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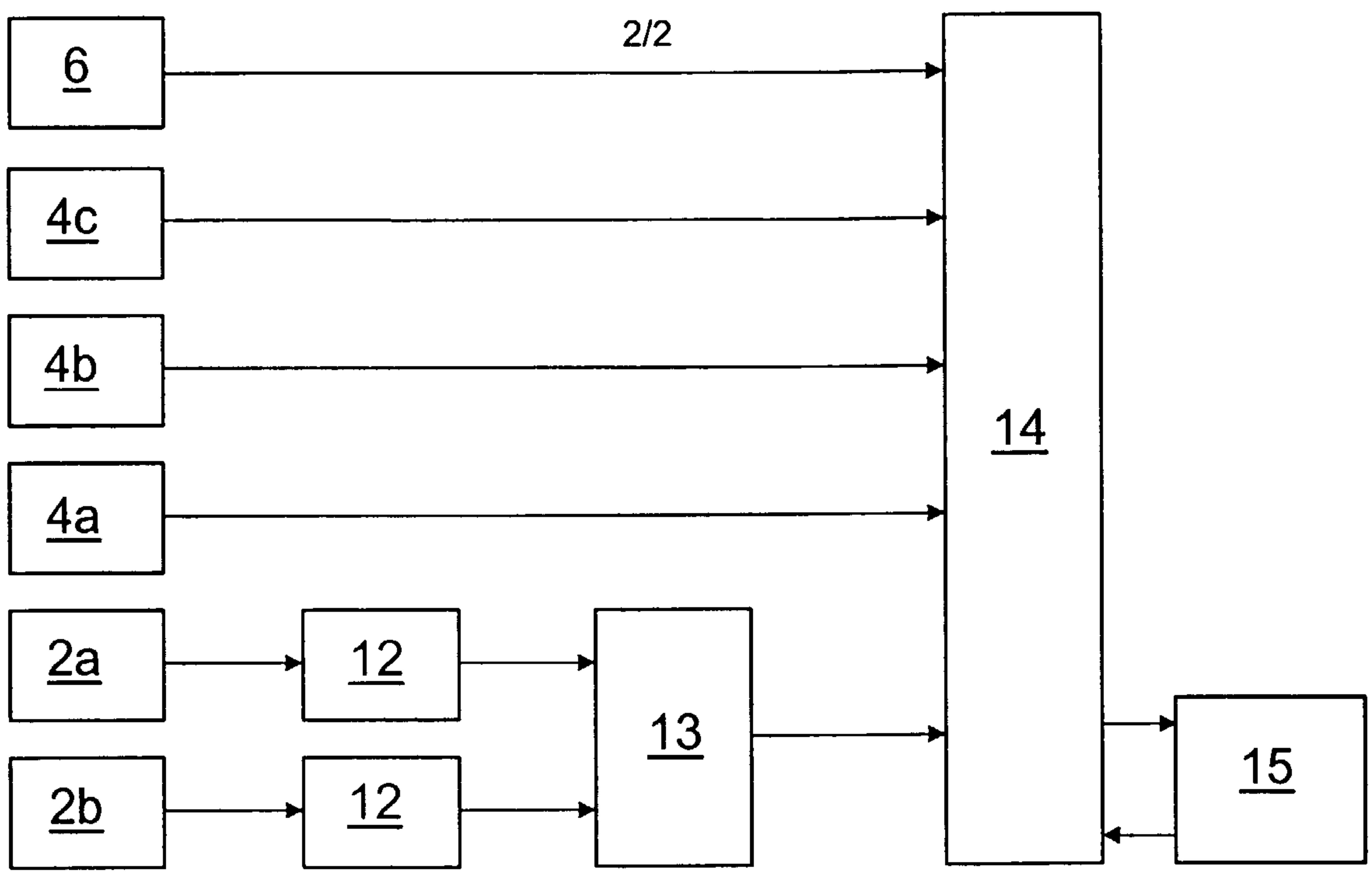

(57) Abrégé/Abstract:
A method and an arrangement for determining the weight of a load in a mining vehicle, in which method and arrangement a non-linear Kalman filter is used to determine the weight (m) of the load.

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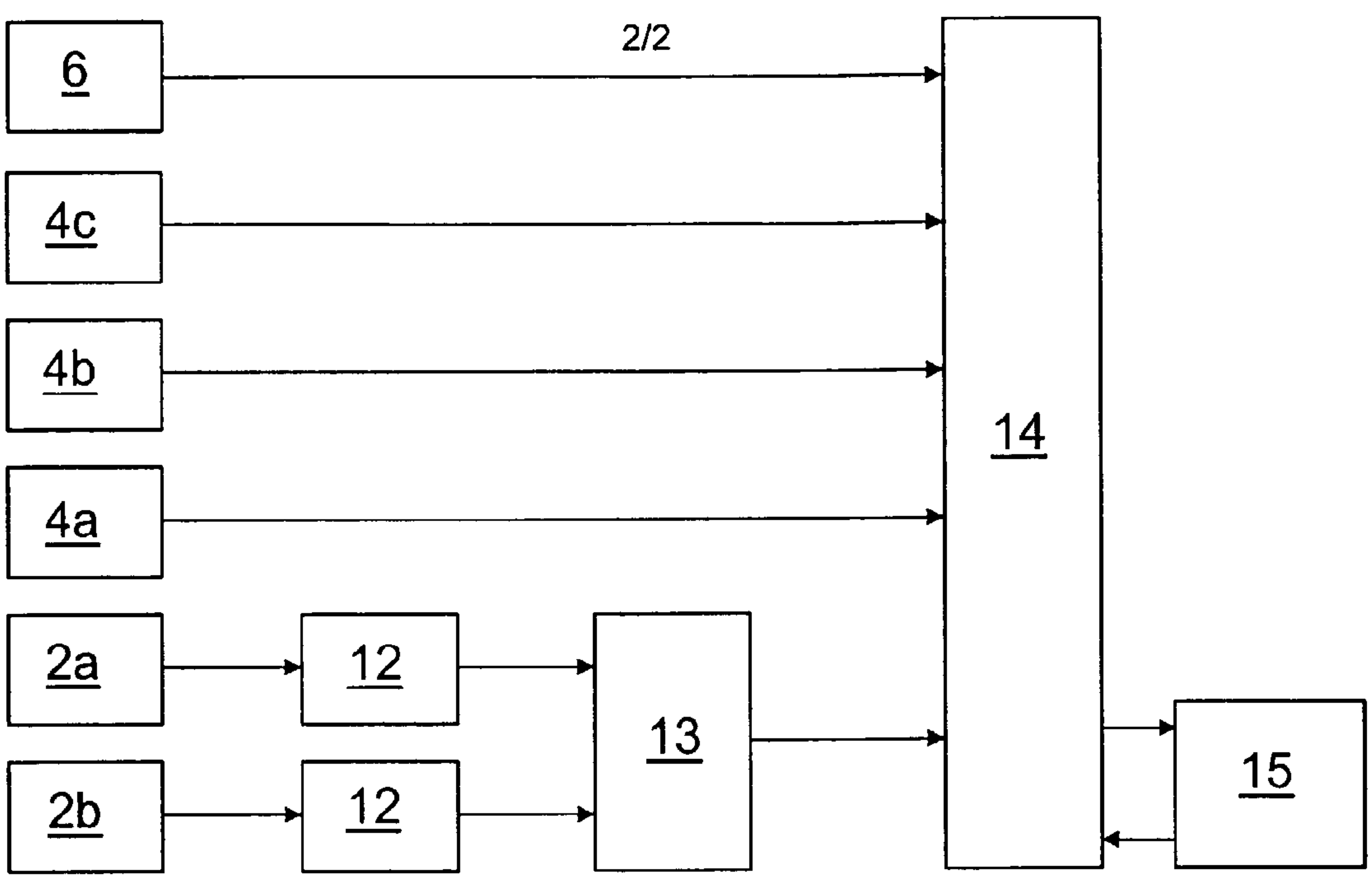
(54) Title: METHOD AND ARRANGEMENT FOR DETERMINING WEIGHT OF LOAD IN MINING VEHICLE



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METHOD AND ARRANGEMENT FOR DETERMINING WEIGHT OF LOAD IN MINING VEHICLE

[0001] The invention relates to a method of determining the weight of a load in a mining vehicle, in which method the load weight is determined on the basis of measuring signals obtained from separate measuring means.

[0002] The invention further relates to an arrangement for determining the weight of a load in a mining vehicle, which arrangement comprises means for determining the weight of the load.

[0003] Mining vehicles, such as dumpers and wheel loaders, transport blasted rock from a blasting location to a dump location. Because this is a fairly high-speed operation and the transportation distances are relatively short, weighing must be done while the vehicle is moving so as not to disturb production. For the following process, it is, however, necessary to know how much blasted rock has been transported for further processing. Real-time weighing information makes it possible to already monitor material flows inside the mine, thus facilitating production control and planning. Planning for preventive maintenance of machines is also made possible by utilising real-time weighing information.

[0004] A known solution weighs a load by measuring the cylinder pressure caused by the load in the lifting cylinder that moves the system made up of lifting arms and a bucket or dump box. The pressure is measured on both sides of the lifting cylinder several times during a certain measuring period, and the load in the bucket is calculated on the basis of the average of the obtained pressure differences. The effect of the tilting of the machine and the position of the lifting arms or dump box on the pressure difference measured in the lifting cylinder is compensated by means of compensation coefficients. The calculation method is linear and load determination is done while the machine is moving. When calibrating the measuring system, pressure is first measured with an empty bucket or dump box and then by using a load having a known weight in the bucket or dump box.

[0005] In a stable state, the obtained measuring values are relatively correct and the load in the vehicle can be determined at an adequate accuracy. The problem is, however, that due to the quickly driven and short distances, weighing must be done during the drive, in which case the tilting of the vehicle, bumps on the road and several other factors affect the final result of the weighing, and in certain situations, a systematic error towards one direction may easily occur. In addition, a problem with the solution is applying a linear method to a non-linear system and that even additional measurings used are not enough to compensate for all errors caused by drive-time measuring in the level of the pressure signal. One drawback is using a fixed measuring time when calculating the average of the pressure differences from measuring signals oscillating at varying period lengths.

[0006] WO publication WO99/09379 discloses a method that utilises a neural network and fuzzy logic to determine the weight of a mining vehicle load on the basis of measuring signals measured by sensors. Variables to be measured can be for instance the cylinder pressure of the lifting cylinders of a bucket or dump box, the tilting of the vehicle in both longitudinal and lateral direction and the position of the lifting arms of the bucket or the position of the dump box. The weight of the payload in the vehicle can be determined on the basis of the measured variables and the dimensions and geometry of the bucket or dump box mechanics. A non-linear model based on a neural network and fuzzy logic leads to better weighing results than the linear method described above, but the drawbacks of this method are the calibration of the machine, the large amount of training data required to define a calculation algorithm, and the fact that the calculation algorithm is machine-specific.

[0007] US publication 4,919,222 discloses a method and apparatus for determining the weight of a load in a loading vehicle. Determining the load weight is based on measuring the cylinder pressure of the lifting cylinders of the bucket and the position of the lifting arms of the bucket when the bucket is lifted. A signal representing the load weight is defined on the basis of the cylinder pressure of the lifting cylinders and the position of the lifting arms of the bucket and any random pressure variations in the measurements are removed using curve fitting and averaging. The resulting curve representing the load weight is interpolated or extrapolated in relation to curves defined during the calibration of the apparatus for the purpose of determining the weight of the load in the bucket. A drawback in the method described in the publication is, however, that the method is dependent on the lifting rate of the bucket that needs to be taken into consideration in the method. In addition, when the track of the loading vehicle is very bumpy, thus causing the vehicle to tilt quite a lot, it is not possible to obtain a sufficiently accurate weighing result.

[0008] FI patent 94,677 discloses a method based on measuring the deformation of structures for measuring loads directed to structures, especially the weight of a load in a vehicle. The method is suitable for calculating the load caused by static loads that are practically stationary in relation to the structures, but it cannot be used to calculate the load in a moving vehicle.

[0009] It is an object of the present invention to provide a new method and arrangement for weighing the load of a mining vehicle, with which method and arrangement weighing can be done at a sufficient accuracy even when the vehicle is moving.

[0010] The method of the invention is characterized in that a non-linear Kalman filter is used to determine the weight of the load.

[0011] Further, the arrangement of the invention is characterized in that the arrangement comprises a calculation unit that is arranged to utilise a non-linear Kalman filter.

[0012] The essential idea of the invention is that the weight of a load in a mining vehicle is determined by a non-linear Kalman filter that estimates the weight of the load in the vehicle, which load weight cannot be directly measured, by means of measuring signals obtained from measuring means located in the vehicle.

[0013] The invention provides the advantage that by using a non-linear Kalman filter, a better estimate can be made on the weight of the vehicle load, because to solve a non-linear problem, a non-linear method is used, by means of which it is also possible to minimise the impact of the noise included in the measurements on the estimated load weight. Another advantage is that the calibration of the method is simple and that the method need not be specifically trained to identify different masses. Further, the determination of the load weight is done faster and more accurately than in the prior art methods.

[0014] The invention is described in more detail in the attached drawings, in which

Figure 1 is a schematic representation of a dumper used in mines, to which the method of the invention is applied,

Figure 2 is a schematic representation of a wheel loader used in mines, to which the method of the invention is applied,

Figure 3 is by way of example a schematic representation of an application of a non-linear Kalman filter and an apparatus that can be used to determine the weight of the load for instance in the dumper of Figure 1, and

Figure 4 is a schematic representation of the operating principle of the non-linear Kalman filter.

[0015] Figure 1 is a schematic representation of a dumper having a body 1 on wheels and a dump box 3 fastened at its rear end by joints 2 to the body 1. To empty the dump box 3, lifting cylinders 4 are connected between it and the body 1, and when the dump box 3 is lowered to its down position, its front end rests on top of supports 5. Further, the dumper has sensors 6 based on gravitational force to measure the inclination of the body 1 in relation to the horizontal both in the longitudinal and lateral direction of the dumper. The inclination of the dump box 3 in relation to the body 1 can be measured for instance by using angular sensors in the joints 2 or by measuring the volume of pressure fluid fed into the lifting cylinders 4 and calculating the inclination of the dump box 3 on the basis of it and by means of the geometry between the cylinder 4 fastening points and the joints 2.

[0016] Figure 2 is a schematic representation of a wheel loader having a body 1 on wheels and a bucket 9 fastened to it on lifting arms 7 through joints 8, and the bucket turns around joints 10 in relation to the lifting arms 7. A separate tilting cylinder 11 tilts the bucket 9 in relation to the lifting arms 7, and a lifting cylinder 4 between the lifting arms 7 and the body 1 lifts the bucket 9. Further, the wheel loader has in the manner shown in Figure 1 inclination sensors 6 based on gravitational force for measuring the inclination of the wheel loader in relation to the horizontal on the basis of earth's gravity in both longitudinal and lateral direction of the wheel loader. The position of the bucket 9 in the elevation of the body 1 can be defined by using angular sensors in the joints 8, for instance, and calculating on the basis of the measuring information provided by them and using the geometry of the lifting arms 7 the lifting height of the bucket 9 when it is turned in the most upright position by means of its turning cylinder 11. Alternatively, the lifting height can also be defined by measuring the volume of pressure fluid fed into the cylinder 4, whereby it is possible to calculate the lifting height on the basis of said volume and the length of the joints and the cylinder 4.

[0017] Figure 3 is a schematic representation of an apparatus utilising a non-linear Kalman filter and suitable for determining for instance the weight of a load transported by a dumper according to Figure 1, with which apparatus it is possible to measure the load in the dumper when the vehicle is either moving or stationary, in which case the method and apparatus of the invention can also be utilised in connection with an automatic filling of the bucket of a wheel loader to make sure that the bucket is full. For the actual measuring, measuring sensors or measuring means are used, of which two measuring sensors 2a and 2b are strain gauges, for instance, that are mounted in a suitable place with respect to the joints 2 of the dump box 3 on both sides of the dumper body 1. Further, the apparatus comprises sensors 4a and 4b for measuring the pressures of the pressure fluid of the lifting cylinders 4 on both the side of the lifting cylinders 4 where the pressure fluid is fed and the side from which the pressure fluid flows out. By means of these sensors, the weight of a load can be defined at a sufficient accuracy in a basically static situation on a horizontal base.

[0018] Measuring signals from the strain gauges 2a and 2b are forwarded through amplifiers 12 to a calculation unit 13 that calculates the position of the dump box 3 that has been defined as described earlier, and from the calculation unit 13, the parameter describing the position of the dump box 3 is forwarded to the input of a block 14 implementing the non-linear Kalman filter. The calculation of the position of the dump box 3 can also be included as part of the actual Kalman algorithm. The block 14 implementing the non-linear Kalman filter also receives measuring signals from the pressure sensors 4a and 4b, the temperature of the pressure fluid from a temperature sensor 4c of the cylinder 4 and the inclination of the vehicle measured by the inclination sensors 6. The block 14 can be a microprocessor, signal processor or another corresponding calculation unit capable of performing pre-programmed functions.

[0019] When weighing the load while the dumper is either stationary or moving, the operator lifts the dump box 3 in such a manner that it detaches from the supports 5 shown in Figure 1. An indicator light then lights in front of the operator as a sign that only the cylinders 4 and joints 2 support the dump box 3. After this, the operator presses the button for weighing the load. The weighing can also start automatically after a certain period of time has elapsed since the dump box was lifted. The block 14 implementing the non-linear Kalman filter estimates the weight of the load in the vehicle on the basis of the inclination of the dump box 3 calculated in the calculation unit 13, the measured cylinder pressures, the temperature of the pressure fluid and the tilting of the vehicle. Figure 3 also shows a memory unit 15 for storing for instance the estimated weight of the load and other values measured, calculated or estimated during the estimation of the load weight. The memory unit 15 also stores the initial values required by the non-linear Kalman filter for beginning the estimation process and described in the description of the operation of the non-linear Kalman filter of Figure 4. When beginning the estimation process, the initial values are read from the memory unit 15 to the block 14 implementing the non-linear Kalman filter. The memory unit 15 can also be arranged as part of the calculation unit 14, but for clarity's sake, the memory unit 15 is shown as a separate component in Figure 3.

[0020] Figure 4 shows on a general level the operation of the non-linear Kalman filter used in estimating the weight of a load to be weighed. The model of the weighing system, which comprises the dump box 3 or bucket 9 of the mining vehicle, the lifting arms 7 and the lifting cylinders 4 and/or tilting cylinder 11 to move them, and the measuring means described above, is dynamic, non-linear and discretely-timed. The dynamics of the system can be described by the equation

$$\mathbf{x}(k+1) = \mathbf{f}[k, \mathbf{x}(k)] + \mathbf{v}(k), \qquad (1)$$

wherein $\mathbf{x}(k + 1)$ is the actual state of the system at the time instant $k + 1$, $\mathbf{f}()$ is a non-linear function corresponding to the state transition matrix of the system, $\mathbf{x}(k)$ is the actual state of the system at an earlier time instant k and vector $\mathbf{v}(k)$ is white process noise with a zero mean value that describes a modelling error between the actual system and the model made of the system, the modelling error having the expected value of

$$E[\mathbf{v}(k)] = 0$$

and the variance of

$$E\left[\mathbf{v}(k)\mathbf{v}(j)^T\right] = \mathbf{Q}(k)\delta_{kj},$$

wherein $\mathbf{Q}(k)$ is a covariance matrix of the process noise, i.e. model noise, δ_{kj} is Kronecker's delta, wherein $\delta_{kj} = 1$ when $k = j$ and otherwise 0, and T describes the transposition operation of the matrix. For instance, when defining the weight m of the dumper load, the system model can take into consideration the high and low pressures P_y and P_a of the lifting cylinder of the dump box, the tilting γ of the machine, the position s of the dump box, and the temperature L of the pressure fluid, e.g. hydraulic oil. A state vector $\mathbf{x}$ of the non-linear state model of the weighing system of the vehicle would then comprise six elements

$$\mathbf{x} = \left[m, p_y, p_a, \gamma, s, L\right]^T .$$

Of these, all others but the actual weight *m* of the load are measurable variables. The measurement of the temperature *L* of the pressure fluid can also be left out of the above-mentioned measurements without any essential change in the accuracy of the estimate of the load weight *m*. The dependency of the load weight *m* on said measurements is non-linear, i.e. the function **f**() describing the dynamics of the weighing system shown in formula (1) is non-linear. In addition, other factors that are not directly measurable can also be taken into consideration in the function **f**() describing the model of the load weight *m*.

[0021] The estimation of the state of the system and thus also the weight *m* of the load using a non-linear Kalman filter is done as follows.

[0022] At the time instant *k*, the actual state of the system is **x**(*k*) 20. The actual state 21 at the next time instant *k* + 1 is according to formula (1)

$$\mathbf{x}(k+1) = \mathbf{f}\left[k, \mathbf{x}(k)\right] + \mathbf{v}(k) ,$$

and the corresponding measurement 22 at the time instant *k* + 1 is

$$\mathbf{z}(k+1) = \mathbf{h}\left[k+1, \mathbf{x}(k+1)\right] + \mathbf{w}(k+1) , \qquad (2)$$

wherein the measurement function **h**() is generally a non-linear function, but within the scope of this invention, the measurement function **h**() can also be linear, and **w**(*k*) is white measuring noise with a zero mean value that describes the error summed to the measurements from the measuring devices and measuring environment. The expected value of the measuring noise **w**(*k*) is

$$E\left[\mathbf{w}(k)\right] = 0$$

and its variance is

$$E\left[\mathbf{w}(k)\mathbf{w}(j)^T\right] = \mathbf{R}(k)\delta_{kj},$$

wherein **R**(k) is the covariance matrix of the measuring noise.

[0023] The estimate $\hat{\mathbf{x}}(k|k)$ 23 of the actual state **x**(k) at the time instant k is an approximation of the conditional expected value of the actual state,

$$\hat{\mathbf{x}}(k|k) \approx E\left[\mathbf{x}(k)|\mathbf{Z}^k\right]$$

formed on the basis of measurements $\mathbf{Z}^k = \{\mathbf{z}(1), \mathbf{z}(2), \ldots, \mathbf{z}(k)\}$ accumulated by the time instant k. So as to be able to estimate the state of the system at the time instant k+1, the non-linearities of the system must be linearized from the function **f**() describing the dynamics of the model close to the state estimate $\hat{\mathbf{x}}(k|k)$23 of the time instant k. The Taylor series development is used in the linearization, and depending on whether only first-order terms are used or whether second-order terms are also included, either a first or second-order filter is obtained. Linearization of a non-linear function is also used when calculating a measurement prediction $\hat{\mathbf{z}}(k+1|k)$ 25. By means of the Taylor series development, the following representation is obtained for a second-order filter

$$\begin{aligned}\mathbf{x}(k+1) &= \mathbf{f}\left[k, \hat{\mathbf{x}}(k|k)\right] + \mathbf{f}_x(k)\left[\mathbf{x}(k) - \hat{\mathbf{x}}(k|k)\right] \\ &+ \frac{1}{2}\sum_{i=1}^{n_x} e_i\left[\mathbf{x}(k) - \hat{\mathbf{x}}(k|k)\right]^T f_{xx}^i(k)\left[\mathbf{x}(k) - \hat{\mathbf{x}}(k|k)\right] + \mathrm{KAT} + \mathbf{v}(k)\end{aligned}, \quad (3)$$

wherein n_x is the number of states that in this case is six, e_i is an i^{th} n_x-dimensional basis vector whose i^{th} component is one and other components are zero, KAT describes higher-order terms that in this case can be excluded and

$$\mathbf{f}_x(k) = \left[\nabla_x \mathbf{f}(k, \mathbf{x})^T\right]^T \Big| \mathbf{x} = \hat{\mathbf{x}}(k|k) \quad (4)$$

is the Jacobian 29 of the vector **f** calculated at $\hat{\mathbf{x}}(k|k)$ 23, and

$$f_{xx}^{i}(k) = \left[\nabla_x \nabla_x^T f^i(k,\mathbf{x})\right]_{\mathbf{x}=\hat{\mathbf{x}}(k|k)} \tag{5}$$

is a part 29 of the Hesse matrix calculated on the basis of the i^{th} component of the vector **f**.

[0024] After the linearization, the prediction $\hat{\mathbf{x}}(k+1|k)$ 24 of the state

$$\begin{aligned}\hat{\mathbf{x}}(k+1|k) &= E\left\{\mathbf{f}\left[k,\hat{\mathbf{x}}(k|k)\right]\right\} + E\left\{\mathbf{f}_x(k)\left[\mathbf{x}(k)-\hat{\mathbf{x}}(k|k)\right]\right\} \\ &+ E\left\{\frac{1}{2}\sum_{i=1}^{n_x} e_i\left[\mathbf{x}(k)-\hat{\mathbf{x}}(k|k)\right]^T f_{xx}^{i}\left[\mathbf{x}(k)-\hat{\mathbf{x}}(k|k)\right]\right\}\end{aligned} \tag{6}$$

at the time instant k for the time instant k+1 is obtained as a conditional expected value of equation (3) formed on the basis of the measurements $\mathbf{Z}^k$ accumulated by the time instant k when the terms of a higher than second order are excluded due to their minor effect. The accuracy of the calculation can, however, be increased by taking the terms of a higher than second order into consideration. Because on average, a first-order term has a zero mean value on the basis of

$$\hat{\mathbf{x}}(k|k) \approx E\left[\mathbf{x}(k)|\mathbf{Z}^k\right],$$

the following is obtained as the state prediction $\hat{\mathbf{x}}(k+1|k)$ 24 for the time instant k+1

$$\hat{\mathbf{x}}(k+1|k) = \mathbf{f}\left[k,\hat{\mathbf{x}}(k|k)\right] + \frac{1}{2}\sum_{i=1}^{n_x} e_i \,\mathbf{tr}\left[f_{xx}^{i}(k)\mathbf{P}(k|k)\right], \tag{7}$$

wherein the **tr** operation is the sum of the diagonal elements of the square matrix and $\mathbf{P}(k|k)$ 28 is the covariance of the state at the time instant k. The prediction error of the state is obtained by subtracting equation (7) from equation (3). By multiplying the thus obtained prediction error by its own transposition and by producing a conditional expected value from it in relation to the measurements $\mathbf{Z}^k$, the predicted covariance $\mathbf{P}(k+1|k)$ 30 of the state is obtained

$$\mathbf{P}(k+1|k) = \mathbf{f}_x(k)\mathbf{P}(k|k)\mathbf{f}_x(k)^T + \frac{1}{2}\sum_{i=1}^{n_x}\sum_{j=1}^{n_x} e_i e_j^T \mathbf{tr}\left[f_{xx}^i(k)\mathbf{P}(k|k)f_{xx}^j(k)\mathbf{P}(k|k)\right] + \mathbf{Q}(k). \tag{8}$$

[0025] On the basis of the state prediction calculated in formula (7), it is possible to calculate at the time instant k a prediction $\hat{\mathbf{z}}(k+1|k)$ 25 for the measurement for the time instant $k+1$

$$\hat{\mathbf{z}}(k+1|k) = \mathbf{h}\left[k+1, \hat{\mathbf{x}}(k+1|k)\right] + \frac{1}{2}\sum_{i=1}^{n_z} e_i \mathbf{tr}\left[h_{xx}^i(k) + \mathbf{P}(k+1|k)\right], \tag{9}$$

wherein e_i is i^{th} n_z-dimensional basis vector, and in the case of this example, n_z is five, i.e. the number of measurements. On the basis of the actual measurement $\mathbf{z}(k+1)$ 22 and the measurement prediction $\hat{\mathbf{z}}(k+1|k)$ 25, it is possible to calculate the residual, i.e. innovation, $\upsilon(k+1)$ 26 of the measurement at the time instant $k+1$

$$\upsilon(k+1) = \mathbf{z}(k+1) - \hat{\mathbf{z}}(k+1|k), \tag{10}$$

and the related covariance $\mathbf{S}(k+1)$ 31 of the innovation is

$$\mathbf{S}(k+1|k) = \mathbf{h}_x(k+1)\mathbf{P}(k+1|k)\mathbf{h}_x(k+1)^T + \frac{1}{2}\sum_{i=1}^{n_z}\sum_{j=1}^{n_z} e_i e_j^T \mathbf{tr}\left[h_{xx}^i(k+1)\mathbf{P}(k+1|k)h_{xx}^j(k+1)\mathbf{P}(k+1|k)\right] + \mathbf{R}(k), \tag{11}$$

wherein corresponding to formulas (3) to (5)

$$\mathbf{h}_x(k+1) = \left[\nabla_x \mathbf{h}(k+1, \mathbf{x})^T\right]^T \Big|\, \mathbf{x} = \hat{\mathbf{x}}(k+1|k) \tag{12}$$

and

$$h_{xx}^i(k+1) = \left[\nabla_x \nabla_x^T h^i(k+1, \mathbf{x})\right] \Big|\, \mathbf{x} = \hat{\mathbf{x}}(k+1|k). \tag{13}$$

[0026] The amplification $\mathbf{W}(k+1)$ 32 of the filter can be calculated from the formula

$$\mathbf{W}(k+1) = E\left[\tilde{\mathbf{x}}(k+1)\upsilon(k+1)^T \middle| \mathbf{Z}^k\right], \tag{14}$$

wherein $\tilde{\mathbf{x}}(k+1)$ is the prediction error of the state $\mathbf{x}(k+1)$ 21 based on the information available at the time instant k. The updated estimate of the state, i.e. the filtered value $\hat{\mathbf{x}}(k+1|k+1)$ 27 of the state at the time instant $k+1$ based on the information available at the time instant $k+1$ is

$$\hat{\mathbf{x}}(k+1|k+1) = \hat{\mathbf{x}}(k+1|k) + \mathbf{W}(k+1)\upsilon(k+1) \tag{15}$$

and the updated covariance $\mathbf{P}(k+1|k+1)$ 33 of the state at the time instant $k+1$ based on the information available at the time instant $k+1$ is

$$\mathbf{P}(k+1|k+1) = \mathbf{P}(k+1|k) - \mathbf{W}(k+1)\mathbf{S}(k+1)\mathbf{W}(k+1)^T. \tag{16}$$

[0027] The estimation of the system state, i.e. according to this invention, also the estimation of the load weight *m*, by means of a Kalman filter can, in principle, be divided into three parts: predicting the state, calculating the amplification of the filter, and calculating the residual of the measurement, and on the basis of these, it is possible to calculate an estimate for the system state, and in this case, especially for the load weight *m*. The uncertainties in the weighing system model and the measuring devices affect through the state covariance the amplification of the filter, with which the residual of the measurement is weighted in such a manner that in updating the state estimate, the information provided by the measurements on the state of the system and the state calculated on the basis of the system model are taken into account to a suitable extent, since neither of them alone is completely reliable, i.e. corresponds to the actual system. The obtained updated values are further used in forming the estimate of the next time instant. These calculation cycles are repeated until the state provided by the filter as its output, i.e. in this case especially the weight *m* of the vehicle load, has settled to a certain level that thus corresponds to the estimate of the weight *m* of the load in the vehicle. The estimation can be ended for instance when the variance of the load weight estimate is below a predefined limit value that can be changed, i.e. it is a parameter of the algorithm. To begin calculation the initial value $\hat{\mathbf{x}}(0|0)$ of the state estimate, the state covariance $\mathbf{P}(0|0)$ corresponding to the initial state, and the uncertainties of the weighing system model and the measuring devices are required, all of these being stored in the memory unit 15, from which they are read to the block 14 implementing the non-linear Kalman filter when weighing is started. Values set at the factory to the vehicle in question can be used as the initial values. The first measurement can also be used as the initial value for the states to be measured, in which case the actual estimate calculation is started from the second measurement. The reason why the estimated value of the load weight *m* does not immediately at the first Kalman filter calculation cycle give the correct result is due to the fact that the calculation is started from the initial value of the state that is not necessarily correct. In addition, there is interference in the measuring signals especially at the beginning of the measurement that first must be filtered by the Kalman filter.

[0028] To calibrate the weighing system, the vehicle is loaded with a test load of known weight. To perform calibration for an empty dump box or loading vehicle, it is enough to weigh the empty bucket and one known test load, but it is also possible to use several test loads of different weights. The calibration is performed specifically for each machine. Further, the calibration can be performed again during the use of the machine to compensate for the impact of changes caused by aging of the machine or change of components. In connection with the calibration, the non-linear Kalman filter can also be used to estimate the parameters of the non-linear model of the weighing system.

[0029] Correspondingly, in the manner described above, the weighing can be done by means of a wheel loader, in which case the position of the bucket and other factors can easily be taken into account. In the case of a wheel loader, it is in principle possible to use the measuring diagram of Figure 3, in which case the position of the bucket 9 in the elevation of the body 1 and/or the inclination of the lifting arms 7 are taken into account in the weighing system model. Thus, the state vector **x** of the model and the functions representing the system dynamics change from what is stated above while the principle of load weight *m* estimation remains the same.

[0030] The drawings and the related description are only intended to illustrate the idea of the invention. The invention may vary in detail within the scope of the claims. Thus, the structure of the mining vehicle need not be exactly as described in Figures 1 and 2, but the essential thing is that the estimation of the load weight is based on estimating by means of a non-linear Kalman filter the states of a non-linear model formed of the weighing system. Special applications of the Kalman filter, such as a Wiener filter or the like, can be used in a corresponding manner to determine the weight of the load in the mining vehicle.

CLAIMS

1. A method of determining the weight of a load in a mining vehicle, in which method the load weight (*m*) is determined on the basis of measuring signals obtained from separate measuring means, **characterized** in that a non-linear Kalman filter is used to determine the weight (*m*) of the load.

2. A method as claimed in claim 1, **characterized** in that a non-linear state model is formed of a weighing system comprising a dump box (3) or bucket (9) of a mining vehicle, lifting arms (7) and lifting cylinders (4) and/or tilting cylinder (11) used to move them, and measuring means, and the states of the non-linear state model are estimated by means of the non-linear Kalman filter.

3. A method as claimed in claim 2, **characterized** in that at least one state of the non-linear model of the weighing system comprises the load weight (*m*) of the mining vehicle.

4. A method as claimed in claim 2 or 3, **characterized** in that at least one state of the non-linear model of the weighing system comprises the pressure (p_y, p_a) of the pressure fluid of the lifting cylinder (4).

5. A method as claimed in claim 4, **characterized** in that at least one state of the non-linear model of the weighing system comprises the temperature (L) of the pressure fluid of the lifting cylinder (4).

6. A method as claimed in claim 5, **characterized** in that at least one state of the non-linear model of the weighing system comprises the inclination (γ) of the mining vehicle in relation to the horizontal.

7. A method as claimed in claim 6, **characterized** in that at least one state of the non-linear model of the weighing system comprises the inclination of the dump box (3) in relation to the mining vehicle or the position of the mining vehicle bucket (9) and/or the inclination of the lifting arms (7) in the elevation of the mining vehicle body (1).

8. A method as claimed in any one of the preceding claims, **characterized** in that pre-set values are used as the values of the initial state of the non-linear Kalman filter.

9. A method as claimed in claim 8, **characterized** in that values set at the factory are used as the values of the initial state of the non-linear Kalman filter.

10. A method as claimed in any one of the preceding claims, **characterized** in that the estimation of the load weight is ended after the load weight estimate settles at a certain level.

11. A method as claimed in claim 10, **characterized** in that the estimation of the load weight is ended after the value of the variance of the load weight estimate is below a preset limit value.

12. A method as claimed in any one of the preceding claims, **characterized** in that the non-linear model of the weighing system is calibrated using one or more test loads of known weight.

13. An arrangement for determining the weight of a load transported by a mining vehicle, which arrangement comprises means for determining the weight (*m*) of the load, **characterized** in that the arrangement comprises a calculation unit (14) arranged to utilise a non-linear Kalman filter.

14. An arrangement as claimed in claim 13, **characterized** in that the arrangement comprises measuring means for forming measuring signals to be utilised in determining the weight (*m*) of the load.

15. An arrangement as claimed in claim 14, **characterized** in that the arrangement comprises measuring means (4a, 4b) for measuring the pressure (p_y, p_a) of the pressure fluid of the lifting cylinder (4).

16. An arrangement as claimed in claim 15, **characterized** in that the arrangement comprises measuring means (4c) for measuring the temperature (L) of the pressure fluid of the lifting cylinder (4).

17. An arrangement as claimed in claim 16, **characterized** in that the arrangement comprises measuring means (6) for measuring the inclination (γ) of the mining vehicle in relation to the horizontal.

18. An arrangement as claimed in claim 17, **characterized** in that the arrangement comprises measuring means for measuring the inclination of the dump box (3) in relation to the mining vehicle or for measuring the position of the bucket (9) of the mining vehicle and/or the inclination of the lifting arms (7) in the elevation of the body (1) of the mining vehicle.

19. An arrangement as claimed in any one of claims 14 to 18, **characterized** in that the arrangement comprises a calculation unit (14) for estimating with a non-linear Kalman filter the states of the non-linear state model of the weighing system formed of the dump box (3) or bucket (9) of the mining vehicle, the lifting arms (7) and lifting cylinders (4) and/or tilting cylinder (11) used to move them, and measuring means.

20. An arrangement as claimed in claim 19, **characterized** in that the arrangement comprises a memory unit (15) for storing the estimated states of the state model and/or the initial values required in the estimation.

21. An arrangement as claimed in claim 20, **characterized** in that the calculation unit (14) for estimating the states of the non-linear state model with a non-linear Kalman filter comprises the memory unit (15).

22. An arrangement as claimed in any one of claims 18 to 21, **characterized** in that the arrangement comprises a calculation unit (13) for determining the position of the dump box (3) of the mining vehicle or the position of the bucket (9) and/or the inclination of the lifting arms (7).

23. An arrangement as claimed in claim 22, **characterized** in that the calculation unit (14) that estimates with the non-linear Kalman filter the states of the non-linear state model of the mining vehicle weighing system comprises the calculation unit (13) calculating the position of the dump box (3) or bucket (9) of the mining vehicle and/or the inclination of the lifting arms (7).

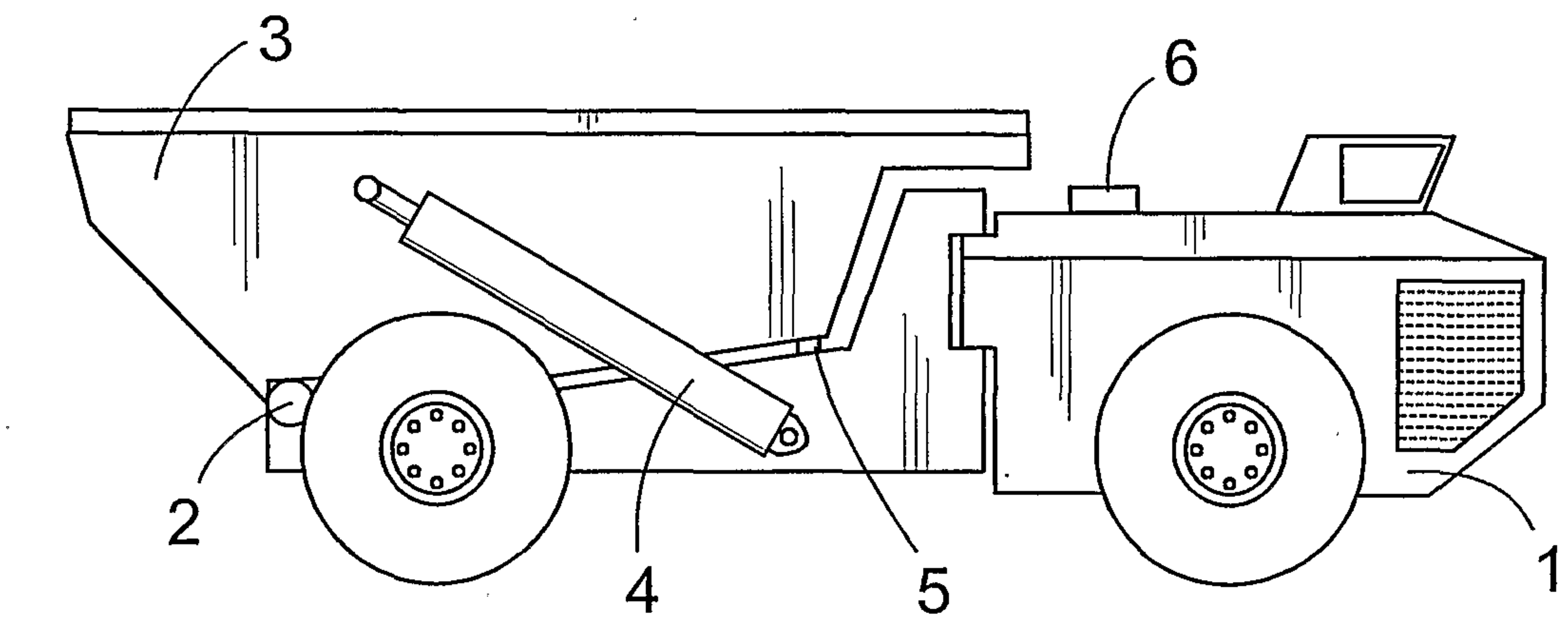


FIG. 1

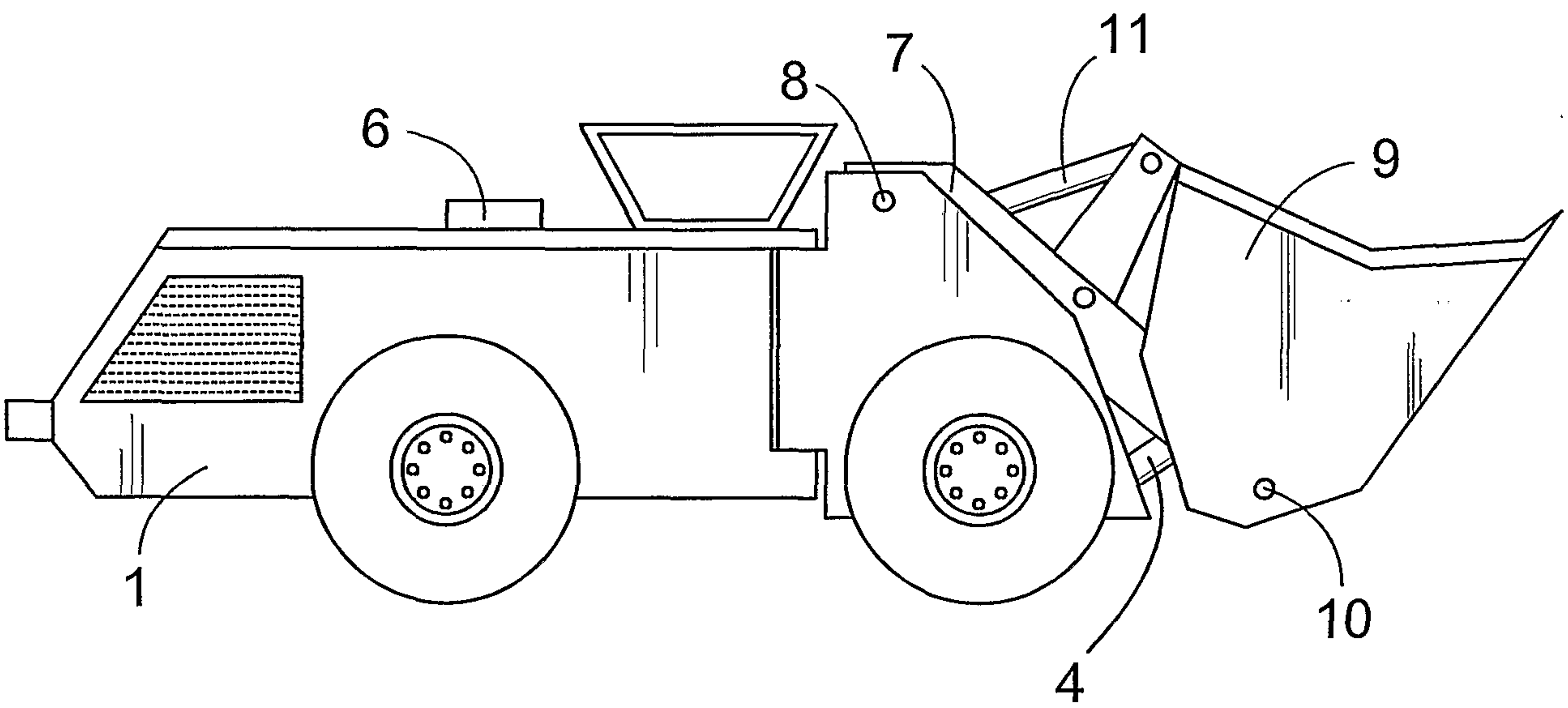


FIG. 2

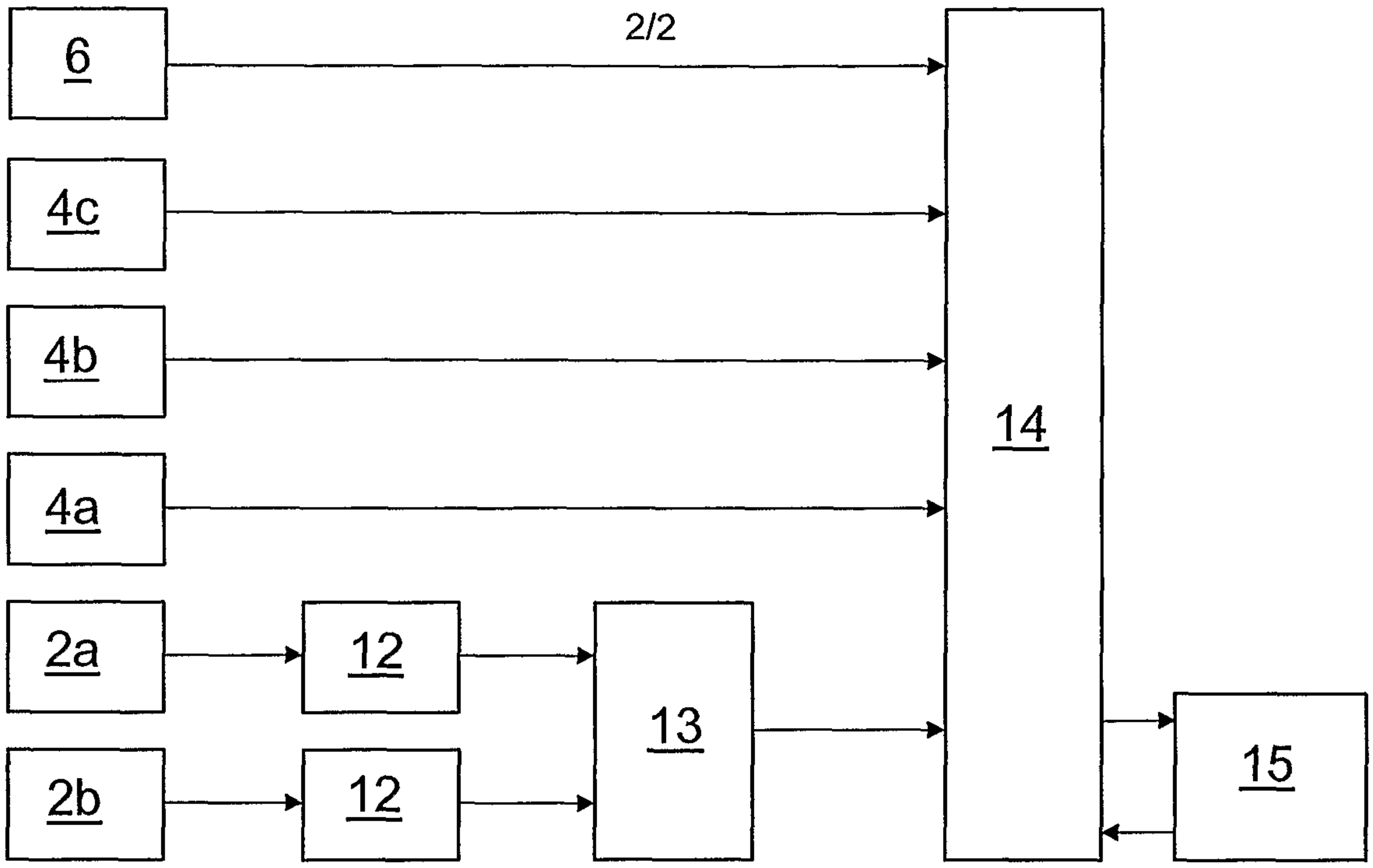

6
4c
4b
4a
2a
2b
12
12
13
14
15

FIG. 3

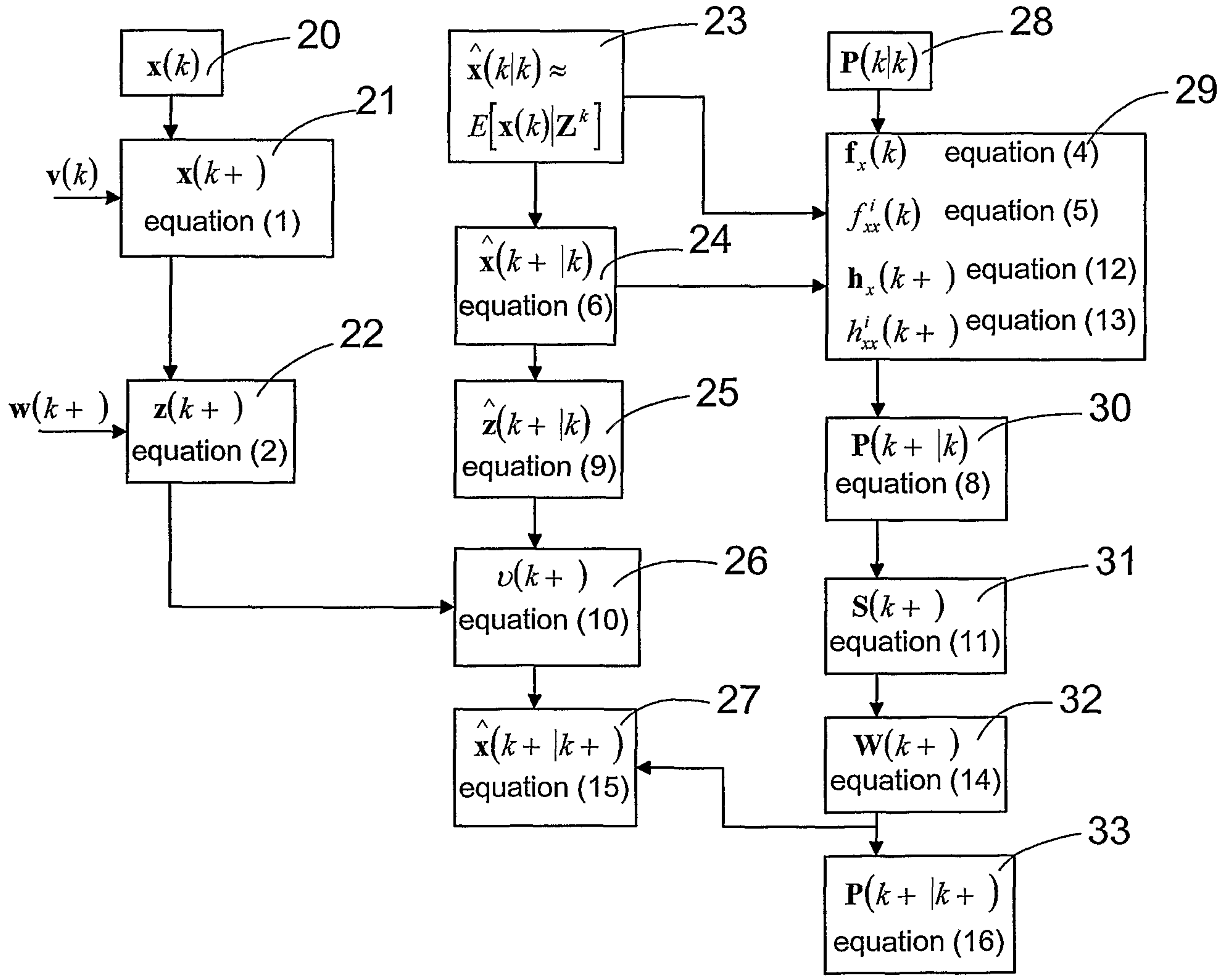
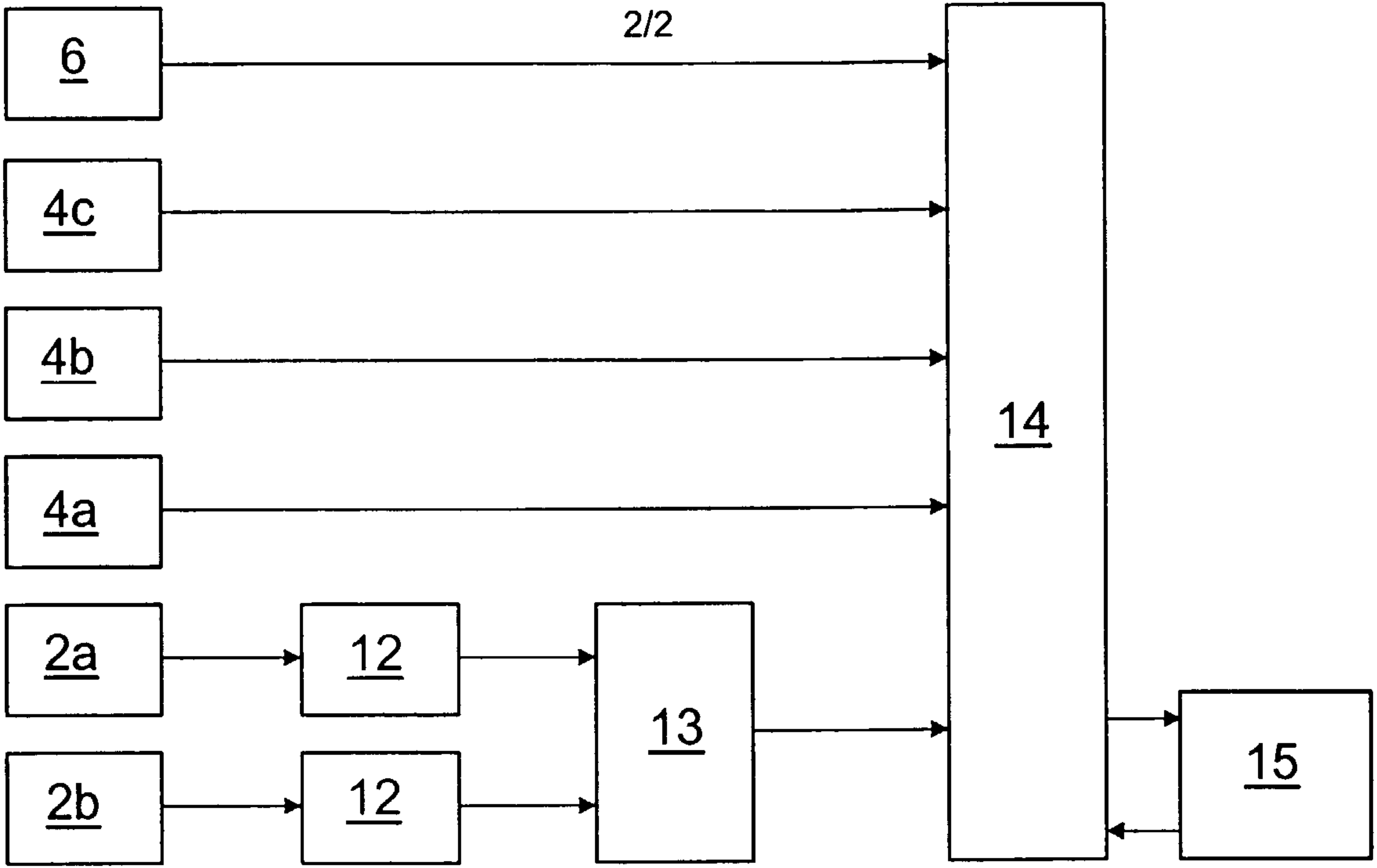

x(k)
20
v(k)
x(k+)
equation (1)
21
w(k+)
z(k+)
equation (2)
22
x̂(k|k) ≈ E[x(k)|Z^k]
23
x̂(k+ |k)
equation (6)
24
ẑ(k+ |k)
equation (9)
25
υ(k+)
equation (10)
26
x̂(k+ |k+)
equation (15)
27
P(k|k)
28
f_x(k) equation (4)
f^i_xx(k) equation (5)
h_x(k+) equation (12)
h^i_xx(k+) equation (13)
29
P(k+ |k)
equation (8)
30
S(k+)
equation (11)
31
W(k+)
equation (14)
32
P(k+ |k+)
equation (16)
33

FIG. 4


6
4c
4b
4a
2a
2b
12
12
13
14
15