

Description

The present invention relates to a synthetic aperture processing system for processing data required from Spaceborne or Airborne sensors.

It has been known for many years that images of the earth's surface may be produced using microwave radiation by the technique known as Sideways-Looking Airborne Radar (SLAR). More recently radars carried in space satellites rather than in aircraft have used. However, the basic technique is the same.

SLAR in its simplest form is described by Jensen et al, Side-looking airborne radar, "Scientific American", (1977) and by Lillesand and Keifer, "Remote Sensing and Image Interpretation", Wiley, New York, 1979. A vehicle carrying a radar transmitter, e.g. an aircraft, is flown over the surface to be studied. Microwave radiation is emitted from the vehicle and the radiation reflected from the underlying surface is received by the vehicle. Two directions may be defined in relation to the vehicle. The azimuth direction is the direction in which the vehicle is moving. The range direction is the direction at right angles to the direction of movement of the vehicle.

The above mentioned publications describe the operation of SLAR in terms of the emission of pulses of microwave radiation and indicate that the resolution (ie the ability to separate two adjacent features on the ground) in the range direction is dependent on the length of the pulse. Commonly a relatively long duration frequency swept pulse is transmitted, in conjunction with a pulse correlation system to achieve an approximately equivalent effect to a short pulse. In the azimuth direction the resolution is dependent on the width of the beam emitted from the vehicle.

It is well known to increase the resolution to the azimuth direction by the technique of synthetic aperture radar. Originally this was done using optical techniques. However it is now possible to replace optical techniques by digital signal processing.

In synthetic aperture radar a vehicle, e.g. an aeroplane or a satellite, carrying a radar aerial or antenna is moved over a surface to be mapped. The radar beam illuminates the surface to be investigated and the movement of the vehicle results in an illuminated or irradiated swath being traced out. As the vehicle moves along its track it emits a succession of radar pulses, typically frequency swept, and receives back radar echoes from each pulse. If the echoes over a given period along track are recorded (sampled) at given time intervals they can be processed to give increased resolution in the azimuth direction. Instead of using a large physical antenna a synthetic aperture is produced. The amplitude of the radar echo at each sampling period is recorded. The echoes which are received after each pulse is emitted result from reflections from objects at successively greater distances from the vehicle. The individual sampled amplitudes can be considered as forming a matrix in which the rows in each column represent information about the illuminated surface in the azimuth direction and the columns represent information about the surface in the range direction. However as initially recorded information about any given object is distributed over the cells of the matrix and it is necessary to compress the data in range and in azimuth to concentrate the data about a given object in a picture cell (pixel) which will be used to represent it in the final image produced.

Synthetic aperture radar using digital signal processing techniques is disclosed in various references. Thus GB 1 540 950 discloses a synthetic aperture using an FFT signal processor. The specification explains that synthetic aperture radar may be used in either squinted or in side-looking mode and discusses the problems of maintaining the data from the radar in range and azimuth focus. GB 1 540 950 proposes to overcome the problem by using a motion compensation computer responsive to the velocity of the vehicle and pulse repetition frequency to maintain the data in range focus, and to vary the pulse rate frequency of the radar to maintain the data in azimuth focus.

EP 83107, discloses a synthetic aperture radar using digital signal processing and discusses the necessity to focus the data in both the range and azimuth directions. The necessity of carrying out range curvature processing is mentioned. This is done to compensate for changes in the distances between the vehicle and a given point from which a signal is reflected.

A considerable number of other approaches to synthetic aperture processing have been described in the literature, of varying applicability, quality and speed of operation. High quality processing has however been restricted to two classes of processor; explicit time domain correlation and range-Doppler frequency domain processing. The primary disadvantage of the time domain correlation approach is that it is computationally demanding although in principle it is as flexible, and provides images of as high a quality, as desired. Frequency domain approaches are of interest because of their computational efficiency, with the best quality achieved prior to this invention by the range-Doppler approach. basic range-Doppler approach to processing involves the following steps, as disclosed for example in US Patent No. 4 471 357:

- 1) Pulse compression, which is performed by correlating pulse echoes intra pulse with a replica of the transmitted signal and achieved either by explicit correlation or frequency domain techniques as appropriate.
- 2) Formation of a sequence of overlapping processing blocks of compressed pulse data, with the size of

the block and overlap determined by the maximum effective illumination time of a point on the ground by the antenna together with processing considerations.

3) Interpulse Fast Fourier Transform (FFT) of each processing block at constant range sample, to generate a PRF (Pulse Repetition Frequency) ambiguous, range-Doppler representation of the data.

4) Formation of a modified range-Doppler processing block by the selection of a new set of rows of data from along curves in the range-Doppler processing block ("Range migration correction"); the locus for data collation corresponding to the range-frequency history of points illuminated by the radar.

5) The multiplication of rows of data in the modified range-Doppler block by an amplitude weighted phase function derived primarily from the reciprocal of the rate of change of Doppler frequency with time, and an inverse FFT of each row.

6) The collation of an image from successive blocks of output data.

Operations 2) through 5) are conventionally referred to as the "azimuth compression" operations.

In the general case of a squinted satellite sensor difficulties with this approach arise as a result of the non-stationarity of the processing functions with both range, and position in time, within a processing block, together with the more general problems of correctly specifying the range-Doppler migration locus and conjugate phase function.

Processing of data by this technique from specific sensors within well defined constraints, has been reasonably successful, although implementations are noted for requiring a degree of ad hoc tuning in any given implementation and suffering quality degradation (in comparison with a time domain processor) to various degrees. Further than this, some combinations of radar system parameters may not allow, prior to this invention, full resolution processing to any reasonable quality by this approach.

It would be advantageous to have a systematic and unified approach to range-Doppler processing which was extendable in principle to provide high quality processing for any balance of radar system parameters. It would also be advantageous to be able to engineer the processor to provide image quality as near to ideal as required.

According to the present invention there is provided a signal processor as defined in Claim 1 below.

The signal processor of the present invention is capable of processing synthetic aperture data to a high quality. Quality may be enhanced by incorporating further features in the processor depending upon the characteristics of the vehicle and antenna system providing the data. Thus in the azimuth compression means it may be desirable to provide additional precision curvature and migration compensation means comprising a short complex correlator with a non-stationary correcting filter selected according to values computed by the parameter generator, operated in the range dimension.

Such additional precision curvature migration compensation means would probably be unnecessary for data from a 5 GHz satellite with a 0.5 second integration time and modest antenna squint but may be desirable for a satellite operating in a frequency of 1.25 GHz with a 2 second integration time and small antenna squint.

The processor design is based on a novel appreciation of the processing problem, which is

(i) to consider the two dimensional transform of the system transfer function;

(ii) to factorise this two dimensional transform in such a way that non stationarities of the system transfer function may be accommodated, and

(iii) to compute the elements of the factorisation of the system transfer function in terms of the co-efficients of the range polynomial, which is determined at all points in the image by the known relative motion.

The two dimensional transform of the system transfer function for a point with range and range time derivatives R_c , $\dot{R}_c$, $\ddot{R}_c$ etc at some time T_c relative to time of closest point of approach with a corresponding instantaneous Doppler frequency $F_c(f) = \frac{-2f}{c} \dot{R}_c$ is approximated as the following two dimensional phase screen as a function of video frequency f and Doppler frequency F :

$$\begin{aligned}
& \exp 2\pi i \left[\frac{(-2fR_c - F_c(f)T_c) - T_c(F - F_c(f))}{c} \right. \\
& + \frac{c}{2f} \frac{1}{R_c^2} (F - F_c(f))^2 + \frac{c}{2f} \frac{2}{R_c^3} \frac{\ddot{R}_c}{R_c^3} \frac{(F - F_c(f))^3}{3!} \\
& + \frac{c}{2f} \frac{3}{R_c^5} \frac{(\ddot{R}_c^2 - \ddot{R}_c \ddot{R}_c)}{R_c^5} \frac{(F - F_c(f))^4}{4!} + \dots \left. \right] \\
& = \exp 2\pi i \theta(f, F)
\end{aligned}$$

Factorisation is achieved by expanding $\theta(f, F)$ as a Taylor series about f_0 , the centre video frequency; thus

$$\theta(f, F) = \theta(f_0, F) + \frac{\partial \theta}{\partial f}(f_0, F)(f - f_0) + g(f, F)$$

The function $g(f, F)$, representing the residual terms may be considered by its expansion about a central Doppler frequency $\hat{F}_c$ and f_0 :

$$g(f, F) = \frac{\partial^2 \theta}{\partial f^2}(f_0, \hat{F}_c) \frac{(f - f_0)^2}{2!} + s(f - f_0, F - \hat{F}_c).$$

$$\frac{\partial^2}{\partial f^2}(\theta_0, \hat{F}_c) = \frac{2}{cf_0} \frac{\dot{R}_c^2}{R_c^3},$$

and provides the primary migration correction for the squint multiplication means b(iii).

$\frac{-c}{2} \frac{\partial \theta}{\partial f}(f_0, F)$ provides range -Doppler selection curves which can be used by the data selection means in the azimuth compression means, and $\theta(f_0, F)$ provides the azimuth phase replica used by the azimuth replica multiplication means.

Comparison of these parameters computed at the edges of the processing block with those applied during azimuth compression provided the resampling and phase adjustment parameters used by the image formation means.

The residual non stationary correlations used by the additional precision curvature and migration compensation means (if present) and by the image formation means are determined by the function s and are applied in range, in range -Doppler space and in along track, in image space respectively. The residual compensation required is very substantially reduced by the use of the preliminary compensation during range compression, such that further corrections may be applied by correlation with short pretabulated filter functions, determined by the difference between the two dimensional frequency domain transfer function applied and that which should have been applied on the basis of the local range polynomial coefficients.

The invention is illustrated by reference to Figure 1 which shows a version of the processor appropriate to a satellite mounted radar at 800 km altitude, 5 GHz operating frequency and squint less than 30 KHz. The version illustrated omits the additional precision curvature and migration compensation means. The range replica multiplication means and squint compensation multiplication means are combined by pre-multiplication of the range frequency domain replica with the primary migration correction. The invention may be implemented either as a software product on some appropriate general purpose architecture, or may be constructed in hardware as a special purpose fast processor.

A particular preferred form of parameter generator comprises a signal processor according to claim 1 wherein the processing parameter generator comprises

- (1) means for computing the latitude and longitude of points approximately in the beam centre at the near, far and centre swath positions on the surface at times corresponding approximately to respective start, centre and end pulses of each processing block;
- (2) means for computing the time offset of each of these points from a closest point of approach and the range at the closest point of approach;
- (3) means for evaluating range, Doppler frequency and successive derivatives of the range with respect to time at a given time;
- (4) means for quadratically fitting calculated parameters as a function of minimum range;

(5) means for generating parameters for each of a plurality of output range pixels comprising means for:- determining range polynomial coefficients by quadratic expansion using required minimum range values;

(6) means for computing block geometric and phase correction factors; and

(7) means for computing block collation parameters.

The invention will now be further illustrated with reference to the drawings where

Figure 1 is a diagrammatic representation of the main elements of the processor,

Figure 2 is a more detailed diagrammatic representation of a range compression means of the processor,

Figure 3 is a more detailed diagrammatic representation of the azimuth compression means, and

Figure 4 is a detailed diagrammatic representation of a specific processor embodying the invention.

The processor may be described as operating fundamentally according to a range-Doppler processing principles, but incorporating many novel features and principles.

Figure 1 shows the basic structure of the processor namely a preprocessor which receives data produced by for example a satellite, and includes a processing parameter generator which generates and stores a table of parameters for use by the successive parts of the processor. Data from the preprocessor is fed in turn to a range compression means 3, and azimuth compression means 4 and an image formation means 5 which generates the final radar image. Figure 2 shows the range compression means 3 in more detail. It comprises a pulse FFT means 6, a pulse replica multiplication means 7, a squint compensation multiplication means 8 and an inverse FFT means 9. Figure 3 shows the azimuth compression means 4 in more detail. This comprises a row FFT means 10, an azimuth replica evaluator means 11, an azimuth spectral buffer means 12, a data selection means 13, an azimuth replica multiplication means 14 and an inverse FFT means 15.

Figure 4 shows the preprocessor and image formation means in more detail. The preprocessor 2 comprises an input processing means 16 which carries out conventional preprocessing of the radar pulses e.g. recorded from a satellite before feeding them to the range compression means. Processing parameter generator 17 receives information about the orbit of the satellite producing the radar pulses together with additional information fed in by the operator of the processor, and information from the input processing of the radar pulses. The processing parameter generator generates and stores the parameters required by the range compression, azimuth compression and image formation means. The image formation means 5 comprises distortion removal means 18 and block merge means 19.

A key element of the design is the processing parameter generator which generates data tables to allow signal processing to operate as a sequence of one dimensional vector operations. Accordingly the operation of the parameter generator and the contents of the data tables that it generates are described first, with the operation of the processor as a whole described with reference to these tables.

Parameter Generator

The primary inputs to the parameter generator are information concerning the relative motion of the platform to the surface to be imaged and the pointing angle and orientation of the antenna. Such data may be typically provided as sampled values of platform vector position and vector time derivatives, sampled values of platform pitch roll and yaw and system parameters describing the orientation of the boresight and boresight plane to the platform co-ordinate system.

Further inputs to the generator comprise information concerning the data start time and data sampling offsets, the radar parameters, the size of image to be generated, the dimensions of processing block sizes to be used and the maximum duration of illumination of any point on the ground to be imaged.

The generator performs the following functions:

(i) It fits a spline to the sampled relative motion and pointing angles of the platform and its antenna, such that the vector position, vector velocity, vector acceleration and orientation of the platform may be evaluated at any required point in time; spline fitting procedures are well known to those skilled in the art;

(ii) It evaluates a centre time for each processing block according to $T_n = T_{n-1} + (N_AZFFT - N_AZREP)/PRF$, where N_AZFFT is the defined processing block size in pulses, PRF is the system pulse repetition frequency, and N_AZREP is the maximum illumination time multiplied by the PRF ; T_1 is provided by the time of the first pulse plus $N_AZFT/2PRF$; and evaluates a start and end pulse index for each processing block according to $PRF * T_n \pm N_AZFFT/2$.

(iii) It computes, for each processing block, at times T_n and $T_n \pm (N_AZFFT - N_AZREP)/2PRF$, coordinates of points on the surface to be imaged in the beam centre at the near side, far side and centre of the illuminated swath. The computation of the coordinates of such points is a routine problem in trigonometry and vector analysis and familiar to those skilled in the art.

(iv) It computes, for each such point at such times, the range from the platform to the point, ΔR , and its

successive time derivatives according to:

$$\Delta R = |\Delta \underline{R}|$$

$$\Delta \dot{R} = \frac{(\Delta \underline{R}, \dot{\underline{R}})}{\Delta R}$$

$$\Delta \ddot{R} = (\dot{\underline{R}}, \dot{\underline{R}} + \Delta \underline{R}, \ddot{\underline{R}} - \Delta \dot{R}^2) / \Delta R$$

$$\Delta \dddot{R} = (\Delta \underline{R}, \ddot{\underline{R}} + 3(\dot{\underline{R}}, \ddot{\underline{R}} - \Delta \dot{R} \ddot{\underline{R}})) / \Delta R,$$

where $\underline{R}, \dot{\underline{R}}$ etc are the platform relative vector time derivatives; computes, for each such point at such times, the time offset of the point to its time of closest approach to the satellite, ΔT , and the corresponding slant range at closest approach, ΔR_{cpa} , by numerical minimisation of $(\Delta \underline{R}(T), \dot{\underline{R}}(T))$ according to procedures familiar to those skilled in such art; computes an approximate fourth time derivative of the scalar range according to:

$$\Delta \dddot{R} = -6.0(\Delta \dot{R} + \Delta \dot{R} \Delta T + \Delta \ddot{R} \Delta T^2 / 2.0) / \Delta T^3$$

so that the extrapolated truncated slant range polynomial satisfies $\Delta \dot{R}(T)=0$ at time of closest approach; and computes a centre Doppler frequency for each such point at such times according to

$$F_0 = \frac{-2f_0 \Delta \dot{R}}{c}$$

(v) It evaluates for each processing block, at each such times, the coefficients of a quadratic fit of each of

$\Delta R, \Delta \dot{R}, \Delta \ddot{R}, \Delta \ddot{R}, \Delta \ddot{R}, F_0$ and ΔT as functions of minimum slant range, ΔR_{cpa} .

(vi) It evaluates, for each processing block, at each such times, for each output minimum range pixel position required, $\Delta R, \Delta \dot{R}, \Delta \ddot{R}, \Delta \ddot{R}, \Delta \ddot{R}, \Delta \dot{R}, F_0$ and ΔT by expansion of the quadratic fitting coefficients.

(vii) It evaluates, for each such output minimum range pixel position required, the coefficients of slant range and phase Doppler frequency polynomials, expanded with reference to the centre frequency at the centre of the processing block F_{BS} , according to:

$$R(F) = R(1) + R(2)(F-F_{BS}) + R(3)(F-F_{BS})^2 + R(4)(F-F_{BS})^3$$

$$\theta(F) = \theta(1) + \theta(2)(F-F_{BS}) + \theta(3)(F-F_{BS})^2 + \theta(4)(F-F_{BS})^3$$

where the coefficients $R(1)-R(4), \theta(1)-\theta(4)$ are initially evaluated according to the local centre frequency F_0 and re-expanded with respect to F_{BS} according to:

$$R(1) = R'(1) + R'(2)(F_{BS}-F_0) + R'(3)(F_{BS}-F_0)^2 + R'(4)(F_{BS}-F_0)^3$$

$$R(2) = R'(2) + 2R'(3)(F_{BS}-F_0) + 3R'(4)(F_{BS}-F_0)^2$$

$$R(3) = R'(3) + 3R'(4)(F_{BS}-F_0)$$

$$R(4) = R'(4); \theta(1)-\theta(4) \text{ similarly, where}$$

$$R'(1) - R'(4) \text{ are given in sample units by:}$$

$$R'(1) = (\Delta R - \text{slant range to first sample}) / \Delta r;$$

$$R'(2) = - \left[\frac{c}{2f_0} \right] \frac{\Delta \dot{R}}{\Delta R \Delta r}$$

$$R'(3) = \left[\frac{c}{2f_0} \right]^2 \frac{(\Delta \dot{R}^2 - \Delta \dot{R} \ddot{R})}{2\Delta R^3 \Delta r}$$

$$R'(4) = - \left[\frac{c}{2f_0} \right]^3 \frac{(3\Delta\dot{R}\Delta\ddot{R}^2 - \Delta\dot{R}\Delta\ddot{R}\Delta\ddot{R}'' - 2\Delta\dot{R}\Delta\ddot{R}^2)}{6\Delta\dot{R}^5\Delta r} ;$$

where

Δr is the range sample width in units of slant range;

$\theta'(2) - \theta'(4)$ are given by:

$$\theta'(2) = \Delta T$$

$$\theta'(3) = \left[\frac{c}{2f_0} \right]_2 \cdot \frac{1}{2\Delta\ddot{R}}$$

$$\theta'(4) = \left[\frac{c}{2f_0} \right]^2 \frac{\Delta\ddot{R}''}{6\Delta\dot{R}^3} ;$$

and the phase origin $\theta'(1)$ is determined by the quadratic fitting coefficients of ΔT and F_0 as functions of R_{cpa} ; with a, b, c, d defined by:

$$\Delta T(R_0) = \Delta T_{\text{mid}} + a(\Delta R_0 - \Delta R_{\text{mid}}) + b(\Delta R_0 - \Delta R_{\text{mid}})^2$$

$$F_0(\Delta R_0) = F_{0\text{mid}} + c(\Delta R_0 - \Delta R_{\text{mid}}) + d(\Delta R_0 - \Delta R_{\text{mid}})^2;$$

$\theta'(1)$ at ΔR_0 is evaluated according to

$$\theta'(1) = T_{\text{mid}} \cdot c \cdot \Delta R_0 + \frac{1}{2}(ac + 2\Delta T_{\text{mid}} \cdot d)(\Delta R_0 - \Delta R_{\text{mid}})^2 + \frac{1}{3}(bc + 2ad)(\Delta R_0 - \Delta R_{\text{mid}})^3 + \frac{1}{2}bd(\Delta R_0 - \Delta R_{\text{mid}})^4.$$

(viii) It computes, for each processing block, for each Doppler frequency column a table of parameters of the form of set of values providing: the number of output samples to be generated at a given frequency offset, and a frequency offset ΔF which is $(F - F_{\text{BS}})$ together with its second and third powers; the table is computed according to the following procedure:

First, for each output row to be generated during range migration correction, the column notionally dividing high and low Doppler frequencies (the "wrap around boundary") is computed from knowledge of the local centre Doppler frequency; then for the first row, the table is initialised for each column according to the relative position of the column to the wrap around boundary; then for each subsequent row, the table entries are modified according to whether a column shift in the wrap around boundary has occurred;

(ix) It computes and tabulates for each processing block a phase adjustment for incorporation into the frequency domain range compression replica, the "linear range migration correction", according to:

$$g(f) = \exp - 2\pi i \left[\frac{2 \Delta\dot{R}_c^2 (f - f_0)^2}{cf_0 \Delta\ddot{R}_c} \right] ;$$

where $\Delta\dot{R}_c$, $\Delta\ddot{R}_c$ are taken from representative centre block values of $\Delta\dot{R}$ and $\Delta\ddot{R}$.

(x) It computes and tabulates for each processing block n, for each output row R_0 the absolute image start and end pixel indices according to:

$$\text{start index}_n(R_0) = \text{end index}_{n-1}(R_0) + 1$$

$$\text{end index}_n(R_0) = \text{INT}(\text{PFR} \cdot T_n + (\text{N_AZFFT} - \text{N_AZREP})/2 + \text{PRF} \cdot \Delta T_n(R_0))$$

$$\text{with end index}_0(R_0) = \text{INT}(\text{PRF} \cdot T_1 - (\text{N_AZFFT} - \text{B_AZREP})/2 + \text{PRF} \cdot T_1(R_0))$$

(xi) It computes for each processing block, for each output row a geometric "stretch factor" to correct for residual block geometric distortion, according to:

stretch factor (R_o) = $1 - \frac{\Delta\theta}{\Delta T_{CPA}}$, where

$$\Delta\theta = (\theta_R(2) - \theta_L(2)) + 2.0 * (\theta_R(3) * (F_c - F_{BSR}) - \theta_L(3) * (F_c - F_{BSL})) \\ + 3.0 * (\theta_R(4) * (F_c - F_{BSR})^2 - \theta_L(4) * (F_c - F_{BSL})^2),$$

$$\Delta T_{CPA} = (N_AZFFT - N_AZREP - 1) / PRF + \Delta T_R(R_o) - \Delta T_L(R_o),$$

where the suffices R and L relate to function values evaluated at end and start of the processing block respectively;

computes for each processing block, for each output row, a real, that is fractionally valued, start sample modulo the processing block according to:

$$\text{start sample}_n(R_o) = (\text{start index}_n(R_o) + (1 - \text{stretch factor}_n(R_o)) * \\ (\text{end index}_n(R_o) + 1 - \text{start index}_n(R_o)) / 2) \bmod N_AZFFT$$

and tabulating: start sample_n(R_o), stretch factor_n(R_o) and

$$(\text{end index}_n(R_o) - \text{start index}_n(R_o) + 1);$$

(xii) It computes, for each processing block, for each output row, an approximate centre frequency $F_{CINT}(R_o)$ which is a multiple of PRF/N_AZFFT , and the corresponding column offset $\Delta COL(R_o)$ according to:

$$F_{CINT}(R_o) = \frac{PRF \times}{N_AZFFT} \text{INT}(F_c \times N_AZFFT / PRF)$$

$$\Delta COL(R_o) = (F_c \bmod PRF) \times N_AZFFT / PRF$$

(xiii) It computes and tabulates for each processing block, for each output row, a heterodyning frequency, $F_{HET}(R_o)$, and a phase offset, $\phi(R_o)$, according to:

$$F_{HET}(R_o) = \frac{\Delta\theta(R_o)}{\Delta T_{CPA}(R_o)} - F_{CINT}(R_o)$$

$$\phi(R_o) = \frac{\Delta\theta(R_o)}{\Delta T_{CPA}(R_o)} * T_{CENTRE}$$

where

$$\Delta\theta(R_o) = (\theta_R(1) - \theta_L(1)) + (\theta_R(2) * (F_c - F_{BSR}) - \theta_L(2) * (F_c - F_{BSL})) \\ + (\theta_R(3) * (F_c - F_{BSR})^2 - \theta_L(3) * (F_c - F_{BSL})^2) \\ + (\theta_R(4) * (F_c - F_{BSR})^3 - \theta_L(4) * (F_c - F_{BSL})^3)$$

$$\Delta T_{CPA}(R_o) = (N_AZFFT - N_AZREP - 1) / PRF + \Delta T_R(R_o) - \Delta T_L(R_o)$$

$$T_{CENTRE} = T_n(R_o) + PRF * (N_AZFFT / 2)$$

(xiv) It tabulates operator specified range and azimuth compression weighting functions.

Data Tables

The following tables are generated for each processing block:

Block Control

- (i) Start pulse
- (ii) End pulse
- (iii) For each output image row: start and end image pixel location.

Range Compression

- (i) Frequency domain pulse reference $\times g(f) \times$ user specified weighting function.

Azimuth Compression

- (i) For each output image row:
 - $R(1)$, $R(2)$, $R(3)$, $R(4)$ coefficients
 - $\theta(1)$, $\theta(2)$, $\theta(3)$, $\theta(4)$ coefficients
- (ii) For each Doppler frequency column (N_AZFFT):
 - For each wraparound:
 - Number of output rows to be generated
 - ΔF , ΔF^2 , ΔF^3 where ΔF is the difference between the column frequency and the centre block expansion frequency.
- (iii) For each output image row:

- Δ COL
- F_{HET}
- ϕ
- (iv) For each output image row:
 - start sample
 - stretch factor
 - number of samples to output.
- (v) User specified azimuth compression weighting function.

10 Range Compression

The system loads each pulse performs an FFT, multiplies the spectral data by the tabulated range compression replica, performs an inverse FFT and outputs the range compressed data; the range compression replica is selected according to the relevant processing block but the update rate is non-critical; the fine detail of the process is well known to those skilled in this art.

Azimuth Compression

Data is processed in overlapping blocks, defined by the block start and end pulse indices. An FFT at constant range is performed one each row of each block; for each frequency column a sampling comb and phase conjugate function is generated, according to:

For each wraparound:

For each output row:

$R_{\text{INDX}}(R_o) = R(1) + R(2)\Delta F = R(3)\Delta F^2 + R(4)\Delta F^3 = 2\pi * (\theta(1) + \theta(2)\Delta F + \theta(3)\Delta F^2 + \theta(4)\Delta F^3);$

For each column, data is interpolated to generate a new column, defined by the sampling comb $R_{\text{INDX}}(R_o)$, by procedures known to those skilled in this art, and multiplied by $\exp-i\theta(R_o)$. Each row of this modified block is then logically shifted in a cyclic fashion by Δ COL, multiplied by the user specified azimuth compression weighting function and an inverse FFT performed;

For each resulting row a sampling comb, A_{INDX} , and phase function, θ , are generated according to:

$A_{\text{INDX}}(N) = (\text{start sample} + (N-1) \times \text{stretch factor}) \bmod N_{\text{AZFFT}}$, for $N = 1$ to number of samples to output;
 $\theta(N) = 2\pi * (\phi + \frac{F_{\text{HET}}}{\text{PRF}} \times (\text{start image location} + (N-1) - \text{start pulse}))$;

and a modified row is interpolated according to the cyclic sampling comb A_{INDX} , according to procedure known to those skilled in such art, and each resulting pixel is multiplied by $\exp-i\theta(N)$. The resulting block of output image is then output to storage.

Block Merge

The final coherent image is assembled row by row from the contiguous blocks of image data; each row is offset in the image frame by the start pixel location of the row in the first image block less the minimum start pixel location.

The resulting coherent image is obtained in coordinates of minimum slant range and time of closest approach, is at baseband with respect to the range dimension and at offset Doppler frequencies provided by the F_{HET} tabulation.

Claims

1. A signal processor for synthetic aperture radar carried by a moving vehicle including an antenna, the radar using a beam which has a centre and is scanned over a surface to be imaged and mapped so as to trace out thereon a swath having near, far and centre positions, which processor comprises:
 - (a) a processing parameter generator (17) including processing blocks;
 - (b) range compression means (3) comprising:
 - pulse FFT means (6) for performing an FFT on pulse echoes, and providing spectral data,
 - pulse replica multiplication means multiplying the spectral data by a range compression function provided by the processing parameter generator (7) to effect pulse correlation, and
 - first inverse FFT means (9) for performing an inverse FFT on the multiplied spectral data; and
 - (c) azimuth compression means (4) comprising:

- ΔCOL
- F_{HET}
- ϕ

(iv) For each output image row:

- start sample
- stretch factor
- number of samples to output.

(v) User specified azimuth compression weighting function.



10 Range Compression

The system loads each pulse performs an FFT, multiplies the spectral data by the tabulated range compression replica, performs an inverse FFT and outputs the range compressed data; the range compression replica is selected according to the relevant processing block but the update rate is non-critical; the fine detail of the process is well known to those skilled in this art.

Azimuth Compression

Data is processed in overlapping blocks, defined by the block start and end pulse indices. An FFT at constant range is performed one each row of each block; for each frequency column a sampling comb and phase conjugate function is generated, according to:

For each wraparound:

For each output row:

$$R_{\text{INDX}}(R_o) = R(1) + R(2)\Delta F = R(3)\Delta F^2 + R(4)\Delta F^3 = 2\pi * (\theta(1) + \theta(2)\Delta F + \theta(3)\Delta F^2 + \theta(4)\Delta F^3);$$

For each column, data is interpolated to generate a new column, defined by the sampling comb $R_{\text{INDX}}(R_o)$, by procedures known to those skilled in this art, and multiplied by $\exp-i\theta(R_o)$. Each row of this modified block is then logically shifted in a cyclic fashion by ΔCOL , multiplied by the user specified azimuth compression weighting function and an inverse FFT performed;

For each resulting row a sampling comb, A_{INDX} , and phase function, θ , are generated according to:

$$A_{\text{INDX}}(N) = (\text{start sample} + (N-1) \times \text{stretch factor}) \bmod N_{\text{AZFFT}}, \text{ for } N = 1 \text{ to number of samples to output};$$

$$\theta(N) = 2\pi * (\phi + \frac{F_{\text{HET}}}{\text{PRF}} \times (\text{start image location} + (N-1) - \text{start pulse}));$$

and a modified row is interpolated according to the cyclic sampling comb A_{INDX} , according to procedure known to those skilled in such art, and each resulting pixel is multiplied by $\exp-i\theta(N)$. The resulting block of output image is then output to storage.

Block Merge

The final coherent image is assembled row by row from the contiguous blocks of image data; each row is offset in the image frame by the start pixel location of the row in the first image block less the minimum start pixel location.

The resulting coherent image is obtained in coordinates of minimum slant range and time of closest approach, is at baseband with respect to the range dimension and at offset Doppler frequencies provided by the F_{HET} tabulation.

Claims

1. A signal processor for synthetic aperture radar carried by a moving vehicle including an antenna, the radar using a beam which has a centre and is scanned over a surface to be imaged and mapped so as to trace out thereon a swath having near, far and centre positions, which processor comprises:
 - (a) a processing parameter generator (17) including processing blocks;
 - (b) range compression means (3) comprising:
 - pulse FFT means (6) for performing an FFT on pulse echoes, and providing spectral data,
 - pulse replica multiplication means multiplying the spectral data by a range compression function provided by the processing parameter generator (7) to effect pulse correlation, and
 - first inverse FFT means (9) for performing an inverse FFT on the multiplied spectral data; and
 - (c) azimuth compression means (4) comprising:



row FFT means (10) for performing an FFT on rows of data selected at constant range from overlapping blocks of range compressed data,

azimuth replica multiplication means (14) to effect multiplication of the selected data with complex data, and

second inverse FFT means (15) to effect the inverse transform of rows of the processed data; characterised in that the processing parameter generator is arranged for computation of processor filter parameters, from the vehicle motion and antenna geometry, for use by the other sections of the processor (3, 4, 5);

in that the range compression means (3) comprises between the pulse replica multiplication means (7) and the first inverse FFT means (9):

squint compensation multiplication means (8) to effect second order migration correction, the inverse FFT means then performing an inverse FFT on the multiplied and compensated spectral data;

in that the azimuth compression means (4) comprises between the row FFT means (10) and the azimuth replica multiplication means (14):

azimuth replica evaluator means (11), comprising range and phase polynomial evaluators and a complex exponentiator to derive the complex data from polynomial range and phase coefficients calculated by the processing parameter generator,

azimuth spectral buffer means 12, comprising a bank of storage to contain an adequately large number of row transforms, and

data selection means 13 comprising an interpolator to effect selection of data along curves in the spectral buffer means according to values computed by the range polynomial evaluator, the azimuth replica multiplication means then effecting multiplication of the selected data with the complex data generated by the phase polynomial evaluators,

and in that the processor comprises:

(d) image formation means (5) connected at the output of the azimuth compression means and comprising image resampling and buffering means to effect image block geometric and phase discontinuity removal and image collation.

2. A signal processor according to claim 1 wherein the processing parameter generator (17) comprises:

(1) means for computing the latitude and longitude of points approximately in the beam centre at the near, far and centre swath positions on the surface at times corresponding approximately to respective start, centre and end pulses of each processing block;

(2) means for computing the time offset of each of these points from a closest point of approach and the range at the closest point of approach;

(3) means for evaluating range, Doppler frequency and successive derivatives of the range with respect to time at a given time;

(4) means for quadratically fitting calculated parameters as a function of minimum range;

(5) means for generating parameters for each of a plurality of output range pixels comprising means for determining range polynomial coefficients by quadratic expansion using required minimum range values;

(6) means for computing block geometric and phase correction factors; and

(7) means for computing block collation parameters.

3. A signal processor according to claims 1 or 2 wherein the processing parameter generator has means for generating and storing for each of a plurality of blocks of data to be processed to produce the image, the following data tables;

a block control data table comprising a start pulse, an end pulse and a start and end image pixel location for each of a plurality of output rows;

a range compression data table comprising the product of frequency domain pulse reference, $g(f)$, where $g(f)$ is

$$\exp(-2\pi i \left[\frac{2}{cf_0} \frac{\Delta \dot{R}_c^2}{\Delta \ddot{R}_c} \frac{(f-f_c)^2}{2} \right]),$$

f is the bandwidth, f_c is the centre video frequency,



$\Delta \dot{R}_0$ is the first time derivative of range, and
 $\Delta \ddot{R}_0$ is the second time derivative of range, and a predetermined weighting function; and
 an azimuth compression data table including rows and columns of Doppler frequency data and comprising for each of a plurality of output image rows

- (i) coefficients of slant range polynomials of Doppler frequency expanded with reference to a centre frequency at the centre of a processing block;
- (ii) for a respective column of Doppler frequency data dividing high and low Doppler frequencies in each Doppler frequency data column, the number of output rows to be generated and ΔF , ΔF^2 and ΔF^3 , where ΔF is the difference in absolute Doppler frequency between the column frequency and a centre block expansion frequency;
- (iii) for each of a plurality of output range rows, a column offset, a heterodyning frequency and a phase offset;
- (iv) for each output image row, a start sample, a stretch factor, and a number of samples to output; and
- (v) a predetermined azimuth compression weighting function.

Patentansprüche

1. Signalverarbeitungsanlage für ein Radar mit künstlicher Strahleröffnung, das auf einem sich bewegenden Fahrzeug mit einer Antenne angeordnet ist, wobei das Radar mit einem Strahl arbeitet, der einen Mittelpunkt umfaßt und mit dem eine bildlich wiedergabende und kartographisch zu erfassende Oberfläche abgetastet wird, um einen Streifen mit Nah-, Fern- und Mittelstellungen abzustecken, und wobei die Verarbeitungsanlage folgende Komponenten umfaßt:

(a) einen Verarbeitungsparametergenerator (17) mit Verarbeitungsbausteinen;

(b) eine Bereichskomprimierungsvorrichtung (3) mit:

einer Impuls-FFT-Vorrichtung (6) zur Durchführung einer schnellen Fourier-Transformation von Impulseechos und zur Lieferung von Spektraldaten,

einer Impuls-Wiedergabe-Multiplikationsvorrichtung (7) zur Multiplikation der Spektraldaten mit einer vom Verarbeitungsparametergenerator stammenden Bereichskomprimierungsfunktion zur Durchführung einer Impulskorrelation, und

einer ersten inversen FFT-Vorrichtung (9) zur Durchführung einer schnellen inversen Fourier-Transformation ausgehend von den multiplizierten Spektraldaten; und

(c) einer Azimutkomprimierungsvorrichtung (4) mit:

einer Zeilen FFT-Vorrichtung (10) zur zeilenweisen schnellen Fourier-Transformation von bei konstantem Bereich aus überlappenden Blöcken bereichsverdichteter Daten ausgewählten Datenzeilen,

einer Azimut-Wiedergabe-Multiplikationsvorrichtung (14) zur Multiplikation der ausgewählten Daten mit komplexen Daten, und

einer zweiten inversen FFT-Vorrichtung (15) zur Durchführung einer schnellen inversen Fourier-Transformation von aus den verarbeiteten Daten bestehenden Zeilen;

dadurch gekennzeichnet, daß der Verarbeitungsparametergenerator zur Berechnung von Filterparametern der Verarbeitungsanlage anhand der Fahrzeugbewegung und der Antennenengeometrie zur Benutzung durch die anderen Bereiche der Verarbeitungsanlage (3, 4, 5) vorgesehen ist;

daß die Bereichskomprimierungsvorrichtung (3) zwischen der Impuls-Wiedergabe-Multiplikationsvorrichtung (7) und der ersten inversen FFT-Vorrichtung (9)

zur Durchführung einer schnellen inversen Fourier-Transformation eine Multiplikationsvorrichtung (8) zur Winkelfehlerkompensation umfaßt, um eine Wanderungskorrektur zweiter Ordnung vorzunehmen, wobei dann von der inversen FFT-Vorrichtung eine schnelle inverse Fourier-Transformation der multiplizierten und kompensierten Spektraldaten durchgeführt wird;

daß die Azimutkomprimierungsvorrichtung (4) zwischen der Zeilen FFT-Vorrichtung (10) und der Azimut-Wiedergabe-Multiplikationsvorrichtung (14) folgende Komponenten umfaßt:

eine Azimut-Wiedergabe-Auswertungsvorrichtung (11) mit polynomischen Bereichs- und Phasenauswertegeräten und einer komplexen Potenzierungsvorrichtung, um die komplexen Daten von durch den Verarbeitungsparametergenerator errechneten polynomischen Bereichs- und Phasenkoeffizienten abzuleiten,

eine Azimut-Spectralpuffervorrichtung (12) mit einer Speicherbank zur Aufnahme einer ausreichend großen Anzahl von Zeilentransformationen und

eine Datenauswahlvorrichtung (13) mit einem Interpolator, um Daten entlang Kurven in der Spek-



tralpuffervorrichtung in Abhängigkeit von durch das polynomische Bereichsauswertungsgerät errechneten Werten auszuwählen, wobei von der Azimut-Wiedergabe-Multiplikationsvorrichtung dann eine Multiplikation der ausgewählten Daten mit den durch die polynomischen Phasenauswertungsgeräte erzeugten komplexen Daten durchgeführt wird;

und dadurch gekennzeichnet, daß die Verarbeitungsanlage umfaßt:

(d) eine an den Ausgang der Azimutkomprimierungsvorrichtung angeschlossene Bildherstellungsvorrichtung (5) zur Herstellung von Bildern mit Bildwiederholungs- und -puffervorrichtung, um Geometrie- und Phasenfehler im Bildblock beseitigen und Bilder mischen zu können.

2. Signalverarbeitungsanlage nach Anspruch 1, dadurch gekennzeichnet, daß der Verarbeitungsparameter-generator (17) die folgenden Komponenten umfaßt:

(1) eine Vorrichtung zur Errechnung der Breite und Länge von ungefähr in der Strahlmitte gelegenen Punkten in den Nah-, Fern- und Mittelstellungen des Streifens an der Oberfläche zu Zeitpunkten, die in etwa den jeweiligen Start-, Mittel- und Endimpulsen eines jeden Verarbeitungsbausteins entsprechen;

(2) eine Vorrichtung zur Errechnung der Zeitverschiebung eines jeden dieser Punkte von einem nächstgelegenen Annäherungspunkt und des Bereichs bzw. der Entfernung am nächstgelegenen Annäherungspunkt;

(3) eine Vorrichtung zur Auswertung des Bereichs bzw. der Entfernung, der Dopplerfrequenz und nachfolgender Ableitungen des Bereichs bzw. der Entfernung in Abhängigkeit vom jeweiligen Zeitpunkt;

(4) eine Vorrichtung zur quadratischen Einordnung errechneter Parameter in Abhängigkeit vom Mindestbereich bzw. von der Mindestentfernung;

(5) eine Vorrichtung zur Erzeugung von Parametern für jeden einzelnen einer Vielzahl von Ausgangsbereichsbildpunkten mit einer Vorrichtung zur Bestimmung der bereichspolynomischen Koeffizienten durch quadratische Erweiterung mit Hilfe der erforderlichen Mindestbereichswerte;

(6) eine Vorrichtung zur Errechnung von Blockgeometrie- und Phasenkorrekturfaktoren; und

(7) eine Vorrichtung zur Errechnung von Blockmischparametern.

3. Signaverarbeitungsanlage nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß der Verarbeitungsparametergenerator mit einer Vorrichtung ausgestattet ist, um für jeden einzelnen einer Vielzahl von zur Herstellung des Bildes zu verarbeitenden Datenblöcken die folgenden Datentabellen zu erstellen und abzuspeichern:

eine Blockleitdatentabelle mit einem Startimpuls, einem Endimpuls sowie einem Anfangs- und Endbildpunkt für jede einer Vielzahl von Ausgangszeilen;

eine Bereichskomprimierungsdatentabelle mit dem Produkt der Frequenzbereichsimpulsreferenz, $g(f)$, wobei $g(f)$ ist:

$$\exp \left(-2\pi i \left[\frac{2}{cf_0} \frac{\Delta \dot{R}_c^2}{\Delta \ddot{R}_c} \frac{(f - f_0)^2}{2} \right] \right)$$

f = die Bandbreite;

f_0 = die Videoabstimmfrequenz;

$\dot{R}_c$ = die Ableitung erster Ordnung für den Bereich und

$\ddot{R}_c$ = die Ableitung zweiter Ordnung für den Bereich und eine vorbestimmte Bewertungsfunktion; und

eine Azimutkomprimierungsdatentabelle mit Zeilen und Spalten von Dopplerfrequenzdaten und mit folgenden Daten für eine jede einer Vielzahl von Ausgangsbildzeilen:

(i) Koeffizienten von Schrägbereichspolynomen der mit Bezug auf eine Mittenfrequenz in der Mitte eines Verarbeitungsblocks erweiterten Dopplerfrequenz;

(ii) für eine jeweilige Spalte von Dopplerfrequenzdaten zur Unterteilung hoher und niedriger Dopplerfrequenzen in jeder Dopplerfrequenzdatenspalte die Anzahl der zu generierenden Ausgangszeilen und ΔF , ΔF^2 und ΔF^3 , wobei ΔF die Differenz als absolute Dopplerfrequenz zwischen der Spaltenfrequenz und einer Mittelblockerweiterungsfrequenz darstellt;

(iii) für jede einer Vielzahl von Ausgangsbereichszeilen eine Spaltenverschiebung, eine Überlagerungsfrequenz und eine Phasenverschiebung;



- (iv) für jede Ausgangsbildzelle ein Startmuster, einen Streckungsfaktor und eine Anzahl von Ausgangsmustern; und
- (v) eine vorbestimmte Bewertungsfunktion für die Azimutkomprimierung.

5

Revendications

1. **Processeur de signal pour radar à synthèse d'ouverture monté sur un véhicule en mouvement incluant une antenne, le radar utilisant un faisceau qui présente un centre et qui est balayé sur une surface à imager et topographier de manière à déplacer dessus une zone d'exploration comportant des positions approchée, éloignée et centrale, le processeur comprenant:**
 - (a) un générateur de paramètres de traitement (17) incluant des blocs de traitement;
 - (b) un moyen de compression de distance (3) comprenant:
 - un moyen de transformée de Fourier rapide par impulsions (6) pour effectuer une transformée de Fourier rapide (ou FFT) sur des échos d'impulsions et pour produire des données spectrales,
 - un moyen de multiplication de répliques d'impulsions (7) qui multiplie les données spectrales par une fonction de compression de distance fournie par le générateur de paramètres de traitement afin d'effectuer une corrélation d'impulsions, et
 - un premier moyen de transformée de Fourier rapide inverse (9) pour effectuer une FFT inverse des données spectrales multipliées; et
 - (c) un moyen de compression en azimut (4) comprenant:
 - un moyen de transformée de Fourier rapide de rangée (10) pour effectuer une FFT sur des rangées de données sélectionnées à une distance constante à partir des blocs en chevauchement des données comprimées de distance,
 - un moyen de multiplication de répliques en azimut (14) pour effectuer une multiplication des données sélectionnées par des données complexes, et
 - un second moyen de transformée de Fourier rapide inverse (15) pour effectuer la transformée inverse sur les rangées des données traitées;
 - caractérisé en ce que le générateur de paramètres de traitement est agencé de manière à calculer des paramètres de filtre de processeur à partir du mouvement du véhicule et de la géométrie de l'antenne en vue d'une utilisation par les autres sections du processeur (3, 4, 5);
 - en ce que le moyen de compression de distance (3) comprend entre le moyen de multiplication de répliques d'impulsions (7) et le premier moyen de FFT inverse (9);
 - un moyen de multiplication de compensation d'erreur de direction (8) pour effectuer une correction de migration d'ordre deux, le moyen de FFT inverse effectuant alors une FFT inverse des données spectrales multipliées et compensées;
 - en ce que le moyen de compression en azimut (4) comprend entre le moyen de FFT de rangée (10) et le moyen de multiplication de répliques en azimut (14):
 - un moyen d'évaluateur de répliques en azimut (11) comprenant des évaluateurs polynomiaux de distance et de phase et un exponentiateur complexe pour déduire les données complexes à partir des coefficients polynomiaux de distance et de phase calculés par le générateur de paramètres de traitement,
 - un moyen de mémoire tampon de spectre en azimut (12) comprenant une banque de stockage destinée à contenir un nombre adéquat important de transformées de rangées, et
 - un moyen de sélection de données (13) comprenant un interpolateur afin d'effectuer une sélection de données le long de courbes contenues dans le moyen de tampon spectral en fonction de valeurs calculées par l'évaluateur polynomial de distance, le moyen de multiplication de répliques en azimut effectuant alors une multiplication des données sélectionnées par les données complexes générées par les évaluateurs polynomiaux de phase,
 - et en ce que le processus comprend:
 - (d) un moyen de formation d'image (5) connecté à la sortie du moyen de compression en azimut et comprenant un moyen de ré-échantillonnage d'image et de mise en mémoire tampon pour effectuer une suppression de discontinuité de géométrie de bloc d'image et de phase et un classement d'image.
2. **Processeur de signal selon la revendication 1, dans lequel le générateur de paramètres de traitement (17) comprend:**
 - (1) un moyen pour calculer la latitude et la longitude de points qui se trouve approximativement au centre du faisceau, au niveau des positions de zone d'exploration approchée, éloignée et centrale situées



sur la surface en des instants qui correspondent approximativement à des impulsions respectives de début, de centre et de fin de chaque bloc de traitement;

(2) un moyen pour calculer le décalage temporel de chacun de ces points par rapport à un point d'approche le plus proche ainsi que la distance au niveau du point d'approche le plus proche;

(3) un moyen pour évaluer la distance, la fréquence Doppler et les dérivées par rapport au temps successives de la distance à un point donné;

(4) un moyen pour ajuster de manière quadratique les paramètres calculés selon une fonction d'une distance minimale;

(5) un moyen pour générer des paramètres pour chacun d'une pluralité de pixels de distance de sortie comprenant un moyen pour déterminer des coefficients polynomiaux de distance par dilatation quadratique utilisant des valeurs de distance minimale nécessaires;

(6) un moyen pour calculer des facteurs de correction de géométrie de bloc et de phase; et

(7) un moyen pour calculer des paramètres de classement de bloc.

3. Processeur de signal selon la revendication 1 ou 2, dans lequel le générateur de paramètres de traitement comporte un moyen pour générer et stocker pour chacun d'une pluralité de blocs de données qui doivent être traités pour produire l'image des tables de données suivantes:

une table de données de commande de bloc comprenant une impulsion de début, une impulsion de fin et un emplacement de pixel d'image de début et de fin pour chacune d'une pluralité de rangées de sortie;

une table de données de compression de distance comprenant le produit d'une référence d'impulsion de domaine de fréquence $g(f)$, où $g(f)$ s'exprime comme suit:

$$\exp \left(-2\pi i \left[\frac{2}{c f_0} \frac{\Delta \dot{R}_c^2}{\Delta \ddot{R}_c} \frac{(\bar{f} - f_c)^2}{2} \right] \right)$$

où f est la largeur de bande, f_c est la fréquence vidéo centrale,

$\Delta \dot{R}_c$ est la dérivée temporelle d'ordre un de la distance et,

$\Delta \ddot{R}_c$ est la dérivée temporelle d'ordre deux de la distance, ainsi qu'une fonction de pondération prédéterminée; et

une table de données de compression en azimuth incluant des rangées et des colonnes de données de fréquence Doppler et comprenant pour chacune d'une pluralité de rangées d'image de sortie:

(i) des coefficients des polynômes de distance oblique d'une fréquence Doppler dilatée par rapport à une fréquence centrale située au centre du bloc de traitement;

(ii) pour une colonne respective des données de fréquence Doppler, la division des fréquences Doppler haute et basse de chaque colonne de données de fréquence Doppler, le nombre de rangées de sortie qui doit être généré ainsi que ΔF , ΔF^2 et ΔF^3 , où ΔF est la différence en fréquence Doppler absolue entre la fréquence de colonne et une fréquence de dilatation de bloc central;

(iii) pour chacune d'une pluralité de rangées de distance de sortie, un décalage de colonne, une fréquence hétérodyne et un décalage de phase;

(iv) pour chaque rangée d'image de sortie, un échantillon de départ, un facteur d'étalement et un certain nombre d'échantillons à émettre en sortie; et

(v) une fonction de pondération de compression en azimuth prédéterminée.