Scientific Implications of a 16 MHz XCELL

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Operation of the AT correlators at a basic rate of 16 MHz instead of the originally planned 10 MHz has an impact on the scientific capabilities of the AT in the areas of continuum sensitivity, bandwidth smearing and spectral line observations. There are also some practical consequences for the LBA. Some of the consequences of going to a 16 MHz clock rate are:

(1) an increase in the maximum bandwidth from 160 to 256 MHz. This improves the sensitivity of continuum observations by about 27% - equivalent to a 60% increase in observing time over a 160 MHz bandwidth.

(2) Bandwidth smearing is increased by a factor 1.6. This will affect only wide-field continuum observations at L-band and can be avoided by trading correlation products for frequency channels.

(3) The number of narrowand i.f. filters required is increased by one. The required bandwidths are: 0.5, 1, 2, 4, 8, 16, 32, 64, 128 and 256 MHz.

(4) The compact array and LBA will have a compatible set of i.f. bandwidths and sampling rates. Digital output from LBA tapes can be fed directly into the correlator without conversion. The eventual upgrade to a 64 MHz bandwidth for the LBA can be immediately accommodated in the compact array i.f. system.

(5) The maximum velocity coverage for CO observations at 115 GHz is increased from 415 to 665 km/s per i.f. channel. This greatly improves the spectral line capability at this frequency for observations of the galactic centre and external galaxies.

Provided the XCELL chips can operate at 16 MHz without degradation of performance or lifetime the increased bandwidth and LBA compatibility are ample reasons for changing to a 16 MHz clock rate.

Discussion

If a 16 MHz operating rate is possible for the XCELL chips the natural bandwidths for the AT become 2^n x 16 MHz instead of 2^n x 10 MHz. The current specifications with a 10 MHz clock are for n = -4 (0.625 MHz) to n = 5 (160 MHz). The upper limit on n is set by the number of parallel inputs to a module (32). The lower limit is determined by spectral line considerations. For the same range of n, a 16 MHz XCELL gives bandwidths from 1 MHz to 256 MHz. The maximum bandwidth for continuum observations is therefore a factor 1.6 greater than for a 10 MHz XCELL. This represents an increase in sensitivity for continuum observations of about 27%, equivalent to a 60% reduction in observing time for the same sensitivity as an observation made with a bandwidth of 160 MHz.

A consequence of synthesis mapping with this much bandwidth is radial smearing with distance from the field centre. This is a linear function of the percentage bandwidth and the distance. For a factor 1.6 increase in bandwidth there is 1.6 times as much radial smearing at the edge of the field. In the worst case for the AT (L-band) 256 MHz bandwidth observations will be smeared by about 50 F/N for the 6-km array, where F is the distance from the field centre (in units of a primary beamwidth) and N is the number of frequency channels used. With 16 frequency channels per product, the smearing is about a factor three near the first null in the primary beam pattern. This is a lot of smearing, but there are various ways around it. In the first place, there is little to be gained from making continuum observations at 256 MHz (1 bit) instead of 128 MHz (2 bit). Doing that reduces the smearing by a factor two with only a minor reduction in sensitivity. One can also reduce the smearing by using more frequency channels (at the expense of correlation products) or by going to a narrower bandwidth. Finally, the number of observations likely to be affected by bandwidth smearing is low.

For spectral line observations the important thing is to provide useful velocity coverage and resolution for all types of objects. The velocity coverage is given by $V = B/f_o \times c$ where B is the bandwidth, f_o is the observing frequency and c is the speed of light. The velocity resolution is given by $\Delta v = wV/N$ where N is the number of frequency channels and w is a factor which accounts for the weighting used (generally between 1.2 and 2.0).

At high observing frequencies wide bandwidths are important in order to provide sufficient velocity coverage to include the line emission plus some baseline for reference. With a 160 MHz bandwidth the maximum velocity coverage possible in a single correlation product at 115 GHz is about 415 km/s. This is not enough for good observations of the galactic centre, which requires a velocity range of about 500 km/s, or for observing external galaxies, many of which require a range of about 1000 km/s. By increasing the bandwidth to 256 MHz the maximum velocity coverage at 115 GHz becomes 665 km/s. This is enough for the galactic centre and increases greatly the number of galaxies which can be comfortably observed without concatenating i.f.s or shifting the local oscillator.

At low observing frequencies narrow bandwidths are required in order to achieve the desired velocity resolution with a finite number of frequency channels. For observations of astrophysical masers a velocity range of about 100 km/s and a resolution of 0.1 km/s is required. This means that 1000 channels should be used (preferably 2000 channels with Hanning smoothing). The lowest frequency masers known are at 1612 MHz. At this frequency 100 km/s corresponds to a bandwidth of 0.54 MHz. Thus, for the 16 MHz XCELL another IF filter (0.5 MHz) will be required to bring the L-band velocity coverage down to 100 km/s. There are L-band observations (e.g. isolated HI clouds; OH absorption) which might benefit from even lower bandwidths. However, few lines are expected with widths narrower than 0.1 km/s so a minimum bandwidth of 500 KHz should suffice.

By reconfiguring the XCELL chips within a module an increase in the effective number of frequency channels with decreasing bandwidth can be accomplished up to a factor 32. The maximum number of channels per module available without using recirculation is limited to 16x32 = 512. If the XCELL operates at 16 MHz this many channels are available for bandwidths of 256/32 = 8 MHz and below. For the 10 MHz XCELL the same limit applies beginning at 5 MHz. In order to achieve a velocity resolution of 0.1 km/s at L-band two modules will be needed per correlation product for a 0.5 MHz bandwidth unless recirculation is implemented.

There are important advantages for the LBA in going to a 16 MHz clock. One is that the compact array i.f. filters will have the same bandwidths as the Mark III tape recorder system. This compatibility will make it easier to provide the required input signals for the recorders, and also to accurately phase and tie the array. Another is that the digitized tape recorder output can be fed directly into the correlator without conversion. Finally, when the upgrade to a 64 MHz LBA bandwidth is accomplished, the compact array i.f. system will be nicely matched to a 64 MHz tied array output.