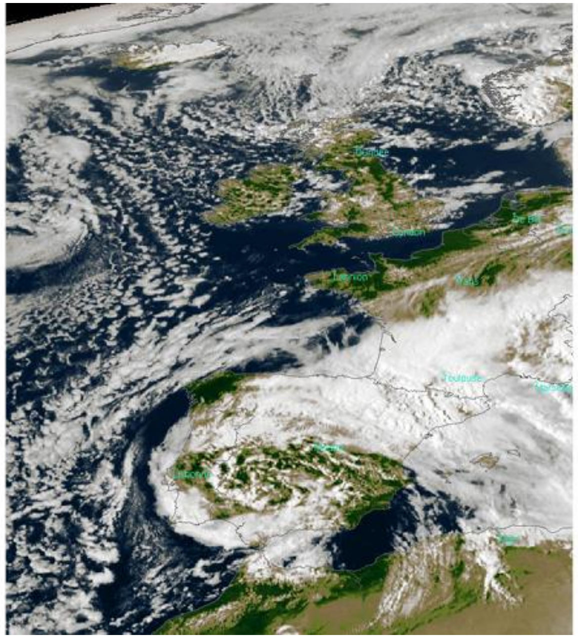
SCISYS DCP Activities

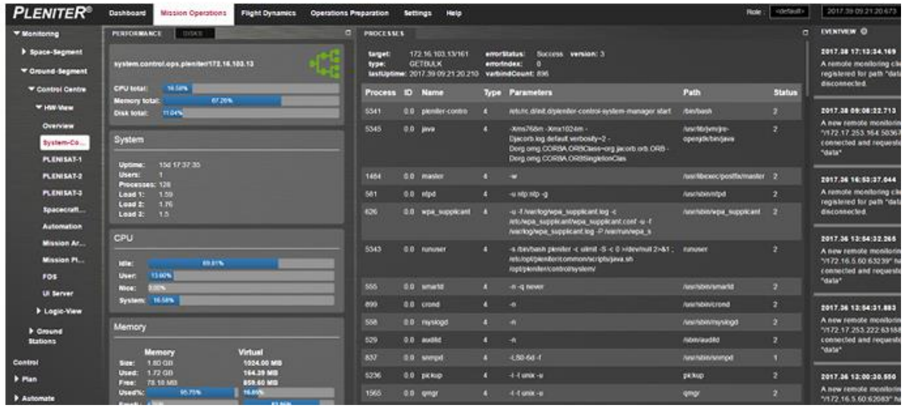
Presentation

Dr. Paul Crawford & Thomas Mehr

October 10th, 2018





Agenda – SCISYS History of DCP Involvement

- DRGS (Direct Readout Ground Station)
- HRDCP – Eumetsat Study on New Generation DCP Protocol
- Adaption of DRGS for Eumetsat MTP & MSG
- DRGS & Simulation Tools for Eumetsat MTG
- DCP Transmitter – ESA ARTES-5.1 Project
  - » Transmitter Prototype Development
  - » New Air Radio Interface – now known as “Enhanced DCP”

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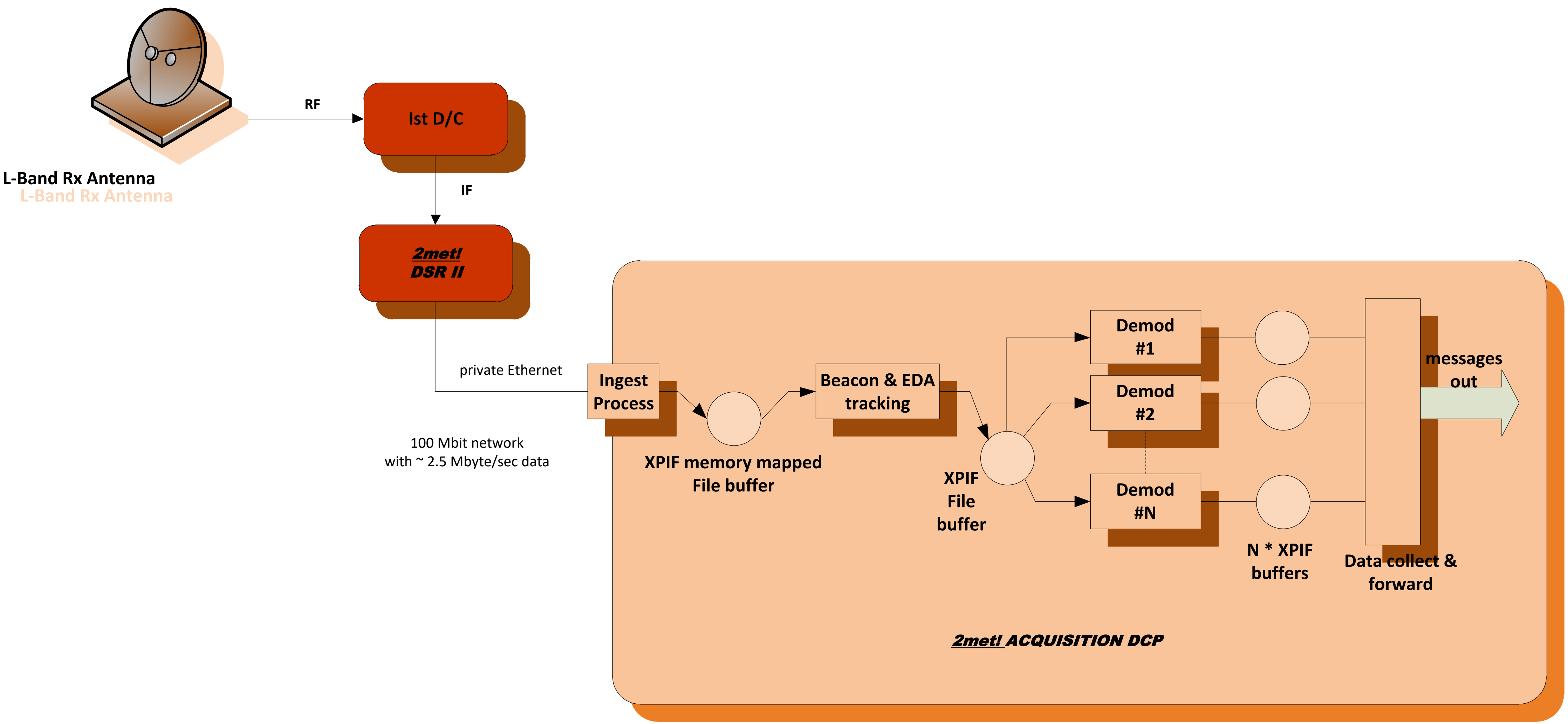
DRGS (Direct Readout Ground Station)

Principle of Operation

DRGS – Block Diagram



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DRGS – Overview

- Common principle for
  - MSG/MTP SRDCP (100 Baud) & HRDCP (1200 Baud)
  - GOES 300 Baud & 1200 Baud
  - INSAT (4800 Baud)
  - (EDCP)
- Antenna receives analogue signal in L-band
- Downconversion to 1st IF (140MHz / 70MHz)
- DSRII digitises to complex baseband signal
- Data samples forwarded via Ethernet
- Further data processing performed in software (SDR)

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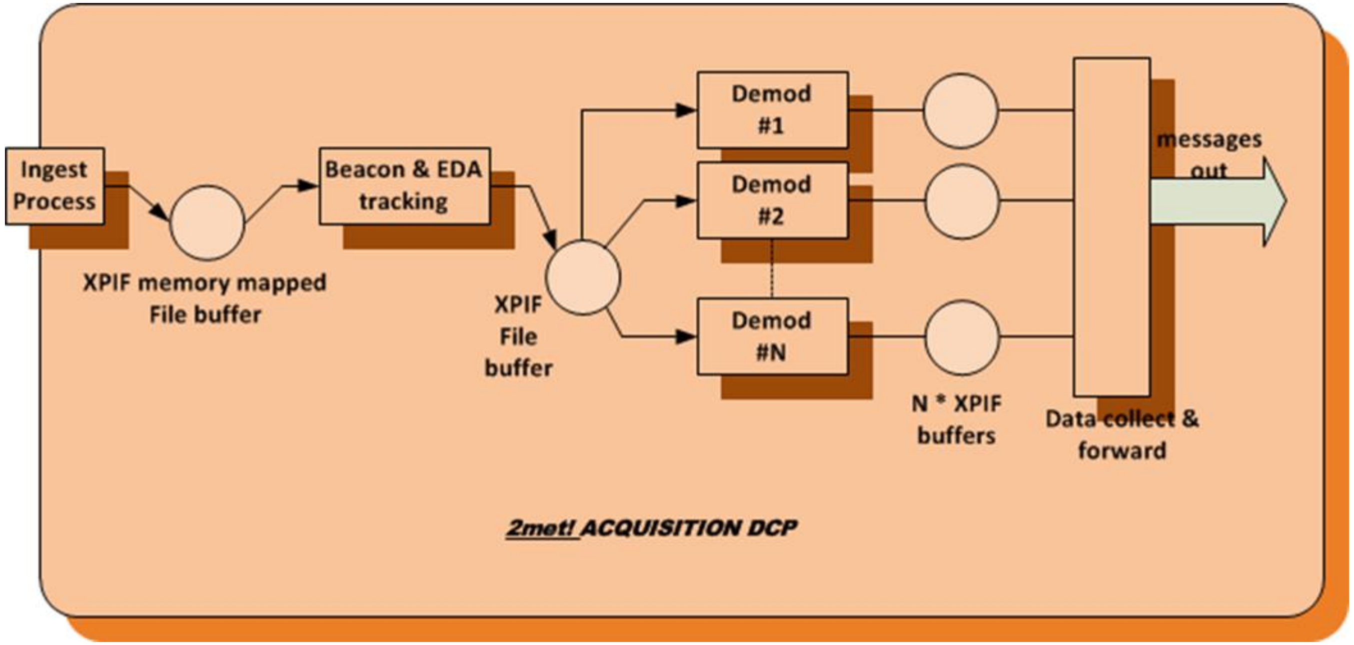
DRGS – DSRII

- IF Input 130 – 150 MHz / 70MHz (customization is possible)
- Conversion to final IF of around 13.75 MHz / 10.5 MHz
- Digitization and conversion to a complex baseband signal cantered on zero Hz
- Two internal AGC (Automatic Gain Control) systems
- NTP (Network Time Protocol) over Ethernet
- Output
  - » Stream of 16 bit I/Q complex samples
  - » 500 kHz sample rate
  - » Additional monitoring data and time stamping
  - » 2.5 MByte/second

DRGS – SDR Architecture 1



- Stand alone processing packages
  - » Beacon Tracking
  - » EDA Tracking
  - » Demodulation
- Additional: Data Ingest, M&C, Message Dispatch

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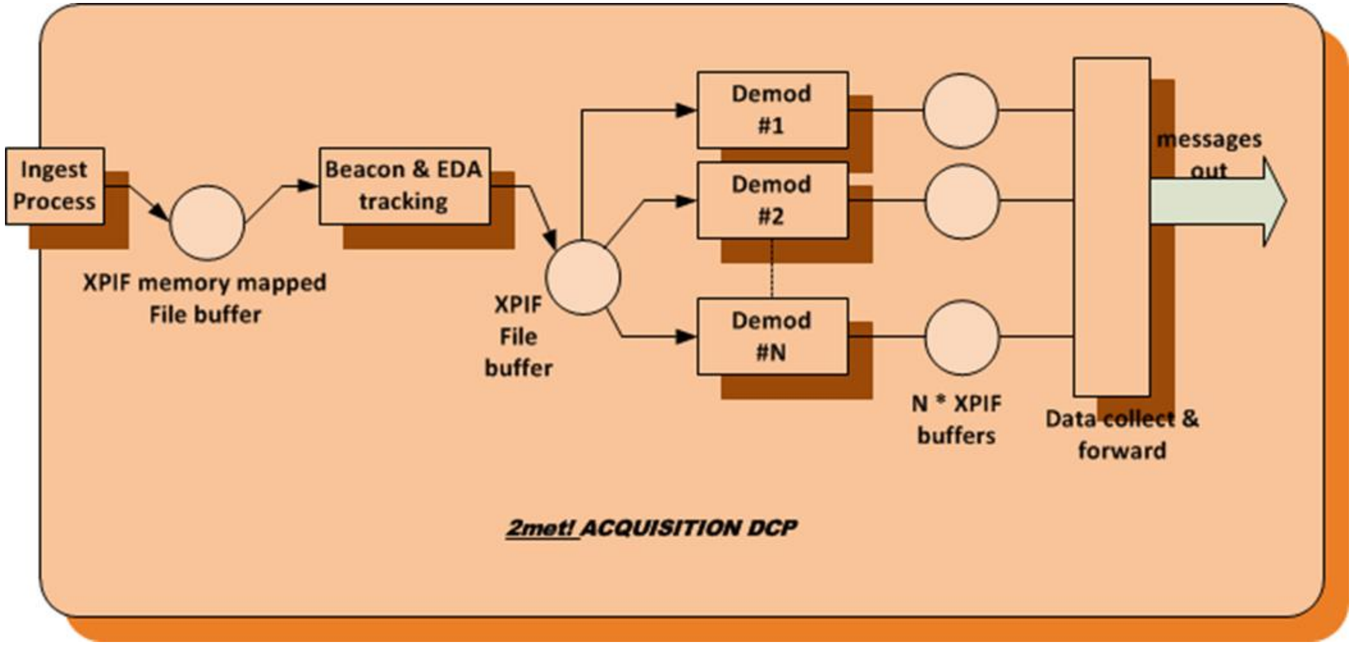
DRGS – SDR Architecture 2



- Interfaces between "near-real-time" processes
  - » Circular buffers implemented as memory-mapped files
  - » Memory-mapping allows for virtually no disk IO
- Circular buffers
  - » Read simultaneously by one or many processes (Non-blocking)

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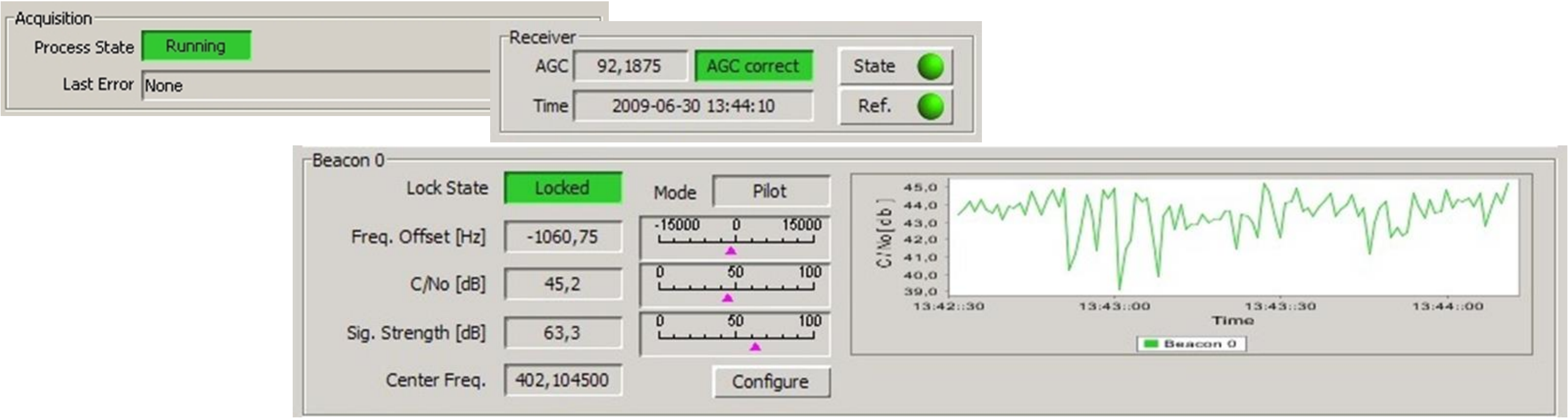
DRGS - Beacon Tracker

- Frequency correction and amplitude calibration based on a known uplink beacon (pilot) signal
- Support of multiple beacons
- Can also use “message feedback” where properly received DCP transmissions are used for a statistical estimate of those parameters



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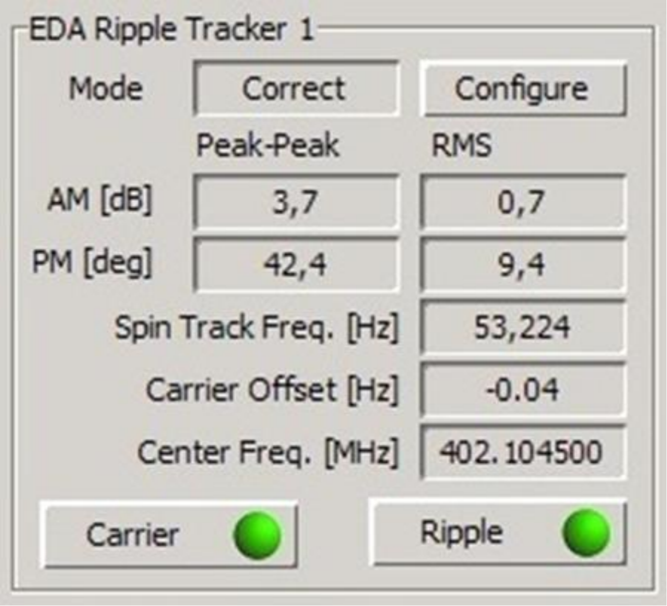
DRGS – EDA Tracker

- Adaptive correction of phase and amplitude ripple induced by the Meteosat 1st and 2nd generation Electronically De-spun Array antenna
- This process was added later on EUMETSAT request



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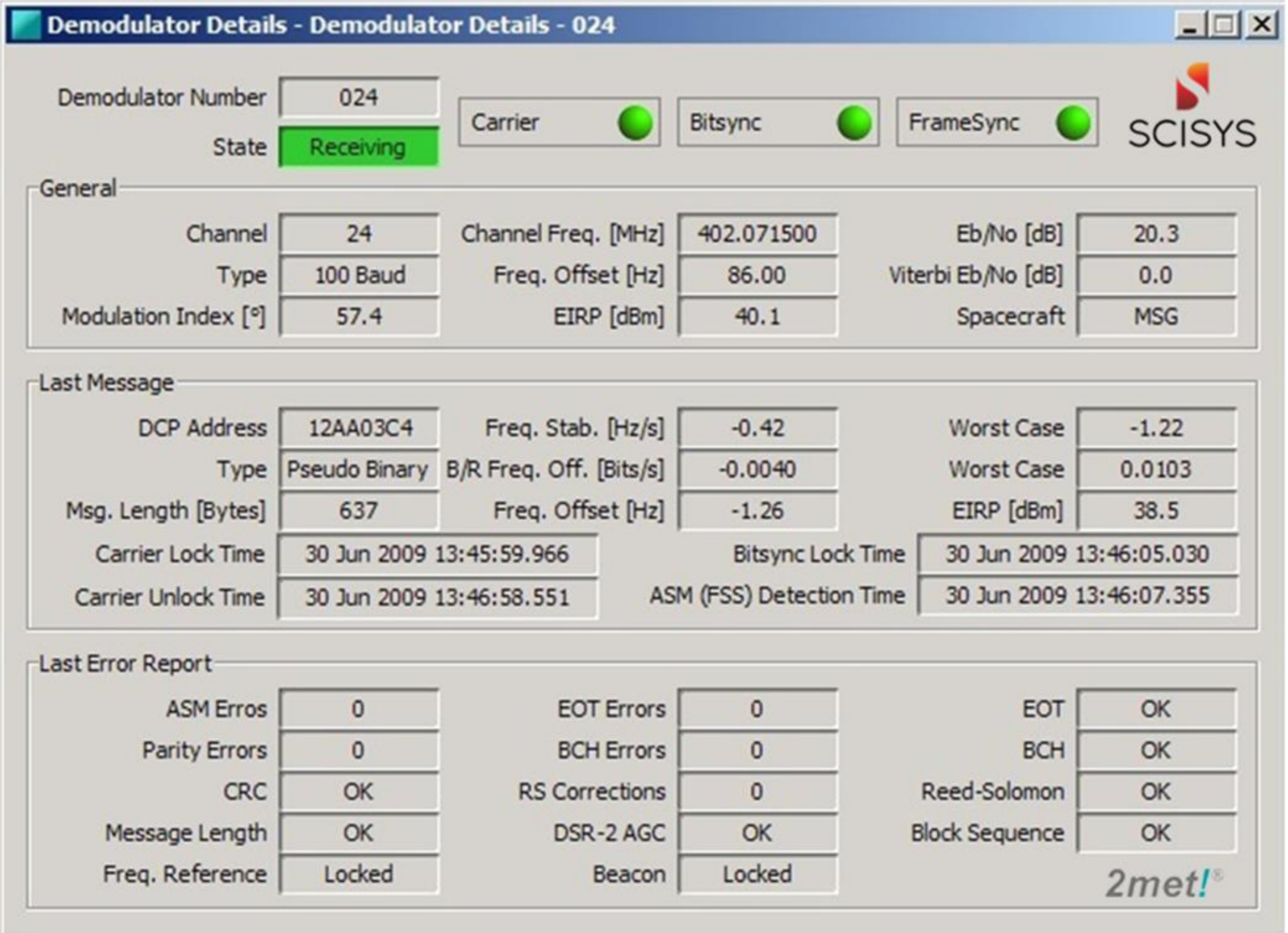
DRGS – Demodulator

- Performs frequency selection, filtering and demodulation of DCP messages
- In turn calls a decoder program to implement the various Forward Error Correction systems used in the different DCP standards
- Spread over multiple processes to allow multiple core CPUs and/or distributed systems to be used effectively



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DRGS – SDR Advantages

- Very little hardware dependency
  - Several types of “receiver” can function as the digitizer
  - Provision of spares and long-term support much easier
- Scalable by design
  - Number of demodulators limited by total CPU performance of server(s) used
  - With time CPU performance gets cheaper !
- Upgradable
  - New features and bugs fixable by simple software update
  - Roll-back also simple
- Analysis support
  - Can capture the IF signal to disk in real-time for later analysis
  - Allows investigation of failed DCP messages to determine possible causes (DCP-TX fault, interference, etc.)

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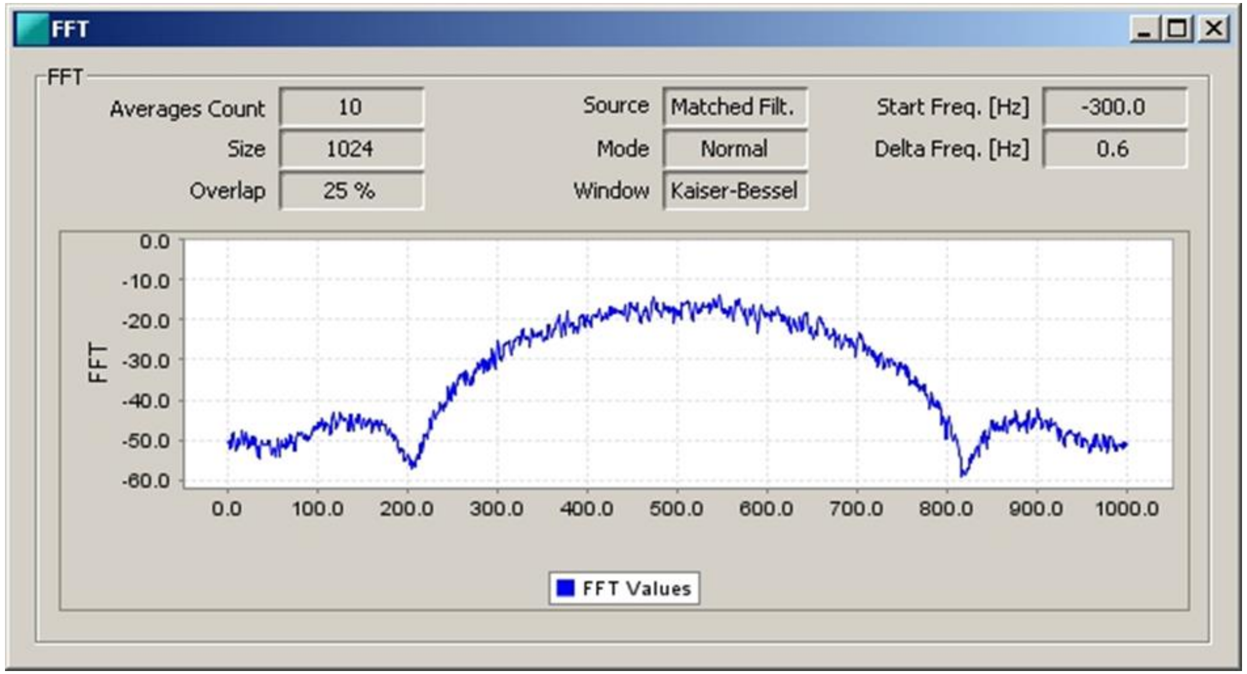
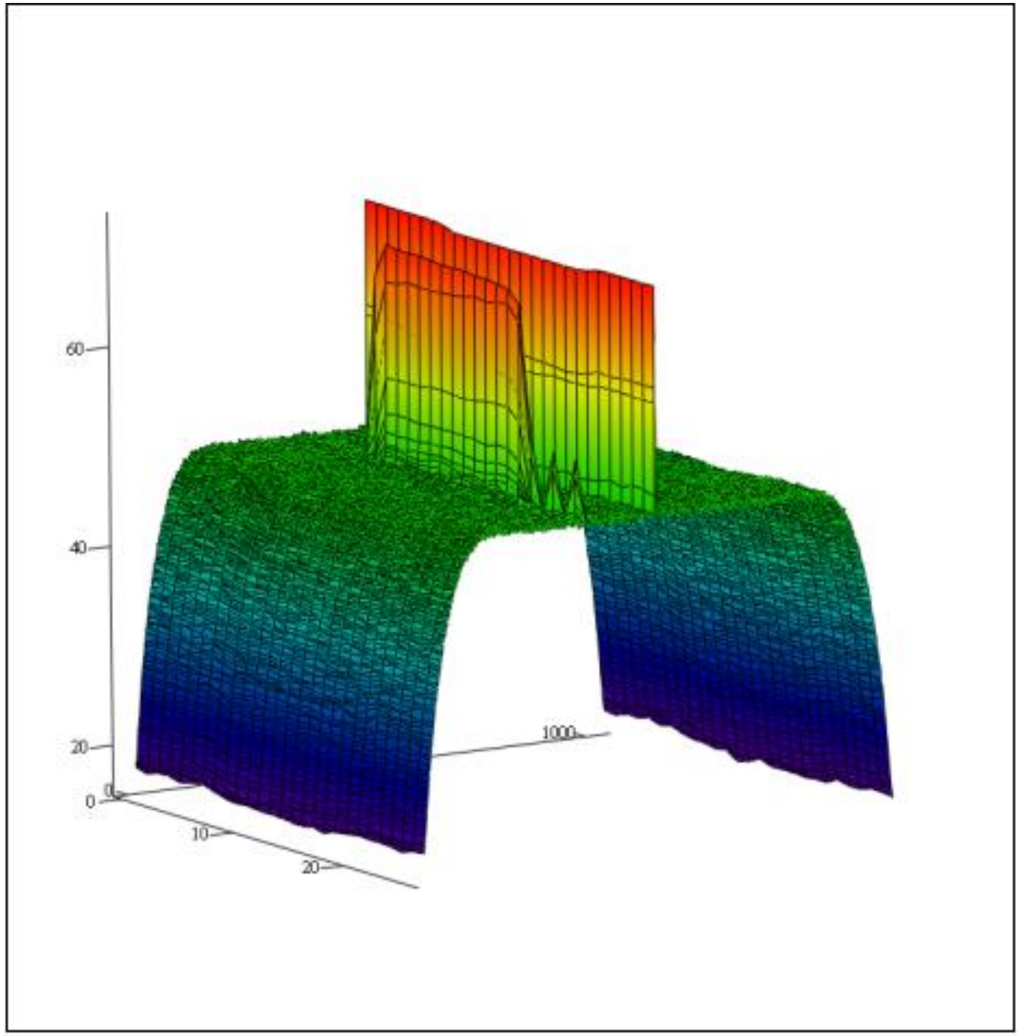
DRGS – Features

Real-Time FFT



Retrospective Analysis



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HRDCP – Meteosat High Rate DCP

Eumetsat Study on New Generation DCP Protocol
Pre-Operational Prototyping Phase

HRDCP – Motivation

- Shortcomings of legacy SRDCP
  - » Low data rate (100bps)
  - » No FEC → High E_b/N_o required for acceptable BER
  - » Poor resilience with respect to pulsed interference
  - » Error detection based on parity bits only
  - » Poor data rate to bandwidth ratio
  - » Uses limited alphabet only not suited to binary/compressed data transfer

HRDCP – Motivation

- Problems with GOES DCP
  - 8-PSK modulation very sensitive to phase noise or platform movement
  - Trellis coding needs 7dB E_b/N_o for 1E-6 BER
  - Poor resilience with respect to pulsed interference
  - Typically needs 2-4dB more E_b/N_o than FEC requirement (due to phase noise and carrier recovery issues)
  - Error detection based on parity bits
  - Options for binary mode, RS FEC and compression foreseen, but not yet standardised or implemented

HRDCP – Goals

- Similar data rates to GOES (1200 Baud in 3kHz channel) but more power efficient (lower E_b/N_o)
- Robustness w.r.t. phase noise, platform movement, pulsed interference
- Modulation and coding scheme capable to cope also with AM/PM ripple induced by Electronically Despun Antenna
- Reliable message throughput, 1E-5 message failure rate (rather than BER)
- Indication of good/bad status
- Use CCSDS recommendations whenever possible

HRDCP – Characteristics

- Use of Offset QPSK modulation for reasonable bandwidth efficiency and phase noise tolerance (also BPSK mode available for testing)
- Concatenated FEC system using CCSDS recommended convolution & Reed-Solomon codes, good with pulsed interference
- Binary message system with very robust error checking using a 32-bit CRC, suited to compressed or uncompressed data of any type
- Live tests showed good operation to an E_b/N_o of 5dB, around 5dB better in practice than the GOES 1200 Baud system (→ only 32% TX power needed)

HRDCP – Implementation

- Transmitter
  - » Software based design using an Agilent E4403B signal generator with its real time modulation option
  - » Laboratory grade signal purity and stability
  - » Output at 70MHz IF for laboratory tests (receiver input) or at 402MHz as exciter for UHF high power amplifier during live satellite testing
- Receiver
  - » Existing DRGS system with extensions developed for HRDCP use
  - » 4 physical Baud rates (300, 600, 1200 and 2400)
  - » 2 modulation types (BPSK and the preferred OQPSK)
  - » Selection of RS and convolution code combinations

MTG

DRGS & Simulation tools for Eumetsat MTG

MTG – DCP Concept

- Modification of DCP downlink
  - » Not using the “bent pipe” analogue transponder common in L-band
  - » Avoid very demanding phase noise specification in Ka-band
- On-board digitization of UHF uplink (12 bit / 3Msps)
- Digitized data stream multiplexed into the other instrument data streams and transmitted to the Ground Stations in Ka Band
- Signal acquisition, demodulation, decoding and demultiplexing at two redundant Ground Stations
- Ground station diversity to allow for compensation of susceptibility to weather conditions in Ka-band downlink.

MTG – DCP Phase Noise

- TX certification phase noise achievable at UHF with 10MHz reference oscillator specification of -90dBc/Hz at 10Hz offset
  - » Good quality TXCO
- L-band around -100dBc/Hz
  - » Exceptional TCXO or good OCXO
- Ka-band equivalent is better than -122dBc/Hz
  - » High performance OCXO
  - » Difficult for space-qualified part

	Frequency (MHz)	L(f) at 10Hz offset (dBc/Hz)	L(f) at 10MHz	Design value (5dB margin)
UHF	402	-52	-84.1	-90
L-band Ground Station	1,680	-52	-96.5	-102
L-band Spacecraft	1,278	-52	-94.1	-100
Ka-band G/S	18,000	-52	-117.1	-123
Ka-band S/C	17,598	-52	-116.9	-122
Ka-band G/S	26,000	-52	-120.3	-126
Ka-band S/C	25,598	-52	-120.2	-126

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MTG – DCP RX Solution

- Proven DRGS software ported to 64-bit Linux OS
- Additional modules created to support MTG data acquisition
  - » Decapsulation of the sampled data from MTG ground stations
  - » Conversion from 12-bit real to 16-bit I/Q format to match DRGS
- Improved user interface to manage hundreds of channels
- DCP-RX systems consist of three servers
  - » CTRL_SRV for M&C, Beacon Tracking, Message collection and dispatch
  - » PROC_SRV for demodulation of up to 704 channels
  - » NAS_SRV for data dumps (operationally not necessary)
- Fewer DCP channels can easily be implemented on a single server system!

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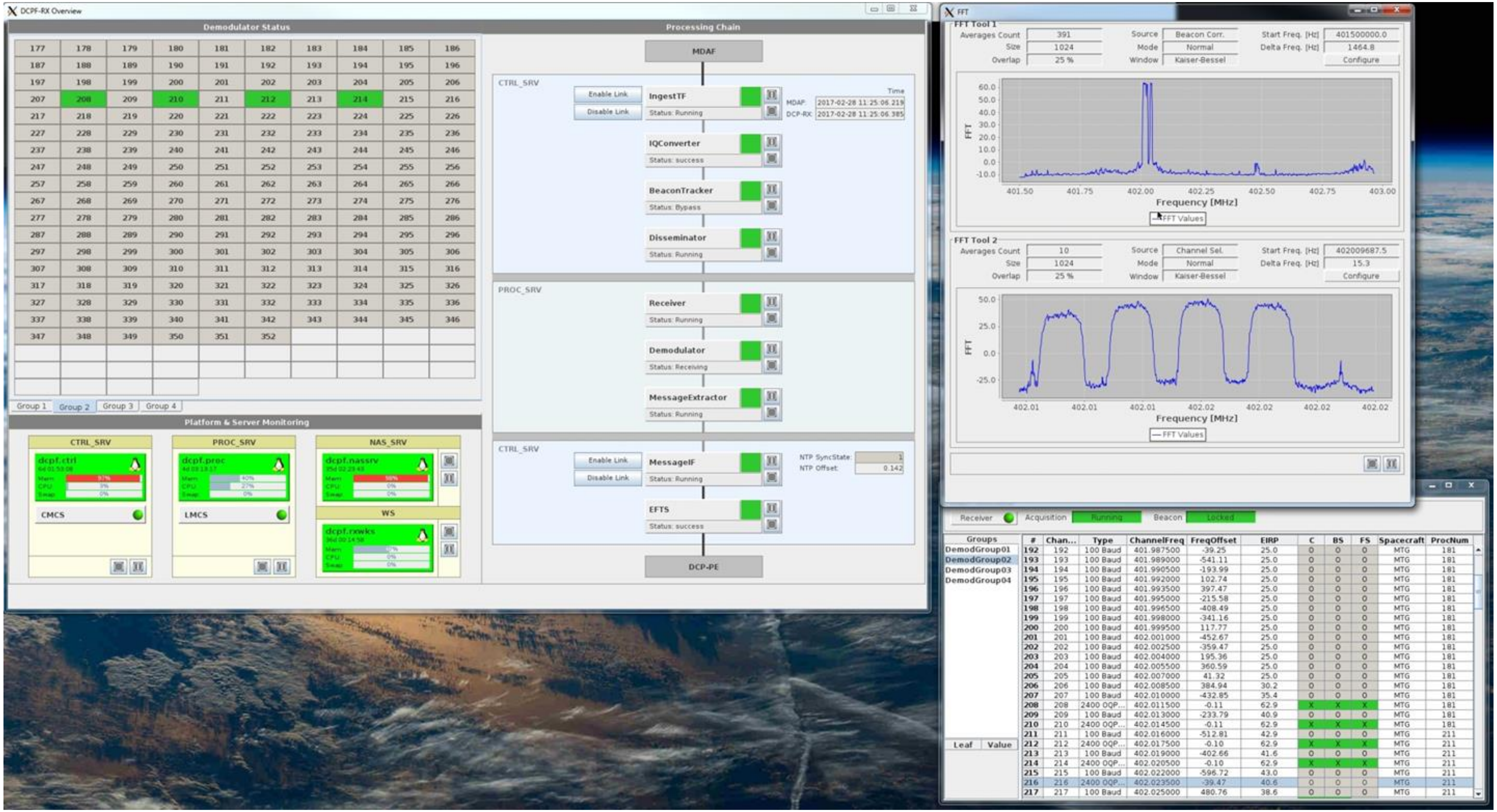
MTG – DCP RX MMIs



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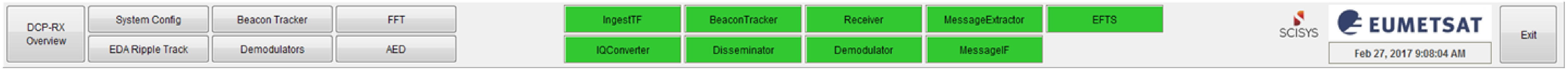
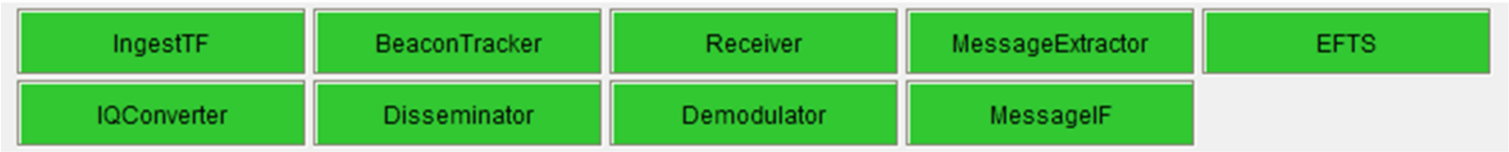
MTG – DCP RX MMIs

- Menu Area
  - Permanently visible
  - Shows status of software units
  - Offers start of additional displays and tools





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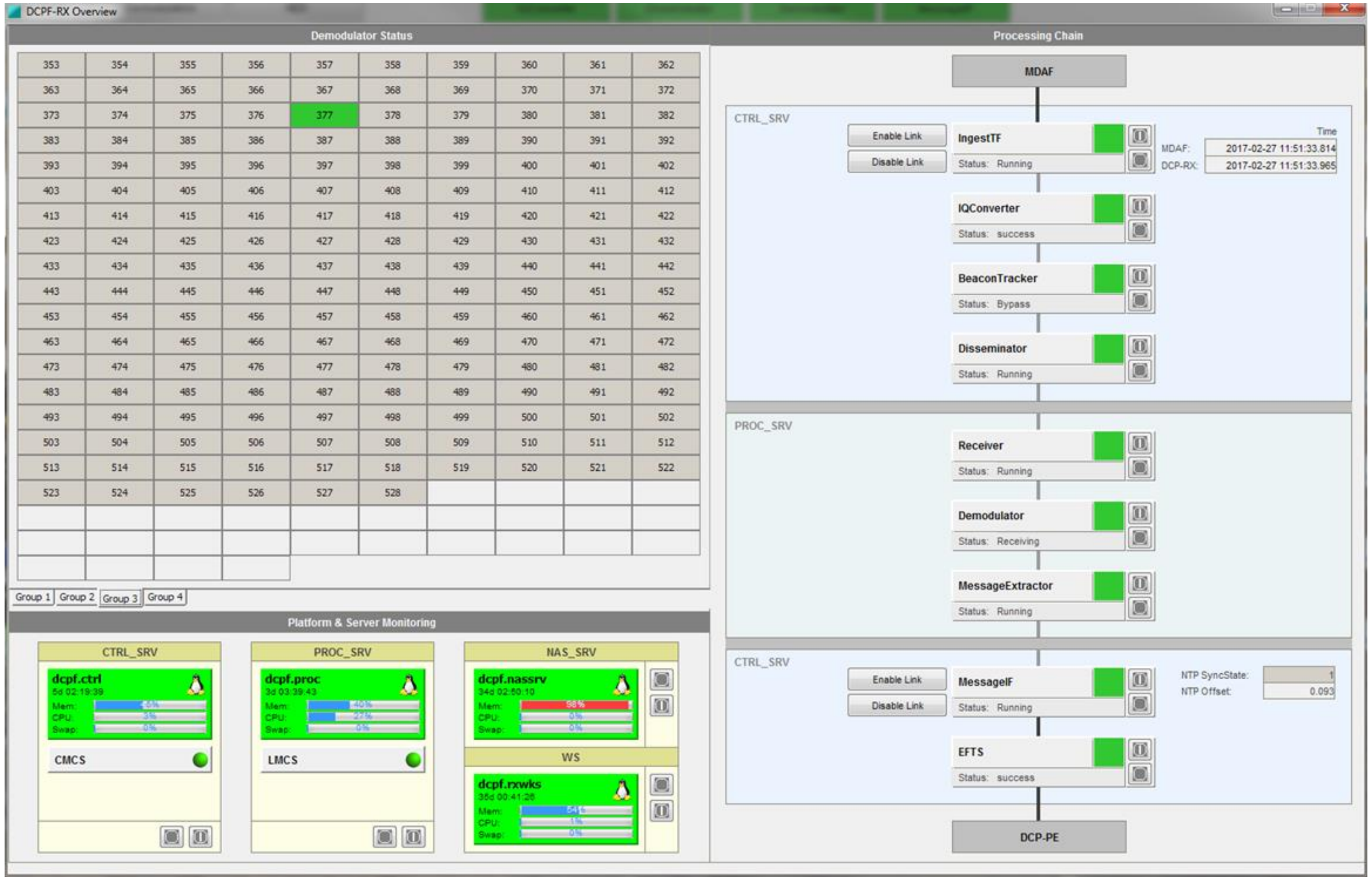
MTG – DCP RX MMIs

- DCP-RX Overview
  - » Divided into several functional parts



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MTG – DCP RX MMIs

- DCP-RX Overview
  - » Processing Chain: shows the several software units (SUs) from end-to-end
  - » Offers controlling capabilities: enable/disable links, start/stop SUs

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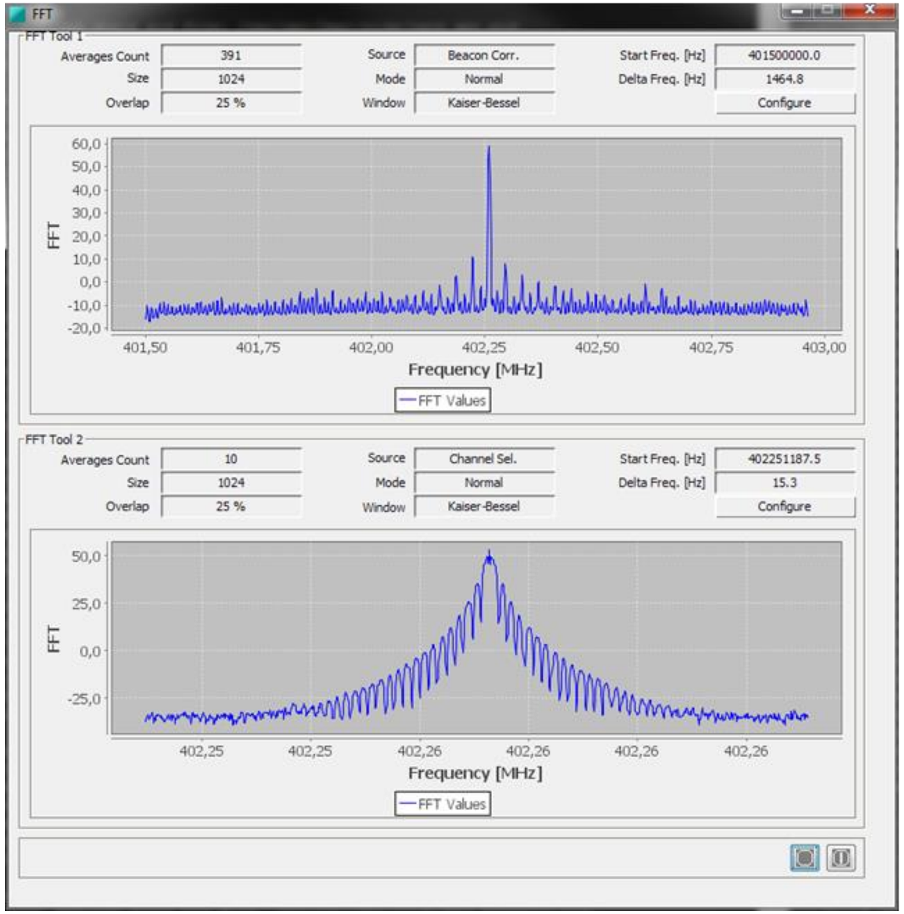
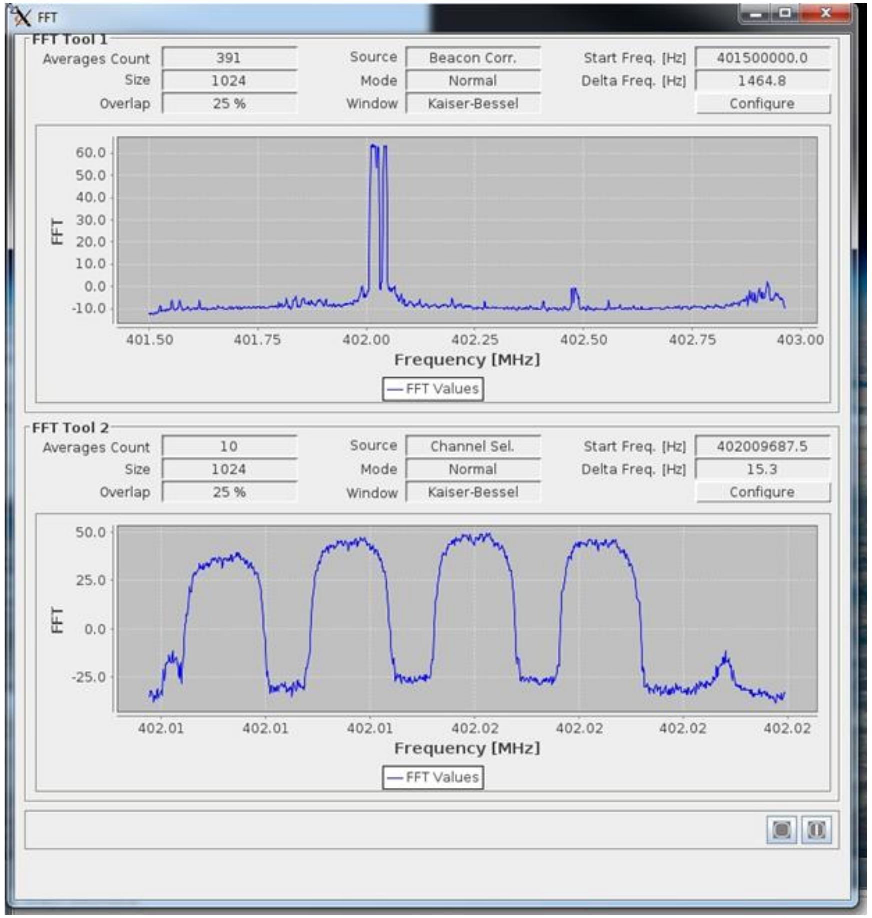
MTG – DCP RX MMIs

- FFT Tool
  - » Shows FFTs, allows to start/stop and reconfigure FFT process
  - » Can be used to find problems on the DCP link





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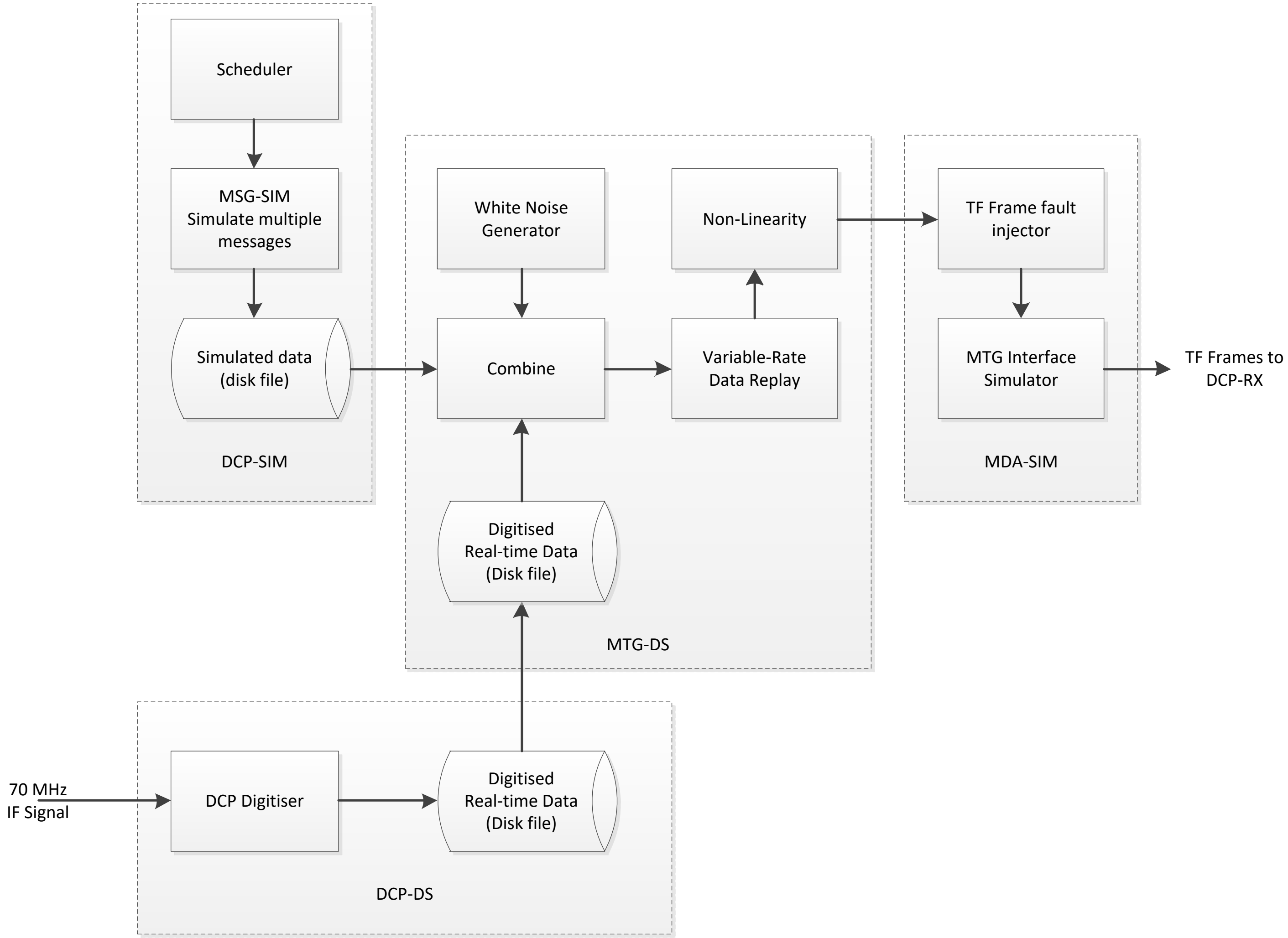
MTG – Test Concept

- Testing in the absence of the MTG is performed with a test suite provided by SCISYS

- DCP-TST (Test Tools)
  - » **DCP-SIM -** DCP Simulator
  - » **DCP-DS** - DCP Digitiser
  - » **MTG-DS -** MTG Digitiser Simulator
  - » **MDA-SIM -** MTG Mission Data Acquisition Simulator



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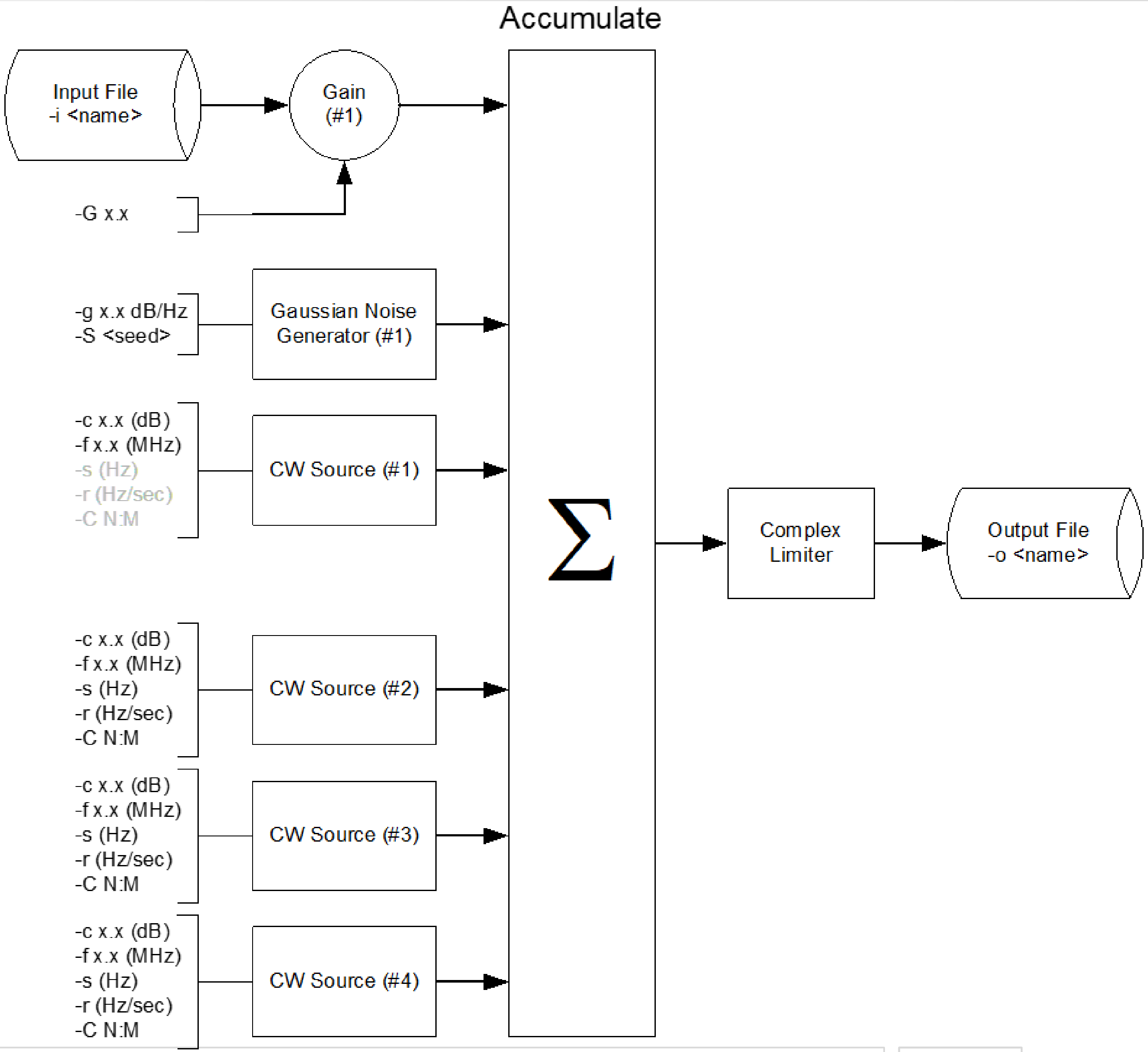
MTG – Test Concept

Block Diagram

MTG-Combine



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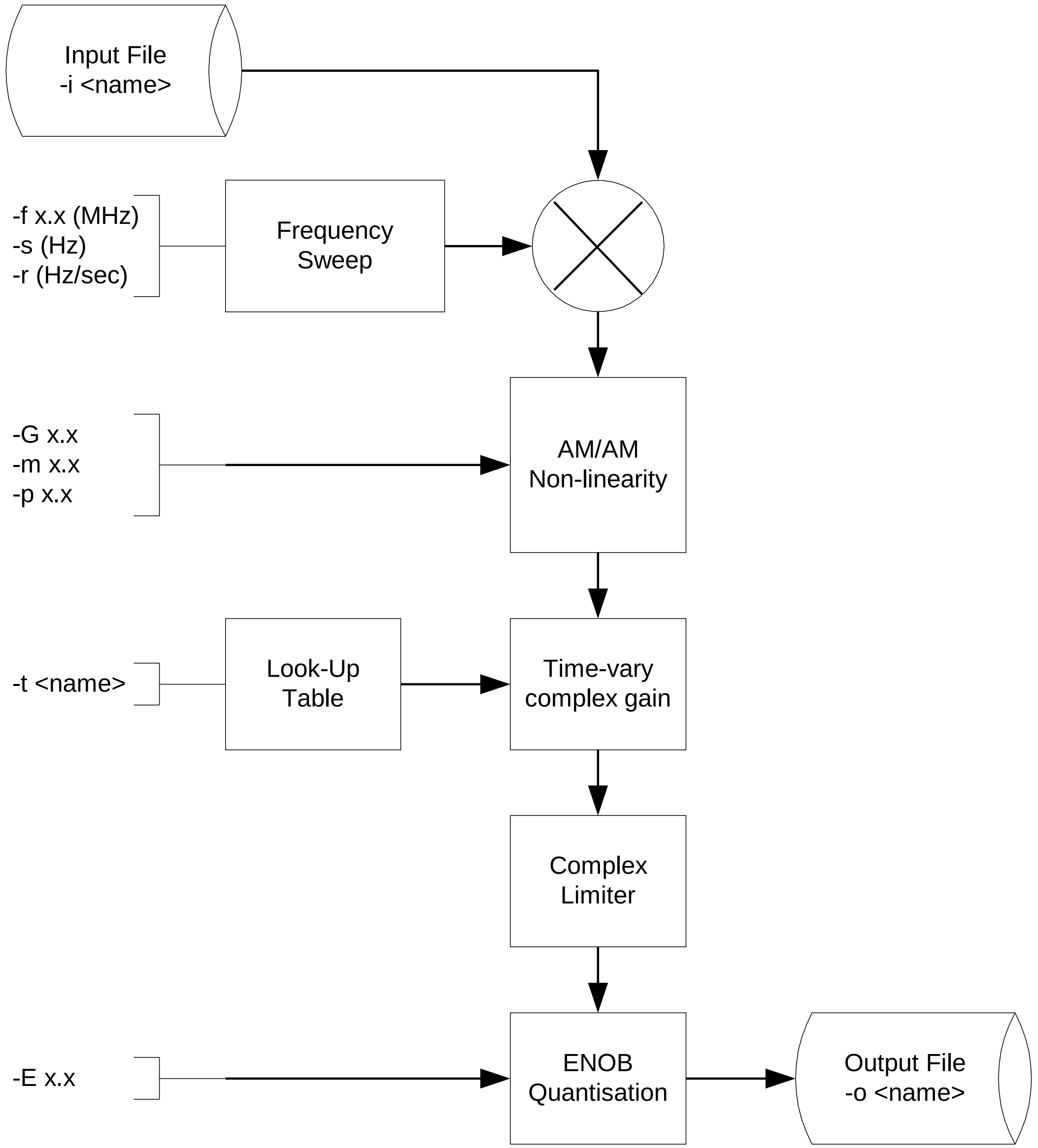
MTG – Test Concept

Block Diagram

MTG-Nonlinearity



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MTG – Test Concept

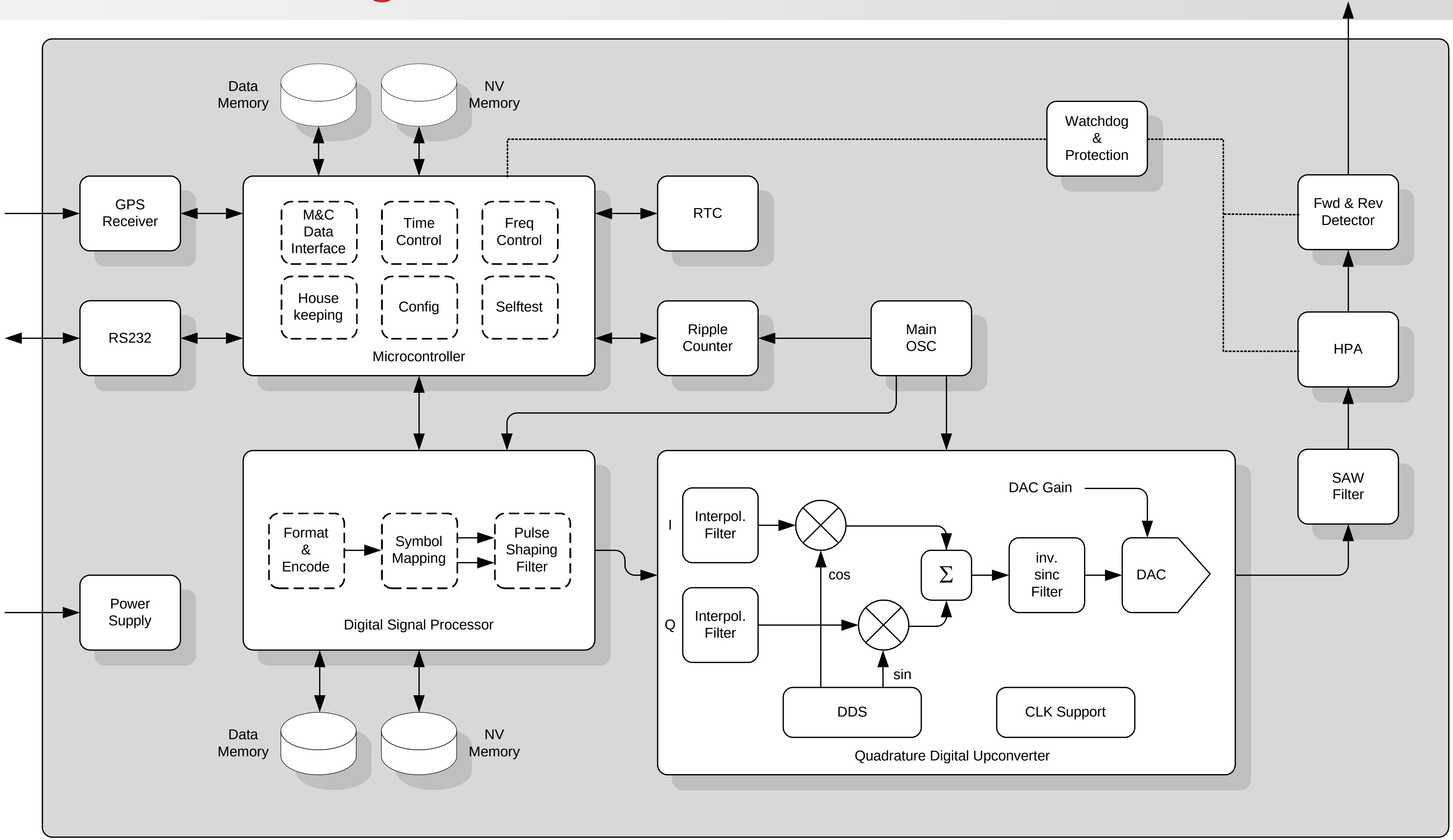
- Possibilities
  - » Generation of complex DCP signals
    - › According to a schedule
    - › Up to 704 DCP signals
    - › Up to one hour repeat pattern
    - › At various power levels and supports ‘error’ cases
  - » Apply
    - › White Gaussian noise
    - › Non-linearity effects
    - › CW signals for pilot or interference simulation
    - › Loss of sample frames
    - › Digital corruption of data for specific demodulator and decoder tests
  - » Further possibilities with appropriate time-varying Look-Up Tables
    - › Apply phase noise
    - › Simulate Ocean Buoy Effects

Transmitter Prototype Development

Transmitter Prototype Development – Scope

- Part of Study "High Rate Data Collection Platform Prototype Development" under ESA Contract in ARTES 5.1 Technology Program
- Development of DCP Transmitter Reference Design
  - » Support METEOSAT SR/HR-DCP and GOES-300/1200
  - » Technology / Market Survey
  - » Requirements Analysis & Definition
  - » Architectural & Detailed Design
- Validation of DCP Transmitter Reference Design
  - » Implementation of Engineering Model Prototype (TRL = 5)
  - » Test and Verification
  - » HRDCP Certification

DCP-TX Block Diagram



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DCP-TX HW Architecture

- Microcontroller
  - » Scheduling / Timing
  - » User Interface
  - » Power Control
- Baseband Processing in Software (DSP)
  - » Interpolation up to Moderate Sample Rate
  - » Flexibility (Software Defined)
  - » Formatting, Encoding, Pulse Shaping
- I/Q Modulation and Up-Conversion (QDUC)
  - » Final Interpolation, Digital Modulation, Up-Conversion
  - » Carrier NCO Generation, Clock Control
  - » Degree of Integration / Optimisation (FPGA) → low power
  - » LO Leakage, I/Q Imbalance (both better than analogue)

DCP-TX HW Architecture

- TCXO
  - » Power Consumption
  - » Phase Noise
  - » Frequency Stability
  - » Size

- Frequency / Time Correction (GPS, Temperature)
  - » Timeliness Requirement (+/- 250ms)
  - » Frequency Accuracy (125Hz @ 400MHz → ~ 0.3ppm)
  - » Frequency Drift during Transmission (1Hz/s)
  - » Operating Temperature Range (-40°C … +50°C)

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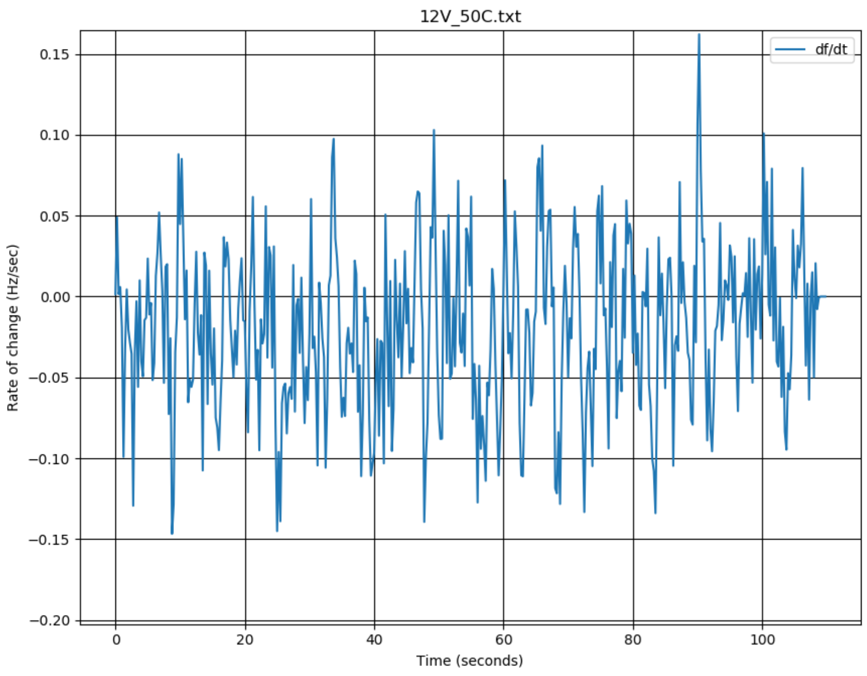
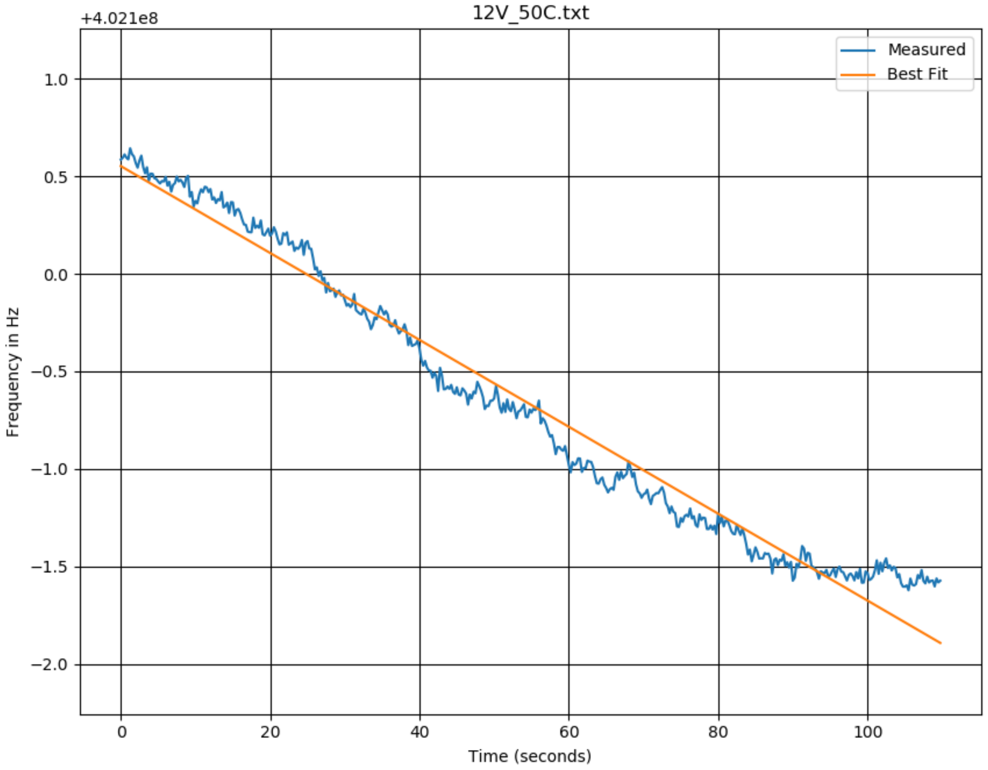
DCP-TX Main Design Drivers

- Frequency Stability / Drift
- Timelines of Transmissions
- Phase Noise
- Low Power Consumption
- Flexibility
- Low Cost
- Maintenance Free
- Operating Temperature / Voltage Range

Frequency Stability / Drift

- TCXO Stability: ±0.5ppm
- Additional Temperature LUT
- GPS Correction for slow changing effects (e.g. ageing)





Less than 5Hz drift during 110s transmission

Less than 5Hz drift during > 20 hours of operation

Rate of change < ±0.2Hz/s

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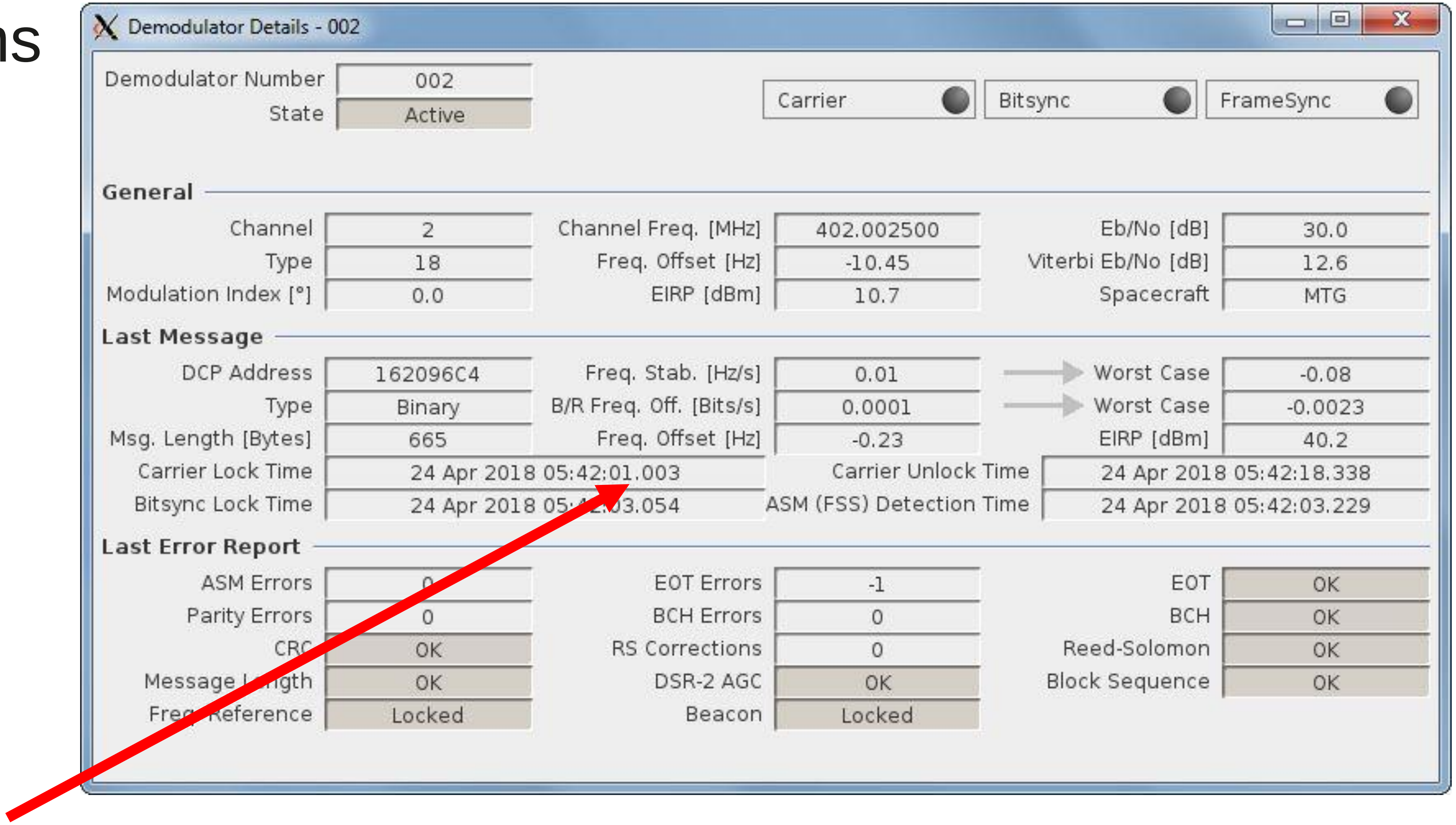
Timeliness of Transmission

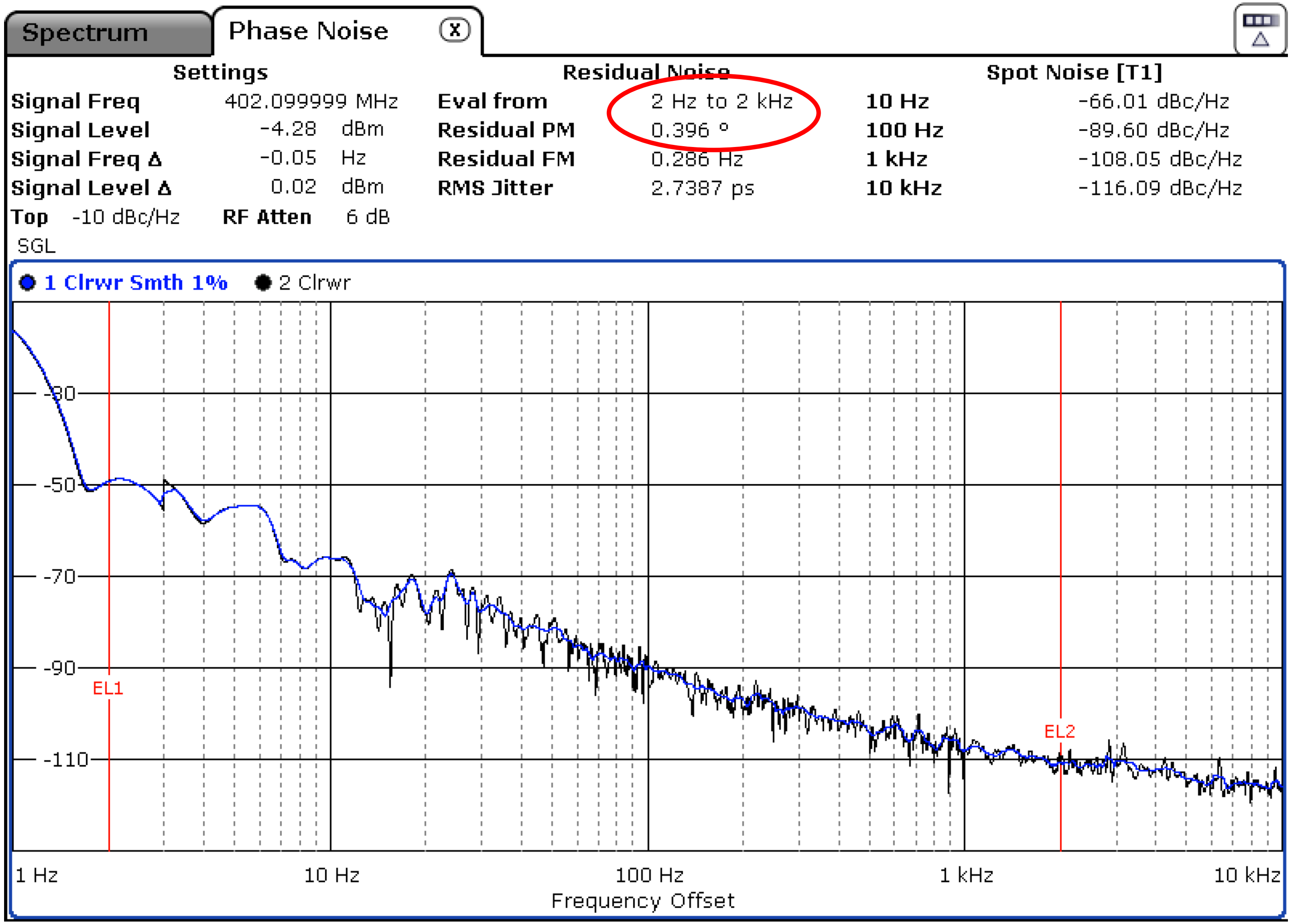
- Requirement: ±250ms



- GPS Corrected RTC
- Verified by Receiver Time Tags

Phase Noise

- Spec: 2° RMS when integrated from 2Hz to 1kHz
- → -53dBc/Hz @ 10Hz offset from 400MHz carrier



Low Power Consumption

- Initial Requirement: max. 10mA @ 12V Idle Power
- Benchmark: 3mA @ 12V Idle Power
- Idle power dominates overall power budget
  - » Microcontroller Power Saving Modes
  - » Voltage Islands controlled by µC
- → 3.5mA @ 12V in Idle Mode

Flexibility / Costs / Maintenance

- Flexibility
  - » Same hardware for legacy and new air interface
  - » All missions supported by single firmware
- Costs
  - » Usage of “standard” COTS components
  - » Single side populated PCB
  - » Automatic calibration possible
- Maintenance
  - » Fully digital design
  - » No manual adjustments/ re-calibration necessary
  - » No serviceable parts

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Testing

- Laboratory Tests over Full Voltage / Operating Temperature Range

- METEOSAT HRDCP Certification Test
  - Blind Test (formatting & encoding)
  - Laboratory Tests
  - Long Run Test over Satellite

- Simulations

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Delta to Production Unit

- Minor Hardware Improvements to Main PCB
- Better GPS Module
- Operation for long periods without GPS Lock
- Automatic Calibration and Production Tests
- HPA Improvements
- Long Term Tests
- Data Logger Interface

New Air Radio Interface

Enhanced DCP (EDCP)

EDCP – Scope

- Part of Study “High Rate Data Collection Platform Prototype Development” under ESA Contract in ARTES 5.1 Technology Program

- Definition of New Air Interface
  - » Analysis of DCP System Scenarios
  - » Survey
  - » Possible Fields of Improvement
  - » Analysis of Compatibility Aspects
  - » Requirements Definition
  - » Architectural & Detailed Design (common hardware)

- Prototype Validation (Proof of Concept)
  - » Implementation of Engineering Model Prototype (TRL < 5)
  - » Design and Implementation of Receiver
  - » Test, Simulation and Verification

EDCP – Background

- Definition of a new air interface to extend the appeal of the DCP system to both new and existing users
- Potential new options constrained by existing space-side assets
  - » Current and planned DCP transponders on GEO satellites of Eumetsat, NOAA, JMA, etc.
- Conducted a survey of existing and potential new users to find out what aspects are important
- Survey was send to 31 possible participants
- Received 19 responses
- Discussed with Eumtesat who proposed the EDCP name

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EDCP – Additional Resources

- Web pages relating to EDCP are:
  - » ESA project web page: https://artes.esa.int/projects/hrdcp
  - » SCISYS web page for DCP: https://www.2met.com/hrdcp/

- Document bundle available on request from SCISYS with:
  - » End user survey results
  - » Analysis of survey results
  - » Technical note on data link layer and alert concepts
  - » Extract from final test report covering EDCP simulation
  - » ESA project final report
  - » Eumetsat summary document presented to CGMS

EDCP – Survey Results

- Almost all suggestions for new use-cases of the DCP system involve movement
  - » Animal tracking & Distress beacons are examples where low power/speed is appropriate.
  - » Aircraft, Ship and Logistics/Transport are examples where current (or higher) speed operation is appropriate.
- Other questions relating to movement tolerance showed a very strong interest
- The question of data integrity, something already greatly improved with HRDCP over other systems, was one that also drew strong support
- Only other strong opinion was that standby power consumption is an important factor
- SCISYS DCP Activities

EDCP – Design Constraints

- Largely due to re-use of existing space-side hardware and coexistence with existing DCP users
- Bandwidth
  - » 3000Hz current HRDCP option
  - » Meteosat use currently low so more theoretically possible
  - » 2250Hz for GOES maximum likely
  - » GOES major market
- EIRP
  - » Significantly more than legacy/HRDCP a problem for DC power and possibly spacecraft transponder loading
  - » Significantly less a risk for interference lock problems
- Complexity / Licensing
  - » Wide adoption important for DCS approval, so other manufacturers need easy deployment

EDCP – Design Study

- Considered wide range of modulation formats
- Coherent modulation considered necessary for good power efficiency
- Analysed models for system phase noise
  - » Oscillators in TX / transponder/ RX
  - » Ocean buoy movements
  - » Ionospheric effects similar
  - » Transport effects simpler (just consider Doppler limit for road / rail / aircraft cases)
- Analysed performance in terms of phase noise tracking for coherent demodulation
- Analysed FEC performance

EDCP – Design Choices

- Speed around 400 Baud (in 2250Hz channel)
- Proposed modulation is Pi/2 BPSK
  - Good phase noise tolerance
  - Low peak to average should ease HPA design
- Also implemented standard BPSK
  - Same good phase noise tolerance
  - Low risk as already supported in receiver
- FEC system adapted from HRDCP
  - Easy implementation for existing manufacturers of HRDCP TX
  - Has choice of RS code block for better power efficiency with short messages
  - Has symbol interleaver for better phase noise tolerance
  - Pilot symbols for advanced tracking in future demodulators
- Data link layer (frame format) same as HRDCP

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EDCP – Performance Simulation

- Used same software demodulator as Eumetsat use for their DCP facility
- Simulation tool chain included:
  - Gaussian additive noise
  - Interference from fixed or sweeping/pulsed CW sources
  - FM and AM effects based on an example ocean buoy message in 15 m/s wind speed storm conditions
- Simulation included legacy systems and EDCP proposal
- ESA project phase noise modelling limited:
  - Observed ocean buoy effects used
  - Movement and oscillator noise combined

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EDCP – Further Simulation

- SCISYS supporting masters student Thilo Moldenhauer
- Masters project looking as modelling phase noise and ocean movement effect for use in such simulation tools
- Aim to model:
  - » Land case dominated by oscillator noise
  - » Sea case based on oscillator noise and Pierson-Moskowitz Wave Spectrum
- Some preliminary results from Sep 2018 included here
- Testing with Thilo Moldenhauer also resulted in some minor bug-fixes for the simulation tool chain
- Amplitude effects due to multipath reflection are **not** covered here!
  - » AM effects were used in ESA study based on recorded data

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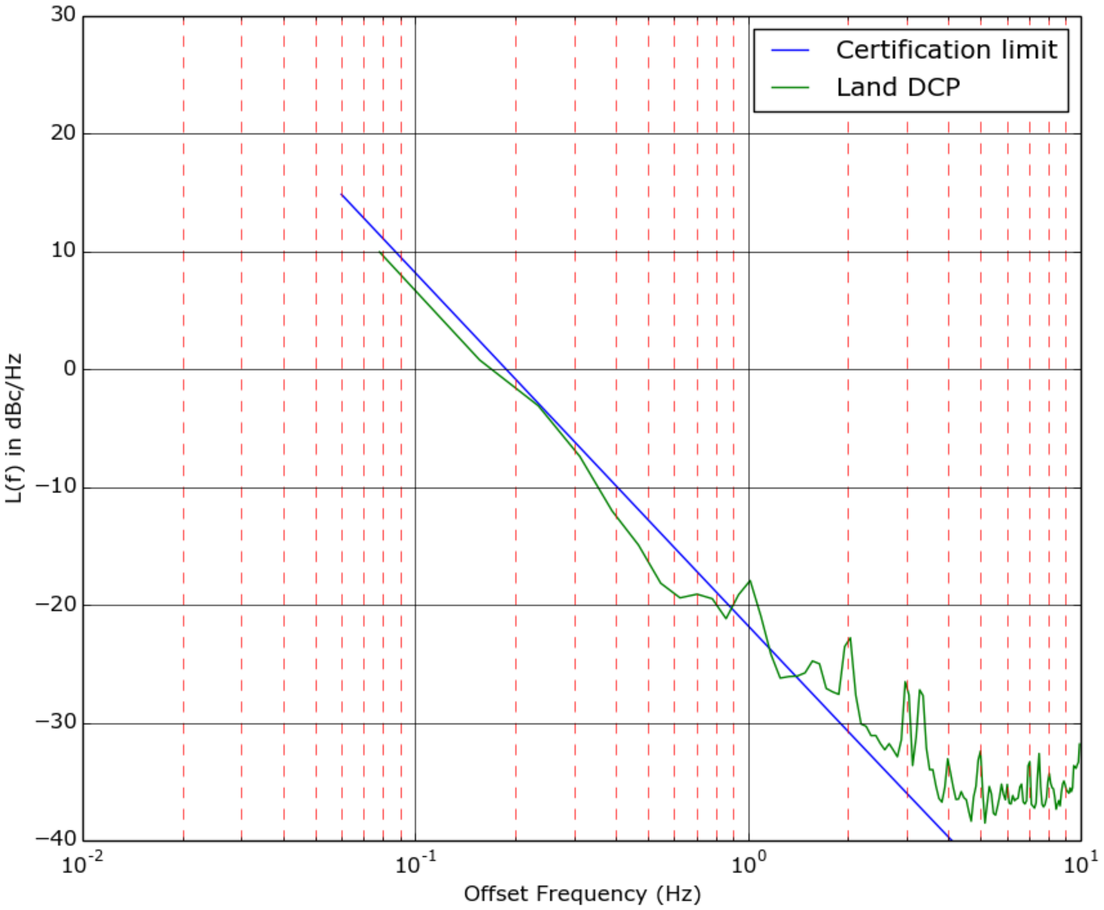
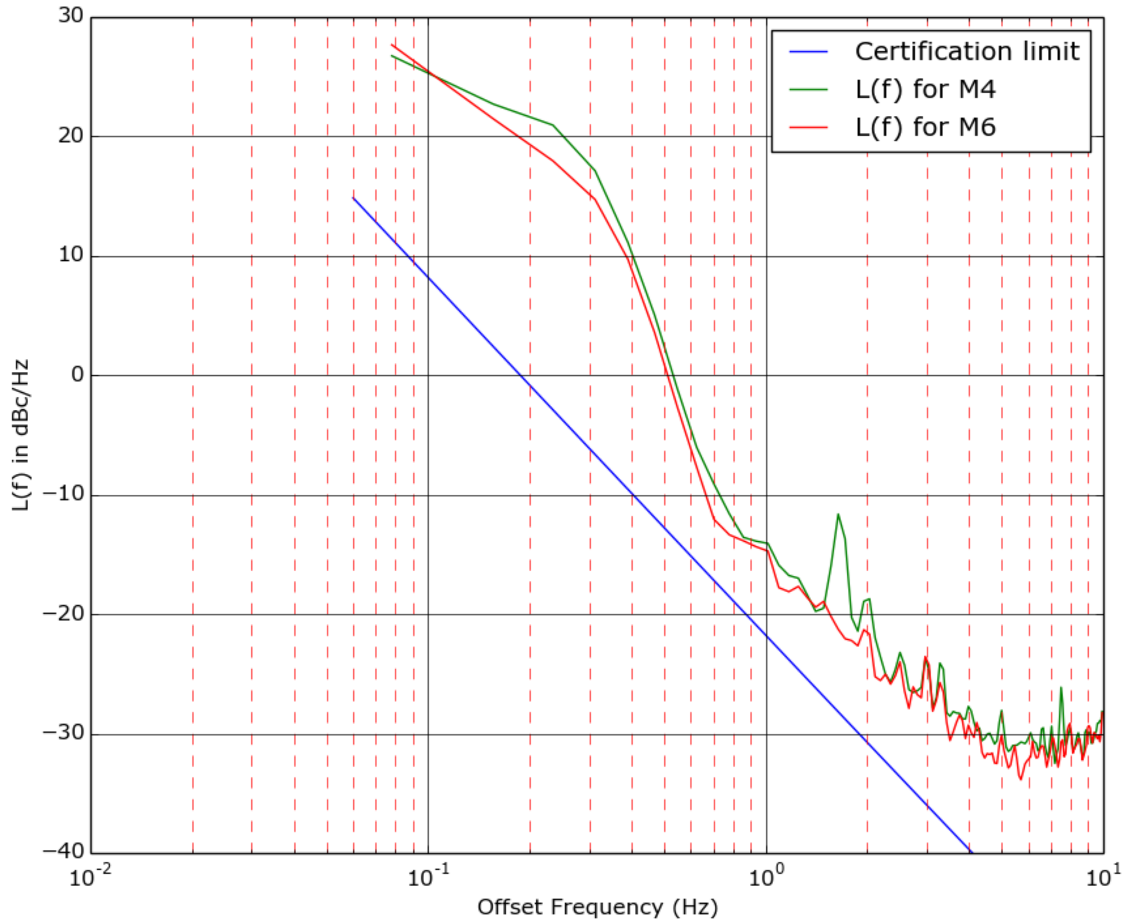
EDCP – Land Model Observation

- Observed phase noise spectrum from a known land-based DCP transmitter
- Overall results show combined TX, quiet ionosphere, satellite, and RX performance
- Close to the Eumetsat/NOAA certification limit for typical oscillator with a $1/f^3$ spectrum
- Normally TX are 5dB or so better



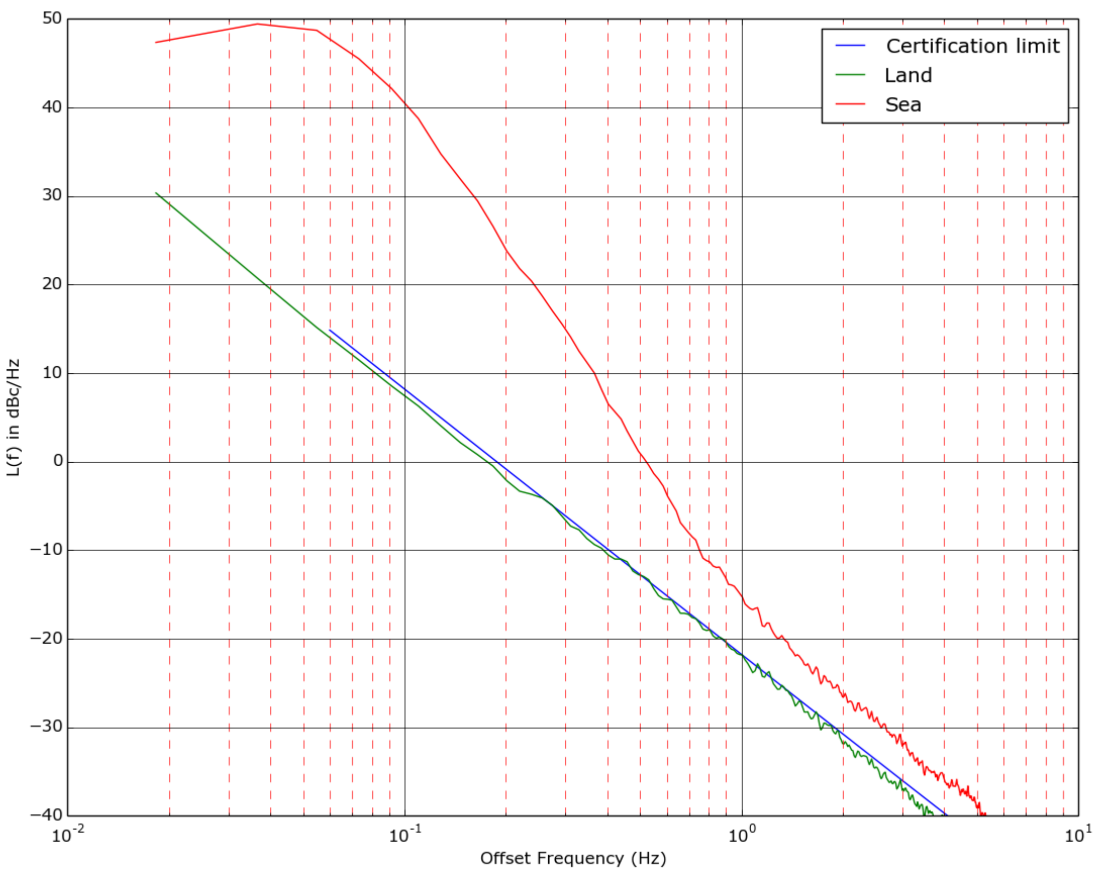
EDCP – Sea Model Observation

- Observed phase noise spectrum from known sea buoy operated by Irish Marine Institute
- Data from storm 4th Feb 2008
- Wind speed around 15 m/s (Beaufort scale 7 “near gale”)
- Above ~0.7Hz show elevated oscillator-like noise
- Below ~0.7Hz show greatly elevated noise due to wave motion



EDCP – Sea Model Simulation

- Land case simply the $1/f^3$ oscillator model meeting certification limits
- Sea case has certification model at +5dB and Pierson-Moskowitz Wave Spectrum
- Planned P-M spectrum slightly modified to account for estimated buoy platform resonance around 0.35Hz



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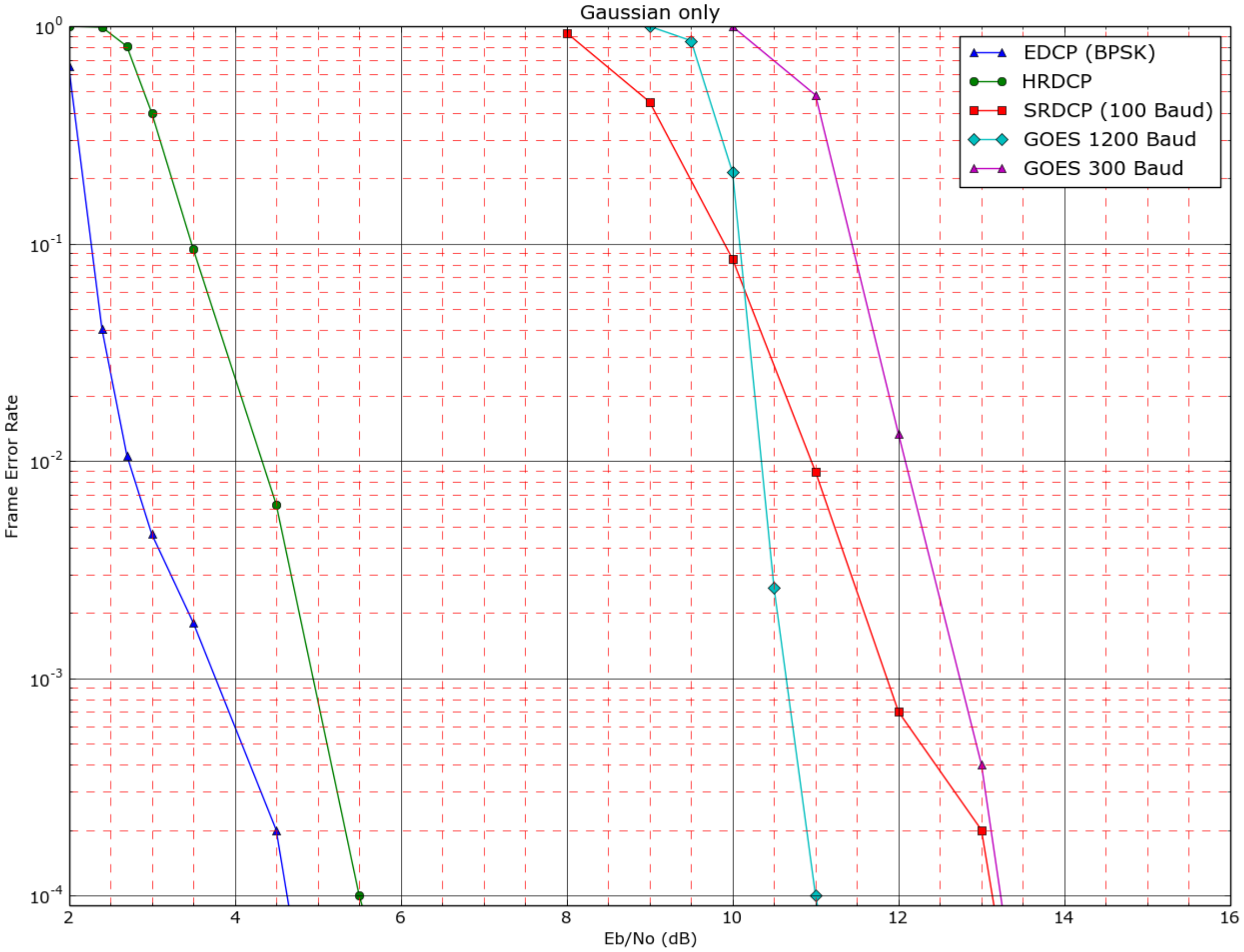
EDCP – AGWN Results (10k messages of 600 bytes)



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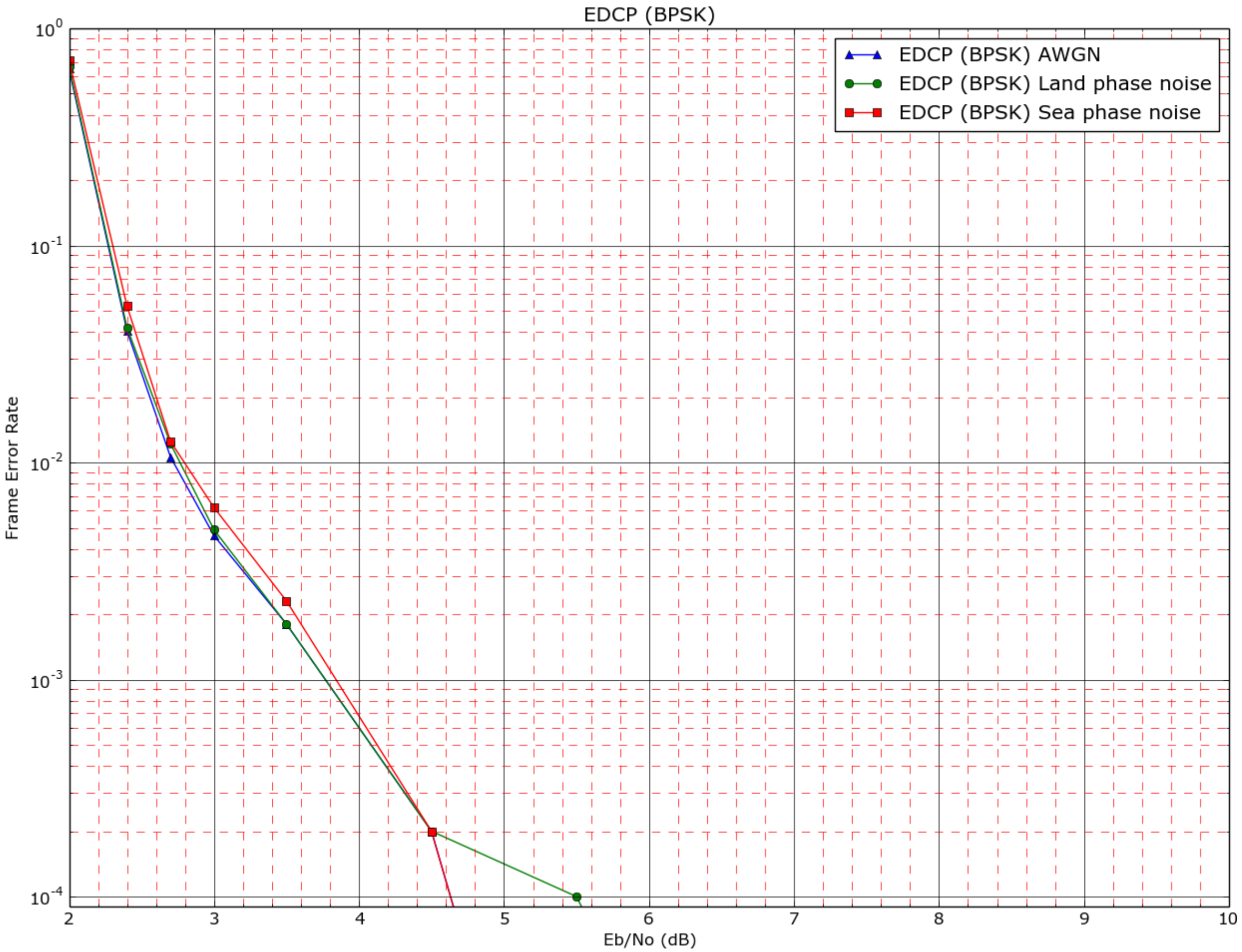
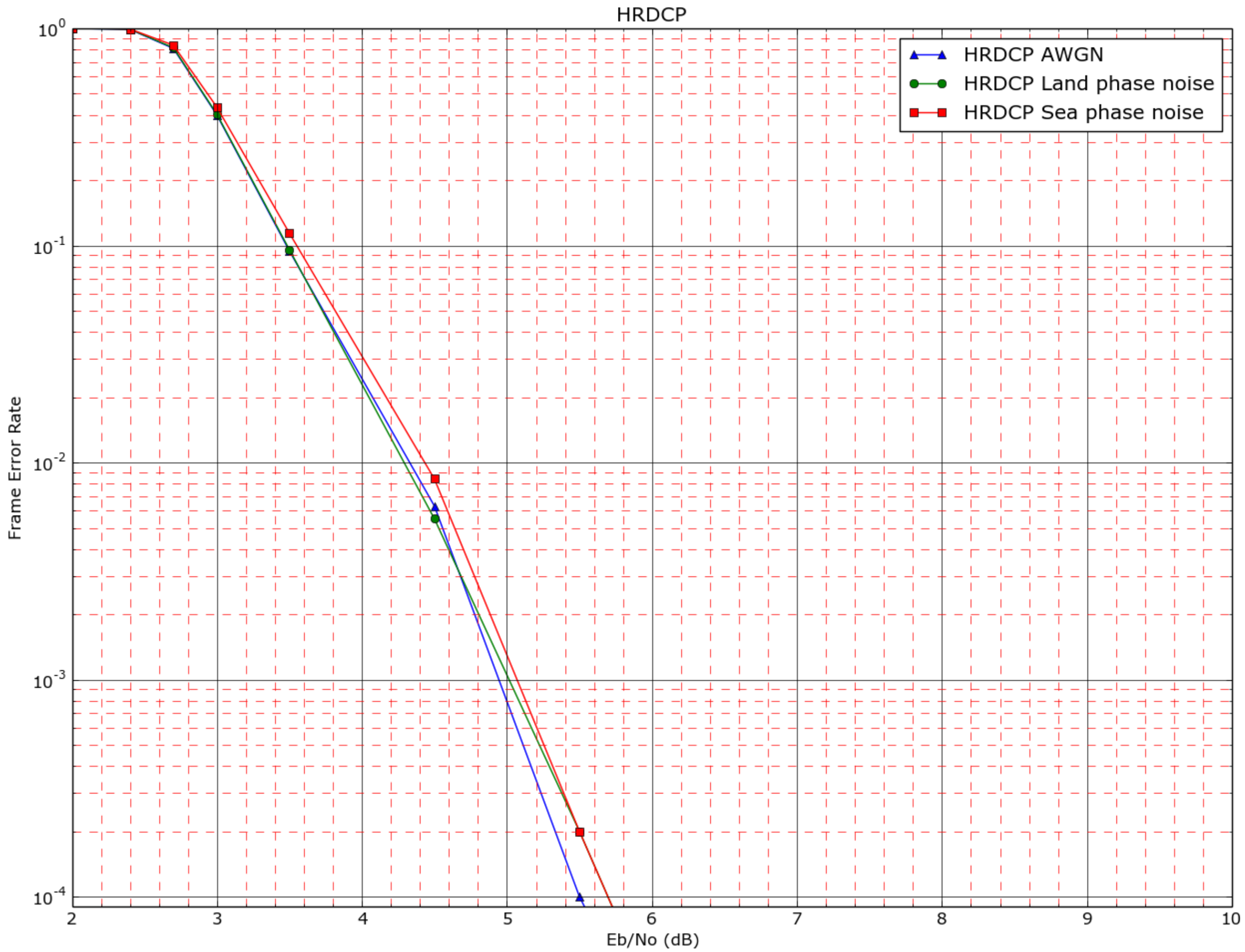
EDCP – Phase Noise Tolerance (EDCP BPSK)



EDCP – Phase Noise Tolerance (HRDCP – default 5Hz PLL)



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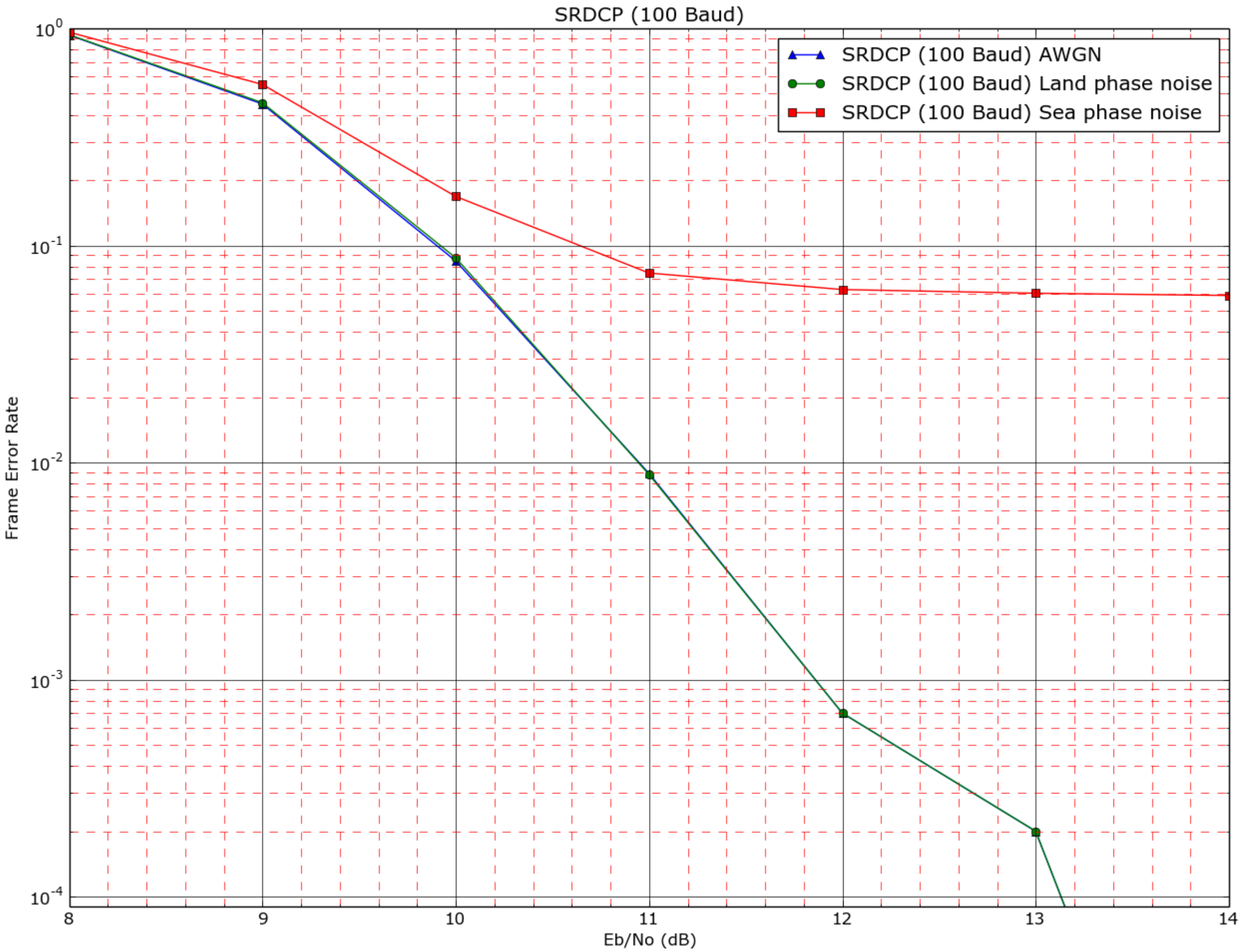
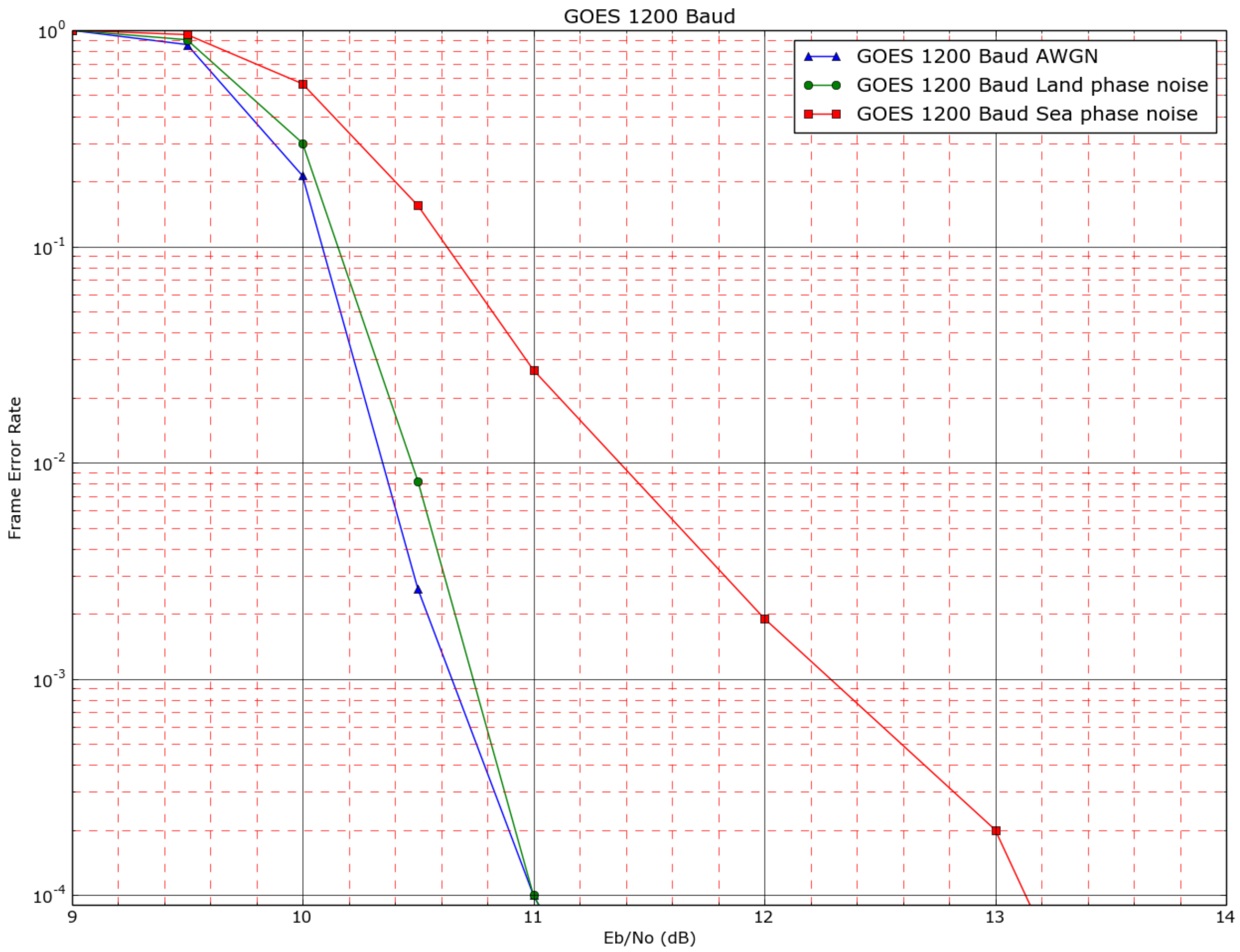
EDCP – Phase Noise Tolerance (SRDCP – default 2Hz PLL)



EDCP – Phase Noise Tolerance (GOES 1200 Baud)



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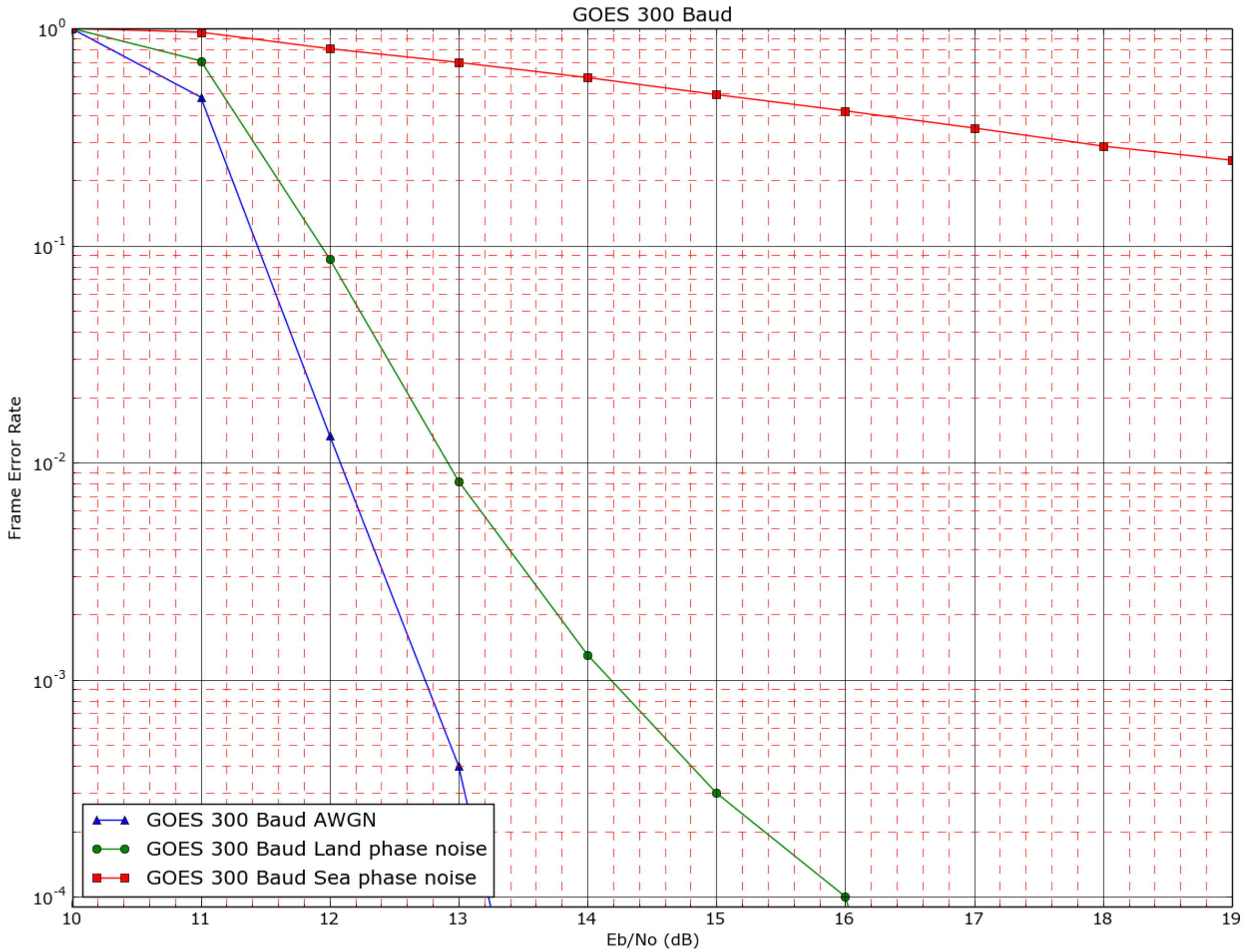
EDCP – Phase Noise Tolerance (GOES 300 Baud)



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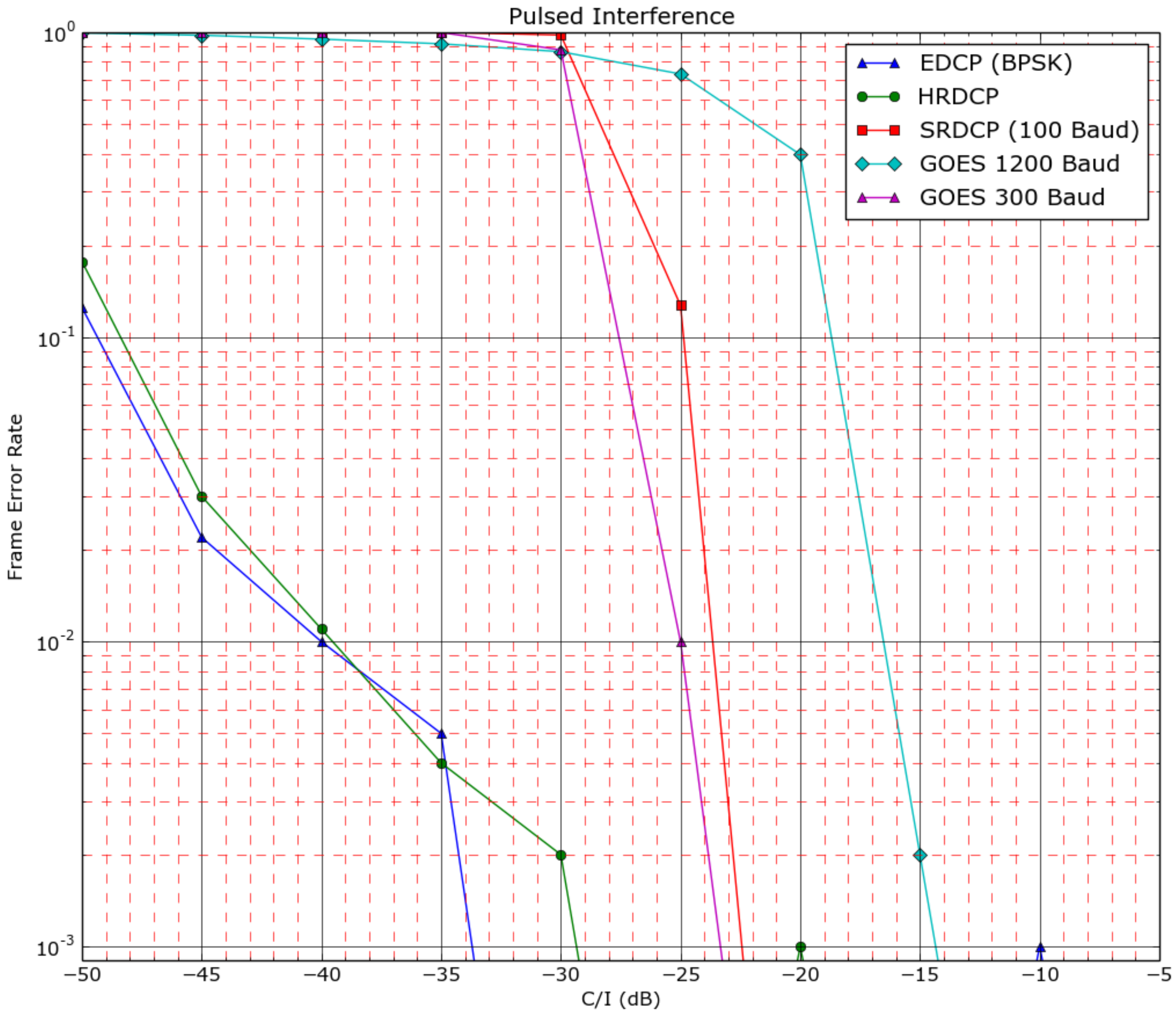
EDCP – Pulsed Interference Results (1k messages)



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EDCP – Simulation Results

- Gaussian case shows that EDCP & HRDCP have around 6dB advantage over SRDCP and GOES systems
- EDCP only implemented with ESA project's 2250Hz choice
- New "sea model" revealed bit-slip problem for SRDCP demodulator
- HRDCP tracking default values can be improved
- EDCP (BPSK) better than HRDCP, even with such improvements!
- EDCP Pi/2 results showed more work on demodulator needed (theoretical performance is same as BPSK)
- EDCP AM/FM results within 0.25dB of Gaussian-only performance
- Interference results show EDCP and HRDCP to be much better than SRDCP/GOES as expected

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EDCP – Summary of Systems

Parameter	100 Baud	GOES 300	GOES 1200	HRDCP	EDCP (ESA)	EDCP (1.5kHz)	EDCP (750Hz)
CW Duration	5.0s	0.5s	0.25s	2.0s	1.0s	1.0s	1.0s
Clock & Sync Time	2.65s	0.12s	0.03s	0.16s	0.218s	0.31s	0.768s
Clock Pattern	250 bits	3 bits	3 bits	128 bits	128 bits	128 bits	128 bits
Sync Word Length	15-bit	15-bit	15-bit	64-bit	64-bit	64-bit	64-bit
Mod (Preamble)	Bi-Phase-L / PSK	BPSK	BPSK	BPSK	BPSK (also π/2)	BPSK (or π/2 ?)	BPSK (or π/2 ?)
Mod (Data)	(same as preamble)	8-PSK	8-PSK	Offset QPSK	(same as preamble)	(same as preamble)	(same as preamble)
Symbol Rate	100	150	600	1200	880	620	250
Filtering	3 pole Bessel	RRC α = 1.0	RRC α = 1.0	RRC α = 0.5	RRC α = 1.0	RRC α = 1.0	RRC α = 1.0
Channel Spacing	1500Hz	750Hz	2250Hz	3000Hz	2250Hz	1500Hz	750Hz
Primary FEC	None	R=2/3 Trellis	R=2/3 Trellis	Concatenated R=½ Viterbi, RS(255,223), I=3	Concatenated R=½ Viterbi with choice of RS block size	Concatenated R=½, Viterbi with choice of RS block size	Concatenated R=3/4, Viterbi with choice of RS block size
Other FEC		Symbol interleave dropped in V2	Symbol interleave dropped in V2		1 in 12 pilot symbols and symbol block interleaver	1 in 12 pilot symbols and symbol block interleaver	1 in 12 pilot symbols and symbol block interleaver
End of Transmission	31-bit marker	8-bit marker	8-bit marker	Message length in header.	Message length in header.	Message length in header.	Message length in header.
Error Detection	Parity & alphabet	Parity (optional)	Parity (optional)	32-bit CRC	32-bit CRC	32-bit CRC	32-bit CRC
E_b/N_o for 1E-3 FER (noise only)	11.5dB	13dB	10.6dB	5dB	4dB	4dB ?	5dB ?
User throughput after overheads	87.5 bit/s	263 bit/s (parity) 300 bit/s (none)	1050 bit/s (parity) 1200 bit/s (none)	1049 bit/s	355 bit/s	251 bit/s	152 bit/s
Binary Support	No	Not yet	Not yet	Yes	Yes	Yes	Yes

EDCP – Conclusions from ESA Project

- Simulation results very promising
- Implemented and tested on engineering model hardware
- Developed under ESA project for 2250Hz channel slot to fit both Eumetsat HRDCP and GOES 1200 Baud allocations
- Discussion for modifications to use 1500 Hz channel slots (SRDCP) and possibly 750 Hz slots (GOES 300 Baud)
- Additional work on BPSK Pi/2 demodulator desirable
- Additional optimisation of demodulator for legacy missions desirable
- Wider discussion within DCP community on data link layer / common header ideas

EDCP – Way forward?

- Feedback from DCS community!
- Selection of EDCP options:
  - » Channel spacing(s) to be supported: 750 / 1500 / 2250Hz?
  - » Modulation mode BPSK or π/2 BPSK
  - » Standard header ideas?
  - » Message authentication?
- Improve simulation tools
  - » Turn masters project in to usable verified tools for phase noise modelling
- Further demodulator work:
  - » Fix π/2 mode to match BPSK performance
  - » Implement pilot symbol tracking, or drop this feature?
  - » General optimisation for legacy missions
- Live testing over Eumetsat MSG, also with NOAA, JMA?

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Thank you for your Attention!

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Contact us

We are happy to help.

SCISYS Deutschland GmbH
Dr. Peter Scheidgen
Borgmannstrasse 2
44894 Bochum, Germany

peter.scheidgen@scisys.de
scisys.de/space
+49 234 9258112
+49 234 9258190

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