Prof. Dr.-Ing. K. Grüger:

**TV studio signals from analog to digital UHD and beyond**

Faster = better temporal resolution  
Higher = higher spatial resolution  
Stronger = more bits/pixel

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Interface</th>
<th>Bit Rate (Gbit/s)</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCIR ...</td>
<td>analog</td>
<td>5 MHz</td>
<td>270Mbit/s</td>
</tr>
<tr>
<td>SMPTE 259</td>
<td>SD-SDI</td>
<td>1.5 Gbit/s</td>
<td>1080p/50</td>
</tr>
<tr>
<td>SMPTE 292</td>
<td>HD-SDI</td>
<td>3 Gbit/s</td>
<td>1080p/60</td>
</tr>
<tr>
<td>SMPTE 372</td>
<td>3G-SDI</td>
<td>6 Gbit/s</td>
<td>2160p/50</td>
</tr>
<tr>
<td>SMPTE 424</td>
<td>not standard yet</td>
<td>12 Gbit/s</td>
<td>2160p/50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24 Gbit/s</td>
<td>2160p/120</td>
</tr>
</tbody>
</table>

**Reasons for Serial Digital Interface**

- Analog CVBS signals: limited to standard definition  
  - still used for black burst (BB) central genlock clock generator
- VGA signals: analog, many wires
- **coaxial serial digital interface (SDI) signals**
  - clear unidirectional routing and wiring  
  - broadcast approved and easy upgradable  
  - embedded audio with up to 16 audio channels (for HD-SDI)  
  - consumer devices adaptable by HDMI interface boxes
- Ethernet-Signals (currently)
  - currently: without guaranteed bandwidth and latency  
  - „Audio Video Bridging“ just under research  
  - IP cheap only for non-real time signals (editing)

**Comparison viewing area / image resolution human eyes<=> cinema & TV**

- Viewing area of average human: about 10800x6600
- **8K = 8192(7680) x 4320 (UHD, „UHDTV2“)**
- **4K = 4096(3840) x 2160 (D-Cinema, UHD) („UHDTV1“)**
- **Recommended viewing distances**
  - TV: 6 x h  
  - HDTV: 3 x h  
  - 4K: 1.5 x h  
  - 8K: 0.75 x h
- **Recommended viewing distances**
  - **56° (ITU), >36° (D-Cinema)**
  - **96° (ITU)**
- Rule of thumb:
  - **ca. 180°**
Principle of electronic scan and reproduction

- Synchronized line-by-line transmission of 2D image
  - traditional: cathode ray tube (CRT)

1st field
2nd field
2:1 interlace scanning: 2 fields (2 partial scans) + blanking + synchronization = 1 frame

Standard definition TV with 4:3 aspect ratio:
- 525/2:1/60Hz ("NTSC") => 720x480 with 30fps (480i/30)
- 625/2:1/50Hz ("PAL") => 720x576 with 25fps (576i/25)

Why 2:1 interlace? Why different frequencies for "NTSC" and "PAL"?

Shutter-Speed versus AC-Current-Frequency

- USA: 60Hz-AC => 30Hz/60Hz-TV with 30fps
- Europe: 50Hz-AC => 25Hz/50Hz-TV with 25fps

Bulb lights: Continuous mean power some lights (arc light, fluorescent tube):
- flicker at 100Hz or even 50Hz

230V 50Hz P=U^2/R
100Hz

"Synchro-Scan": 1/25s or 1/50s or 1/100s shutter speed => reduced flickering, but juddering

Europe's TV problem
- Bulb lights: Continuous mean power some lights (arc light, fluorescent tube):
- flicker at 100Hz or even 50Hz

2:1-Interlace

- Advantages
  - CRT: large areas flicker with field frequency (i.e. 50Hz or 60Hz) => higher frequency than frames per second (fps) => hardly visible
  - 2:1 reduced bandwidth (analog and uncompressed digital)
  - only in analog TV: easy to realize
- Disadvantages
  - CRT: edges and other details flickering with fps frequency (i.e. 25Hz or 30Hz)
  - Effective visual resolution is about 0.7 of theoretical value ("Kell factor")
- Today: Bad effects for video compression by source coding!!!
- Facts:
  - Standard TV and today's HDTV studio technology uses interlace
  - only cinema uses progressive frames today (at 24fps)

Worldwide digital Standard TV recommendation ITU-R BT.601 + SMPTE 259M

- Worldwide standard(s) for digital sampling structure:
  - Recommendation CCIR 601 => today ITU-R BT.601 => 13.5 MHz luminance sampling frequency (+ more)
    - simple analog/digital conversion and vice versa
    - unified raw data rate and unified active samples/raster line
    - but:
      - interlace
      - different line counts/frame
      - different fps (480i/30 and 576i/25)
      - 29.97fps instead of 30fps for NTSC
  - Worldwide standard for digital TV signal transmission:
    - Recommendation "CCIR 656" for SDI => today ITU-R BT.656 (first CCIR 656 caused severe RF interference => superseded by SDI=SMPTE 259M) => 270 Mbit/s with 4:2:2 color subsampling (8 or 10 bits) => transmission using single SDI coaxial cable (75 Ohm)
540Mbit/s, MUSE, Eureka, HD-MAC and others

- Progressive digital standards: 540Mbit/s...
- Towards HDTV: the mainly analog experiments...
  - NTSC => MUSE: 480 lines * 2 = 960 lines @ 60Hz
  - PAL/SECAM => Eureka: 576 lines * 2 = 1152 lines @ 50Hz
  - several drawbacks
    » mostly analog, anamorphic digital processing 1440 pixel/line
    » interlace 2:1 or even more (MUSE, HD-MAC)
- Today: „Unified“ HDTV standards with various fps-Values
  - 720p @23.98, @24, @25, @29.97, @30, @50, @59.94, @60
  - 1080p @23.98, @24, @25, @29.97, @30
  - 1080i @50, @59.94, @60
  - 1080p 16:9 1920x1080 (1280x720)

SDI transmission within TV studios today

- SDI => SD-SDI = 270Mbit/s (4:3) for 576i25 and 480i
- some variations 360Mbit/s (16:9 USA), 540Mbit/s (= 2x270 for progressive)
- today: not really important any longer...
- HD-SDI with < 1.5Gbit/s (typically 4:2:2 color subsampling)
  - 1080i50 (= 1080i/25)
  - also possible: 720p50 (720p/50), 1080p25, 1080p24
  - 1080i59.97 => with various variants for example in USA
- ARD/ZDF/Arte/... following IRT-Recommendation (IRT = Institut für Rundfunktechnik = their research institute)
  720p/50 (better broadcast quality without interlace!)

Technologies for progressive transmission

- Most HDTV cameras + video mixer offer HD-SDI or HDMI
  - technological limits (cable length versus signal frequency)
  - HD-SDI dual link technology could be possible but is uncomfortable
  - example: Panasonic AG-AC160A
    » AVC-HD with up to "1080p60" on SDHC memory cards, but only HD-SDI (and HDMI respectively) with 1.5 Gbit/s (up to "1080i60")
- But 3G-SDI technology is already available/desired
  - many popular crossbar switches with 3G-SDI
  - key component for digital studio video networks
  - just electronic components => comparatively cheap
  - many (cheap) I/O components support 3D-SDI and/or dual-link HD-SDI
  - many (cheap) converters support 3D-SDI and/or dual-links HD-SDI
  - but: main application is 2K, 12bit video and 4:4:4:4-sampling (RGB with alpha)
  - first „economic“ video mixers and cameras with 3G-SDI available

Development in theory and reality

- Theory:
  » 10G-SDI (SMPTE ST 435:2012) should be the next step (connectors=optical IP)
  » electrical SDI components should be replaced by optical SDI
  (see optical LC connector): band width, max distance, interference,...
- Bloody reality (available or announced for June/July 2014!):
  » Blackmagic Design offers a bunch of cheap devices
    » USRA 4K Camera with 12G-SDI (5,509 €)
    » Studio Camera with 12G-SDI (3840x2160) (1,839 €)
    » Production Camera with 6G-SDI (2,735 €)
    » ATEM production studio 4K with 6G-SDI (1,509 €)
    » Hyperdeck Studio (Recorder) with 6G-SDI (1,019 €)
    » Decklink SDI 4K (PCI-E I/O) with 6G-SDI (265 €)+...
  » Consumer 4K-TV-sets are already available, but have interface problems
- Keep in mind:
  Money is one of the most important technical parameters

Attention!!! +accessories +VAT („MwSt“)
**Parameters of today’s reality**

- **Electrical 12G-SDI (10bit/4:2:2)**
  - up to 3840x2160p60

- **Electrical or optical 6G-SDI**
  - up to 3840x2160p30 or 1920 x 1080p60

**Danger!**

- IR beams for optical SDI may harm your eyes!
- Optical components tend to be disturbed even by small amounts of dirt!
  - Some promising optical components are not available any longer
  - Trend: Optical for long distances, Converter, Electrical for short distances

**Challenges for Ultra HDTV ("4K") data rates**

- **How to unify fps to a single value?**
  - High Frame Rate (HFR) desired
    - Trend: Cinematographers want to have 48 fps (=2x24fps)
      - reasons: cinema’s fps does not even meet today’s requirements
    - UHD video can be improved by 120fps (=4*30fps)
      - Europe: thinks about 100fps (4*25)
      - Math: 150fps = 5*30fps = 6*25fps = similar to 6*24fps or 300fps = ... what about flickering?

- **High Dynamic Range (HDR) desired**
  - 12bit...16bit/sample instead of 8 or 10bit
  - 4:4:4:4 or 4:4:4 instead of 4:2:2 chroma subsampling

\[
16bit/px*3components*120fps*4096*2160px/frame = 5760bit/px*8847360px = 50,960,793,600bit/s = \geq 50Gbit/s
\]

**Solutions for the near (?) future**

- Multiple wires: Dual-Link, Quad-Link,...
- HEVC + other improvement => 4K@50fps or 60fps feasible today or soon (Eutelsat)
  - perhaps new source codecs specialized for HFR
  - perhaps new source codecs specialized for HDR

- **N.Bohr: "Prediction is very difficult, especially if it’s about the future."**
  - => Go slowly forward step-by-step
  - => Check your way regularly

**Why not a single worldwide TV standard?**

- **Historic decisions for power distribution in**
  - USA
    - Westinghouse
      - 100-127V (today mainly 110V)
      - 60Hz (instead of 50Hz)
    - later improvement for arc-lighting equipment
  - Germany (Europe)
    - AEG
      - 220V (today 230V+-10%)
      - 50Hz (instead of 40Hz)
    - earlier improvement for bulb light

- **Analog TV System**
  - 525lines/2:1/60Hz ("NTSC")
  - 625lines/2:1/50Hz ("PAL")
  - +PAL N/PAL M
  - +various others (mainly SECAM versions)