APPENDIX J
LINEAR TAPE OPEN TECHNOLOGY

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LTO is a digital data tape standard developed by Hewlett-Packard, IBM, and Quantum as an open format standard. Open format means that users will have multiple sources of product and media. The open nature of LTO technology also provides a means of enabling compatibility between different vendors' offerings. The LTO consortium uses the term *Ultrium* to refer to the implementation of LTO. The Ultrium format is the "high capacity" implementation of LTO technology.

The LTO tape is provided in a sealed cartridge. The cartridge is single-reel, which means that the whole tape is wrapped around a single reel when the cartridge is not loaded in a drive. During the loading process, the threader of the drive catches the leader pin of the tape and threads it through the drive and the machine reel. During the Read/Write process, the tape is stored on the machine reel and the cartridge.

J.1 LTO GENERATIONS

Six generations of LTO have been defined and, as of this writing, four of these have been implemented. Table J.1 repeats Table 6.7. Figure J.1 illustrates the differences among the different generations (vertical scales are log scales). Note that each successive generation of LTO has twice the capacity of the preceding generation, with the exception of a larger jump from LTO-5 to LTO-6. However, the data transfer rate does not grow as rapidly. LTO-2 has twice the transfer rate of LTO-1; and LTO-3 has twice the transfer rate of LTO-2. For succeeding generations, the transfer rate increases by a factor of 1.5 from one generation to the next.

Table J.1 LTO Tape Drives

	LTO-1	LTO-2	LTO-3	LTO-4	LTO-5	LTO-6	LTO-7	LTO-8
Release date	2000	2003	2005	2007	2010	TBA	TBA	TBA
Compressed capacity	200 GB	400 GB	800 GB	1600 GB	3.2 TB	8 TB	16 TB	32 TB
Compressed transfer rate (MB/s)	40 MB/s	80 MB/s	160 MB/s	240 MB/s	280 MB/s	525 MB/s	788 MB/s	1.18 GB/s
Linear density (bits/mm)	4880	7398	9638	13250	15142			
Tape tracks	384	512	704	896	1280			
Tape length	609 m	609 m	680 m	820 m	846 m			
Tape width (cm)	1.27	1.27	1.27	1.27	1.27			
Write elements	8	8	16	16	16			
WORM?	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Encryption Capable?	No	No	No	Yes	Yes	Yes	Yes	Yes
Partitioning?	No	No	No	No	Yes	Yes	Yes	Yes

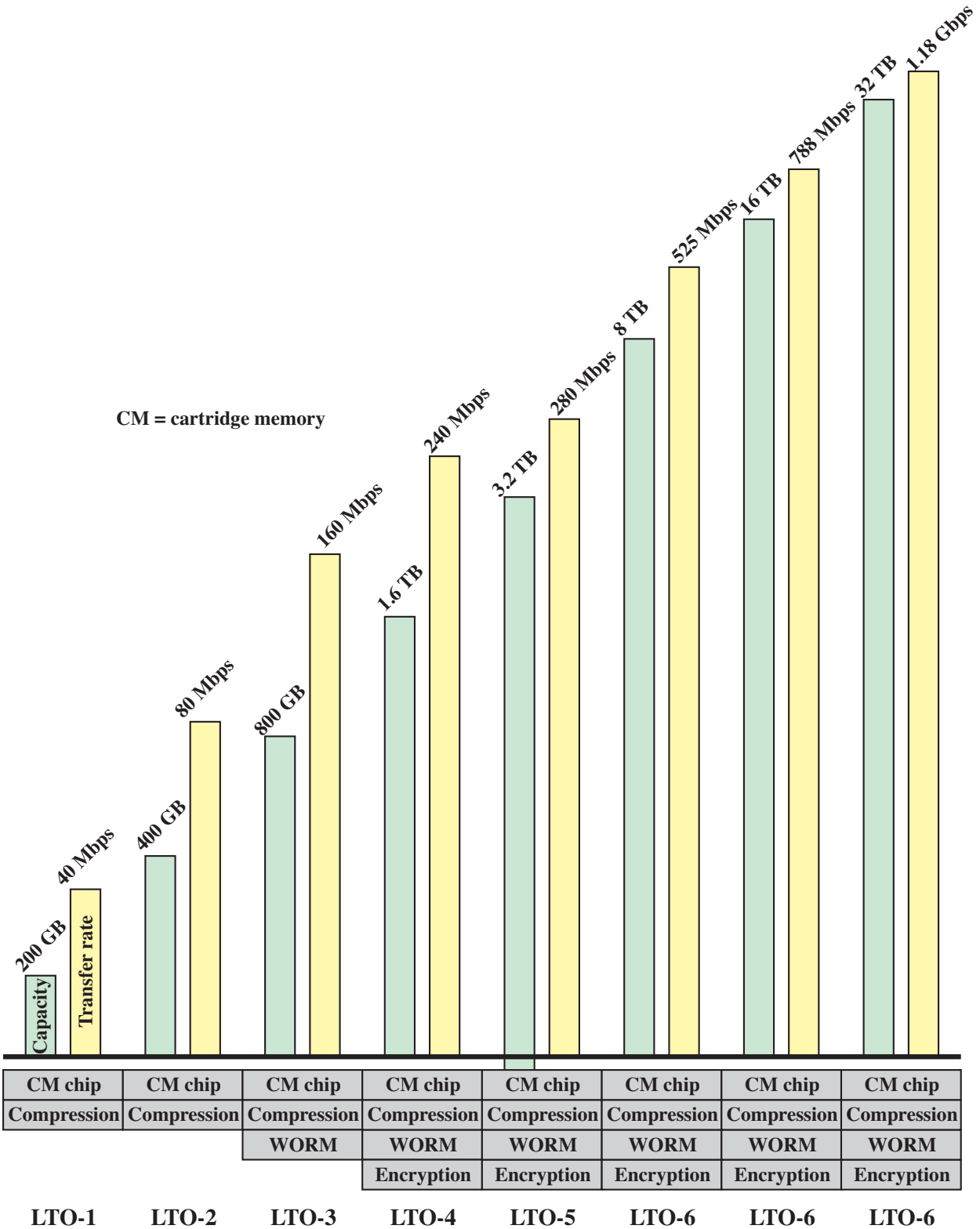

Figure J.1 LTO Generations

Cartridge Memory (CM) Chip

Each LTO tape cartridge includes a CM chip, which is a serial Electronically Erasable Programmable Read-Only Memory (EEPROM) with both read-only and rewritable areas. The CM chip contains information about the cartridge and the tape (such as the name of the manufacturer that created the tape), as well as statistical information about the cartridge's use. The LTO-CM also helps determine the reliability of the cartridge by storing data about its age, how many times it has been loaded, and how many errors it has accumulated. Whenever a tape cartridge is unloaded, the tape drive writes any pertinent information to the cartridge memory.

Compression

To increase data storage density, LTO systems make use of a data compression algorithm known as the streaming lossless data compression (SLDC) algorithm. This algorithm was approved as a standard by the international standards organization, Ecma International [ECMA01].

In essence, the SLDC algorithm looks for repeating strings of two or more data bytes. Information about the length (number of bytes) and position (offset up to 1023 byte position) of the first such string is substituted in place of subsequent copy or copies of that same string. The amount of compression is thus highly variable, depending on the nature of the data to be compressed.

WORM

Starting with the LTO-3 specification, LTO supports a Write Once Read Many (WORM) cartridge option. The WORM option is implemented by algorithms that use information stored in the LTO CM and that is mastered on the tape

medium itself at the time of manufacture. Specifically, the ROM portion of the CM includes a designator code indicating that this is a WORM cartridge. The servo pattern, described subsequently, recorded along the complete length of the magnetic tape media contains a specific identifier in the Servo Manufacturer's Word8 indicating that the medium is WORM. In general terms, the WORM capability operates as follows:

- **Initialization:** Some identifying information is put at the start of the tape, followed immediately by an end-of-data (EOD) designator.
- **Writing:** Once the LTO Ultrium tape drive has established that the LTO Ultrium magnetic tape cartridge is WORM, the drive does not allow data to be written prior to the EOD location on the tape medium. This functionality preserves all prior written data as non-rewriteable and non-erasable. Prior to initiating a write command, the LTO Ultrium tape drive determines that the current logical position of the LTO Ultrium magnetic tape media is at EOD. A new EOD is written at the end of each write session. Each EOD data set contains a copy of the LTO Ultrium Tape Cartridge Memory (LTO-CM), which includes the WORM Cartridge Type and Format Type identifiers, at the time the EOD is created.
- **Reading:** During the reading process, the drive compares information store with each data set to information in the CM to detect any tampering with the data.

Encryption

Starting with LTO-4, the LTO includes an encryption capability making use of the Advanced Encryption Standard (AES). LTO is an optional hardware feature implemented in the tape drive. Keys must be presented to the drive from an external key management system. Key management is not part of the LTO specification.

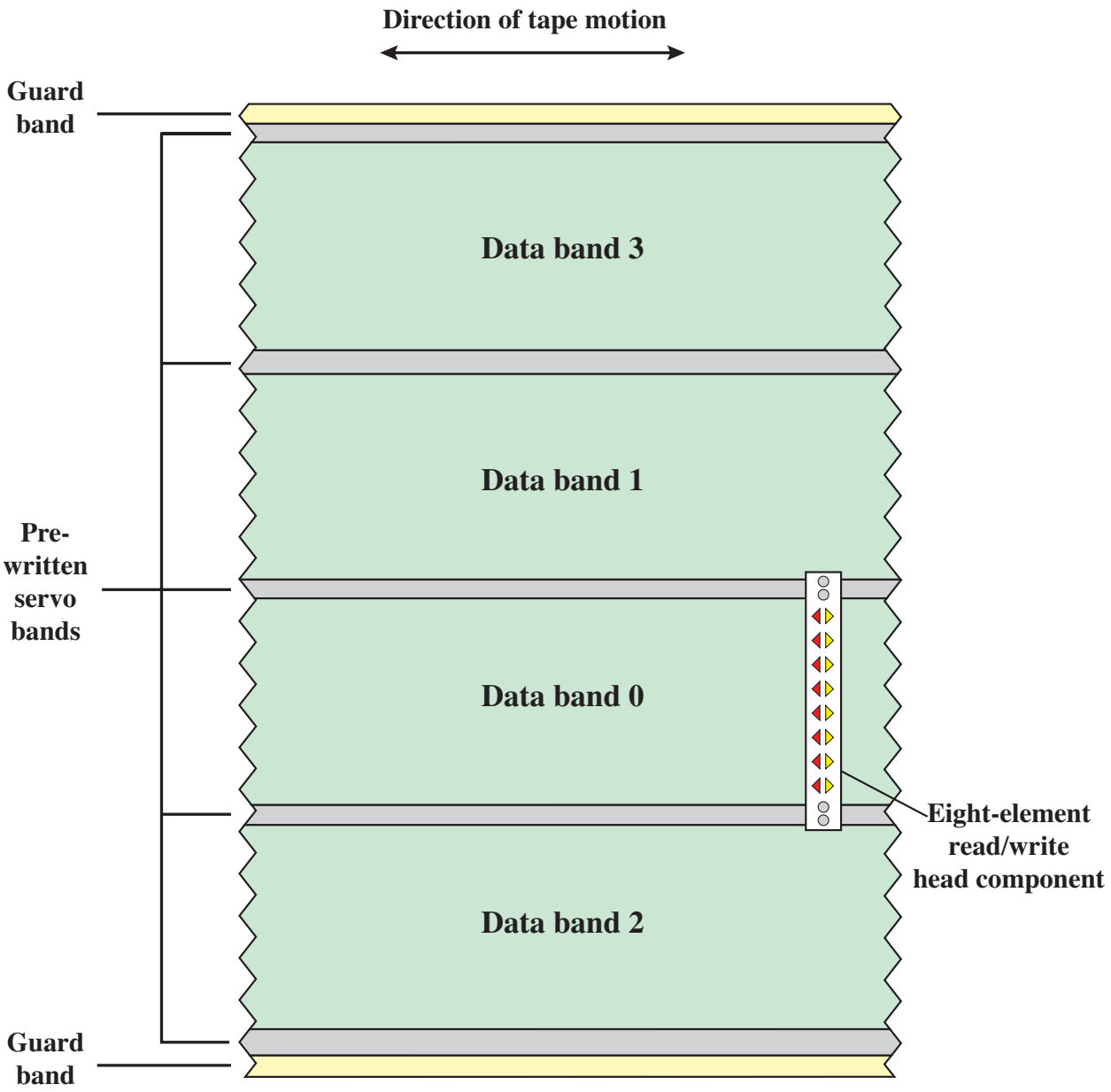

Figure J.2 LTO Tape Format

J.2 LTO FORMAT

Figure J.2 illustrates the LTO tape format. The figure shows the full width of the tape and a portion of the length of the tape. The width is divided into the following areas:

- **Guard bands:** These border the top and bottom edge of the tape. No data are written in these bands.
- **Data bands:** The full tape width includes four data bands. The read/write head spans a single band. For writing the bands are filled sequentially, beginning with band 0, then band 1, then band 2, then band 3. Each band in turn consists of a number of tracks, with each track being one bit wide.
- **Servo bands:** The servo bands provide location information to the head as it writes and verifies data tracks within that band. The process of positioning the head on the tape is an interaction between the head, the media, and the servo elements of the system. Servo bands enable accurate positioning of the tape drive head over the data track, ensuring that the head does not stray onto an adjacent track. They are necessary to support high-data densities on the tape where the tracks are extremely close together. The servo bands are written when the cartridge is manufactured, before the cartridge is usable for data storage and retrieval.

There is a single read/write head capable of reading or writing 8 bits at a time, using 8 read or write heads positioned over 8 tracks. The head spans one band and, using guide marks on the servo band, can be positioned over different sets of tracks within the band.

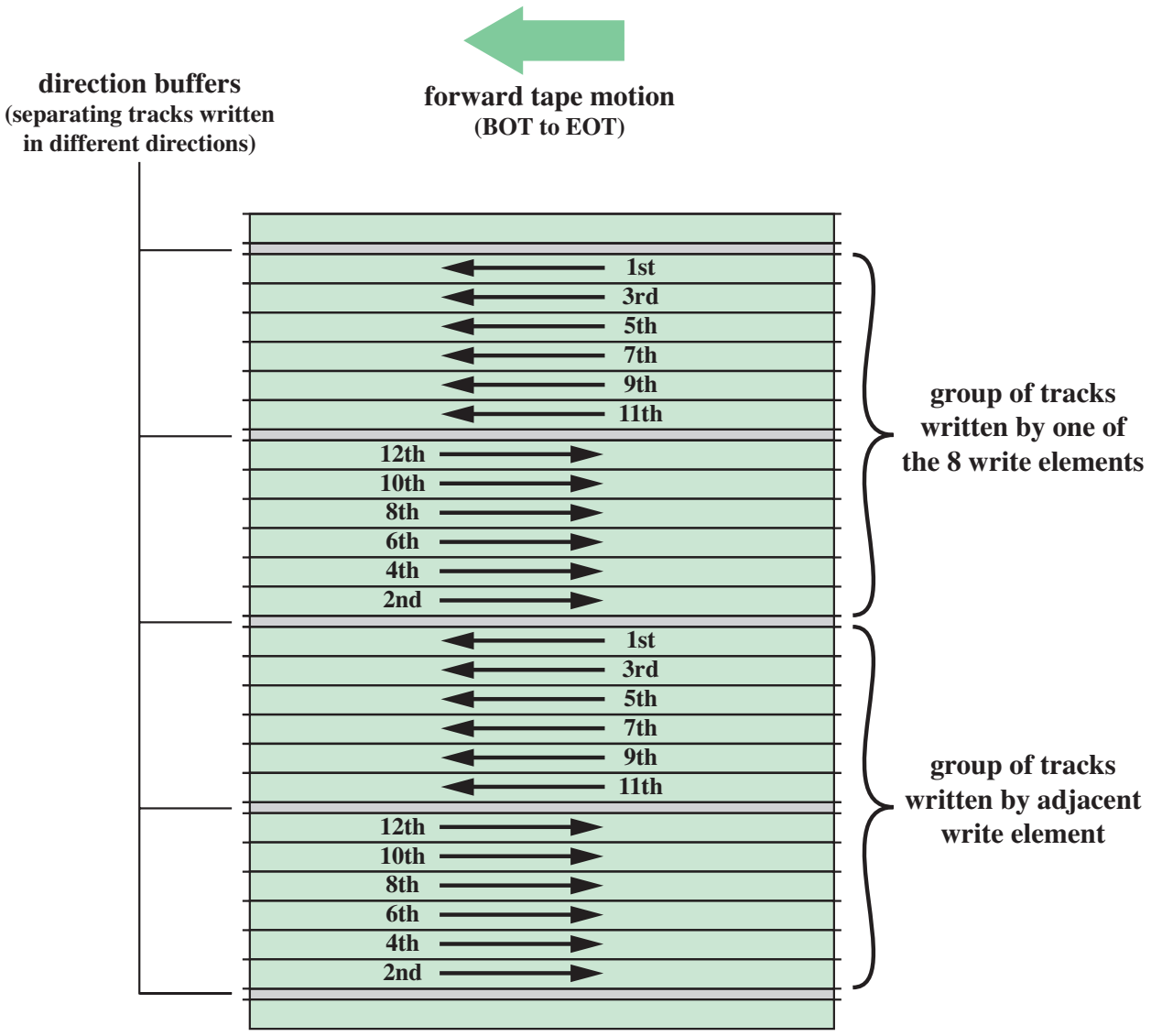

Figure J.3 Portion of Data Band Showing LTO-1 Track-Writing Sequence

J.3 LTO OPERATION

Within each band, each write element writes a number of adjacent tracks in a back and forth fashion referred to as *serpentine*. Figure J.3 illustrates the process for LTO-1. Each write element writes 12 tracks within each band. The numbers in the figure indicate the order in which tracks are written and the arrows indicate the direction of motion of the tape.

The drive mechanism makes multiple passes from the beginning of the tape to the end of the tape and back to read or write the full capacity of the cartridge. On pass one of a round-trip down the length of the tape and back, eight tracks are read or written, concurrently. At the end of the tape, pass two of the round-trip starts.

Figure J.3 shows the operation of two of the write elements. For LTO-1 and LTO-2, there are 8 write elements in a head. They operate in parallel to transfer data one byte at a time. Thus, the 8 bits of each byte stored on the tape are in 8 separate tracks of one band. Further, the 8 tracks used to store a single byte at a time are separated from each other in the manner shown in the figure. A group of tracks recorded concurrently in the physical forward or the physical backward direction is called a **wrap**. Wraps recorded while the tape is moving from BOT to EOT are forward wraps; wraps recorded while the tape is moving from EOT to BOT are reverse wraps.

The space between tracks written in opposing directions is called a **direction buffer**. This space is designed to minimize magnetic interference between tracks written in opposite directions (cross-track interference).

References

ECMA01 Ecma, International. *Streaming Lossless Data Compression Algorithm.* Standard ECMA-321, June 2001. http://www.ecma-international.org/publications/standards/ECMA-321.htm