Synchronous Digital Fiber-Optic Networks for Multichannel Video Transmission

By Kenneth Regnier

New terms such as "multimedia," "video compression," and "communications superhighways" are continually appearing in today's television system planning, and the underlying structure of these concepts is digital technology and transmission. In modern communications structures, fiber optics is the dominant medium for terrestrial transmission of digital signals, and digital fiber-optic systems are becoming well established for transporting high-quality video, audio, and data signals.

Digital coding enables a very robust transport medium and has other practical system advantages. A multilevel, synchronous, time-division multiplex (TDM) architecture is the key element in realizing the flexible, high-performance advantages of digital transmission. The ability of a digital system to interface with multiple signal formats and the emerging telecommunications optical network standards is another important advantage. Considerations for a synchronous TDM, including an advanced design for distributing clock signals, and signal interfacing aspects of a digital system will be covered in this paper.

Key Attributes

Digital fiber-optic systems for video transmission require several important characteristics to make them practical from both a cost and implementation standpoint. Systems should make efficient use of optical fiber by transporting multiple channels of video and audio on a single fiber. However, they must also offer cost-efficient methods to transport a single channel of video on one fiber for small systems and for contribution or distribution circuits within multichannel trunking systems.

A digital system should be easy to expand or extend, and it should be easy to drop and insert signals along the network. When these changes in system topology (including routing or switching signals) are all done in the digital domain, transparent video and audio signal performance is ensured.

A third attribute of growing importance is the ability of these networks to accept a variety of signal formats and to interface with telecommunications networks that typically carry telephone (voice) and data circuits. Signal formats for transmission on video networks might include video encoded at different levels of digitizing accuracy, compressed video, advanced or high-definition video, and high data rate nonvideo digital signals.

Synchronous Time-Division Multiplex (TDM)

Hardware-based, synchronous time-division multiplexing is used as a cost-efficient, practical way to achieve the attributes of multiple-channel operation and digital drop/insert capability. The multiplex design is optimized for maximum data transfer efficiency by minimizing the amount of data "overhead" needed to operate the multiplex structure. This allows the maximum amount of transmission channel capacity to be available for signal "payload." Maximizing channel capacity is important because the main function of these systems is to transport multiple channels of high data rate video signals rather than large numbers of lower-rate voice and data circuits. For that reason these systems are often referred to as "dedicated" or "private networks."

Synchronous time-division multiplex (TDM) in the digital domain not only facilitates multichannel capability, but also allows every channel to be fully independent. Video channels can thus be added or removed from an optical transmission channel without affecting any other signal or other part of the system. The same advantage also applies when TDM is used with such auxiliary services as audio and data signals.

In the context of this paper, synchronous TDM means that all digital signals entering a TDM are frequency-synchronous with one system clock and have a common data rate. The TDM input data rates are fixed, as is the output data rate. This minimizes system complexity, cost, and the amount of data overhead required for TDM synchronizing and channel management.

Phasing between signal data and signal clock can become difficult to maintain at high data rates; for example, at 100 Mbits/sec or more, a difference of only a few inches in cable length can cause significant variances in clock/data phase. Therefore, a valuable design feature for practical system implementation is to allow incoming data to a TDM to be only frequency-synchronous and not necessarily in a fixed-phase relationship with system clock. This enhances system reliability and allows for easy reconfiguration because phasing of the data inputs and outputs to the TDM is not critical in relation to system clock.

When a synchronous TDM is used in systems that are providing continuous, uninterruptible video service, it must be designed to reliably and quickly resynchronize after transmission errors or interruptions. It should also have the ability to retain channel integrity and synchronization with any combination of input/output signals.

A synchronous TDM structure within a transmission system can also have a multilevel hierarchy (e.g., multiple TDM units operating within a system), each with a different but scalable data rate. This is useful when

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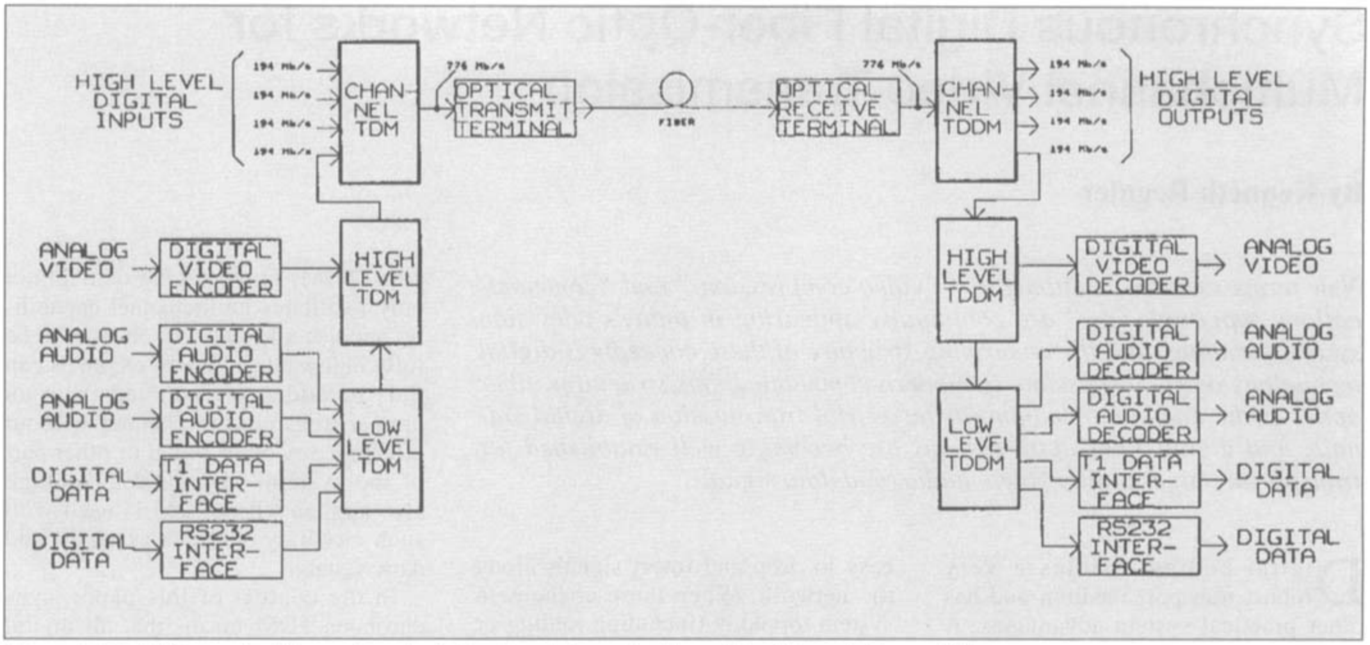

Figure 1. Digital fiber-optic video system: basic functional elements with multilevel time-division multiplex.

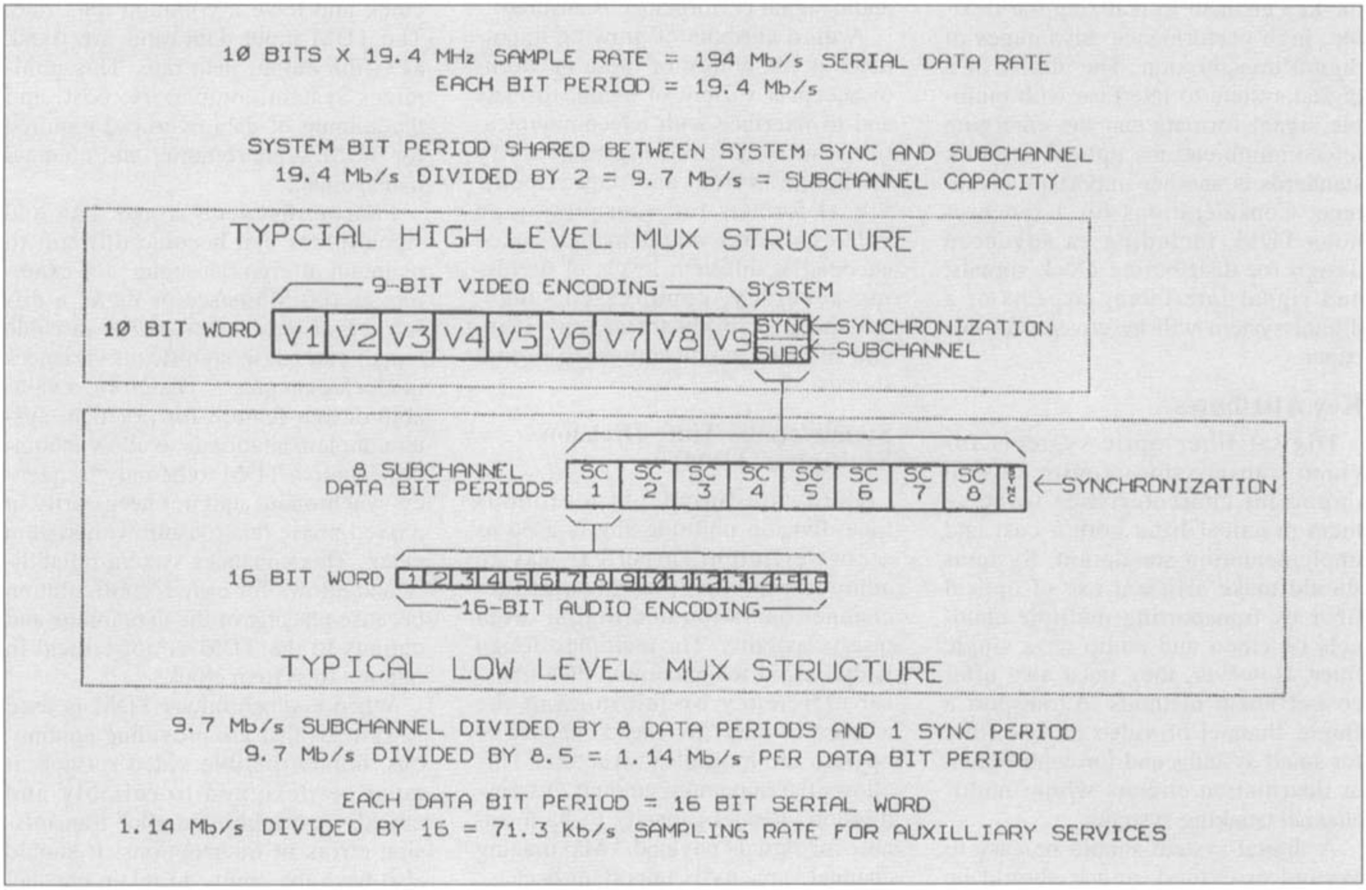

Figure 2. Synchronous time-division multiplex: typical multilevel, digital hierarchy.

systems must accept a variety of different signals. Figure 1 illustrates the basic elements of a digital fiber-optic transmission system and where a multilevel TDM hierarchy fits within the system. Figure 2 shows the structure of a multilevel TDM that is used in one type of digital system.

System Reference Clock

Synchronous digital transmission systems require some type of timing reference to synchronize the overall system, often referred to as "system clock." Clock distribution is generally implemented either externally or internally to the main data transmission system. Large digital telephony

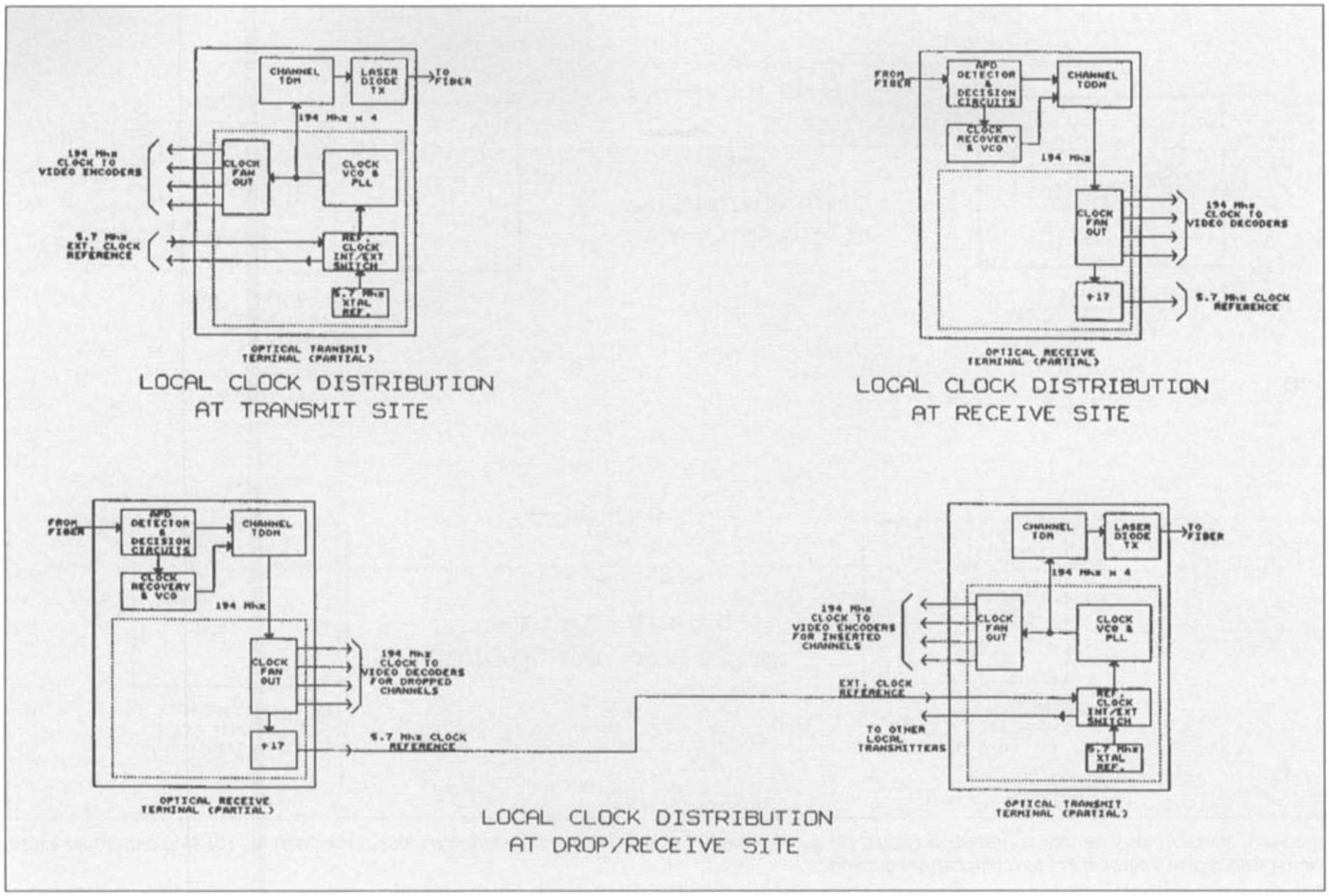

Figure 3. System reference clock: typical clock distribution as part of the data-transmission system.

networks often use a standalone transmission system to distribute system clock to all terminal equipment sites. System clock is generally a much lower data rate signal than a high-capacity data transmission system, and as a result, the separate transmission of clock can sometimes be a different medium than the data system.

When system clock is carried internally within the data system, overall system cost and implementation complexity are generally reduced. However, this places an added burden on the main data transmission system to reliably transport and manage system reference clock signals. In this type of system, a reference clock signal is generally embedded in the main transmission data stream. It is then recovered at each receive site for decoding the data stream, synchronizing demultiplexers, and synchronizing new signals at a drop/insert site. System clock reference signals at receive and transmit sites should also be part of hot-standby redundant configurations. Figure 3 illustrates typical configurations for clock distribution within a system.

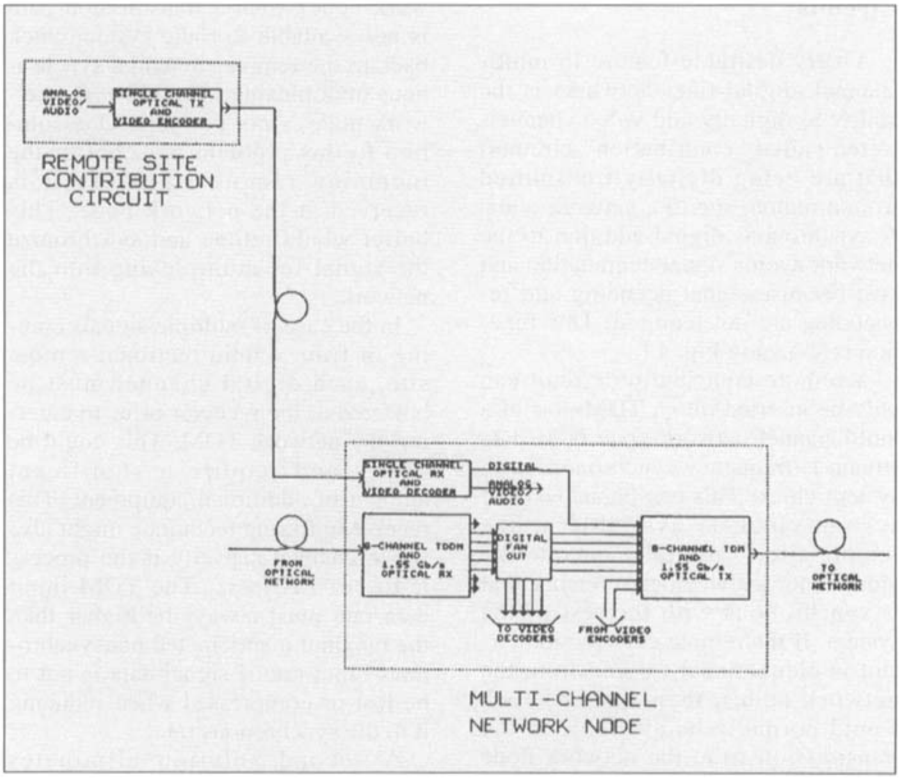

Figure 4. Digital fiber-optic video system: synchronous remote contribution circuit within a multi-channel network.

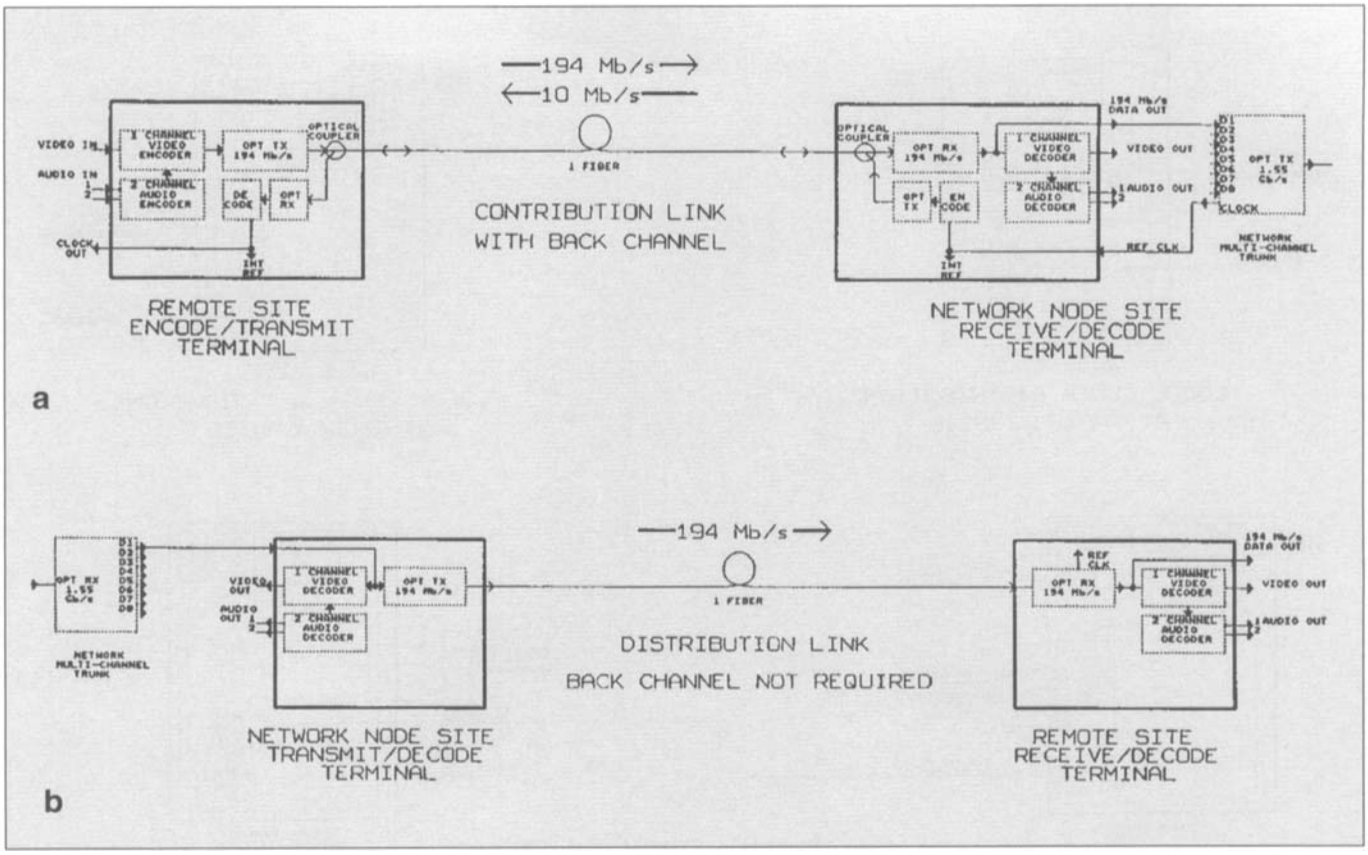

Figure 5. Synchronous remote contribution circuit: (a) single-channel video circuit with reference clock back channel; (b) single-channel video circuit with digital interconnect to multichannel network.

Synchronous Contribution Circuits

A very desirable feature in multichannel, digital-fiber networks is the ability to digitally add video channels (often called "contribution" circuits) that are being digitally transmitted from a remote site to a network node. A synchronous digital addition to the network avoids signal degradation and cost because signal decoding and re-encoding are not required. This function is shown in Fig. 4.

A remote contribution circuit can only be inserted into a TDM port of a multichannel network node if its data stream is frequency-synchronous with system clock. This can be achieved if system clock is available at the remote site to digitally encode the video input with a clock reference that is synchronous with the rest of the system. If the remote contribution circuit is bidirectional (to and from the network node), then system clock would normally be available in the transmission from the network node back to the remote site.

However, if the contribution circuit is unidirectional (remote site to network node), then a transmission path is not available to route system clock back to the remote site and a synchronous multiplexing insertion at the network node is not possible. One solution to this problem is to buffer the incoming remote signal as it is received at the network node. This buffer would retime and synchronize the signal for multiplexing into the network.

In the case of multiple signals coming in from a unidirectional remote site, each digital channel must be buffered at the receiver prior to entering the network TDM. This could be costly and require a significant amount of additional equipment. This receive buffering technique might also waste channel capacity if the process is to be "lossless." The TDM input data rate must always be higher than the maximum anticipated nonsynchronous input rate if signal data is not to be lost or compressed when reducing it to the synchronous rate.

A second solution eliminates receive buffering while at the same time adding some bidirectional versatility to the system. This can be done without requiring a full-return transmission path on either a second fiber or by optical multiplexing (WDM) on one fiber. It is possible to simultaneously and continuously transmit a low data rate digital signal in the reverse direction on the same optical fiber and at the same optical wavelength as the high data rate forward transmission (Fig. 5).

A duplex transmission link operating on one fiber at the same optical wavelength in both directions is very desirable from both a cost and operational standpoint. This is achieved by diplexing the forward and reverse signals using optical couplers at the terminal ends. However, this causes some interference between the forward and reverse signals that degrades the signal-to-noise ratio (SNR) of the link. This degradation can be minimized by the normal reverse isolation of the couplers, and by shaping the power-frequency spectrums of each signal in order to separate and filter the high data rate forward stream from the low data rate reverse stream.

Figure 6 is an example of the spec-

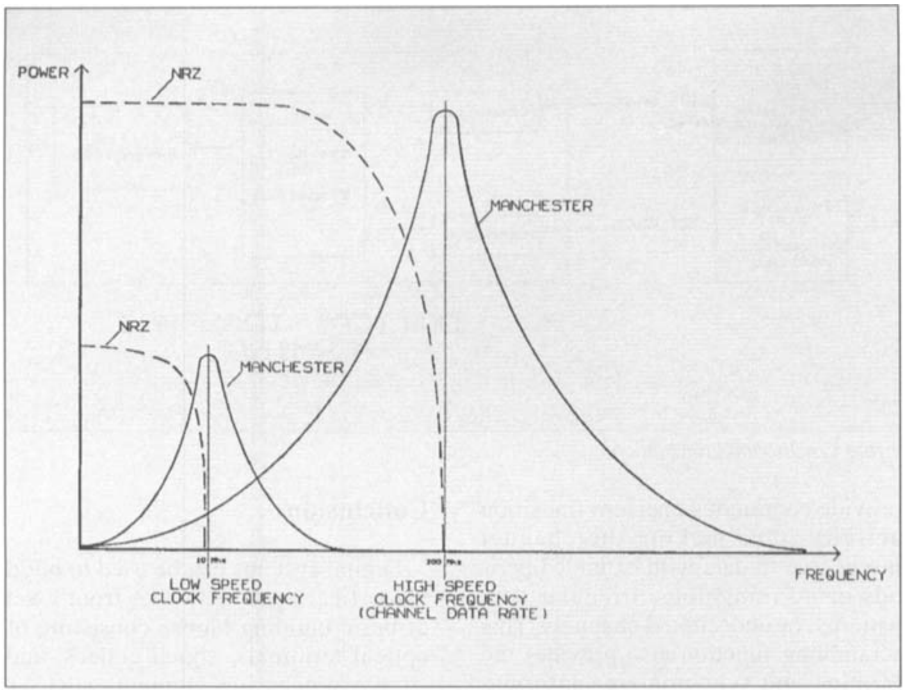

Figure 6. Power-frequency spectrum shaping: Manchester line coding and NRZ line coding.

trum shaping that is used to achieve separation of the data streams. The dashed line shows a typical spectrum of a digital signal that has been line coded to an NRZ format commonly used in digital transmission. A continuous spectrum extending from a low frequency (as determined by the maximum run length of one/zero transitions) to a maximum frequency approaching the bit rate of the data stream is produced. Significant interference will occur if this coding is used on the forward and reverse data streams of the optically diplexed system. The low-frequency components of the high-speed data stream will degrade the SNR of the low-speed data stream and, conversely, the spectrum of the low-speed data stream will contribute noise to the high-speed data stream.

However, a substantial improvement can be made in the received SNR of both the low-speed and high-

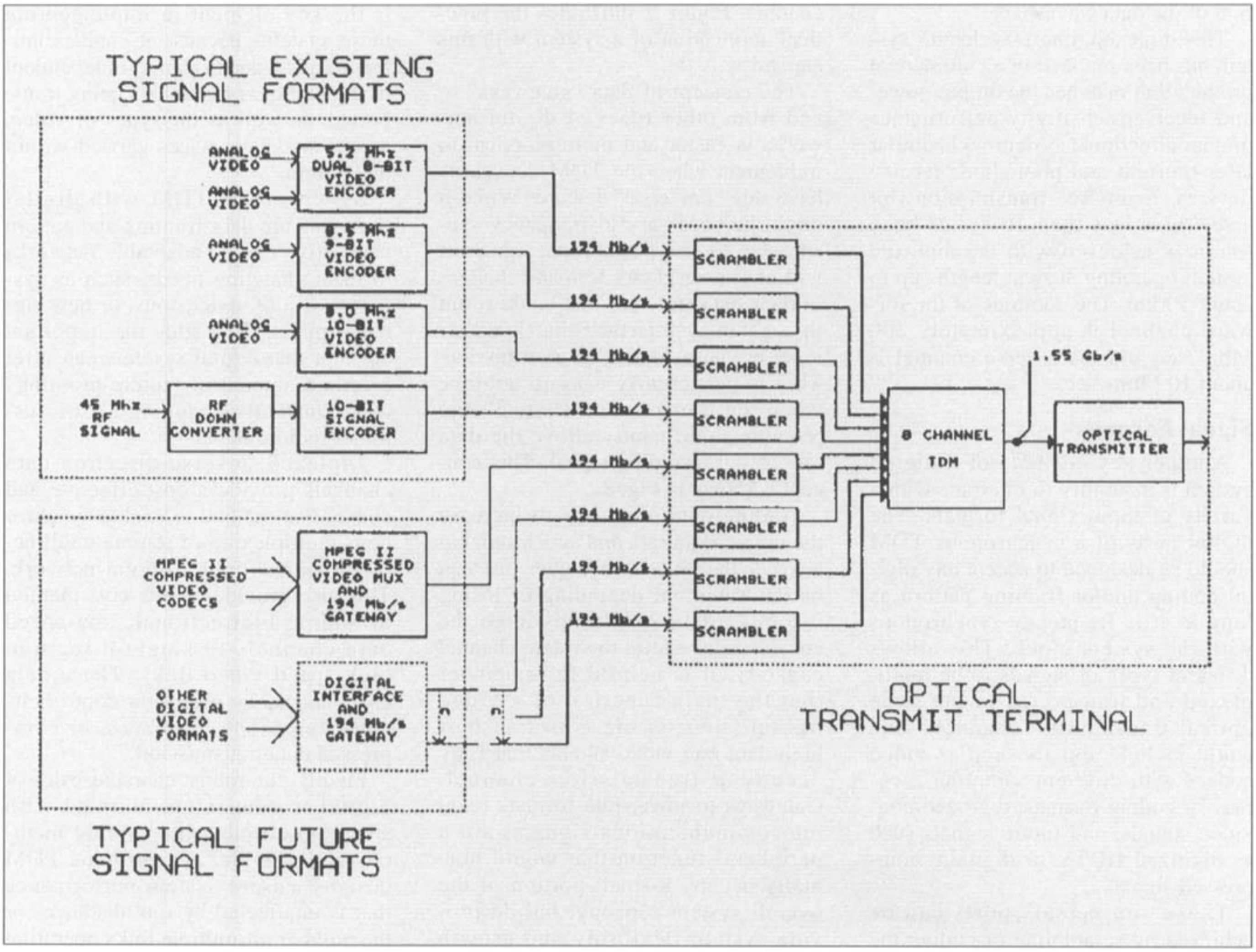

Figure 7. Input signal formats: "universal" digital transmission ports data format/pattern insensitive due to scramblers.

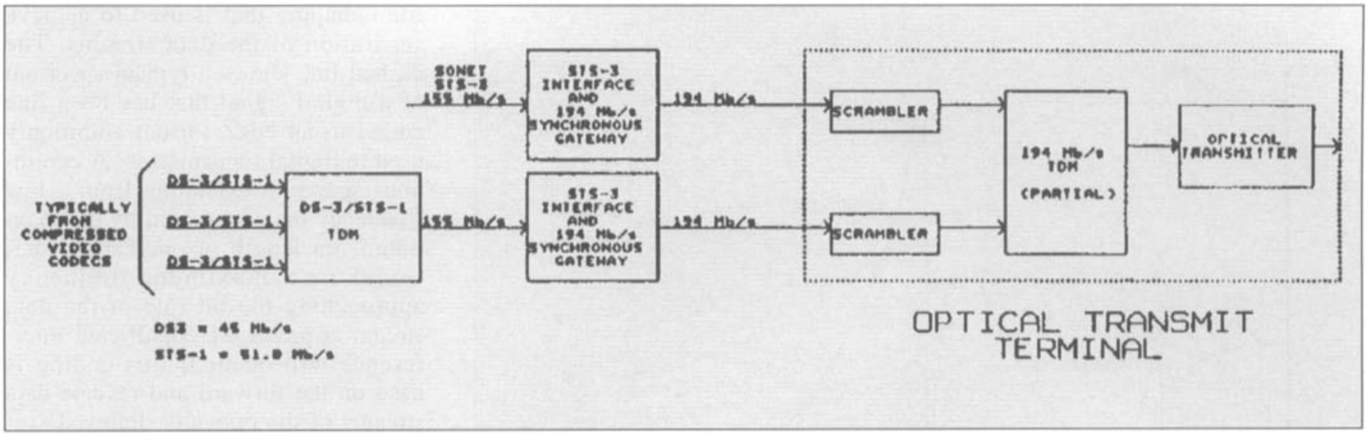

Figure 8. Input data gateways: lower rate to higher rate synchronous translation.

speed channels by using a transmission channel line code with a power spectrum that falls away quickly from a desired center or clock frequency. A biphase or Manchester code will yield such a spectrum (Fig. 6). With these response characteristics, practical filters can be designed to separate each data stream with very little degradation of the data waveshape.

This diplexed, one-wavelength system has been realized in a commercial product that matches the output power and receiver sensitivity performance of a unidirectional system with similar laser transmit and photodiode receive devices. Error-free transmission (bit error rates less than 10^{-9}) has been routinely achieved with the diplexed system operating at span lengths up to about 50 km. The data rate of the forward channel is approximately 200 Mbits/sec and the reverse channel is about 10 Mbits/sec.

Signal Formats

Another key attribute of a digital system is its ability to interface with a variety of input signal formats. The digital ports of a synchronous TDM should be designed to accept any digital coding and/or framing pattern as long as it is frequency-synchronous with the system clock. This allows different types of signals to be multiplexed and transported in the same optical transmission channel. This could include signals such as video codecs with different sampling accuracy or coding formats, digitized nonvideo signals, and future signals such as digitized HDTV or digitally compressed signals.

These "universal" ports can be achieved by scrambling or coding the incoming data on each TDM port to provide continuous one/zero transition activity, thus making the channel insensitive to data with extended periods of no transitions, irregular data patterns, or unoccupied channels. This scrambling function also provides the framing and synchronizing information necessary for the receive demultiplexer to identify and separate each channel. Figure 7 illustrates the practical application of a system with this capability.

The concept of data "gateways" to and from other types of digital networks is easier and more practical to implement when the TDM data ports have this "universal" feature. While it might be necessary to frequency-synchronize some types of input signals, it will not be necessary to make changes in their data structure that could result in a gateway interface that is either lossy or causes degraded transmission. This is particularly easy to achieve when the transmission channel rate remains significantly above the data rate of the incoming signal. This concept is shown in Fig. 8.

Adding extra data bits to increase the output data rate and synchronizing a lower date rate to a higher one can be done without degrading or losing incoming data. While this might be considered wasteful to system channel capacity, it is helpful to remember that the main function of a video transmission system is to transport high data rate video signals that fully occupy a transmission channel. Gateways to lower-rate formats (e.g., telecommunications signals) are a peripheral function that would normally occupy a small portion of the overall system capacity, but do provide system flexibility and growth potential.

Conclusion

Digital systems can be used to build video fiber-optic networks from a set of basic building blocks consisting of optical terminals, signal codecs, and simple processing elements such as digital fanouts and switches. Synchronous time-division multiplexing is the key element in implementing these systems because it enables uniform signal performance independent of the number of channels being transported, as well as the types of video, audio, or data services carried within the system.

Synchronous TDM with digital ports that are data-framing and pattern insensitive enable adaptable networks to meet changing needs, such as system additions, extensions, or new signal formats. This adds the important concept that digital systems can offer a certain amount of "future-proofing" to a constantly changing set of customer requirements.

Diplexed, reverse-direction data channels provide a cost-effective and convenient method to enable synchronous multiplexing of remote unidirectional signals into a digital network. This also provides a low-cost method of adding bidirectional, low-speed data channels to single-direction, high-speed video links. These data channels can be useful for control circuits, telephone interfaces, or compressed data transmission.

Finally, the robust characteristics of digital transmission, coupled with spectrum-efficient line coding methods and reliable, synchronous TDM designs, ensure system performance that is unaffected by link distances or the number of multiple links operating within a network.