Description

TECHNICAL FIELD

The present invention comprises a method for rapidly controlling the frequency of a coherent radio-receiver which, via a channel which is subjected to interference, receives signal-sequences which include at least one synchronizing-sequence and at least one data-sequence, said method comprising the following signal-processing steps of:

- converting a received signal-sequence to a baseband signal,
- A/D-converting the baseband signal to points in an intended analysis plane;
- adapting a Viterbi-algorithm having a desired number of states to the prevailing interference of the channel with the aid of adaptation signals obtained from the synchronizing sequence, the number of said adaptation signals being equal to the number of states in the Viterbi-algorithm; and
- Viterbi analysing the sequence of points in the signal analysis plane such as to finally determine the data bit sequence, as well as an apparatus for carrying out the method.

BACKGROUND ART

In many radio transmission systems, for instance time-divided so-called TDMA-systems, it is important that transmitter and receiver are well synchronized. It is also highly important that the local frequency generator of the receiver is locked very accurately to the transmitter frequency, particularly in the case of coherent transmission systems. An arrangement of apparatus for such a radio-transmission system is described in the article "Radio Test Performance of a Narrowband System" by Sjernvall, Hedberg and Ekemark, published in IEEE Vehicular Tech. Tampa, Florida, USA, June 1987.

The frequency error in a receiver where the receiver frequency has been at least roughly set is estimated in a frequency-error calculating device, and a control processor generates a correction signal for each new transmitted signal- sequence in accordance with the size of the correction obtained during the preceding signal sequence and in accordance with the estimated frequency error. The correction signal is sent to a controllable local oscillator, according to the aforesaid article a so-called frequency synthesizer, which is constructed to generate mixing signals, the frequencies of which are corrected in dependence on the control-processor signal. This signal is digital and in practice is converted to analogue form in a digital/analogue converter before being sent to the local oscillator. Consequently, the number of stages in which the oscillator output frequency can be adjusted is dependent on the number of binary bits which the converter is able to convert. When a relatively small and simple converter is used, either the maximum frequency swing from the local oscillator will be small or the frequency stages will be relatively large.

The transmitted signal can be subjected to interference in systems of the aforesaid kind. This interference or disturbance may, for instance, be in the form of an added noise-signal or in the form of multiple-path propagation due to repeated reflection of the signal against buildings, mountains etc.. This is often the case in mobile radio transmissions, as is described in an article published in the Norwegian technical journal Telektronikk Nr 1, 1987, Torleiv Maseng and Odd Trandem: "Adaptive digital phase modulation". The article describes a coherent receiver which incorporates an equalizer in the form of an adaptive viterbi-analyser. The transmitted signal comprises periodically recurring signal sequences which include a synchronizing sequence and a data sequence as mentioned in the aforegoing. The signals are frequency-mixed and converted in an analogue-digital converter, in the aforedescribed manner, and stored in a memory. The Viterbi-analyzer is adapted to the prevailing transmission characteristics of the channel with the aid of the synchronizing sequence, these characteristics being determined primarily by said multiple path propagation. The data sequence is analyzed in the Viterbi-analyzer for the purpose of extracting the content of the original transmitted signal.

An article in IEEE/IEICE Global Communications Conference, Tokyo, Nov. 15-18, 1987 by Franz Edbauer: "Coded 8-DPSK Modulation with Differentially Coherent Detection - An Efficient Modulation Scheme for Fading Channels" describes a radio receiver equipped with a Viterbi-analyzer. This analyzer assists in controlling the frequency of a received signal. According to this article, the Viterbi-analyzer is set permanently and cannot be adapted to handle variations in channel conditions for instance.

A more detailed description of the Viterbi-algorithm applied in the Viterbi-analyzer is given in Richard E. Blahut: "Theory and practice of error control codes", chapter 12, Addison-Wesley 1983.

DISCLOSURE OF THE INVENTION

It is mentioned in the aforesaid article published in the journal Telektronikk that during signal transmission a small drift in frequency can occur, which is manifested in the form of a successive phase-shift of the receiver bits. When this phase-shift is small, no compensation is necessary. When the phase-shift reaches a given value, however, there is a danger that an decision-error will be made in the Viterbi-analyzer when analyzing the data-sequence. The present invention is based on the concept of utilizing the

states which occur in the Viterbi-analysis to effect an adjustment of the phase of the signal intended for analysis in the Viterbi-analyzer. In this respect all of the Viterbi-analysis states are used and the values extracted for each state are compared with the signal to be analysed, in order to achieve the aforesaid phase-adjustment. The invention has the characterizing features set forth in the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

An exemplifying embodiment of the invention will now be described with reference to the accompanying Figures 1 to 9 of which

Figure 1 is a block-schematic illustrating a known radio receiver;

Figure 2 is a diagram illustrating signal-sequences in a time-divided transmission system;

Figure 3 illustrates a complex numeric coordinate system with signal modulation;

Figure 4 is a diagram illustrating time-displaced bit-sequencies;

Figure 5 is a block schematic of a known adaptive Viterbi-equalizer;

Figure 6 illustrates a complex numerical coordinate system with signal points;

Figure 7 is a block schematic of the Viterbi-equalizer incorporating the inventive frequency-control facility;

Figure 8 illustrates a numerical coordinate system with distance and angle deviations between signal-points; and

Figure 9 is a diagram illustrating a further signal-sequence format.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 illustrates schematically a radio receiver which is intended for use with a system that incorporates time-divided transmission of information in digital form. A received signal S is mixed-down in a known manner in a receiver stage 1 which includes a low-frequency and an intermediate frequency stage. The receiver stage 1 receives a high-frequency and an intermediate-frequency signal from a local oscillator 2, for instance a frequency synthesizer. The mixed signal, the baseband signal, is converted in an analogue-digital converter and stored in a memory in a buffer 3. A signal is sent from the buffer to a block 4, which includes an equalizer and means for calculating frequency error. This frequency-error calculating means may comprise a calculating unit in which the frequency error is calculated on the basis of the successively changed phase-positions of the received signal in relation to the expected or anticipated phase-positions of said signal. Data relating to the frequency error is supplied to a control processor 5, which calculates a control signal for correction of the local-oscillator frequency. This control signal is digital and is converted in a D/A-converter 6, prior to being sent to the local oscillator 2. The mixing signal generated in the oscillator is changed in small increments, owing to the fact that the D/A-converter 6 converts only limited number of bits. This results in a residual frequency-error, which can cause errors in the transmitted signal. Such frequency-errors can also occur in receivers in which frequency is controlled more accurately.

The block 4 produces an output signal S1 which corresponds to the received signal S. The signal S1 is sent to a block 7 which includes a channel-decoder and a speech-decoder, and means for converting the decoded signal S1 to an analogue speech-signal. The speech signal is sent to a loudspeaker 8.

Radio receivers of the kind described briefly in the aforegoing may be included in a system that incorporates time-division signal transmission. The system has time-division channels which are N in number, as illustrated in Figure 2. Each user is assigned a given time slot n during which a signal frequency is transmitted. Each signal sequence includes a synchronizing-sequence S0 and data-sequence D0 which contains the information to be passed-on. The signals in the signal sequences relevant in the case of the present invention are coherent, and an example of one such coherent signal is illustrated in Figure 3. The signal is represented by a vector V0 in a complex numeric coordinate system with the real axis referenced I and the complex axis referenced Q. A transmitted "1" corresponds to a phase-rotation through one quarter of a revolution in a positive sense, whereas a transmitted "0" corresponds to a phase-rotation through one quarter of a revolution in a negative sense between the points A, B, C and D. The vector V0 can be stated in a conventional manner, by its real and imaginary parts, or in polar coordinates in terms of its length and its angle relative to the positive I-axis.

Each transmitted "1" and "0" takes up a given time-interval in the signal sequence, the so-called bit time. Figure 4 illustrates schematically a signal diagram in which T signifies time and t0 is the bit time. As before mentioned, the transmitted signal can reach the receiver via a direct path between the transmitter and the receiver and via one or more routes or paths along which the signal is reflected against mountains buildings etc.. The reflected signals travel a longer path than the direct signal, which results in a time-shift t1 between direct and reflected signals. The time-shift t1 may extend to several bit-times and cause intersymbol interference of the received signal S. The shorter the bit-time, the more bits that are accommodated within the time shift and the more serious the intersymbol interference.

As mentioned in the aforegoing, the receiver of the Figure 1 embodiment includes an equalizer. The incoming mixed and digitalized signal is processed in the equalizer, in order to be able to extract the content

of the originally transmitted signal. In the case of an inventive receiver constructed in accordance with Figure 5, the equalizer comprises, in a known manner, an adaptive Viterbi-analyzer 10 which is used, in accordance with the invention, to control the frequency of the signal entering the Viterbi-analyzer. The use of a Viterbi-analyzer as an adaptive equalizer is described in the aforesaid article published in the journal Telektronikk and will be outlined summarily herebelow in connection with figure 5. The Viterbi-analyzer is connected to the buffer 3 shown in Figure 1. The buffer is also connected to a correlator circuit 12 which, in turn, is connected to a filter circuit 13. The output of the filter circuit is connected to the Viterbi-analyzer. The Viterbi-analyzer is provided with a desired number of states $M = 2^m$, where $m = 2,3 \ldots$.

The Viterbi-analyzer is adapted in the following manner to the channel conditions which prevail during a signal sequence. As illustrated in Figure 2, the received signal-sequence includes the synchronizing sequence SO, which is received by the correlator 12 from the buffer 3. The known synchronizing-sequence is stored in the correlator and the correlator compares the bit-pattern of the known synchronizing-sequence with the wave form of the received synchronizing-sequence. The correlator sends a signal F to the filter circuit 13, in which a filter is built-up in order to correspond to the transmission properties of the channel during the duration of the received signal-sequence, so-called channel estimation. The Viterbi-analyzer 10 receives the data-sequence DO from the buffer 3, and with the assistance of a signal G from the filter circuit 13 is able to determine the content of the data-sequence DO by carrying out a large number of traditional Viterbi-calculations. Assume, for instance, that one of the signal points in DO received by the Viterbi-analyzer 10 lies in a point E1, as illustrated in Figure 6. The position of this point is contingent, inter alia, on the degree of accuracy to which transmitter and receiver are synchronized. Subsequent to full analysis in the Viterbi-analyzer 10, there is determined a final bit-sequence which is transmitted with the signal S1 for conversion to a speech-signal in accordance with Figure 1.

As before mentioned, the received bits may undergo a successive phase shift, which in unfavourable circumstances may be so large as to make it highly improbable that the bits can be referred to any of the points A, B, C or D in Figure 3. This problem is solved in accordance with the invention by utilizing the states and transitions in the Viterbi-analyzer 10 for controlling the frequency of the received signal-sequence. This frequency control is performed for each state and corresponds to a successive shift in the phase-position of the received signal points.

It should be noted that in the aforedescribed embodiment the signal-points have been given in a complex numeric coordinate system having the coordinates I,Q. This has been illustrated in Figure 5 by double signal-paths, one for each coordinate. The signal-points, for instance the signal-point E in Figure 6, can be given by a radius R and an angle ϕ.

According to one embodiment of the invention, described below with reference to Figures 7 and 8, the aforedescribed adaptive Viterbi-analyzer can be used for rapid frequency-control purposes. Figure 7 illustrates the Viterbi-analyzer 10 with the correlator circuit 12 and the filter circuit 13. The Viterbi-analyzer is adapted with the aid of the synchronizing-sequence in the manner described above with reference to Figure 5. As before mentioned, the Viterbi-analyzer functions with individual states which are $M=2^m$, $m=2,3 \ldots$, in number, according to the example the m=2, and the incoming signal is branched-up with a branch 19 for each state. The incoming signal-point is referenced E_T, where the index T signifies that the signal-point refers to the time-point T. The signal-processing procedure will be described solely in respect of the first state and signal paths of the remaining states have been indicated in broken lines in Figure 7. The signal-point E_T, which is also shown in Figure 8, is applied to a phase-shifter 20. In the case of the first state, the phase-shifter 20 has shifted E_T to a point $E_{T,1}$, where the index numeral refers to the state number. $E_{T,1}$ is shifted through an angle $V_{T,1}$, which is the correction predicted for the first state at time T. The signal-point $E_{T,1}$ is sent to a comparison circuit 21, which also receives a predicted signal point value U_1^K from the filter-circuit 13. The index numeral 1 of the reference U_1^K refers to the first state, the letter K refers to the relevant transition between the states and in the case of the illustrated embodiment can assume either one of the two values K=O and K=1. The signal-points U_1^o and U_1^1 are illustrated in Figure 8 and have angular deviations in relation to $E_{T,1}$ designated $\Delta\phi_{T,1}^o$ and $\Delta\phi_{T,1}^1$ respectively. The distances between the signal-points $E_{T,1}$ and U_1^o and U_1^1 are respectively designated $\Delta S_{T,1}^o$ and $\Delta S_{T,1}^1$. The comparison circuit 21 is operative to compare the positions of the signal-points $E_{T,1}$ and U_1^o respective U_1^1 and calculates said angular deviations $\Delta\phi_{T,1}^K$ and the distances $\Delta S_{T,1}^K$. The comparison circuit 21 sends the signal $\Delta\phi_{T,1}^K$ to a control loop-filter circuit 22 and the signal $\Delta S_{T,1}^K$ to the first state in the Viterbi-analyzer 10. The Viterbi-analyzer chooses the best path in the path-memory of the analyzer, thereby determining which of the transitions K=O or K=1 is the best transition in this instance. The value obtained thereby, designated K^1, is used to determine which of the internal variable values of the control loop-filter circuits 22 are selected to survive as the internal state of the control circuit associated with successor state no 1. In the example and according to the Viterbi state transition principle, the control circuit variables of either state 1 or M/2+1 would become the new control variables for state 1, according as K^1=0 or 1. A similar cal-

culation in the Viterbi trellis decides whether the Viterbi state contents, including control loop-filter circuit 22 contents, of state 1 or M/2+1 survive to become the new contents of state 2. Likewise the Viterbi state transition principle in this binary example decides which of state i's or state (M/2+i)'s contents survive to become the new contents of states 2i-1 and 2i.

In a more general Viterbi algorithm perhaps envisaged for non-binary signals or having more than two predecessor states competing to survive as a successor state, the control loop-filter circuit 22 values of that predecessor state which survives become the control circuit values of the successor state.

The control loop-filter circuit values may for example consist of an integral $I_{T,K}$ of past angular deviations $\Delta\phi_{T,1}{}^{K1}$ designed to filter out rapidly varying fluctuations due to noise, as well as the $\Delta\phi_{T,1}{}^{K1}$ of the surviving transition K^1, and an estimate $F_{T,1}$ of the frequency error (time derivative of phase) which may be updated using the surviving $\Delta\phi_{T,1}{}^{K1}$ value according to known servo-control theory. In this way a phase correction signal V, corresponding to the signal $V_{T,1}$, is obtained, which successively shifts the phase of incoming signal-points for the first state. When $I_{T,K}$, $\Delta\phi_{T,1}{}^{K1}$ and $F_{T,1}$ are used to predict the next phase value at time T+ΔT for state 1, a so-called PID (proportional integral derivative) controller can for example be constructed. It can be named that the parameters of the control algorithm in the control loop-filter circuit 22 can be programmable and even chosen depending on the observed received signal characteristics.

As before mentioned, the incoming signal-point E_T is branched-up so as to provide a branch for each state. Each branch is phase-shifted per se in a phase-shifter 20 with a phase correction signal which is calculated for each state per se in the manner described above with respect to the first state. The distance differences, often referred to as "metrics", are also calculated for each state per se, in accordance with the above. The distance differences are processed in the Viterbi-analyzer 10 in a known manner, and the analysis results in a sequence of bits which are converted, for instance, to a speech signal in the manner described above with reference to Figure 1.

The invention according to the described exemplifying embodiment can be applied to a signal-transmission system whenever a Viterbi-analyzer can be used. Examples of modulation forms which can be utilized are QAM-modulation, Quadrature Amplitude Modulation or GMSK-modulation, Gaussian Minimum Shift Keying.

The GMSK-modulation form is described in more detail in Conference Proceedings Digital Cellular Radio conference, October 12-14 1988, Hagen, Westphalia FRG, in an article by Ulrich Langewellpott: "Modulation, Coding and Performance".

There has been described in the aforegoing an arrangement for controlling the phase of the signal arriving at a Viterbi-analyzer. The invention also relates to a frequency-control method which can be applied with the aid of the aforedescribed arrangement. A preferred method includes the following known steps:

The received signal-sequence S is mixed-down with a known frequency to a baseband signal. This signal is converted in an analog-digital converter to form signal-points (I,Q), which are then stored. The received signal is subjected to interference during the signal-transmission procedure, for instance, due to multiple path-propagation, and the data speed is relatively high and consequently intersymbol-interference can occur. Consequently, the received signal is equalized, which in the case of the inventive method is effected with the aid of a known Viterbi-algorithm. This algorithm is adapted to prevailing channel-conditions in a known manner, with the aid of the synchronizing-sequence SO. The transmitted data-sequence DO is analyzed in the Viterbi-analyzer through a relatively large number of calculating stages, so as to extract the bit-sequence of the data-sequence. The inventive method comprises the following additional stages:

The incoming signal-point E_T is branched-up in identical signal-points, the number of which is equal to the number of states in the selected Viterbi-algorithm. For the first state, the phase of the signal-points is shifted through the angle $V_{T,1}$, which is the phase-correction estimated for the first state at T. The phase-shift is changed in the following manner. The phase-shifted signal-point $E_{T,1}$ is compared with the signal-points $U_1{}^K$. These signal-points are obtained from the synchronizing sequence SO of the signal-sequence in a known manner when adapting the Viterbi-algorithm to the channel. When carrying-out the comparison, the angular deviations $\Delta\phi_{T,1}{}^K$, and the distances $\Delta S_{T,1}{}^K$ in the complex numeric coordinate system I,Q are calculated for each of the transitions in the Viterbi-algorithm. The best transition of the two transitions K=O or K=1 is determined in each case through the Viterbi-analysis in a known manner, with the aid of the distances $\Delta S_{T,1}{}^K$. One of the calculated angular deviations $\Delta\phi_{T,1}{}^{K1}$ is selected together with the internal values of one of the control loop-filter circuits 22 according to the selected value of K. The selected value of $\Delta\phi_{T,1}{}^{K1}$ is used to update the selected control circuit values according to known control theory, and the updated values become the control circuit values of the new successor state. In this way the phase-correction signal V is obtained, which is the new value of $V_{T,1}$ for the first state. Correspondingly, the angle-shift signal is calculated for the remaining states, through which the remaining branched signal-points E_T are phase-shifted prior to analysis in accordance with the Viterbi-algorithm. Phase corrections for following incoming signal points are successively calculated in a similar manner.

A format for the transmitted signal-sequence, including a synchronizing-sequence SO and a subsequent data-sequence DO, has been described with reference to Figure 2. Figure 9 illustrates an alternative signal-sequence format, in which the synchronizing-sequence SO is located in the centre of the signal-sequence and embraced on either side by data-sequences D1 and D2. An inventive receiver can be constructed such that the frequency of the receiver will be controlled in the following manner, when demodulating this latter signal-sequence.

As described in the aforegoing, the Viterbi-analyzer is adapted through the synchronizing-sequence SO. Demodulation of D1 commences at a point D11 and terminates at a point D12. Demodulation of D2 then continues, commencing at a point D21 and terminating at a point D22, or vice versa. Angles which correspond to $\Delta\phi_{T,1}^{K}$ for the data-sequence D1 are herewith calculated successively, and the angles are filtered and integrated in the aforedescribed manner. Corresponding calculations for the data-sequence D2 are carried out subsequent hereto, wherein the final values in the control loop-filter circuit 22 of the best state surviving from D1 can be used to derive starting values for the control circuits for demodulation of D2. It should be observed that when the transmitted signal-sequence has the format illustrated in Figure 9, it is necessary to store the received signal in a memory, preferably subsequent to A/D-conversion. No such storage is necessary in the case of a signal format such as that illustrated in Figure 2.

In the case of the aforedescribed embodiments, the transmitted signal-sequence SO, DO has been binary modulated in the manner described with reference to Figure 3. The Viterbi-analyzer 10 utilized for demodulating the signal-sequence has two possible transitions between the states, corresponding to the two levels in the binary code. It is also possible to apply the invention in those cases when the transmitted signal-sequence has several modulation levels, hich is often the case when the signal is modulated in accordance with the aforesaid QAM-modulation principle. The Viterbi-analyzer used in this case for demodulation and for accomplishing the inventive frequency-control has several possible transitions between the states. More specifically, the number of transitions is equal to the number of modulation levels for the modulation form selected. The number of signal-points U_1^K in the adaptation signal from the filter circuit will also increase. In the example described with reference to Figure 7 and 8, the signal-points are two in number, K=O and K=1. In the case of the more general modulation-forms the number of signal-points is equal to the number of modulation levels, and the number of angular deviations $\Delta\phi_{T,1}^{K}$, and the distances $\Delta S_{T,1}^{K}$ is also equal to the number of modulation levels.

A method and an arrangement in which the signal-point E_T was branched-up with a branch 19 for each state, had been described in the aforegoing with reference to Figure 7. All branch-signal points are processed simultaneously in the mutually parallel branches, and each branch includes the phase-shifter 20, the comparison-circuit 21 and the control loop-filter circuit 22. However, it is possible in accordance with the invention to process the branch-signal points E_T for the individual states sequentially at time-point T, instead of employing the aforesaid parallel signal-processing procedure. In this alternative case, the signal-point E_T are stored in a memory and the branch-signal points are fed-out sequentially. The branch-signal point for each state is processed in the manner described with reference to Figure 7 for the first state. The phase-correction signals V for the individual states are stored in memories and are utilized in the aforedescribed manner for successive shifting of the subsequently incoming signal points.

It can be mentioned that the invention can just as well be implemented by applying the phase-correction signal V for each state to the adaption signals U_i^K as an alternative to application to incoming singal points $E_{T,i}$.

Claims

1. A method for rapidly controlling the frequency of a coherent radio-receiver which, via a channel which is subjected to interference, receives signal-sequences which include at least one synchronizing-sequence and at least one data-sequence, said method comprising the following signal-processing steps of:
   - converting a received signal-sequence to a baseband signal,
   - A/D-converting the baseband signal to analysis-oriented signal-points in a signal-plan;
   - adapting a Viterbi-algorithm having a desired number of states to the prevailing interferences of the channel with the aid of adaptation signals obtained from the synchronizing sequence, the number of said adaptation signals being equal to the number of states in the Viterbi-algorithm; and
   - Viterbi-analyzing the analysis-oriented signal-points in the data sequence through a relatively large number of calculating stages, such as to finally determine the bit-sequence of the data-sequence;

   characterized in that the method comprises the further signal-processing steps of:
   - splitting at a time-point (T) one of the analysis-oriented signal-points (E_T) into branch-signal points (E_T), the number of which is equal to the number of states of the Viterbi-algorithm;

A format for the transmitted signal-sequence, including a synchronizing-sequence SO and a subsequent data-sequence DO, has been described with reference to Figure 2. Figure 9 illustrates an alternative signal-sequence format, in which the synchronizing-sequence SO is located in the centre of the signal-sequence and embraced on either side by data-sequences D1 and D2. An inventive receiver can be constructed such that the frequency of the receiver will be controlled in the following manner, when demodulating this latter signal-sequence.

As described in the aforegoing, the Viterbi-analyzer is adapted through the synchronizing-sequence SO. Demodulation of D1 commences at a point D11 and terminates at a point D12. Demodulation of D2 then continues, commencing at a point D21 and terminating at a point D22, or vice versa. Angles which correspond to $\Delta\phi_{T,1}{}^{K}$ for the data-sequence D1 are herewith calculated successively, and the angles are filtered and integrated in the aforedescribed manner. Corresponding calculations for the data-sequence D2 are carried out subsequent hereto, wherein the final values in the control loop-filter circuit 22 of the best state surviving from D1 can be used to derive starting values for the control circuits for demodulation of D2. It should be observed that when the transmitted signal-sequence has the format illustrated in Figure 9, it is necessary to store the received signal in a memory, preferably subsequent to A/D-conversion. No such storage is necessary in the case of a signal format such as that illustrated in Figure 2.

In the case of the aforedescribed embodiments, the transmitted signal-sequence SO, DO has been binary modulated in the manner described with reference to Figure 3. The Viterbi-analyzer 10 utilized for demodulating the signal-sequence has two possible transitions between the states, corresponding to the two levels in the binary code. It is also possible to apply the invention in those cases when the transmitted signal-sequence has several modulation levels, which is often the case when the signal is modulated in accordance with the aforesaid QAM-modulation principle. The Viterbi-analyzer used in this case for demodulation and for accomplishing the inventive frequency-control has several possible transitions between the states. More specifically, the number of transitions is equal to the number of modulation levels for the modulation form selected. The number of signal-points $U_1{}^{K}$ in the adaptation signal from the filter circuit will also increase. In the example described with reference to Figure 7 and 8, the signal-points are two in number, K=O and K=1. In the case of the more general modulation-forms the number of signal-points is equal to the number of modulation levels, and the number of angular deviations $\Delta\phi_{T,1}{}^{K}$, and the distances $\Delta S_{T,1}{}^{K}$ is also equal to the number of modulation levels.

A method and an arrangement in which the signal-point E_T was branched-up with a branch 19 for each state, had been described in the aforegoing with reference to Figure 7. All branch-signal points are processed simultaneously in the mutually parallel branches, and each branch includes the phase-shifter 20, the comparison-circuit 21 and the control loop-filter circuit 22. However, it is possible in accordance with the invention to process the branch-signal points E_T for the individual states sequentially at time-point T, instead of employing the aforesaid parallel signal-processing procedure. In this alternative case, the signal-point E_T are stored in a memory and the branch-signal points are fed-out sequentially. The branch-signal point for each state is processed in the manner described with reference to Figure 7 for the first state. The phase-correction signals V for the individual states are stored in memories and are utilized in the aforedescribed manner for successive shifting of the subsequently incoming signal points.

It can be mentioned that the invention can just as well be implemented by applying the phase-correction signal V for each state to the adaption signals $U_l{}^{K}$ as an alternative to application to incoming singal points $E_{T,l}$.

Claims

1. A method for rapidly controlling the frequency of a coherent radio-receiver which, via a channel which is subjected to interference, receives signal-sequences which include at least one synchronizing-sequence and at least one data-sequence, said method comprising the following signal-processing steps of:
   - converting a received signal-sequence to a baseband signal,
   - A/D-converting the baseband signal to analysis-oriented signal-points in a signal-plan;
   - adapting a Viterbi-algorithm having a desired number of states to the prevailing interferences of the channel with the aid of adaptation signals obtained from the synchronizing sequence, the number of said adaptation signals being equal to the number of states in the Viterbi-algorithm; and
   - Viterbi-analyzing the analysis-oriented signal-points in the data sequence through a relatively large number of calculating stages, such as to finally determine the bit-sequence of the data-sequence;

   characterized in that the method comprises the further signal-processing steps of:
   - splitting at a time-point (T) one of the analysis-oriented signal-points (E_T) into branch-signal points (E_T), the number of which is equal to the number of states of the Viterbi-algorithm;

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- phase-shifting the branch-signal point (E_T) of respective states through an angle ($V_{T,1}$) which is associated with respective state, such as to obtain a corrected signal-point ($E_{T,1}$);
- comparing the corrected signal-point ($E_{T,1}$) for respective states with the adaptation signal (U_1^K) for that state thereof which has signal-points (U_1^0, U_1^1) the number of which is equal to the number of possible state-transitions in the Viterbi-algorithm;
- calculating for each state angular deviations ($\Delta\phi_{T,1}^K$) between the corrected signal-point ($E_{T,1}$) and the signal-points (U_1^0, U_1^1) of the adaptation signal;
- calculations in accordance with the Viterbi-algorithm are made for each state on the distances ($\Delta S_{T,1}^K$),
- selecting for each state one of the transitions (K^1) on the basis of these calculations;
- calculating separately for each state an angular deviation ($\Delta\phi_{T,1}^{K^1}$ of the selected transition (K^1) between the signal point ($E_{T,1}$) and the adaption signal ($U_1^{K^1}$);
- subjecting the angular deviation ($\Delta\phi_{T,1}^{K^1}$) to a control loop filter algorithm (22) to calculate a phase correction signal (V) for each state; and
- using the so calculated phase correction signals (V) separately for each state to phase shift either the next incoming branch-signal point (E_T) in the data sequence (D0) or the adaption signal (U_1^K).

2. Method according to claim 1 characterized by, for each state of the Viterbi algorithm, re-initialising internal states of a control loop-filter algorithm (22) using previous internal states of the control loop-filter algorithm (22) indicated by the selected transition (K^1), the control loop-filter algorithm including low-pass filtering, integration or differentiation to yield a desired signal phase-tracking behaviour.

3. A method according to claim 1 or 2, characterised by utilizing the final values of the phase correction signals (V) and the control-loop filter algorithm (22) internal states at the end of processing one of the signal sequences (SO,DO) in order to determine suitable initial states of both the phase correction signals (V) and the control-loop filter algorithm at the start of processing the next signal sequence.

4. A method according to claims 1, 2 or 3 in which the signal sequence consists, in time-sequence, of a data-sequence, a synchronising sequence and a further data sequence, and in which at least the first data sequence is stored prior to Viterbi-analysis, characterised by the use of the final states of the phase-correction signals (V) and of the control-loop filter algorithm after processing the first data sequence to determine suitable initial states of the phase correction signals (V) and of the control-loop filter algorithm for starting processing of the second data sequence.

5. An arrangement for carrying out the method of Claim 1 with a coherent radio-receiver which, via a channel subjected to interference, receives signal-sequences which include at least one synchronizing-sequence and at least one data-sequence, said arrangement comprising
   - a receiver-stage for signal-reception and conversion of a received signal-sequence to a baseband signal;
   - an A/D-converter which is connected to the receiver stage and which is operative to convert the baseband signal to analysis-oriented signal-points;
   - an adaptive Viterbi-analyzer which is connected to the A/D-converter and comprises adaptation circuits and which Viterbi-analyzer has a desired number of states and is adapted to the interference prevailing in the channel with the aid of adaptation signals, the number of which equals the number of states, and which are derived from the synchronizing-sequence by the adaption circuits, the adapted Viterbi-analyzer processing the analysis-oriented signal-points in the data-sequence in a relatively large number of calculating stages, thereby finally determining the bit-sequence of the data-sequence, characterized in that the arrangement further comprises
   - a signal-dividing circuit (19) which, at a time-point (T), is operative to divide one of the analysis-oriented signal-points (E_T) into branch-signal points, the number of which is equal to the number of states (M) of the Viterbi-analyzer (10);
   - phase-shifter (20) which are connected to the signal-dividing circuit (19) and which are operative to phase-shift the branch-signal point for the respective state through an angular value ($V_{T,1}$) belonging to said state, therewith to form a corrected signal-point ($E_{T,1}$);
   - comparison circuits (21) which are each connected to a respective phase-shifter (20) and to the adaptation circuits (13), said comparison circuits (21) being operative to compare the corrected signal-point ($E_{T,1}$) for each state with the adaption signal (U_1^K) for the state which has signal-points

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(U_1^0, U_1^1) whose number corresponds to each possible state-transition (K=O, K=1) in the Viterbi-analyzer (10), wherein the comparison circuit (21) for respective state between the corrected signal-point ($E_{t,1}$) and the signal-points (U_1^0, U_1^1) of the adaptation signal calculate distances ($\Delta S_{T,1}^K$) and angular deviations ($\Delta\phi_{T,1}^K$) and send the distances ($\Delta S_{T,1}^K$) to the respective state in the Viterbi-analyzer (10), and

- control circuits (22) each being connected to a respective comparison circuit (21) and to a corresponding state in the Viterbi-analyzer, wherein the Viterbi-analyzer (10) according to its algorithm for each state (M) carries-out calculations on the distances ($\Delta S_{T,1}^K$) and on the basis of these calculations sends the selected transition (K^1) to the respective control loop-filter circuit (22) which obtains the angular deviations ($\Delta\phi_{T,1}^K$) from its respective comparison circuit (21) and processes the angular deviation ($\Delta\phi_{T,1}^0$, or $\Delta\phi_{T,1}^1$) corresponding to the transition (K^1) selected, this signal-processing constituting a control-loop filter algorithm according to known control theory which may include integration,differentiation or other form of filtering such as to calculate separately for each state an estimate of the phase correction signal (V).

Patentansprüche

1. Verfahren zur schnellen Steuerung einer Frequenz eines kohärenten Funkempfängers, der über einen der Interferenz ausgesetzten Kanal Signalfolgen empfängt, die mindestens eine Synchronisierungsfolge und mindestens eine Datenfolge enthalten, wobei das Verfahren folgende Signalverarbeitungsschritte aufweist:
   - Umwandeln einer empfangenen Signalfolge in ein Basisbandsignal,
   - A/D-Umsetzung des Basisbandsignals in analyseorientierte Signalpunkte in einer Signalebene;
   - Anpassen eines Viterbi-Algorithmus mit einer gewünschten Anzahl von Zuständen an die vorherrschenden Interferenzen eines Kanals mit Hilfe von Anpassungssignalen, die aus der Synchronisierungfolg gewonnen wurden, wobei die Anzahl der Anpassungssignale der Anzahl der Zustände im Viterbi-Algorithmus entspricht; und
   - Viterbi-Analyse der analyseorientierten Signalpunkte in der Datenfolge durch eine relativ große Anzahl von Berechnungsstufen, derart, daß am Ende die Bitfolge der Datenfolge bestimmt wird;

   dadurch **gekennzeichnet**, daß das Verfahren weiter folgende Signalverarbeitungsschritte aufweist:
   - Aufspalten bei einem Zeitpunkt (T) einen der analyseorientierten Signalpunkte (E_T) ind Zweigsignalpunkte (E_T), deren Anzahl der Anzahl der Zustände des Viterbi-Algorithmus entspricht;
   - Verschiebung der Phase des Zweigsignalpunktes (E_T) entsprechender Zustände um einen Winkel ($V_{T,1}$), der dem entsprechenden Zustand zugeordnet ist, derart, daß ein korrigierter Signalpunkt ($E_{T,1}$) erhalten wird;
   - Vergleichen des korrigierten Signalpunktes ($E_{T,1}$) für jeweilige Zustände mit dem Anpassungssignal (U_1^K) für den betreffenden Zustand, der Signalpunkte (U_1^0, U_1^1) aufweist, wobei die Anzahl der Anzahl der möglichen Zustandsübergänge im Viterbi-Algorithmus entspricht;
   - Berechnung für jeden Zustand der Winkelabweichungen ($\Delta\phi_{T,1}^K$) zwischen dem korrigierten Signalpunkt ($E_{T,1}$) und den Signalpunkten (U_1^0, U_1^1) des Anpassungssignals;
   - Ausführen von Berechnungen gemäß dem Viterbi-Algorithmus für jeden Zustand auf den Abständen ($\Delta S_{T,1}^K$),
   - Auswählen eines der Übergänge (K^1) auf der Basis dieser Berechnungen für jeden Zustand;
   - getrennte Berechnung einer Winkelabweichung ($\Delta\phi_{T,1}^{K1}$) des gewählten Übergangs (K_1^1) zwischen dem Signalpunkt ($E_{T,1}$) und dem Anpassungssignal (U_1^{K1}) für jeden Zustand;
   - Unterziehen der Winkelabweichung ($\Delta\phi_{T,1}^{K1}$) einem Regelschleifenfilteralgorithmus (22), um ein Phasenkorrektursignal für jeden Zustand zu berechnen; und
   - getrenntes Benutzen der so berechneten Phasenkorrektursignale (V) für jeden Zustand, um entweder den nächsten einlaufenden Zweigsignalpunkt (E_T) in der Datenfolge (DO), oder das Anpassungssignal (U_1^K) in der Phase zu schieben.

2. Verfahren nach Anspruch 1, gekennzeichnet durch die Re-Initialisierung innerer Zustände eines Steuerschleifenfilteralgorithmus (22) für jeden Zustand des Viterbi-Algorithmus, unter Benutzung vorheriger, durch gewählten Übergang (K^1) angezeigter Zustände des Steuerschleifenfilteralgorithmus (22), wobei der Steuerschleifenfilteralgorithmus eine Tiefpaßfilterung, eine Integration oder Differentiation umfaßt, um einen gewünschten Signalphasengleichlauf herbeizufüh-

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ren.

3. Verfahren nach Anspruch 1 oder 2, gekennzeichnet durch die Verwendung der Endwerte des Phasenkorrektursignals (V) und der inneren Zustände des Steuerschleifenfilteralgorithmus (22) am Ende der Verarbeitung einer der Signalfolgen (SO, DO), um geeignete Anfangszustände sowohl der Phasenkorrektursignale (V), als auch des Steuerschleifenfilteralgorithmus für den Beginn der Verarbeitung der nächsten Signalfolge zu bestimmten.

4. Verfahren nach Anspruch 1, 2 oder 3, bei dem die Signalfolge im zeitlichen Ablauf aus einer Datenfolge, einer Synchronisierungsfolge und einer weiteren Datenfolge besteht, und bei dem mindestens die erste Datenfolge vor der Viterbi-Analyse gespeichert wird, gekennzeichent durch die Benutzung der ersten Zustände des phasenkorrigierten Signals (V) und des Steuerschleifenfilteralgorithmus nach dem Verarbeiten der ersten Datenfolge, zur Bestimmung geeigneter Anfangszustände der phasenkorrigierten Signale (V) und des Steuerschleifenfilteralgorithmus, zum Beginnen der Verarbeitung der zweiten Datenfolge.

5. Anordnung zur Durchführung des Verfahrens nach Anspruch 1 bei einem kohärenten Funkempfänger, der über einen der Interferenz ausgesetzten Kanal Signalfolgen empfängt, die mindestens eine Synchronisierungsfolge und mindestens eine Datenfolge aufweisen, wobei die Anordnung aufweist:
   - eine Empfängerstufe für den Signalempfang und die Umwandlung einer empfangenen Signalfolge in ein Basisbandsignal;
   - einen A/D-Umsetzer, der an die Empfängerstufe angeschlossen ist und zum Umsetzen des Basisbandsignals in analyseorientierte Signalpunkte dient;
   - einen adaptiven Viterbi-Analysator, der an den A/D-Umsetzer angeschlossen ist und Anpassungsschaltungen umfaßt, wobei der Viterbi-Analysator eine gewünschte Anzahl von Zuständen aufweist und an die im Kanal vorherrschende Interferenz mit Hilfe von Anpassungssignalen angepaßt wird, deren Anzahl der Anzahl der Zustände entspricht, und die von der Synchronisierungsfolge durch Anpassungsschaltungen abgeleitet werden, wobei der Viterbi-Analysator die analyseorientierten Signalpunkte in der Datenfolge in einer relativ großen Anzahl von Berechnungsstufen verarbeitet und dadurch schließlich die Bitfolgen der Datenfolge bestimmt, dadurch **gekennzeichnet**, daß die Anordnung weiter aufweist:
   - eine Signalteilerschaltung (19), die bei einem Zeitpunkt (T) die Unterteilung eines der analyseorientierten Signalpunkte (E_T) in Zweigsignalpunkte durchführt, deren Anzahl der Anzahl der Zustande (M) des Viterbi-Analysators (10) entspricht;
   - Phasenschieber (20), die an die Signalteilerschaltung (19) angeschlossen sind und die Phasenverschiebung der Zweigsignalpunkte für den entsprechenden Zustand durch einen Winkelwert ($V_{T,1}$) bewirken, der zu dem Zustand gehört, um damit einen korrigierten Signalpunkt ($E_{T,1}$) zu bilden;
   - Vergleichsschaltungen (21), von denen jede an einem entsprechenden Phasenschieber (20) und an die Anpassungsschaltungen (13) angeschlossen ist, wobei die Vergleichsschaltungen (21) zum Vergleichen des korrigierten Signalpunktes ($E_{T,1}$) für jeden Zustand mit dem Anpassungssignal (U_1^K) für denjenigen Zustand wirksam werden, der Signalpunkte (U_1^0, U_1^1) besitzt, deren Anzahl jedem möglichen Zustandsübergang (K=0, K=1) im Viterbi-Analysator (10) entspricht, in welchem die Vergleichsschaltungen (21) für den jeweiligen Zustand zwischen dem korrigierten Signalpunkt ($E_{T,1}$) und den Signalpunkten (U_1^0, U_1^1) des Anpassungssignals Abstände ($\Delta s_{T,1}^K$) und Winkelabweichungen ($\Delta\phi_{T,1}^K$) berchnen, und die Abstände ($\Delta s_{T,1}^K$) an den entsprechenden Zustand im Viterbi-Analysator (10) liefern; und
   - Steuerschaltungen (22), von denen jede an eine entsprechende Vergleichsschaltung (21) und einen entsprechenden Zustand im Viterbi-Analysator angeschlossen ist, wobei der Viterbi-Analysator (10) entsprechend seinem Algorithmus für jeden Zustand (M) Berechnungen der Abstande ($\Delta s_{T,1}^K$) durchführt, und auf der Basis dieser Berechnungen den gewählten Übergang (K^1) an die entsprechende Schleifenfilterschaltung (22) liefert, die die Winkelabweichungen ($\Delta\phi_{T,1}^K$) von ihrer entsprechenden Vergleichsschaltung (21) erhält und die Winkelabweichung ($\Delta\phi_{T,1}^0$ oder $\Delta\phi_{T,1}^1$) entsprechend dem gewählten Übergang (K^1) verarbeitet, wobei diese Signalverarbeitung einen Steuerschleifenalgorithmus entsprechend bekannter Regeltheorie bildet, der eine Integration, Differentiation oder eine andere Form der Filterung umfaßt, derart, daß für jeden Zustand getrennt ein Schätzwert des Phasenkorrektursignals (V) berechnet wird.

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Revendications

1. Un procédé pour commander rapidement la fréquence d'un radiorécepteur cohérent qui reçoit, par l'intermédiaire d'un canal qui est soumis à un brouillage, des séquences de signal qui comprennent au moins une séquence de synchronisation et au moins une séquence de données, ce procédé comprenant les étapes de traitement de signal suivantes :
   - on convertit une séquence de signal reçue en un signal en bande de base,
   - on applique une conversion-A/N au signal en bande de base pour donner des points de signal orientés vers l'analyse, dans un plan de signal ;
   - on adapte un algorithme de Viterbi ayant un nombre d'états désiré au brouillage existant du canl, à l'aide de signaux d'adaptation qui sont obtenus à partir de la séquence de synchronisation, le nombre de ces signaux d'adaptation étant égal au nombre d'états dans l'algorithme de Viterbi ; et
   - on applique une analyse de Viterbi aux points de signal orientés vers l'analyse dans la séquence de données, par un nombre relativement grand d'étapes de calcul, de façon à déterminer finalement la séquence de bits de la séquence de données ;

   caractérisé en ce que le procédé comprend les étapes de traitement de signal supplémentaires suivantes :
   - on divise à un instant (T) l'un des points de signal orientés vers l'analyse (E_T) en points de signal de branche (E_T), dont le nombre est égal au nombre d'états de l'algorithme de Viterbi ;
   - on déphase le point de signal de branche (E_T) d'états respectifs d'un angle ($V_{T,1}$) qui est associé à l'état respectif, de façon à obtenir un point de signal corrigé ($E_{T,1}$) ;
   - on compare le point de signal corrigé ($E_{T,1}$) pour des états respectifs avec le signal d'adaptation (U_1^K) pour cet état correspondant, qui a des points de signal (U_1^0, U_1^1) dont le nombre est égal au nombre de transitions d'état possibles dans l'algorithme de Viterbi ;
   - on calcule pour chaque état des écarts angulaires ($\Delta\phi_{T,1}^K$) entre le point de signal corrigé ($E_{T,1}$) et les points de signal (U_1^0, U_1^1) du signal d'adaptation ;
   - on effectue des calculs conformément à l'algorithme de Viterbi pour chaque état, sur les distances ($\Delta S_{T,1}^K$),
   - on sélectionne pour chaque état l'une des transitions (K^1) sur la base de ces calculs ;
   - on calcule séparément pour chaque état un écart angulaire ($\Delta\phi_{T,1}^{K1}$) de la transition sélectionnée (K^1) entre le point de signal ($E_{T,1}$) et le signal d'adaptation (U_1^{K1}) ;
   - on soumet l'écart angulaire ($\Delta\phi_{T,1}^{K1}$) à l'action d'un algorithme de filtre de boucle de commande (22), pour calculer un signal de correction de phase (V) pour chaque état ; et
   - on utilise les signaux de correction de phase ainsi calculés (V), séparément pour chaque état, de façon à déphaser soit le point de signal de branche entrant suivant (ET) dans la séquence de données (D0), soit le signal d'adaptation (U_1^K).

2. Procédé selon la revendication 1, caractérisé en ce que, pour chaque état de l'algorithme de Viterbi, on réinitialise des états internes d'un algorithme de filtre de boucle de commande (22) en utilisant des états internes précédents de l'algorithme de filtre de boucle de commande (22) qui sont indiqués par la transition sélectionnée (K^1), l'algorithme de filtre de boucle de commande comprenant un filtrage passe-bas, une intégration ou une différentiation pour donner un comportement de poursuite de phase de signal désiré.

3. Un procédé selon la revendication 1 ou 2, caractérisé en ce qu'on utilise les valeurs finales des signaux de correction de phase (V) et les états internes de l'algorithme de filtre de boucle de commande (22) à la fin du traitement de l'une des séquences de signal (S0, D0), de façon à déterminer des états initiaux appropriés à la fois des signaux de correction de phase (V) et de l'algorithme de filtre de boucle de commande au début du traitement de la séquence de signal suivante.

4. Un procédé selon les revendications 1, 2 ou 3, dans lequel la séquence de signal comprend, en séquence temporelle, une séquence de données, une séquence de synchronisation et une séquence de données supplémentaire, et dans lequel la première séquence de données, au moins, est enregistrée avant l'analyse de Viterbi, caractérisé par l'utilisation des états finals des signaux de correction de phase (V) et de l'algorithme de filtre de boucle de commande après le traitement de la première séquence de données, pour déterminer des états initiaux appropriés des signaux de correction de phase (V) et de l'algorithme de filtre de boucle de commande, pour commencer le traitement de la seconde séquence de données.

5. Un dispositif pour mettre en oeuvre le procédé de la revendication 1 avec un radiorécepteur cohérent qui reçoit, par l'intermédiaire d'un canal sou-

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mis à un brouillage, des séquences de signal qui comprennent au moins une séquence de synchronisation et au moins une séquence de données, ce dispositif comprenant :

- un étage récepteur pour la réception de signal et la conversion d'une séquence de signal reçu en un signal en bande de base ;
- un convertisseur A/N qui est connecté à l'étage récepteur et qui convertit le signal en bande de base en points de signal orientés vers l'analyse ;
- un analyseur de Viterbi adaptatif qui est connecté au convertisseur A/N et qui comprend des circuits d'adaptation, cet analyseur de Viterbi ayant un nombre d'états désiré et étant adapté au brouillage existant dans le canal, à l'aide de signaux d'adaptation dont le nombre est égal au nombre d'états, et qui sont obtenus à partir de la séquence de synchronisation, par les circuits d'adaptation, l'analyseur de Viterbi adapté traitant les points de signal orientés vers l'analyse dans la séquence de données, par un nombre relativement grand d'étapes de calcul, pour déterminer ainsi finalement la séquence de bits de la séquence de données, caractérisé en ce que le dispositif comprend en outre :
- un circuit de division de signal (19) qui, à un instant (T), divise l'un des points de signal orientés vers l'analyse (E_T) en points de signal de branche, dont le nombre est égal au nombre d'états (M) de l'analyseur de Viterbi (10) ;
- des déphaseurs (20) qui sont connectés au circuit de division de signal (19) et qui déphasent le point de signal de branche pour l'état respectif, d'une valeur angulaire ($V_{T,1}$) correspondant à cet état, pour former ainsi un point de signal corrigé ($E_{T,1}$) ;
- des circuits de comparaison (21), connectés chacun à un déphaseur respectif (20) et aux circuits d'adaptation (13), ces circuits de comparaison (21) ayant pour action de comparer le point de signal corrigé ($E_{T,1}$) pour chaque état avec le signal d'adaptation (U_1^K) pour l'état, qui a des points de signal (U_1^0, U_1^1) dont le nombre correspond à chaque transition d'état possible (K = 0, K = 1) dans l'analyseur de Viterbi (10), le circuit de comparaison (21) pour un état respectif entre le point de signal corrigé ($E_{T,1}$) et les points de signal (U_1^0, U_1^1) du signal d'adaptation calculant des distances ($\Delta S_{T,1}^K$) et des écarts angulaires ($\Delta\phi_{T,1}^K$), et transmettant les distances ($\Delta S_{T,1}^K$) à l'état respectif dans l'analyseur de Viterbi (10), et
- des circuits de commande (22), chacun d'eux étant connecté à un circuit de comparaison respectif (21) et à un état correspondant dans l'analyseur de Viterbi, l'analyseur de Viterbi (10) accomplissant des calculs sur les distances ($\Delta S_{T,1}^K$), conformément à son algorithme, pour chaque état (M), et transmettant, sur la base de ces calculs, la transition sélectionnée (K^1) au circuit de filtre de boucle de commande respectif (22) qui obtient les écarts angulaires ($\Delta\phi_{T,1}^K$) à partir de son circuit de comparaison respectif (21), et qui traite l'écart angulaire ($\Delta\phi_{T,1}^0$ ou $\Delta\phi_{T,1}^1$) correspondant à la transition (K^1) sélectionnée, ce traitement de signal constituant un algorithme de filtre de boucle de commande conforme à la théorie de la commande connue, qui peut comprendre une intégration, une différentiation ou une autre forme de filtrage, de façon à calculer séparément pour chaque état une estimation du signal de correction de phase (V).

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