LS/CX Upgrade Scientific Options Memo

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Background

The LS/CX upgrade project proposes to increase the maximum instantaneous bandwidth of the 20cm, 13cm, 6cm, and 3cm receivers on the ATCA to take advantage of the increased correlator capacity made available by the CABB upgrade. The project, as proposed, would merge the 20 and 13cm bands, increasing the frequency coverage from the present (1.25 - 1.8 GHz & 2.2 – 2.5 GHz) bands to approximately 1.1 – 3 GHz. Similarly, the 6 and 3 cm bands would be merged from the current (4.4 – 6.9 GHz & 8.0 – 9.2 GHz) bands to approximately 4 – 12 GHz. These frequency ranges could be accessed by the two 2 GHz bands available to CABB. The project can be broken roughly into three scientific parts: upgrade the signal path to get the existing 20, 13, 6, and 3 cm bands into CABB; upgrade the LNAs on the 20/13 cm system to allow access to 1.1 – 3 GHz; and upgrade the LNAs on the 6/3 cm system to allow access to 4 – 12 GHz. In this memo we discuss the scientific benefits and costs of each stage. More detail on the scientific background to the project can be found in the science case dated 3 October 2006.

Stage 1 - LS/CX into CABB:

The first stage of the project involves ensuring that the current receiver systems can be correlated in CABB prior to the decommissioning of the old correlator. Obviously if we are to continue to have access to the centimetre bands at the ATCA this part of the upgrade is absolutely essential. This stage of the project will provide an immediate increase in instantaneous bandwidth accessible from 2 x 128 MHz at 20cm and/or 13cm to 550 MHz (the full range of the 20 cm receiver) **or** 300 MHz at 13cm. For projects in only the 20cm band this provides an increase in instantaneous sensitivity of about 50%. There is virtually no improvement in the 13cm band. For projects that require maximal bandwidth, such as the Lunar-Cherenkov experiment described in the full science case, the slight increase in bandwidth is advantage.

It is important point to note here that, as currently specified, the switchover to CABB will remove the capability to do simultaneous observations at 20 and 13 cm. Approximately 15% of the current observing proposals request this mode, and it constitutes an even larger percentage of observing time. For most of these projects, such as spectral index studies of star-forming regions or radio galaxies, the loss of simultaneity will mean a doubling in the observing time required to do dual frequency projects. For the Faraday tomography experiment described in the science case for the LSCX upgrade the loss of simultaneity does not make up for the slight increase 20cm bandwidth. For the class of projects that involve monitoring time-variable phenomena, the loss of simultaneity means the irrecoverable loss of information about the multi-frequency time behaviour of sources.

From the ATCA community's perspective the loss of the capability to observe 20 and 13 cm simultaneously is unacceptable as a long-term solution. An obvious remedy to the temporary loss is to quickly upgrade the LNAs to receive the 20/13 cm bands in a single 1.9 GHz bandwidth as planned. An alternative path would be to combine the current narrowband 20 & 13 cm into a single spectrum to regain simultaneous access to the 20/13 bands. This is not scientifically preferred but would be an acceptable solution if Stage 2 could not proceed. In either case it is imperative that the simultaneous access to 20 & 13 cm be restored quickly.

Stage 2 – L/S LNA Upgrade:

The second stage of the plan is to upgrade the LNAs to merge the 20 and 13cm receivers into a single 1.9 GHz bandwidth from 1.1 – 3 GHz. As described in the science case, this project is motivated by the desire to improve the continuum sensitivity of the ATCA and enable new highly exciting scientific projects that demand maximal instantaneous bandwidths for pseudo-spectral analysis. One such project is magnetoionic tomography and RM studies of the Milky Way and nearby universe (led by Gaensler). This topic is one of the key scientific drivers for the Square Kilometre Array as well ASKAP. With a broad instantaneous bandwidth the ATCA would have an unrivalled capability to probe a wide range of rotation measure space. Similarly, searches for Lunar Cherenkov radiation (led by Ekers) rely on the proposed increased bandwidth to effectively increase the time resolution of their searches for nanosecond pulses. For this application the detectability of the signal goes linearly with total bandwidth (as opposed to as the square root for most radio astronomy applications). For continuum studies the improved bandwidth will provide an improvement in instantaneous sensitivity of ~270%, significantly reducing the observing time required for any 20 or 13 cm projects. Furthermore, the improved bandwidth gives a significant improvement in *u-v* coverage due to multi-frequency synthesis techniques. The techniques developed to image data with a 3:1 frequency coverage will be applicable to EVLA (provided the timescales are short) and SKA.

An important consideration in this project is the interference environment at Narrabri in the 1.1 – 3 GHz band. This has been evaluated by Mal Smith in a comprehensive survey and attached as an appendix here. The conclusion from this RFI survey is that there are no unexpected obstacles in this band. Access below 1.2 GHz is not recommended because of strong transmitters, however this was not specified in the current plan. In the 1.2 – 3 GHz range the strongest transmitters are already known to observers. The improvements in CABB (multi-bit sampling, channel isolation) will make coping with the interfering signals easier although part of the system design may include notch filters for strong RFI. Furthermore, access to an extended frequency range will enable observers to recover sensitivity lost in the current system to RFI.

This stage of the project provides very large increases in instantaneous sensitivity (~270%), access to an area of parameter space that is not (nor will be) accessible by any other Southern hemisphere telescope, and solves the problem of loss of 20 and 13cm simultaneous accessibility. From the community perspective this is very highly ranked upgrade path.

Stage 3 – C/X LNA Upgrade:

The third stage of the project plan is to upgrade the 6/3 cm receivers for access to the full frequency band from 4 – 12 GHz. The dominant scientific drivers for this stage of the project are increased continuum sensitivity and better access to spectral regions not presently available or poorly covered. With the LNA upgrade the instantaneous bandwidth will increase from 2.0 GHz at 6 cm and 1.2 GHz at 3cm accessible with CABB and the current receivers to 2 x 2.0 GHz anywhere in the 4 - 12 GHz range. In terms of instantaneous sensitivity this is a modest improvement of only ~12%. The main scientific benefit lies in the improved access to the spectrum. For example, the upgrade would significantly improve (by a factor of ~2.5) the system temperature at the important 6.6 GHz methanol (CH_3OH) line, which lies at the upper frequency limit of the current 6 cm receiver. Projects that model the spectral energy distribution of sources, such as star-forming regions and radio galaxies, would benefit from access to parts of the centimetre spectrum that are currently unavailable.

The RFI environment in the 4 – 12 GHz band was also assessed by Mal Smith and shows that this band is relatively clean and should pose no impediments to the proposed upgrade.

This third stage provides improvements in spectral access and sensitivity, but these could be considered marginal. From the scientific community's perspective this is a low ranked project.

Summary

The first stage of the project, the input of the current centimetre receivers into CABB, is as critical to the continued success of the ATCA. In its current inception this first step will remove the capability to simultaneously observe at 20 and 13 cm. As a long-term solution this is unacceptable to the community and some solution to re-enable simultaneous 20 and 13 cm observations is needed. The preferred solution, because of its scientific gains, is to upgrade the L/S receivers with an LNA covering the entire 1.2 – 3 GHz band (avoiding the RFI below 1.2 GHz). This second stage of the project provides an enormous increase in instantaneous sensitivity of ~270% and enables new scientific pursuits that cannot be attempted with any other telescope. This is a highly ranked upgrade path. The third stage of the project, an upgrade to the C/X receivers for coverage of the entire 4-12 GHz band, will marginally improve the continuum sensitivity in this band and provide improved spectral access. This upgrade path is desirable but much lower ranked than the L/S upgrade.