N4391C Optical Modulation Analyzer

General Information

The Keysight N4391C Optical Modulation Analyzer (OMA) enables development of the coherent technologies required to advance performance in modern communication systems, such as those found in and connecting data centers. It consists of a Keysight UXR real-time oscilloscope and a calibrated coherent optical receiver. The N4391C builds on the UXR Series oscilloscope's industry-leading noise and bandwidth performance and Keysight's reliable and flexible vector signal analysis (VSA) software.

The N4391C is in a class by itself shipped as a fully calibrated optical modulation analysis system. Out of the box, you can immediately characterize and analyze your coherent interface of choice, with confidence it can support the next development on your roadmap thus simplifying your test equipment decision by protecting investment. While it comes ready to tackle any line side optical measurement, it can also be configured to address the many characterization and measurement processes performed requiring electrical connection by going directly to the oscilloscope's input ports.

Complex modulated signals are common in long-distance transmission across dense wavelength division multiplexing (DWDM) links. However, newly proposed technologies for intra-data center interconnections use the coherent approach in the O-band, addressing higher data throughput with reduced power consumption. Keysight now offers OMA-coherent receivers for the O-band in addition to coherent receivers that work in the C-band and L-band.

KEYSIGHT

Applications

The demand for higher throughput is pushing beyond the 64 Gbaud rolling out now (400ZR) to 120 Gbaud (800ZR & 800LR) and beyond. The Keysight N4391C helps you keep pace with the demand for test equipment that can handle the symbol rate classes of transceivers for 800 Gb/s, 1.2 Tb/s, and 1.6 Tb/s, from early advanced research through the development phase.

Not only are symbol rates increasing but coherent technology offers the prospect of increasing throughput via modulation formats with more bits per symbol. As this implies a lower signal to noise ratio margin, the performance of the test system is of key concern. The UXR oscilloscope's effective number of bits (ENOB) performance of 5.4 enables the N4391C to meet this challenge.

The Keysight N4391C provides operating bandwidth up to 110 GHz and myriad options for selecting modulation formats. Options include support for user-defined modulation formats, all at a high ENOB at highest bandwidths.

Product details

In each C/L-band configuration, the optical coherent receiver is comprised of an internal power monitor, internal C-band LO, LO output and external LO input. The O-band version requires an external LO tunable laser operating in the 1.3 µm band.

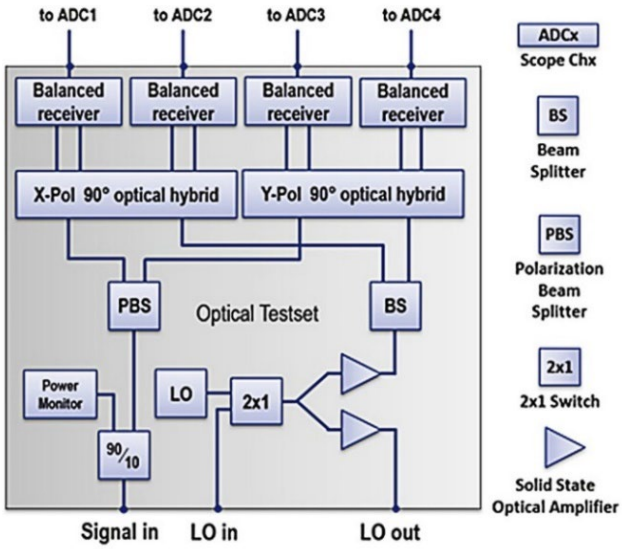

Figure 1. Block diagram of the calibrated coherent optical receiver

Turn-key solution

Compared to the time-consuming and resource-intensive implementation of a home-grown optical modulation analysis solution, the fully integrated N4391C provides a fully specified and reliable test instrument that helps greatly reduce time-to-market. With guaranteed and characteristic specifications right out of the box, Keysight takes responsibility for accurate and reliable test results which can only be achieved with a turn-key solution.

On-site verification and adjustment function

The on-site verification and adjustment function contained in the OMA software enables to verify the performance of a N4391C system and to apply adjustments if necessary. Calibrating the system in its operating environment maximizes system performance and minimizes down-time. Assuming a current oscilloscope calibration, the additionally required equipment comprises a tunable laser source, e.g., N7711A or N7779C, a variable optical attenuator, e.g., N7752C, and a polarization synthesizer, e.g., N7786C, all connected to, and controlled by the N4391C via LAN or USB. The recommended re-calibration cycle is 1 year.

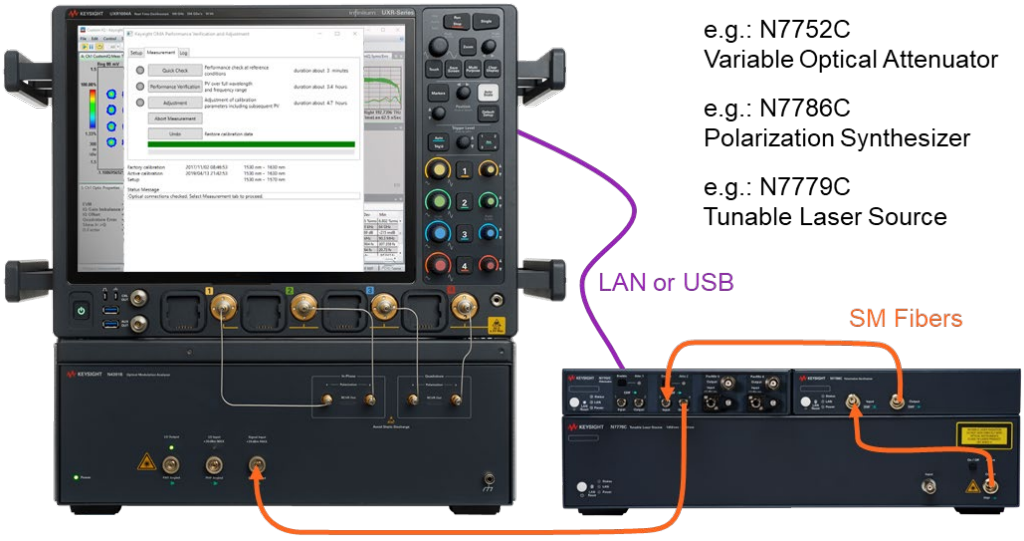

Figure 2. On-site performance verification and adjustment setup

Integrated Coherent Receiver test

Integrated Coherent Receiver (ICR) modules are key components in coherent transmission systems and are more challenging to test than direct-detection Receiver Optical Sub-Assemblies (ROSAs), as the ICRs have phase-sensitive signal detection and provide four electrical outputs and two optical inputs. The test instruments used in ROSA S21 testing cannot be used in a similar way for S-parameter testing of ICRs, making S-parameter testing very challenging.

To help users set up S-parameter tests for ICRs in significantly less time than developing their own solution, the N4391C includes incorporates ICR test software that measures:

- S21 magnitude responses
- IQ skew, XY skew
- IQ angle
- IQ and XY gain imbalance
- EVM noise floor
- Image suppression

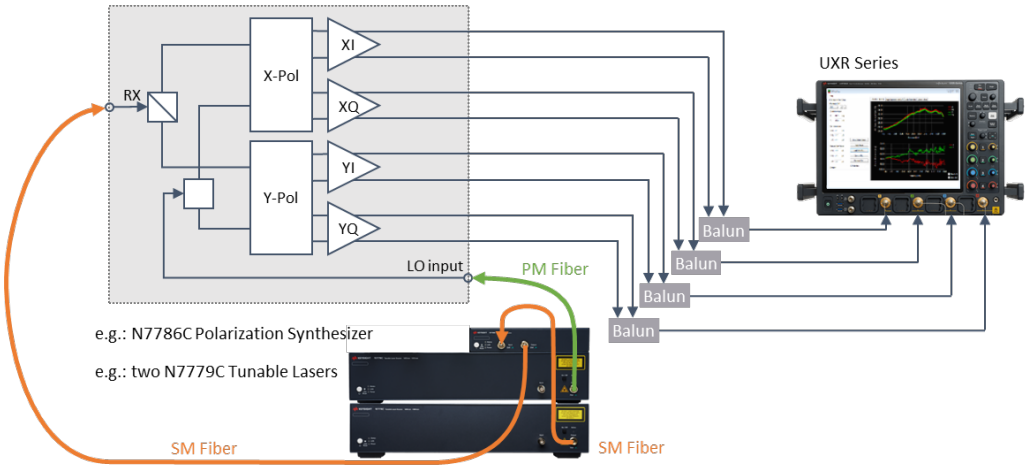

Figure 3. Test setup for an integrated coherent receiver

Coherent optical device test function

Coherent optical devices such as dual-polarization IQ modulators and intradyne coherent receivers must be tested in their different development stages and qualified by the system integrators.

The coherent optical device test function of the OMA software forms a turn-key solution for the characterization of these devices. One user interface provides control of all instruments, i.e., an Arbitrary Waveform Generator (AWG), the OMA, and in case of Rx devices, a polarization synthesizer, through a single software package. With one DUT connection you can get everything done, which saves test time, and reduces the uncertainty introduced by connecting and reconnecting the device. The coherent optical device test function provides:

- S21 magnitude and phase responses
    - IQ skew, XY skew

The setup can be customized in three different ways for transmit device testing, receive device testing and sequential testing of both, transmit and receive devices. Furthermore, it can be extended to perform system-level tests as well as wavelength and power calibration of the laser.

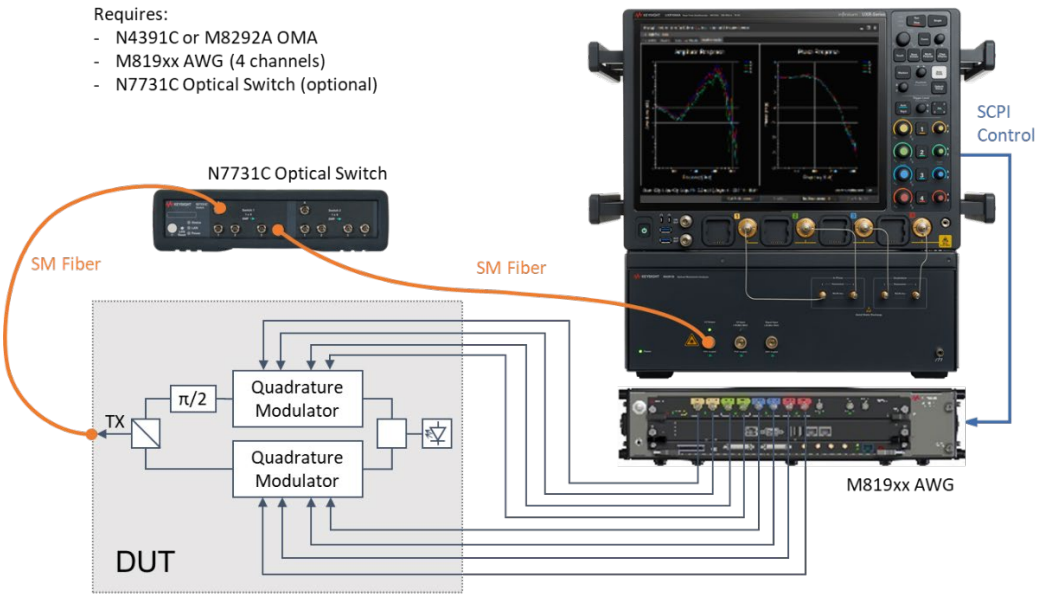

Figure 4. Test setup for a coherent optical transmitter

Select from two oscilloscope RF connector types

The N4391C comes in two configurations based on the RF connector type of the UXR oscilloscope: 1.85 mm and 1.0 mm. In either case, the optical coherent receiver has the connector type matching to the respective oscilloscope and internal hardware appropriate for the highest bandwidth offered as per connector type. It offers C/L-band and O-band variants with factory calibration up to 70 GHz in combination with the 1.85 mm UXR oscilloscope and a C/L-Band variant with factory calibration up to 110 GHz in combination with the 1.0 mm UXR oscilloscope. The OMA system is field upgradable from the purchased frequency up to maximum frequency.

Introducing with the new N4391C OMA, optical and electrical bandwidth licensing for the oscilloscope and the OMA itself is independent and independently upgradable. This scheme recognizes that the oscilloscope works in two use models: as part of the OMA system where optical bandwidth is necessary and in standalone oscilloscope operation (OMA optical front-end disconnected) where electrical bandwidth is key. Because the modes are independent, you can enable what your teams need when they need it.

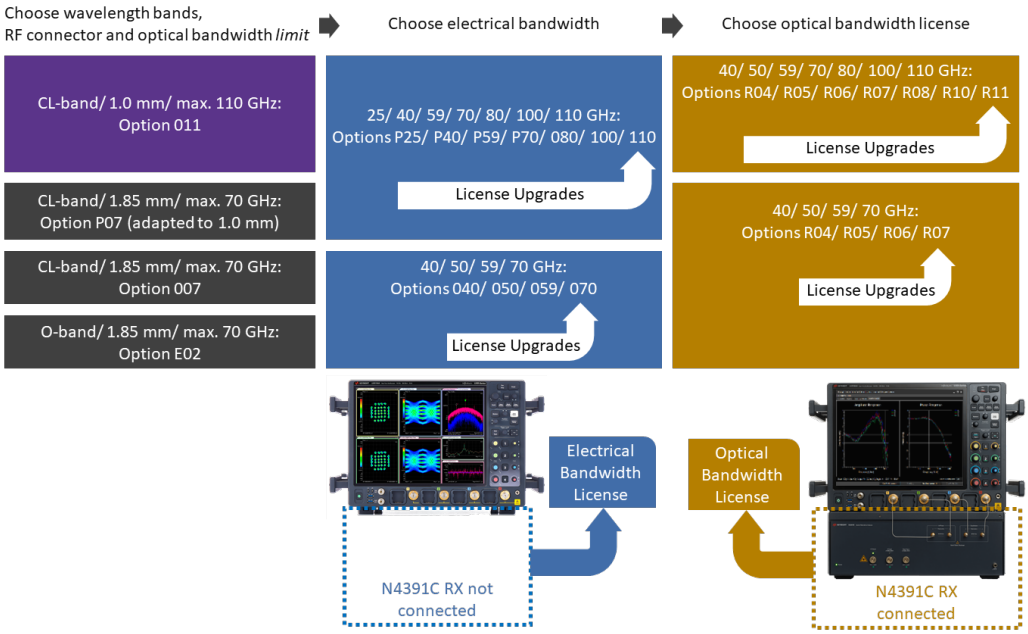

Figure 5. Configuring the Optical Modulation Analyzer to your current and future needs

Each of the N4391C's configurations is upgradable to higher bandwidths for both electrical and optical use models. Configurations based on the 1.85 mm connector can be 40 GHz, 50 GHz, 59 GHz, or 70 GHz, upgradable in these steps to a maximum of 70 GHz. Configurations based on the 1.0 mm connector can be 40 GHz, 59 GHz, 70 GHz, 80 GHz, 100 GHz, or 110 GHz, upgradable in these steps to the maximum 110 GHz.

Specifications

N4391C system specifications

Specification parameter	N4391C-007, N4391C-P07, N4391C-E02	N4391C-011
Maximum detectable symbol rate [1]	140 Gbaud with 70 GHz optical bandwidth license	220 Gbaud with 110 GHz optical bandwidth license
Sample rate	256 GSa/s	
Operating frequency range [1]	DC–40|50|59|70 GHz	DC–40|59|70|80|100|110 GHz
Maximum record length [5]	2 GSa max., 500 MSa standard	
ADC Resolution	10 bits	
Number of 4 channel UXR oscilloscopes	1	
Optical wavelength operating range [4]	1527.60 nm to 1630.0 nm (Options 007, P07) 1270 nm to 1340 nm (Option E02)	1527.60 nm to 1620 nm
Relative skew after correction	Typical < ± 0.5 ps	
Optical phase angle of I-Q mixer after correction	Typical 90° ± 0.5°	
Image suppression [2]	Typical > 35 dB	
EVM Noise floor [2]	Typical < 1.1% at 2.5 GHz Typical < 1.8% at 10 GHz	Typical < 1.5% at 2.5 GHz Typical < 2.3% at 10 GHz
Sensitivity [3]	Typical -20 dBm (using internal LO)	
	Typical -18 dBm (using external LO)	

1. Depending on optical licensing option; max. detectable symbol rate assumes signal with Nyquist pulse shaping being fully captured within the system bandwidth
2. Valid at the following reference conditions
   - Sampling rate 256 GSa/s
   - Optical continuous wave signal at optical input port
   - Signal power > +7.5 dBm, 160 mV range
   - Optical frequency is offset by 2.5/10 GHz from local oscillator frequency
   - Vector analyzer I-Q spectrum span set to 12.5/40 GHz
   - QPSK demodulation
   - 10/40 Gbaud symbol rate
   - PolStokesAlign set to “Single Polarization”
   - KFPhaseTrack with carrier phase variance set to 1E-4
   - Result length set to 500 symbols
   - Raised cosine filter selected as reference filter
   - 25°C ± 5 K environmental temperature
3. Valid at EVM = 32.5% for 32 Gbaud DP-QPSK corresponding to raw BER = 1E-3
4. Access to full wavelength range requires external LO
5. If the licensed bandwidth for optical measurements is higher than the bandwidth for electrical measurements, the following limitations apply:
   - Measurements with more than 499 MSamples memory depth are prevented.
   - The OMA works only with Keysight lasers for external LO. These must be visible in VISA/connection expert. Otherwise, the bandwidth will fall back to the licensed electrical bandwidth.
   - The measurement update rate is significantly reduced.

Absolute Maximum Ratings

Specification parameter	N4391C-007, N4391C-E02, N4391C-P07, N4391C-011
Maximum signal input power	+14 dBm
Maximum signal input power damage level	+20 dBm
External local oscillator maximum input power	+20 dBm

UXR Key Specifications

For details on the Infiniium UXR-Series Oscilloscopes please refer to data sheet 3123-1313.EN

Specification parameter	UXR0404B, UXR0404BP	UXR0504B	UXR0594B, UXR0594BP	UXR0704B, UXR0704BP
Analog input channels	4	4	4	4
Analog -3 dB bandwidth	40 GHz	50 GHz	59 GHz	70 GHz

Specification parameter	UXR0804B	UXR1004B	UXR1104B
Analog input channels	4	4	4
Analog -3 dB bandwidth	80 GHz	100 GHz	110 GHz

N4391C Optical Receiver Specifications

General parameters	N4391C-007, N4391C-P07	N4391C-E02	N4391C-011
Digitally compensated bandwidth [1]	Typical > 70 GHz	Typical > 70 GHz	Typical > 110 GHz
Signal input wavelength range [2]	1527.60 nm to 1630 nm	1270 nm to 1340 nm	1527.60 nm to 1620 nm
Receiver polarization extinction ratio	> 40 dB		
Average input power monitor accuracy	Typical ± 0.5 dB		

Internal Local Oscillator (LO) and LO output	N4391C-007, N4391C-P07, N4391C-011
Wavelength (frequency) range	1527.6 nm to 1570.0 nm (196.25 THz to 190.95 THz)
Absolute wavelength uncertainty	Typical ± 22 pm
Frequency resolution	100 MHz (0.8 pm at 1550 nm)
Linewidth	Typical < 100 kHz
Sidemode suppression ratio	Typical > 50 dB
RIN	Typical -145 dB/Hz (10 MHz to 40 GHz)
Wavelength settling time	Typical < 30 s
Optical CW output power	Typical > +14 dBm (at 1550 nm)
	Typical > +12 dBm (full wavelength range)

Local Oscillator input	N4391C-007, N4391C-P07, N4391C-011	N4391C-E02
External local oscillator input power range	0 dBm to +14 dBm	0 dBm to +14 dBm
Small signal gain, external laser input to local oscillator output	Typical 27 dB at 1550 nm and –20 dBm LO input power	n/a
Saturation output power at –3 dB compression	Typical +15 dBm	n/a

1. Maximum correction 10 dB.
2. Access to full wavelength range requires external LO.

General Characteristics

	N4391C-007, N4391C-E02, N4391C-P07, N4391C-011
Dimensions (wide x height x deep)	
Oscilloscope	43.5 cm (17.1") x 31,1 cm (12.24") x 56.1 cm (22.05")
Optical Coherent Receiver	43.1 cm (17”) x 17 cm (6.7”) x 55.2 cm (21.7”)
Complete Instrument	53 cm (20.9”) x 48 cm (18.9”) x 55.2 cm (21.8”)
Weight	
Oscilloscope	40.8 kg (90 lbs)
Optical Coherent Receiver	11.2 kg (24.7 lbs)
Environmental	
Storage temperature range	–40° C to +70° C
Operating temperature range	+5° C to +35° C
Humidity	15% to 80% relative humidity, non-condensing
Operating altitude	0 to 2000 m
Power	
UXR Oscilloscope voltage	220V AC, 50 to 60 Hz
Power	2615 VA
Optical Receiver voltage	100 to 240V AC, 50 to 60 Hz
Power	300 VA
Safety designed to and tested to	IEC61010-1, UL61010, CSA22.2 61010.1
EMC tested to	IEC61326-1
Warm-up time	30 minutes
Recommended re-calibration interval	1 year

Explanation of Terms

Operating frequency range

The operating frequency range is the frequency range of corrected signal spectral components by de-embedding for frequency and relative phase characteristics of the individual hardware.

Sensitivity

The sensitivity limit corresponds to the received signal Power at the input interface for which a 32 Gbaud DP-QPSK signal exhibits an EVM of 32.5% or less. An EVM of 32.5% corresponds to a BER of 1E-3 for assumed Additive White Gaussian Noise (AWGN).

Ordering Information for New Product

1) Configure system setup

N4391C-007	Coherent Receiver, 1.85 mm (max. 70 GHz) incl. one license for OMA software
N4391C-E02	Coherent Receiver, 1.85 mm (max. 70 GHz, 1310 nm) incl. one license for OMA software, requires external O-band tunable laser
N4391C-P07	Coherent Receiver, 1.85 mm (max. 70 GHz), adapted to 1 mm, incl. one license for OMA software
N4391C-011	Coherent Receiver, 1 mm (max. 110 GHz) incl. one license for OMA software
Select coherent receiver optical bandwidth option [1]	
N4391C-04R [1]	Coherent receiver optical bandwidth 40 GHz
N4391C-05R [1]	Coherent receiver optical bandwidth 50 GHz
N4391C-06R [1]	Coherent receiver optical bandwidth 59 GHz
N4391C-07R [1]	Coherent receiver optical bandwidth 70 GHz
N4391C-08R [1]	Coherent receiver optical bandwidth 80 GHz (requires option 011, 1 mm)
N4391C-10R [1]	Coherent receiver optical bandwidth 100 GHz (requires option 011, 1 mm)
N4391C-11R [1]	Coherent receiver optical bandwidth 110 GHz (requires option 011, 1 mm)
Select one of these UXR oscilloscopes or integration option together with N4391C-007 or N4391C-E02	
N4391C-040	Infiniium UXR0404B Real-Time Oscilloscope, 40 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.85 mm
N4391C-050	Infiniium UXR0504B Real-Time Oscilloscope, 50 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.85 mm
N4391C-059	Infiniium UXR0594B Real-Time Oscilloscope, 59 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.85 mm
N4391C-070	Infiniium UXR0704B Real-Time Oscilloscope, 70 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.85 mm
N4391C-M00	Integration of customer owned UXR0404, UXR0504, UXR0594 or UXR0704 Oscilloscope
Select one of these UXR oscilloscopes or integration option together with N4391C-P07 or N4391C-011	
N4391C-P25	Infiniium UXR0254BP Real-Time Oscilloscope, 25 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.0 mm
N4391C-P40	Infiniium UXR0404BP Real-Time Oscilloscope, 40 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.0 mm
N4391C-P59	Infiniium UXR0594BP Real-Time Oscilloscope, 59 GHz, 256 GSa/s, 4 Ch, 200 MSa/Ch, 1.0 mm
N4391C-P70	Infiniium UXR0704BP Real-Time Oscilloscope, 70 GHz, 256 GSa/s, 4 Ch, 200 MSa/Ch, 1.0 mm
N4391C-080	Infiniium UXR0804B Real-Time Oscilloscope, 80 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.0 mm
N4391C-100	Infiniium UXR1004B Real-Time Oscilloscope, 100 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.0 mm
N4391C-110	Infiniium UXR1104B Real-Time Oscilloscope, 110 GHz, 256 GSa/s, 4Ch, 200 MSa/Ch, 1.0 mm
N4391C-M01	Integration of customer owned UXR0804, UXR1004 or UXR1104 Oscilloscope

Mandatory software	
89601200C	Basic vector signal analysis and hardware connectivity, transportable license
89601AYAC	Digital demodulation analysis incl. Custom IQ, transportable license
N4391EM0C	License for optical modulation analysis and device test
N4391EM2C	License for N4391C optical modulation bandwidth control
2) Optional software	
89601BHFC	Custom OFDM modulation analysis
3) Recommended LO laser source for N4391C-E02	
N7779C-113	Step- Tunable Laser Source, High Power and Low SSE, 1240 – 1380 nm
Accessories	
N4391C-801	Adapter accessory kit for instrument with 1 mm connectors
N4391C-RK1	Rack Mount Kit for N4391C optical modulation analyzer

1. Options N4391C-xxR determine the bandwidth available for optical measurements. The bandwidth available for electrical measurements is determined by the Infiniium UXR Real-Time Oscilloscope. If the licensed bandwidth for optical measurements is higher than the bandwidth for electrical measurements, the following limitations apply:
   - Measurements with more than 499 MSamples memory depth are prevented.
   - The OMA works only with Keysight lasers for external LO. These must be visible in VISA/connection expert. Otherwise, the bandwidth will fall back to the licensed electrical bandwidth.
   - The measurement update rate is significantly reduced.

Ordering Information for Upgrades

1) Configure system setup, select one of the two upgrade options

N4391C-UG1 [1]	Recycle customer's N4391A-110 for N4391C-007 including latest OMA software
N4391C-UG2 [1]	Recycle customer's N4391A-120 for N4391C-007 including latest OMA software
N4391C-UG3 [1]	Recycle customer's N4391A-120 for N4391C-011 including latest OMA software
Select one of these UXR oscilloscopes or integration option together with N4391C-UG1 or UG2	
N4391C-040	Infiniium UXR0404B Real-Time Oscilloscope, 40 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.85 mm
N4391C-050	Infiniium UXR0504B Real-Time Oscilloscope, 50 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.85 mm
N4391C-059	Infiniium UXR0594B Real-Time Oscilloscope, 59 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.85 mm
N4391C-070	Infiniium UXR0704B Real-Time Oscilloscope, 70 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.85 mm
N4391C-M00	Integration of customer owned UXR0404, UXR0504, UXR0594, or UXR0704 Oscilloscope
Select one of these UXR oscilloscopes or integration option together with N4391C-UG3	
N4391C-P25	Infiniium UXR0254BP Real-Time Oscilloscope, 25 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.0 mm
N4391C-P40	Infiniium UXR0404BP Real-Time Oscilloscope, 40 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.0 mm
N4391C-P59	Infiniium UXR0594BP Real-Time Oscilloscope, 59 GHz, 256 GSa/s, 4 Ch, 500 MSa/Ch, 1.0 mm
N4391C-P70	Infiniium UXR0704BP Real-Time Oscilloscope, 70 GHz, 256 GSa/s, 4 Ch, 500 MSa/Ch, 1.0 mm
N4391C-080	Infiniium UXR0804B Real-Time Oscilloscope, 80 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.0 mm
N4391C-100	Infiniium UXR1004B Real-Time Oscilloscope, 100 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.0 mm
N4391C-110	Infiniium UXR1104B Real-Time Oscilloscope, 110 GHz, 256 GSa/s, 4Ch, 500 MSa/Ch, 1.0 mm
N4391C-M01	Integration of customer owned UXR0804, UXR1004 or UXR1104 Oscilloscope
2) Optional software	
89601BHFC	Custom OFDM modulation analysis

Coherent receiver optical bandwidth upgrades

N4391CU	Upgrade of N4391C Optical Modulation Analyzer
N4391CU-U50 [2]	Upgrade coherent receiver optical bandwidth from 40 GHz to 50 GHz
N4391CU-U59 [2]	Upgrade coherent receiver optical bandwidth from 50 GHz to 59 GHz
N4391CU-U70 [2]	Upgrade coherent receiver optical bandwidth from 59 GHz to 70 GHz
N4391CU-U80 [2, 3]	Upgrade coherent receiver optical bandwidth from 70 GHz to 80 GHz
N4391CU-U10 [2, 3]	Upgrade coherent receiver optical bandwidth from 80 GHz to 100 GHz
N4391CU-U11 [2, 3]	Upgrade coherent optical receiver bandwidth from 100 GHz to 110 GHz
Hardware upgrades	
N4391CU-U21 [4]	Upgrade of N4391C-007 to N4391C-011

2. Software licenses will be transferred to the N4391C system.
3. N4391CU-U50/U59/U70/U80/U10/U11 upgrades only the bandwidth available for optical measurements.
   The bandwidth available for electrical measurements is determined by the Infiniium UXR Real-Time Oscilloscope.
   N4391CU-U50/U59/U70/U80/U10/U11 prevents measurements with more than 499 MSamples memory depth.
   With N4391CU-U50/U59/U70/U80/U10/U11, the OMA works only with Keysight lasers for external LO. These must be visible in VISA/connection expert. Otherwise, the bandwidth will fall back to 59 GHz or less, whichever electrical bandwidth is licensed.
   N4391CU-U50/U59/U70/U80/U10/U11 reduces the measurement update rate significantly.
4. N4391CU-U80/U10/U11 require a 1.0 mm optical coherent receiver N4391C-011.
5. Upgrade of optical coherent receiver only. Does not include upgrade of the oscilloscope. Please contact your Keysight representative for details.

Shipping Content (Preliminary)

	N4391C-007, N4391C-E02	N4391C-011, N4391C-P07[1]
1 x Oscilloscope depending on ordered option	UXR0404B/ UXR0504B/ UXR0594B/ UXR0704B	UXR0404BP/ UXR0594BP/ UXR0704BP/ UXR0804B/ UXR1004B/ UXR1104B
1 x Optical coherent receiver		
4 x Rigid RF cable assembly	1.85 mm (m)	1.0 mm (m)
1 x Optical mouse, USB		
1 x 104 key standard keyboard with USB connector		
1 x Quick start guide (English)		
3 x 81000NI Fiber Connector Adapter FC/APC		
1 x Calibration certificate		
1 x Test Data Sheet		
3 x License Certificates OMA and VSA Software (additional Certificates depending on additional ordered software)		
1 x China RoHS Addendum for Photonic Test and Measurement Products		
1 x Cable-Assembly USB-Plug A TO B 4-COND 0.5 m		
1 x Wrench – 2 mm thick dual	6 and 7 mm	
1 x Wrench-Torque	8-in-lb, 5/16 inch	4-in-lb 6 mm
4 x Adapter, Ruggedized Female	1.85 mm	1.0 mm
1 x Wrench-Torque Special Double-end		14 mm-open end 4-in-lb and 10-in-lb
1 x Heel Ground Strap		
1 x ESD MAT Cord		
1 x ESD Warning Sticker Sheet		
1 x China RoHS Addendum for Oscilloscope		
1 x Keysight Safety Leaflet		
1 x Tips for Preventing Damage to Oscilloscopes		
2 x Local Power Cords		

1. Line-side processing limited to 70 GHz with N4391C-P07.

Optical Instruments Online Information

Optical modulation analyzers
www.keysight.com/find/oma

Optical test instruments
www.keysight.com/find/oct

Lightwave component analyzers
www.keysight.com/find/lca

Polarization solutions
www.keysight.com/find/pol

Electro-optical converters
www.keysight.com/find/ref

Optical test instruments accessories
www.keysight.com/comms/oct-accessories

Keysight photonic discussion forum
www.keysight.com/find/photonic_forum