NATIONAL RADIO ASTRONOMY OBSERVATORY
Tucson, Arizona

MEMO jan 29, 1988

TO: hybrid spectrometer group
FROM: Anders Emrich

SUBJECT: Software for data reduction

There are some points that are unclear concerning the software package for the NRAO HySpec, mostly about methods compensating for systematic errors. This note will point out a few items and try to come up with suggestions.

The four major points will be:

1-measurement of total power within a subband and threshold level control
2-time domain to frequency domain transform
3-image rejection
4-linking of subspectra

1 TP and ADC

Precise measurement of the total power within a subspectra will be important to avoid platforming in the final spectrum. There are several methods of measuring the total power depending on the ADC and ALC design. A few basic designs are outlined below.

a-Separate total power measurement followed by ALC and fixed threshhold ADC. This method is conservative and the Van Vleck correction is straightforward. Problems could be dc-drifts in the ADC and non linearity in the TP-detectors, both possible to compensate for in software. Very large dynamic range.

b-As above without continous level control. More complicated to do a correction for non ideal threshold levels in the ADC. Would probably need to use total power information and 0 lag to do that? (dc drifts and total power variation both increase the 0 lag). A dc level feedback would ease the problem. Dynamic range limited to 1-2 dB without efficiency degradation.

c-Feedback of comparator output to the treshold levels. Using either the threshhold levels or a separate TP-detector.). Straightforward Van Vleck correction. > 6dB dynamic range. The threshold type TP indicator should be very linear but suffers from noise degradation because it measures voltage instead of power. (???)

d-No ALC and fixed threshold levels, using the 0-lag as total power detector. Sensetive to dc drifts, a feed back of the dc or a separate measurment of the comparators outputs is probably needed. More complicated Van Vleck corrections. 1-2 dB dynamic range without degradation. The 0-lag detector should be easier to calibrate then a diod type detector.

With state of the art SIS receivers with Tsys=100 K Orion can create a 2-3 dB dynamic range and chopper wheel calibration requires a 6 dB range. A 1 dB calibration signal would probably be better to use in any case as this is more within the working conditions of the system.

2-Transforms

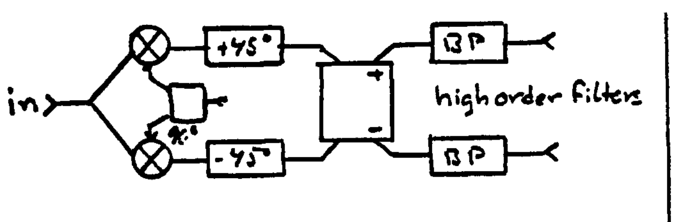
The most popular transform in this case is of course the FFT. It is fast, robust and well know but suffers from sidelobe effects and poor resolution if these are removed by windowing.

Another method that doesn't have these drawbacks is the MEM (Maximum Entropy Method), also called AR for Auto Regressive or all poles method. This method has no inherent sidelobe effect and can give superresolution in the spectrum under certain circumstances, but is more sensetive to noise (higher resolution!), especially if too many poles are used.

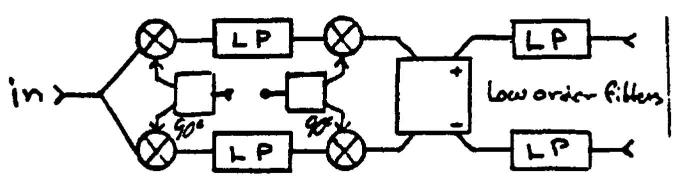
These methods complements each other, the FFT suitable for resolved spectra and the MEM for high resolution with good signal to noise ratio. Both methods should be included in the package. The sidelobe effect could be problematic for the sideband rejection processing outline below.

3-Enhanced image rejection

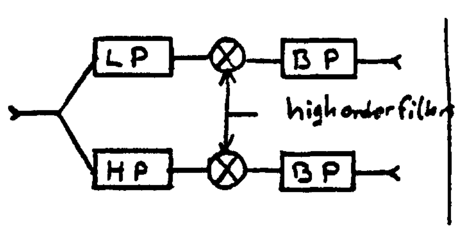
Image cancelation techniques will have a limited supression of the unwanted sideband becouse of amplitude and phase errors in the implementation. A standard implementation could look like:



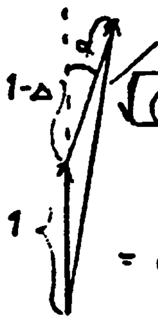
If the passive phaseshifter would be substituted by for a filter and a mixer in both the upper and lower part of the circuit a linear phaseshift would be created and a better sideband rejection would be possible.



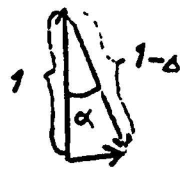
A conservative design without phase cancelation technique could be implemented as (A Dowd memo 13)



But let us now look at what really happens in the system. We introduce a phase and an amplitude error and look at the results.



non suppressed = $\frac{\sqrt{(1+(1-\Delta)\cos\alpha)^2+((1-\Delta)\sin\alpha)^2}}{2}$ in amplitude = compression



suppressed = $\frac{\sqrt{(1-(1-\Delta)\cos\alpha)^2+((1-\Delta)\sin\alpha)^2}}{2}$ in amplitude = rejection

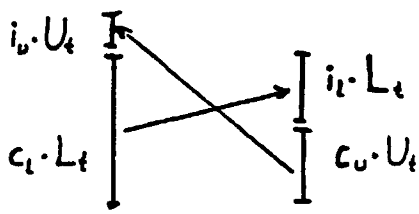
by phase and amplitude errors

	Δ = 0		0.05		0.1		0.15		0.2	
α = 0	1.00	0	0.975	0.025	0.95	0.05	0.925	0.075	0.9	0.1
2	1.00	0.017	0.975	0.030	0.95	0.053	0.925	0.077	0.9	0.101
4	1.00	0.035	0.974	0.042	0.949	0.06	0.924	0.082	0.899	0.104
6	0.999	0.052	0.974	0.057	0.949	0.07	0.924	0.089	0.899	0.110
8	0.997	0.070	0.973	0.072	0.947	0.083	0.924	0.099	0.897	0.112

This table shows that an amplitude error creates a larger compression of the non suppressed sideband than a phase error for the same rejection factor. This can be used to find out if the bad rejection is mostly because of phase error or amplitude error by comparing the filter bandpass shape to the total circuit bandpass shape and the rejection shape. 0.1-0.2 dB precision is probably needed but the correlator itself could be used to obtain this.

This small scale ripple effect could cause problems when using reference smoothing techniques if not compensated for. (Same smoothing in the calibration for example).

Let us now see what this will give us in the measured spectrum, channel pair by channel pair.



$$L_m = c_l \cdot L_t + U_t \cdot i_u$$

$$U_m = c_u \cdot U_t + L_t \cdot i_l$$

$$L_t = \text{Lower true} = \left(L_m - \frac{i_u U_m}{c_u}\right) / c_L$$

$$U_t = \text{Upper true} = \left(U_m - \frac{i_l \cdot L_m}{c_l}\right) / c_u$$

} will disappear in calibration

(This is a mathematicly derived result!)

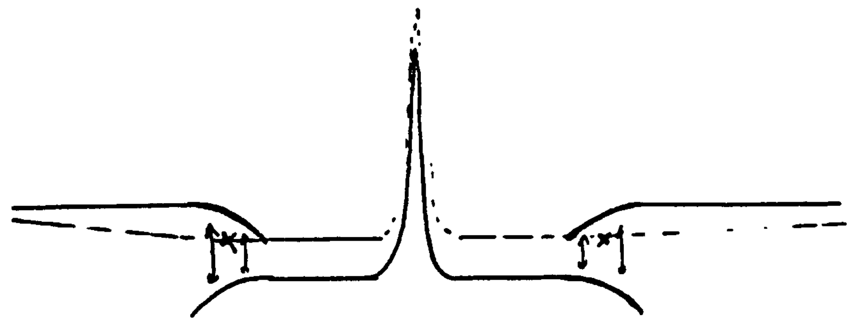
The image coefficients are easy to measure by just inserting a signal in one band and compare the results in both bands but the compression factor within the parenthesis is harder to evaluate. Using the difference of phase and amplitude error compression is probably needed but the factor should be somewhere 0.95 and 0.99. An improvement of 5-10 dB image rejection should be possible.

What if we dont look at both bands? It will be well worth to have fast look at the other sideband as we still will have a 20 dB rejection, a 1 minute look would give an equivalent observing time of more than 100 hours for a compensation with the same noise level.

The method could also be used for resolving folding effects around the overlapp points due to aliasing, or for enhanced sideband rejection in the frontend.

4-Linking of subspectra

As tests have shown there can be problem in linking subspectra together, small steps could be created because of non linearities in the total power measurments. This should be compensated for to the first order by calibrating the detectors, easily done by using the platforming effect as calibrator. We also have redundant information in the overlap region that can by used. These overlapping channels can be used in several ways, one is outlined below.



1-calculate an average difference over the overlap region, weighted by the bandpass shape and the deviation of the total power count from some basic figure.

2-Use this difference to either multiply the subband values in both signal and reference to compensate for the gap, or add a linear baseline to the subband in the final spectrum.

3-Make a weighted avarage channel by channel in the overlap region.

Algorithm examples

MAIN PROCESS:

```
For both signal and reference
     get autocorrelation funtion
     get total power information
     (normalise)
     Van Vleck correction(+ threshhold correction?)
     transform (FFT+window or MEM)
     (denormalise = multiply by TP)
     (link subspectra)
     (enhance image rejection)
(smooth reference)
signal-reference/reference x calibration
(link subspectra)
(enhance image rejection)
```

ENHANCED IMAGE REJECTION

```
for each channel
     newch[i]=oldch[i]-imagefactor[i]*oldch[imagefreq[i]]
```