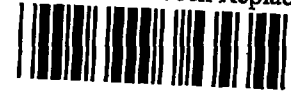


DESCRIPTION

Mobile radio receiver for a radio transmission system.

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The invention relates to a mobile radio receiver for a radio transmission system, such receiver comprising a recognition arrangement for searching a received digital signal for pulses of a frequency correction burst contained with a predeterminable frequency in the digital signal and for determining their pulse positions,
5 and a frequency estimation arrangement for forming frequency estimates for the predeterminable frequency.

The invention further relates to a radio transmission system which includes such a mobile radio receiver.

Mobile radio receivers of this type are necessary, for example, for the
10 Pan-European mobile radio system referenced D-network in Germany. In this mobile radio system, for example, speech signals are transmitted in digitized form along with other digital signals by way of a Time-Division Multiple Access method (TDMA). For this purpose, the available frequency band is subdivided into separate frequency bands and a specific number of subscriber channels are accommodated in each separate
15 frequency band in the time-division multiplex mode. The method of accessing within a radio cell is synchronous *i.e.* the separate time slots are organized in frames. When a connection is set up between a base station and a mobile radio station, there is the resulting problem of initial synchronization.

In the article entitled "Anfangssynchronisation der Mobilstation im D-
20 Netz", G. Frank, W. Koch, PKI Technische Mitteilungen 1/1990, pp. 43 to 49, a mobile radio receiver of the type mentioned in the opening paragraph is described. For initial synchronization in that arrangement a frequency correction burst (FCB) is transmitted along with other information signals between a base station and the mobile radio receiver over a broadcast control channel (BCCh). This frequency correction burst
25 is used for fine frequency synchronization of the mobile radio receiver with the base station and for coarse synchronization with regard to the time slot position. The frequency correction burst consists of a sequence of 148 zeroes which are transformed

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by means of a specific modulation method, for example, GMSK modulation, into a pure sine-shaped signal shifted relative to the carrier frequency of the received digital signal by the frequency of the frequency correction burst. For detecting the frequency correction burst and thus for identifying what is commonly referred to as the Broadcast Control Channel (BCCh), a recognition arrangement designated as BCCh recognition is provided. The recognition arrangement searches a signal that can be derived from the received digital signal for pulses in the frequency correction burst. This search is made in a plurality of successive observation intervals. Pulses whose pulse position in time and whose maximum value are determined are derived from the frequency correction burst. A criterion for the actually received frequency correction burst is from the average height of the detected pulses. If no frequency correction burst is found, a control unit uses a new frequency channel for a further search. If the frequency correction burst has been positively recognised, the time shift of the frequency correction burst is determined on the basis of the position in time of the detected maximums of the recognised i.e. detected pulses. Subsequently, a frequency estimation arrangement is activated which derives frequency estimates of the frequency of the frequency correction burst. Then, a frequency-tracking value is determined for a local oscillator arranged in the HF circuit of the mobile radio receiver on the basis of a rather large number of frequency estimates of the frequency estimation arrangement.

It is an object of the invention to improve the initial synchronization of a mobile radio receiver of the type mentioned in the opening paragraph with a base station.

In a mobile radio receiver of the type mentioned in the opening paragraph this object is achieved, in that the recognition arrangement comprises an averaging circuit for averaging with weight factors pulse positions that have been determined in successive observation intervals, the weight factors being dependent on the individual pulse heights of the pulses.

An input signal of the recognition arrangement may, for example, be the digital signal, or a signal that can be derived from the received digital signal and is produced from normal and quadrature components of the baseband signal of the received digital signal. The signal that can be derived from the received digital signal is first filtered by means of a narrow bandpass filter whose bandwidth is harmonized with the maximum frequency tolerance that can be expected of the pulses in the frequency



correction burst. Then, a value of the filtered signal is determined, as a result of which a one-timeslot-long rectangularly-shaped pulse characteristic of the frequency correction burst is produced. Such a rectangular pulse is filtered by means of a matched filter. The detection of the pulse positions is then effected by determining the maximum of the
5 output signal of the matched filter within an observation interval. An observation interval then has a length which is to be at least as long as the largest distance between two successive pulses which are based on the frequency correction burst. Determining the position of the maximum in the observation interval provides the information about the pulse position. The maximum then always characterizes the end of a frequency
10 correction burst. The successively provided weighted averaging of the pulse positions thus determined within successive observation intervals provides a high degree of evaluation accuracy. The averaging circuit then weights the pulses determined within successive observation intervals in accordance with their individual pulse heights. An enhanced accuracy is obtained when the number of averagings is increased. The
15 improved evaluation accuracy also provides an improved initial synchronization of the mobile radio receiver with a base station.

A possible dependence of the weight factors on the individual pulse heights to obtain a proper initial synchronization is achieved, in that the weight factors are proportional to the individual pulse heights of the pulses.

20 A further improved evaluation accuracy is achieved, in that the recognition arrangement comprises a first threshold former for taking only the pulses into account whose pulse heights exceed a predeterminable threshold.

An accurate detection of the exact pulse position is made possible, in that the recognition arrangement and/or the frequency estimation arrangement comprise(s) a
25 bandpass filter for filtering the digital signal and a signal that can be derived from the digital signal respectively, or a frequency mixer for the complex multiplication of the digital signal or the signal that can be derived from the digital signal by a predeterminable mixing signal, with a succeeding low-pass filter especially one with a linear phase shift as a function of frequency. The multiplication produces a frequency
30 shift of the signal that can be derived from the received digital signal, so that instead of an expensive bandpass filtering only a low-pass filtering of the two quadrature components is necessary. Due to a highly linear phase shift as a function of frequency of the low-pass filter *i.e.* a group delay which is as flat as possible, accurate detection



of the exact pulse positions is possible. Especially a filter having the Bessel characteristic can be utilized as a low pass filter here.

Rectangularly-shaped pulses having a duration of a time slot, which are then used for detecting the pulse positions of the frequency correction burst, are
5 obtained in that the recognition arrangement comprises a value generator or a squaring circuit respectively, after the bandpass and the low-pass filter respectively. The detection reliability is further enhanced by means of a squaring operation instead of a value generation. A fast and reliable detection of the pulses is effected in that the recognition arrangement comprises a first decision arrangement which is provided for
10 determining a first decision signal taken into account when the frequency correction burst was determined, by checking whether in a predeterminable number of observation intervals at least one determined pulse exceeds a predeterminable threshold. This does increase the probability of a pulse simulation, it is true, but the probability of a pulse that is not recognised is reduced more than proportionally.

15 An even greater reliability with respect to the decision whether a frequency correction burst is present is achieved, in that the frequency estimation arrangement comprises a means for forming a quality parameter assigned to each determined frequency estimate, which quality parameter can also be used for determining the frequency correction burst. A further enhanced reliability with the
20 detection of the frequency correction burst is provided, in that the frequency estimation arrangement comprises a second decision arrangement for deriving a second decision signal taken into account for determining the frequency correction burst.

A possible way of computing the quality parameter is found, in that the means for forming the quality parameter comprises a reciprocator for determining the
25 quality parameter from the reciprocal value of the squared distance of the estimated and the real phase variation.

A reliable determination of the frequency deviation between the local oscillator and the oscillator of the base station is made, in that the frequency estimation arrangement comprises an averaging circuit for forming weighted averaged estimates
30 from a predeterminable number of frequency estimates of determined frequency correction bursts and the individually assigned quality parameters for the tracking by the oscillator of the mobile radio receiver.

Determining the frequency is improved, in that the frequency estimation



arrangement comprises a second threshold former for taking into account only the quality parameters that exceed a predeterminable threshold.

In the following the invention will be further explained with the aid of the
5 embodiments represented in the drawing Figures, in which:

Fig. 1 shows a radio transmission system comprising a base station and a mobile radio receiver;

Fig. 2 shows an embodiment of a recognition arrangement of a mobile radio receiver; and

10 Fig. 3 shows an embodiment of a frequency estimation arrangement of a mobile radio receiver.

Fig. 1 shows a radio transmission system comprising a base station 1 and a mobile radio receiver 2. From the mobile radio receiver 2 only the basic arrangement
15 for initial synchronization with the blocks involved in the initial synchronization is represented. Such a mobile radio receiver 2 can be used, for example, in the GSM system. A received digital signal e is first applied to a HF receiving circuit 3. By means of a baseband conversion circuit 4 for producing normal and quadrature components I , Q , a two-channel conversion to the baseband is effected as described, for example, in
20 DE-A 39 38 126.9. The quadrature components I , Q are sampled in an analog-to-digital converter 5 and digitized. At the output of the analog-to-digital converter 5 a signal z is then available having a real component (= normal component) and an imaginary component (= quadrature component). The signal z is applied to a recognition arrangement 6 and/or a frequency estimation arrangement 7.

25 In the recognition arrangement 6 the digital signal z is searched for pulses of a frequency correction burst contained in the received digital signal e . The recognition arrangement produces a signal T signifying the pulse position of the frequency correction burst, and also produces a first decision signal a .

On the basis of the frequency estimates the frequency estimation
30 arrangement 7 determines a frequency deviation signal f' as well as a second decision signal b . The decision signals a , b are applied to an evaluation arrangement 8a whose output signal drives a control arrangement 8. The output signal T of the recognition arrangement 6 and the output signal f' of the frequency estimation arrangement 7 are



also applied to the control arrangement 8. The control arrangement 8 is connected to the HF circuit 3 for causing the frequency of a local oscillator available in the HF circuit 3 of the mobile radio receiver 2 to follow the oscillator frequency of the transmitter 1, and supplies clock signals t_1 , t_2 to the recognition arrangement 6 and the frequency
5 estimation arrangement 7 respectively.

The mode of operation of the mobile radio receiver 2 with respect to the basic initial synchronization between mobile radio receiver 2 and base station 1 is further described in the article entitled "Anfangssynchronisation der Mobilstation im D-Netz", G. Frank, W. Koch, PKI Technische Mitteilungen 1/1990. The mode of
10 operation of the recognition arrangement 6 and the frequency estimation arrangement 7 will be further explained in conjunction with the drawing Figs. 2 and 3.

Fig. 2 shows an embodiment of a recognition arrangement 6 for a mobile radio receiver 2 as it is shown in Fig. 1. The reference characters already used with respect to Fig. 1 are used here too. The recognition arrangement 6 is supplied with a
15 signal z derived from the received digital signal. This derived signal is multiplied by a predeterminable first mixing signal m_1 in a frequency mixer 9. A value generator 12 is provided after an amplitude control arrangement 10 followed by a low-pass filter 11. The recognition arrangement 6 further includes an optimal matched filter 13 (MF). The matched filter 13 produces an output signal i , which designates the pulses in the
20 frequency correction burst, so that in the following the reference character i is also used for referencing the pulses. The output signal i is transported to a maximum-recognition arrangement 15. The maximum-recognition arrangement is supplied with a first clock signal t_1 . At the output of the maximum-recognition arrangement 15 signals t , U are available, the signal t being the pulse position of the pulses i in the frequency correction
25 burst, and the signal U indicating their associated pulse height, so that in the following also the reference character t is used for identifying a pulse position *i.e.* of a determined pulse in the burst, and the reference character U is used for denoting the associated pulse height. The signal t is applied to an averaging circuit 14 at whose output a signal T is present which indicates the pulse position of the frequency correction burst. The
30 signal U is transported to an arrangement 16 which discards the pulse heights U that fall short of a predeterminable threshold. At the output of the arrangement 16 a modified signal U_s is present which is applied to the averaging circuit 14 for determining a weighted average. The modified signal U_s is also applied to a decision arrangement 17,



18, 19 at the output of which a first decision signal a is present. The decision arrangement 17, 18, 19 comprises a threshold switch 17, a succeeding counter 18 as well as a decision circuit 19.

The digital signal z is processed, in essence, in the manner already
5 described in PKI Technische Mitteilungen 1/1990, pp. 43 to 49, except for the determination of the signals t , U at the output of the maximum-recognition arrangement 15. By merely generating a squared value instead of a normal value of the output signal of the low-pass filter 11, the value generator 12 can enhance the detection reliability. Besides, the low-pass filter 11 advantageously has a linear phase shift as a function of
10 frequency as this is possible, more specifically, with a low-pass filter 11 having Bessel characteristics. The maximum-recognition arrangement 15 determines a pulse position t relative to each first clock signal t_1 , where the period of the clock signal t_1 corresponds to the length of an observation interval. The search of the maximum-recognition arrangement 15 always relates to an observation interval which is selected to be so large
15 as to include at least a frequency correction burst. To increase the detection reliability, the maximum-recognition arrangement 15 repeats the search for the maximum pulses in a plurality of successive observation intervals.

The averaging circuit 14 averages the determined pulse positions t with weight factors. The pulses t whose pulse heights U fall short of a predeterminable
20 threshold are discarded for the determination of the weighted average. The pulse heights U_s assigned to those of the pulses t which exceed the threshold determined by the arrangement 16 are used as weight factors for the remaining pulses t . Thus, the following holds for the formation of the output signal T of the recognition arrangement 6, which signal signifies the pulse position of the frequency correction burst: $T =$
25 $\Sigma t \cdot U_s / \Sigma U_s$. For deciding whether a pulse has or has not been determined to be a pulse of the frequency correction burst, the output signal U_s of the arrangement 16 is evaluated in the decision arrangement 17, 18, 19 by way of the threshold switch 17, the counter 18 and the decision circuit 19. The first decision signal a available at the output of the decision circuit 19 is evaluated, as shown in Fig. 1 and already explained in the
30 description with reference to Fig. 1, by the evaluation arrangement 8a in Fig. 1. The measures described with reference to Fig. 2 decidedly improve the detection reliability of the pulse positions and the overall result is an improved initial synchronization of the mobile radio receiver with a base station.



Fig. 3 shows an embodiment of a frequency estimation arrangement 7 for the mobile radio receiver 2 shown in Fig. 1. The frequency estimation arrangement is supplied with a signal z that can be derived from the received digital signal e . Subsequently, a band limitation takes place which is performed by an equivalent arrangement comprising a frequency mixer 20 and a succeeding low-pass filter 21. The frequency mixer 20 is supplied with the signal z as well as a second mixing signal m_2 . After the low-pass filter 21, phase calculation arrangements 22, 23 (Cordic algorithm and phase unwrapping) are provided, the arrangement 22 being supplied with a second clock signal t_2 . The arrangement 22 produces for its output signal a signal τ corresponding to the phase, from which a phase τ_z with a constant phase variation is calculated in the arrangement 23. The frequency estimation arrangement 7 further includes an arrangement 24 for performing a linear regression calculation like the one that has already been described in the article entitled "Anfangssynchronisation der Mobilstation im D-Netz", PKI Technische Mitteilungen 1/1990, pp. 43 to 49. At the output of the arrangement 24 for performing the linear regression, signals $\hat{s}$, S_N are available; the signal $\hat{s}$ signifying frequency estimates and the signal S_N signifying the squared distance between the estimated and the real phase variation, so that in the following the reference character $\hat{s}$ is also used for signifying one frequency estimate and the reference character S_N is used for signifying the squared distance. The signal $\hat{s}$ is applied to an averaging circuit 25 at whose output a signal f' is available signifying a frequency deviation. The signal S_N is applied to a reciprocator 26. At the output of the reciprocator 26 a signal g is available which is used as a quality parameter for expressing the reliability of the frequency estimate in question, which signal will also be referenced quality parameter g in the following. The quality parameter is transported to an arrangement 27 which discards the signal values of the quality parameter that fall short of a predeterminable threshold. At the output of the arrangement 27 a modified quality parameter g_s is available which is applied to the averaging circuit 25 for a weighted averaging. The modified quality parameter g_s is further applied to a decision arrangement 28, 29, 30 at whose output a second decision signal b is available. The decision arrangement 28, 29, 30 comprises a summator 28, a succeeding threshold switch 29 as well as a decision circuit 30.

The digital signal z is processed, up to the determination of the signals g , b , substantially in the way already described in PKI Technische Mitteilungen 1/1990,



pp. 43 to 49. The frequency deviation f' between the local oscillator of the mobile radio receiver and a base station is then determined in the frequency estimation arrangement 7 after the conversion to the baseband and after the possible pulse positions of the occurred frequency control signals have been determined in the recognition arrangement

- 5 6. The values not stemming from a frequency correction burst are then discarded. In the phase calculation arrangement 22 there is first a calculation of the main value of the phase of the complex baseband signal z , for example, by means of the CORDIC algorithm. Subsequently, in the arrangement 23 a continuous phase variation T is established in that all phase jumps in the calculated phase T_z are discarded (phase
- 10 unwrapping), which phase jumps may be reduced to the fact that the calculated main value of the phase T_z is limited to the range $\pm\pi$, while the sought phase of the received digital signal shows a continuous variation and may adopt random values. Based on this continuous phase variation the arrangement 24 performs a linear regression to calculate the frequency estimates $\hat{s}$, as this has also been described in the article entitled
- 15 "Anfangssynchronisation der Mobilstation im D-Netz", PKI Technische Mitteilungen 1/1990, pp. 43 to 49. The frequency estimate $\hat{s}$ may then be calculated in accordance with the following equation:

$$20 \quad \hat{s} = c \cdot \sum_{m=1}^M m [\varphi(M+m+1) - \varphi(M-m+1)] ; \quad M = (N-1)/2 ; \quad N \text{ odd}$$

- N here denotes the number of measured values per frequency correction burst. The linear regression is only performed for the duration of a frequency correction burst. The initial factor c takes into account the proportional control factor yielded by the selected implementation for calibrating the measured values. Subsequently, in the averaging
- 25 circuit 25, a weighted averaging is performed of all the frequency estimates $\hat{s}$ available at the output of the arrangement 24, so that at the output of the averaging circuit 25 the following value is produced for the frequency deviation f' :

$$30 \quad f' = \sum_{i=1}^I g_s(i) \cdot \hat{s}(i) / \sum_{i=1}^I g_s(i) ;$$

Here I characterizes the number of measurements that have taken place. The result of the weighted averaging is available at the output of the averaging circuit 25 as signal f' , which signifies the frequency deviation between the local oscillator and the oscillator of

the base station. For the weighted averaging, each frequency estimate $\hat{s}$ is averaged with a weight that corresponds to the modified quality parameter g_s of the frequency estimation. For determining this quality parameter the arrangement 24 also determines the squared distance S_N of the estimated and real phase variations in addition to the frequency estimates $\hat{s}$. A possible way of calculating S_N is:

$$S_N = N \sum_{n=1}^N \varphi^2(n) - \left[\sum_{n=1}^N \varphi(n) \right]^2 - \frac{1}{c^2} \frac{12}{N^2-1} (\hat{s})^2 .$$

In the reciprocator 26 the reciprocated value of the squared distance S_N is calculated. In this manner the quality parameter g is obtained to judge the reliability of the frequency estimate concerned. Not until this quality parameter g or the modified quality parameter g_s for the weighted averaging in the averaging circuit 25 has increased will the required accuracy for determining the frequency deviation f' under conditions of fading be obtained. A second improvement of the frequency determination is achieved when the quality parameter g is modified by a suitably selected threshold in the arrangement 27 before being averaged. All values falling short of this threshold are then zeroed. As denoted in Fig. 3, the quality parameter g can also be utilized as a second decision signal b with the aid of the decision arrangement 28, 29, 30 which operates in corresponding fashion to the decision arrangement described with respect to Fig. 2. The decision signal b is also used for determining/detecting the frequency correction burst, and to form complementary to signal a , a second decision signal for deciding on whether a frequency correction burst has been found or not, as this is shown in Fig. 1 and is also described with respect to Fig. 1. For producing the decision signal b all determined modified quality parameters are added together in summator 28. The output signal of the summator 28 is applied to the threshold switch 29 and the succeeding decision circuit 30.

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CLAIMS:

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1. Mobile radio receiver (2) for a radio transmission system, such receiver comprising a recognition arrangement (6) for searching a received digital signal (e) for pulses (i) of a frequency correction burst contained with a predeterminable frequency in the digital signal (e) and for determining their pulse positions (t), and a frequency
5 estimation arrangement (7) for forming frequency estimates ($\hat{s}$) for the predeterminable frequency, characterized in that the recognition arrangement (6) comprises an averaging circuit (14) for averaging with weight factors (Us) pulse positions (t) that have been determined in successive observation intervals, the weight factors (Us) being dependent on the individual pulse heights (U) of the pulses (i).
- 10 2. Mobile radio receiver as claimed in Claim 1, characterized in that the weight factors (Us) are proportional to the individual pulse heights (U) of the pulses (i).
3. Mobile radio receiver as claimed in one of the Claims 1 or 2, characterized in that the recognition arrangement (6) comprises a first threshold former (16) for taking only the pulses (i) into account whose pulse heights (U) exceed a
15 predeterminable threshold.
4. Mobile radio receiver as claimed in one of the Claims 1 to 3, characterized in that the recognition arrangement (6) and/or the frequency estimation arrangement (7) comprise(s) a bandpass filter for filtering the digital signal (e) and a signal (z) that can be derived from the digital signal (e) respectively, or a frequency
20 mixer (9, 20) for the complex multiplication of the digital signal (e) or the signal (z) that can be derived from the digital signal (e) by a predeterminable mixing signal (m1, m2), with a succeeding low-pass filter (11, 21) specifically one with a linear phase shift as a function of frequency.
5. Mobile radio receiver as claimed in one of the Claims 1 to 4,
25 characterized in that the recognition arrangement (6) comprises a value generator or a squaring circuit (12, 22) after the bandpass filter and low-pass filter (11, 21) respectively, and/or in that the recognition arrangement (6) comprises a first decision arrangement (17, 18, 19) which is provided for determining a first decision signal (a)



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taken into account when the frequency correction burst was determined, by checking whether in a predeterminable number of observation intervals at least one determined pulse (i) exceeds a predeterminable threshold.

6. Mobile radio receiver as claimed in one of the Claims 1 to 5,
5 characterized in that the frequency estimation arrangement (7) comprises a means (24, 25) for forming a quality parameter (g) assigned to each determined frequency estimate ($\hat{s}$), which quality parameter can also be used for determining the frequency correction burst, and/or in that the frequency estimation arrangement (7) comprises a second decision arrangement (28, 29, 30) for deriving a second decision signal (b) taken into
10 account for determining the frequency correction burst.
7. Mobile radio receiver as claimed in Claim 6, characterized in that the means for forming the quality parameter (g) comprises a reciprocator (24) for determining the quality parameter (g) from the reciprocal value of the squared distance (S_N) of the estimated and the real phase variation.
- 15 8. Mobile radio receiver as claimed in one of the Claims 6 or 7, characterized in that the frequency estimation arrangement (7) comprises an averaging circuit (25) for forming weighted averaged estimates (f') from a predeterminable number of frequency estimates ($\hat{s}$) of determined frequency correction bursts and the individually assigned quality parameters (g) for the tracking by the oscillator of the
20 mobile radio receiver (2).
9. Mobile radio receiver as claimed in one of the Claims 1 to 8, characterized in that the frequency estimation arrangement (7) comprises a second threshold former (27) for taking into account only the quality parameters (g) that exceed a predeterminable threshold.
- 25 10. Radio transmission system comprising at least a base station (1) and at least a mobile radio receiver (2) as claimed in one of the Claims 1 to 9, the radio transmission system being provided for transmitting radio signals between base station (1) and mobile radio receiver (2).

