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Single-mode and multimode RF over fiber link technology for radio telescopes

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To increase instrument sensitivity and directivity, radio astronomy has been using phased-array technology for their receivers since the early 1960s. First interferometers (radio astronomy phased array receivers) consisted of only few receivers per array and were separated a few kilometres apart. Today's systems have baselines of hundreds up to thousands of kilometres and are composed of countless antenna elements.

With the Square Kilometre Array (SKA) [1], the scale of interferometers will be redefined: More than one hundred thousand receivers will be connected to create a single or several virtual antennas. The sheer number of links required and the length of the links impose severe cost constraints on every single one of them. Another challenge is the remote installation of these instruments for reasons of minimal man-made RF background noise exposure, which imposes power, reliability, maintenance, and construction constraints. Furthermore, the extremely low power level that needs to be detected, which is below the thermal noise floor, does not allow for the faintest instrument-generated electromagnetic interference at the antenna location, thus analog-to-digital conversion and digital signal transmission and consolidation must not be located anywhere close to the antenna, and were moved to a "central processor", located up to 10 km from the antenna location.

The lack of suitable link solutions on the market forced us to develop a new analog link technology that meets all of the above requirements, in addition to the following scientific ones: frequency band: 50 – 350 MHz, gain: ~ 20 dB, SFDR: ~ 80 $dB{\cdot}Hz^{2/3}$.

Of the technology candidates available, we quickly had to exclude electrical coaxial links because of their large attenuation, requiring repeating amplifiers and the associated costs. We thus decided to focus on analog optical signal transmission (RF over fiber). Intuitively, multimode technology has a cost advantage over single-mode technology because of its more relaxed optical alignment tolerances in the transceiver packaging, but requires more expensive low-loss multimode fibers. Single-mode solutions are more expensive to integrate, but can use cost-effective low-loss fibers. To understand the trade-offs involved, we built links in both technologies.

We were able to meet the specifications and requirements with both technologies, and demonstrated multimode links over an equivalent distance of 7 km and the potential of reaching 10 km [2], and single-mode links over 10 km. Power consumption is less than 120 mW per single-mode and 320 mW per multimode link. The entire single-mode link can be built for less than 50 Euro, whereas the multimode link is cost competitive for distances of up to about 2 km. Beyond 2 km, fiber costs render multimode technology inferior over single-mode links for this set of requirements.

Currently, our single-mode links are installed and undergo field testing in the Murchison Widefield Array in Australia, which serves as a precursor for the SKA, as it offers an environmentally comparable location to that of the SKA. Besides its use in radio astronomy, we look forward to seeing our RF over fiber technology make important contributions in related fields for both scientific and industrial applications.

1. Square Kilometre Array, official website: https://www.skatelescope.org/

2. J. Weiss, "VCSEL Based Radio-over-Fiber Link for the Low Frequency Aperture Array Receiver of the SKA," in Asia Communications and Photonics Conference 2014, OSA Technical Digest (online) (Optical Society of America, 2014), paper ATh2E.3.