Satellite Communications Prototyping and Deployment with NI COTS Components

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High-density, wide-area communication coverage based on low Earth orbit (LEO) satellite networks is transforming the way satellite communications (SATCOM) are utilized. This forces architectures, waveforms, and user applications to be considered differently. LTE has recently been expanded to SATCOM, and 5G will soon follow the same path. This opens up new applications and a new set of architectures that can be considered. Military applications must explore low probability of intercept (LPI) waveforms to avoid detection, as well as anti-jam architectures and waveforms to combat deliberate or unintended interference in congested and contested spectrum.

Satellite Communications

Main Drivers for Satellite Communication Applications

01
High density, wide-area telecommunication coverage using LEO satellites

02
Multitude of imaging and sensing applications in agriculture, urban planning, mining, and forestry leveraging low-cost CubeSats

03
Renewed vigor in planetary exploration and human space programs

04
Emerging focus on creating satellite-based assets for C5ISR applications in defense and homeland security

The NI Solution for SATCOM Prototyping

01
Multichannel synchronization across USRP SDRs or PXI modules enables multiuser MIMO (MU-MIMO) and coherent Tx/Rx schemes.

02
Robust, high-bandwidth data movement capabilities with FPGA and other processing elements to support forward error correction (FEC), channel coding, or other complex DSP prototyping.

03
Physical layer implementations built on SDR may combine with open-source stacks to provide a complete end-to-end prototyping testbed.

04
Integration with Python, MathWorks MATLAB® software, LabVIEW, C++, and other programming languages ensures simplified integration into existing workflows.

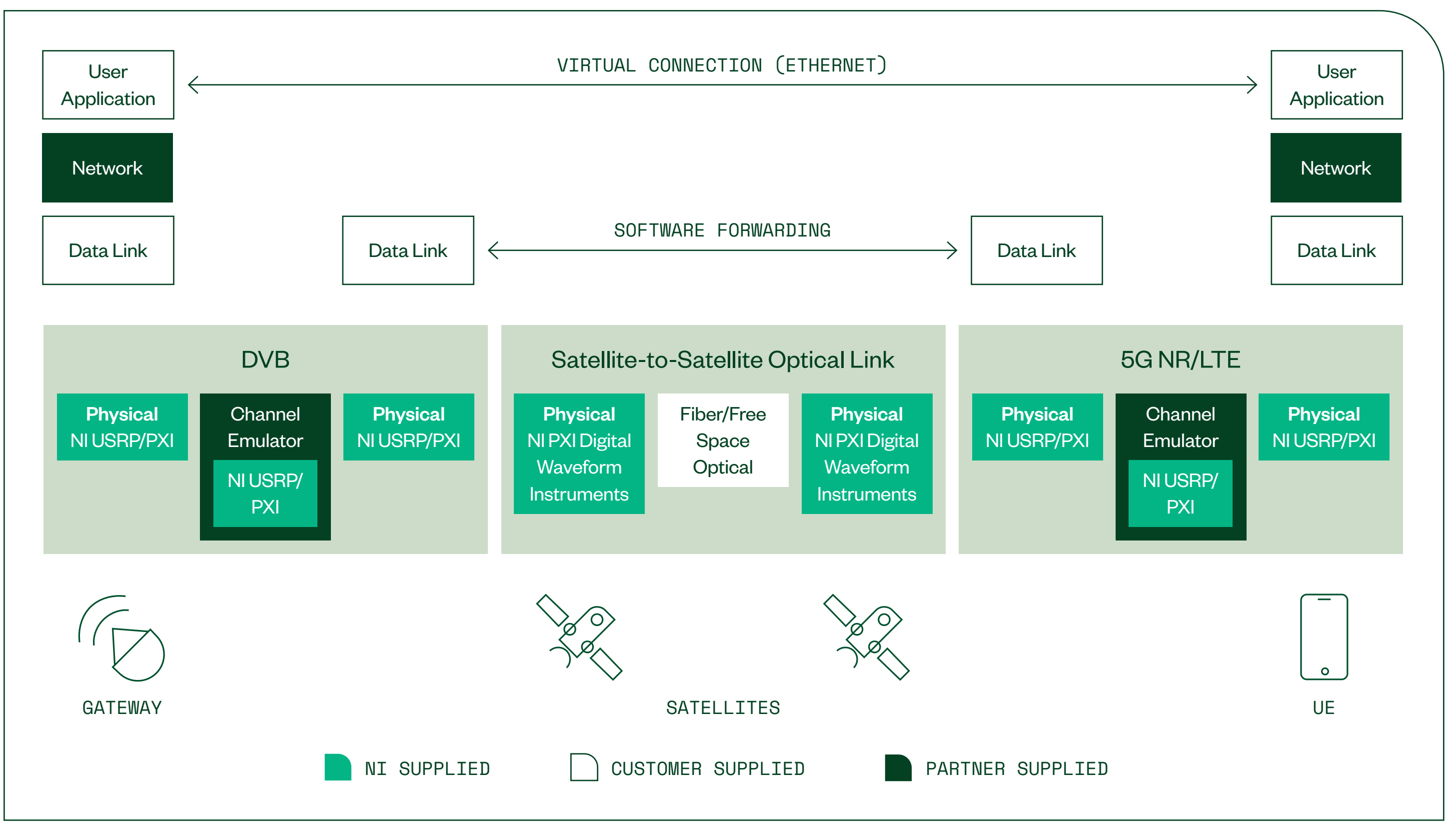


FIGURE 01
Complete SATCOM Prototyping Testbed with NI COTS Components

Requirements of Hardware and Software for SATCOM Prototyping

01

Wideband, flexible radios for spread spectrum and frequency hopping techniques

02

Multichannel phase coherency for digital beamforming

03

Integration with open-source network layer stack IP to support end-to-end testbeds

04

Compatibility with various software toolchains for easy integration into current development workflows

05

Integration of RF capabilities with various compute elements

Advantages of Using COTS Components for SATCOM Prototyping

01

Multiple R&D focus areas addressed with the same hardware infrastructure.

02

Maximize code reuse with system interoperability across a broad product portfolio.

03

Rapidly prototype systems with a choice of programming environments including LabVIEW and open-source tools.

04

Unparalleled scalability for prototyping novel SATCOM waveforms and systems with a common platform and programmatic interface.

Requirements of Deployed SATCOM Receivers

Satellite and space communication transponders demand reliable performance under a variety of propagation environment variables. Along with performance, link availability and low SWaP (size, weight, and power) are other critical parameters for onboard transponders.

Compact size and low power consumption can impose constraints on the onboard communication transmitters. This transfers the onus of performance to ground receivers. Ground receivers should not only receive and extract signals at very low power but also be intelligent enough to detect fading conditions and recover fast. Further, receivers are expected to have multiple personalities to work on different missions with different onboard transponders. Finally, as the data rate, waveforms, and quality of service requirements are becoming more stringent, it’s difficult to standardize on specific vendor-defined models of receivers.

Deploying SATCOM Receivers with COTS RF Modules

One unique approach that solves this problem is to standardize on software defined radio (SDR) platforms that offer COTS RF front ends for radio channel acquisition and generation, and are scalable. These SDRs include deterministic FPGA-based processors at the baseband to implement standard and user-defined communication schemes.

In summary, the requirements for ground-based modems are:

- Modular and COTS RF front ends
- Scalable and time deterministic baseband processors
- Support for multichannel phase-coherent acquisition/generation
- Wide bandwidth along with high sensitivity
- Flexibility to implement standard and non-standard communication schemes

Applications of Deployed SATCOM Systems Built with NI COTS Components

- Telemetry, telecommand, and ranging: full/half-duplex commanding; verification of satellites, launch vehicles, space stations, crew modules, rovers and re-entry vehicles, and line of sight (LOS) ranging of spacecraft
- Audio and video links: Full/half-duplex communication between space crew and ground station
- Data links: Point-to-point or multipoint one-way links to communicate sensor/payload information from spacecraft to ground stations
- Satellite communication system: Using satellite as a relay to establish audio/video/data links from a point on ground (hub) to multiple points on ground (terminals)

NI PXI RF and Microwave Tx/Rx Options for SATCOM Prototyping and Deployment

SPEC	PXIE-5832 VST	PXIE-5841 VST	PXIE-5785 FLEXRIO	PXIE-5764 FLEXRIO	PXIE-5668 VSA
Instrument Type	Transceiver	Transceiver	Transceiver	Digitizer	Vector Signal Analyzer
RF Architecture	Direct Conversion	Direct Conversion	Direct Sampling	Direct Sampling	Superheterodyne
Channel Count	1 Tx; 1 Rx	1 Tx; 1 Rx	2 Tx; 2 Rx	4 Rx	1 Rx
Frequency Coverage	5 – 21 GHz; 23 – 44 GHz	9 kHz – 6 GHz	6 GHz Rx; 2.85 GHz Tx	400 MHz	20 Hz – 26.5 GHz
Instantaneous Bandwidth*	1 GHz	1 GHz	2.5 GHz	400 MHz	765 MHz
Tuning Resolution**	4.45 uHz	888 nHz	N/A	N/A	533 nHz
Maximum Input Power	+36 dBm (RF) +25 dBm (IF)	+24 dBm (fc < 120 MHz) +33 dBm (fc ≥ 120 MHz)			+30 dBm
Synchronization Architecture	LO Sharing; 10 MHz; Hardware Start Trigger; Sample Clock Alignment	LO Sharing; 10 MHz; Hardware Start Trigger; Sample Clock Alignment	Ref Clock Sharing; Sample Clock Alignment; Hardware Start Trigger	Ref Clock Sharing; Sample Clock Alignment; Hardware Start Trigger	LO Sharing; 10 MHz; Hardware Start Trigger; Sample Clock Alignment
Backend Data Interface	PCIe Gen 3 x8	PCIe Gen 3 x8	PCIe Gen 3 x8	PCIe Gen 3 x8	PCIe Gen 2 x8
Single Module Backplane Streaming Performance***	1 GHz IBW	1 GHz IBW	1.25 GHz IBW	1.25 GHz IBW	765 MHz IBW
Front Panel Data Interface	x4 GTH Transceivers	x4 GTH Transceivers	x4 GTH Transceivers	x4 GTH Transceivers	n/a
Specification Type	Warranted with Calibration Service	Warranted with Calibration Service	Typical	Typical	Warranted with Calibration Service
Relative Cost Per Channel	$$$	$$$	$$	$	$$$

* CONSULT INDIVIDUAL PRODUCT SPECIFICATION DOCUMENTS FOR FREQUENCY PLAN

** TUNING RESOLUTION COMBINES LO STEP SIZE CAPABILITY AND FREQUENCY SHIFT DIGITAL SIGNAL PROCESSING (DSP) IMPLEMENTED ON THE FPGA

*** PERFORMANCE FOR MULTICHANNEL SYSTEMS WILL BE LIMITED BY SYSTEM THROUGHPUT

TABLE 01

PXI-based Tx/Rx modules for SATCOM prototyping and deployment include transceivers, digitizers, and vector signal analyzers

NI PXI RF and Microwave Tx/Rx Options for SATCOM Prototyping and Deployment

SPEC	USRP B2XX	USRP N310 / N32X	USRP X310	USRP E320	USRP X410
Frequency	70 MHZ – 6 GHZ	3 MHZ – 6 GHZ (N32X) 10 MHZ – 6 GHZ (N310)	10 MHZ – 6 GHZ	70 MHZ – 6 GHZ	1 MHZ – 7.2 GHZ
Bandwidth	56 MHZ	200 MHZ (N32X) 100 MHZ (N310)	160 MHZ (UBX) 80 MHZ (TwinRX)	56 MHZ	400 MHZ
Channels	2 TX, 2 RX	2 TX, 2 RX (N32X) 4 TX, 4 RX (N310)	2 TX, 2 RX (UBX) 4 RX (TwinRX)	2 TX, 2 RX	4 RX, 4 TX
RF Performance	GOOD	BEST	BEST	GOOD	BETTER
Architecture	INTEGRATED	INTEGRATED	CONFIGURABLE W/ DAUGHTERBOARDS	INTEGRATED	INTEGRATED
Communication	USB	10 GBE OR PCIE	10 GBE OR PCIE	10 GBE	100/10/1 GBE OR PCIE
Synchronization	2X2 MIMO	UP TO 128 X 128 (N32X) FULL PHASE SYNCHRONIZATION	2X2 MIMO (UBX) 4 RX (TwinRX)	2X2 MIMO	4X4 MIMO
Software Support	GNU RADIO, C++, PYTHON, MATLAB, LABVIEW	GNU RADIO, C++, PYTHON, MATLAB, RFNOC	GNU RADIO, C++, PYTHON, MATLAB, RFNOC, LABVIEW, LABVIEW FPGA	GNU RADIO, C++, PYTHON, MATLAB, RFNOC	GNU RADIO, C++, PYTHON, RFNOC, LABVIEW *Q4 2021
Key Features	Low SWaP-C, Highly portable	Stand Alone, Wide bandwidth, Multichannel Sync Ready (N32X)	Configurable RF Front End, Programmable FPGA	Low-SWaP, Embedded Deployable, Standalone	RFSOC Based, 5G Ready, Wide Band, Multichannel

TABLE 02

USRP SDRs range from low-SWaP to high-performance and can be used for SATCOM prototyping and deployment. NI recommends the N320 and N321 SDRs for multichannel systems, due to the ability to share local oscillators for phase coherency across an array.

NI Hardware Products

USRP SDRs

A USRP Software Defined Radio Device provides a software-defined RF architecture to design, prototype, and deploy wireless systems with custom signal processing. Hardware options range from low-cost to high-performance radios with large, open FPGAs. You can develop with LabVIEW or open-source code.

USRP N320/1

The USRP N320 and N321 are networked software defined radios that provide reliability and fault tolerance for deployment in large-scale and distributed wireless systems. These devices simplify control and management of a network of radios by introducing the unique capability to remotely perform tasks such as updating software, rebooting, factory resetting, self-testing, host PC/ARM debugging, and monitoring system health. The USRP N320 and N321 are all-in-one devices that include the Zynq-7100 SoC baseband processor, two SFP+ ports, a QSFP+ port, a built-in GPSDO module, and a variety of other peripheral and synchronization features.

A unique feature of the USRP N321 is the ability to share export Tx and Rx local oscillators in a star configuration to multiple other N321 or N320 devices, for phase-coherent operation.

USRP X410

The NI Ettus USRP X410 is a high-performance, multichannel software defined radio. The SDR is designed for frequencies from 1 MHz to 7.2 GHz, tunable up to 8 GHz and features a two-stage superheterodyne architecture with four independent TX and RX channels capable of 400 MHz of instantaneous bandwidth each. Digital interfaces for data offload and control include two QSFP28 interfaces capable of 100 GbE, a PCIe Gen3 x8 interface, as well standard command, control, and debug interfaces: USB-C JTAG, USB-C console, and Ethernet 10/100/1000. The USRP X410 is an all-in-one device built on the Xilinx Zynq UltraScale+ ZU28DR RF System on Chip (RFSoC) with built-in digital up and down conversion and onboard Soft-Decision Forward Error Correction (SD-FEC) IP.

PXI

NI PXI systems provide high-performance modular instruments and other I/O modules that feature specialized synchronization and key software features for test and measurement applications from device validation to automated production test. NI is the PXI industry leader, with the broadest array of best-in-class products and services on the market.

PXI CHASSIS

The PXI chassis is the backbone of a PXI system and compares to the mechanical enclosure and motherboard of a desktop PC. It provides power, cooling, and a communication bus to the system, and supports multiple instrumentation modules within the same enclosure. PXI uses commercial PC-based PCI and PCI Express bus technology while combining rugged CompactPCI modular packaging, as well as key timing and synchronization features. Chassis range in size from two to 18 slots to fit the needs of any application, whether its intentions are to be a portable, a benchtop, a rack-mount, or an embedded system.

PXI Vector Signal Transceiver

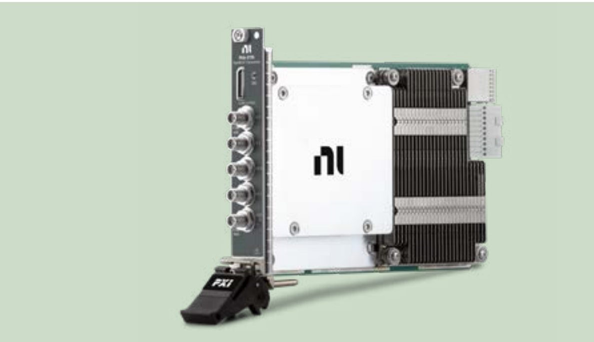
The PXI Vector Signal Transceiver (VST) combines an RF and baseband vector signal analyzer and generator with a user-programmable FPGA and high-speed serial and parallel digital interfaces for real-time signal processing and control from baseband to mmWave.

PXIE-5841 VECTOR SIGNAL TRANSCEIVER

6 GHz, 1 GHz Bandwidth, RF PXI Vector Signal Transceiver—The PXIe-5841 is a vector signal transceiver (VST) with 1 GHz of instantaneous bandwidth. It combines vector signal generator, vector signal analyzer, and high-speed serial interface capabilities with FPGA-based real-time signal processing and control. The PXIe-5841 features the flexibility of a software defined radio architecture with RF instrument class performance. This VST delivers the fast measurement speed and small form factor of a production test box with the flexibility and high performance of R&D-grade box instruments.

PXIE-5832 VECTOR SIGNAL TRANSCEIVER

44 GHz, 1 GHz Bandwidth, mmWave PXI Vector Signal Transceiver—The PXIe-5832 provides FPGA-based processing along with the combined functionality of a vector signal analyzer and a vector signal transceiver. You can use the PXIe-5832 to perform stimulus and response measurements in the 5 GHz to 21 GHz and the 22.5 GHz to 44 GHz frequency ranges. Additionally, the PXIe-5832 features multiport configuration options that integrate solid-state mmWave switching to the 22.5 GHz to 44 GHz frequency range.



PXIE-5875 FLEXRIO IF TRANSCEIVER

12-Bit, 6.4 GS/s, 2-Channel PXI FlexRIO IF Transceiver—The PXIe-5785 enables direct RF acquisition up to 6 GHz and generation up to 3 GHz with 12 bits of resolution. You can use it in a dual-channel mode at 3.2 GS/s or in a single-channel interleaved mode at 6.4 GS/s. The PXIe-5785 is ideal for applications that require wideband acquisition and generation with multichannel synchronization, including radar, electronic warfare, and communications. The FlexRIO driver includes support for acquiring and generating waveforms out of the box, and you can use the LabVIEW-programmable Xilinx Kintex UltraScale FPGA to implement custom algorithms for real-time signal processing.

PXIE-5668 VECTOR SIGNAL ANALYZER

Up to 26.5 GHz PXI Vector Signal Analyzer—The PXIe-5668 offers wide bandwidth with high measurement performance and speed. It meets the challenging requirements of applications such as wireless communications, radio frequency integrated circuit characterization, radar test, spectrum monitoring, and signal intelligence. With its implementation as a PXI instrument, the PXIe 5668 also features the fast measurement speed required for high-volume manufacturing test, and multi-instrument synchronization capabilities for phase-coherent MIMO test. You can use the optionally included PXIe-5698 preamplifier to improve dynamic range and sensitivity near the instrument noise floor.

PXI DIGITAL WAVEFORM INSTRUMENTS

PXI Digital Waveform Instruments generate and analyze static and dynamic digital waveforms that interface to digital electronics using single-ended and differential voltage levels.

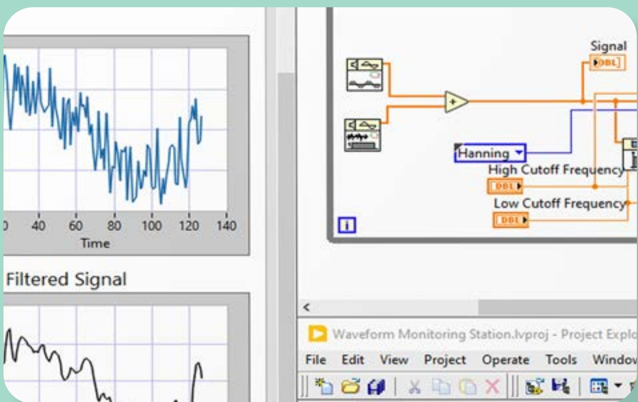
PXI Digital Waveform Instruments feature up to 32 channels, can sample and generate digital waveforms at up to 200 MHz, and interface with various standard TTL and low-voltage differential signals (LVDS), as well as settable voltage levels. These devices offer per clock cycle, per channel bidirectional control and phase shifting. They include deep onboard memory with triggering and pattern sequencing. Some models also support double data rate (DDR) technology and real-time hardware data comparison.

In an end-to-end SATCOM prototyping testbed, Digital Waveform Devices may be used to generate and analyze waveforms that are sent over fiber or free-space optical (FSO) links, imitating inter-satellite laser links.

NI Software Products

LabVIEW

LabVIEW is a graphical programming environment engineers use to develop automated research, validation, and production test systems.



LabVIEW allows researchers and engineers to build systems, fast.

- Thousands of available analysis functions
- Configurable, interactive display elements
- Drivers for automating every instrument and data acquisition hardware
- Connectivity to other languages and industry-standard protocols

Open-Source Software

The USRP Hardware Driver™ (UHD) software API supports application development on all USRP SDR products. Using a common software interface is critical as it increases code portability, allowing applications to transition seamlessly to other USRP SDR platforms when development requirements expand or new platforms are available. Therefore, it enables a significant reduction in development effort by allowing you to preserve and reuse your legacy code so you can focus on new algorithms. For more detailed information visit our knowledge-base article on UHD.

UHD also offers cross-platform support for multiple industry standard development environments and frameworks, including RFNoC, GNU Radio, LabVIEW, and MathWorks MATLAB and Simulink® software. And to ensure you have no restrictions on how you use UHD, it is available on Linux, Windows, and Mac OS.

GNU Radio is a free software development framework that provides signal processing functions for implementing software-defined radios. The framework offers a graphical design approach in addition to supporting development in Python and C++. Supported globally by the open-source community and widely used in government, commercial, and academic environments, GNU Radio gives users access to a diverse set of existing projects focused on wireless communications research and implementation of real-world radio systems.

Third-Party Software/Stacks

OAI

Established in 2014, the OpenAirInterface Software Alliance (OSA) is a French non-profit organization ("Fonds De Dotation"), funded by corporate sponsors. OSA currently provides a standard-compliant implementation for a subset of Release 10 LTE for UE, eNB, MME, HSS, SGw, and PGw on standard Linux-based computing equipment (Intel x86 PC/ARM architectures). The software is freely distributed by the Alliance under the terms stipulated by the OSA license model. It can be used in conjunction with standard RF laboratory equipment available in many labs. The primary future objective is to provide an open-source reference implementation which follows the 3GPP standardization process starting from Rel-13, the evolutionary path towards 5G, and that is freely available for experimentation on commodity laboratory equipment.

Software Radio Systems (SRS)

Software Radio Systems (SRS) provides L1, L2, and L3 solutions for a range of wireless technologies including LTE/LTE-Advanced/NB-IoT and DVB-S2/RCS2. The open-source srsUE application is an LTE UE terminal running on a PC. Coupled with the USRP family of front ends, srsUE provides a powerful tool for network analysis and diagnostics, vulnerability testing, and R&D. Portable, high-performance libraries accelerate SDR product development and custom scan, sniffer, analysis, and fuzzing tools accelerate test and verification while lowering investment costs.

ns-3

ns-3 is a discrete-event network simulator for internet systems, targeted primarily for research and educational use. ns-3 is free, open-source software, licensed under the GNU GPLv2 license, and maintained by a worldwide community.

Specifications Achieved by NI Partners and Customers using COTS Components

Building upon NI's COTS components, customers and NI partners have successfully developed and deployed ground receivers for SATCOM. This section indicates performance metrics that customers and partners have achieved. Contact NI for more information, or to be put in touch with a partner that can provide turnkey systems that meet these specifications.

PARAMETER	SPECIFICATION
Adaptive Gain Control (AGC) Gain	90 dB, Automatic/ Manual Control
AGC Loop Rate	0.1 ms, 1 ms, 10 ms
Doppler Shift (Locking Range)	±250 kHz
Data Rate	Up to 20 MSymbols/s
Input Line Coding	NRZ (non-return-to-zero) L/M/S Bi-ϕ (biphase) L/M/S DM-M/S (only with PCM/FM & PCM/PM) RNRZ (randomized non-return-to-zero) (PN11 / PN15)
Demodulation Schemes	Analog AM, FM, PM Sub-carrier PM/ PCM, PCM/FM Digital m-ary PSK, OQPSK, SOQPSK, m-ary APSK, m-ary QAM, GMSK
Subcarrier Frequency	100 kHz to 20 MHz
Error-Control Coding	Fixed and Adaptive Coding and Modulation (ACM) Variable rate Convolution Coding, Reed-Solomon, Turbo, and LDPC Descrambler (user-defined block size)
Acquisition Threshold	Eb/No < -1.5 dB
Reacquisition Threshold	Eb/No < -5 dB
Reacquisition Time	< 350 bits
BER (Bit Error Rate) Performance	Within 1 dB of theoretical performance for Symbol rate < 1 MSymbols/s Within 1.5 dB of theoretical performance for Symbol rate > 1 MSymbols/s
BER Test Pattern	Up to PN31 or user defined sequence of 32 bits

TABLE 03

Specifications Achieved by NI Partners and Customers using COTS Components

Performance Achievable with NI Partner Capabilities

Turnkey solutions from partners can:

- Form an integrated system with RF front end and baseband processing, programmable for RF/IF acquisition up to 6 GHz
- Provide up to five channels for diversity combining and best channel selection (BCS)
- Include integrated software for acquisition, pre-processing, demodulation, decoding, and bit synchronization
- Be programmable for multiple missions like electronic ground support equipment (EGSE), ground station telemetry receivers, data link receivers, spread spectrum ranging, and tracking receivers
- Include taps to capture data from intermediate stages of receiver to ascertain reception quality
- Incorporate add-on capabilities like real-time spectrum analysis (RTSA) and RF/digital recording
- Be compliant with CCSDS 401.0-B for radio frequency and modulation systems, CCSDS 131.0-B-3 for telemetry (TM) synchronization and channel coding, and CCSDS 131.2-B-1 for high-rate TM applications
- Integrate with third-party data link layer and network layers to offer a full-spectrum TM Space Data Link service
- Integrate with telecommand transmitter and closed-loop Communications Operation Procedure (COP-1) Automatic Request for Retransmission (ARQ) processing
- Incorporate add-on system interfaces like LVDS, MIL-STD-1553, ARINC 429, Serial RapidIO, Serial FPDP (SFPDP), and GigE / 10 GigE to support data distribution

NI Services and Support

NI offers a variety of solution integration options customized to your application-specific requirements. You can use your own internal integration teams for full system control or leverage the expertise of our worldwide network of Alliance Partners to obtain a turnkey system.

Contact your account manager or call or email us to learn more about how NI can help you increase product quality and accelerate test timelines at (888) 280-7645 or info@ni.com.

NI Services and Support

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- Turnkey Solution Delivery and Support
- Repair and Calibration
- Global Support
- Prototyping and Feasibility Analysis
- Training and Certification

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