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Some Remarks about Three-level Sampling

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In the spectral line case, sampling to three levels is, at the Nyquist rate, a factor of 1.27 more sensitive than two-level sampling. Although this advantage is reduced if oversampling is used, it still remains, and will remain in some degree for any problem in which the bandwidth of the tape recording system exceeds the natural bandwidth of the observation. This includes not only spectral line observations, but also low frequency observations (below about 1 GHz) where the available spectrum is likely to be limited by interference.

In cases where the tape recorder bandwidth is the limiting factor, the three-level sampling has essentially the same signal to noise ratio as the two-level, provided the three-level sampled data are encoded five samples into eight bits (3**5=243, 2**8=256; it fits).

There are other advantages as well for three-level sampling. Even at the high frequencies, it is worth while narrowing the RF bandwidths, to minimize our exposure to interference, since it can be done without loss of signal to noise ratio. Second, the correlator design becomes easier and less expensive, because the clock rate is reduced by a factor of 1.6 for the same recorder bit rate, an advantage that much more than makes up for the slight extra complexity of a full three-level by three-level correlator (rather than the three- by two-level conventional in VLB correlators).

A few remarks should be made about the mechanics of encoding and decoding three-level to binary. It seems easiest to do at a 25MBit/second rate. Wider channels would be converted by paralleling converters. At a 25MBits/sec rate, we have 320 ns to produce our 8 bit byte, or 64 ns for each three-level sample. This is sufficient to encode by a simple multiply-and-add algorithm. Multiplying by three is a single adder (adding the number to the number shifted left one) and adding in the new sample is also a single adder. The carry propagation time through an eight bit ECL adder is less than 20ns. So the propagation through two adders and a register could just about be done in 64ns. It looks like encoding a 25Mbit stream would require about 10 ECL wirewrap chips (four adder chips, two registers, and a generous allowance of four for control). Faster streams would require paralleling. A rack of VCRs (100MBits/sec) would require about 40 chips (half of a small socket plane) for doing this encoding. This doesn't seem exessive.

Decoding is probably most conveniently done in a 256*10 bit memory. The cycle time for a 25MBit/sec stream is, as above, 320 ns, which may be slightly too fast for a conventional MOS ROM, and may require paralleling or use of bipolar ROM. Even so, the cost of the decoder does not seem excessive. If done in bipolar, it seems likely that it could be done in a single (but expensive) 24 pin chip.

Given the spectral line sensitivity arguments it seems to me very clear that we should implement three-level sampling. Given that we do so, the question arises as to whether there are arguments of comparable strength for the implementation of two-level sampling. It seems to me that there are not. Two-level sampling appears to be a very expensive add-on of no obvious advantages.

The things that must be added to the system for two-level sampling are considerable and expensive. Besides the samplers themselves, one for each IF stream, one needs additional baseband filters, 1.6 times broader banded than the equivalent three-level filter, one filter for each IF channel and each bandwidth implemented. One also needs to make the correlator work 1.6 times faster. In either possible correlator technology, it is likely that this will increase the cost of the correlator by something very close to the ratio of speeds: 1.6. The order of magnitude price for the two-level add-on is a million dollars.

Are there any advantages to two-level sampling to make up for the above considerable costs? I shall knock over a few straw men.

"Three-level samplers require ALCs on each channel before sampling." Indeed they do--but the cost pales to insignificance relative to those discussed above.

"The three-level clipping correction is a nuisance to apply--two-level is well known and easy to program." Yes it is; however, it isn't necessary very often. We haven't used it at all at the VLA because it is a nuisance, and we still have other problems at higher levels than it introduces. If it were a problem, we could include it; it is only a bit of manpower.

"There are some cases where you are willing to sacrifice the signal to noise ratio in order to get a wider simultaneous band." For instance, a wide water maser source, where one would like to have the whole thing at once for phase referencing. This case is at least realistic, and it is only my judgement that suggests that it is not worth the cost of the add-on.

"All VLBI has been two-level. We might have unanticipated problems." This is perhaps the strongest objection, in the sense that it is the real impulse behind other, much weaker arguments. The only answer is that there are some of us who have been doing interferometry with three levels for a decade, and don't find it contributing to our problems.

In summary, it seems to me that the VLBA system should be built as a three-level system, and that consideration should be given to whether a two-level operation mode is justified as an optional add-on.