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National Aeronautics and
Space Administration

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DIGITAL TELEVISION STANDARDS for NASA

Version 3.0

NASA TECHNICAL STANDARD

FOREWORD

This standard is approved for use by the National Aeronautics and Space Administration (NASA) Headquarters and all NASA Centers and is intended to provide a common framework for consistent practices across NASA programs. It was developed by the NASA Digital Television Working Group (DTVWG) and by the NASA Office of the Chief Information Officer, Architecture and Infrastructure Division, to assist the development and implementation of Digital Television (DTV) systems that support the Agency.

Since the 1980s, the technology and equipment used for the acquisition, contribution, production and distribution of television has been moving from the traditional world of analog signals, recording formats and signal processing into the digital realm. Digital video systems, starting with cameras and recorders for image acquisition, through systems for program contribution and production, to final signal distribution are now in use in most television facilities. The commencement of commercial terrestrial DTV broadcasting in October of 1998 signified the initial availability of end-to-end DTV capability in the United States. This culminated with the end of full power analog broadcasting in June of 2009.

The U.S. standard for terrestrial DTV broadcasting established by the Federal Communications Commission (FCC) is based on work recorded in document A/53 prepared by the Advanced Television Systems Committee (ATSC). In addition to specifying a method for broadcasting a digital representation of the traditional U.S. 525 line interlace scan television format, the ATSC A/53 document detailed many new television formats and variations for both Standard and High Definition Television (SDTV and HDTV). Although the FCC adopted most aspects of the ATSC recommendations when it established the standard for U.S. DTV broadcasting, it declined to specify the use of any particular picture format or formats. However, the formats listed in table 3 of the ATSC A/53 document are generally accepted in the television industry as the formats to be used for broadcasting. The result of this action has been that instead of just one format of television for all uses, there are now many different available types and levels of quality of DTV.

During the era of a single analog U.S. standard video signal format, American National Standards Institute (ANSI)/Society of motion Picture and television Engineers (SMPTE) 170M-1994, there has been no real need for NASA to develop Agency-wide television signal standards. The fact there were so many new and different picture formats and signal processing methods available demonstrated the reason for NASA to establish standards for DTV. These standards were needed so there may be common methods developed for the acquisition and production of DTV information and for the distribution and interchange of DTV signals and video products within, and external to, the Agency.

Requests for information, corrections, or additions to this standard should be directed to the NASA DTV Program Office, Marshall Space Flight Center (MSFC), Huntsville AL 35812. Requests for general information concerning standards should be sent to the NASA Technical Standards Program Office, Office of the Chief Engineer, NASA Headquarters, Washington DC 20546. This and other NASA standards may be viewed and downloaded from our NASA Standards Homepage: http://standards.nasa.gov.

Linda Y. Cureton
Chief Information Officer

REVISION HISTORY

Version 1.0: Original approved document, April 4, 2000.

Version 2.0: Update to include corrections and additional DTV guidelines, September 18, 2007.

Version 3.0: Update with additional DTV guidelines and quality parameters, April 1, 2011.

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DIGITAL TELEVISION STANDARDS FOR NASA

1. SCOPE AND APPLICABILITY

1.1 Scope. The DTV system standards described in this document are associated with those industrial or professional systems used to produce full motion and full resolution digital video imagery that is suitable for critical closed circuit or broadcast use and which is normally distributed over wide bandwidth communications systems designed for the transmission of television. It is not the intention of the DTVWG or of the Office of the Chief Information Officer to imply or endorse the use of any specific commercial vendor standards, designs or hardware.

For the purposes of this document, the uses for video acquisition, contribution, production and distribution within NASA are considered as falling into one of two broad categories: *Engineering* and *Publication*. *Engineering* video is defined as video imagery that is acquired primarily for the purpose of being used by NASA or other authorized personnel, either in real-time or post-event, to observe, analyze, or document a NASA technical or operational activity. Examples of *Engineering* video include imagery of space launch and space flight activities, flight vehicle tests, laboratory and facility testing, scientific experiments, and training. *Publication* video is defined as video imagery that is acquired primarily for the purpose of being integrated into live television segments or edited programs that are created for disseminating information concerning NASA activities within the agency and/or for release to the news media or the public. Examples of these programs include educational or training videos, televised briefings or press conferences, video-file material, live-shots and video coverage of other NASA events. Acquisition for *Publication* video often strives for high artistic as well as high technical imaging performance. It is also noted that *Publication* video programs may be produced partially or in their entirety using video imagery originally acquired for *Engineering* purposes. NASA organizations must carefully determine their requirements and then select and use appropriate equipment and systems which are compliant with this standard for satisfying their particular video imagery needs.

These DTV standards shall apply to all NASA Center systems infrastructure used to acquire, produce and distribute *Engineering* and *Publication* video. It is recognized that the specific analysis needs or unique constraints associated with certain flight, test or laboratory imaging could require the use of specialized imagery systems which may not precisely adhere to these DTV standards. If any programs or projects that use specialized systems require NASA Center DTV infrastructure services, they shall be required to convert their non-standard signals or products to meet the NASA DTV infrastructure standards at an interface point.

This document does not, at this time, discuss or provide standards for the implementation of digital video other than regular full motion and full resolution systems or which use other than wide band communications systems designed specifically for standard video transmission. This includes systems used for video surveillance, for very high speed imagery, for teleconferencing video or for the streaming distribution of live video or on-demand video segments to viewers over a computer intranet or the Internet. It is expected that future versions of this or other similar documents will address NASA standards for these other types of digital motion imagery.

1.2 Applicability. This standard recommends engineering practices for NASA programs and projects. It may be cited in contracts and program documents as a technical requirement or as a reference for guidance. Adherence to this standard and its provisions is the responsibility of program/project management and the performing organization. It is recognized that some specific circumstances, such as activities jointly pursued with a commercial or international partner, may involve or require the use of DTV equipment which varies from these standards. However, organizations are otherwise obliged to use systems which adhere to the guidance within this document unless there are specific functional or performance requirements of a particular DTV application, project or program which prohibit using these standards. Inquiries regarding exceptions to this standard should be directed to the NASA DTV Program Control Board. Information about requesting an exception is available from the DTV Working Group voting member at each center.

2. ACRONYMS AND DEFINITIONS

2.1 Acronyms

2.1.1	AES/EBU	Audio Engineering Society/European Broadcasting Union
2.1.2	ANSI	American National Standards Institute
2.1.3	ATSC	Advanced Television Systems Committee
2.1.4	AAC	Advanced Audio Coding
2.1.5	AVC	Advanced Video Coding
2.1.6	CCD	Charge Coupled Device
2.1.7	CODEC	EnCOder/DECoder or COmpression/DECompression
2.1.8	DCT	Discrete Cosine Transform
2.1.9	DTV	Digital Television
2.1.10	DTVWG	Digital Television Working Group
2.1.11	DVD	Digital Versatile Disk
2.1.12	FCC	Federal Communications Commission
2.1.13	GOP	Group Of Pictures
2.1.14	HDSDI	High Definition Serial Digital Interface
2.1.15	HDTV	High Definition Television
2.1.16	IEEE	Institute of Electrical and Electronic Engineers
2.1.17	ISO	International Organization for Standardization
2.1.18	MPEG	Moving Pictures Experts Group
2.1.19	NTSC	National Television Standards Committee
2.1.20	SDI	Serial Digital Interface
2.1.21	SDTV	Standard Definition Television
2.1.22	SMPTE	Society of Motion Picture and Television Engineers

2.2 Definitions.

2.2.1 Acquisition. The initial capture of video imagery.

2.2.2 Acquisition Equipment. Equipment used for the initial capture of video imagery. It can be Production Level quality, but in the case of High Definition Television (HDTV) field camcorders, it may have to compromise some aspects of image quality in order to have a one-piece camcorder configuration.

2.2.3 Contribution Level. A lower quality of video distribution between facilities but which is still acceptable for use for production or post-production.

2.2.4 Distribution Level. A lower quality of video distribution between facilities or from facilities to users acceptable for final user viewing, but not for production or post-production.

2.2.5 Engineering Video. A category of NASA video acquired primarily to observe, analyze, or document a technical or operational activity. Engineering Video is further divided into Critical and Non-Critical sub-categories.

2.2.6 HDTV (High Definition Television). Video with $\geq$ 720 active scan lines.

2.2.7 Interlace Scan. Video scanning method where each image frame is scanned in two parts or fields. One field consists of the odd numbered scan lines, the second of the even numbered scan lines. Sometimes referred to as 2:1 scanning.

2.2.8 Pixel. In digital television, the smallest element in the makeup of an image.

2.2.9 Production, Post-Production. Manipulation of images by switching, special effects, or editing to create a video program. Production is generally real-time creation for immediate release. Post-production is generally not real-time and is associated with editing for creation of recorded video programs.

2.2.10 Production Level. The highest quality of video used within a facility for live programming or for the manipulation of video imagery after acquisition (post-production)

2.2.11 Progressive Scan. Video scanning method where the each image frame is scanned in one continuous pass without dividing the frame into fields (see Interlace Scan). Sometimes referenced to as 1:1 scanning.

2.2.12 Publication Video. A category of NASA video acquired primarily for the purpose of disseminating information concerning activities within the agency or to the news media and the public. Publication Video is further divided into Critical, Non-Critical and Informal sub-categories.

2.2.13 Scan Line. Smallest vertical unit of a video picture, which runs horizontally across the screen. Pixels make up scan lines.

2.2.14 SDTV (Standard Definition Television). Video with <720 active scan lines. For U.S systems, this is 480 or 486 active scan lines.

2.2.15 Segmented Frame. Video scanning method where each image frame is initially scanned in one continuous pass (see Progressive Scan), but then divided into two fields for recording or transmission, one field consisting of the odd numbered scan lines, the second consisting of the even numbered lines.

2.2.16 Video Frame. Total scan lines that comprise a complete video picture. Analogous to a frame of film in a motion picture.

3. NASA DTV STANDARDS

This document establishes three major categories of NASA DTV standards:

- Acquisition and Production Picture Formats
- Video/Audio Signal Sampling Representation and Compression
- Interfaces

The DTVWG has engaged in considerable analysis, testing and debate regarding these areas and has arrived at the conclusions detailed in this section. Rationale for these choices is contained in the appendices to this document.

The Foreword of this document states that these NASA standards are needed so there may be common methods developed for the acquisition and production of DTV information and for the distribution and interchange of DTV signals and video products within, and external to, the agency. These standards are also intended to establish minimum levels for functional and quality performance characteristics considered acceptable for critical NASA video requirements. This position has been taken to help avoid the type of problems that have occurred in producing video products of historic events due to the use of lower quality recording formats such as VHS, 8mm and U-Matic to acquire NASA video in the past. Thus these standards provide guidance to NASA organizations for the selection of hardware and software to satisfy DTV requirements. DTV equipment and systems do exist in the marketplace which vary in functional capabilities and/or do not meet the performance specifications of these standards for critical applications. NASA organizations may be tempted to use equipment other than that which meets these standards due to its lower cost or because of other considerations such as the compact size or low weight of some available items. However, as stated earlier in section 1.2 Applicability, organizations are otherwise obliged to use systems which adhere to the guidance within this document unless there are specific functional or performance requirements of a particular DTV application, project or program which prohibit using these standards.

Several levels of these standards have been established related to the use of the NASA video being acquired. In section 1.1 of this document, the major categories of *Engineering* and *Publication* video were defined. These two categories can be further divided into *Critical, Non-Critical* and *Informal* video. These two categories are further divided into *Critical, Non-Critical* and for *Publication Video* only, *Informal* video sub categories. Systems used for *Critical* video acquisition normally require the highest technical imaging performance and thus require the highest standards. Some less critical video, which may include imagery not meant to capture important details or aspects of the activity or which is not intended for further elaborate post production use may have reduced image performance requirements. Less stringent technical standards can be applied to this *Non-Critical* sub-category. These lower standards can also allow the use of less expensive equipment to meet these less critical needs. For *Publication* video, a third sub-category, *Informal Publication Video*, can be defined. It is recognized that some video may be considered important documentation of a historic event or otherwise newsworthy, even though it may be of lower quality or may have been acquired using non-professional or non-traditional means including low cost consumer equipment, hand-held mobile devices or captured from the Internet. Thus *Informal Publication* video may not only have lower quality performance, but may also differ in basic picture format. Such *Informal* video is not considered adequate for any NASA *Engineering* application. The tables in this section list the standards for these different sub-categories where applicable.

The referenced applicable standards are published by organizations such as the American National Standards Institute (ANSI), the Audio Engineering Society/European Broadcasting Union (AES/EBU), the Institute of Electrical and Electronic Engineers (IEEE), and the Society of Motion Picture and Television Engineers (SMPTE). Moving Picture Experts Group (MPEG) standards are published by the International Organization for Standardization (ISO).

3.1 Acquisition and Production Picture Formats

The tables in this section list the DTV picture format standards selected for acquisition and production of standard and high definition television. Selection of a DTV picture format includes the selection of an individual frame size in horizontal and vertical pixels, the image aspect ratio, the scanning method used and the frame rate. For the acquisition of most high definition video, the NASA standard shall be 720 progressive (720P) at 59.94 frames per second. For the transfer of motion picture film based imagery material to high definition video or for the acquisition of selected *Publication* category video which specifically requires the highest static image resolution, an optional alternative to 720P is to use 1080 progressive or segmented frame at 23.98, 29.97 or 59.94 frames per second. For the acquisition of standard definition video, the NASA standard shall be 480 interlace at 29.97 frames per second. Acquired video used for *Informal Publication* may vary from these picture formats.

TABLE IA. High Definition Television Format

ACTIVE PICTURE PIXEL SIZE (H x V)	PICTURE ASPECT RATIO	SCANNING METHOD	FRAME RATE	APPLICABLE STANDARD
1280 X 720*	16:9	Progressive (1:1)	59.94 Hz	SMPTE 296M-2001

*Also acceptable for many applications are acquisition equipments or systems that process or record HDTV using fewer than 1280 horizontal luminance samples down to ¾ square pixel format (i.e. 960 pixels) using sub sampling, off-set pixels or similar techniques to reduce bandwidth requirements. The horizontal resolution of the camera or recorder output signal shall be scaled to a full 1280 pixels.
Note: For HDTV distributed for final viewing, terrestrial broadcast standards for 720P stipulate using 1280 horizontal pixels.

TABLE IB. Optional HDTV Format for Film Transfer and Special Publication

ACTIVE PICTURE PIXEL SIZE (H x V)	PICTURE ASPECT RATIO	SCANNING METHOD	FRAME RATE	APPLICABLE STANDARD
1920 X 1080**	16:9	Progressive (1:1) or Segmented Frame	23.98 Hz, 29.97 Hz or 59.94 Hz	SMPTE 274M-2003

**It is recommended that equipment or systems that process or record 1080P HDTV using fewer than 1920 horizontal luminance samples not be used for acquisition to maintain the highest quality of master video transfers from film.
Note: It is expected that video material acquired in this format would typically be transferred to another picture format for production or for final distribution.

TABLE II. Standard Definition Television Format

ACTIVE PICTURE PIXEL SIZE (H x V)	PICTURE ASPECT RATIO	SCANNING METHOD	FRAME RATE	APPLICABLE STANDARD
720 X 480/486 (Non-Square Pixel)	4:3 or 16:9	Interlace (2:1)	29.97 Hz	ANSI/SMPTE 125M-1995 (4:3) ANSI/SMPTE 267M-1995 (16:9)

Note: SDTV distributed for final viewing may also be encoded using fewer than 720 horizontal pixels (e.g. 704, 640, 544, 528, 480 or 352) to reduce bandwidth requirements, however terrestrial broadcast standards for 480I stipulate using 704 or 640 horizontal pixels.

3.2 Video/Audio Signal Sampling Representation and Compression

The tables in this section list the DTV standards for signal sampling representation and compression.

TABLE III. Video Signal Sampling Representation – HDTV and SDTV

FUNCTION	SIGNAL SAMPLING REPRESENTATION	WORD LENGTH
Acquisition for Critical Engineering or Publication	Complete chroma information sampling on every video line. Signal representation may be 4:4:4, 4:2:2, 4:1:1, 3:1:1, etc. Luminance or chroma image sub-sampling or resolution filtering may be performed per the specific recording format	8 bit minimum
Acquisition for Non-Critical Engineering or Publication and Informal Publication	4:4:4, 4:2:2, 4:1:1 or 4:2:0. Luminance or chroma image sub-sampling or resolution filtering may be performed per the specific recording format	8 bit minimum
Video Editing or Duplication Using 3:1:1, 4:1:1 or 4:2:0 Acquisition Formats	Editing and duplication may be accomplished if transfers and manipulation of the recorded bit stream occur unaltered in a native (e.g. DV) or "dub" mode such that no decoding and re-encoding of the video signal is performed.	8 bit minimum
Production and Postproduction	4:4:4 or 4:2:2; No luminance or chroma image sub-sampling. No resolution filtering.	8 bit minimum
Intra/Inter-Center and External Transfer for Critical Contribution	4:2:2; No luminance or chroma image sub-sampling. No resolution filtering.	8 bit minimum
Intra/Inter-Center and External Transfer for Non-Critical Contribution	4:2:2 or 4:2:0	8 bit minimum
Distribution for Viewing	4:2:0	8 bit
Archiving	Use a production quality format for completed video programs. May use an acquisition format for unaltered original material or material "cuts only" edited from an acquisition format.	8 bit minimum

TABLE IV. Video Compression – HDTV and SDTV

FUNCTION	COMPRESSION
Acquisition for Critical Engineering or Publication	Dependent upon the characteristics of the specific recording format and compression method used, but shall be intra-frame based. If using intra-frame 4:2:2 MPEG-2 or DV, shall use a video data rate of no less than 100 Mbps for HDTV and no less than 30 Mbps for SDTV. If using 4:1:1 DV shall use a video data rate of no less than 25 Mbps for SDTV. Also may use systems that employ other codecs at data rates which provide equal or better performance. See Annex VQ for further video quality recommendations.
Acquisition for Non-Critical Engineering or Publication and Informal Publication	Dependent upon the characteristics of the specific recording format and compression method used. May be intra-frame or GOP based, 4:2:2, or 4:2:0. See Annex VQ for further video quality recommendations.
Video Editing or Duplication Using 3:1:1, 4:1:1 or 4:2:0 Acquisition Formats	Editing and duplication may be accomplished if transfers and manipulation of the recorded bit stream occur unaltered in a native (e.g. DV) or "dub" mode such that no decoding and re-encoding of the video signal is performed.
Production and Post-Production	Uncompressed or intra-frame compression less than or equal to 5:1 if 4:2:2 MPEG-2 or DV. Also may use systems that employ other codecs at data rates which provide equal or better performance. See Annex VQ for further video quality recommendations.
Intra/Inter-Center and External Transfer for Critical Contribution	HDTV: If MPEG-2, 4:2:2 Profile @ High Level; GOP size less than or equal to 15 frames; video data rate greater than or equal to 30 Mbps. SDTV: If MPEG-2, 4:2:2 Profile @ Main Level; GOP size less than or equal to 15 frames; video data rate greater than or equal to 8 Mbps. Also may use systems that employ other codecs at data rates which provide equal or better performance. See Annex VQ for further video quality recommendations.
Intra/Inter-Center and External Transfer for Non-Critical Contribution	HDTV: If MPEG-2, 4:2:0 Profile @ High Level; GOP size less than or equal to 15 frames; video data rate greater than or equal to 24 Mbps. SDTV: If MPEG-2, 4:2:0 Profile @ Main Level; GOP size less than or equal to 15 frames; video data rate greater than or equal to 6 Mbps. Also may use systems that employ other codecs at data rates which provide equal or better performance. See Annex VQ for further video quality recommendations.
Distribution for Viewing	HDTV: If MPEG-2, Main Profile @ High Level; GOP size user defined; video data rate greater than or equal to 12 Mbps. If MPEG-4, High Profile@Level 4.1, GOP size user defined (typically 15 frame); video rate greater than or equal to 12 Mbps. SDTV: If MPEG-2, Main Profile @ Main Level; GOP size user defined; video data rate greater than or equal to 3 Mbps. (If sub-sampled) Also may use systems that employ other codecs at data rates which provide equal or better performance. See Annex VQ for further video quality recommendations.
Archiving	Use a production quality format for completed video programs. May use an original acquisition format for unaltered original material or material "cuts only" edited from an acquisition format.

TABLE V. Audio Signal Sampling Representation and Compression

FUNCTION	APPLICABLE STANDARD
Acquisition, Production, Post-Production and Archiving	AES3, 48 KHz audio signal sampling or the native format of unaltered Acquisition material.
Intra/Inter-Center and External Transfer for Critical Contribution	MPEG-1 Layer 2 (ISO 11172-3) at a rate greater than or equal to 128 Kbps per channel or Advanced Audio Coding (AAC) (MPEG-2 Part 7 / MPEG-4 Part 3) at a rate greater than or equal to 96 Kbps per channel.
Intra/Inter-Center and External Transfer for Non-Critical Contribution	ATSC/Dolby AC-3 (Dolby Digital), MPEG-1 Layer 2 (ISO 11172-3) or AAC.
Distribution for Viewing	ATSC/Dolby AC-3 (Dolby Digital), MPEG-1 Layer 2 (ISO 11172-3) or AAC.

3.3 Interfaces

Standardized data transfer interfaces need to be established for distribution of DTV within and between the NASA Centers and for the release of digital video to external NASA customers, the news media and the public. Interfaces are also needed for receiving digital video from flight vehicles such as the International Space Station (ISS) and the vehicles of future programs. The initial specification of signal interfaces for transmission applications are listed in the tables below. These define interfaces for the transfer of uncompressed or compressed DTV between a source and a destination or between a source and a transmission path. That path may involve an interface to a transport or network mechanism, such as with TCP/IP, or directly to a physical media, such as with a cable or fiber. Further specification of other interfaces will be developed appropriate to specific applications, based on the standards presented in the previous sections.

TABLE VI. Uncompressed Signal Transmission – HDTV and SDTV

FORMAT	INTERFACE DATA RATE	WORD LENGTH	APPLICABLE STANDARD
HDTV	1483.5 Mbps	10 bit	SMPTE 292M-2004
SDTV	270/360 Mbps	10 bit	ANSI/SMPTE 259M-1997 Levels C & D
HDTV and SDTV	Up to 10.2 Gbps	8, 10 or 12 bit	High Definition Multimedia Interface (HDMI) V1.3 or higher

TABLE VII. Compressed Signal Transmission – HDTV and SDTV

FORMAT	INTERFACE DATA RATE	WORD LENGTH	APPLICABLE STANDARD
HDTV and SDTV	270 Mbps	8 bit minimum	Digital Video Broadcasting Asynchronous Serial Interface (DVB-ASI)
HDTV and SDTV	Varies	8 bit minimum	MPEG Transport Stream (MPEG-2 Part 1 / ISO 13818-1) for both MPEG-2 and MPEG-4 transmission
SDTV	100/200/400/800 Mbps	8 bit minimum	Institute of Electrical and Electronic Engineers (IEEE) 1394

APPENDIX A

DISCUSSION OF PICTURE FORMATS

HDTV

In making the original choice of a HDTV picture format for NASA, several constraints were considered. One assumed constraint was that available equipment would typically not work to more than one format, so a single HDTV picture format standard would need to be chosen. Another constraint, given existing standards, was the need to be able to transfer signals using equipment that conformed to the SMPTE 292M-1996 High Definition Serial Digital Interface (HDSDI). Another desire was to assure compatibility with the broadcast television community by choosing from among the picture formats defined by the ATSC.

Since these original studies, some of these assumptions have been challenged. Equipment exists that can operate in more than one picture format standard. However, the transferring of imagery from one HDTV standard to another, while possible, may introduce image degradation or other problems. So it is still considered desirable to use one agency picture format standard for acquisition, contribution and production rather than having centers, projects, programs or organizations choose their own, and perhaps different, standards. Most professional equipment still uses the HDSDI interface, although the DVB-ASI interface can also be used for the transfer of compressed HDTV signals. Plus, in addition to normal terrestrial and satellite transmission methods, options for transferring contribution video now include real-time or non-real-time transmission as serial streams or as files over computer networks using the Internet Protocol. The desire for commonality with the broadcast television community cannot be completely fulfilled since that group does not use a single picture format standard. Another recognized factor is that broadcasters often acquire or produce video in one format and distribute to the public in another, particularly with scripted programs. So having an agency standard HDTV picture format in common with broadcasters is not possible for all cases.

As defined by the ATSC, HDTV has three major picture formats:1280 X 720 progressively scanned at 24, 30 or 60 frames per second (FPS) (720P@24/30/60);1920 X 1080 progressively scanned at 24 or 30 FPS (1080P@24/30); and 1920 X 1080 interlace scanned at 30 FPS (1080I@30). The last format is sometimes referred to as 1080I@60 by some in the video industry by referring to the *field* per second or vertical refresh rate of the image. Note that the frame rates may be even integer or slightly offset values such as 29.97 and 59.94 FPS to ease compatibility with the existing NTSC infrastructure. However the integer values are often listed for brevity even though the actual frame rate used may be an offset value. All standard HDTV formats use a square pixel representation and a 16:9 image aspect ratio. Interlace scan HDTV was first developed in the late 1970s. It was initially an analog method with 1125 total lines per frame of which 1035 were active image lines, although the number of active lines was later increased to 1080. The image is scanned using a two to one interlace method similar to the existing NTSC 525 line system. With this method, two fields, one for the even numbered lines and one for the odd lines, are sequentially scanned to capture each video frame. Since this method also displays the two fields in sequence, it provides an image refresh rate that is twice the actual frame rate. Some refer to this characteristic as a type of analog compression which was very useful during the era of picture tube displays. With the progressive method, each complete video frame is captured in one continuous scan. The display refresh rate using this method is normally the same as the frame rate. A variant of progressive scan is segmented frame, which initially scans the entire image but transfers the image in two segments similar to interlace fields. Although acquisition and production is done in several different formats, all HDTV broadcast distribution in the U.S. is done in either 720P@59.94 or 1080I@29.97.

A series of tests were conceived and conducted by the DTVWG to compare available interlace scan and progressive scan HDTV equipment. The 1080I@30 and 720P@60 formats were compared. A report on the results of these tests can be found on the NASA DTV web site (https://share.nasa.gov/teams/msfc/dvwg/default.aspx - Digital Television Working Group/Standards/Shared Documents) or can be obtained from the NASA DTV Project Office. The tests demonstrated comparable resolution and quality of the two formats when images were viewed in real time. Interlace video displayed some image artifacts that are introduced by the scanning method, but these are not significant for most general viewing. No similar artifacts appeared to be introduced by progressive scanning. However, when the video was captured and analyzed in still frame (and additionally in still field for interlace video), significant differences between the scanning methods became apparent. It was shown that interlace artifacts can alter the appearance of an object. It has been determined by research, and verified by equipment manufacturers, that the scanning characteristics of the Charge Coupled Device (CCD) image sensors used in higher quality interlace HDTV cameras cause considerable distortion of fine detail image material that appears 1-2 video lines (pixels) tall. Better quality progressive scan HDTV cameras also use CCD sensors, but the scanning characteristics of these devices are different. Similar image detail distortions do not occur when true progressive scan image sensors are used. Additional tests were performed to assess the results of transcoding from one format to the other. These tests showed that progressive scan source video transcodes to interlace without generating additional artifacts, but that artifacts existing in interlace scan source video carry over when transcoded to progressive. Both formats produced excellent results when down converted to 525 line interlace scan video. The artifacts associated with interlace scanning effectively negate some of the originally expected resolution advantage of 1080I@30 over 720P@60. The results of this testing plus knowledge gained from other research has proven to the DTVWG the general superiority of the progressive scan method over the traditional interlaced method for HDTV acquisition and production particularly for *Engineering* video requirements. It is also generally accepted within the television production and broadcast communities that progressive scan master recordings are superior for transcoding to all DTV formats. Thus, progressive scan HDTV was chosen by the DTVWG to ultimately be the NASA standard for acquisition. These tests were performed several years ago, but the method of scanning with CCD image sensors has not changed. The test results with CCD sensors are still valid. Complementary Metal Oxide Semiconductor (CMOS) sensors are fundamentally different from CCDs. CMOS sensors are becoming more common, especially in smaller format cameras. The scanning method used for CMOS sensors differs from CCDs to the point where many of the interlace artifacts from CCD scanning methods are not apparent, but will still have inter-field jitter for freeze frame applications.

The tests mentioned in the previous paragraph were performed in 1999. Although these tests were done some time ago, as of this writing, the method of scanning with CCD image sensors has not changed. The test results with CCD sensors are still considered valid. Complementary Metal Oxide Semiconductor (CMOS) sensors are fundamentally different from CCDs. CMOS sensors have become more common, especially in smaller format cameras. The scanning method used in CMOS sensors differs from CCDs such that many of the interlace artifacts from CCD scanning methods are no longer apparent in real time, but still display inter-field jitter when using freeze frame.

The DTVWG considered the use of the 1920 X 1080 progressive @ 60 FPS (1080P@60) format (thought to be the “Holy Grail” of HDTV). 1080P@60 is defined under SMPTE 274M but was not included as one of the initial ATSC standard distribution formats. The available equipment that supports this format is normally used only in very high end applications. Use of this format with current technology usually requires either the use of a form of mezzanine compression or use of a dual HDSDI link connection (SMPTE 372M) although the television industry has also worked to develop a serial digital interchange standard based on a data transfer rate of approximately 3 Gbps (SMPTE 424M). Since the use of 1080P@60 acquisition is not currently practical for most NASA applications (and budgets), it is not to be considered for the principal HD picture format standard at this time. The use of 1080P@60 is allowed as an optional format for selected applications. Broad use of 1080P@60 remains a goal when and if future developments allow the practical use of this format.

Some within NASA had originally suggested the initial use of 1080I@30 HDTV equipment and then to transition to a progressive format later. It was argued that, at that time, interlace equipment was already widely available, that 1080I provides much higher spatial resolution than existing NTSC and that the 60 Hz field rate provides high temporal resolution. This course of action was not recommended by the DTVWG because of the issues associated with interlace scanning artifacts, the demonstrated advantages of progressive scanning and of the problems and expense that could be associated with performing an additional format transition. The DTVWG recommended no further acquisition of interlace scan HDTV equipment and limiting the use of this format to that equipment which may have already been purchased within the agency. The DTVWG continues to recommend the use of a progressive scan HDTV acquisition standard. It is acknowledged that some projects and programs, specifically the Space Shuttle and the ISS, have continued to use 1080I equipment. This compromise to use 1080I on orbit was made due to the requirements of international partners, who also arranged for much of this acquisition and video signal processing equipment to be flight certified.

The task at hand was to choose a progressive scan format that, assuming a long-term goal of migrating to 1080P@60, may be considered an interim HDTV format. However, a consideration needed to be that this might also remain the permanent NASA HDTV format if 1080P@60 does not become a practical alternative in the future. The choice then appeared to be between 1080P@24/30, which favors higher spatial resolution, and 720P@60, which favors higher temporal resolution.

The DTVWG originally noted that few available HDTV displays had the resolution capability to be able to show a dramatic image difference between 1080P and 720P. That has changed as monitors of several display technologies capable of displaying 1080P have become more prevalent. Also noted is that some playback systems and displays convert 720P or 1080I input signals to 1080P for display, similar to how some standard definition DVD Video systems convert the 480I recordings and display 480P or 1080I. However, many HDTV camcorders and some broadcasters horizontally sub-sample the video, reducing any spatial resolution advantage of originating in 1080. Also noted is that 1080P@24/30 can exhibit substantial flicker if displayed in its native format, although newer high refresh rate monitors can mask this effect. More likely, 1080P@24/30 would often have to be converted to 1080I@30 for distribution or display, thus losing some of the benefit of progressive scanning.

The capability of the 720P@60 format to acquire 60 progressively scanned frames per second is a very important consideration. Many researchers and operational groups have expressed a preference for a high television frame rate, and as well for progressive scanning. 720P@60 provides double the temporal resolution of the 1080P@30 format. This attribute is very useful in that it allows this format to capture twice as much information about fast moving events. In commercial broadcasting, this format has shown an advantage in the coverage of high motion events such as sports. Since most HDTV monitors can now display 720P@60 in its native format, all of the temporal as well as spatial information captured by this format can be used.

The DTVWG studied some practical equipment considerations. As this document was originally being prepared, there were two sources of cameras and video recorders for 1080P@24/30. There were four manufacturers of 720P@60 cameras, and two of these made video recorders in the format. Available routing and distribution equipment could support either format. Some HDTV signal processing, test and production equipment could operate in 1080P@24/30 whereas nearly all such equipment could operate in 720P. With respect to choosing the 1080P@24/30 format, one manufacturer indicated there was a degree of backward compatibility to their existing formats afforded due to an ability to playback recordings of interlace scan SDTV and HDTV material on proposed 1080P@24/30 equipment. An opinion supporting this approach was expressed by some due to this proposed capability to play old tapes on newer equipment. Overall, the DTVWG did not consider this to be a significant factor due to the limited amount of NASA owned interlace scan HDTV equipment. Based on discussions with two major manufacturers of HDTV equipment, it was considered unlikely that future 1080P@60 equipment will provide any such backward compatibility. The DTVWG assumed that some degree of temporal and/or spatial transcoding would be required to convert any existing material to 1080P@60, regardless of which interim HDTV format was chosen. The DTVWG also believed it would more likely be desired to play any existing interlace scan recordings, either standard or high definition, on native format equipment and perform sophisticated motion compensated de-interlacing and any needed up conversion in a separate processor to more effectively transcode this material to a progressive scan high definition format for further production. The overall costs associated with the implementation of either the 720P or 1080P format were expected to be similar.

Another consideration was looking at which HDTV formats are being adopted by others. The International Telecommunications Union (ITU) has issued standards that establish both 1280 X 720 and 1920 X 1080 as common image formats. Some broadcast networks have chosen 1080I@30 as their broadcast distribution standard while others have chosen 720P@60. However, it should be noted that progressive formats such as 720p@24 and 1080P@24 are being commonly used as a video replacement for motion picture film for the acquisition and production for many episodic television productions which are subsequently distributed using 720P@60 or 1080I@30. No network has chosen 1080P as a broadcast standard although some high definition optical discs are recorded in a 1080P@24 format. Other US Government agencies, notably the Department of Defense, have standardized on 720P@60. Although there was no clear guidance derived from this particular study, any influence of this factor would seem to lead NASA to follow the choice of other US Government agencies.

It is the opinion of the DTVWG that the temporal resolution advantage of 720P@60 would generally be of more value for a broader range of NASA motion imagery acquisition applications than other HDTV formats. As an interim standard format, 720P@60 provides progressive scanning, the highest available frame rate and much higher spatial resolution than standard NTSC video. The DTVWG also considers 720P@60 to be a suitable permanent HDTV format if acquisition using 1080P@60 never becomes a practical and affordable reality. As a result, the DTVWG has selected 720P to be the initial NASA HDTV standard picture format for most new video acquisition. An offset frame rate of 59.94 Hz, rather than the integer rate of 60, has been chosen to facilitate real time down or up conversion to or from the legacy NTSC format.

Some special, selected DTV applications can take advantage of the additional spatial resolution of 1080P@24/30 where the lower frame rate of that format is not an issue. One of these is the transfer of motion picture film based material to video. Another is the acquisition of selected video material in the *Publication* category that strives for very high static image quality. For these specific uses, the 1080P format using a frame rate of either 23.98, 29.97 and also 59.94 as appropriate for the specific material, is an optional video acquisition alternative to 720P. However, using 1080 acquisition may not provide a significant improvement in many cases. Ongoing DTVWG tests of available cameras have indicated that effective results using 1080 acquisition requires the use of high end equipment with large (i.e. 2/3 inch) image sensors and high quality lenses in order to produce a readily visible improvement over 720P. With semi-professional and consumer equipment, often very little, if any, difference can be seen between 720P, 1080I and 1080P. In practical terms, the resolution of this lower cost gear, which typically uses smaller three chip or single chip imagers and low to medium quality lenses, looks more like very good quality standard definition than real high definition video.

Once video material has been acquired, further decisions are required about the format to be used for contribution, production and final distribution of the video. In most cases, contribution video should remain in the original acquisition picture format. This is also normally true for production and post production as well, although if productions use a mixture of progressive and interlace source material, it is sometimes preferred to produce in 1080I since many types of equipment used to transcode 1080I to a progressive format actually drop the resolution to 540P during the processing thus reducing the quality of the interlace video. The choice of a final distribution format may depend on the distribution media or method. In many cases, distribution in the normal broadcast picture format standards of 720P@60 or 1080I@30 is appropriate. In some circumstances, distribution in 720P or 1080P@24 or 30 may make more sense, such as if the final product is encoded as an MPEG-4, Windows Media or Quicktime file.

SDTV

The DTVWG acknowledges that traditional interlace scan, 525 line, 29.97 frame per second video will be a part of NASA imaging systems for many years to come. Although progressive scan video has been demonstrated to be superior, the continued use of the vast amount of existing equipment as a source of NASA video imagery cannot be excluded. In recent years, acquisition and production equipment has been commonly available which digitally represents this originally analog standard, typically using 720 X 480 active pixels. Note that this SDTV acquisition and production format differs slightly from any of the ATSC distribution formats in that it uses 720 pixels per horizontal line, rather than 704 or 640 (square pixel). This is not really a problem or a constraint, as the number of horizontal pixels would normally be resized as needed within a broadcast distribution encoder. Digital 525 line acquisition and production equipment usually conforms, or can be readily adapted to, the SMPTE 259M Serial Digital Interchange (SDI) Standard. There are many NASA video requirements that can continue to be adequately satisfied using this format. Thus the digital representation of traditional 525 line interlace scan video, 480I at a frame rate of 29.97 Hz, is to be the NASA SDTV standard picture format.

There are variations of SDTV standards which specify a 16:9 image aspect ratio instead of the normal 4:3. It is presumed that wide aspect SDTV would be useful for display on wide aspect monitors and could also be more suitable for up-conversion for use in HDTV production. An alternative method of generating 16:9 aspect video imagery using existing 4:3 aspect equipment is to use the “shoot and protect” technique. This means to shoot the video using the full standard 4:3 aspect ratio, but ensure that important portions of the image fall within a central 16:9 area of the frame. This ensures an up-conversion done by cropping the top and bottom of the frame will not lose important content. As an option to standard 4:3 aspect ratio equipment, the use of 16:9 capable SDTV systems, which use either an anamorphic squeeze technique or which black out upper and lower portions of a 4:3 frame, are allowed under this standard.

There are also standards for progressive scan SDTV, also known as Extended Definition Television (EDTV). This technique demonstrated superior performance to regular interlace scanning, however, only a small amount of progressive scan SDTV equipment has been available. The DTVWG concluded that adopting a progressive scan STDV standard may be a confusing and unneeded intermediate step between interlaced scan SDTV and the progressive scan HDTV standard. Thus, a progressive scan SDTV format was not included in this standard.

APPENDIX B

DISCUSSION OF VIDEO/AUDIO SIGNAL SAMPLING REPRESENTATION AND COMPRESSION

Video Signal Sampling Representation

There are many video signal sampling structures used to digitize video. These structures are used to reduce the amount of raw image data to be processed without severely affecting the image content. Generally, the chroma (color) information is not sampled at the same resolution as the luminance (black & white) portion of the picture. The human eye perceives most resolution from luminance information. This allows color information to be sub-sampled, compared to luminance, without an apparent loss of image detail. As image luminance information and information in the green color spectrum is almost equal, luminance can be used to derive the green information. Red and blue information is then often sub-sampled to reduce overall bandwidth requirements. There are sampling structures that perform full bandwidth sampling, but these are primarily used for very high end video, still or computer graphics imaging systems. This type of sampling is expressed as 4:4:4, indicating that within a 4 X 4 block of luminance pixels, there is also a 4 X 4 block of both red and blue. For production video systems, 4:2:2, with a 4 X 4 luminance sample and two 2 X 2 blocks of red and blue is the preferred standard. Acceptable acquisition formats for critical use sometimes use less than 4:2:2, but always perform complete color information sampling on every line of video. 4:1:1 and 3:1:1 are other common sampling structures for acquisition formats. 4:1:1 is used by SDTV systems such as DV, DVCAM, DVCPRO and Digital 8mm. The sampling structure used by the Sony HDCAM format is 3:1:1. The 4:1:1 and 3:1:1 formats provide a compromise between cost, complexity, resolution and bandwidth requirements for acquisition systems. The most important factor in sampling video for critical acquisition, contribution or production is to perform some sampling of all color signal information components on every scan line. This is necessary to have sufficient color information for further post production processing of the video. The 4:2:0 method samples the red or blue color components on every other video line. This method is used in consumer and lower quality industrial acquisition formats. It is also used for distribution to users including Blu-Ray, DVD Video, direct broadcast satellite, ATSC terrestrial broadcast and QAM cable TV transmissions. 4:2:0 sampling is generally considered acceptable for distribution of a finished product for user viewing, but not for the acquisition, contribution or production of video for *Critical Engineering* or *Publication* applications because of the limitations introduced by the reduction in color information. Although it is acknowledged that for certain acquisition requirements, such as airborne or spaceflight applications, the use of smaller and lighter equipment may be necessary. Typically, this type of equipment uses 4:2:0 sampling and/or long GOP compression and its use does result in a performance compromise.

Data word length refers to the number of bits used to represent the voltage level of a signal sample. In all cases, the minimum word length for NASA DTV systems shall be 8 bits. The formats of the SDI and HDSDI transmission standards allow use of word lengths up to 10 bits. Use of more than 8 bit words to represent a signal sample provides a higher fidelity video signal with a better signal to noise ratio. Equipment that uses a word length of 10 bits or more is highly recommended for production systems and may also be used for acquisition or contribution systems. Most available distribution systems and media use 8 bit words, which shall be the minimum NASA standard for the distribution of signals, programs and media for final viewing.

Video Signal Compression

Video compression is employed to enable the very high bit rate of uncompressed video to be reduced so that transmission or recording systems with limited bandwidth capabilities can be used or so many video signals can be fit within a given bandwidth. Compression for DTV uses multiple standards, depending upon the specific requirements and application. Unlike the compression normally used for data files, most digital video compression is lossy. A video signal that is compressed, transmitted, decompressed and then reconstructed is no longer identical to the original signal. Typically, the higher the amount of compression used results in a lower fidelity reconstructed video signal.

Many video compression systems in common use are based on the use of some form of Discrete Cosine Transform (DCT) encoding. Other available systems use wavelet or fractal based encoding. Current systems for compressing DTV operate at data rates that range from less than 12 to 360 Mbps for HDTV and from less than 3 to nearly 100 Mbps for SDTV. The compression format used by many types of signal distribution equipment is MPEG-2, which is also the standard codec used for digital broadcast, cable, satellite and DVD Video distribution. The DTV working group has tested various MPEG-2 equipment and has developed recommendations for the selection of parameters such as the composition of the Group of Pictures (GOP) and data rate. Other available equipment uses different compression formats including newer standard codecs such as H.264/MPEG-4 Part 10 Advanced Video Coding (AVC) and VC-1 plus some proprietary codecs. These newer codecs can provide similar performance to MPEG-2 at significantly lower bit rates, although there may also be an increase in encoder and decoder complexity and processing time. High definition optical disc formats can use several different codecs including MPEG-2 and AVC. Available equipment for acquisition, contribution and production use a variety of video compression techniques so attempting to establish specific agency standards for these systems is not really practical, although some guidelines for various quality levels have been developed based on testing and experience.

In order to maintain high quality, production systems must use higher data rates and low ratio, intra-frame compression on non sub-sampled or resolution filtered video. If using intra-frame 4:2:2 MPEG-2 or DV compression, production equipment should use a compression ratio of 5:1 or less. For acquisition systems, it is often necessary to use somewhat more compression than production equipment, but it is preferred to also use intra-frame compression to better capture temporal information because video can have significant changes from frame to frame that severely challenge inter-frame (GOP type) compression systems. Compression requirements for contribution video are less stringent than for acquisition or production. A HDTV signal compressed to about 30-45 Mbps using 4:2:2 MPEG-2 with a long GOP can be used as a contribution source, such as for media release or for input to production systems. This also represents a good range of target rates so that E-3 (34.368 Mbps) and T-3 (44.736 Mbps) long haul transmission services can be used. DTVWG tests have shown that low motion NASA SDTV can be compressed using 4:2:2 MPEG-2 with a long GOP to as low as 8 Mbps and still be used as a contribution source. Compressing a HDTV signal to 19.4 Mbps, or less, using the ATSC A/53 transmission standard results in a picture which is suitable for real-time viewing, but which has typically lost too much information to be usable as a contribution input for production. The compression of progressive source material has been shown to be more efficient than the compression of interlace material. Tests have shown that the viewing quality of 4:2:0 MPEG-2 compressed 720P can be adequate with average rates of 12 Mbps. Low motion, sub-sampled SDTV 4:2:0 MPEG-2 compressed to as low as 3 Mbps can still provide good viewing quality. However whenever possible, a data rate higher than these minimums should be used.

Video Recording Formats

Tape, disk and solid state formats can be used for recording DTV and there are multiple variations of each type available. Video tape recording formats are typically restricted by the signal sampling and compression designs of specific vendor equipment. For many years, video tape was the principal recording method used, however, more and more video recording is now being performed using other methods. Data tape, solid state and magnetic or optical disk based formats can be more flexible regarding signal sampling and compression choices, depending more on how the compressors are integrated to the system design. A vendor that packages a codec with his system may only offer support of certain compression schemes. Other vendors market their products as a general purpose recorder able to accept almost any data format.

There have been several professional digital video tape formats that supported recording HDTV. Some early reel-to-reel and large cassette formats are no longer available. As of this writing, there are still a few tape formats in use. Panasonic produces the HD-D5 format which was originally designed as a SMPTE 125/259M recorder for standard definition component serial digital video at 270 Mbps. With the addition of a codec and SMPTE 292M inputs and outputs, the D5 became a HDTV intra-frame recorder. There is no sub-sampling of luminance or chroma in HD-D5. Sony makes HDCAM, which is a 145 Mbps, 1080 line based HDTV recording system. HDCAM initially captures a 4:2:2 sampled picture at full 1920 X 1080 resolution and then performs sub-sampling. Horizontal resolution is reduced from 1920 to 1440 pixels in luminance and from 960 to 480 pixels in each of the color channels. The end result is a picture that is sampled at 3:1:1 based on a 1440 X 1080 picture. HDCAM-SR is a higher quality variant of this format that records 1080 video at full resolution. Panasonic has DVCPRO-HD, which uses ¼" tape and records at approximately 100 Mbps. It is capable of working in both interlace and progressive modes, although for 1080, the horizontal resolution is reduced from 1920 to 1280 pixels in luminance.

As SDTV became popular, several other video recording formats were introduced. These included tape formats such as DV, DVCAM, DVCPRO, DVCPRO-50, Digital-S, Digital Betacam, Betacam SX and MPEG-IMX. Other consumer formats which record directly to DVD-Video, hard disc drives or solid state memory also appeared. The most common signal interface for professional SDTV digital recorders is SMPTE 259M. There are other available interfaces, such as Institute of Electrical and Electronic Engineers (IEEE) 1394 (AKA Firewire and iLink). IEEE 1394 is primarily used as an interface between DV based acquisition/recording equipment and desktop computer based non-linear editors. IEEE 1394 cannot normally be routed over long distances which preclude its use as a primary interface for distribution.

Other professional acquisition formats are available that record using other than tape media. Some can also record either SDTV or HDTV. Sony has the XDCAM/XDCAM-HD format which records 480 or 1080 video on optical discs. The Panasonic P2 and Grass Valley Infinity formats record 480, 720 or 1080 video on solid state memory. The Ikegami Editcam uses a hard disc drive pack or solid state memory to record HD video.

As the development of DTV equipment has progressed, there have been lower cost HDTV acquisition systems developed and introduced for the consumer and industrial markets. These include the HDV and AVCHD camcorder formats which have been available in both interlace and progressive models. HDV is based on the DV tape format but uses the MPEG-2 codec to compress an HDTV signal to fit within the 25 Mbps recording capability of the DV tape. Tests were performed by the DTVWG on several higher grade HDV camcorders to gauge their performance. In general, the camera performance of these units was quite good, even though they used very small image sensors and lower cost lenses. However, the performance of the recording portion was not. The recordings showed considerable compression artifacts. The AVCHD format uses the AVC codec and also highly compresses an HDTV signal. AVCHD typically uses solid state, hard drive or optical disc recording. These HDV and AVCHD systems are not considered suitable acquisition formats for critical NASA HD requirements, principally because they use 4:2:0 signal sampling and also employ a very high amount of inter-frame video compression which causes visible image artifacts. It is tempting to use this equipment because of its compact size and relatively low cost, however, due to the color sampling limitations the use of equipment in these formats should be limited to non-critical applications. It is expected that the development of HDTV acquisition systems will continue and that other formats using AVC, VC-1, MJPEG-2000 or other codecs will appear.

There are a number of separate units which record using other media. Some record video directly to optical disc. There are also several recorders available which use hard discs drives and a variety of different codecs. Some fixed units are PC based and others are rack mount units. Compact units which use an IEEE 1394 interface can serve as a portable outboard recorder attached to DV based camcorders. Lower cost units typically use 4:2:0 sampling and a high amount of inter-frame compression resulting in distribution quality recordings at best. Other units have HD-SDI inputs and record a very high quality full resolution intra-frame 4:2:2 signal. Most of these intra-frame recorders are compliant with NASA Standard 2818 for Critical recording and can be used as a substitute for a high quality video tape recorder.

A primary issue with both SDTV and HDTV acquisition formats which use less than full resolution and other than 4:2:2 sampling such as DV, DVCAM, DVCPRO, HDCAM, HDV and AVCHD plus many hard drive, solid state and optical disc recorders, is the inability of these formats to withstand multiple decoding and re-encoding cycles without degrading the image. As discussed earlier, the process of encoding a video signal eliminates some of the original image information. The more an image is compressed, the more information becomes irretrievably lost. Performing successive decode and re-encode cycles, as is done when transferring a signal between devices that use compression, will result in picture degradation. If the production processing needed to fulfill a particular video requirement is limited to simple cuts-only editing and duplication, then using an acquisition format to produce a video product is acceptable. Studio versions of acquisition recorders have “dub” mode capability, which allows a bit-for-bit clone of the original material to be made when editing and duplicating. However, complex video production incorporating keying, animation, graphics and other effects often requires multiple cycles to and from tape, even when non-linear editing is employed. Manufacturer tests from Panasonic, and anecdotal information from Sony and Turner Entertainment indicates HDCAM and DVCPRO-HD begin to develop compression artifacts starting with the 5th decode/encode cycle. Testing by Turner Entertainment indicated that a HDTV recorder that does not sub-sample luminance and chroma and which keeps compression at 5:1 or less, showed no compression artifacts after 20 decode/encode cycles.

Several hard disc based recorders, including the P2 and Infinity solid state, XDCAM (SD) optical disc and Editcam hard disc formats meet or exceed the NASA standards for acquisition systems for ***Critical*** *Engineering* and *Publication* applications.

Available component digital video *tape* recording formats that also meet or exceed these standards include:

HDTV: HD-D5, D12 (DVCPRO-HD), HDCAM-SR (for 1080P only).

SDTV: Preferred 4:2:2 Systems: D1, D5, D10 (MPEG-IMX), Digital Betacam and DVCPRO-50. Allowed 4:1:1 Systems: Digital 8mm, DV, DVCAM, D7 (DVCPRO).

Of the available non-tape portable camcorders and recorders using disk drives or solid-state memory, these formats are known to meet or exceed NASA standards for acquisition systems for ***Critical*** *Engineering* and *Publication* HDTV applications: Grass Valley Infinity (disk or Compact Flash (CF) card); AJA KiPro and KiPro Mini; Convergent Designs Flash XDR and Nano-Flash CF card recorders; Panasonic P2 recorders and camcorders in AVC-I 100 Mbps; and Fast Forward Video Elite HD

Audio Signal Sampling and Compression

The digital audio production standard is AES3 (also called AES/EBU). AES3 defines a high fidelity uncompressed stereo audio signal with an approximate data rate of 3 Mbps. This is more than adequate for most normal agency use. However, there may be a requirement for six or more production audio channels. Since most video recorders can record no more than four audio channels, and most distribution infrastructures can distribute only two audio channels, a technique for adding additional production grade audio tracks to allow six or more channels of sound is needed. The Dolby E system is a popular solution available to accomplish this. One significant feature of Dolby E is that the interface to other equipment is at the normal AES3 level. Dolby E allows up to eight channels of audio to be compressed into an AES3 channel. Using AES3 as a common standard allows Dolby E or another similar system to be added without modification to existing digital audio systems.

One digital standard for audio that accompanies a long haul contribution video signal is MPEG-1 Layer 2 (ISO 11172-3). This compression method can incorporate digital audio input signals sampled at several rates, including 32, 44.1 and 48 KHz. Using this method, the audio data rate can be reduced significantly and still maintain quality suitable for production use. It has been demonstrated that 16 bit, 48 KHz sampled audio can be reduced to 128Kbps with no readily detected change from the original signal. Another newer standard is Advanced Audio Coding (AAC) (MPEG-2 Part 7 / MPEG-4 Part 3). This method is also very versatile. It can transmit excellent quality 16 bit, 48 KHz sampled audio at a data rate of 96 Kbps per channel.

The FCC standard for audio to accompany U.S. broadcast DTV is Dolby AC-3 (also called Dolby Digital). AC-3 provides the capability to transmit compressed digital mono, stereo or multi channel audio. AC-3 includes a system for multiplexing up to five full bandwidth audio channels and one reduced bandwidth low frequency effects (subwoofer) channel into a single digital signal. Called 5.1 channel audio, this encoded signal has been processed such that it is not possible to decode the sound into 6 discrete channels of sufficient fidelity for production. AC-3 processing takes advantage of psycho-acoustic characteristics of human hearing to reduce bandwidth. The result is that individual channels will often be missing large amounts of audio information, however, the lack of sound in one channel can be masked by sound on another.

APPENDIX C

DISCUSSION OF INTERFACES

Interfaces for DTV is an area within the video industry that continues to evolve. As this situation becomes more stable with the maturity of regular DTV program production and distribution, it may be necessary to update existing or to introduce new interface standards for NASA. Listed below are examples of the information needed to specify interfaces:

- Electronic Medium
  - Satellite
  - Terrestrial

- Recorded Medium
  - Video Tape Formats
  - Disc, Solid State or Other Media Formats

- Signal Characteristics
  - Physical Interface
  - Electrical Interface
  - Signal Protocol
  - Transmission Type
  - Transmission Protocol

There exist signal standards for the transfer of uncompressed DTV from one piece of equipment to another. SMPTE 292M-2004 is the High Definition Serial Digital Interface (HDSDI) standard for HDTV and uses a data transfer rate of approximately 1.5 Gbps. SMPTE 259M-1997 is the Serial Digital Interface (SDI) standard for SDTV and nominally transfers at a rate of 270 Mbps but can also be used at 360 Mbps. Another newer uncompressed DTV interface standard is the High Definition Multimedia Interface (HDMI). This standard, which continues to develop through several versions, is now used in most consumer equipment for connections such as from an optical disc player to a flat panel display.

There also exist standards for the transfer of compressed DTV between equipment. One of these is the Digital Video Broadcasting - Asynchronous Serial Interface (DVB-ASI) standard which defines a method for transferring compressed video over a standard 270 Mbps SMPTE 259M SDI interface. There is also the Institute of Electrical and Electronic Engineers (IEEE) 1394 (also called Firewire and iLink) interface standard which is often used to connect equipment that uses the DV or HDV standard. Another common protocol for transfer of compressed video as files or using a variety of communication schemes and rates is the MPEG Transport Stream (MPEG-2 Part 1 / ISO 13818-1).

Other interfaces for DTV systems internal to NASA will need to be defined for several areas. One of these is between systems for receiving from or for transmitting to spacecraft and systems that provide ground video distribution and processing services. As spacecraft develop DTV capabilities, those systems will need to provide interfaces compliant with the ground DTV system standards. This rule will also need to apply to other NASA program or project spacecraft, aircraft, test facility and laboratory video as well. If particular imaging requirements make the use of non-standard or unique video systems necessary, the signals generated by these systems will need to be converted in order for these projects to be able to use the video recording, production and distribution services provided by the standards based ground infrastructure. This includes services to support the distribution of information as required by the NASA Charter. Programs or projects that use non-standard video methods will probably also need to provide the equipment used to distribute, record and display that imagery in its native format.

Another internal area needing DTV interface definition is for the transfer of video between NASA Centers. While the responsibility for providing inter-center video distribution services belongs to the NASA Integrated Services Network (NISN), the technical specifications for the interface to these services will be defined by the DTVWG and used by all of NASA to assure a quality DTV interchange capability. The current inter center Multi Channel DTV capability plus some mission video support systems which transfer video packaged in the Internet Protocol as well as systems which use more traditional video transmission techniques have been configured with equipment that uses the standard DTV signal interfaces described above.

Definition of interfaces for the transfer of DTV external to NASA is also necessary. External interfaces include other government agencies, NASA partners such as CSA, ESA, JAXA and RSA, universities, industry and the news media. In many cases, this only requires informing those organizations in which picture format NASA DTV will be distributed and which signal transfer interface is to be used, but in others it may require negotiating specific signal conventions, formats or conversion responsibilities.

NASA Standard 2818 Annex AR
Interim Aspect Ratio Guidelines
For
NASA Video Acquisition and Television Production

The guidelines in this annex are provided for the acquisition of NASA video imagery and the production of NASA television programs both for engineering and publication use during the era of the transition in use from traditional 4:3 to wide screen 16:9 aspect ratio acquisition equipment and displays. The principle reason for this guidance is to assist NASA organizations to create new video products that can be viewed on either traditional or wide aspect displays without losing important image content.

1.0 Acquisition of New Video Imagery:

1.1 All new image material being acquired in a wide screen 16:9 aspect ratio, in either Standard Definition (SD) or High Definition (HD), should be “protected for 4:3” as much as practical. This means that placing important image content in the far left or right of the image should be avoided so that the vital information is retained if the image is later cropped to a traditional 4:3 aspect ratio.

1.2 All new image material being acquired in a traditional 4:3 aspect ratio using legacy Standard Definition equipment should be “protected for 16:9” as much as practical. This means that placing important image content in the very top or bottom of the image should be avoided so that the vital information is retained if the image is later cropped to a wide screen 16:9 aspect ratio.

2.0 Production of Television Programs:

Programs may be live productions or edited pieces intended for later playback using various media or distribution methods. Typically, programs are created in either SD using legacy capabilities or in HD where those capabilities exist. Programs, whether live or recorded, are also often up or down-converted to different picture formats for additional distribution.

2.1 Standard Definition Programs:

All SD programs should be produced in 4:3 aspect ratio.

2.1.1 The complete image of new or legacy 4:3 aspect SD source material is to be normally used as is.

2.1.2 Wide screen SD source material is to be cropped to 4:3 and, if necessary, trans-coded to the SD production picture format (such as from 480p to 480i).

2.1.3 Wide screen HD source material is to be cropped to 4:3 and down-converted to the SD production picture format.

2.1.4 Creation of high definition versions of a new or legacy 4:3 aspect ratio SD productions will normally be done by up-converting the image to the HD format and “pillar boxing” (adding side bars) to create a wide screen 16:9 aspect image. An alternative for previously “letter-boxed” SD material is to crop the image to 16:9 and then scale and up-convert to an HD picture format. This method avoids the “window-boxed” effect that occurs when up-converting “letter-boxed” SD material.

2.1.5 Internet and Mobile/Handheld format versions of new or legacy 4:3 aspect ratio SD programs can be created by down-converting the image to a required picture format resolution (such as 320H X 240V). If needed, wide screen versions can be created by either cropping or adding side bars to create a wide screen image and down-converting to the required resolution (such as 640H X 360V for Internet or 416H X 240V for ATSC M/H).

2.2 High Definition Programs:

All HD programs should be produced in 16:9 aspect ratio.

2.2.1 Traditional 4:3 aspect ratio source material should be either cropped to 16:9 or "pillar-boxed" (add side bars) to change the image aspect ratio to 16:9 plus scaled or up-converted as necessary to the specific HD production picture format.

2.2.2 Wide screen SD source material should be up-converted to the specific HD production picture format.

2.2.3 The complete image of HD source material is to be normally used as is or, if necessary, trans-coded to the specific HD production picture format (such as from 1080i to 720p).

2.2.4 Creation of SD 4:3 aspect ratio versions of an HD production can be done in two ways: One is by cropping the image to 4:3 and down-converting the program to SD. This method provides a full screen 4:3 aspect ratio image, but may result in the loss of important parts of the image if 4:3 protection was not done for the 16:9 source material. Alternatively, the HD program can be down converted to SD in a "letter-boxed" format with bars at the top and bottom of the 4:3 display. This method retains the complete original image, which may be important for some uses, but central image content will be displayed smaller and at a lower resolution than when a 4:3 crop method is used.

2.2.5 Internet and Mobile/Handheld format versions of HD productions can be created in a cropped 4:3 aspect ratio (such as 320H X 240V) or in a wide screen aspect ratio (such as 640H X 360V for Internet or 416H X 240V for ATSC M/H).

2.2.6 Overlay or stand alone graphics added to a wide screen production should be "protected for 4:3" so that the vital information is retained if the program is later cropped to a traditional 4:3 aspect ratio.

NASA Standard 2818 Annex VQ

Additional Video Quality Guidelines For NASA Video Signal Sampling Representation and Compression

The guidelines in this annex are intended to expand upon the material presented in Tables III and IV of NASA Standard 2818 to provide additional guidance concerning performance criteria for video signal sampling representation and compression used during the acquisition or for the transmission of NASA video imagery. The principle reason for this guidance is to provide better definition of minimum acceptable video quality to assist NASA organizations in the development or selection of equipment for the acquisition of video, for the transmission of video signals and for the production of television and video products.

1.0 Measurement of Video Quality:

The NASA Digital Television Working Group (DTVWG) has recognized the need to provide more direct, definitive and easy to understand standards, measures and guidelines for video quality for the various categories of video defined in NASA Standard 2818. This has been difficult to achieve because objective and repeatable measurement of video quality has typically required somewhat complex testing. Plus there are many characteristics and factors to consider that affect the quality of video. These include: the complexity and lighting of the scene being imaged; the characteristics and quality of the video camera lens and imager system; camera or lens motion; camera operating settings and technique; the quality of signal processing; the type and quality of video signal encoder and decoder; the quality of the display; etc. Due to these various factors, specifying minimum digital video quality is, unfortunately, not as easy as just specifying a particular minimum data rate when using a particular codec. The impact of these other factors must be considered.

It has often been observed that systems used for video compression or transcoding vary widely in performance. Also, the performance of a particular system will vary based on the image content being processed. A system may look perfect on one scene and have obvious artifacts on another, even though the data rate and other settings are the same.

In the past, performance assessments of video systems have been conducted by using panels of viewers who evaluated quality by making rigorous, disciplined observations. NASA Standard 2818 has indirectly specified quality performance by suggesting minimum bitrates when using particular video compression methods and sampling conventions. There now exist some sophisticated, albeit pricey, video quality test equipment which has helped this situation by providing semi-automated ways to make these measurements without the need for panels of human viewers. Two available video quality analysis systems are the Tektronix PQA and the Video Clarity Clearview. These systems can be very useful to gauge the quality of signal processing when encoding and subsequently decoding digital video for transmission or storage, or for when transcoding video from one format to another. Typical test methods involve use of a variety of standard scenes or sequences as an input which is compared with the output after processing. Some of the measurements generated employ picture quality algorithms which attempt to reproduce characteristics of human visual perception and observations by panels of viewers. These measurements include calculations that use the Differential Mean Opinion Score (DMOS) which models the results of observations of trained, expert viewers, and others based on the Sarnoff Just Noticeable Difference (JND) model, including the Tektronix Picture Quality Rating (PQR) and the Video Clarity JND, which simulate the results of observations by non-expert viewers. Another test method measures pixel to pixel and frame to frame changes that can be expressed as a Peak Signal to Noise Ratio (PSNR). These methods have been used to establish these additional guidelines for NASA video which are better indicators of quality than merely specifying sampling conventions, compression methods and data rates.

The DTVWG has developed test sequences representative of NASA video requirements that provide a range of complexity of material including imagery that is relatively easy to encode and decode and other scenes that are more challenging. Testing has been performed using three scenes. Two of the scenes are meant to exercise video systems with high detail (spatial resolution) and fast movement (temporal resolution). One of these scenes shows a fountain in a park setting and the other a waterfall. Both of these scenes are meant to challenge video compression systems to gauge their ability to handle more demanding requirements. Another scene shows two crew members during ingress to a NASA high-altitude research aircraft. This scene represents moderate spatial and temporal resolution and is representative of many typical NASA video documentation requirements. Copies of these test sequences can be obtained by contacting the DTV Project Office at the Marshall Space Flight Center.

In some cases, it is not possible to use reference sequences to test equipment. One example is if a camcorder being tested does not have a separate digital signal input. Another is where there is no external recorder that matches an internal camcorder recording format that can be used to record the test sequences. In these cases, a test method is to use a high quality, preferably uncompressed, external recorder connected to the camcorder via an uncompressed digital output port. Images of scenes similar to the normal test sequences are then shot and recorded on both the internal and high quality external recorders. The high quality recording is then ingested in the measurement system and becomes the reference sequence. The internal camcorder recording is also ingested in to the measurement system as the test recording. A comparison is then made to measure the performance of the internal recorder relative to the high quality external recorder. This method also allows a separate evaluation to be made of the performance of just the camera portion of the camcorder.

2.0 Video Quality Performance Criteria:

The following tables present quality performance criteria for the various categories and uses of NASA video. For each of the test sequences, minimum measurements for PQR/JND, DMOS and PSNR are provided. Although the tests used to develop these criteria were performed using 720P material, the results are also applicable to other picture formats.

Acquisition for Critical Engineering or Publication (These performance criteria represent the capabilities of 10 bit, 4:2:2, all I frame systems that do not subsample, such as AVC-Intra.)			
Scene	PQR/JND	DMOS	PSNR
Fountain	≤ 1.0 average	≤ 0.8 average	≥41.5 db average
Waterfall	≤ 0.8 average	≤ 0.7 average	≥40.5 db average
Crew Ingress	≤ 0.3 average	≤ 0.15 average	≥46 db average

Acquisition for Critical Engineering or Publication (These performance criteria represent the capabilities of 8 bit, 4:2:2, all I frame systems that also use horizontal sub sampling, such as DVCPRO-HD.)			
Scene	PQR/JND	DMOS	PSNR
Fountain	≤ 1.2 average	≤ 1.6 average	≥37.5 db average
Waterfall	≤ 1.6 average	≤ 2.6 average	≥36.5 db average
Crew Ingress	≤ 0.35 average	≤ 0.2 average	≥45 db average

Acquisition for Non-Critical Engineering or Publication (These performance criteria represent the capabilities of 8 bit, 4:2:0, long GOP systems, such as AVCHD.)			
Scene	PQR/JND	DMOS	PSNR
Fountain	≤ 2.0 average	≤ 4.2 average	≥37db average
Waterfall	≤ 3.4 average	≤ 13.7 average	≥31.0db average
Crew Ingress	≤ .95 average	≤ 1.0average	≥40.5 db average
Production and Post Production (These performance criteria represent the capabilities of intermediate compression system used in video editors, such as ProRes422HQ.)			
Scene	PQR/JND	DMOS	PSNR
Fountain	≤ 0.35 average	≤ 0.12 average	≥49db average
Waterfall	≤ 0.4 average	≤ 0.2 average	≥49db average
Crew Ingress	≤ 0.2 average	≤ 0.05 average	≥51.5 db average

Intra/Inter Center and External Transfer for Contribution of Critical Video (These criteria represent the desired performance using 4:2:2, long GOP encoders and decoders.)

Scene	PQR/JND	DMOS	PSNR
Fountain	≤ 0.35 average	≤ 0.12 average	≥49db average
Waterfall	≤ 0.4 average	≤ 0.2 average	≥49db average
Crew Ingress	≤ 0.2 average	≤ 0.05 average	≥51.5 db average

Intra/Inter Center and External Transfer for Contribution of Non-Critical Video (These criteria represent the desired performance using 4:2:0, long GOP encoders and decoders.)			
Scene	PQR/JND	DMOS	PSNR
Fountain	≤ 3.5 average	≤ 15 average	≥33.1db average
Waterfall	≤ 5.6 average	≤ 40.4 average	≥29.2db average
Crew Ingress	≤ 1 average	≤ 1.1 average	≥40.2 db average

Note-These measurements are directly from the one pass Adtec encoder tests done for the HDTV encoder shootout. To get a true picture, we would need to do an MPEG-4 encode at 12 Mbps video rate, then turn that around through another pass done at MPEG-2.

Distribution for Viewing (These criteria represent the desired performance using 4:2:0, long GOP encoders and decoders.) (Typical for 720P using MPEG2 at 12 Mbps.)			
Scene	PQR/JND	DMOS	PSNR
Fountain	≤ 3.5 average	≤ 15 average	≥33.1db average
Waterfall	≤ 5.6 average	≤ 40.4 average	≥29.2db average
Crew Ingress	≤ 1 average	≤ 1.1 average	≥40.2 db average

Note-Digital broadcast, cable and satellite television typically measures 3-5 PQR/JND for moderate and 5-9 for challenging material … indicating that current "broadcast quality" TV is significantly rate limited and actually not very good compared with typical as acquired video.