Innovative Design Concepts for the Low-Cost Remote Sensing Satellites

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Timely natural disaster assessment by FORMOSAT-2
Why Innovation is important for Next Remote Sensing Satellites

• Lowering development cost
• Component availability
• Shortening the lead time
• Breaking technology barriers

Formosate-2 observes the disintegration Antarctic warming claims of breakdown of Ice Shelf
FORMOSAT-2, with 891 km SSO, is currently the unique satellite having capabilities to daily image anywhere worldwide.
Topics of Study

Working on the 2\textsuperscript{nd} remote sensing satellite with considering to establishing indigenous platform, investigation on new design concepts has been conducted, such as

- Orbit design
- High-speed image compression processor on FPGA
- Time Delay Integration
- Instrument Re-focusing
Orbit Selection Criteria

- Shorter revisit cycle
- Larger coverage areas
- More launcher candidates
- Low orbit maintenance need
- Lower orbit is good for smaller imaging instrument and development budget

Wish:
- Low orbit
- Daily revisit
- Global coverage

solution not exist
Mean Revisit Cycle @24 Deg Latitude

FOR=25 deg
FOR=30 deg
FOR=35 deg
FOR=45 deg

1.6 days
561km Sun Synchronous Orbit

Field-of-Regard 45 degree

It is daily revisit, but the global coverage is only 40%

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Revolutions per day</th>
<th>Repeat Cycle of Ground Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>561 km</td>
<td>15</td>
<td>Daily</td>
</tr>
<tr>
<td>666 km</td>
<td>14 2/3</td>
<td>Every 3 days</td>
</tr>
<tr>
<td>720 km</td>
<td>14 1/2</td>
<td>Every 2 days</td>
</tr>
<tr>
<td>891 km</td>
<td>14</td>
<td>Daily</td>
</tr>
</tbody>
</table>
561km WP Sun Sync Orbit

- Applying a perturbation (WP), altitude deviation, on the 561 km Sun Sync Orbit, the ground track will shift
  - westward for high perturbation, eastward vice versa
- The ground track will shift between west limit and east limit
- The more global coverage can be achieved
561km WP Global Coverage
Image Chain Architecture

Clock Driver
Pre-Amplifier

TDI 12000 pixel
CDS PGA ADC
Timing Generator
Power Converter

FPGA
Video Processing

FPGA
Compression/encryption

FPA IPU
High-Speed Image Compression Processor on non-space-qual FPGA

- The high-speed computation capability is very demanding for future remote sensing satellites
- ASIC processor is very expensive, difficult to acquire, and not expandable for future missions

<table>
<thead>
<tr>
<th>Calculation item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line rate</td>
<td>3300 lines per second</td>
</tr>
<tr>
<td>Pixel per channel</td>
<td>6000 pixels</td>
</tr>
<tr>
<td>Bits per pixel</td>
<td>12 bits</td>
</tr>
<tr>
<td>Bits per second</td>
<td>~ 240Mbits /sec</td>
</tr>
<tr>
<td>Throughput</td>
<td>120 ~ 240Mbps</td>
</tr>
</tbody>
</table>
Development Work

- Our development process of the high speed compression processor:
CCSDS 122.0 Std Selected

- CCSDS 122.0 standard, a highly advanced wavelet-tree–based algorithm, applying a 3-Level DWT, tailored to space imaging, quality equal to JPEG 2000
- Lower implementation complexity and budgets
- Optimized to line by line input data (pushbroom data)
- No image buffer required in front of the DWT
- compression at user defined constant data rates or image quality

From CCSDS 122.0 Green Book
Data Compression Performance

- Example: Compression by Embedded Encoding (CCSDS 122) at CR = 8 and CR = 32

From CCSDS 122.0 Green Book
## Choice of FPGA Platform

<table>
<thead>
<tr>
<th></th>
<th>RTAX-5 family</th>
<th>Virtex-4 QPRO or XQR2V</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Actel</td>
<td>Xilinx</td>
</tr>
<tr>
<td><strong>Single Event Upset</strong></td>
<td>SEU-hardened flip-flops (LET&gt;&gt;40) that employ built-in Triple Module Redundancy (TMR)</td>
<td>SEU Detection, Correction and Mitigation</td>
</tr>
<tr>
<td><strong>Radiation</strong></td>
<td>~ 200 Krad</td>
<td>&gt; 100 Krad</td>
</tr>
<tr>
<td><strong>Single Event Latch-Up</strong></td>
<td>Protected</td>
<td>Protected Anti-fuse</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Expensive</td>
<td>Cheap</td>
</tr>
<tr>
<td><strong>Gate-count</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

Virtex platform is selected
Partial Re-configuration (Virtex FPGA)

Partial re-configuration technology

• Repair single upsets in individual Frames
• No loss of service
• No functional disruptions
• Partial Configuration Cycles => 3.1μs

Readback Configuration ➔ Configuration data frame CRC check ➔ Correction
In-flight Instrument Re-focusing

- The in-flight re-focusing, commanding from ground, is to adjust the residual alignment error due to micro-setting, gravity release, vacuum, etc. for higher contrast quality.
- The smart material type re-focusing is proposed.
Time Delay Integration

• TDI imager can operate at extremely low light levels, thus relaxing the requirement for the larger size of aperture for camera.
• Signal level increases as the number of TDI stages increases
• The MTF (image quality), however, decreasing as the TDI stages increases
• The optimization is conducted.
MTF of Jitter Effect Image

- the current result of the wheel disturbance test, based on the small reaction wheel EM, as shown in following Figure. It can be expected, the trend of the large wheels will be likely similar.
- Roughly the 330 Hz and 160 Hz disturbance zoom are critical.

Note: imaging will right follow maneuver.
MTF calculations for these images are shown in the next slide.
TDI Simulation Images: MTF results

MTF original

MTF TDI—4 lines

MTF TDI—8 lines

MTF~0.14

MTF~0.135

MTF~0.12
Conclusion

• The concept of lowering cost doesn't mean the sacrifice of performance.
  ✓ It shall mean the more efficient ways of system design.
• The innovative design concepts have been seriously investigated.
• It will be appreciated for the chance to exchange experience
Launch Taiwan Space Program Into Higher Orbit And Beyond ....

Thank You for Your Attention