CHAPTER 4

SIGNAL PROCESSING ALGORITHMS

4.1 Introduction. In addition to the computation of the three radar moments (Part B of this Handbook), the signal processing includes several additional processing steps designed to enhance the meteorological information content of the data. The sections that follow describe the functional attributes of this processing and identify the known operational considerations.

4.2 Automatic Pulse Repetition Frequency Selection. The automatic pulse repetition frequency (PRF) technique analyzes echo returns in the lowest elevation scan, determines that PRF yielding the smallest obscuration, and assigns that to the elevation scans contained in the lowest 7.0°. This new VCP definition is downloaded to the RDA and invoked at the beginning of the next VCP.

Using data from the surveillance waveform in the lowest elevation scan, echo power is computed. Then a measure of the overlaid echoes is computed for five PRFs from the allowable Doppler ranges for that site. The PRF yielding the least overlaid echo is selected for subsequent processing up to 7.0° in elevation. Above that elevation, there are no problems with overlaid echoes.

4.3 Point Clutter Rejection. Strong point clutter in the power-sum array is censored by the programmable signal processor, using the following algorithm.

Clutter Detection -- The rules for detecting strong point clutter are as follows: The nth bin is declared to be a point clutter cell if its power value exceeds those of both its second nearest neighbors by a threshold factor (TCN). In other words,

if	P(n)	exceeds	TCN*P(n-2)
and	P(n)	exceeds	TCN*P(n+2)

where

TCN	is the point clutter threshold factor (always greater than 1.0),
P(n)	is the power-sum value for the nth range cell, and
n	is the 250 meter (500 meter in long pulse mode) range cell index.

Clutter Censoring -- The formulae for censoring strong point clutter in the power-sum array P(n) via data substitution are as follows. If the nth range cell is an isolated clutter cell (i.e., it is a clutter cell, but neither of its immediate neighboring cells is a clutter cell), the replacement schemes:

Replace	P(n-l)	with	P(n-2)
Replace	P(n)	with	0.5*P(n-2) + 0.5*P(n+2)
Replace	P(n+l)	with	P(n+2)

If the nth and (n+l)th range bins constitute an isolated clutter pair, the bin replacement scheme is:

Replace	P(n-l)	with	P(n-2)
Replace	P(n)	with	P(n-2)
Replace	P(n+l)	with	P(n+3)
Replace	P(n+2)	with	P(n+3)

Note: Strings of three or more successive clutter cells are prevented by the nature of the algorithm.

4.4 <u>Analog to Digital Converter Gain and Bias Compensation</u>. The A to D converter function contains test features serving two purposes. During normal operation, these tests are used to null out DC biases which would degrade the base data. During calibration operations, these features input test signals to monitor A to D converter bias and linearity performance.

4.5 <u>Automatic Gain Control Prescaling.</u> The Automatic Gain Control (AGC) in the receiver adjusts overall system gain to ensure receiver response is linear. Larger input signals cause the AGC to automatically insert attenuation into the received signal path to prevent receiver saturation. This introduces a nonlinear component to the measured signal power. The signal processor uses information from the AGC control circuits to compensate for the added attenuation, forcing the overall signal response to be linear.

4.6 <u>Clutter Filtering.</u> The Hardwired Signal Processor performs clutter filtering, removing up to 30 dB of clutter power in the reflectivity channels and up to 50 dB of clutter power in the Doppler channels. Filtering is accomplished by a classic high pass filter designed to remove components of the received signal below an established frequency. Hardware implementation is by means of a time domain, recursive, 5-pole elliptic infinite impulse response filter. The filters do not discriminate between signal components associated with clutter from those associated with actual meteorological returns, removing all signal components below the pass band point. This can introduce a bias in reflectivity estimation for weather signals which have significant low velocity components. The filters also require initialization upon pulse repetition frequency changes and perform best when the PRF is held constant. As such, they are unsuitable for the batch mode. For batch mode, a simple 2 pulse canceller is used. These filters also introduce a phase distortion component which makes them unsuitable for anticipated signal processing techniques such as range velocity ambiguity mitigation based on phase coding.

4.7 Interference Suppression. The receiver can have an optional interference suppression unit installed. This hardware, when active, monitors received signals in the frequency band just above and just below the bandwidth of the receiver. If significant amounts of RF energy are detected just outside the main receiver channel, the presence of interference is assumed and a flag is sent to the signal processor while the interference is perceived to be active. The HSP contains hardware controlled by this flag which can affect the processed data on a bin by bin basis. For the reflectivity estimates, if the interference flag is set during a current bin, valid data from a previous bin is repeated. This continues as long as the interference suppression flag is active. This minimizes reflectivity bias errors due to interference detection. For the Doppler channels, the data value is set to zero for bins while the flag is active. This minimizes velocity estimate errors due to contamination from interference.

4.8 Range Averaging. The receiver contains a hardware matched filter component which is designed to maximize signal to noise ratios for the return signals. It is out of necessity designed for optimal performance for the short pulse mode only. When operating in long pulse (VCP 32 for example) an additional signal processing function is needed. In the PSP, an additional operation is performed on data collected in the long pulse mode. This operation averages time-series samples over 750 meter range segments and reduces the time series sampling rates from one sample per 250 meters to one sample per 750 meters. Formulas for the filtering and sample rate reduction are given:

For each m in 0 …NP_S-1,

$$I(0,m) = (2/3)I'(0,m) + (1/3)I'(1,m)$$
$$Q(0,m) = (2/3)Q'(0,m) + (1/3)Q'(1,m)$$

For each m in 0 …NP_S-1 and each n in 1 …N-1,

$$I(n,m) = (1/3)I'(3n-1,m) + (1/3)I'(3n,m) + (1/3)I'(3n+1,m)$$
$$Q(n,m) = (1/3)Q'(3n-1,m) + (1/3)Q'(3n,m) + (1/3)Q'(3n+1,m)$$

Where

NP_S = the number of surveillance sweeps in the radial.

N is the number of 750 meter range resolution cells in the output time series

I'(k,m) and Q'(k,m) are the in-phase and quadrature components of one of the input surveillance time-series arrays for the kth 250 meter range cell of the mth sweep.

I(n.m) and Q(n,m) are the in-phase and quadrature components of the corresponding time series array for the nth 750 meter range cell of the mth sweep.

For the surveillance time series only, this function combines the echo power from four 250 meter cells into a single one kilometer estimate for short pulse mode and averages two 500 meter cells into a single one kilometer output for long pulse mode.

4.9 Range Unfolding. The programmable signal processor resolves range ambiguity of radial velocity and spectrum width by assigning each 250 m (500 m in long pulse) range cell to one of the following three categories:

- Valid Doppler return (which may be derived from either first, second, third, or fourth trip echoes)
- Insufficient signal-to-noise ratio (SNR) Doppler return,
- Overlaid Doppler return.

The determination of overlaid Doppler returns is made by comparing the echo power for each range cell, which is obtained from a low pulse repetition frequency waveform, to the echo power from each other cell that will be overlaid, i.e., folded, on this cell under a high pulse repetition waveform. If, for the high pulse repetition frequency, the unambiguous range is ra, the returns at a distance, d, from the radar will be overlaid with returns from d$\pm$nra, where n is an integer. For each range cell, the echo power is compared to the echo power of all the other range cells separated by an integer multiple of r_a. If the echo power for the range cell is not greater than the echo power of every other potentially overlaid cell by a threshold parameter (TOVER, default 5 dB), then the Doppler return for this cell is not valid, i.e., it is either overlaid or insufficient. If the echo power for this cell does exceed any significant echo power from overlay candidates by this threshold parameter, then the cell will be labeled valid, subject to the SNR test, described below.

Echo power is compared to the noise level in order to determine those range cells with an insufficient SNR. If the echo power is greater than the noise level by a threshold parameter, then the cell is labeled as being either valid or overlaid, depending on the result of the above test. If the echo power is not greater than the noise level by this threshold parameter, then it is labeled as insufficient, independent of the above test.

4.10 Velocity Dealiasing. Although velocity dealiasing is part of signal processing, i.e., it is not a meteorological algorithm, this algorithm is executed in the RPG computer.

The base data Doppler velocities from the radar are ambiguous. Velocities outside the region $\pm V_{NyQ}$ (Nyquist velocity) are shifted by the radar by $\pm 2n\ V_{NyQ}$ into $\pm V_{NyQ}$ where n is an integer. These errors, or aliasing of the velocity, are corrected by using continuity of velocity along radials and between adjoining radials at the same range. The velocity dealiasing algorithm proceeds as follows:

For each radial, the ambiguous velocity at each sample bin is compared with the unambiguous velocity at a previous (closer in range) sample bin. Only velocities that come from range bins meeting the SNR threshold and that are not range folded are considered good. The five bins closer to the radar are searched for a valid sample. When the previous five sample bin values indicate below SNR threshold or range folded, a nine-point average of surrounding data is used for comparison. The nine points will include the four preceding unambiguous values along the same radial and five values from the previous radial. The five values are taken from the bin adjacent to the sample volume and the next four bins in increasing range. When a nine-point average cannot be computed, the algorithm looks back (toward the radar) up to 30 range cells (adaptable value) on the current working radial, and ahead (away from the radar) up to 15 range cells (adaptable value) on the previous saved radial. If a velocity for comparison cannot be found, the value is rejected as bad. If a valid velocity for comparison is found, the algorithm compares the difference in these velocities to a threshold (TH_l). This threshold is typically 5 m s^{-1} (10 knots) for clear air mode, and 10 to 15 m s^{-1} (19 to 29 knots) for precipitation mode. If the velocity difference is greater than TH_1, the algorithm attempts to place the ambiguous velocity to within TH_1 of its nearest radial neighbor (or nine- point average, etc.) by adding or subtracting integer multiples of 2 V_{NYQ}

If the nearest radial neighbor is within five range cells, but the ambiguous velocity cannot be dealiased to within a velocity difference TH_1 of this neighbor, the ambiguous velocity is compared to a nine-point average of its neighbors. This nine-point average is as defined above. If the ambiguous velocity can be dealiased to within a derived threshold TH_2 of the nine-point average, it is dealiased. If the ambiguous velocity is not within TH_2, nor can it be dealiased to within TH_2, the ambiguous velocity is rejected as bad. TH_2 is the larger of TH_1, 40% of the nine-point average, or twice the standard deviation of the nine points.

When the ambiguous velocity is locally isolated, the current working radial (up to 30 range cells toward the radar) or previous saved radial (up to 15 range cells away from the radar) is searched for a velocity with which to be compared. If such a velocity is found, and the ambiguous velocity is within a velocity difference threshold TH_3 or can be dealiased to within TH_3, it is dealiased. If a velocity to compare with is found, but the ambiguous velocity cannot be dealiased to within TH_3, the ambiguous velocity is rejected as bad. The threshold TH_3 is typically 1.5 TH_1.

The algorithm also checks for dealiasing errors. This is referred to as reunfolding. It will correct such errors on the current working radial when either: 1) a site-adaptable number of range cells, NUM_1, exhibit large velocity differences, TH_4, in azimuth, or 2) two large velocity jumps of opposite sense, exceeding TH_5 in magnitude, exist along the radial and the jumps are separated by no more than a site-adaptable number of range cells, e.g., 75. The parameter NUM_1 is typically 5 for clear air mode and 10 for precipitation mode. TH_4 is approximately 60% of the Nyquist interval. The parameter TH_5 is the smaller of 80% of the Nyquist interval and 45 m s^{-1} (87 knots). For the case of large azimuthal shear, velocities are reunfolded using a least-squares technique. The technique compares the velocity in question with its nearest neighbor in the preceding azimuth and nearest neighbor in the same radial (farther from the radar). The velocity in question is reunfolded if, by adding or subtracting a Nyquist interval to or from it, the sum of squared velocity differences between the velocity in question and its two neighbors is minimized.

If the reunfolded radial contains no large velocity jumps, it may be copied for subsequent use. If only one large velocity jump exceeding TH_5 in magnitude is identified along the current working radial, this radial will not be copied for subsequent use. The copy of the previous radial is allowed to be up to five radials old. If five successive radials have large velocity jumps, azimuthal information becomes unavailable for dealiasing.

If five consecutive velocities have been removed from the radial, an attempt is made to replace them. For each rejected velocity, a reference velocity is calculated. This reference velocity is either a radial neighbor or the average of the 15 unambiguous velocities along the previous radial (the four closer, the current, and the ten further in range). When the first value removed in the string of five is within a relaxed threshold TH_6 of the reference velocity or can be dealiased to within this threshold, the initially removed velocity is replaced. If the rejected velocity can be dealiased to within TH_6 of the reference velociy, it is dealiased. The threshold TH_6 is the lesser of 40% of the Nyquist interval and 22.5 m s^{-1} (44 knots). Once the first rejected velocity is replaced, subsequent replacement uses the threshold TH_3 to compare the next rejected velocity and a running average of the replaced velocities.