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TO: VLBA AEER ARW

FROM: Alan E.E. Rogers & Alan R. Whitney

SUBJECT: Multi-level sampling options for VLBA

A] 3-level sampling

For spectral line the relative SNR is given by

$$S/N = (2/\pi)\ (e^{-d^2/2})^2/2 \int_d^\infty \frac{e^{-x^2/2}}{\sqrt{2\pi}}\,dx$$

where d is the decision level in units of sigma. The SNR is optimised with $d=0.61\sigma$ and yields a degradation factor (the inverse of the relative SNR) equal to 1.235. For continuum the relative SNR should take into account the number of bits needed to record the data in any comparison. For the 3-level case the information rate (for optimal encoding) is

$$R = -p_o \log_2 p_o - (1-p_o) \log_2 (1-p_o)/2$$

$$\text{where } 1-p_o = 2\int_d^\infty \frac{e^{-x^2/2}}{\sqrt{2\pi}}\,dx$$

The figure shows how the normalised continuum degradation factor (for a fixed number recorded bits) varies with decision level in the case of 3-level sampling. The optimum performance is achieved at $\sigma \simeq .9$ and results in a loss factor of 1.49 at 1.22 bits/sample or about 5% better than the 2-level loss factor of $\pi/2=1.57$. However this gain assumes optimal encoding of the samples taking into account their probability distribution. In practice three 3-level samples would probably be encoded into 5 bits or take 1.67 bits/sample*. In this case the 3-level degradation factor would be optimised by choosing the decision level which optimises the spectral case which results in a net degradation factor of 1.59. This is about 1% worse than the 2-level case.

B] Degradation factors for multi-level and oversampling

The Table shows the degradation factors. In my opinion we have 4 options:

1] 2-level sampling plus oversampling for spectral line case

*or 5 samples into 8 bits at 1.6 bits/sample

2] 3-level sampling plus oversampling for the spectral line case

3] 2-level sampling for continuum plus 3-level sampling and oversampling for spectral line

4] 2-level sampling for continuum plus 4-level sampling and oversampling for spectral line

In my opinion we must support 2-level sampling option for the following reasons:

a] It is well understood and very immune to instrumental defects.

b] It is immune to interference effects which may saturate the AGC or alter the decision threshold during recovery.

c] It is the only easy way of avoiding calibration errors in the case of strong pulsars.

d] It optimises continuum sensitivity more easily than does the 3-level case which requires an AGC or dynamic threshold.

e] It is compatible with present VLBI systems

On the basis of the above I would like to eliminate option 2 and consider only 1, 3, and 4. If cost were not a consideration option 4 provides the best performance. However it is likely that option 4 will result in significant complications in the processor which would be avoided in option 1 and to a lesser extent in option 3. Thus I will examine only the added hardware required in option 3 to see if it is worth the 17% improvement it yields for spectral line observations in the 4 X Nyquist oversampled case.

C] Added hardware needed to provide 3-level sampling

a] 3-level sampler + AGC for each of 32 channels or approx 64 I.C.'s per acquisition system

b] Encoding of 3 samples into 5 bits for each of 32 channels or approx 96 I.C.'s per acquisition system

c] Additional intermediate bandwidth filters

e.g. 4 Mbit/sec sample rate would need 2 MHz filter for 2 level sampling and 2X3/5 = 1.2 MHz filter for 3-level sampling

or intermediate sample rates to use the same filters.

d] Decoding of 5 bit blocks into three 3-level samples or approximately 64 I.C.'s per acquisition system

e] 3X3 level feature in VLSI correlator chip - already provided

Assume $10 per IC a somewhat optimistic estimate for the addition cost for 10 acquisition systems would be $22,400. A similar addition sum would probably be needed in the processor.

# Levels	Mode	Nyquist	2 x Nyquist	3 x Nyquist	4 x Nyquist	Encoding
2	spectral	1.57	1.35	1.29	1.27	
2	continuum	1.57	--	--	--	1 bit/sample
3	spectral	1.23	1.13	1.11	1.09	
3	continuum	1.59	--	--	--	5/3 bits/sample
4	spectral	1.13	1.07	1.06	1.05	
4	continuum	1.69	--	--	--	2 bits/sample
3	continuum	1.49	--	--	--	1.22 bits/sample

TABLE MULTI-LEVEL AND OVER-SAMPLING DEGRADATION FACTORS

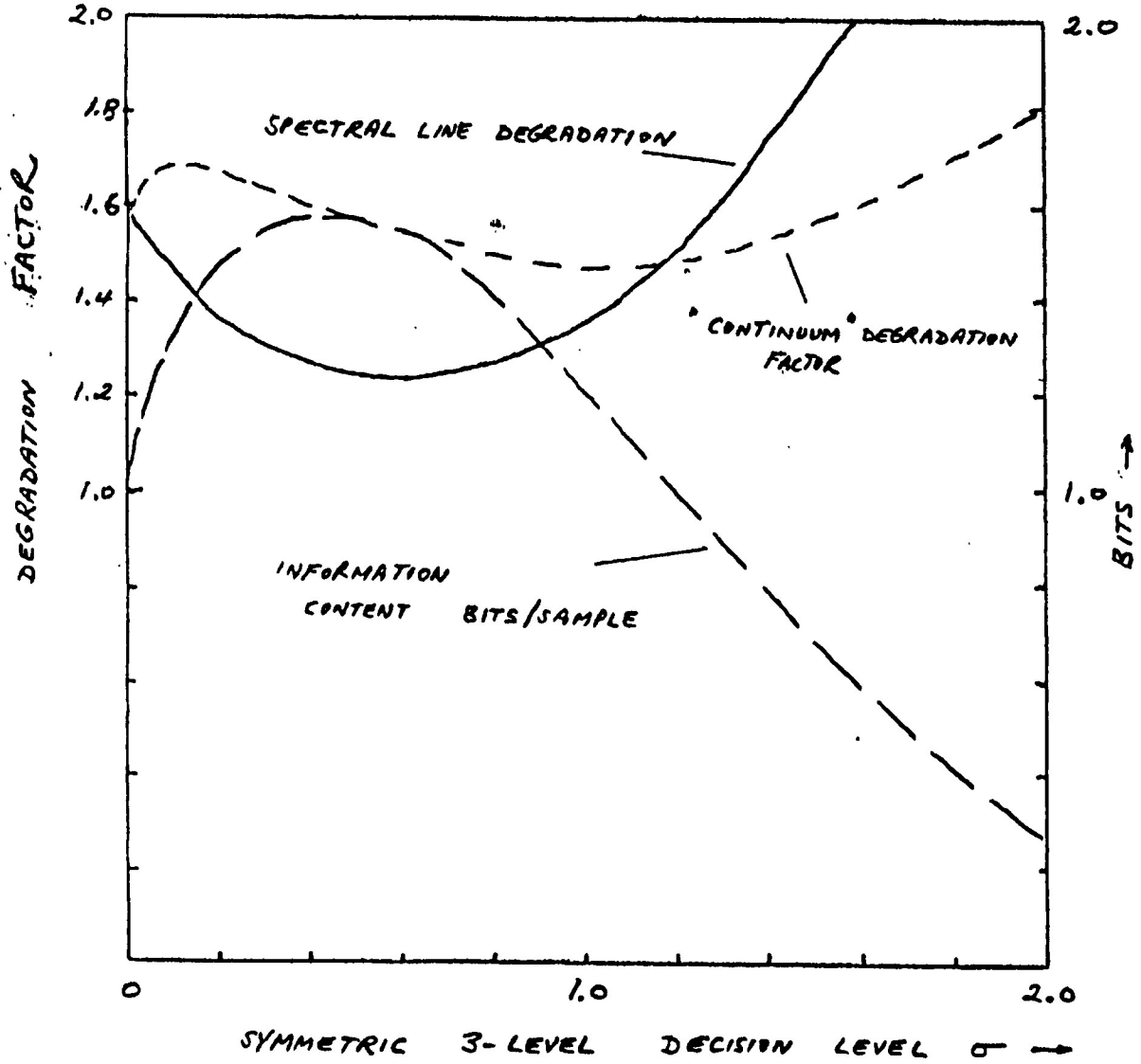

Figure Degradation factors for 3-level sampling of continuum and spectral line data