Applications for Fibre Optics In Radio Astronomy

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Abstract
This paper describes how fibre optic communications play an important role in new telescopes for radio astronomy. It will detail a number of development projects on radio telescopes, worldwide. The Atacama Large Millimetre Array, a $700million project that requires data transfer of 7.68Tera bit/s is used as a detailed example.

Fibre in Radio Astronomy [1]
New instruments in astronomy, designed for the advanced study of astronomy and cosmology, such as the origins of galaxies, stars and planets, require high sensitivity and high resolution. Radio astronomy uses aperture-synthesis techniques to achieve the high resolutions required for this area of research. These techniques involve the transfer of signals from separated antennas to a central correlator location.
Currently, data transfer from antenna to the correlator is performed by narrow-band communication systems, such as microwave or coaxial cable links. When these systems are not practical, for instance, when antenna are distributed across continents, simultaneous observations are recorded on magnetic tapes and subsequently shipped to the correlator.
These forms of data transfer are limited. The bandwidth of microwave links is restricted to ~30MHz by regulations or costs. Coaxial cable lengths are limited to ~1-2km by attenuation and the bandwidth is limited in the region of 50-100MHz at these distances. Tape recording currently has a maximum recording rate of 1Gbit/sec. Since the sensitivity of the telescope is proportional to the square root of the bandwidth, any restriction here will affect the performance of the instrument. In addition, tape recording techniques introduce a significant time lag between observation and correlation, whilst tapes are packed and shipped from the observation site.
Data transfer by fibre optics offers several advantages over existing methods. The additional bandwidth, improved reliability and reduced interference available using fibre transmission will improve and extend the operation of existing and future telescopes.
For instruments that have antennas spread across the globe, the ability to transmit data over continents via fibre will provide results much earlier than tape recording techniques, thus increasing the efficiency of observing sessions.

Development Projects
In recent years a number of development projects have been set up to investigate the radio telescopes of the future. These highly sensitive instruments will rely on fibre optics to transmit the very high data rates they require. The Bit Error Rate (BER) required by the astronomy community is a maximum of 10^{-6} BER. This is less stringent than the requirements for telecommunications networks.
Development projects include:

- e-MERLIN [2] – Upgrade of MERLIN (Multi-Element Radio Linked Interferometer Network) the UK's national radio imaging facility.
- European Consortium for VLBI [3],[4] – (Very Long Baseline Interferometry) The European arm of an international facility with antenna spread across the globe.

- ALMA [5] – Atacama Large Millimetre Array. A brand new instrument in development today, and scheduled to start construction in 2002. This instrument will be completed in 2010.

Each of these projects has a slightly different requirement of the fibre links.
The e-MERLIN antennas are spread across the UK. The links could be up to 500km in length and can be provisioned by private point-to-point links, or, using dark fibre over operator owned networks.
The antennas in the VLBI network are far too distant from the correlator location (JIVE, The Netherlands) to consider private links. Here, it will be necessary to operate over the switched network that exists in Europe.
The ALMA link is necessarily a purpose built fibre link from the antenna to the correlator location. The following section will discuss the design of this link in more detail.

Data Transfer over Fibre Optic Links for ALMA[6].
The ALMA telescope is made up of 64, 12 meter antennas spread across a site located at an elevation of 5000m in the Atacama Desert, Chile. Each of the 64 antennas can be moved to one of 250 possible locations on the site to produce a dynamic array. The longest link from antenna location to the centre of the site will be 25km. Figure 1 shows an artist's impression of what the site will look like.
ALMA is a $700 million project, funded by an international consortium of research councils from the USA and Europe and developed by astronomers located across the globe. When completed, it will be a prestigious instrument that will benefit the astronomy community with new science.

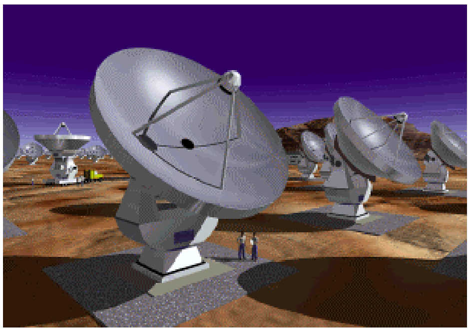

Figure 1. Artist's impression of the ALMA site.

The fibre optic data transfer system is an important part of the instrument. Over the whole site the data transfer system will transport 7.68 Tera bits/sec of data. A fibre optic link from each of the 64 antennas will carry 12 wavelengths at 10Gbit/sec to the correlator, over a single fibre using Dense Wavelength Division Multiplexing techniques (DWDM). The use of a single fibre in this application will simplify the connections at the array site, where each of the 250 possible antenna locations will be connected at a patch panel. Here, the 12 transmitters at the 64 antennas can be connected through to the 12 receivers at the correlator.
The 120Gbit/sec signals are made up from 4 bands, each with 2 polarisations at 2GHz bandwidth digitised to 3 bits precision and encoded.
When encoded, a frame of 128bits is expanded to 160 bits by the addition of 16 checksum bits, a 10 bit synchronisation pattern, a 5 bit frame alignment count and an additional bit used for external synchronisation. The frame is then scrambled using the same frame synchronous scrambling methods (FSS) used in synchronous digital hierarchy (SDH). This produces 12 channels at precisely 10Gbit/sec each. This differs from the 9.953Gbit/sec line rates used in STM-64 telecommunication systems.

The fibre links are required to carry the digital signals from each of the 64 antenna to a central correlator housing, which could be located at the array site, or as much as 70km away from the site centre in the local village of San Pedro de Atacama.
Figure 2. Shows a sketch of the proposed link design for a correlator located on the array site. The 12 transmitters are 10Gbit/sec EA modulated devices housed on four digital boards (one per band). The 12 signals are then multiplexed onto a single fibre using 200GHz spacing. An Erbium Doped Fibre Amplifier is placed before the de-multiplexer and receiver to compensate for the loss over the link.
The DWDM de-multiplexer separates the signals, which are fed into three 4x4 matrix switches used for switching the receiver bands, represented by three wavelengths, to the four quadrants of the correlator. The signal is then received at the correlator and should have a maximum BER of 10^{-6}.

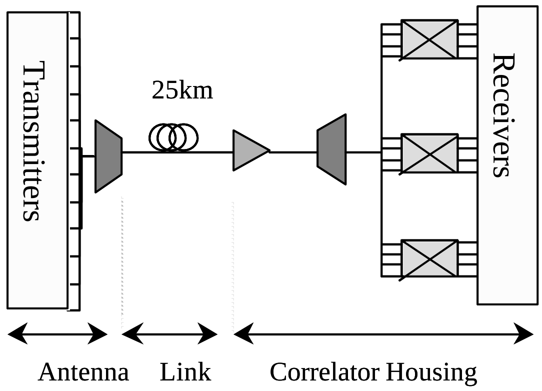

Figure 2. Proposed design for the IF data transfer links

Summary
Fibre optics will play an essential part in the radio telescopes of the future. The large bandwidth available over fibre links will enable astronomers to build sensitive, high resolution telescopes required for future research into extragalactic astronomy and cosmology, star formation across the Universe, stellar evolution and studies of the extreme conditions around black-holes.
Examples of developments on this area are the
e-MERLIN project in the UK, the VLBI project across Europe and the ALMA project, which is a $700 million international collaboration.
The design for the ALMA IF data transfer system has been outlined. 64 separate links will transmit a total of 7.68 Tera bits/sec using DWDM techniques over a maximum distance of between 25 and 95km, depending on correlator location.

References

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