Data Storage Technology Overview

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Agenda

• History and Trends of Automotive Storage

• Data Storage Types and Data Recording Scenarios

• Considerations of Storage
A Powerful Platform

PORTFOLIO BREADTH

TECHNOLOGY ENGINE

~14,000 active patents

GLOBAL SCALE

62,000+ employees worldwide
Evolution of Automotive Data Storage

1981
Electro Gyrocatar

1985
Digital Navigation

1987
First CD-ROM Navigation System

1997
First DVD Navigation System

2001
First HDD Navigation System

2005
First SD Card Navigation System

~2008
First e.MMC Navigation System

Coming Soon!
First UFS System

Transparencies

Cassette Tapes

CD-ROM

DVD

HDD

SD/microSD Card

e.MMC

UFS
Automotive Data Storage Today

**HUD/DIGITAL CLUSTERS**
- Informative to Predictive
- AR HUDs and Cluster

**TELEMATICS GATEWAY/OTA**
- Receive updates
- Communication between cars and infrastructure

**V2X**
- Communicate between and improve safety

**NAVIGATION**
- 2D to 3D navigational maps

**DRIVE RECORDER**
- Mobile apps
- Entertainment
- Information hub

**INFOTAINMENT**
- Aftermarket moving to built-in

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Automotive Storage Trends

- **Density**: Needs increasing
- **Speed**: Of data increasing
- **Usage**: Models changing
- **Quality**: Targets are still ZERO dppm!
Data Storage Enabling the Car of the Future

Changing Storage Usage Models

Faster Boot and Read Speeds
Operating systems and applications are getting more complex

Wider Temperature Environments
More powerful processors

New Write-intensive Workloads
Multi-camera recording, autonomous drive, data telematics
Automotive Data Storage Tomorrow

FUTURE

VIRTUAL MACHINES
- Compute domains for combining resources
- Stores knowledge
- Updates when something new is learned

AI Database
- Stores knowledge
- Decision maker
- Main computer to control self-driving vehicles

BODY CONTROLS
- Controls various functions in the car
- Logging vehicle information for insurance, maintenance, etc.

LOCATOR/SENSOR FUSION
- Precisely identifies where the vehicle is located on the map

AUTONOMOUS DRIVE
- Fleet TaaS/MaaS

TaaS/MaaS
Growth of Data Storage in Vehicles

3D/HD Mapping • Infotainment/Navigation • Digital Clusters • Telematics Gateways • V2V/V2I Comms • Autonomous Drive • Data Recorders

- Application stack + HMI (voice, gesture, etc)
  - 32GB

- Maps (3D/HD)
  - 64-128GB+

- Augmented Reality
  - 16-128GB+

- Autonomous drive OS + App Stack
  - 32-512GB

- Drive Recorder
  - 32GB-2TB+

- Hypervisor + multiple OS
  - 8-64GB

- DashCams, Cluster, Telematics/V2X, Body control
  - 8-64GB
In Car Storage v. Cloud Storage

Connectivity

Latency

Cost
Automotive Data Storage Types and Scenarios for Data Recording
## Types of Data Storage Technology

Each storage technology has a different role

<table>
<thead>
<tr>
<th>Volatile Storage</th>
<th>Non-volatile Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DRAM</strong> – Used for storing data that the processor is using. Very fast read/write capabilities</td>
<td><strong>Magnetic</strong></td>
</tr>
<tr>
<td><strong>Magnetic</strong></td>
<td></td>
</tr>
<tr>
<td>– <strong>HDD</strong> – High data storage capacity, but not suited to applications with shock/vibe</td>
<td>– <strong>Tape</strong> – High data storage capacity, but not suited to applications with shock/vibe</td>
</tr>
<tr>
<td><strong>Flash</strong></td>
<td><strong>Flash</strong></td>
</tr>
<tr>
<td>– <strong>NOR</strong> – Low storage capacity and resilient to shock/vibe</td>
<td>– <strong>NAND</strong> – High storage capacity and resilient to shock/vibe</td>
</tr>
</tbody>
</table>

*Other data storage products exist but are not commercially viable today*
What is Used Today for Event Data Recorders

• DRAM + NOR flash
  – Very limited amount of data (kilobytes-megabytes)
  – Data is constantly written into DRAM but only transferred to NOR when there is an Event
Estimated Data Generation by SAE Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Cameras</th>
<th>Radar Sensors</th>
<th>Ultrasound Sensors</th>
<th>LiDAR</th>
<th>Gigabytes Generated per hour (Low)</th>
<th>Gigabytes Generated per hour (High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>0–1</td>
<td>0</td>
<td>0–4</td>
<td>0</td>
<td>0</td>
<td>280</td>
</tr>
<tr>
<td>Level 1</td>
<td>1–4</td>
<td>3–5</td>
<td>4–8</td>
<td>0</td>
<td>520</td>
<td>2,220</td>
</tr>
<tr>
<td>Level 2</td>
<td>4–8</td>
<td>5–8</td>
<td>8–12</td>
<td>0–2</td>
<td>1,700</td>
<td>6,000</td>
</tr>
<tr>
<td>Level 3</td>
<td>7–10</td>
<td>6–9</td>
<td>8–12</td>
<td>1–3</td>
<td>4,700</td>
<td>7,800</td>
</tr>
<tr>
<td>Level 4</td>
<td>9–16</td>
<td>11–21</td>
<td>8–12</td>
<td>3–5</td>
<td>6,700</td>
<td>16,700</td>
</tr>
<tr>
<td>Level 5</td>
<td>9–17</td>
<td>11–23</td>
<td>8–16</td>
<td>3–6</td>
<td>6,700</td>
<td>17,300</td>
</tr>
</tbody>
</table>

Note: Data assumes 24bpp.
Source: IDC, November 2019

Cameras will be the biggest driver of Data.
Higher resolution (4K/8K), higher frame rate will drive this even more.
### Data Generated

**Running Autopilot 2.5**

<table>
<thead>
<tr>
<th>Description</th>
<th>H-Pixel</th>
<th>V-Pixel</th>
<th>Frames per Second</th>
<th>Megabits per Second</th>
<th>Gigabytes Generated per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front narrow, max distance: 820ft, 35-degree field of view</td>
<td>1,280</td>
<td>960</td>
<td>30</td>
<td>885.00</td>
<td>398</td>
</tr>
<tr>
<td>Front main, max distance: 260ft, 50-degree field of view</td>
<td>1,280</td>
<td>960</td>
<td>30</td>
<td>885.00</td>
<td>398</td>
</tr>
<tr>
<td>Front fisheye, max distance: 195ft, 150-degree field of view</td>
<td>1,280</td>
<td>960</td>
<td>30</td>
<td>885.00</td>
<td>398</td>
</tr>
<tr>
<td>Left pillar, 195ft, 80-degree field of view</td>
<td>640</td>
<td>480</td>
<td>30</td>
<td>221.00</td>
<td>100</td>
</tr>
<tr>
<td>Right pillar, 195ft, 80-degree field of view</td>
<td>640</td>
<td>480</td>
<td>30</td>
<td>221.00</td>
<td>100</td>
</tr>
<tr>
<td>Left repeater, 325ft, 60-degree field of view</td>
<td>640</td>
<td>480</td>
<td>30</td>
<td>221.00</td>
<td>100</td>
</tr>
<tr>
<td>Right repeater, 325ft, 60-degree field of view</td>
<td>640</td>
<td>480</td>
<td>30</td>
<td>221.00</td>
<td>100</td>
</tr>
<tr>
<td>Rear, max distance: 160ft, 140-degree field of view</td>
<td>1,160</td>
<td>720</td>
<td>30</td>
<td>601.00</td>
<td>271</td>
</tr>
<tr>
<td>Long-range radar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-range ultrasound x 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>4,155.12</td>
<td>1,872</td>
</tr>
</tbody>
</table>

*Note: Data assumes 24bpp.*

*Source: IDC, November 2019*
Scenario 1: Data Written to DRAM First

- Data written to DRAM and then non-volatile storage when event occurs
- NAND Flash endurance exceeds Level 5 estimate data rate and supports over 3000 incidents a year recorded 2 minutes each for >15 years

### Data Recorder - TB Written

<table>
<thead>
<tr>
<th>Card Capacity (GB)</th>
<th>16</th>
<th>32</th>
<th>64</th>
<th>128</th>
<th>256</th>
<th>512</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB Writes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 years +</td>
<td>31</td>
<td>63</td>
<td>125</td>
<td>250</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>X3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 5 years</td>
<td>32000</td>
<td>64000</td>
<td>128000</td>
<td>256000</td>
<td>512000</td>
<td>1024000</td>
</tr>
</tbody>
</table>

### Data Recorder - Expected Life (Years)

#### Recording Bit Rate (Mbps) | Recorded time per incident (seconds) | Number of incidents a year | Device Capacity (GB) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.155</td>
<td>30</td>
<td>100</td>
<td>21030</td>
</tr>
<tr>
<td>4.155</td>
<td>60</td>
<td>100</td>
<td>10515</td>
</tr>
<tr>
<td>4.155</td>
<td>90</td>
<td>100</td>
<td>7010</td>
</tr>
<tr>
<td>4.155</td>
<td>30</td>
<td>300</td>
<td>7010</td>
</tr>
<tr>
<td>4.155</td>
<td>60</td>
<td>300</td>
<td>3505</td>
</tr>
<tr>
<td>4.155</td>
<td>90</td>
<td>300</td>
<td>3505</td>
</tr>
<tr>
<td>4.155</td>
<td>30</td>
<td>600</td>
<td>2337</td>
</tr>
<tr>
<td>4.155</td>
<td>60</td>
<td>600</td>
<td>2337</td>
</tr>
<tr>
<td>4.155</td>
<td>90</td>
<td>600</td>
<td>1168</td>
</tr>
<tr>
<td>50</td>
<td>120</td>
<td>3000</td>
<td>15</td>
</tr>
</tbody>
</table>

#### Level 5

- NAND Flash endurance exceeds Level 5 estimate data rate and supports over 3000 incidents a year recorded 2 minutes each for >15 years
### Scenario 2: Continual Recording to NAND Flash

- Data written continuously directly to NAND flash storage
- NAND Flash endurance exceeds Level 5 estimate data rate and can support over 50Mbps for over 15 years

<table>
<thead>
<tr>
<th>Data Recorder - TB Written</th>
</tr>
</thead>
<tbody>
<tr>
<td>Write Amplification Factor: 1.5</td>
</tr>
<tr>
<td>Memory X3</td>
</tr>
<tr>
<td>P/E Cycles 100000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Card Capacity (GB)</th>
<th>5</th>
<th>10</th>
<th>19</th>
<th>39</th>
<th>78</th>
<th>155</th>
<th>303</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB Writes</td>
<td>316</td>
<td>631</td>
<td>1263</td>
<td>2525</td>
<td>5051</td>
<td>10101</td>
<td>19729</td>
</tr>
<tr>
<td>GB Writes</td>
<td>32322</td>
<td>64646</td>
<td>1292929</td>
<td>2585859</td>
<td>5171717</td>
<td>10343434</td>
<td>20202020</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Recorder - Expected Life (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recording Bit Rate (Mbps)</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Level 2</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>Level 5</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>90</td>
</tr>
</tbody>
</table>
Considerations for Storage

• What type of data is stored

• What is the data stream bit rate
  – Cameras the largest drivers with higher resolution frame rates increasing

• What frequencies and length of events if only events recorded (Scenario 1)

• How long events need to be available in on-board storage
  – 1 week, 1 month, 6 months?

Use cases matter
Questions
Embedded Storage Interface Evolution

*Increasing read/write speeds to storage*

- **eMMC v4.41** 104 MB/s
- **eMMC v4.5** 200 MB/s
- **eMMC v5.0** 400 MB/s
- **UFS v1.1** 720 MB/s
- **UFS v2.1** 1,440 MB/s
- **PCIe NVMe**
Overall Storage Requirements Changing

- Read/Write Intensive
- High Data retention
- Low to mid capacities
- Temperature not extreme
- Low performance

- Read/Write Intensive
- High data retention
- Mid to high capacities
- Extreme temperature
- High performance