

# Transporting Production/Mastering-Quality Digital Video Signals Through the Public Network Using SONET/SDH and ATM Technology

By William C. Philipson and Steven L. Storozum

*This paper describes a method for transporting a variety of high-quality, standards-based digital video signals through the global synchronous optical network/synchronous digital hierarchy (SONET/SDH) public network infrastructure by using cost-effective, flexible asynchronous transmission mode (ATM) technology. The difficulties of creating nonstandard SONET/SDH tributaries within concatenated synchronous transport signals are bypassed by using ATM-based multiplexing techniques. This approach greatly simplifies the design of SONET/SDH video terminal equipment, while permitting transmission of lower speed data channels along with the high-speed video signals along the SONET/SDH backbone. With the use of the techniques described in this paper, any combination of digital video signals can be transported. Finally, due to the extensibility of ATM technology, these production-quality and mastering-quality video signals can be combined with lower speed, compressed video signals in any feasible mix that does not exceed the maximum backbone bandwidth.*

Many video production and post-production organizations have converted to digital video operations as the advantages of an all-digital plant have become clear. Along with this move to digital origination, storage, routing, and editing, the need has arisen to transport the resulting high-bandwidth digital video signals over long distances.

Means for transporting these uncompressed digital video signals have, to date, primarily comprised fiber optic overlay networks due to the complexity and expense of using other methods. However, these networks are inherently limited in scope and require that the fiber-optic interconnect be solely or mostly dedicated to video signals.

Furthermore, the advent of digital video broadcasting will require transport of high-bandwidth digital video

signals that represent either uncompressed or lightly compressed high-definition video over large distances. The only universal way to accomplish this will be to find a way to use high-speed carrier backbone connections to transport these signals.

This paper describes some of the technological issues involved when using high-bandwidth carrier connections based on the synchronous optical network (SONET) and synchronous digital hierarchy (SDH) standards. Rationale is presented for using asynchronous transfer mode (ATM) transport through a SONET/SDH backbone. A proposed transport system architecture is described, and the key requirements for a high-bandwidth, video-oriented SONET/SDH-ATM multiplexer are outlined.

## Background

Over the last several years, there has been a fortuitous coincidence involving the video and the telecommunications worlds. Video production has standardized on digital video technologies; at the same time, standards bodies have developed a coherent

approach to delivering digital television to the consumer. Video signals therefore have migrated into the digital domain, and moreover, serial digital video interface (SDI) technology and high-definition television (HDTV) have upped the requirement for digital transmission bandwidths for production video. Production video systems will not only transport realtime digital video, but also various non-realtime signals, as well as data describing the digital video signal (metadata) and synchronized, editable audio.

Simultaneously, there has been a massive growth in the capacity of telecommunications backbones. This growth is being fueled by many factors, including increased corporate data transmission requirements, multiple phone lines per consumer, and on-line usage patterns that keep telephone connections active for hours rather than minutes. New technologies such as dense wavelength-division multiplexing (DWDM) and photonic switching are being introduced into the telephone network to keep pace with these needs. It is apparent that in the near term, there will be a many-fold increase in backbone bandwidth that will consequently have the potential to make that bandwidth significantly more affordable.

The convergence of digital video bandwidth needs with the increasing supply of telecommunications backbone bandwidth indicates a possible opportunity for production, post-production, and primary distribution video users. If the bandwidth is available to transport SDI and HDTV signals across the worldwide standardized SONET/SDH network, then it is to the advantage of the television industry to devise a way to use these networks for transporting digital video signals.

There are, however, a number of

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## TRANSPORTING PRODUCTION/MASTERING-QUALITY DIGITAL VIDEO SIGNALS THROUGH THE PUBLIC NETWORK USING SONET/SDH AND ATM TECHNOLOGY

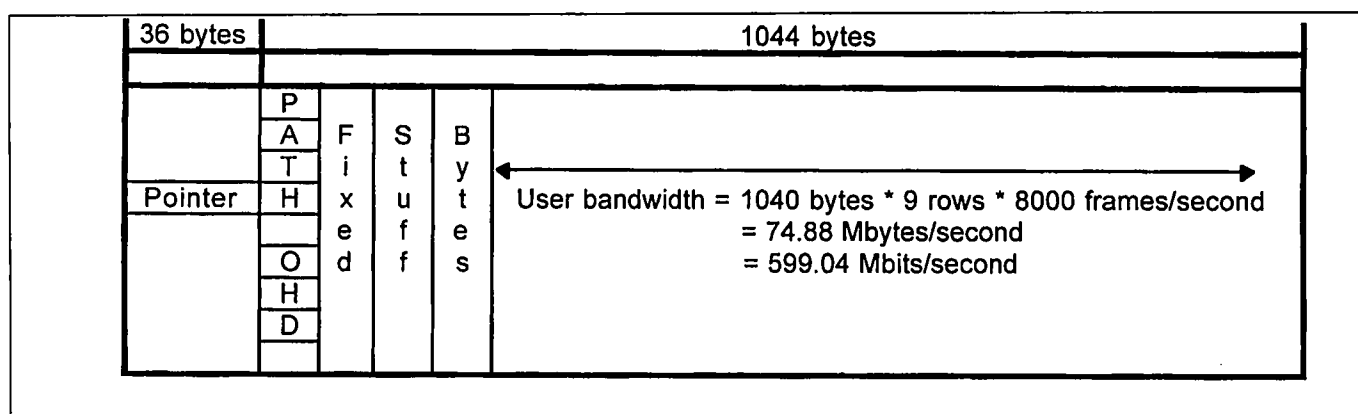


Figure 1. 622 Mbit/sec SONET/SDH concatenated frame.

technical hurdles that must be overcome before the SONET/SDH network can be used for realtime, uncompressed, or lightly compressed digital video. A key issue is the mismatch between digital video bit rates and those of a SONET/SDH network. Table 1 indicates the respective digital transport hierarchies and their relation to video transport specifications.

A scheme for justifying the mismatched data rates is of primary concern. If this can be accomplished, then the SONET/SDH transmission system can permit provisioning of appropriate amounts of bandwidth based on the type of video being transported. The hierarchical, scaleable natures of both the video and telecommunications systems seem to be well-matched.

Also, the very nature of realtime, uncompressed video is such that it must have the highest transmission priority. Unlike data protocols such as transport control protocol/internet pro-

ocol (TCP/IP), there is no way to recover from dropped packets in a realtime video transmission.

Video signal latency must be tightly controlled as well. Low-delay paths with a static amount of delay are permissible, but delay variability will severely corrupt a realtime video signal. This observation implies that if a realtime video signal must be switched, the switching mechanism must either not rely on the statistical probability of available bandwidth and delay, but rather must guarantee a low-latency, assured bandwidth route through the system.

An additional concern is the asymmetric nature of video transmission. The video signal is unidirectional, or there is a low data rate control signal in the return path. There are many instances as well where a full-bandwidth video signal may be sent in one direction and a low-bandwidth compressed video signal may be returned.

This is less of a system functionality issue and more of a bandwidth provisioning issue for carriers and so is not considered in this paper.

### Transporting High-Quality Video Over SONET/SDH and ATM Networks

As shown in Table 1, the SONET/SDH hierarchy has the potential of carrying various types of digital broadcast/production/post-production video signals. This paper focuses on the issues surrounding transport of 270 Mbit/sec signals through a SONET/SDH STS-12/STM-4, 622 Mbit/sec telecom network. The arguments given can be scaled up to support 360 Mbits/sec over the 622 Mbit/sec backbone or 1.5 Gbit/sec HDTV over a 2.488 Gbit/sec, STS-48/STM-16 network, or they can be scaled down to support lower data rate digital video signals over SONET/SDH networks.

The first observation is that a "concatenated" SONET/SDH stream must be used when sending 270 Mbit/sec signals. The SONET/SDH payload must not contain any internal framing information that would otherwise be used in telephony applications. A concatenated SONET/SDH 622 Mbit/sec frame structure is shown in Fig. 1.

Not only must the 270 Mbit/sec signal be mapped into the payload area of the 622 Mbit/sec frame, accommodation must be made for the different clocking requirements of SONET/SDH and video networks. SONET/SDH transmission results in the loss of a precise timing reference with which to regenerate the video signal, either analog or digital, at the network output

Table 1 — SONET/SDH Data Rates and Corresponding Video Data Rates

Accepted SONET/SDH Data Rate	Digital Video Data Rate
155.52 Mbits/sec; 149.76 Mbits/sec payload (OC-3/STS-3/STM-1)	133 Mbits/sec (10-bit digitized analog video without audio)
622.08 Mbits/sec; 599.04 Mbits/sec payload (OC-12/STS-12/STM-4)	270 Mbits/sec (SMPTE 259M-C SDI) 360 Mbits/sec (SMPTE 259M-D SDI; proposed compressed HDTV)
2.488 Gbits/sec; 2.396 Gbits/sec payload (OC-48/STS-48/STM-16)	1.5 Gbits/sec (uncompressed HDTV)

## TRANSPORTING PRODUCTION/MASTERING-QUALITY DIGITAL VIDEO SIGNALS THROUGH THE PUBLIC NETWORK USING SONET/SDH AND ATM TECHNOLOGY

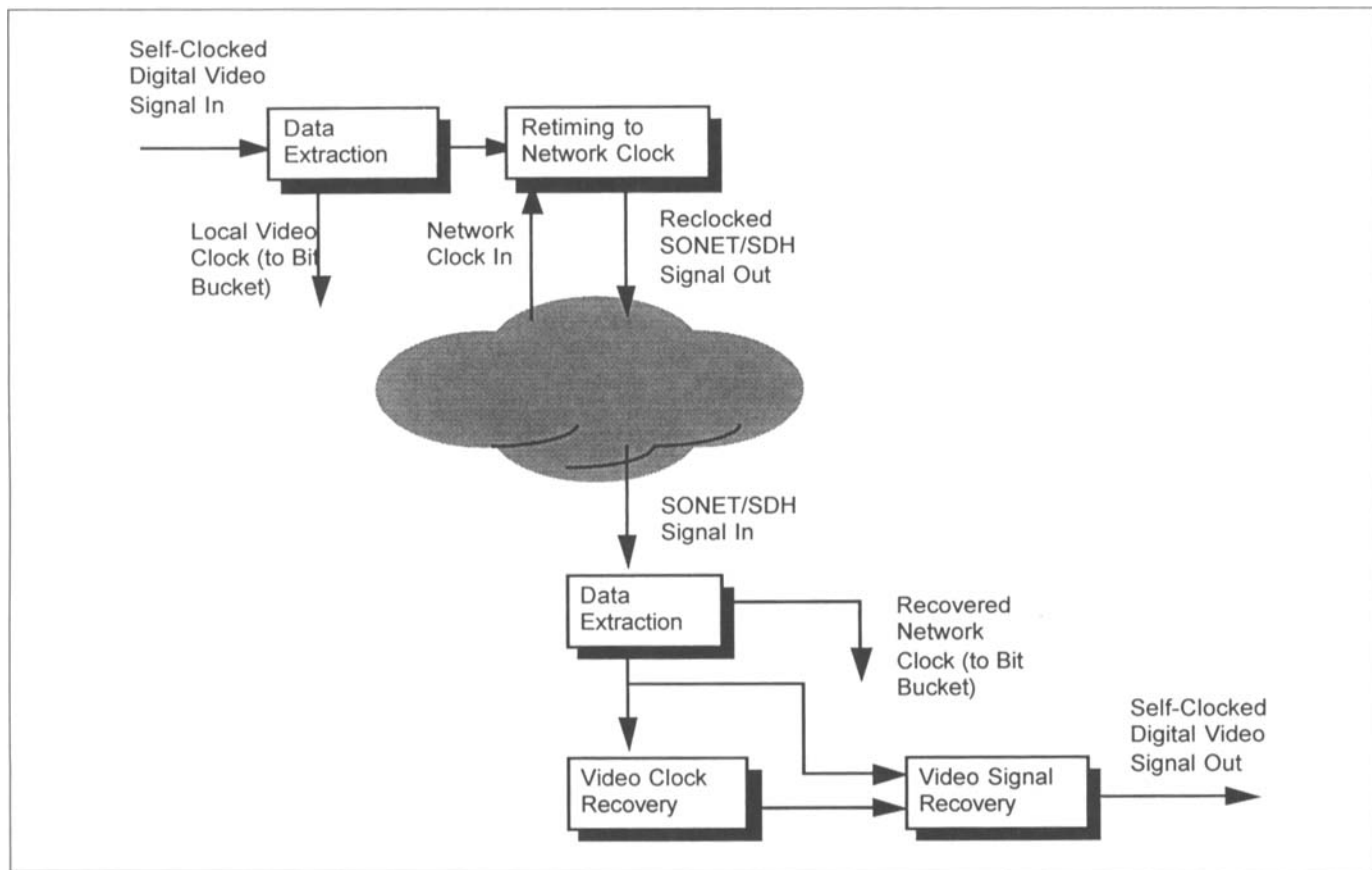


Figure 2. SONET/SDH video clock recovery.

port. At the network input port, where video data are loaded into the SONET/SDH payload, the video clock is discarded in favor of SONET/SDH network clocking.

As the SONET/SDH payload passes from one point to another as it traverses the network, the clock with which the SONET/SDH signal is transmitted also slightly varies in frequency and phase. These timing differences, which are unavoidable in real-world systems, are accommodated by shifting the starting location of the payload within the SONET/SDH frame, a process called pointer justification. Figure 1 shows the location of the pointer "word" that indicates where in the frame the data starts. At the network output port, the removal of the SONET/SDH overhead and the effects of pointer adjustments can adversely impact the video signal unless they are buffered.

At the network output port, the only way to compute the clock rate with which the video entered the network is by inspecting the long-term average

rate of arrival of the video data. A stable, jitter-free clock meeting video requirements must be regenerated based on this average. This challenge is difficult, but not impossible, to overcome. Figure 2 shows the concept behind these statements.

Once the raw SONET/SDH clocking issues have been solved, there remains another thorny topic, that of mapping the video payload appropriately into the SONET/SDH frame. Payload mapping can be a complex process, as evidenced by those mappings already defined for multiplexing lower rate, asynchronous/plesiosynchronous voice/data tributaries into SONET/SDH carriers.

This complexity can be avoided by utilizing ATM for video transport through SONET/SDH networks. ATM divides the payload to be transported into 48-byte cells prefixed by a 5-byte header. The header contains addressing and control information in four bytes, with a fifth byte containing an error detection and correction word protecting the other four header bytes.

Although ATM increases the overhead required to transport the video (decreasing the effective payload), it vastly simplifies inserting and recovering the payload from the SONET/SDH network. ATM mapping is a part of the SONET/SDH standard and is accomplished by placing ATM cells contiguously, back-to-back into the SONET/SDH payload. If at any time no ATM cell is available from the video source due to the mismatch between video timing and SONET/SDH timing, a "null," or empty, ATM cell is automatically inserted into the SONET/SDH payload, and this padding is automatically discarded when the payload exits the SONET/SDH network. Thus payload mapping and timing justification are accomplished very simply, at the cost of decreased data transmission capacity.

The specific characteristics of high-bit-rate video allow some significant simplifications to be made to the fairly complex ATM standards. Although the ATM cell headers defined by the

## TRANSPORTING PRODUCTION/MASTERING-QUALITY DIGITAL VIDEO SIGNALS THROUGH THE PUBLIC NETWORK USING SONET/SDH AND ATM TECHNOLOGY

ATM standards allow thousands of different users to share SONET/SDH payloads using a variety of data and quality of service, video requires a much reduced subset of options because fewer channels and only one quality of service are likely to be accommodated.

Because the video ATM data will remain isolated in dedicated SONET/SDH channels, full compliance with the entire, complex suite of ATM protocols is not required, with consequent savings in hardware and software complexity. This still allows leveraging the extensive work done in developing ATM but selectively implementing those characteristics and features that make sense for a "mostly video" network.

This leveraging notably permits use in video transport systems of off-the-shelf very large scale integrated circuits developed for SONET/SDH ATM applications primarily aimed at higher volume markets such as local area network/wide area network/internet applications. These complex devices already comply with all SONET/SDH and ATM standards requirements, relieving the equipment designer of the onerous task of translating extensive written standards into compliant physical circuits.

To some extent, the leveraging also applies to software development, because a video network will represent a much-simplified subset of the other applications to which SONET/SDH and ATM are being applied.

Thus the major "technology cost" of using SONET/SDH and ATM for video transport is the increase in clock regeneration complexity described above.

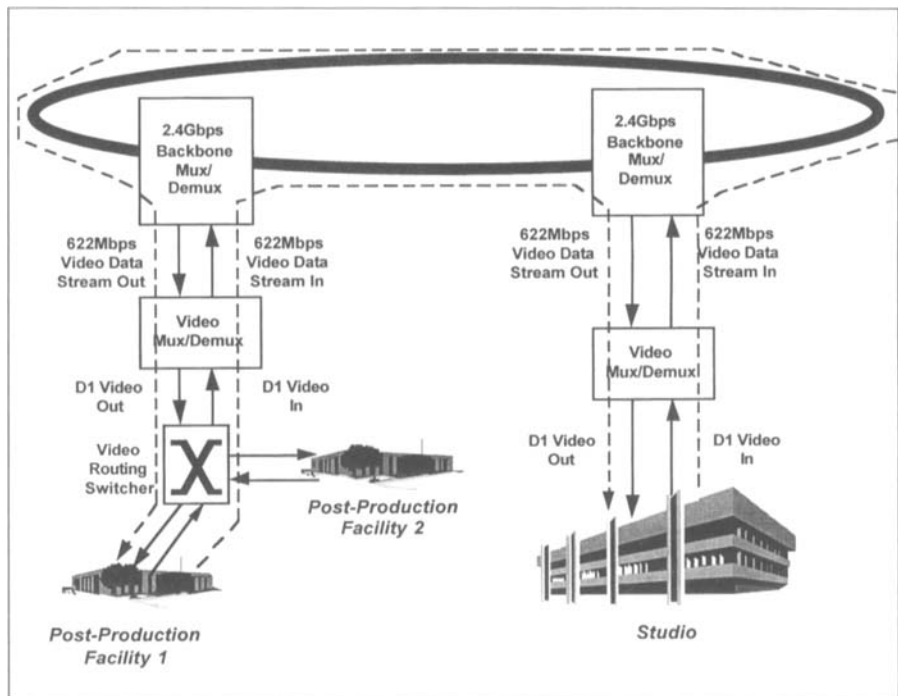


Figure 4. Switching signals through SONET/SDH backbones using a video routing switcher.

### Coexistence of High-Quality Video and Other Signals in a SONET/SDH Backbone

Most ATM applications involve low per-port transmission rates relative to switch capacity. Using today's technology, ATM switches typically expect 45 Mbits/sec or less per user port. Additionally, these switches have been designed with the assumption that traffic distribution will be statistical in its arrival time and its speed, permitting oversubscription of ATM switch fabrics. The standard ATM cell supports oversubscription by way of the cell loss priority bit in the ATM cell header. If this bit is set, the cell that follows may not be dis-

carded, but if it is not set, the cell can, under certain circumstances, be removed from the cell stream. This removal might result in a garbled data packet, but higher-layer protocols typically handle garbled packets by requesting packet retransmission. Packet retransmission is possible and in fact is likely to occur in non-real-time data interchanges.

Uncompressed video, however, has special requirements that are at odds with an oversubscribed ATM switching fabric. First, the data arrival rate of uncompressed, digital video is fixed, and the speed of an uncompressed video signal is fixed at levels much higher than the typical ATM switch has been designed to handle. In addition, there is no error correction mechanism possible with live video, so that if a cell is dropped, its information is forever lost and its absence may corrupt the video signal itself. Therefore there is nothing in the nature of these key video signal features that can take advantage of some of the main benefits of ATM switching, namely, the ability of the switch to drop cells when congested, relying on retransmission, and to handle many lower-speed connections even when the switch is oversubscribed.

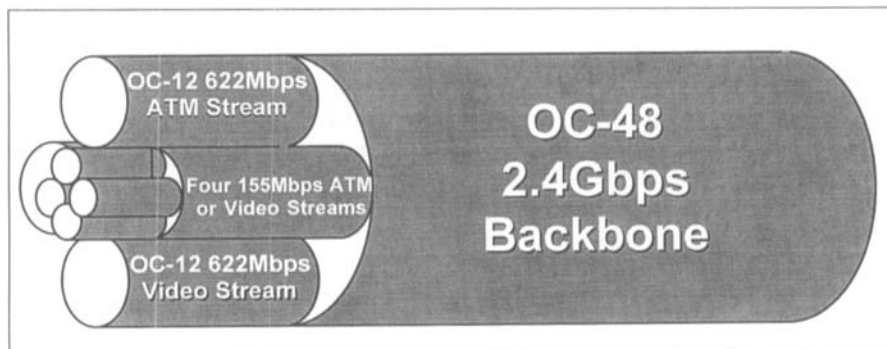


Figure 3. Video and voice/data sharing a 2.4 Gbit/sec backbone.

## TRANSPORTING PRODUCTION/MASTERING-QUALITY DIGITAL VIDEO SIGNALS THROUGH THE PUBLIC NETWORK USING SONET/SDH AND ATM TECHNOLOGY

One other difficulty that the dropping of ATM cells would cause with the digital video signal is that it would become very difficult to recover video clocking if cells were randomly discarded by the ATM switch. In a SONET/SDH network, timing may be affected by the 3-byte-long pointer that absorbs clock differences between network elements, as described above. However, dropping random ATM cells causes 53-byte-long timing fluctuations that would be manifest as massive jitter on the incoming signal. The key issue is that, in an oversubscribed ATM network, the quality of the clock on the incoming signal at the receiver is simply unknown and, thus, very difficult or expensive to accommodate in circuit design.

Even if the technical hurdles of handling realtime uncompressed digital video signals through an ATM switch are overcome, adding high-speed ports to an ATM switch will increase that switch's cost. Unfortunately, high-quality video signals sent through carrier networks today are not significant sources of revenue for the carrier, and so any video services of these types offered through a carrier's ATM network must be priced low, relative to the amount of bandwidth the service requires. It is thus difficult for carriers to economically justify the use of ATM switching for production/mastering-quality video transport services through their network.

Both the technical and economic arguments indicate that ATM switching may not be the best solution for transporting very high speed digital video signals through carrier networks. Rather, it is proposed that the most cost-efficient method of using a SONET/SDH backbone for video transport would be to dedicate certain portions of the backbone to uncompressed or lightly compressed video traffic and the rest to conventional voice/data/compressed video information. All information may be mapped into cells in the backbone, but the high-speed video could be either delivered point-to-point or could be switched using much less expensive, high-speed video routing switches of the type that are currently deployed in many production and transmission environments. Figure 3 illustrates the

concept of sharing high-speed SONET/SDH backbones.

The concept of using a video routing switcher in conjunction with a SONET/SDH backbone is illustrated in Fig. 4. Here, multiple post-production facilities can connect on demand to the studio, permitting remote editing or reviewing of video content. Because all routing is done with standard-technology video routing switches, cost to implement this system is kept to a minimum.

### Proposed System Architecture

One possible system architecture for multiplexing video signals into a SONET/SDH-ATM cell stream is illustrated in Fig. 5.

In this architecture, inputs to the multiplexer are converted to byte-wide format and fed into a first-in first-out (FIFO) data storage circuit. Clock recovery and serial-to-parallel conversion is performed on the signals in the process. The data do not have to be frame-aligned unless error checking is required.

A field-programmable gate array (FPGA) would allocate bandwidth to the different inputs to keep each channel flowing at a roughly constant rate, reading one ATM cell worth of data out of the FIFO and adding the ATM cell header. The formatted ATM cells are then input to the ATM cell to STS-12c/STM-1c mapper.

The ATM cell to STS-12c/STM-1c

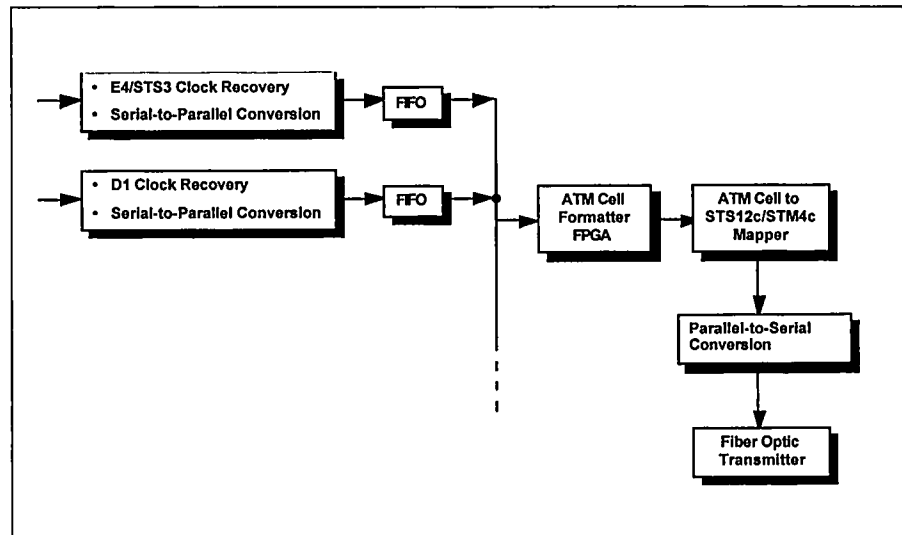


Figure 5. 622 Mbit/sec SONET/SDH-ATM video multiplexer.

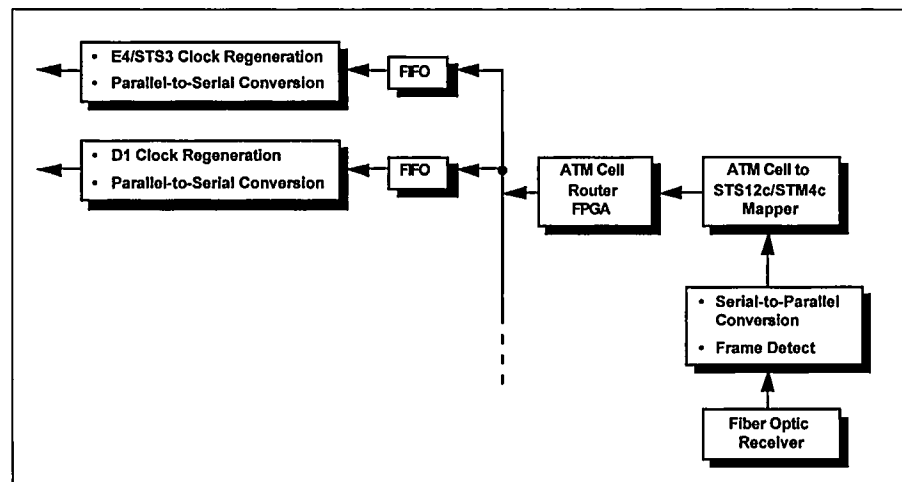


Figure 6. 622 Mbit/sec SONET/SDH-ATM video demultiplexer.

## TRANSPORTING PRODUCTION/MASTERING-QUALITY DIGITAL VIDEO SIGNALS THROUGH THE PUBLIC NETWORK USING SONET/SDH AND ATM TECHNOLOGY

mapper accepts completed ATM cells into its internal FIFO and then maps them into a formatted STS 12c/STM-4c frame, which is output byte serially. This signal is then converted to a serial 622 Mbit/sec stream and drives an optical transmitter.

Note that this design can be accomplished with off-the-shelf hardware, with the exception of the FPGA chip. This chip must be designed, but speeds within the system are low enough to keep the cost of FPGA chip technology reasonable.

The corresponding demultiplexer is shown in Fig. 6.

The ATM cell to SONET/SDH mapper requires byte-aligned data, so the serial-to-parallel conversion circuit must perform frame detection; this is a standard feature of several available receiver ICs. The mapper extracts the ATM payload from the STS-12c/STM-4c frame, locates ATM cell boundaries, and provides them through an internal FIFO. A custom FPGA is then required to read the ATM cell header and route the recovered cell payload to the correct output channel FIFO. Unless required for error checking, D-1 data are passed through the system as received.

The system architecture described here has the advantage of being able to accommodate any non-SONET/SDH, video-oriented digital data rate up to a certain maximum. Thus a 360 Mbit/sec interface can be devised to permit either SMPTE 259M-D 16 x 9-format serial digital video signals or future compressed HDTV signals operating at 360 Mbits/sec. A nationwide production/primary distribution network using the SONET/SDH infrastructure is therefore made possible, permitting, for example, networks to distribute HDTV signals to their affiliates in a format that permits insertion of local "bugs," or station identifiers, in the corner of the image.

### Conclusion

By using ATM chip technology in conjunction with SONET/SDH transmission technology, a system can be devised to affordably transport video-oriented digital signals through carrier networks over long distances. Instead of using an ATM switching fabric to route the signals, a point-to-point/

daisy-chain system can be constructed with the ability to drop and insert video channels through conventional routing switch technology. This combination of technologies lowers system cost and complexity so that carriers

can offer reasonably priced, uncompressed digital video transport to broadcasters, studios, and post-production facilities as well as government, medical, and educational institutions.

### THE AUTHORS



**William C. Philipson** is a senior engineer with Video Products Group, Inc., where he designs video and audio transmission equipment. He earned his BSEE and MSEE degrees at Columbia University and served with the Navy Seabees before securing civilian employment as an engineer. Through a variety of employers, he has been involved with fiber-optic transmission systems since 1984, with emphasis on video and audio transport since 1992.

Philipson has spoken on various topics in fiber-optic and communications technologies throughout his career, most recently at the Bellcore-sponsored Broadband and Emerging Video Services Conference that focused on issues surrounding broadcast-quality video signal transport by transmission service providers. He has also been active in the Video Services Industry Forum group that has addressed various video transmission-related standards issues between vendors and Bell operating companies.

**Steven L. Storozum** has over 20 years of experience developing and marketing data, video, and voice communications technology products, specializing in fiber optics. As vice-president of marketing and sales for Video Products Group, Inc., he devises and implements strategies for public network and fiber-optic contribution-



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Prior to his present position, he served as product line manager for fiber/DS3/SONET/ATM backbone data transmission equipment and for multiprotocol LAN hubs at ADC Fibermux Corp. He previously held the position of product manager for analog video transmission products at PCO, Inc.; helped to launch an Ethernet LAN equipment supplier, American Photonics, Inc.; and held engineering and marketing positions with McDonnell Aircraft Corp. and ITT Electro-optical Products Div.

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Storozum earned a B.A. in physics from Washington University in St. Louis, MO, an MSEE from Carnegie-Mellon University, in Pittsburgh, PA, and has pursued Ph.D. studies in electrical engineering at Carnegie-Mellon University and at Virginia Tech, Blacksburg, VA. He is an active member of SMPTE, IEEE, the Video Services Industry Forum, and the American Physical Society.