BRAND — a VLBI Receiver to Cover the Band from 1.5 GHz to 15.5 GHz

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In the course of the Joint Research Activity BRAND *(BRoad-bAND)* of RadioNet4 we intend to develop the prototype of a true wide-band VLBI receiver for prime focus operation in the European VLBI Network (EVN). It will cover the frequency range of about 1.5 GHz to 15.5 GHz. The receiver will have a single wide-band feed and amplifier. The analogue signal will not be mixed, but sampled directly for further processing. We will describe the project together with some of the science drivers.

Keywords: VLBI, Instrumentation: interferometers.

1 Introduction

The European VLBI Network (EVN) is a heterogeneous VLBI array which offers observing time organised in three major sessions per year. In each of the sessions about 3 (sometimes up to 5) different wavebands are scheduled. The most common observing wavebands are 18 and 6 cm, other observing wavebands include 90, 50, 21, 13, 5, 4, 1 and 0.7 cm. However, unlike the VLBA rapid switching between the different receivers/bands is not possible as some EVN telescopes require hours to change a receiver. So no multi-band simultaneous observations are possible with the EVN, while this mode is heavily used on the VLBA. Still, better frequency agility in the EVN has been of high priority for many years.

Recent technical development of broad-band LNAs and feeds may improve the situation. One example is the geodetic VGOS system [1], another example is the receiver covering 1.5 GHz to 5.5 GHz, developed within the RadioNet3 JRA DIVA project*. Furthermore, the most modern VLBI backends offer now very large input bandwidths like the DBBC3 [2], also developed by DIVA, which offers $2\times$ or

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*http://www.radionet-eu.org/diva

4×4 GHz bandwidth on input with output data-rates of 32 Gbps or 64 Gbps. Recently a DBBC3 with 4×4 GHz bandwidth has been assembled which delivers as much as 128 Gbps with 2-bit samples. Such data rates can be recorded using a Mark 6 [3] or the EVN "FlexBuff" system. All of the above led us to propose the devlopment of multi-wavelength VLBI for the range of 1.5 GHz to 15.5 GHz.

2 Scientific Motivation

The VLBA offers fast switching between its receivers with switching times of about 10 s. This is a very attractive option for observers, as they can observe two, three or more frequency bands in one run. This unique capability resulted in a high user demand for this mode of observation. In addition to saving valuable observing time, spectral index maps can be made for the same observing epoch. If phase-referencing is used, precise registration of source positions is possible between the maps made at different frequency bands. One of the scientific applications enabled by this capability is the precise determination of core shifts in the jets of active galactic nuclei.

Unfortunately the EVN has failed to implement frequency flexibility at all telescopes even though this has been a priority for more than 15 years. Some antennas at least can switch between sub-sets of receivers on the order of minutes or faster.

A truly wide-band receiver could cover two or more bands simultaneously, which would allow to observe in a similar way as the geodetic VGOS antennas. Like for VGOS, the raw correlated data of such a wide-band observation could be fringe-fitted over the whole frequency range where the non-linear term as a function of observing frequency introduced by the Ionosphere has to be fitted simultaneously with the linear slopes of the phase over frequency (delay) and time (delay-rate). If the different observed sub-bands of the total frequency range can be connected coherently via this fringe-fit, the phase relation of these sub-bands is defined, such that maps resulting from the different sub-bands are registered correctly relative to each other.

While VGOS has started with a design of 4×1 GHz bands in the range from 2.3 GHz to 14 GHz, a receiver covering a wide-range quasi continuously would be superior due to potentially more usable bandwidth, and smaller gaps between the sub-bands, which should make fringe-fitting over the whole range more reliable. Very effective mitigation of RFI even before the LNA would be indispensable.

Provided such a wide-band receiver can be built it will be much superior to fast switching of receivers. The UV-coverage would be vastly improved due to wide frequency band covered, but multi-frequency imaging software is another requirement.

A receiver with a bandwidth from 1.5 GHz to 15.5 GHz would be compatible with VGOS and would allow again for the "old" EVN antennas to participate in joint geodetic VLBI, allowing future updates of high precision antenna positions and contributions to the International Celestial Reference Frame. But also "world" arrays could be formed together with the VGOS network for special observations/occasions.

The impact of this receiver on spectral line VLBI would be high, as several different maser types in different frequency bands could be observed simultaneously with proper positional registration. Variations of polarised emission as a function of frequency could be studied over a very wide frequency range without ambiguities in rotation measures. Even some single-dish observations could profit, like flux variation studies which could be done in many bands at the same time, like determining rotation measures, as well as observations of pulsars over a very wide frequency range.

3 Proposed technical solution for a receiver from 1.5 GHz to 15.5 GHz

The BRAND proposal for a single cooled prototype receiver covering 1.5 GHz to 15.5 GHz for the EVN (and other telescopes) was submitted and accepted by the European Comission as part of the RadioNet project. The BRAND prototype will be developed between January 2017 and summer 2020. It will be installed at the Effelsberg radio telescope for testing in single dish mode and interferometric mode. Partner institutions of BRAND are Max Planck Institute for Radio Astronomy in Bonn (Germany), Istituto di Radioastronomia in Noto (Italy), Onsala Space Observatory (Sweden), Instituto Geográfico Nacional – Yebes Observatory (IGN, Spain), Netherlands Institute for Radio Astronomy (ASTRON) and Ventspils International Radio Astronomy Centre (VIRAC, Latvia).

The project will merge technology developed for VGOS in the last 10 years [9], with our experience gained in the previous RadioNet3 JRA DIVA. The innovative characteristics will be the huge 1:10 frequency range, superconducting RFI filters, analogue signal processing without any frequency conversion, direct RF sampling of the full band, extremely high output bit-rate, and digital conversion of linear to circular polarisation, as the receiver will have a linear feed.

The feed is the most challenging part of the whole receiver. It will be designed for prime focus operation, as the appropriate wide-band feeds like the eleven feed [5], the quad-ridged Flare Horn (QRFH) [6] or Dyson conical quad-spiral array (DYQSA) [7] are most advanced. Nevertheless, one WP is devoted to studying solutions for secondary focus, as the aim beyond RadioNet is to deploy BRAND receivers at all EVN stations.

The effect of unavoidable strong radio interference in some parts of the frequency band of the receiver [8] will be greatly reduced via HTS (High Temperature Superconductor) filters [10], so that the LNA/amplification chain and the digitiser will be protected from saturation. The HTS RFI filters will have to be adapted for each site. For this reason, in one WP the local RFI situation will be measured — for the more easily accessible sites — and will be assembled into a document for each telescope, together with other local requirements and interfaces.

LNAs and amplifiers seem to be available on the market, so that the emphasis here is to find an optimal design. The analogue part of the receiver will only consist of the LNA, the amplifier chain, and the signal transport to the backend/digitizer. Broad-band RF over fiber optic (FO) links will be considered to transport the RF signal from the output of the front-end to the input of the digitizer. FO links allow the transportation of large bandwidths over long distances with modest insertion losses, unlike coaxial cables, which would introduce a large slope across the 1.5 to 15.5 GHz band and would imply the use of very complicated equalizers.

The analogue signal will be digitised by a sampler which can handle the full band in one chip. The output data-rate will be up to 128 Gbps. The digital back-end part of the receiver can be used also for other reiceivers with an IF less than 15.5 GHz. Firmware will include direct sampling conversion, poly-phase filterbank, and digital down-converter. This firmware will allow to select any parts of the input band. The linear polarisation will be converted to circular in firmware. Additional digital RFI mitigation will be applied, multi-band total power detector and possibly a polarimeter will be included.

The advantages for the user and the observatories will be that new improved science can be carried out with the EVN equipped with BRAND receivers. Fewer receivers have to be maintained and more observing time will de facto become available, as all bands between 1.5 GHz and 15.5 GHz will be available simultaneously. With this novel capability the EVN would take a leading role in VLBI.

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