MILLIMETER ARRAY
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Some Remarks on MMA System Design

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Despite the conclusions of the MMA proposal, I feel that there are substantial advantages to an all digital, FX approach to signal processing, because it gives rise to a conceptually simple, highly modular system. I shall discuss a system based on the technology of the VLBA correlator: an FX system built around special purpose butterfly chips with a 32MHz clock rate.

The scientific question to be decided is how much bandwidth should be instantaneously analysed for spectroscopy. The scientists, naturally, will want as much as possible. On the other hand, the cost of the correlator will increase nearly linearly with that bandwidth, and will be a very expensive part of the system, even with a minimum acceptable bandwidth.

Just for purposes of discussion, lets consider an analysed bandwidth of 128 MHz, which is surely near the minimum, if not below it. This is 450 km/s at 86 GHz, only 170 at 230 GHz. This could be used to analyse a single spectrum of that width, or split in two to analyse two spectra of half that width (which could be at quite different frequencies if two LOs are provided in front of the sampler). This is, however, clearly too little bandwidth be make it worthwhile splitting it four ways. If many lines are to be covered simultaneously, for variability or phase referencing reasons, it is more effective to timeshare between them on a rapid cycle.

I shall describe below a definitely non-optimised straw-man system built on these principles.

The IF, after final frequency conversion, would be fed into a sampler module with a 2 GHz sample clock. There would be two (one/polarization) of these samplers (if enough money is invested in the correlator to get enough bandwidth analysed to justify splitting it in 4, one might have 4 samplers). After the VLA experience with bandpass problems introduced in the analog data transmission system, I favor locating the samplers at the antennas, even without an analysis of what the problems are likely to be with a modern data transmission system. I do not address here the question of the number of bits per sample - I suspect that two or three is an appropriate answer.

These bits would be sent to the correlator building, presumably on a bundle of optical fibers.

After the sample stream is reconstructed at the correlator building, it would be delayed to a common clock, and then sent to a serial to parallel converter which would send successive blocks of 64 samples to a string of butterfly chips. A seven chip deep FFT string would apply fringe rotation, apply the sub-sample portion of the delay, and do the FFT such that the output is a set of complex samples of 32MHz wide channels. Successive samples of the same channel may then be obtained from successive FFT strings in the engine. This stage of processing requires 7*64 = 448 butterfly chips for each sampler, a large but not oppressively large number. Two such boxes (one for each polarization (sampler)) would be required for each antenna.

To provide the further spectral analysis, one could in principle select some (4 for a 128 MHz analysed bandwidth) of these datastreams and feed them into a further set of FFT strings, which for a very small price (perhaps 40 chips) will then analyse the spectrum to whatever degree of fineness is desired. In practice it is probably possible to do rather better than this, in effect factoring the FFT to produce much lower response to out-of-band signals than just taking the raw 32MHz channels. Most such schemes seem to involve some data exchange among the last stages of the FFT strings, and the complexity of that is not yet clear to me.

The spectral correlator then consists of a set of 4*40*40 cross correlators. The VLBA correlator is, by comparison, 8*20*20, just half the size. This spectral correlator is about 3200 chips. However, the complexity of the correlator is not adequately measured by the number of chips; the need for having long runs of wire on a two dimensional grid, and preserving clocking integrity over these fairly large chip arrays makes the job more difficult than the antenna based engines, despite the larger total number of chips in the latter.

The size of the correlator doubles, of course, if it is desired to produce full polarization cross products. I suspect that this is sufficiently uncommonly needed in the spectroscopic case that sacrificing half the analysed bandwidth to get it would be acceptable.

The remaining 32MHz channels could be analysed in a continuum correlator. Little thought has gone into the question of how best to do continuum correlation in modern digital logic. It seems to me that it might be just possible to design a chip that would accept samples from 20 antennas, shifted in at a 32MHz rate, and perform the 210 cross multiplications in the time that the next set of 20 samples was being shifted in. If necessary to simplify the logic, assumptions could be made about the RMS and correlation of the samples, which would be acceptable for a continuum correlator. Then, a 32MHz continuum correlator would consist of 160 chips, or the full continuum, cross polarized correlator for 1 GHz in each polarization, of 20,000 chips. Per unit bandwidth, this approach would need only about one fifth as many chips as a full spectral correlator.

All of the above depend on a rather specialized form of "glue" to hold things together, shuffling samples from various FFT strings to arrange the data in the correct order for the next stage of processing. It it might be worthwhile to design special "sample shuffler" chips to do this. Actually, a modest number of gates is needed for these functions, but the number of pins is critical. The correlator would contain perhaps 2000 such "sample shuffler" chips if they could have of the order of 100 pins, but might need 20,000 if they can have only 24 pins.

To summarize, the advantages of this sort of digital approach are:

- Only two LO synthesizers per antenna, with widely spaced lockpoints (say 200 MHz spacing).
- Only two sampler modules per antenna.
- Digital data transmission, with no effect of the transmission system on bandpasses.
- No analog lobe rotators.
- A very modular construction, with the largest module only about 1000 chips.