



# **One Terabyte and beyond**

## **The technology for high capacity serpentine recording**

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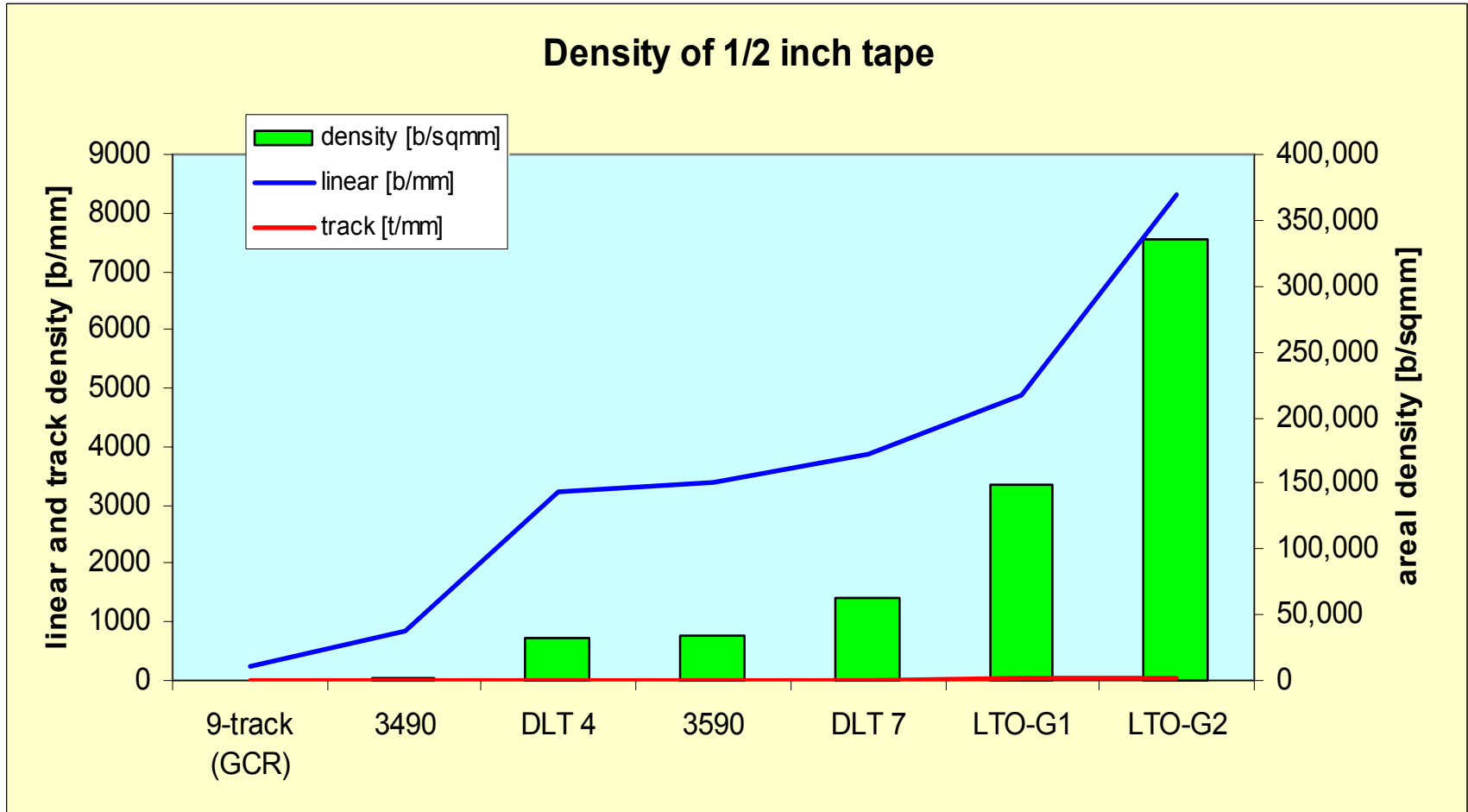


# Recording density of 1/2 inch tape

- Recording density of 1/2 inch tape below  $0.4\text{Mb/mm}^2$ 
  - ◆ User capacity about 60% - 70% of recording capacity
- For 1 TB cartridge capacity:  $\sim 1\text{Mb/mm}^2$
- MEII technology: increase above  $10\text{Mb/mm}^2$



# Areal density of 1/2 inch tape





# Capacity increase

- Future capacity increase will come from several sources
  - ◆ Increase in track density
    - Track density about 1/300 of linear density
  - ◆ Increase in linear density
  - ◆ Increase in tape length
    - Tape thickness is currently 7  $\mu\text{m}$
    - Future: 5  $\mu\text{m}$  and below
      - ◆ Tape length  $\sim 1\text{km}$  with 5  $\mu\text{m}$
- Increase in track density is important for future capacity increase

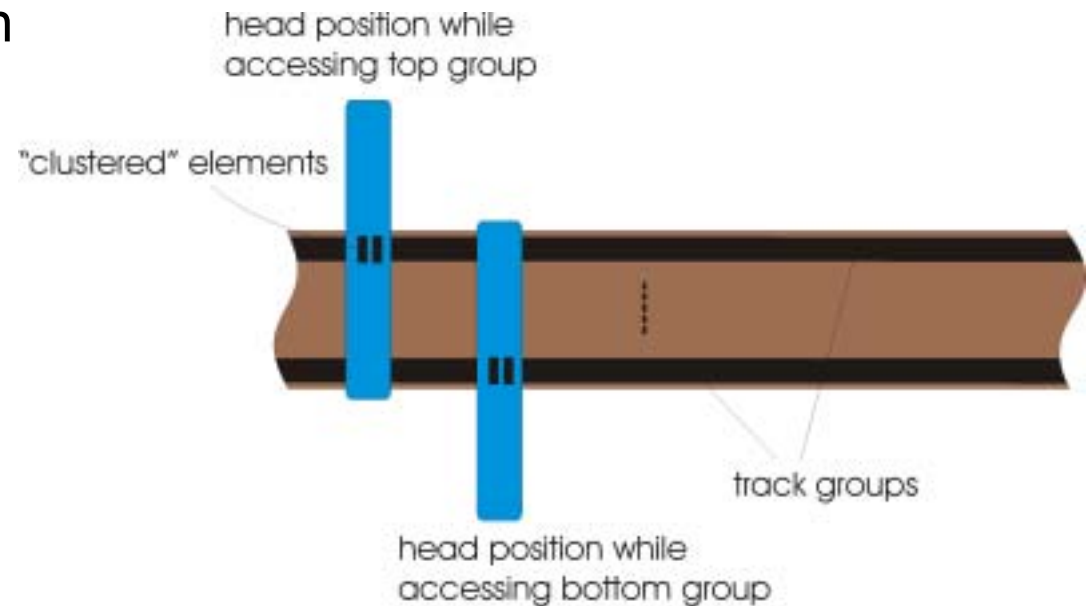


# Increasing the capacity

- With improvements of current technology capacity may approach 1TB
- To go beyond 1TB an enabling technology is required

# Obstacles

- Decrease in track width requires very fast frequency response of the actuator
  - ◆ Mass of head imposes limits
  - ◆ Mass of heads increased because of “clusters”
    - Length of head  
 $\approx 2x$  tape width





# Obstacles

- Flying height of tape over head difficult to control
  - ◆ Two major parameters for flying height:
    - Winding tension
      - ◆ Decreases with thinner tape
      - ◆  $\sim 0.5\text{N}$  for  $7\ \mu\text{m}$  thick tape
    - Tape speed
      - ◆ Increases for faster transfer rate



# Obstacles

- Number of passes to access all data on tape is increasing
  - ◆ Number of tracks on tape is increasing faster than number of simultaneously accessed tracks
  - ◆ Currently  $\sim 100$  passes
  - ◆ Future  $> 1,000$  passes
  - ◆ Tape wear and contamination is increased
    - Contamination critical with high density recording



# Obstacles

- Biggest obstacles to increase recording density in tape drive
  - ◆ Bit errors caused by contamination
  - ◆ Errors caused by mis-registration (TMR)
  - ◆ Loss of signal caused by tape/head separation



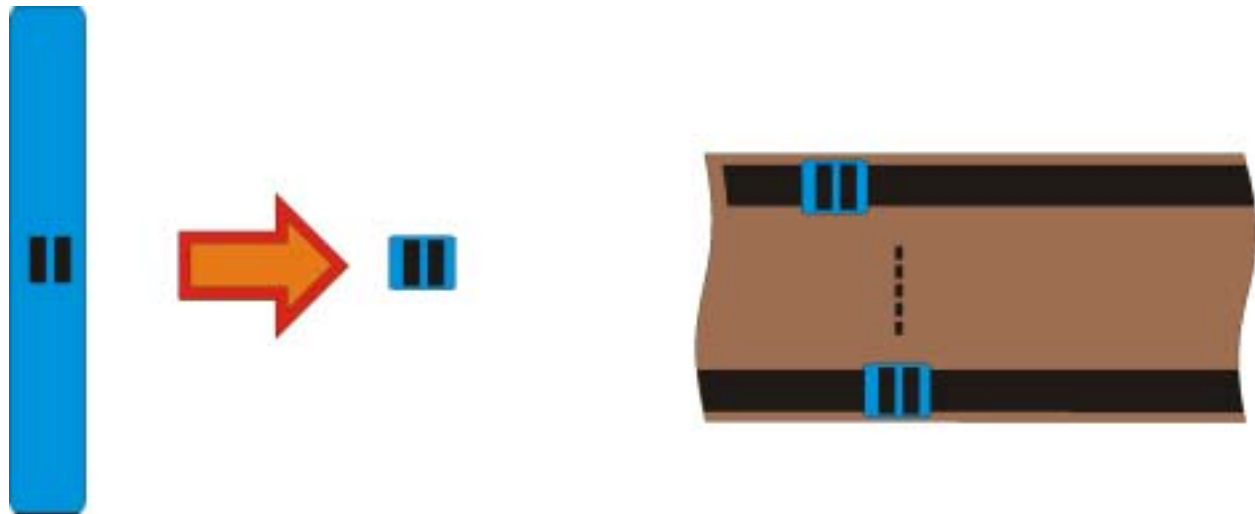
# MEII Technology

- Technology to solve all three problems
  - ◆ Contamination caused by high number of passes
  - ◆ Low mass head for fast track following
  - ◆ Tight control of flying height



# MEII Technology

- Traditional system: tape flies over head
  - ◆ Large, rigid head with one degree of freedom
- MEII technology: head flies over tape
  - ◆ Small, movable head
  - ◆ Length of head  $\ll$  tape width





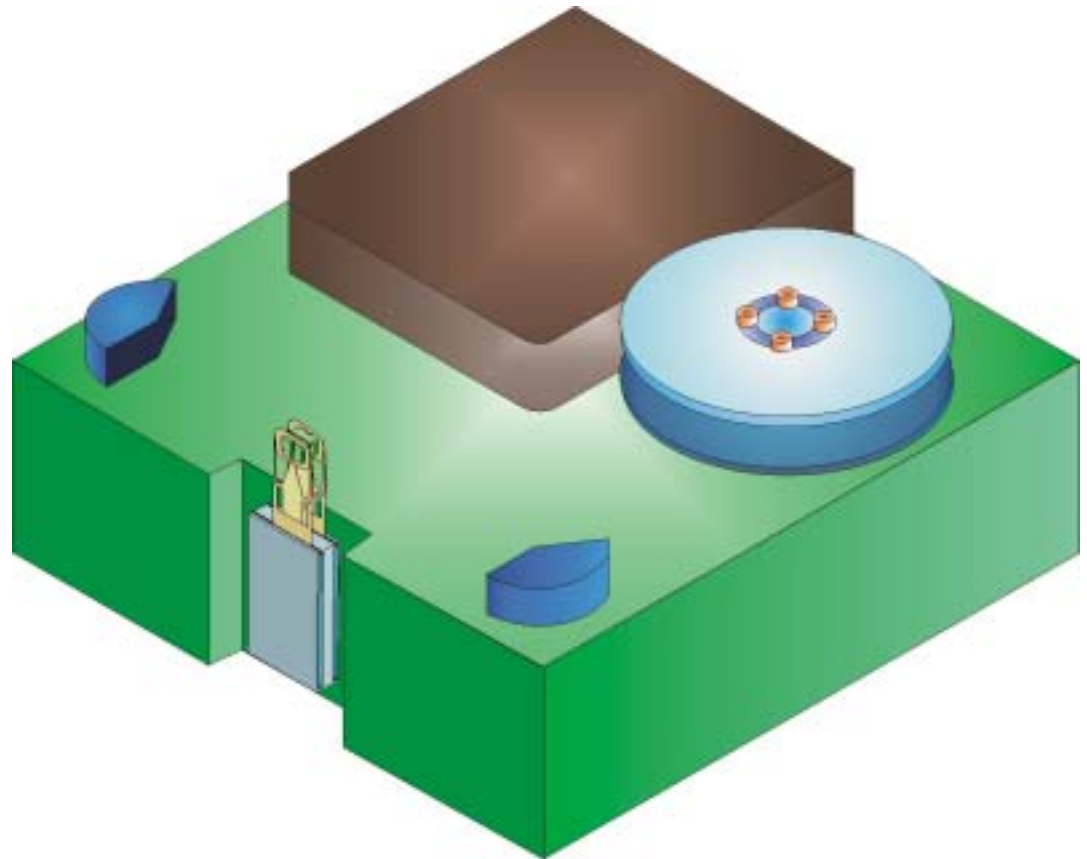
# MEII Technology

## ■ MEII technology

- ◆ Head to tape contact only in groups that are accessed
  - Number of head-tape passes is reduced
- ◆ Small head
  - Length of head  $\ll$  tape width
  - Low mass – less than 1g
- ◆ Control of flying height
  - Flying height is independent of tape tension
  - Flying height can be controlled

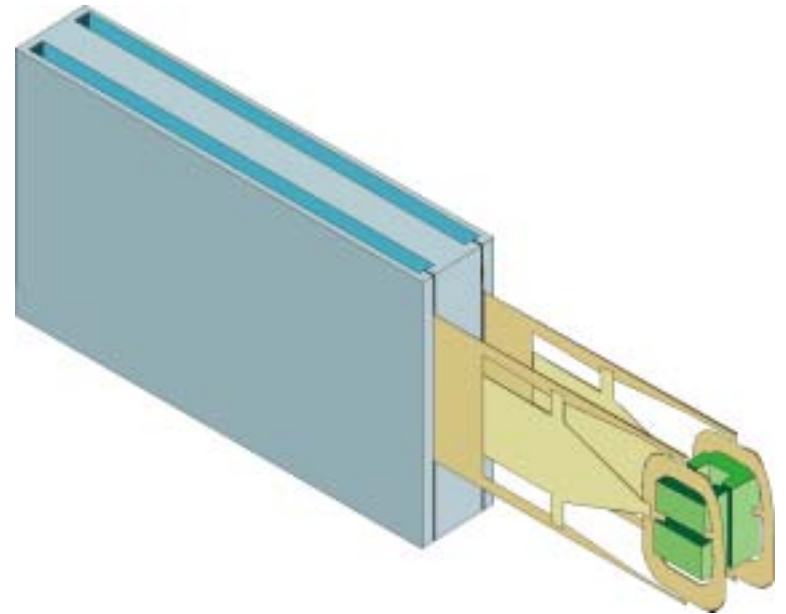
# Implementation 1

- 1/2 inch cartridge tape drive
- Dual arm actuator



# Actuator and head

- Head is mounted on flexure
- Flexure on opposite side of tape has opposing surface
- Flexure force controls flying height
- Opposing surface can be replaced by second head
  - ◆ Dual sided recording requires modification of tape

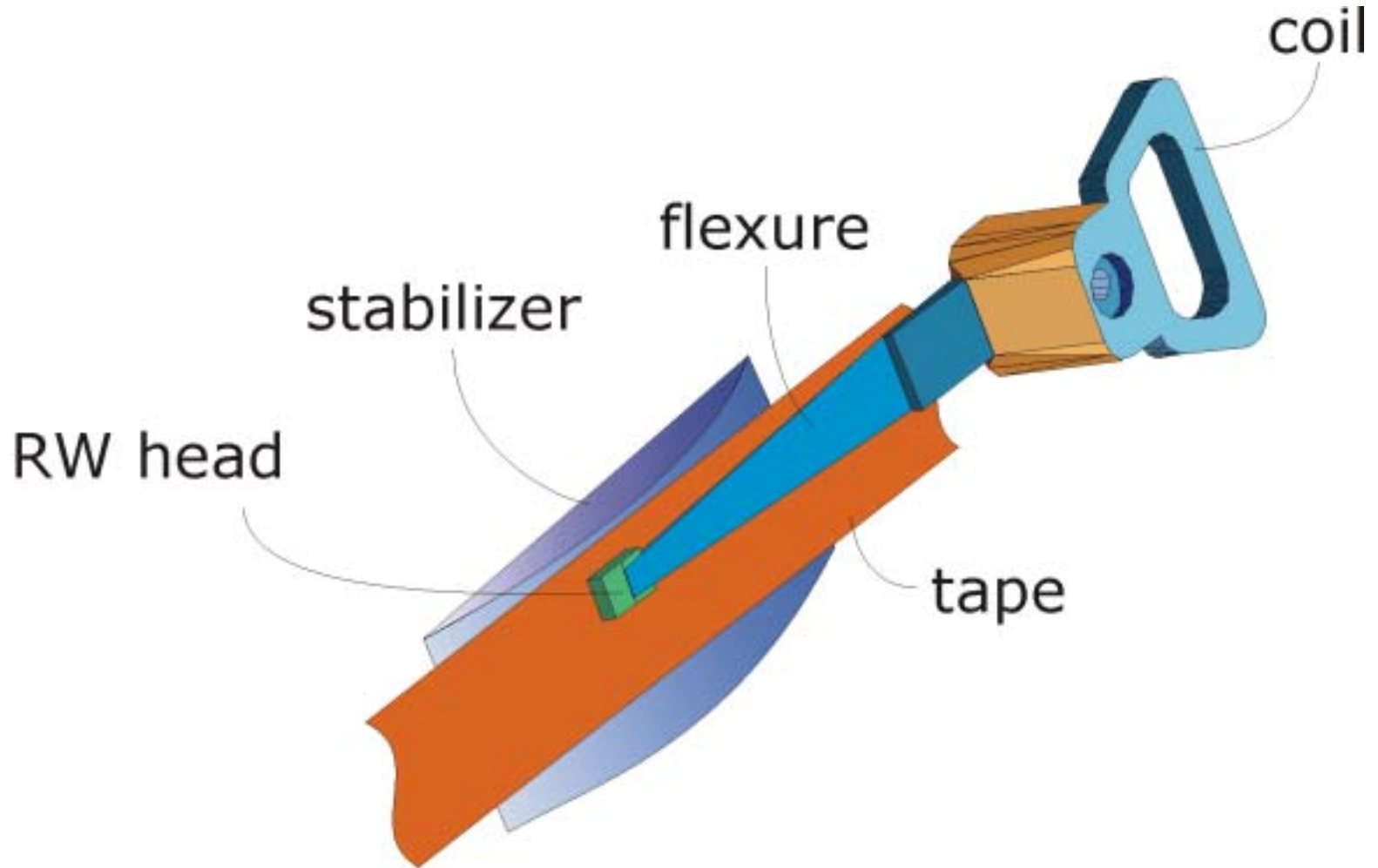




# Advantages

- Compatible with existing formats
  - ◆ LTO
  - ◆ SDLT
- Possibility of dual side recording
- Maximum track density
  - ◆ With current tape and head: 5,000 tpi
    - 5  $\mu\text{m}$  track pitch
  - ◆ With modified tape and head: 20,000 tpi
    - 2,5  $\mu\text{m}$  track pitch
    - Dual sided tape

# Implementation 2





# Implementation 2

- Lower, balanced mass
- Electronics (write driver, read pre-amp) can be mounted on arm
- Maximum track density
  - ◆ With current tape and head: 5,000 tpi
    - 5  $\mu\text{m}$  track width
  - ◆ With modified tape and head: > 50,000 tpi
    - Sub- $\mu\text{m}$  track width



# Implementation 2

- Recording at a small azimuth
- Very fast track following
- Requires stabilizer
- Single sided or dual sided



# Development tasks

- Technology is “borrowed” from disk industry
  - ◆ Using disk technology in tape has many advantages
  - ◆ Adaptation of disk technology to tape is challenging



# Development tasks

## ■ Head

- ◆ Smaller track width
- ◆ Carrier
- ◆ Contour

## ■ Actuator

- ◆ Loading mechanism
- ◆ Control of force to counteract flying height



# Development tasks

## ■ Tape

### ◆ Dual sided

- Magnetic imprint between layers
- Inner layer friction

## ■ Tape path

- ◆ Improved guiding (control of lateral tape movement)
- ◆ Improved tape handling

## ■ Servo

- ◆ Improved pre-written servo band
- ◆ Improved tension control



# Development steps

## ■ Step 1

- ◆ 5  $\mu\text{m}$  track width, single sided, actuator 1
- ◆ 2 Mb/mm<sup>2</sup>

## ■ Step 2

- ◆ 2.5  $\mu\text{m}$  track width, dual sided, actuator 1
- ◆ 7 Mb/mm<sup>2</sup>

## ■ Step 3

- ◆ 1  $\mu\text{m}$  track width, dual sided, actuator 2
- ◆ > 15 Mb/mm<sup>2</sup>



# Areal density of future 1/2 inch tape

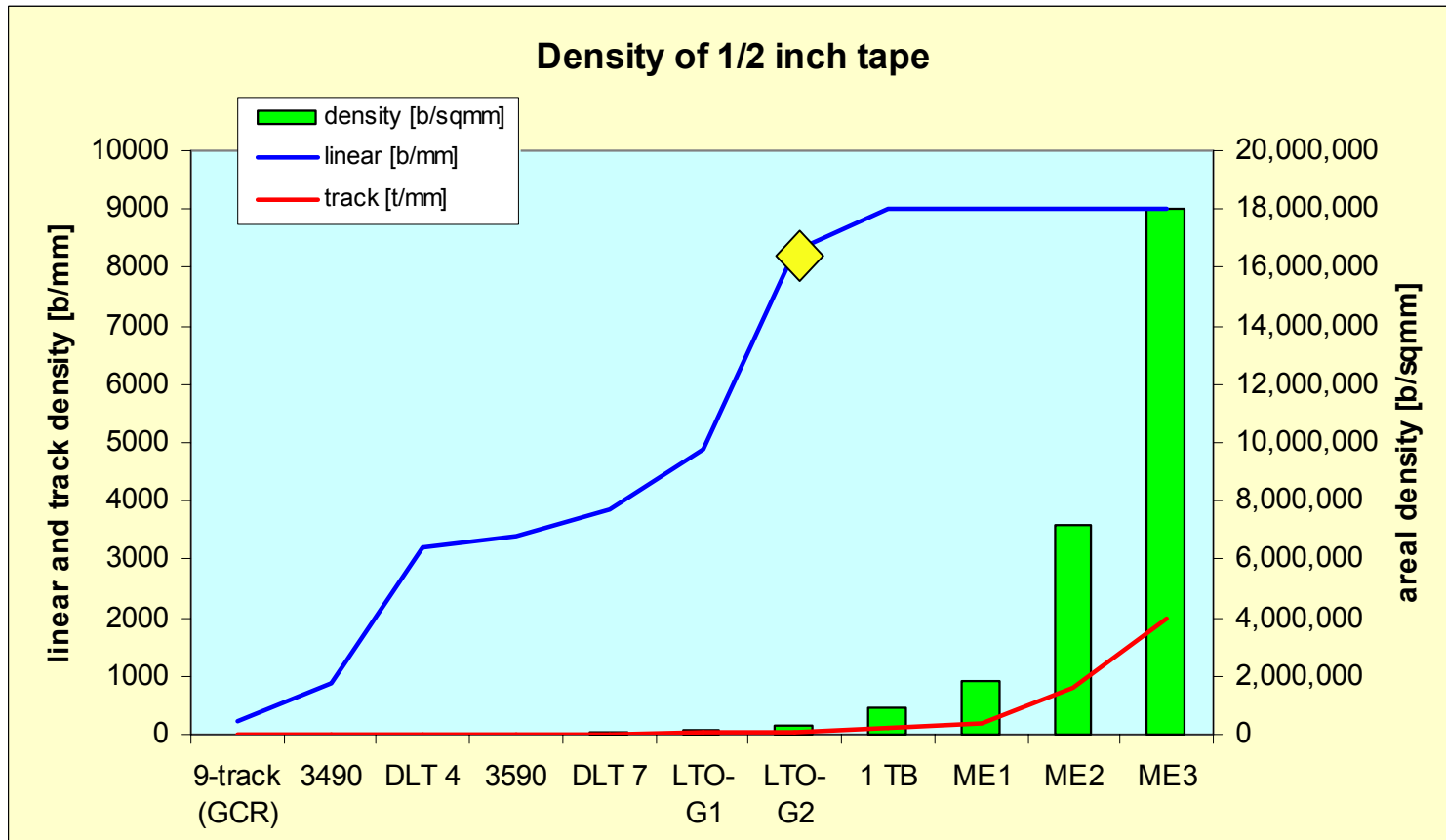
## ■ Assumptions

- ◆ Increase of linear density to 9,000 b/mm  
(~10% increase above LTO)
- ◆ Tape length 800 m (~ 30% increase)

■ 1TB	~1 Mb/mm <sup>2</sup>
■ ME1	2 Mb/mm <sup>2</sup>
■ ME2	7 Mb/mm <sup>2</sup>
■ ME3	>15 Mb/mm <sup>2</sup>



# Areal density of future 1/2 inch tape





# Status

- Technology not new
  - ◆ Bernoulli drives
  - ◆ Disk drives
- Technology new for tape
  - Technology modifications
    - ◆ Testing
- Goal: First implementation in 2004



# Tape is alive

- Primary function of tape will be archive
  - ◆ High volumetric capacity
  - ◆ Low cost
  - ◆ Very high reliability
  
- By adopting disk technology tape will stay ahead of disk