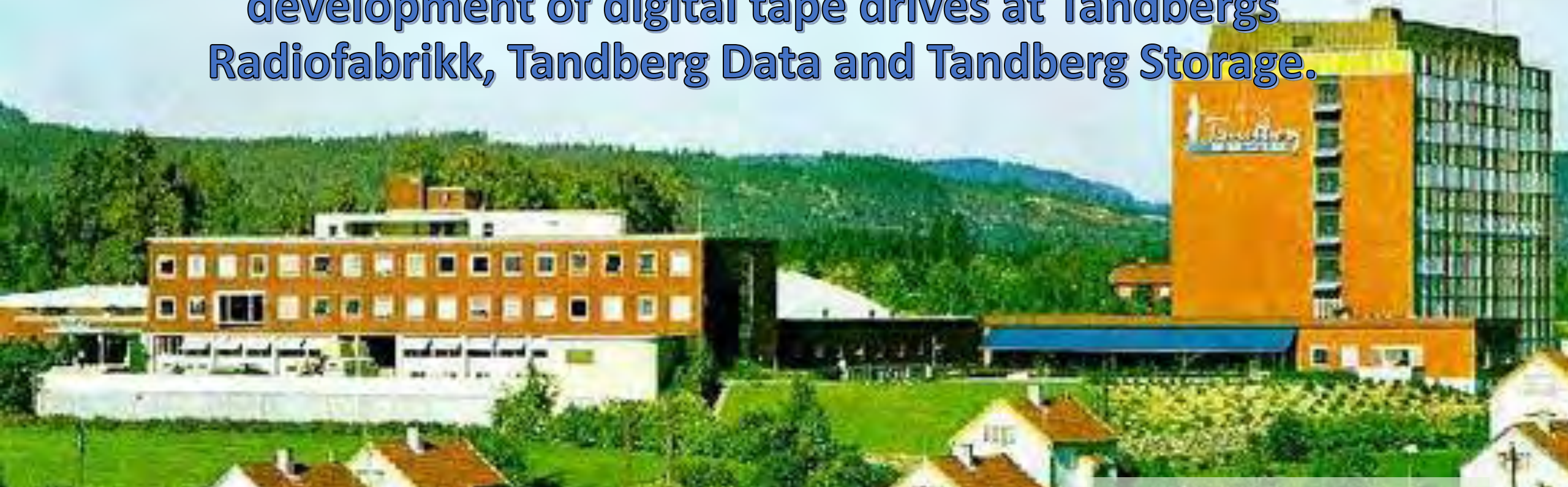
From 20 MBytes to 2 TBytes

Erik Solhjell:

The technology, the engineers and the history behind the development of digital tape drives at Tandbergs Radiofabrikk, Tandberg Data and Tandberg Storage.



Background

- Vebjørn Tandberg established Tandbergs Radiofabrikk in 1933
- In 1934 came the first successful radio, Huldra 1
- 42 weekly working hours for everybody was established in 1937 and free pension insurance was introduced in 1938
- 39 weekly working hours was introduced in 1948, 28 years before it was establish as an official law in the whole of Norway. The creative engineer Lorentz Nødtvedt was also hired this year to head the development of the first Tandberg Audio tape recorders. It was released in 1952. This was followed by a series of steadily more advanced audio recorders, making the name Tandberg known all over the world.
- In 1970 came the first instrumentation recorder and the development of the first digital tape drive started this same year.

1978

1952

From 1970 to 2009 –
Three technology epochs over 39 years

½ " LTO cartridge

2003 → 2009

¼ " QIC cartridge

1979 → 2003

½ " Reel to Reel
and ¼ " kassett

1970 → 1978

1970: Tandberg focuses on digital tape storage

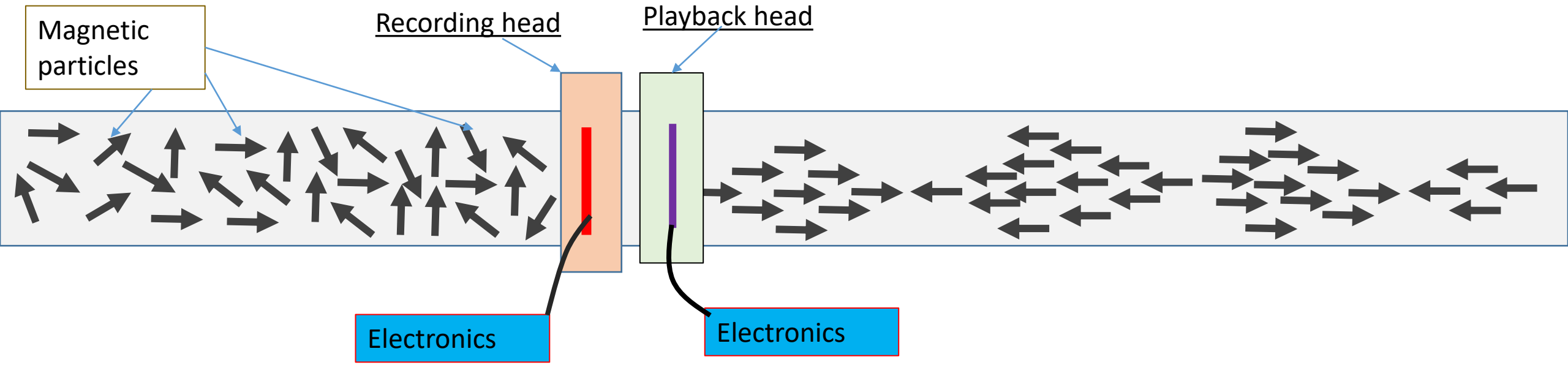
- In 1970 two creative Norwegian engineers, Gunnar Reichborn Kjennerud and Petter Brevik, both with development experience from USA, started work at Tandbergs Radiofabrikk. The goal: Develop new and competitive digital tape drives.
- **Gunnar Reichborn Kjennerud:**
  - He headed the development of the TDM 1000 tape drive based upon 10,5" reel-to-reel ½ " tape.
- **Petter Brevik:**
  - He headed the development of a digital tape cartridge drive TDC 3000 based upon a new tape cartridge DC300 from 3M using ¼ " tape.

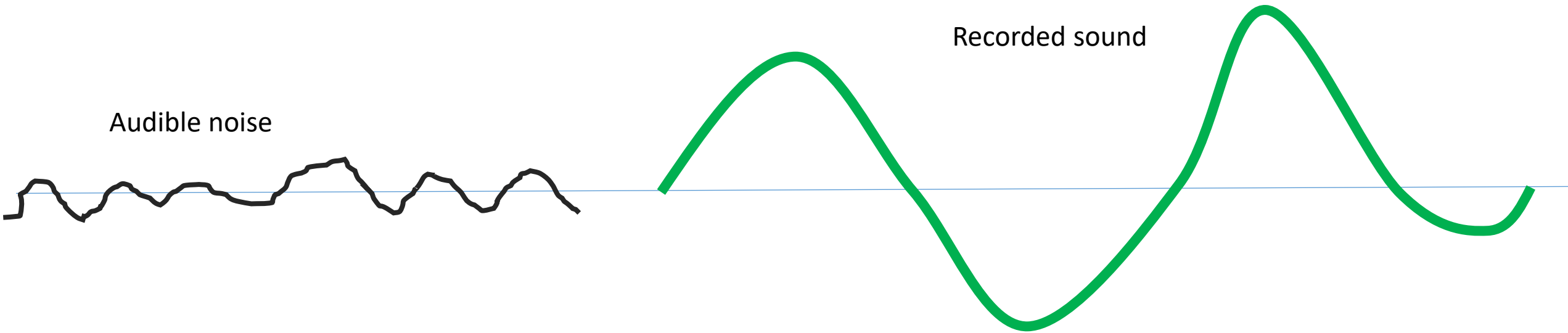
TDM 1000 and TDC 3000

TDC 3000

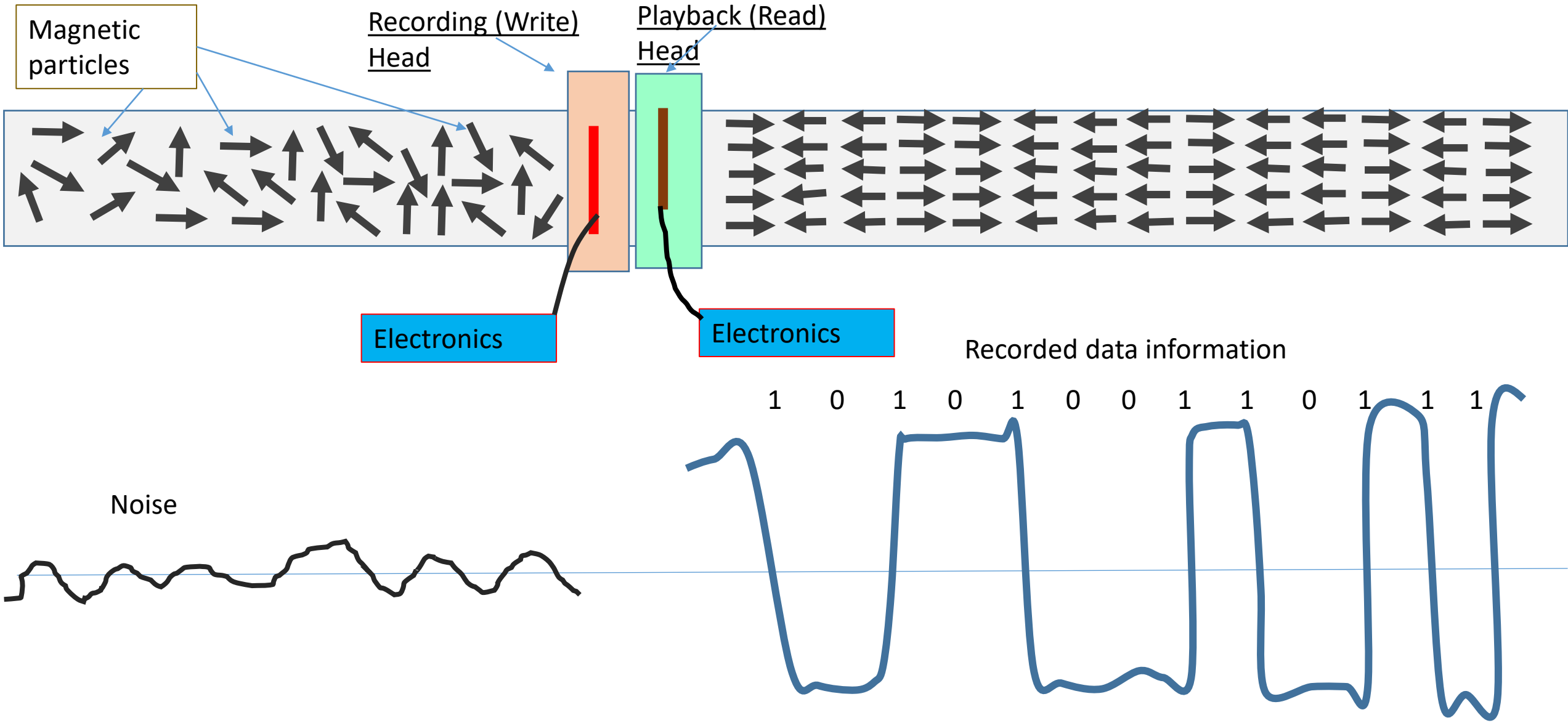
Sales manager Per Werner Hansen with the TDM1000 tape drive at National Computer Conference in New York in May 1973.

Magnetic Audio Recording (simplified)





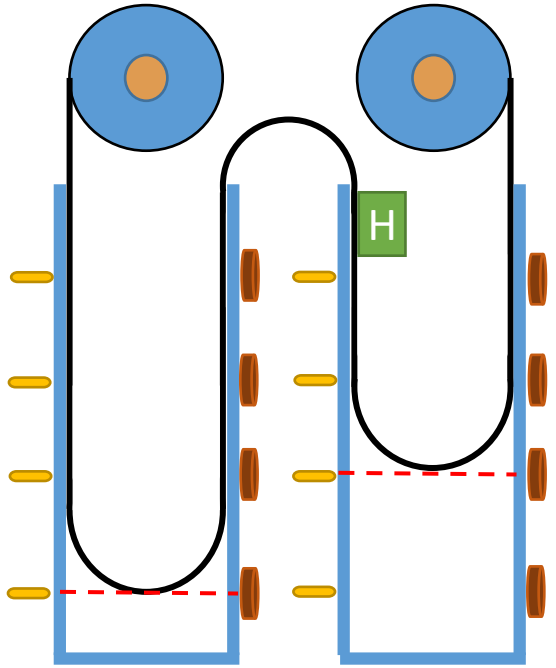
Magnetic Digital Data Recording (simplified)



TDM1000 – The first Digital Tape Drive

- A major technology step from Tandbergs Radiofabrikk:
  - A very advanced mechanical design controlling the tape operation via two vacuum columns where the tape position was sensed by light
  - A Read/Write head that was moved away during tape loading and unloading and moved towards the tape with a very high precision during reading and writing
  - 9 tracks, initially 22 Mbytes with NRZ1 recording; then 45 Mbytes using PE recording

Per Kristian Fossum and Tom Johannessen testing the new TDM1000 in 1973



TDM 1000

- The technology with many advanced features proved to be more difficult than originally anticipated and the release date for regular production was significantly delayed
- The original capacity with 22 MBytes (using NRZI-coding) was increase to 45 MBytes by using Phase-encoding (PE). In 1973 this was viewed as a lot of data on just one single tape reel(diameter 10,5" / 27 cm)!
- Unfortunately, the manufacturing process was complicated and time consuming with expensive parts, reducing profit to a very low level.

Finally, TDM 1000 was released and some key customers came aboard

- Norsk Data shipping systems to CERN
- Kienzle Datensysteme
- Litton Industries

-- but sales volumes never reached the original targets

TDC 3000 became a longrunning success-story

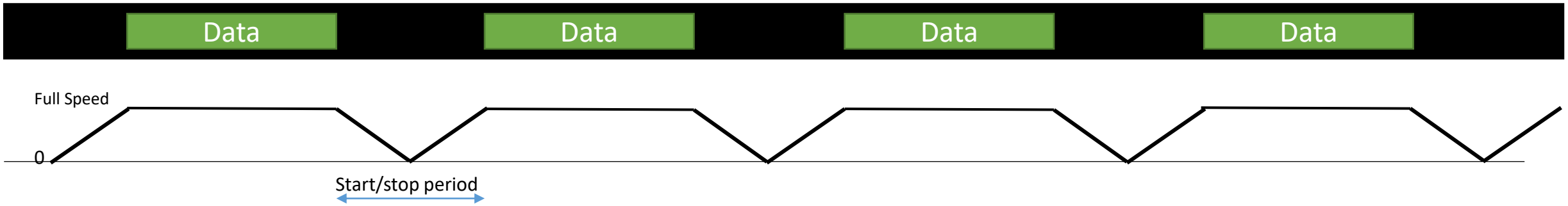
- Although storage capacity was low, approx. 2,5 Mbytes, TDC 3000 was manufactured and sold over many years.
- LM Ericsson in Sweden and Northern Telecom in USA (both focused on telecommunication) used the TDC3000 in their systems.
- A TDC 3000 drive was also used for data recording in Skylab, the first US space station.
- Production went on for 15 years!

Manufacturing hall around 1983

Litton Industries, oil exploration and «streaming tape»

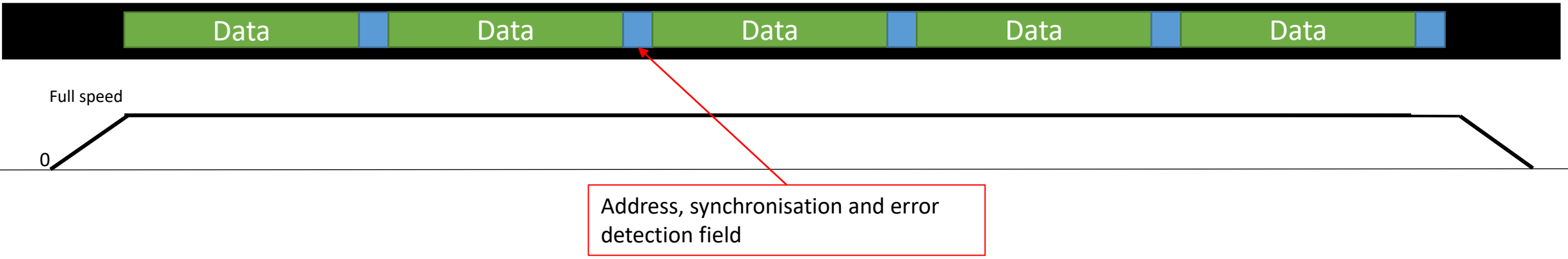
- Litton Industries in Houston focused on oil exploration on land. They drilled many deep holes or wells around a large test area and used TDM1000 to record seismic data generated by a controlled explosion in one of these holes and many measuring instruments placed in all the other holes.
- But the current tape technology was not ideal for this job:
  - First, the tape drive must start the tape operation and get the tape up to speed. This takes time.
  - Data was then recorded on the tape as soon as the tape had achieved correct speed. However, only a limited amount of data (one “block”) could be written. Thereafter the tape operation had to stop.
  - Stopping the tape also takes some time.
  - The whole process must be repeated in order to write more data.
  - This hole process took time (and squandering tape area that could be used for data recording).
  - Litton had a problem: They needed to record data also during the start/stop phases.
- This gave me the idea to the new tape drive principle which later was called «streaming tape»

The principle of starting and stopping the tape drive:



The «Streaming tape»-technology:

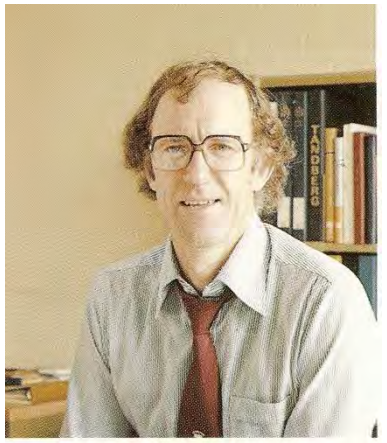
- The tape runs continuously from one end to the other
- Data is still recorded in blocks.
- Between each block is an area with no regular data, but contains specific recorded control information:
  - Synchronization field
  - Block Address
  - Error detection (later also error correction) information.
- This method avoids the time consuming (and tape area consuming) start/stop periods. Litton could record data almost continuously, thereby simplifying their oil exploration job significantly.
- I suggest we should apply for a patent on this new principle, but the top management said no as in their opinion this principle was so universal that it should be available for all competitors
- IBM later invented the term «streaming tape»
- In just a few years a majority of all digital tape drives used this streaming tape principle.



Competition gets tougher

- During the second half of the 1970's the competition for the TDM1000 became worse
  - The TDM1000 tape drive as still very difficult, expensive and time consuming to produce and the competiton had typically similar tape drives with less complicated technology and therefore also lower prices.
- One competitor was Cipher in California
- We approached Cipher and suggested a cooperation, but Cipher's management was not interested.
- However, a couple of the key development engineers at Cipher wanted to do something else and together we started up a new company, Tandberg Data Inc. in San Diego. Main goal was to develop a new and mechanically mush simpler and less costly tape drive. The result was a very nice tape drive, the TD-1050.
- While all the tape drive design was done in San Diego, the data control electronics (the "formatter") was developed in Oslo. The total product worked very well and was price competitive.
- *But then, on 13. December 1978, Tandbergs Radiofabrikk went bankrupt……*

1979 – 2003: We focus on QIC-technology



After a short period Tandberg Data (TAD) was established 22. March 1979 with Ralph Høibakk as CEO.

New product strategy was established:

- Main focus was now advanced data terminals
- Since the tape drive business had shown low sales and very low profit margins over several years, the management focus felt that ½" tape drives was not the way to og: Too big, too complicated and too expensive.
  - From a size point of view the TDC 3000 was closer to what we believed the marked wanted; however it was obvious that the marked was looking for products with lower cost and significantly higher storage capacities.
  - It was time for a new tape drive product and in my head I had a clear opinion about how it should look and be designed!
  - But with the top management's main focus being on data terminals, it turned out to be very difficult to get approval that Tandberg Data should also focus on the development of new tape drive technology. However, we were finally given a go ahead ("but do not spend too much money")

The Road towards QIC:

- With a small but enthusiastic group of development engineers we focused on a new type of digital tape drive:
  - More compact (same size as 8" floppy disk stations)
  - Same cartridge as used in TDC 3000 but with longer tape (3M DC300XL)
  - Employ the «streaming tape» principle: Faster, higher capacity and continuous data transfer
  - Mechanical simple and less complicated to produce and more cost competitive
  - With very limited resources (2-3 engineers in the beginning) the development took much longer than originally anticipated. The TAD management team was very skeptical to the whole development plan and viewed market opportunities as minimal.

The QIC-organization is established:

- The beginning of the 1980s saw several new tape drive competitors coming on board, all with the same basic concept:
  - 3M DC300XL cartridge
  - Streaming tape principle
  - Same form factor as 8" floppy disk drive
- The biggest and technically strongest competitor: Archive
- 3M was in contact with all the players and they were concerned:
  - Happy that almost everybody focused on the 3M-cartridge
  - But very afraid that incompatibility between the various manufacturers could led to chaos and less market acceptance.
- Therefore: *We need to establish Standards*!

The QIC-organization is established(2):

- In a series of meetings during 1982-83 the basic foundation for the QIC organization was established with the independent data storage consultant Ray Freeman as the facilitator
- Four members (including TAD) started QIC in 1982.
- Over the following years the QIC group grew to more than 100 member companies or associated companies.
- The group developed standards both for various tape formats and for the actual interface to the drives.
- The activity in the QIC group was high during the whole 1980s and long into the 1990s.
- Towards the end of the 1990s it became obvious that time was running out for the 3M Cartridge technology. The standardization worked slowed gradually down and was finally stopped.
- But the QIC standardization work was a success story: More than 15 million QIC drives were sold world wide during these years.

TDC 3200, The first cartridge streamer from TAD

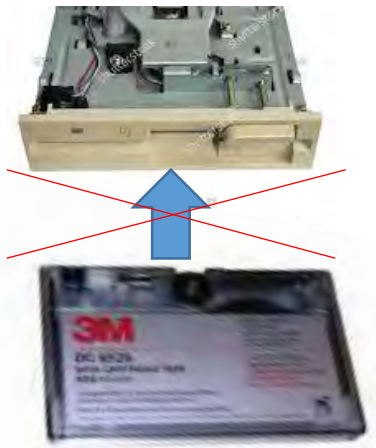
- Originally launched in 1981 with 4 tracks and a capacity of 20 MBytes.
- Same form factor as 8" floppy disk drives
- «Serpentine» write- and read-operation, i.e. recording (and reading) on one track at a time as the tape moved forward or backwards.
- Later the product was adapted to the first QIC standard QIC-11 (same capacity and cartridge)
- No success on the market:
  - Already the market was moving away from the 8” product form factor and demanded physically smaller tape drives with the same form factor as half height 5 ¼ " floppy disk drives

A mechanical challenge–

- The new half height 5 ¼" form factor was not well suited to the 3M cartridge as it was originally designed:

8" Floppy disk:

5 ¼" Floppy Disk:



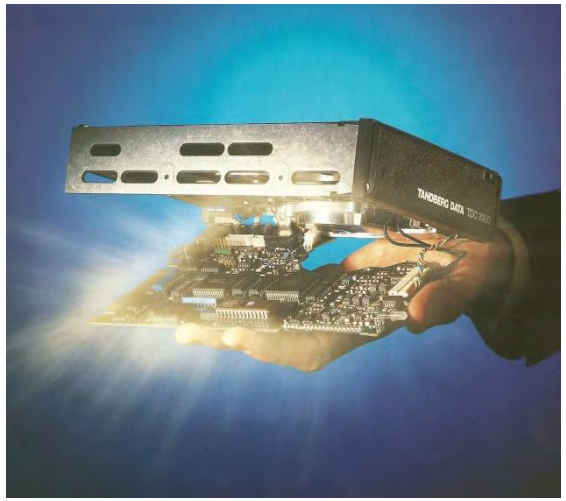
The solution:

- Guttorm Rudi was our main mechanical designer
- He came up with a design that allowed for sidewise insertion of the cartridge without a mechanically complicated mechanism
- The result was a solid and simple basic concept that later would be sold in millions….

The patent war…

- All competitors were hard working on the same basic challenge: *Find a simple way to insert the 3M cartridge into a tape drive with the same form factor as a half height 5 ¼ " floppy drive*
- TAD applied for a patent on our design
- Our key competitors Archive and Wangtek applied for their own (and similar) patents,
  - Archive 14 days ahead of TAD, Wangtek a few weeks after TAD
- After some negotiations TAD and Archive made an agreement and thereby avoided a conflict.
- Wangtek did not and was sued by Archive. They lost and had to pay a substantial amount of money.

The TDC 3300 takes off…



- The first version of the TDC 3300 drive was launched in 1984 with a capacity of 20 MBytes, but this was rapidly increased to 45 and later 60 Mbytes by using 9 tracks and longer tapes (QIC-24)
- Finally the market started to see the benefit of these tape drives and sales slowly grew.
- But there were a constant demand for even more storage capacity …….

We were very proud of our new tape drives

- In the computer arena TAD at this time was mainly known for advanced data terminals
- So, in order to get known, we run a series of ads both in Norway and abroad

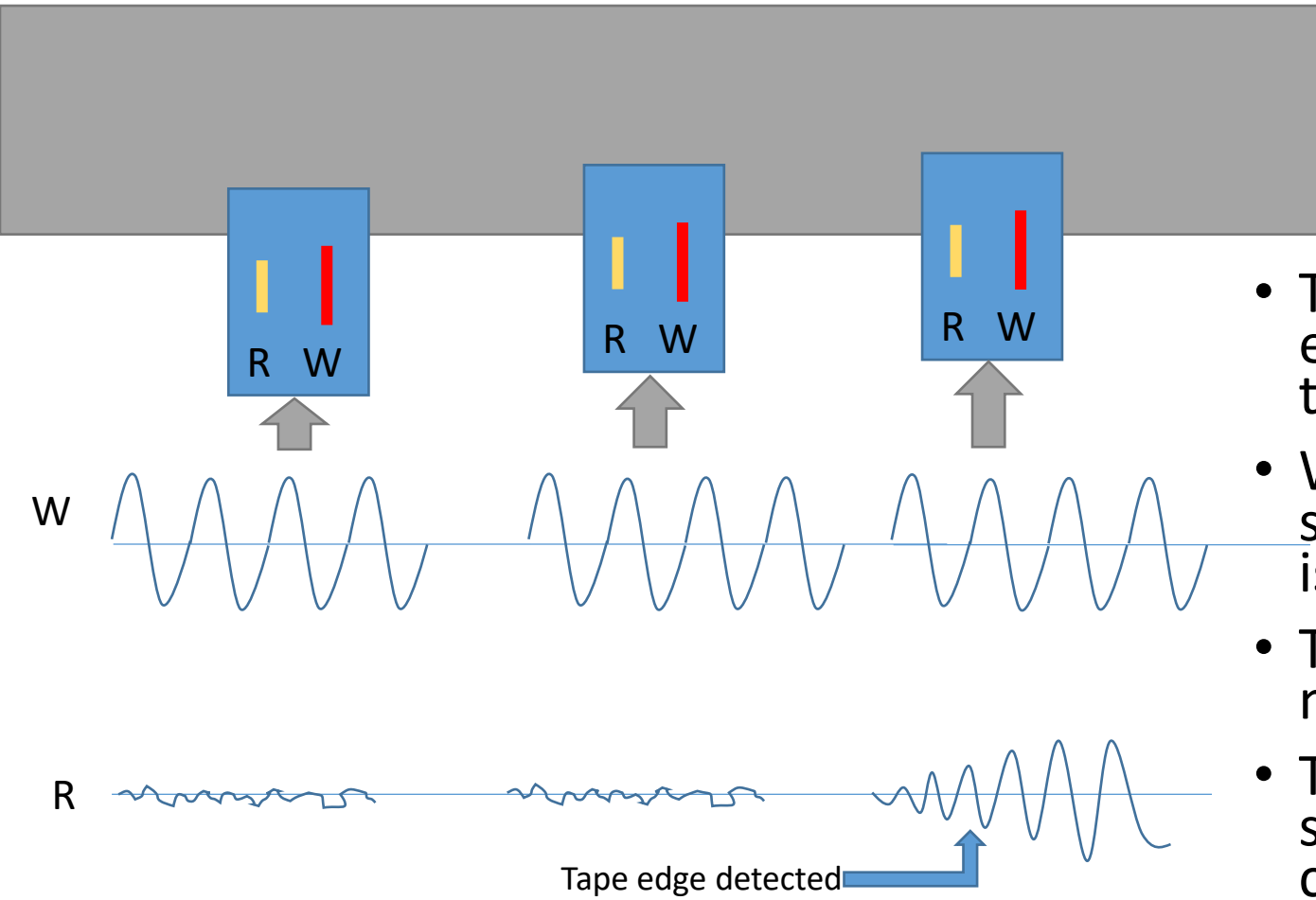
«A Jumbo jet flying at the speed of light just 30 meters above ground – on the mountainous west side of Norway»

(The ad idea: Describing the challenge of keeping the running tape so stable and in so extremely close contact with the head during the fast read and write operation)

The edge seeking patent

- In order to further increase capacity it was necessary to increase the number of tracks on the tape. To do so required more precise measurement of the actual tape position. This was difficult since there were position variations from cartridge to cartridge.
- I finally came up with a fairly simple solution: Finding the tape edge by using the head.

The principle of tape edge seeking:



- The head with the Write (W) and Read (R elements is moved below the edge of the tape.
- While the tape is moving, the head is moved slowly upwards while a constant write signal is sent to the write head.
- The output from the read head is constantly monitored.
- The exact tape edge position is defined as soon as the signal from the read element can be distinguished from signal noise.
- We applied and got a patent on this principle and licensed this technology to all our competitors

IBM gets on board…

- Gradually, the sales of Tandberg Data's tape streamers grew after the TDC3300 drive was launched:
  - ICL and Nixdorf became the first OEM customers
  - The distribution market also started to grow .
- But to really achieve large volumes, we understood that it was necessary to land one of the «big ones» in the OEM arena: Data General, DEC, Compaq, IBM….
  - We worked long and hard towards all these companies (and several others), but IBM was clearly the most tempting one…..
- During the whole 1986 we run a series of technical sales meetings at IBM locations, mainly in the US but also in a few other places.
- Finally, just before Christmas 1986 we got IBM Rochester interested.
- After a half year with very hard work meeting tough demands from IBM, we began delivering drives to IBM summer 1987 (for use with IBM AS400).

The Sky is the Limit….

- The IBM agreement opened up a new world for us:
  - Until spring 1987, production of TDC3300 had been very traditional and staying at a low level of 100-150 per week.
  - With IBM on board, volume requirements changed dramatically.
  - A very competent team directed by Svein Frodahl turned our production strategy completely around and established in a very short time maybe the most efficient and at the same time quality focused tape drive production set-up in the world.
  - And this was done with almost no increase in the number of workers on the line. Automation at all levels was the key word everywhere.
  - And the sales volumes grew rapidly, to over 300 000 tape streamers per year, and all delivered with the same excellent quality.

Quality focus

- IBM introduced the 6 sigma quality concept for us and demanded that we should establish this system for the whole company including of course in our own drive design work and in the whole production set-up.
- This was close to a revolution in quality focus and thinking for the whole organization from top to bottom. It required hard work over many months (and years) to implement this concept with our Colin Jeneson as one of the key internal driving forces.
- Later, we had visits from many of the biggest OEMs in the computer industry all over the world, and they were all very impressed about the way we had implemented our 6 sigma quality concept and how effective the production was running.

Tandberg Data: We were proud of our quality

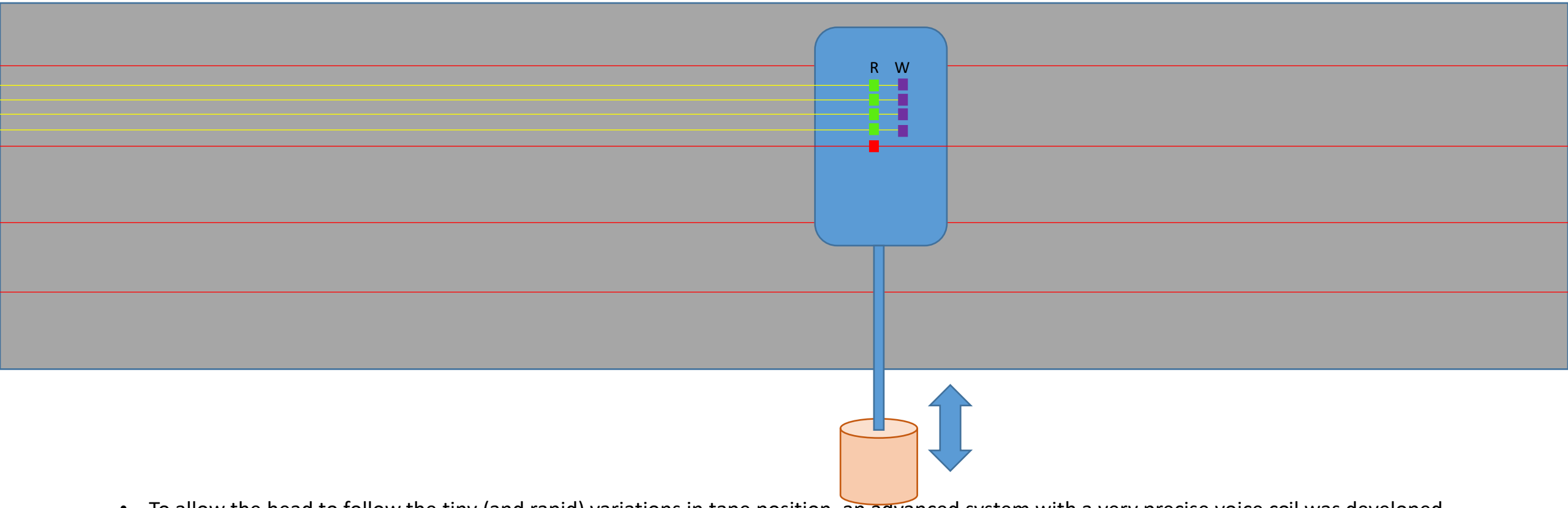
Streaming tape drives becomes TAD's main focus:

- From the modest beginning in the early 1980s, tape drives gradually became the dominating sales product within TAD:
- 1994:
  - TAD is the largest IT-producer in Norway
  - Of a total revenue (tape drives and data terminals) of 1,24 Billion NOK (Norwegian krone) (approx. 210 Million US $ at that time) TAD had a profit of 33 million NOK.
  - The sales of streaming tape drives this year was 855 million NOK with a profit of 46 million NOK.

MLR –Multitrack Linear Recording
More Technology Advancements

- The market pressure for even more storage capacity and higher data rates was constantly high
- To achieve this we needed more tracks (and narrower tracks) and it was also necessary to write and read several tracks in parallel
- Unfortunately, compared to disk drives, a tape is not very stable as it moves across the head at high speed. It will constantly change position (up and down); not much, but with many narrow tracks enough to make traditional recording methods impossible.
- We had to find a way so that the head could follow the tiny up-and-down movements of the head.
- The solution (originally proposed by 3M) was the implementation of special prerecorded servo tracks on the tape.
- These servo tracks were recorded by the tape manufacturers (primarily 3M) during their production of the tape itself. Then during regular write or read operations, the tape drive started by finding one of these prewritten servo tracks and then had a built-in system to constantly monitor and follow this servo track during the write and/or read operation.

MLR-Technology:

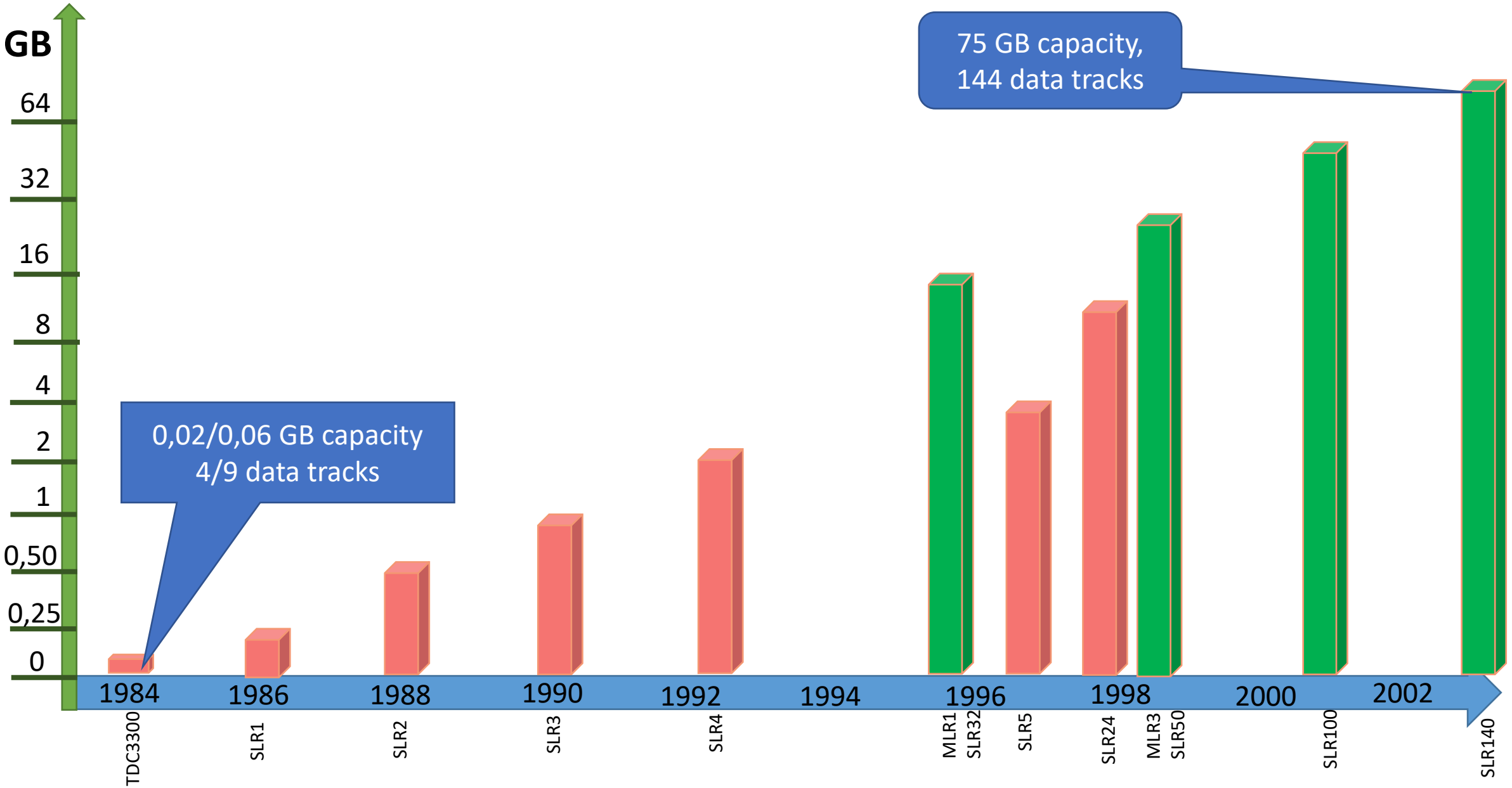


- To allow the head to follow the tiny (and rapid) variations in tape position, an advanced system with a very precise voice coil was developed to control the head (and move it from position to position). This voice coil system also included a smart damper system designed so that the head could follow the tiny rapid position variations of the servo track without any overshoot.
- This whole MLR technology took far more time and man power to develop and get into production than I had originally anticipated. The time consumption and associated cost scared the financial guys within TAD's management and Board more than I realized at that time and this later led to decisions moved Tandberg Data slowly away from tape drives.
- However, once completed, the MLR technology proved to be very robust and sound and the core technology later served as the technical foundation for the development of Tandberg's LTO tape drives.

Then even Compaq came on board as a customer

- For many years Compaq in Houston was one of the driving forces in the PC world and we made several unsuccessful attempts to sign the company up as a customer.
- Finally, based on a simple idea sketch on a paper napkin just prior to a meeting in Houston, they got interested.
- In just 4-5 months we managed to develop and get into volume production a new low cost tape drive (the SLR5) with 4 GBytes capacity and a very competitive price point. Over the following years this product became the QIC streamer with the largest sales volumes in the regular QIC market. In addition to Compaq, in 1998 SLR5 was implemented at several other large OEMs:
  - IBM
  - Siemens
  - Fujitsu
  - And many others

A development Period to be Proud of…



In 2001 Tandberg passed the 3 Million drives delivered mark…

- **Oslo, Norway, March 22, 2001 -- Tandberg Data ASA (OSE:TAD) today announced that it has shipped its third million SLR tape drive to the market. This important milestone reflects the proven, wide acceptance of SLR tape drive technology, SLRtape media and automation products. Over the past two decades, SLR technology has established itself as the industry standard in price-performance, reliability, scalability and backward compatibility in the tape storage market.**

➢ **In total over these years Tandberg Data delivered almost 4 million QIC compatible tape drives to customers all around the globe. (More than 25% of all QIC drives sold world wide)**

Then around year 2000, things got more difficult

- In 1995 new investors came on board with more short-term focus
  - Short term projects with less technology risks were now the main focus
  - New CEOs came and left
- 1997: A license agreement was made with Quantum to produce and sell their DLT type streaming tape drives
  - DLT was a single-type tape cartridge technology originally developed by DEC in 1984. Like the QIC technology, the DLT (and companion SDLT) technology started to be outdated towards the end of the 1990s.
  - Still, the top management and the Tandberg Data Board decided to go for a license agreement instead of developing an alternative and more modern and advanced technology ourselves (in cooperation with possible partners).
  - This license agreement and the implementation of the DLT and SDLT drives in Tandberg's production required a lot of lab resources; thereby reducing Tandberg's technical capabilities regarding new tape drive developments
- 1998:
  - Compaq acquired DEC. This immediately led to a total stop in shipments of SLR tape drives to Compaq and significantly increased the pressure on TAD's finance.
  - The response from the Board and top management was a decision to gradually reduce our own tape drive development programs and focus much more on automation systems. The pressure to focus more and more activities on automation increased even more after year 2000.

The need to focus on new Tape Technology

- As early as in 1995/96 we realized that the QIC-technology slowly was approaching it's practical limits with respect to further increase in storage capacities and data rates.
- During these years I had several meetings with key technical decisions makers within tape drive technology at companies like Quantum, IBM and HP.
- Although competitors, we were also friends and could talk fairly openly about possible new ways to create new and very competitive tape drive solutions.
- In a couple of these meetings I suggested it maybe was time for a complete new tape cartridge, based on a single reel concept similar to DLT and we had some very interesting discussions around this subject.
- However, I never got any concrete feedback from these discussions.
- Then, in year 2000, the LTO tape cartridge and tape drive technology was announced.

2000-2003: The End of the QIC/SLR-Periode

- 2000:
  - IBM, HP and Seagate launches LTO1, a new 100 GBytes tape drive based on a single-reel cartridge (LTO).
- During 2001 and 2002 I tried very hard to get acceptance from the management and the Board to begin our own development of an LTO tape drive, but got only a NO.
- In 2003 TAD launched the last QIC-type streamer, the SLR150:
  - From a technology point-of-view a beautiful and very robust tape drive with 75 GBytes capacity, high data rate and very advanced read/write and error correction schemes.
  - It was also competitively priced (compared to LTO) but the market clearly favored the LTO as the way to go: New technology with a much longer technical horizon and several manufacturers with a solid standardization scheme.
- But the top management and the Board had made its decision:
  - Tape is not the future!
  - TAD shall not develop any more tape drives, not even LTO.
  - Tape drive development shall be terminated at TAD!!

➢ Many difficult and challenging discussions: I finally suggested that we could create a new company to develop LTO tape drives and I offered to take over the whole tape drive development team into the new company if the company was given an acceptable financial start capital of 50 Million NOK.

- Finally, the management and the Board approved this and Tandberg Storage (TST) was established in summer 2003.

2003-2005: Tandberg Storage develops LTO2

- The next generation of LTO tape drives, LTO2 with native capacity of 200 GBytes was launched by IBM, HP and Quantum in 2003
- Therefore, TST had to initially focus on the development of an LTO2 drive.
- Our total development team consisted of approximately 35 engineers so the challenge was very big. However, the team was very dedicated to our initial goal of a 2-years development time and our MLR technology background was a very good foundation.
- We did not achieve the 2-years development time goal, but were not very far off..

The Tandberg Storage LTO2 tape drive

- **200 GBytes native,**
- **Prototype ready by summer 2004**
- **However, the work to get the drive certified by the LTO committee and at the same time setting up a whole new production line took more time than anticipated.**
- **However, in June/July 2005 the drive was ready for market launch**

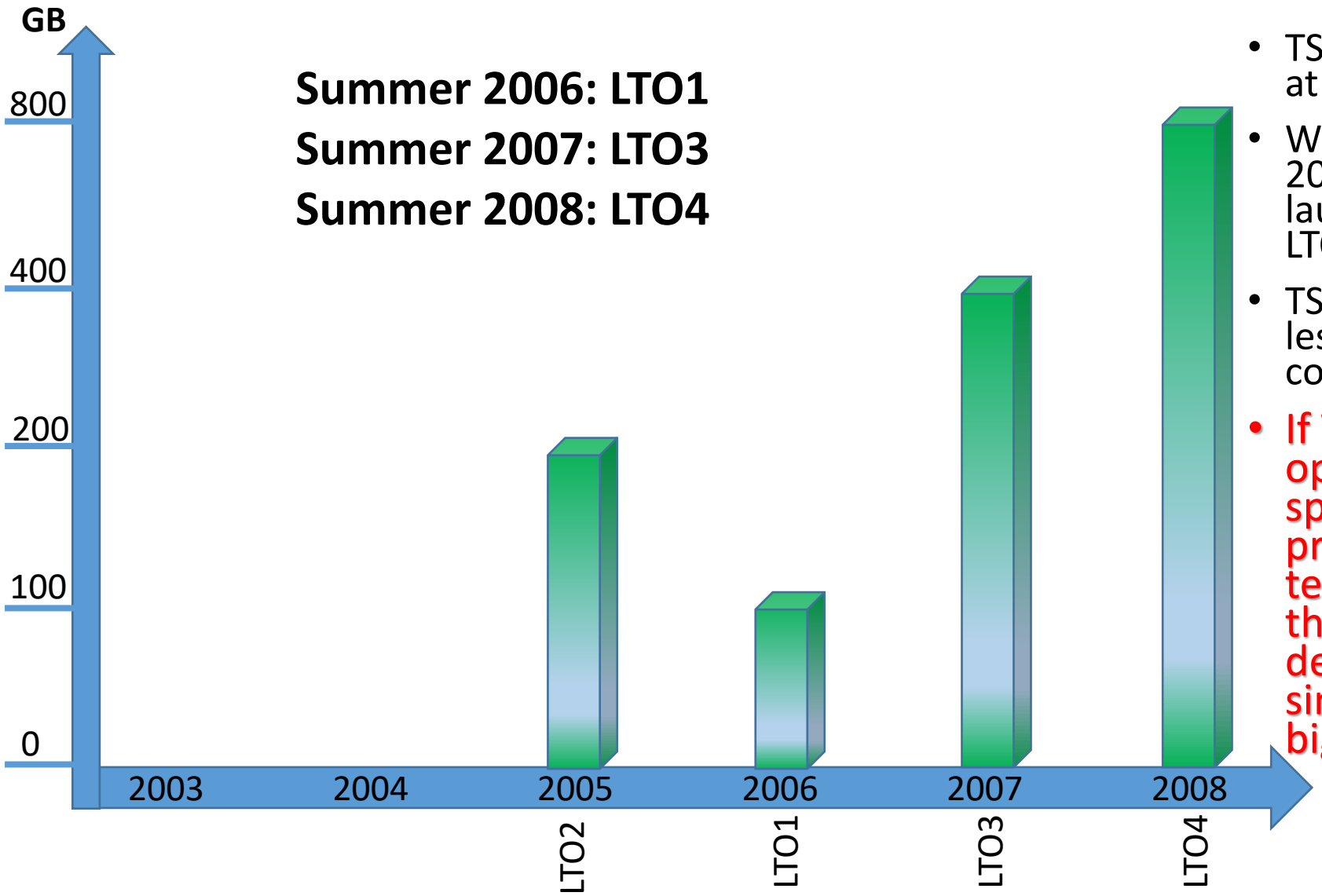
A Positive Beginning:

- As the largest shareholder in TST (>33%) TAD insisted that the two companies should enter an agreement giving TAD all sales rights to the LTO drives between 2005 and 2007.
- But TST should participate actively in the sales work towards large OEMs.
- Already in autumn 2004 IBM Rochester decided to go for our LTO2 drive.
- As the sales started in summer 2005 we rapidly gained market acceptance and got more OEMs on board
- For a long time, IBM was the most important one and we always had an excellent relationship with that company
- With more OEMs on board, and especially after we also signed up with Dell, the volumes tsarted to increase quite rapidly.

2005-2008: Demand for rapid Development of more Drives

- The LTO-consortium continued to launch new LTO standards and tape drives.
- TST (and TAD) had to try to regain the originally lost time as rapidly as possible
- During the following three years 2005 to 2008 the internal tape drive development continued at a very high pace with basically the same engineering group that originally began in TST.

TST's development of LTO-drives



Summer 2006: LTO1
Summer 2007: LTO3
Summer 2008: LTO4

- TST managed to launch tape drives at a very high data rate:
- When our LTO2 was launched in in 2005 it was 5 years after the initial launch of LTO1 and 3 years after LTO2 originally was launched.
- TST launched LTO4 in spring 2008, less than 1 year after IBM as the first company launched its LTO4 drive.
- If TST had been given the opportunity to continue this high speed efficient development program, the company had the technology, the know-how and the experience to be able to develop new LTO drives almost simultaneously with the three big competitors.

The Road towards the End (1):

- By the end of 2007 TST/TAD supplied LTO half height drives to 25% of the world market for these drives.
- Still due to this sales success, TST financially was not in good shape since the originally agreement gave TAD a large share of the sales profit.
- Tad had at the same time large financial problems due to a very bad decision to buy Exabyte
- The original sales agreement between TST and TAD called for TST to take all OEM sales by itself from 2008 onwards. However, during a series of difficult management meetings in spring 2008 it became clear that TAD had no intention to honor this agreement.

The Road towards the End(2):

- In spring 2008 approximately 50-55% of all LTO tape drive sales through TST/TAD went to OEMs,; the rest to various Distribution channels controlled by TAD.
- Summer 2008 and without TST knowledge, TAD entered an agreement with TST's biggest competitor HP whereby TAD immediately should switch from using TST LTO drives to HP LTO drives in all their shipments to the Distribution channel.
- The result seen from TST's side was that almost 50% of the total revenue and approx. 2/3 of the total profit disappeared overnight and TST had no way to survive.
- TAD then gave a ridiculous low offer to all share holders in TST and they in reality could only accept the offer.
- Thereafter, TAD almost immediately either laid off or fired almost all development engineers and for all practical purposes the development of new tape drives cape to an abrupt stop.
- Then in April 2009 TAD went bankrupt and this forced TST to declare bankruptcy the day after.
- Thereby, a long and proud Norwegian technology history became abruptly terminated.

A very sad ending....

The technology development that started with Lorentz Nødtvedt and the audio tape drives back in 1948, and then

- continued in 1970 with the focus on digital tape drives with Gunnar Reichborn-Kjennerud and Petter Brevik, and then
- continued with Ralph Høibakk and the focus on QIC technology after 1978, and then
- continued with the rapid and successful LTO development from 2003,
- suddenly just became history in 2008/9.

But We shall still be very Proud of what We together achiveed during these Years!

- Approx. 5 million tape drives of various categories were designed, produced and sold during these 39 years for a revenue of far more than 10 Billions NOK.
- **It shows that even in a small country like Norway our top engineering skills and creativity can compete with the best ones around the world!**