Optical communications work best over relatively short distances in space

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In a straight comparison, for space applications over long distances, RF systems achieve greater maximum data rates than optical communications systems.

Optical communication systems have advantages over RF systems that include a wider bandwidth, larger capacity, lower power consumption, more compact equipment, greater security against eavesdropping, and immunity from interference. Because of this they are expected to revolutionize space system architectures.

Although there have been only a few in-orbit demonstrations so far, experiments to verify the advantages of in-orbit optical communications should continue, and full-scale demonstrations would follow. It is therefore important to investigate the appropriate characteristics of such communication systems and to identify which systems are best suited for various configurations of space networks.

One basic characteristic of optical systems is that the electrical power of the signal is proportional to the square of the received optical power. This is in contrast to RF systems, where the electrical power of the signal is proportional to the received RF power. The received optical power is inversely proportional to the square of the link distance, so the signal-to-noise ratio of optical systems degrades more quickly over increasing distance than with RF systems. We examined two optical systems and one RF system, and concluded that optical systems are more suitable for communicating over a relatively shorter distances in space than RF systems.

One optical system we investigated operates at a wavelength of 0.8 μm using intensity modulation (IM) and direct detection (DD) with an avalanche photodiode based on SILEX ( Semiconductor Intersatellite Laser Experiment) technology. SILEX is the first in-orbit inter-satellite laser communication link, and was demonstrated in November 2001. The other system uses 1.5 μm wavelength optical preamplifiers with on-off keying. Erbium-doped fiber amplifiers (EDFAs) are used as a booster amplifier in the transmitter and as a low-noise preamplifier in the receiver. Transmitter and receiver antenna diameters of 10 cm and 1 m, respectively, are assumed for both systems.

The RF system parameters we studied are drawn from GEOTAIL, the spacecraft launched in 1992 to explore the geomagnetic tail up to 1,000,000 km from the Earth. It operates in the x-band frequency of 8.47 GHz, with transmitting and receiving antenna diameters of 18 cm and 64 m, respectively.

The maximum achievable data rates for the optical and RF communication systems at a bit error ratio of $10^{-6}$ are plotted versus distance (R) in Figure 1. The data rates for the IM-DD and the EDFAs systems are higher than for the RF systems at distances less than 10^6 km, but are proportional to R^{-4} beyond that.

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The crossover in communication performance occurs at around $10^7$ km. This is because the data rate of the RF signal is always proportional to $R^{-2}$, in contrast to the dependence found in the optical systems. The RF system is therefore preferable for the Mars-to-Earth communication link distance of around $10^8$ km.

It may be necessary to abandon the use of optical systems over longer distances, unless new technologies, such as special modulation and coding techniques and antenna configurations, are developed. Promising technologies are emerging. Researchers have recently developed a technique that goes beyond the classically-understood limits of a communication channel defined by Shannon’s law, using a so-called quantum circuit in the receiver. Further progress in quantum physics may open other possibilities for long-distance optical communication.

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