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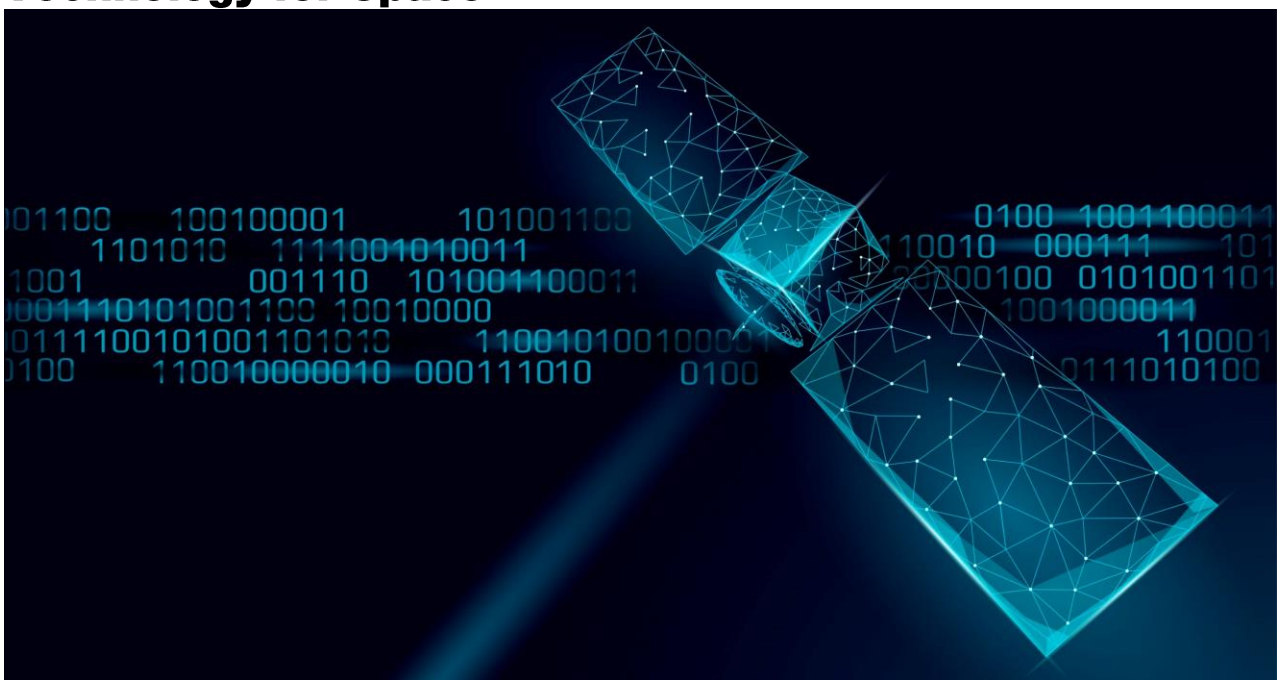
Quantum Communication—Aerospace Is Leading the Development of "Spooky Action at a Distance" Technology for Space



This visualization shows that classical (non-quantum) bits must be either a 1 or a 0. In a quantum information system, the way to tell whether a bit is a 1 or a 0 can be arbitrarily defined, so knowing how to interpret each bit is crucial to interpreting the quantum signal.

Quantum mechanics has a reputation for being difficult to understand, but then again, so does rocket science. Aerospace is already intimately familiar with why the difficulties of rocket science are worth mastering, and quantum communication technology is an example of why quantum mechanics is similarly important.

Quantum communication takes advantage of properties unique to the physics of quantum mechanics, which opens new paradigms for communication that cannot be realized by today's classical (non-quantum) communication.

One of the key properties of quantum communications is the security it provides—it has the ability to detect eavesdropping. Quantum mechanics also has other applications such as cryptography, sensing and computing, and many of these applications are already being incorporated into terrestrial systems. Aerospace is leading industry efforts to implement quantum technology for space, so that our national security space (NSS) customers can understand how best to take advantage of the unique capabilities of quantum enabled applications.

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Background: Quantum systems can seem non-intuitive at first glance, and therefore, a short story may help illustrate some of the concepts involved:

> *Imagine two daring agents named Alice and Bob, who are separated on a dangerous mission. Alice has discovered some crucial secrets that she wants to transmit to Bob, but she needs to consider the risk of an eavesdropper, Eve, discovering the message. Alice decides to use quantum communication protocols because this method will enable a secure method AND allow her to determine if eavesdropping occurred.*
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> *Alice sends a series of randomly generated coded series of quantum signals to Bob, who receives this series of quantum codes and notes when he can clearly detect and identify them. Alice and Bob can now communicate over an open (public) channel and compare the measured codes and perform a comparison of the values.*
>
> *If the comparison reveals errors in Bob's measurements, Alice would know that some tampering by Eve had occurred. If not, Alice would then form a "secure key" with the remaining bits that only she and Bob know. Eve, on the other hand, would have no way of knowing which message bits are real and the intercepted message would be non-sensical.*

In a quantum information system, the basic unit of information is a qubit (quantum bit), and in some ways, a qubit is like a self-destructing coded message. The information carried by a qubit is encoded in a quantum state through the polarization of an individual photon. Due to its quantum nature, measuring this state changes it, and any information about its initial state prior to the measurement is lost. Therefore, receiving and interpreting a quantum signal can only be done once, as even the first attempt at reading it would result in its destruction.

The no-cloning theorem in quantum mechanics prohibits the copying of an unknown quantum state, so trying to put the signal back together is physically impossible, and the receiver would immediately know if there had been an intruder. In our story, when Eve intercepts the signal between Alice and Bob, the quantum state of the signal is disturbed, causing the errors in Bob's measurements when Alice looks at them. Therefore, they know that Eve was eavesdropping on their transmission.

Quantum encryption protocols have been implemented in terrestrial systems around the globe. This security is just one of the many capabilities of quantum systems that are impossible to implement in classical systems. Classical information can be transmitted using quantum methods, but there is quantum information that cannot be manipulated or transmitted in any other way.

There are no classical "words" to express some quantum concepts. Information built on uniquely quantum phenomena like superposition and entanglement (what Einstein called "spooky action at a distance") can only be transmitted via qubits, so quantum communication systems also have applications in networking quantum computers or transmitting data from quantum sensors. Classical communication also has its own unique advantages and the capabilities of both systems are complementary, encouraging implementation of both classical and quantum communication in spaceborne security assets.

Aerospace Actions: As the leading FFRDC for the space enterprise, Aerospace has been working to support its customers on this emerging technology. Aerospace's support is aimed at assessing and improving the readiness of quantum communications technology. First, at the core technological level, Aerospace scientists and engineers understand the fundamental quantum mechanics and the systems engineering aspects needed to advise the customer on what can—or cannot—be accomplished with proposed technology solutions.

Second, Aerospace has experience in maturing the readiness level of different technologies. Existing terrestrial quantum communication devices are analyzed to determine how they could be successfully deployed in the space environment, and Aerospace's partnership with an industry counterpart recently resulted in Small Business Innovation Research (SBIR) funding to further develop their technology.

Third, Aerospace is performing systems-level analyses to better understand how to integrate quantum communication systems and their capabilities into existing space architectures, and another industry counterpart contracted Aerospace for such analyses. All this work requires active research and analysis, both fundamental and applied, and experimentation and testing in Aerospace laboratories, which boast a fully functional testbed to characterize all aspects of quantum communication.

Value: The combination of fundamental understanding, experience with technology development and enterprise-level vision places Aerospace in a unique role, well-positioned to shepherd the implementation of quantum communication technologies in space.

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