CSIRO DIVISION OF RADIOPHYSICS

THE AUSTRALIA TELESCOPE

FILE : AT/20.1.1/016

LEVEL and GAIN CONTROL in the AT

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The current system diagrams (AT/20.1.1/015, figs 1,3 and 4) show coarse and fine level controls prior to each sampler and gain controls before the array "tying" point. The purpose of this note is to define the range and resolution of these controls and to discuss briefly their operation.

Fine Level Control

Error signals for the fine level control and for sampler DC offset correction are derived at the central site by monitoring the distribution of samples amongst the available states. This monitoring obviously has to be done *before the superimposed 0/180° phase changes are removed* by bit reversal, etc. For all sampling modes the error signal for DC offset is:

$$\varepsilon_{DC} = \frac{N_+ - N_-}{N_+ + N_-}$$

where N_+ and N_- are the numbers of positive and negative samples respectively. For the 1 and 2 bit samplers at the antennas, and the 2 bit narrow band samples at the centre, this quantity is measured at the input to the line correlator. For the 4 bit samplers at the antennas it is measured at the 64 MHz continuum correlator after conversion to 2 bits.

The errors for level control at the 2 and 4 bit samplers are derived at these same places and are given by:

$$\varepsilon_{LC} = \frac{N_{1+} + N_{1-}}{N_{1+} + N_{2+} + N_{1-} + N_{2-}} - 0.658$$

where N_{1+} and N_{2+} are the numbers of samples in the lower and upper positive ranges respectively. A zero error implies that the 2 bit sampler level is set at 0.95 of the RMS signal level. A positive error means that the sampler level was set higher than this and needs to be reduced. Note that for the 4 bit converter, one pair of the available levels must be set at ±0.95 RMS.

These levels will become the equivalent 2 bit reference levels after 4-2 bit conversion. For the best distribution of samples over the 16 ranges of the 4 bit sampler, it is the third level which should be set at 0.95 RMS. Thus the *truth table for the 4-2 bit converter* is shown (over):

4 bit	2 bit	
0111	01	
0110	01	
0101	01	
0100	01	
0011	01	+0.95 RMS
0010	00	
0001	00	
0000	00	0
1000	10	
1001	10	
1010	10	-0.95 RMS
1011	11	
1100	11	
1101	11	
1110	11	
1111	11	

These error quantities are accumulated over an integration period (or more for very fast observations). They are transmitted to the appropriate data sets during the following integration period and implemented at the end of that integration.

If the coarse level control is to have steps of 2 dB, then the range of the fine controller should be such that the *spacing between levels can be adjusted approx. ±15% in steps of approx. 1%.*

The offset or zero level must however, be set much more precisely. If the signal to be sampled has RMS and DC values V_{RMS} and V_{DC} and has a bandwidth β_N that after correlation will be subdivided into N_{ch} channels of bandwidth β then if the DC sampler error in the zero frequency channel is to be no more than 10% of the noise:

$$\left(\frac{V_{DC}}{V_{RMS}}\right)^2 < \frac{\beta}{10\,\beta_N\,\sqrt{\beta\tau}} = \frac{1}{10\sqrt{N_{ch}\,\beta_N\tau}}$$

In practice this requirement is too stringent because the zero frequency channel can be discarded and only its sidelobes in the other channels remain important. With "Hamming" type windowing these sidelobes are only about 1%. We therefore might reduce the precision required by a factor of ~100 in power. A further slight reduction could be obtained if the transform of the window actually used were scaled to fit the zero frequency data and subtracted from the entire spectrum. This would have to be done before any gain correction or frequency shifting were done.

If we neglect this latter possibility and assume 1% "hamming" sidelobes, a 12-hour integration, and the largest value of $N_{ch}\,\beta_N$ that can be associated with a given sampler, we arrive at the following requirements for allowable DC offsets:

Sampler	β_N (MHz)	Number channels	β	$\frac{V_{DC}}{V_{RMS}}$
1 bit (antenna)	256	128	2 MHz	5.2×10^{-4}
2 bit (antenna)	128	256	0.5 MHz	5.2×10^{-4}
4 bit (antenna)	64	512	125 kHz	5.2×10^{-4}
2 bit (centre)	4	8192	0.49 kHz	5.2×10^{-4}
2 bit (tied array)	4	8192	0.49 kHz	5.2×10^{-4}

Note that the specification given earlier for the accuracy of the *non-zero reference levels* of the samplers was $\approx$1% of V_{RMS}. The *zero reference level* on the other hand, must be set to $\approx$0.05% of V_{RMS}, that is, to ~20 times greater precision.

Coarse Level Control

In the previous section we assumed *steps of 2 dB* for this control. The range required depends on two parameters: (1) the extent to which the gains of the numerous receiver configurations can be pre-set to give a constant output level, and (2) the variation of system temperature during observations. A range of ~3 dB should be enough to compensate for (1). Much larger variations than this will be encountered during observations at X-band and above due to atmospheric emission and during observations of the Sun at all frequencies. In the worst case, the atmospheric emission can rise to ~300K, i.e. an increase of 8-10 dB over the normal system temperature. (Data obtained in such adverse conditions is probably not useable anyway.) For solar observations 2 x 20 dB steps should be adequate.

Thus a *range of ~12 dB attenuation in 2 dB steps* will provide adequate coarse level control with the addition of *2 steps of 20 dB attenuation for solar observations.*

Error signals for the coarse level controllers are derived from a detector-integrator continuously monitoring the signal at the input to each sampler. Corrections to the signal level are however, only to be made in the interval between integrations and must be coordinated with the fine level control so that a 2 dB course step is accompanied by a compensating 2 dB step in the sampler reference levels. Probably a single microprocessor should be used to control the attenuators and sampler reference levels with error inputs from both the level monitor at the sampler and the sample distribution monitor at the correlator.

Gain Control

When the compact array is to be "tied" for use as an element of the LBA the gains of all channels have to be equalized prior to being summed. If the gain of the "tied" beam were the only consideration, then gain steps of 2 dB would result in a degradation of < 3% in tied array sensitivity. A more stringent requirmeent however, is that imposed by the need for accurate polarization measurements. For this purpose the tied array gain must be the same in each polarization. Thus if 1% polarization is to be detectable, then the gains of the two arrays must not differ by more than 2% in power. To achieve this it is not necessary for channels from different antennas to have the same gains. Large differences between antennas reduce sensitivity but only differences between polarization channels in a given antenna will cause the two polarized tied array beams to differ. The power gains of corresponding channels therefore need to be set to

$$\frac{2\sqrt{6}}{\sqrt{2}}\,\% \quad = 3.5\% \text{ or } 0.15 \text{ dB}.$$

Thus steps of 0.25 dB are required in the gain control attenuators.

The error signals to control these attenuators are provided by phase sensitive detectors on each channel immediately prior to the "tying" point. These monitor the modulated noise added to the channels at the RF.

As was the case for the level control attenuators the gain control attenuators should only be switched between integrations. Gain switching and monitoring must be coordinated with the operation of the coarse level control attenuator at the 4-bit sampler. Any change in its state produces a direct change in channel gain.

The range of the gain control attenuators should be about the same as for the level control attenuators. They have to compensate for the difference in gain between channels in the narrow band tuning stages and in principle also have to remove attenuation switched in by the level controllers at the front end samplers in response to increases in atmospheric emission. In fact we are only aiming to keep the gains equal rather than to maintain an absolute value. Common level variations can therefore be removed by the level controllers which follow the tying points, and therefore a more limited range of gain control can be accepted. Attenuator stages of 0.25, 0.5, 1,2 and 4 dB should be adequate.

After the tying points it is not necessary to maintain the gains of the tied array channels equal. If the noise switching at each antenna is phased to give synchronous switching at the tied array point, then the actual gain of each tied channel can be monitored with a PSD in the usual way just prior to sampling. The level controllers can then be allowed to operate independently on each polarization channel.

Computer links to gain and level monitors and controllers

The outputs of all gain and level monitors and actual attenuator settings must be made available to the synchronous computer via appropriate data sets so that calibration factors can be derived. Likewise, these calibration factors must then be made available to the controllers.

Phase of attenuators

Because attenuators can be switched in and out at random times they should introduce phase changes of $\ll 1^\circ$ when switched. If this cannot be achieved, then phase calibration tables will need to be maintained for each attenuator so that the correlator control computer can make appropriate corrections.

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