'Photogrammetric Week '97' D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1997.

Digital Storage Devices for Photogrammetry and Remote Sensing

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ABSTRACT

Data acquisition for remote sensing or photogrammetry applications leads to increasingly high data rates which require storage capacity on-board of the satellites and in the ground segment. For the different stages of the data chain from the sensor to the user different technologies of storage devices are applied, some of them specially designed for its task. The paper describes the different storage device technologies and the impact onto costs and operation.

1. INTRODUCTION

Monitoring of the environment, photogrammetry, cartography or management of resources with remote sensing by satellites or aircraft requires high geometric resolution and multispectral approach to fulfill the needs of modern highly specified analysis. As consequence high sensor data rates (Reiniger, 1997) are generated with stringent demands on the storage and transmission of the data stream to the ground segment for further processing and archiving.

Global acquisition of data sets however can only be realized by the installation of world wide networks of ground receiving stations with the capacity to record the data stream in real time during data reception (like ERS satellites) or by the on-board storage of selected full (SPOT satellite) or reduced (ENVISAT satellite) resolution scenes. The technical characteristics of the data stream led to the development of specialized storage devices for the recording and preservation of remotely sensed data.

On the way from the generation of data to its final application or preservation of future use, high capacity storage devices are following the data stream as shown in Figure 1. In principle the following different storage devices have to be regarded:

- on-board recorders for the storage of selected high resolution scenes or global data sets buffered for a retransmission to dedicated ground stations or users,
- recording devices for the storage of the acquired primary satellite data stream during reception at the ground stations,
- temporary computer storage capacity during data processing, product generation and data evaluation,
- archiving capacity for long-term preservation of historical relevant data sets.

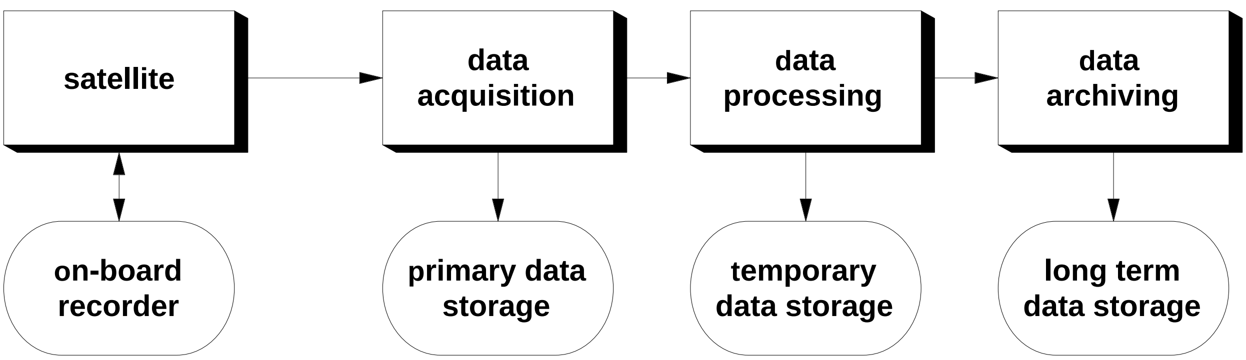

Figure 1: Different levels of storage devices.

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2. SENSOR DATA STORAGE ON-BOARD OF SATELLITES

The storage of sensor data on-bord of spacecrafts has already a long history. Although being a very delicate technology space data recorders (SDRs) are mandatory for many remote sensing missions. The most important characteristic of SDRs is the ability to decouple the sensing of data from time scheduling and from data rate requirements (by rate transformation) for the transmission of data to a ground station.
By this effect the continuous sensing and storage of sensor data, generating only low data rates but with long observation times, like the LBR (Low Bit Rate) sensors ATSR, GOME, Altimeter on-board of ERS satellites, and requiring a fast retransmission (playback) of the integral data set during the limited contact time with the groundstation is possible. For ENVISAT the four SDRs (with a capacity of 30 Gbit each), record the global data sets at 4.5 Mbit/sec and replay it at 50 Mbit/sec (factor 1: 12). The typical SDR for such application is shown in Figure 2 with the ERS tape recorder (ESA, 1996). The recorder has been designed to store a full orbit of continuous 1.1 Mbit/sec LBR data stream on its 3 000 ft of ¼-inch magnetic tape, leading to a total capacity of 6.5 Gbit. During 15 min of contact time with Kiruna ground station it replays the stored data at a rate of 15 Mbit/sec (in reverse direction).
The transmission of remote sensing images from interplanetary spacecraft is extremely limited in bandwidth (data rates) by the large distances and the limited electrical energy on-board of the space craft. A provision of image data is therefore only technical feasible by intermittent storage of data on tape and replay in time translated (reduced) data rate. Taking full advantage of the technical capabilities of the on-bord recorder of the NASA/JPL GALILEO interplanetary probe was the only solution to solve the problems with the non deployed high gain transmission antenna and to obtain high resolution data from Jupiter and the Jovian moons. There high resolution data obtained at 806 kbit/sec was translated by the recorder to 7.7 kbit/sec, buffered in the on-bord computer and could then be transmitted to earth via the small low-gain antenna (ODETICS, 1997a). A number of discoveries was made on this voyage to Jupiter (e.g. evidence of continuous volcanic activity on moon Lo etc.).

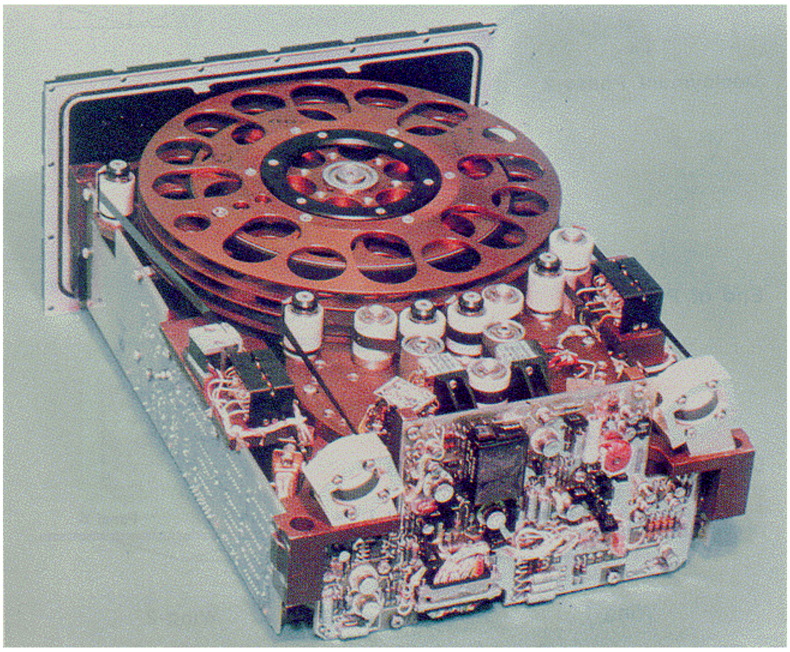

Figure 2: ERS LBR data recorder.

Modern earth observation satellites (SPOT, Radarsat, ADEOS) make use of on-bord tape recorders for the recording of a limited number of selected high resolution scenes over regions that are either not

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covered by the ground network or need to be processed at a central site in short delay after acquisition. With the present capacity of the recorders (e.g. 76 Gbit capacity of the Radarsat recorder) up to 15 minutes of image data can be stored per orbit. It should however be mentioned that this operation is very stringent for the present mechanical tape recorders and limit the lifetime of the equipment. As consequence some of the recorders failed unfortunately during mission lifetime.
The present technology of on-bord storage recorders is based on mechanical drives with belt type tape material. This type of recorders implies special operation requirements on the satellite and the ground stations to optimize lifetime of the recorders (reverse play back) and to minimize tape recorder influence on the satellite and its sensors (attitude). Latest on-bord recorder technology is changing to solid-state recorders (SSRs). First fully qualified units for earth observation will be for the Earth Watch “Early Bird“ satellite to be launched in the near future. The recorder, shown in Figure 3. will have a capacity of 16 Gbit, built up of 1 000 DRAM modules of 16 -Mb each.

Figure 3: State of the art technology SSR on-board recorder.

The recorder weighs less than 12 pounds and consumes only 13 watts of electrical power during record and playback operation. Variations of this recorder are already scheduled for the NASA/SSTI Clark mission, for the Orb View and the RADARSAT 2 satellites. Variations on this type of SSRs will allow in the future much higher data rates (up to 2.4 Gbit/sec) and storage capacities higher than 200 Gbit (ODETICS, 1997b). An overview on the different satellites and the on-board storage capacity is given in Table 1.

Satellite	No of recorders	Goal	Capacity	Data rate
ERS	**2 SDR**	**LBR data**	**6.5 Gbit**	**1.1/ 15 Mbit/sec**
SPOT	**1 SDR**	**Imagery data**	**72 Gbit**	**50/50 Mbit/sec**
RADARSAT	**1 SDR**	**SAR data**	**72 Gbit**	**105/85 Mbit/sec**
RADARSAT 2	**1 SSR**	**SAR data**	**160 Gbit**	**105 Mbit/sec**
ADEOS	**1 SDR**	**Imagery**	**72 Gbit**	**60 Mbit/sec**
ENVISAT	**3SDR; 1 SSR**	**LBR, SAR data**	**30 Gbit**	**4.5/ 50 Mbit/sec**
Early Bird	**2 SSR**	**Imagery data**	**16 Gbit**	**150 Mbit/sec**
SSTI	**1 SSR**	**Imagery data**	**88 Gbit**	**unknown**

Table 1: On-board recording capacity of present earth observation satellites.

3. DATA STORAGE IN GROUND SEGMENTS

The storage of data in ground segments has various aspects and involves different storage technologies and objectives, each in the same way important for the overall data production process.

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At the front end the storage of the primary (crude) satellite data stream during data acquisition is most critical, as lost or erroneous recorded data cannot be recovered. The primary data stream is satellite oriented and cannot be processed directly due to its high data rates and its satellite telemetry oriented structure. The storage technologies and devices therefore are, as well, satellite data stream oriented and not computer compatible. For long years data ingestion into the processing computers was limited to reduced playback operation due to the limited computer speed. This led as consequence to a application oriented data selection and processing instead of a production oriented processing. Large amounts of untranscribed data therefore are still to be transcribed for data preservation and for future processing.

Data storage on production level is normally performed in the ground segment in temporary, rolling archives with multi-user access, serving as intermittent data buffer to compensate for time delays during the different production stages and as a back-up storage during maintenance and system outage times. The storage devices are normally large disc spaces or digital tapes devices with medium term storage lifetime, like exabytes.

The long term preservation of data requires methods that assure data safety and accessibility of information independent from the life cycle of equipment, media and formats. The cyclic data maintenance and refreshment of the data set and the increasing data volumes require the application of automated technologies like robotics and optical storage devices.

All different processing stages require different technologies of data storage and data maintenance. The most important technologies of storage devices in the ground segment for earth observation data will be now discussed.

3.1 High density digital recorders

The recording of the primary data stream, transmitted to the ground receiving stations has to secure a widely error free storage in real time and its reconstruction at adequate processing speed. This task was, until recently, not possible by computer compatible periphery as the data rates (between 40 and 110 Mbit/sec) and a data volumes larger than 100 Gbit (20 Gbytes) could not be handled by the computer CPU, the operating software, the interfaces and the storage peripherals. Therefore the HDDR (High Density Digital Recorder) technology had to be introduced, based first on multi-channel Wideband Instrumentation recorders, developed for telemetry purpose, or later based on digital video recorders, developed for professional television broadcasting. Although the packing densities in this technology exceeded 30 000 bpi (bits per inch and track and therefore being regarded as high in comparison with the packing densities of CCTs), the recording of the data stream, generated by remote sensing satellites required more than one data track, realized either by splitting of the data stream into multiple parallel recorded channels (instrumentation recorder) or by sequential recording on parallel helical (scan generated) data tracks. The data quality of HDDR recording (measured by the bit error rate BER) is limited by the high packing density and the production quality of the tapes. The principle source of errors generated during recording is the “tape dropout“ - the usually abrupt and severe loss of data from a short length of tape due to improper dispersion, surface flaws, physical damage, geometric distortion or end of magnetization time (after about 10 years). Even certified tapes, properly cleaned and demagnetized are seldom capable of maintaining an error rate better than 10^{-7} without error detection and correction. The structure of HDDT recording had therefore to be organized to improve the error performance by additional error correction of the data recorded. It contains therefore data blocs comprised of synchronization words, sensor data and error correction information. As consequence the absolute volume of information stored on an HDDT is up to 30% higher than the sensor data, leading to increased tape-length and to higher tape velocities. Various methods to correct tape errors were developed by the individual recorder manufacturers, all leading to bit error rates better than 10^{-10}, even for the critical tape cross play operation.

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3.1.1 Longitudinal Recorders (Instrumentation tapes)

Longitudinal recording of remote sensing data is performed since the early days of earth observation based on the multi-channel instrumentation recorder technology. Limited by an individual channel data rate of maximal of 4.75 Mbit/ sec a total number of 24 channels (application data) plus 2 channels (error correction) are required to store a typical data stream (ERS) of 105 Mbit/ sec. Error correction (Thorn EMI, 1986) on instrumentation recorders is achieved by CRC correction of each individual track in longitudinal direction and by CRC correction in “across“ direction for the 12 tracks of each head stack, as shown in Figure 4.
The remaining two data channels of the standard 28 channel head stack configuration are used for time code and annotation data. Instrumentation recorders can be operated in constant speed or constant density configuration. With a maximal tape length of 9600 feet of the 1 inch size tape a recording capacity of 15 Gbytes (equivalent 15 min recording time) can be achieved. The technical limit of this type of recorders is given by a 42 channel track configuration and 240 ips tape velocity, resulting in a possible data rate of 240 Mbit/ sec.

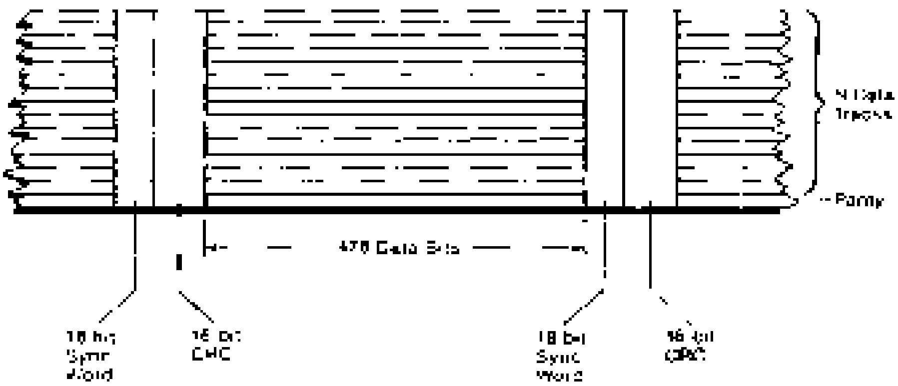

Figure 4: Data track configuration of instrumentation recorders.

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Instrumentation tape recorders are the standard technical installation at almost all earth observation ground stations. Unfortunately a standardization could never be achieved among the different recorder manufacturers. Therefore the ground segments had to be equipped with several different types of recorders to allow the interchange of tapes between different satellites and ground stations.

3.1.2 Helical Recorders (Video-Cassette tapes)

Helical scan recording for real time capture of satellite primary data has been introduced in the early 1990 to respond to the increasing demand on data volume and data rates. The combination of field-proven rotary head technology with cassette based tape transport developed for professional digital television production under the ANSI (American National Standard Institute) had only be modified at the front-end to provide HDDT recording with data capacities up to 770 Gbits (D-1 Large cassette) and data rates up to 256 Mbit/ sec. At the same time the storage costs/ Gbit and the volume of large data archives could be drastically reduced.

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The achieved tape density and the organization of the data structure (SONY Corp., 1996) on the data tape are similar to the longitudinal recording with the difference that the length of a data block is determined by the length of the helical track on the tape, given in Figure 5, and a pre- and postamble information had to be added as identification of start- and stop section of the data block. Equivalent to longitudinal recording additional (longitudinal) annotation tracks for time code, reference control information and voice recording are provided.

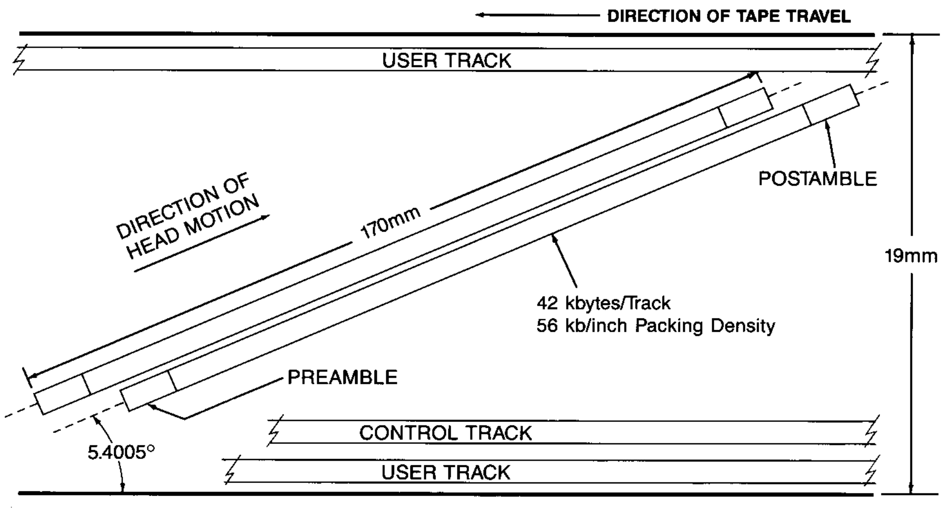

Figure 5: Data structure of helical scan recorders.

Error correction with helical scan recording is limited onto longitudinal error correction. Powerful error correction, resulting in bit error rates of better than 10^{-10} are achieved by FEC (Forward Error Correction) codes like the famous Reed Solomon code. The structure of one individual data block is given in Figure 6.

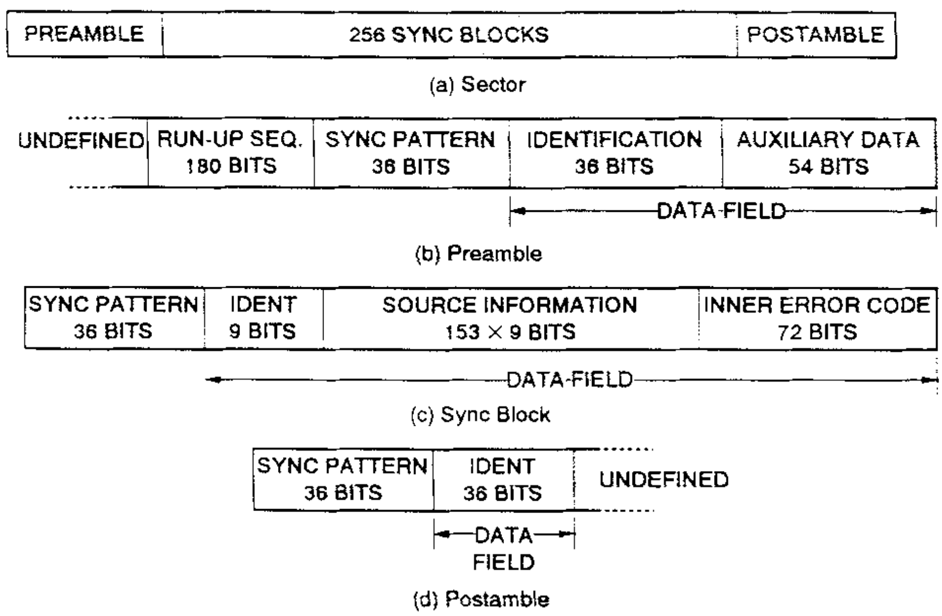

Figure 6: Data block structure.

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The helical scan technology represents a link between the HDDT technology and the state of the art computer compatible Direct Digital Archive technology as this type of recorder can be operated in two different modes. In the HHDT mode it fully replaces the instrumentation recorder. In a second mode this technology can be fully operated like a high speed computer peripheral with computer compatible file structures and parallel input/ output interface structure and therefore work as an archive storage device.

3.2 Direct archiving technology

The direct archive technology is designed to replace the HDDRs, traditionally needed in ground stations, by advanced technology which allows the ingestion of live or playback serial data streams of earth observation satellites and transforms it directly into computer-compatible form. As part of the acquisition process, it generates subsampled and auxiliary data, which can be used by other systems to compile or update the catalogue for user access. The users can then, shortly after acquisition, browse this data over a network and place orders for imagery data that meets their needs in terms of coverage, time and quality. In the direct archive process the serial data stream, received by the ground station, will be first ingested by a RFC (Reconfigurable Frame Correlator) unit, which synchronizes the data stream according to the satellite specific structure, performs framing and serial-to-parallel conversion and stores it on a RAID (Redundant Array of Independent Discs). The RAID stores the incoming raw data stream until the acquisition is been complete and works as a high capacity real-time buffer between the acquisition and the data handling process. Typical RAID capacity is 20-80 Gbytes, sufficient space to store up to 8 satellite passes on it. After completion of the acquisition process the data set will be formatted into data files of level 0 or RAW-type (e.g. Framed Raw Expanded Data) and recorded onto computer peripheral tapes (DLT) or directly transferred via LAN to the processing and archiving facilities. This technology has distinct advantages like high performance, low cost media, high reliability, robotics archive compatibility and direct onward processing without the necessity to involve frame correlators etc.

3.3 RAM disc technology

The application of solid state RAM technology as primary data storage of earth observation data was only realized in very specialized systems and for limited data capacity. To date the investment cost for RAM disc technology is still too high to allow this technology to be applied as standard, however the development direction indicates the same change for front end storage devices as it happened in the on-board side.

3.4 Comparison of the different storage devices

A comparison of the different technologies is given in Table 2, showing the technical characteristics and the investment and operational costs of different storage devices, indicating clear cost advantages of the optical discs and a high technical potential for RAM discs in the future.
The three different generations of recorder technology to record the primary satellite data stream are displayed in Figure 6. There, the Instrumentation tape recorder technology is given at the right (P&G SE 9000 recorder and the coaxial honeywell 101e drive), the SONY DIR 1000 cassette tape (lower left) and the MDA Digital Direct Archive (upper left), all installed at the D-PAF, at the German Remote Sensing Data Center, DLR Oberpfaffenhofen.

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	HDDTs	magn. Tapes	magn. Disks	Optical Disks	RAM
Capacity GB	15	165	9....27	5	many
Speed MB/s	20	20	10	1.0	≥ 20
Removability	yes	yes	no	yes	no
Media lifetime yrs	≈ 10	≈ 10	-	≈ 30	-
Drive reliability Mhrs	0.1	0.01...0.1	1.0		high
Investment costs/GB	20 kUS$	10 kUS$	250 US$	500 US$	6 kUS$
Operation costs /GB	20 US$	3 US$	-	5 US$	-

Table 2: Comparison of the different storage device technologies.

Figure 6: Three generations of storage devices at D-PAF.

4. DATA ARCHIVING TECHNOLOGY

The long- term preservation of earth observation data is of vital interest for the society, as remote sensing data can already represent a consistent, geometrically and temporally high resolution and global documentation on the dynamics of the human environment. Long term data preservation is a very challenging task, requiring common data policy, storage strategy and compatible technology on a worldwide level. Data archiving is technologically challenging, too, because the life time of the information to be preserved is magnitudes higher than the lifetime of the equipment, the media and the data formats used and is not only limited to the datasets but also to metadata and processing algorithms. Robotics devices and high data throughput are mandatory to control the high and steadily increasing data volumes and number of user accesses. The technology of storage devices for archiving purposes becomes important regarding data volume, throughput and safety. While archiving technology of the first generation, built up by WORMs of 6.5 Gbytes was limited to a total capacity of 300 Gbytes, the second generation is already operating with DLT drives of 40 Gbytes storage capacity and a possible data volume of up to 100 TByte.

5. CONCLUSIONS

The storage of data is a crucial element in remote sensing. The technology of storage devices in the various stages of the remote sensing end-to-end system is very distinct and adapted to the application. Especially the primary data storage and the data archiving are still challenging technologies, which are very much affected by the highly dynamic evolution in this field.

6. REFERENCES

ESA (1996): ERS-2: A Continuation of the ERS-1 Success. ESA Bulletin No 83, ESA Paris.

ODETICS (1997a): Odetics Recorders on Galileo enables High Resolution Imagery. Company Publication, Anaheim, USA.

ODETICS (1997b): Remote Sensing Products. Company Publication, Anaheim, USA.

Reiniger, K. (1997): Auslegung von Bodenstationen für satellitengestützte Fernerkundung. Deutsche Geodätische Kommission, Reihe C, München, Germany.

SONY Corp. (1996): DIR-1000 recorder. Technical manual, Sony, Japan.

Thorn EMI (1986): Modern Instrumentation tape recording, an Engineering Handbook, third edition. Thorn EMI, Library of Congress, catalog number 78-60084, London.