# COMMAND RANGING & TELEMETRY UNIT

## CORTEX CRT Quantum

### CRT QUANTUM USER’S MANUAL

**DTU 100042**

### EVOLUTIONS

<table>
<thead>
<tr>
<th>Is.</th>
<th>Rev.</th>
<th>Date</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>X</td>
<td>May 1998 to April 2001</td>
<td>6-U CRT-NT units with Windows NT OS</td>
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<tr>
<td>2</td>
<td>X</td>
<td>Jan. 2002 to Mar. 2003</td>
<td>4-U CRT-NT units with Windows NT OS</td>
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<tr>
<td>4</td>
<td>X</td>
<td>June 2008 to …</td>
<td>CRT DS with Windows XPe</td>
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<tr>
<td>5</td>
<td>0</td>
<td>January 27, 2012</td>
<td>CRT Quantum with Windows 7e</td>
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ACRONYMS & ABBREVIATIONS

SYMBOLS:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>Percent</td>
</tr>
<tr>
<td>±</td>
<td>Plus or minus</td>
</tr>
<tr>
<td>≥</td>
<td>Greater than or equal</td>
</tr>
<tr>
<td>≤</td>
<td>Less than or equal</td>
</tr>
<tr>
<td>&amp;</td>
<td>And</td>
</tr>
<tr>
<td>≅</td>
<td>Approximately</td>
</tr>
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</table>

PREFIXES:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Nano-</td>
</tr>
<tr>
<td>µ</td>
<td>Micro-</td>
</tr>
<tr>
<td>m</td>
<td>Milli-</td>
</tr>
<tr>
<td>k</td>
<td>Kilo-</td>
</tr>
<tr>
<td>M</td>
<td>Mega-</td>
</tr>
<tr>
<td>G</td>
<td>Giga-</td>
</tr>
</tbody>
</table>

UNITS:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ampere</td>
</tr>
<tr>
<td>b</td>
<td>Byte</td>
</tr>
<tr>
<td>bps</td>
<td>Bit per second</td>
</tr>
<tr>
<td>C</td>
<td>Celsius</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
</tr>
<tr>
<td>F</td>
<td>Farad</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>rpm</td>
<td>revolutions per minute</td>
</tr>
<tr>
<td>Ω</td>
<td>Ohms</td>
</tr>
<tr>
<td>s</td>
<td>Second</td>
</tr>
<tr>
<td>sps</td>
<td>Symbol per second</td>
</tr>
<tr>
<td>s/s</td>
<td>Sample per second (ks/s, Ms/s,....)</td>
</tr>
<tr>
<td>V</td>
<td>Volt</td>
</tr>
</tbody>
</table>
### ABBREVIATIONS:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>Applicable Document</td>
</tr>
<tr>
<td>AGC</td>
<td>Automatic Gain Control</td>
</tr>
<tr>
<td>AM</td>
<td>Amplitude Modulation</td>
</tr>
<tr>
<td>AQPSK</td>
<td>Asynchronous Quadrature Phase Shift Keying</td>
</tr>
<tr>
<td>ASB</td>
<td>Anti Side Band</td>
</tr>
<tr>
<td>ASCII</td>
<td>American Standard Code for Information Interchange</td>
</tr>
<tr>
<td>BB</td>
<td>BaseBand</td>
</tr>
<tr>
<td>BER</td>
<td>Bit Error Rate</td>
</tr>
<tr>
<td>BP-L/M/S</td>
<td>BiPhase-Level/Mark/Space</td>
</tr>
<tr>
<td>BPSK</td>
<td>Binary Phase Shift Keying</td>
</tr>
<tr>
<td>BTs</td>
<td>Bandwidth Filter per Symbol Period</td>
</tr>
<tr>
<td>BW</td>
<td>BandWidth</td>
</tr>
<tr>
<td>CADU</td>
<td>Channel Access Data Unit</td>
</tr>
<tr>
<td>CLCW</td>
<td>Command Link Control Word</td>
</tr>
<tr>
<td>CLK</td>
<td>Clock</td>
</tr>
<tr>
<td>CNR</td>
<td>Carrier to Noise Ratio</td>
</tr>
<tr>
<td>COP</td>
<td>Command Operation Procedure</td>
</tr>
<tr>
<td>CPFSK</td>
<td>Continuous Phase Frequency Shift Keying</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>CTL</td>
<td>Check To Lock</td>
</tr>
<tr>
<td>dBc</td>
<td>dB with respect to the un-modulated carrier</td>
</tr>
<tr>
<td>DBP-L/M/S</td>
<td>Differential Bi-Phase-Level/Mark/Space</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DCU</td>
<td>Diversity Combining Unit</td>
</tr>
<tr>
<td>DM-M/S</td>
<td>Delay Modulation – Mark / Space (Miller code)</td>
</tr>
<tr>
<td>DQPSK</td>
<td>Differential Quadrature Phase Shift Keying</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital Signal Processor</td>
</tr>
<tr>
<td>D/C</td>
<td>frequency Down Converter</td>
</tr>
<tr>
<td>FFT</td>
<td>Fast Fourier Transform</td>
</tr>
<tr>
<td>FM</td>
<td>Frequency Modulation</td>
</tr>
<tr>
<td>FSK</td>
<td>Frequency Shift Keying</td>
</tr>
<tr>
<td>GMSK</td>
<td>Gaussian Minimum Shift Keying</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HBW</td>
<td>High BandWidth</td>
</tr>
<tr>
<td>IF</td>
<td>Intermediate Frequency</td>
</tr>
<tr>
<td>IFM</td>
<td>IF Modulator</td>
</tr>
<tr>
<td>I/F</td>
<td>Interface</td>
</tr>
<tr>
<td>I/O</td>
<td>Input/Output</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LBW</td>
<td>Low BandWidth</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
</tr>
<tr>
<td>LEOP</td>
<td>Launch &amp; Early Orbit Support</td>
</tr>
<tr>
<td>LO</td>
<td>Local Oscillator</td>
</tr>
<tr>
<td>LSB</td>
<td>Least Significant Byte (Bit)</td>
</tr>
</tbody>
</table>
LTS  Lock To Search
MCS  Monitoring & Control Software
MMI  Man Machine Interface
MSB  Most Significant Byte (Bit)
MSP  Main Signal Processing module
MTDI Multiple Tabbed Document Interface
M&C  Monitoring & Control
NA   Not Applicable
NCO  Numerically Controlled Oscillator
NRZ-L/M/S Non Return to Zero-Level/Mark/Space
OQPSK  Offset Quadrature Phase Shift Keying (also called SQPSK)
PC   Personal Computer
PCM  Pulse Coded Modulation
PLL  Phase Locked Loop
PM   Phase Modulation
PMR  PM Receiver
pp   Peak to peak
PRBS Pseudo Random Bit Sequence
PS   Power Supply
PSK  Phase Shift Keying
QPSK  Quadrature Phase Shift Keying
RAU  Ranging Unit
RF   Radio Frequency
RMS  Root Mean Square
RNG  RaNGing
RNRZ-L/M/S Randomized Non Return to Zero-Level/Mark/Space
R-S  Reed Solomon
SCC  Satellite Control Center
SLE  Space Link Extension
SOQPSK Shaped Offset Quadrature Phase Shift Keying
SPS  Signal Processing Software
SQPSK Staggered Quadrature Phase Shift Keying (see OQPSK)
SNR  Signal to Noise Ratio
TC  TeleCommand
TCP/IP Transport Control Protocol / Internet Protocol
TCR  Time Code Reader & Generator
TCU  Telecommand Unit
TM   TeleMetry
TMS  TeleMetry Simulator
TMU  TeleMetry Unit
TVU  TC Verification Unit
UQPSK Unbalanced Quadrature Phase Shift Keying
UTC  Universal Time, Coordinated
U/C  frequency Up Converter
Vpp  Volt Peak to Peak
VCDU  Virtual Channel Data Unit
VDU   Video Display Unit
VSWR  Voltage Standing Wave Ratio
WAN   Wide Area Network
CAUTION

CAUTION
RISK OF ELECTRICAL SHOCK
DO NOT OPEN

CAUTION: TO REDUCE THE RISK OF ELECTRIC SHOCK,
DO NOT REMOVE COVER (OR BACK).
REFER SERVICING TO QUALIFIED PERSONNEL.

LEGEND

The exclamation point within an equilateral triangle is intended to alert the user to the presence of important operating and maintenance (servicing) instructions in the literature accompanying the product.

The lightning flash with an arrowhead symbol within an equilateral triangle, is intended to alert the user to the presence of uninsulated ‘dangerous voltage’ within the product’s enclosure that may be of sufficient magnitude to constitute a risk of electric shock to persons.
IMPORTANT SAFETY INSTRUCTIONS

This product is designed and manufactured to meet strict quality and safety standards (conformity to “EN 60950:2002 standard: Safety of information technology equipment.

However, you should be aware of the following installation and operation precautions:

Take heed of warning and instructions

You should read all the safety and operating instructions before operating this apparatus. Retain this handbook for future reference and adhere to all warnings in the handbook or on the apparatus.

Water and moisture

To reduce the risk of fire or electric shock, do not expose this apparatus to rain or moisture. The presence of electricity near water can be dangerous. Do not use the apparatus near water.

Object or liquid entry

Take care that objects do not fall and liquids are not spilled into the product chassis through any openings.

Installation

Ensure that the product chassis ventilation is not impeded. Do not block any ventilation openings. Install in accordance with the manufacturer’s instructions.

Cleaning

Unplug the unit before cleaning. Clean only with dry cloth. This product should normally only require a wipe with a soft, damp, lint-free cloth. Do not use paint thinner or other chemical solvents for cleaning.
Opening of the product chassis

TO REDUCE THE RISK OF ELECTRIC SHOCK, DO NOT REMOVE COVER (OR BACK).

NO USER SERVICEABLE PARTS INSIDE; THE PRODUCT CHASSIS SHOULD ONLY BE OPENED BY QUALIFIED PERSONNEL FOR MAINTENANCE PURPOSE (EXCEPT FOR OPPOSITE INSTRUCTIONS IN THE USER’S MANUAL).

Technical Maintenance

Refer all servicing to qualified maintenance personnel. Servicing is required when apparatus has been damaged in any way, such as power supply cord is damaged, liquid has been spilled or objects have fallen into the apparatus, the apparatus has been exposed to rain or moisture, does not operate normally, or has been dropped.

THE QUALIFIED MAINTENANCE PERSONNEL MUST TAKE REASONABLE PRECAUTIONS TO FACE THE OBVIOUS DANGERS.

Powers sources

Only connect the apparatus to a power supply of the described in the operating instructions or as marked on the apparatus.

Turning off the power switch does not completely isolate this product from the power line so remove the plug from the socket if not using it for extended period of time.

Unplug this apparatus during lightning storms.

Power cord protection

Power supply cords should be routed so that they are not likely to be walked on or pinched by items placed upon or against them, paying particular attention to cords and plugs, and the point where they exit from the appliance

Grounding

WARNING: THIS APPARATUS SHALL BE CONNECTED TO A MAINS SOCKET OUTLET WITH A PROTECTIVE EARTHING CONNECTION.

THE APPLIANCE MUST BE CONNECTED TO AN ELECTRICAL GROUND AND THE POWER CORD IS DESIGNED FOR THAT.

Lifting the unit

IF THIS APPARATUS WEIGHS OVER 25KGS, SO TAKE EXTREME CARE WHEN LIFTING OR MOVING THIS UNIT. WE RECOMMEND THAT TWO PEOPLE ARE AVAILABLE TO LIFT THIS UNIT.
Battery replacement and disposal

CAUTION: RISK OF EXPLOSION IS BATTERY IS REPLACED BY AN INCORRECT TYPE. DISPOSE OF USED BATTERIES ACCORDING TO THE INSTRUCTIONS

CE MARKING

The symbol on the PC chassis indicates that it is in compliance with the Electromagnetic Compatibility directive (2004/108/CEE) and the low Voltage directive (73/23/CEE) of the European Union (EU). A certificate of compliance is available by contacting technical support. This equipment is a:

✔ Group 1 Class A product

Recommendation concerning the cabling:

CE certification has been carried out with 3-meter interconnecting cables with remote equipment.

ZODIAC DATA SYSTEMS recommends the use of high quality interconnecting cables type. The high quality recommended user interconnecting cables are “shield twisted pair” or “coaxial cable” industrial type with cable shield. The cable shield will provide the necessary mechanical protection.

Not using this high quality designed cable could result in unexpected intersystem/extrasystem electromagnetic emission and susceptibility.

INTERNATIONAL SECURITY STATEMENT

France, Canada:  L'appareil doit être connecté à une prise de terre

Suomi:  Laite on liitettävä suojamaadoituskoskettimilla varustettuun pistorasiaan

Norge:  Apparatet må tilkoples jordet stikkontakt

Sverige:  Apparaten skall anslutas till jordat uttag
1. OVERVIEW
1.1 SCOPE

This manual contains the information necessary to install, configure, operate and maintain the ZODIAC DATA SYSTEMS PC-based Command Ranging & Telemetry Unit (CORTEX CRT Quantum).

The Cortex CRT Quantum is the newest version of the Cortex CRT and Cortex DS and can be supplied in different versions:
- Cortex CRT XL Quantum, with 1U Simplified Panel
- Cortex CRT XL Quantum, with 3U Full I/O Panel
- Cortex CRT DS Quantum, with 3U Full I/O Panel

The document is divided into four main sections:

- **Section 1** is a general overview, including basic features and performances, and a comparison chart between the Cortex CRT XL, CRT XL2 and CRT XL Quantum
- **Section 2** is a description of the hardware and I/O connections,
- **Section 3** is a functional presentation of the equipment,
- **Section 4** describes the operating procedures,
- **Section 5** describes the hardware and software maintenance procedures.

Project-specific information and additional data on the CORTEX CRT Quantum hardware and interface are attached in annex:

- **Annex 1** is a detailed description of the CORTEX CRT Quantum Ethernet interface with remote TCP-IP Clients.
- **Annexes 2 and 3** give the layout of the Digital I/O board and the Main Signal Processing board.
- **Annex 4** is a description of the PC compatible workstation.
- **Annex 5** gives the hardware and software configuration of the CORTEX CRT Quantum at delivery and describes the project-specific features, if any.
1.2 CORTEX CRT QUANTUM MAIN FEATURES

CORTEX CRT Quantum main features are:

✔ PC-based Architecture with Windows Operating System

✔ User-friendly and Intuitive Graphic User Interface

✔ Wide Range of Configuration Parameters and Status

✔ Extensive Use of Digital Signal Processing Techniques for Enhanced Performances, Upgradability and Flexibility

✔ High Integration with Drastically Reduced Hardware for Increased Availability

✔ No Tuning, no Preventive Maintenance

✔ Full Compatibility with the VME-based CORTEX, CORTEX\textsuperscript{NT} and CORTEX XL / CORTEX XL2 Previous Generations. Refer to the Comparison Chart in chapter 1.5 for details of the minor differences between CRT Quantum and CRT XL/XL2

✔ The CORTEX CRT Quantum supports all types of TT&C missions and standards:

- Satellite Assembly, Integration and Testing, Pre-launch Testing,
- Station Keeping, Launch & Early Orbit Operation Support (LEOP),
- GEO or LEO, Three-axis or Spin-stabilized Satellites,
- Low Data Rate (House Keeping Operations) or High Data Rate Processing.
1.3 MISSION OF THE CORTEX CRT QUANTUM

The Command Ranging & Telemetry Unit (CORTEX CRT Quantum) fulfils the function of:

- Satellite telemetry processing (up to six telemetry chains for low-rate applications),
- Satellite telecommanding,
- Satellite tracking (range and Doppler measurement),

at IF and baseband, in a satellite control station.

1.3.1 Telemetry Processing

- Low rate and high rate telemetry processing,
- Video demodulation (PM, FM or AM) for low rate applications,
- PCM demodulation (PCM/PM, PCM/FM, BPSK, QPSK, OQPSK, SOQPSK, GMSK or AQPSK) for high rate applications,
- Carrier identification: high or low index mode, automatic or manual acquisition,
- Pre-Detection and Post-Detection Diversity Combining,
- Sub-carrier demodulation (BPSK, PCM/PM or PCM/FM),
- Bit synchronization. PSK and BP-L ambiguity resolution,
- Viterbi decoding,
- Frame synchronization,
- Descrambling,
- Reed Solomon or Turbo decoding,
- Telemetry storage on the hard disk and playback,
- Frame (or raw data) time-tagging,
- On request or automatic data transmission to the Telemetry Clients,
- Real-time decommutation with graphical display,
- VC extraction for CCSDS recommendations,
1.3.2 Satellite Telecommanding

- Reception and checking of TCP-IP telecommand messages from the Telecommand Clients,
- PCM encoding,
- Modulation at baseband (FSK, BPSK, BPSK+AM, etc.),
- IF modulation (PM or FM) and Doppler compensation,
- Compliance to CCSDS recommendations (COP1),
- Loopback demodulation/verification.

1.3.3 Satellite Tracking (Range and Doppler Measurement)

- Reception and checking of TCP-IP ranging requests from the Ranging Clients,
- Ranging tone or code generation, Tone phase tracking,
- IF modulation (FM or PM) and Doppler compensation,
- Phase-shift measurement,
- Ambiguity resolution and distance computation,
- Range data time-tagging and transmission to the Ranging Clients.
- Doppler measurement and time-tagging.

1.3.4 Simulation & Testing

The CORTEX CRT Quantum incorporates powerful built-in simulation capabilities for functional and performance test purposes:

- Simulation of a PSK or PCM telemetry signal from TM formats stored on the hard disk or received over the ETHERNET LAN from a remote Simulation Client,
- IF modulation (PM, FM, BPSK, QPSK, OQPSK or AQPSK),
- Automatic BER measurement,
- Real time IF spectrum analysis,
- Equipment self-testing at boot,
- Noise generation (option).
1.4 ARCHITECTURE

1.4.1 Functional Block Diagram

Figure 1: CORTEX CRT Quantum Functional Block Diagram
1.4.2 Hardware Architecture

The CORTEX CRT Quantum comprises the following elements:

- A PC-compatible workstation,
- One Main Signal Processing board (ZODIAC DATA SYSTEMS),
- One Digital I/O board, associated to the 3U Interconnection panel (ZODIAC DATA SYSTEMS),
- One Interconnection Panel, 1U model for IF and Time & Frequency signals, 3U model for full interconnectivity (ZODIAC DATA SYSTEMS),

![Figure 2: Hardware Architecture](image-url)
1.4.2.1 PC-compatible Workstation

The PC-compatible workstation includes (see Annex 4 for a detailed description):

- A rack-mountable industrial PC chassis (19-inch width, 7-inch height).
- A dual-Intel Xeon CPU board, fitted with one processor (standard) or two processors (option).
- An integrated 8-inch color display (800x600 SVGA) with Touchscreen, a keyboard and a pointing device for local operation,
- Two Ethernet interfaces,
- A 2.5" HDD,
- USB drives and DVD ROM drive,
- For extended storage purposes, a second 2.5" HDD is proposed in option.

1.4.2.2 Main Signal Processing Board

1.4.2.2.1 MAIN FEATURES

The Main Signal Processing board features are:

- Amplification, filtering and Analog-to-Digital conversion of the IF signals (carrier from 66 to 74 MHz) on three separate analog input stages,
- Analog-to-Digital conversion of the two Auxiliary signals (baseband or IF),
- IRIG-B or NASA-36 time code decoding for data time-tagging,
- Transmission of the digital video signal or/and PCM data to the IF Modulator board,
- 5, 10 or 100 MHz clock reception and distribution to all components requiring synchronization to an accurate reference frequency.
1.4.2.2.2 **DOWNLINK INPUT SIGNAL SELECTION**

Up to four IF carriers can be simultaneously demodulated (IF Receivers 1, 2, 3 & 4) with limitations (data rate, bandwidth,...) that are described in Section 3. Selection of the IF or Auxiliary signals is by analog or digital switches as shown in next figure:

![Diagram of IF stage #1, #2, #3, and IF Receivers 1, 2, 3, 4 with Nominal and Alternate signals]

**Figure 3**: Downlink Input Signal Selection

On the MSP board, each IF Receiver can be separately programmed to receive:

- IF-1 or IF-2 or IF-3 or Auxiliary-1 or Auxiliary-2.

Each analog switch on the Main Signal Processing board (IF # 1, IF # 2 and IF # 3) allows to select a **Nominal** or **Alternate** IF signal.

**Auxiliary** input stages have limited hardware (no amplification, no filtering, no AGC). They only allow to receive noise-free signals with low amplitude variations (typically: test loops at baseband or IF, Telecommand data demodulation, etc...).
1.4.2.2.3 **UPLINK OUTPUT SIGNAL SELECTION**

Up to two IF modulators are available (license–dependant : one or two or no modulator enabled).

Four IFM licenses / operating modes are proposed :

1. **Video only** : the IF Modulator receives a video modulating signal for FM or PM modulation of the carrier.
2. **PCM only** : the IF Modulator receives a PCM signal for PCM/PM, PCM/FM, BPSK, QPSK or OQPSK modulation of the carrier.
3. **Video + PCM** : the IF Modulator receives a video or/and a PCM signals and supports the modulation schemes of the two above modes.
4. **PCM + PCM** : the IF Modulator receives two PCM signals for PCM/PM, PCM/FM, BPSK, QPSK, OQPSK or AQPSK modulation. In QPSK, OQPSK and AQPSK mode, the first PCM signal is for I channel and the second for Q channel.

The carrier frequency is adjustable between 66 and 74 MHz.

Performing analog filters on the IF output stage ensures proper rejection of unwanted emissions (spurious and harmonics).

The IF Modulators board is connected to the PCI Express bus for monitoring and control by the CPU board.

1.4.2.3 **Interconnection Panel**

Two models of Interconnection Panel allows for easy connection of the chassis to its environment.

The 1U Interconnection Panel provides access through BNC connectors to the main signals used in Satellite TT&C operations :

- IF Inputs
- IF Outputs
- IRIG-B or NASA-36 time
- Reference Clock 1 & 2

In addition, a break-out cable is supplied to provide access to the Video and AGC signals.

The 3U Interconnection Panel provides full access to all signals available on the Cortex CRT Quantum. These include, in addition to the main signals described above :

- Video Output 1 & 2
- AGC Output 1, 2 & 3
- Data & Clock Input & Output, 4 sets
- Tracking signals (when delivered with a Cortex DTR configuration)
- 1-PPS
- Miscellaneous I/O

The Interconnection Panel is used as the interface between the Digital I/O and Main Signal Processing boards and the external world :

- Frequency up and down converters,
- Time and frequency generation sub-system,
- Test equipment.

A detailed description of the Interconnection Panel is available in Section 2.
1.4.3 Software

The CORTEX CRT Quantum is supplied with the following application software packages:

◆ The Signal Processing Software package (SPS),
◆ The Monitoring & Control Software package (MCS),
◆ Optional CCSDS protocols: Command Operation Procedure (COP), SLE Gateway,
◆ Project-specific software packages (see Annex 5).

These software are executed under the control of Windows Operating System. Software configuration at delivery is described in Annex 5.

1.4.3.1 Local or Remote M&C

The Signal Processing software and Monitoring & Control software communicate by means of connected sockets under TCP-IP protocol. Consequently, the notion of local or remote M&C is no longer applicable to the CORTEX CRT Quantum: since the software package can be installed into any remote PC-based computer connected to the LAN, there is no difference between operating the equipment locally (front panel keyboard and screen) or remotely.

1.4.3.2 Signal Processing Software Package

Depending on the mission requirements, the Signal Processing software package includes the following licenses:

◆ Telemetry software license (number of TM chains, modulation, data decoding, diversity combining, etc...),
◆ Satellite telecommanding software license,
◆ Satellite ranging software license,
◆ Simulation software license.
◆ Telemetry storage on the hard disk for further transfer to the Control Center (ftp, replay or off-line).

1.4.3.3 Monitoring & Control Software Package

The Monitoring & Control software package features monitoring & control of the chassis. It also authorizes a limited number of functions that are normally dedicated to the Control Center:

◆ Satellite ranging (phase measurement and distance computation),
◆ Satellite telecommanding (limited capabilities),
◆ Telemetry decommutation of a limited set of parameters, with graphical display.

Refer to the Cortex CRT MCS User’s Manual for more information.
1.4.3.4 Command Operation Procedure Software Package (COP)

The Command Operation Procedure software allows to receive CCSDS-compliant TC messages at segment or transfer frame or CLTU level, to check, to reshape and to retransmit them at CLTU level to the Signal Processing Software package. This optional software also communicates with the Signal Processing software by means of connected sockets under TCP-IP protocol.

1.4.3.5 SLE Gateway Software Package (CSGW)

The CORTEX SLE Gateway (CSGW), which is fully integrated in the CORTEX Unit, adds SLE services to the CORTEX system. The following services are supported by the CORTEX SLE Gateway:

- SLE Return All Frames (RAF) Service in «online timely», «online complete» and «offline» delivery modes
- SLE Return Channel Frame (RCF) Service in «online timely», «online complete» and «offline» delivery modes
- SLE Forward CLTU Service

CORTEX systems incorporating CSGW act as SLE service provider, and are able to provide the RAF, RCF and CLTU service to any SLE service user. CSGW support both version 1 and 2 of the SLE services.

1.4.3.6 Password Protection

The following functions are password-protected:

- Windows login, Auto login enabled
- CORTEX CRT Quantum configuration (refer to the Cortex MCS User’s Manual),
- Satellite telecommanding from the Monitoring & Control software. Separate passwords for TC database modification and for TC transmission (refer to the Cortex MCS User’s Manual),
- Reset of TCP-IP connections from the «TCP-IP» window (refer to the Cortex MCS User’s Manual),

Default setting at delivery: **cortex** (login function). Other functions: no password.
1.4.3.7 CORTEX Configuration at Delivery

The CORTEX CRT Quantum is supplied with the hardware components and software licenses (number of telemetry chains, TM bit rate, decoding capability, commanding and ranging capability, etc...) covering the Customer requirements. The configuration of the CORTEX at delivery (hardware components & licenses) is saved to a Flash Memory chip on the MSP module.

**WARNING:**

Swapping of the MSP Module from CORTEX A to CORTEX B is not allowed if CORTEX B is more performing than CORTEX A (supports licenses which are not implemented in CORTEX A).


1.4.3.8 Software Version

Software version at delivery is described in Annex 5 of the User Manual, in the Factory Acceptance Test Report.
## 1.5 COMPARISON BETWEEN CRT QUANTUM AND CRT XL/XL2

The table below lists the minor differences between CRT Quantum and CRT XL/XL2:

<table>
<thead>
<tr>
<th>Item</th>
<th>CRT XL2</th>
<th>CRT XL</th>
<th>CRT XL Quantum</th>
<th>CRT DS Quantum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downlink processing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of IF Inputs</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>IF Input switch</td>
<td>Nominal/Alternate</td>
<td>Nominal/Alternate</td>
<td>Nominal/Alternate</td>
<td>Nominal/Alternate</td>
</tr>
<tr>
<td>IF Input level</td>
<td>-5 to -95 dBm</td>
<td>-5 to -95 dBm</td>
<td>-15 to -105 dBm</td>
<td>-15 to -125 dBm</td>
</tr>
<tr>
<td>Auxiliary inputs</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Number of Demodulators</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>PM/FM demodulation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PLL type</td>
<td>2(^{nd}) order</td>
<td>2(^{nd}) order</td>
<td>2(^{nd}) order</td>
<td>2(^{nd}) &amp; 3(^{rd}) order</td>
</tr>
<tr>
<td>PLL Bandwidth</td>
<td>10 Hz to 3 kHz</td>
<td>10 Hz to 3 kHz</td>
<td>10 Hz to 3 kHz</td>
<td>0.1 Hz to 3 kHz</td>
</tr>
<tr>
<td>BPSK, QPSK, OQPSK</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>AQPSK, GMSK</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sine Subcarrier</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Square Subcarrier</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes (LBW)</td>
</tr>
<tr>
<td>Low BW Telemetry</td>
<td>40 Hz to 128 kHz, 10 bps to 25 kbps</td>
<td>40 Hz to 128 kHz, 7 bps to 25 kbps</td>
<td>40 Hz to 128 kHz, 7 bps to 25 kbps</td>
<td>40 Hz to 128 kHz, 7 bps to 25 kbps</td>
</tr>
<tr>
<td>High BW Subcarrier Telemetry</td>
<td>5 kHz to 2 MHz, 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz, 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz, 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz, 100 bps to 600 kbps</td>
</tr>
<tr>
<td>High BW PCM Telemetry</td>
<td>100 bps to 20 Mbps</td>
<td>100 bps to 40 Mbps</td>
<td>100 bps to 40 Mbps</td>
<td>100 bps to 40 Mbps</td>
</tr>
<tr>
<td>Viterbi decoder rate</td>
<td>½</td>
<td>½</td>
<td>½</td>
<td>½</td>
</tr>
<tr>
<td>Reed-Solomon</td>
<td>223/255</td>
<td>223/255</td>
<td>223/255</td>
<td>223/255</td>
</tr>
<tr>
<td>Turbo decoder rate</td>
<td>No</td>
<td>½</td>
<td>½</td>
<td>½, ¼, ⅛, ⅓, ⅕</td>
</tr>
<tr>
<td>LDPC ½ decoder</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Item</td>
<td>CRT XL2</td>
<td>CRT XL</td>
<td>CRT XL Quantum</td>
<td>CRT DS Quantum</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------</td>
<td>--------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td><strong>Uplink processing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of IF outputs</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Nominal IF level</td>
<td>0 to -80 dBm</td>
<td>0 to -80 dBm</td>
<td>0 to -80 dBm</td>
<td>0 to -80 dBm</td>
</tr>
<tr>
<td>Alternate IF level</td>
<td>-20 to -100 dBm</td>
<td>-20 to -100 dBm</td>
<td>-20 dBm</td>
<td>-20 dBm</td>
</tr>
<tr>
<td>Number of Modulators</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>PM/FM modulation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>BPSK, QPSK, OQPSK</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>AQPSK, GMSK</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sine Subcarrier</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes (LBW)</td>
</tr>
<tr>
<td>Square Subcarrier</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes (LBW)</td>
</tr>
<tr>
<td>Low BW Telecommand</td>
<td>40 Hz to 100 kHz  7 bps to 10 kbps</td>
<td>40 Hz to 100 kHz  7 bps to 10 kbps</td>
<td>40 Hz to 100 kHz  7 bps to 10 kbps</td>
<td>40 Hz to 100 kHz  7 bps to 10 kbps</td>
</tr>
<tr>
<td>High BW Subcarrier Telecommand</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
</tr>
<tr>
<td>High BW PCM Telecommand</td>
<td>100 bps to 1 Mbps</td>
<td>100 bps to 1 Mbps</td>
<td>100 bps to 1 Mbps</td>
<td>100 bps to 1 Mbps</td>
</tr>
<tr>
<td>Low BW Simulator</td>
<td>40 Hz to 128 kHz  7 bps to 19 kbps</td>
<td>40 Hz to 128 kHz  7 bps to 19 kbps</td>
<td>40 Hz to 128 kHz  7 bps to 19 kbps</td>
<td>40 Hz to 128 kHz  7 bps to 19 kbps</td>
</tr>
<tr>
<td>High BW Subcarrier Simulator</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
<td>5 kHz to 2 MHz 100 bps to 600 kbps</td>
</tr>
<tr>
<td>High BW PCM Simulator</td>
<td>100 bps to 20 Mbps</td>
<td>100 bps to 20 Mbps</td>
<td>100 bps to 40 Mbps</td>
<td>100 bps to 40 Mbps</td>
</tr>
<tr>
<td>Convolutional encoder rate</td>
<td>½</td>
<td>½</td>
<td>½</td>
<td>½</td>
</tr>
<tr>
<td>Reed-Solomon (simulator only)</td>
<td>223/255</td>
<td>223/255</td>
<td>223/255</td>
<td>223/255</td>
</tr>
<tr>
<td>Turbo encoder rate (simulator only)</td>
<td>No</td>
<td>½</td>
<td>½</td>
<td>½, ⅗, ⅕, ⅓, ⅕, ⅓</td>
</tr>
<tr>
<td>LDPC ½ encoder (simulator only)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Ranging processing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tone frequency</td>
<td>Up to 100 kHz</td>
<td>Up to 500 kHz</td>
<td>Up to 1.5 MHz</td>
<td>Up to 1.5 MHz</td>
</tr>
<tr>
<td>ESA Code length</td>
<td>Up to 18</td>
<td>Up to 18</td>
<td>Up to 24</td>
<td>Up to 24</td>
</tr>
<tr>
<td>Regenerative PN</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>T2B and T4B</td>
</tr>
<tr>
<td>Integration time</td>
<td>0.25 s to 5 s</td>
<td>0.25 s to 5 s</td>
<td>0.25 s to 500 s</td>
<td>0.25 s to 500 s</td>
</tr>
<tr>
<td>PLL Bandwidth</td>
<td>0.1 Hz to 8 Hz</td>
<td>0.1 Hz to 8 Hz</td>
<td>0.1 Hz to 8 Hz</td>
<td>0.001 Hz to 8 Hz</td>
</tr>
<tr>
<td>Item</td>
<td>CRT XL2</td>
<td>CRT XL</td>
<td>CRT XL Quantum</td>
<td>CRT DS Quantum</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------</td>
<td>--------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Time &amp; Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference clock inputs</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Reference clock freq</td>
<td>5 MHz, 10 MHz</td>
<td>5 MHz, 10 MHz</td>
<td>5 MHz, 10 MHz, 100 MHz</td>
<td>5 MHz, 10 MHz, 100 MHz</td>
</tr>
<tr>
<td>Time code</td>
<td>IRIG-B122 NASA-36</td>
<td>IRIG-B122 NASA-36</td>
<td>IRIG-B122 NASA-36 IRIG-B 5 MHz</td>
<td>IRIG-B122 NASA-36 IRIG-B 5 MHz</td>
</tr>
<tr>
<td>Time code max amplitude</td>
<td>10 Vpp</td>
<td>10 Vpp</td>
<td>6 Vpp</td>
<td>6 Vpp</td>
</tr>
<tr>
<td>Time tag resolution</td>
<td>Millisecond Microsecond</td>
<td>Millisecond Microsecond</td>
<td>Millisecond Microsecond Nanosecond</td>
<td>Millisecond Microsecond Nanosecond</td>
</tr>
<tr>
<td>Time tag accuracy (external 1PPS)</td>
<td>10 µs</td>
<td>10 µs</td>
<td>100 ns</td>
<td>100 ns</td>
</tr>
<tr>
<td>Test Points</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uplink test sets</td>
<td>Set#1 and #2</td>
<td>Set#1 and #2</td>
<td>Set#1 to #4</td>
<td>Set#1 to #4</td>
</tr>
<tr>
<td>Downlink test sets</td>
<td>Set#3 and #4</td>
<td>Set#3 and #4</td>
<td>Set#1 to #4</td>
<td>Set#1 to #4</td>
</tr>
<tr>
<td>LBW Uplink LV TTL test points</td>
<td>Shared with Set#1 and #2</td>
<td>Shared with Set#1 and #2</td>
<td>Independant</td>
<td>Independant</td>
</tr>
<tr>
<td>RS422 test sets</td>
<td>No</td>
<td>No</td>
<td>Set#3 and #4</td>
<td>Set#3 and #4</td>
</tr>
<tr>
<td>Operating System</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating system</td>
<td>Windows 2000 Windows XPe</td>
<td>Windows 2000 Windows XPe</td>
<td>Windows 7e 32 bits</td>
<td>Windows 7e 32 bits</td>
</tr>
</tbody>
</table>

*Figure 4: CRT Quantum, CRT XL and CRT XL2 Comparison Chart*
1.6 CORTEX CRT QUANTUM PERFORMANCES

On the CORTEX CRT Quantum most functions are performed digitally, mainly by powerful FPGAs. The following functions and signal processing performances are listed (this list corresponds to a fully equipped CORTEX CRT Quantum unit):

- IF reception
- Telemetry processing
- IF modulation
- Satellite ranging
- Satellite telecommanding
- Telemetry simulation
- Time code decoding and data time-tagging.
- Reference frequency

PERFORMANCES LISTED IN THIS SECTION ARE TYPICAL VALUES MEASURED IN BEST CASE CONDITIONS. SOME FUNCTIONALITIES MAY STILL BE IN DEVELOPMENT PHASE. PLEASE, CONTACT ZODIAC DATA SYSTEMS FOR MORE INFORMATION.

PROGRAMMING RESOLUTION: REFER TO ANNEX 1. CONFIGURATION PARAMETERS ARE SPECIFIED OVER 32-BIT INTEGERS OR SINGLE-PRECISION FLOAT (8-BIT EXPONENT AND TWO's-COMPLEMENT 24-BIT MANTISSA). HOWEVER, THE RESOLUTION CAN BE LIMITED BY THE HARDWARE DESIGN.
1.6.1 IF Reception

1.6.1.1 Analog Reception

1.6.1.1.1 IF STAGES

- IF input stages: 3
- IF input ports: 2 per input stage (Nominal & Alternate)
- Input bandwidth: 50 to 90 MHz (-3 dB bandwidth)
- Input impedance: 50 Ω
- VSWR: ≤ 1.25
- Isolation between channels: ≥ 80 dB
- Aliasing rejection: ≥ 80 dB
- Maximum noise level: -20 dBm (or No = -96 dBm/Hz for 40 MHz noise bandwidth)
- AGC range (CRT XL Quantum): -15 to -105 dBm
- AGC range (CRT DS Quantum): -15 to -120 dBm
- AGC time constant: 0.1, 1, 10, 100 or 1,000 ms
- AGC mode: Analog AGC: Non coherent
  Digital AGC: Non coherent before carrier acquisition
  then coherent (for PM and direct PCM, in a few Hz)

1.6.1.1.2 AUXILIARY INPUTS

Two Auxiliary input ports allow receiving baseband or IF signals for test purposes (example: TC demodulation at IF):

- Input ports: 2
- Input signal: Baseband or IF signal
- Input bandwidth: At baseband: DC to 20 MHz
  At IF: 0 to 90 MHz
- Input signal level: At baseband: 0.1 to 0.5 Vpp
  At IF: 0 to -20 dBm
- AGC: No
- Input impedance: 50 Ω
1.6.1.2 PM and FM Demodulation

- **Input carrier frequency**: 60 to 78 MHz
- **Spectrum analysis**: Yes (spectrum analysis and IF demodulation are mutually exclusive)
- **IF level measurement accuracy**: < 2 dB

1.6.1.2.1 PM Demodulation

- **Carrier acquisition modes**: Automatic (global FFT analysis) or Manual (sweeping)
- **Carrier acquisition**: Select highest component, for low modulation index (< ≈ 1.3 rad.)
  Spectrum correlation, for high modulation index (anti-sideband)
- **Acquisition & tracking range**: ± 10 to ± 500 kHz
- **PLL type and 2 Bn Loop bandwidth (CRT XL Quantum)**
  - 2nd order
  - 10 Hz, 30 Hz, 100 Hz, 300 Hz, 1000 Hz or 3000 Hz
- **PLL type and 2 Bn Loop bandwidth (CRT DS Quantum)**
  - 2nd and 3rd order
  - 0.1 Hz, 0.3 Hz, 1 Hz, 3 Hz, 10 Hz, 30 Hz, 100 Hz, 300 Hz, 1000 Hz, 3000 Hz
  - User-selectable 0.1 Hz to 3000 Hz
- **Acquisition threshold (CRT XL Quantum)**
  - C/No = 20 dB.Hz (for 2Bn = 10 Hz). Measured on a pure carrier
- **Acquisition threshold (CRT DS Quantum)**
  - C/No = 8 dB.Hz (for 2Bn = 1 Hz). Measured on a pure carrier
- **Tracking threshold**: ≤ acquisition threshold
- **Maximum Doppler rate**: ≤ 50 kHz/s and C/N0 > 50 dB.Hz (for 2 Bn = 1,000 Hz)
  - ≤ 100 kHz/s and C/N0 > 60 dB.Hz (for 2 Bn = 3,000 Hz)
- **Output video bandwidth**: DC to 2 MHz
- **Doppler measurement**: IF offsets and cumulated phase variations (Integrated Doppler)
- **Diversity combining**: Optional. Post-combination. Up to 3-dB gain with equal-strength signals

1.6.1.2.2 FM Demodulation

- **Pre-detection filter bandwidth**: 10, 5, 3, 1.5, 1 MHz, 500, 300, 150, 100, 50, 30, 15, 10 and 5 kHz (single-side at 1 dB)
- **PCM/FM BER degradation**: 2 dB typical at Eb/No = 7 dB, with the matched pre-detection filter
- **AFC time constant**: 1, 10, 100 or 1000 ms
- **Discriminator number of periods**: 1 to 16
- **Output video bandwidth**: Depends on the Pre-Detection filter and Discriminator programming
1.6.1.3 Direct PCM Demodulation

1.6.1.3.1 IF DEMODULATION

- Demodulation: PCM/PM, BPSK, QPSK, OQPSK, SOQPSK, GMSK, AQPSK, UQPSK
- Input carrier frequency: 60 to 78 MHz
- Carrier acquisition range: ±10 to ±500 kHz
- Carrier acquisition modes: see Section 3.3.2.1
- Demodulation IF bandwidth: Automatically adjusted in accordance to the selected bit rate
- Unbalanced QPSK: Up to 20 dB unbalance
- Acquisition threshold (CRT XL Quantum): 
  \( \text{Eb}/\text{No} \leq 0 \text{ dB for symbol rates } \geq 1 \text{ kbps} \)
  IF level \( \geq -85 \text{ dBm} \)
- Acquisition threshold (CRT DS Quantum): 
  \( \text{Eb}/\text{No} \leq -8 \text{ dB or } -5 \text{ for QPSK modes with 0.01 % PLL BW, for symbol rates } \geq 10 \text{ kbps, IF level } \geq -85 \text{ dBm} \)
- Doppler measurement: IF offsets and cumulated phase variations (integrated Doppler)
- IF level measurement accuracy: < 2 dB
- Diversity combining: Pre-detection or post-detection combining (optional)
  Up to 3-dB gain with equal-strength signals
- Spectrum analysis: Yes (spectrum analysis and IF demodulation are mutually exclusive)

1.6.1.3.2 BIT SYNCHRONIZATION AND DECODING

- PCM decoding: NRZ-L/M/S, BP-L/M/S, DBP-M/S, DM-M/S, R-NRZ and V35
- Viterbi decoding: CCSDS 101.0-B-6 (§ 2.1)
- Bit rate: 100 bps to 20 Mbps (after decoding. License-dependant. See § 3.3.1.2)
- QPSK ambiguities solving: By the frame synchronizer (Synchronization word detection phase)
  Single or dual input Viterbi decoding
  Separate Viterbi decoding on I and Q channels
  Differential QPSK decoding (DQPSK, DOQPSK, DSOQPSK)
  See section 3.3.7 for more details
- Matched filter: Integral & Dump, Raised Cosine or Root Raised Cosine
- Roll-off factor: 0.1 to 1
- 2Bn Carrier PLL BW (CRT XL Quantum): 0.03, 0.1, 0.3, 1 and 3 % of symbol rate
- 2Bn Carrier PLL BW (CRT DS Quantum): 0.01, 0.03, 0.1, 0.3, 1 and 3 % of symbol rate
  User configurable (0.001% to 10%)
Bit synchronizer PLL BW (2 Bn)  Carrier loop bandwidth /10

- BER degradation  ≤ 1 dB vs theory if  BR < 10 Mbps, ≤ 2 dB if BR < 40 Mbps
    In case of BP, DM : ≤ 1 dB if  BR < 5 Mbps, ≤ 2 dB if BR < 10 Mbps

(always ensure the received spectrum fits to the 50-90 MHz IF Receiver input bandwidth).

- Synchronization threshold  ≤ 0 dB (Eb/No) for symbol rates ≥ 1 ksps (10 dB at 100 sps)

- Eb/No measurement  Yes (0.5 dB accuracy)
1.6.2 Telemetry Processing

1.6.2.1 Low Bandwidth Telemetry

- **Input**: IF Receiver output
- **Demodulation**: BPSK (direct bit synchronization available)
- **Sub-Carrier Frequency**: 40 Hz to 128 kHz
- **Bit Rate**: 10 to 25,000 bps (with NRZ code)
  - 7 to 25,000 bps with PACK-EXT License
- **Number of sub-carriers**: \( \leq 6 \)
- **Bandwidth**: Automatically adjusted to the selected bit rate and sub-carrier frequency
- **PSK demod./Bit sync. loop BW % of the Bit Rate**
  - 10% / 10% (Ultra Wide)
  - 1% / 1% (Wide)
  - 0.3% / 0.1% (Narrow)
- **Acquisition threshold (*)**
  - \( \text{Eb/No} \leq 0 \text{ dB (narrow BW), 2 dB (wide BW), 10 dB (Ultra Wide BW)} \)
  - (*) at bit sync level
- **Viterbi decoding**: 7, ½ according to CCSDS 101.0-B-6 (§ 2.1)
- **PCM coding**: BP-L/M/S, NRZ-L/M/S
- **BER degradation**: \( \leq 1 \text{ dB vs theory (typical)} \)
- **Eb/No measurement**: Yes

1.6.2.2 High Bandwidth Telemetry with Sub-carrier

- **Input**: IF Receiver output or Auxiliary input
- **Demodulation**: BPSK, PCM/PM (direct bit synchronization available)
  - Option: PCM/FM capability (discriminator filter available)
- **Sub-Carrier Frequency**: 5 kHz to 2 MHz
- **Bit Rate**: 1000 bps to 600 kbps (up to 300 kbps for BP-L code)
  - 1000 bps to 5 Mbps PM/PCM, 1000 bps to 15 Mbps FM/PCM (after decoding. License-dependant. See § 3.3.1.1)
- **Bandwidth**: Automatically adjusted to the selected bit rate and sub-carrier frequency
- **PSK Demodulator & Bit Synchronizer PLL BW (CRT XL Quantum)**
  - 3%, 1%, 0.3% or 0.1% of BR
- **PSK Demodulator & Bit Synchronizer PLL BW (CRT DS Quantum)**
  - 10%, 3%, 1%, 0.3%, 0.1%, 0.03% or 0.01% of BR
- **Bit Sync. acquisition range**: ± 4 × PLL BW if the PLL BW is set to 0.1 or 0.3 % of BR
  - ± 2 × PLL BW if the PLL BW is set to 1 or 3 % of BR
- Acquisition threshold (CRT XL Quantum)
  \[ \text{Eb}/\text{No} \leq 0 \, \text{dB} \]
  -2 dB for direct NRZ bit sync. (narrowest BW) for symbol rate \( \geq 1 \, \text{ksps} \)
  10 dB for symbol rates < 1 ksps at 100 sps

- Acquisition threshold (CRT DS Quantum)
  \[ \text{Eb}/\text{No} \leq -8 \, \text{dB} \text{ for 0.03\% and Symbol rates > 10 ksps} \]
  -2 dB for direct NRZ bit sync. (narrowest BW) for symbol rate \( \geq 1 \, \text{ksps} \)
  10 dB for symbol rates < 1 ksps

- Viterbi decoding
  7, \( \frac{1}{2} \) according to CCSDS 101.0-B-6 (§ 2.1)

- PCM decoding
  NRZ-L/M/S, BP-L/M/S, DBP-M/S, DM-M/S and R-NRZ

- BER degradation vs theory
  \[ \leq 1 \, \text{dB if BR < 10 Mbps}, \]
  \[ \leq 2 \, \text{dB if BR < 20 Mbps} \]
  \[ \leq 1 \, \text{dB if BR < 5 Mbps (BP or DM codes)} \]
  \[ \leq 2 \, \text{dB if BR < 10 Mbps (BP or DM codes)} \]

- Direct Bit Sync. acquisition time
  \[ \leq 150 \, \text{bits if Bit Sync. Loop BW = 0.1 or 0.3 \% of BR} \]
  \[ \leq 100 \, \text{bits if Bit Sync. Loop BW = 1 or 3 \% of BR} \]

- Eb/No measurement
  Yes
1.6.2.3 Frame Synchronization. Telemetry Storage

- Frame synchronization
  - Synchronization word size: 8 to 32 bits
    - 64, 96, 128, 192 for Turbo decoding
    - 64 bits for LDPC ½
  - Frame size: 10 to 32,000 bytes
  - Synchronization strategy:
    - SYN (0 to 7 errors, up to 64 errors for Turbo-decoding, up to 32 errors for LDPC ½)
    - CTL (0 to 7 errors)
    - LTS (0 to 7 frames)
    - Bit slippage (0, 1 or 2 bits)
  - Synchronization word on I or Q: Yes

- Frame filtering
  - 64-bit frame mask: Yes

- CCSDS decoding transfer frame level:
  - Convolutional Viterbi: Yes
  - Soft decision: Yes
  - Bit error rate monitoring: Yes
  - Lock detector: Yes
  - Reed-Solomon: Yes
  - Scrambling: Yes
  - Interleave factor: Automatically programmed

- Turbo decoding
  - Rates: 1/2, 1/3, 1/4 and 1/6
  - Output: up to 5 Mb/s
  - Block length: 1784, 3568, 7136 and 8920 bits

- LDPC Decoding
  - Rates: ½
  - Output: up to 10 Mb/s
  - Block length: 4096 bits

- CCSDS decommutation
  - CADU & VCDU: Yes

- Telemetry storage on hard disk
  - Time-tagged frames or blocks

- Telemetry replay
  - Yes (TM data re-modulation by the TMS in Replay mode)

- Off-line telemetry transmission
  - Yes (direct transfer to the LAN of stored telemetry)
1.6.3 IF Modulation

- Number of IF Modulator boards: 1 or 2 (IFM-1, IFM-2)
- Modulation: FM, PM, BPSK, QPSK, OQPSK, AQPSK
- Carrier frequency (CRT XL Quantum): 60.0 to 78.0 MHz
- Carrier frequency (CRT DS Quantum): 60.0 to 78.0 MHz (226 to 234 MHz as option)
- Carrier frequency resolution: 14 pHz (250 MHz / 2^64)
- IF output bandwidth: 50-90 MHz (-3 dB bandwidth)
- Modulating signal: Internal and external analog video signals (base band)
  - Internal or external PCM data streams
- External analog input: 2 Vpp / 50 Ω
- PCM modulation filtering: None, Raised or Root Raised & roll-off factor
- Frequency deviation: 0 to ±5 MHz
- Modulation index: 0 to 2.5 radians
- IF output ports (per IFM): 2 (Nominal & Test)
- Output level: Nominal output: 0 to -80 dBm
  - Alternate output: -20 dBm
- Output level setting accuracy: ≤±1 dBm (Nominal port, from 0 to -50 dBm, at 70 MHz)
- Output impedance / VSWR: 50 Ω / ≤1.30
- Carrier frequency stability: As per the reference clock (internal or external)
- Unwanted emissions: ≤-60 dBc, from 0 to -20 dBm output level
- IF phase noise (CRT XL Quantum):
  - -43.5 dBc/Hz at 10 Hz, falling to -120 dBc/Hz at 1 MHz
  - ≤0.5° RMS in 1-MHz bandwidth (0.2° typical)
- IF phase noise (CRT DS Quantum):
  - -70 dBc/Hz at 10 Hz, falling linearly to -120 dBc/Hz at 1 MHz
  - ≤0.5° RMS in 1-MHz bandwidth (0.2° typical)
- Carrier sweep range: ±1 to ±1,000 kHz
- Carrier sweep rate: 1 Hz/s to 175 kHZ/s
- Carrier sweep offset: 0 to 1 MHz (signed)
- Sweep step: NCO refreshed every microsecond
1.6.4 Satellite Ranging

- **Ranging standards**: ESA tone and ESA code standards
  - ESA-like and USB tone standards
  - Programmable frequencies and tone sequence
  - INMARSAT and LMCO tone standards
  - PN Codes (CRT DS Quantum only)

- **Ranging tones**
  - Tone frequency: 2 Hz to 1.5 MHz
  - Number of tones: 1 major tone, 1 to 6 minor tones (8 for USB)

- **Code length**: 0 to 24 (ESA code standard), 2 or 4 (PN Codes)

- **Integration time**: 0.25 to 500 seconds

- **Downlink tone tracking**: 2\(^{nd}\)-order digital PLL

- **PLL bandwidth (2 Bn)**
  - 0.1 to 8 Hz (CRT XL Quantum)
  - 0.001 to 8 Hz (CRT DS Quantum)

- **Measurement standard deviation**: ≤ 1 dB vs theory in the presence of noise

- **Phase measurement resolution**: 0.0055° \((360°/2^{16})\)

- **PN Ranging Measurement degradation**: < 0.5 dB from theory (vs noise). See section 3.6.12

- **Ambiguity solving** (after Doppler compensation on minor tones and programmable phase corrections)

- **Distance measurement resolution**: 1 ns

- **Local ranging capability**

- **Doppler Rate Aid capability and Doppler Aid capability**
1.6.5 Doppler Measurement

- Measurement technique: By tracking the phase variations on the IF Receiver PLL
- Measurement rate: 10 ms
- Measurement sampling rate: User-programmable from 0.1 to 10 seconds (TCP-IP level)
- Phase measurement resolution: \( \frac{360}{2^{11}} \) (in degrees)
- Phase values: 64-bit words
- Phase counter capacity: \( \approx \) 4 years (at 70 MHz)
- Doppler data: 32-bit frequency offsets (computed by the CORTEX software, based on the programmed sampling rate), or 64-bit phase counter values

- Performances vs noise: Phase measurement jitter vs noise:
  \[ \sigma_{\text{PHASE}} = \sqrt{\frac{2B_n}{C \cdot N_e}} \] (in radian)
  
  where \( 2B_n \) is the programmed IFR PLL loop bandwidth (in Hz)

  Frequency jitter vs noise (*):
  \[ \sigma_{\text{FREQ}} = \sqrt{\frac{2}{2\pi T_s}} \cdot \sigma_{\text{PHASE}} \] (in Hz)
  
  where \( T_s \) is the programmed integration time (in seconds)

  Range rate jitter vs noise (*):
  \[ \sigma_{\text{FRANGE_RATE}} = \sqrt{\frac{2}{2\pi T_s}} \cdot \sigma_{\text{PHASE}} \] (in Hz)

(*) Frequency & range rate computation not supported by the CORTEX.
1.6.6 Satellite Commanding (Low Bandwidth Mode)

- **Supported commands**
  - Clear or Scrambled TC message transmission
  - High-level TC requests (see Annex 5)
  - Wait and verify with time-out & retry instruction
  - Pause instruction, Grouped instructions
  - TC message transmission at programmed time
  - Last radiation time request
  - Idle pattern generation

- **Supported protocols**
  - Satellite-specific protocols (see Annex 5)
  - CCSDS COP-1

- **Modulation**
  - FSK, no blanking
  - FSK + half-bit blanking. Duty cycle : 50/50 (default setting)
  - BPSK, BPSK+AM
  - BPSK SQUARE
  - Satellite-specific modes (contact ZODIAC DATA SYSTEMS for more information)

- **PCM coding**
  - BP-L/M/S, NRZ-L/M/S, RZ

- **Convolutional coding**
  - No

- **Bit rate**
  - 10 to 10 000 bps, 7 to 10000 bps with PACK-EXT Licence

- **BPSK SCF**
  - 100 Hz to 125 kHz

- **FSK tone frequency (0/1)**
  - 100 Hz to 100 kHz

- **Execute tone frequency**
  - 100 Hz to 100 kHz

- **Pseudo-earth tone frequency**
  - 100 Hz to 100 kHz

- **SCF and BR stability**
  - As per the reference clock (external or internal)

- **Execute and pseudo-earth pulses**
  - Programmable duration (10 µs to 10 000 seconds in 10-µs step)
  - Programmable period (10 µs to 10 000 seconds in 10-µs step)
  - Programmable number of pulses (1 to 65536)

- **Idle pattern**
  - Programmable length (1 to 16 bits) and contents

- **Preamble length**
  - 0 to $2^{24}$ bits

- **Pause duration**
  - 10 µs to 10 000 seconds in 10-µs steps

- **Synchronized TC protocol**
  - S/W license. PCM & FMRT modes. High-level commanding interface. Pulses monitoring

- **Local TC capability**
  - MS ACCESS database. Customized databases on request.
1.6.7 Satellite Commanding (High Bandwidth Mode)

- Supported commands: Clear TC message transmission, Pause instruction, Grouped instructions, TC message transmission at programmed time, Last radiation time request, Idle pattern generation

- PCM coding: as per LBW mode

- Convolutional coding: Yes

- Modulation: BPSK or no sub-carrier (direct PCM on the carrier)

- Bit rate: 100 bps to 1 Mbps (direct PCM on the carrier), 100 bps to 250 kbps (PCM on a sub-carrier)

- Sub-carrier frequency: 5 kHz to 2 MHz

- Idle pattern: as per LBW mode

- Preamble length: as per LBW mode

- Pause duration: as per LBW mode

- Local TC capability: as per LBW mode.

The following restrictions apply to the capabilities of the High Bandwidth TCU:

- TC Scrambling is not supported

- FSK modulation at baseband is not supported

- Execute instruction is not supported

- Data+Execute request is not supported
1.6.8 Telemetry Simulation

- Simulated telemetry data source
  - Simulated telemetry files (TMS in File mode)
  - Stored telemetry files (TMS in Replay mode)
  - Data received on the LAN (TMS in LAN mode)
  - Pseudo Random Bit Sequence (TMS in Pseudo mode)

- PRBS polynomial & length
  \( X^{15} + X + 1 \). 32767 bits.

- Output
  - BPSK, BPSK SQUARE, PCM/PM, PCM/FM or direct PCM

- SCF
  - 40 Hz to 128 kHz (low bandwidth)
  - 5 kHz to 2 MHz (high bandwidth, with sub-carrier)

- Bit Rate
  - 10 bps to 19 kbps (low bandwidth setting)
  - 7 bps to 19 kbps with PACK-EXT Licence
  - 1 to 600 kbps (high bandwidth, sub-carrier)
  - 1 kbps to 20 Mbps (high bandwidth, direct PCM) and 40 Mbit/s in case of use of Viterbi \( 1/2 \)

- PCM coding
  - NRZ-L/M/S, BP-L/M/S, DBP-M/S, DM-M/S, V35

- BPSK modulation
  - ON or OFF

- Polarity of transmitted NRZ-L
  - Normal or inverted

- SCF and BR stability
  - As per the reference clock (external or internal)

- File size
  - 32768 bytes (File mode). No limitation (Replay mode)

- Automatic BER calculation
  - Yes (TMS in Pseudo mode)

1.6.9 Doppler Compensation

1.6.9.1 Carrier, Sub-Carrier and Bit Rate

- Availability
  - CRT XL Quantum : uplink only, licence dependant
  - CRT DS Quantum : uplink and downlink

- Doppler compensation range
  - ± 4 MHz

- Doppler compensation rate
  - 3 mHz/s to 52 kHz/s

- Doppler compensation sampling
  - 1 s, 0.1 s, 0.01 s and 0.001 s

- Doppler compensation step
  - NCO refreshed every 160 µs, 16 µs, 1.6 µs and 0.16 µs
1.6.10 Time Code & Reference Clock Interface

The CORTEX CRT Quantum must be connected to an external timing system in the following cases:

◆ If the equipment is to be used for satellite ranging or accurate Doppler measurement. Due to the high level of performance of the unit, an external reference clock (GPS-based for example) is required to ensure phase shift and frequency measurement with the required accuracy.

◆ If the equipment must be used for launch or transfer orbit support or control of LEO satellites (high Doppler). In that case, it may be necessary to connect the chassis to an external time reference (GPS-based IRIG-B code generator for example) for accurate time-tagging of the ranging, Doppler and telemetry data.

The internal 10-MHz clock accuracy and stability on the Main Signal Processing board allows the CORTEX CRT Quantum to fulfill its mission in most other station keeping scenarios.

The external reference clock frequency is either 5, 10 or 100 MHz and is received on two ports in active redundancy. Clock selection (internal clock, external clock from port 1 or port 2) is programmable and offers several priority scenarios. Frequency selection (5, 10 or 100 MHz) is automatic, at boot. However, performances of the unit cannot be guaranteed if the external reference clock signal is corrupted or if the frequency is not exactly 5, 10 or 100 MHz.

1.6.10.1 Time Code Decoding & Data Time-tagging

- Input code: IRIG-B, IRIB 5 MHz or NASA-36
- Amplitude: 6 Vpp max
- Impedance: 1 MΩ
- Polarity and direction: Positive and forward
- Error by-pass: 7 frames
- 1-PPS input: Yes. TTL. Maximum rise and fall time: 20 ns
- Time tagging accuracy: ± 50 µs (without external 1-PPS), ± 100 ns (with external 1-PPS)
- Flywheel mode: Yes
- Leap second & leap year management: Yes

1.6.10.2 Reference Frequency

1.6.10.2.1 EXTERNAL REFERENCE

- Input port: 2 ports. Programmable auto-selection
- Frequency: 5, 10 or 100 MHz sine or square
- Acquisition range: > 5 kHz for 100 MHz, > 500 Hz for 10 MHz, > 250 Hz for 5 MHz
- Impedance: 50 Ω
- Level: 0.5 to 5 Vpp
  DC max. = ± 4 V
1.6.10.2.2 **INTERNAL REFERENCE**

- **Frequency**  
  10 MHz

- **Frequency stability**  
  ≤ ± 5 ppm ageing first year  
  ≤ ± 2 ppm ageing following years  
  ≤ ± 15 ppm vs temperature variations (10° to 40°)

- **Frequency adjustment**  
  No (factory configured)

1.6.11 **Mechanical - Environment**

- **Industrial PC chassis**  
  Height : 4 rack spaces (7 inches)  
  Width : 19 inches  
  Depth : 550 mm

- **Main Signal Processing board**  
  5 PCI Express slots

- **Weight**  
  ≈ 25 kg (configuration dependant)

- **Built-in ventilation unit**

- **Operating temperature**  
  + 10 °C to + 35 °C (+ 40 °C in degraded mode)

- **Storage temperature**  
  - 20 °C to + 60 °C

- **Relative humidity**  
  40 % to 90 % non condensing

- **Temperature alarms**  
  Front panel LED (model dependant) & TCP-IP status (IPMIMonitor tool)

- **Front panel color**  
  RAL 5023

1.6.12 **Supply**

- **Power Supply Voltage range**  
  90-264 VAC

- **Supply frequency range**  
  47-63 Hz

- **Maximum consumption**  
  5 Amp. peak, 230 VAC / 10 Amp. peak, 115 VAC

- **Nominal consumption**  
  1.5 Amp., 230 VAC / 3 Amp., 115 VAC

1.7 **SOFTWARE LICENSES**

Consult ZODIAC DATA SYSTEMS for detailed information on the software licenses.
1.8 REFERENCE DOCUMENTATION

For in-depth knowledge of the system, the reader can consult the following documents referred to in the text as RDx, where x corresponds to the document number below:

- **CCSDS Recommendations:**
  
  (1): CCSDS Recommendations and Reports – Fall 2005 (Compact Disc)

- **ESA Documentation:**

  (2): Radio Frequency and Modulation Standard
  
  ESA PSS-04-105 - Issue 1, 1989

  (3): Packet Telecommand Standard
  
  ESA PSS-04-107 - Issue 2, 1992

  (4): Packet Telemetry Standard
  
  ESA PSS-04-106 - Issue 1, 1988

  (5): Ranging Standard
  
  TTC-A-04 - Issue 1, July 1980

- **ZODIAC DATA SYSTEMS Documentation:**


  (7): Command Operation Procedure (COP) - Interface Control Document STI 100017

  (8): SLE Gateway - User’s Manual DTU 100236

  (9): SLE Gateway - Interface Control Document STI 100013_SLE

- **Microsoft Documentation (Windows):**

  (10): Refer to MICROSOFT
1.9 INSTALLATION

The Cortex CRT is a standard 19" rack mount equipment, 4U height, 550 mm deep.

The equipment must be installed in a 19” cabinet.

The installation must follow the following guidelines :

- Use a 19” cabinet of 600mm depth or more.
- Use of open-front cabinets is preferable. If the cabinet has a closed front door, make sure that sufficient airflow is forced into the cabinet from the floor up.
- The airflow in the Cortex CRT is from the front and top to the back of the unit. Assign at least 1U of free space above the Cortex CRT unit for proper cooling. In the front of the 19” cabinet, preferably use a 1U blanking plate with a grid to allow the airflow into the Cortex CRT unit from the front of the cabinet.
- Place an extractor fan unit at the top of the 19” cabinet. Place it at the rear end of the cabinet rather than the front end to extract the warm air that may accumulate at the rear of the Cortex CRT units.
- Use L-shaped brackets in the 19” cabinet to sustain the weight of the equipment. L-shaped brackets model depends upon the cabinet manufacturer. Please contact your 19” cabinet vendor for proper L-shaped bracket selection.
- If you wish to use sliding rails, make sure that the 19” cabinet has enough stability to avoid falling forward when the Cortex CRT is pulled out. The following sliding rails can be used: Schroff, model 20110-094.
- Remove the keyboard drawer retaining screws (refer to the sticker on the side of the unit) and keep these screws for future shipments.
- For Cortex CRT units based on PC models that include a sliding front panel, remove the front panel retaining screws (refer to the sticker on the side of the unit) and keep these screws for future shipments.
- Use 4 bolts to secure the Cortex CRT unit to the 19” cabinet, using the 2 holes on each side of the front panel. Bolts and captive nuts are supplied by your 19” cabinet vendor. Make sure that the bolts are long enough to reach the nuts in the 19” cabinet rails.
- Connect the Cortex CRT to an AC power supply socket equipped with proper grounding.
- If additional grounding is desired, use the grounding bolt and nut located at the lower left corner at the rear of the Cortex CRT unit and connect to the closest grounding point in the 19” cabinet, using a copper wire or preferably a grounding braid.
- Place the BNC interconnection panel at the back of the 19” cabinet, such that you have an easy access to the connectors for maintenance purposes. Make sure that the cables between the BNC panel and the rear connectors on the unit shall not be accidentally disconnected when an equipment is pulled forward or when personnel has to reach the rear of an equipment inside the 19” cabinet.
1.10 SHIPPING

**IMPORTANT SHIPPING INSTRUCTIONS - Refer to User’s Manual for more details**

1. Secure the keyboard drawer using the supplied screws
2. Disconnect VGA and keyboard cables at the rear of the unit and protect cables
3. Protect the equipment from humidity using a sealed bag
4. Use the supplied shipping container for proper shock protection

Incorrect equipment preparation and/or incorrect packing is a frequent source of problems.

In order to avoid damage to the equipment during shipment, please follow these rules:

1. a. Secure the keyboard drawer using the supplied screws. A non-secured drawer may slide out during shipment and may become damaged or even cause damage to the chassis structure. Please refer to the sticker on the sides of the unit and to the picture below for identification of the keyboard drawer retaining screws.

1. b. For Cortex CRT units using a PC with a sliding front panel, secure the front panel using the supplied screws. A non-secured front panel may slide out during shipment and may become damaged or even cause damage to the chassis structure. Please refer to the sticker on the sides of the unit and to the picture below for identification of the front panel retaining screws.

2. Disconnect the VGA and Keyboard/Mouse cables at the rear of the unit and secure them along the rear panel using adhesive tape. Shipping the Cortex CRT unit with the VGA and Keyboard/Mouse cables connected may result in severe damage to the rear panel connectors, or even to the CPU board inside the unit.

3. Protect the Cortex CRT unit from humidity by placing it in a sealed bag. The bag used in the original shipment from Zodiac Data Systems can be re-used, if it has been cleanly cut during unpacking. Shipping an unprotected unit may result in damage caused by condensation, especially if the unit is shipped from a country in a hot and wet climate.
4. Use a shipping container that provides adequate shock protection. The original Zodiac Data Systems cardboard and laminated wood container with internal foam lining has been qualified for adequate protection of the Cortex units under transportation environments per Mil-Std-810-F, and is therefore ideally suited unless it has suffered damages from a previous shipment. Never use a non adequate container such as a cardboard box with chips, or bubble film. Shipping in a non adequate container will result in severe damage in most cases.

5. If the cables connecting the BNC panel to the Cortex CRT are being shipped, always use an ESD dissipative bag for packing the cables, such as the one used by Zodiac Data Systems in the original shipment. Using a regular plastic bag may result in accumulating static electricity charges in the cables, which will result in damaging or destroying the IF input amplifiers when the cables are connected to the unit.
2. HARDWARE DESCRIPTION
2.1 CORTEX CRT QUANTUM INTEGRATION

2.1.1 Mounting of the Boards

A sticker at the rear panel of the equipment shows how the boards must be mounted in the chassis. Do not change this setting.

All I/O ports are located at the rear panel of the chassis.

See Annex 4 for an accurate description of the PC-compatible workstation.

The cabling of the PC-compatible workstation is described in Annex 4.
2.2 NETWORK INTERFACES

2.2.1 CPU Board Ethernet Port

Connection to the Ethernet LAN is by means of two RJ45 connectors (100 Mbps or 1 Gbps Base-T standard).

The two ports can be used to either connect to separate sub-networks, or can be used in a Group on the same network, using the Intel Pro-Teaming utility (not included).

Other connectors on the CPU board provide interfaces to other devices such as:

- External keyboard & mouse,
- External VDU,
- TC Scrambler (RS-232 COM1 port).

The number of connectors and their mechanical characteristics depend on the model of PC-compatible workstation. Refer to Annex 4 for a detailed description of the board.
2.2.2 TCP-IP Interfaces

All data (TM, TC, Ranging, Monitoring & Control, Logging, etc…) are exchanged between the Signal Processing Software and the external world (Monitoring & Control Software, COP Software, Control Center clients, etc…) over a single Ethernet port. The CORTEX CRT Quantum acts as a TCP-IP server for all types of data transfer. Data are exchanged using the connected-sockets communication protocol.

Some data flows accept multiple clients at a time (monitoring, logging, telemetry, Doppler and spectrum analysis data), while other flows accept only one client at a time (equipment configuration and reset, satellite telecommanding).

Each type of transfer flow is allocated a specific port number which the clients use for connecting themselves to each «service». Port numbers are listed below (including TCP-IP ports on the optional COP Software package):

<table>
<thead>
<tr>
<th>DATA FLOW</th>
<th>PORT NUMBER</th>
<th>MAXIMUM NUMBER OF CONNECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORTEX Monitoring Data (MON)</td>
<td>3000</td>
<td>8</td>
</tr>
<tr>
<td>CORTEX Control Data (CTRL)</td>
<td>3001</td>
<td>1</td>
</tr>
<tr>
<td>CORTEX Reset (RST)</td>
<td>3002</td>
<td>1</td>
</tr>
<tr>
<td>Satellite Telecommand Data (TC)</td>
<td>3020</td>
<td>1</td>
</tr>
<tr>
<td>Simulated Data # 1 (SIM-1)</td>
<td>3021</td>
<td>1</td>
</tr>
<tr>
<td>Simulated Data # 2 (SIM-2)</td>
<td>3022</td>
<td>1</td>
</tr>
<tr>
<td>Ranging Data (RNG)</td>
<td>3034</td>
<td>1</td>
</tr>
<tr>
<td>Ranging Data (MEAS)</td>
<td>3035</td>
<td>5</td>
</tr>
<tr>
<td>Logging Data (LOG)</td>
<td>3040</td>
<td>5</td>
</tr>
<tr>
<td>Spectrum Analysis Data (SPA)</td>
<td>3050</td>
<td>4 (total for all IFRs)</td>
</tr>
<tr>
<td>Doppler or Analysis Data (DOP)</td>
<td>3060</td>
<td>8 (total for all IFRs)</td>
</tr>
<tr>
<td>Doppler Compensation port (DOPC)</td>
<td>3065</td>
<td>1</td>
</tr>
<tr>
<td>Telemetry Data (TM)</td>
<td>3070</td>
<td>24 (total for all TM channels)</td>
</tr>
<tr>
<td>COP Monitoring Data (COP-MON)</td>
<td>3100</td>
<td>4</td>
</tr>
<tr>
<td>COP Control Data (COP-CTRL)</td>
<td>3101</td>
<td>1</td>
</tr>
<tr>
<td>COP Satellite Telecommand Data (COP-TC)</td>
<td>3120</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1: Ethernet Ports Addresses
A detailed description of this interface (excluding COP ports) is available in Annex 1. The COP software Ethernet interface is described in RD6.

Next figure illustrates the data flows between CORTEX CRT Quantum software components and between the CORTEX CRT Quantum and the external world:

Figure 6: TCP-IP Interfaces
2.2.3 UDP Interface for Telemetry Data Flow

The telemetry data flow (TM) is available on a UDP port in multicast mode. The UDP TM service can be controlled from registry keys (see section: 4.2.8.10 UDP Telemetry Data).

<table>
<thead>
<tr>
<th>DATA FLOW</th>
<th>PORT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDP TM DATA</td>
<td>3075</td>
</tr>
</tbody>
</table>

*Table 2: UDP Ports Addresses*
2.3 CORTEX CONNECTION TO THE EXTERNAL WORLD

2.3.1 Interconnection Panels and associated cables

Refer to Annexe 5 to determine which of the following two Interconnection Panel is supplied with your Cortex CRT Quantum Unit.

The Interconnection Panel consists of a printed circuit board mounted on a metal panel and connected to the 68-pin male connector of the Digital I/O board via a Vport Samtec cable.

The signals corresponding to Downlink IF inputs (except the Auxiliary ones), Uplink IF outputs and 5/10 MHz Reference clock inputs are routed to the Interconnection Panel using double-shield RG223/U coaxial cables. Each single coaxial cable is marked at both ends by a sleeve to easily identify the proper connections.

The signals corresponding to Downlink Auxiliary inputs, Uplink Video modulating inputs, Time code and 1PPS inputs are routed to the Interconnection Panel using a dedicated multiple cable based on double-shield FILOTEX 21822 coaxial cable. Each coaxial cable is marked at panel end by a sleeve to easily identify the proper connections.

The signals corresponding to Video, AGC and tracking AZ/EL outputs are routed to the Interconnection Panel using another dedicated multiple cable based on double-shield FILOTEX 21822 coaxial cable. Each coaxial cable is marked at panel end by a sleeve.

2.3.1.1 Simplified Interconnection panel (1U)

I/O ports on the Interconnection Panel are all fitted out with BNC female connectors. Next figure illustrates the 1U panel appearance. The Interconnection Panel is delivered with the associated set of cables.

![Figure 7: 1U Simplified Interconnection Panel](image)

An additional breakout cable provides access to Video 1, Video 2, AGC 1, AGC 2 and AGC 3 as BNC Male connectors. The breakout cable can be used as such for test purposes, or can be connected to unused BNC connectors on the 1U panel in order to obtain a BNC Female connection. For example, if the Alternate IF inputs and outputs are not used, the breakout cable can be connected as such:

- Video 1 and Video 2: use Alternate IF Uplink BNC connectors
- AGC 1, AGC 2 and AGC 3: use Alternate IF Downlink BNC connectors
2.3.1.2 Full Interconnection panel (3U)

I/O ports on the Interconnection Panel are all fitted out with **BNC female connectors**. Next figure illustrates the 3U panel appearance. The Interconnection Panel is delivered with the associated set of cables.

![Figure 8: 3U Full Interconnection Panel](image)

Please follow the picture below for properly connecting and securing the ribbon cable to the back side of the interconnection panel:

![Figure 9: Ribbon cable connection and securing](image)
## 2.3.2 I/O Connectors description

The connectors are described based on the groups of functions highlighted by lines and a general label on the interconnection panels.

<table>
<thead>
<tr>
<th>CONNECTOR TYPE</th>
<th>CONNECTOR PANEL LABEL</th>
<th>CABLE SLEEVE LABEL</th>
<th>MSP MODULE CONNECTOR LABEL</th>
<th>SIGNAL</th>
<th>ELECTRICAL CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNC Female</td>
<td>NOMINAL IF 1</td>
<td>UL NOM IF1</td>
<td>IF out NOM 1</td>
<td>IFM-1 Nominal IF output port</td>
<td>50-90 MHz (-3 dB bandwidth) 0 to - 80 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>ALTERNATE IF 1</td>
<td>UL ALT IF1</td>
<td>IF out ALT 1</td>
<td>IFM-1 Alternate IF output port</td>
<td>50-90 MHz (-3 dB bandwidth) - 20 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>NOMINAL IF 2</td>
<td>UL NOM IF2</td>
<td>IF out NOM 2</td>
<td>IFM-2 Nominal IF output port</td>
<td>50-90 MHz (-3 dB bandwidth) 0 to - 80 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>ALTERNATE IF 2</td>
<td>UL ALT IF2</td>
<td>IF out ALT 2</td>
<td>IFM-2 Alternate IF output port</td>
<td>50-90 MHz (-3 dB bandwidth) - 20 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>VIDEO IN 1</td>
<td>UL VIDEO IN1</td>
<td>Note 1</td>
<td>Auxiliary video input to IFM-1 (analog signal)</td>
<td>100 Hz - 2 MHz 2 Vpp - 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>VIDEO IN 2</td>
<td>UL VIDEO IN2</td>
<td>Note 1</td>
<td>Auxiliary video input to IFM-2 (analog signal)</td>
<td>100 Hz - 2 MHz 2 Vpp - 50 Ω</td>
</tr>
<tr>
<td>CONNECTOR TYPE</td>
<td>CONNECTOR PANEL LABEL</td>
<td>CABLE SLEEVE LABEL</td>
<td>MSP MODULE CONNECTOR LABEL</td>
<td>SIGNAL</td>
<td>ELECTRICAL CHARACTERISTICS</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------</td>
<td>-------------------</td>
<td>---------------------------</td>
<td>--------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>BNC Female</td>
<td>NOMINAL IF 1</td>
<td>DL NOM IF1</td>
<td>IF in NOM 1</td>
<td>Nominal IF input port # 1</td>
<td>45-95 MHz (-3 dB bandwidth) -15 to -120 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>ALTERNATE IF 1</td>
<td>DL ALT IF1</td>
<td>IF in ALT 1</td>
<td>Alternate IF input port # 1</td>
<td>45-95 MHz (-3 dB bandwidth) -15 to -120 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>NOMINAL IF 2</td>
<td>DL NOM IF2</td>
<td>IF in NOM 2</td>
<td>Nominal IF input port # 2</td>
<td>45-95 MHz (-3 dB bandwidth) -15 to -120 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>ALTERNATE IF 2</td>
<td>DL ALT IF2</td>
<td>IF in ALT 2</td>
<td>Alternate IF input port # 2</td>
<td>45-95 MHz (-3 dB bandwidth) -15 to -120 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>NOMINAL IF 3</td>
<td>DL NOM IF3</td>
<td>IF in NOM 3</td>
<td>Nominal IF input port # 3</td>
<td>45-95 MHz (-3 dB bandwidth) -15 to -120 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>ALTERNATE IF 3</td>
<td>DL ALT IF2</td>
<td>IF in ALT 3</td>
<td>Alternate IF input port # 3</td>
<td>45-95 MHz (-3 dB bandwidth) -15 to -120 dBm, 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>AUXILIARY 1</td>
<td>DL AUX1</td>
<td>Note 1</td>
<td>Auxiliary input port # 1</td>
<td>DC to 90 MHz 0.1 to 0.5 Vpp (at BB) 0 to -20 dBm (at IF) 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>AUXILIARY 2</td>
<td>DL AUX2</td>
<td>Note 1</td>
<td>Auxiliary input port # 2</td>
<td>DC to 90 MHz 0.1 to 0.5 Vpp (at BB) 0 to -20 dBm (at IF) 50 Ω</td>
</tr>
<tr>
<td>CONNECTOR TYPE</td>
<td>CONNECTOR PANEL LABEL</td>
<td>CABLE SLEEVE LABEL</td>
<td>MSP MODULE CONNECTOR LABEL</td>
<td>SIGNAL</td>
<td>ELECTRICAL CHARACTERISTICS</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------</td>
<td>-------------------</td>
<td>---------------------------</td>
<td>--------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>BNC Female</td>
<td>IRIG IN</td>
<td>IRIG IN</td>
<td>Note 1</td>
<td>Reference time code input (IRIG-B122, NASA-36, IRIG 5 MHz)</td>
<td>0.1 to 6 Vpp 100 kΩ</td>
</tr>
<tr>
<td>BNC Female</td>
<td>5/10 MHz IN1</td>
<td>REF 1</td>
<td>REF 1</td>
<td>Reference clock input # 1</td>
<td>5 or 10 MHz 0.2 to 5 Vpp DC ± 4 V 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>5/10 MHz IN2</td>
<td>REF 2</td>
<td>REF 2</td>
<td>Reference clock input # 2</td>
<td>5 or 10 MHz 0.2 to 5 Vpp DC ± 4 V 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>10 MHz OUT</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>Internal 10 MHz reference clock output</td>
<td>TTL 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>1-PPS IN</td>
<td>1-PPS IN</td>
<td>Note 1</td>
<td>Reference 1-PPS clock input</td>
<td>LVTTL/TTL high imp.</td>
</tr>
<tr>
<td>BNC Female</td>
<td>1-PPS OUT</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>Internal 1-PPS reference clock output</td>
<td>TTL 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>SYNC. PULSE IN</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>External synchronization pulse input</td>
<td>LVTTL/TTL high imp.</td>
</tr>
</tbody>
</table>
### Connector Type

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>Connector Panel Label</th>
<th>Cable Sleeve Label</th>
<th>MSP Module Connector Label</th>
<th>Signal</th>
<th>Electrical Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNC Female</td>
<td>SET #1</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>Data I, Data Q, Clock IN Data I, Data Q, Clock OUT (see section 2.3.4.2 for details)</td>
<td>See section 2.3.4.2</td>
</tr>
<tr>
<td>BNC Female</td>
<td>SET #2</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>Data I, Data Q, Clock IN Data I, Data Q, Clock OUT (see section 2.3.4.2 for details)</td>
<td>See section 2.3.4.2</td>
</tr>
<tr>
<td>BNC Female DA-15 Female</td>
<td>SET #3</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>Data I, Data Q, Clock IN Data I, Data Q, Clock OUT (see section 2.3.4.2 for details)</td>
<td>See section 2.3.4.2</td>
</tr>
<tr>
<td>BNC Female DA-15 Female</td>
<td>SET #4</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>Data I, Data Q, Clock IN Data I, Data Q, Clock OUT (see section 2.3.4.2 for details)</td>
<td>See section 2.3.4.2</td>
</tr>
<tr>
<td>BNC Female</td>
<td>VIDEO 1</td>
<td>VIDEO OUT 1</td>
<td>Note 3</td>
<td>Uplink &amp; downlink video test signals (see section 2.3.4.1 for assignment to internal signals)</td>
<td>DC to 25 MHz (-3 dB attenuation) 2Vpp (adjustable, see note 4) 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>VIDEO 2</td>
<td>VIDEO OUT 2</td>
<td>Note 3</td>
<td>Uplink &amp; downlink video test signals (see section 2.3.4.1 for assignment to internal signals)</td>
<td>DC to 25 MHz (-3 dB attenuation) 2Vpp (adjustable, see note 1) 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>AGC OUT 1</td>
<td>AGC OUT 1</td>
<td>Note 3</td>
<td>AGC voltage Output 1 Non coherent AGC : significant from -20 dBm to –60 dBm, Coherent IF level : significant from 0 dBm to –100 dBm</td>
<td>0 to 10 V, 10 dB/V + 2 V = -20 dBm, +10 V = -100 dBm Requires high impedance input</td>
</tr>
<tr>
<td>BNC Female</td>
<td>AGC OUT 2</td>
<td>AGC OUT 2</td>
<td>Note 3</td>
<td>AGC voltage Output 1 Non coherent AGC : significant from -20 dBm to –60 dBm, Coherent IF level : significant from 0 dBm to –100 dBm</td>
<td>0 to 10 V, 10 dB/V + 2 V = -20 dBm, +10 V = -100 dBm Requires high impedance input</td>
</tr>
</tbody>
</table>

Note 1: 2Vpp (adjustable, see note 4)

Note 2: I/O NUM board

Note 3: Uplink & downlink video test signals (see section 2.3.4.1 for assignment to internal signals)

Note 4: 50 Ω
<table>
<thead>
<tr>
<th>CONNECTOR TYPE</th>
<th>CONNECTOR PANEL LABEL</th>
<th>CABLE SLEEVE LABEL</th>
<th>MSP MODULE CONNECTOR LABEL</th>
<th>SIGNAL</th>
<th>ELECTRICAL CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TEST POINTS (continued)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BNC Female</td>
<td>AGC OUT 3</td>
<td>AGC OUT 3</td>
<td>Note 3</td>
<td>AGC voltage Output 1 Non coherent AGC: significant from -20 dBm to –60 dBm, Coherent IF level: significant from 0 dBm to –100 dBm</td>
<td>0 to 10 V, 10 dB/V + 2 V = -20 dBm, +10 V = -100 dBm Requires high impedance input</td>
</tr>
<tr>
<td>BNC Female</td>
<td>Sts Out/J25 to Sts Out/J28</td>
<td>Note 2</td>
<td>I/O NUM board</td>
<td>Video Test Points (see section 2.3.4.1 for assignment to internal signals)</td>
<td>LVTTL 50 Ω</td>
</tr>
<tr>
<td>BNC Female</td>
<td>EXT 1 to EXT 6</td>
<td>Not supplied</td>
<td>Not supplied</td>
<td>Reserved</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>AZ / EL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-D 25</td>
<td>AZ+</td>
<td>Not supplied</td>
<td>Not supplied</td>
<td>Azimuth Error (Antenna Tracking)</td>
<td>Refer to Cortex DTR User’s Manual</td>
</tr>
<tr>
<td></td>
<td>AZ-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EL+</td>
<td></td>
<td></td>
<td>Elevation Error (Antenna Tracking)</td>
<td>Refer to Cortex DTR User’s Manual</td>
</tr>
<tr>
<td></td>
<td>EL-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note 1**: These signals are on a cluster of 6 miniature coaxial connectors on the rear panel of the MSP module.

**Note 2**: These signals are on a multiwire ribbon cable connected to the IONUM board located on a panel above the computer I/O connectors. Direct connection to the Samtec multipin connector is not recommended.

**Note 3**: These signals are on a cluster of 10 miniature coaxial connectors on the rear panel of the MSP module. For Cortex CRT applications, only 5 of the 10 connectors are used.

**Note 4**: Signal level can be adjusted from registry keys. See section 4.2.8.9.4.

*Table 3: I/O Connector Panel*
2.3.3 Industrial Computer Rear Panel description

The connection of the various signals to the user system is normally performed through the Interconnection Panel described in 2.3.1.

The computer connections (LAN, VGA, USB keyboard & mouse, RS232) are directly available on the Industrial Computer rear panel.

The picture below lists and identifies the various connections to the computer ports, and the I/O connectors of the Cortex CRT Quantum dedicated hardware.

![Rear panel connectors](image)

**Figure 10 : Rear panel connectors**

<table>
<thead>
<tr>
<th>CONNECTOR</th>
<th>USAGE</th>
<th>CONNECTOR</th>
<th>USAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AC Power input</td>
<td>13</td>
<td>Downlink – IF Nominal 1</td>
</tr>
<tr>
<td>2</td>
<td>Mechanical Ground</td>
<td>14</td>
<td>Downlink – IF Alternate 1</td>
</tr>
<tr>
<td>3</td>
<td>VGA</td>
<td>15</td>
<td>Downlink – IF Nominal 2</td>
</tr>
<tr>
<td>4</td>
<td>Keyboard &amp; Mouse - USB</td>
<td>16</td>
<td>Downlink – IF Alternate 2</td>
</tr>
<tr>
<td>5</td>
<td>NIC1 - LAN</td>
<td>17</td>
<td>Downlink – IF Nominal 3</td>
</tr>
<tr>
<td>6</td>
<td>NIC2 - LAN</td>
<td>18</td>
<td>Downlink – IF Alternate 3</td>
</tr>
<tr>
<td>7</td>
<td>Uplink – IF Nominal 1</td>
<td>19</td>
<td>Video Out &amp; AGC outputs</td>
</tr>
<tr>
<td>8</td>
<td>Uplink – IF Alternate 1</td>
<td>20</td>
<td>IRIG In, 1-PPS In, Video In, Auxiliary In</td>
</tr>
<tr>
<td>9</td>
<td>Reference Frequency 1</td>
<td>21</td>
<td>Test Points, 1-PPS Out, Sync Pulse In</td>
</tr>
<tr>
<td>10</td>
<td>Reference Frequency 2</td>
<td>22</td>
<td>Reserved</td>
</tr>
<tr>
<td>11</td>
<td>Uplink – IF Nominal 2</td>
<td>23</td>
<td>Reserved</td>
</tr>
<tr>
<td>12</td>
<td>Uplink – IF Alternate 2</td>
<td>24</td>
<td>COM-1 (normally unused)</td>
</tr>
</tbody>
</table>

*Table 4 : I/O Connector Panel*
2.3.4 Test points configuration

The Interconnection Panel has a number of analog and TTL test points, as described in the table above. Depending on the software licenses, some of these test points may be disabled.

For instance, a standard CORTEX machine for station keeping operations (low bandwidth uplink and downlink), the following « Video test points » only are available (see next table for more details):

- VIDEO 1 & VIDEO 2 (analog out)
- Sts Out/J25 to J28 (TTL, 50 Ω buffered)

Moreover, for a multi-mission machine with high data bandwidth requirements for the TMU, TMS or/and the TCU, the available tests points are the full sets of test points (SET # 1 to SET # 4), for input & output from/to high bandwidth functional units.

Refer to Annex 5 (section 1.5) for test points assignment in your machine.
### 2.3.4.1 Video Test Points

The Video test points are fully programmable from the « CONFIG » window (refer to the MCS User’s Manual and the TCP/IP Interface Specification, Global Table) for monitoring any baseband signal for **Low Bandwidth applications**:

<table>
<thead>
<tr>
<th>Setting</th>
<th>Analog Test Points (Uplink Signals)</th>
<th>LV TTL Test Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TCU</strong></td>
<td>TCU : analog output (FSK, PSK, Execute tone, ...)</td>
<td>TCU output : data, clock &amp; transmit status</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CLK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NRZL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PCM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TX (1)</td>
</tr>
<tr>
<td><strong>RAU</strong></td>
<td>RAU : analog output (range tones or modulated S/C)</td>
<td>RAU output : tone rank &amp; tone ID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FIRST (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TONE (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TONE (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TONE (3)</td>
</tr>
<tr>
<td><strong>TMS</strong></td>
<td>TMS : analog output (PCM/BPSK)</td>
<td>TMS output : data &amp; clock (if PSK modulation ON)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CLK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NRZL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PCM</td>
</tr>
<tr>
<td><strong>IFM-i</strong></td>
<td>IFM : analog input (for TCU or TMS modulating signal only)</td>
<td>IFM input : data &amp; clock of modulating signal</td>
</tr>
<tr>
<td>(i = 1 or 2)</td>
<td></td>
<td>CLK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NRZL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PCM</td>
</tr>
</tbody>
</table>

**Table 5** : Interconnection Panel. Uplink Video Test Points

- **Note 1**: Active (5 V) during FSK or PSK modulation or transmission of an Execute or pseudo-earth pulse.

- **Note 2**: Set to 5 V at the beginning of the ranging sequence (transmission of first tone). Drops to 0 V at:
  - the first measurement performed on the first tone (INMARSAT and LMCO standards) or
  - the first measurement on the major tone (ESA, ESA-like, USB, and ESA code standard).

- **Note 3**: Binary-coded identity of the transmitted tones (0 = 0 V, 1 = 5 V):
ESA and ESA-like tone standards:

<table>
<thead>
<tr>
<th></th>
<th>No tone</th>
<th>Major</th>
<th>Minor 1</th>
<th>Minor 2</th>
<th>Minor 3</th>
<th>Minor 4</th>
<th>Minor 5</th>
<th>Minor 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>J26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>J27</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>J28</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

USB tone standard:

<table>
<thead>
<tr>
<th></th>
<th>No tone</th>
<th>Major</th>
<th>Minor 1</th>
<th>Minor 2</th>
<th>Minor 3</th>
<th>Minor 4</th>
<th>Minor 5</th>
<th>Minor 6</th>
<th>Minor 7</th>
<th>Minor 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>J26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>J27</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>J28</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

INMARSAT and LMCO tone standards:

<table>
<thead>
<tr>
<th></th>
<th>Major Tone</th>
<th>Minor 1</th>
<th>Minor 2</th>
<th>Minor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>J26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>J27</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>J28</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

ESA code standard:

<table>
<thead>
<tr>
<th></th>
<th>Start of sequence ...</th>
<th>... end of sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Idle state</td>
<td>Major tone (set time)</td>
</tr>
<tr>
<td>J26</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>J27</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>J28</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

(1) : 3-bit counter (J1 = LSB and J2 = MSB; 0 = 0 V, 1 = 5 V). Set to 001B when the RAU starts transmitting the first code. The counter is then incremented by 1, for each transmitted code and, at the end of the sequence, when the major tone is transmitted alone for accurate phase measurement. Example: if the code length is set to 18, the number of transmitted codes is 9. The counter will take the following values (in decimal): 0 (major tone set time), 1, 2, ..., 6, 7, 0, 1 (end of code transmission), 2 (phase measurement on major tone).
2.3.4.2 TTL and RS422 Data I/Os

Four sets of TTL test points labeled SET #1 (connectors J1, J5, J9, J13, J17, J21), SET #2 (connectors J2, J6, J10, J14, J18, J22), SET #3 (connectors J3, J7, J11, J15, J19, J23) and SET #4 (connectors J4, J8, J12, J16, J20, J24) are available. SET #3 and SET #4 are also available as RS422 on a separate connector.

SET #1 to 4 can be used for data & clock I/Os on the High bandwidth TMU, TCU and TMS units. The assignment is factory configured, but can also be modified by the user as described in section 4.2.8.9.

Refer to Annex 5 (section 1.5) for uplink and downlink data I/Os assignment in your machine.

Refer to section 3.3.7 for more details on the usage on Downlink I/O test points.

Refer to section 3.4.1 for more details on the usage on Uplink I/O test points.

<table>
<thead>
<tr>
<th>TEST POINT</th>
<th>SIGNAL DESCRIPTION</th>
<th>ELECTRICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SET #1 I in / J1</td>
<td>Uplink: I channel input (NRZL) to the TMS or TCU Downlink: I channel input to the associated TMU (decoding or F/S)</td>
<td>LVTTTL/TTL high imp.</td>
</tr>
<tr>
<td>SET #2 I in / J2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #3 I in / J3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #4 I in / J4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #1 Q in / J5</td>
<td>Uplink: Q channel input (NRZL) to the TMS or TCU (for QPSK and OQPSK modulation only) Downlink: Q channel input to the associated TMU (decoding or F/S) (QPSK or OQPSK demodulation only)</td>
<td>LVTTTL/TTL high imp.</td>
</tr>
<tr>
<td>SET #2 Q in / J6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #3 Q in / J7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #4 Q in / J8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #1 Clk in / J9</td>
<td>Uplink: clock input to the TMS or TCU, refer to paragraph 4.2.8.9.1 and 4.2.8.9.2 for sampling polarity Downlink: Clock input to the associated TMU (decoding or F/S), refer to paragraph 0 for sampling polarity</td>
<td>LVTTTL/TTL high imp.</td>
</tr>
<tr>
<td>SET #2 Clk in / J10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #3 Clk in / J11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #4 Clk in / J12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #1 I out / J13</td>
<td>Uplink: I channel output (NRZL) of the TMS or TCU Downlink: Bit synchronizer or Decoder output (I channel) of the associated TMU (see Note 1)</td>
<td>TTL 50 Ω</td>
</tr>
<tr>
<td>SET #2 I out / J14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #3 I out / J15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #4 I out / J16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #1 Q out / J17</td>
<td>Uplink: Q channel output (NRZL) of the TMS or TCU (for QPSK and OQPSK modulation only) Downlink: Bit synchronizer output (Q channel) of the associated TMU (QPSK or OQPSK demodulation only)</td>
<td>TTL 50 Ω</td>
</tr>
<tr>
<td>SET #2 Q out / J18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #3 Q out / J19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #4 Q out / J20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #1 Clk out / J21</td>
<td>Uplink: clock output of TMS or TCU, refer to paragraph 4.2.8.9.1 and 4.2.8.9.2 for data update polarity Downlink: Clock output of the associated TMU, refer to paragraph 0 for data update polarity</td>
<td>TTL 50 Ω</td>
</tr>
<tr>
<td>SET #2 Clk out / J22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #3 Clk out / J23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SET #4 Clk out / J24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note 1: merged I & Q channels if parameter TP : I/Q INTERLEAVE is set to ENABLE (Refer to the MCS User’s Manual and the TCP/IP Interface Specification (TMU Table) for more information on I/Q interleave, I/Q swap, I/Q invert and PCM encoding on the test points).

Table 6: Interconnection Panel. TTL Data I/Os
For applications requiring RS422 Differential signal interfacing, SET #3 and SET #4 can be used. The picture and table below describes the pin assignment of the RS422 connector.

![DA-15 Female connector, front view](image)

**Figure 11 : DA-15 Female connector, front view**

<table>
<thead>
<tr>
<th>PIN #</th>
<th>SIGNAL NAME</th>
<th>IN/OUT</th>
<th>SIGNAL DESCRIPTION</th>
<th>ELECTRICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I_IN_POS</td>
<td>IN</td>
<td>I Data Input, positive</td>
<td>RS-422</td>
</tr>
<tr>
<td>2</td>
<td>Q_IN_POS</td>
<td>IN</td>
<td>Q Data Input, positive</td>
<td>RS-422</td>
</tr>
<tr>
<td>3</td>
<td>CLK_IN_POS</td>
<td>IN</td>
<td>Clock Input, positive</td>
<td>RS-422</td>
</tr>
<tr>
<td>4</td>
<td>GND</td>
<td></td>
<td>Ground</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>GND</td>
<td></td>
<td>Ground</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I_OUT_NEG</td>
<td>OUT</td>
<td>I Data Output, negative</td>
<td>RS-422</td>
</tr>
<tr>
<td>7</td>
<td>Q_OUT_NEG</td>
<td>OUT</td>
<td>Q Data Output, negative</td>
<td>RS-422</td>
</tr>
<tr>
<td>8</td>
<td>CLK_OUT_NEG</td>
<td>OUT</td>
<td>Clock Output, negative</td>
<td>RS-422</td>
</tr>
<tr>
<td>9</td>
<td>I_IN_NEG</td>
<td>IN</td>
<td>I Data Input, negative</td>
<td>RS-422</td>
</tr>
<tr>
<td>10</td>
<td>Q_IN_NEG</td>
<td>IN</td>
<td>Q Data Input, negative</td>
<td>RS-422</td>
</tr>
<tr>
<td>11</td>
<td>CLK_IN_NEG</td>
<td>IN</td>
<td>Clock Input, negative</td>
<td>RS-422</td>
</tr>
<tr>
<td>12</td>
<td>GND</td>
<td></td>
<td>Ground</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>I_OUT_POS</td>
<td>OUT</td>
<td>I Data Output, positive</td>
<td>RS-422</td>
</tr>
<tr>
<td>14</td>
<td>Q_OUT_POS</td>
<td>OUT</td>
<td>Q Data Output, positive</td>
<td>RS-422</td>
</tr>
<tr>
<td>15</td>
<td>CLK_OUT_POS</td>
<td>OUT</td>
<td>Clock Output, positive</td>
<td>RS-422</td>
</tr>
</tbody>
</table>

**Table 7 : Interconnection Panel. RS422 Data I/Os**
3. FUNCTIONAL DESCRIPTION
3.1 MONITORING & CONTROL

Refer to the Cortex CRT TCP/IP Interface Document, STI 100013_CRT in Annex 1.

3.1.1 Monitoring

3.1.1.1 Standard Monitoring Protocol

The CORTEX CRT Quantum supplies its status upon request from a Monitoring Client. On reception of a monitoring request, the CORTEX CRT Quantum checks its validity. If the request is correct, it returns a monitoring message embedded in an ETHERNET packet to the Control Center. In case of invalid request, the CORTEX CRT Quantum returns a negative acknowledgment message.

A monitoring message contains the current configuration of the unit (expected frequency, operating mode, etc...), dynamic status (IF level, Eb/No, frequency offset, etc...) and alarms (Time alarm, hardware alarm, etc...).

Depending on the configuration of the CORTEX CRT Quantum at delivery, up to nine functional units are available:

<table>
<thead>
<tr>
<th>UNIT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFR</td>
<td>IF Receiver: performs FM, PM, BPSK, QPSK, OQPSK, SOQPSK, GMSK, AQPSK demodulation at IF</td>
</tr>
<tr>
<td>TMU</td>
<td>Telemetry Unit: performs demodulation at baseband, bit synchronization, data decoding and frame synchronization</td>
</tr>
<tr>
<td>TCU</td>
<td>Telecommand Unit: performs TC data modulation at baseband, TC tones transmission</td>
</tr>
<tr>
<td>RAU</td>
<td>Ranging Unit: performs tone generation and demodulation, phase and distance measurement</td>
</tr>
<tr>
<td>TMS</td>
<td>Telemetry Simulator: generates a BPSK or PCM telemetry signal for test purposes</td>
</tr>
<tr>
<td>IFM</td>
<td>IF Modulator: performs modulation at IF (FM, PM, BPSK, QPSK, OQPSK, AQPSK)</td>
</tr>
<tr>
<td>DCU</td>
<td>Diversity Combining Unit: polarization combining in post-detection mode</td>
</tr>
<tr>
<td>NGU</td>
<td>Noise Generator Unit</td>
</tr>
</tbody>
</table>

Table 8: The Functional Units of the CORTEX CRT Quantum

For test purpose (telemetry BER and range measurement degradation with noise), a Noise Generator license can be provided (no additional hardware required) for adding noise to the uplink IF carrier (optional feature).

The Monitoring Client can request:

- the high-level monitoring table of the CORTEX CRT Quantum,
- the monitoring table of a particular unit (IFR, TMU, IFM, TCU, TMS, Noise Generator, etc...),
- the project-specific monitoring table,
- the whole set of monitoring tables.
Up to eight Monitoring Clients can be simultaneously connected to the Monitoring port. For more detail on the contents of the monitoring messages, refer to Annex 1.

### 3.1.1.2 Low Bandwidth Monitoring Protocol

The low bandwidth monitoring protocol allows to save TCP-IP network bandwidth by sending monitoring messages only when at least one configuration parameter or/and one status/alarm have changed.

Monitoring messages are transmitted on request or automatically at programmable time interval.

Depending on the received monitoring request, two types of monitoring tables can be transmitted:

- Fixed-size monitoring tables (as per the standard monitoring protocol) containing all parameters, status and alarms, including the ones that haven’t changed.
- Variable-size monitoring tables reflecting only the parameter, status and alarm changes.

### 3.1.2 Control

Configuration commands received from a Control Client allow configuring the equipment (example: change the uplink carrier frequency on the IF Modulator) or triggering and action (example: restart the carrier acquisition process on the IF Receiver).

A detailed description of the Graphical User Interface is available in the Cortex MCS User’s Manual. See also Annex 1 for more details on the configuration parameters and configuration commands syntax.

Simultaneous connection of several Control Clients to the Control port is not allowed for security reasons.
3.2 LOGGING

3.2.1 General

The CORTEX CRT Quantum reports on the Logging port all changes in its configuration, as well as satellite TC requests, TC instructions and associated acknowledgement messages exchanged over the Telecommand port.

Up to five Logging Clients can be simultaneously connected to the Logging port. For more detail on the contents of the logging messages, refer to Annex 1.

3.2.2 Storage of Logging Data

Logging messages (configuration changes and telecommanding messages) can be stored in a FIFO-structured file (circular buffer) on the hard disk.

TCP-IP logging messages are directly stored to the disk (messages are not re-shaped). See Annex 1 (STI100013_TTC, Section 2.8.2) for a detailed description of the logging messages.

TCP-IP messages are not divisible: if a message cannot be entirely stored at the end of the file (not enough space left), it will be stored from the beginning of the file.

The storage function can be enabled/disabled and the file size changed in the Windows registry (see section 4.2.8.7.2).
3.3 IF DEMODULATION & TELEMETRY PROCESSING

3.3.1 Demodulation Capability

3.3.1.1 Low & High Bandwidth TMU

Next table summarizes the maximum bit rate and sub-carrier frequency supported by the TMU in Low and High bandwidth modes:

<table>
<thead>
<tr>
<th>Telemetry Unit Setting</th>
<th>IF Receiver Setting</th>
<th>Rate (see next section)</th>
<th>Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Bandwidth</td>
<td>Video mode</td>
<td>SCF ≤ 128 kHz</td>
<td>PCM/BPSK/PM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR ≤ 25 kbps</td>
<td>PCM/BPSK/FM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR ≤ 25 kbps</td>
<td>PCM/PM</td>
</tr>
<tr>
<td>High Bandwidth</td>
<td>Video mode</td>
<td>If sub-carrier present :</td>
<td>PCM/BPSK/PM</td>
</tr>
<tr>
<td>with sub-carrier</td>
<td></td>
<td></td>
<td>PCM/BPSK/FM</td>
</tr>
<tr>
<td>demodulation capability</td>
<td></td>
<td></td>
<td>PCM/PM/FM</td>
</tr>
<tr>
<td>(HBW with S/C)</td>
<td></td>
<td></td>
<td>(if PCM/FM option)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PCM/FM/FM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(if PCM/FM option)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If no sub-carrier      :</td>
<td>PCM/PM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR ≤ 5 Mbps (***)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>If no sub-carrier      :</td>
<td>PCM/FM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR ≤ 15 Mbps (***)</td>
<td></td>
</tr>
<tr>
<td>High Bandwidth, direct</td>
<td>PCM mode</td>
<td>BR ≤ 20 Mbps (*)</td>
<td>PCM/PM</td>
</tr>
<tr>
<td>PCM</td>
<td></td>
<td></td>
<td>PCM/BPSK</td>
</tr>
<tr>
<td>(HBW, direct PCM)</td>
<td></td>
<td></td>
<td>PCM/QPSK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR ≤ 20 Mbps (*)</td>
<td>PCM/OQPSK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SQQPSK, GMSK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR ≤ 20 Mbps on each rail (*)</td>
<td>PCM/AQPSK</td>
</tr>
</tbody>
</table>

Table 9: Demodulation Capabilities

(*) : Maximum bit rates. May be less if several high bandwidth telemetry chains are enabled (see next table for bit rate and symbol rate limitations on high bandwidth telemetry chains without sub-carrier).

(**) : NRZ codes, PM/PCM BIP < 2.5 Mbps, FM/PCM BIP < 1 Mbps
### 3.3.1.2 Demodulation without Sub-Carrier

Next table gives the maximum bit and symbol rates for high bandwidth telemetry chains without sub-carrier:

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Viterbi Decoding</th>
<th>Differential Decoding</th>
<th>Programmed Bit Rate</th>
<th>Bit Synchronizer Output</th>
<th>Frame Synchronizer Input</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>maximum BW (1)</td>
<td>restricted BW (1)</td>
<td>maximum BW (1)</td>
</tr>
<tr>
<td><strong>BPSK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCM/PM PCM/FM</td>
<td>Disabled</td>
<td>NRZ-L/M/S</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>20 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enabled</td>
<td>NRZ-L/M/S</td>
<td>20 Mbps</td>
<td>20 Mbps</td>
<td>20 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DBP-M/S</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td></td>
<td>Enabled</td>
<td>DBP-M/S</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td><strong>QPSK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td>NRZ-L/M/S</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>10 Msps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enabled</td>
<td>NRZ-L/M/S</td>
<td>40 Mbps</td>
<td>20 Mbps</td>
<td>20 Msps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DQPSK</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>10 Msps</td>
</tr>
<tr>
<td><strong>OQPSK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td>NRZ-L/M/S</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>10 Msps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enabled</td>
<td>NRZ-L/M/S</td>
<td>20 Mbps</td>
<td>20 Mbps</td>
<td>10 Msps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DOQPSK</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>10 Msps</td>
</tr>
<tr>
<td><strong>AQPSK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td>NRZ-L/M/S</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>20 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enabled</td>
<td>NRZ-L/M/S</td>
<td>20 Mbps</td>
<td>20 Mbps</td>
<td>20 Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td>BP-L/M/S</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td></td>
<td>Enabled</td>
<td>BP-L/M/S</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td><strong>GMSK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enabled</td>
<td>NRZ-L</td>
<td>20 Mbps</td>
<td>20 Mbps</td>
<td>10 Msps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td>NRZ-L</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>10 Msps</td>
</tr>
</tbody>
</table>

(1) : depending on the telemetry **licenses** installed in the machine, the data bandwidth (BW) will be either **Maximum** or **Restricted**.

(2) : maximum bit and symbol rates are per channel

**Table 10**: Performance Limitations for Direct PCM Demodulation
Note:

- The performances limitations for QPSK and OQPSK demodulation with NRZ-L/M/S decoding are significant in the case of separate decoding on I and Q channels for ambiguities solving too.
- The performances limitations for AQPSK demodulation apply to each Telemetry Unit (I & Q channels).

3.3.1.2.1 Constellation Convention

IF demodulation is as per the following counterclockwise convention:

\[
S(t) = \frac{A}{\sqrt{2}} \left[ e^{j\beta(t)} + e^{j\alpha(t)+\pi/2} \right] e^{j\omega t} \text{ gives } \text{Re}\{S(t)\} = s(t) = A \left[ (-1)^{q(t)} \cos(\omega t) - (-1)^{i(t)} \sin(\omega t) \right]
\]

where \( i(t) \) and \( q(t) = 0 \) or 1 :

\[
\begin{align*}
10 & \quad \sin \quad I/Q \\
00 & \quad \cos \\
11 & \quad 01
\end{align*}
\]

I and Q outputs can be swapped on the IF receiver in case of clockwise convention.

3.3.1.2.2 AQPSK Processing

The AQPSK telemetry chain consists of an IF Receiver feeding two telemetry units (TMU-A and TMU-B) in parallel. The demodulation algorithm depends on whether TMU-A is used for the highest or lowest bit rate bit rate.

If TMU-A is used for the highest bit rate, the IF Receiver operates in QPSK mode and it will lock only when both Bit Synchronizers are locked. This locking process is robust since the performances do not depend on the bit rates ratio and the data themselves. The drawback is that the acquisition and tracking threshold is based on the highest bit rate (the higher the bit rate, the higher the threshold). This scenario is recommended when both bit rates are very close to each other.

Oppositely, if TMU-A is used for the lowest bit rate, the IF Receiver operates in BPSK mode on the lowest rate channel and it is declared locked as soon as TMU-A is locked and whatever TMU-B status is (locked or unlocked).

In this mode, the acquisition and tracking threshold will be much better (lower) than in the first scenario. The drawback is that the highest bit rate signal has to be rejected by the lowest bit rate processing bandwidth to avoid performance degradation. In other words, this mode should be used only when the bit rate ratio between the two channels is as high as possible (ideally greater than 4, higher than 2 in any case). It is also desirable that the lowest bit rate demodulation remains available even if the highest bit rate one is not.
3.3.1.2.3 GMSK DEMODULATION

Gaussian Minimum Shift Keying (GMSK) is a constant envelope, Continuous Phase Modulation (CPM). It is derived from Minimum Shift Keying (MSK) with the addition of a baseband Gaussian filter that further reduces side lobe levels and spectral bandwidth. The product of the Gaussian filter bandwidth and the coded symbol period at the input to the modulator, referred to as the $B_{Ts}$ factor, is used to differentiate between GMSK modulations of varying bandwidth efficiencies.

GMSK is inherently a differential Continuous Phase Modulation (i.e., the information is carried in the change of the phase rather than the phase itself). A differential decoder is needed at the receiver which increases the BER by approximately a factor of two. By pre-coding the GMSK signal at the transmitter to remove the inherent differential encoding, the BER can be halved.
3.3.1.2.4 SOQPSK DEMODULATION

Shaped Offset QPSK (SOQPSK) is a constant envelope Continuous Phase Modulation (CPM). It is derived from OQPSK with the addition of a baseband filter that further reduces side lobe levels and spectral bandwidth. Filter shapes are defined for SOQPSK-TG, -MIL, -A and –B.

SOQPSK can be combined with a differential decoder to remove the phase ambiguity of the modulation. BER will be increased by a factor of two.
3.3.1.3 FM demodulation

The number of periods of the FM discriminator can be configured between 1 to 16. The output amplitude depends on the selected Pre-Detection filter and the discriminator number of periods.

Let us take the example of an input IF carrier which is FM modulated by a pure sub-carrier, this signal being in the Pre-Detection filter bandwidth. The digital phase output $\phi(n)$ of the Cartesian-to-polar converter is:

$$\phi(n) = \frac{2^N}{2\pi} \left[ (\omega - \omega CF) \frac{n}{F_s} + \frac{\Delta F}{f_{sc}} \cos \left( \omega c \frac{n}{F_s} \right) \right] + \phi(0)$$

where:

- $n$ is the sample time index,
- $N$ is the number of bits on which the phase and the frequency are coded,
- $\omega CF$ is the pulsation of the Center Frequency transposing synthesizer-NCO,
- $\omega c$ is the pulsation of the input signal carrier,
- $\omega sc$ is the pulsation of the input modulation sub-carrier,
- $F s$ is the sampling frequency,
- $f sc$ is the frequency of the input modulation sub-carrier,
- $\Delta F$ is the FM frequency deviation.

The frequency output $f(n)$ of the differentiator is:

$$f(n) = \frac{2^N}{2\pi} \left[ (\omega - \omega CF) \frac{D}{F_s} + \frac{\Delta F}{f_{sc}} \times (-2) \sin \left( \omega c \frac{D}{2} \right) \sin \left( \omega c \left( n + \frac{D}{2} \right) \frac{1}{F_s} \right) \right]$$

where $D$ is the differentiator delay.

The frequency output $f_{\text{norm}}(n)$ normalized on Full Scale is:

$$f_{\text{norm}}(n) = \frac{D (f sc - f CF)}{F s / 2} + \frac{D \times \Delta F}{F s / 2} \times \frac{\sin \left( \frac{\pi f_{sc}}{F s} D \right)}{\pi \frac{f_{sc}}{F s} D} \times (-1) \sin \left( \omega c \left( n + \frac{D}{2} \right) \frac{1}{F_s} \right)$$

The level of the sub-carrier on frequency output is (expressed in dBFS):

$$f_{\text{norm}}(f sc) = 20 \log_{10} \left[ \frac{D \times \Delta F}{F s / 2} \right] - 3 + 20 \log_{10} \left\{ \frac{\sin \left( \frac{\pi f_{sc}}{F s} D \right)}{\pi \frac{f_{sc}}{F s} D} \right\}$$

We notice that:

- in the first term, the demodulated output is amplified when the discriminator delay is increased or when the Cartesian-to-polar sampling frequency $F s$ is decreased,
- the Sinc term filters the output with a bandwidth which is increased when the Cartesian-to-polar sampling frequency $F s$ is increased or when the discriminator delay is decreased.
Here are the values of the Cartesian-to-polar sampling frequency $F_s$ corresponding to the different Pre-Detection filters:

<table>
<thead>
<tr>
<th>Pre-Detection Filter</th>
<th>Cartesian-to-Polar Sampling Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 MHz</td>
<td>50 Msps</td>
</tr>
<tr>
<td>5 MHz</td>
<td>20 Msps</td>
</tr>
<tr>
<td>3 MHz</td>
<td>20 Msps</td>
</tr>
<tr>
<td>1.5 MHz</td>
<td>10 Msps</td>
</tr>
<tr>
<td>1 MHz</td>
<td>5 Msps</td>
</tr>
<tr>
<td>500 kHz</td>
<td>2.5 Msps</td>
</tr>
<tr>
<td>300 kHz</td>
<td>1.25 Msps</td>
</tr>
<tr>
<td>150 kHz</td>
<td>625 ksps</td>
</tr>
<tr>
<td>5 to 100 kHz</td>
<td>312.5 ksps</td>
</tr>
</tbody>
</table>

Table 11: Cartesian-to-Polar Sampling Frequencies

3.3.1.4 IF Level Measurement

For PM, direct PCM/PM and coherent AM demodulation, the measured IF level is the level of the remnant carrier. For BPSK, QPSK, OQPSK, SOQPSK, GMSK, AQPSK, the measured IF level is the signal energy. For FM and non-coherent AM demodulation, the IF level is measured within the the pre-detection bandwidth.

3.3.1.5 Low Bandwidth TMU

For low bandwidth applications (PCM/BPSK/PM, BR < 25 kbps and SCF < 128 kHz), the Bit Synchronizer can operate in two modes: Normal mode or Extended mode.

- In the Normal mode, the Bit Synchronizer features a standard PLL for regenerating the PCM clock.
- In the Extended mode, the Bit Synchronizer regenerates the PCM clock from the BPSK sub-carrier. This mode requires that the PCM clock and the BPSK sub-carrier are synchronous (derived from the same reference clock).

The Extended mode should be selected whenever the PCM transition rate is not sufficient to maintain the PLL locked in Normal mode (NRZ PCM code with long series of zeros or ones).

The operating mode can be changed in the Windows registry (for more details, see also Section 4.2.8.3).
3.3.2 IF Carrier Acquisition

3.3.2.1 Acquisition Algorithms

3.3.2.1.1 FFT – WIDE SPECTRUM

Based on spectrum analysis with aliasing. This algorithm is fast and rather robust to noise. In case of low signal to noise ratio, the acquisition performance depends on the demodulation scheme.

3.3.2.1.2 FFT – NARROW SPECTRUM

Based on spectrum analysis. This algorithm is robust to noise and Doppler rate. Very low bit rates require higher FFT resolution; hence acquisition is slower and proportional to the acquisition range and loop bandwidth.

3.3.2.1.3 SCANNING SWEEP

The software sweeps the acquisition range by regular steps and selects the most significant signals. Acquisition time is directly proportional to the acquisition range, the symbol rate and the loop bandwidth.

3.3.2.1.4 HIGHEST SPECTRUM LINE

Based on spectrum analysis. Selection of the highest spectrum line rising out of the noise. Used for acquiring a remnant IF carrier, PM modulated by a sub-carrier or a PCM signal, with a modulating index such that the side lobes are lower than the carrier.

---

**Ex: Video Signal**

![Diagram of Video Signal](image)
### 3.3.2.1.5 CENTER SPECTRUM LINE

Based on spectrum analysis. Identification of the spectrum lines rising out of the noise and selection of the center one. Used for acquiring a remnant IF carrier, PM modulated by a sub-carrier or a PCM signal, with any modulating index up to carrier disappearance \( m = 2.406 \) radians. **Not available for PM PLL BW below 10 Hz.**

**Ex: Video Signal**

**Ex: PCM/PM with Bi-Phase**
3.3.2.1.6 **Barycentre Frequency**

Based on spectrum analysis and used for FM demodulation with low frequency deviation (< 500 kHz peak). Spectrum identification and selection of the spectrum barycenter.
3.3.2.1.7 **MANUAL SWEEP**

The IF Receiver sweeps the whole spectrum in the programmed carrier acquisition range until it finds a signal on which it can lock. After programming the IF Receiver in Manual mode, the frequency offset is set to the lower limit of the acquisition range (example -130 kHz).

Sweeping starts when the Operator click on icon in the top-level window (Refer to the MCS User’s Manual and the TCP/IP Interface Specification – IFR Restart). For each carrier or pseudo-carrier found in the spectrum (telemetry lateral band, spurious...), the IF Receiver will attempt to phase lock to the signal.

When the IF Receiver is locked, sweeping can be restarted by clicking again the icon. After the spectrum has been totally scanned, the frequency offset is again set to the lower limit of the acquisition range.

Note that the loop bandwidth can be changed while the spectrum is being scanned.

3.3.2.1.8 **ACQUISITION BY-PASS**

The tracked frequency is the center frequency set by the user.
3.3.2.2 IF Receiver in Video Mode

Next table gives the acquisition and tracking C/No and Doppler rate thresholds according to the PLL bandwidth:

<table>
<thead>
<tr>
<th>PLL BANDWIDTH (HZ)</th>
<th>WORST CASE C/NO (DB.HZ)</th>
<th>WORST CASE DOPPLER RATE (HZ/S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>30</td>
<td>400</td>
</tr>
<tr>
<td>300</td>
<td>35</td>
<td>1800</td>
</tr>
<tr>
<td>1000</td>
<td>40</td>
<td>10000</td>
</tr>
<tr>
<td>3000</td>
<td>45</td>
<td>15000</td>
</tr>
</tbody>
</table>

3.3.2.2.1 PM and Coherent AM Demodulation

<table>
<thead>
<tr>
<th>OPERATING MODE</th>
<th>CARRIER ACQUISITION MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic</td>
<td>Highest spectrum line</td>
</tr>
<tr>
<td>Manual</td>
<td>Manual sweep</td>
</tr>
<tr>
<td>NORMAL</td>
<td>CENTER SPECTRUM LINE</td>
</tr>
<tr>
<td>HIGH INDEX</td>
<td></td>
</tr>
</tbody>
</table>

3.3.2.2.2 FM Demodulation

<table>
<thead>
<tr>
<th>OPERATING MODE</th>
<th>CARRIER ACQUISITION MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic</td>
<td>Barycenter frequency</td>
</tr>
<tr>
<td>Manual</td>
<td>Acquisition by-pass</td>
</tr>
</tbody>
</table>

3.3.2.2.3 By-pass, Spectrum and Non-Coherent AM Modes

The acquisition process is by-passed in these modes (by-passed IFR, Spectrum analysis and non-coherent AM).
3.3.2.3 IF Receiver in PCM Mode

Next table gives the acquisition and tracking Es/No thresholds according to the PLL bandwidth:

<table>
<thead>
<tr>
<th>PLL BANDWIDTH (% SR)</th>
<th>WORST CASE Es/No (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>-8</td>
</tr>
<tr>
<td>0.03</td>
<td>-5</td>
</tr>
<tr>
<td>0.1</td>
<td>-2</td>
</tr>
<tr>
<td>0.3</td>
<td>+2</td>
</tr>
<tr>
<td>1</td>
<td>+4</td>
</tr>
<tr>
<td>3</td>
<td>+4</td>
</tr>
</tbody>
</table>

Next table gives the acquisition and tracking Doppler rate threshold for the IF Receiver in direct PCM mode (no sub-carrier) and with the PLL bandwidth $\geq 0.1\%$, the symbol rate $\geq 10$ kps, the Eb/No $\geq 12$ dB and the acquisition range set to $\pm 500$ kHz:

<table>
<thead>
<tr>
<th>DEMODULATION</th>
<th>WORST CASE DOPPLER RATE (Hz/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>$5 \times$ Symbol Rate x PLL bandwidth (Max = 40 kHz/s)</td>
</tr>
<tr>
<td>XQPSK</td>
<td>$2 \times$ Symbol Rate x PLL bandwidth (Max = 10 kHz/s)</td>
</tr>
</tbody>
</table>

Note: It must be checked that the programmed acquisition range and the expected maximum Doppler values are consistent. The higher the acquisition range is, the longer will be the acquisition process.

3.3.2.3.1 PCM/PM Demodulation

<table>
<thead>
<tr>
<th>CARRIER ACQUISITION MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORMAL</td>
</tr>
<tr>
<td>HIGH INDEX</td>
</tr>
<tr>
<td>Highest spectrum line</td>
</tr>
<tr>
<td>Center spectrum line</td>
</tr>
</tbody>
</table>
### 3.3.2.3.2 BPSK, QPSK, OQPSK, SOQPSK, GMSK Demodulation

<table>
<thead>
<tr>
<th>Symbol Rate</th>
<th>&lt; 150 KSPS</th>
<th>≥ 150 KSPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT Narrow spectrum</td>
<td></td>
<td>FFT wide spectrum</td>
</tr>
</tbody>
</table>

### 3.3.2.3.3 AQPSK Demodulation

<table>
<thead>
<tr>
<th>Highest Symbol Rate (First TMU)</th>
<th>&lt; 150 KSPS</th>
<th>≥ 150 KSPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT Narrow spectrum</td>
<td></td>
<td>FFT wide spectrum</td>
</tr>
</tbody>
</table>
3.3.3 IF Carrier Tracking

Once the carrier frequency is acquired as per previous section, tracking is launched using Phase-Locked Loop technique.

Cortex CRT XL Quantum uses a 2\textsuperscript{nd} order PLL for carrier tracking.

CRT DS Quantum can be configured to 2\textsuperscript{nd} order PLL or 3\textsuperscript{rd} order PLL, using the PLL order registry parameter (see chapter 4.2.8.2.5). This section describes the performances for tracking only, acquisition performance is not depending on the loop order and is described in chapter 3.3.2.2.

3.3.3.1 2\textsuperscript{nd} Order PLL

This is the most commonly used PLL. However for demanding applications, this loop has one drawback:

- Expected C/N0 is sizing the loop bandwidth
- Loop bandwidth is sizing the Doppler rate

Example: The C/N0 drives the choice of the Loop Bandwidth. If you want to track a signal with a low C/N0, you have to choose the narrowest loop bandwidth in order to increase the ratio S/N.

With this hypothesis, reducing the bandwidth implies a lower tracking performance for the Doppler rate.

And finally, the Doppler generates a phase error bias in the loop of

$$\phi_e = \frac{\alpha}{(2BL)^2} \cdot \text{DopplerRate}$$

\(\alpha\) is a constant value (approx. 7.05) and it is relative to damping factor (0.7 in case of Cortex)

The total phase error is composed with \(\phi_e\) and \(\sigma\) which is the standard deviation.

$$\sigma = \frac{2B_n}{\sqrt{2 S N_0}} \quad \text{with} \quad S \ N_0 \quad \text{Signal Noise ratio input (dB.Hz)}$$

The PLL cannot manage an bias error superior to \(\frac{\pi}{2}\), so the maximum admissible Doppler Rate cannot exceed

$$\text{DopplerRate} < \left(\frac{2BL}{7.05}\right)^2 \left(\frac{\pi}{2} - 4\sigma\right)$$

Example: With 2BL=100 Hz, and \(\frac{S}{N_0} = 40 \text{ dB.Hz}\), the maximum Doppler Rate is:

$$R = \left(\frac{2BL}{7.05}\right)^2 \left[\frac{\pi}{2} - 4\sqrt{\frac{2B_n}{2 S N_0}}\right] < 1826 \text{ Hz/s}$$
The graph below shows the theoretical tracking capacity of the 2\textsuperscript{nd} order PLL. The real limit on the Cortex CRT-DS is slightly lower (typically 15% less).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{tracking_capacity_graph.png}
\caption{2\textsuperscript{nd} Order PLL Tracking capacity}
\end{figure}
3.3.3.2 3\textsuperscript{rd} Order PLL

The 3\textsuperscript{rd} order loop is used when you have to manage not only Doppler, but also Doppler Rate.

- Doppler Rate is the derivative of the Frequency Shift. Unit is $\text{Hz.s}^{-1}$
- Doppler Acceleration is the derivative of Doppler Rate. Unit is $\text{Hz.s}^{-2}$

Example: With the same conditions as the 2\textsuperscript{nd} order loop, with the 3\textsuperscript{rd} order loop, you are theoretically able to track an infinite Doppler rate. The limitation is now on the acceleration of the Doppler shift.

The 3\textsuperscript{rd} order loop relaxes the Doppler rate constraint, phase bias is not generated any more by the Doppler rate but by Doppler acceleration according to the following formula:

$$\phi = \frac{\alpha}{(2BL)^2} \cdot \text{Doppler Acceleration}$$

In the same idea, the value of $\alpha$ is resulting from internal optimization and experience. In the Cortex CRT-DS, the value is equal to $\alpha \approx 130$.

The limitation is done with the kind of equation as 2\textsuperscript{nd} order loop, i.e. $\sigma + \phi \leq \frac{\pi}{2}$.

The graph below shows the theoretical tracking capacity of the 3\textsuperscript{rd} order PLL. The real limit on the Cortex CRT-DS is lower (typically ½ the theoretical limit).

![Graph of 3\textsuperscript{rd} Order PLL Tracking Capacity](image)

*Figure 13: 3\textsuperscript{rd} Order PLL Tracking capacity*
3.3.4 Doppler Measurement

A single Doppler port is used for transmitting **IF offset measurements** or **integrated phase measurements**.

### 3.3.4.1 Sampling Mode

Elementary accumulated phases are sampled at the rate specified by the parameter « Doppler measurement sampling rate » (every 100 ms to every 10 seconds). Phase generation period depends on the sampling rate value.

If the sampling rate is a multiple of 10 ms, the accumulated phases are generated each 10 ms in order to take advantage from raw data. Thus, Doppler measurement is based on exact values of phase.

If the sampling rate is not a multiple of 10 ms, the raw accumulated phases are sampled every 10 ms. To obtain the accumulated phase at the desired date, an interpolation process is used.

### 3.3.4.2 Accumulated Phase Format

Elementary 32-bit phase values are accumulated in a 96-bit internal counter. The 21 least significant bits and the 11 most significant bits are discarded and the resulting 64-bit phase values are made available to remote Doppler clients.

The accumulated phase resolution is \( \frac{1}{2^{11}} \) cycle (\( \frac{2\pi}{2^{11}} \) radian = 0.175°).

Thus, the 64-bit phase counter capacity is: \( 2^{85} \frac{IF \times 2^{12}}{T} \) (in seconds) where IF is the input IF frequency.

For example, at 70 MHz, the counter capacity is more than 4 years.

Samples are stored for further transmission, in a measurement block which size is programmable between 1 and 1000 elementary measurement(s). The first measurement in the block is time-tagged.

### 3.3.4.3 Interpolation Process

In some cases, when the sampling rate and the generation rate are asynchronous, a linear interpolation is applied to provide the accumulated phases at the required sampling frequency.

Such an interpolation generates an error. Let’s call \( \varphi_{\text{err}} \) the interpolated phase, \( \varphi_{\text{err}} \) the phase error, \( T \) the 10-ms period and \( \varepsilon \) the time between 0 and \( T \) when the phase is interpolated.

\[
\varphi_{\text{int}}(t+\varepsilon) = \varphi(t) + \frac{\varphi}{T} [\varphi(t+T) - \varphi(t)]
\]

The Taylor expression of the phase at \( t+\varepsilon \) is:

\[
\varphi(t+\varepsilon) = \varphi(t) + [F + D(t)]\varepsilon + D(t)\frac{\varepsilon^2}{2} + R(\varepsilon + \varepsilon) ,
\]

where \( D(t) \) is the input Doppler and \( R(\varepsilon) \) the rest such that:

\[
\sup_{t \in (0,T)} |D''(\varepsilon)| (\text{Lagrange overestimation}).
\]

\[
\varphi_{\text{err}}(t+\varepsilon) = \varphi_{\text{int}}(t+\varepsilon) - \varphi(t+\varepsilon) = \frac{\varphi}{T} [\varphi(t+T) - \varphi(t)] - \frac{D(t)}{2} \varepsilon (T - \varepsilon) + \frac{\varepsilon^3}{T} \times R(\varepsilon + T - R(\varepsilon + T)
\]

so

\[
\sup_{t \in (t_0,t+T)} \left| \frac{T^2}{8} \times \sup_{x \in [t+T]} D'(t) + \frac{T^3}{3} \times \sup_{x \in [t+T]} D''(\varepsilon) \right|
\]
For instance, a Doppler rate of 1000 Hz/s with a second-order Doppler variation of 10 Hz.s\(^{-2}\) give a phase error lower than \((0.0125 + 3.33 \times 10^{-5})\) cycle.

In most cases, user would not use cranky values for the sampling rate. Thus, no interpolation would be applied, because accumulated phase are generated synchronously with the sampling rate dates.

### 3.3.4.4 Doppler Computing

The Doppler measurements are computed owing to the accumulated phase interpolated every \(T_s\) seconds according to the formula

\[
    \Delta f = f_{DR} - f_{IFR} = \frac{\phi(t+T_s) - \phi(t)}{T_s},
\]

where \(\phi(t)\) is the accumulated phase, \(f_{DR}\) is the Doppler frequency, \(f_{IFR}\) is the IF Receiver center frequency and \(\phi\) the accumulated phase with a resolution of \(2^{-32}\) cycle.

The Doppler error is

\[
    \epsilon = \frac{\phi(t+T_s) - \phi(t)}{T_s}.
\]

With \(\phi(t+T_s) = \phi(t) + T_s \times \phi'(t) + \frac{T_s^2}{2} \times \phi''(t) + \frac{T_s^3}{6} \times \phi'''(t) + R \phi(t+T_s)\)

where \(R \phi = \frac{T_s^4}{4!} \times \sup_{x \in [T_s+T_s]} \left\| \phi^{(4)}(x) \right\|\),

and \(\phi(t+T_s/2) = \phi(t) + T_s \times \phi'(t) + \frac{T_s^2}{2} \times \phi''(t) + R \phi(t+T_s/2)\)

where \(R \phi(t+T_s/2) = \frac{T_s^3}{3!} \times \sup_{x \in [T_s+T_s]} \left\| \phi^{(3)}(x) \right\|\).

So \(\epsilon = \frac{T_s^2}{4!} \times \sup_{x \in [T_s+T_s]} \left\| \phi^{(4)}(x) \right\|\).

A typical second-order Doppler variation of 10 Hz.s\(^{-2}\) and third-order Doppler variation of \(10^4\) Hz.s\(^{-3}\) give a phase error lower than \((4.16 \times 10^3 + 6.25 \times 10^9)\) Hz for a sampling period \(T_s\) of 0.1 s, and lower than \((41.6 + 6.25 \times 10^3)\) Hz for a sampling period \(T_s\) of 10 s.

### 3.3.4.5 Impact of Phase Errors on Doppler Computing

If \(\phi_{err}\) is the error on the accumulated phase, the error on the computed Doppler is lower than \(\frac{1}{2^{32}} \times \frac{2 \phi_{err}}{T_s}\), where \(T_s\) is the sampling period.

So, the maximum error on the Doppler computing due to the linear interpolation on the second-order phase variation is \(\leq \frac{DR \times T_s^3}{24}\).

For example, with a Doppler rate of 1000 Hz/s, the maximum error will be 0.43 Hz for a sampling period of 0.1 s and 0.0043 Hz for a sampling period of 10 s.

The relation between range rate and Doppler is: \(\Delta f = \frac{-2\pi v}{c}\), where \(f\) is the satellite carrier frequency, \(v\), the radial velocity (range rate) and \(c\) the light celerity.

For a 2.2-GHz beacon, the corresponding range rate error will be 2.93 cm/s for a sampling period of 0.1 s and 0.293 mm/s for a sampling period of 10 s.
3.3.4.6 Sampling Period Resolution

3.3.4.6.1 ERROR DUE TO COMPUTING

The accumulated phase and Doppler sampling is processed owing to an internal 64 bits- NCO running at \( T = 10 \text{ ms} \). The effective sampling period is:

\[
T_{\text{eff}} = \frac{2^{64}}{\text{incr}} T
\]

where \( \text{incr} \) is the NCO phase increment. So the resolution on the period is:

\[
\frac{\text{incr} + e}{\text{incr}} \approx 2^{64} \times e
\]

where \( e \) is the error made on the phase increment computing (in this computing \( T_{\text{eff}} \) is approximated by \( T \), and \( e \) is considered as \( <<< \) incr).

Due to double-float format limitations, \( e = 2^{14} \) is higher than the possible error (11 bits come from the difference between the 64 bits and the 53 bits mantissa of the double-float representation, on which up to 3 bits may be lost in the computing process).

When \( T_s = 10 \text{ s} \) (worst case), the resolution is \( 6.8 \times 10^{-12} \text{ s} \).

This resolution is effective when the programmed sampling period is a value for which the floating representation does not generate any error (examples: 10 s, 1 s or 0.125 s).

An error \( \epsilon \) made on the sampling period generates an error on the Doppler estimation:

\[
\frac{\phi(t) - \phi(t-T_s)}{T_s} - \frac{\phi(t) - \phi(t-T_s)}{T_s + \epsilon} = \frac{\epsilon}{T_s(T_s + \epsilon)} = \frac{\epsilon}{T_s} \times f(t-T_s/2) \times \frac{f}{T_s}
\]

where \( f \) is the current IF frequency.

With a typical value of 70 MHz, the Doppler computing error will be 3.8 mHz with \( T_s = 0.125 \text{ s} \).

3.3.4.6.2 ERROR DUE TO FLOATING REPRESENTATION

The floating representation may generate an error in \( T_s \leq T_s \times 2^{-23} \) (for example, \( 0.1 + 1.49 \times 10^{-9} \text{ s} \) in the case of 0.1 s programming), which could have generated an error on Doppler estimation of \( f(t-T_s/2) \times 2^{-23} \).

But this floating representation is converted into double, owing to rounding processing, so that this error is not added to the previous one (provided that the programmed sampling period does not have more than 5 digits in its fractional part).
3.3.5 Diversity Combining

3.3.5.1 General

The CORTEX CRT Quantum allows to combine two IF signals from two different polarizations, in post-detection or pre-detection mode. This processing is available when the IF Receivers are in Video mode (PM or FM demodulations) or PCM mode (direct PCM demodulation).

Two operating modes are supported:

- Automatic selection of the best telemetry channel (no combination),
- Combination of the two signals, with up to 3-dB gain when both signals have the same level.

3.3.5.1.1 POST DETECTION DIVERSITY COMBINING

The combining system is based on two independent IF Receivers (called Channel A and Channel B) which outputs are weighted from the IF level information in Video mode or Eb/N0 information in PCM mode, and then added to produce a PCM or Video signal which is then processed by the Frame Synchronizer (PCM mode) or BPSK demodulator(s) (Video mode). The Frame Synchronizer or BPSK demodulator(s) can also be directly connected to the output of any one of the two channels. Diversity combining is available for these types of modulation schemes:

- **Video mode**: PM demodulation,
- **PCM mode**: PCM/PM, PCM/BPSK, PCM/QPSK or PCM/OQPSK (not yet supported in PCM/AQPSK mode).

![Figure 14: Post detection Diversity Combining : functional block diagram](image)

For fast locking, as soon as an IF Receiver gets locked, the second receiver automatically by-passes the carrier acquisition phase and attempts to phase lock onto a carrier which frequency is given by the first receiver (expected IF + computed IF offset). The same process applies when a receiver unlocks: it then attempts to directly phase-lock onto the carrier since its frequency is accurately measured by the other Receiver.
3.3.5.1.2 **Pre Detection Diversity Combining**

The combining system is based on two independent IF Receivers (called Channel A and Channel B) which outputs are first filtered, before being weighted from the IF levels information and then added to produce a Video signal which is then processed by PSK demodulator(s), Ranging task or Tracking. Pre Detection Diversity combining is available for these types of modulation schemes:

- **Video mode**: PM, FM, coherent AM, non coherent AM demodulations,
- **PCM mode**: PCM/PM, PCM/BPSK, PCM/QPSK or PCM/OQPSK.

Carrier acquisition and tracking are independent.

![Pre Detection Diversity Combining: functional block diagram](image)

The **Pre Detection Filters** have to be configured and are processing the two IF signals before combining with bandwidths from 5 kHz to 13 MHz.

A spectral display of DCU output is available permanently.

In the case of FM or non-coherent AM demodulations, a PLL is used to compensate the relative phase between the two channels. The PLL bandwidths are: 30 kHz, 10 kHz, 3 kHz, 1 kHz, 300 Hz, and 100 Hz.

In the case of PCM demodulations, relative phase ambiguity between constellations is resolved before combining the two channels.
3.3.5.2 Outputs

3.3.5.2.1 POST DETECTION DIVERSITY COMBINING

- **In Video Mode**: the DCU has two separate outputs. Output # 1 can be routed to a low bandwidth telemetry unit (TMU) while Output # 2 can feed either a low bandwidth telemetry unit or a high bandwidth telemetry unit with sub-carrier. Each DCU output can be separately programmed to Channel A or Channel B or Best Channel or Combined Channels.

- **In PCM Mode**: the DCU offers a single output (Output# 1) connected to a high bandwidth, direct PCM telemetry unit.

**Note**: a status in the DCU monitoring table indicates which IF Receiver is Channel A and which one is Channel B.
Next figure illustrates the signal paths through the combining system:

**POST DETECTION DIVERSITY COMBINING IN VIDEO MODE:**

![Diagram of Video Mode Combining](image)

**POST DETECTION DIVERSITY COMBINING IN PCM MODE:**

![Diagram of PCM Mode Combining](image)

*Figure 16: Post detection Diversity Combining outputs*
3.3.5.2.2 Pre Detection Diversity Combining

- **In Video Mode**: the DCU has two separate outputs. Output #1 can be routed to either a low bandwidth telemetry unit or a high bandwidth telemetry unit with sub-carrier. Output #2 is available for Tracking processing (DTR). Each DCU output can be separately programmed to Channel A, Channel B, Best Channel or Combined Channels.

- **In PCM Mode**: the DCU has one output. Output #1 is connected to a high bandwidth direct PCM telemetry unit.

**PCM Mode with dynamic Bit Rate Switch**: a second direct PCM telemetry unit may be connected to the same DCU output to demodulate another bit rate in the case of dynamic bit rate switch. TMU A has to be set with the highest bit rate and TMU B with the lowest bit rate. The lowest bit rate has to be a sub-multiple of the highest bit rate. Hence, the IFRs will remain locked during bit rate switch, the frame synchronizer of the corresponding TMU becoming locked while the other one becoming unlocked.

**Note**: a status in the DCU monitoring table indicates which IF Receiver is Channel A and which one is Channel B.

**Pre Detection Diversity Combining in Video Mode**:

**Pre Detection Diversity Combining in PCM Mode**:

*Figure 17: Pre detection Diversity Combining outputs*
3.3.5.3 Signal Processing

The combining function can be in 4 different status:

- **Disable** if the diversity combining is disabled.
- **Alarm** if the diversity combining is enabled and if the equipment is not correctly configured. It is the case when:
  - In **Video mode**:
    - The demodulation mode is not the same for Channel A and Channel B, or
    - The carrier acquisition ranges of the two IF Receivers do not overlap, or
    - The pre detection filters differ in case of pre detection diversity combining.
  - In **PCM mode**:
    - The demodulation mode is not the same for Channel A and Channel B, or
    - The carrier acquisition ranges of the two IF Receivers do not overlap, or
    - The pre detection filters differ in case of pre detection diversity combining.

In alarm conditions, diversity combining is inhibited: Channel A is routed to output 1 while Channel B is routed to output 2. The two receivers are totally independent.

- **Unlocked** if the PLL between the two channels fails to lock in Pre Detection Diversity combining. In this case, diversity combining is inhibited: Channel A is routed to output 1 while Channel B is routed to output 2.

- **OK**: The equipment is correctly configured and the diversity combining is enabled. The combining gain (versus best channel selection) is:

  \[
  10 \log_{10} \left( 1 + 10^{ \frac{L_e b_{\text{best channel}} - L_e b_{\text{worst channel}}}{10} } \right)
  \]

![Combining Gain Graph](attachment:combining_gain_graph.png)
When the two IF signal levels differ by more than 10 dB, the DCU automatically switches from Combining to Best Channel mode. In this case, the DCU switches back to Combining mode only when this difference decreases to less than 9.5 dB.

The relative amplitude of a channel (A or B) is given by:

\[
\frac{Amplitude_{Channel}}{Amplitude_{Channel_A} + Amplitude_{Channel_B}} \times 100
\]

In the case of combining on direct PCM IF Receivers, the Eb/N0 status are used to compute the combining coefficients (instead of the IF levels in the case of video IF Receivers).

The sum of the relative signal amplitudes is 100. The best case (3-dB gain) is when both IF Receivers are locked onto equal-strength signals.

### 3.3.5.4 Signal Routing

The effective signal routing may differ from the programmed routing in the following conditions:

- When the diversity combining is disabled, or
- When the combining status is set to **Alarm** (alarm conditions are described above), or
- During IF signal acquisition. Note that when both IF Receivers are unlocked, Channel A is routed to output 1 and Channel B to output 2.
3.3.6 Data Decoding

The PCM bit stream from the Bit Synchronizer is processed in the following order (license-dependant):

- Bi-Phase, DM-M or DM-S decoding,
- Convolutional Viterbi decoding (one dual or single-input decoder or two separate single-input decoders on I and Q channels),
- Differential QPSK decoding (DQPSK or DOQPSK, DSOQPSK),
- Differential decoding (NRZ-M or NRZ-S),
- R-NRZ decoding,
- Frame synchronization,
- Descrambling,
- Reed-Solomon decoding or Turbo decoding,
- Data time-tagging, storage and transmission to the Telemetry Clients.

Selection of the data decoding technique is by configuration commands addressed to the TMU.

3.3.6.1 Descrambling

Scrambling technique is used to maintain bit or symbol synchronization on the telemetry processing chain, by always having a minimum bit transition density on the received telemetry signal. Scrambling is not required when telemetry transmission uses certain modulation techniques (for example bi-phase PCM coding) or convolutional codes.

Descrambling by the CORTEX CRT Quantum complies to the CCSDS recommendation 101.0-B-3 (Blue Book - May 1992). The pseudo-random sequence should be generated using the following polynomial:

\[ h(x) = x^8 + x^7 + x^5 + x^3 + 1 \]
### 3.3.6.2 Convolutional Decoding

Convolutional coding technique is well suited for telemetry channels with predominant Gaussian noise. Convolutional decoding and error-correction by the CORTEX CRT Quantum complies to the CCSDS recommendation 101.0-B-3 (Blue Book - May 1992). The following coding characteristics should be used:

- Convolutional code with maximum likelihood (Viterbi) decoding
- Code rate : 0.5 bit per symbol
- Constraint length : 7 bits
- Connection vectors : G1 = 1111001 ; G2 = 1011011
- Phase relationship : G1 is associated with first or second symbol
- Symbol inversion : Programmable on output path of G2 (inverted or not inverted)

The TMU monitoring table indicates if the Viterbi decoder is locked or unlocked and gives the symbol error rate.

### 3.3.6.3 Reed-Solomon Decoding

Reed-Solomon coding technique is well suited for burst error correction. It can be used in conjunction with Viterbi coding to allow data reconstruction with the lowest error probability. Reed-Solomon decoding and error-correction by the CORTEX CRT Quantum complies to the CCSDS recommendation 101.0-B-3 (Blue Book - May 1992). The following coding characteristics should be used:

- J = 8 bits per R-S symbol
- E = 16 R-S symbol error correction capability within a R-S codeword (coded to decoded information ratio = 255/223),
- Symbol interleave factor : 1 to 8, auto-adjusted (frame-length dependent, see below),
- Virtual Fill factor : auto-adjusted (frame-length dependent, see below),
- Selection of the Beta base (default setup for all SPS versions) or the Alpha base (available in SPS version E4R32 and higher)
- Other characteristics : see CCSDS recommendation 101.0-B-3.

Formula for the determination of the Interleave I depending upon the frame length FL (bytes, including ASM):

\[
\begin{align*}
I = 1 : & \quad 36 < FL \leq 259 \\
1 < I \leq 8 : & \quad 255 \times (I-1) + 4 < FL \leq 255 \times I + 4
\end{align*}
\]

Formula used for the determination of the Virtual Fill Q (bytes):

\[
Q = \frac{255 \times (FL - 4)}{I}
\]

Decoder Error if Q is not integer

The TMU monitoring table indicates the number of corrected R-S symbols.

If the number of errors in the frame exceeds the maximum number of correctable errors, the **Bad Transfer Frame Counter** is incremented.
3.3.6.4 Turbo Decoding

Licensing (per CCSDS 131.0-P-1.0.4):

Implementers should be aware that a wide class of turbo codes is covered by a patent by France Télécom and Télédiffusion de France under US Patent 5,446,747 and its counterparts in other countries.

Potential user agencies should direct their requests for licenses to:

Mr. Christian Hamon
CCETT GIE/CVP
4 rue du Clos Courtel
BP59, 35512 CESSION SEVIGNE Cedex, France
Tel: +33 2 99 12 48 05, Fax: +33 2 99 12 40 98
E-mail: christian.hamon@cnet.francetelecom.fr

Turbo decoding and error-correction by the CORTEX CRT Quantum complies to CCSDS recommendation 101.0-B-6 (Blue Book - October 2002). The Turbo decoder implements the Log-MAP algorithm and with 4 bits input quantized soft values.

The following coding characteristics should be used:

\[ IT = \frac{BSIZE}{(BSIZE+142)} \times \frac{Fck}{2 \times D} \]

Where:
- IT is the number of turbo iterations performed (rounded by \( \frac{1}{2} \))
- D is the payload (or decoded) bit rate (bps)
- BSIZE is the payload size in bits
- Fck is the clock frequency of the decoding engine : 66 MHz or 50 MHz depending on the license.

Note 1: decoded frames are available on TCP/IP port without synchronization word systematically.

The Payload block size is set through the Frame/block size parameter. If turbo decoding is turned on (i.e. TURBO RATE = 1/2), this parameter is read as a number of bits. If the Payload block size does not correspond to CCSDS standard (i.e. different from 1784, 3568, 7136, 8920) it will cause an alarm.
Figure 18: Probability of Bit Error versus Eb/No.
Ref: Turbo-Concept - CCSDS turbo decode progress report 5 - May 23, 2008
### 3.3.6.5 Probability of Bit Error

Probability of bit error versus Eb/No for various coding techniques is given by the following curves:

![Figure 19: Probability of Bit Error versus Eb/No](image-url)
The following formulas allow to calculate the theoretical Eb/No value, from the carrier to noise ratio at IF Receiver input, for different telemetry modulation schemes (refer to Bessel tables. \( J_0 = \) carrier, \( J_1 = \) modulating signal).

### 3.3.6.5.1 **CASE 1 : PCM/BPSK/PM (LOW OR HIGH BANDWIDTH)**

- **Telemetry only**:
  
  \[
  \frac{E_b}{N_0} = \frac{C}{N_0} + 10 \log(2J_1^2(TM)) - 10 \log(BR)
  \]

- **Telemetry and ranging tones**:
  
  \[
  \frac{E_b}{N_0} = \frac{C}{N_0} + 10 \log(2J_1^2(TM)) + 20 \log(J_0(RNG)) - 10 \log(BR)
  \]

- **Normal & dwell telemetry and ranging tones**:
  
  \[
  \frac{E_b}{N_0(\text{NORMAL})} = \frac{C}{N_0} + 10 \log(2J_1^2(\text{NORMAL})) + 20 \log(J_0(\text{Dwell})) + 20 \log(J_0(\text{RNG})) - 10 \log(BR(\text{NORMAL}))
  \]

### 3.3.6.5.2 **CASE 2 : HIGH BANDWIDTH DIRECT PCM (PCM/PM)**

- **Telemetry only**:
  
  \[
  \frac{E_b}{N_0} = \frac{C}{N_0} - 10 \log(BR) + 20 \log(\sin \Phi), \text{ with } \Phi = \text{modulation index}
  \]

### 3.3.6.5.3 **CASE 3 : HIGH BANDWIDTH DIRECT PCM (BPSK)**

- **Telemetry only**:
  
  \[
  \frac{E_b}{N_0} = \frac{C}{N_0} - 10 \log(BR)
  \]
3.3.6.6 LDPC ½ Decoding

Licensing (per CCSDS 131.0-P-1.0.4) :

Implementers should be aware that the codes optimized for deep space applications are covered by US Patent 7,343,539.

Potential user agencies should direct their requests for licenses to:

Office of Technology Transfer,
California Institute of Technology,
1200 E. California Blvd., Mail Code 210-85,
Pasadena, CA 91125

LDPC ½ and error-correction by the CORTEX CRT-DS complies with CCSDS recommendation CCSDS 131.0-P-1.0.4, Pink Book, August 2009. The LDPC ½ decoder implements the Log-MAP algorithm and with 6 bits input quantized soft values.

The following coding characteristics should be used:

→ Payload block size (bits) : 4096 (*)
  (*) Contact factory for availability of 1024 and 16384
→ Code rate : ½
→ Up to 65536 iterations depending on the bit rate.
→ On-the-fly configuration
→ CCSDS recommended synchronization word (default) or user set synchronization words
→ Other characteristics: see CCSDS 131.0-P-1.0.4, Pink Book, August 2009

Note 1 : decoded frames are available on TCP/IP port without synchronization word systematically.

The number of iteration is Bit rate dependant. It could be estimated by the formula

\[ IT = \frac{800 \times 10^6}{BR} \leq 65536 \]

The Payload block size is set through the Frame/block size parameter. If LDPC decoding is turned on (i.e. LDPC RATE = 1/2), this parameter is read as a number of bits. If the Payload block size does not correspond to CCSDS standard, it will cause an alarm.
Figure 20: Probability of Bit Error versus Eb/No.
3.3.7 Ambiguities Solving, I/O Ports & By-passing Capabilities

- **Color code:**
  - Light blue: SPS software task
  - Yellow: Performed by hardware and software

- **Connector label** on the Interconnection Panel: *italic* characters.

### 3.3.7.1 Low Bandwidth TMU

**Figure 21: TM Chain: I/O Ports (LBW)**

- Phase ambiguity solving is by the Frame Synchronizer or by the differential decoder (if PCM code is NRZ-M or NRZ-S).
- External input to the Frame Synchronizer and Viterbi decoder: not available.
- Data and Clock output: not available.
- Auxiliary inputs: restricted to noise & spurious-free signal with limited amplitude variations
- Direct input to PSK Demodulator: set the IF Receiver to « By-pass » mode and select Auxiliary port # 1 or # 2
- Direct input to the Bit Synchronizer: set the IF Receiver to « By-pass » mode and the SCF to 0 on the Telemetry Unit. Select Auxiliary port # 1 or # 2. The signal is expected to have no DC offset at the AUXILIARY input.
3.3.7.2 High Bandwidth TMU with Sub-carrier

a- Nominal case (TMU table/offset 26 = 0. GUI : Frame Sync. Input = Internal):

b- External Input to Frame Synchronizer (TMU table/offset 26 = 1. GUI : Frame Sync. Input = Ext. F/S):
c- **External Input to Viterbi Decoder** (TMU table/offset 26 = 2. GUI : Frame Sync. Input = Ext. Vit. 1):

- Phase ambiguity solving is by the frame synchronizer or by the differential decoder (if the PCM code is NRZ-M or NRZ-S).
- Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if one of the downlink data I/Os Test Sets is enabled. See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.
- In the case of external Viterbi input (scenario c), only hard-decision is available, with the corresponding performances.
- Auxiliary inputs : restricted to noise & spurious-free signal with limited amplitude variations.
- Direct input to the PSK Demodulator : set the IF Receiver to « By-pass » mode (or set Offset 29 in the Telemetry Unit table to 1 or 2) and select Auxiliary port # 1 or # 2.
- Direct input to the Bit Synchronizer : set the IF Receiver to « By-pass » mode (or set Offset 29 in the Telemetry Unit table to 1 or 2) and the SCF to 0 on the Telemetry Unit. Select Auxiliary port # 1 or # 2.

**Figure 22 : TM Chain : I/O Ports (HBW with sub-carrier)**
3.3.7.3 High Bandwidth Direct PCM : no Viterbi Decoding

a. Nominal case (TMU table/offset 26 = 0. GUI : Frame Sync. Input = Internal) :

b. External Input to Frame Synchronizer (TMU table/offset 26 = 1. GUI : Frame Sync. Input = Ext. F/S) :

![Diagram](image)

- Data routing for BPSK and PCM/PM demodulation is on I channel.
- Phase and channel ambiguity solving is by the Frame Synchronizer if differential encoding is not used. In BPSK and PCM/PM mode, phase ambiguity solving is by the differential decoder (if differential encoding is used).
- Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if one of the downlink data I/Os Test Sets is enabled. See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.
- Auxiliary inputs: restricted to noise & spurious-free signal with limited amplitude variations.
- Direct input to the Bit Synchronizer: Not available.

*Figure 23: TM Chain: I/O Ports (HBW direct PCM)*
3.3.7.4 High Bandwidth Direct PCM : Single Viterbi Decoding

a. **Nominal case** (TMU table/offset 26 = 0. GUI : Frame Sync. Input = Internal) :

![Diagram of Nominal case](image)

- IF inputs
- Aux. inputs
- PCM/PM, BPSK, QPSK, OQPSK demodulator & B/S
- I
- Q
- BP, DM-M decoder
- Viterbi decoder
- Differential decoder
- Frame Synchronizer
- Differential encoder
- Invert/swap
- I out

b. **External Input to Frame Synchronizer** (TMU table/offset 26 = 1. GUI : Frame Sync. Input = Ext. F/S) :

![Diagram of External Input](image)

- IF inputs
- Aux. inputs
- PCM/PM, BPSK, QPSK, OQPSK demodulator & B/S
- I rail
- Q rail
- BP, DM-M decoder
- Viterbi decoder
- differential decoder
- Frame Synchronizer
- differential encoder
- invert/swap
- I out

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- **Data routing for BPSK and PCM/PM demodulation is on I channel.**

- **Phase ambiguity solving is by the differential decoder.** In QPSK, OQPSK and SOQPSK mode, channel ambiguity solving is by the single dual-input Viterbi decoder.

- **Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if one of the downlink data I/Os Test Sets is enabled.** See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.

- **Hard decision applies to external input to the Viterbi decoder (scenario c).**

- **Auxiliary inputs** : restricted to noise & spurious-free signal with limited amplitude variations.

- **Direct input to the Bit Synchronizer** : Not available.

---

*Figure 24: TM Chain : I/O Ports (HBW direct PCM with Single Viterbi)*

- Data routing for BPSK and PCM/PM demodulation is on I channel.
- Phase ambiguity solving is by the differential decoder. In QPSK, OQPSK and SOQPSK mode, channel ambiguity solving is by the single dual-input Viterbi decoder.
- Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if one of the downlink data I/Os Test Sets is enabled. See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.
- Hard decision applies to external input to the Viterbi decoder (scenario c).
- Auxiliary inputs : restricted to noise & spurious-free signal with limited amplitude variations.
- Direct input to the Bit Synchronizer : Not available.
3.3.7.5 High Bandwidth Direct PCM : Dual Decoding

a. Nominal case (TMU table/offset 26 = 0. GUI : Frame Sync. Input = Internal) :

b. External Input to Frame Synchronizer (TMU table/offset 26 = 1. GUI : Frame Sync. Input = Ext. F/S) :
c. **External Input to Viterbi Decoders** (TMU table/offset 26 = 2. GUI : Frame Sync. Input = Ext. Vit. 1) :

- **Figure 25 : TM Chain : I/O Ports (HBW direct PCM with dual Viterbi)**
  
  - Channel and phase ambiguities are solved by the I/Q interleave function (prior frame synchronization) in the following cases :
    - OQPSK with dual differential encoding,
    - OQPSK with dual [convolutional + differential] encoding.
  
  - Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if one of the downlink data I/Os Test Sets is enabled. See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.
  
  - Hard decision applies to external input to the Viterbi decoders (scenario c).
  
  - Auxiliary inputs : restricted to noise & spurious-free signal with limited amplitude variations.
  
  - Direct input to the Bit Synchronizer : Not available.
3.3.7.6 High Bandwidth Direct PCM : DQPSK or DOQPSK

a. **Nominal case** (TMU table/offset 26 = 0. GUI : Frame Sync. Input = Internal) :

![Diagram showing nominal case]

b. **External Input to Frame Synchronizer** (TMU table/offset 26 = 1. GUI : Frame Sync. Input = Ext. F/S) :

![Diagram showing external input case]
c. **External Input to DQPSK Decoder** (TMU table/offset 26 = 2. GUI : Frame Sync. Input = Ext. Vit. 1):

![Diagram of TM Chain: I/O Ports (HBW direct PCM, Differential Coding)]

- Channel and phase ambiguities are solved by the DQPSK/DOQPSK decoder. In DQPSK mode, output data must be interleaved for complete ambiguity solving.

- Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if one of the downlink data I/Os Test Sets is enabled. See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.

- Auxiliary inputs: restricted to noise & spurious-free signal with limited amplitude variations.

- Direct input to the Bit Synchronizer: Not available.
3.3.7.7 High Bandwidth Direct PCM : Dual + Differential Decoding

a. Nominal case (TMU table/offset 26 = 0. GUI : Frame Sync. Input = Internal) :

b. External Input to Frame Synchronizer (TMU table/offset 26 = 1. GUI : Frame Sync. Input = Ext. F/S) :
c. External Input to Viterbi Decoders (TMU table/offset 26 = 2, GUI : Frame Sync. Input = Ext. Vit. 1) :

Channel and phase ambiguities are solved by the DQPSK/DOQPSK decoder. In DQPSK mode, output data must be interleaved for complete ambiguity solving.

Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if one of the downlink data I/Os Test Sets is enabled. See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.

Hard decision applies to external input to the Viterbi decoders (scenario c).

Auxiliary inputs : restricted to noise & spurious-free signal with limited amplitude variations.

Direct input to the Bit Synchronizer : Not available.

Figure 27: TM Chain : I/O Ports (HBW direct PCM with dual Viterbi& Differential Decoding)
3.3.7.8 High Bandwidth Direct PCM : AQPSK

This demodulation scheme requires two independent TMU.

a. Nominal case (TMU table/offset 26 = 0. GUI : Frame Sync. Input = Internal):


Phase ambiguity is solved by the frame synchronizers or by the Differential Decoders when available.

Test points and external input to the Frame Synchronizer or Viterbi Decoder are available if two of the downlink data I/Os Test Sets are enabled. See section 2.3.4.2, Annex 5 and TMU monitoring table, status offset 26 for more details.

Hard decision applies to external input to the Viterbi decoders (scenario c).

Auxiliary inputs : restricted to noise & spurious-free signal with limited amplitude variations.

Direct input to the Bit Synchronizer : Not available.

---

Figure 28 : TM Chain : I/O Ports (HBW direct PCM AQPSK Decoding)
3.3.8 Frame Synchronization

Frame synchronization is performed only if parameter *Frame Synchronizer* is set to *on*.

### 3.3.8.1 Frame Synchronization Strategy

Whatever the telemetry operating mode may be (Normal, Test mode 1 or Test mode 2), the technique used to identify the telemetry frames is the same: it consists of finding the synchronization word which marks the beginning of the frame in the NRZL signal output by the bit synchronizer and in reacting correctly to a loss of lock. This process is illustrated by next figure:

- **SEARCH phase (S):**
  
  In this mode, the frame synchronizer compares the signal bit by bit, until it matches the expected synchronization word to within n bits where « n » is a programmable error factor, referred to as the synchronization threshold (SYN). The synchronization threshold can vary from 0 to 7 (inclusive). A programmable mask can also be applied to the synchronization word to ignore corrupted bits in the synchronization word resulting from a spacecraft failure.

- **CHECK phase (C):**
  
  Before moving onto the LOCK mode, the frame synchronizer will check « i » consecutive occurrences of the synchronization word (to within n errors). The contents of the telemetry block between two synchronization words is not checked. During this phase, any occurrence of an incorrect synchronization word returns the frame synchronizer to the SEARCH mode. « i » is programmable between 0 and 7 (inclusive) and referred as the CTL (Check-To-Lock) threshold. To go from SEARCH to LOCK, the frame synchronizer must receive i+1 correct synchronization words except when i = 0 (in that case, the frame synchronizer will transmit frames starting from the frame containing the first occurrence of a correct synchronization word).

- **LOCK phase (L):**
  
  In the LOCK mode, the frame synchronizer merely checks the occurrence of a new synchronization word (to within n errors) every frame. The window in which the synchronization word should be found is enlarged by ± N bits (N = bit slip parameter = 0, 1 or 2 bits) to cope with potential bit slip in the telemetry demodulation process.

- **FLYWHEEL phase (F):**

  Transmission errors (signal heavily affected by noise) or loss of PSK demodulator lock may occur: the frame synchronizer will then only return to SEARCH mode after « j » consecutive occurrences of incorrect synchronization words (number of errors greater than the synchronization threshold). « j » is programmable between 0 and 7 (inclusive) referred to as the LTS (Lock-To-Search) threshold.

The frame synchronizer synchronizes the frame in accordance with the SYN, CTL, LTS and Bit Slip parameters provided to it:
3.3.8.2 PSK Ambiguity Solving

PSK ambiguity solving is performed by the frame synchronizer during the SEARCH phase (and only during this phase). If the comparison between the expected synchronization word and a given window on the received NRZL data stream is not successful, a second comparison is made after inversion of the telemetry data. If this second comparison is successful (to within n bits), the signal inversion is confirmed and the frame synchronizer switches to the CHECK phase.

3.3.8.3 Frame Synchronizer Operating Modes

The frame synchronizer can operate in three modes:

- **In Normal Mode:**

  In Normal mode, each reconstructed minor frame (including the synchronization word) is checked (if the CRC or checksum verification has been activated) and then embedded in an ETHERNET packet which is time-tagged and transmitted to the Telemetry Clients (whatever the result of the CRC or checksum verification). The frame verification result (OK or NOK) is reported to the Monitoring Clients (Frame Check alarm). It is also reported to the Telemetry Clients (frame check result in each telemetry message). The Frame Check alarm is not latched: it is automatically cleared on reception of a good frame.
\[ \text{In Test mode 1:} \]

As per the Normal mode (compatibility with the VME-based CORTEX).

\[ \text{In Test mode 2:} \]

Test mode 2 differs from Test mode 1 in that the telemetry frames are not transmitted to the Telemetry Clients.

### 3.3.9 Frame Verification

Reconstructed frames will be verified only if parameter Frame Checking is set to CRC or Checksum.

The CRC is user-programmable via two parameters: CRC Polynomial (CRC16, CCITT, etc...) and CRC Preset Value (usually all bits set to 0 or to 1).

The checksum value is supposed to be the last byte of each frame. The CRC Preset Value is added to the computed checksum: if the frame checksum does not include the synchronization word, enter the one’s complement of the synchronization word in the CRC Preset Value.

The CRC and Check Sum algorithms may include or not include the synchronization word depending on the registry setting (See section 4.2.8.3.5).

### 3.3.10 Telemetry Frames or Raw Data

When the Frame Synchronizer is ON, reconstructed frames are time-tagged and transmitted to the Telemetry Clients. The telemetry message size is determined by the minor frame size (IRIG format), or the transfer frame size (CCSDS format).

When the Frame Synchronizer is OFF, telemetry data from the Bit Synchronizer are stored into programmable fixed-length messages that are time-tagged and then transmitted to the Telemetry Clients. The telemetry message size is determined by the block size.

### 3.3.11 Telemetry Data Time-Tagging

The time-tag in each telemetry message transmitted to the Telemetry Clients corresponds to the reception of the last bit, rising edge (if the telemetry time-tagging flag is set to 0 in the Windows registry) or first bit, rising edge (if the flag is set to 1) of the telemetry frame (Frame Synchronizer ON) or the telemetry block (Frame Synchronizer OFF). Note: the first bit of the telemetry frame is the first bit of the Synchronization Word. Default time-tagging flag is « Last bit ».

The time-tag accuracy (provided that the selected time-tag coding is Code 2 – Refer to the MCS User’s Manual and to the TCP-IP Interface Specification) is within ± 50 µs (without external 1-PPS) or ± 100 ns (with external 1-PPS) of the reference time supplied to the CORTEX CRT Quantum.
3.3.12 Real-time or Off-line Telemetry Server

3.3.12.1 Telemetry Request

Real-time and off-line telemetry data are transmitted only on reception of a telemetry request from the Telemetry Client. On reception of a telemetry request, the CORTEX CRT Quantum checks its validity and returns a negative telemetry acknowledgment message (invalid request) or Telemetry Messages (valid request) to the Telemetry Client.

The telemetry request specifies:

- The telemetry **channel number** or storage area on the disk (TM-A to TM-F),
- Frame masking data (Virtual Channel extraction in CCSDS mode, etc...),
- The amount of **buffered telemetry** data to transmit (see next section) for real-time telemetry only,
- The type of **data flow** : « single frame/block transmission » (a telemetry request is required for each frame or block) or « permanent flow » or « permanent flow + dummy TM » (see below).
- Only in case of **request for off-line telemetry data** : number of telemetry files to transmit or date of first and last frame or block to transmit.

Up to 24 simultaneous connections are accepted on the Telemetry port (all telemetry channels merged). In the « single frame transmission » mode, it is not required to close the connection between two consecutive TM packets. It is the client’s responsibility to ensure that the data acquisition rate by the host computer will avoid losing telemetry data.

3.3.12.2 Telemetry Buffers

Reconstructed telemetry blocks or frames are routed to the Telemetry port through a circular buffer in volatile memory. The size of the buffer is configurable from 256 to 1024 frames or blocks (system configuration, not reported to Monitoring Clients). Buffer management is ensured by two pointers:

- The « write » pointer is incremented by 1 each time a frame or a block is written to the buffer by the frame synchronizer,
- The « read » pointer is incremented by 1 each time a frame or a block is transmitted to the Telemetry Client. Incrementing rate for the « read » pointer is limited by the rate in writing the frames or blocks to the buffer (obviously, a client cannot receive frames or blocks that have not been yet stored into the buffer !).

At client’s connection, the « read » pointer is set to [« read » pointer - N], N being programmable from 0 (request for immediate transmission of real time telemetry) to the maximum size of the buffer (the buffer must be emptied before the CORTEX CRT Quantum starts transmitting real time telemetry).

If, for any reason, the acquisition rate by the Telemetry Client is lower than the production rate by the frame synchronizer, then each time the « read » pointer is passed by the « write » pointer, the full amount of data stored in the buffer is discarded.
3.3.12.3 Telemetry Data Flows

Three types of data flow can be selected:

3.3.12.3.1 SINGLE FRAME/BLOCK TRANSMISSION

In this mode, the channel number and the number of buffered TM blocks/frames are only checked on reception of the first telemetry request. In the subsequent requests they are ignored. The socket must be closed and then re-open to modify the request.

3.3.12.3.2 PERMANENT FLOW

In this mode, only the first request is checked and processed. Subsequent requests are ignored. The socket must be closed and then re-open to modify the request. When the telemetry chain unlocks (loss of signal,...), data transmission is stopped.

3.3.12.3.3 PERMANENT FLOW & DUMMY TM

As per the « permanent flow ». When the telemetry chain unlocks, dummy frames or blocks are transmitted until telemetry re-acquisition. The dummy frames/blocks transmission rate is derived from the programmed telemetry bit rate plus 100 ms delay on each frame/block (example: if the frame duration is 1 second, then dummy frames will be transmitted at the rate of one frame every 1.1 second to the Telemetry Clients). Dummy frames or blocks indicate that the telemetry chain is unlocked (this information is also available to Monitoring Clients) and that the loss of telemetry is not due to a LAN failure.

The use of dummy frames transmission is highly recommended when the telemetry receiver is likely to stay unlocked for a significant amount of time (15 minutes or more), such as before AOS in a LEO application. Using dummy frames transmission insures that data transmission activity is maintained on the TM port and avoids the TM port from being scheduled to a low priority by the operating system, resulting in possible loss of data at AOS.

Important: It should be noted that whatever the type of data flow on the Telemetry port (permanent flow or permanent flow with dummy TM or single frame/block transmission), dummy frames or blocks are automatically generated and stored in the telemetry circular buffer as soon as the telemetry chain is unlocked, and the amount of buffered telemetry data specified in the telemetry request includes dummy frames or blocks.

3.3.13 Telemetry Data Decommutation

Telemetry decommutation is normally carried out by the Control Center.

However, the MCS software allows up to thirty two 32-bit telemetry words to be decommutated, transcoded and displayed in real-time at the Graphical User Interface (telemetry « Quick Look »). Refer to the MCS User’s Manual.
3.3.14 Telemetry Data Storage on the Disk

To each telemetry channel (up to 6 channels are available for low-rate applications) is allocated a storage area on the disk organized as a FIFO structure. Modification of the storage capacity (maximum number of files and file size) is by system parameters and requires restarting the CORTEX CRT Quantum.

Telemetry frames or blocks of raw data (or dummy frames if the telemetry chain is unlocked) are stored on the disk (default files: `c:\Program Files\In-snec\crtxnt\Tmu\Ftmui`, where i = telemetry chain number [a to f] and j = 1 to N, N being the number of files in the storage area) under the form of telemetry messages as specified in Annex 1 (see Section 2.4). Telemetry data are binary-coded. The file name and access path can be changed in the Windows registry.

**Note**: storage of dummy telemetry frames or blocks can be disabled in the Windows registry (see section 4.2.8.3).

**Example**: store 24 hours of telemetry data (one data stream only), 2048 bps, 256-byte minor frames:

- Telemetry packet size: 64 bytes (TCP-IP header, time-tag, miscellaneous status)
- 256 bytes (TM data)
- 4 bytes (TCP-IP postamble)
- Total: 324 bytes

- Minor frame duration: (8 x 256) : 2048 = 1 second
- Required storage size: 24 x 3600 = 86,400 frames ≈ 28 Mbytes

Telemetry storage can be activated/inhibited by a Control Client. Once the storage function has been activated, the following commands are available:

- Select the first file to write (1 is the identifier of the first file in the storage area),
- Program the « stop writing » conditions (see below),
- Start writing data to the selected file,
- Stop writing data,
- Resume writing data, from the current position in the storage area.

The identifier of the current file as well as the position of the write pointer in the file, is available in each TMU monitoring table.

The « stop writing » conditions are:

- Stop on reception of a « Stop writing » command,
- Stop when the programmed number of files has been written. This number of files is less or equal to the number of files of the storage area.

The file FTMU in each TMU repository (`C:\Program Files\In-Snec\crtxnt\TMUx`, x= A..F) contains information about the records FTMUn, n=1..N.
While FTMU is an ASCII file, it should not be modified by any other mean than the signal processing software provided with Cortex units. For consistency, FTMUn files should not be deleted/modified either, except in the case of a full clean up of the repository.

The FTMU file contains an entry for each FTMUn files in the same repository, as in the example below:

```
1 5 0087653b:000467d2 00878ed5:000f14ed 19000 0
2 5 00878ed6:000177bd 0087b870:000c24d9 19000 0
3 5 0087b870:000dc9e8 0087e20b:000934c4 19000 0
4 5 0087e20b:000ad9d5 00880ba6:000644b2 19000 0
5 5 00880ba6:0007e9c0 00883541:0003549c 19000 0
6 5 00883541:0004f9ac 008856f0:000d9b46 19000 0
7 2 01e282fe:000ec39d 0000009b:00044bf8 19000 3
8 1 01901f5c:0007d278 01903898:0004ae0f 19000 3
```

Each entry has the following fields:

- File number (number “n” in the FTMUn file name).
- Sequence number: it is incremented when a new recording session occurs for the TMU. All the files used for a session have the same sequence number.
- Time-tag of the first frame stored in the file: two words separated by a colon. Each word is a 32-bit hexadecimal value.
- Time-tag of the last frame stored in the file: two words separated by a colon. Each word is a 32-bit hexadecimal value.
- Bitrate configuration used when recording the frames
- Time code configuration used when recording the frames. First and Last time-tags comply to the time code.
3.4 IF MODULATION & TELEMETRY SIMULATION

3.4.1 Uplink Resources

Factory setting of the IF Modulator depends on the Customer requirements (type of modulation, data bandwidth), and CORTEX resources:

1. IFM set to **Video mode only**: the IFM supports FM or PM modulation. The carrier is modulated by any combination of video base band signals.

2. IFM set to **PCM mode only**: the IFM supports PCM/PM, PCM/FM, BPSK, QPSK, OQPSK modulation. The carrier is modulated by a single PCM data stream.

3. IFM set to **Video + PCM mode**: the IFM supports scenarios 1 & 2 (see § 3.4.1.2.1.2 for more details).

4. IFM set to **PCM + PCM mode**: the IFM supports scenario 2 as well as AQPSK modulation (two asynchronous I & Q PCM data streams).

   ➢ IFM set to **DSSS mode**: the IFM supports spread spectrum modulation (refer to DTU 100211).

Next sections describe the functional performances of the IFM for different mission scenarios:

- **Color code**:

  - Light blue: SPS software task
  - Yellow: Performed by hardware and firmware

- **Connector label** on the Interconnection Panel: *italic* characters.
### 3.4.1.1 Low Bandwidth Scenario

- The uplink IF carrier is modulated by any combination of low bandwidth base band signals (TCU, TMS, RAU or external analog video input).

- Signal bandwidth is limited to 125, 250 or 500 kHz (factory setting).

- IF modulation is limited to PM and FM.

- Sub-cARRIER generation can be by-passed on the TMS.

- The base band video signals can be monitored if the uplink **Video Test points** (VIDEO 1 or 2, Sts Out/J25 to J28) are enabled (see section Annex 5).

- IFM factory setting: **Video only** or **Video + PCM**.

**Figure 30 : Low Bandwidth Uplink Scenario**
3.4.1.2 High Bandwidth Scenarios

- The IF carrier is modulated by a video or/and PCM signal.
- In case of single high bandwidth PCM signal, all modulation schemes are supported: PCM/PM, PCM/FM, BPSK, QPSK, OQPSK modulation, with filtering capability (matched filters).
- Sub-carrier generation can be by-passed.
- Signal bandwidth: ≤ 2 MHz if the sub-carrier is enabled or up to 40 Mbps for direct PCM modulation (modulation dependant).
- TCU or TMS monitoring (data + clock) on output test points if one data I/O test set is enabled (see section 2.3.4.2 and Annex 5).
- External data & clock input on test points if one data I/O test set is enabled (see section 2.3.4.2 and Annex 5).
- IFM factory setting: PCM only or Video + PCM or PCM + PCM). Sub-carriers are not allowed in PCM and PCM + PCM modes.

3.4.1.2.1 PM AND FM MODULATION

3.4.1.2.1.1 SINGLE PCM INPUT SIGNAL

![Diagram](Figure 31: High Bandwidth Uplink Scenario with PCM Input Signal (PM, FM))
3.4.1.2.1.2 VIDEO + PCM INPUT SIGNALS

- Next figure shows an IF Modulator set to Video + PCM mode for FM or PM modulation of the IF carrier by a low bandwidth signal (low bandwidth TCU or RAU) and a high bandwidth PCM signal (high bandwidth TMS).

- IF modulation is limited to PM and FM.

- Matched filters are not available.

Figure 32: High Bandwidth Uplink Scenario with PCM and Video Input Signals (PM, FM)
3.4.1.2.2 BPSK MODULATION

![Diagram of BPSK modulation](image1)

**Figure 33**: High Bandwidth Uplink Scenario (BPSK)

3.4.1.2.3 QPSK AND OQPSK MODULATION

3.4.1.2.3.1 WITHOUT CONVOLUTIONAL ENCODING

- PCM encoding is disabled,
- In case of external PCM input, I & Q signals must be phase-aligned, even for OQPSK modulation (half-symbol offset on Q channel is by the IFM).

![Diagram of QPSK and OQPSK modulation without convolutional encoding](image2)

**Figure 34**: High Bandwidth Uplink Scenario (QPSK, OQPSK without Convolutional Encoding)
3.4.1.2.3.2 WITH SINGLE CONVOLUTIONAL ENCODING

- If the convolutional encoder is disabled, PCM encoding is not supported.

![Graph of Single Convolutional Encoding](image)

**Figure 35**: High Bandwidth Uplink Scenario (QPSK, OQPSK with Single Convolutional Encoding)

3.4.1.2.3.3 WITH DUAL CONVOLUTIONAL ENCODING

![Graph of Dual Convolutional Encoding](image)

**Figure 36**: High Bandwidth Uplink Scenario (QPSK, OQPSK with Dual Encoding)

3.4.1.2.3.4 WITH DIFFERENTIAL ENCODING

![Graph of Differential Encoding](image)

**Figure 37**: High Bandwidth Uplink Scenario (QPSK, OQPSK with Differential Encoding)
3.4.1.3.5 **WITH DUAL CONVOLUTIONAL AND DIFFERENTIAL ENCODING**

![Diagram of high bandwidth uplink scenario](image)

**Figure 38**: High Bandwidth Uplink Scenario (QPSK, OQPSK with Dual and Differential Encoding)
3.4.1.2.4 AQPSK MODULATION

- AQPSK modulation requires two high bandwidth TMS.

- IFM factory setting: PCM + PCM mode.

- TMS monitoring (data + clock) on output test points if one data I/O test set is enabled for each TMS (see section 2.3.4.2 and Annex 5).

- External data & clock input on test points if one data I/O test set is enabled for each TMS (see section 2.3.4.2 and Annex 5).

![Diagram: High Bandwidth Uplink Scenario (AQPSK)]

*Figure 39: High Bandwidth Uplink Scenario (AQPSK)*
3.4.2 Noise Generator Option

3.4.2.1 IFM Output Stage Architecture

![IFM Output Stage Architecture](image)

3.4.2.2 C/No Adjust

The Noise Generator is not designed to be used without a carrier. Using the noise generator with the carrier disabled may result in a remnant signal at 70 MHz, thus causing the IF receiver to lock on this remnant signal. The carrier-to-noise ratio in a 1-Hz bandwidth (C/No) can be programmed between 15 and 100 dB.Hz.

When the IF carrier is modulated at least by a video signal, the noise energy remains fixed and the carrier level is automatically adjusted to the required C/No value.

When the IF carrier is exclusively modulated by a PCM signal:

- If the symbol rate (SR) is higher than 1 Msps, the noise energy remains fixed and the carrier level is automatically adjusted to the required C/No value.
- Below 1 Msps and for very low noise conditions (for instance C/No > 70 dB.Hz @ 100 ksps), the noise energy will be automatically adjusted to the required C/No value.

3.4.2.3 Noise Bandwidth

The noise spectrum is centered on 70 MHz and its bandwidth depends on the IFM setting (video mode or PCM mode).

In video mode, the peak-to-peak noise bandwidth is fixed (50 MHz).

In PCM mode, the peak-to-peak noise bandwidth depends on the symbol rate:

- 50 MHz if the symbol rate is higher than 3.125 Msps,
- Between 8 and 12 times the symbol rate (with a minimum of 800 kHz) when the latter is less than 3.125 Msps.
3.4.3 Telemetry Simulation

3.4.3.1 General

The Telemetry Simulator (TMS) allows for exhaustive testing of all of the software functionalities and hardware resources in the CORTEX CRT Quantum:

**Functional tests** Telemetry reception and processing without noise (IF and baseband demodulation, bit synchronization, data decoding, frame synchronization).

**Performance tests** BER measurement in the presence of noise, by comparing bit by bit the PCM signal generated by the TMS to the regenerated PCM from a bit synchronizer.

For example, to set up a test loop at IF, the IFM output must be connected to the IFR input, either directly (if necessary, insert an attenuator in the loop so that the IFR input level remains within -5 / -95 dBm) or via an external IF Patch Panel or Matrix.

3.4.3.2 Operating modes

Here are the different operating modes proposed by the TMS:

- **File**: the modulating data are contained in files. Eight files per TMS are available on the Hard Disk. The directory containing these 8 files is configurable in registry (see § 4.2.8.8.1). The file to be processed is selected owing to the parameter **File Number**, and the **Format Length** defines the number of octets to be processed at the beginning of the selected file.

- **Pseudo**: the data are internally generated by the fixed polynomial \( x^{15} + x^{14} + 1 \). This mode allows BER measurement by bit comparison between the emitted data and the ones received by the Telemetry Unit selected owing to the parameter **TM Flow for BER**. The generated unique frame contains first the **Sync. Word** programmed in the associated TMU (according to the TMU **Sync. Word Length**), and completes it with the pseudo data in order to reach the **Frame Length** configured in the associated TMU too. The TMU Frame Synchronizer has to be enabled and locked.

  If the configuration of the TMS or the associated TMU is changed, the TMS must be restarted (set the TMS parameter **Output** to Disable and then to Enable).

- **LAN**: the data are received on the TCP-IP Simulated port (SIM) for immediate modulation (no storage on disk).

- **Replay**: the modulating data are read from the storage buffer of a downlink Telemetry Unit to be associated owing to the parameter **TM Flow for BER**. The complete file is replayed. The directory containing the TMU storage files is configurable in registry (see § 4.2.8.3.2). The index of the TMU storage file to be replayed is configured owing to the parameter **File Number**, up to the upper limit of the TMU.

  Do not activate this mode while storing data on the disk.
BERT File: the modulating signal is generated as in the case of File mode, and the BER is measured by comparing the emitted data with the ones received by the Telemetry Unit selected owing to the parameter TM Flow for BER. This processing can performed only on an unique repeated frame: the TMU Frame Length and the TMS Format Length have to be configured at the same value. The TMU Frame Synchronizer has to be enabled and locked. This mode is useful for BER measurement purpose on repeated pattern.

BERT PRN: the data are generated from pseudo-noise sequence. The generator polynomial is selected by the parameter PRN generator polynomial degree, according to the following table. The vector of initial states is in every case at the value 1. The sequence length is \((2^{\text{polynomial degree}})-1\). The BER is measured by processing with the same polynomial the data received by the Telemetry Unit selected owing to the parameter TM Flow for BER. The TMU Frame Synchronizer has to be disabled.

<table>
<thead>
<tr>
<th>degree</th>
<th>polynomial</th>
<th>degree</th>
<th>polynomial</th>
<th>degree</th>
<th>polynomial</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>(x^5+x^3+1)</td>
<td>12</td>
<td>(x^{12}+x^{11}+x^8+x^6+1)</td>
<td>19</td>
<td>(x^{19}+x^{18}+x^{17}+x^{14}+1)</td>
</tr>
<tr>
<td>6</td>
<td>(x^6+x^5+1)</td>
<td>13</td>
<td>(x^{13}+x^{12}+x^{10}+x^9+1)</td>
<td>20</td>
<td>(x^{20}+x^{17}+1)</td>
</tr>
<tr>
<td>7</td>
<td>(x^7+x^6+1)</td>
<td>14</td>
<td>(x^{14}+x^{13}+x^8+x^6+1)</td>
<td>21</td>
<td>(x^{23}+x^{19}+1)</td>
</tr>
<tr>
<td>8</td>
<td>(x^8+x^6+x^3+1)</td>
<td>15</td>
<td>(x^{15}+x^{14}+1)</td>
<td>22</td>
<td>(x^{22}+x^{21}+1)</td>
</tr>
<tr>
<td>9</td>
<td>(x^9+x^5+1)</td>
<td>16</td>
<td>(x^{16}+x^{15}+x^{13}+x^4+1)</td>
<td>23</td>
<td>(x^{23}+x^{18}+1)</td>
</tr>
<tr>
<td>10</td>
<td>(x^{10}+x^7+1)</td>
<td>17</td>
<td>(x^{17}+x^{14}+1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>(x^{11}+x^6+1)</td>
<td>18</td>
<td>(x^{18}+x^{11}+1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12: PRN generator polynomials
3.4.3.3 Encoding

The Telemetry Simulator provides the capabilities of scrambling and convolutional, Reed-Solomon, Turbo encoding and LDPC \( \frac{1}{2} \) encoding. These capabilities are provided to test the corresponding decoding functionalities in the downlink Telemetry Units, which are license dependent.

In Low, Intermediate and High Bandwidth modes, these scrambling and encoding capabilities are available in File, Pseudo and BERT File operating modes. Moreover, in Intermediate and High Bandwidth modes, Convolutional encoding is available in the other modes too.

3.4.3.3.1 Convolutional Encoding

This processing provides the capabilities corresponding to the Rate \( \frac{1}{2} \), constraint length 7 Viterbi encoding recommended in § 3 of CCSDS 131.0-B-1. The corresponding decoding is license dependent.

The real-time Convolutional encoding is available only with an Intermediate and High Bandwidth Telemetry Simulator. When using a Low Bandwidth Telemetry Simulator in兰 or Replay mode, the encoding must be pre-calculated in the data.

The availability of the Convolutional encoding depends upon the fact that the TMS operates in Low Bandwidth mode or in Intermediate/High Bandwidth mode.

- LBW mode : available only in File, Pseudo and BERT File operating modes.
- IBW/HBW mode : available all operating modes

It is activated by programming the parameter Data Encoding to the desired combination of Viterbi, Viterbi Inverted and Scrambling.

3.4.3.3.2 Reed-Solomon

This processing provides the capabilities corresponding to the 223/255 encoding recommended in § 4 of CCSDS 131.0-B-1, including virtual filling and interleaving. The corresponding decoding is license dependent.

The Reed-Solomon encoding is available in the File, Pseudo and BERT File operating modes.

It is activated by programming the parameter Frame Encoding to Reed-Solomon. For SPS version E4R32 and higher, the Reed-Solomon encoding is selectable as base Beta or Alpha (default is Beta for previous versions). The frames are generated by using the parameters Sync. Word, Sync. Word Length and Frame Length of the TMU associated owing to the parameter TM Flow for BER/Encoding. The interleaving depth and the need of virtual filling are automatically deduced from the TMU Frame Length.

In Pseudo mode, the encoded frame length is the Frame Length of the associated TMU. It corresponds to the length of (sync. Marker + codeblock), which has to be configured for TMU frame synchronization too.
In **File** mode, the uncoded data have to be placed at their location in the emitted codeblock, hence, after the bytes corresponding to the Attached Sync. Marker. Moreover, it is possible to repeat the encoding of several consecutive frames. In this case, the TMS **Format Length** has to match the several frames which have to be encoded, and so to be configured to the value corresponding to the TMU **Frame Length** times the number of encoded frames. In this case the data shall be organized in the file according to the following structure:

```
ASM
Check Symbols
Uncoded transfer frame #1
ASM
Check Symbols
Uncoded transfer frame #2
ASM
Check Symbols
Uncoded transfer frame #N
```

\[\text{TMS Format Length} = N \times \text{TMU Frame Length}\]

**Figure 41**: TMS File structure for Reed-Solomon encoding

### 3.4.3.3 **TURBO-CODE**

This processing provides the capabilities corresponding to the encoding recommended in § 5 of CCSDS 131.0-B-1. The corresponding decoding is license dependent. The minimum code rate: 1/2, 1/3, 1/4 or 1/6 is resource dependent.

The Turbo-encoding is available in the **File**, **Pseudo** and **BERT File** operating modes.

It is activated by programming the parameter **Frame Encoding** to Turbo-code. The frames are generated by using the parameters **Frame Length** and **Turbo Code Rate** of the TMU associated owing to the parameter **TM Flow for BER/Encoding**. In the particular case of Turbo decoding, the TMU **Frame Length** has to be configured with the uncoded information block length, **expressed in bits**. The Sync. Marker is automatically deduced from the TMU **Turbo Code Rate**.
In Pseudo mode, the Frame Length of the associated TMU must be configured with the information block length expressed in bits. The length of (sync. Marker + Turbo codeblock) is given by the formula:

\[
\frac{1}{r}(32 + K + 4),
\]

where \( r \) is the code rate and \( K \) the information block length in bits.

In File mode, the information data blocks (and only them) have to be provided in the selected file. Moreover, it is possible to repeat the encoding of several consecutive blocks. In this case, the TMS Format Length has to match the several frames which have to be encoded, and so to be configured to the value corresponding to the TMU Frame Length times the number of encoded blocks (Hence, in this case, the TMS format length is expressed in bits too). In this case the data shall be organized in the file according to the following structure:

![Figure 42: TMS File structure for Turbo encoding](image-url)

### Table 13 : Turbo code : information block and codeblock lengths

<table>
<thead>
<tr>
<th>code rate</th>
<th>1/2</th>
<th>1/3</th>
<th>1/4</th>
<th>1/6</th>
</tr>
</thead>
<tbody>
<tr>
<td>sync. marker length</td>
<td>64</td>
<td>96</td>
<td>128</td>
<td>192</td>
</tr>
</tbody>
</table>
3.4.3.3.4 LDPC ½ Encoding

This processing provides the capabilities corresponding to the encoding recommended in § 5 of CCSDS 131.0-P-1.0.4, Pink Book, August 2009. The corresponding decoding is license dependent. The code rate is 1/2.

The LDPC-encoding is available in the File, Pseudo and BERT File operating modes.

It is activated by programming the parameter Frame Encoding to LDPC-code. The frames are generated by using the parameters Frame Length and LDPC Code Rate of the TMU associated owing to the parameter TM Flow for BER/Encoding. In the particular case of LDPC decoding, the TMU Frame Length has to be configured with the uncoded information block length, expressed in bits. The Sync. Marker is automatically deduced from the TMU LDPC Code Rate.

<table>
<thead>
<tr>
<th>Information block length</th>
<th>Code Block Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>bits [bytes]</td>
<td>bits [bytes]</td>
</tr>
<tr>
<td>Code rate</td>
<td>1/2</td>
</tr>
<tr>
<td>4096 [512x1]</td>
<td>8192 [1024]</td>
</tr>
<tr>
<td>sync. marker length</td>
<td>64</td>
</tr>
</tbody>
</table>

Table 14: LDPC code : information block and codeblock lengths

In Pseudo mode, the Frame Length of the associated TMU must be configured with the information block length expressed in bits. The length of (sync. Marker + LDPC code block) is given by the formula:

\[
\text{Length} = 64 + \frac{K}{r}
\]

where \( r \) is the code rate and \( K \) the information block length in bits.

In File mode, the information data blocks (and only them) have to be provided in the selected file. Moreover, it is possible to repeat the encoding of several consecutive blocks. In this case, the TMS Format Length has to match the several frames which have to be encoded, and so to be configured to the value corresponding to the TMU Frame Length times the number of encoded blocks (Hence, in this case, the TMS format length is expressed in bits too). In this case the data shall be organized in the file according to the following structure:
Figure 43: TMS File structure for LDPC encoding
3.4.4 Uplink Digital IF Filter

3.4.4.1 General

On the Cortex CRT XL units, the IF Modulator has a configurable Digital IF Bandpass Filter. This filter is not available on Cortex CRT XL2 units.

The Digital IF Filter is designed for use in Video modulation scheme (PM or FM modulation).

The Digital IF Filter is not designed for use in Direct PCM modulation (PM/PCM, BPSK, QPSK, OQPSK). For Direct PCM modulation, the use of Pulse Shaping filters is recommended (Root Raised Cosine, Raised Cosine).

3.4.4.2 Filter characteristics

Six filters are pre-configured and eight filters are available for Custom design.

The pre-configured filters are identified by a “label” corresponding to the half-bandwidth at 0.1 dB attenuation.

The curves below show the half-band response of each filter:

- **“125 kHz” filter:**
  - 3 dB bandwidth: 1.36 MHz

- **“250 kHz” filter:**
  - 3 dB bandwidth: 2.06 MHz
"500 kHz" filter:

-3 dB bandwidth: 2.4 MHz

"1 MHz" filter:

-3 dB bandwidth: 3.66 MHz

"2 MHz" filter:

-3 dB bandwidth: 5.5 MHz

"4 MHz" filter:

-3 dB bandwidth: 8.46 MHz
3.5 SATELLITE TELECOMMANDING

3.5.1 General

Satellite commanding is by the Telecommand Unit (TCU). The CORTEX CRT Quantum is a TC server for only one client at a time. The satellite telecommanding protocol describes three types of TCP-IP messages:

- **Satellite TC requests**: the request includes a TC message to be transmitted to the spacecraft. The TC message can be transmitted:
  - in **clear mode**,
  - or **scrambled** by an external TC Scrambler.

- **TC instructions**: they specify an action to be performed by the CORTEX CRT Quantum.
  - « Wait & Verify » with Time-out and Retry instruction.
  - « Execute » instruction.
  - « Pause » instruction.
  - « Wait for Absolute Time » instruction.
  - « TCU Unlock » instruction.
  - « NOP » instruction.
  - « Stop Idling » instruction.
  - « Group » instruction.
  - « Set Delay » instruction.

- **High level satellite TC requests**:
  - « Data + Execute » TC request.

Satellite TC requests and TC instructions are checked (via a check-sum) and acknowledged by the CORTEX CRT Quantum (negative or positive command acknowledgement message).

In case of anomaly (bad check-sum), the connection is automatically closed by the CORTEX CRT Quantum after sending an acknowledgement message with error code « 2 » to the Telecommand Client (socket closure will avoid any potential synchronization problem). On socket closure, the CORTEX CRT Quantum automatically flushes all pending TC instructions and satellite TC requests. Such anomaly is very unlikely to appear since all data transfers are guaranteed by the TCP-IP protocol.
### 3.5.1.1 Satellite TC Request

Used for sending any number of bits, according to the user-defined modulation characteristics: FSK or PSK modulation, PCM code, bit rate, sub-carrier frequency. The TC message is stored in the TC encoder on the TCU for potential repetition.

The TC message to send is split into 32-bit words, but the exact number of bits to send may be any number. The MSB of each word is modulated first. The TC message to transmit is supposed to include all necessary synchronisation word, on-board decoder address, spare bit, data word, command CRC, but does not include any preamble or idle pattern.

At the time the satellite TC request is received, the command encoder may be:

- stopped,
- or idling,
- or modulating a TC message.

- If the **command encoder is stopped**: it first rises the carrier for the duration specified in parameter *RF set time* (this time may shortened in the case where parameter *CMM1 CLCW* is on and when CMM1 flag in the telemetry matches the expected value).

  Then, the command encoder modulates the preamble (the preamble structure is fixed: 1010101010... and the preamble length is programmable via the Control port), and if parameter *CMM2 CLCW* is on, it checks the corresponding bit(s) in the telemetry and then modulates the TC message. Should any check fail, the sequence is aborted. Refer to Figure 46 for more detail.

  **Note**: in BPSK mode, it is possible to **pre-transmit the unmodulated BPSK sub-carrier** for a programmable number of bits (see Section 4.2.8.5.1), before transmitting the data (Sub-carrier modulation).

- If the **command encoder is idling**: it waits for the current idle pattern to be fully transmitted (idle pattern contents and length are programmable via the Control port), and then modulates the TC message.

- If the **command encoder is modulating a TC message**: the new TC message is modulated back to back at the end of the last one, without any idle inserted (only if the idle pattern generator is enabled. If the idle pattern generator is disabled, the TCs are separated by a preamble pattern).

  Should idling be inserted between two consecutive TC messages, the idle pattern may be explicitly inserted at the end of the first one, or at the beginning of the last one, or a « Pause » instruction may be inserted between the two satellite TC requests.

  Each operation is executed once the previous is finished.

  If no more satellite TC request is awaiting or if a « Wait & Verify » or « Pause » or « Wait for Absolute Time » instruction is received, the command encoder turns to idling, except if it received a « Stop Idling » instruction. When idling, the command encoder always modulates an integer number of idle patterns as defined by the control parameters.
3.5.1.2 « Wait & Verify » Instruction with Time-out and Retry

This TC instruction allows to verify in the telemetry flow that a telecommand was correctly executed by the spacecraft. The telemetry flow reflecting telecommand execution is selected by a TCU configuration command received on the Control port.

- **Byte offset, mask and expected value:**
  
  The words to consider in the telemetry flow are defined by their byte offset in the frame. Each word may be up to 32 bits long, using successive Telemetry Data Fields as necessary (MSB's first). Each word is ANDed with the associated mask before being compared to the expected value. All words are guaranteed to be picked up in the same minor frame. Successive frames are considered till the verification is successful or time-out expiry.

- **TC message retransmission:**
  
  If the time-out has elapsed before the verification is successful, and if the number of retries specified by the instruction is not 0, the TC message from the last TC request is re-transmitted to the spacecraft. If the number of retries has been reached, status *Locked-out* is posted in the TCU monitoring table and all successive satellite TC requests and TC instructions in the queue are rejected till a « TCU Unlock » instruction is received from the Telecommand Client.

3.5.1.3 « Execute » Instruction

This TC instruction allows to send execute pulses to the spacecraft. The following parameters are specified by the instruction: number of pulses, pulse duration and pulse period. The Execute tone frequency is programmed via the Control port.

3.5.1.4 « Pause » Instruction

This TC instruction forces the CORTEX CRT Quantum to wait for the specified time interval. May be used to insert calibrated time intervals between two consecutive TC messages.

3.5.1.5 « Wait for Absolute Time » Instruction

This TC instruction allows to process a satellite TC request at a precise date and time. The timing accuracy depends on:

- the idle mode (ON or OFF),
- the idle pattern length (the TC encoder always transmit an integral number of idle patterns),
- the preamble length,
- the bit rate,

other sources of error being in the range of ± 2ms.

Processing of TC instructions and requests in the queue is stopped until the specified date and time are reached or when a « Wait for Absolute Time » abort command is received over the Control port.

Status *Wait for Absolute Time* is available in the TCU monitoring table.
3.5.1.6 « TCU Unlock » Instruction

This TC instruction allows to re-enable the command encoder after the « Locked-out » flag has been set in the TCU monitoring table. It is the case when :

- An « Abort all Pending TC Operations » command is received on the Control port,
- A « Wait & Verify » instruction fails,

3.5.1.7 « NOP » Instruction

This TC instruction may be used for checking the link connectivity with the CORTEX CRT Quantum.

3.5.1.8 « Stop Idling » Instruction

This TC instruction allows to stop idling (idle pattern modulation). Idling will automatically restart upon transmission of the next TC message or preamble. The « Idle ON/OFF » command, received on the Control port, is strictly equivalent to the « Stop Idling » instruction.

3.5.1.9 « Group » Instruction

This TC instruction allows to force a deterministic behavior of the CORTEX CRT Quantum timing in the case where TC flow is received via a WAN with unpredictable transmission delays. The group operation specifies the number of satellite TC requests or/and TC instructions that the CORTEX CRT Quantum should wait for before beginning the execution of the first one.

Upon receiving a « Group » instruction, the CORTEX CRT Quantum checks (flow ID, Op. Code, Check-sum,...) and stores in memory all following satellite TC requests or/and TC instructions, up to the specified number. Then, it acknowledges the « Group » instruction.

If all checks are successful, the satellite TC requests or/and TC instructions in the group are successively executed and then acknowledged.

Should any satellite TC request or/and TC instruction in the group be corrupted, the TC encoder will return the Telecommand Client a negative acknowledgement message for the « Group » instruction as well as for each elementary satellite TC request or/and TC instruction, and then discard all of the satellite TC requests or/and TC instructions stored in memory.

Should a new « Group » instruction be issued by the Telecommand Client before all satellite TC requests or/and TC instructions associated to the current « Group » instruction have been received, the current « Group » instruction is aborted (satellite TC requests or/and TC instructions already stored in memory are discarded and a negative acknowledgement message is returned to the Telecommand Client for each of them) while the new « Group » instruction is accepted and restarts the storage process.
3.5.1.10 « Data + Execute » TC Request

The « Data+Execute » Satellite TC request is a high-level TC request for sending data and Execute pulses to the spacecraft.

3.5.2 Satellite TC Requests and Instructions Sequencing

Next figure shows how the TC requests and instructions are processed (reception over the LAN, modulation by the TCU and acknowledgement message transmission over the LAN).
Ethernet IN

TCU OUT

Ethernet OUT

Acknowledge of :

TC1 TC2 I1 TC3 I2 TC4 TC5 I3

TC1 to TC5 : TC requests.
I1 : "Pause" instruction. Duration = D1
I2 : "Stop idling" instruction
I3 : "Execute" instruction

TCP-IP messages on TC port
TC data modulation
TCU idling
Execute tone transmission

Absolute time T1 : I4

Figure 44 : Telecommand Timing
3.5.3 CLCW Checking & IF Carrier Sweeping

The CORTEX CRT Quantum provides IF carrier sweeping to allow fast carrier acquisition by the on-board receiver in case of high Doppler. Five sweeping modes are available:

- **OFF**: The carrier frequency remains fixed.

- **ON**: Step 1: add programmed offset to programmed IF frequency
  Step 2: increase frequency to \((F_0 + \text{offset} + \text{sweep range})\)
  Step 3: decrease frequency to \((F_0 + \text{offset} - \text{sweep range})\)
  Goto step 2

- **AUTO**: Carrier sweeping automatically started when uplinking a telecommand. Sweeping automatically stopped when the on-board RF receiver is locked.

- **AUTO+RZ**: Idem AUTO mode, with the carrier automatically returned to the programmed frequency when the on-board RF receiver is locked (see RZ mode).

- **RZ**: Return to the programmed frequency \((F_0)\). The RZ protocol depends on the \(\text{RzMode}\) flag in the Windows registry. On reception of the RZ command:
  - If flag \(\text{RzMode} = 0\):
    On reception of the RZ command, immediately sweep back to \(F_0\) using the programmed sweep rate.
  - If flag \(\text{RzMode} = 1\):
    On reception of the RZ command, continue the sweep until the current or the next positive sweep slope (increasing frequency) crosses the programmed frequency \((F_0)\), then stop sweeping. If the sweep slope cannot cross the programmed frequency (e.g.: the sweep offset is positive and greater than the sweep range), immediately sweep back to \(F_0\) using the programmed sweep rate (as per \(\text{RzMode} = 0\)).
  - If flag \(\text{RzMode} = 2\):
    On reception of the RZ command, continue the sweep until the current or the next negative sweep slope (decreasing frequency) crosses the programmed frequency \((F_0)\), then stop sweeping. If the sweep slope cannot cross the programmed frequency (e.g.: the sweep offset is negative and greater than the sweep range), immediately sweep back to \(F_0\) using the programmed sweep rate (as per \(\text{RzMode} = 0\)).

**Important**:

- The sweep rate can be changed dynamically while sweeping.
- If the carrier frequency \((F_0)\) or the sweep range or the sweep offset is re-programmed while sweeping, the sweep is stopped, the carrier is returned to the programmed frequency \((F_0)\) and the sweep resumes.
Figure 45: Processing of the IFM Configuration Commands
Proper transmission of a TC message can be checked by means of two flags (named CMM1 and CMM2) in the telemetry flow. CMM1 flag, when ON, indicates that the on-board RF receiver is locked onto the carrier and that the TC preamble can be uplinked. CMM2 flag, when ON, indicates that the on-board bit synchronizer is locked and that the TC message can be transmitted.

**Figure 46: Satellite Telecommanding Protocol with CLCW Check & Carrier Sweeping**
SWEEPING MODE ON THE IFM

Y

SWEEPING OFF REQUIRED?

N

STOP SWEEPING

Y

SWEEPING ON REQUIRED?

N (RZ REQUIRED)

START SWEEPING
Add Offset to programmed frequency
Always start sweeping toward highest frequency, even if IFM returning to F₀ in other direction

Sweep back to F₀ (see RZ command description above)

Figure 47: Configuring the Sweeping Mode on the IFM
3.5.4 TC Demodulation by a Telemetry Chain

For test purposes, it is possible to demodulate a PM or FM-modulated telecommand message using a telemetry chain (IFR + TMU and associated frame synchronizer). The demodulated message is then automatically bit-by-bit compared to the transmitted message and any discrepancy reported in the TC acknowledgement message returned to the TC Client.

This feature is available for TC messages edited at the front panel of the CORTEX CRT Quantum or remote TC requests (clear or scrambled), received over the LAN.

To perform the test, the IF Modulator output must be looped back onto the IF Receiver through an IF or RF loop (ensure that the signal level at the IF Receiver input is within the range -5 / -95 dBm). Then, the following parameters should be set locally or remotely (Refer to the MCS User’s Manual):

**TMU**
- **Frame Synchronizer**: Enable
- **SYN**: 0 (the Synchronization Word is supposed to be error-free)

**TCU**
- **Preamble Length**: > 1000 bits (to lock the PSK demodulator and the Bit Synchronizer)
- **Demod. TM flow**: TM-A or TM-B or TM-C (depending on test loop setup)
- **Demod. Check**: ON (next TC request is to be demodulated)
- **Idle Pattern length**: > 0 (to keep the Bit Synchronizer locked)

Once the TC request has been received on the CORTEX CRT Quantum, the synchronization word is automatically set to the first bits of the transmitted TC message (16, 24 or 32-bit synchronization word, depending on the TC message length). Parameter **Frame/block Size** is automatically programmed to the size of the TC message, rounded up to the nearest byte (if the TC message size is greater than 10 bytes) or programmed to 10 if the TC message size is less or equal to 10 bytes.

The reconstructed TC message is then compared to the transmitted message. A positive (successful comparison) or negative (the comparison failed) TC acknowledgement message is returned over the LAN and the TC transmission (TC request and acknowledgement) reported on the Logging port. The reconstructed TC message is available on the Telemetry port.

**Important**: The reconstructed TC message can be displayed on the GUI (Quick Look window). In this case, the TC message must be long enough to avoid any under-sampling by the Quick Look function (typically, the TC message duration must be ≥ 1 second). For short TC messages, open a connection to the TM port from a remote computer or manually program the frame synchronizer.

Should the telemetry chain fail to reconstruct the TC message (wrong loop setting,...) within N seconds from the end of transmission of the message by the TCU (N being equal to 480 bits + 1 second), a negative TC acknowledgement message is returned over the LAN and the TC transmission (TC request and acknowledgement) reported on the Logging port.
3.5.5 Local Satellite Telecommanding Capabilities

Using the Cortex MCS software, it is possible to locally edit, store, retrieve and uplink telecommand messages at the front panel of the CORTEX CRT Quantum. This function is password-protected (separate password for telecommand database update and for TC transmission). It is highly recommended to restrict this capability to tests purposes only (TCU programmed in TC Simulation mode). At delivery, the TC database may contain TC requests and instructions that have been used for factory acceptance of the unit. It is then the Customer’s responsibility to update the database in accordance with mission requirements. Refer to the Cortex MCS User’s Manual for more details.

3.5.6 Telecommand Socket Closure

In case of socket closure on the Telecommand port, the CORTEX CRT Quantum automatically flushes satellite TC requests and TC instructions awaiting in the telecommand input queue and IDLE generation is inhibited.

3.5.7 TC Watchdog

The TC watchdog mechanism consists in:

- Monitoring the TCP-IP activity on the TC port,
- Disconnecting the TC client and dropping the IF carrier in case of abnormal activity on the TC port.

3.5.7.1 Activation/Inhibition of the TC Watchdog Mechanism

- The TC watchdog mechanism can be activated or inhibited via a registry key (see Section 4.2.8.5.4).
- The TC watchdog mechanism is inhibited by setting the registry key to 0.
- The TC watchdog mechanism is activated by setting the registry key to a positive value (> 0).
- The TC watchdog mechanism remains inhibited (whatever the setting of the registry key) as long as the TC port is unused (no TC Client connected).

3.5.7.2 TC Watchdog Mechanism

- TC watchdog timer: a timer is started each time a TC client opens a connection to the TC port.
- The TC watchdog time-out value can be adjusted via the RF Fall Time parameter (TCU).
- The TC watchdog timer is re-started each time a valid TCP-IP message (TC request or TC instruction: see Annex 1, STI 100013_TTC) is received on the TC port.
- The TC watchdog timer is not re-started when an invalid (bad syntax) or unidentified message is received on the TC port.
- The RF Fall Time parameter can be dynamically adjusted while the TC watchdog timer is running.
- TC connection closure: the connection to the TC port is automatically released when the TC watchdog time-out is reached.
3.5.8 Telecommand Unit Testing

When the TCU is programmed in TC Simulation mode, TC requests and TC instructions received on the Telecommand port are normally processed and acknowledged but the TC tones (pure tone or FSK or PSK signal) are not transmitted to the IF Modulator.

3.5.9 « COP » Software Package

The optional « COP » software package communicates with the Signal Processing Software package and remote SCC Clients via Ethernet, under TCP-IP protocol. Five types of data transfer are to be considered:

- **« COP » Monitoring** :
  The Monitoring port (COP-MON) is used to remotely acquire current the « COP » status. The « COP » can be monitored simultaneously by up to four TCP-IP clients.

- **« COP » Control** :
  The Control port (COP-CTRL) is used to remotely program the « COP » functional parameters. The « COP » can be controlled by only one TCP-IP client at a time.

- **Satellite Telecommand Data (Segments, Transfer Frames or CLTUs) from the TC Clients** :
  The Telecommand port (COP-TC) is used to receive TC Segment Frames from remote Telecommand Clients and to return associated acknowledgement or information messages.

- **Satellite Telecommand Data (CLTU) to the Signal Processing Software** :
  Satellite telecommands are transmitted, at CLTU level, to the Telecommand port (TC) on the Signal Processing Software. The Signal Processing Software provides all functionalities associated to the physical layer.

- **Telemetry Data from the Signal Processing Software** :
  Telemetry data are provided to the « COP » via the Telemetry port (TM) on the Signal Processing Software. These data are used to check the CLCW status and satellite ID.

❖ IF carrier ON/OFF : the IF carrier is automatically dropped when the connection to the TC port is released. Note that the TC watchdog mechanism is not be used to activate the IF carrier.
3.5.10 Carrier and modulation sequencing

The sequencing of carrier activation and modulation depends upon the setups at the time when a TC request is received.

3.5.10.1 Carrier OFF, no Idle pattern

When Carrier is OFF and Idle length is 0 at the time a TC request is received, the following sequence will be met.

If the parameter “RF Fall Time” is set to 0, the carrier will not be returned to OFF at completion of the CLTU and consequently subsequent TC requests will be processed as shown in 3.5.10.2.

3.5.10.2 Carrier ON, no Idle pattern

When Carrier is ON and Idle length is 0 at the time a TC request is received, the following sequence will be met. Parameters “RF Set Time” and “RF Fall Time” have no impact.
3.5.10.3 Carrier OFF and Idle pattern

When Carrier is OFF and an Idle pattern has been defined (Idle length is not 0) at the time a TC request is received, the following sequence will be met.

If the parameter “RF Fall Time” is set to 0, the carrier will not be returned to OFF at completion of the CLTU and consequently subsequent TC requests will be processed as shown in 3.5.10.2.

3.5.10.4 Carrier ON and Idle pattern

When Carrier is ON and an Idle pattern has been defined (Idle length is not 0) at the time a TC request is received, the following sequence will be met. Parameters “RF Set Time” and “RF Fall Time” have no impact.
3.5.11 Progressive modulation index

This feature is available for SPS version E4R32 and higher.

When activated, this feature allows the modulation amplitude (index in PM mode, deviation in FM mode) to be gradually increased from zero to the requested value, instead of instantly raised from zero to the requested value.

The modulation increases in 6 steps of 65.536 ms each, resulting in a total time of 393.216 ms to raise from zero to the nominal amplitude.

The modulation increase follows a geometric law with a ratio of 2 between two steps.

The progressive modulation index feature, when activated, applies to the TCU and RAU signal.
3.6 RANGE MEASUREMENT

3.6.1 General

The unit in charge of range measurement is the Ranging Unit (RAU). The RAU is a very precise phase-meter. It measures the instantaneous phase-difference between the internally-generated tone and the same tone echo-returned by the spacecraft. These measurements are performed at different frequencies, allowing to calculate a propagation time and consequently a distance. Ambiguity solving (ESA, ESA-like and USB tone standards, ESA code standard) is by the minor tones or PN code while the measurement accuracy is determined by the major tone. Minor tones are derived from the major tone by division. The RAU supplies phase measurements as well as two-way « distance » values expressed in nanoseconds.

3.6.1.1 Supported Standards

The RAU supports all types of tone standards, with tone frequencies in the range 2 Hz - 500 kHz

- ESA-like and USB tone standards (programmable frequencies and tone sequence)
- INMARSAT and LMCO tone standards
- ESA code standard
- Continuous mode for the ESA tone, ESA-like and USB standards
- PN Codes (CRT DS Quantum)

3.6.1.2 Ranging Ports

Two ranging ports are used for ranging data transfer to and from the Ranging Clients : RNG & MEAS. On reception of a ranging request on port RNG, the CORTEX CRT Quantum returns a ranging primary transaction response showing acceptance or rejection of the request. On completion (or premature termination in case of anomaly) of the ranging sequence, the CORTEX CRT Quantum transmits simultaneously a ranging secondary transaction response on port RNG to indicate the ranging sequence is terminated and a ranging transaction response containing the measurement data on port MEAS. For a detailed description of the ranging messages, see Annex 1, Section 2.7. Simultaneous connection of several Ranging Clients to port MEAS is accepted. Only one Ranging Client can open a connection to port RNG.

3.6.1.3 « Local » Ranging Client

Using the Cortex MCS software, range measurement can also be initiated. Phase measurements from the Ranging Unit are displayed in aggregated form (minimum, maximum, average and standard deviation values on each tone) as well as a two-way propagation delay (in nanoseconds) and a one-way distance (in meters) for the standards supporting ambiguity solving (ESA, ESA-like and USB tone standards, ESA code standard). Should the ranging process fail (hardware failure, open loop, etc...), data are not displayed at the front panel.
3.6.1.4 Continuous Mode (All modes except INMARSAT and LMCO)

In ESA-tone, ESA-like, ESA-Code, PN Ranging and USB standards, it is possible to keep on sending the major tone and ranging continuously after the normal sequence termination. This mode is activated by setting the Number of Sequences to 0.

The Continuous mode is not strictly a new standard. It simply allows the Control Center to receive a continuous range data stream without having to regularly send range requests to the CORTEX CRT.

When the Continuous mode is enabled:

- The time interval between two consecutive measurements on the major tone is automatically changed to 100 ms (instead of 250 ms).
- Minor tones emission and ambiguity resolution is done only once upon reception of a range request on the Ranging port.
- The first ranging transaction response message sent over the Measurement port contains phase and time measurements or only time measurements according to the received request. Subsequent messages - received while the major tone is continuously transmitted - contain only time measurements. The number of measurements in a ranging transaction response messages is programmable (parameter Number of measurements on major tone).
- On completion of the standard ESA, ESA-like or USB range sequence, the CORTEX keeps on transmitting the major tone alone and the measurement phase extends until a Stop ranging request is received.
- In Continuous mode, the time interval between two consecutive ranging transaction response messages depends on the programmed number of measurements and measurement sampling ratio.
- Tone transmission stops on reception of a Stop ranging request.
3.6.1.5 Ranging Sequence (All modes except INMARSAT and LMCO)

The ranging sequence is as follows:

1. Reception of a ranging request from the Ranging Client on port RNG. The request indicates the type of measurement to perform: calibration (ranging loop at IF or RF) or range measurement.

2. The RAU checks the validity of the ranging request and returns, on port RNG, a primary transaction response message to the Ranging Client showing whether the request was correct or not (bad syntax), or indicating that the CORTEX CRT Quantum was in alarm or not properly configured to accept the ranging request. In case of request rejection, the sequence is then aborted.

3. If the ranging request is accepted, the RAU computes the tone definition tables. Should this computation fail, a « programming » alarm is triggered and stored in the RAU monitoring table; the ranging sequence is aborted and the RAU returns, on port RNG, a negative secondary transaction response message with a code indicating « wrong programming ».

4. If the computation is successful, the RAU starts the measurement sequence. Should the ranging sequence fail (open loop, loss of lock, etc...), a negative secondary transaction response message is returned to the Ranging Client with a code indicating the type of failure (open loop or loss of lock or hardware alarm). If the measurement is successful, phase measurements are processed and stored in a ranging transaction response message which is returned to the Ranging Client on port MEAS.

5. Step 4 is automatically repeated (N-1) times if the programmed number of sequences (N) is greater than 1.

If the selected ranging standard is ESA tone, ESA-like, ESA-Code, PN Ranging or USB and if the programmed number of sequences is 0, then the CORTEX enter the Continuous mode: permanent transmission of the major tone, phase offset measurement, distance update and transmission of ranging transaction response messages until a Stop ranging request is received on the RNG ranging port.

Next figure illustrates the above process.
Ranging request received on port RNG?

- NO
  - YES
    - Request accepted
      - NO bad syntax or bad configuration
      - YES
        - Return positive primary acknowledgement message on port RNG

- YES
  - Tables computation successful?
    - NO return negative secondary acknowledgement message on port RNG
    - YES tone transmission/reception, phase measurement

- YES
  - Ranging sequence successful?
    - NO open loop, H/W failure...
    - YES
      - Process & time-tag measurements. Decrement sequence counter
      - Return transaction message on port MEAS

- NO continuous mode requested?
  - NO sequence counter = 0?
    - YES
      - Return positive secondary acknowledgement message on port RNG
  - YES
    - YES stop ranging command received?
    - NO

Figure 48: Ranging Sequence Flow Chart
3.6.2 Frequency Programming

For the ESA, INMARSAT and LMCO tone standards, the tone frequencies are fixed. For all other standards, the major and minor tone frequencies are fully programmable:

### 3.6.2.1 Major Tone Frequency

The major tone frequency is programmed according to the following rule:

\[
F_{\text{MAJOR\_TONE}} = 500 \times \frac{P_{\text{MAJOR\_TONE}}}{Q_{\text{MAJOR\_TONE}}} \text{ (in kHz)}
\]

with the following restrictions:

- \(5 \leq Q_{\text{MAJOR\_TONE}} \leq 125\) (else, the configuration command is rejected).
- \(1 \leq P_{\text{MAJOR\_TONE}} \leq 256\) (else, the configuration command is rejected).
- \(P_{\text{MAJOR\_TONE}} < Q_{\text{MAJOR\_TONE}}\) (else, the ranging requests are rejected).
- Depending on factory settings (refer to Annex 5), \(F_{\text{MAJOR\_TONE}} \leq 100\) kHz, 500 kHz or 1.5 MHz (tone and ESA code standards).

### 3.6.2.2 Minor Tone Frequencies (ESA-like and USB Tone Standards)

The minor tone frequencies are programmed according to the following rule:

\[
F_{\text{MINOR\_TONE}} = 500 \times \frac{P_{\text{MINOR\_TONE}}}{Q_{\text{MINOR\_TONE}}} \text{ (in kHz)}
\]

with the following restrictions:

- \(1 \leq Q_{\text{MINOR\_TONE}} \leq 500\) kHz (800 kHz for USB Tone standard)
- \(1 \leq P_{\text{MINOR\_TONE}} \leq 500\) kHz
- \(P_{\text{MINOR\_TONE}} < Q_{\text{MINOR\_TONE}}\) (else, the ranging requests are rejected).
- In ESA-like and USB standards, the ratio between Q factors of two minor tones can be a non integer value (see note below) but the Q factor for any minor tone must be a multiple of \(Q_{\text{MAJOR\_TONE}}\)
- \(F_{\text{MINOR\_TONE}} > 1.8\) Hz (ESA-like and USB standard).
- \(F_{\text{MINOR\_TONE}} \leq 500\) kHz (RAU output filter bandwidth).

**IMPORTANT NOTE (TONE STANDARDS):**

**USING NON-INTEGER RATIOS BETWEEN MINOR TONE « Q » FACTORS ALLOWS TO INCREASE THE AMBIGUITY DISTANCE MUCH BEYOND THE WAVELENGTH OF THE LOWEST VIRTUAL MINOR TONE.**

**IN THIS CASE, THE « FIXED SEQUENCE » OR « NO FIXED » OPERATING MODE MUST BE SELECTED TO AVOID FALSE AMBIGUITY SOLVING (SEE SECTION 3.6.4.7, SCENARIOS 2 & 4).**
3.6.3 Downlink Tones Processing

3.6.3.1 Tone Acquisition

3.6.3.1.1 PHASE-LOCKED LOOP

Major tone acquisition for all standards as well as minor tones acquisition and demodulation for the INMARSAT and LMCO standards, is performed by a 2\textsuperscript{nd}-order digital PLL. The loop bandwidth (2B_n) is programmable between 0.1 and 8 Hz. The RAU features automatic loop bandwidth adjustment at tone acquisition for fast acquisition in case of high Doppler rate.

3.6.3.1.2 DOPPLER COMPENSATION (ESA, ESA-LIKE AND USB STANDARDS)

Since satellite range measurement is not instantaneous, the major challenge consists in being able to accurately track the satellite all along the ranging sequence (taking care of zero-crossing on the tone phases) and to compensate the phase measurements on the minor tones for the satellite motion prior resolving the ambiguity.

This compensation is of paramount importance in the case of LEO satellites where using raw phase data for the minor tones would make the ambiguity solving impossible.

Doppler compensation is at two levels:

- Doppler compensation during minor tone integration.
- Correction of the phase measurements on the minor tones so that all minor tone phases are related to a single time reference corresponding to the time-stamp in the ranging transaction response message (first phase measurement on the major tone).
3.6.3.2 Ambiguity Solving & Quality Factor

Ambiguity solving is performed during minor tones (ESA, ESA-like and USB tone standards) or PN codes (ESA code standard) transmission. For the INMARSAT and LMCO standards, only raw phase-shift measurements are delivered.

In the ranging transaction response message returned to the Ranging Client, the status Quality Factor provides a confidence indication on the ambiguity solving (a value of 100 denotes correct ambiguity solving).

3.6.3.2.1 ESA, ESA-LIKE AND USB TONE STANDARDS

For these ranging standards, ambiguity solving consists in finding the propagation delay that best matches the phase measurements on the minor and major tones. For every tone, the relation between the propagation time and the phase measurement is given by:

\[ \Delta \theta_{idx\_tone} = (F_{idx\_tone} \times \tau) \mod 1 \]

with:
- \( \Delta \theta_{idx\_tone} \): phase-shift value measured on “idx_tone” tone, expressed in cycles
- \( F_{idx\_tone} \): frequency of “idx_tone” tone in Hz
- \( \tau \): propagation delay in second

These phase-shift measurements take into account the Board and Ground corrections and the Doppler compensation.

Once estimated the delay \( \hat{\tau} = (CN_{MRT} + \Delta \theta_{MRT}) / F_{MRT} \), where \( F_{MRT} \) is the Major Tone frequency, \( CN_{MRT} \) is the number of cycles on the Major Tone computed by the ambiguity solving, we define the ambiguity solving quadratic error \( ARqerr \) as (where \( N_{MinT} \) is the number of Minor tones):

\[ ARqerr = \frac{1}{1+N_{MinT}} \sum_{i=1}^{N_{MRT}} [(\Delta \theta_i - F_i \times \hat{\tau}) \mod 0.5]^2 \]

In the computing of \( ARqerr \), for each minor tone, an a posteriori estimation error is computed as the difference between the phase measured on this tone and the phase obtained from the estimated propagation delay \( \hat{\tau} \).

The Quality factor \( Q \) is defined as:

\[ Q = 100 - 200 \times \sqrt{ARqerr} \]

This Quality factor will mainly depend on the noise level (S/No at RAU input) and on the un-compensated ground or on-board non-linearities (if any). It depends also on the ranging standard, number of used minor tones, and integration time on each minor tone.
The following *Quality Factor* values should be observed in various noise conditions, in the case of ESA *mode*, with a 1 Hz *loop bandwidth* and an *Integration time* of 1 s:

<table>
<thead>
<tr>
<th>S/N₀ (dB.Hz)</th>
<th>Quality Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>No extra noise</td>
<td>100</td>
</tr>
<tr>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>35</td>
<td>98</td>
</tr>
<tr>
<td>25</td>
<td>95</td>
</tr>
<tr>
<td>20</td>
<td>93</td>
</tr>
<tr>
<td>20</td>
<td>97 (Integration time = 5s)</td>
</tr>
</tbody>
</table>

One should note that the probability of having an erroneous ambiguity solving is very high when Q ≤ 92.

In fact, if Q < 95, it is recommended to increase the *Integration Time* on minor tones and, if possible, to reduce the *PLL bandwidth*. Indeed, as indicated in the previous table, at a signal-to-noise ratio S/No = 20 dB.Hz, by setting the *Integration Time* at 5 s instead of 1 s, the *Quality Factor* increases from 93 to 97.

The *Quality Factor* can be < 95 in the case of bad programming too. It is advised to check the programming of:

- Minor tones frequencies
- Ground Correction
- Board Correction
- Sequence Timing & Ambiguity Resolution
- Maximum Distance.
3.6.3.2.2 **ESA Code Standard**

For each code, ambiguity solving consists in synchronizing the received code with a local replica of the emitted code. Given the ESA code properties, only 4 code positions are possible for the received signal. Compared to the emitted code, it can be in-phase, in-quadrature, in-opposition or in-inverted quadrature.

By the way, to determine the position of the received code, only two correlations need to be computed:

- the correlation $P_{\text{norm}}$ of the received code against an in-phase replica of the emitted code,
- the correlation $Q_{\text{norm}}$ of the received code against an in-quadrature replica of the emitted code.

In ideal condition (no-noise, no non-linearities), we systematically obtain that the normalized correlation of one correlator output values ±1 whereas the other correlator output is null. As quality indication for ambiguity solving on each code, we define for each (with the index I) the Quality Indicator $Q_I$:

$$Q_I(i) = \left| P_{\text{norm}}(i) - Q_{\text{norm}}(i) \right|$$

where $P_{\text{norm}}$ and $Q_{\text{norm}}$ are the correlation values normalized on 1.

This indicator values 1 in ideal condition and decreases to value 0 as far as the noise conditions are degraded (worst case when $P_{\text{norm}} = Q_{\text{norm}}$).

To have a confidence indicator, we define the **Quality Factor** $Q$ as:

$$Q = 100 + 10 \log \left[ \frac{\text{Min}_{i=1}^{N_{\text{codes}}} Q_I(i)}{N_{\text{codes}}} \right]$$

This **Quality Factor** will mainly depend on the noise level (S/No at RAU input) and on the un-compensated ground or on-board non-linearities (if any). It depends also on the **Integration time** on each minor tone.

The following **Quality Factor** values should be observed in various noise conditions, with a **Code length** of 18, a Major Tone frequency of 114,754 Hz, a 1 Hz **Loop bandwidth**, and the **Integration time** = 1 s:

<table>
<thead>
<tr>
<th>S/No (dB.Hz)</th>
<th>Quality Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 45</td>
<td>97</td>
</tr>
<tr>
<td>45</td>
<td>96</td>
</tr>
<tr>
<td>35</td>
<td>96</td>
</tr>
<tr>
<td>25</td>
<td>93</td>
</tr>
<tr>
<td>20</td>
<td>89</td>
</tr>
<tr>
<td>20</td>
<td>92</td>
</tr>
</tbody>
</table>

$(\text{Integration time} = 5s)$

One should note that the probability of false ambiguity solving is very high when $Q \leq 85$.

In fact, if $Q < 89$, it is recommended to increase the **Integration Time**. Indeed, as indicated in the previous table, for a signal-to-noise ratio of 20 dB.Hz, by setting the **Integration Time** to 5 seconds instead of 1 second, the **Quality Factor** increases from 89 to 92.
### 3.6.3.3 Phase-shift Measurement

Phase measurements transmitted to the Ranging Client are raw phase measurements ($\Delta \Phi_{\text{RAW}}$), whatever the selected ranging standard:

$$\Delta \Phi_{\text{RAW}} = \text{(Transmitted tone instantaneous phase)} - \text{(Received tone instantaneous phase)}$$

In the ESA, ESA-like and USB standards, raw phase measurements are then corrected to obtain net phase measurements for ambiguity solving and distance computation. Phase correction depends on the ranging request contents:

If the ranging request is a « range measurement request », the following correction applies:

$$\Delta \Phi_{\text{NET}} = \Delta \Phi_{\text{RAW}} - \Delta \Phi_{\text{SPECTRUM}} - \Delta \Phi_{\text{BOARD_CORR}}$$

If the ranging request is a « calibration request », the following correction applies:

$$\Delta \Phi_{\text{NET}} = \Delta \Phi_{\text{RAW}} - \Delta \Phi_{\text{SPECTRUM}} - \Delta \Phi_{\text{GROUND_CORR}}$$

where:

- $\Delta \Phi_{\text{SPECTRUM}}$: Compensation for phase inversion or ± 90°-offset.
- $\Delta \Phi_{\text{GROUND_CORR}}$: Compensation for contribution to phase measurement of ground equipment that are inserted in the station calibration loop but not used during satellite range measurement (example: Test Loop Translator).
- $\Delta \Phi_{\text{BOARD_CORR}}$: Compensation for satellite contribution to range measurement.

The above correction parameters are programmable by commands received on the Control port.

### 3.6.3.4 Phase-shift Correction for Ambiguity Solving

**IMPORTANT:**

PHASE-SHIFT CORRECTION ONLY APPLY TO TONE STANDARDS WITH AMBIGUITY SOLVING (ESA AND ESA-LIKE).

#### 3.6.3.4.1 « Spectrum Correction »

Parameter *Spectrum Correction* ($\Delta \Phi_{\text{SPECTRUM}}$) allows to compensate for phase offset due to frequency mixing and FM/PM ranging loops. Any of the following scenario can be selected:

- No spectrum correction.
- Spectrum inversion due to the presence of an IF or RF frequency mixer in the ranging loop. Phase measurements are corrected by 180°.

- FM (uplink) and PM (downlink) modulation schemes. Phase measurements are corrected by + 90°.

- Spectrum inversion and FM/PM loop: phase measurements are corrected by - 90°.

3.6.3.4.2 « GROUND CORRECTION »

Parameter *Ground Correction* ($\Delta \Phi_{\text{GROUND\_CORR}}$) is programmable tone by tone and only applies to « calibration » requests. It allows to compensate for phase delays due to the presence of equipment that are used during station calibration but are normally not inserted in the range measurement loop (typically, the RF Test Loop Translator and associated couplers and connection cables, mounted in the antenna hub for converting and routing the uplink signal to the downlink path).

3.6.3.4.3 « BOARD CORRECTION »

Parameter *Board Correction* ($\Delta \Phi_{\text{BOARD\_CORR}}$) is programmable tone by tone and only applies to « range measurement » requests. It allows to compensate for spacecraft contribution to the range measurement.
3.6.3.5 Doppler Rate Aid and Doppler Aid

3.6.3.5.1 Doppler Effects

The spacecraft radial motion relative to the ground station introduces a change on frequency, called Doppler shift, both on the range tones and the radio frequency link carrier.

The two-way Doppler shift on the range tones is given by:

\[ f_{\text{dop, tone}}(t) = f_{\text{tx, tone}}(t) - f_{\text{rx, tone}} = \frac{-2f_{\text{tx, tone}}}{c}v_r(t) \]

where:
- \( f_{\text{dop, tone}} \) = Tone Doppler shift
- \( f_{\text{dop, carrier}} \) = Carrier Doppler shift
- \( f_{\text{tx, tone}} \) = Major or minor tone transmitted frequency
- \( f_{\text{rx, tone}} \) = Major or minor received frequency
- \( v_r \) = Radial velocity

This formula indicates that, if the spacecraft velocity varies in time, the Doppler frequency shift is also time varying. Its first-order variation is called Doppler Rate (radial satellite acceleration).

We can also define the two-way phase error \( \theta_{\text{tone}}(t) \), that corresponds to the difference between the original phase of the transmitted tone and the phase of the received one:

\[ \theta_{\text{tone}}(t) = -2\pi f_{\text{tx, tone}} \frac{2r(t)}{c} \]

The spacecraft range is directly estimated from this quantity, as:

\[ \hat{r}(t) = \frac{c}{2\pi f_{\text{tx, tone}}} \theta_{\text{tone}}(t) \]

3.6.3.5.2 Carrier Doppler Shift in Coherent Mode

In the case of a coherent transponder, the Doppler shift affecting the carrier frequency is defined by:

\[ f_{\text{rx}}(t) = \frac{n}{m} f_{\text{tx}} - 2\frac{n}{m} \frac{v_r(t)}{c} f_{\text{tx}} \]

This relation is obtained similarly as the ranging tone one, except that it is necessary to consider that the up-link carrier differs from the down-link carrier. We can note that the major and minor tones undergo the same Doppler effect as the carrier frequency. The ratio between the carrier Doppler shift and the tone Doppler shift is then:

\[ \frac{f_{\text{dop, tone}}}{f_{\text{dop, carrier}}} = \frac{f_{\text{tx, tone}}}{n f_{\text{tx}}} \]

where \( m \) and \( n \) are integers so that: \( \frac{f_{\text{rx}}}{f_{\text{tx}}} = \frac{n}{m} \), with:

- \( f_{\text{rx}} \) = ground station received frequency
- \( f_{\text{tx}} \) = ground station transmitted frequency.
3.6.3.5.3 CARRIER DOPPLER SHIFT IN NON-COHERENT MODE

In non-coherent mode, the Doppler shift on the received carrier frequency depends on the operating mode: one-way RF lock or two-way RF lock.

Besides, because the transponder locally generates the downlink carrier, the actual downlink frequency is unknown and it can exist a frequency bias of several kHz, due to on-board oscillators drift, with respect to the expected downlink frequency.

Consequently, contrary to the coherent mode case, there isn’t an exact a priori knowledge of the ratio between the carrier Doppler shift and the tone Doppler shift. This ratio:

\[
\frac{f_{\text{dop, tone}}}{f_{\text{dop, carrier}}}
\]

can only be approximated, using the expected value of the transponder downlink frequency. It also depends on the tracking mode.

**Example**: Let us consider the following system:

- Spacecraft Mode : Non-Coherent Two-way RF lock
- Expected Downlink Carrier : 2250 MHz
- Ranging Tone Frequency : 0.5 MHz
- Downlink Frequency Bias : 20 kHz

The approximated Carrier Doppler shift/Tone Doppler shift ratio values:

\[
\frac{f_{\text{dop, tone}}}{f_{\text{dop, carrier}}} = \frac{4500}{4500} = \frac{2250}{0.5}
\]

whereas its actual value is:

\[
\frac{f_{\text{dop, tone}}}{f_{\text{dop, carrier}}} = \frac{4500}{4500} = \frac{2250}{0.5} + 0.02.
\]

3.6.3.5.4 DOPPLER RATE AID PRINCIPLE AND ARCHITECTURE

Given the current Ranging receiver performances, it appears that, to obtain accurate measurements at low signal to noise ratio, the PLL bandwidth should be narrowed. On the other hand, if the Doppler rate is high, the selection of a wider PLL bandwidth is required to reduce the error bias. To be able to cope with Doppler Rate at very low ranging SNR, the classical PLL is improved by adjoining it a Doppler Rate Aid software module.

Carrier Doppler shift measurement is performed by the IF Receiver. Having a priori knowledge of the complete system frequency plan (ground-station up-link and down-link Radio Frequency, spacecraft operating mode, spacecraft turn-around ratio, ...), the Doppler shift affecting the major range tone can be deduced from the carrier Doppler shift (see the previous equations for definition of the ratio between the carrier Doppler shift and the tone Doppler shift*).

The Doppler Rate Aid principle is that the ranging receiver uses (as expected tone frequency) the emitted tone frequency corrected by the estimate of the Tone Doppler shift. Hence, because the PLL has only to handle the residual phase error, the bias should disappear and, even in presence of high Doppler Rate, low bandwidth PLL could be used.
To configure the Doppler Rate Aid module, two additional parameters are introduced:

- **Doppler Rate Aid / Doppler Aid** (Off / Doppler Rate)
- **Carrier Doppler shift/Tone Doppler shift ratio** (expressed in floating format).

At the ranging session end, the RAU fills the new status **PLL Frequency Offset** that gives the remaining offset frequency handled by the Ranging PLL.

![Figure 49: Doppler Rate Aid Architecture](image)

3.6.3.5.5 **DOPPLER AID PRINCIPLE AND ARCHITECTURE**

**Available in SPS versions E4R39 and higher**

This feature is available for ESA, ESA-like and USB standards only.

Under some circumstances, the Carrier Doppler is not measured with enough accuracy to allow the use of Doppler Rate Aid. This is particularly the case when the satellite is operated in Non-Coherent mode. The bias on the Carrier Doppler, when using Doppler Rate Aid, would induce a bias in the Major Tone frequency at the input to the PLL and therefore would induce a Ranging measurement error. In order to cope with a large Doppler offset at PLL acquisition time, without introducing a bias in the measurement in such situations, the PLL acquisition capability is improved by the Doppler Aid algorithm.

The calculation of the Major Tone Doppler shift from the Carrier Doppler is performed as in the Doppler Rate Aid algorithm. However, the Major Tone Doppler shift is used at PLL initialization only, and is not provided to the PLL input during lock acquisition and tracking. Therefore, the Doppler Aid algorithm can be described as follows:
To configure the Doppler Aid module, The Doppler Rate Aid / Doppler Aid parameter is set to “Doppler”, and the Carrier Doppler shift / Tone Doppler shift is set appropriately depending upon the satellite operation (Coherent vs Non Coherent).
3.6.3.6 Range Measurements Sampling

As the sampling rates 250 ms or 100 ms and the generation rate are asynchronous, a linear interpolation is applied to provide the range measurements.

The Major Tone PLL is updated every \((13.1072 / 8) = 1.6384\) ms.

Such an interpolation generates an error. Let’s call \(\phi_{\text{inter}}\) the interpolated phase, \(\phi_{\text{err}}\) the phase error, \(T\) the 1.6384 ms period and \(\epsilon\) the time between 0 and \(T\) when the phase is interpolated.

\[
\phi_{\text{inter}}(t+\epsilon)=\phi(t)+\epsilon \times \left[ f_{\text{MT}}(t)-F_{\text{UL}} \right], \text{ where } f_{\text{MT}}(t) \text{ is the received Major Tone frequency, and } F_{\text{UL}} \text{ the emitted one.}
\]

The Taylor expression of the phase at \(t+\epsilon\) is:

\[
\phi(t+\epsilon)=\phi(t)+f_{\text{MT}}(t)-F_{\text{UL}} \times \frac{\epsilon^2}{2} + R_e(t+\epsilon), \text{ where } R_e(t) \text{ the rest such that:}
\]

\[
\|R_e(t+\epsilon)\| \leq \frac{\epsilon^3}{3!} \sup_{x \in x+T} \left\| f''(x) \right\| \text{ (Lagrange overestimation).}
\]

\[
\phi_{\text{err}}(t+\epsilon)=f_{\text{MT}}'(t) \times \frac{\epsilon^2}{2} + R_e(t+\epsilon)
\]

The Major Tone Doppler and second order variation are deduced from the IF input frequency \(f(t)\) and the RF beacon frequency \(F_{\text{RF}}\) following:

\[
f_{\text{MT}}'(t) \frac{F_{\text{RF}}}{F_{\text{UL}}} f(t) \text{ and } f_{\text{MT}}''(t) \frac{F_{\text{RF}}}{F_{\text{UL}}} f'(t)
\]

The range delay error \(R_{\text{err}}(t)\) is:

\[
R_{\text{err}}(t) \frac{\phi_{\text{err}}(t)}{F_{\text{UL}}}
\]

so

\[
\|R_{\text{err}}(t+\epsilon)\| \leq \frac{1}{F_{\text{RF}}} \left[ \frac{T^2}{2} \times \sup_{x \in x+T} \left\| f'(x) \right\| + \frac{T^3}{6} \times \sup_{x \in x+T} \left\| f''(x) \right\| \right]
\]

A typical Doppler rate of 1000 Hz/s and a typical second order Doppler variation of 10 Hz.s\(^{-2}\) give a range delay error lower than \(6.1 \times 10^{-13}\) s, very lower than 1 ns.
3.6.4 Other Programming Parameters

The following parameters are remotely programmable by commands received on the Control port:

3.6.4.1 Number of Measurements & Sequences

The number of measurements on the major and minor tones is programmable between 0 and 999. The number of measurements programmed on the minor tones is not significant for the ESA tone, ESA-like, and USB standards.

The ranging sequence can be automatically repeated up to 32 times (one ranging transaction response message sent over the LAN at the end of each sequence).

3.6.4.2 Tone Validation and Tone Sequence (ESA-like and USB tone standards)

The tone sequence is fully programmable. To each tone is allocated a number from 0 to 7 for ESA-like, to 9 for USB. 0 indicates that the tone is not transmitted. Any other value indicates that the tone is transmitted; the value gives the tone rank in the ranging sequence (1: tone transmitted first).

3.6.4.3 Measurement Sampling

It is possible to sample the measurements and transmit only one measurement out of N to the Ranging Client, N being any integer value from 1 (transmit all measurements) to 100 (transmit 1% of the measurements). The total duration of the ranging sequence will change accordingly since the number of measurements transmitted to Ranging Client will in any case be equal to the programmed number of measurements.

The first result transmitted to the Ranging Client corresponds to the first measurement performed on the major tone (ESA, ESA-like and USB standards) or on the first transmitted tone (INMARSAT and LMCO standards).

3.6.4.4 Integration Time

The duration of the correlation process (« Integration time ») on each minor tone or PN code is programmable between 250 ms to 2500 ms in 250-ms steps.

This parameter should only be programmed for the ESA, ESA-like and USB standards.
3.6.4.5 Tone Level ratio

For the ESA, ESA-like and USB standards, the minor tones being superposed to the major tone, it is necessary to program the level ratio between the two tones:

Let's call $M_{\text{ambig}}$ the absolute Major tone modulation index for ambiguity resolution, $M_{\text{ambig}}$ the absolute Minor tone modulation index and $M_{\text{meas}}$ the absolute Major tone modulation index for measurements phase.

The IFM ranging modulation index (let's call it $ldx$), offset 6 in IFM table, has to be configured with:

$$ldx = M_{\text{ambig}} + M_{\text{ambig}}$$

The **Major/Total amplitude ratio for ambiguity resolution** has to be configured with the value of $M_{\text{ambig}} / ldx$.

In this case $M_{\text{ambig}} = ldx \times \text{ratio}$ and $M_{\text{ambig}} = ldx \times (1 - \text{ratio})$.

The **Major/Total amplitude ratio for measurements** has to be configured with the value of $M_{\text{meas}} / ldx$ in the range $[0.01 - 1.0]$. Value 0 is used for compatibility with previous software (equivalent to value 1).

This parameter is not significant for the INMARSAT, LMCO and ESA code standards.

3.6.4.6 PLL Bandwidth

The PLL loop bandwidth is programmable from 0.1 Hz to 8 Hz (Cortex CRT Quantum), and from 0.001 Hz to 8 Hz (CRT DS Quantum). See Section 3.6.12 for detailed performances in the presence of noise and Doppler. For the INMARSAT and LMCO standards, the loop bandwidth must be set between 1 Hz and 8 Hz. Lower values are not compatible with the tone set times. For other standards, see also next section.
3.6.4.7 Sequence Timing & Ambiguity Solving

3.6.4.7.1 ESA, ESA-LIKE AND USB TONE STANDARDS

Configuration parameters:

- Sequence timing & ambiguity solving,
- Minimum satellite-to-earth distance,
- Maximum satellite-to-earth distance,

allow accurate adjustment of the ranging sequence duration and a more efficient ambiguity solving for the ESA and ESA-like tone standards.

Parameter **Sequence Timing & Ambiguity Resolution** is for selecting any of the following scenarios (parameters T, Ta and Ts : see Figure 52):

- **Scenario 1 (select All Fixed):**

  The major tone set time depends on the selected RAU PLL bandwidth (parameter **PLL Bandwidth**). The minor tone set time is fixed:

  **Major tone**:
  - PLL bandwidth (2Bn) = 1 to 8 Hz: \( T_a = T_s = 2 \) (in seconds)
  - PLL bandwidth (2Bn) < 1 Hz: \( T_a = T_s = \frac{2}{2Bn} \) (in seconds)

  Example: if the PLL bandwidth is set to 0.4 Hz, \( T_a = T_s = 5 \) seconds

  **Minor tones**:
  - \( T = 0.5 \) (in second)

  Ambiguity solving (distance computation) is performed in the range 0 to the wavelength of the lowest virtual minor tone. Do not use this setting in case of non-integer ratio between minor tone « Q » factors.

- **Scenario 2 (select Fixed seq.):**

  Set times for the major and minor tones are as per scenario 1.

  Ambiguity solving (distance computation) is performed over the distance range specified by the Operator. Use this setting in case of non-integer ratio between minor tone « Q » factors.

- **Scenario 3 (select Fixed amb.):**

  The set time for the major and minor tones depends on two factors:

  - the RAU PLL bandwidth (parameter **Loop Bandwidth**)
  - the maximum one-way satellite distance (parameter : **Maximum Distance**)

  **PLL bandwidth (2Bn) = 1 to 8 Hz**:

  \[ T_a = T_s = 2 + \frac{2d}{c} \] (in seconds)

  \[ T = \frac{2d}{c} \] (in seconds)
PLL bandwidth (2Bn) < 1 Hz:

\[ T_a = T_s = \frac{2}{2Bn} + \frac{2d}{c} \text{ (in seconds)} \]

\[ T = \frac{2d}{c} \text{ (in seconds)} \]

where \( d \) is the programmed maximum satellite-to-earth distance and \( c \) is the light speed (3 \( \times \) 10^8 m/s). Values are rounded up to the nearest whole number of resolution steps (resolution step \( \approx \) 13.1 ms).

Ambiguity solving (distance computation) is performed in the range 0 to the wavelength of the lowest virtual minor tone. Do not use this setting in case of non-integer ratio between minor tone « Q » factors.

- Scenario 4 (select No fixed):

  The set times for the major and minor tones are as per scenario 3. Ambiguity solving is as per scenario 2. Use this setting in case of non-integer ratio between minor tone « Q » factors.

### 3.6.4.7.2 ESA Code Standard

The ambiguity distance is given by the code length parameter.

The tone and code set times (sequence timing) are automatically adjusted, depending on the loop bandwidth, the code length and the tone frequency (see sections 3.6.11.3 to 3.6.11.5).
3.6.5 Measurement Time-Tagging

The time-tag in the ranging transaction response message corresponds to:

- the first phase measurement performed on the first tone of the ranging sequence (INMARSAT and LMCO standards),

- the first «distance» calculation of the ranging message (ESA, ESA-like and USB tone standards, ESA code standard).

Every measurement in the ranging transaction response message can be easily dated by simply adding to the time-tag the appropriate number of time intervals separating two consecutive measurements.
3.6.6 Ranging Transaction Messages

3.6.6.1 Range Measurement

The ranging transaction response message for a range measurement request contains:

- Two-way « Distance » values, in nanoseconds (after ambiguity solving. Not significant for the INMARSAT and LMCO standards,
- The ambiguity solving quality factor (not significant for the INMARSAT and LMCO standards).

Then, for each tone and only in case of request for phase and time measurements:

- Major tone phase-shift values ($\Delta \Phi_{\text{RAW}}$), excluding « Spectrum Correction » and « Board Correction ».
- Minor tone phase-shift values ($\Delta \Phi_{\text{RAW}}$). For the ESA, ESA-like and USB tone standards, the CORTEX CRT Quantum returns average phase-shift values, including Doppler compensation but excluding « Spectrum Correction » and « Board Correction ». Not significant for the ESA code standard.
- Correction for spectrum offsets and on-board phase-delay ($\Delta \Phi_{\text{SPECTRUM}} + \Delta \Phi_{\text{BOARD_CORR}}$) for each tone.

All phase values are expressed in degrees, with a resolution of $360^\circ/2^{16} \approx 0.0055^\circ$.

3.6.6.2 Calibration Measurement

The ranging termination message for a calibration measurement request contains:

- Two-way « Distance » values, in nanoseconds (after ambiguity solving. Not significant for the INMARSAT and LMCO standards),
- The ambiguity solving quality factor (not significant for the INMARSAT and LMCO standards).

Then, for each tone and only in case of request for phase and time measurements:

- Major tone phase-shift values ($\Delta \Phi_{\text{RAW}}$), excluding « Spectrum Correction » and « Ground Correction ».
- Minor tone phase-shift values ($\Delta \Phi_{\text{RAW}}$). For the ESA, ESA-like and USB standards, the CORTEX CRT Quantum returns average phase-shift values, including Doppler compensation but excluding « Spectrum Correction » and « Ground Correction ». Not significant for the ESA code standard.
- Correction for spectrum offsets and ground phase-delay ($\Delta \Phi_{\text{SPECTRUM}} + \Delta \Phi_{\text{GROUND_CORR}}$) for each tone.

All phase values are expressed in degrees, with a resolution of $360^\circ/2^{16} \approx 0.0055^\circ$. 
3.6.6.3 Time and Doppler Measurement

On reception over the Ranging port of a request for Time and Doppler measurements (request message offset # 4 = 3) the ranging transaction response messages returned to the ranging Client contain the following information:

- Two-way time (range) values in nanoseconds (after ambiguity solving),
- Synchronized (see note 1) Doppler and range measurements,
- Ambiguity solving quality factor,
- Measurement sampling period,
- IF level,
- Carrier and input center frequencies.

The ranging Sampling rate parameter is used (not the Doppler sampling parameter).

Doppler measurement data are still available over the Doppler port. Doppler compensation and Doppler rate aid functions remain also available.

Note 1: the first range and Doppler measurements in every ranging transaction response message can be synchronized to even seconds by setting the registry key SynchroMode to 1 (access path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Signal Processing\Rau).
3.6.7 Storage of Ranging Messages

Ranging messages can be stored in two FIFO-structured files (circular buffers) on the hard disk.

The first file is for storing ranging request messages, primary acknowledgement messages and secondary acknowledgement messages.

The second file is for storing ranging transaction response messages (phase and/or time measurements).

TCP-IP messages are not divisible: if a message cannot be entirely stored at the end of a file (not enough space left), it will be stored from the beginning of the file.

The storage function can be enabled/disabled and the file size and access path modified in the Windows registry.

- **Records format** (see Annex 1 for a detailed description of the ranging messages):

  - **Range data**: as per STI100013_TTC, Tables 55 (Time & Phase) or 56 (Time only)

  - **Range request**: as per STI100013_TTC, Table 52, modified as follows (time-tag adding):
    - Offset 0-2 TCP-IP message header
    - Offset 3-4 Time-tag (CORTEX CRT Quantum format)
    - Offset 5-7 as per offset 3-5 in Table 52

  - **Acknowledgement**: as per STI1000013_TTC, Tables 53-54, modified as follows (time-tag adding):
    - Offset 0-2 TCP-IP message header
    - Offset 3-4 Time-tag (CORTEX CRT Quantum format)
    - Offset 5-6 as per offset 3-4 in Table 52
3.6.8 ESA Tone Standard

3.6.8.1 General

The ranging procedure consists of a sequential transmission of tones. Initially, the highest frequency tone (called “major tone”) is transmitted alone to allow the transponded tone to be acquired by the ground equipment (IF receiver and RAU).

By means of a digital PLL, the RAU produces a phase-locked replica of this tone from which replicas of the lower tones are derived by division. The first minor tone is then transmitted along with the major tone, long enough to phase-match its synthesized replica. The minor tone is then removed, replaced by the next tone and so one.

When all minor tones have been transmitted, the RAU then continues to function only with the major tone and measurement are performed.

3.6.8.2 Tone Frequencies

3.6.8.2.1 Virtual Tones

The frequency plan recommended by the ESA standard consists of seven sinusoidal tones:

- Major tone: 100 kHz
- Minor tones: 20.000 kHz, 4.000 kHz, 800 Hz, 160 Hz, 32 Hz, 8 Hz

The minor tones are derived from the major tone by division. The dividing ratio is an integer value (5), except for the two last minor tones for which the ratio is equal to 4. The one-way ambiguity distance is ≈ 18,750 km.

3.6.8.2.2 Real Tones

Due to uplink and downlink spectrum occupancy considerations, the minor tones are transmitted according to the following equivalent scheme (although range measurement will be based on virtual tones):

- Major tone: 100 kHz
- Minor tones: 20.000 kHz, 16.000 kHz, 16.800 kHz, 16.160 kHz, 16.032 kHz, 16.008 kHz

The above list corresponds to the order in which the tones are transmitted: this order is fixed. All tones are phase-coherent.

P and Q factors and tone transmission rank for the ESA standard are:
<table>
<thead>
<tr>
<th>TONE RANK (1 = FIRST)</th>
<th>Q (2)</th>
<th>P (2)</th>
<th>VIRTUAL TONE FREQUENCY (KHZ)</th>
<th>REAL TONE FREQUENCY (KHZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (note 1)</td>
<td>5</td>
<td>1</td>
<td>100.000</td>
<td>100.000</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>1</td>
<td>20.000</td>
<td>20.000</td>
</tr>
<tr>
<td>5</td>
<td>125</td>
<td>4</td>
<td>4.000</td>
<td>16.000</td>
</tr>
<tr>
<td>4</td>
<td>625</td>
<td>21</td>
<td>0.800</td>
<td>16.800</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
<td>101</td>
<td>0.160</td>
<td>16.160</td>
</tr>
<tr>
<td>2</td>
<td>15625</td>
<td>501</td>
<td>0.032</td>
<td>16.032</td>
</tr>
<tr>
<td>1</td>
<td>62500</td>
<td>2001</td>
<td>0.008</td>
<td>16.008</td>
</tr>
</tbody>
</table>

Table 15: ESA Tone Standard. Tone Definition

Note 1: the major tone is transmitted first but the phase measurements on that tone are performed only after minor tones transmission.

Note 2: P and Q factors for the ESA standard are « hard-wired » (not programmable).

3.6.8.3 Ranging Sequence

Next figure illustrates the ranging measurement sequence:
1. On reception of a ranging request from the Ranging Client, the RAU computes the tone definition tables (only the first time a ranging request is received for the current RAU configuration). Then, if the computation is successful, the RAU starts transmitting the major tone. Status *Measurement Progress* in the RAU monitoring table starts incrementing.

2. $T_a$ seconds later, transmission of the first minor tone along with the major tone ($T$-second set time).

3. Average phase measurement for the first minor tone. Parameter *Integration Time* ($IT$) is programmable from 250 ms to 500 s in 250-ms steps.

   Steps 2 and 3 are repeated for minor tones 2, 3, 4 and 5.

4. Transmission of the sixth minor tone along with the major tone.

5. Average phase measurement for the sixth minor tone. The major tone is then transmitted alone during $T_s$ seconds.

6. First phase measurement on the major tone and ambiguity solving. The RAU simultaneously acquires the current time from the Time Code Reader for further time-tagging of the ranging transaction response message.

7. Status *Measurement Progress* is equal to 100. Phase and « distance » measurements are returned to the Ranging Client(s) in a ranging transaction response message.

Phase measurements on the major tone are performed at regular time interval (One measurement every 250 ms). These measurements are corrected as described in § 3.6.3.4. For each measurement on the major tone is calculated a « distance » in nanoseconds. The calculation takes into account (ambiguity solving) phase drift due to spacecraft motion during major tone transmission.

The total duration of the ranging sequence depends on four factors:

- the measurement sampling ratio,
- the minor tone integration time,
- the number of measurements on the major tone,
- the tone set time (based on the PLL bandwidth and the maximum satellite distance).
Assuming that these parameters are: 1 (no measurement under-sampling), 250 ms (integration time), 10 measurements on the major tone and default tone set time (see scenario 1, section 3.6.4.7.1) with the RAU bandwidth in the range 1 to 8 Hz, the sequence duration is (tone definition tables computation time not included):

- Transmission of the major tone alone: 2 s
- Minor tone 1 (set time + integration): 0.75 s
- Minor tones 2, 3, 4, 5 & 6 (0.75 x 5): 3.75 s
- Transmission of the major tone alone: 2 s
- 10 measurements on the major tone (0.25 x 9): 2.25 s

**Total sequence duration**: 10.750 seconds

If the sampling ratio is set to 2 (1 measurement out of 2 is transmitted to the Ranging Client), the sequence duration is augmented accordingly:

- Transmission of the major tone alone: 2 s
- Minor tone 1 (set time + correlation): 0.75 s
- Minor tones 2, 3, 4, 5 & 6 (0.75 x 5): 3.75 s
- Transmission of the major tone alone: 2 s
- 10 measurements on the major tone (0.25 x 18): 4.5 s

**Total sequence duration**: 13 seconds
3.6.9 ESA-like and USB Tone Standards

The ESA-like and USB standards differ from the ESA one in that the following parameters are programmable:

- Major and minor tone frequencies (P and Q factors),
- Number of minor tones (up to 6 for the ESA-like and up to 8 for the USB standard),
- Tone transmission rank,
- In the USB mode only, the lowest minor tone integration time is the programmed integration time multiplied by 4, allowing for higher ratio between the two last minor tones (see example in section 3.6.9.4: the ratio between virtual tones #1 and #2 is 16) and a higher ambiguity distance due to the very low frequency of the lowest minor tone.

Next figure illustrates a USB ranging sequence with the lowest minor tone being transmitted first):

![Figure 52: Ranging Sequence (USB Standard)](image)

3.6.9.1 Frequency Programming

The major tone frequency is programmable according to the following rule:

$$F_{\text{MAJOR\_TONE}} = 500 \times \frac{P_{\text{MAJOR\_TONE}}}{Q_{\text{MAJOR\_TONE}}} \text{ (in kHz)}$$

with the restrictions described in § 3.6.2.1.

The minor tone frequencies are programmable according to the following rule:

$$F_{\text{MINOR\_TONE}} = 500 \times \frac{P_{\text{MINOR\_TONE}}}{Q_{\text{MINOR\_TONE}}} \text{ (in kHz)}$$

with the restrictions described in § 3.6.2.2.
3.6.9.2 Number of Tones and Transmission Rank

The number of minor tones is programmable from 1 to 6 for the ESA-like standard and 1 to 8 for the USB standard. The minor tones transmission rank is also fully programmable.

3.6.9.3 Real and Virtual Minor Tone Frequency

The virtual minor tone frequency is: \( F_{\text{MINOR TONE, VIRTUAL}} = \frac{500}{Q_{\text{MINOR TONE}}} \) (in kHz)

The real minor tone frequency is: \( F_{\text{MINOR TONE, REAL}} = F_{\text{MINOR TONE, VIRTUAL}} \times P_{\text{MINOR TONE}} \) (in kHz)

3.6.9.4 Ambiguity Distance

3.6.9.4.1 INTEGER RATIO BETWEEN Q FACTORS

If the ratio between two adjacent minor tone « Q » factors is an integer value, the one-way ambiguity distance is half the wavelength of the lowest virtual minor tone.

Example 1: ESA-like mode with all real tones in the range 22-28 kHz:

<table>
<thead>
<tr>
<th>TONE RANK (1 = FIRST)</th>
<th>Q</th>
<th>P</th>
<th>VIRTUAL TONE (Hz)</th>
<th>REAL TONE (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>18</td>
<td>1</td>
<td>27 777.78</td>
<td>27 777.78</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
<td>4</td>
<td>5 555.56</td>
<td>22 222.22</td>
</tr>
<tr>
<td>5</td>
<td>450</td>
<td>21</td>
<td>1 111.11</td>
<td>23 333.33</td>
</tr>
<tr>
<td>4</td>
<td>2 250</td>
<td>101</td>
<td>222.22</td>
<td>22 444.44</td>
</tr>
<tr>
<td>3</td>
<td>11 250</td>
<td>501</td>
<td>44.44</td>
<td>22 266.67</td>
</tr>
<tr>
<td>2</td>
<td>56 250</td>
<td>2 501</td>
<td>8.89</td>
<td>22 231.11</td>
</tr>
<tr>
<td>1</td>
<td>281 250</td>
<td>12 501</td>
<td>1.78</td>
<td>22 224.00</td>
</tr>
</tbody>
</table>

The one-way ambiguity distance is approximately:

\[
\frac{300,000}{1.78 \times 2} = 84.270 \text{ km}
\]
Example 2: USB mode with a 500 kHz major tone and a very low minor tone frequency (0.625 Hz) for an extended ambiguity distance:

<table>
<thead>
<tr>
<th>TONE RANK (1 = FIRST)</th>
<th>Q</th>
<th>P</th>
<th>VIRTUAL TONE (HZ)</th>
<th>REAL TONE (HZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>5</td>
<td>5</td>
<td>500 000</td>
<td>500 000</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>1</td>
<td>100 000</td>
<td>100 000</td>
</tr>
<tr>
<td>7</td>
<td>25</td>
<td>1</td>
<td>20 000</td>
<td>20 000</td>
</tr>
<tr>
<td>6</td>
<td>125</td>
<td>1</td>
<td>4 000</td>
<td>4 000</td>
</tr>
<tr>
<td>5</td>
<td>625</td>
<td>6</td>
<td>800</td>
<td>4 800</td>
</tr>
<tr>
<td>4</td>
<td>3 125</td>
<td>26</td>
<td>160</td>
<td>4 160</td>
</tr>
<tr>
<td>3</td>
<td>12 500</td>
<td>101</td>
<td>40</td>
<td>4 040</td>
</tr>
<tr>
<td>2</td>
<td>50 000</td>
<td>401</td>
<td>10</td>
<td>4 010</td>
</tr>
<tr>
<td>1</td>
<td>800 000</td>
<td>7 001</td>
<td>0.625</td>
<td>4 375.625</td>
</tr>
</tbody>
</table>

The one-way ambiguity distance is approximately:

\[
\frac{300,000}{0.625 \times 2} = 240,000 \text{ km}
\]

3.6.9.4.2 **NON-INTEGER RATIO BETWEEN Q FACTORS**

The ESA-like and USB standards allow to select non integer ratios between minor tone « Q » factors. The advantage of this solution is to increase the ambiguity distance much beyond the wavelength of the lowest virtual minor tone. In this case, the one-way ambiguity distance can be directly derived from the Least Common Multiple (LCM) of all « Q » factors.

Example: all real tones are in the range 47-53 kHz:

<table>
<thead>
<tr>
<th>TONE RANK (1 = FIRST)</th>
<th>Q</th>
<th>P</th>
<th>VIRTUAL TONE (HZ)</th>
<th>REAL TONE (HZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (note 1)</td>
<td>10</td>
<td>1</td>
<td>50 000.0</td>
<td>50 000.00</td>
</tr>
<tr>
<td>6</td>
<td>170</td>
<td>16</td>
<td>5 882.4</td>
<td>47 058.8</td>
</tr>
<tr>
<td>5</td>
<td>180</td>
<td>19</td>
<td>2 777.8</td>
<td>52 777.8</td>
</tr>
<tr>
<td>4</td>
<td>850</td>
<td>88</td>
<td>1 176.5</td>
<td>51 764.7</td>
</tr>
<tr>
<td>3</td>
<td>4 250</td>
<td>449</td>
<td>117.6</td>
<td>52 823.5</td>
</tr>
<tr>
<td>2</td>
<td>21 250</td>
<td>2 249</td>
<td>23.5</td>
<td>52 917.6</td>
</tr>
<tr>
<td>1</td>
<td>106 250</td>
<td>11 249</td>
<td>4.7</td>
<td>52 936.5</td>
</tr>
</tbody>
</table>
The LCM is:

- \(Q_{\text{min}6} = 170 = 5 \times 17 \times 2\)
- \(Q_{\text{min}5} = 180 = 5 \times 2^2 \times 3^2\)
- \(Q_{\text{min}4} = 850 = 5^2 \times 17 \times 2\)
- \(Q_{\text{min}3} = 4250 = 2 \times 5^3 \times 17\)
- \(Q_{\text{min}2} = 21250 = 2 \times 5^4 \times 17\)
- \(Q_{\text{min}1} = 106250 = 2 \times 5^5 \times 17\)

The \(\text{LCM} = 2^2 \times 5^5 \times 17 \times 3^2 = 1,912,500\), corresponding to a virtual tone of \((500,000/1,912,500) = 0.2614 \text{ Hz}\)

The one-way ambiguity distance is approximately:

\[
\frac{300,000}{0.2614 \times 2} = 573.750 \text{ km}
\]
3.6.10 INMARSAT / LMCO Tone Standards

3.6.10.1 General

The ranging procedure consists of a sequential transmission of four tones (1 major and 3 minor). Typically, the minor tones are transmitted first, starting with the lowest frequency tone, followed by the major tone. On each tone, a 6-second set time allows all ground and on-board receivers in the ranging loop to lock onto the signal and the various PLLs to stabilize.

The tone order can be programmed as well as the number of measurements on each tone. Tone frequencies are fixed. Ranging sequences with 2, 3 or 4 identical tones are accepted.

3.6.10.2 Tone Frequencies

The frequency plan consists of four tones, derived by division from the 10-MHz reference clock:

- **Major tone**: 27,778 kHz \(\left(10^7/360\right)\).
- **Minor tones**: 3968 Hz \(27.778/7\),
  283 Hz \(3968/14\),
  35 Hz \(283/8\).

P and Q factors for the INMARSAT and LMCO standards are « hard-wired » (not programmable):

<table>
<thead>
<tr>
<th>Q</th>
<th>P</th>
<th>\text{Virtual Tone Frequency}</th>
<th>\text{Real Tone Frequency}</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1</td>
<td>27.777778 kHz</td>
<td>27.777778 kHz</td>
</tr>
<tr>
<td>126</td>
<td>1</td>
<td>3968.25 Hz</td>
<td>3968.25 Hz</td>
</tr>
<tr>
<td>1764</td>
<td>1</td>
<td>283.45 Hz</td>
<td>283.45 Hz</td>
</tr>
<tr>
<td>14112</td>
<td>1</td>
<td>35.43 Hz</td>
<td>35.43 Hz</td>
</tr>
</tbody>
</table>

*Table 16: INMARSAT/LMCO Tone Standard. Tone Definition*

3.6.10.3 Minor Tone Sub-Carrier

For reasons of modulation efficiency, the minor tones phase-modulate a 19-kHz sub-carrier (INMARSAT standard) or a 27,778-kHz sub-carrier (LMCO standard). The default setting for the modulation index is 0.8 radian (can be adjusted in the Windows registry).
3.6.10.4 Ranging Sequence

Next figure illustrates the ranging measurement sequence:

![Ranging Sequence Diagram]

**Figure 53**: Ranging Sequence (INMARSAT/LMCO Standards)

1. RAU in idle state: mute output.

2. On reception of a ranging request from the Ranging Client, the RAU computes the tone definition tables (only the first time a ranging request is received for the current RAU configuration. Duration: < 3 seconds). Then, if the computation is successful the RAU starts transmitting the first tone (major tone or 19-kHz or 27.778-kHz sub-carrier phase-modulated by any of the four minor tones).

3. 6 seconds later (tone set time), the RAU instantaneously performs the first phase measurement and simultaneously acquires the current time from the Time Code Reader for further time-tagging of the ranging transaction response message. Next measurements on the first tone take place every **100 ms**.

4. For the second, third and fourth tones, the process is similar.

5. End of phase measurement on the fourth tone. Idle state.
The total duration of the ranging sequence depends on the measurement sampling ratio and the number of measurements on each tone. Assuming 10 measurements per tone and a sampling ratio of 1 (all measurements transmitted), the sequence duration (computation time for tone definition tables not included) is:

- 1\textsuperscript{st} tone set time \hspace{1cm} 6 seconds
- Measurement on 1\textsuperscript{st} tone \hspace{1cm} 0.9 second
- 2\textsuperscript{nd} tone set time \hspace{1cm} 6 seconds
- Measurement on 2\textsuperscript{nd} tone \hspace{1cm} 0.9 second
- 3\textsuperscript{rd} tone set time \hspace{1cm} 6 seconds
- Measurement on 3\textsuperscript{rd} tone \hspace{1cm} 0.9 second
- 4\textsuperscript{th} tone set time \hspace{1cm} 6 seconds
- Measurement on 4\textsuperscript{th} tone \hspace{1cm} 0.9 second

Total sequence duration \hspace{1cm} 27.6 seconds

If the sampling ratio is set to 4 (1 measurement out of 4 transmitted to Ranging Client), the sequence duration is:

- 1\textsuperscript{st} tone set time \hspace{1cm} 6 seconds
- Measurement on 1\textsuperscript{st} tone \hspace{1cm} 3.6 seconds
- 2\textsuperscript{nd} tone set time \hspace{1cm} 6 seconds
- Measurement on 2\textsuperscript{nd} tone \hspace{1cm} 3.6 seconds
- 3\textsuperscript{rd} tone set time \hspace{1cm} 6 seconds
- Measurement on 3\textsuperscript{rd} tone \hspace{1cm} 3.6 seconds
- 4\textsuperscript{th} tone set time \hspace{1cm} 6 seconds
- Measurement on 4\textsuperscript{th} tone \hspace{1cm} 3.6 seconds

Total sequence duration \hspace{1cm} 38.4 seconds
3.6.11 ESA Code Standard

3.6.11.1 General

The ranging sequence consists of a sequential transmission of a tone which is phase-modulated by a series of codes, used for ambiguity solving. Initially, the tone is transmitted to allow the transponded tone to be acquired by the ground equipment (IF Receiver and RAU).

By means of a digital PLL, the RAU produces a phase-locked replica of this tone. Then the lowest code modulates the tone. Then the code is replaced by the following codes and so on until the longest code. Each transmitted code is correlated with the demodulated code to determine the number of tone cycles in the range.

When all codes have been transmitted, the RAU continues transmitting the tone, allowing for accurate range measurement.

The PLL is a second-order whose the bandwidth (2Bn) is programmable from 0.1 to 8 Hz (Cortex CRT Quantum) or 0.001 Hz to 8 Hz (CRT DS Quantum).

3.6.11.2 Frequency Programming

The tone frequency is programmable through major tone parameters according to the following rule:

\[ F_{\text{tone}} = 500 \times \frac{P_{\text{major tone}}}{Q_{\text{major tone}}} \text{ (in kHz)} \]

with the restrictions described in § 3.6.2.1.

3.6.11.3 Code Programming

Ambiguity solving is performed by code transmission. The code sequence is defined by the parameter Code length \( N = 0 \) to 24). Each code consists in a PCM/PM (modulation index is 45°) modulated binary messages where bits and tone cycles transitions are synchronized. The binary message number \( n \) (where \( 0 < n \leq N \)) is pseudo-noise sequence of length \( 2^n \) bits derived from the following expression:

\[ C_n = Q_1 \oplus Q_2 \oplus Q_3 \oplus \ldots \oplus Q_n \]

where \( \oplus \) is XOR binary operator, \( Q_1 \) is 10101..., \( Q_2 \) is 110011001..., \( Q_3 \) is 11110000111100001... and so on.

Only even codes are transmitted. Therefore the last emitted code number (M) can be different from N:

- If \( N = 0 \), \( M = 2 \).
- If \( N \) is odd, \( M = N + 1 \).
- If \( N \) is even, \( M = N \).

For example, if \( N = 4 \), codes 2 and 4 are transmitted. If \( N = 7 \), codes 2, 4, 6 and 8 are transmitted.
For a given $M$, the **maximum ambiguity solving** is given by the following formula:

$$T = \frac{2^M}{F_{\text{TONE}}} \text{ (in seconds)}$$

Thus $N$ shall be chosen such as the two-way expected delay be lower than $T$.

### 3.6.11.4 Tone & Code Set Time

The code set time ($T$) is defined by the above formula. The tone set time is computed according to the following formulas (see next figure, parameters $T$, $T_a$ and $T_s$):

**RAU PLL bandwidth = 1 to 8 Hz:**

$$T_a = T + 2 \text{ (in seconds)}$$

$$T_s = T + 4 \text{ (in seconds)}$$

**RAU PLL bandwidth < 1 Hz:**

$$T_a = T + \frac{2}{2B_n} \text{ (in seconds)}$$

$$T_s = T + \frac{4}{2B_n} \text{ (in seconds)}$$

**Note:** Set time values are rounded up to the nearest whole number of resolution steps (resolution step $\approx 13.1$ ms).

### 3.6.11.5 Ranging Sequence

Next figure illustrates the ranging measurement sequence with $N = 6$ or 7:

![Figure 54: Ranging Sequence (ESA Code Standard with N = 7)](image-url)
1. On reception of a ranging request from the Ranging Client, the RAU computes the tone and codes definition tables. Then, if the computation is successful, the RAU starts transmitting the tone. Status *Measurement Progress* in the RAU monitoring table starts incrementing.

2. \( T_a \) seconds later, transmission of code 2 (T-second set time).

3. Correlation process for the first code. The duration (parameter *Integration Time*) is programmable from 250 ms to 2500 ms.

   Steps 2 and 3 are repeated for codes 4 and 6.


5. Correlation process for code 8. The tone is then transmitted during \( T_s \) seconds (time necessary for the PLL to stabilize).

6. First phase measurement on the tone and ambiguity solving. The RAU simultaneously acquires the current time from the Time Code Reader for further time-tagging of the ranging transaction response message.

7. Status *Measurement Progress* is equal to 100. Phase and « distance » measurements are returned to the Ranging Measurement Client(s) in a ranging transaction response message.

Phase measurements on the tone are performed at regular time interval (One measurement every 250 ms). These measurements are corrected as described in § 3.6.3.4. For each measurement on the tone is calculated a « distance » in nanoseconds. The calculation takes into account (ambiguity solving) phase drift due to spacecraft motion during tone transmission.

The total duration of the ranging sequence depends on six factors:

- the tone frequency,
- the measurement sampling ratio,
- the integration time,
- the number of measurements on the tone,
- the code length,
- the loop bandwidth.

Assuming that these parameters are: 300 kHz (tone frequency), 1 (no under-sampling), 1000 ms (integration time), 10 measurements on the tone, 7 (code length. Transmitted codes = 2, 4, 6, 8) and 1 Hz (loop bandwidth), the sequence duration is (the time to compute the tone definition tables is not included):

- Pre-transmission of the tone : 2.01 s
- Codes 2, 4, 6 & 8 (set time + integration) : 4.05 s
- Transmission of the pure tone : 4.01 s
- 10 measurements on the tone (0.25 x 9) : 2.25 s

**Total sequence duration** : 12.32 seconds
3.6.12 PN Codes Standard (Regenerative PN Ranging)

Available under licence on Cortex CRT DS Quantum

3.6.12.1 General

The ranging sequence consists in a continuous transmission of a pseudo noise sequence, which is a logical combination of six binary periodic PN components used for ambiguity solving. One of these PN components, called the range clock, represents the major tone.

By means of a digital PLL, the RAU produces a phase-locked replica of the major tone. The PN components are correlated with the demodulated code to determine the number of major tone cycles in the range.

The PLL is a second-order whose bandwidth (2Bn) is programmable from 0.001 to 8 Hz.

3.6.12.2 Frequency Programming

The tone frequency is programmable through major tone parameters according to the following rule:

\[ F_{\text{TONE}} = 500 \times \frac{P_{\text{MAJOR.TONE}}}{Q_{\text{MAJOR.TONE}}} \] (in kHz)

with the restrictions described in § 3.6.2.

The tone frequency is half of the Chip Rate. According to CCSDS 414.1-R-1 RED BOOK (April 2008), two chip rates are selected:

<table>
<thead>
<tr>
<th>Q</th>
<th>P</th>
<th>CORTEX CHIP RATES</th>
<th>CCSDS CHIP RATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>30</td>
<td>1,034,483 chips/s</td>
<td>1,034,295 chips/s</td>
</tr>
<tr>
<td>29</td>
<td>60</td>
<td>2,068,966 chips/s</td>
<td>2,068,590 chips/s</td>
</tr>
</tbody>
</table>

Table 17: Available chip rates on Cortex

3.6.12.3 Code Programming

The PN sequence is defined by the parameter Code length \((N = 2 \text{ or } 4)\). \(N = 2\) for Weighted-Voting Balanced Tausworthe (T2B), and \(N = 4\) for T4B. The parameter Code length, in the case of PN Codes Standard, gives a correlation degree between the range clock and the emitted ranging sequence. The T2B PN code structure is used to optimize the integration time. The T4B PN code structure is used to increase the ranging accuracy.

The periodic PN components are:

\[ C_1 = +1 \ -1 \ (\text{the range clock}) \]

\[ C_2 = +1 \ +1 \ +1 \ -1 \ -1 \ -1 \]

\[ C_3 = +1 \ +1 \ -1 \ 1 \ -1 \ +1 \ -1 \ +1 \ -1 \]

\[ C_4 = +1 \ -1 \ +1 \ -1 \ +1 \ -1 \ -1 \ +1 \ +1 \ -1 \ +1 \ -1 \ +1 \ -1 \]

\[ C_5 = +1 \ +1 \ +1 \ -1 \ -1 \ +1 \ -1 \ -1 \ +1 \ -1 \ -1 \ +1 \ -1 \ +1 \ +1 \ -1 \ +1 \ -1 \]

\[ C_6 = +1 \ +1 \ -1 \ 1 \ -1 \ +1 \ -1 \ +1 \ -1 \ +1 \ -1 \ +1 \ -1 \ +1 \ +1 \ -1 \ +1 \ -1 \]
The periodic ranging sequence is a combination of PN components:

\[ C_{TB} = \text{sign}(2C_1 + C_2 - C_3 - C_4 + C_5 - C_6) \]
\[ C_{TB} = \text{sign}(4C_1 + C_2 - C_3 - C_4 + C_5 - C_6) \]

with length \( L = 2 \times 7 \times 11 \times 15 \times 19 \times 23 = 1,009,470 \) chips

For a given chip rate, the maximum ambiguity solving is given by the following formula:

\[ T = \frac{L}{F_{\text{chip}}} - \frac{1}{2 \times F_{\text{tone}}} \] (in seconds)

### 3.6.12.4 Shaping Filter

The shaping filter has the following impulse response:

\[ h(t) = \begin{cases} \sin(\pi t / T_c) & 0 \leq t \leq T_c \\ 0 & \text{elsewhere} \end{cases} \]
### 3.6.12.5 Tone & Code Set Time

The code set time \( T \) is defined by the above formula. The tone set time is computed according to the following formulas (see next figure, parameters \( T, T_a \) and \( T_s \)):

#### RAU PLL bandwidth = 1 to 8 Hz:

\[
T_a = T + T_{\text{BAT}} + 2 \quad \text{(in seconds)}
\]
\[
T_s = T + 4 \quad \text{(in seconds)}
\]

#### RAU PLL bandwidth < 1 Hz:

\[
T_a = T + T_{\text{BAT}} + \frac{2}{2Bn} \quad \text{(in seconds)}
\]
\[
T_s = T + \frac{4}{2Bn} \quad \text{(in seconds)}
\]

where \( T_{\text{BAT}} \): Onboard acquisition time (ms) is the time between the reception of the uplink signal and the regeneration of the downlink signal by the onboard receiver.

1. **Note**: Set time values are rounded up to the nearest whole number of resolution steps (resolution step \( \approx 13.1 \text{ ms} \)).

2. **RAU Integration Time**:

The integration time is programmable from 0.25 s to 500 s. The next table gives the normalized correlation time of the 6th PN component:

<table>
<thead>
<tr>
<th>Ranging Sequence</th>
<th>Normalized Correlation Time ( \tau_{\text{cor}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balanced Weighted-voting Tausworthe, Code Length = 4</td>
<td>509.0</td>
</tr>
<tr>
<td>Balanced Weighted-voting Tausworthe, Code Length = 2</td>
<td>30.71</td>
</tr>
</tbody>
</table>

#### Table 18: CCSDS recommendation for Integration time

For a given acquisition probability \( P_{\text{el}} \) of the code and for a given \( S/N_0 \), the integration time \( IT \) is:

\[
IT = \frac{\tau_{\text{cor}} \times \left( \text{erfc} \left( \frac{P_{\text{el}}}{IT} \right) \right)^2}{\frac{S}{N_0}}
\]
3.6.12.6  Ranging Sequence

Next figure illustrates the ranging measurement sequence:

1. On reception of a ranging request from the Ranging Client, the RAU computes the tone and codes definition tables. Then, if the computation is successful, the RAU starts generating and transmitting the ranging sequence. Status **Measurement Progress** in the RAU monitoring table starts incrementing.

2. Correlation process of the received ranging sequence. The duration (parameter **Integration Time**) is programmable from 0.25 s to 500 s.

3. Stabilization of the PLL during **Ts** seconds.

4. First phase measurement on the tone and ambiguity solving. The RAU simultaneously acquires the current time from the Time Code Reader for further time-tagging of the ranging transaction response message.

5. Status **Measurement Progress** is equal to 100. Phase and « distance » measurements are returned to the Ranging Measurement Client(s) in a ranging transaction response message.

Phase measurements on the tone are performed at regular time interval (One measurement every 250 ms). These measurements are corrected as described in § 3.6.3.4. For each measurement on the tone, a « distance » is calculated in nanoseconds. The calculation takes into account (ambiguity solving) phase drift due to spacecraft motion during tone transmission.

The total duration of the ranging sequence depends on five factors:

- the tone frequency,
- the measurement sampling ratio,
- the integration time,
- the number of measurements on the tone,
- the loop bandwidth.
Assuming that these parameters are: 500 kHz (tone frequency), 1 (no under-sampling), 4.3 s (integration time), 10 measurements on the tone and 1 Hz (loop bandwidth), the sequence duration is (the time to compute the tone definition tables is not included):

- Pre-transmission of the tone : 3.01 s
- Integration time : 4.30 s
- 10 measurements on the tone (0.25 x 9)+Ts : 7.26 s

Total sequence duration : 14.57 seconds
3.6.13 Ranging Performances vs Noise & Doppler

Ranging tones reception (and demodulation for the minor tones) is performed by a 2nd-order digital PLL. The programmable loop bandwidth ($2B_n = 0.1$ to 8 Hz for all tones) allows to cope with any mission requirements (launch, transfer orbit or station keeping operations) or any type of spacecraft (LEO, GEO). Use the following formulae to calculate the performances of the CORTEX CRT Quantum in the presence of noise and Doppler rate:

$$Bias_{Doppler} = \frac{2\pi R}{\omega_n^2} \text{ (in radian)}$$

$$\sigma_{Noise} = \sqrt{\frac{2B_n^2}{2SN_0^2}} \text{ (in radian)} \quad \text{and} \quad \sigma_{Noise} = \frac{1}{R_{RC}} \sqrt{\frac{2B_n^2}{2SN_0^2}} \text{ (radian) in case of PN Codes}$$

$$2B_n = \omega_n (\xi + \frac{1}{4\sigma})$$

With:
- $\sigma$: Standard deviation on the major tone
- $2B_n$: Bi-lateral loop bandwidth (in Hz)
- $R$: Doppler rate (in Hz/s)
- $\xi$: Damping factor (0.7)
- $\omega_n$: Loop pulsation (in radian/second)
- $SN_0$: Signal-to-Noise ratio at RAU input (in dB.Hz)
- $R_{RC}$: In-phase correlation percentage (Major tone; PN sequence)
  - $= 0.9387$ for T4B and 0.6274 for T2B

Example: $\frac{SN_0}{N_0} = 38$ dB.Hz, $R = 0.007$ Hz/s on the major tone. The degradation of the measurement on the major tone vs the loop bandwidth is:

<table>
<thead>
<tr>
<th>LOOP BANDWIDTH (2BN)</th>
<th>$\sigma_{Noise}$</th>
<th>$Bias_{Doppler}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hz</td>
<td>0.51°</td>
<td>2.80°</td>
</tr>
<tr>
<td>2 Hz</td>
<td>0.72°</td>
<td>0.70°</td>
</tr>
<tr>
<td>4 Hz</td>
<td>1.01°</td>
<td>0.18°</td>
</tr>
<tr>
<td>8 Hz</td>
<td>1.44°</td>
<td>0.04°</td>
</tr>
</tbody>
</table>

Table 19: Ranging Performances with Noise & Doppler Rate
3.7 DOPPLER COMPENSATION

3.7.1 General

The Doppler Compensation mechanism is used for real time adjustment of the uplink and downlink IF carrier frequency, bit rate and chip rate. The Doppler compensation mechanism drastically improves signal acquisition and tracking performances of the on-board and station IF Receivers.

The Doppler Predictions are initialised by a request containing a time reference (based on IRIG B reference), a time offset and a frequency offset. This compensation will be applied by the Cortex when the time offset (execution date) is reached.

3.7.2 Concerned Units

The units concerned by Doppler Compensation Process are:

- IFM, Carrier compensation
- TCU, Sub-Carrier and/or Bit Rate compensation
- TMS, Sub-Carrier and/or Bit Rate compensation
- IFR, Carrier compensation
- TMU, Sub-Carrier and/or Bit Rate compensation

Note: In case of diversity combining, it is recommended to send the same Doppler prediction table to both of the IFRs.
3.7.3 Doppler Compensation Process

The Doppler prediction table contains pairs of (Time Offset, Frequency Offset) describing a Doppler trajectory. The time offsets can be non-linear. The SPS linearly interpolates the Doppler trajectory depending on the interpolation step which can take four values: 1 s, 0.1 s, 0.01 s, and 0.001 s (synchronized by 1pps signal).

Once the execution date is reached by the IRIG-B reference, the hardware starts updating the NCO (every 160 µs, 16 µs, 1.6 µs, 0.16 µs) until the end of compensation process.

The next figure illustrates the Doppler compensation process:

![Doppler Compensation Process](image)

*Figure 56 : Doppler Compensation Process*

Four states describe the process:

- **Off**: the compensation is disabled.
- **NoData**: the compensation is enabled and waiting for a request.
- **Wait**: the request is received and accepted, the Cortex waits for the execution date to be reached.
- **InProgress**: the process is running.

During the execution of a table, if the Doppler compensation is disabled, the interpolation continues until the end of compensation where the last offset applied is kept.
3.7.3.1 Doppler Compensation Mechanism

Each entry in the compensation table consists in a pair of values: \( \Delta t_i \) and \( \Delta F_i \), where:

- \( \Delta t_i \) is the time offset to the previous entry (or to the absolute time for the first entry of an Initialization table).

Important: the higher the expected Doppler rate, the narrower the time offsets should be and vice versa. It should be noted that the frequency curve derived from the \( \Delta t_i / \Delta F_i \) entries is sampled by the CORTEX software every 13 ms (see next figures).

Depending on the selected \( \Delta t_i \), the uplink carrier compensation can be as accurate as to within ± 1 Hz.

- \( \Delta F_i \) is the frequency correction [Compensated IF – Programmed IF] applicable to the uplink carrier.

![Figure 57: Doppler Variations for a LEO Spacecraft Pass](image)

The above picture shows typical Doppler variations during a LEO satellite pass. The maximum Doppler is observed at low elevation (horizon) while the maximum Doppler rate is observed at zenith pass.
Next figure shows the reconstructed frequency curve by the CORTEX with low distortion of the high Doppler rate area due to the use of a higher sampling rate (ΔTi).

*Figure 58: Doppler Compensation from Ephemeris Files*
3.7.4 Doppler Compensation Instruction Set

3.7.4.1 Doppler Table Initialization

Constructs a new internal Doppler Compensation table. If a Doppler Compensation is in progress, the current Doppler Compensation is stopped (the current Internal Doppler Compensation table is cleared).

Error Code:

- Invalid instruction: frequency offset result is less than –7,812,500 Hz, or larger than 7,812,500 Hz.
- Invalid date/time: starting time is close to the current time (if CheckTime is enabled).

3.7.4.2 Append Doppler Table

Append the existing internal Doppler Compensation Table.

Error Code:

- Invalid instruction: frequency offset result is less than –7,812,500 Hz, larger than or equal to 7,812,500 Hz.
- Invalid date/time: last Doppler Compensation date of the existing table added to the first offset time is close to the current time (if CheckTime is enabled).
- Append Instruction Rejected: no Internal Doppler Compensation table exist, or the sequence counter is not following the current sequence counter, or the number of values of the current Doppler Compensation table plus the number of Doppler compensation values of Append instruction is larger than 32,000.

3.7.4.3 Clear Doppler Table

If Doppler Compensation is in progress, the current Doppler Compensation is stopped and the Internal Doppler Compensation table is cleared. While Doppler Compensation is ON on any unit, the last frequency offset is applied to these units with a frequency rate value of 0.

If Doppler Compensation is not in progress, no table needed to be cleared. But, all previous applied frequency offsets are set to zero.

3.7.4.4 Save Doppler Table

Save the current Internal Doppler Compensation table.

Error Code:

- No Doppler Table available: no Internal Doppler Compensation table exist.
- File not available: software cannot create the file.
3.7.4.5 Load Doppler Table

Load the specified file to construct the Internal Doppler Compensation table. If the Internal Doppler Compensation table exists, this one is cleared.

Error Code:

− File not Available : specified file missing, or cannot be read, or the file isn’t a DeepSpace Doppler Compensation file.

3.7.4.6 Doppler Table Start Date

Provides the information about the Start Date of the currently loaded Doppler Table

3.7.4.7 Doppler Table End Date

Provides the information about the End Date of the currently loaded Doppler Table
3.7.5 Time Management

Two cases are demonstrated, the first one concerns the leap year (cf Figure 47), the second is about the extra few seconds added each year to compensate the IRIG-B Clock (cf Figure 59 : Leap year). In the two cases, we have a slipping of execution dates equivalent to 3600x24 seconds for leap year or the value of IRIG-B compensation. To avoid this situation, the MCS gives possibilities to the user to inform the SPS about leap years and time offsets. Refer to the MCS User’s Manual.

**Note:** the maximum time between sending the Doppler compensation request and the execution date is 170 days.

**Figure 59 : Leap year**

**Figure 60 : IRIG-B compensation**
4. OPERATION MANUAL
4.1 STARTING AND CONFIGURING THE CORTEX

4.1.1 First Steps

4.1.1.1 Starting the PC Workstation

1. Verify that the CORTEX has not been damaged during transportation. If needed, open the top cover and verify that the electronic sub-assemblies are in good condition.

2. Check that the CORTEX chassis is properly grounded and connected to the AC power via the appropriate power cord.

3. Switch on the chassis (ON/OFF switch is at the rear panel). Allow 8 to 10 seconds for the power supply to start.

4. At the front panel display, follow Windows boot-up sequence. The unit is configured to Automatic Login as Cortex account.

4.1.1.2 Starting the Signal Processing Software

At the end of the Windows boot-up sequence, the Signal Processing software is automatically started. If the Demodulator board is present, the following SPS icon (lower right corner) appears:

![SPS Icon](image)

If the board is not mounted in the chassis or in the case of a major hardware problem, the following message appears:

![Hardware Initialization Error](image)

and the SPS icon remains yellow:

![Yellow SPS Icon](image)

4.1.1.3 Starting the Monitoring & Control Software

Once the Signal Processing software is running, the Monitoring & Control software is automatically started. If needed, connect the MCS to the SPS for starting the GUI.

A detailed description of the Graphical User Interface is given in the next sections.
4.1.2 Factory Configuration

The CORTEX has been configured in factory in accordance with the required hardware components (electronic cards, etc…) and software licenses (maximum bit rate supported, data decoding licenses, data processing license, etc…).

Each CORTEX unit comes with a factory acceptance test book showing the detailed hardware and software configuration of the unit at delivery.

4.1.3 Software Exit & CORTEX Shutdown

4.1.3.1 Exiting the Monitoring & Control Software

To exit the Monitoring & Control Software, click on **File** menu and select **Exit** or click on [X] in the upper right corner of the MCS window. If any configuration parameter has been changed since the MCS Document was updated on the disk, the following message is displayed:

Click on Yes to update the CTX Document on the disk. Otherwise, click on No or Cancel the command.

4.1.3.2 Exiting the Signal Processing Software

To exit the Signal Processing Software (SPS), click on the SPS icon at the lower right part of the screen and select **Exit**.

4.1.3.3 Restarting the SPS & MCS

Assuming the application software (SPS + MCS) has been stopped, click on shortcut menu **Start** / **All Programs** / **Startup** / **crtxstart** to restart it.

To restart the MCS only, click on shortcut menu **Start** / **All Programs** / **Cortex Signal Processing** / **Cortex CRT Monitoring & Control**.

To restart the SPS only, click on shortcut menu **Start** / **All Programs** / **Cortex Signal Processing** / **Cortex CRT Signal Processing**. In case of multi-configuration menu, this shortcut starts the SPS Menu selection dialog with the last menu highlighted.
4.1.3.4 CORTEX Shutdown

PRIOR TO SWITCHING OFF YOUR CORTEX PRODUCT

SHUT DOWN THE PC-COMPATIBLE WORKSTATION (CLICK ON Start / Shutdown).

FAILURE TO OBSERVE THIS PROCEDURE CAN AFFECT DATA ON THE DISK AND THE SYSTEM ITSELF.

4.1.4 Screen Saver

WARNING:

TO AVOID PREMATURE AGEING / FAILURE OF THE LCD AND DATA TRANSFER PROBLEMS ON THE PCI EXPRESS BUS,

DO NOT CHANGE THE SCREEN SAVER SETTING

THE SCREEN SAVER INSTALLED AT DELIVERY IS “DPMS”
ONLY THE “DPMS” SCREEN SAVER ALLOWS TO SWITCH THE LCD BACKLIGHT OFF

4.1.5 Third-Party Software

WARNING:

DO NOT INSTALL THIRD-PARTY SOFTWARE

SUCH AS ANTI-VIRUS, FIREWALL, NTP TIME SYNCHRONIZATION, OR OTHER SOFTWARE THAT INSTALLS A RESIDENT PROCESS. FAILURE TO COMPLY WITH THIS RESTRICTION MAY RESULT IN UNSTABLE OPERATION OF THE EQUIPMENT AND/OR NON COMPLIANCE WITH THE SPECIFICATIONS
4.2 SIGNAL PROCESSING SOFTWARE (SPS)

4.2.1 CTX Documents

CTX Documents are configuration files created and managed by the CORTEX SPS.

A CTX Document contains the whole set of configuration parameters that have been previously stored on the disk under file extension .CTX.

A default CTX Document (cortex-nt.ctx) is loaded by the SPS when the CORTEX is started, and is used to configure the machine. A copy of this file (CTX Table) is maintained in SRAM and is updated whenever the CORTEX configuration is changed by the operator. The CTX Table is automatically saved to the CTX Document on the hard every 10 seconds and at application ending.

Additional CTX Documents reflecting up to ten mission-specific configurations can be created by the operator.

CTX Documents are binary files; they cannot be displayed on the screen or printed out.

4.2.2 SPS Start Sequence

The default CTX Document loaded by the SPS when the CORTEX is started is C:\Program Files\In-sneic\crtxnt\cortex-nt.ctx. The CORTEX is configured from the contents of this file. This file represents the last active CTX Document.

**STEP 0**: Windows boot up sequence.

**STEP 1**: The Signal Processing Software (SPS) is automatically started. The CORTEX is configured from parameters stored in cortex-nt.ctx file. A copy of the file is maintained in RAM (CTX Table).

**STEP 2**: The Monitoring & Control Software (MCS) (local GUI or remote MCS) opens a TCP-IP connection to the Monitoring port and starts monitoring the machine. The CTX Table is updated when configuration requests are received on the TCP-IP Control port.

**STEP 3**: The cortex-nt.ctx file is automatically refreshed every 10 seconds and at application ending.

*Figure 61: SPS Start Sequence*
4.2.3 Configuring the CORTEX from CTX Documents

A set of 10 CTX Documents is available on the disk, in addition to the last active CTX Document (Default: cortex-nt.ctx).

CTX Documents are stored in a single directory D:\ZDS\Data\CRT\Menu<x>\CTXDocument. Each one has a predefined name with .CTX extension (default names at delivery: SatCnf_01.CTX to SatCnf_10.CTX).

4.2.3.1 CTX Document Name Table

Management of the CTX Documents is via the CTX Document Name Table. This table assigns a name to each CTX Document, to make file selection easier for the operator (see STI 100013 for table format).

The CTX Document Name Table is transmitted over the LAN on reception of a monitoring request with component code 200_H.

The CTX Document Name Table is not included in the set of tables returned to the monitoring client on reception of a monitoring request for All component tables.

The CTX Document Name Table is automatically saved to the disk (D:\ZDS\Data\CRT\Menu<x>\CTXDocument\NameTable.TXT) whenever the name of a CTX Document is changed or at application ending.

The CTX Document Name Table is ASCII-coded.

4.2.3.2 CTX Document Storage and Loading

CTX Documents can be created, modified, (re)named and loaded via two configuration commands (see Annex 1, section 2.3.2.3) available in the CTX Document Management window (refer to the MCS User’s Manual and the TCP-IP Interface Specification):

- **Save command**: name and store the active CTX Table into one of the 10 CTX Documents on the disk.
- **Load command**: select and load one of the 10 CTX Documents and reconfigure the CORTEX.

The CTX Document name can also be modified by editing the NameTable.TXT file before starting the CORTEX SPS. If a CTX Document is not available (not existing or corrupted), the assigned name is set to an empty character string.

In the CORTEX Series monitoring table (offset 16) and in the Global CORTEX CRT monitoring table (offset 22), the **CTX Document ID** status indicates which one of the 10 CTX Documents was previously loaded or stored and whether or not this CTX Document was modified since loaded or stored (**Update CTX Document** status). See STI 100013 and STI 100013_CRT in Annex 1 for more details.

Both status are set to 0 at boot.
REMOTE USERS

Start Application

Set CTX Document ID status to 0
Set Update CTX Document status to 0

Load CTX Document in RAM

Loaded

Load CTX Document Name Table

Loaded

Store CTX Document #N with Label

Accept

Set CTX Document ID status to N.
Set Update CTX Document status to 0.

Save Active CTX Table to CTX Document # N

Saved

Save CTX Document Name Table

Saved

Configuration Request

Accept

Set Update CTX Document status to 1

Every 10 seconds: save Active CTX Table to the disk.

Saved

Load CTX Document #N

Accept

Set CTX Document ID status to N.
Set Update CTX Document status to 0.

Apply all configuration parameters

Loaded

Save Active CTX Table to CTX Document #N

Saved

CTX Document Name Table

Saved

Loaded

CTX Document # N

Loaded

CTX Document Name Table

CTX Document ID status to N.
Set Update CTX Document status to 0.

Load CTX Document Name Table

CTX Document # N

(*): If file error, set all parameters to their default value

Figure 62: CTX Document Management
4.2.4 Start-up Menu Selection by Remote Access Control (RAC)

The RAC functionality is supported by all CORTEX products (CRT, HDR, ACS, ...).

4.2.4.1 General

On some CORTEX products (CORTEX CRT, CORTEX HDR, etc…) a start-up menu offers several high-level architectures (combination of hardware and software resources) corresponding to different mission requirements.

When starting up the CORTEX software, menu selection can be done either locally (user interface described hereafter) or remotely (Remote Access Control) by sending control commands to a specific RAC data server on the CORTEX machine (RAC port # 3003). Control commands are described in the Ethernet ICD STI 100013, section 2.6.

Starting a new menu while the CORTEX is running takes only a few seconds (2 seconds best case, up to 20 seconds when a new FPGA software needs to be downloaded from the hard disk to the target FPGA).

The following commands are supported:

- **Stop the active menu**: the CORTEX application software is not stopped but all IP connections (to the monitoring port, telemetry port, ranging ports, etc…), except the connections to the RAC port, are automatically closed. The connection status on the top level window of the GUI indicates DISCONNECTED.

- **Start a new menu**: select and start a new menu.

- **Check the active menu**: indicates the active menu.

- **Load the menu table**: on reception of this command, the CORTEX returns the list of available menus.

4.2.4.2 Menu Selection at SPS Start-up

When the SPS software is started, the following window appears on the screen:

---

**CORTEX Start/Stop Menu**

- **Current Configuration**:
  - 2: Diversity Combining on Hbw TM direct Pcm

- **Default CTX Files**:
  - cortex:nt2.CTX

- **Registry path**:
  - Default2

- **Buttons**:
  - Start menu
  - Stop menu
  - Close

---
The window shows the last loaded menu (active menu when the CORTEX software was restarted). Ignore or close this window if you agree with the proposed menu.

To select another menu, open the list of menus, select a menu and click on **Start Menu** (or wait until time-out expiration).

At any moment the above window can be re-opened by clicking on the SPS icon at the lower right corner of the screen (« Antenna » icon) and selecting option **Select Menu**:

<table>
<thead>
<tr>
<th>Save</th>
<th>Ctrl-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit</td>
<td></td>
</tr>
<tr>
<td>Select menu</td>
<td></td>
</tr>
<tr>
<td>About cortex...</td>
<td></td>
</tr>
</tbody>
</table>

Stop the active menu (click on **Stop Menu**) before selecting and starting (click on **Start Menu**) another menu.
4.2.4.3 MCS Graphical User Interface

From the ZODIAC DATA SYSTEMS MCS the operator can access the RAC server by clicking successively, in the upper toolbar, on  **Window → Menu_Selection**, or by clicking on the **icon.**

Next picture shows the operational scenarios offered by the start-up menu. Use the **Stop** active menu and **Start** new menu pushbuttons to re-configure the CORTEX.

![Figure 63: MCS Menu Management Window](image-url)
4.2.5 SPS Version Identification

4.2.6 Common Data

Software version at delivery is described in Annex 5 (Section 1) and, with more detail, in the CORTEX Acceptance Test Report.

- To know the version of the PROMed software (ZODIAC DATA SYSTEMS electronic cards), refer to the Acceptance Test Report (see also the marking on the PROM chips).

- To know the Signal Processing Software (SPS) version and what version of software is downloaded at boot to the ZODIAC DATA SYSTEMS electronic cards, click on at the lower right corner of the display and select About Cortex:

![About Cortex Window]

Figure 64: About CORTEX CRT Quantum SPS: Software Version

The SPS is built around an SPS kernel (supporting multiple CORTEX products such as the CORTEX CRT, CORTEX HDR, CORTEX ACS, CORTEX RTR, etc…) and a product-specific SPS software layer.

The header of the above window shows the version of the SPS kernel (example: Version 2.4).
4.2.6.1 CORTEX CRT Quantum Specific Data

The inner window shows the following version numbers:

- SPS software layer specific to the CORTEX CRT Quantum product (example: 5,13,0,1).
- Main Signal Processing Software product file and version
- Firmware Issue: shows the Main Signal Processing board model and serial number
- DSP Version: Issue, Revision and Build number.
- Main Signal Processing board, PROMed FPGA software: MSP PCI Express FPGA: Issue and Revision.
- Main Signal Processing board, downloaded FPGA software
  - MSP Master FPGA: Type, Issue, Revision
  - MSP Slave FPGA: Issue, Revision
- Downlink Analog board, downloaded FPGA software: Issue and Revision.
- Uplink Analog board, downloaded FPGA software: Issue and Revision.
4.2.7 CORTEX CRT Quantum File System Architecture

The CORTEX CRT Quantum software can be found in the following directories. **Do not move or modify these files or directories.** These directories are not accessible by Cortex User.

<table>
<thead>
<tr>
<th>ACCESS PATH</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C:\Program Files\ZDS</td>
<td>Root directory</td>
</tr>
<tr>
<td>\cortex</td>
<td>Kernel Signal Processing Software: system files.</td>
</tr>
<tr>
<td>\CrtxMcs</td>
<td>Graphical Kernel binary</td>
</tr>
<tr>
<td>\CrtxMcs \Internal</td>
<td>Kernel Language Translation Files</td>
</tr>
<tr>
<td>\CRT \Msp</td>
<td>Microblaze Binary file (.hex) Firmware FPGA binary files</td>
</tr>
<tr>
<td>\CRT \Sps</td>
<td>CRT Signal Processing Software</td>
</tr>
<tr>
<td>\CRT \Mcs</td>
<td>CRT Graphical binaries</td>
</tr>
<tr>
<td>\CRT \Mcs\Internal</td>
<td>CRT Language Translation Files</td>
</tr>
<tr>
<td>\Startup</td>
<td>All startup files</td>
</tr>
<tr>
<td>\Tools \Monitor</td>
<td>All files for IPMIMonitor tools</td>
</tr>
</tbody>
</table>
The CORTEX CRT Quantum Datas can be found in the following directories. These directories can be changed but the path must be configured in registry (see below):

<table>
<thead>
<tr>
<th>ACCESS PATH</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>D:\ZDS\Data</td>
<td>Root directory</td>
</tr>
<tr>
<td>D:\ZDS\Data\CRT</td>
<td>The ASCII-coded <em>upgrade.txt</em> file gives the current CORTEX software configuration (SPS, MCS, etc...)</td>
</tr>
<tr>
<td>D:\ZDS\Data\CRT \SPS</td>
<td>CRT Signal Processing Software : other files CrtConfig_i.CTX</td>
</tr>
<tr>
<td>D:\ZDS\Data\CRT \SPS \Filter</td>
<td>IF filters coefficients files</td>
</tr>
<tr>
<td>D:\ZDS\Data\CRT \SPS \CTXDocument&lt;i&gt;</td>
<td>« CTX Document Name » Table and « CTX Document » files</td>
</tr>
<tr>
<td>D:\ZDS\Data\CRT \Tms1 &amp; \Tms2</td>
<td>Simulated telemetry files (TMS in FILE mode)</td>
</tr>
<tr>
<td>D:\ZDS\Data\CRT \Mcs</td>
<td>CRT Graphical Software : other files CrtConfig_i.MCS</td>
</tr>
<tr>
<td>D:\ZDS\Data\CRT \Mcs \DBase</td>
<td>TC Data Base</td>
</tr>
<tr>
<td>D:\ZDS\Data\Storage\ &lt;\Menui&gt; \Log</td>
<td>Logging data storage area (default setting)</td>
</tr>
<tr>
<td>D:\ZDS\Data \Storage\ &lt;\Menui&gt; \Log</td>
<td>Range data storage area (default setting)</td>
</tr>
<tr>
<td>D:\ZDS\Data \Storage\ &lt;\Menui&gt; \Tmui</td>
<td>Telemetry storage area (default setting)</td>
</tr>
<tr>
<td>D:\ZDS\Data \Storage\ &lt;\Menui&gt; \Doppler</td>
<td>Doppler compensation files</td>
</tr>
<tr>
<td>D:\ZDS\Data\COP</td>
<td>Command Operation Procedure software (COP). Optional</td>
</tr>
</tbody>
</table>
4.2.8 SPS System Parameters Modification

SPS System parameters can be adjusted in the Windows registry. System parameters are high-level parameters that cannot be changed without stopping the CORTEX SPS application software:

The following is a list of the value entries and sub keys referenced for CORTEX CRT Quantum product.

This is not intended to be a complete list of all value entries and sub keys for ZODIAC DATA SYSTEMS applications in the Windows Registry. Please note that the entries in the Registry depend on the applications and services installed on the CORTEX.

**WARNING:**

THE KEYS IN “SIGNAL PROCESSING” PATH CANNOT BE MODIFIED.

4.2.8.1 General Procedure for Changing a Registry Key

1. Click on Start / Run
2. Start the Windows registry editor (regedit)
3. Select referenced sub key path. Path root is [HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT] for single configuration mode and for the menu one in the case of multi-configuration, and the path is [HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault2] for the menu 2.
4. Double click on desired parameter, and change the value
5. Close the editor window
6. Stop and restart the CORTEX software

In multi-configuration mode, there is one set of parameters by menu selection. The menu ID is added to sub key path. For example, the path for ‘Non Coherent / Coherent AGC’ parameters is [HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault] for single configuration mode and for the menu one in the case of multi-configuration,
4.2.8.2 IF Reception

4.2.8.2.1 NON-COHERENT / COHERENT AGC

To program the AGC test points voltage in non-coherent or coherent mode:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Global
Keyword: CAGcoherente
Default setting at delivery: 0 (non coherent AGC)

The 12 least significant bits (bit 0 = LSB) of the registry key are used to program the AGC test points:

- Bits 0-3: Non-coherent vs Coherent
  - 0: AGC voltage corresponding to the signal energy in a 10 MHz bandwidth (non-coherent mode)
  - 1: AGC voltage corresponding to the IF carrier level (coherent mode)

- Bits 4-7: AGC test point #1. Not significant if bit 0 = 0
  - 0: IF carrier level measured by IF Receiver #1
  - 1: IF carrier level measured by IF Receiver #2
  - 2: IF carrier level measured by IF Receiver #3
  - 3: IF carrier level measured by IF Receiver #4
  - 4: IF carrier level measured by IF Receiver #5
  - 6: Unused
  - E: IF carrier level measured by DCU #2
  - F: IF carrier level measured by DCU #1

- Bit 8-11: AGC test point # 2: as per bits 4 to 7

- Bit 12-15: AGC test point # 3: as per bits 4 to 7

Examples: enter 0 for the AGC test points in non-coherent mode. Enter 65 or 101 for the AGC test points in coherent mode (IFR #1 on AGC #1 and IFR #2 on AGC #2).

The origin of the AGC information is as follows:

- IFR: signal level received by the corresponding IFR
- DCU, post-detection: signal received on the best channel if DCU in Video mode, not significant if DCU in PCM mode
- DCU, pre-detection: not significant
4.2.8.2.2 **DQPSK, DOQPSK, DSOQPSK AND GMSK CODE**

**Polynomial code for DQPSK**:

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Preferences\Ifrx` (x=1 to 5)
Keyword: `DQPSKcode`
Default setting at delivery: `0xC5A3AC35`

The 2 MSB byte are used to I polynomial value and 2 LSB byte are used to Q polynomial value.

**Polynomial code for DOQPSK, DSOQPSK, Differential GMSK**:

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Preferences\Ifrx` (x=1 to 5)
Keyword: `DOQPSKcode`
Default setting at delivery: `0x3C3C9999`

The two MS Bytes are used for I polynomial value and the two LS bytes for Q polynomial value.

4.2.8.2.3 **IF RECEIVER LOCKING THRESHOLD**

To change the IFR locking threshold:

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Preferences\Ifrx` (x=1 to 5)
Keyword: `IFThreshPM`
Default setting at delivery (Cortex CRT XL Quantum): `970` (decimal)
Default setting at delivery (Cortex DS Quantum): `1300` (decimal)

Enter the locking threshold in 0.1 dBm step. Example: `970 = -97 dBm`.

4.2.8.2.4 **I/Q SWAP INVERTED (NT COMPATIBILITY)**

Inverts the IF spectrum and allows the I and Q output to be identical to the Cortex NT (inverted compared to the Cortex XL).

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Preferences\Ifrx` (x=1 to 5)
Keyword: `SwapInvert`
Default setting at delivery: `0`

Enter 0 for non inverted spectrum and I/Q swap (XL mode), 1 for inverted spectrum and I/Q swap (NT compatibility).

4.2.8.2.5 **PLL ORDER**

 Allows the IFR to use 2\textsuperscript{nd} or 3\textsuperscript{rd} Order PLL (Cortex DS Quantum only)

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Preferences\Ifr`
Keyword: `PllOrder`
Default setting at delivery: `0`
Enter 0 for 2\textsuperscript{nd} Order or 1 for 3\textsuperscript{rd} Order PLL
4.2.8.2.6 VIDEO SIGNAL OUTPUT (NT COMPATIBILITY)

Allows Video Output compatibility with the Cortex NT unit

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\ifrx`

(x=1 to 5)

Keyword: `CompatibleNT`

Default setting at delivery: 0

Enter 0 for XL mode, 1 for Coherent AM demodulation upon PM selection (NT compatibility), 10h for band-limited Video output (NT compatibility)
4.2.8.3 Telemetry Processing

4.2.8.3.1 Telemetry Buffers in RAM

To modify the size of the TM buffer in RAM, used in TM frame history from TCP-IP.

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Signal Processing\Tmux
(x = TM chain number)

Keyword: BufferNbr
Default setting at delivery: 256 (frames/blocks)

Enter a number between 4 and 1024 (in decimal) or between 4 and 400 in hexadecimal. The size is expressed in number of frames or blocks.

4.2.8.3.2 Telemetry Data Storage on the Disk

Telemetry frames can be stored on the disk for further replay or transfer over the LAN. Important: prior changing these values, check free space on the hard disk (using Windows Explorer).

To change the file name and access path:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Tmux
(x = TM chain number)

Keyword: FileDir
Default setting at delivery: D:\ZDS\Data\Storage\Menu1\|Tmui\Ftmu

Change the file name and access path (extension 1 to N will be automatically appended to the selected name).

To change the number of files:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Tmux
(x = TM chain number)

Keyword: StorageNum
Default setting at delivery: 8 (files)

To change the file size:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Tmux
(x = TM chain number)

Keyword: StorageSize
Default setting at delivery: 32768 (bytes)

4.2.8.3.3 Bit Synchronizer Mode

The Bit Synchronizer can be programmed to operate either in the standard mode (standard Bit Synchronizer) or the extended mode (phase-locked to the BPSK sub-carrier). The extended mode is available for low bandwidth applications with the Viterbi license only:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Tmux
(x = TM chain number)

Keyword: BSCoherent
Default setting at delivery: 0 (standard mode)

Enter 0 (standard mode) or 1 (Bit synchronizer phase-locked to the BPSK sub-carrier).
4.2.8.3.4 REMOVAL OF THE R-S CODEBLOCK AND SYNCHRONIZATION WORD

To customize the telemetry message (Annex 1, STI 100013_CRT, section 2.4.4) with the R-S decoding license:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-Snec\CortexNT\SetDefault\Signal Processing\Tmux
(x = TM chain number)

Keyword: RsCode
Default setting at delivery: 0 (transmit the R-S codeblock & SW)

Set bit 0 to 0 for transmitting the R-S code and the SW or 1 for removing the R-S code and the SW.

Set bit 1 to 0 for standard Frame Check result field (offset 6) or to 1 for reporting the number of errors corrected by the R-S decoder in byte 1 of the Frame Check Result field.

4.2.8.3.5 REMOVAL OF THE SYNCHRONIZATION WORD FOR FRAME CHECKING

To include or exclude the synchronization word for CRC or Check Sum verification:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Tmux
(x = TM chain number)

Keyword: CRCwithoutSW
Default setting at delivery: 0 (SW included in CRC or Check Sum checking)

Set the keyword to 0 (SW included) or 1 (SW excluded).

4.2.8.3.6 REMOVAL OF DUMMY FRAMES FOR TM STORAGE

To remove or not the dummy frames in telemetry data storage files:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Tmux
(x = TM chain number)

Keyword: NoDummy
Default setting at delivery: 0 (Dummy frames stored on the disk)

Set the keyword to 0 (Dummy frames stored) or 1 (dummy frames not stored).

4.2.8.3.7 SWAP G1 AND G2 BEFORE VITERBI DECODER

To swap G1 and G2 before Viterbi decoder:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Tmux
(x = TM chain number)

Keyword: SwapG1G2
Default setting at delivery: 0 (G1 before G2) (or G1 on I, G2 on Q)

Set the keyword to 0 (G1 before G2) or 1 (swap G1 and G2).
4.2.8.3.8 **TURBO DECODING FRAME SYNCHRONIZATION WORD**

To modify the default synchronization words specified for each rate (CCSDS 101.0-B-6., Blue Book, October 2002)

Registry path : `HKEY_LOCAL_MACHINE\SOFTWARE\In-snet\CortexCRT\SetDefault\Preferences\Tmuxx`

(x = TM chain number)

Keyword : **Asm_1_2**
Default setting at delivery : `034776C7272895B0`

Keyword : **Asm_1_3**
Default setting at delivery : `25D5C0CE8990F6C9461BF79C`

Keyword : **Asm_1_4**
Default setting at delivery : `034776C7272895B0FCB88938D8D76A4F`

Keyword : **Asm_1_6**
Default setting at delivery : `25D5C0CE8990F6C9461BF79CDA2A3F31766F0936B9E40863`

Note : the frame synchronization word length is derived from the code rate.
4.2.8.4  IF Modulation

4.2.8.4.1  RZ PROTOCOL

To modify the RZ flag (carrier sweeping function on the IF Modulator, Return to Zero protocol):

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Ifm\x (x = A or B)
Keyword: RzSweepMode
Default setting at delivery:  0 (standard RZ protocol)

Enter enter:
0 - standard RZ protocol
1 - RZ from a positive frequency slope only
2 - RZ from a negative frequency slope only
0x100 – Disable modulation during sweeping process

4.2.8.4.2  DQPSK, DOQPSK CODE

Polynomial code for DQPSK encoding:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Ifm\x (x = A or B)
Keyword: DQPSKcode
Default setting at delivery:  0xA3C5CA53

The 2 MSB byte are used to l polynomial value and 2 LSB byte are used to Q polynomial value.

Polynomial code for DOQPSK encoding:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Ifm\x (x = A or B)
Keyword: DOQPSKcode
Default setting at delivery:  0x69693C3C

The 2 MSB byte are used to l polynomial value and 2 LSB byte are used to Q polynomial value.

4.2.8.4.3  IF UPLINK SPECTRUM INVERSION

To invert the IF output spectrum:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Ifm\x (x = A or B)
Keyword: SpectInvert
Default setting at delivery:  0 (non inverted spectrum)

Enter 0 (non inverted spectrum) or 1 (inverted spectrum)

4.2.8.4.4  SWAP G1 AND G2 AFTER VITERBI ENCODING

To swap G1 and G2 after Viterbi encoder.

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Ifm\x (x = IFM number)
Keyword: SwapG1G2
Default setting at delivery:  0 (G1 before G2)

Set the keyword to 1 to swap G1 and G2.
4.2.8.5 Telecommanding

4.2.8.5.1 TRANSMISSION OF THE UN-MODULATED TC SUB-CARRIER

To modify the duration of transmission of the un-modulated BPSK sub-carrier by the TCU (applies only to BPSK modulation):

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-snc\CortexCRT\SetDefault\Preferences\Tcu`
Keyword: `SendScf`
Default setting at delivery: `0`

Enter `0` (immediate sub-carrier modulation) or a positive, whole number of bits. Example: for 1-second pre-transmission, enter `1000` if the TC bit rate is `1000` bps.

4.2.8.5.2 CMM DATA FORMAT

To modify the CMM data format for TC/TM loop verification (CMM1 & 2 flags, mask and expected value):

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-snc\CortexCRT\SetDefault\Preferences\Tcu`
Keyword: `CmmOption`
Default setting at delivery: `0` (8-bit data)

Enter `0` (8-bit data, LSB aligned) or `1` (32-bit data, MSB aligned).

4.2.8.5.3 « GROUP » INSTRUCTION SIZE

To modify the maximum number of TC requests/instructions in a « Group » instruction:

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-snc\CortexCRT\SetDefault\Preferences\Tcu`
Keyword: `BufferNbr`
Default setting at delivery: `32` (requests or instructions)

Enter any value between `32` and `500` (in decimal) or between `20` and `1F4` (in hexadecimal).

4.2.8.5.4 TC WATCHDOG

To Enable/Disable the TC watchdog mechanism, Allows to automatically close the connections to the TC port and drop the IF carrier.

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-snc\CortexCRT\SetDefault\Preferences\Tcu`
Keyword: `Watchdog`
Default setting at delivery: `0` (disable)

Enter `0` to inhibit the TC watchdog; enter any positive value to activate it.
4.2.8.5.5 **EXTENDED IDLE PATTERNS (1 TO 255)**

To define the extended idle patterns.

Registry path : `HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Tcu`
Keyword : `ExtIdlex (x = 1 to 255)`
Default setting at delivery : `0`

Configure the value of the extended Idle pattern, up to 8192 bits. The index of the pattern is selected owing to the 8 MS bits of the Idle pattern configuration parameter. The extended idle pattern is entered as a series of hexadecimal values, using the Binary Value feature of the Registry Editor. When the length of the extended idle pattern is not a multiple of a byte, the value must be left-justified and the last byte is padded with zeros.

4.2.8.5.6 **EXTENDED PREAMBLE PATTERNS (1 TO 255)**

To define the extended preamble patterns.

Registry path : `HKEY_LOCAL_MACHINE\SOFTWARE\In-s nec\CortexCRT\SetDefault\Preferences\Tcu`
Keyword : `ValPreax (x = 1 to 255)`
Default setting at delivery : `0`

Configure the value of the extended Preamble pattern, up to 8192 bits. The index of the pattern (x) is selected owing to the 8 MS bits of the Preamble pattern configuration parameter. The extended preamble pattern is entered as a series of hexadecimal values, using the Binary Value feature of the Registry Editor. When the length of the extended preamble pattern is not a multiple of a byte, the value must be left-justified and the last byte is padded with zeros.
4.2.8.6 Ranging

4.2.8.6.1 Ranging Sub-carrier Modulation Index

To adjust the ranging sub-carrier modulation index (INMARSAT and LMCO standards only):

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sne\CortexCRT\SetDefault\Preferences\Rau
Keyword: SubCarrierIndex
Default setting at delivery: 80

Enter the modulation index in hundredths of radian (example: enter 80 for 0.80 radian)

4.2.8.6.2 Range Data Storage

Enable and configure the storage of ranging messages to the disk:

To enable/disable the storage function:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sne\CortexCRT\SetDefault\Preferences\Rau
Keyword: Storage
Default setting at delivery: 0 (disable)

Enter 0 to disable the storage. Enter 1 to enable the storage

To change the file name and access path:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sne\CortexCRT\SetDefault\Preferences\Rau
Keyword: FileDir
Default setting at delivery: D:\ZDS\Data\Storage\Menu1\Log\Ranging

Range data are stored in a first file with extension .mea. Range requests and acknowledgement messages are stored in a second file with extension .req

To change the range data file size:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sne\CortexCRT\SetDefault\Preferences\Rau
Keyword: StoreSize
Default setting at delivery: 4096 (bytes)

To change the range request and acknowledgement data file size:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sne\CortexCRT\SetDefault\Preferences\Rau
Keyword: StoreSizeR
Default setting at delivery: 4096 (bytes)

4.2.8.6.3 Synchronized Doppler & Range Measurements

Synchronize Doppler and range measurements onto even seconds:

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sne\CortexCRT\SetDefault\SignalProcessing\Rau
Keyword: SynchroMode
Default setting at delivery: 0 (data not synchronized)

Enter 0 (data not synchronized) or 1 (synchronized Doppler & range data)
4.2.8.7 Logging Data Storage & Data Time-tagging

4.2.8.7.1 Telemetry Time-tagging

To modify the telemetry time-tagging (Time-tag the last or first bit of each TM frame/block).

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Tmux
\x = TM chain number

Keyword: **DateFrame**
Default setting at delivery: 0

Enter 0 to time-tag the last bit of each telemetry frame or block; enter 1 to time-tag the first bit of each telemetry frame or block, enter 2 to time-tag the first bit after the synchronization word.

4.2.8.7.2 Logging Data Storage

To enable/disable logging data storage on the disk:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Global

Keyword: **Storage**
Default setting at delivery: 0

Enter 0 to disable the storage. Enter 1 to enable the storage.

To change the file name and access path:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Global

Keyword: **FileDir**
Default setting at delivery: D:\ZDS\Data\Storage\Menu1\Log\Event

The file extension for logging data is .log.

To change the file size:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Global

Keyword: **StoreSize**
Default setting at delivery: 4096 (bytes)

4.2.8.7.3 PC Clock Synchronization to IRIG Time

Allows the PC time to be synchronized to IRIG-B time.

**Note:** the unit must be set as Time zone GMT, no daylight saving time.

To enable/disable the plug-in IRIG B / Auto leap year feature:

Registry path: \HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\Irig

Keyword: **Enable**
Default setting at delivery: 0 (inactive)

Enter 0 (inactive) or 1 (active).
To enable/disable the IRIG update of the PC clock:
Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-Snec\CortexCRT\SetDefault\Preferences\Irig
Keyword: IrigUpdate
Default setting at delivery: 0 (inactive)
Enter 0 (inactive) or 1 (active).

To enable/disable the automatic leap year update:
Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-Snec\CortexCRT\SetDefault\Preferences\Irig
Keyword: AutoLeapYear
Default setting at delivery: 0 (inactive)
Enter 0 (inactive) or 1 (active).

When AutoLeapYear is activated, the leap year setup does not need to be managed through Global CORTEX CRT Table. It is automatically managed by the SPS by checking the current year in the Windows Clock.

4.2.8.8 Telemetry Simulation

4.2.8.8.1 Access to Simulated TM Files

To modify the name and access path of the simulated telemetry files (TMS1 or TMS2 in File mode):
Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\TMSx (x = TMS number)
Keyword: FileDir
Default setting at delivery: D:\ZDS\Data \CRT\Tms1\Ftms
D:\ZDS\Data \CRT\Tms2\Ftms
Extension _01.txt to _08.txt will be automatically appended to the selected name.

4.2.8.8.2 Swap G1 and G2 after Viterbi Encoding

To swap G1 and G2 after Viterbi encoder.
Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\TMSx (x = TMS number)
Keyword: SwapG1G2
Default setting at delivery: 0 (G1 before G2)
Set the keyword to 1 to swap G1 and G2.
4.2.8.9 Test Points Allocation & Tuning

For High Bandwidth CORTEX configuration, the four sets of TTL test points (Set # 1, 2, 3, 4) can be allocated, from the following registry keys, to the TMS, TCU and TMUs.

4.2.8.9.1 HBW TELECOMMAND UNIT (TCU)

To allocate a set of test points to the TCU.

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sneic\CortexCRT\SetDefault\Preferences\Tcu
Keyword: TPoutSet
Default setting at delivery: 0 (test points disabled)

Set the Byte 0 of keyword in the range 1 to 4 to select test points Set # 1 to Set # 4

Additional settings:
Byte 1 bit 0:
  0 for Data Out Updated on Rising edge of Clk Out, Data In sampled on Falling edge of Clk In
  1 for Data Out Updated on Falling edge of Clk Out, Data In sampled on Rising edge of Clk In

Byte 1 bit 2:
  0 for Data output before the encoders (NRZ-L)
  1 for Data output after PCM and convolutional encoders

Byte 1 bit 3:
  0 for LVTTL
  1 for RS422

4.2.8.9.2 HBW TELEMETRY SIMULATOR (TMS)

To allocate a set of test points to a TMS.

Registry path: HKEY_LOCAL_MACHINE\SOFTWARE\In-sneic\CortexCRT\SetDefault\Preferences\Tms\(x = TMS number)\Keyword: TPoutSet
Default setting at delivery: 0 (test points disabled)

Set the Byte 0 of keyword in the range 1 to 4 to select test points Set # 1 to Set # 4

Additional settings:
Byte 1 bit 0:
  0 for Data Out Updated on Rising edge of Clk Out, Data In sampled on Falling edge of Clk In
  1 for Data Out Updated on Falling edge of Clk Out, Data In sampled on Rising edge of Clk In

Byte 1 bit 2:
  0 for Data output before the encoders (NRZ-L)
  1 for Data output after PCM and convolutional encoders

Byte 1 bit 3:
  0 for LVTTL
  1 for RS422
4.2.8.9.3 **HBW Telemetry Units (TMU).**

To allocate a set of test points to a TMU:

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Preferences\Tmux\(x = telemetry chain number)`

Keyword: `TPoutSet`

Default setting at delivery: `0` (test points disabled)

Set the Byte 0 of keyword in the range 1 to 4 to select test points Set #1 to Set #4

Additional settings:

Byte 1 bit 0:
- 0 for Data Out Updated on Rising edge of Clk Out, Data In sampled on Falling edge of Clk In
- 1 for Data Out Updated on Falling edge of Clk Out, Data In sampled on Rising edge of Clk In

Byte 1 bit 2:
- 0 for I/Q ambiguity not managed on test points
- 1 for enabling the automatic management of the I/Q ambiguity in QPSK modes

Byte 1 bit 3:
- 0 for LVTTL
- 1 for RS422

4.2.8.9.4 **VIDEO 1 & 2 Output Level Setting**

To adjust the output level on the VIDEO 1 & 2 test points:

Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-sneC\CortexCRT\SetDefault\Preferences\Global`

Keyword: `VidOut1dcg2` and `VidOut2dcg2`

Default setting at delivery: `0` (test points disabled)

Each registry key is a bit field (bit 0 = LSB):

- **DC removal**: Bit 0: 0 (no action) or 1 (remove DC)
- **Signal amplification**:
  - Bits 4 to 7: Output gain shift value
  - Bits 8 to 15: Output gain mantissa value
  - From the output gain shift and mantissa values, the signal gain is computed as:

  \[
  \text{Gain} = \frac{\text{mantissa}}{2^{\text{shift}}}
  \]

- **Signal level offset**:
  - Bits 16 to 23: Video offset compensation in 2’s-complement format
  - Enter 10 exp(required offset in Volt)

**Examples** (for VIDEO 1 test point):

1. To activate DC suppression: `VidOut1dcg2 = 0x000001`
2. To add a +200 mV offset: `VidOut1dcg2 = 0x020000`
3. To add a –200 mV offset: `VidOut1dcg2 = 0xFE0000`
4. To apply a Gain = 1.4296875: `VidOut1dcg2 = 0x00B710`
5. To apply a Gain = 0.6875: `VidOut1dcg2 = 0x00B000`
4.2.8.10 UDP Telemetry Data

To change the UDP server port number:
Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\UdpTm`
Keyword: `PortTm`
Default setting at delivery: 3075
Enter 0 to disable the UDP service.

To change the Multicast IP Address:
Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\UdpTm`
Keyword: `MultiAddr`
Default setting at delivery: "227.11.13.17"
Enter any valid and unused Multicast address. Address range: 224.0.0.0 through 239.255.255.255.

To change the Multicast TMU Base address:
Registry path: `HKEY_LOCAL_MACHINE\SOFTWARE\In-snec\CortexCRT\SetDefault\Preferences\UdpTm`
Keyword: `MultiPort`
Default setting at delivery: 10000

With default definition for Multicast IP and port:
- TMU-A frames are provided to 127.11.13.17::10000
- TMU-B frames are provided to 127.11.13.17::10001
...etc...
5. MAINTENANCE PROCEDURES
5.1 PREVENTIVE MAINTENANCE

5.1.1 Caution
Refer to important Caution on page xviii of this User's Manual

5.1.2 Important Safety Instructions
Refer to important safety instructions on page xix of this User’s Manual

5.1.3 General instructions

5.1.3.1 Mechanical Inspection and Cleaning

It is recommended to take the following precautions to get the best performance from the system:

♦ Do not carry out any dust-producing work in the room housing the CORTEX CRT Quantum. Clean the air filters regularly to avoid electronic components overheating.

♦ Use only alcohol or a water-based cleaner on the front and rear panels of equipment. Other solvents may damage the keys, LCD and markings.

♦ Perform a regular operating check on the fan units (check for any abnormal temperature rise, check the air flow at the air exhaust). The system is not designed for permanent operation without ventilation.

♦ Preventive maintenance: it is recommended to change the Pentium cooling fan every 3 years.

5.1.3.2 Handling Precautions

WARNING:

SOME OF THE HARDWARE COMPONENTS USE CMOS TECHNOLOGY AND CAN BE DAMAGED BY ELECTROSTATIC DISCHARGE FROM YOUR CLOTHES OR BODY. ALWAYS USE AN ANTI-STATIC BRACELET WHEN WORKING ON THE CORTEX CRT QUANTUM TO REPLACE A BOARD OR COMPONENT.

♦ Never remove a board from the CORTEX CRT Quantum without switching it off first and removing the power cord!

♦ When a module has been removed from the chassis, it is essential to handle and store it with care. It is particularly important to ensure it is not exposed to electrostatic shocks.

♦ Certain precautions must also be taken when reinstalling a board in the chassis: when plugging the board into the PCI Express bus connectors, never force it; screw the board strip attaching screws back into the frame; reinstall the connector locking screws. Only then may the CORTEX CRT Quantum be switched back on.

♦ To avoid damaging the equipment, never grab the chassis by the front panel cover plate.

♦ The keyboard and peripheral drawers must be locked during transportation.
♦ Take extreme care when handling the chassis with the peripheral and/or keyboard drawer(s) unlocked.

♦ Do not lift up the keyboard drawer while opening or closing it.

5.1.3.3 **Wait after power off**

It is recommended to wait for at least one minute to re-power on the chassis after power off.

5.1.3.4 **CPU Load Considerations**

ZODIAC DATA SYSTEMS DOES NOT WARRANTY CORTEX CRT QUANTUM PERFORMANCES
IF ADDITIONAL SOFTWARE ARE LOADED / EXECUTED ON THE MACHINE.

5.1.3.5 **Software Loading**

Avoid using floppy disks from unidentified sources. Presence of virus may severely affect the performances of the equipment or crash the software.
5.2 HARDWARE INVESTIGATION & REPAIR

5.2.1 LED Indicators

5.2.1.1 Analog Downlink board

The analog Downlink board is one of the boards constituting the Main Signal Processing board. It is the one dedicated to the six IF downlink inputs. Five LEDs are located on this printed circuit board (open the top cover to check them). See Annex 2.

- **D1** Red LED. Illuminates to indicate that an IF input ADC is overloaded (shall not be illuminated in regular operations).
- **D2** Yellow LED. Illuminates to indicate that the local FPGA Digital Clock Manager is unlocked (shall not be illuminated in regular operations).
- **D3** Green LED. Blinking at 2 Hz to show that the 250 MHz reference clock is present in the local FPGA (shall blink at 2 Hz in regular operations).
- **D4** Green LED. Blinking at 1 Hz to show that the 125 MHz reference from the digital mother board is present in the local FPGA (shall blink at 1 Hz in regular operations).
- **D5** Green LED. Illuminates to indicate that the local FPGA has been correctly downloaded by the SPS application (DONE signal, shall be illuminated in regular operations).

At power-on unit, all the LEDs shall be illuminated, except D5.

5.2.1.2 Analog Uplink board

The analog Uplink board is one of the boards constituting the Main Signal Processing board. It is the one dedicated to the IF uplink outputs and the reference clock inputs. Five LEDs are located on this printed circuit board (open the top cover to check them). See Annex 2.

- **D1** Green LED. Blinking at 2 Hz to show that the 250 MHz reference clock is present in the local FPGA (shall blink at 2 Hz in regular operations).
- **D2** Yellow LED. Illuminates to indicate that the IFM#2 DAC Digital Clock Manager is unlocked (shall not be illuminated in regular operations).
- **D3** Red LED. Illuminates to indicate that one of the IF output DACs does not work correctly (shall not be illuminated in regular operations).
- **D4** Green LED. Blinking at 1 Hz to show that the 125 MHz reference from the digital mother board is present in the local FPGA (shall blink at 1 Hz in regular operations).
- **D5** Green LED. Illuminates to indicate that the local FPGA has been correctly downloaded by the SPS application (DONE signal, shall be illuminated in regular operations).

At power-on unit, all the LEDs shall be illuminated, except D5.
### 5.2.1.3 Digital mother Board

The digital Mother board is one of the boards constituting the Main Signal Processing board. It is the one dedicated to the interface between the chassis and the Main Signal Processing board, and the main digital signal processing, performed by the Master and Slave FPGAs.

Two LEDs are located at the front panel of the board. See Annex 2.

- **D13** Green LED. Turns to green and flashes at 1 PPS to show that the processing of the interface between the Main Signal Processing board and the chassis is correctly downloaded and running.
  
  Unlit (or high rate flashing) in case of Main Signal Processing board or CPU board failure or in case of problem on the PCI bus.

- **D14** Red LED. Lit during firmware maintenance.

Eleven LEDs are located on the printed circuit board (open the top cover to check them). See Annex 2.

- **D1** Red LED. Illuminates to indicate that there is an error on the DMA transfer on PCIe (shall not be illuminated in regular operations).

- **D2** yellow LED. Microblaze load indicator. Partially lit. Not significant.

- **D3** Green LED. IT indicator. Partially lit. Not significant.

- **D4** Blue LED. Illuminates to indicate that the PCIe interface FPGA has been correctly loaded at boot-up (illuminated in normal operations)

- **D5** Red LED. Illuminates to indicate that the Master FPGA Digital Clock Manager is unlocked (shall not be illuminated in regular operations).

- **D6** Orange LED. Blinking at 2 Hz to show that the 250 MHz reference clock is present in the Master FPGA (shall blink at 2 Hz in regular operations).

- **D7** Green LED. Blinking at 1 Hz to show that the 125 MHz reference from the digital mother board is present in the Master FPGA (shall blink at 1 Hz in regular operations).

- **D8** Blue LED. Illuminates to indicate that the Master FPGA has been correctly downloaded by the SPS application (DONE signal).

- **D9** Red LED. Illuminates to indicate that the Slave FPGA Digital Clock Manager is unlocked (shall not be illuminated in regular operations).

- **D10** Orange LED. Blinking at 2 Hz to show that the 250 MHz reference clock is present in the Slave FPGA (shall blink at 2 Hz in regular operations).

- **D11** Green LED. Blinking at 1 Hz to show that the 125 MHz reference from the digital mother board is present in the Slave FPGA (shall blink at 1 Hz in regular operations).

- **D12** Blue LED. Illuminates to indicate that the Slave FPGA has been correctly downloaded by the SPS application (DONE signal).
5.2.1.4 Video board

The video board is one of the boards constituting the Main Signal Processing board. It is the one dedicated to the base band video outputs. Four LEDs are located on this printed circuit board (open the top cover to check them). See Annex 2.

D1  Red LED. Not significant. Is permanently lit.
D2  Orange LED. Not significant. Should be permanently unlit.
D3  Green LED. Blinking at 1 Hz to show that the 125 MHz reference from the digital mother board is present in the local FPGA (shall blink at 1 Hz in regular operations).
D4  Blue LED. Illuminates to indicate that the local FPGA has been correctly downloaded at boot up (DONE signal, shall be illuminated in regular operations).
5.2.2 Temperature Alarm

5.2.2.1 IPMI Monitor Temperature Sensors

The motherboard of the PC Workstation has several sensors for monitoring the Pentium processors and board temperature.

These sensors are permanently monitored by a dedicated software tool IPMI Monitor. To run this software, click on START -> PROGRAM -> IPMI Monitor -> IPMI Monitor.

Check the three following status in the list:

<table>
<thead>
<tr>
<th>STATUS NAME</th>
<th>TYPICAL VALUE @ 22°C AMBIENT</th>
<th>ALARM THRESHOLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseboard Temp.</td>
<td>34 °C</td>
<td>52 °C</td>
</tr>
<tr>
<td>Processor 1 THERM Margin</td>
<td>-50 °C</td>
<td>0 °C</td>
</tr>
<tr>
<td>Processor 2 THERM Margin</td>
<td>same as Processor 1, only if Processor 2 is installed</td>
<td></td>
</tr>
<tr>
<td>System Fan 1</td>
<td>verify that there is no alarm (red line)</td>
<td></td>
</tr>
<tr>
<td>System Fan 2</td>
<td>verify that there is no alarm (red line)</td>
<td></td>
</tr>
</tbody>
</table>

These alarms are reported to the remote monitoring clients via the Global CORTEX Monitoring table (Annex 1, STI 100013, <product name>, Table 6, offset 41) and at the CORTEX GUI (bottom status bar. Refer to the MCS User’s Manual).

5.2.2.2 MSP Temperature Sensors

The MSP module has its own temperature sensors. These sensors are permanently monitored by the CORTEX software and the measured temperature values reported in the Global CORTEX M&C table and displayed in the CONFIG window of the MMI.

Alarm thresholds are:

<table>
<thead>
<tr>
<th>BOARD TEMPERATURE</th>
<th>FPGA TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 °C (Yellow alarm)</td>
<td>115 °C (Yellow alarm)</td>
</tr>
<tr>
<td>70 °C (Red alarm)</td>
<td>115 °C (Red alarm)</td>
</tr>
</tbody>
</table>

Typical temperature values @ 22°C ambient:

- Master FPGA: 45 °C at board level and 65 °C at FPGA level
- Slave FPGA: 45 °C at board level and 65 °C at FPGA A level
5.2.2.3 What to do in case of Temperature Alarm

In case of temperature alarm:

- **Immediately shutdown and switch off the chassis to avoid any damage to the hardware.**
- Verify that the air exhaust system of the housing rack works properly,
- Verify that the air intake and exhaust grids are clear. Important: a free rack space must be provided above and below the chassis,
- Check the cooling fans on both sides of the chassis, at the rear panel of the chassis (power supply module) and on both CPU processors.
- Return the chassis to ZODIAC DATA SYSTEMS or its maintenance representative if the problem cannot be fixed on site.
5.2.3 PC Workstation Maintenance

Refer to Annex 4 for detailed instructions on how to change:

- The power supply module
- The fan units
- The disk drives: floppy, hard disk and CD ROM
- The display assembly
- The keyboard/trackball.

5.3 SOFTWARE UPGRADE & INSTALLATION

The CORTEX CRT software comes under the form of Compact Disks (CD ROM): 

- **Windows Operating System**: to re-install the operating system after a disk failure, use ZODIAC DATA SYSTEMS CD-ROM *Windows 7 Embedded Restore for CORTEX*.

- **CORTEX CRT software**: to re-install or upgrade the CORTEX CRT software, use ZODIAC DATA SYSTEMS CD-ROM reference *CORTEX CRT <Customer_name> 100xxx <Project_name>*. The CD includes the Cortex CRT application software, Cortex CRT Quantum board driver, and the user documentation.

Strictly follow the install procedure described at the back of the CD ROMs.
6. ANNEX 1 : CORTEX CRT ETHERNET INTERFACE
7. ANNEX 2:

MAIN SIGNAL PROCESSING BOARD
<table>
<thead>
<tr>
<th>COMMAND RANGING &amp; TELEMETRY UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORTEX SERIES – CRT Quantum - USER’S MANUAL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ZDS Ref :</th>
<th>DTU 100042</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is. : 5</td>
<td>Rev. 0</td>
</tr>
<tr>
<td>Customer Ref :</td>
<td></td>
</tr>
<tr>
<td>Date : Jan 27, 2012</td>
<td></td>
</tr>
</tbody>
</table>

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8. ANNEX 3 : DIGITAL I/O BOARD
9. ANNEX 4 :

PC-COMPATIBLE WORKSTATION
10. ANNEX 5:
PROJECT-SPECIFIC DATA
CORTEX SERIES