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Bandwidth Synthesis With Two Channels

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D. Shaffer, in VLBA memo number 148, considered the use of the VLBA in a bandwidth synthesis mode. Specifically, he compared bandwidth synthesis done via a few fixed frequency channels with that done by a single, frequency agile, channel. He concluded that the former was noticeably superior, a conclusion to which I will not take exception. However, it seems worthwhile to extend this comparison to comparing a few fixed channels with two frequency agile channels. This is done below.

The arrangement of a few channels in a minimum redundancy array (per J. Leech) to synthesize a nearly uniform coverage is, by now, a well understood technique. The use of two agile channels, although intrinsically simpler, is novel, and we should devote a moment's thought to how one would use them.

The appropriate method of combining results would, as in the fixed channel case, appear to be the fourier transform. That is, the two dimensional fourier transform of the correlation coefficients is taken, in the frequency and time directions. The peak is found and its location gives the delay and fringe frequency offsets of the source from the a priori model. The properties of a observational technique can be examined by looking at the "beam", that is, the result given if all correlations are replaced by unity.

A conceptually simple technique to use two channels would be to simply have a linear sweep in frequency. Then, viewed from either the frequency or time directions, the observations appear to have uniform coverage, and the "beam" has the sine(x)/x form given for uniform coverage in the sections along either the delay or fringe frequency axis, and the first sidelobes, along these axes, are 21% of the maximum. However, the highest sidelobes fall off these axes. The highest occurs when there is one turn of phase in both frequency and time directions; the height of this sidelobe is 61%. The power in this sidelobe can probably be spread out by coding the frequency as a more complex function of time. (It should be noted that unlike fourier mapping, we are here simply interested in resolving ambiguities, so the peak sidelobe is the only item of interest, not rms value or any other sidelobe measure.) On the other hand, once LO offsets have been determined, the residual in fringe frequency is likely to be much smaller than one turn in the observation, so that concentrating the ambiguity power off the delay axis may be highly desirable.

In practice, of course, a linear frequency sweep is too much trouble to implement. One would switch frequencies in discrete steps, of size some reasonable fraction of the bandwidth. The time between steps would, again for practical reasons, be rather large, large enough that the geometric delay of up to 21 ms could be neglected. Thus, for the figures appropriate for the VLBA, one would picture switching the LO by perhaps 5 MHz every half second. Thus, if the front end bandwidth was 500 MHz instantaneous, an observation would last 25 seconds. If more time on source was desired, one could then repeat the observation, or, since the maximum channel separation contributes most to the knowledge of delay, simply leave the channels at maximum separation. In fact, since the end time of an observation is much easier to control than the beginning time, one would probably enter the observation with the maximum channel separation, and then sweep the two channels together, starting 25 seconds before the end (or making a longer, slower sweep if the source is weak and needs more time to resolve the ambiguities).

The technique does not depend on the short-term LO stability, as Shaffer points out that the single channel method does. Because the two channels are symetrically disposed about the center frequency, short term LO phase variations will not move the position of the peak in the delay direction (they can drop its amplitude, of course, by loss of coherence). They can, clearly, change the location of the peak in the fringe frequency direction, as they must in any method.

I have not thought very clearly about the problem of pulsar observations. However, it seems likely that the method will work substantially unchanged if the time between frequency switches is made rather longer than a pulse period. This would limit one to a minimum observation length of one minute for a one second pulsar. On the other hand, one might be able to do substantially better by tracking a pulse as dispersion sweeps it through the frontend bandpass. Thus one would synthesize a wide bandpass not only for delay determination, but also for signal to noise ratio.

Finally, the bottom line. Which method is better? It is very close. The two agile channel method has the advantage that the largest sidelobes are found off the delay axis, where other information can help reject ambiguities (having an ambiguity of 40 mHz in fringe frequency after relative LO rates have been determined seems rather unlikely). On the other hand, it loses a few percent in signal to noise ratios, because in practice, the LO switching times would be synchronized in UTC instead of relative to the wavefront. The decision is close enough that I could not recommend abandonment of the few static channel method, although the two agile channel method seems slightly superior to me.