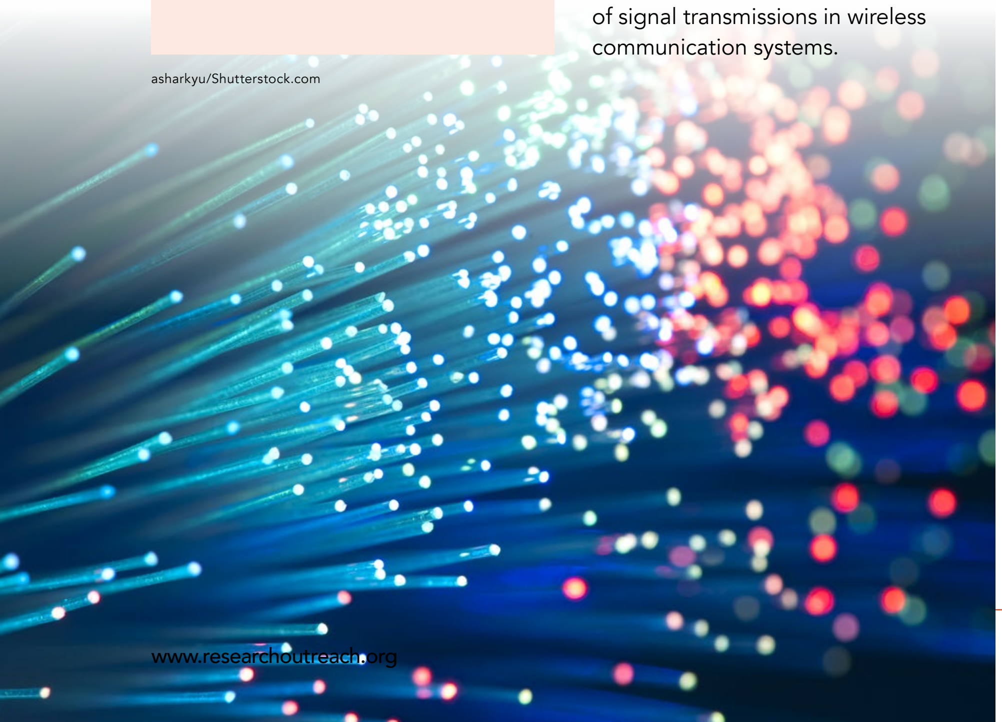
Converting to terahertz communications

The amount of data we generate globally is now accelerating at a breakneck pace. As this transformation occurs, exchanges of terahertz signals could become a crucial aspect of future communication systems, yet without a way to efficiently convert these waves to and from optical signals, such a prospect has remained unfeasible so far. In his research, Professor Cyril Renaud at University College London, addresses the issue through a novel photodiode device, which exploits some of the latest advances in both electronics and photonics.

Over the course of just a few decades, the tools we use to communicate with each other have transformed almost beyond recognition, and for now, the pace of this change shows no signs of slowing down. As the technological landscape transforms around us, the amount of data generated globally is growing exponentially. In 2018, humanity generated 130 exabytes of data in a single month for the first time – more information than was ever generated over a large majority of human history.

Such staggering growth has been strongly driven by the rise of wireless mobile devices, which have opened up internet access to many millions of people – particularly in the developing world. Inevitably, this is now putting an increasing strain on the wireless channels used to convey these signals to individual devices. Without new innovations, the infrastructures we rely on to communicate with each other could come under severe strain in the near future. In order to keep on top of our increasing demand for data, researchers and engineers are now aiming to accomplish higher rates of signal transmissions in wireless communication systems.



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TERAHERTZ CARRIER FREQUENCIES

One critically important aspect for researchers to consider in achieving this goal is the 'bandwidth' of wireless signals. The term describes the range of frequencies occupied by an information-carrying signal: with higher bandwidths, individual signals can convey more information, regardless of their specific frequencies. This creates a strong incentive for conveying terahertz frequencies – which fall between microwave and infrared frequencies on the electromagnetic spectrum. In the field of radio communications, these waves are the highest possible frequency at which signals can be transmitted.

With the bandwidths required by modern wireless communication systems now exceeding tens of gigahertz, such high frequencies are becoming increasingly desirable. Before systems can realistically operate at these frequencies, however, they face a major obstacle. As they travel through the atmosphere, terahertz waves will readily interact with features ranging from water droplets to oxygen molecules, causing them to be scattered in unwanted directions. Ultimately, this makes them all but impossible to transmit over large distances, and entirely unsuitable for large-scale wireless networks.

CONVERTING BETWEEN WAVELENGTHS

Professor Renaud proposes that this problem can be overcome by transmitting signals most of the way to their destinations using optical frequencies. Crucially, this can be done via well-established networks of fibre optic cables, which form the backbone of modern internet infrastructures.

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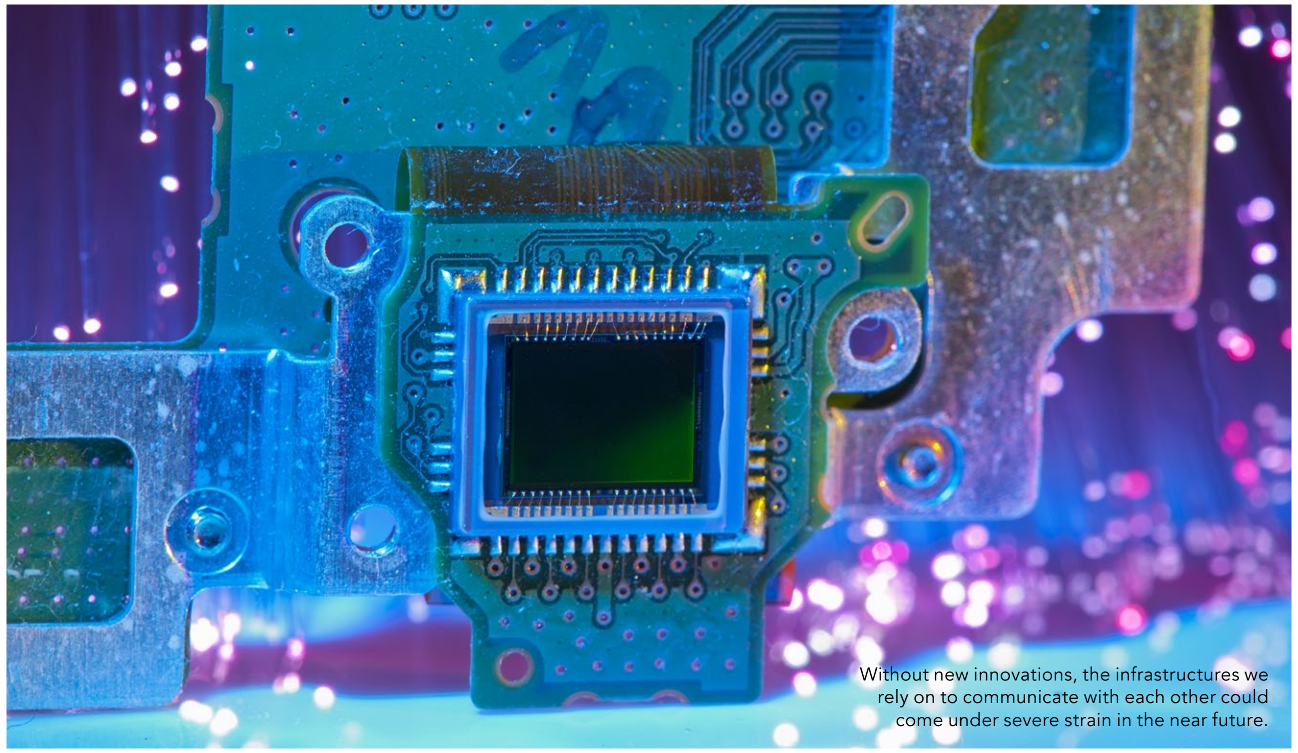

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Once they are within the same building or local area as the receiving wireless device, these frequencies can then be converted into wireless terahertz signals, using an antenna. Finally, they can travel the last few tens or hundreds of metres to their destination, with little attenuation from the atmosphere.

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Such a system has clear advantages, but there is still another hurdle to overcome: the conversion between signals and electrical currents is not entirely efficient, meaning the information carried by a signal can be lost in the process. Through his research, Professor Renaud addresses this problem through cutting-edge technologies, integrating principles from both electronics and photonics – a term describing how signals can be transmitted and received through the manipulation of light.

LIMITATIONS IN REGULAR PHOTODIODES

Converting light into an electrical current requires a device named a 'photodiode'. These devices contain a linear arrangement of three semiconductors within an applied electric field. Two of these semiconductors are doped with different types of molecular impurity, giving them different properties: while one acts as an electron donor, the other readily absorbs them. In between these materials, a pure semiconductor contains no impurities. When an electron in this layer meets a photon with the right energy, it is excited to a higher energy level, and swept by the electric field to a positively charged cathode. In its place, a positively charged 'hole' is left behind, which is swept to a negatively charged anode.

Altogether, this process generates a 'photocurrent' that can be used to generate an optical signal. However, this can only occur after a certain response time – describing the time taken for both electron and hole to transit to their respective electrodes. If response times are longer, the bandwidths which can be transmitted from the photodiode become lower – creating a trade-off between the sensitivity of the device and the amount of information it can convey. So far, this has made the devices unsuitable for the indoor terahertz communications systems which Professor Renaud envisages.

IMPROVING PERFORMANCE WITH UTC-PDS

In his latest research, Professor Renaud has pioneered the use of 'Uni-Travelling Carrier PhotoDiodes' (UTC-PDs) – high-speed, high-output power devices which can overcome many of the issues faced by conventional photodiodes. Like their conventional counterparts, these photodiodes also contain three semiconductor materials in a linear arrangement. This time, however, the middle photon-absorbing layer is doped with impurities which accept electrons, while the electron-accepting layer is left pure. When an electric field is applied to this arrangement, its specific placements of impurities mean that the holes generated by incoming photons will respond extremely quickly.

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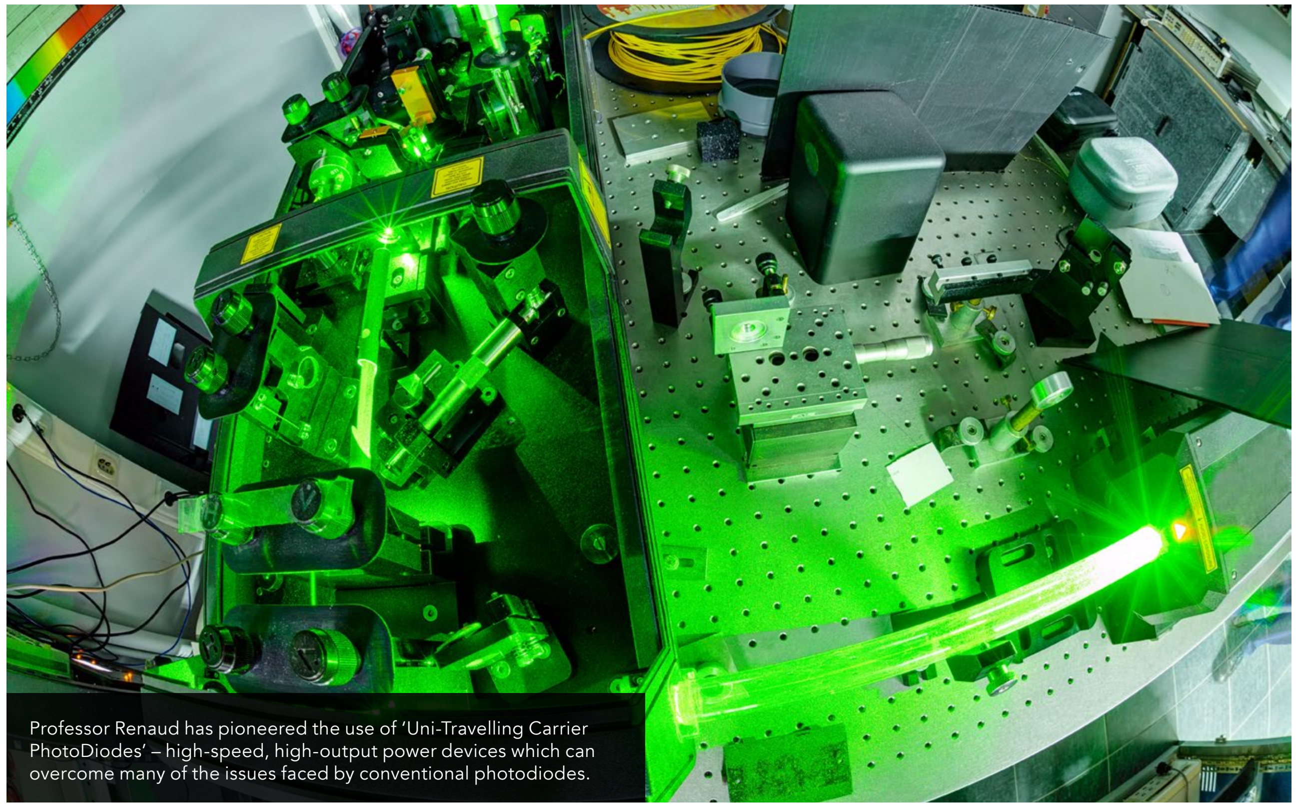

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Where the overall photodiode response time is mainly limited by the slower transits of holes in conventional devices, the semiconductor arrangement in a UTC-PD means it is only limited by electron transport. In turn, the novel device reduces limitations on the bandwidth of the signal being converted, reducing the need for a trade-off between performance, and the amount of information to be conveyed. When applied to terahertz waves, this approach opens up new opportunities for communication systems which convey wireless, high-bandwidth signals over long distances.

UNPRECEDENTED OUTPUT POWER

To demonstrate the promising capabilities of the UTC-PD, Professor Renaud and his colleagues have carried out a number of experiments to measure and assess their maximum output power. Typically, an upper limit is imposed on this value by a combination of thermal effects, and the saturation of electric charge - limiting the efficiency of conversion between terahertz waves and electrical current. The research team have now conceived a new approach to modelling the performance of UTC-PDs, particularly when the devices are integrated with antennae.

Through their results, the researchers clearly showed how the behaviours of electrons and holes within UTC-PDs enable significantly higher maximum output powers than those possible in conventional diodes. In turn, this makes them ideal for converting high frequencies like terahertz waves to high degrees of efficiency. Furthermore, Professor Renaud and his colleagues have demonstrated clear advantages for the use of UTC-PDs in photomixing – where two laser beams with specific frequencies are overlapped, and focused onto a single device, generating terahertz waves.

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IMPROVING COMMUNICATION SYSTEMS

Having demonstrated a strong basis for antennae which efficiently transmit and receive terahertz signals, Professor Renaud's team have made significant progress towards indoor wireless networks incorporating the signals. If achieved, these networks would allow users of wireless devices to transmit and receive data at far higher rates than seemed possible until only recently.

Through future work, the research team now hope to further exploit cutting-edge principles of photonics to integrate UTC-PDs with other elements of photonic converters, including lasers, amplifiers, and modulators. In turn, this would enable the team to carry out advanced photonic operations using devices the size of computer chips. If their approach becomes more widely adopted, it could become a key element of communication systems worldwide; ensuring our accelerating use of data can safely continue well into the future.

Behind the Research

Professor Cyril Renaud

E: c.renaud@ucl.ac.uk **T:** +44 (0) 20 7679 3982 **W:** https://iris.ucl.ac.uk/iris/browse/profile?upi=CRENA49

Research Objectives

Professor Renaud's research ranges from photonic devices to photonic system with particular interest in photodiodes, integrated photonic, THz photonics, sensor systems and wireless communication systems.

Detail

Cyril Renaud
Dept of Electronic and Electrical Engineering
University College London
Torrington Place, London
WC1E 7JE, UK

Bio

Cyril C. Renaud received his Engineering degree from the Ecole Supérieure d'Optique, Orsay, France, and the Diplôme d'Etudes Approfondies (D.E.A.) in optics and photonics from the University Paris XI, Orsay, 1996. He spent one year as a Project Engineer with Sfim-ODS, working on the development of microchips lasers and portable range finders. He then joined the Optoelectronics Research Centre, University of Southampton in 1998 to work on diode pumped high-power ytterbium-doped fibre-lasers, with particular interest on Q-switched system and 980-nm generation. It led to the award of a PhD in 2001. He is currently a Professor of photonics at University College London, and Programme Director for the UCL/Cambridge Doctoral Training Centre in Connected Electronic and Photonic Systems. He has published more than 200 peer reviewed journals and international conferences, and three patents.

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Collaborators

Professor Alwyn J. Seeds

References

Renaud, C.C., Seddon, J., Graham, C., Lin, X. and Seeds, A.J. (2019, November). High Speed Photodetectors. In *2019 Asia Communications and Photonics Conference (ACP)* (pp. 1-3). IEEE.

Nagatsuma, T., Ducournau, G. and Renaud, C.C. (2016). Advances in terahertz communications accelerated by photonics. *Nature Photonics,* 10(6), pp.371-379. https://doi.org/10.1038/nphoton.2016.65

Personal Response

What would be the advantages of integrating UTC-PDs into chip-scale devices?

"Key to the success of the technology is to prove its efficiency and in particular reduced energy consumption. Chip-scale integration would enable the different components that are essential to the converter to be connected with lower losses thus optimising the energy efficiency while reducing size. One exciting direction for this research would be to integrate the devices on a silicon-based platform to produce a seamless electronic and photonic integrated microchip."

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