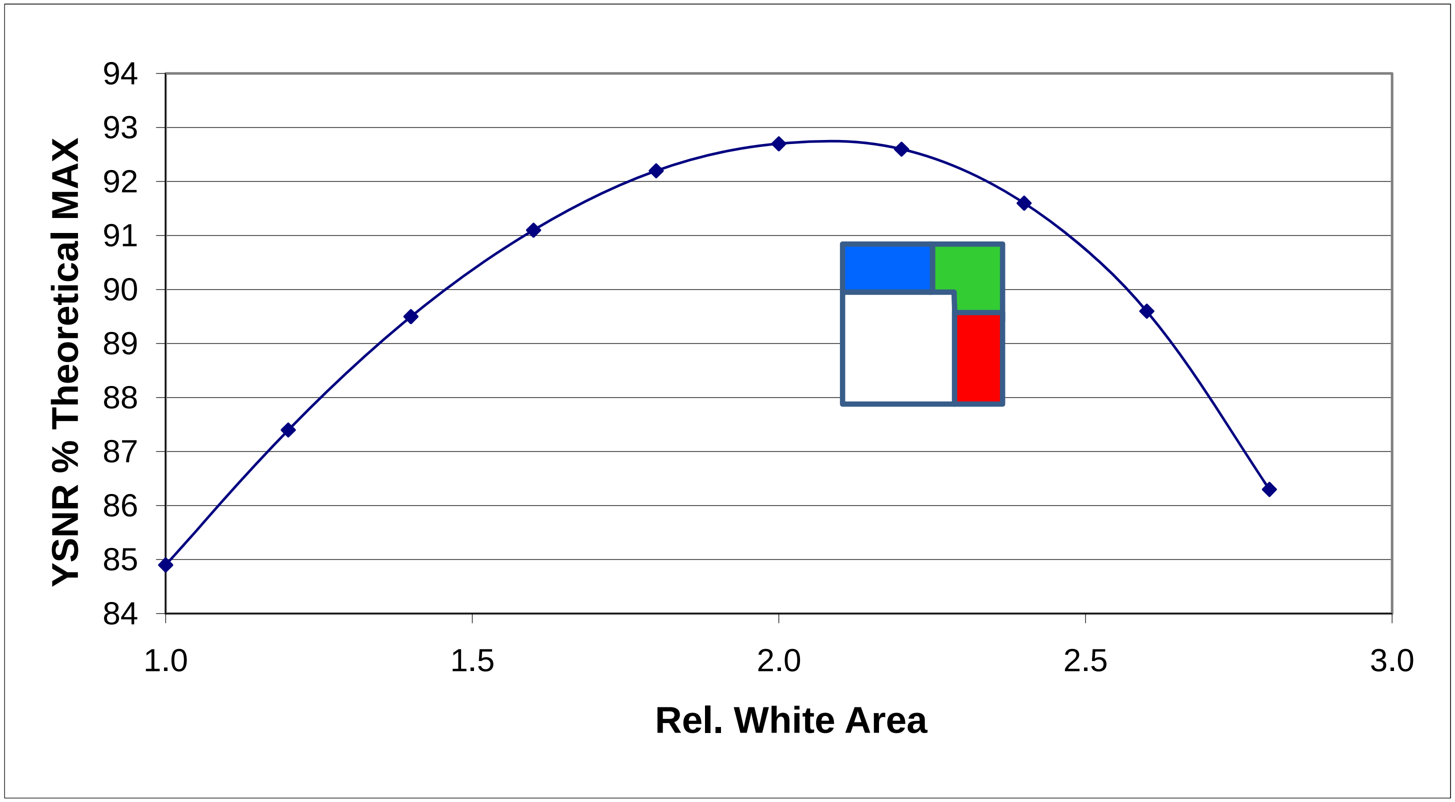
CFA	NAME	L1 NOISE = 23 e- rms, L2 NOISE = 2 e- rms: YSNR	COLOR		COLOR=1: YSNR	L1 NOISE = 2 e- rms, L2 NOISE = 2 e- rms: YSNR	COLOR		COLOR=1: YSNR
	RGBG					55%	0.27		67%
	RBCY					56%	0.47		52%
	RGBW					74%	0.27		85%
	RCGW					64%	1.12		
	CYMW					71%	1.02		
	RWGW					75%	2.06		
	RWBW					51%	2.20		

CFA	NAME	L1 NOISE = 23 e- rms, L2 NOISE = 2 e- rms: YSNR	COLOR		COLOR=1: YSNR	L1 NOISE = 2 e- rms, L2 NOISE = 2 e- rms: YSNR	COLOR		COLOR=1: YSNR
	C2M2	14%	0.85		28%	35%	0.85		46%
	C2Y2	7%	0.62		16%	28%	0.62		43%
	G2M2	12%	0.40		32%	46%	0.40		62%
	G1M2	19%	0.77		33%	52%	0.77		58%
	G2W2	8%	1.42			35%	1.42		
	G1W2	32%	4.07			58%	4.07		
	M2Y2	7%	0.53		18%	34%	0.53		53%
	R1C2	23%	0.84		33%	49%	0.84		58%
	R1W2	20%	3.74			52%	3.74		
	B1Y2	7%	0.68		10%	31%	0.68		39%
	B1W2	39%	4.96			63%	4.96		
	W1M2	16%	3.29			51%	3.29		
	W1W2	30%	6.78			46%	6.78		
	G1W1 W1M2	34%	0.77		55%	81%	0.77		90%
	G1W1 W1W2	52%	4.07			86%	4.07		
	X3	10%	5.52			54%	5.52		

Effect of L1 and L2 Thickness

EFFECT OF THICKNESS				
L1 (um)	L2 (um)	L2 (EFF)	YSNR 1L	YSNR 2L
1	2	4	85%	93%
1	1.75	3.5	85%	90%
1	1.5	3	84%	86%
1	1.25	2.5	83%	80%
0.5	1.75	3.5	84%	84%
1	1.75	3.5	85%	90%
1.5	1.75	3.5	85%	91%

Effect of Pixel Size Ratioing in Kernel
(e.g., RGBW case)



Summary of Results

- YSNR10 can be improved, but not by a large amount
- Color quality might be ok, but not better than RGBG, or RGBW
- Need a simple way to read out two layers. Additional fabrication complexity can reduce appeal of using two-layers.
- Not recommended at this time.
- Pixel size ratio in kernel effect on YSNR interesting