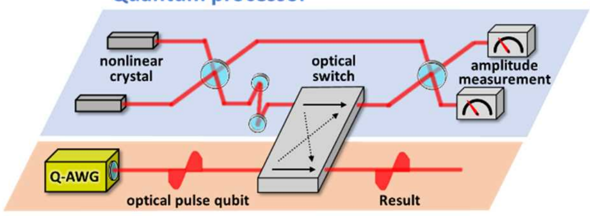
R&D Theme

Research and development on time-domain multiplexed general-purpose optical quantum computer

Progress until FY2022

1. Outline of the project

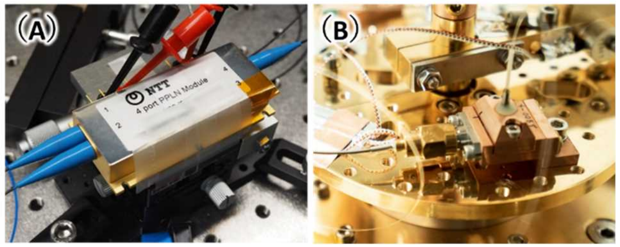
Research is progressing in various physical systems towards the implementation of practical quantum computers. In most systems, a major challenge lies in the requirement of highly complex quantum processors necessary for practical quantum computing. On the other hand, optical system can perform practical quantum computing with compact quantum processors. As such quantum processors have already been demonstrated, the main focus of developments is the generation of optical qubits. As an optical qubit source, we proposed the Quantum Arbitrary Waveform Generator (Q-AWG). The Q-AWG is a versatile quantum light source that can output arbitrary quantum states of light with arbitrary pulse waveforms. Due to its high versatility, the Q-AWG can serve as the core light source for practical optical quantum computers, and it has the potential to solve various challenges that arise during the path to the implementation of practical quantum computers. The Q-AWG is truly an "ultimate quantum light source," and its realization would greatly accelerate the development of optical quantum computers.



An optical quantum computer consisting of a quantum processor and a Q-AWG.

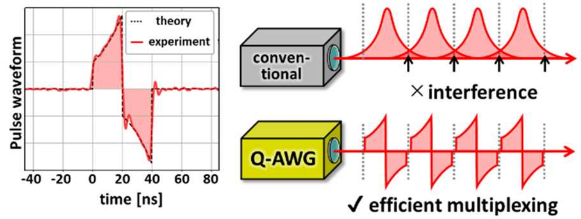
2. Outcome so far

In FY 2022, we developed a method to precisely control the pulse waveform of quantum light according to objectives, thus establishing the fundamental technology for the Q-AWG. By using this method, we generated qubits with specialized pulse waveforms required for the operation of optical quantum processors. It had been challenging to achieve arbitrary pulse waveforms and control them while minimizing the loss of quantum light. To address these issues, we developed a novel method to indirectly control the pulse waveform through highly broadband quantum entangled light. The generation of broadband quantum entangled light utilized the optical parametric amplification module developed in FY 2021. Additionally, superconducting nanowire single-photon detectors were employed to ensure the strong non-classicality of the generated qubits. These devices are closely related to optical communication technology, highlighting the significant acceleration of quantum technology through interdisciplinary fusion in FY 2022.



(A) optical parametric amplification module
(B) superconducting nanowire single-photon detector

The qubits generated by this method possess a special pulse waveform known as a balanced time-bin waveform. This waveform is required for the operation of optical quantum processors, but its realization was unknown prior to this method. With this achievement, it has become possible to input qubits into quantum processors, opening up prospects for demonstrations of optical quantum computing. Furthermore, the balanced time-bin waveform has a distinctive shape that does not have tails on both ends. This enables the qubits to be spaced more closely together than with conventional methods, allowing for the input of a large number of qubits into quantum processors. By fully utilizing the potential of the currently used optical parametric amplification module, it is possible to input up to one billion qubits. This number overwhelms other physical systems where scalability is a challenge, making it a game-changer towards the implementation of practical quantum computers.



Balanced time-bin waveform necessary for the quantum processors and efficient multiplexing of qubits.

3. Future plans

We will integrate the Q-AWG and quantum processors to advance the actual use of optical quantum computers, including implementation of real machines and cloud migration. At the same time, we will improve the Q-AWG for generating fault-tolerant qubits. Through these two strategies, we will steadily approach the realization of large-scale, fault-tolerant, and universal quantum computers. Furthermore, by actively leveraging the excellent technological platform of optical communication, as demonstrated in this research, we expect that the technological developments mentioned above will advance at an unprecedented pace.