

The invention relates to a method and a device for the transmission of digital data in a transmission channel where the frequency shifts, which are slowly variable, are large with respect to the data rate, and where the short-term phase and frequency instabilities make it difficult or impossible to produce a phase-locked loop.

The known n-area frequency shift keying uses a set of $n = 2^k$ frequencies (TELECOMMUNICATIONS AND RADIO ENGINEERING, Vol. 24, No 8, August 1970 pages 37 to 40). To each of these frequencies, there corresponds a block or symbol of k bits to be transmitted. If the imperfections of the transmission channel introduce large frequency errors, it is sometimes possible to compensate for these errors globally on reception, but the filters enabling the discrimination of the transmitted frequency from among the n possible frequencies, must have a sufficient bandwidth to accept the residual or total errors of the transmission channel. Consequently the spacing between the successive frequencies chosen must take account of this bandwidth.

Such a modulation method has disadvantages: considering the wide band necessary in order to take account of possible deviations, the sensitivity is degraded either by the noise band of the filters being too large, or because of the lock-on conditions of a phase loop when it is possible to produce such a phase loop.

- The band occupied for the transmission of information is wide: it is at least equal to n times the frequency errors.

The method and the device for the transmission of data by differential frequency shift keying according to the invention enable these disadvantages to be overcome.

According to the invention, the method for the transmission of digital data, is characterized in that it consists:

- when transmitting, in an encoding by differential frequency shift keying about a centre modulation frequency F_0 , while associating with each symbol consisting of k bits to be transmitted a frequency shift ΔF , selected from a table containing 2^k possible frequency shifts respectively associated with the 2^k possible symbols of k bits, in adding, and respectively subtracting, this shift respectively to or from the frequency associated with the preceding symbol according to whether the preceding frequency is lower or higher than the modulation centre frequency, and in transmitting the corresponding frequency during the period of the symbol, the modulation signal resulting from this encoding being passed on for the purpose of transmission.

- when receiving, in the decoding, after reception, of the associated modulation by estimating for the duration of the symbols contained in signal segments, the latter being defined by means of a synchronization signal having the modulation frequency and synchronized with the received modulated signal, an estimation of the frequencies successively received, and in deriving therefrom the corresponding frequency shifts and thus the received symbols.

Another object of the invention is the transmission device intended to implement this method.

According to the invention, the digital data transmission device using differential frequency shift keying, is characterized in that it associates:

- in the transmitter, a modulator comprising a modulation encoder, intended to receive a sequence of symbols of k bits to be transmitted, and to encode these symbols in terms of frequency shift values selected from a totality of 2^k predetermined frequency shifts, and a frequency synthesizer which synthesizes, using these frequency shift values, the sequence of frequencies which constitutes the modulation signal, the frequency synthesized during the interval of a symbol being the

frequency associated to the preceding symbol, increased or decreased by the frequency shift depending upon whether the preceding frequency is less or greater than a centre modulation frequency,

- 5 - and, in the receiver, a demodulator for detecting the frequencies successively received in the signal segments defined by a synchronization signal at the frequency of the symbol modulation (SS1).

10 The invention will be better understood and other characteristics will appear with the help of the following description given with reference to the appended figures in which:

- Figure 1 shows, for a particular example, the sequence of bits to be transmitted and the sequence of
15 corresponding frequencies coming from the modulator using the transmission method according to the invention;
- Figure 2 is a block diagram of the modulator of the transmission device according to the invention;
- Figure 3 is a block diagram of the demodulator of
20 the transmission device according to the invention;
- Figure 4 shows an example of the signals in the demodulator.

25 The method for the transmission of data according to the invention uses a special modulation method which consists in associating with a symbol of k bits a frequency shift with respect to the previously transmitted frequency, this frequency shift being chosen from among $n = 2^k$ possible values.

30 If R is the data rate of the data to be transmitted, the modulation rate is therefore R/k symbols/second. The frequency shifts are preferably chosen to be equal to multiples of the spacing between the zeroes of the spectrum of a signal of finite duration, equal to the duration T_s of a symbol associated
35 with a pure frequency, i.e. spaced by $1/T_s = R/k$.

 If F_0 is the nominal centre transmission frequency, the frequencies of the actually transmitted

signals are for example $F_0 \pm R/2k$; $F_0 \pm 3R/2k$;
 $F_0 \pm 5R/2k$; $F_0 \pm (2^{k+1} - 3) \cdot R/2k$. (1)

The frequency shifts DF corresponding to the transmission of 2^k different blocks of k bits are
 5 multiples of R/k :

0, R/k , $2R/k$, $3R/k$, etc ... $(2^k - 1) \cdot R/k$.

If F_i is a frequency chosen among the above-mentioned frequencies which has been transmitted for a given block of rank i . When the next block of k bits, of
 10 rank $i+1$, corresponds to the frequency shifts DF_{i+1} , one of the frequencies $F_i + DF_{i+1}$ or $F_i - DF_{i+1}$ is transmitted. The sign of the shift is chosen as follows:

- if F_i is lower than the centre frequency F_0 , the frequency shift DF_{i+1} is added to the previous frequency:
 15

$$F_{i+1} = F_i + DF_{i+1}$$

if F_i is higher than the centre frequency F_0 , the frequency shift DF_{i+1} is subtracted from the previous frequency:

20
$$F_{i+1} = F_i - DF_{i+1}.$$

The following numerical example will give a better understanding of the method for the transmission of data by differential frequency shift keying according to the invention. If the data bits are grouped
 25 in twos, i.e. $k = 2$, $n = 2^k = 4$ frequency shifts must be chosen, which correspond respectively to the pairs of bits 00, 01, 10, and 11. If the centre frequency of the modulator F_0 is equal to 1 KHz, and if the data rate R to be transmitted is equal to 200 bits per second, the
 30 corresponding frequencies coming from the modulator, given by the expressions (1) above are as follows:

1000 ± 50 Hz, 1000 ± 150 Hz, 1000 ± 250 Hz, i.e. a batch of frequencies which is as follows: 750, 850, 950, 1050, 1150 and 1250 Hz. The shifts corresponding to the
 35 pairs 00, 01, 10 and 11 can therefore respectively be 0, 100, 200 and 300 Hz.

Thus, if at a given time the transmitted frequency

was $F_i = 950$ Hz for example, and if the sequence of data to be transmitted is constituted from the following series of pairs : 00, 01, 11, 10, 11 and 01, the sequence of frequencies successively coming from the modulator

5 will be as follows: 950 Hz, zero shift associated with the pair 00; 1050 Hz, shift of 100 Hz corresponding to the pair 01 added to 950 Hz; 750 Hz, shift of 300 Hz corresponding to the pair 11 subtracted from 1050 Hz; 950 Hz, corresponding to the shift of 200 Hz associated

10 with the pair 10 added to 750 Hz; 1250 Hz, corresponding to a shift of 300 Hz corresponding to the pair 11 added to 950 Hz; and finally 1150 Hz corresponding to a shift to 100 Hz associated with the pair 01 subtracted from 1250 Hz. The table in Figure 1 summarizes the succession of

15 pairs, the series of corresponding frequency shifts and the series of transmitted frequencies associated with the frequency shifts corresponding to this sequence of bits.

Figure 2 is a simplified block diagram of a modulator of the data transmission device according to the invention. This modulator comprises a modulation encoder

20 which groups the bits to be transmitted in symbols of k bits and associates with each symbol a value of frequency shift DF , in the way mentioned above. For this purpose, the encoder includes a table in memory

25 associating these predetermined frequency shift values with each block. These values are applied to the control input of a frequency synthesizer 20 which, on the basis of the frequency F_i generated for the previous symbol, synthesizes the frequency F_{i+1} in such a way that, as

30 mentioned above, if the frequency F_i was lower than the centre frequency F_0 the frequency shift D_{i+1} is added to the previous frequency and, if the previous transmitted frequency is higher than the centre frequency F_0 , the transmitted frequency F_{i+1} is the previous

35 frequency F_i reduced by the frequency shift DF_{i+1} . The sequence of digital data to be transmitted applied to the input of the modulator can result from an encoding of

the error detecting and/or correcting type, normally used in digital data transmission devices.

Figure 3 shows the block diagram of the demodulator of the transmission device according to the invention.

5 The transmitted signal, after passing through the transmission channel, is applied to the input of a sampling circuit 100, the sampling of the received signal being performed at a rate given by the sampling clock H_E such that the subsequent computation of the fast Fourier
10 transform resulting from these samples may be performed over a band corresponding to the frequencies coming from the modulator increased by the frequency deviations introduced by the transmission channel. For example, with the modulation rate mentioned above, $R/k = 100$
15 symbols per second, the sampling frequency can be 12.8 KHz, the frequency deviations in the transmission channel being in the order of 1 kilohertz.

The series of samples coming from the sampling circuit 100 is applied to a first fast Fourier transform
20 circuit, 110, followed by a modulation decoder circuit 120, and to a second fast Fourier transform circuit, 130. The first Fourier transform circuit is used for the demodulation, the other is used for the synchronization of the symbols. This latter function can be avoided in
25 the case in which the symbol synchronization can be obtained in another way in the receiver. This is the case, in particular, in energy dispersion links where the synchronization of the symbols is derived from a code synchronization.

30 In the embodiment shown in Figure 3, the demodulation device comprises a time base 240 supplying a symbol synchronization signal, 250, applied to the Fourier transform circuit 110 for the demodulation and synchronized with the received signal in such a
35 way that the Fourier transform, in the frequency domain, is computed over signal segments of duration equal to the duration of a symbol corresponding substantially to the



frequency levels of the received signal. For this purpose, a symbol synchronization signal SS2 shifted by a half-symbol with respect to SS1, is applied to the control input of the Fourier transform circuit 130 intended for the synchronization. The analysis of the spectral lines coming from the Fourier transform circuit 130 enables the determination of the shift to be applied to the synchronization signal SS1 in order to synchronize it appropriately with respect to the received signal. In fact, when the local symbol synchronization signal SS2, supplied by the time base 140, is exactly shifted by a half-symbol with respect to the received signal, the same frequency appears twice successively with the same amplitude in the Fourier transforms of two successive signal segments. This amplitude is reduced by 6 dB with respect to that which would be obtained with a symbol frequency precisely synchronized with the received signal. When the local symbol synchronization signal SS2 is not exactly shifted by a half-symbol, two spectral lines appear successively at the same frequency, but with different amplitudes. If the first detected spectral line is higher than the second one, the local symbol synchronization signal must be delayed, and conversely if the first spectral line is lower than the second one.

Figure 4 shows an example of the signals in the demodulator. The first diagram shows the received signal, constituted from a succession of frequency levels, of durations equal to the duration of a symbol TS. In practice, because of the transmission channel, the received frequencies $F'_i, F'_{i+1} \dots$ are not equal to the transmitted frequencies $F_i, F_{i+1} \dots$ it is assumed that at the moment of the reception the symbol synchronization signal SS1 is that shown in Figure 4 and exhibits an advance with respect to the received signal.

The analysis of the Fourier transform of the signal received, over signal tranches equal to the duration of a symbol, gives the following results: each signal

segment leads to the obtaining of a spectral line at the frequency F'_i corresponding to a large fraction of the transmitted power and a small fraction of the power transmitted at the next frequency F'_{i+1} .

The demodulation method used is as follows: For the demodulation, only the spectral lines whose power exceeds a predetermined threshold are selected. If a single response is greater than this predetermined threshold, its frequency is considered as corresponding to the transmitted frequency.

If several responses are detected, the responses whose amplitudes are not included within a suitable range with respect to the average of the preceding results are eliminated; thus jamming signals at fixed frequency can be eliminated. The same applies to responses which are incompatible with the frequency shifts introduced during transmission, and which are possible taking account of the previously selected frequency. In this case the strongest of the non-eliminated responses is selected.

Finally, if no response is satisfactory taking account of the previously described criteria, it will be considered:

- that there is erasure, if an error correcting code is used;
- that the strongest response compatible with an authorized frequency shift denotes the received frequency, if no correcting code can process the erasures, after the demodulation.

In order to obtain suitable synchronization, the Fourier transform circuit 130 analyses the signal according to segments equal to the duration of a symbol but shifted by a half-symbol, as mentioned above, and as shown in Figure 4. Thus, the de-synchronization can be computed by a differential method by comparing the amplitudes of the spectral lines at the same frequency in two successive signal segments SS2. In fact, in the

first signal segment detected a spectral line at the frequency F'_1 and a spectral line at the frequency F'_{i+1} are detected; similarly during the next period of the synchronization signal SS2 the spectral lines at the frequencies F'_{i+1} and F'_{i+2} can be detected. If the symbol synchronization SS2 was precisely shifted by a half-symbol with respect to the received signal, the amplitude of the spectral lines at the same frequency detected in two successive periods of SS2 would be equal.

The difference between the amplitudes of these spectral lines at the same frequency is directly proportional to the synchronization deviation if the transmission is performed at constant amplitude. If, as in the case shown in Figure 4, the fraction of the level at the frequency F'_{i+1} is greater in the first period of SS2 than in the second, the synchronization computation circuit 150 which analyses the results of the Fourier transform circuit 130 commands a delay of the signals SS1 and SS2 coming from the time base, 140, the delay being proportional to the detected amplitude difference; conversely, in the case in which the first spectral line has a lower amplitude than the second one, the synchronization computing circuit 150 commands an advance of SS1 and SS2 proportional to the amplitude difference. The synchronization computing device 150 of course performs an appropriate filtering.

The computed points of the fast Fourier transform are spaced by an amount equal to the symbol frequency $1/T_s$. If the frequency errors due to the transmission channel shift the frequency F_i in such a way as to bring F'_i between two computed points, the result of this is a reduced response for the two frequencies corresponding to the two adjacent computed points with respect to that which would have been able to be measured if the received frequency corresponded to a computed point of the transform. These amplitudes depend on the exact position of the frequency F'_{i+1} with respect to the two

computed points of the FFT. If on reception, in a way which is known per se, samples coming from the sampling circuit are weighted according to a predetermined window enabling the response to be modelled at the desired frequency in order to perform a filtering, the amplitudes of the computed points of the Fourier transform also depend on the weighting window. An interpolation computation taking account of all these elements therefore enables the estimation of the received frequency with an accuracy better than the transform computing step, and the correction of the measured amplitude.

The invention is not limited to the embodiment, described in detail above, of the transmission method according to the invention. In particular, in order to improve the security and speed of the synchronization, it is possible to introduce into this modulation method a supplementary constraint in such a manner that there is a frequency hop at each new symbol, whatever its value. For this purpose two additional frequencies must be defined in addition to those which have been defined previously in order that no block of k bits is assigned a zero frequency shift.

Furthermore, in a second embodiment the acquisition of the frequency measurements by the fast Fourier transformation over a wide band, such as described above can constitute an approximate measurement of these frequencies and of the frequency shifts induced by the transmission channel. In this case, a more accurate measurement of the transmitted frequencies, and of the corresponding frequency shifts is implemented for the demodulation and the synchronization, using a set of digital filters, which are more selective and frequency-adjusted by the approximate measurement, but having a reduced bandwidth. Observation of the evolution of frequency errors, an evolution which is slow with respect to the symbol frequency, enables the rectification, if necessary of the centring of the set of filters. The amplitudes of the spectral lines detected by this set of

filters are processed for the demodulation and synchronization like those coming from the Fourier transform circuits in the first embodiment.

This type of modulation can be applied whenever the frequency errors of the transmission channel are much larger than the modulation frequency itself, particularly when the phase and frequency instabilities prevent the locking on of a phase-locked loop. A typical example of application is the transmission of digital data at a low data rate by satellite, using high carrier frequencies.

CLAIMS

1. Method for the transmission of digital data, characterized in that it consists:

- when transmitting, in an encoding by differential frequency shift keying about a centre modulation frequency F_0 , while associating with each symbol consisting of k bits to be transmitted a frequency shift DF , selected from a table containing 2^k possible frequency shifts respectively associated with the 2^k possible symbols of k bits, in adding, and respectively subtracting, this shift respectively to or from the frequency associated with the preceding symbol according to whether the preceding frequency is lower or higher than the modulation centre frequency, and in transmitting the corresponding frequency during the period of the symbol, the modulation signal resulting from this encoding being passed on for the purpose of transmission.

- when receiving, in the decoding, after reception, of the associated modulation by estimating for the duration of the symbols contained in signal segments, the latter being defined by means of a synchronization signal having the modulation frequency and synchronized with the received modulated signal, an estimation of the frequencies successively received, and in deriving therefrom the corresponding frequency shifts and thus the received symbols.

2. Method according to Claim 1, characterized in that the 2^k possible frequency shifts are regularly spaced multiples of the clock rate of the symbols.

3. Method according to either of Claims 1 or 2, characterized in that the estimation of the received frequency in a signal segment is performed on the basis of a Fourier transformation of this signal segment, by detecting in the Fourier transform the most probable received frequency as a function of the frequency used for the preceding signal segment and the possible



frequency shifts.

4. Method according to any of Claims 1 to 3, characterized in that an estimation of the synchronization of a signal having the modulation frequency generated on reception is performed on the basis of the Fourier transforms of two received successive signal segments, spaced by the duration of one half-symbol in relation to the synchronization signal, by comparing the amplitudes of the spectral lines having the same frequency which corresponds to the transmitted frequency as detected in these two successive signal segments, the synchronization signal being correctly synchronized, when these two lines have the same amplitude, while it precedes or is delayed respectively with respect to the received signal when the spectral line detected in the first segment is greater, or respectively smaller, than the one detected in the second segment, the difference in amplitude enabling the control of the resynchronization.

5. Method according to either of Claims 3 or 4, characterized in that the estimation of the received frequency by means of the Fourier transform method results in a rough measurement of the received frequency, a filtering which takes into account this rough measurement for determining the filter bandwidth being performed in order to achieve a precise measurement of the received frequency.

6. Digital data transmission device using differential frequency shift keying, characterized in that it associates:

- in the transmitter, a modulator comprising a modulation encoder (10), intended to receive a sequence of symbols of k bits to be transmitted, and to encode these symbols in terms of frequency shift values selected from a totality of 2^k predetermined frequency shifts, and a frequency synthesizer (20) which synthesizes, using these frequency shift values, the sequence of frequencies which constitutes the modulation signal, the frequency



synthesized during the interval of a symbol being the frequency associated to the preceding symbol, increased or decreased by the frequency shift depending upon whether the preceding frequency is less or greater than a centre modulation frequency,

- and, in the receiver, a demodulator for detecting the frequencies successively received in the signal segments defined by a synchronization signal at the frequency of the symbol modulation (SS1).

7. Transmission device according to Claim 6, characterized in that the demodulator is a digital one and comprises a sampling circuit (100), a Fourier transform circuit (110), connected to the output of the sampling circuit, having a control input, which receives a symbol synchronization signal (SS1) synchronized with the received signal, and a decoder circuit (120), which on the basis of the spectrum of each signal segment received during the interval of a symbol estimates the received frequency contained in this segment as well as the corresponding frequency shift, taking into account the estimated frequency of the preceding segment.

8. Transmission device according to either of Claims 6 or 7, characterized in that the demodulator comprises means for locally generating by means of a time base (140) a signal (SS1) having the symbol frequency and being synchronized with the received signal, which means comprise a circuit (100) for sampling the received signal, a Fourier transform circuit (130) having a signal input connected to the output of the sampling circuit (100) and a control input which receives a signal having the symbol frequency (SS2) and being shifted by an interval equal to that of a half-symbol in relation to the synchronization signal (SS1), and a synchronization computing circuit (150), which compares the amplitudes of the spectral lines having the same frequency in the spectra of two successive signal segments shifted with respect to each other by a half-symbol, the



synchronization computing circuit having an output connected to the shift control input of the time base (140) which is activated when the amplitudes of the spectral lines having the same frequency are not equal.

9. Transmission device according to either of Claims 7 or 8, characterized in that the demodulator comprises a set of selective digital filters having a reduced bandwidth and being centred on the estimated frequencies by the decoder circuit (120), in order to make the estimated frequency values more accurate and to derive therefrom the frequency shifts and the transmitted symbols.

