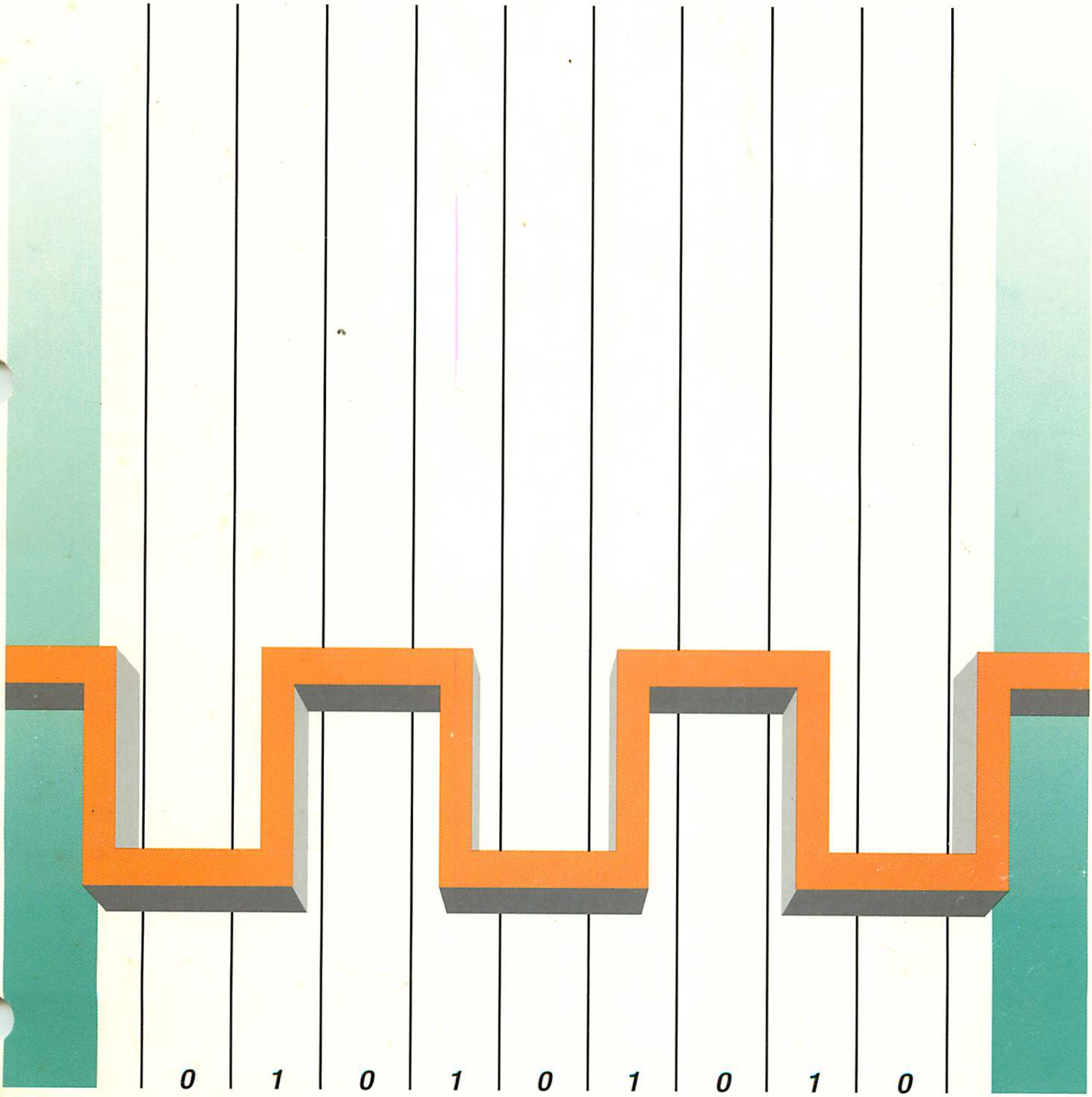
Grass Valley Group®

Digital Television: The Transition



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Digital Television: The Transition

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Preface

As we move into the 21st century, one thing is certain: there will be changes in signal formats. For many, this change means digital.

For those who use, buy or sell some form of video in their businesses, change can be an expensive proposition fraught with questions and uncertainty. Is this change being driven solely by the availability of technology, or has a genuine need for improvement emerged? Will an investment in digital be cost effective now? Will my use of video in the future truly demand digital? How extensively and when do I change?

For some, digital formats and the plethora of equipment already on the market have become familiar. While for others, digital may seem new and the way uncertain. With this booklet, our intent is to provide you with a reference to help you better understand the emerging world of digital video. And to make any decision to use digital signal formats an easier one.

The Grass Valley Group has been committed to a partnership with our customers for over 30 years. We hope this booklet will be useful to you as we move into the 21st century and deal with changes together.

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Why digital television?

• Virtually unlimited generations of clean video

Duplication in the digital domain is a dream come true. No matter how many generations, every copy retains the quality of the original (until video tape recorder *error concealment* fails).

• Totally stable gain & frequency response

The digital signal saves labor. Maintenance is virtually eliminated since no adjustments will be needed to assure *cable equalization* in the digital domain. Digital data can be recovered from the equalized serial signal with 100% accuracy, providing a program signal with completely stable characteristics.

• Multi-layered effects with no quality loss

In the analog realm, layering of picture elements means each generation adds noise and other degradations to the total effect. With Grass Valley Group digital equipment, additional generations are as crisp as the original, resulting in clean, *multi-layered effects*.

• Virtually eliminates signal degradation & phasing problems

Digital video is much less susceptible to many of the problems which plague the analog world—hum, *gain* and *phase errors*, and crosstalk. Even noise is less of a problem in digital than in analog. Digital signals are distinct enough to maintain their integrity through a variety of conditions. There is no accumulation of *group delay*, line or *field time distortions*, and *differential gain* or *phase*.

• Completes a two-decade trend to all-digital

The progression to all digital television has been occurring for almost two decades as numerous pieces of digital equipment have appeared. It all started with the digital *time base corrector*, which made it possible to use lower cost helical scan video tape formats for broadcast. Not long after that, digital effects systems were developed that provide real-time video image control previously available only through film optical effects. Then came *character generators*, graphic systems, *still stores*, the digital disk recorder and so on. But the arrival of digital video tape machines stimulated the real push for the all-digital television system that is now becoming a reality.

error concealment – A technique used when error correction fails (see error correction). Erroneous data is replaced by data synthesized from surrounding pixels.

error correction – A scheme that adds overhead to the data to permit a certain level of errors to be detected and corrected.

cable equalization – The process of altering the frequency response of a video amplifier to compensate for high-frequency losses in coaxial cable.

multi-layer effects – A generic term for a mix/effects system that allows multiple video images to be combined into a composite image.

gain – Any increase or decrease in strength of an electrical signal. Gain is measured in terms of decibels or number-of-times of magnification.

phase error – The incorrect relative timing of a signal in relation to another signal. If the time for one cycle of a signal is represented as 360° along a time axis, the phase position for the second signal is called phase angle expressed in degrees.

group delay – A signal defect caused by different frequencies having differing propagation delays (delay at 1 MHz is different from delay at 5 MHz).

field-time (linear) distortion – An unwarranted change in video signal amplitude that occurs in a time frame of 16 ms.

differential gain – A change in subcarrier amplitude of a video signal caused by a change in luminance level of the signal.

differential phase – A change in subcarrier phase of a video signal caused by a change in luminance level of the signal.

time base corrector – Device used to correct for time base errors and stabilize the timing of the video output from a tape machine.

character generator (CG) – A computer used to generate text and sometimes graphics for video titles or captions.

still store – Device for storage of specific frames of video.

serial digital – Digital information that is transmitted in serial form. Often used informally to refer to serial digital television signals.

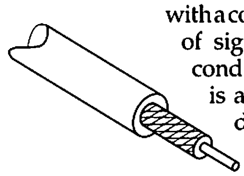
routing switcher – An electronic device that routes a user-supplied signal (audio, video, etc.) from any input to any user-selected output(s).

analog – An adjective describing any signal that varies continuously as opposed to a digital signal that contains discrete levels.

production switcher (vision mixer) – A device that allows transitions between different video pictures. Also allows keying and matting (compositing).

parallel cable – A multi-conductor cable carrying simultaneous transmission of data bits. Analagous to the rows of a marching band passing a review point.

coaxial cable – A transmission line with a concentric pair of signal carrying conductors. There is an inner conductor and an outer conductor metalic sheath. The sheath aids in preventing external radiation from affecting the signal on the inner conductor and minimizes signal radiation from the transmission line.



Coaxial cable

The next few years will be a transition period where digital and analog will live side-by-side. Digital tape recorders will live alongside analog C-format machines; a *serial digital routing switcher* will coexist with an *analog production switcher* and vice versa. It is the purpose of this booklet to make dealing with this hybrid environment easier and potentially less expensive.

Why *serial* digital?

Digital television began by using parallel schemes. The future of digital equipment lies in a serial standard for the following reasons:

- **Dramatically lowers cabling costs because existing cabling can be used**

Parallel cabling is expensive and difficult to terminate. For serial, *high quality coaxial* (coax) *cabling* can be used.

- **Solves parallel connector size problems**

Parallel cabling is multi-conductor, requiring large 25 pin connectors, which are bulky. Standard coax cabling is simple and saves space—all the information is sent over one wire.

- **Allows much longer coax cable runs**

Parallel cabling has a limited distance over which parallel data can be reliably sent: a maximum of 50 meters. Serial data can be passed through standard coax cable up to 300 meters long.

composite analog – An encoded video signal, such as NTSC or PAL video, that includes horizontal and vertical synchronizing information.

VTR (videotape recorder) – A device which permits audio and video signals to be recorded on magnetic tape.

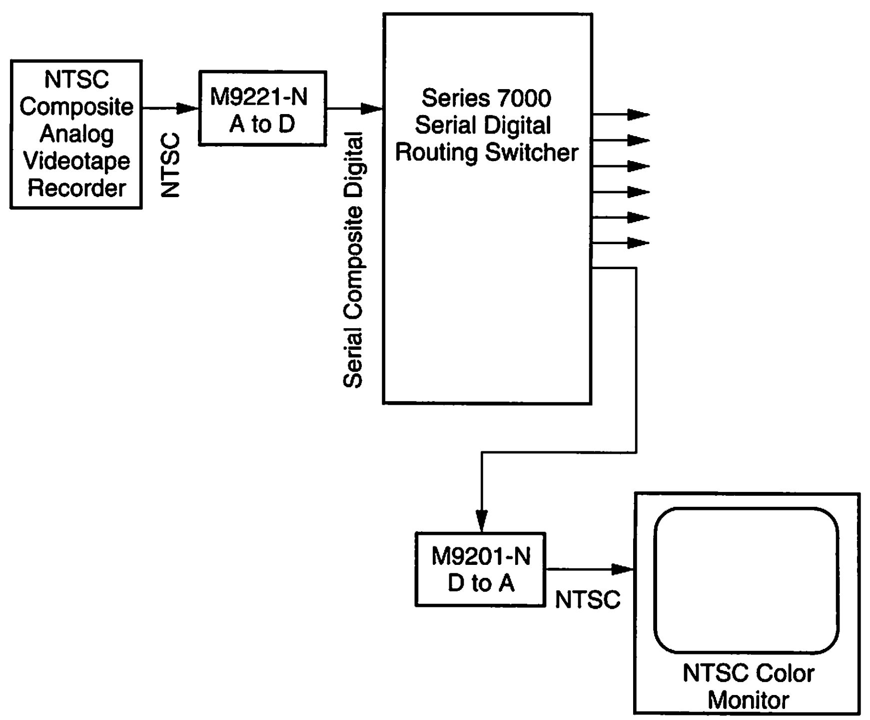
A-to-D Converter (analog-to-digital) – A circuit that uses digital sampling to convert an analog signal into a digital representation of that signal.

D-to-A converter (digital to analog) – A device that converts digital signals to analog signals.

Systemization—how to interconnect all types of equipment

Composite analog (VTRs, satellite feeds)

Many facilities will have analog composite *VTRs* for many years to come and may wish to route their output through a digital routing switcher, along with other serial digital signals. This can be accomplished with an *A-to-D converter* prior to routing. If monitoring is required at the receiving end, then a *D-to-A converter* can also be used.



Conversion of composite analog to serial composite digital and back (A-to-D and D-to-A)

composite digital – A digitally encoded video signal, such as NTSC or PAL video, that includes horizontal and vertical synchronizing information.

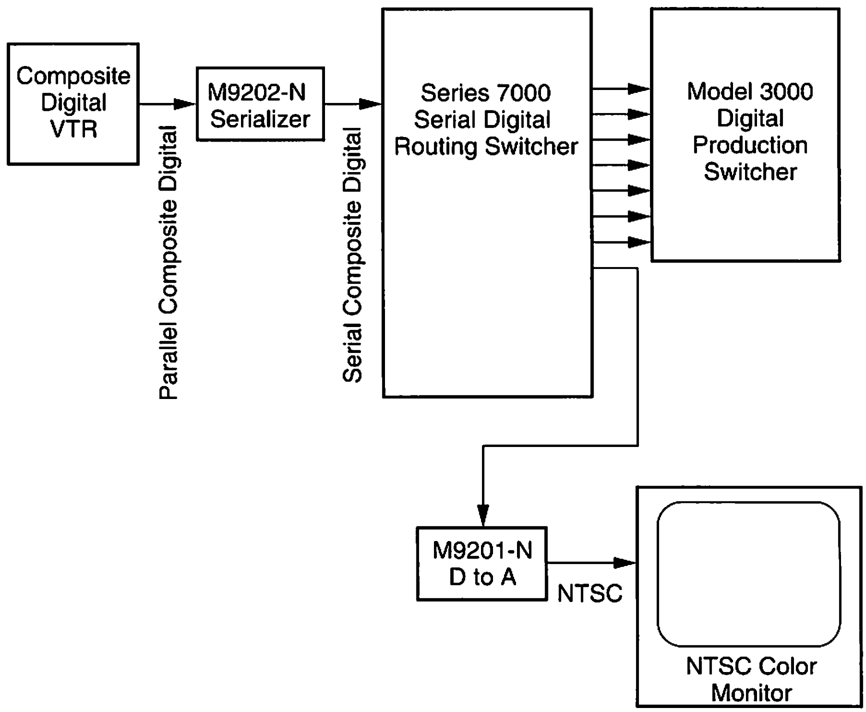
I/O – Abbreviation of *input/output*. Typically refers to sending information or data signals to and from devices.

DVTR – Abbreviation of *digital videotape recorder*.

serializer – A device that converts parallel digital information to serial digital.

Composite digital (VTRs)

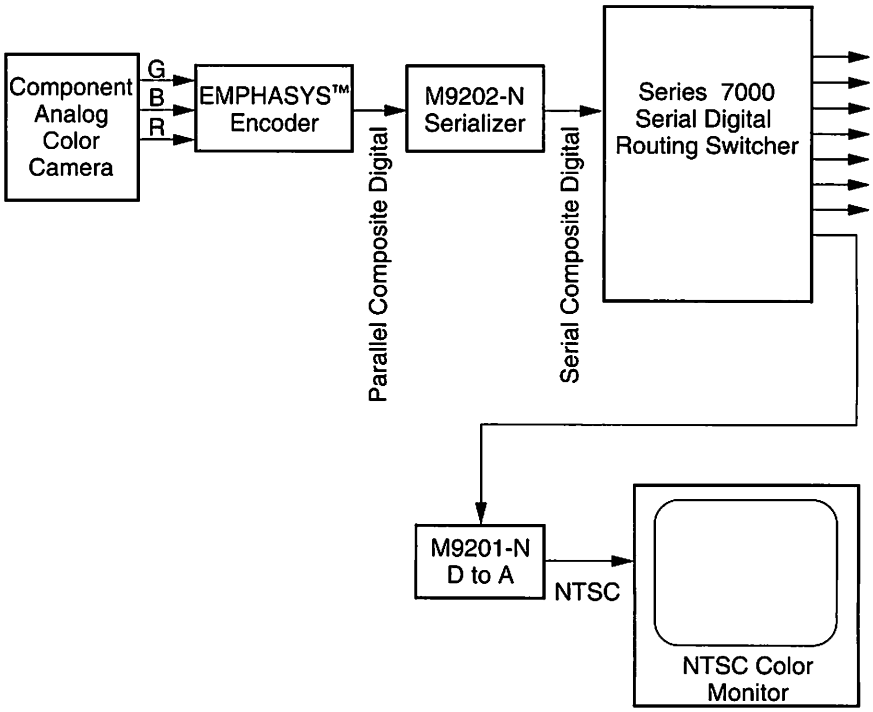
Digital VTRs come in many formats, both component and composite. These may have parallel or serial I/Os. If the *DVTRs* have only parallel I/Os, a *serializer* is required to get their outputs into a serial digital routing switcher.



Conversion of parallel composite digital to serial composite digital

Component analog (cameras, VTRs)

Component analog VTRs and cameras are widely used in many facilities. If there is a need to route their signals using a composite digital router, the signals must first be encoded, and if necessary, serialized, before they are applied to the router. Encoders and serializers can be *NTSC* or *PAL*, depending on the application.



Conversion of component analog to serial composite digital

component analog – The unencoded analog output of a camera, videotape recorder, etc., consisting of 3 primary color signals: red, green, and blue (RGB) that together convey all necessary picture information. In some component video formats, these three components have been translated into a luminance signal and two color difference signals, for example, Y, R-Y, B-Y.

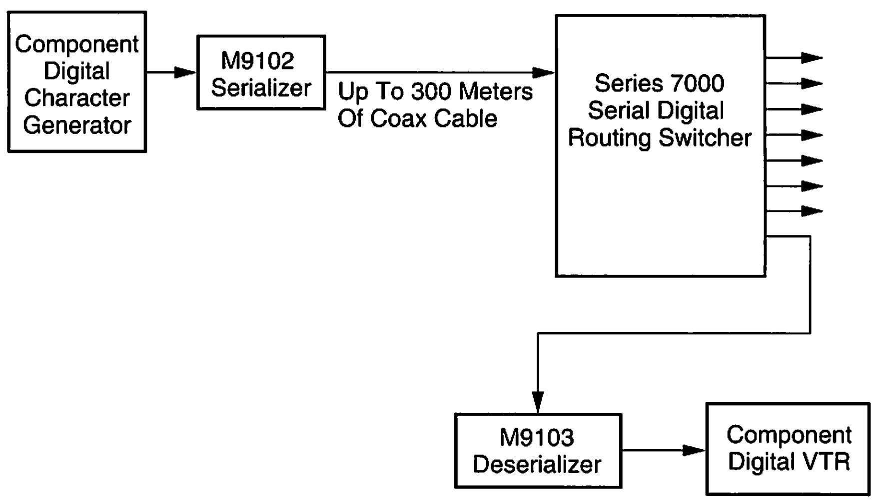
NTSC (National Television Systems Committee) – Organization that formulated standards for the NTSC television system. Now describes the American system of color telecasting which is used mainly in North America, Japan, and parts of South America. NTSC television uses a 3.579545 MHz subcarrier whose phase varies with the instantaneous hue of the televised color and whose amplitude varies with the instantaneous saturation of the color. NTSC employs 525 lines per frame and 59.94 fields per second.

PAL (Phase Alternate Line) – The name of the color television system in which the E'_V component of burst is inverted in phase from one line to the next in order to minimize hue errors that may occur in color transmission. PAL-B (also called PAL-I) is a European color TV system featuring 625 lines per frame, 50 fields per second, and a 4.43361875 MHz subcarrier. Used mainly in Europe, China, Malaysia, Australia, New Zealand, the Middle East, and parts of Africa. PAL-M is a Brazilian color TV system with phase alternation by line, but using 525 lines per frame, 60 fields per second, and a 3.57561149 MHz subcarrier.

Component digital (VTRs, CGs, paint systems, still stores, disc recorder)

component digital – A digital representation of a component analog signal set, most often Y, B-Y, R-Y. The encoding parameters are specified by CCIR 601. The parallel interface is specified by CCIR 656 and SMPTE 125M (1991).

Component digital devices have traditionally had parallel I/Os and have interfaced with other parallel I/O devices. However, as the video industry moves toward serial digital as the method of distribution, the equipment with parallel I/Os will require serializers to convert the parallel signals to serial format. This will be especially important as serial digital routing systems become more prevalent.



Typical conversion of parallel component digital sources to serial

Routing both composite and component signals within the same router

All routers are not capable of handling both composite and component signals. The Series 7000 routes both types at the following data rates: 143, 177, 270, and 360 Mb/s. Individual inputs and outputs can be defined to handle a specific data rate. Of course, mixed format operation in one matrix requires that the expected input to output formats be the same.

propagation delay (path length) – The time it takes for a signal to travel through a circuit, piece of equipment, or a length of cable.

nanosecond (ns) – One billionth of a second: 1×10^{-9} or 0.000000001 second.

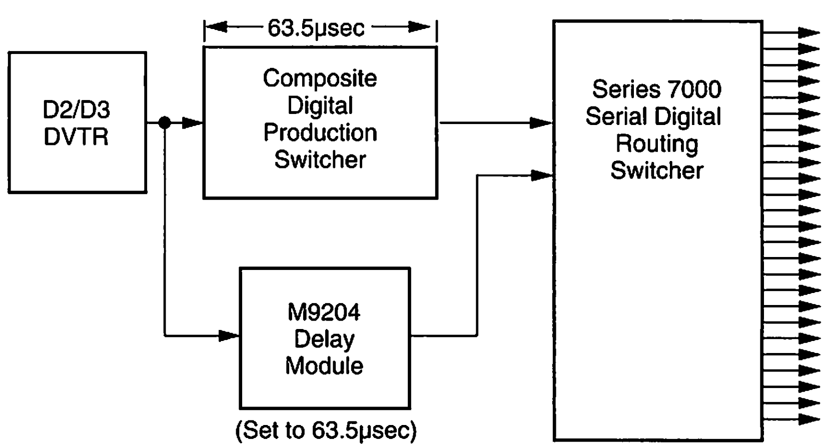
microsecond (µs) – One millionth of a second: 1×10^{-6} or 0.000001 second.

Timing compensation

Timing is very important in television systems. However, the processing delay of some digital equipment is significantly longer than analog equipment. *Propagation delay* in analog video products is usually measured in *nanoseconds*. Equivalent digital equipment has delays measured in *microseconds* because processing is done in clock cycle increments which take time, resulting in delay. That's why digital delay devices are necessary in many cases.

A typical example is illustrated below where a D2 or D3 DVTR source needs to go to both a digital production switcher and to a routing switcher. The output of the digital production switcher must be in time with the DVTR at the input of the routing switcher. However, a typical digital production switcher has a processing delay of one line or 63.5µs (microseconds). By routing the signal through a delay module set to 63.5µs, the two signals arrive at the same time.

While frame stores could be used, the expense is not justified. GVG's M9104 component digital and M9204 composite digital delay units can be used for these long delays. These units can delay the serial digital signal up to 9 TV lines.



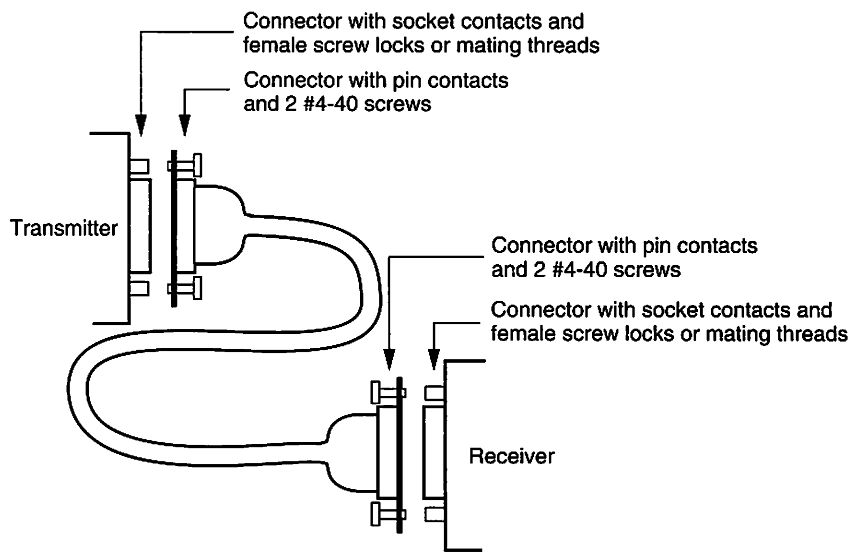
Typical timing compensation

Technical

Parallel vs. serial

With the impending introduction of the first digital VTRs in the mid 1980's, manufacturers settled on digital "interconnectability" standards. The *CCIR-601* standard specified a component digital video signal sampled at 13.5 MHz, but did not specify the interface. The *SMPTE 125M* (was RP-125) standard which was derived from CCIR-601, specified a parallel interconnect scheme using a time multiplex system to interleave the luminance and color difference signals and a separate pair of wires for each data bit and clock. SMPTE 125M also calls for a 25 pin "D" connector.

While these standards aided "interconnectivity", it didn't take long for the shortcomings of the parallel interface to become apparent. Facilities accustomed to using coax were faced with the increased bulk and cost of parallel cable, the increased time and cost required to terminate the cable, and the limited length over which parallel data could reliably be sent. Another method was needed, and preferably one using common coax and BNC connectors.



Pin	Signal Line	Pin	Signal Line
1	Clock	14	Clock Return
2	System Ground A	15	System Ground B
3	Data 9	16	Data 9 return
4	Data 8	17	Data 8 return
5	Data 7	18	Data 7 return
6	Data 6	19	Data 6 return
7	Data 5	20	Data 5 return
8	Data 4	21	Data 4 return
9	Data 3	22	Data 3 return
10	Data 2	23	Data 2 return
11	Data 1	24	Data 1 return
12	Data 0	25	Data 0 return
13	Cable Shield		

SMPTE 125M parallel interconnect scheme

CCIR-601 – An international standard for component digital television from which was derived the SMPTE 125M (was RP-125) and EBU 3247E standards. CCIR defines the sampling systems, matrix values, and filter characteristics for both Y, Cr, Cb and RGB component digital television.

time-multiplex – In this case, a technique for transmitting three signals at the same time on a group of parallel wires (parallel cable).

SMPTE (Society of Motion Picture and Television Engineers) – A professional organization that recommends standards for the television and film industries.

SMPTE 125M (was RP-125) – The SMPTE recommended practice for bit parallel digital interface for component video signals. SMPTE 125M defines the parameters required to generate and distribute component video signals in a parallel fashion.

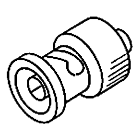
Serial was the answer. Although the serial data rates were fast, they were well within the capabilites of coaxial cable. See Data Rates table below.

Data Rates	
525/60 NTSC Serial Digital	= 143 Mb/s
625/50 PAL Serial Digital	= 177 Mb/s
Component Serial Digital	= 270 Mb/s
EDTV 16x9 Component Digital (proposed)	= 360 Mb/s

Cabling

The best grades of precision video cables are designed to exhibit low losses from very low frequencies (near DC) to around 10 MHz. In the serial digital world, cable losses in this portion of the spectrum are of practically no consequence. It is in the higher frequencies associated with transmission rates of 143, 177, 270, or 360 Mb/s where losses are considerable. Fortunately, the robustness of the serial digital signal makes it possible to equalize these losses quite easily. So, when converting from analog to digital, the use of existing, quality cable runs should pose no problem. Don't be surprised, however, if cable manufacturers seize the opportunity and introduce new, low-loss, foam dielectric cables specifically designed for serial digital.

BNC – Abbreviation of *bayonet Neill-Concelman.* A cable connector used extensively in television and named for its inventor.



All "standard" *BNC* connectors have a characteristic impedance of 50 ohms. The impedance "mismatch" to coax is of little consequence at analog video frequencies because the wavelength of the signals is many times longer than the length of the connector. But with serial digital's high data rate (and attendant short wavelengths), the impedance of the connector is much more important. For this reason, 75-ohm BNCs are used on all GVG equipment with serial digital I/O to ensure the best transfer of data. The selected 75-ohm connector will mate non-destructively with the 50-ohm BNC connectors.

patch panel – A manual method of routing signals using a panel of receptacles for sources and destinations and wire jumpers to interconnect between them.

The same holds true for other "passive" elements in the system such as *patch panels.* In order to avoid reflections due to impedance discontinuities, these elements should also have a characteristic impedance of 75 ohms. Existing 50-ohm patch panels will probably be okay in most instances, but new installations should consider using 75-ohm patch panels.

Several patch panel manufacturers now offer 75-ohm versions designed specifically for serial digital applications.

What about terminations? They too should be 75 ohms with no significant reactive component to 300 MHz. On the other hand, it is likely that fewer terminations will be used because most serial digital devices are self-terminating. However, some devices, such as test equipment, use loop-throughs with good success.

Sampling & quantizing

Sampling - Process where analog signals are measured and stored digitally millions of times per second.

The first step in the digitizing process is to *"sample"* the continuous variations of the analog signal. By looking at the analog signal at discrete time intervals, a sequence of voltage samples can be stored, manipulated and, later, reconstructed.

Nyquist sampling theorem - The interval between successive samples must be equal to or less than one-half of the period of the highest frequency present in the signal.

quantization - The process of converting a continuous analog input into a set of discrete output levels.

In order to recover the analog signal accurately, the sample rate must be rapid enough not to have missed important information. Generally, this requires the sampling frequency to be at least twice the highest analog frequency. In the real world, the frequency is a little higher than twice. (The *Nyquist Sampling Theorem* says that the interval between successive samples must be equal to or less than one-half of the period of the highest frequency present in the signal.)

The second step in the process of digitizing video is to *"quantize"* by assigning a digital number to the voltage levels of the sampled analog signal—256 levels for 8-bit, 1024 for 10-bit video, and up to several thousand for audio.

To get the full benefit of serial digital, 10-bit processing is required. While current tape machines are 8-bit, SMPTE 125M calls out 10-bit as the standard. Grass Valley Group was an early leader in supporting 10-bit technology, and for good reason. Processing at less than 10-bits causes unacceptable truncation and rounding. Grass Valley Group equipment internally employs bit rates far beyond 10 in order to keep the results of mathematical calculations accurate. Grass Valley Group's digital disk recorder (DDR) records and reproduces a full 10-bit data stream.

contouring - Video picture defect due to quantizing at too coarse a level.

Visible or audible defects will be revealed in the picture if the quantization levels are too coarse (too few levels). The name for these defects in video is called *"contouring"* of the picture. However, the good news is that random noise and picture details present in most video signals actually aid the concealment of these contouring effects by adding a natural randomness to them. Sometimes, the number of quantizing levels must be reduced — for example, when the output of a 10-bit processing device is to be fed to an 8-bit recorder. In this case, contouring effects may be minimized by the deliberate addition of a small amount of random noise *(dither)* to the signal. This technique is known as randomized rounding.

The bottom line is that if we take samples accurately and frequently and quantize in fine steps, we will be able to recover a *waveform* that is indistinguishable from the original, particularly if the signal has 10-bit resolution.

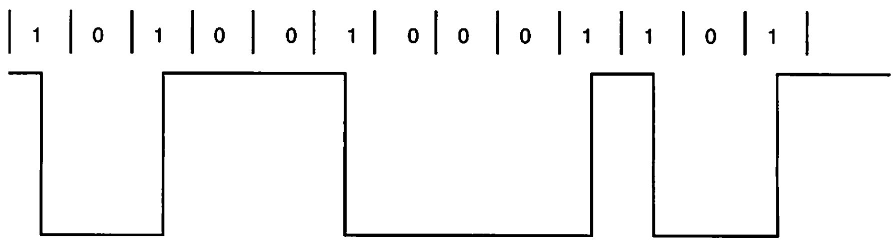
Scrambling

To carry serial digital signals on a single wire, bit clock rate information must be transmitted with the data. The parallel data is first converted to serial in a shift register and becomes serial *NRZ* data.

This data is not well suited for transmission because *clock recovery* becomes difficult if there are long strings of consecutive ones and zeros. To compensate for this, the serial data is *scrambled* to aid clock recovery from the serial signal and to produce better spectral distribution.

After scrambling, the signal is transformed to *NRZI* (Non Return to Zero Inverted) to make the signal polarity insensitive. Thus, a 1 in the scrambled data stream is converted to a transition in the encoded data stream, and a 0 in the scrambled data stream is encoded as no transition.

This data stream can be recovered and descrambled in circuits similar to the scrambler circuits. Synchronization codes have been incorporated in the digital video signal, allowing the receiving *deserializer* to recognize the beginning of particular words. This, in turn, allows for division of the serial signal into parallel *digital words*.



NRZI

dither – Typically, a random low-level signal which may be added to an analog signal prior to sampling. Dithering is used to mask contouring. Typically consists of white noise of one quantizing level peak-to-peak amplitude.

waveform – The shape of an electromagnetic wave. A graphical representation of the relationship between voltage or current and time.

NRZ – Non return to zero. A coding scheme that is polarity sensitive. 0 = logic low; 1 = logic high.

clock recovery – The reconstruction of timing information from digital data.

scrambling – 1. To transpose or invert digital data according to a prearranged scheme in order to break up the low-frequency patterns associated with serial digital signals. 2. The digital signal is shuffled to produce a better spectral distribution.

NRZI – Non return to zero inverted. A coding scheme that is polarity insensitive. 0 = no change in logic; 1 = a transition from one logic level to the other.

deserializer – A device that converts serial digital information to parallel.

digital word – The number of bits treated as a single entity by the system.

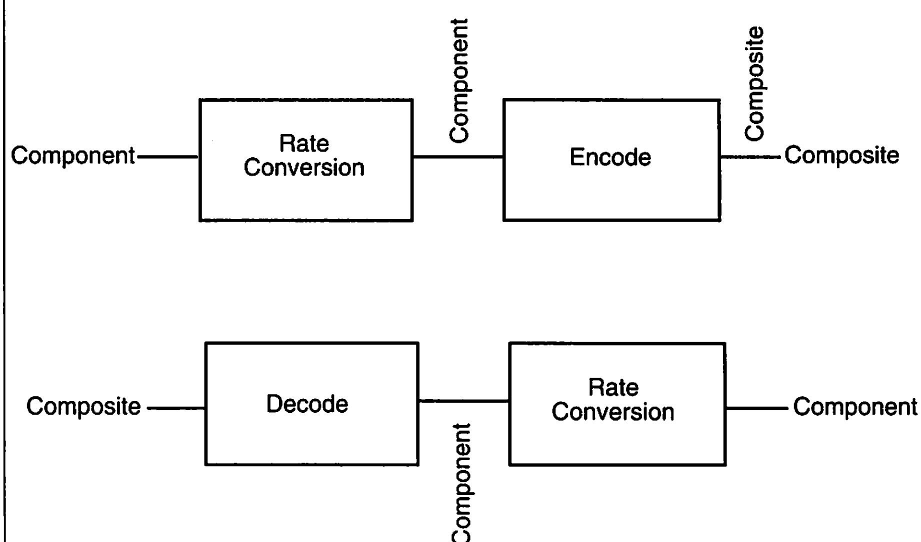
rate conversion – 1. Technically, the process of converting from one sample rate to another. The digital sample rate for the component format is 13.5 MHz; for the composite format it is either 14.3 MHz for NTSC or 17.7 MHz for PAL. 2. Often used incorrectly to indicate both resampling of digital rates and encoding/decoding.

format conversion – The process of both encoding/decoding and resampling of digital rates.

Rate conversion / format conversion

When moving between component digital and composite digital in either direction, there are two steps. One of the steps is the actual encoding or decoding. The other step is the conversion of the sample rate from one format to the other. The digital sample rates for these two formats are different: 13.5 MHz for component digital and 14.3 MHz for NTSC composite digital (17.7 MHz for PAL). This second step is called *"rate conversion."* Often the term "rate conversion" is used to mean both encoding/decoding and resampling of digital rates. Strictly speaking, rate conversion is taking one sample rate and making another sample rate out of it. For our purposes we'll use the term *"format conversion"* to mean both the encode/decode step and resampling of digital rates. (In digital audio, pure rate conversion, vs. format conversion, is used to move between various sample rates.)

The format conversion process sequence is dependent upon direction. For component to composite the sequence is rate conversion followed by encode. For composite to component the sequence is decode followed by rate conversion.



Format conversion process

One example of the need for format conversion involves moving video out of composite digital to component digital in order to do post-production on the material. This is especially true with PAL. It is much easier to do production in component because you don't have to wait for every eighth field (colour framing boundary) to match two pieces of video together; instead you can match them every two fields (motion frame). You have four times the opportunity. Additionally, it is a higher quality format since luminance and chrominance are handled separately.

Other examples of the need for format conversion involve moving from component digital to composite digital. Sources that are component digital may need to get to a composite digital switcher or effects machine. Or a source from a component digital *telecine* may need to get to a composite digital suite. Furthermore, tapes produced in component digital may need to be distributed or archived in composite digital.

telecine – A device for capturing movie film as a video signal.

The two major contributors to the quality of this process are the encoding or decoding process and the sample rate conversion. If either one is faulty, the quality of the final product suffers. Grass Valley Group's preferred implementation is to use the most exacting procedures for both.

In order to accurately change the digital sample rate, computations must be made between two different sample rates and *interpolations* must be calculated between the physical location of the source *pixel* data and the physical location of destination pixel data. Of the approximatley 709,000 pixel locations in a PAL composite digital frame, all, except one, must be mapped (calculated).

interpolation – In digital video, the creation of new pixels in the image by some method of mathematically manipulating the values of neighboring pixels both spacially and temporally.

pixel – The smallest distinguishable and resolvable area in a video image. A single point on the screen. In digital video, a single sample of the picture. Derived from the words *picture element*.

In order to accomplish this computationally intense conversion, an extremely accurate *algorithm* must be used. If the algorithm is accurate enough to deal with conversions from and to PAL, then NTSC conversions using the same algorithm are also accurate. To ensure quality video, a sophisticated algorithm must be employed and the hardware must produce precise *coefficients* and minimize rounding errors.

algorithm – A set of rules or processes for solving a problem in a finite number of steps.

truncation – Deletion of lower significant bits on a digital system. Usually results in digital noise.

coefficient – A number (often a constant) that expresses some property of a physical system in a quantitative way.

Regeneration

Although a video signal may be digital, the real world through which that signal passes is analog. Consequently, it is important to consider the analog distortions which affect a digital signal. These include *frequency response rolloff* caused by cable attenuation, *phase distortion*, *noise*, *clock jitter*, and *baseline shift* due to AC coupling. While a digital signal will retain the ability to communicate its data despite a certain number of these distortions, there is a point beyond which the data will not be recoverable.

frequency response rolloff - A gradual decrease in how effectively a circuit or device passes signals of different frequencies applied to it.

phase distortion - Alterations to a signal as it passes through a network or transducer whose phase shift is a function of frequency. (Graf)

noise - Unwanted disturbance within an electronic system. Interference present in a video picture.

clock jitter - Undesirable random changes in clock phase.

baseline shift - A change in the average DC level of a digital signal caused by a temporary inequality of zeros and ones.

Long cable runs are the main cause of signal distortion. Most digital equipment provides regeneration, in some form, at all the inputs in order to compensate for cable runs of varying lengths. Regeneration of the digital signal generally means to recover data from an incoming signal and to retransmit it with a clean waveform using a stable clock source. Regeneration of a digital signal will allow it to be transmitted farther and sustain more analog degradation than a signal which already has accumulated some analog distortions.

In serial digital video, there are two kinds of regeneration: serial and parallel.

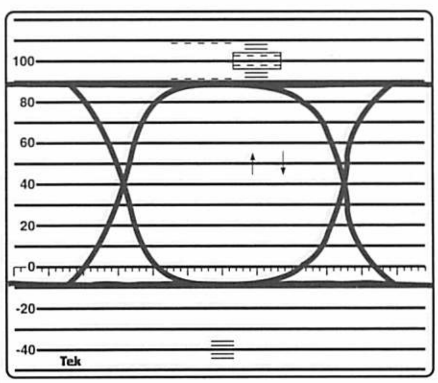
reclocking - The process of clocking the data with a regenerated clock. Analogous to the effect that a flywheel has on a rough running engine; it smooths the rapid speed variation without changing the overall speed.

Serial regeneration is simplest and consists of cable equalization (if necessary), clock recovery, data recovery, and retransmission of the data using the recovered clock. A phase locked loop (PLL) with an LC or RC oscillator is used to regenerate the serial clock frequency, a process called *reclocking*.

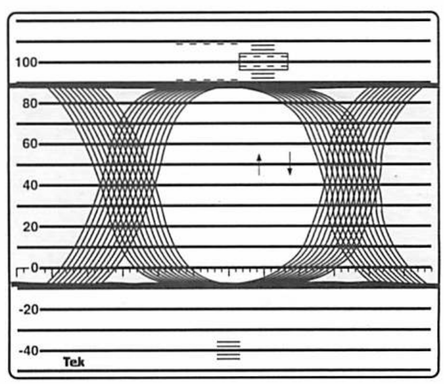
Parallel regeneration is more complex and involves three steps: (1) deserialization; (2) parallel reclocking using a crystal-controlled time base; and (3) serialization.

Each form of regeneration can reduce jitter outside its PLL bandwidth, but jitter within the loop bandwidth will be reproduced and may accumulate significantly with each regeneration. A serial regenerator will have a loop bandwidth on the order of several kilohertz. A parallel regenerator will have a much narrower bandwidth on the order of several Hertz. Therefore, a parallel regenerator can reduce jitter to a greater extent than a serial regenerator, at the expense of greater complexity. In addition, the inherent jitter in a crystal controlled time base (parallel regenerator) is much less than that of an LC or RC oscillator time base (serial regenerator).

Regeneration obviously cannot be performed an infinite number of times because of PLL oscillator jitter. Serial regeneration can typically be performed several dozen times before a parallel regeneration is necessary.



Digital signal with no jitter



Digital signal with jitter
(note horizontal eye opening is reduced)

AES/EBU digital audio and multiplexing

Digital audio is becoming a common ingredient in digital television for many of the same reasons given for digital video. Digital audio is also becoming popular in the home with CD players and DAT recorders.

The Audio Engineering Society in the United States and the European Broadcast Union have similar interface standards: AES3-1991 and EBU Tech. 3250E. Because of early cooperation between these two organizations and the closeness of the resulting specifications, the industry frequently uses the term *AES/EBU* interface. The primary difference between the AES and the EBU specification is that the EBU standard specifies the use of transformers.

AES/EBU – Informal name for a digital audio standard established jointly by the Audio Engineering Society and European Broadcasting Union organizations.

NICAM (near instantaneous companded audio multiplex) – A digital audio coding system originally developed by the BBC for point-to-point links. A later development, NICAM 728, is used in several European countries to provide stereo digital audio to home television receivers.

Several sampling frequencies are used with this standard: 32 kHz is used with the *NICAM* 728 digital stereo audio television system in several countries and some digital recording devices; 44.1 kHz is used primarily in CDs; and 48 kHz is the professional sampling frequency and is used with DAT recorders and digital television transmission.

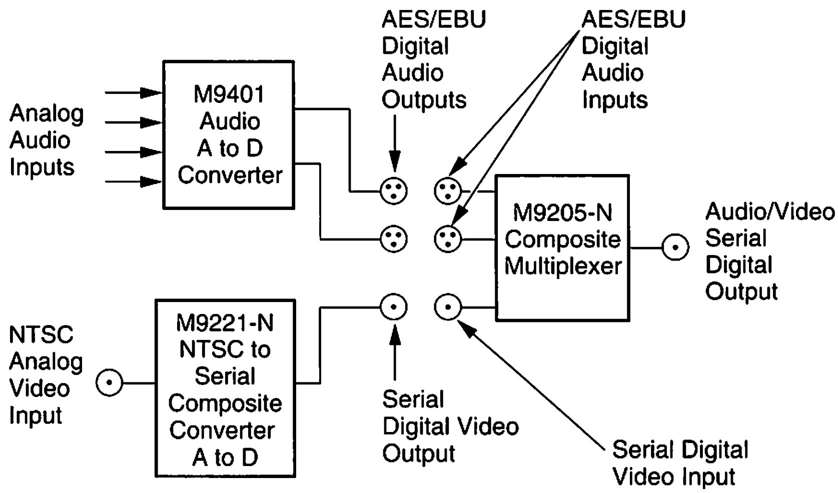
As with video, resolution is very important and ranges from 16-bit to 24-bit. CDs are 16-bit, and professional devices are either 18 or 20-bit. Although 20-bit is highly desirable from a professional audio standpoint, 20-bit A to D converters are currently very expensive and require a lot of power and cooling. It is expected that these difficulties will be overcome in the near future.

The AES/EBU interface supports two channels of digital audio (one stereo pair) and uses an XLR connector. Although XLRs are spelled out in the standard, they may not be practical when used with a routing switcher, for example, because of their large size. For that reason terminal blocks or BNC connectors are often used.

bit stream – A continuous series of bits transmitted on a line.

multiplexer (mux) – Device for combining two or more electrical signals into a single, composite signal.

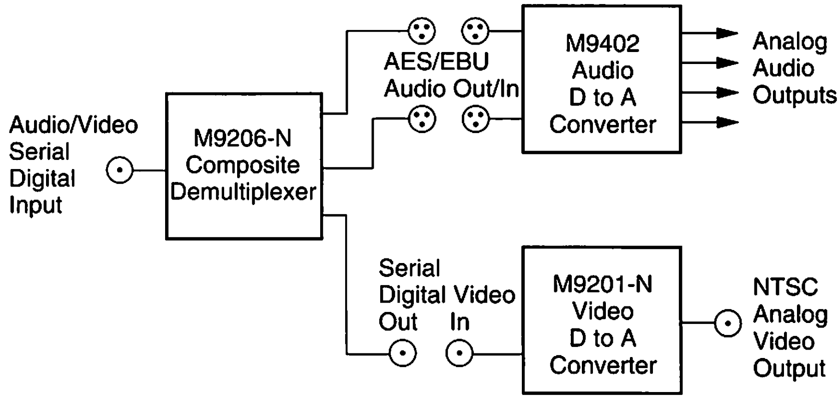
Because AES/EBU digital audio can be transmitted on a single digital *bit stream*, it is possible to combine the digital video bit stream and the digital audio bit stream together and transmit this data on a single coaxial cable. This is accomplished with a *multiplexer* module which combines the digital video and digital audio together using a formatter circuit. The composite digital standard supports two AES/EBU stereo pairs (four audio channels), while the component digital standard supports four or more AES/EBU stereo pairs (8 or more audio channels).



Typical multiplexer system

demultiplexer (demux) – A device used to separate two or more signals that were previously combined by a compatible multiplexer and transmitted over a single channel.

This combined data is easy to route around a facility, but it will be necessary to separate the audio from the video again so that the audio and video can be treated separately. This is accomplished with a *demultiplexer* and a deformatter circuit. Digital-to-analog converters can be used for both the video and audio to revert to analog, if desired.



Typical demultiplexer system

Test and measurement of serial digital television signals

Test and measurement of serial digital television signals is a new concept to most people familiar only with analog signals. Where analog test equipment is generally available and well known, digital test equipment is just now becoming available.

Digital signal waveform analysis is a new dimension in test and measurement for television facilities. Serial digital has high *bandwidth* requirements, and noise and distortion affect digital transmission differently than the more familiar analog systems. To make the transition to serial digital test equipment more economical, new capabilities have been added to traditional analog television test equipment, such as the Tektronix 1730D Waveform Monitor.

Analysis of data in the *horizontal interval* is a key part of format verification and can be accomplished while the system is in service. Horizontal interval checks include whether *TRS-ID* is valid or in the wrong location, whether ancillary data packets are formatted correctly, and whether excluded values appear where allowed. Another method of serial digital testing, Error Detection and Handling (*EDH*), has proven to be a sensitive and accurate way to determine whether the system is operating correctly. Although EDH works on the digital data, its primary function is to test the transmission path operation. If EDH detection systems are incorporated in serial digital equipment, EDH can be one of the key elements in automatic detection of equipment failure in large digital installations. A proposal for implementing EDH into serial digital equipment is currently under consideration by SMPTE.

Analog measurements of the serial digital waveform viewed on an appropriate *scope* or monitor can, with several overlaid time sweeps, produce a waveform known as an *eye pattern*. Any defect in the system that closes the eye will reduce the usefulness of the received signal. Accurate measurements of the eye pattern can be made with the Tektronix 1730D Waveform Monitor.

bandwidth – 1. The difference between the upper and lower limits of a frequency, often measured in megahertz (MHz). 2. The complete range of frequencies over which a circuit or electronic system can function with less than a 3 dB signal loss. 3. The information carrying capability of a particular television channel.

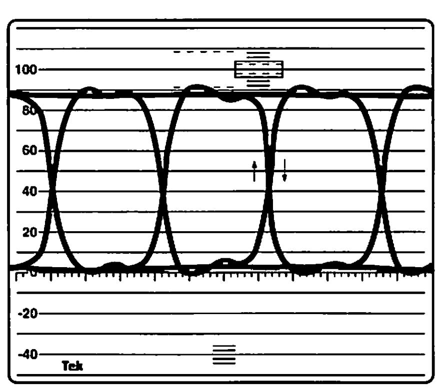
horizontal interval (horizontal blanking interval) – The time period between lines of active video.

TRS-ID (timing reference signal identification) – A reference signal used to maintain timing in composite digital systems. It is four words long.

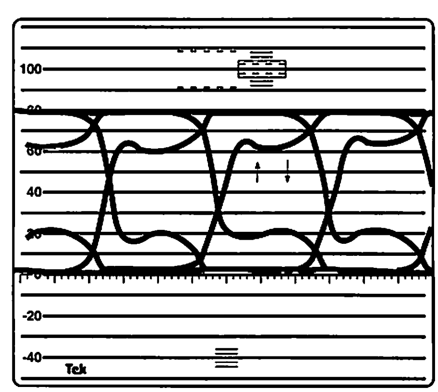
EDH (error detection and handling) – A proposed SMPTE recommended practice RP-165 for recognizing inaccuracies in the serial digital signal. It may be incorporated into serial digital equipment and employ a simple LED error indicator.

scope – Short for oscilloscope (waveform monitor) or vectorscope, devices used to measure the television signal.

eye pattern – A waveform used to evaluate channel performance.



Normal eye pattern on monitor



Closure of eye due to system defect

When evaluating, installing, or repairing serial digital equipment, it is extremely important to know how well the serial digital transmission system is operating. A serial digital signal is very robust and is generally easily recoverable. However, the system can crash without warning if it is close to entering the detection error-limited region. Error rate analysis, combined with experimentation, may incorrectly lead to the conclusion that error detection provides an automatic and electronic means of determining when a serial digital transmission system is broken. Unfortunately, it does not necessarily provide an early warning for sudden system failure.

To prevent the "falling off the digital cliff" syndrome, it is necessary to perform tests that will stress the system in order to determine the amount of headroom between the operating level and the crash point. (Stress testing is best done when a system is first installed.) One common method is to add cable to the transmission path until the error rate becomes observable on a picture monitor or EDH indicator. In operational systems, stress tests can be performed using conventional test signals in serial digital form or by using *pathological signals* in serial digital form. The Tektronix TSG 170D (NTSC), TSG 273 (PAL), and the TSG 422 (component CCIR 601 525/625) test signal generators produce these pathological signals.

pathological signal – Signal that tests the equalizer response and VCO (voltage controlled oscillator) capabilities of a serial receiver. The signal is serial digital with long repetitions of "zeros" or high dc content.

As more serial digital devices are introduced into the marketplace, equipment with additional serial related features will be made available for test and measurement. Until then, the methods described above provide adequate safeguards to ensure signal fidelity.

Answers to common questions

Why should I consider digital at all?

Analog video is subject to differential phase errors, noise and other artifacts because anything added to it becomes part of the analog signal. Digital video is less susceptible to most errors and degradation and produces superior results. Multiple generations of video tape can be made without any noticeable variation from the master tape.

Why should I consider serial digital over the parallel digital format I am currently using?

Parallel digital uses expensive, bulky 25-conductor cables. Serial uses coaxial cable, resulting in considerable cost savings. Also serial digital can use cables up to 300 meters (1,000') long instead of about 50 meters (165') for parallel cables.

Isn't digital more expensive than analog?

As more and more facilities change to digital and digital switchers, routers, disk recorders, and VTRs, and other digital devices (including circuit components) come down in price, digital audio and video will actually be more cost-effective than analog. In addition, digital is more stable than analog and adjustments and maintenance will be less frequent.

Is reclocking necessary?

reclocking – The process of clocking the data with a regenerated clock.

jitter – An undesirable random signal variation with respect to time.

Reclocking a serial digital signal when using a serial digital distribution amplifier or large serial digital routing switcher is highly desirable. Reclocking allows recovery from *jitter* errors and is recommended for signals that require long cable runs.

Why is a serializer necessary?

Most digital television equipment in use today has a parallel interface. This limits cable runs to 50 meters or less. Converting to serial digital allows cable runs to 300 meters and automatic cable equalization is generally provided. As new equipment comes to the market place, serializers may be required only for the older equipment since newer equipment will be delivered with serial I/Os.

Will I have more timing problems with serial digital equipment than I do now with analog equipment?

No. Analog video equipment has propagation delays, usually measured in nanoseconds. Some digital equipment (mainly image processing) has even longer delays measured in micro seconds, TV lines, and even frames. This is because processing is done in clock cycle increments, which take time, resulting in delay.

Is digital audio delay equal to digital video delay?

Digital audio and video transmission equipment typically have similar, very short delays. However, digital video processing equipment may have delays much longer (sometimes several frames) than those of audio equipment. The audio and video delays should be kept the same throughout the system. Even a one frame error can be noticeable. Digital audio delays may be necessary to compensate for the delays of video equipment.

How can I get digital audio out of the serial digital video stream?

A demultiplexer removes digital audio from the serial digital video data stream. Ancillary data, which includes AES/EBU digital audio, occurs during each horizontal line and a "Deformatter" circuit is required.

Why are 75 ohm BNC's necessary?

For many years the industry has used 50-ohm BNCs with 75-ohm coaxial cable. For 5 to 10 MHz video signals, this was adequate. However, we are now transmitting up to 270 Mb/s and will most likely be transmitting at 360 Mb/s (EDTV) in the future. At those rates, impedance mismatch is more important. For optimum transfer characteristics, it is recommended that 75- ohm BNCs and 75-ohm patch panels be used for serial digital signals.

Glossary – Reference

AES – Audio Engineering Society

AES/EBU – Informal name for a digital audio standard established jointly by the Audio Engineering Society and European Broadcasting Union organizations.

algorithm – A set of rules or processes for solving a problem in a finite number of steps.

Aliasing – Defects in the picture typically caused by insufficient sampling or poor filtering of digital video. Defects are typically seen as jaggies on diagonal lines and twinkling or brightening in picture detail.

analog – An adjective describing any signal that varies continuously as opposed to a digital signal that contains discrete levels.

A-to-D Converter (analog-to-digital) – A circuit that uses digital sampling to convert an analog signal into a digital representation of that signal.

bandwidth – 1. The difference between the upper and lower limits of a frequency, often measured in megahertz (MHz). 2. The complete range of frequencies over which a circuit or electronic system can function with less than a 3 dB signal loss. 3. The information carrying capability of a particular television channel.

bit – A binary representation of 1 or 0. One of the quantized levels of a pixel.

bit parallel – Byte wise transmission of digital video down a multi-conductor cabe where each pair of wires carries a single bit. This standard is covered under SMPTE125M, EBU 3267-E and CCIR 656.

bit serial – Bit wise transmission of digital video down a single conductor such as coaxial cable. May also be sent through fiber optics. This standard is covered under CCIR 656.

bit slippage – 1. Occurs when word framing is lost in a serial signal so that the relative value of a bit is incorrect. This is generally reset at the next serial signal, TRS-ID for composite and EAV/SAV for component. 2. The erroneous reading of a serial bit stream when the recovered clock phase drifts enough to miss a bit. 3. A phenomenon which occurs in parallel digital data buses when one or more bits gets out of time in relation to the rest. The result is erroneous data. Differing cable lengths is the most common cause.

bit stream – A continuous series of bits transmitted on a line.

BNC – Abbreviation of *bayonet Neill-Concelman*. A cable connector used extensively in television and named for its inventor.

byte – A complete set of quantized levels containing all of the bits. Bytes consisting of 8 to10 bits per sample are typical.

cable equalization – The process of altering the frequency response of a video amplifier to compensate for high-frequency losses in coaxial cable.

CCIR – International Radio Consultative Committee, an international standards committee.

CCIR-601 – An international standard for component digital television from which was derived the SMPTE 125M (was RP-125) and EBU 3247E standards. CCIR defines the sampling systems, matrix values, and filter characteristics for both Y, Cr, Cb and RGB component digital television.

CCIR-656 – The physical parallel and serial interconnect scheme for CCIR-601. CCIR 656 defines the parallel connector pinouts as well as the blanking, sync, and multiplexing schemes used in both parallel and serial interfaces. Reflects definitions in EBU Tech 3267 (for 625 line signals) and in SMPTE 125M (parallel 525) and SMPTE 259M (serial 525).

channel coding – Describes the way in which the 1s and 0s of the data stream are represented on the transmission path.

character generator (CG) – A computer used to generate text and sometimes graphics for video titles or captions.

clock recovery – The reconstruction of timing information from digital data.

coaxial cable – A transmission line with a concentric pair of signal carrying conductors. There is an inner conductor and an outer conductor metalic sheath. The sheath aids in preventing external radiation from affecting the signal on the inner conductor and minimizes signal radiation from the transmission line.

coding – Representing each level of a video signal as a number, usually in binary form.

coefficients – A number (often a constant) that expresses some property of a physical system in a quantitative way.

component analog – The unencoded analog output of a camera, videotape recorder, etc., consisting of 3 primary color signals: red, green, and blue (RGB) that together convey all necessary picture information. In some component video formats, these three components have been translated into a luminance signal and two color difference signals, for example, Y, R-Y, B-Y.

component digital – A digital representation of a component analog signal set, most often Y, B-Y, R-Y. The encoding parameters are specified by CCIR 601. The parallel interface is specified by CCIR 656 and SMPTE 125M (1991).

composite analog– An encoded video signal, such as NTSC or PAL video, that includes horizontal and vertical synchronizing information.

contouring – Video picture defect due to quantizing at too coarse a level.

composite digital – A digitally encoded video signal, such as NTSC or PAL video, that includes horizontal and vertical synchronizing information.

contouring – A video picture defect which may be caused by quantization that is too coarse.

D-1 – A component digital video recording format that conforms to the CCIR-601 standard. Records on 19mm magnetic tape. (Often used incorrectly to indicate component digital video.)

D-2 – A composite digital video recording format. Records on 19mm magnetic tape. (Often used incorrectly to indicate composite digital video.)

D-3 – A composite digital video recording format. Records on 1/2" magnetic tape. Uses the same composite digital signal format as D-2.

DDR – A hard disk based, random access recording system for video and audio.

delay – The time required for a signal to pass through a device or conductor.

demultiplexer (demux) – A device used to separate two or more signals that were previously combined by a compatible multiplexer and are transmitted over a single channel.

deserializer – A device that converts serial digital information to parallel.

differential gain – A change in subcarrier amplitude of a video signal caused by a change in luminance level of the signal.

differential phase – A change in subcarrier phase of a video signal caused by a change in luminance level of the signal.

digital word – The number of bits treated as a single entity by the system.

discrete – Having an individual identity. An individual circuit component.

dither – Typically, a random low-level signal which may be added to an analog signal prior to sampling. Dithering is used to mask contouring. Typically consists of white noise of one quantizing level peak-to-peak amplitude.

dither component encoding – A slight expansion of the analog signal levels so that the signal comes in contact with more quantizing levels. The results are smoother transitions. This is done by adding white noise (which is at the amplitude of one quantizing level) to the analog signal prior to sampling.

drift – Gradual shift or change in the output over a period of time due to change or aging of circuit components. Change is often caused by thermal instability of components.

D-to-A converter (digital to analog) – A device that converts digital signals to analog signals.

DVTR – Abbreviation of *digital videotape recorder.*

EAV – End of active video in component digital systems

EBU – European Broadcasting Union. An organization of European broadcasters that, among other activities, produces technical statements and recommendations for the 625/50 line television system.

EBU TECH.3246-E – The EBU recommendation for the parallel interface of 625 line digital video signal. It is now replaced by 3267-E. EBU TECH.3246-E was derived from CCIR-601 and contributed to CCIR-656 standards.

EDH (error detection and handling) – A proposed SMPTE recommended practice RP-165 for recognizing inaccuracies in the serial digital signal. It may be incorporated into serial digital equipment and employ a simple LED error indicator.

EQ (equalization) – Process of altering the frequency response of a video amplifier to compensate for high-frequency losses in coaxial cable.

encoder – In video, a device that forms a single, composite color signal from a set of component signals.

error concealment – A technique used when error correction fails (see error correction). Erroneous data is replaced by data synthesized from surrounding pixels.

error correction – A scheme that adds overhead to the data to permit a certain level of errors to be detected and corrected.

eye pattern – A waveform used to evaluate channel performance.

field-time (linear) distortion – An unwarranted change in video signal amplitude that occurs in a time frame of 16 ms.

format conversion – The process of both encoding/decoding and resampling of digital rates.

frequency modulation – Modulation of sine wave or "carrier" by varying its frequency in accordance with amplitude variations of the modulating signal.

gain – Any increase or decrease in strength of an electrical signal. Gain is measured in terms of decibels or number-of-times of magnification.

group delay – A signal defect caused by different frequencies having differing propagation delays (delay at 1 MHz is different from delay at 5 MHz). -

horizontal interval (horizontal blanking interval) – The time period between lines of active video

interpolation – In digital video, the creation of new pixels in the image by some method of mathematically manipulating the values of neighboring pixels both spacially and temporally.

I/O – Abbreviation of *input/output*. Typically refers to sending information or data signals to and from devices.

jaggies – Slang for the stair-step aliasing that appears on diagonal lines. Caused by insufficient filtering, violation of the Nyquist Theory, and/or poor interpolation.

jitter – An undesirable random signal variation with respect to time.

MAC – Multiplexed Analog Component video. This is a means of time multiplexing component analog video down a single transmission channel such as coax, fiber or a satellite channel. Usually involves digital processes to achieve the time compression.

microsecond (µs) – One millionth of a second: 1 x 10^{-6} or 0.000001 second.

Miller squared coding – A DC-free channel coding scheme used in D-2 VTRs.

multi-layer effects – A generic term for a mix/effects system that allows multiple video images to be combined into a composite image.

multiplexer (mux) – Device for combining two or more electrical signals into a single, composite signal.

nanosecond (ns) – One billionth of a second: 1 x 10^{-9} or 0.000000001 second.

NICAM – (near instantaneous companded audio multiplex) - A digital audio coding system originally developed by the BBC for point-to-point links. A later development, NICAM 728, is used in several European countries to provide stereo digital audio to home television receivers.

non-linear encoding – Relatively more levels of quantization are assigned to small amplitude signals, relatively fewer to the large signal peaks.

nonlinearity – Having a gain varying as a function of signal amplitude.

NRZ – Non return to zero. A coding scheme that is polarity sensitive. 0 = logic low; 1 = logic high.

NRZI – Non return to zero inverted. A coding scheme that is polarity insensitive. 0 = no change in logic; 1 = a transition from one logic level to the other.

NTSC (National Television Systems Committee) – Organization that formulated standards for the NTSC television system. Now describes the American system of color telecasting which is used mainly in North America, Japan, and parts of South America.

Nyquist sampling theorem – Intervals between successive samples must be equal to or less than one-half the period of highest frequency.

PAL (Phase Alternate Line) – The name of the color television system in which the E'_V component of burst is inverted in phase from one line to the next in order to minimize hue errors that may occur in color transmission.

parallel cable – A multi-conductor cable carrying simultaneous transmission of data bits. Analagous to the rows of a marching band passing a review point.

patch panel – A manual method of routing signals using a panel of receptacles for sources and destinations and wire jumpers to interconnect between them.

peak to peak – The amplitude (voltage) difference between the most positive and the most negative excursions (peaks) of an electrical signal.

phase distortion – A picture defect caused by unequal delay (phase shifting) of different frequency components within the signal as they pass through different impedance elements – filters, amplifiers, ionospheric variations, etc. The defect in the picture is "fringing"—like defraction rings—at the edges where the contrast changes abruptly.

phase error – A picture defect caused by the incorrect relative timing of a signal in relation to another signal.

phase shift – The movement in relative timing of a signal in relation to another signal.

pixel – The smallest distinguishable and resolvable area in a video image. A single point on the screen. In digital video, a single sample of the picture. Derived from the words *picture element*.

PRBS – Pseudo random binary sequence.

production switcher (vision mixer) – A device that allows transitions between different video pictures. Also allows keying and matting (compositing).

propagation delay (path length) – The time it takes for a signal to travel through a circuit, piece of equipment, or a length of cable.

quantization – The process of converting a continuous analog input into a set of discrete output levels.

quantizing noise – The noise (deviation of a signal from its original or correct value) which results from the quantization process. In serial digital, a granular type of noise only present in the presence of a signal.

rate conversion – 1. Technically, the process of converting from one sample rate to another. The digital sample rate for the component format is 13.5 MHz; for the composite format it is either 14.3 MHz for NTSC or 17.7 MHz for PAL. 2. Often used incorrectly to indicate both resampling of digital rates and encoding/decoding.

reclocking – The process of clocking the data with a regenerated clock.

resolution – The number of bits (four, eight, ten, etc.) determines the minimum discernable step of the digital signal.

4-bits = a resolution of 1 in 16
8-bits = a resolution of 1 in 256
10-bits = a resolution of 1 in 1024

Eight bits is the minimum acceptable for broadcast TV.

RP-125 – See SMPTE 125M

routing switcher – An electronic device that routes a user-supplied signal (audio, video, etc.) from any input to any user-selected output(s).

sampling – Process where analog signals are measured, often millions of times per second for video.

sampling rate – The number of discrete sample measurements made in a given period of time. Often expressed in megahertz for video.

SAV – Start of active video in component digital systems

scope – Short for oscilloscope (waveform monitor) or vectorscope, devices used to measure the television signal.

scrambling – 1. To transpose or invert digital data according to a prearranged scheme in order to break up the low-frequency patterns associated with serial digital signals. 2. The digital signal is shuffled to produce a better spectral distribution.

serial digital – Digital information that is transmitted in serial form. Often used informally to refer to serial digital television signals.

serializer – A device that converts parallel digital information to serial digital.

SMPTE (Society of Motion Picture and Television Engineers) – A professional organization that recommends standards for the television and film industries.

SMPTE 125M (was RP-125) – The SMPTE recommended practice for bit parallel digital interface for component video signals. SMPTE 125M defines the parameters required to generate and distribute component video signals on a parallel interface.

still store – Device for storage of specific frames of video.

sync word – A synchronizing bit pattern, differentiated from the normal data bit patterns, used to identify reference points in the television signal; also to facilitate word framing in a serial receiver.

telecine – A device for capturing movie film as a video signal.

temporal aliasing – A visual defect that occurs when the image being sampled moves too fast for the sampling rate. A common example is wagon wheels that appear to rotate backwards.

time base corrector – Device used to correct for time base errors and stabilize the timing of the video output from a tape machine.

time-multiplex – In the case of CCIR-601, a technique for transmitting three signals at the same time on a group of parallel wires (parallel cable).

TRS – Timing reference signals in composite digital systems (four words long)

TRS-ID (timing reference signal identification) – A reference signal used to maintain timing in composite digital systems. It is four words long.

truncation – Deletion of lower significant bits on a digital system. Usually results in digital noise.

VTR (video tape recorder) – A device which permits audio and video signals to be recorded on magnetic tape.

waveform – The shape of an electromagnetic wave. A graphical representation of the relationship between voltage or current and time.

125M – See SMPTE 125M

4:2:2 – A commonly-used term for a component digital video format. The details of the format are specified in the CCIR-601 standard document. The numerals 4:2:2 denote the ratio of the sampling frequencies of the single luminance channel to the two color difference channels. For every four luminance samples, there are two samples of each color difference channel. See *CCIR-601*.

4fsc – Four times subcarrier sampling rate used in composite digital systems. In NTSC this is 14.3 MHz. In PAL this is 17.7 MHz.

Recommended Bibliography

The Art of Digital Video and *The Art of Digital Audio* by John Watkinson, Focal Press, London and Boston

Digital Specifications

Video

Sample/data rates	**Sample rate**	**Data rate (serial)**
Composite NTSC	14.3 MHz	143 Mb/s
Composite PAL	17.7 MHz	177 Mb/s
Component	13.5 MHz; 6.75 MHz; 6.75 MHz (4:2:2)	270 Mb/s
Component Widescreen	18 MHz; 9 MHz; 9 MHz (under consideration)	360 Mb/s (under consideration)
Maximum cable lengths for accurate signal transfers	**Parallel** 50 meters	**Serial** 300 meters
Cable types	25 pin "D" connector	coax with 75-ohm BNC connector
Coding	NRZ	Scrambled NRZI (non-return-to-zero inverted)

Audio

Audio	**Resolution**	**Sampling frequency**
Sample rates		
Digital television transmission, AES/EBU audio, and DAT recorders	16 / 18 / 20 /24 bits	48 kHz
Compact disks	16	44.1 kHz
NICAM digital stereo audio TV (UK) and some digital recording devices	16	32 kHz

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