Large-Format Digital Acquisition for Broadcast Television: Friend or Foe?

Laurence Thorpe
Canon U.S.A., Inc.
What is meant by Large Format?
Motion Picture Film

- **35mm Film**
  - 3-Perf
    - SMPTE 59 – 1988 Style D Specification
  - 4-Perf
    - SMPTE 59 – 1988 Style A Specification
  - Super 35mm Film

- **Super 35mm Film**
  - 3-Perf
    - SMPTE 59 – 1988 Style D Specification
  - 4-Perf
    - SMPTE 59 – 1988 Style A Specification
  - 1.79

- **16.0**
  - 21.95
  - 1.37

- **24.92**
  - 18.67
  - 13.87
Relative Image Format Sizes (mm)

- **HDTV 2/3-Inch**
  - 21.95
  - 1.78

- **35mm Film**
  - 24.92
  - 1.37

- **Super 35mm Film**
  - 18.67
  - 1.33

- **1/2-Inch**
  - 9.6
  - 3.9
  - 6.97

- **1/3-Inch**
  - 5.4
  - 2.9
  - 5.2
PL Mount

Developed by ARRI

Adopted by most Motion Picture Film Cameras
The quite recent history of Digital Large Format Origination
Digital Cinema Standardization

- **Begin Digital Cinema Standardization**: 1997
- **ITU Geneva**: 1999
- **Digital Cinema Initiative (DCI)**
  - **DCI Spec (2k and 4K)**
  - **SMPTE 2036-1-2007 (2k and 4K and 8K)**
- **Television Broadcasting Agenda**
  - **ITU-R Rec BT.1769 (2k and 4K and 8K)**
- **SMPTE 2048-1-2012 (2k and 4K Production)**
- **Digital Cinema Distribution Master**
  - **SMPTE ST 428 – 19:2010 (series)**
Emergence of Digital Cinematography

- 1997: 1st HD Camcorder
- 1999: 2/3-inch Tri-Imager
- 2003: 24P System
- 2004: "Film Camera" Revisions
- 2004: HD-based Digital Cinematography
- 2005: Digital "Film Cameras"
Arrival of 35mm Digital Cinematography

1997 - 2012

1st HD Camcorder

2/3-inch Tri-Imager HD-based Digital Cinematography

24P System

“Film Camera” Revisions

Digital “Film Cameras”

Genesis

Dalsa

ARRI D-20/21

Phantom

35mm Single-Imager HD / 2K Digital Cinematography
2006  Red Makes its 4K Debut
History of Digital Cinematography

1st HD Camcorder

2/3-inch Tri-Imager HD-based Digital Cinematography

24P System

“Film Camera” Revisions

Digital “Film Cameras”

Genesis

Dalsa

ARRI D-20/21

Phantom

RED One

F35

35mm Single-Imager Digital Cinematography
Sep 2008 Arrival of an Upstart

The hybrid HD DSLR

Full Frame CMOS Image Sensor

Developed at the request of AP and Reuters who sought:

• High resolution still images for newspapers

• Addition of motion video for website publishing
History of Digital Cinematography

1997 - 24P System
1998 - "Film Camera" Revisions
1999 - Digital "Film Cameras"
2000 - 2/3-inch Tri-imager HD-based Digital Cinematography
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2010 - Digital "Film Cameras"
2011 - 2/3-inch HD-based Digital Cinematography
2012 - Digital "Film Cameras"

1st HD Camcorder

- 24P System
- "Film Camera" Revisions
- Digital "Film Cameras"

35mm
- Single-imager Digital Cinematography

5D Mk II

- ARRI D-20/21
- Phantom
- RED One
- F35
5D Mk II Penetrates Hollywood
Full-Frame 35mm
36 x 24mm

Super-35mm
24.6 x 13.8 mm

1/3-inch
5.2 x 2.9 mm
Success of the 5D Mk II

• Extremely shallow Depth of Field
  – Excited many Directors of Photography and Cinematographers

• Full Frame 35mm Image Sensor
  – Offers a very wide angle of view
Success of the 5D Mk II

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• Availability of wide range of EF lenses
• Unusually high sensitivity
• Very good color reproduction
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• Very good color reproduction

• Very Low Cost
Shortcomings of the 5D Mk II

• Low cost Downconversion to 1920 x 1080 HD video format
  – Resulted in significant aliasing

• Unusually shallow Depth of Field
  – Made maintaining focus a major challenge
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• Low cost Downconversion to 1920 x 1080 HD video format
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  – Made maintaining focus a major challenge

• No 24P – only 30P

• Audio

• Manual control
  – Ideally using familiar camera controls, of aperture, shutter, and ISO.
Large-Format Single-Sensor Cameras

2008 to Date

Emergence of Multiple Manufacturers of Large-Format Single-Sensor Cameras
Large Format Single Sensor

• Today, consideration of large format single sensor cameras is bound up in discussions of HD or 2K or 4K

• It is important to recognize that HD is still the center of the broadcast television universe
Driving Force Behind Large Format Cameras

- Movie Origination
  - High-budget Feature Films
  - Low-budget Feature Films

- TV Commercial Production
  - High-budget national spots
  - Low-budget local spots

- Independent Filmmaking

- Broadcast Television Production
Video Origination

Small-Format

Tri-Sensor

HD Camera
Three Image Sensor Camera

Camera-Lens Mounting Flange

LENS

Green Image Sensor

ND  OLP  IR  CC

Flange Back
Direct Origination of Full RGB 444
Video Origination

Large-Format

Single-Sensor

Camera
Single-Sensor Large Format Camera

Camera Flange

LENS

Solid State Imager

Aperture Plane

Aperture

Flange to Aperture Depth (51.99mm)

Flange to Imager Depth (52mm)
The RAW Output of the Single Sensor

- CFA
- Single-Sensor
  - Encoded Color Information
  - RAW Image File Creation
    - Black / White Representation
      - Linear Pixel Data
      - Proprietary File Format and Syntax
The Debayering Process

Color Filter Array

Single-Sensor

Encoded Color Information

RAW Image File Creation

Black / White Representation

Linear Pixel Data

Proprietary File Format and Syntax

Decide & Reconstruct R G B

Interpolate Sparsely-sampled images to reconstruct full-plane RGB images

Demosaicking Process

Final Image Processing

Gamma-Color Space

Reconstruction of Full RGB 444
Image Quality

The Essential Imaging Difference Between Large and Small Image Formats is one of Depth of Field.
Controlling Depth of Field

• Image Format Size is the primary determinant

• Modified by
  – Lens Focal Length
  – Object Distance from Lens
  – Lens Aperture Setting
Depth of Field (DOF)

Anything within DOF Zone will appear as if it were in focus.
Small Image Format Size
Small Image Format is associated with a Long Depth of Field
Small Image Format Size

Creative Values of the Long Depth of Field
Long Depth of Field

is regularly exploited in program genres
where the desire is to convey
maximum visual information
about environs
NEWS:
Need to see the Reporter
Need to see Action being reported
NEWS:
Need to see the Reporter
Need to see Action being reported
Sometimes required to capture the totality of a given environment.
Sometimes desirable to capture the totality of a given environment.
Sometimes expected to capture the totality of a given environment
Long Depth of Field

Sometimes required to capture the totality of a given environment
Sometimes required to capture the totality of a given environment
Long Depth of Field

The 2/3-inch image format size supports a Deep Depth of Field

The 1/3-inch image format supports an even Deeper Depth of Field
Hierarchy in Image Format Size

Large

Image Format Size
Creative Value
of the
Shallow Depth of Field
Shallow Depth of Field

is exploited in program genres
where the desire is to direct the viewers' attention
to a specific subject
by blurring backgrounds
and sometimes also foregrounds
Shallow Depth of Field can be creatively exploited to direct attention to a specific subject within a scene.
Shallow Depth of Field Focuses Attention
Defocused Foreground and Background
Concentrates attention on the subject of interest
Very shallow Depth of Field used to direct attention to the loneliness of the subject while the surrounding environment is “detuned”
Rack Focusing exploits Shallow Depth of Field to synchronize imagery with the person speaking. This is used in TV drama and movies.
Let us now Look at All that is presently available in Image Format Sizes
The 1/3-inch image format is x3.5 times smaller than that of the 2/3-inch HDTV format.
Global Interchange of HD Lenses and Cameras

BTA  S-1005-A Standard  (B4 Mount)

<table>
<thead>
<tr>
<th>2/3-inch Cameras</th>
<th>2/3-inch Lenses</th>
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<tbody>
<tr>
<td>– Grass Valley/Thomson</td>
<td>– Angenieux</td>
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<tr>
<td>– Hitachi</td>
<td>– Canon</td>
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<tr>
<td>– Ikegami</td>
<td>– Cooke</td>
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<tr>
<td>– Panasonic</td>
<td>– Fujinon</td>
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<tr>
<td>– Sharp</td>
<td>– Zeiss</td>
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<td>– Sony</td>
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2/3-inch is dominant in the Television Studio and in Television Sports.
2/3-inch Tri-Sensor Camcorders are Ubiquitous
2/3-inch Tri-Sensor Camcorders are Ubiquitous

1/3-inch Tri-Sensor Cameras are now flourishing in ENG
1/3-inch Single-Sensor Cameras

Are now
Significantly Augmenting
the Arsenal of ENG Acquisition
Choices in Image Sensor Size

The New Era

of

Large-Format Single-Sensor Cameras
Large Format HD Cameras

ARRI ALEXA

Phantom FLEX

Weisscam HS-2

Panavision GENESIS

Super 35mm

Canon EOS 300

Sony F35

Canon EOS 100

Sony SWR-9000PL
Choices in Image Sensor Size

Television

Historical Perspective on the Image Format Sizes
Era of 30mm Plumbicon Pickup Tube
Era of 30mm Plumbicon Pickup Tube

Era of 2/3-inch Pickup Tube
Era of 30mm Plumbicon Pickup Tube

Era of 2/3-inch Pickup Tube

Era of 2/3-inch CCD and CMOS Image Sensor
Era of 30mm Plumbicon Pickup Tube

Era of 2/3-inch Pickup Tube

Era of 2/3-inch CCD and CMOS Image Sensor

Era of 1/2-inch, 1/3-inch and 1/4-inch CCD & CMOS
Era 1/3-inch and 1/4-inch

Era of 2/3-inch Sensor

Full Frame 35mm

Super 35mm

Era of Large-Format Single-Sensor

Canon U.S.A., Inc.

The Long-lived 30 mm Pbo had a considerably shallower Depth of Field than today’s 2/3-inch cameras.
The contemporary Super 35 mm single-sensor Cameras have a modestly shallower Depth of Field than the former 30 mm Pbo.
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What are the Implications for Broadcast Television Production?
Broadcast Television Production

Television Program Genres
- Episodic
- Drama
- Sports

- Light Entertainment Shows
  - Reality
  - Sitcom
  - Cooking
  - Court
  - Talk

- News
- News Magazine

- Documentary
Large Format Camera: Friend or Foe?

Choosing the Right Camera for a Specific Program Genre
Criteria for Choosing a Camera/Camcorder

• **Image Quality**
  – Aesthetics and “Look” sought for a specific program genre

• **Ergonomics**
  – Size, form factor, weight,
  – Disposition of interfaces and controls

• **Deliverables**
  – Signal outputs, recording formats and files

• **Costs**
  – Basic camera/camcorder, accessories
Image Quality

Primary Determinants of Image Quality

– Image sensor size
– Number of image sensors
– Lens choices

Cinematographers speak of:

– The Image Sensor as the “Canvas”
– The Lens as the “Brush”
Multiple Dimensions of Image Quality

Still Imaging

1. Depth of Field

2. Sensitivity
   1. Brightness of the image

3. Picture Sharpness

4. Tonal Reproduction
   1. Contrast Range for the nominally exposed image

5. Dynamic Range
   1. Total exposure latitude of the image

6. Color Reproduction
   1. Reproduction of facial skin tones
   2. Color gamut
Multiple Dimensions of Image Quality

Motion Imaging

– Standard Picture Capture Rates
  • 60P, 30P, 24P, 60i

– Slow Motion
  • Variable Frame Rates up to 120fps

– Fast Motion
  • Variable Frame Rates down to 1 fps
HDTV Acquisition

The HDTV Lens and Camera are an Intimately Intertwined Imaging System
## HDTV Acquisition and Image Quality

### Image Quality Factors

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<thead>
<tr>
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<th>HD LENS</th>
<th>HD CAMERA</th>
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<tr>
<td>Sensitivity</td>
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<tr>
<td>Sharpness</td>
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<tr>
<td>Tonal Reproduction</td>
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<td>Exposure Latitude</td>
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<td>Electronic Sensitivity</td>
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<td>• Sharpness</td>
<td>MTF (Optical)</td>
<td>MTF (Opto-electronic)</td>
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<td>• Tonal Reproduction</td>
<td>Black Reproduction</td>
<td>Black Reproduction + Transfer Characteristic</td>
</tr>
<tr>
<td>• Exposure Latitude</td>
<td>Optical Dynamic Range</td>
<td>Sensor Dynamic Range</td>
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<tr>
<td>• Color Reproduction</td>
<td>Spectral Response</td>
<td>Spectral Response + Electronic Matricing</td>
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New Innovation in HDTV Origination

How a 4K Single Image Sensor Produces Exceptional HDTV Performance
The 4K Bayer Color Filter Array can be spatially separated into:

- RED \(1920 \times 1080\)
- Blue \(1920 \times 1080\)
- Green 1 \(1920 \times 1080\)
- Green 2 \(1920 \times 1080\)
Direct Readout from 4K Image Sensor:

R G B 4 : 4 : 4

“Super” Green

Direct High-speed Parallel Readout

Canon
At the Readout level

Horizontal Sample Period

At the Photosite level

One Line Period

1/2-pixel

2160

Gr : 1080

Gb : 1080
Contending with Aliasing

Horizontal MTF

Total Response

Optical Low Pass Filter

CMOS Aperture

1st Order Sideband

2nd Order Sideband

Nyquist

TVL/ph

0 1080 2160 4320

100%

0
Must Still Contend with 2nd Order Sideband
Defeating Nyquist

Remaining Alias stimulation
“Super Green” Directly Benefits Luma Output

\[ Y = 0.213R + 0.715G + 0.072B \]

(Rec 709 standardized matrix)
Create Bit serial Data Interface

SMPTE ST 425-1-2011

R      G      B      + A

3G SDI

High-speed Parallel Data Readout

4K CMOS Image Sensor

R 1080
Gr 1080
Gb 1080
B 1080

G+

R 1080
G+ 1080
B 1080

3G SDI
CMOS Image Sensor System

8.3
Mpixel

High
Speed
Readout

Photo
Site
Opto
Electronic
Transform

High
Bit-Depth
4:4:4:4
Processing

“Super”
Green

4:4:4:4
Progressive
Readout
(High Bit-Depth)

3G SDI
Serial 12-bit 4:4:4 @60P

10-bit 4:2:2 @120P

To
On
Board
MPEG-2
Codec

To

R
Gr
Gb
B

Y
Cr
Cb

RGB Digital Processing

To 1080
To 1080
To 1080

Canon
Special HD / 2K Imaging Attributes of C500

• No De-Bayer process
  – No reconstruction errors

• No Compression
  – No related artifacts

• RGB 4 : 4 : 4
  – Full Color Space

• Super Green
  – Produces high MTF Luma with very low aliasing

• 12-Bit
  – Faithful reproduction of Wide Dynamic Range

• Canon Log
  – Protects 12-stop Dynamic Range in recording
What Might be the Applications for Large-Format Single-Sensor Cameras in Broadcast Television?
Broadcast Television Production

Television Program Genres

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<td>Drama</td>
<td>Very High</td>
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<td>Highest Quality</td>
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<tr>
<td>(Shallow Depth of Field)</td>
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<tr>
<td><strong>Light Entertainment Shows</strong></td>
<td>Acceptable (Deep Depth of Field)</td>
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*DOF* stands for Depth of Field.
Large Format Cameras: *Friend or Foe?*

- The Large-format Single-Sensor Camera
  - Clearly has important applications in various broadcast television program genres
Large Format Cameras: *Friend or Foe?*

- The Large-format Single-Sensor Camera
  - Clearly has important applications in various broadcast television program genres

- In the sense that such cameras augment the production arsenal
  - it is submitted that they are FRIEND indeed to the Broadcaster
Thank You for Your Attention