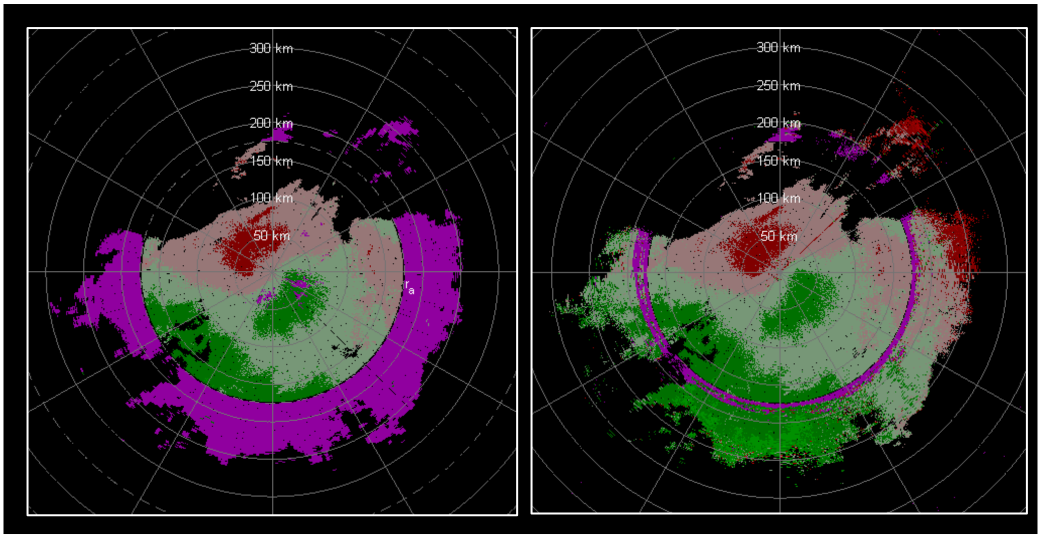
NEXRAD Range-Velocity Ambiguity Mitigation
SZ-2 Algorithm Recommendation



Range-velocity ambiguities on the current WSR-88D (left) and
using the recommended SZ-2 algorithm (right)
(KOUN, 10/08/02 1511 GMT)

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1. Introduction

This report describes the improvements to the SZ-2 algorithm as reported in the FY2003 NCAR-NSSL Interim Report, “NEXRAD Range-Velocity Ambiguity Mitigation SZ(8/64) Phase Coding Algorithm Recommendations”, 15 August, 2003. The SZ-2 algorithm herein described has been updated with respect to censoring and clutter filtering,

The recommended SZ-2 implementation is by-in-large an extension of the aforementioned Interim Report. However, the following important changes have been made: 1) ground clutter is no longer assumed to be only in the first trip, 2) a spectral based ground clutter filter “GMAP” by SIGMET is now used, and 3) censoring logic and thresholds have been updated.

The first revision (dated July 2005) includes changes to handle incorrectly defined ground clutter maps (e.g., operator-defined “filter everywhere” maps) and refinement of the rules to handle clutter in multiple trips. The latest revision (dated May 2006) includes modifications to use dynamic windows, unbiased spectrum width computations, and efficient processing of non-overlaid echoes.

To facilitate the programming of these changes, the recommended SZ-2 code builds on the existing prototype implementation by the ROC. In addition, the latest revision brings the algorithm description much closer to the actual RVP-8 implementation.

The revision from 04/13/07 includes logic changes (pages 6 and 7) to correctly handle data windowing when the default window is not rectangular. These changes are also needed for compatibility with Super Resolution.

The latest revision from November 2007 includes a simple fix for the 4th trip overlay case (step 14.ii) and improved power-ratio recovery-region censoring rules and thresholds (step 24 and updated table with censoring thresholds).

When implemented on the NEXRAD ORDA the recommended SZ-2 algorithm will significantly outperform the legacy range-velocity mitigation algorithm. However, the SZ-2 algorithm is still in its infancy and needs to be tested on much more experimental data. Further refinements can and should be made to obtain the best data quality and to minimize the amount of censored data.

2. SZ-2 Algorithm Description

The SZ-2 algorithm was first introduced by Sachidananda et al. (1998) in a study of range-velocity ambiguity mitigation using phase coding. Unlike the stand-alone SZ-1 algorithm, SZ-2 relies on power and spectrum width estimates obtained using a long pulse repetition time (PRT). The SZ-2 algorithm is computationally simpler than its stand-alone counterpart as it only tries to recover the Doppler velocities associated with strong- and weak-trip signals and the spectrum widths associated with the strong-trip signal. Analogous to the legacy "split cut", the volume coverage pattern (VCP) is designed such that a non-phase-coded scan using a long PRT is immediately followed by a scan with phase-coded signals using a short PRT at the same elevation angle. Hence, determination of the number and location of overlaid trips can be done by examining the overlay-free long-PRT powers.

The following is a functional description of the SZ-2 algorithm tailored for insertion into the signal processing pipeline of the RVP-8. The description is divided into two parts: long PRT processing and short PRT processing with emphasis given to the latter. The algorithm is specified in a general manner and is not constrained to specific PRT values.

2.1. Long-PRT Processing

2.1.1. Assumptions

1) There is no phase modulation of the transmitted pulses.
2) There are no overlaid echoes.
3) The number of pulses transmitted in the dwell time is M_L.
4) The number of range cells is $N_L = T_{s,L}/\Delta t$, where $T_{s,L}$ is the pulse repetition time (long PRT) and Δt is the range-time sampling period (e.g., in the legacy WSR-88D $\Delta t = 1.57$ µs).
5) The algorithm operates on one range cell of time-series data at a time (M_L samples).

2.1.2. Inputs

1) Time series data for range cell n: $V_{n,L}(m) = I_{n,L}(m) + jQ_{n,L}(m)$, for $0 \le m < M_L$, where m indexes the samples (or pulses).

2.1.3. Internal Outputs

These outputs are saved internally for later use during the short-PRT processing:

1) Clutter filtered powers: $P_L(n)$, for $0 \le n < N_L$
2) GMAP removed powers: $C_L(n)$, for $0 \le n < N_L$
3) Spectrum widths: $w_L(n)$, for $0 \le n < N_L$

2.1.4. External Output

1) Reflectivity: $Z_L(n)$, for $0 \le n < N_L$

2.1.5. Algorithm

SZ-2 processing in the long-PRT scan is an extension of the processing performed in any of the operational surveillance scans. Time-series data are clutter filtered using the GMAP clutter filter only in those locations where the bypass map indicates ground clutter contamination. Clutter-filtered time-series data are used to compute total power and lag-one correlation (R_L) estimates. The signal power (P_L) is obtained after subtracting the noise power from the total power, and spectrum width (w_L) is estimated from the P_L/R_L ratio. P_L, w_L, and the powers removed by GMAP (C_L) are saved internally to be used later during the short-PRT processing. A reflectivity estimate, Z_L, is obtained from P_L after proper censoring and scaling as usual.

2.2. Short-PRT Processing

2.2.1. Assumptions

1) The phases of the transmitted pulses are modulated with the SZ(8/64) switching code.
2) Regardless of the number of pulses transmitted in the dwell time M = 64 pulses worth of data are supplied to the algorithm.
3) The number of range cells is $N = T_s/\Delta t$, where T_s is the pulse repetition time (short PRT) and Δt is the range-time sampling period (e.g., in the legacy WSR-88D Δt = 1.57 μs).
4) Range cells in the short-PRT scan are **perfectly aligned** with range cells in the long-PRT scan. This is important for determining short-PRT trips within the long-PRT data. Note: Misalignments may occur, for example, due to T_s/Δ_t not being an integer number or due to one or more samples being dropped.
5) Long- and short-PRT radials are perfectly aligned in azimuth. This is true for the ORDA system, which collects data on indexed radials.
6) The algorithm operates on one range cell (M samples) of time-series data at a time, but requires all cells to perform strong-point clutter suppression.

2.2.2. Inputs

1) Phase-coded time series data cohered to the 1st trip: $V_n(m) = I_n(m) + jQ_n(m)$, for $0 \le m < M$, where m indexes the samples (or pulses) and n indexes the range gates.
2) Ground-clutter-filtered powers and spectrum widths from the long-PRT scan: P_L and w_L. These vectors correspond to the long-PRT scan radial that has the same (or closest) azimuth to the phase-coded radial in (1).
3) GMAP removed powers: C_L. This vector corresponds to the long-PRT scan radial that has the same (or closest) azimuth to the phase-coded radial in (1).
4) Range-dependent ground clutter filter bypass map corresponding to the long- and short-PRT radials (B). B can be either `FILTER` or `BYPASS`, indicating the presence or absence of clutter, respectively.
5) Measured SZ(8/64) switching code: $\psi(m)$, for $-3 \le m < M$.
6) Censoring thresholds:
   $K_{SNR,Z}$: signal-to-noise (SNR) threshold for determination of significant returns for reflectivity,
   $K_{SNR,V}$: signal-to-noise (SNR) threshold for determination of significant returns for velocity,
   K_{IGN}: power ratio threshold to ignore trips with small total powers,
   K_s: signal-to-noise ratio (SNR) threshold for determination of strong trip recovery,
   K_w: signal-to-noise ratio (SNR) threshold for determination of weak trip recovery,
   $K_r(w_{Sn}, w_{Wn}, t_{diff})$: maximum strong-to-weak power ratios (P_S/P_W) for recovery of the weaker trip for different values of trip number difference ($t_{diff} = |t_S - t_W|$), strong- and weak-trip normalized spectrum widths ($w_{Sn} = w_S/2v_a$ and $w_{Wn} = w_W/2v_{a,L}$, where v_a and $v_{a,L}$ are the maximum unambiguous velocities corresponding to the short and long PRT, respectively). The value of K_r is determined using the spectrum-width-dependent constants C_T (threshold), C_S (slope), and C_I (intercept).

K_{CSR1}: clutter-to-strong-signal ratio (CSR) threshold for determination of strong trip recovery,
K_{CSR2}: clutter-to-weak-signal ratio (CSR) threshold for determination of weak trip recovery,
K_{CSR3}: clutter-to-signal ratio (CSR) threshold for determination of clutter presence,
$w_{n,max}$: maximum valid normalized spectrum width estimated from the long-PRT data.
$K_{x0}, K_{x1}, K_{s0}, K_{s1}$: clutter-to-noise ratio region definitions and correction slopes.

The table below shows the recommended values for the censoring thresholds in the SZ-2 algorithm. These are expected to be refined during the testing and validation stages of the SZ-2 algorithm implementation.

<table>
<tr><th>Censoring threshold</th><th colspan="5">Recommended value</th><th>Notes</th></tr>
<tr><td>$K_{SNR,Z}$</td><td colspan="5">Value from VCP definition</td><td></td></tr>
<tr><td>$K_{SNR,V}$</td><td colspan="5">Value from VCP definition</td><td></td></tr>
<tr><td>K_{IGN}</td><td colspan="5">100</td><td>20 dB</td></tr>
<tr><td>K_s</td><td colspan="5">0.5012</td><td>−3 dB</td></tr>
<tr><td>K_w</td><td colspan="5">1.5849</td><td>2 dB</td></tr>
<tr><td rowspan="12">K_r</td><td colspan="2"></td><td>$w_{Wn} < 0.2032$</td><td>$0.2032 \leq w_{Wn} < 0.2612$</td><td>$w_{Wn} \geq 0.2612$</td><td rowspan="12">Step 24 describes the computation of K_r based on C_T, C_S, and C_I. Note that these thresholds depend on the trip number difference of the overlaid trips (t_{diff}).</td></tr>
<tr><td rowspan="3">$t_{diff} = 1$</td><td>C_T</td><td>45 dB</td><td>45 dB</td><td>$-\infty$</td></tr>
<tr><td>C_S</td><td>−772 dB</td><td>−772 dB</td><td>0</td></tr>
<tr><td>C_I</td><td>0.0656</td><td>0.0619</td><td>∞</td></tr>
<tr><td colspan="2"></td><td>$w_{Wn} < 0$</td><td>$0 \leq w_{Wn} < 0.3773$</td><td>$w_{Wn} \geq 0.3773$</td></tr>
<tr><td rowspan="3">$t_{diff} = 2$</td><td>C_T</td><td>45 dB</td><td>45 dB</td><td>$-\infty$</td></tr>
<tr><td>C_S</td><td>−772 dB</td><td>−772 dB</td><td>0</td></tr>
<tr><td>C_I</td><td>0</td><td>0.0401</td><td>∞</td></tr>
<tr><td colspan="2"></td><td>$w_{Wn} < 0.2032$</td><td>$0.2032 \leq w_{Wn} < 0.2612$</td><td>$w_{Wn} \geq 0.2612$</td></tr>
<tr><td rowspan="3">$t_{diff} = 3$</td><td>C_T</td><td>45 dB</td><td>45 dB</td><td>$-\infty$</td></tr>
<tr><td>C_S</td><td>−772 dB</td><td>−772 dB</td><td>0</td></tr>
<tr><td>C_I</td><td>0.0328</td><td>0.0291</td><td>∞</td></tr>
<tr><td>K_{CSR1}</td><td colspan="5">31622.8</td><td>45 dB</td></tr>
<tr><td>K_{CSR2}</td><td colspan="5">1000</td><td>30 dB</td></tr>
<tr><td>K_{CSR3}</td><td colspan="5">31.6228</td><td>15 dB</td></tr>
<tr><td>$w_{n,max}$</td><td colspan="5">0.25</td><td>This is equivalent to ~4.5 m s^{-1} for PRT #1</td></tr>
<tr><td>K_{x0}</td><td colspan="5">Same as in ORDA</td><td></td></tr>
<tr><td>K_{x1}</td><td colspan="5">Same as in ORDA</td><td></td></tr>
<tr><td>K_{s0}</td><td colspan="5">Same as in ORDA</td><td></td></tr>
<tr><td>K_{s1}</td><td colspan="5">Same as in ORDA</td><td></td></tr>
</table>

2.2.3. Outputs

1) Doppler velocities for 4 trips: $v(n), 0 \le n < 4N$
2) Spectrum widths for 4 trips: $w(n), 0 \le n < 4N$
3) Return types for Doppler velocity and spectrum width for 4 trips: $type_v(n)$ and $type_w(n)$, $0 \le n < 4N$. As in the legacy WSR-88D, *type* can take the values `NOISE_LIKE`, `SIGNAL_LIKE`, or `OVERLAID_LIKE`. These are used to qualify the base data moments sent to the RPG as being non-significant returns, significant returns, or unrecoverable overlaid echoes, respectively.

2.2.4. Algorithm

. Compute autocorrelation normalization factors
For $0 \le n < N$
    . Determine overlaid trips
    If $t_{Ao} \neq -1$
        (There is at least one trip to recover based on long-PRT powers)
        . Determine ground clutter location
        If $t_A \neq -1$
            (There is at least one trip to recover based on clutter location and long-PRT powers)
            If $t_C \neq -1$
                (There is clutter contamination)
                $winType$ = `WIN_BLACKMAN`
                . Apply data window
                If $t_C \neq 0$
                    (Clutter is not in the 1st trip)
                    . Cohere to ground clutter trip
                End
                . Filter ground clutter
            Else
                (There is no clutter contamination)
                $k_{GMAP} = 0$
                $clutter_{GMAP} = 0$
                $winType$ = `WIN_RECT`
                $V_w = V$
            End
            . Cohere to trips A and B
            . Compute lag-one autocorrelations for trips A and B
            . Determine strong and weak trips
            If $t_C = -1$
                (There is no clutter contamination)
                $winType$ = `WIN_DEFAULT`
                If $winType \neq$ `WIN_RECT`
                    . Apply data window
                    . Compute lag-one autocorrelation for strong trip
                End
            End
            . Compute total power
            . Compute strong-trip velocity
            If $t_W \neq -1$
                (There are overlaid echoes)
                . Compute strong-trip lag-two autocorrelation
                If $t_C = -1$
                    (There was no clutter contamination)
                    $winType$ = `WIN_VONHANN`

. Apply data window to original strong-trip cohered signal
End
. Compute discrete Fourier transform
. Apply processing notch filter
. Compute inverse discrete Fourier transform
. Compute weak-trip power
. Cohere to weak trip
. Compute weak-trip lag-one autocorrelation
. Retrieve weak-trip spectrum width
. Adjust powers
. Compute strong-trip spectrum width using R_1/R_2 estimator
Else
(There are no overlaid echoes)
. Adjust powers
. Compute strong-trip spectrum width using R_0/R_1 estimator
End
Else
(There are no trips to recover based on clutter location)
$clutter_{GMAP} = 0$
$t_S = t_W = -1$
End
Else
(There are no trips to recover based on long-PRT powers)
$clutter_{GMAP} = 0$
$t_S = t_W = t_C = -1$
End
. Compute SNR threshold adjustment factors
. Determine censoring and moments
End
. Filter strong point clutter
. Determine outputs

1) Compute autocorrelation normalization factors (Outputs: nf_0, nf_1, nf_2)

Three normalization factors (for autocorrelation computations at lags 0, 1, and 2) are computed for each data window (rectangular, von Hann, and Blackman) as follows:

For i = `WIN_RECT, WIN_VONHANN, WIN_BLACKMAN`

h = WINDOW(i)

$$nf_0(i) = \left[\sum_{m=0}^{M-1} h^2(m) \right]^{-1}$$

$$nf_1(i) = \left[\sum_{m=0}^{M-2} h(m)h(m+1) \right]^{-1}$$

$$nf_2(i) = \left[\sum_{m=0}^{M-3} h(m)h(m+2) \right]^{-1}$$

End

It is assumed that the function WINDOW(.) returns a sequence $h(m)$, $0 \leq m < M$ with the corresponding data window (with or without scaling).

2) Determine overlaid trips (Inputs: P_L, C_L. Outputs: t_{Ao}, t_{Bo}, r, t, P, Q)

The signal powers (after noise and clutter have been removed) from trips 1 to 4, i.e., $P_L(n)$, $P_L(n + N)$, $P_L(n + 2N)$, and $P_L(n + 3N)$, are used to determine t_{Ao} and t_{Bo}, the recoverable trips, according to the following algorithm (note that this assumes **perfect alignment** of range cells between the long and short PRTs).

(Collect long-PRT filtered and unfiltered powers for 4 trips)
For $0 \leq l < 4$
  If $n + lN < N_L$
    (Within the long-PRT range)
    (Filtered power)
    $P(l) = P_L(n + lN)$
    (Unfiltered or total power)
    $Q(l) = P(l) + C_L(n + lN)$
  Else
    (Outside the long-PRT range)
    $P(l) = 0$
    $Q(l) = 0$
  End
  (Trip number)
  $t(l) = l$
End

(Rank long-PRT filtered powers)
Sort vectors *P, Q,* and *t* so that powers $P(0)$, $P(1)$, $P(2)$, and $P(3)$ are in descending order with their corresponding total powers as $Q(0)$, $Q(1)$, $Q(2)$, and $Q(3)$ and trip numbers as $t(0)$, $t(1)$, $t(2)$, and $t(3)$. Note that trip numbers are 0, 1, 2, or 3. In what follows, a −1 will be used to indicate an invalid trip number.

(Determine trip-to-rank mapping)
For $0 \leq l < 4$
    $r[t(l)] = l$
End

Note: $t(rank)$ will be used to get the trip number for a given rank and $r(trip)$ to get the rank of a given trip.

(Determine potentially recoverable trips based on long-PRT filtered powers)
If $P(0) > NOISE.K_{SNR,V}$
    (The strongest trip signal is a significant return; therefore, it is recoverable)
    $t_{Ao} = t(0)$
    If $P(1) > NOISE.K_{SNR,V}$
        (The second strongest trip signal is a significant return; therefore, it is recoverable)
        $t_{Bo} = t(1)$
    Else
        (The second strongest trip signal is not a significant return; therefore, it is not recoverable)
        $t_{Bo} = -1$
    End
Else
    (The strongest trip signal is not a significant return; therefore, none of the trips are recoverable)
    $t_{Ao} = -1$
    $t_{Bo} = -1$
End

In the above algorithm, $K_{SNR,V}$ is the SNR threshold to determine significant returns for velocity and spectrum width estimates. This should be obtained from the VCP definition.

Note: If $t_{Bo} = -1$, only one trip is recoverable. If $t_{Ao} = -1$, no trips are recoverable.

3) Determine ground clutter location (Inputs: B, P_L, C_L, P, Q, r, t, t_{Ao}, t_{Bo}. Outputs: t_A, t_B, t_C)

In the case of overlaid clutter, an additional check is made using the long-PRT powers to prevent a catastrophic failure of the algorithm due to an incorrectly defined clutter map.

```
(Determine trips with clutter)
n_C = 0
For 0 ≤ l < 4
    If n + lN < N_L
        (Within the long-PRT range)
        If B(n + lN) = FILTER
            (There is clutter in the l-th trip; therefore, store clutter trip number and increment
            clutter trip count)
            clutterTrips(n_C) = l
            n_C = n_C + 1
        End
    End
End
If n_C > 1
    (According to the Bypass map there is overlaid clutter; therefore, re-determine trips with
    clutter using both Bypass map and long-PRT powers)
    n_C = 0
    For 0 ≤ l < 4
        If n + lN < N_L
            (Within the long-PRT range)
            If B(n + lN) = FILTER and C_L(n + lN) > P_L(n + lN) K_CSR3
                (There is clutter in the l-th trip)
                clutterTrips(n_C) = l
                n_C = n_C + 1
            End
        End
    End
End

(Handle clutter)
If n_C = 0
    (No clutter anywhere; therefore, clutter filter will not be applied)
    t_C = –1
ElseIf n_C = 1
    (Non-overlaid clutter)
    t_C = clutterTrips(0)
    If t_C ≠ t_A
        (The strong trip does not contain clutter)
        If t_C = t_B
```

(The weak trip contains clutter)
If $P(0) > Q(1)\, K_{IGN}$
(Strong signal is K_{IGN}-times larger than the total signal in the trip with clutter; therefore, clutter can be ignored and the weak signal is not recoverable)
$t_B = -1$
$t_C = -1$
End
Else
(One of the unrecoverable trips contains clutter)
If $P(0) > Q[r(t_C)]\, K_{IGN}$
(Strong signal is K_{IGN}-times larger than the total signal in the trip with clutter; therefore, clutter can be ignored)
$t_C = -1$
End
End
End
ElseIf $n_C = 2$
(Overlaid clutter in two trips)
CwS = FALSE *(clutter with strong signal)*
CwW = FALSE *(clutter with weak signal)*
CwU = FALSE *(clutter with unrecoverable signals)*
For $0 \le l < n_C$
If $clutterTrips(l) = t_A$
(The trip with the strong signal contains clutter)
CwS = TRUE
ElseIf $clutterTrips(l) = t_B$
(The trip with the weak signal contains clutter)
CwW = TRUE
Else
(One of the trips with unrecoverable signals contains clutter)
CwU = TRUE
$t_{CU} = clutterTrips(l)$
End
End
If CwS and CwW
(Clutter is with the strong and weak trips, weak signal cannot be recovered)
$t_B = -1$
If $P(0) > Q(1)\, K_{IGN}$
(Trip with weak signal can be ignored)
$t_C = t_A$
Else
(None of the trips can be recovered, ignore clutter)
$t_A = -1$
$t_C = -1$
End
ElseIf CwS and CwU

(Clutter is with the strong and one of the unrecoverable trips)
If $P(0) > Q[r(t_{CU})]\, K_{IGN}$
(Trip with unrecoverable signal can be ignored)
$t_C = t_A$
Else
(None of the trips can be recovered, ignore clutter)
$t_A = -1$
$t_B = -1$
$t_C = -1$
End
ElseIf *CwW* and *CwU*
(Clutter is with the strong and one of the unrecoverable trips)
If $P(0) > \{Q(1) + Q[r(t_{CU})]\}\, K_{IGN}$
(All trips with clutter can be ignored and weak signal cannot be recovered)
$t_B = -1$
$t_C = -1$
ElseIf $P(0) > Q[r(t_{CU})]\, K_{IGN}$
(Trip with unrecoverable signal can be ignored)
$t_C = t_B$
ElseIf $P(0) > Q(1)\, K_{IGN}$
(Trip with weak signal can be ignored and weak signal cannot be recovered)
$t_B = -1$
$t_C = t_{CU}$
Else
(None of the trips can be recovered, ignore clutter)
$t_A = -1$
$t_B = -1$
$t_C = -1$
End
ElseIf *CwU*
(Clutter is with both of the unrecoverable trips)
If $P(0) > [Q(2) + Q(3)]\, K_{IGN}$
(All trips with clutter can be ignored)
$t_C = -1$
ElseIf $P(0) > Q(2)\, K_{IGN}$
(One of the trips with unrecoverable signals can be ignored)
$t_C = t(3)$
ElseIf $P(0) > Q(3)\, K_{IGN}$
(One of the trips with unrecoverable signals can be ignored)
$t_C = t(2)$
Else
(None of the trips can be recovered, ignore clutter)
$t_A = -1$
$t_B = -1$
$t_C = -1$
End

End
ElseIf $n_C = 3$
(Overlaid clutter in three trips)
CwS = FALSE
CwW = FALSE
CwU = FALSE
For $0 \leq l < n_C$
If $clutterTrips(l) = t_A$
(The trip with the strong signal contains clutter)
CwS = TRUE
ElseIf $clutterTrips(l) = t_B$
(The trip with the weak signal contains clutter)
CwW = TRUE
Else
(One of the trips with unrecoverable signals contains clutter)
CwU = TRUE
$t_{CU} = clutterTrips(l)$
End
End
If CwS and CwW and CwU
(Weak trip is unrecoverable)
$t_B = -1$
If $P(0) > \{Q(1) + Q[r(t_{CU})]\} K_{IGN}$
(Trips with weak and unrecoverable signals can be ignored)
$t_C = t_A$
Else
(None of the trips can be recovered, ignore clutter)
$t_A = -1$
$t_C = -1$
End
ElseIf CwS and CwU
If $P(0) > [Q(2) + Q(3)] K_{IGN}$
(Trips with unrecoverable signals can be ignored)
$t_C = t_A$
Else
(None of the trips can be recovered, ignore clutter)
$t_A = -1$
$t_B = -1$
$t_C = -1$
End
Else
If $P(0) > [Q(1) + Q(2) + Q(3)] K_{IGN}$
(All trips with clutter can be ignored and weak trip is unrecoverable)
$t_B = -1$
$t_C = -1$

ElseIf $P(0) > [Q(1) + Q(2)]\ K_{IGN}$

(Trips with weak and one unrecoverable signal can be ignored and weak trip is unrecoverable)

$t_B = -1$

$t_C = t(3)$

ElseIf $P(0) > [Q(1) + Q(3)]\ K_{IGN}$

(Trips with weak and one unrecoverable signal can be ignored and weak trip is unrecoverable)

$t_B = -1$

$t_C = t(2)$

ElseIf $P(0) < [Q(2) + Q(3)]\ K_{IGN}$

(Both trips with unrecoverable signals can be ignored)

$t_C = t_B$

Else

(None of the trips can be recovered, ignore clutter)

$t_A = -1$

$t_B = -1$

$t_C = -1$

End

End

Else ($n_C = 4$)

(Overlaid clutter in four trips)

(Weak trip is unrecoverable)

$t_B = -1$

If $P(0) > [Q(1) + Q(2) + Q(3)]\ K_{IGN}$

(Trips with weak and both unrecoverable signals can be ignored)

$t_C = t_A$

Else

(None of the trips can be recovered, ignore clutter)

$t_A = -1$

$t_C = -1$

End

End

Note: If $t_A = -1$, none of the trips are recoverable.

4) Apply data windowing (Input: V, *winType*. Output: V_W)

h = WINDOW(*winType*)

$V_W(m) = V(m)h(m)$, for $0 \le m < M$,

where h is either the rectangular, von Hann, or Blackman window function.

5) Cohere to ground clutter trip (Inputs: V_W, t_C, ψ. Output: V_{CW})

Time series data are cohered to trip t_C to filter ground clutter:

$V_{CW}(m) = V_W(m)\exp[-j\phi_{t_C,0}(m)]$, for $0 \le m < M$,

where ϕ_{k_1,k_2} is the modulation code for the k_1-th trip with respect to the k_2-th trip, obtained from the measured switching code ψ. In general,

$\phi_{k_1,k_2}(m) = \psi(m-k_1) - \psi(m-k_2)$, for $0 \le m < M$.

6) Filter ground clutter (Inputs: V_{CW}. Outputs: V_{CF}, k_{GMAP})

Time series data V_{CW} are filtered using the GMAP ground clutter filter to get V_{CF} as follows:

i) Discrete Fourier Transform

$$F_{CW}(k) = \frac{1}{M}\sum_{m=0}^{M-1} V_{CW}(m) e^{-j\frac{2\pi mk}{M}}, \text{ for } 0 \le k < M.$$

ii) Power spectrum

$$S_{CW}(k) = \left|F_{CW}(k)\right|^2, \text{ for } 0 \le k < M.$$

iii) Ground Clutter Filtering

$$S_{CF} = \text{GMAP}\left(S_{CW}\right)$$

Note: The receiver noise power is not provided to GMAP. In addition to the filtered power spectrum, GMAP returns the amount of clutter power removed ($clutter_{GMAP}$). Moreover, GMAP should be modified to return the number of spectral coefficients with clutter (k_{GMAP}). Note that k_{GMAP} is `iGapPoints` in SIGMET's `fSpecFilterGMAP()` function.

iv) Phase reconstruction

Use the original phases except in those spectral components notched and reconstructed by GMAP:

$$\varphi_{CF}(k) = \begin{cases} 0, & k_{GMAP} > 0 \text{ and } \\ & \left[k \le (k_{GMAP}-1)/2 \text{ or } k \ge M-(k_{GMAP}-1)/2\right], \text{ for } 0 \le k < M, \\ Arg[F_{CW}(k)], & \text{otherwise} \end{cases}$$

where $Arg(.)$ indicates the complex argument or phase.

v) Inverse Discrete Fourier Transform

$$V_{CF}(m) = \sum_{k=0}^{M-1} \sqrt{S_{CF}(k)} e^{j\varphi_{CF}(k)} e^{j\frac{2\pi mk}{M}}, \text{ for } 0 \le m < M.$$

7) Cohere to trips A and B (Inputs: V_W, V_{CF}, t_A, t_B, t_C, ψ. Outputs: V_A, V_B)

The original (cohered to the 1st trip: $t = 0$) or ground-clutter-filtered (cohered to trip t_C) signal is now cohered (if necessary) to trips t_A and t_B using the proper modulation codes.

(Get trip to cohere from)
If $t_C \ne -1$
    $t_X = 0$
Else
    $t_X = t_C$
End
If $t_A \ne -1$
    (Strongest trip is recoverable; therefore, cohere to trip A if needed)
    If $t_A \ne t_X$
        (Cohere to trip A)
        $V_A(m) = V_W(m)\exp[-j\phi_{t_A,t_X}(m)]$, for $0 \le m < M$
    Else
        (Cohering is not needed)
        $V_A(m) = V_{CF}(m)$, for $0 \le m < M$
    End
Else
    (Signal was unrecoverable)
    $V_A(m) = 0$, for $0 \le m < M$
End

If $t_B \ne -1$
    (Strongest trip is recoverable; therefore, cohere to trip B if needed)
    If $t_B \ne t_X$
        (Cohere to trip B)
        $V_B(m) = V_W(m)\exp[-j\phi_{t_B,t_X}(m)]$, for $0 \le m < M$
    Else

(Cohering is not needed)
$V_B(m) = V_{CF}(m)$, for $0 \le m < M$
End
Else
(Signal was unrecoverable)
$V_B(m) = 0$, for $0 \le m < M$
End

In the previous algorithm, ϕ_{k_1,k_2} is the modulation code for the k_1-th trip with respect to the k_2-th trip, obtained from the switching code ψ as in step 5.

8) Compute total power (Inputs: V_A, *winType*. Output: $\tilde{P}_T$)

$$K = nf_0(winType)$$
$$\tilde{P}_T = K\sum_{m=0}^{M-1}\left|V_A(m)\right|^2 .$$

Note: ideally, this is the short-PRT total power in all trips with the clutter power in trip t_C removed; i.e., $\tilde{P}_T \approx P(0)+P(1)+P(2)+P(3)+NOISE$ (this assumes no overlaid clutter).

9) Compute lag-one autocorrelations for trips *A* and *B* (Inputs: V_A, V_B, t_A, t_B, *winType*. Outputs: R_A, R_B)

$$K = nf_1(winType)$$
If $t_A \ne -1$
(Strongest trip is recoverable; therefore, compute lag-one autocorrelation)
$$R_A = K\sum_{m=0}^{M-2}V_A^*(m)V_A(m+1)$$
Else
(Strongest trip is not recoverable)
$R_A = 0$
End
If $t_B \ne -1$
(Second strongest trip is recoverable; therefore, compute lag-one autocorrelation)
$$R_B = K\sum_{m=0}^{M-2}V_B^*(m)V_B(m+1)$$
Else
(Second strongest trip is not recoverable)
$R_B = 0$
End

10) Determine strong and weak trips (Inputs: V_A, V_B, R_A, R_B, t_A, t_B. Outputs: V_S, R_S, t_S, t_W)

The final strong/weak trip determination is done using the magnitude of the lag-one autocorrelation estimates (equivalent to using the spectrum widths) from the actual phase-coded data.

If $|R_A| \geq |R_B|$
(Trip A is strong, trip B is weak)
$t_S = t_A$
$t_W = t_B$
$R_S = R_A$
$V_S(m) = V_A(m)$, for $0 \leq m < M$
Else
(Trip B is strong, trip A is weak)
$t_S = t_B$
$t_W = t_A$
$R_S = R_B$
$V_S(m) = V_B(m)$, for $0 \leq m < M$
End

11) Compute strong-trip velocity (Input: R_S. Output: v_S)

$$v_S = -\frac{v_a}{\pi} Arg(R_S),$$

where v_a is the maximum unambiguous velocity corresponding to the short PRT ($v_a = \lambda/4T_s$, and λ is the radar wavelength).

12) Compute the strong-trip lag-two autocorrelation (Input: V_S, *winType*. Output: R_{S2})

$$K = nf_2(winType)$$

$$R_{S2} = K\sum_{m=0}^{M-3} V_S^*(m)V_S(m+2).$$

13) Compute discrete Fourier transform (DFT) (Input: V_S. Output: F_S)

$$F_S(k) = \frac{1}{M}\sum_{m=0}^{M-1} V_S(m)e^{-j\frac{2\pi mk}{M}}, \text{ for } 0 \leq k < M.$$

14) Apply processing notch filter (Inputs: F_S, v_S, t_S, t_W, t_C, k_{GMAP}. Outputs: F_{SN}, NW)

The PNF is an ideal bandstop filter in the frequency domain; i.e., it zeroes out the spectral components within the filter's cutoff frequencies (stopband) and retains those components outside the stopband (passband). With the PNF center (v_S) in m s^{-1} units, the first step consists of mapping the center velocity into a spectral coefficient number. Next, the stopband is defined by moving half the notch width above and below the central spectral coefficient (these are wrapped around to the fundamental Nyquist interval) and adjusting the position to always include those coefficients that originally had ground clutter. However, the notch width depends on the strong- and weak-trip numbers. For strong and weak trips that are one or three trips away from each other, the modulation code is the one derived from the SZ(8/64) switching code. On the other hand, for strong and weak trips that are two trips away from each other, the modulation code is the one derived from the SZ(16/64) switching code. While the processing with a SZ(8/64) code requires a notch width of 3/4 of the Nyquist interval, the SZ(16/64) is limited to a notch width of one half of the Nyquist interval.

i) Central spectral coefficient computation:

$$k_o = \begin{cases} -v_S \frac{M}{2v_a}, & \text{if } v_S \le 0 \\ M - v_S \frac{M}{2v_a}, & \text{if } v_S > 0 \end{cases}$$

k_o should be rounded to the nearest integer.

ii) Notch width determination:

$$NW = \begin{cases} M/2, & \text{if } |t_S - t_W| \ne 1 \text{ and } t_W \ne -1 \\ 3M/4, & \text{otherwise} \end{cases}$$

iii) PNF center adjustment (perform only if clutter was with the strong signal)

If $t_C = t_S$ and $k_{GMAP} > 0$

$k_{ADJ} = (k_{GMAP} - 1)/2 + k_{GMAP\_EXTRA}$

if $\lfloor \frac{NW-1}{2} \rfloor - k_{ADJ} < k_o < \frac{M}{2}$

$k_o = \lfloor \frac{NW-1}{2} \rfloor - k_{ADJ}$

ElseIf $\frac{M}{2} \le k_o < M - \lceil \frac{NW-1}{2} \rceil + k_{ADJ}$

$k_o = M - \lceil \frac{NW-1}{2} \rceil + k_{ADJ}$

End

End

Note: The computation of k_{ADJ} includes an empirical constant k_{GMAP_EXTRA}. Simulations suggest that k_{GMAP_EXTRA} should be set to 1 to obtain better results.

iv) Cutoff frequency computation:

$$k_a = \begin{cases} k_o - \left\lfloor \frac{NW-1}{2} \right\rfloor, & \text{if } k_o - \left\lfloor \frac{NW-1}{2} \right\rfloor \geq 0 \\ k_o - \left\lfloor \frac{NW-1}{2} \right\rfloor + M, & \text{if } k_o - \left\lfloor \frac{NW-1}{2} \right\rfloor < 0 \end{cases},$$

$$k_b = \begin{cases} k_o + \left\lceil \frac{NW-1}{2} \right\rceil, & \text{if } k_o + \left\lceil \frac{NW-1}{2} \right\rceil < M \\ k_o + \left\lceil \frac{NW-1}{2} \right\rceil - M, & \text{if } k_o + \left\lceil \frac{NW-1}{2} \right\rceil \geq M \end{cases}.$$

v) Notch filtering:

$$F_{SN}(k) = \begin{cases} \dfrac{F_S(k)}{\sqrt{1-\frac{NW}{M}}}, & \begin{array}{l}\text{if } k_b < k < k_a \text{ for } k_b < k_a \text{ or} \\ \text{if } 0 \leq k < k_a \text{ or } k_b < k < M \text{ for } k_a < k_b\end{array} \\ 0, & \text{otherwise} \end{cases}, \text{ for } 0 \leq k < M.$$

Note: The factor $\sqrt{1-\frac{NW}{M}}$ normalizes the filtered signal in order to preserve its power.

In the previous equations $\lfloor x \rfloor$ is the nearest integer to *x* that is smaller than *x*, and $\lceil x \rceil$ is the nearest integer to *x* that is larger than *x*; k_o, k_a, and k_b are zero-based indexes.

15) Compute inverse discrete Fourier transform (IDFT) (Input: F_{SN}. Output: V_{SN})

$$V_{SN}(m) = \sum_{k=0}^{M-1} F_{SN}(k) e^{j\frac{2\pi mk}{M}}, \text{ for } 0 \leq m < M.$$

16) Compute weak-trip power (Input: V_{SN}, *winType*. Output: $\tilde{P}_W$)

$$K = nf_0(winType)$$

$$\tilde{P}_W = K \sum_{m=0}^{M-1} \left| V_{SN}(m) \right|^2 .$$

Note: ideally, this would be the short-PRT total power in all trips except the strong trip; i.e., $\tilde{P}_W \approx P\left[r(t_W)\right] + P(2) + P(3) + NOISE$ (this assumes no overlaid clutter and that the PNF completely removed the strong trip).

17) Cohere to weak trip (Inputs: V_{SN}, t_S, t_W, ψ. Output: V_W)

$$V_W(m) = V_{SN}(m) \exp\left[-j\phi_{t_W,t_S}(m)\right], \text{ for } 0 \leq m < M,$$

where ϕ_{k_1,k_2} is the modulation code for the k_1-th trip with respect to the k_2-th trip, obtained from the switching code ψ as in step 5.

18) Compute weak-trip lag-one autocorrelation (Input: V_W, *winType*. Output: R_W)

$$K = nf_1(winType)$$
$$R_W = K \sum_{m=0}^{M-2} V_W^*(m) V_W(m+1).$$

19) Retrieve weak-trip spectrum width (Input: w_L, t_W. Output: w_W, *wAlgo*)

(Flag spectrum width computation method for final step)
$wAlgo(n + t_W N)$ = `LONG_PRT_ESTIMATOR`
(Retrieve long-PRT spectrum width estimate)
$w_W = w_L(n + t_W N)$.

20) Adjust powers (Inputs: P, $\tilde{P}_T$, $\tilde{P}_W$, t_W. Outputs: P_S, P_W)

i) Strong-trip power adjustment:

If $t_W \neq -1$
(Subtract short-PRT out-of-trip powers and noise power from total power)
$P_S = \tilde{P}_T - \tilde{P}_W$
Else
(Subtract long-PRT out-of-trip powers and noise power from total power)
$P_S = \tilde{P}_T - \left[P(1) + P(2) + P(3) + NOISE\right]$
End
If $P_S < 0$
(Clip negative powers to zero)
$P_S = 0$
End

ii) Weak-trip power adjustment:

If $t_W \neq -1$
(Weak trip is recoverable; therefore, subtract long-PRT out-of-trip powers and noise power from weak power)
$P_W = \tilde{P}_W - [P(2) + P(3) + NOISE]$
If $P_W < 0$

(Clip negative powers to zero)

$P_W = 0$

End

Else

$P_W = 0$

End

In the previous equations *NOISE* is the receiver noise power.
Note: while P_S is used both for censoring and in the computation of the strong-trip spectrum width, P_W is used solely for censoring purposes.

21) Compute strong-trip spectrum width using the R_0/R_1 estimator (Inputs: P_S, R_S. Output: w_S, *wAlgo*)

(Flag spectrum width computation method for final step)
wAlgo($n + t_S N$) = `R0_R1_ESTIMATOR`

(Compute spectrum width)

If $|R_S| = 0$

(Lag-one correlation is zero; therefore, signal is like white noise having the maximum possible spectrum width)

$w_S = v_a / \sqrt{3}$

ElseIf $P_S < |R_S|$

(Lag-one correlation is larger than the power; therefore, signal is very coherent having the minimum possible spectrum width)

$w_S = 0 \ (\mathrm{m\ s^{-1}})$

Else

(Spectrum width computation)

$$w_S = \frac{v_a}{\pi}\left[2\ln\left(\frac{P_S}{|R_S|}\right)\right]^{1/2}$$

End

If $w_S > v_a / \sqrt{3}$

(Clip large values of spectrum width)

$w_S = v_a / \sqrt{3}$

End

Here v_a is the maximum unambiguous velocity corresponding to the short PRT ($v_a = \lambda/4T_s$ and λ is the radar wavelength).

22) Compute strong-trip spectrum width using the R_1/R_2 estimator (Inputs: R_S, R_{S2}. Output: w_S, *wAlgo*)

(Flag spectrum width computation method for final step)
$wAlgo(n + t_S N)$ = `R1_R2_ESTIMATOR`

(Compute spectrum width)
If $|R_{S2}| = 0$

(Lag-two correlation is zero; therefore, signal is like white noise having the maximum possible spectrum width)

$w_S = v_a / \sqrt{3}$

ElseIf $|R_S| < |R_{S2}|$

(Lag-two autocorrelation is larger than lag-one autocorrelation; therefore, signal is very coherent having the minimum possible spectrum width)

$w_S = 0 \text{ (m s}^{-1}\text{)}$

Else

(Spectrum width computation)

$$w_S = \frac{v_a}{\pi}\left[\frac{2}{3}\ln\left(\frac{|R_S|}{|R_{S2}|}\right)\right]^{1/2}$$

End
If $w_S > v_a / \sqrt{3}$

(Clip large values of spectrum width)

$w_S = v_a / \sqrt{3}$

End

Here v_a is the maximum unambiguous velocity corresponding to the short PRT ($v_a = \lambda/4T_s$ and λ is the radar wavelength).

23) Compute SNR threshold adjustment factors (Inputs: C_L, $clutter_{GMAP}$, Outputs: $AdjK_{SNR}Short$, $AdjK_{SNR}Long$)

This is also referred to as dB-for-dB or log-for-log censoring.

Apply the following algorithm twice with the following sets of parameters:

1) $C = C_L(n + t_C N)$ and $AdjK_{SNR}Long = AdjK_{SNR}$,
2) $C = clutter_{GMAP}$ and $AdjK_{SNR}Short = AdjK_{SNR}$.

(Compute CNR)
If $C > 0$

$CNRdB = 10\log_{10}(C/NOISE)$

Else

    CNRdB = 0
End
(Compute SNR threshold adjustment in dB depending on CNR region)
If $CNRdB \le K_{x0}$
    $deltaTh = 0$
ElseIf $CNRdB \le K_{x1}$
    $deltaTh = K_{s0}\,(CNRdB - K_{x0})$
Else
    $deltaTh = K_{s0}(K_{x1} - K_{x0}) + K_{s1}(CNRdB - K_{x1})$
End
(Compute SNR threshold adjustment factor)
$AdjK_{SNR} = 10^{deltaTh/10}$

24) Determine censoring and moments (Inputs: P, Q, t, r, P_S, P_W, R_S, R_W, R_{S2}, w_S, w_W, t_S, t_W, t_C, t_{Ao}, t_{Bo}, $AdjK_{SNR}Short$, $AdjK_{SNR}Long$, $clutter_{GMAP}$. Outputs: T_0, R_0, R_1, R_2, $type_v$, $type_w$)

(Adjust powers based on clutter filtering)
For $0 \le l < 4$
    If $t_C = t(l)$
        $PQ(l) = P(l)$
    Else
        $PQ(l) = Q(l)$
    End
End

(Go through 4 trips)
For $0 \le l < 4$
    (Initially tag for no censoring)
    CENSOR = `NO_CENSORING`

    (Check for significant long-PRT power)
    If *CENSOR* = `NO_CENSORING` and $P[r(l)] < NOISE.K_{SNR,V}$
        CENSOR = `SNR_LONG_PRT`
    End

    (Strong-trip censoring)
    If $t_S = l$
        (Short-PRT SNR censoring)
        If *CENSOR* = `NO_CENSORING` and $P_S < NOISE.K_{SNR,V}$
            CENSOR = `SNR_SHORT_PRT_STRONG_TRIP`
        End

        (Short-PRT CNR censoring)
        If *CENSOR* = `NO_CENSORING` and $P_S < NOISE.K_{SNR,V}.AdjK_{SNR}Short$
            If $t_W = -1$

CENSOR = CNR_SHORT_PRT_STRONG_TRIP_NON_OVLD
Else
If $P[r(t_W)] < NOISE.K_{SNR,Z}.AdjK_{SNR}Long$
CENSOR = CNR_SHORT_PRT_STRONG_TRIP_NON_OVLD
Else
CENSOR = CNR_SHORT_PRT_STRONG_TRIP_OVLD
End
End
End

(Long-PRT CSR censoring)
If *CENSOR* = NO_CENSORING and $t_C \neq -1$ and $\{Q[r(t_C)] - P[r(t_C)]\} > P[r(t_S)]\ K_{CSR1}$
If $t_W = -1$
CENSOR = CSR_LONG_PRT_STRONG_TRIP_NON_OVLD
Else
If or $P[r(t_W)] < NOISE.K_{SNR,Z}.AdjK_{SNR}Long$
CENSOR = CSR_LONG_PRT_STRONG_TRIP_NON_OVLD
Else
CENSOR = CSR_LONG_PRT_STRONG_TRIP_OVLD
End
End
End

(SNR censoring)*
If $t_W \neq -1$
(Weak trip was recovered)
If *CENSOR* = NO_CENSORING and
$PQ[r(t_S)] < \{PQ[r(t_W)] + PQ(2) + PQ(3) + NOISE\}K_s$
CENSOR = SNRS_LONG_PRT_STRONG_TRIP
End
Else
If *CENSOR* = NO_CENSORING and
$PQ[r(t_S)] < [PQ(1) + PQ(2) + PQ(3) + NOISE]K_s$
CENSOR = SNRS_LONG_PRT_STRONG_TRIP
End
End

(Weak trip censoring)
ElseIf $t_W = l$
(Short-PRT SNR censoring)
If *CENSOR* = NO_CENSORING and $P_W < NOISE.K_{SNR,V}$
CENSOR = SNR_SHORT_PRT_WEAK_TRIP
End

(Short-PRT CNR censoring)
If *CENSOR* = `NO_CENSORING` and $P_W < NOISE.K_{SNR,V}.AdjK_{SNR}$
CENSOR = `CNR_SHORT_PRT_WEAK_TRIP`
End

(Long-PRT CSR censoring)
If *CENSOR* = `NO_CENSORING` and $t_C \neq -1$ and $Q[r(t_C)] - P[r(t_C)]\} > P[r(t_W)]\ K_{CSR2}$
CENSOR = `CSR_LONG_PRT_WEAK_TRIP`
End

(SNR censoring)*
If *CENSOR* = `NO_CENSORING` and $PQ[r(t_W)] < [PQ(2) + PQ(3) + NOISE]K_w$
CENSOR = `SNRS_LONG_PRT_WEAK_TRIP`
End

(Power-ratio recovery-region censoring)
If *CENSOR* = `NO_CENSORING` and $P[r(t_S)] > P[r(t_W)]\ K_r(w_S/2v_a,\ w_W/2v_{a,L},\ |t_S - t_W|)$
CENSOR = `RECOV_REGION`
End

(Clutter-not-with-strong-trip censoring)
If *CENSOR* = `NO_CENSORING` and $t_C \neq -1$ and $t_C \neq t_S$
CENSOR = `CLUTTER_LOCATION`
End

(Long-PRT saturated spectrum width censoring)
If *CENSOR* = `NO_CENSORING` and $w_W/2v_{a,L} > w_{n,max}$
CENSOR = `SATURATED_WIDTH`
End

(Unrecoverable censoring)
Else
If *CENSOR* = `NO_CENSORING`
(Check for censoring due to clutter location in step 3)
If $t_{Ao} = l$ or $t_{Bo} = l$
CENSOR = `CLUTTER_LOCATION`
Else
CENSOR = `UNRECOVERABLE`
End
End
End

(Handle censoring)
Switch *CENSOR*
Case `NO_CENSORING`

(Do not censor data)
$type_v(n + lN)$ = `SIGNAL_LIKE`
$type_w(n + lN)$ = `SIGNAL_LIKE`
If $t_S = l$
    $R_0(n + lN) = P_S$
    $R_1(n + lN) = R_S$
    $R_2(n + lN) = R_{S2}$
Else
    $R_0(n + lN) = P_W$
    $R_1(n + lN) = R_W$
    $R_2(n + lN) = 0$
End
$T_0(n + lN) = R_0(n + lN) + clutter_{GMAP}$

Case `SNR_LONG_PRT,`
`SNR_SHORT_PRT_STRONG_TRIP,`
`SNR_SHORT_PRT_WEAK_TRIP,`
`CSR_LONG_PRT_STRONG_TRIP_NON_OVLD,`
`CNR_SHORT_PRT_STRONG_TRIP_NON_OVLD`
(Censor as noise-like data)
$type_v(n + lN)$ = `NOISE_LIKE`
$type_w(n + lN)$ = `NOISE_LIKE`
$R_0(n + lN) = P[r(l)]$
$R_1(n + lN) = 0$
$R_2(n + lN) = 0$
$T_0(n + lN) = Q[r(l)]$

Case `SNRS_LONG_PRT_STRONG_TRIP,`
`SNRS_LONG_PRT_WEAK_TRIP,`
`CNR_SHORT_PRT_WEAK_TRIP,`
`CSR_LONG_PRT_WEAK_TRIP,`
`CSR_LONG_PRT_STRONG_TRIP_OVLD,`
`CNR_SHORT_PRT_STRONG_TRIP_OVLD,`
`RECOV_REGION,`
`CLUTTER_LOCATION,`
`UNRECOVERABLE`
(Censor as overlaid-like data)
$type_v(n + lN)$ = `OVERLAID_LIKE`
$type_w(n + lN)$ = `OVERLAID_LIKE`
$R_0(n + lN) = P[r(l)]$
$R_1(n + lN) = 0$
$R_2(n + lN) = 0$
$T_0(n + lN) = Q[r(l)]$

Case `SATURATED_WIDTH`
(Censor weak-trip spectrum width only)
$type_v(n + lN)$ = `SIGNAL_LIKE`
$type_w(n + lN)$ = `OVERLAID_LIKE`
$R_0(n + lN) = P_W$

$R_1(n + lN) = R_W$
$R_2(n + lN) = 0$
$T_0(n + lN) = R_0(n + lN) + clutter_{GMAP}$
End
End

In the previous algorithm, $K_{SNR,Z}$ and $K_{SNR,V}$ are the SNR thresholds to determine significant returns for reflectivity and velocity, respectively. These should be obtained from the VCP definition as in the legacy WSR-88D. K_s and K_w are the minimum SNRs needed for recovery of the strong and weak trips, respectively. Here, the noise consists of the whitened out-of-trip powers plus the system noise. K_r is the maximum P_S/P_W ratio for recovery of the weaker trip. K_r is a function of the trip number difference t_{diff}, the normalized strong and weak trip spectrum widths $w_{Sn} = w_S/2v_a$ and $w_{Wn} = w_W/2v_{a,L}$, and is defined as

$$K_r(w_{Sn}, w_{Wn}, t_{diff}) = \begin{cases} 10^{C_T(w_{Wn},t_{diff})/10}, & w_{Sn} < C_I(w_{Wn}, t_{diff}) \\ 10^{\{C_S(w_{Wn},t_{diff})[w_{Sn} - C_I(w_{Wn},t_{diff})] + C_T(w_{Wn},t_{diff})\}/10}, & w_{Sn} \ge C_I(w_{Wn}, t_{diff}) \end{cases},$$

where C_T is the threshold, C_S is the slope and C_I is the intercept all of which depend on t_d and w_{Wn} as listed in the table of recommended censoring thresholds. v_a and $v_{a,L}$ are the maximum unambiguous velocities corresponding to the short and long PRT, respectively. K_{CSR1} and K_{CSR2} are the clutter-to-signal ratio (CSR) thresholds for determination of recovery of the strong and weak trip, respectively ($K_{CSR2} \le K_{CSR1}$). K_2 is the power ratio threshold for the determination of significant clutter in the overlaid case. Lastly, $w_{n,max}$ is the maximum valid normalized spectrum width estimated from the long-PRT data.

25) Filter strong point clutter (Inputs: T_0, R_0, R_1, R_2. Outputs: T_0, R_0, R_1, R_2)

The algorithm is the same as in the legacy RDA (this is also implemented in the ORDA).

26) Determine outputs (Inputs: R_0, R_1, R_2, $wAlgo$. Outputs: v, w)

i) Compute Doppler velocity

For $0 \le n < 4N$

$$v(n) = -\frac{v_a}{\pi} Arg\left[R_1(n)\right]$$

End

where v_a is the maximum unambiguous velocity corresponding to the short PRT ($v_a = \lambda/4T_s$, where λ is the radar wavelength).

ii) Compute spectrum width

For $0 \le n < 4N$
Switch *wAlgo*(n)
Case 0
(Spectrum width was not computed for this gate. This assumes that wAlgo is set to zero for all gates at the beginning of each radial)
$w(n) = 0$
Case `LONG_PRT_ESTIMATOR`
$w(n) = w_L(n)$
Case `R0_R1_ESTIMATOR`
If $|R_1(n)| = 0$
$w(n) = v_a / \sqrt{3}$
ElseIf $R_0(n) < |R_1(n)|$
$w(n) = 0$
Else
$$w(n) = \frac{v_a}{\pi}\left[2\ln\left(\frac{R_0(n)}{|R_1(n)|}\right)\right]^{1/2}$$
End
Case `R1_R2_ESTIMATOR`
If $|R_2(n)| = 0$
$w(n) = v_a / \sqrt{3}$
ElseIf $|R_1(n)| < |R_2(n)|$
$w(n) = 0$
Else
$$w(n) = \frac{v_a}{\pi}\left[\frac{2}{3}\ln\left(\frac{|R_1(n)|}{|R_2(n)|}\right)\right]^{1/2}$$
End
End
If $w(n) > v_a / \sqrt{3}$
$w(n) = v_a / \sqrt{3}$
End
End