WAVELENGTH ELECTRONICS

# High-Definition Video Broadcasting with QCLs



## ABSTRACT

Free-space communications can overcome logistical barriers and infrastructures of broadband connections in remote or rural areas. By using long wave infrared (LWIR) quantum cascade lasers (QCLs) as optical sources, high data rates can be transmitted error-free, eliminating the need for physical connections. By experimenting with live video broadcasting at different levels of video formats, researchers realized free-space live video broadcasting with a room temperature QCL with a wavelength of 8.1 µm. The high-definition video format (1280 pixels x 720 pixels) is transmitted at a data rate of 1.485 Gbits/s without any errors. A higher-definition format transmission (HD1080p59.94 at 2.970 Gbit/s) is also demonstrated, but further actions need to be taken to achieve error-free results. This design shows promising results for applications in free-space optics and communications based on mid-infrared wavelengths.

## FREE-SPACE COMMUNICATION

Internet is a critical factor for the development of countries in terms of education, health, and science.[1] Although the number of Internet users has rapidly increased in the last two decades from only 413 million users in 2000 to over 4.88 billion users in 2021, remote and rural areas do not have the same access as more developed areas. Less than a quarter of the world's population has access to a personal broadband Internet connection. Therefore, the drive to expand the current high-speed Internet network is growing.

Broadband Internet in remote areas is possible, but it is not realistically achievable. **Figure 1** shows a rural area with cell tower transmission but without broadband Internet connection. In such situations, broadband Internet connections are not justifiable. The infrastructure of broadband Internet creates logistical difficulties, such as buried fiber wires, as well as their very high costs.[1] Although fiber optic connections use light for higher transmission speeds, they are still restrained by the physical connections needed in buried lines, material and labor costs.

Similar to fiber optics, free space communication uses light for data transmission. However, free space optics transmit the light through the atmosphere - free space, whereas fiber optics transmit the light through an optical cable. Free space technology has the potential to be one of the key tools to develop lower-cost broadband Internet connection.[1] In the same way cell towers and Wi-Fi connections transmit data to networks through the atmosphere, free space communication can help transfer data at a high rate in remote areas without the need for time- and labor-intensive infrastructure.

**Figure 1. Aerial view of mobile phone cell tower over forested rural area illustrating the lack of fiber-based broadband Internet service**

## PROBLEMS AND GOALS

Free space communication systems can use a large range of wavelength domains. From short wave to long wavelength radio domain, every wavelength has a designated use. Radio frequencies and Wi-Fi networks have intrinsic limitations: data transmission rates are limited and they have a degrading sensitivity to atmospheric conditions.[1] These problems can lead to difficulties in development of communication in free space. There is a need for a free-space communication system to develop lower cost broadband Internet connection that is reliable in inclement weather as well as having error-free data transmission.

Long wave infrared (LWIR) has advantages of low-attenuation and low-scattering behavior in the atmosphere. Low-attenuation and low-scattering properties are crucial in free-space light propagation. Quantum cascade lasers (QCLs) use cascade intersubband transitions in quantum wells and heterostructure lattices to emit wavelengths from mid-IR to far-IR. Because the output of QCLs can reach up to several watts, they can be utilized as the primary optical source for free space communications. QCLs also have a very low carrier lifetime, relating to energy released as photons, and an absence of relaxation oscillation frequency. Both of these qualities are practical for high-speed direct modulation.[1]

With free-space communication based on an LWIR emitting QCL, a high-speed data transmission rate on the order of multi-Gbits per second is a possibility. This realization could pave the way to future real-field free-space optical link using LWIR wavelength with ground-to-ground or ground-to-satellite networks.[1]

## METHOD

Researchers from the Institut Polytechnique de Paris, France; Beijing, China; and New Mexico, USA have developed a QCL for high-definition video broadcasting for free-space communications. By broadcasting live video at a high data rate, researchers can demonstrate the potential of QCLs as the optical source for free-space communication transmission.

The designed QCL and the details of the light-intensity-voltage (LIV) curves at various temperatures can be seen in **Figure 2**. The physical properties of the QCL are carefully designed for maximum power output, precise wavelength emission, and increased modulation bandwidth. The QCL emits light at a wavelength of 8.1 μm in the LWIR domain. The ridge width is 8 μm with a short cavity length of 0.5 mm. This cavity length minimizes the parasitic capacitance of the QCL, increasing the modulation bandwidth. Fortunately, this QCL only has around 1.7 W electrical consumption for maximum optical power. Although the maximum beam power is only 10 mW at 140 mA and 12 V, the losses are very weak at this wavelength in the atmosphere and do not affect the quality of the transmission.[1] The QCL is maintained at a constant temperature, and its current is precisely driven by Wavelength Electronics' QCL2000 LAB QCL driver.

**Figure 2** shows a threshold current of 110 mA at a temperature of 293 K. The maximum beam power of 10 mW is seen at 140 mA and 12 V. From the inset of **Figure 2**a, a single mode is exhibited for currents below 140 mA.

This developed QCL makes high data rate transmission in the atmosphere possible with minimal loss. The reduced distortion enables beams to propagate through free space without errors. The absence of a relaxation oscillation resonance ensures the modulation bandwidth is large enough for the high definition video broadcasting.

**Figure 2**b shows the importance of building optimized electrical contacts to take advantage of the modulation capabilities of the QCL. The maximum 3-dB bandwidth found with this QCL is 700 MHz for bias currents above 125 mA.[1]

**Figure 3** shows the experimental setup for the video broadcasting. This includes the QCL with current driver as well as a computer connected to an HDMI/SDI converter to create the modulated signal. The low noise current from the QCL driver is combined with the RF modulated signal from the

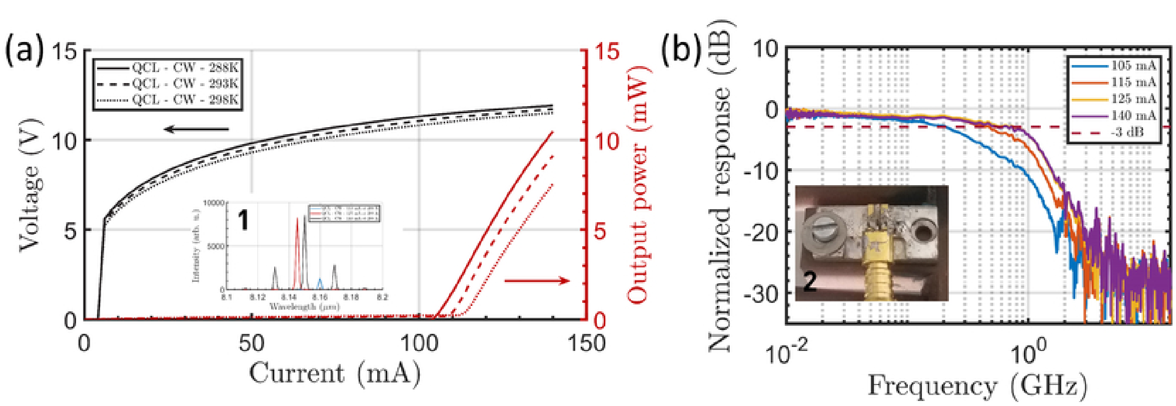


**Figure 2. (a) Light-intensity-voltage (LIV) curves for various temperatures; the bottom inset shows the spectrum of the laser for three different bias currents while keeping the temperature at 288 K: 110 mA, 125 mA and 140 mA. (b) S12 measurements for four different bias currents: 105 115, 125, 140 mA. One can see how the electrical bandwidth of the QCL increases with bias current and is then kept unchanged for values above 125 mA. The maximum 3-dB bandwidth is 700 MHz. The inset in the bottom left shows the QCL under study, with optimized connectors for high speed operation.**[1]

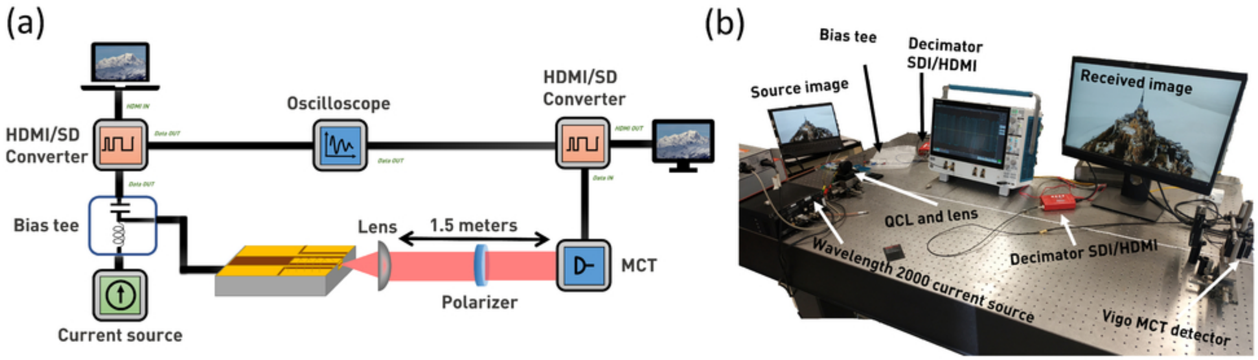


**Figure 3. (a) Experimental setup for the video broadcasting. We tried three different formats which correspond to three different data rates: 3G1080p59.94, HD720p59.94 and SD480p59.94 for respectively 2.970 Gbits/s, 1.485 Gbits/s, and 270 Mbits/s. (b) Picture of the setup for high-definition video broadcasting with an 8.1 microns QCL.[1]**

converter with a bias tee. This is the electrical signal that the QCL receives to generate a modulated beam that impinges the MCT detector 1.5 m away. The signal detected from the QCL is converted once again and displayed on a TV monitor with an HDMI cable for viewing. This setup allows for live transmission viewing on a remote screen.

## RESULTS

The video broadcasting results can be seen in **Figure 4** for three different video formats: SD480i59.94, HD720p59.94, and 3G1080p59.94. Audio is also embedded in the HDMI format and transmitted alongside the video, and it can be heard through speakers in the TV monitor. All three video formats are transmitted at different data rates.

The SD480i59.94 and the HD720p59.94 formats both achieved error-free transmission. These formats correspond to data rates of 270 Mbits/s and 1.485 Gbits/s, respectively. The 1080p format had a required data rate of 2.970 Gbits/s, and the bandwidth of the detector and laser became detrimental at this point leading to errors in the transmission.[1] The transmission is still of very high quality, but error-free results cannot be guaranteed without changes in the setup. The right panel of **Figure 4** shows the distorted signal for this 1080p format.

With the developed 8.1 μm wavelength QCL, a free-space high-definition broadcasting system is demonstrated with error-free results for two different video formats. The research is a proof-of-concept of a 1.485 Gbits/s data transmission without errors in the LWIR domain. This design can be resistant to degraded atmospheric conditions compared to other shorter wavelength systems.[1]

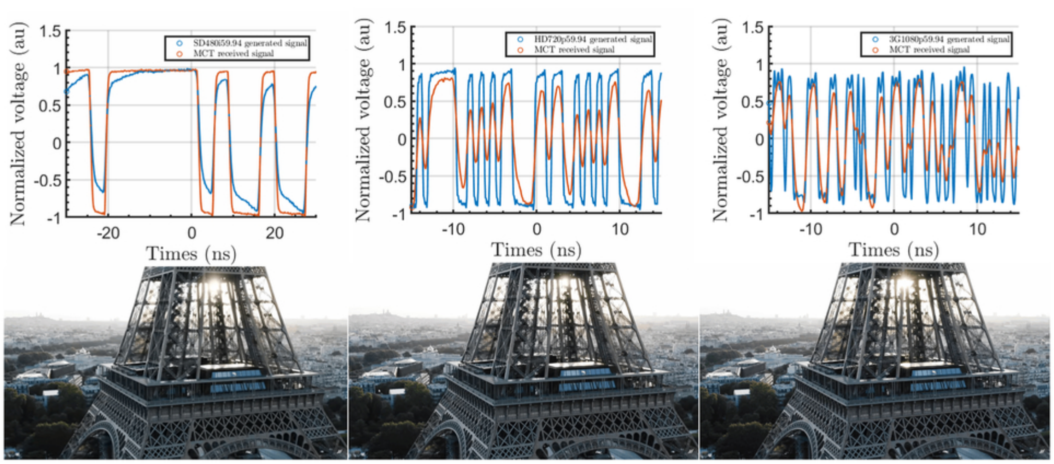


**Figure 4. Video 1 : QCL transmission at 8.1 μm for three different formats SD480i59.94, HD720p59.94 and 3G1080p59.94 corresponding to different data rates : 270 M Bits/s, 1.485 G bits/s and 2.970 G bits/s. In blue, and in orange, we have respectively the generated signal and the received signal by the MCT. The transmission is error free for the two first formats mentioned. On the bottom of the figure, we can find the image obtained on the screen at the reception for the three different formats.[1]**

This QCL data transmission setup can be considered for long distance free-space communications as the absorption of the atmosphere attenuation at this wavelength is roughly 3 dB per kilometer.[1] This error-free transmission can also be utilized for long periods of time without disconnect. Overall, this experiment paves the way toward free-space communication with rates of dozens of Gbits per second with LWIR QCLs.

## WAVELENGTH'S ROLE

High definition video broadcasting requires high precision and stable control of the quantum cascade laser in signal transmission. Wavelength Electronics' QCL driver, QCL2000 LAB, enabled precise current control with minimal electronic noise from the QCL. The driver also allows analog modulation of up to 2-3 MHz for wavelength modulation. This allowed the QCL to emit a constant, uninterrupted signal that is subsequently modulated for communication purposes. The transmission was studied for several hours at a time, indicating the long term stability of the QCL2000 LAB current driver.

The stability of the QCL bias current is critical for consistent electrical bandwidth of the QCL. Wavelengths' low noise, high stability QCL driver, QCL2000 LAB, can precisely deliver up to 2 A to the laser. This benchtop QCL driver instrument exhibits noise performance of 1.3 µA RMS up to 100 kHz with an average current noise density of 4 nA/√Hz. Additional features, such as the intuitive touchscreen interface, USB and Ethernet connections, rack mountability, and adjustable output current and compliance voltage enable custom setup in any design. Brown-out, overvoltage, key switch, turn-on delay, and current ramp protect the user and the QCL from potential damage and electrical faults.

The QCL2000 LAB QCL driver instrument enables high definition video broadcasting with a data rate of 1.485 Gbits/s with low noise and stable laser output. This makes the developed QCL system a reliable tool for real-field applications in free-space communication.

| PRODUCTS USED |
|---|
| QCL2000 LAB |

| KEYWORDS |
|---|
| Quantum cascade laser, mid-infrared photonics, free-space communication, data transmission, high-definition video broadcasting, QCL, LWIR, attenuation |

## REFERENCES

1. Pierre Didier, Ke Yang, Olivier Spitz, Alice Guillaume-Manca, Junqi Liu, and Frédéric Grillot "High-definition video broadcasting with a room-temperature quantum cascade laser emitting in the long-wave infrared domain", Proc. SPIE 12021, *Novel In-Plane Semiconductor Lasers XXI*, 120210D (2022); https://doi.org/10.1117/12.2608511

## USEFUL LINKS

- QCL2000 LAB Product Page

## PERMISSIONS

Figures 2, 3, 4 and data used for this case study were obtained from Reference 1. Permission was granted for use of the images and data from SPIE and the corresponding author(s) of Reference 1.

Captions for Figures 3 and 4 were modified for consistency.

No changes were made to the other images or the captions. They are presented here in their original form.

**REVISION HISTORY**

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| A | December 2022 | Initial Release |