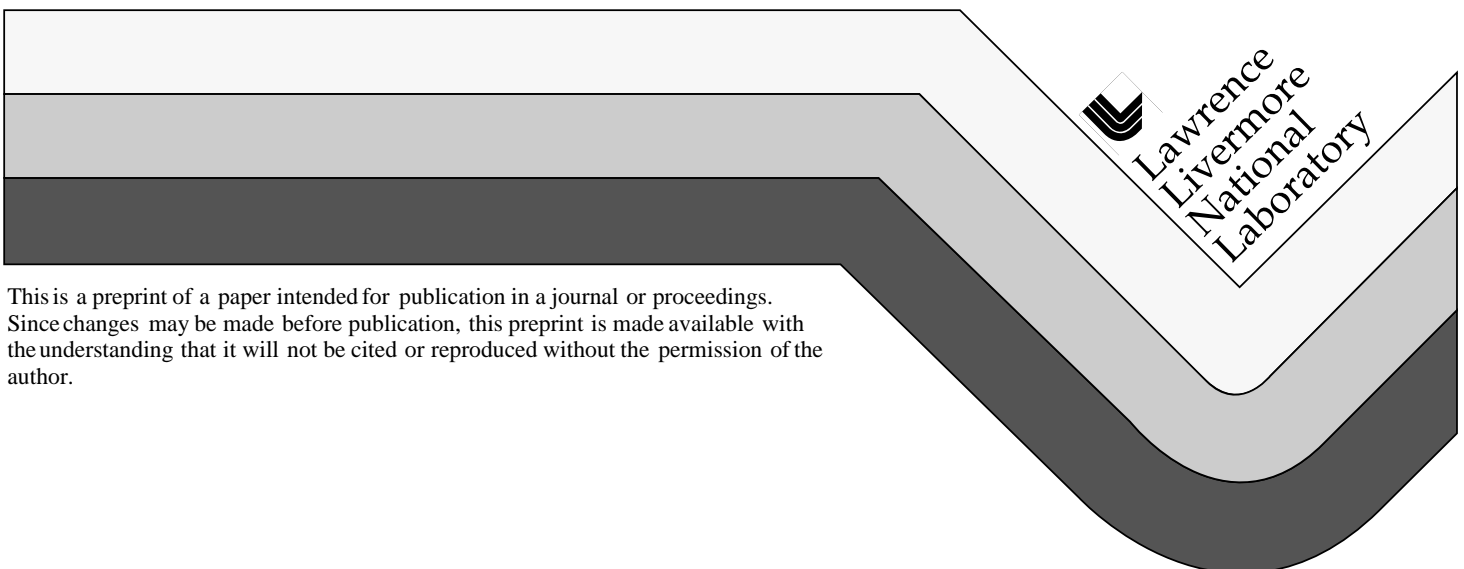# Digital Signal Coding

R. Gaunt

This paper was prepared for submittal to the
Association for Computing Machinery
Special Interest Group on Computer Graphics (SIGGRAPH) '97 Conference
Los Angeles, CA
August 3-8, 1997

May 1997

Lawrence Livermore National Laboratory

Digital Signal Coding

Ross Gaunt
Lawrence Livermore National Laboratory

It seems that digital video has gone by as many names as Jim Blinn has Siggraph ribbons. Some of its various formats and names are: DV, D1, 4:2:2, CCIR 601-1, ITU-Rec. 601-4,, SMPTE RP125M, and SMPTE 259M.   CCIR and CCITT were both absorbed into their parent organization, the International Telecommunications Union (ITU), so technically speaking, CCIR 601 has been renamed to ITU-Rec. 601-4   ("Rec." stands for recommendation).   But convention is often hard to change, so for some time you will see and hear D1 and CCIR 601 used for serial digital component video.   Below are brief descriptions of the various names and formats for digital video.

Format Specifications

ITU-Rec. 601-4	Encoding parameter standard for component digital video.
SMPTE 125M	Component video signal 4:2:2-Bit-Parallel digital interface.
SMPTE 259M	10-bit 4:2:2 component and 4fsc NTSC composite digital serial interface.

Note, 4fsc indicates an analog composite video signal that is digitized at four time the subcarrier clock rate.

Tape formats

D1	Sony 4:2:2 component digital with 8-bit recording and no compression.
D2	Ampex and Sony 4Fsc composite digital with 8-bit recording and no compression.
D3	Panasonic 4fsc composite digital with 8-bit recording and no compression.
D4	There is no D4.
D5	Panasonic 4:2:2 component digital with 10-bit recording and no compression.
D6	Digital high definition recorder. Luma sampling is 72MHz, chroma is 36Mhz, 8-bit.
D7	Proposed standard for the Panasonic DVCPRO format. It is 4:1:1 component with 8-bit recording and 5:1 compression using discrete cosine transfer, 25Mb/s data rate.
Betacam SX	Sony 4:2:2 component with 8-bit recording and MPEG-2 Studio Profile compression of 10:1.
CamCutter	Avid 4:2:2 component digital with 8-bit recording and proprietary compression.
DCT	AMPEX component format using 2:1 compression.
Digital Betacam	Sony 4:2:2 component digital with 10-bit recording and 2:1 compression.
Digital-S	JVC 4:2:2 component with 8-bit recording and 3.3:1 DCT compression.
DVCAM	Sony 4:1:1 component with 8-bit recording and 5:1 DCT compression.
DVPRO-50	Panasonic format similar to D7 but 4:2:2, 3.3:1 compression, 50Mb/s data rate.

Transmission Standards

SDI	Sony implementation of SMPTE-259M-1993, often called serial D1 or serial 601.
SDDI	Sony, Serial Digital Data Interface. Network protocol for SDI.
SSA	Scitex. Serial Storage Architecture. SCSI bus replacement, 128 bits per packet, arbitration free, store-while-forward.
CSDI	Philips, Panasonic. Compressed Serial Digital Interface local network protocol for SDI. Transmission of data at 4 x speed.
FiberChannel	Serial Rec. 601 over fiber. 800Mb/s, can carry SCSI-IP, IP, HiPPI-FP.
IEEE-1394	Firewire. Serial transmission of Rec. 601 real time video.

Okay, Jim Blinn has more ribbons than video has names.

Basics of Rec. 601 4:2:2, 525/60

- Rec. 601 does not specify any compression or transmission scheme.

- The luminance channel (Y) is sampled at four time the subcarrier frequency
  (3.375MHz x 4 =13.5Mhz).

- Color-difference channels (C_r, C_b) are sampled at two times the subcarrier frequency:
  6.75Mhz.   Note that V = R-Y, and U = B-Y are analog color spaces and that C_r and C_b are
  different color spaces for digital video, see 'Color Spaces' document.

- The total sampling rate is 27MHz = 13.5MHz + 6.75MHz + 6.75MHz. For uncompressed video
  601's data-transmission is 167Mbits per sec, which is the rate associated with D1 & D5.

- The earlier 8-bit recommendation serial bit rate was 243 Mbits/s, but SMPTE 259M
  superseded it with a 10-bit, 270 Mbits/s standard.

- There are 720 luminance samples of active video per horizontal line, and 360 color-difference
  samples of active video per horizontal line, for a total of 1440 samples per line.

- Sampled data may be in 8-bit (0-255) or 10-bit (0-1023) format.
  Y :   8-bit :   220 quantization levels, 16=black, 235=white.
             10-bit : 877 quantization levels, 64=black, 940=white.
  C_r, C_b: 8-bit: 225 quantization levels, 0 signal = 128, 128 signal = 255.
             10-bit: 897 quantization levels, 0 signal = 64, 128 signal = 960.
  The narrower than expected quantization ranges allow for analog filter undershoot and
  overshoot.

- FF_h and 00_h are reserved for timing reference signaling.

- There is no sampling of the blanking intervals, but instead there are the data words: Start of
  Active Video (SAV) and End of Active Video (EAV).

- The period of the blanking intervals may include supporting data, such as time code or
  digital audio.

- Horizontal byte designations:

0 - 1439	Active video
1440 - 1443	End of active video
1471	Horizontal sync
1712 - 1715	Start of active video

- Rec. 601 4:4:4 is similar to Rec. 601 4:2:2 except the Cb and Cr signals are sampled at 13.5MHz,
  720 chroma samples per line.

Byte Ordering for Serial Transmission
- For 4:2:2 Y, C_b, C_r, the serial ordering is:

  C_{B0}, Y_0, C_{R0}, Y_1, C_{B2}, Y_2, C_{R2}, Y_3, C_{B4}, Y_4, C_{R4}, ...
- For 4:4:4 Y, Cb, Cr the serial ordering is:

  C_{B0}, Y_0, C_{R0}, C_{B1}, Y_1, C_{R1}, C_{B2}, Y_2, C_{R2}, C_{B3}, Y_3, C_{R3}, ...

Misc.
Various manufacturers have added extensions for adding an alpha channel or sampling at higher rates.
- Alpha, or key channel: sampled at Y rate (13.5MHz), usually written as 4:0:0 (monochrome) or as 4:2:2:4.
- Color-Difference channels may be sampled at Y rate, written as 4:4:4. With an alpha channel, it is shown as 4:4:4:4.
- Sampling may be increased to 27Mhz, and is shown as 8:8:8, or 8:8:8:8.

REFERENCES:

James Blinn, "The World of Digital Video", IEEE Computer Graphics & Applications, September 1992, pp. 106-112.

David Bourgin, Color FAQ, http://www.hooked.net/users/rld/color_faq.html.

Curtis Chan, "Strictly TC: Digital Video", Broadcast Engineering, February 1994, p. 10.

Steve Epstein, "Transition to Digital: Digital Basics, part 1", Broadcast Engineering, August 1995, pp. 12-14.

Paul McGoldrick, "Digital Basics: The Basics of Digital Video", Broadcast Engineering, January 1996, P. 108.

Paul McGoldrick, "Digital Basics: D-1, Component Digital", Broadcast Engineering, March 1996, p. 306.

Charles A. Poynton, Tutorial: "Fundamentals of Color Reproduction", Siggraph 1993.

SMPTE Standards for Advanced Television and High Definition Production.

Technical Information Department • Lawrence Livermore National Laboratory
University of California • Livermore, California 94551