FleXLink
Multi-Gigabit Data
Downlink End-to-End Chain

WHITE PAPER: MAXIMIZING THROUGHPUT IN SATELLITE TO GROUND TRANSMISSIONS

SPACE SEGMENT
- TRANSMITTER
  - CODING + MODULATION
  - ACM
- HIGH POWER AMPLIFICATION
- ONBOARD ANTENNA
- UPLINK/TT&C RECEIVER

GROUND SEGMENT
- RECEIVER
  - DEMODULATOR + DECODER
  - ACM
- DISTRIBUTION
- PROCESSING
- UPLINK/TT&C TRANSMITTER
- ANTENNA + LNA

Tesat-Spacecom JUNE 2017 Kongsberg Spacetec
Executive Summary

Earth Observation (EO) and Intelligence, Surveillance and Reconnaissance (ISR) Systems equipped with Synthetic Aperture Radar (SAR) and/or High Resolution Optical instruments are designed for high-performance operations in terms of fast revisit time, for very short system response time and for providing actionable intelligence with low data latency. However, higher speeds and increasing bandwidth for data download are needed as the marketplace becomes more saturated and competitive with increasing numbers of satellites, from both commercial and government stakeholders. The increased reliance on this data for increasingly more urgent applications has created demand for decreasing latency, for all datasets, including Earth observation, radar, communication, and weather satellites.

A satellite system is mainly composed of two segments – space and ground – that are connected by an important and complex network of communications that enables efficient management of the operations and data. Each of these segments is important for the successful collection and distribution of the data towards creating the actionable intelligence and solutions that are greatly needed by society, academia and governments worldwide.

This paper shares details regarding a new data transmission solution to efficiently use the available radio frequency (RF) bandwidth most commonly used for downlink. A discussion of advantages compared to legacy systems is included. The solution includes a Gigabit Modulator (the Space Segment) and a High Rate Demodulator and Front-End Processor (HRDFEP, the Ground Segment), which when combined provide customers with a full End-to-End Solution for faster, more robust data downlinks.

The solution has been verified using engineering models. Key benefits include automated adaptability for varying RF link conditions; the amount of data automatically adjusts according to the link budget, maximizing throughput of data volume and speed.

The solution comes from two respected companies, Tesat-Spacecom (for the Space Segment) and Kongsberg Spacetec (for the Ground Segment).

Benefits of FleXLink
○ Maximizing Data Throughput
○ Minimized Latency of Data
○ Reduced Ground Station Contacts
○ High Spectrum Efficiency
○ High Transmit Power Efficiency
○ Verified Technology
○ A Reliable End-to-End Solution

The key technology is Adaptive Coding & Modulation (ACM) allowing the volume of data to adapt to link budget characteristics.
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Problem Statement

The amount of data being collected from satellites is extremely high and continually increasing, putting severe pressure on downlink providers. Contributing to the increases in data volume are increasing numbers of EO, ISR, SAR and communications satellites; the increasing resolution of the data from these satellites; and the increasing number of multiple-instrument missions. In addition, there is continued pressure for near real-time delivery and decreased latency.

The demand will continue to increase as higher-resolution next-generation sensors and the numbers of platforms proliferate in the coming years. For example, about 3,600 smallsats are predicted to launch in the next 10 years, according to a recent Euroconsult report, the majority for Earth observations.*

LIMITED FREQUENCY BANDS AVAILABLE

The limited amount of radio spectrum available has been an ongoing issue and the demand for it is insatiable. Traditionally, downlink systems have used the X-Band (8,025-8,400 MHz) due to its robustness regarding weather influences on the link budget (rain fade). However, the X-Band is bandwidth-limited, making high-order modulation schemes yielding to high bandwidth efficiency a very interesting technology. The upper Ka-Band (25.5-27 GHz) is an attractive alternative. It offers considerably more bandwidth, though it does suffer from rain fade.

LIMITED DATA RATES IN LEGACY SYSTEMS

The current limitation in fixed coding and modulation systems does not allow users to take advantage of higher data rates available during improved link conditions.

*Source: http://www.euroconsult-ec.com/7_July_2016
Proposed Technical Solution

2.1 FleXLink System Description

The FleXLink end-to-end solution transfers space-borne instrument data to the ground for processing, at maximized rates within a defined spectrum and power budget. Data is coded and modulated in space by the modulator and transmitted to ground in X- or Ka-Band through the high-power amplifier and the transmitter antenna.

On the ground, the receiver antenna will track the satellite. The demodulator will demodulate and decode the data, and regenerate instrument source packets. The demodulator measures received data quality. Data rate to ground is maximized by the Adaptive Coding and Modulation (ACM) uplink, making a closed loop system. At high propagation losses (long range, heavy rain, polluted atmosphere) and interference, the spacecraft’s modulator is commanded to use more robust modulation and coding, ensuring error-free data, although at a lower rate.

Similarly, higher order modulation and code rates are selected under good receive conditions, resulting in a higher data rate to the ground while maintaining error-free data quality, and still within the same spectrum and transmit power budget.

FleXLink SYSTEM ARCHITECTURE
IMPROVED DATA RATES WITH FleXLink

With FleXLink, adaptive coding and modulation allows the data rate to adapt to varying link conditions and allows users to maximize data throughput.

Adaptive Coding & Modulation
4 min @ 2 Gbps
3 min @ 1.6 Gbps
2 min @ 1.3 Gbps
1 min @ 1 Gbps

Switches to 8-PSK When Link Improves

Transmission Starts with Most Robust Modulation QPSK

Transmitted Data Volume >120 Gbyte

Data Transmission Volume Increasing to >120 Gigabytes with FleXLink

The Gigabit Modulator as the core part of the system on board the satellite is designed for a maximum output symbol rate of 500 MBaud. It is equipped with redundant high-speed serial links enabling a maximum user input data rate of 2000 Megabits per Second (Mbps). The modulated signal is digitally predistorted in order to compensate for the non-linearity of the subsequent Travelling Wave Tube Amplifier (TWTA) or Solid State Power Amplifier (SSPA), which is essential for the high-order modulation scheme. Full qualification of the modulator will be achieved in the beginning of 2018.

The High Rate Demodulator and Front End Processor (HRDFEP) are perfectly suited as the counterpart to the Gigabit Modulator described above. The unit includes the full set of ACM/VCM modes like the modulator. Excellent performance near the Shannon Bound is achieved with high-performance SCCC decoding utilizing the latest high-end FPGA technology.
ADAPTIVE TECHNIQUES FOR VARYING LINK BUDGET CONDITIONS

The Ka-Band suffers from higher rain fade and thus benefits from the adaptive or variable coding and modulation schemes provided by FleXLink. This allows maximizing the throughput without keeping large margins in the link budget.

Adapting to varying link conditions by switching between modulation and coding schemes maximizes data throughput as illustrated in the following figures, with the signal to noise ratio (SNR) on the left (vertical axis).

Enhanced Data Throughput

SOLUTION BASED ON WELL ESTABLISHED SPACE INDUSTRY STANDARDS

The Consultative Committee for Space Data Systems (CCSDS) outlined challenges in 2012, which issued a recommendation aiming at exactly this kind of high-rate applications. The usage of the CCSDS 131.2.B.1 waveforms combines Serial Concatenated Convolutional Codes (SCCC) and higher order modulation formats allowing adaptation of the transmission parameters to the channel conditions during a satellite-to-ground contact by means of Variable and Adaptive Coding and Modulation (VCM/ACM), and thus enables the user to maximize the downlink data capacity per fly-over.

VERIFIED END-TO-END PERFORMANCE

Furthermore, end-to-end compatibility and cutting-edge performance have been verified on an Engineering Model (EM)/prototype with a realistic end-to-end hardware test performed in the development labs. This set up included the nonlinear amplification of a space-type TWTA including the required predistortion technique for linearization of the channel.
LEGACY DATA RATES VS. FleXLink DATA RATES

Legacy systems employ solutions in X-Band or solutions in Ka-Band with limited rates.

<table>
<thead>
<tr>
<th>Modulation Scheme</th>
<th>Band</th>
<th>Architecture</th>
<th>Antenna Polarization</th>
<th>Data Rate [Mbps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>X</td>
<td>1 Channel</td>
<td>Single</td>
<td>250</td>
</tr>
<tr>
<td>8-PSK</td>
<td>X</td>
<td>1 Channel</td>
<td>Single</td>
<td>500</td>
</tr>
<tr>
<td>QPSK</td>
<td>Ka</td>
<td>2 Channels (adjacent)</td>
<td>Single</td>
<td>900</td>
</tr>
</tbody>
</table>

FleXLink offers waveforms with high-spectral efficiency. It allows the use of dual polarization antennas in X-Band, and two channels in both X-Band and Ka-Band.

<table>
<thead>
<tr>
<th>Modulation Scheme</th>
<th>Band</th>
<th>Architecture</th>
<th>Antenna Polarization</th>
<th>Data Rate [Mbps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-APSK</td>
<td>X</td>
<td>1 Channel</td>
<td>Single</td>
<td>1200</td>
</tr>
<tr>
<td>64-APSK</td>
<td>X</td>
<td>2 Channels</td>
<td>Dual</td>
<td>2400</td>
</tr>
<tr>
<td>32-APSK</td>
<td>Ka</td>
<td>1 Channel</td>
<td>Single</td>
<td>2000</td>
</tr>
<tr>
<td>32-APSK</td>
<td>Ka</td>
<td>2 Channels (adjacent)</td>
<td>Single</td>
<td>4000</td>
</tr>
</tbody>
</table>

In this example application, the data downlink volume increases from 75 Gigabytes in the legacy solution to >120 Gigabytes in the FleXLink solution.

2.1.1 FleXLink Space Segment

2.1.1.1 Overview

The Gigabit Modulator, as the heart of the space segment of FleXLink, offers a ground-breaking solution for high-speed data transmission from space to ground. Cutting-edge technology like signal predistortion for amplification over a nonlinear space type RF power amplifier has been successfully demonstrated.

The modulator design consists of the following sections:

- Interface Section including the input data and TM/TC interfaces and configuration parameter setting;
- ModCod Section performing coding, modulation, predistortion and digital-to-analog conversion;
- RF Section serving for modulation in X-Band and optional up-conversion to Ka-Band;
- DC/DC Section for generation of the secondary supply voltage from the satellite bus voltage.
Full EM Assembly including DC/DC Converter (DC Side / RF Side)

- All transmission parameters including modulation and coding and predistortion coefficients can be controlled via serial TM/TC interface techniques.
- Nonlinear predistortion compensates for travelling wave tube nonlinearity.

**Static Linear Predistortion**

*Received Constellation, not Linearised*

*With Static Linear Predistortion OBO = 3 dB*

**Effect of Linearization by Predistortion**
2.1.1.2 Space Segment Architectures

The Gigabit Modulator is ideally suited for advanced data downlink subsystems in X-Band and Ka-Band employed onboard Earth Observation Satellites and Scientific Missions.

It offers the following benefits:

- Increased throughput by variable or adaptive coding and modulation.
- Integrated predistorter allows utilization of high order modulation scheme and optimization of amplifier back-off in combination with both TWTAs and SSPAs.
- Very flexible design in terms of:
  - Modulation and coding scheme (27 different schemes);
  - Data Rate and Symbol Rate which are adaptable in a large range;
  - Output frequency (5 MHz step size either in X- or Ka-Band).

The figure below shows a 2-out-of-3 redundancy design that allows achieving a data rate of up to 4000 Mbit/s over 2 active channels in Ka-Band depending on the chosen modulation and coding scheme.
A comparable architecture allows achieving up to 2400 Mbit/s in X-Band when employing a dual polarization antenna concept with 2 active channels.

Dual Polarization Architecture in X-Band with up to 2400 Mbit/s

2.1.2 FleXLink Ground Segment

2.1.2.1 Overview

MEOS® Capture HRDFEP is a complete receiver solution for satellite data capture and processing in the ground segment. The HRDFEP Max model supports Ka-Band and the very efficient FleXLink, offering the highest data rates by utilizing the CCSDS SCCC protocol.

The HRDFEP Max offers automated operation, fast data processing and detailed status reporting. Its most vital properties are its high reliability and usability, and very low implementation losses. The current HRDFEP model has been sold worldwide and is used by numerous commercial companies and government customers.

The HRDFEP SCCC fully supports the CCSDS SCCC protocol, including all 27 combinations of modulation and coding. It is designed to provide robust, efficient data capture even at very high data rates.
The unit consists of the following main functional blocks:
- RF FleXLink input section with interface to ground station antenna downconverter;
- SCCC demodulator, adaptive equalizer and SCCC decoder;
- Front End Processor (FEP) with CCDSS processing up to Instrument Source Packs (ISP) level;
- Data buffering and storage with Rolling Archive (RA) automatic storage space management;
- Data distribution section: Near real-time (NRT) and offline, streaming and file-based;
- Space Link Extension (SLE) data distribution protocol;
- Extensive quality reporting and statistics database;
- Monitoring and control system for local and remote operation, manual and automatic operational modes;
- Local and remote GUI / MMI / HMI;
- Redundant hot swap disks and redundant power supply configured for optimal availability.

2.1.2.2 Ground Segment Architecture

![HRDFEP MAX](image)

Figure 2.1: MEOS Capture HRDFEP Functional Block

The MEOS® Capture HRDFEP provides 2 independent receiver channels for CCSDS SCCC / FleXLink and legacy satellite downlinks. Both channels are configured to support a wide range of satellites and downlink characteristics.

Following demodulation of symbols to a bit stream, data is decoded using the SCCC, LDPC or legacy Reed-Solomon decoders. Frame synchronization, VCDU time & status tagging and ingestion to disk files are performed by the FEP blocks. Ingested VCDU data is handled in a Rolling Archive circular data storage. The RA management system frees up disk space by deleting the oldest data as needed. The ISP Processor blocks generate Instrument Source Packs (ISPs), also known as APs, from the VCDU files. The generated ISP files are stored in a separate Rolling Archive data storage.

Output data is distributed to the user by near real-time or offline data distribution. Near real-time distribution is TCP/IP-based and includes TCP socket with rate control, as well as Space Link Extension (SLE). Offline distribution is file-based and includes FTP, SFTP and FTPS.
2.1.2.3 Space Link Extension

The main task of the satellite downlink is to transmit data from the satellite’s storage to ground. The ground station must then transmit the data further to a data processing center via the ground network. This second transfer represents an extension of the downlink, and completes the transfer of satellite data to the processing system’s input data buffer. Timely, robust and efficient data delivery is crucial for total system performance and reliability.

CCSDS has developed a standard for transmission of VCDUs, which is called Space Link Extension (SLE). Utilizing this standard means that networks of ground stations and data processing facilities can transfer and share data seamlessly.

MEOS® Capture HRDFEP supports the SLE standard as one out of several protocols for NRT or offline data distribution. The data user can retrieve data from the HRDFEP using User Initiated Binding (UIB), typically used for scheduled ground system solutions. The HRDFEP can also push data to the user by utilizing Provider Initiated Binding (PIB), which is very useful for autonomous (data driven) operation.

The efficiency of the HRDFEP’s SLE implementation introduces only a small network overhead, allowing it to transfer data at rates close to the effective network capacity. The HRDFEP also supports file-based transfers of data directly at the Instrument Source Packet level.
Applications of FleXLink

The most critical applications for which FleXLink are best suited are those that require minimum data latency after acquisition, and extremely high bandwidth. These include, but are not limited to:

- Change and object detection;
- Critical infrastructure, sites, events and assets monitoring;
- Damage assessment;
- Disaster management;
- Environmental monitoring;
- Image intelligence;
- Oil spill detection and monitoring;
- Open ocean surveillance (ship detection, illegal fishing, smuggling);
- Sea port monitoring;
- Surface movement monitoring;
- Topographic and thematic mapping.

As data requirements increase in these areas, the need to receive the data in actionable time (15-30 minutes) becomes more prevalent. Currently many of these data latency requirements are not being met. FleXLink will enable satellite operators to meet these data latency requirements.

In short, FleXLink will enable Satellite Operators, in the Earth Observation realm, to:

- Enhance resilience of systems and capabilities;
- Improve persistence of information in key areas of interest (AOIs);
- Provide near real-time GEOINT information.
Conclusion

FleXLink offers an end-to-end solution that provides a multi-gigabit data downlink rate – ideal for companies with the higher data demands of EO, SAR, and ISR. FleXLink provides maximized transmission time in a fly-by of LEO orbiting satellites.

Although ACM technology has been available for a few years, most legacy systems are data-rate limited. FleXLink now offers ground-breaking data rates.

Data latency has been an issue for many years, as “near real-time” meant in the past that the Earth Observation data would be delayed due to downlink capacity. With FleXLink the term “near real-time” will become a reality.

The innovative adaptive coding and modulation of FleXLink allows the most efficient use of available bandwidth in X-Band and also migration to Ka- and higher bands. This, together with the lowest implementation losses, provides maximized data volume to ground within the satellite transmit power budget.

The performance of this solution has been verified with an engineering model in an end-to-end test setup. The equipment will be space qualified and available early 2018.

FleXLink provides satellite data providers with a way to relieve the pressure to quickly get all their data to ground, which has haunted them for many years, by partnering with two companies that are well established. The suppliers of FleXLink, Tesat-Spacecom and Kongsberg Spacetec, understand the data and timeliness demands of the remote sensing sectors, and stand best positioned to meet their needs.

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Annex

6.1 Verified Performance and Specifications

6.1.1 Measurements of Complete End-to-End System

An extensive measurement campaign of the engineering model has been performed demonstrating the data-rate capability and the high performance of the encoding and modulation algorithms. These tests have been performed using the prototype ground station receiver mentioned above.

Within the EM test campaign, measurements of the performance for the transmit chain have also been conducted, including a space-type high-power amplifier (TWTA) in Ka-Band. The figure below shows the measurement setup.
Digital predistortion for linearization of the amplification chain is one key feature that enables high-order modulation.

The following figures show the constellation diagrams for a 64-APSK modulated X-Band signal at the maximum output symbol rate of 500 MBaud in a comparison with and without nonlinear amplification:

![Constellation Diagrams](image)

**Measurement Results of End-to-End System in Real Operation**

Very low signal degradation shows the excellent performance of the predistortion; note that the system is operating at an output backoff of only 2.8 dB!

The following figure shows bit error rate measurement results for one adaptive coding and modulation (ACM) scheme for each modulation order (QPSK, 8PSK, 16/32/64-APSK) at 500 MBaud symbol rate. It includes results for simulated values without signal degradation (“Theory”); measured values for the modulator and demodulator (“Mod & Demod”); and measured values for the complete End-to-End Chain (“E2E Chain”) with modulator, TWTA and demodulator.
Tesat Spacecom has developed the Flexible Gigabit Modulator for next-generation data downlink systems that feature operation in both X-Band and Ka-Band and at the same time allows to adaptively switch between 27 modulation and coding schemes (ModCods). These ModCods are based on ground-breaking Serial Concatenated Convolutional Codes (SCCC) that yield much higher performance than legacy Forward Error Correction (FEC) schemes.

This equipment allows transmission of up to 1200 Mbit/s in X-Band and 2000 Mbit/s in Ka-Band using high order modulation schemes (16/32/64-APSK).

Additionally, it features:

- Legacy modulation schemes QPSK & 8-PSK.
  - Full compliance to all ACM/VCM modes with SCCC coding according to CCSDS standards.
  - Redundant high-speed serial links enabling a maximum user input data rate of 2 Gbps.

- Digital predistortion for linearization based on post-HPA feedback loop.

Kongsberg Spacetec has developed the MEOS® Capture HRDFEP for current and future satellite downlinks. The unit is fully compatible with the modulator.

Main features include:

- Full compliance with the 27 ModCods mentioned above.
- Additionally supports legacy modulation and coding schemes (B-PSK; QPSK, 8-PSK, 16-QAM).
- Close to Shannon limit performance.
- Adaptive downlink impairment equalizer.
- Inpass and postpass quality reporting.
6.1.2.1 Space Segment

The electrical and mechanical design of the High Data Rate Modulator has been established and successfully verified with an EM. Finalization of qualification is ongoing and will be concluded in Q1/2018.

### Table 6.1.2.1 Demodulator Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Link Characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encoding</td>
<td>SCCC according to CCSDS 131.2.B.1</td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 8-PSK, 16-APSK, 32-APSK, 64-APSK</td>
<td>according to CCSDS 131.2.B.1</td>
</tr>
<tr>
<td>Physical layer framing</td>
<td>according to CCSDS 131.2.B.1</td>
<td></td>
</tr>
<tr>
<td>Roll-off</td>
<td>0.2, 0.25, 0.3, 0.35</td>
<td></td>
</tr>
<tr>
<td>Predistortion</td>
<td>5th order polynomial predistorter</td>
<td></td>
</tr>
<tr>
<td>Output symbol rate</td>
<td>10 ... 500 MBaud</td>
<td></td>
</tr>
<tr>
<td><strong>RF Signal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrier frequency range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-Band version</td>
<td>8.025 ... 8.4 GHz</td>
<td></td>
</tr>
<tr>
<td>Ka-Band version</td>
<td>25.5 ... 27 GHz</td>
<td></td>
</tr>
<tr>
<td>Phase Noise</td>
<td>&lt; 1 °rms (10 kHz to 250 MHz)</td>
<td></td>
</tr>
<tr>
<td><strong>Budgets</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td>30 W</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>2.5 kg</td>
<td></td>
</tr>
<tr>
<td><strong>Operational Characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>&lt; 1200 FIT</td>
<td></td>
</tr>
<tr>
<td>Lifetime</td>
<td>15 years</td>
<td></td>
</tr>
<tr>
<td><strong>User Data Interface</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical layer</td>
<td>Bidirectional link using TKL2711-SP (WizardLink)</td>
<td></td>
</tr>
<tr>
<td>Net user data rate</td>
<td>2 Gbit/s</td>
<td></td>
</tr>
<tr>
<td>Redundancy</td>
<td>Redundant signals and connectors</td>
<td></td>
</tr>
<tr>
<td><strong>TM/TC Interfaces</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serial TM/TC interface</td>
<td>BSD according to ECSS-E-ST-50-14C</td>
<td>Read&amp;Write of configuration parameters (details on request)</td>
</tr>
<tr>
<td>for all transmission parameters including modulation &amp; coding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-level commands</td>
<td>LV-HV according to ECSS-E-ST-50-14C</td>
<td>Modulator ON/OFF</td>
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<tr>
<td>Bi-level telemetry</td>
<td>BDM according to ECSS-E-ST-50-14C</td>
<td>ON/OFF telemetry</td>
</tr>
<tr>
<td>Redundancy</td>
<td>Redundant signals and connectors</td>
<td></td>
</tr>
<tr>
<td><strong>Power Bus Interface</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus Voltage</td>
<td>21 ... 38 V</td>
<td>Options: 50 V, 100 V</td>
</tr>
</tbody>
</table>

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6.1.2.2 Ground Segment

The High Rate Demodulator & Front End Processor (HRDFEP) developed by Kongsberg Spaceteck is perfectly suited as the counterpart to the Gigabit Modulator from Tesat. The unit includes the full set of ACM modes like the modulator.

Table 6.1.2.2 MEOS Capture HRDFEP External Interfaces

<table>
<thead>
<tr>
<th>Interface</th>
<th>Type</th>
<th>Physical</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF1 / IF2</td>
<td>Analogue IF input signal</td>
<td>2 Channels</td>
<td>FlexLink input signal</td>
</tr>
<tr>
<td>Clk/Data</td>
<td>Baseband data inputs</td>
<td>ECL, LVDS</td>
<td>Baseband input data</td>
</tr>
<tr>
<td>Data</td>
<td>TCP/IP</td>
<td>Ethernet / RJ45</td>
<td>Distributed output data</td>
</tr>
<tr>
<td>M&amp;C</td>
<td>TCP/IP</td>
<td>Ethernet / RJ45</td>
<td>Scheduling, Monitoring &amp; Control</td>
</tr>
<tr>
<td>Time</td>
<td>NTP, PTP, IRIG-B</td>
<td>Ethernet / IRIG-B</td>
<td>System time synchronization, data time tagging</td>
</tr>
</tbody>
</table>

Table 6.1.2.3 MEOS Capture HRDFEP Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demodulator (HRD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Symbol Rate</td>
<td>1 ... 500 MBaud</td>
<td></td>
</tr>
<tr>
<td>Net User Data rate</td>
<td>2.6 Gbit/s per channel</td>
<td></td>
</tr>
<tr>
<td>Modulation for CCSDS 131.2.B.1</td>
<td>QPSK, 8-PSK, 16-APSK, 32-APSK, 64-APSK</td>
<td></td>
</tr>
<tr>
<td>Legacy Modulation</td>
<td>BPSK, CBPSK, QPSK, OQPSK, 1/2 UQPSK, 1/4 UQPSK, 1/8 UQPSK, 8PSK, 16QAM</td>
<td></td>
</tr>
<tr>
<td>IF Frequency</td>
<td>720, 1200MHz</td>
<td></td>
</tr>
<tr>
<td>Roll-off</td>
<td>0.2, 0.25, 0.3, 0.35 for SCCC</td>
<td>0.2 – 1 for legacy modulations</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>-5 dBm to -50 dBm</td>
<td></td>
</tr>
<tr>
<td>Doppler on Carrier</td>
<td>1500 kHz</td>
<td></td>
</tr>
<tr>
<td>Max Carrier Doppler Rate</td>
<td>100 kHz/s</td>
<td></td>
</tr>
<tr>
<td>VSWR</td>
<td>&lt; 1.5</td>
<td></td>
</tr>
<tr>
<td>Equalization</td>
<td>Adaptive equalizer</td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>10 MHz or 100 MHz</td>
<td></td>
</tr>
<tr>
<td>Front-End Processor (FEP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame synchronization</td>
<td>CCSDS AOS/PT, TDM</td>
<td></td>
</tr>
<tr>
<td>Forward Error Correction / Detection</td>
<td>SCCC Turbo codes, LDPC 7/8, LDPC DVB-S2, R-S (255, 239), R-S (255, 223), CRC checking</td>
<td></td>
</tr>
<tr>
<td>Frame Appending</td>
<td>Frame sync status, Reed-Solomon status, Time-stamping</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
<td>Remark</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCDU</td>
<td>Splitting and sorting of VCDUs</td>
<td></td>
</tr>
<tr>
<td>ISP (AP)</td>
<td>ISP (AP) service processing</td>
<td></td>
</tr>
<tr>
<td>CFDP</td>
<td>CCSDS File Delivery Protocol, Class 1 &amp; 2</td>
<td></td>
</tr>
<tr>
<td><strong>Distribution</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near Real-Time</td>
<td>TCP socket with rate control</td>
<td>Compression, encryption, XML meta data, checksums</td>
</tr>
<tr>
<td>Post Pass File Transfer</td>
<td>FTP, SFTP, FTPS</td>
<td></td>
</tr>
<tr>
<td>CCSDS Space Link Extension (SLE)</td>
<td>RAF, RCF</td>
<td>PIB, UIB</td>
</tr>
<tr>
<td></td>
<td>Online Complete, Online Timely</td>
<td></td>
</tr>
<tr>
<td><strong>Automatic Storage Management</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA Administration</td>
<td>Deletion of oldest data</td>
<td></td>
</tr>
<tr>
<td>Data Locking</td>
<td>Data can be manually locked</td>
<td></td>
</tr>
<tr>
<td><strong>Baseband Data Inputs / Outputs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channels</td>
<td>2 x serial clock/data, separate or merged (I+Q) data</td>
<td>Polarity &amp; phase adjustments</td>
</tr>
<tr>
<td>Electrical</td>
<td>Differential ECL</td>
<td>LVDS</td>
</tr>
<tr>
<td><strong>Special Features</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BER Tester</td>
<td>Four selectable standard polynomials</td>
<td></td>
</tr>
<tr>
<td>Data Pattern Generator</td>
<td>Frame generator</td>
<td>PN generator</td>
</tr>
<tr>
<td>Report</td>
<td>Status report file generation</td>
<td></td>
</tr>
<tr>
<td><strong>Operational Mode</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autonomous (Data Driven)</td>
<td>Preset mission</td>
<td>Automatic mission detection</td>
</tr>
<tr>
<td>Automatic Commanding</td>
<td>Automatic generation of sat / contact list</td>
<td></td>
</tr>
<tr>
<td>Manual Commanding</td>
<td>Commanding via GUI or SW API</td>
<td></td>
</tr>
<tr>
<td>Scheduling</td>
<td>Commanding via schedule file</td>
<td></td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height x Width x Depth (cm)</td>
<td>21.8 x 48.26 x 73.22</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>Approximately 40 kg</td>
<td>Depends on disk configuration etc.</td>
</tr>
<tr>
<td>Power</td>
<td>100-240 volts, 50-60 Hz</td>
<td>&lt;700W</td>
</tr>
<tr>
<td>Operational Temperature</td>
<td>10°C to 35°C</td>
<td></td>
</tr>
<tr>
<td>Operational Relative Humidity</td>
<td>10-90%</td>
<td></td>
</tr>
</tbody>
</table>
6.1.3 Additional High-End Application: Optical/RF Relay Payloads

Another field of application is optical/RF data relay payloads that also benefit from the bandwidth and power-efficient modulation and coding schemes.

**Principle Relay Payload Concept**

Relay Payloads allow longer contact times and therefore enable near real-time Earth Observation missions. This principle is shown in the following sketch:

**Data Relay Transmission in Comparison to Direct Transmission to Ground**

6.2 Heritage

6.2.1 Tesat-Spacecom Heritage

Tesat-Spacecom has delivered approximately 120 modulators in X-Band and Ka-Band for both commercial and institutional markets in the last 15 years for:

- Earth observation missions
- Scientific missions (e.g. constellations for meteorological applications)
- Near Earth and deep space missions
- RF/optical relay payloads
Currently, Tesat is involved in multiple ongoing hardware projects for meteorological, scientific and commercial missions with more than 50 modulators to be delivered in the coming 5 years.

Examples of Downlink Systems Including Tesat Modulators

6.2.2 Kongsberg Spacetec Heritage
Kongsberg Spacetec (KSTP) has 10 years of heritage providing more than 150 demodulators to ground stations and satellite checkout systems:

- Earth observation missions
- Scientific missions (e.g. constellations for meteorological applications)
- Meteorological satellite receiving stations

KSPT is currently involved in projects related to ground networks for new satellite missions for ESA, Eumetsat, NOAA and NASA. Also, private ground networks are provided for commercial service providers.

An important area of development is high-rate ground stations involving Ka-Band antennas, receivers, and control systems, including systems that use the entire available Ka-Band spectrum of 1.5 GHz.

7 Survey
Please provide feedback via this survey: http://bit.ly/FleXLinkSurvey

8 Contacts
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