Appendix 03
Manufacturers and Products for Fiber-Optic QKD

1 LuxQuanta

LuxQuanta Technologies S.L., a privately held company, was founded in 2021 as a spin-off of the Institute of Photonic Sciences (ICFO) in Barcelona. The company develops quantum key distribution (QKD) systems with a focus on continuous-variable QKD and positions its NOVA LQ product as Europe's first market-ready CV-QKD system. LuxQuanta has a European ownership structure. Corning and GTD were early industrial investors. In 2024, the company received €2.5 million from the EIC Accelerator program. This was followed in 2025 by a Series A financing round of €8 million, led by Big Sur Ventures and A&G. LuxQuanta is considered one of Europe's leading providers of CV-QKD and is closely involved in EuroQCI programs.

1.1 Nova LQ

As of November 2025, LuxQuanta has exactly one commercial QKD product line called "NOVA LQ." This is a 19"-rack system for fiber-optic QKD, based on CV-QKD. LuxQuanta's devices implement the Gaussian-modulated coherent-state (GMCS) protocol, i.e., a CV-QKD protocol (see Appendix**Fehler! Verweisquelle konnte nicht gefunden werden.**). This requires that, on the receiver's side (at Bob's), the received signal be compared with a reference signal. There is a possibility that this reference signal is already generated by Alice and transmitted together with the quantum signal, which enables certain attacks. LuxQuanta states that it instead uses a true local oscillator at the receiver, which is considered more secure.

Another unique feature of LuxQuanta's devices is that the quantum channel can share the fiber optic cable with other users without being disrupted. The technology required for this is called "DWDM (Dense Wavelength-Division Multiplexing)." Put simply, this means that the quantum channel uses, for example, blue light, while other users transmit red and green light through the same fiber. In reality, however, the wavelengths used are in the infrared range. This technology therefore also makes it possible for the quantum channel and the public classical communication channel to be routed through the same optical fiber.

1.2 Generation 1

The first generation of NOVA LQ was launched in March 2023 and, according to the manufacturer, can bridge distances of up to 40 km over a standard optical fiber, which corresponds to an attenuation of approximately 8 dB. An initial prototype was already in use on a 30-km route prior to the market launch in September 2022. In an interview with a user (see Section 1.3), the following was said about a first-generation LuxQuanta device: "The key rate is approximately 10 kbit/s at 3 dB (corresponding to a distance of approx. 15 km) and 1.4 kbit/s at 5 dB (corresponding to approx. 25 km). The device runs very stably." In comparison with other QKD devices, the device from LuxQuanta was described as very reliable. The acquisition costs were estimated in this survey at "approx. 180,000 euros per link." Unfortunately, official price information could not be found.

Unfortunately, no information on the key rate for Generation 1 devices could be found on the manufacturer's website.

1.3 Generation 2

According to the manufacturer, the second generation, which was launched in March 2025, achieves a range of up to 100 km or a channel attenuation of 20 dB. LuxQuanta states that the second generation achieves a data rate of 100 kbit/s at 4 dB and 1 kbit/s at 16 dB. This corresponds to approximately 100 times the data rate of the first generation.

However, the following should be noted:

- Despite extensive research, no other sources could be found that provide information on the data rate of the second generation. Apparently, nothing had been published on this topic by November 2025.

- It is highly likely that LuxQuanta does not specify the practical final key rate after error correction and privacy amplification on its website, but rather the raw key rate after sifting—that is, before the aforementioned post-processing steps. This assumption is supported by the fact that the manufacturer does not use the terms "secret key rate" or "final key rate" anywhere, as some other manufacturers do.

The manufacturer's specifications are therefore not directly comparable to user experiences, as they most likely pertain to different metrics.

1.4 Standardization

LuxQuanta devices implement the ETSI standardization ETSI-QKD-004/014 intended for QKD, which allows them to be integrated into KMS systems (KMS = Key Management System) alongside devices from other manufacturers that also implement this standard, thereby supporting multi-vendor interoperability.

LuxQuanta even participates in EuroQCI pilot projects that explicitly build ETSI-compliant QKD infrastructures and is listed there as the "European CV-QKD reference system."

2 Quantum Optics Jena (QOJ)

Quantum Optics Jena GmbH (QOJ) is a startup spun off from Fraunhofer IOF in 2020 that develops quantum optical components and entanglement-based QKD systems. In 2024, QOJ secured Series A funding of €8.5 million, led by Join Capital and supported by, among others, the Fraunhofer Technology Transfer Fund and bm|t (the investment fund of the Free State of Thuringia). QOJ offers entanglement-based QKD solutions for fiber-optic networks as well as subsystems for future QKD satellites. In a field test with envia TEL in 2024, the company demonstrated a 60-km QKD connection and describes itself as the only commercial provider of multi-user QKD systems, active in Spain, Austria, Slovakia, and the U.S., among other countries.

2.1 Elvis QKD Systems: Technology and Protocols

QOJ markets its fiber-based QKD systems under the name "Elvis." The systems essentially consist of three components:

- An entangled photon pair source with typical pair rates of more than 40–50 million pairs/s (depending on the wavelength). QOJ refers to its source as an "HD source," where "HD" stands for "High Dimensional." This means that the entangled states can utilize more than two dimensions (or degrees of freedom).
- Polarization analysis and control modules ("PAM") with automatic self-calibration and active polarization control; available with SPAD or SNSPD detectors.
- A proprietary protocol implementation ("LLC") explicitly specified as an implementation of a BBM92-based protocol.

Technically, this constitutes a discrete, entanglement-based QKD with polarization encoding and a BBM92-like protocol.

SPAD detectors *(SPAD = Single-Photon Avalanche Diode)* are compact, relatively inexpensive, and easy-to-operate semiconductor single-photon detectors, but they have low efficiency, high noise (and therefore an increased error rate), and a long dead time. (Dead time is the time that must elapse after a measurement before the detector is ready for the next measurement.

SNSPD detectors (SNSPD = Superconducting Nanowire Single-Photon Detector) are superconducting single-photon detectors. They are highly efficient, exhibit low noise, and have short dead times. However, they are expensive to purchase and require cryogenic cooling, which makes operation complex and costly.

2.2 Elvis 800 and Elvis 1500 variants

These two variants differ in the wavelength of the photons used and, as a result, in their application scenarios:

- Elvis 800 is designed for short-range fiber-optic networks up to 8 km in length and for free-space links. Elvis 800 can also be used for satellite QKD and is better suited for laboratory applications.
- Elvis 1500 was developed for use with standard telecommunications fibers, making this variant more suitable for medium- and long-distance fiber-optic links.

2.3 Key rate

The manufacturer specifies a secure key rate of 1500 bit/s for both variants when the attenuation is 10 dB. This 10 dB corresponds to approximately 50 km for a standard optical fiber. The term "Secure Key Rate" suggests that it refers to the final key rate relevant to the user after postprocessing. This manufacturer specification contrasts with a user's statement (see Section 1.3), who reports only about 400 bit/s for the same attenuation. Even with very low attenuation (0 dB, i.e., immediate proximity or a few meters), only about 1000 bit/s could be achieved. Additionally, this interview also noted that more than 10 dB was barely manageable , meaning that the device used was only suitable for distances up to a maximum of approximately 50 km.

A 2022 publication by the Fraunhofer Institute reported that over a distance of approximately 70 km, more than 300,000 AES keys of 256 bits each were generated in 10 days, corresponding to a key rate of just under 90 bit/s, and the CEO of QOJ (Kevin Füchsel) stated that approximately 300 bits/s were achieved in the laboratory under comparable attenuation conditions.[1]

The sources cited are directly or indirectly linked to the manufacturer and provide values that are significantly below the official manufacturer specification of 1500 bits/s, but they are also clearly above the cited individual user report.

Although additional sources were found that mention the use of QOJ devices, concrete details regarding the key rate are consistently missing.

The Q-net-Q Consortium (a research network funded by the German Federal Ministry of Education and Research [BMBF] that is establishing a nationwide quantum communication test network in Thuringia) explicitly describes the 70-km connection using the Elvis system as the limit of what is currently possible with this class of devices.

The experience report gathered in the interview also described that the device used functioned largely stably, but a software issue with the receiver unit was also reported, which is difficult to assess without reports from other users. The clear and exemplary graphical user interface was highlighted as a positive feature. Among other things, this web interface displays the number of 256-bit keys in the ETSI key pool.

2.4 Costs

The acquisition costs were stated in the case study as "approx. 250,000 euros per link." Official price information could not be found. Nor could any other relevant information from other sources be found.

[1] https://www.iof.fraunhofer.de/en/pressrelease/2022/quantum-keys-exchange-successful.html

2.5 Standardization and KMS Integration

QOJ is strongly involved in ETSI activities related to QKD standardization, both technically and organizationally (including participation in the ETSI QKD working group). At the product level, the following is particularly relevant:

The Elvis software explicitly supports the ETSI API GS QKD 014 and the SKIP protocol.

The QKD-KMS of the AIT (Austrian Institute of Technology) lists QOJ as a tested and integrated QKD manufacturer for its ETSI-014-compatible KMS interface, alongside several other providers (LuxQuanta, IDQ, KEEQuant, Think Quantum, Q*Bird, QTI, and others).

This classifies QOJ, similar to LuxQuanta, as an ETSI-compliant QKD provider with multi-vendor KMS compatibility.

3 ThinkQuantum

ThinkQuantum Srl is a spin-off of the University of Padua founded in 2021 and based in Sarcedo (Province of Vicenza, Italy). The company develops QKD systems and quantum random number generators and, according to its own statements, covers the entire value chain from design and manufacturing to commissioning. ThinkQuantum emphasizes a fully European ownership structure and a close partnership with the optics company Officina Stellare, which primarily contributes optomechanical expertise and space experience.

3.1 QUKY Platform: Technology and Protocol

ThinkQuantum's fiber- and free-space-based QKD product line is called QUKY. The platform consists of a transmitter (QUKY-TX, "Alice") and a receiver (QUKY-RX, "Bob"). Technically, it is a discrete, polarization-encoded BB84 QKD:

- Protocol: 3-state BB84 with a decoy state ("3-state 1-decoy BB84"), which is secure against general attacks.
- Encoding: Polarization of the photons implemented using the patented IPOGNAC polarization encoder, which is designed to enable high thermal and mechanical stability as well as a very low intrinsic quantum error rate.
- Randomness: A very fast QRNG (Quantum Random Number Generator) is integrated into each transmitter; all state and basis selections are fed

directly from this "QRN2Qubit" stream (without pseudo-random expansion).

- Synchronization: Using Qubit4Sync, synchronization is handled directly via the quantum signals; a separate synchronization channel is not required. As a result, a single simplex fiber between Alice and Bob is sufficient.

QUKY is designed for fiber-optic, free-space, and future satellite links. The systems operate either in the C-band or O-band; if necessary, the quantum signal channel can coexist with classical data traffic on the same fiber using DWDM.

3.2 Variants and manufacturer specifications regarding performance

According to the official QUKY brochure, there are several configurations:

- **Standard**: The typical secret key rate is specified as 2.2 kb/s at 13 dB attenuation, which, given the typical attenuation in fiber optics of approximately 0.2 dB per km, can be interpreted as a distance of approximately 65 km. The maximum channel attenuation is stated as 20 dB. (This can be interpreted as a maximum fiber length of 100 km.)
- **Premium**: The typical secret key rate is specified as 4.4 kb/s at 13 dB (corresponding to 65 km), and the maximum channel attenuation as 24 dB (corresponding to 120 km)
- **SNSPD variant / external detector**: typical secret key rate: 18 kb/s at 13 dB, and maximum channel attenuation: "at least 33 dB" (corresponding to 165 km) "and beyond." This variant promises customer-specific solutions.

In addition, ThinkQuantum offers a "Research & Education" configuration for its devices, in which internal parameters are accessible and raw keys can be exported.

The brochure explicitly refers to the "Secret Key Rate" and also specifies a security parameter of 10^{-15} for key lengths of 10^7 bits. This is a strong indication that this is the final key rate after error correction and privacy amplification, and not a raw sifted key rate.

3.3 Published Field Tests and Long-Term Experience

Several scientific papers from the Padua group and partners describe field tests with QUKY platforms from ThinkQuantum:

- In an in-field study on the coexistence of QKD and classical data traffic in a 13-km metropolitan network (attenuation ~6.7 dB), an average secret key rate of approximately 1.7 kb/s over 24 hours is reported using a commercial, polarization-based QUKY system; in a variant with modified wavelengths, the average rates are 680 b/s and 480 b/s, respectively.
- Further experiments report on free-space links ranging from a few hundred meters to about 600 m, sometimes combined with several kilometers of fiber optic cable. For a 230-m free-space link plus 4 km of fiber in the Vienna testbed, an average secret key rate of ~600 b/s (even in rain) is reported; in an intermodal demonstration with 600 m of free space + 500 m of fiber, rates of up to 4 kb/s are achieved.

While other publications report specific key rates, they do not mention either the bridged distance or the attenuation, which is why these results are not reproduced here.

A field report by a European research team stated that a ThinkQuantum system was even used with channel attenuation of up to 25 dB, which roughly corresponds to the maximum value of the premium variant, but more likely to a custom solution. With this configuration, a key rate of 5.4 kbit/s was achieved at 10 dB (corresponding to approx. 50 km of fiber optic cable), and 7 kbit/s at 3 dB (approx. 15 km of fiber optic cable). These rates are significantly **higher** than the typical manufacturer specifications for the standard and premium configurations at 13 dB (2.2 and 4.4 kb/s, respectively), but are entirely realistic if a premium or SNSPD setup was used, or if the figures represent short-term maximum values rather than long-term averages.

Overall, this work demonstrates that QUKY systems in realistic networks—with the coexistence of conventional data, DWDM, and sometimes challenging weather and channel conditions—achieve secret key rates ranging from several hundred bit/s to several kbit/s at attenuations in the range of approximately 6–12 dB. The values are in the expected range of the manufacturers' specifications, but mostly slightly below them, which is typical for long-term averages in practical setups.

3.4 Further details from the individual report

It was reported that the ThinkQuantum device was able to bridge the greatest distance among all tested devices, but it was also reported that most problems occurred in this particular case. The detector failed several times and had to be repaired. There were also software issues that could be circumvented by a reboot, but this could only be initiated on-site at the device and could not be resolved via a remote connection. However, this individual report is contrasted by several publications of field trials with ThinkQuantum devices in which no such problems were mentioned. There are even reports describing operation lasting several days, and even several months, without serious failures. This discrepancy suggests that reliability may depend heavily on the specific device model, the detectors used, and the software version.

Additionally, the report mentions a free-space link of approximately 200 m, which fits well within the range of published free-space demonstrations (200–600 m and beyond).

3.5 Costs

In the interview, the acquisition costs were stated as approximately €180,000 per link (Alice+Bob). No official price lists or verifiable data from other sources could be found; the figure cited is in the same order of magnitude as other commercial DV-QKD systems, but must be understood as an informal estimate by a user and not as a list price.

3.6 Standardization, Integration, and Interoperability

ThinkQuantum explicitly positions QUKY as an ETSI-compliant QKD platform:

- Supported interfaces: ETSI GS QKD 004 (Key Delivery Interface) and ETSI GS QKD 014 (QKD API); additional proprietary interfaces are available upon request.
- QUKY includes an integrated key management system that supports point-to-point, ring, star, and relay topologies and is specifically designed for multi-node and multi-user operation with optical switches (a single Bob can serve multiple Alices in sequence).
- According to GEANT slides, QUKY has been integrated with HSMs (see Chapter**Fehler! Verweisquelle konnte nicht gefunden werden.**) from various manufacturers (including ADVA, Rohde & Schwarz, Cisco, and Thales) and operated in multi-vendor QKD networks as part of European testbeds alongside systems from ID Quantique, KEEQuant, and QTI.

This makes ThinkQuantum one of the providers offering ETSI-compliant QKD devices with integrated KMS functionality and proven multi-vendor interoperability. In terms of structure and positioning, QUKY thus fits well alongside the previously described systems from LuxQuanta and Quanten Optics Jena: a European DV-QKD provider with strong academic roots, solid ties to standardization, and a practical focus on network integration.

4 KeeQuant

KeeQuant GmbH is a startup founded in 2020 and headquartered in Fürth (Bavaria, Germany). The company is wholly owned by EU-27 entities and builds on research experience from, among others, FAU Erlangen-Nürnberg and the Max Planck Institute for the Physics of Light. KeeQuant positions itself as a European provider of quantum-secure communication with a focus on continuous-variable QKD (CV-QKD) based on established coherent telecommunications technology and integrated photonics. In addition to QKD systems, KeeQuant also develops its own key management systems (KMS) and is involved in numerous European projects (including OPENQKD, DemoQuanDT, QCI-CAT, and SEQRET).

4.1 Andariel Testbed Series: Technology and Protocol

KeeQuant's current flagship QKD product is the Andariel Testbed Series, a fiber-based CV-QKD system. Andariel consists of a transmitter module "Alice" and a receiver module "Bob." Each module is divided into two submodules (an electro-optical section and a post-processing unit).

Technologically, it is a CV-QKD system using Gaussian-modulated coherent states (GMCS):

- The quantum states are generated as coherent states in the C-band (1530–1560 nm); information encoding is performed via continuous quadrature (amplitude/phase) modulation, with GMCS modulation and options such as QPSK/QAM for various operating modes.
- Detection is performed using coherent CV detection in an LLO (Local Local Oscillator) configuration, i.e., the local oscillator is not transmitted over the fiber but is located locally in the Bob module; both polarizations (TE/TM) are read out.
- The system requires a single dark fiber for the quantum signal channel; classical signals for the protocol run over the Ethernet interfaces. According to the datasheet, coexistence with classical data traffic on the same fiber still needs to be developed (quotes from the relevant section in the datasheet: "tbd" and "not specified") and would need to be clarified on a case-by-case basis for each specific project.

Andariel is explicitly designated as a "Testbed Series": The system is fully functional but is not certified or hardened as a product for the protection of classified or highly critical information. It is primarily intended for setting up and testing network infrastructures, KMS interfaces, HSMs, and other components in realistic test environments. In this regard, KeeQuant differs from many other manufacturers only in that KeeQuant communicates this clearly and publicly.

In fact, not a single manufacturer holds a certificate that is valid in Europe. Only ID Quantique (see next section) can claim to have obtained at least one national certificate in South Korea.

4.2 Manufacturer specifications regarding key rate and range

The official data sheet (version 2025-09-26) lists the following specifications for Andariel:

- **Maximum tolerable channel attenuation**: 16 dB on the quantum signal channel, which, using the standard realistic conversion factor (approx. 0.2 dB/km), can be interpreted as a distance of approximately 80 km of standard optical fiber. Regarding higher attenuations (more than 20 dB), it is stated that corresponding products are "under development."
- **Secret Key Rate**: Here, 10 kbit/s is given as a "non-binding guideline." The term "Secret Key Rate" is explicitly used; this strongly suggests that this is the final key rate after error correction and privacy amplification, not a raw sifted key rate.

An earlier set of slides (GEANT presentation 2023) formulates the development goal for Andariel as "more than 10 kbit/s at 10 dB" and "more than 16 dB range." In blog posts by KeeQuant, the transition from previously shorter ranges to the specified 16-dB range is explicitly highlighted as a technological milestone; at the same time, it is noted that the next step is toward certification and further miniaturization (PIC-based integration).

4.3 Field Reports

In an interview (see Method 3 in Section 1.3), the following was described:

- **Attenuation/Range**: According to the team, in practical use, channel attenuation of up to about 10 dB was perceived as a reasonably usable range; higher attenuation levels were not systematically utilized in the specific setup. The discrepancy from the 16 dB specified in the datasheet may be due to issues in the specific implementation.
- **Data rate**: In the team's experimental setup, rates of up to 4 kbit/s were achieved (at high, but unspecified, attenuation). This is clearly below the value listed in the datasheet (10 kbit/s), but still in a comparable range and

may be related to the aforementioned issues in this specific case. In a later operational state, only about 40 bit/s were observed at a fiber length of approximately 1 km; however, the users attribute this to a problem with the fiber-optic link, so this value should be considered an isolated case with no general significance. On the other hand, this specific problem demonstrates that even a minor disruption in the fiber optic cable (e.g., a kink) can quickly put a significant damper on a six-figure euro investment.

- **Reliability**: There was a single instance of hardware failure, which was resolved and had no further consequences.
- **Software**: The user interface and device software were described as still immature (teething problems in the early phase of the product lifecycle). The interviewees also reported difficulties in properly configuring the necessary certificates and credentials for the ETSI 014-based interface in the specific project, which can be seen as an indication of a low level of software maturity in the early testbed phase.

Publicly available testbed reports (e.g., KIT test track, CESNET campus network, QCI-CAT demo) suggest that Andariel was operated in several real-world networks over extended periods. The brief reports published there primarily highlight the successful integration into existing networks and dashboards, but do not provide detailed, published key rates, so the interview data mentioned above cannot be systematically compared with independent figures from the literature.

4.4 Costs

In the interview, the acquisition costs for a KeeQuant system were stated as approximately €160,000–180,000 per link (Alice+Bob). Public price lists or reliable data from other sources are not available (as of November 2025); this figure should therefore be understood— , as with other manufacturers—as an informal user estimate, not as an official list price.

4.5 Standardization, KMS Integration, and Certification

In its documentation, KeeQuant emphasizes a strong focus on standardization and interoperability:

- Interfaces: According to the datasheet, Andariel supports the ETSI specifications GS QKD 004 and GS QKD 014 for key provisioning via REST APIs.

- Proprietary KMS: With KMS1, KeeQuant offers its own key management system, which is explicitly advertised as “fully ETSI GS QKD 014-compatible” and supports various network topologies (mesh, star, linear, etc.).
- Interoperability: The AURORA-KMS from the Austrian Institute of Technology (AIT) lists KeeQuant Andariel as a tested, integrated QKD system alongside devices from LuxQuanta, Quantum Optics Jena, ThinkQuantum, ID Quantique, and others, each via the ETSI interfaces 004/014.

5 ID Quantique (IDQ)

ID Quantique SA is a company founded in 2001 and headquartered in Geneva (Switzerland) and is considered one of the pioneers of commercial QKD systems. In addition to QKD systems, IDQ also offers certified quantum random number generators (QRNGs; NIST-ESV-validated chips and FIPS-140-2-compliant HSM integrations via partners), single-photon detectors, and other solutions for quantum-secure communication, and has an international presence with offices in the U.S., Austria, Singapore, and South Korea, among other locations. The company originated as a spin-off from the University of Geneva and has been majority-owned by the South Korean network operator SK Telecom since 2018; strategic minority investors include Deutsche Telekom (Telekom Innovation Pool). In early 2025, an agreement was also reached for the US company IonQ to acquire a majority stake. IDQ products have been in use for several years in government and financial networks in over 60 countries.

The Vienna-based company Nutshell Quantum-Safe GmbH has been a wholly owned subsidiary of IDQ since 2024 and serves as IDQ’s service and support center for the EU market.

The current product family for production-ready QKD applications is the XG series, consisting of Cerberis XG (metro/medium-range QKD) and Clavis XG (long-range/high-rate QKD). In addition, there is a research platform called Clavis XGR.

5.1 XG Series: Technology and Protocols

The XG Series implements discrete, photon-counting QKD (Discrete Variable QKD, DV-QKD) using two different protocols:

5.1.1 Cerberis XG

- Protocol: COW (Coherent One-Way).
- Intended use: Metro and data center connections with medium range. (According to the Austrian subsidiary Nutshell: "short/medium range")
- Intrinsically polarization-independent optical engine, operating at standard telecommunications wavelengths (O-band or C-band) with a dedicated quantum signal channel (simplex fiber) and a service channel in the C-band; dark fiber is recommended, and O-band multiplexing on a single fiber is also offered as an option (DWDM coexistence).
- Integrated QRNG chip as a random source.

5.1.2 Clavis XG

- Protocol: BB84 with two decoy states.
- Application: high key rates over long backbone links. (Nutshell: "long range")
- Typical configuration: Operation in the C-band over dark fiber; configurations with a range of up to 150 km are available as an option.
- Integrated key management functionality.

Both systems are designed so that key management, monitoring, and network integration are already embedded in the device; they are typically operated as an overlay to existing Layer 1/2/3 HSMs.

5.2 Manufacturer specifications for range and key rate

5.2.1 Cerberis XG (COW-DV-QKD)

The official Cerberis XG datasheet lists the following parameters:

- **Maximum channel loss / range:** 12 dB or 60 km. Optional 16 dB / 80 km and also 18 dB / 90 km
- **Secret key rate** at 12 dB (60 km): "28,000 AES-256 keys per hour" (equivalent to 2.0 kbit/s). At 18 dB (90 km): "14,000 AES-256 keys per hour" (equivalent to 1.0 kbit/s).

The datasheet explicitly refers to these values as the "secret key rate." This is a strong indication that this is the final key rate after error correction and privacy amplification, and not a raw sifted key rate.

5.2.2 Clavis XG (BB84-DV-QKD)

For Clavis XG, the following key figures are derived from the current datasheet and the XG product page:

- **Maximum channel attenuation / range:** 18 dB / 90 km. Optional 24 dB / 120 km and 30 dB / 150 km
- **Secret key rate** at 24 dB (120 km): "14,000 AES-256 keys per hour" (equivalent to 1.0 kbit/s).

In addition to the commercial products mentioned, IDQ also offers the Clavis XGR, which is specifically tailored to the needs of research groups. This means open access to internal parameters and interfaces, but consequently makes it unsuitable for high-security production environments. In a brochure, IDQ advertises that Clavis XGR can achieve up to 400 kbit/s at 12 dB (corresponding to approx. 60 km), and that 400 bit/s is still possible at 40 dB (corresponding to approx. 200 km).

5.3 Practical experience from an interview

The interviewee did not name the specific product, but only the manufacturer IDQ. Comparing the statement that the product can be used at up to 16 dB with the values from the data sheets suggests that Cerberis XG was used. It was also added that IDQ offers a solution for up to 30 dB, but that it would be very expensive. This optional, unselected solution most likely refers to Clavis XG. The following statements therefore very likely refer to **Cerberis XG.**

The user (see Section 1.3) used the device at channel attenuations of 13–16 dB, which can be interpreted as a distance of 65–80 km for standard fiber-optic cables. The device was in use for 3 months and, according to the user (see Section 1.3), performed poorly at shorter distances, though this could also be due to other issues with the IDQ hardware. At the aforementioned distance, a key rate of "up to 2.2 kbit/s" was achieved; however, the key rate fluctuated significantly during the 3-month operational period.

Apart from the fluctuating key rate and its poor performance on short-range connections, no other issues were reported. The device operated stably.

The purchase price was reported to be approximately 130,000 to 140,000 euros. This figure is an informal estimate provided by a single buyer. IDQ or its subsidiary Nutshell have not made any official price lists available. No other sources for purchase prices were found.

5.4 Published field tests and long-term operation

- **SwissQuantum network.** An EU report on the SwissQuantum network describes several IDQ QKD links ranging from 3.7 km to 17.1 km (2.5–5.3 dB attenuation). Over ten months of continuous operation, approximately 300,000 to 800,000 AES-256 keys were distributed daily; corresponding to secret key rates of approximately 0.9 kbit/s to 2.4 kbit/s, with relatively low attenuation. Although an earlier generation of equipment was used here, the orders of magnitude of the key rates are well in line with today's XG specifications.
- **100-Gbps IPsec VPN over 46 km (Clavis XGR).** In a field test published by JPMorgan Chase in 2024, two data centers in Singapore were connected via 46 km of telecom fiber (loss approx. 11.15 dB) using a Clavis XGR system. An average secret key rate of 7.4 kbit/s was achieved over 45 days with high stability; the keys were transferred to next-generation firewalls via the standardized ETSI QKD-014 API to feed 100-Gbps IPsec tunnels. Even though XGR is a research variant, this experiment demonstrates that IDQ systems can deliver a secret key rate of several kbit/s over weeks in real-world networks with attenuation levels of 10–12 dB, which is significantly higher than the specifications listed in the datasheets of systems intended for production use.
- **IDQ itself reports** on large-scale networks, such as a nationwide quantum-secure network in South Korea (approx. 800 km of fiber optic cable, 48 government organizations) and the NQSN+ project in Singapore, where XG systems with Clarion KX-KMS are being deplo . These references are primarily intended to highlight operational experience and interoperability; however, detailed public figures on key rates and distance could not be found there.

5.5 Standardization, KMS, and Certification

IDQ emphasizes the integration of the XG series into a standardized QKD infrastructure.

- **Key Management & Monitoring.** The XG devices integrate the Clarion KX QKD management and monitoring platform and the Quantum Management System (QNET QMS). Clarion KX implements current SDN-QKD-ETSI standards, in particular the REST API ETSI GS QKD 014 for key provisioning, and offers interfaces to classic HSMs from major manufacturers (see chapter**Fehler! Verweisquelle konnte nicht gefunden werden.**).

- **Interoperability.** The XG series is specifically designed for interoperability with common Layer 1/2/3 HSMs (OTN, Ethernet, IPsec). To this end, IDQ collaborates with several manufacturers and utilizes standardized and proprietary interfaces (e.g., the SKIP protocol for Cisco HSMs).
- **National security certification in South Korea.** In 2025, the Clavis XG series was officially certified by the South Korean National Intelligence Service (NIS) as the world's first QKD product for national security applications. The evaluation covered both the QKD system and the embedded KMS (Clarion KX) and was conducted in collaboration with NSR, KRISS, TTA, and the IT Security Certification Center (ITSCC, Common Criteria Body). While this certification is not a global standard, it demonstrates that formal security assessments for QKD systems are already being established, at least at the national level.

6 Quantum Telecommunications Italy (QTI)

QTI s.r.l. (Quantum Telecommunications Italy) is a spin-off of the Italian National Institute of Optics of the National Research Council (INO-CNR) founded in 2020 and headquartered in Florence. QTI describes itself as Italy's first QKD company and develops industry-ready systems and components for quantum key distribution and quantum communication networks. In 2021, Telsy, the security and cryptography subsidiary of the TIM Group, acquired a strategic minority stake, and QTI is officially listed as a subsidiary of Telsy, the security and cryptography center of excellence within the TIM Group. (The TIM Group is a publicly traded company headquartered in Rome. The largest single shareholder is the majority state-controlled Poste Italiane, with approximately 24.8% of the shares.) QTI emphasizes a European supply chain and explicitly positions its products for critical infrastructure, financial, and government networks.

6.1 Quell-X Platform: Technology and Protocol

QTI's current QKD product line is called "Quell-X" and comprises three variants: Quell-X (pure QKD system), Quell-XC (QKD + integrated Telsy HSMs), and Quell-XR (research platform with raw key access). Technically, it is a discrete, photon-counting QKD system (DV-QKD) with time-binary BB84 encoding and decoy states.

Quell-X operates with a simplex single-mode fiber as a quantum channel in the C or O band. The classical channel is routed via a separate Ethernet connection.

6.2 Manufacturer specifications regarding range and key rate

The Quell-X data sheet from March 2025 lists the following specifications:

- **Channel attenuation**: up to 30 dB (corresponding to approx. 150 km)
- **Secret key rate:** 2.4 kbit/s at 10 dB (50 km), 1.7 kbit/s at 20 dB (100 km), 500 bit/s at 25 dB (125 km), and 150 bit/s at 30 dB (150 km)

The datasheet explicitly refers to the "secret key rate," which suggests that the figure refers to the final secret key rate after error correction and privacy amplification, rather than a raw sifted key rate. It is noted as an additional point that the research version, Source-XR, also allows access to raw keys (prior to post-processing).

The manufacturer also emphasizes that the system is designed for point-to-point connections, trusted node chains, and complex topologies (ring, star, SDN-controlled networks) and can be integrated into C- and O-band infrastructures.

6.3 Independent measurements and field tests

A particularly meaningful independent evaluation comes from the European Commission's Joint Research Centre (JRC), which tested a Source-X system including a Key Management Entity (KME). Both laboratory back-to-back measurements and field tests were conducted there using a campus fiber with a loopback configuration.

- **Back-to-back measurements (laboratory):** Attenuation was adjusted from 0 dB to 20 dB using a variable optical attenuator. For attenuations between 5 dB and 20 dB, the measured secret key rate dropped from approximately 2.2 kbit/s to around 1.2 kbit/s. At 0 dB attenuation, the system exhibited atypical behavior: the internal estimation of channel attenuation deviated by several dB from the actual attenuation, and the operating parameters fluctuated significantly. The JRC therefore recommends using an additional attenuator for very short, nearly lossless connections to achieve a stable operating range.
- **Field tests on the JRC campus fiber:** An approximately 600-meter-long single-mode fiber was used in a loopback configuration (round-trip), with a measured baseline attenuation of about 3 dB; additional attenuation was

emulated using the same attenuator. For an additional 5–15 dB (i.e., a total attenuation of approximately 8–18 dB), the secret key rate dropped from approximately 2.6 kbit/s to around 1.7 kbit/s. Again, anomalies were observed at very low and very high total attenuation levels. The system's internal attenuation estimation became inaccurate, though this did not lead to clear security issues.

- In summary, the JRC arrives at the following conclusion: The tested Source-X system is operable at attenuations up to about 20 dB, which in realistic networks corresponds to approximately 100 km of fiber with 0.2 dB/km. The observed secret key rate in this range is around 2.5–2.6 kbit/s; Values in the range of 1–2 kbit/s at 14–18 dB are typical and comparable to other commercial DV-QKD systems based on weak coherent pulses. Over the test period, the system was described as stable and unremarkable in terms of hardware; a single, non-reproducible interruption of the GUI connection occurred, which was resolved by a restart.

Quell-X is also being used in several European pilot projects, including the EQUO project (EuroQCI Industry Consortium) in a metro testbed in Tel Aviv with an approximately 15-km dark fiber link between two data centers, where Quell-X keys are delivered via ETSI-014 to Telsy HSMs (MusaX).

Further field trials, including those with Sparkle and Telsy in Athens and Lisbon, demonstrate integration into existing networks, including sections on submarine fibers. However, they do not provide publicly detailed key rates.

In a single report by a research team—for which there is no official confirmation—it is stated that a QTI system was operated at a channel loss of 30 dB, corresponding to a distance of 150 km. A maximum key rate of 2.5 kbit/s was achieved, which roughly matches the manufacturer's specifications. Criticisms were raised regarding key management issues (key export), which aligns with an observation from the previously mentioned JRC study. That study notes that the management and reconfiguration of parameters essentially occur only during installation by the manufacturer and leave users with little leeway later on. Monitoring functions are available, but flexible end-user configuration is not provided for. There are no known reports of technical problems with the actual QKD components. Taken together, this suggests that difficulties may lie primarily in the KME connection and in the operation/monitoring concept, rather than in the actual QKD protocol.

6.4 Costs

The acquisition costs were reported by the user (see Section 1.3) as approximately €200,000 per link (Alice+Bob). Official price lists or independent confirmations of this are not publicly available. However, the figure is in the same range as other DV-QKD systems of comparable performance and is an informal user estimate from a single customer.

6.5 Standardization, KMS Integration, and Interoperability

QTI places great emphasis on standardization and network integration:

- **KME / KMS:** In addition to Quell-X, QTI offers its own Key Management Entity (QKME) and SDN control solutions (QSDN). The KME interface supports the REST-based ETSI specification GS QKD 014; the JRC evaluation confirms the use of this interface via HTTPS.
- **ETSI Interfaces and SKIP:** In the EQUO architecture, Quell-X is described as a QKD and KME system that delivers keys to Telsy HSMs (MusaX) via ETSI-014 interfaces and the SKIP protocol.
- **Network integration:** QTI and Telsy demonstrated Quell-X-based encryption in metro networks (e.g., Tel Aviv, Athens, Lisbon) in several pilot projects, in each case with integration into existing Layer 2/3 infrastructures and the use of DWDM-capable telecom systems.

Overall, QTI, with the Quell-X platform, can be classified as a European DV-QKD provider that is closely linked, from a technical standpoint, to standardization activities (ETSI, EuroQCI/EQUO) and industrial partners (Telsy/TIM).

7 Q*Bird

Q*Bird B.V. is a spin-off of QuTech/TU Delft founded in 2022 and based in Delft, the Netherlands. The founding team consists of researchers with many years of experience in the field of quantum communication; together, they have “over 30 years of combined experience.” The company develops MDI-QKD systems for scalable, multi-tenant quantum networks. Ownership structure: Q*Bird is privately held; shareholders include the founders led by CEO Ingrid Romijn, as well as the QDNL Participations Fund (Quantum-Delta-NL Fund), which specializes in quantum technologies, and the Cottonwood Technology Fund, supplemented by the publicly funded regional development agency InnovationQuarter. In 2024, Q*Bird received €2.5 million in seed funding for this purpose. The technology is being used, among other places, in a pilot project at the Port of Rotterdam and is utilized in the BeQCI network for a 132-km MDI-QKD link between Belgium and Luxembourg. Q*Bird is part of the "Quantum Delft" and "Quantum Delta NL" ecosystems and is anchored in the Dutch National Quantum Network.

7.1 Falqon Series: Technology and Protocol

The current product line is called the "Falqon Series." It is specifically designed for multi-user networks and bridging long distances, albeit at comparatively low key rates, and consists of two device types:

- **User Nodes ("End Nodes")**: 19-inch devices with a height of 2U, located at the users' sites.
- **Center Hubs:** central nodes that establish the quantum mechanical coupling between the User Nodes.

Technically, this is a Measurement-Device-Independent QKD (MDI-QKD) system with decoy states:

The User Nodes transmit pulses (typically in the C-band 1530–1580 nm, alternatively the O-band around 1310 nm) via standard single-mode fibers to the Center Hub. The Hub performs a Bell-state measurement (BSM) on the incoming pulses. From the results, any two User Nodes can derive a shared key. The detectors are located exclusively in the hub; the end devices do not contain single-photon detectors. This makes the system inherently immune to classical detector side-channel attacks, and the hub does not need to be trusted. The keys are generated only in the end devices.

In terms of network topology, Falqon operates physically in a star network (all user nodes are connected only to the hub). Logically, the network appears fully meshed: Each user node can generate QKD keys with any other user node without the need to establish a dedicated quantum-optical link between them. As a result, both hardware requirements and operating costs scale significantly more cost-effectively th , compared to pure point-to-point QKD systems.

The user nodes are specified as 19-inch devices with 2U height, approximately 70 cm depth, weighing around 30 kg, and with a power consumption of about 200 W. Falqon supports DWDM integration, allowing the quantum signal channel to be multiplexed with classical data channels on the same fiber as needed.

7.2 *Manufacturer specifications regarding range and key rate*

The technical data sheet ("Next-Generation Quantum Cryptography," MQX4000-Line) lists the following key specifications, among others:

- **Maximum channel attenuation:** 40 dB, which corresponds to 200 km of fiber optic cable using standard conversion.
- **Secret key rate:** more than 500 bit/s at 125 km (25 dB)
- **Protocol:** "Measurement Device Independent with Decoy States."
- **Interfaces:** Key delivery interface according to ETSI GS QKD 014 v1 as well as customer-specific APIs; secure key transfer to HSMs/applications via mTLS.
- **Channels:** A single fiber pair is sufficient for both the quantum and service channels; WDM compatibility available upon request.

The specification explicitly refers to the "Secret Key Rate"; in QKD data sheets, this is typically the final secret key rate after error correction and privacy amplification, not the raw sifted key rate.

7.3 *Independent investigations and field tests*

Public technical reports on Falqon have so far focused more on architecture and network topology than on detailed measurement curves.

- **Pilot networks in the Netherlands:** Early prototypes were operated with KPN and Cisco in a three-city network, with QKD keys powering real-world data encryption. Financial transactions were secured for several weeks in collaboration with ABN AMRO ("Quantum Safe Banking"). Eurofiber and Juniper operate an open testbed in the Utrecht area, where Falqon devices are integrated into existing DWDM infrastructures.
- **Port of Rotterdam:** Starting in 2024, a Falqon network will secure critical connections between various locations in the Port of Rotterdam. However, details regarding attenuation and key rates have not been publicly disclosed.
- **BeQCI/EuroQCI Pilot Belgium–Luxembourg:** In 2025, a 132-km MDI-QKD link was put into operation in collaboration with BeQCI and LUQCIA, with a hub in Arlon and end nodes at locations including the University of Luxembourg and the ESA site in Redu. According to the consortium, this is the first cross-border MDI-QKD connection in the Benelux region. Here, too, range and architecture are the primary focus; specific secret key rates were not mentioned in the public announcements.

A simulation study on large-scale quantum networks, referenced in a market report, depicts an MDI network with a Falqon-like topology, in which a secret key rate of approximately 1.5 kbit/s per user is to be achieved for 16 users. However, this is explicitly a blueprint/planning scenario, not measured values from a specific field trial.

The manufacturer's specifications are qualitatively supported by real-world network demonstrators (Port Rotterdam, BeQCI-Link, national testbeds), but publicly available, independent "key rate vs. attenuation" curves are scarcely available as of November 2025.

The user (see Section 1.3) only confirmed the manufacturer's specifications without providing specific practical values for key rates. However, he reported that a dedicated 16-amp circuit for the compressor was required to operate the cryogenic cooler used at the central node, and that the device occupied 21 rack units. Q*Bird provides specifications only for the space requirements of the user nodes (namely 2U, which was also confirmed by the interviewed team), but there are no official specifications regarding the space requirements of the central node.

A positive point mentioned was that the Q*Bird system's scope of delivery included its own management server, which the interviewed team described as a unique selling point. In fact, Q*Bird offers a central management and orchestration system with the "Quantum Domain Controller" (QDC).

7.4 Costs

The interview reported that the Q*Bird system (including the management server) cost approximately 370,000 euros. It should be noted here as well that this is informal information from a single customer. There are no official price lists, and no other sources with pricing information were found.

7.5 Standardization, KMS Integration, and Interoperability

Q*Bird explicitly positions Falqon as a network-integrated QKD platform with standard interfaces:

- **ETSI Interfaces:** The datasheet lists ETSI GS QKD 014 as the supported key delivery API (REST-based). Integration with HSMs and applications typically occurs via mTLS-secured connections; additionally, customer-specific interfaces are offered.
- **Embedded KMS & Quantum Domain Controller (QDC):** Each Falqon user node contains an embedded KMS; keys can be delivered to HSMs,

firewalls, or other applications via multiple IP interfaces. The QDC serves as a higher-level management and orchestration entity for larger networks (topology management, policies, monitoring).

- **Network Integration & DWDM:** Falqon has been integrated into multiple projects with Cisco and Juniper network components, DWDM systems, and Layer 2/3 HSMs. Q*Bird explicitly emphasizes DWDM compatibility, simple remote configuration (NETCONF, RESTCONF, SNMP, CLI), and operation in complex topologies (star, ring, multi-hub networks).

8 Zero/3 (a brand of Quantum Industries)

Zero/3 (brand name "zerothird," legally Quantum Industries GmbH) is a company founded in 2023 and headquartered in Vienna. It emerged from the Viennese quantum technology scene centered around the Institute for Quantum Optics and Quantum Information (IQOQI) and the Quantum Technology Laboratories (QtLabs) and was founded by Felix Tiefenbacher and Rupert Ursin. Zero/3 positions itself as a provider of entanglement-based QKD systems ("eQKD"; the "e" stands for "entanglement") for critical infrastructure, the financial sector, and government networks, and is listed as a supplier in the EuroQCI ecosystem. In 2025, the company closed a seed financing round of approximately €9.5 million (US$10 million), led by Sparring Capital Partners, Findus Ventures, and KGAL; it also receives funding from Austrian innovation programs. The "zerothird" brand is now being actively used as the company's new identity.

8.1 eQKD Platform: Technology and Protocol

Zero/3 / Quantum Industries currently offers a small, clearly focused product portfolio:

- an entanglement-based QKD link for long distances ("Long Distance QKD System," optimized for ~350 km of fiber optic cable),
- a "High Speed QKD System" for high key rates over medium distances (~10–20 km),
- and a standalone polarization-entangled photon pair source as a module for research and integration purposes.

Common to all systems is a discrete, entanglement-based QKD technology based on polarization-entangled photon pairs that implement the BBM92 protocol (Discrete-

Variable-QKD with single-photon detection). On the detector side, superconducting nanowire single-photon detectors (SNSPDs) are used.

In its marketing, Zero/3 strongly emphasizes the difference from classical prepare-and-measure schemes (BB84) and refers to its own technology as “eQKD”—entanglement-based quantum key distribution—with high security due to the monogamy of entanglement.

The systems are optimized for C-band fiber-optic links (DWDM-capable, 100-GHz ITU grid), but are also intended to serve as a connection between satellite ground stations and metropolitan networks in the future.

8.2 Manufacturer specifications regarding range and power range

The publicly accessible product pages of Quantum Industries / Zero/3 are sparing with specific figures regarding key rates. They primarily list application areas:

- **Long Distance QKD System:** entanglement-based BBM92 implementation. The Long-Distance System is designed for fiber-optic links up to 350 km; according to the specifications, it is optimized for approximately 300 km. For 300 km, the manufacturer specifies a secure key rate of more than 100 AES-256 keys per hour. This corresponds to approximately 7 bit/s.
- **Quantum-Secured Interconnects for Data Centers & Metropolitan Quantum Networks for Smart Cities:** also an entanglement-based BBM92 system, optimized for inter-city distances of approximately 10 to 100 km. Specifications on the website: 120 kbit/s at 10 km (2 dB), 20 kbit/s at 50 km (10 dB).

A description provided as part of the LASER World of Photonics Innovation Award 2025 confirms these key points: Zerothird’s eQKD systems use polarization-entangled photon pairs and SNSPD detectors, are designed for short- and long-distance links up to approximately 350 km, and support star topologies for networks.

The reported range of 350 km can likely be understood to mean that this is the distance between Alice and Bob, and that the source of the entangled photons is located exactly between them, meaning that the actual distances between the transmitter and receiver are in the range of 170 to 180 km. Occasionally, the 350 km is converted using the standard fiber loss (0.2 dB/km), which would result in a manageable channel attenuation of up to 70 dB; however, Zero/3 has not released any publicly available data on channel attenuation. Therefore, it seems more likely that the 70 dB channel attenuation is merely a rumor, one that Zero/3 apparently never circulated in the first place.

8.3 Independent Projects, Field Tests, and Network Perspective

Zero/3/Quantum Industries is heavily involved in European programs:

- In the Horizon Europe project "Entanglement-based Quantum Key Distribution Networks (eQKD)," Quantum Industries is named as a key technology partner. The project description explicitly mentions entanglement-based DV-QKD (BBM92) with ranges of up to approximately 350 km and primarily addresses backbone networks for critical infrastructure.
- The company participates in trade shows and conferences (e.g., World of Quantum 2025, DPG Quantum Conference 2025) with presentations on entanglement-based QKD and the commercialization of earlier scientific work.

It is notable that in these public sources, the focus is very strongly on architecture (eQKD networks, star topology, low trusted node density) and scaling arguments, while concrete secret key rates in kbit/s as a function of attenuation or distance are rarely published.

8.4 Practical experience and individual reports

As of November 2025, no concrete long-term key rate measurements have been publicly documented by a neutral party.

In an informal conversation, a price of 500,000 to 600,000 euros per link (1 transmitter, 2 receivers) was mentioned. As with all price quotes, it should be noted that this is the statement of a single interviewee, that no official price quotes are available, and that no other publicly available price quotes can be found.

8.5 Standardization, KMS Integration, and Network Operation

Zero/3 positions its systems as building blocks in comprehensive quantum communication networks. The systems are explicitly described as modular and integrable into HSMs and existing telecom infrastructure; the use of standard ITU-DWDM channels (100-GHz grid) is emphasized. In EuroQCI and national projects, there is mention of integration into SDN-based control planes and key management infrastructures, but specific ETSI document numbers (GS QKD 004 / 014) are not explicitly cited on the product pages. Trade show and project descriptions indicate that the systems are designed for star networks with a central entanglement node, allowing fully meshed logical networks to be established with relatively few nodes. This is a strong selling point compared to pure point-to-point QKD systems.

9 qtlabs (Quantum Technology Laboratories)

Quantum Technology Laboratories GmbH (brand name: "qtlabs") is a company founded in 2017 and based in Vienna; it is considered a spin-off of the Austrian Academy of Sciences (ÖAW). It emerged from quantum research at IQOQI Vienna and was founded by Rupert Ursin and Thomas Scheidl, among others, who had previously been involved in several groundbreaking free-space and satellite QKD experiments. Qtlabs positions itself as a specialist in optical and quantum-based space communication. The company develops hardware and systems for free-space and satellite QKD, particularly optical ground stations, space-qualified quantum sources, and synchronization systems. In 2023, qtlabs received the Austrian "Phoenix" Start-up Award in the spin-off category; Invest-in-Austria describes qtlabs as the only company developing telescopes with integrated quantum receivers and satellite tracking software for "unbreakable quantum communication." qtlabs is part of the Quantum Technologies Group, which includes Quantum Technology Laboratories, Quantum Industries (Zero/3), and Quantum Space Systems. Thus, qtlabs forms the primarily space- and free-space-oriented hardware and engineering arm within a corporate group in which Zero/3 supplies entanglement-based fiber-optic QKD systems.

9.1 Products and Technologies: Free-Space and Satellite QKD

qtlabs' product and service portfolio includes components and systems for optical quantum communication, as well as consulting and development services. Of particular relevance to QKD are:

- **Optical Ground Stations (OGS).** OGS 400 / OGS 800: 40-cm and 80-cm telescope stations, respectively, with integrated quantum signal demodulation for free-space QKD and laser communication. The 80-cm variant (OGS 800 / OGS-80) is described as a turnkey ground station that combines telescope optics, tracking, receiving optics, and a quantum demodulator in a robust housing and is suitable for various QKD protocols as well as optical satcom. These stations are designed for coupling with QKD receivers and key management systems (typically via fiber optics and Ethernet in a server room), as illustrated by integration studies on QKD-OGS in telecommunications networks.

- **Space-QKD hardware and quantum sources.** Qtlabs develops and qualifies space-qualified quantum sources and free-space QKD modules that can be deployed both on satellites (transmitter modules, entanglement-based sources) and on the ground (receiver modules, demodulation units). The technologies are based on polarization-entangled single photons and support classical DV-QKD protocol families (Prepare-and-Measure and entanglement-based methods), with the specific protocol selection depending on the respective space mission.
- **Additional systems and services.** In addition to OGS, qtlabs supplies, among other things, timing synchronization systems, training and demonstration platforms, as well as engineering services for the design of complete Space-QKD links (link budget, site characterization, noise and turbulence models). The products are designed to support both direct satellite-to-end-user links (end-user OGS on buildings) and provider architectures in which the ground station is part of a telecom backbone.

9.2 Applications and Projects

qtlabs serves customers with high security requirements, particularly operators of critical infrastructure, financial institutions, and government agencies seeking to utilize global QKD via satellites and free-space backbones, and has been involved in several QKT projects, including the EuroQCI project “QCIHungary,” the ESA project “Deep-Space Optical Communication (DSOC),” and as an industry partner in research projects.

In addition, qtlabs participates in experimental work on intermodal QKD, which involves actively switching between free-space links and fiber-optic connections. This is a key component for future hybrid QKD networks that combine satellite downlinks, terrestrial free-space links, and fiber-optic backbones.

9.3 Key rates

No key rates attributable to qtlabs have been published to date. This is primarily because Europe and European companies are currently still at a stage with free-space and satellite QKD where the feasibility of such technologies needs to be demonstrated. While practically usable key rates are a long-term goal, there is currently no focus on them.

In research projects associated with individuals in the qtlabs ecosystem but not directly with qtlabs itself, the following key rates have been published:

- **Satellite downlinks:** 0.5–10 kbit/s over 1,000 to 1,200 km.
- **Free-space ground-to-ground links:** 50 bit/s – 100 kbit/s at 1 to 10 km, depending on line of sight, weather, and protocol.

9.4 Role in the ecosystem and relationship to Zero/3

qtlabs and Zero/3 are sister companies within the Quantum Technologies Group: qtlabs primarily covers space and free-space communication (satellites, aircraft, end-user ground stations), while Zero/3 offers production-ready eQKD solutions for fiber-optic backbones and data centers. Both companies draw on the same scientific background at the Austrian Academy of Sciences (ÖAW)/IQOQI, but serve different levels of the global quantum communication network:

- **qtlabs** specializes in providing optical ground stations, space-qualified sources, and engineering for SatQKD and free-space links;
- **Zero/3** provides entanglement-based QKD systems for terrestrial fiber-optic networks, including key delivery interfaces and integration with HSMs.

10 Toshiba

Toshiba Corporation is a major Japanese technology conglomerate (owned since 2023 by a consortium led by Japan Industrial Partners) with global operations. QKD development takes place primarily at the Cambridge Research Laboratory (CRL) of Toshiba Europe Limited in Cambridge (UK). Toshiba has been conducting research on QKD since the late 1990s and reported, among other achievements, the first 100-km QKD demonstration (2003), key rates in the Mbit/s range starting in 2010, and over 10 Mbit/s starting in 2017. Today, Toshiba positions itself as a provider of complete QKD solutions, including hardware, a key management system (Q-KMS), and integration services.

10.1 LD and MU Systems: Technology and Protocol

The current commercial product line for fiber-optic QKD primarily includes:

- **Long-Distance QKD System (LD):** optimized for high key rates over long distances (150 km and more, with 30 dB channel attenuation). Quantum signal in the C-band (1550 nm). Requires two fibers (one for the quantum signal channel, one for service/control channels). Only limited multiplexing coexistence with C-band data; therefore, it is typically carried over separate fibers.

- **Multiplexed QKD System (MU):** optimized for coexistence with classical DWDM data traffic on the same fiber (O-band QKD + C-band data). The quantum signal is in the O-band (1310 nm), the classical data in the C-band (DWDM channels with a total transmit power of up to 100 mW). Operation over a single fiber (simplex pair or bidirectional fiber) on which QKD and multiple 10/100 Gbps channels coexist.

Both systems are discrete, photon-counting DV-QKD systems and implement Toshiba's proprietary T12 protocol, an efficient BB84 protocol with decoy states and phase encoding. Detection is performed using in-house developed, self-differentiating InGaAs APD detectors. Optionally, SNSPDs (single-quantum detectors) can be integrated to further increase the range (demonstrated up to 300 km).

10.2 Manufacturer specifications regarding range and key rate

The publicly available data sheets and company presentations paint the following picture (as of 2022–2025):

- Long-Distance QKD System (LD)
  - Protocol: Toshiba T12 (efficient BB84 with decoy states).
  - Key rate: 300 kbit/s at 10 dB.
  - Maximum range: up to 120 km on ideal single-mode fiber in earlier brochures. More recent product pages cite a channel loss of 30 dB and deployments over 150 km.
  - Detection: self-differentiating semiconductor single-photon detectors.
- Multiplexed QKD System (MU)
  - Protocol: also T12 (efficient BB84 with decoy states).
  - Key rate: 300 kbit/s at 10 dB.
  - Maximum range: 90 km
  - Multiplexing: O-band QKD (1310 nm) coexists with C-band DWDM data (at up to 100 mW total transmit power).

In all current documentation, the term "Secure/Secure Key Rate" is explicitly used, which strongly suggests that this refers to the final secure key rate after error correction and privacy amplification, not a raw sifted key rate.

10.3 Independent field tests and long-term experience

In 2022, a 184-km link with three QKD sections (67 km LD, 50 km MU, 67 km LD) was demonstrated in coexistence with 54 100-Gbit/s channels and one 400-Gbit/s channel:

- Two LD links, each 67 km long, with approximately 13 to 14 dB loss: average secret key rate 260 kbit/s and 272 kbit/s, respectively, stable over 24 hours.
- A 50-km MU link. In the O-band, which was used for the quantum channel, an attenuation of approximately 10 dB was observed. At the same time, data was transmitted in the C-band via the same optical fiber. The key rate depended on the transmit power in the C-band and ranged between 36.5 and 63 kbit/s.

10.4 Long-term record attempts (laboratory)

Toshiba itself reports continuous laboratory operations at more than 1 Mbit/s (2008) and, in 2017, even at more than 10 Mbit/s over short distances (typically 10–20 km), which primarily provide proof of technological feasibility for very high key rates but cannot be compared to production-ready deployment scenarios.

In field tests conducted with Orange in 2023, the coexistence of a QKD channel with 60×100 Gbit/s DWDM channels (6 Tbit/s) over a standard single-mode fiber was demonstrated. An average key rate of 1.47 Mbit/s was achieved over a 64-hour operation period and a fiber length of 20 km. https://arxiv.org/pdf/2305.13742

In 2025, KDDI Research and Toshiba also demonstrated the coexistence of a C-band QKD channel with 33.4 Tbit/s of coherent O-band data over 80 km; here, the focus is clearly on the extreme data capacity, but the publicly available abstracts do not specify detailed secret key rates.

10.5 User Report

The user mentioned in Section 1.3 did not provide any of their own measurement data for Toshiba, but reported that peak rates of up to 600 kbit/s can be achieved with channel losses of approximately 10 dB (corresponding to 50 km of fiber).

10.6 *Standardization, Key Management, and Interoperability*

Toshiba strongly emphasizes compliance with standards and integration with traditional network components: The key management system (Q-KMS) is a standalone, software-based key management system for QKD networks. It supports ETSI GS QKD 014 as a REST API for key provisioning and can distribute keys to various HSMs and applications.

Several demonstrations (Orange/ADVA, BT/Equinix, Austrian government and hospital networks) showcase the integration of LD/MU with HSMs and SDN control planes.

The ECOC 184 km demonstration explicitly uses ETSI GS QKD 014 in conjunction with key management servers and a PKI infrastructure.

10.7 *Security Assessment*

The UK National Physical Laboratory (NPL) has conducted an independent evaluation of Toshiba's QKD technology and verified key physical parameters (e.g., detector noise figures, protocol parameters). This constitutes a technical validation, not a formal security certification in the sense of Common Criteria.

Costs

No publicly available price information for LD and MU systems can be found in the available sources. Neither Toshiba nor its partners publish list prices. The AIT user interviewed cited "more than 300,000 euros," which must be viewed as an unverifiable statement from a single user. As of November 2025, no other reliable public documentation of prices is currently available.