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## Understanding Camera Optics & Smartphone Camera Trends, A Presentation by Brian Klug

by Brian Klug on February 22, 2013 5:04 PM EST

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**SMARTPHONE IMAGING CONSTRAINTS** 

## The Imaging Chain

Since we're talking about a smartphone we must understand the imaging chain, and thus block diagram, and how the blocks work together. There's a multiplicative effect on quality as we move through the system from left to right. Good execution on the optical system can easily be mitigated away by poor execution on the ISP for example. I put arrows going left to right from some blocks since there's a closed loop between ISP and the rest of the system.



The video block diagram is much the same, but includes an encoder in the chain as well.

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## **Smartphone Cameras: The Constraints**

The constraints for a smartphone camera are pretty unique, and I want to emphasize just how much of a difficult problem this is for OEMs. Industrial design and size constraints are pretty much the number one concern — everyone wants a thin device with no camera bump or protrusion, which often leaves the camera module the thickest part of the device. There's no getting around physics here unfortunately. There's also the matter of cost, since in a smartphone the camera is just one of a number of other functions. Material constraints due to the first bullet point and manufacturing (plastic injection molded aspherical shapes) also makes smartphone optics unique. All of this then has to image onto tiny pixels.

## Smartphone Context

Smartphone camera systems have unique constraints

- Very small throw (z-stack, module often thickest part)
- Cost (\$5-15 for module)
- Limited materials (Almost always plastic)
- Unique manufacturing (Aspheres injection molding)
- Horrible operating conditions (Every type of scene)
- Small aperture (Battling ID of phone)
- All while imaging onto tiny pixels (Impossible problem)

Starting with the first set of constraints are material choices. Almost all smartphone camera modules (excluding some exceptions from Nokia) the vast majority of camera optics that go into a tiny module are plastic. Generally there are around 2 to 5 elements in the system, and you'll see a P afterwards for plastic. There aren't too many optical plastics around to chose from either, but luckily enough one can form a doublet with PMMA as something of a crown (low dispersion) and Polystyrene as a flint (high dispersion) to cancel chromatic aberration. You almost always see some doublet get formed in these systems. Other features of a smartphone are obvious but worth stating, they almost always are fixed focal length, fixed aperture, with no shutter, sometimes with an ND filter (neutral density) and generally not very low F-number. In addition to keep modules thin, focal length is usually very short, which results in wide angle images with lots of distortion. Ideally I think most users want something between 35 mm or 50 mm in 35mm equivalent numbers.

I give an example lens catalog from a manufacturer, you can order these systems premade and designed to a particular sensor. We can see the different metrics of interest, thickness, chief ray angle, field of view, image circle, thickness, and so on.

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Smartphone Imaging Constraints - Understanding Camera Optics & Smartphone Camera Trends, A Presentation by Brian Klug

Sensor Size	Sensor Maker	Sensor									information.			
			Composition	Ciass Thickness	Focal Length	CRA 0H0	FOV (D)	F Na	RI 84100%	Effective Image Circle	Mech TTL	vanical FB	Screw Size	Study Design ES MP
1/2.9"	Samsung	3H3	5P	0.3	4.07	30.4'	73.7	22	38.00%	8.50	5.2	1.1	M7.0+P0.35	Design
10.2	Omni Aptina SONY Samsung	OV-8820/30 AR0633 IMX105/175 3H2/5H7	sP	0.3	3.807	32.3	74,4	22	36.60%	6.17	4.45	0.94	M6.5×P0.25	ES
	Omri Aptina	OV-8820 AR0830/33	*	0.3	4.50	24.6*	65.4*	2.8	45.00%	8.00	5.19	1.65	M6.0×P0.35	мР
	Omni Aptina SONY Samsung	OV-8820/30 AR0833 IMX105/175 3H2/3H7	5P	0.21	3.724	30.9	75.1	2.0	37.00%	6.10	4.60	0.83	M6.5×P0.25	Design
	Omni Aptina SONY	OV-8830 AR0833 IMX105/175	5P	0.3	4.38	27.8	66	2.4	30.50%	6.05	5.00	1.05	M6.5×P0.25	мР
1/3.2"			5P	0.3	3.81	29.8*	72.4	2.5	41.90%	6.18	4.71	0.95	M7.0×P0.25	MP
	Samsung	3L1	5P	0.3	4.003	28.6	70.2	2.4	45.00%	6.14	4.81	0.96	M6, 5×P0.25	мР
			5P	0.21	3.46	31.5	76.4	2.4	35.40%	6.012	4.45	0.95	M8, 5×P0.35	Design
1/3*	SONY	MX091/135	§₽	0.3	3.972	28.2	72.9	2.0	31.70%	6.167	5.0	1.0	M6.5=P0.25	Design
	SONY	MX091/135	<u>6</u> P	0.3	3.807	32.3	75.3	2.2	36.00%	6.167	4.45	0.94	M8.5×P0.25	EB
	10.2°	10.2" Samsung 10.2" Omol Aptra Sony Samsung Omol Aptra SDNY Samsung Omol Aptra SDNY Samsung Omol Sony Samsung 10.2" Samsung	12.5" Samsung 3H3 13.2" Omni QV-852020 Aptica AR003 BMC105175 Samsung 2H22H7 Omni QV-8520 Aptica AR083033 Omni QV-8520 AR08303 Aptica AR083033 Aptica AR083033 Aptica AR08303 Aptica AR0830 Aptica AR0830 Ap	10.2" Samsung SH3 SP 10.2" Omni OV-8820200 Softra AR0833 Softra AR0830 Softra Softra Softr	10.8"     Samsung     3H3     SP     0.3       10.2"     Omni     OV-8820200     SP     0.3       10.2"     Dmni     OV-8820     SP     0.3       Omni     OV-8820     SP     0.3       Aptina     AR083033     SP     0.3       Omni     OV-8820     SP     0.3       Aptina     AR083033     SP     0.21       Samsung     3H203H75     SP     0.3       Samsung     3L1     SP     0.3       Samsung     3L1     SP     0.3       Samsung     3L1     SP     0.3       SONY     MX103H155     SP     0.3       SONY     MX003H135     SP     0.3	10.8"     Samsung     3H3     5P     0.3     4.07       13.2"     Omni Aptica AR0833 BNN05175     SP     0.3     3.807       13.2"     Omni SH05175     SP     0.3     3.807       Omni Aptica AR08303     AP     0.3     4.50       Omni Aptica AR083033     AP     0.3     4.50       Omni Aptica AR083033     AP     0.3     4.50       Aptica AR083033     AP     0.3     4.50       Aptica AR083033     AP     0.3     4.50       Aptica AR08303     AP     0.3     4.50       Aptica AR08303     SP     0.21     3.724       Sonvy MX109175     SP     0.3     4.38       10.2"     SP     0.3     3.61       Samsung 3L1     SP     0.3     4.003       10.2"     SONY     MA0091135     SP     0.3     3.672       10.9"     SONY     MA0091135     SP     0.3     3.897	10.8"     Samsung     3+3     5P     0.3     4.67     30.4'       10.2"     Ormi Aptice Aptice Aptice Aptice Stress MAX105175     SP     0.3     3.807     32.3       BONY     MAX105175     SP     0.3     4.67     30.4'       Ormi SU2547     SP     0.3     3.807     32.3       Ormi Aptice Aptica Aptica Aptica Stress Str	12.8"     Samsung     3H3     SP     0.3     4.67     30.4"     73.7"       10.2"     Omni Aptina SDNY     OV-8820200 IMX105175 Samsung     SP     0.3     3.807     32.3     74.4       Omni Aptina SDNY     OV-8820200 IMX105175 Samsung     SP     0.3     4.50     24.6"     65.4"       Omni Aptina Aptina SDNY     OV-8820200 IMX105175 Samsung     SP     0.21     3.724     30.9     75.1       Omni Aptina SDNY     OV-88203 IMX105175 Samsung     SP     0.3     4.36     27.8     66       10.2"     SP     0.3     3.61     29.8"     72.4       SONY     MX105175 MX105175     SP     0.3     4.36     27.8     66       10.2"     SP     0.3     3.61     29.8"     72.4     59     0.3     3.61     29.8"     72.4       SONY     MX0091135     SP     0.3     3.61     29.8"     72.4       SONY     MX0091135     SP     0.3     3.67     32.5     75.3	10.8"     Samsung     3H3     9P     0.3     4.67     30.4'     73.7'     2.2       13.2"     Ormit Aprina BONY Aprina Stranung     OV-8820 MX105175 Samsung     9P     0.3     3.807     32.3     74.4     2.2       Ormit Aprina BONY Aprina Stranung     OV-8820 MX105175     4P     0.3     4.50     24.6"     66.4"     2.8       Ormit Aprina Aprina SONY     OV-8820 MX105175     4P     0.3     4.50     24.6"     66.4"     2.8       Ormit Aprina SONY     OV-8820 MX105175     5P     0.21     3.724     30.9     75.1     2.0       Sony MX105175     SP     0.3     4.36     27.8     66     2.4       10.2"     SP     0.3     3.81     29.8"     72.4     2.5       Sony MX105175     SP     0.3     4.003     28.6"     70.2     2.4       10.2"     SP     0.3     3.61     29.8"     72.4     2.5       Sonvy Sonvy NOV0091/135     SP     0.3     3.697     32.3     75.3     2.2 <td>12.9"     Samsung     3+3     5P     0.3     4.07     30.4"     73.7"     2.2     36.00%       13.2"     Omni Aptica BSUNY Barmung     OV-4820200 MATIOS1Y5 Barmung     SP     0.3     3.807     32.3     74.4     2.2     36.80%       Omni Aptica SUNY Barmung     OV-4820 MATIOS1Y5 Barmung     4P     0.3     4.50     24.6"     65.4"     2.8     45.00%       Omni Aptica Aptica Aptica Aptica Aptica SUNY     OV-4820 MATIOS1Y5 Barmung     SP     0.21     3.724     30.9     75.1     2.0     37.00%       Omni Aptica SUNY     OV-4800 MATIOS1Y5 Barmung     SP     0.3     4.36     27.8     66     2.4     30.50%       10.2"     SP     0.3     3.811     20.8"     72.4     2.5     41.80%       10.2"     SP     0.3     3.81     20.8"     72.4     2.5     41.80%       10.2"     SP     0.3     3.81     20.8"     70.4     2.4     35.40%       10.2"     SONY     MATIOS1TS     SP     0.3     3.877</td> <td>12.8"     Samsung     3H3     5P     0.3     4.07     30.4'     73.7'     2.2     36.00%     6.50       13.2"     Ommi Aptica BNN05175 Barmung     OV-4820200 IMX105175 Barmung     5P     0.3     3.807     32.3     74.4     2.2     36.00%     6.17       Ommi Aptica SDNY     OV-4820 MX105175     6P     0.3     4.50     24.8"     65.4"     2.8     45.00%     6.00       Ommi Aptica SDNY     OV-4820 MX105175     SP     0.3     4.50     24.8"     65.4"     2.8     45.00%     6.00       Ommi Aptica SDNY     OV-4820 MX105175     SP     0.21     3.724     30.9     75.1     2.0     37.0%     6.10       Ommi Aptica SDNY     OV-4800 MX105175     SP     0.3     4.36     27.8     66     2.4     39.50%     6.16       10.2"     SP     0.3     3.61     29.8"     72.4     2.5     41.90%     6.16       10.2"     SP     0.3     3.617     76.4     2.4     36.0%     6.147</td> <td>12.8"     Samsung     3H3     5P     0.3     4.07     30.4<sup>2</sup>     73.7<sup>2</sup>     2.2     36.00%     6.50     5.2       13.2"     Ommi Aprica SDNY     OV-4820200 MATIOSTYPS Samsung     SP     0.3     3.807     32.3     74.4     2.2     36.00%     6.17     4.45       Ommi Aprica SDNY     OV-4820 MATIOSTYPS     SP     0.3     4.50     24.6"     65.4"     2.8     45.00%     6.00     5.19       Ommi Aprica SDNY     OV-4820 MATIOSTYPS     SP     0.21     3.724     30.9     75.1     2.0     37.00%     6.10     4.60       Ommi Aprica SDNY     OV-4800 MATIOSTYPS     SP     0.3     4.36     27.8     66     2.4     39.50%     6.10     4.60       10.2"     SP     0.3     3.61     29.6"     72.4     2.5     41.90%     6.16     4.71       50     0.21     3.46     31.5'     76.4     2.4     35.0%     6.16     4.81       10.2"     SP     0.3     3.61     29.6"</td> <td>12.8"     Samsung     3H3     5P     0.3     4.07     30.4"     73.7"     2.2     36.00%     6.50     5.2     1.1       13.2"     Omni Aprica SDNY     Ourvei SH23H7     Ourvei SP     0.3     3.807     32.3     74.4     2.2     36.00%     6.50     5.2     1.1       0.4"     SP     0.3     3.807     32.3     74.4     2.2     36.00%     6.17     4.45     0.94       Omni Aprica SDNY     OV-8820 Aprica Aprica SDNY     eP     0.3     4.50     24.6"     65.4"     2.8     45.00%     6.00     5.19     1.65       Omni Aprica SDNY     OV-8820 AR06803     eP     0.3     4.50     24.6"     65.4"     2.8     45.00%     6.10     4.60     0.83       SDNY     MAX109175     SP     0.21     3.724     30.9     75.1     2.0     37.00%     6.10     4.60     0.83       10.2"     Omni SDNY     OV-8800 MAX109175     SP     0.3     3.61     29.6"     72.4     2.5     4</td> <td>12.9"     Samsung     3+3     5P     0.3     4.07     30.4"     73.7"     2.2     36.07%     8.50     5.2     1.1     M7.0=P0.35       13.2"     Orming Aprice SDNY     GV-482030 MAX1051775 Samsung     GV-48203 SH21947     SP     0.3     3.807     32.3     74.4     2.2     36.07%     6.17     4.45     0.04     M8.5=P0.25       Ormin Aprice SDNY     GV-48203 MAX105175     4P     0.3     4.50     24.6"     65.4"     2.6     45.07%     6.00     5.19     1.65     M6.0=P0.35       Ormin Aprice SDNY     GV-48203 MAX105175     4P     0.3     4.50     24.6"     65.4"     2.6     45.07%     6.00     5.19     1.65     M6.0=P0.35       Ormin Aprice SDNY     GV-48203 MAX105175     SP     0.21     3.724     30.9     75.1     2.0     37.00%     8.10     4.60     0.83     M6.5=P0.25       0/min SDNY     GV-48303 MAX105175     SP     0.3     3.81     29.8"     72.4     2.5     41.90%     6.16     4.71     0.96</td>	12.9"     Samsung     3+3     5P     0.3     4.07     30.4"     73.7"     2.2     36.00%       13.2"     Omni Aptica BSUNY Barmung     OV-4820200 MATIOS1Y5 Barmung     SP     0.3     3.807     32.3     74.4     2.2     36.80%       Omni Aptica SUNY Barmung     OV-4820 MATIOS1Y5 Barmung     4P     0.3     4.50     24.6"     65.4"     2.8     45.00%       Omni Aptica Aptica Aptica Aptica Aptica SUNY     OV-4820 MATIOS1Y5 Barmung     SP     0.21     3.724     30.9     75.1     2.0     37.00%       Omni Aptica SUNY     OV-4800 MATIOS1Y5 Barmung     SP     0.3     4.36     27.8     66     2.4     30.50%       10.2"     SP     0.3     3.811     20.8"     72.4     2.5     41.80%       10.2"     SP     0.3     3.81     20.8"     72.4     2.5     41.80%       10.2"     SP     0.3     3.81     20.8"     70.4     2.4     35.40%       10.2"     SONY     MATIOS1TS     SP     0.3     3.877	12.8"     Samsung     3H3     5P     0.3     4.07     30.4'     73.7'     2.2     36.00%     6.50       13.2"     Ommi Aptica BNN05175 Barmung     OV-4820200 IMX105175 Barmung     5P     0.3     3.807     32.3     74.4     2.2     36.00%     6.17       Ommi Aptica SDNY     OV-4820 MX105175     6P     0.3     4.50     24.8"     65.4"     2.8     45.00%     6.00       Ommi Aptica SDNY     OV-4820 MX105175     SP     0.3     4.50     24.8"     65.4"     2.8     45.00%     6.00       Ommi Aptica SDNY     OV-4820 MX105175     SP     0.21     3.724     30.9     75.1     2.0     37.0%     6.10       Ommi Aptica SDNY     OV-4800 MX105175     SP     0.3     4.36     27.8     66     2.4     39.50%     6.16       10.2"     SP     0.3     3.61     29.8"     72.4     2.5     41.90%     6.16       10.2"     SP     0.3     3.617     76.4     2.4     36.0%     6.147	12.8"     Samsung     3H3     5P     0.3     4.07     30.4 <sup>2</sup> 73.7 <sup>2</sup> 2.2     36.00%     6.50     5.2       13.2"     Ommi Aprica SDNY     OV-4820200 MATIOSTYPS Samsung     SP     0.3     3.807     32.3     74.4     2.2     36.00%     6.17     4.45       Ommi Aprica SDNY     OV-4820 MATIOSTYPS     SP     0.3     4.50     24.6"     65.4"     2.8     45.00%     6.00     5.19       Ommi Aprica SDNY     OV-4820 MATIOSTYPS     SP     0.21     3.724     30.9     75.1     2.0     37.00%     6.10     4.60       Ommi Aprica SDNY     OV-4800 MATIOSTYPS     SP     0.3     4.36     27.8     66     2.4     39.50%     6.10     4.60       10.2"     SP     0.3     3.61     29.6"     72.4     2.5     41.90%     6.16     4.71       50     0.21     3.46     31.5'     76.4     2.4     35.0%     6.16     4.81       10.2"     SP     0.3     3.61     29.6"	12.8"     Samsung     3H3     5P     0.3     4.07     30.4"     73.7"     2.2     36.00%     6.50     5.2     1.1       13.2"     Omni Aprica SDNY     Ourvei SH23H7     Ourvei SP     0.3     3.807     32.3     74.4     2.2     36.00%     6.50     5.2     1.1       0.4"     SP     0.3     3.807     32.3     74.4     2.2     36.00%     6.17     4.45     0.94       Omni Aprica SDNY     OV-8820 Aprica Aprica SDNY     eP     0.3     4.50     24.6"     65.4"     2.8     45.00%     6.00     5.19     1.65       Omni Aprica SDNY     OV-8820 AR06803     eP     0.3     4.50     24.6"     65.4"     2.8     45.00%     6.10     4.60     0.83       SDNY     MAX109175     SP     0.21     3.724     30.9     75.1     2.0     37.00%     6.10     4.60     0.83       10.2"     Omni SDNY     OV-8800 MAX109175     SP     0.3     3.61     29.6"     72.4     2.5     4	12.9"     Samsung     3+3     5P     0.3     4.07     30.4"     73.7"     2.2     36.07%     8.50     5.2     1.1     M7.0=P0.35       13.2"     Orming Aprice SDNY     GV-482030 MAX1051775 Samsung     GV-48203 SH21947     SP     0.3     3.807     32.3     74.4     2.2     36.07%     6.17     4.45     0.04     M8.5=P0.25       Ormin Aprice SDNY     GV-48203 MAX105175     4P     0.3     4.50     24.6"     65.4"     2.6     45.07%     6.00     5.19     1.65     M6.0=P0.35       Ormin Aprice SDNY     GV-48203 MAX105175     4P     0.3     4.50     24.6"     65.4"     2.6     45.07%     6.00     5.19     1.65     M6.0=P0.35       Ormin Aprice SDNY     GV-48203 MAX105175     SP     0.21     3.724     30.9     75.1     2.0     37.00%     8.10     4.60     0.83     M6.5=P0.25       0/min SDNY     GV-48303 MAX105175     SP     0.3     3.81     29.8"     72.4     2.5     41.90%     6.16     4.71     0.96

During undergrad a typical homework problem for optical design class would include a patent lens, and then verification of claims about performance. Say what you want about the patent system, but it's great for getting an idea about what's out there. I picked a system at random which looks like a front facing smartphone camera system, with wide field of view, F/2.0, and four very aspherical elements.



Inside a patent is a prescription for each surface, and the specification here is like almost all others in format. The radius of curvature for each surface, distance between surfaces, index, abbe number (dispersion), and conic constant are supplied. We can see again lots of very aspherical surfaces. Also there's a doublet right for the first and second element (difference in dispersion and positive followed by negative lens) to correct some chromatic aberrations.

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What do these elements look like? Well LG had a nice breakdown of the 5P system used in its Optimus G, and you can see just what the lenses in the system look like.



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