18. Examples of Time Division Multiplexed PAM and PCM Systems

We have seen in our earlier discussion that time division multiplexing (TDM) can be applied to PAM and PCM signals. We shall discuss two practical TDM PAM and PCM systems here.

In general, the multiplexing operations are usually carried out in two steps: low-data-rate signals are first time-multiplexed to form composite signals of much greater bandwidth; the composite signals are then in turn time-multiplexed with other wideband signals to form the main multiplexed signal. A typical TDM system has the following features:

1. A frame structure must exist.
2. All signals to be multiplexed are serviced at least once in a frame.
3. Each frame is divided into time slots.
4. Each time slot is uniquely assigned to a user.
5. More than one time slot can be assigned to a user.
6. Framing and synchronisation signals must exist to locate the beginning of each frame, time slot, and symbol.
7. Provision must be made to handle small transmission-rate variations from users.

The conceptual diagrams of multiplexing and the framing structure are shown in Figures 18.1 and 18.2, respectively.

Figure 18.1 Conceptual diagram of multiplexing and demultiplexing operations.

Figure 18.2 Typical framing structure.

18.1 PAM System for Radio Telemetry

The PAM system to be discussed is typical of those used for radio telemetry. Signals from 318 different users are sampled, time-multiplexed, and transmitted via radio. The signal bandwidth ranges from 1 Hz to 2 kHz. Some of the signals with the same bandwidth are first time-multiplexed to form composite signals of much greater bandwidth, and the main multiplexer is designed to handle 16 input signals, with a frame duration of 1/2500 seconds. Table 18.1 shows the grouping, bandwidth, sampling rate and the multiplexer input position of the system. Signals are oversampled in this system.

Group	No. of users	No. of spares	Bandwidth per user	Sampling rate	Multiplexer input position
1	3 (1A, 1B, 1C)	0	2 kHz	5,000	2 and 10, 4 and 12, 5 and 13
2	2 (2A, 2B)	0	1 kHz	2,500	3, 6
3	5	3	100 Hz	312.5	7
4	28	4	25 Hz	78	8
5	55	9	5 Hz	39	9
6	115	13	5 Hz	19.5	14
7	110	18	1 Hz	19.5	15

Table 18.1 Grouping, bandwidth, sampling rate and the main multiplexer input arrangement of the TDM PAM system.

The three 2 kHz signals are sampled at 5000 samples per second. Two time slots, spaced 1/5000 seconds apart, must be allocated for each of the 3 users in a frame.

The two 1kHz signals, sampled at 2500 samples per second, are obviously tied directly to the main multiplexer (positions 3 and 6). The low-bandwidth signals in groups 3 to 7 are time-multiplexed to form composite signals. Figure 18.3 shows the frame structure of the time-multiplexed signals in group 3. A sampling rate of 312.5 samples per second makes 8 time slots available. It is apparent that we only use 5 time slots and leave the remaining 3 time slots as spare.

Figure 18.3 Frame structure of the time-multiplexed signals in group 3.

The frame structure of the main multiplexer and the block diagram of the TDM PAM system for radio telemetry are shown in Figures 18.4 and 18.5, respectively. Two synchronisation signals are placed in time slots 1 and 11, and time slot 16 is not used.

Figure 18.4 Composite signal format.

Figure 18.5 TDM PAM system for radio telemetry.

18.2 The T1 Carrier System: North American PCM Telephone System

The *T1 carrier system* was developed in the United States in the early 1960s for digital voice communication over short-haul distances of 10-50 miles. Each channel (user) is first sampled at a rate of 8000 samples per second and quantised using 8-bit μ-law companding. 24 voice channels are then combined into a composite signal denoted as DS1. We thus have a total of 192 bits. One bit is added to this total for synchronisation purposes. A 1010... sequence, in odd-numbered frames, is used for this purpose. There is a total of 193 bits in a frame of duration 1/8000 = 125μs. The *trunk rate* is (193/125) x 10^6 = 1.544 Mbits/s. Figure 18.6 shows the framing structure of the T1 carrier system.

Figure 18.6 The T1 system framing structure.

Other than synchronisation in the usual way, the added framing bit has another purpose. When a telephone call is placed, there is a need for what is called *control signalling* information (on-hook and off-hook) to set up the call. Therefore, in every sixth frame, the least-significant bit in every voice channel is robbed and a signalling bit is placed in that position. A 111000111000... sequence, in even-numbered frames, is used to identify the occurrence of the frame containing signalling bits. The T1 carrier system has found widespread adoption throughout the United States, Canada, and Japan. It also forms the basis for a complete hierarchy of higher-order multiplexed systems, used for longer-distance transmission. This is shown in Figure 18.7.

Figure 18.7 TDM hierarchy, North American telephone system.

In Europe, they adopted the CCITT (Comite Consultatif Internationale de Telegraphique et Telephonique) recommendation. This system multiplexes 32 channels with a trunk rate of 2.048 Mbps. Figure 18.8 shows the TDM hierarchy as recommended by the CCITT.

Figure 18.8 TDM hierarchy, CCITT recommendation.

18.2.1 Bit Stuffing

It was noted earlier that provision must be made to handle small transmission-rate variations from users. To handle small rate variations, we can employ a bit stuffing technique.

Consider the arrangement as shown in Figure 18.9.

Figure 18.9 Elastic buffer for bit stuffing.

The data sequence from each user is fed into a elastic buffer at a rate of R_1 bits per second. The contents of this buffer are then fed to the input of the multiplexer at a higher rate, and the multiplexer also monitors the buffer contents. If the input rate R_1 begins to drop relative to the clock rate R'_1, the buffer contents decrease. When the number of bits in the buffer drops below a predefined threshold level, the multiplexer disables readout of this buffer by the stuff signal, as shown in Figure 18.9. A bit is then stuffed. When the buffer contents rise above the threshold level, sampling of the buffer contents is resumed. An example of the bit-stuffing process is shown in Figure 18.10. Bits are stuffed into the multiplexed data stream at time t = 3 when the input rate of user 1 drops below the threshold level and at time t = 6 when the input rate of user 2 drops below the threshold level.

Figure 18.10 Multiplexing of two data streams with bit stuffing.

At the receiving end, the stuffed bits must be removed from the data stream. As an example, we consider the DS3 frame structure of the TDM hierarchy used by the North Americans, where a composite DS3 signal is formed by multiplexing 7 input data signals at DS2 level (Figure 18.7). Figure 18.11 shows the DS3 framing structure.

Figure 18.11 DS3 framing structure.

Each DS3 frame is divided into 7 subframes. Data and control (X, P, F, M, C) bits are spread out through the frame. Each frame contains $[(12 \times 7) \times 8] \times 7$ = 4704 data bits and 8×7 = 56 control bits. There is a total of 4760 bits in a frame of duration 106.402 μs. The X and P control bits are used for automatic request retransmission (ARQ) and error detection. The 0 or 1 following the F, M, and C control signals denotes the actual bit (0 or 1) transmitted.

The F pattern, 1001 1001 ..., locates the position of the data and control bits, and provides the main framing pattern for synchronisation purposes. The 3-bit pattern provided by the M control bits locates the position of the 7 subframes. Finally, the 3-bit pattern provided by the C control bits identifies which of the 7 channels (users) at DS2 level has been stuffed. Only one stuffed bit per input channel is allowed per frame. Figure 18.12 shows that, when C51 C52 C53 = 111, there is bit stuffing in subframe 5, and when C61 C62 C63 = 000, there is no bit stuffing in subframe 6. The stuffed bit appears as the first information bit of the 12 bits for that input channel, and is added in the last data block of that subframe.

Figure 18.12 Examples of the bit-stuffing process.

Reference

[1] M. Schwartz, Information Transmission, Modulation, and Noise, 4/e, McGraw Hill, 1990.

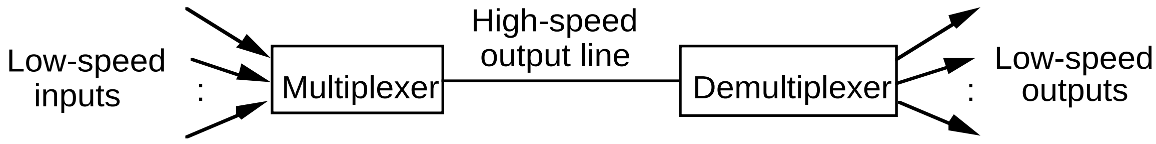

Figure 18.1 Conceptual diagram of multiplexing and demultiplexing operations.

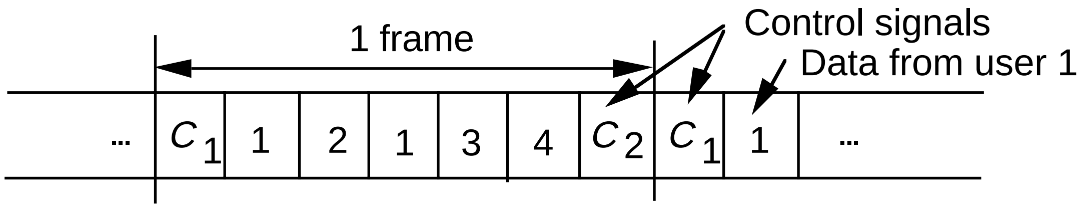

Figure 18.2 Typical framing structure.

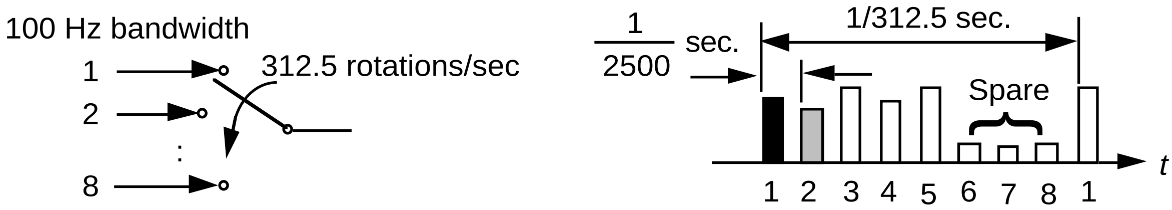

Figure 18.3 Frame structure of the time-multiplexed signals in group 3.

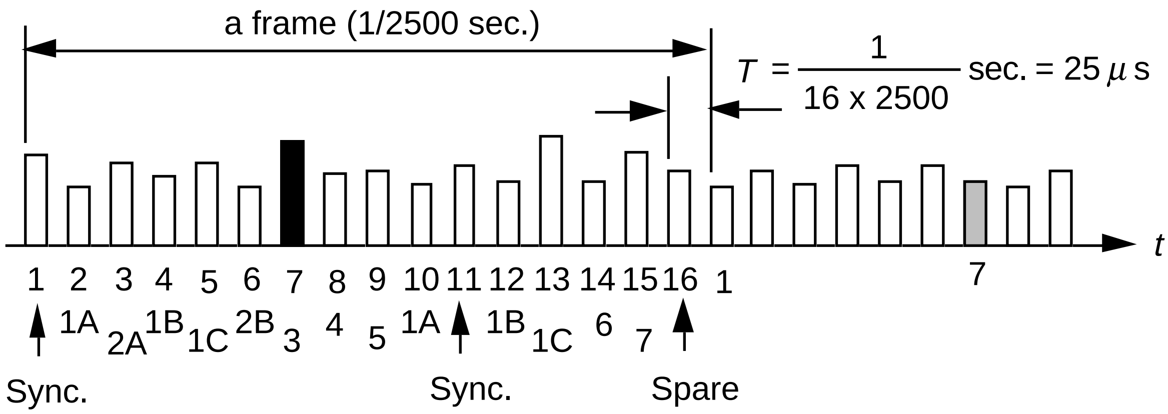

Figure 18.4 Composite signal format.

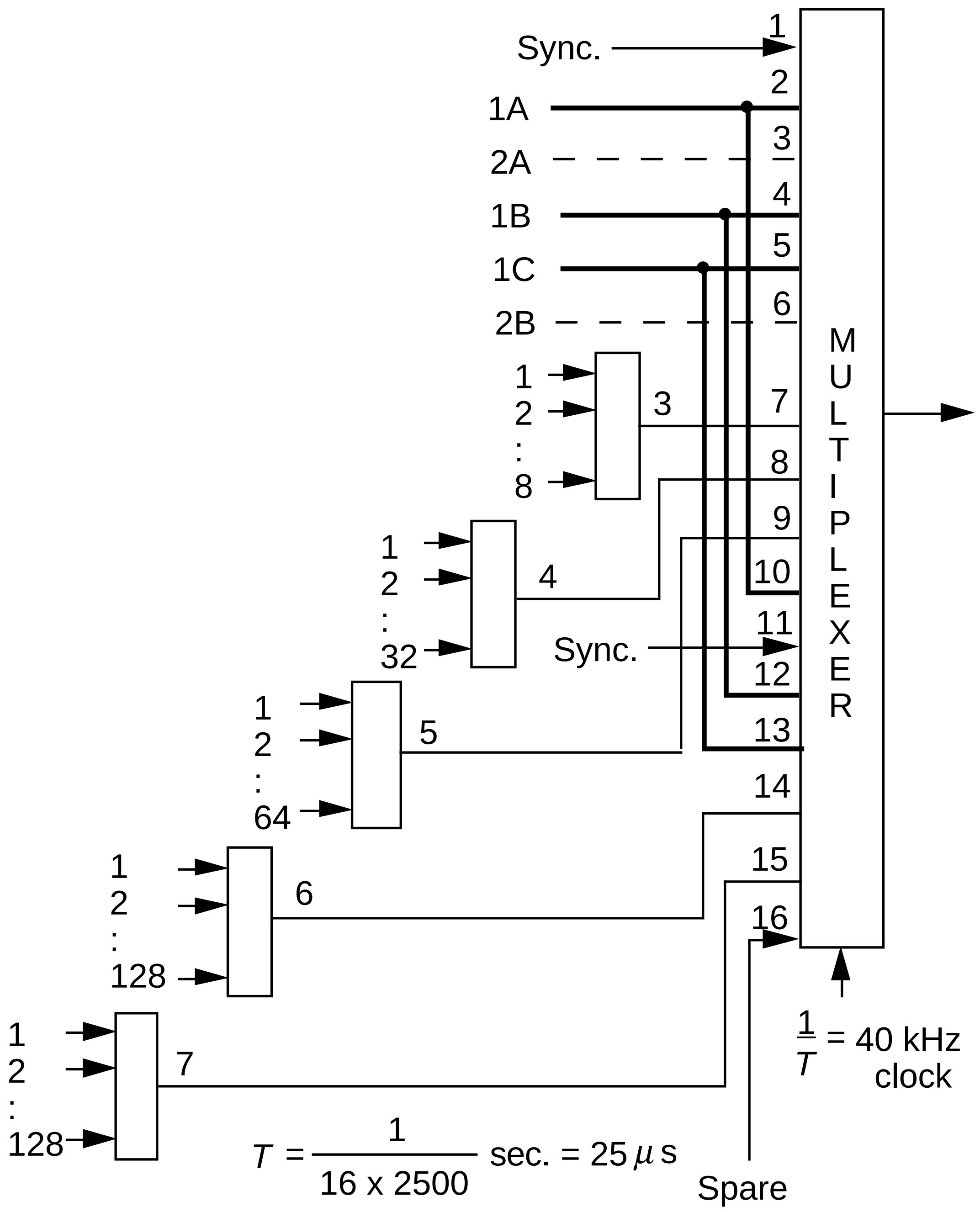

Figure 18.5 TDM PAM system for radio telemetry.

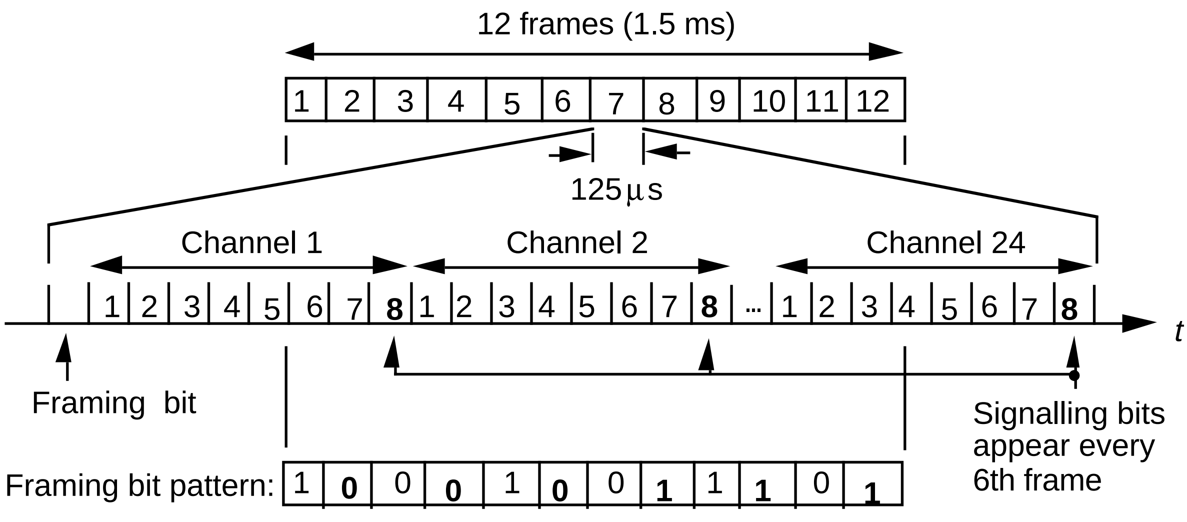

Figure 18.6 The T1 system framing structure.

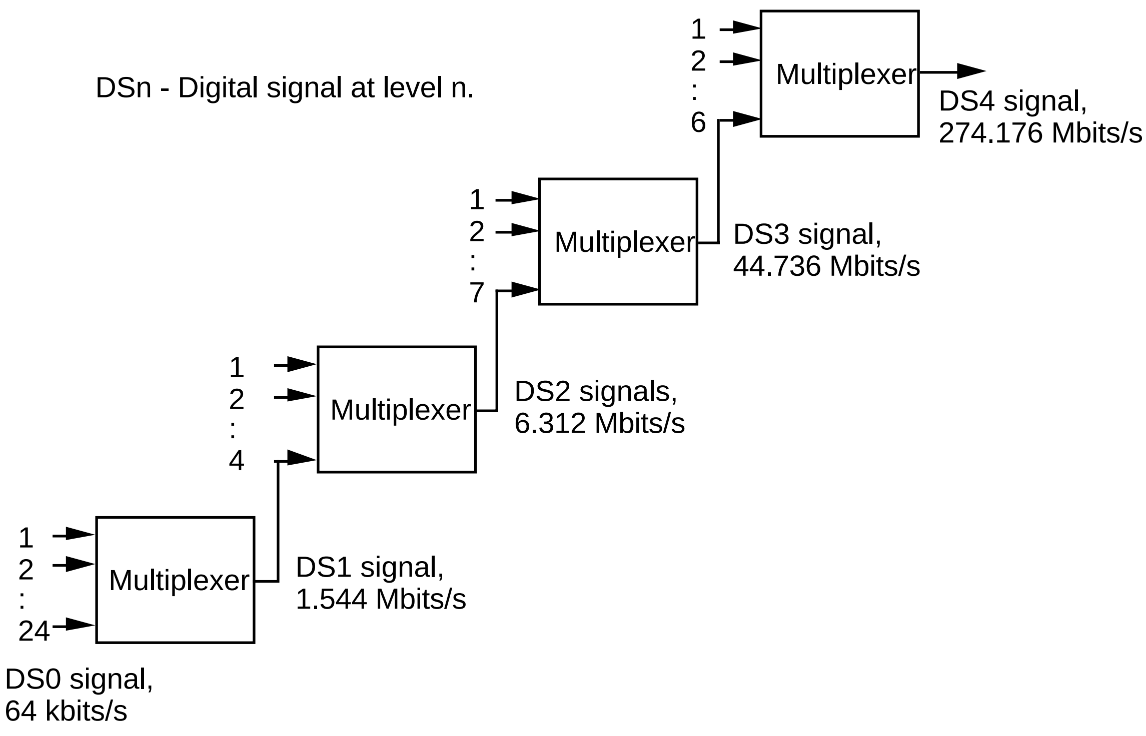

Figure 18.7 TDM hierarchy, North American telephone system.

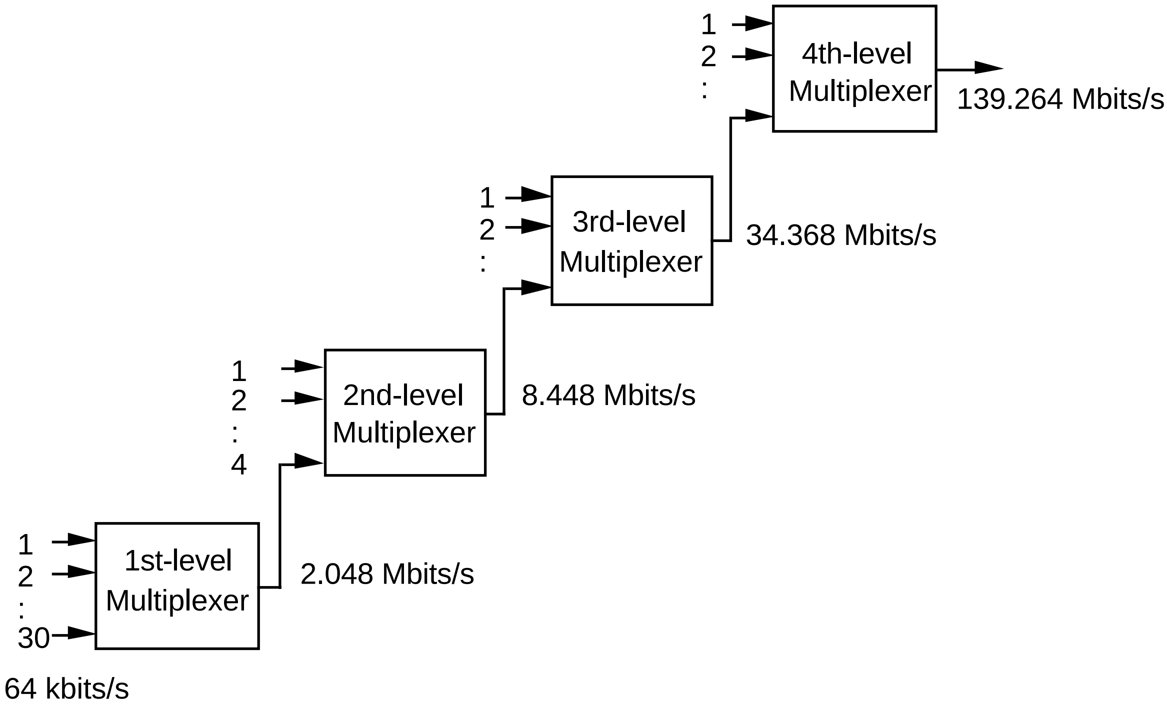

Figure 18.8 TDM hierarchy, CCITT recommendation.

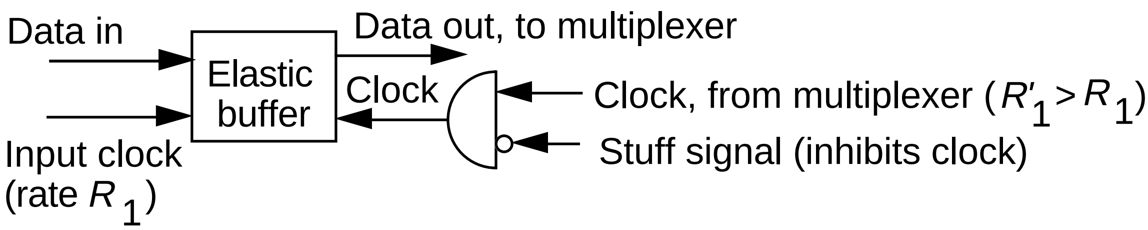

Figure 18.9 Elastic buffer for bit stuffing

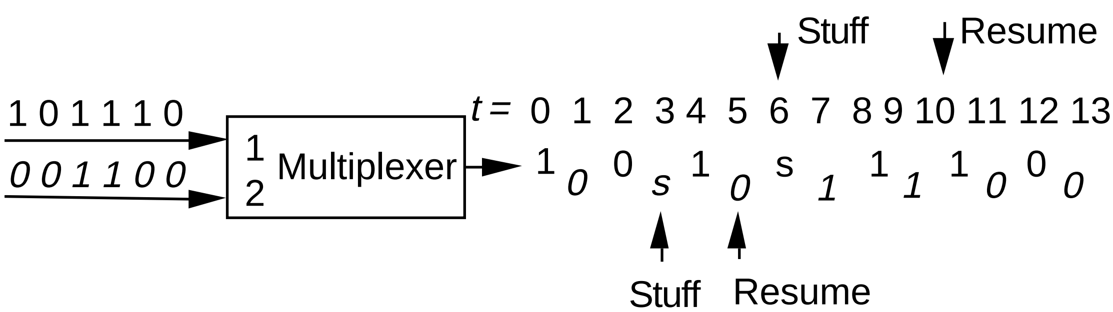

Figure 18.10 Multiplexing of two data streams with bit stuffing.

Start of the frame:

X	(84) F1 (84) C11 (84) F0 (84) C12 (84) F0 (84) C13 (84) F1 (84)	-Subframe 1
X	(84) F1 (84) C21 (84) F0 (84) C22 (84) F0 (84) C23 (84) F1 (84)	-Subframe 2
P	(84) F1 (84) C31 (84) F0 (84) C32 (84) F0 (84) C33 (84) F1 (84)	-Subframe 3
P	(84) F1 (84) C41 (84) F0 (84) C42 (84) F0 (84) C43 (84) F1 (84)	-Subframe 4
M0	(84) F1 (84) C51 (84) F0 (84) C52 (84) F0 (84) C53 (84) F1 (84)	-Subframe 5
M1	(84) F1 (84) C61 (84) F0 (84) C62 (84) F0 (84) C63 (84) F1 (84)	-Subframe 6
M0	(84) F1 (84) C71 (84) F0 (84) C72 (84) F0 (84) C73 (84) F1 (84)	-Subframe 7
		:End of frame

7 DS2 input channels, 12 bits per channel.
7 subframes per frame, 4760 bits per frame, 106.402 μs per frame.
X and P bits provide ARQ and parity checking for error detection.
F1 F0 F0 F1 = 1001 locates the position of information and control bits.
M0M1M0 = 010 locates the position of subframe 2.
C51 C52 C53 identifies which of the 7 DS2 input channels has been stuffed.

Figure 18.11 DS3 framing structure.

M0	(1...84)	F1	(1...84)	C51	(1...84)	F0	(1...84)	C52	(1...84)	F0	(1...84)	C53	(1...84)	F1	(1...84)
0	(1...1)	1	(0...0)	**1**	(1...0)	0	(0...0)	**1**	(0...1)	0	(1...1)	**1**	(1...0)	1	**(10111...0)**

C51 C52 C53 = 111 indicates that there is bit stuffing in subframe 5.

M1	(1...84)	F1	(1...84)	C61	(1...84)	F0	(1...84)	C62	(1...84)	F0	(1...84)	C63	(1...84)	F1	(1...84)
1	(0...0)	1	(1...0)	**0**	(0...0)	0	(1...1)	**0**	(1...1)	0	(1...0)	**0**	(0...1)	1	(0...1)

C61 C62 C63 = 000 indicates that there is no bit stuffing in subframe 6.

Figure 18.12 Examples of the bit-stuffing process.