Correction of the receiving channels fiber optic transmission systems on the basis of PDM and N-OFDM with decimation

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The article describes the implementation of optic transmission systems with combined scheme of multiplexing – N-OFDM-PDM, and rapid changes of the signal between OFDM, OFDMA or N-OFDM. To reduce the computational load on the digital segment, it is proposed a distributed digital signal processing low speed digitization with the use of thinning. For correct decoding, the proposed variant of correction of possible imbalance of the polarization channels.

Keywords: Decimation, NGOA, N-OFDM, PDM, XPIC.

INTRODUCTION

According to the concept of next generation of optical access (NGOA) to improve the efficiency of fiber optic transmission systems (FOTS) provides for the use of combinations of different schemes of multiplexing [1]. An example of this is the implementation of non-orthogonal frequency discrete multiplexing (N-OFDM) and polarization division multiplexing (PDM) [2]. This approach is possible in several variants, depending on the method of setting frequencies of carrier signals of dual polarization: adjacent channel dual polarized (ACDP); co-channel dual polar (CCDP) – Fig. 1 [2].

In turn, standardization of FOTS due to the possibility of rapid changes in the signal between the OFDM, OFDMA or N-OFDM may lead to an increase in the cost of equipment. This is especially true for subscriber hardware segment.

The highest priority solution to this issue is to implement distributed digital signal processing N-OFDM (OFDM), software hardware configuration and use of the elements of the circuit design, focused on low rate of digitizing signals.

MAIN

It is known that use of PDM was not widely used because of the existing restrictions yet. For their elimination in article [2] it is offered to use convergent decisions which are based on Multiple Output-Multiple Input-technology (MIMO). In this case, FOTS with PDM can be provided as the MIMO 2×2 system. Now, the set of options of digital processing is developed for such systems. In turn, one of the directions of lowering of computing load of a digital segment of FOTS is implementation of distributed processing.

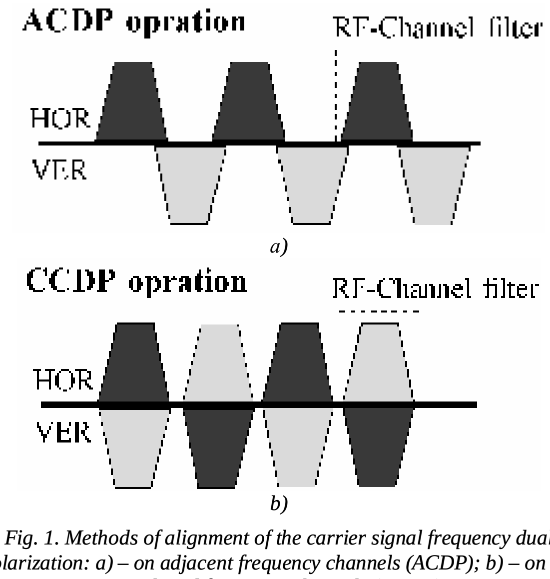

Fig. 1. Methods of alignment of the carrier signal frequency dual polarization: a) – on adjacent frequency channels (ACDP); b) – on the combined frequency channels (CCDP)

For application of the specified approach it is necessary to use decimation operation on the receiving side (fig. 2) [3]. For its execution the digital filters (DF) which decimate an information flow are synthesized and create so-called strobes [4]. According to [5], there are several versions of the specified procedure, which differ by the presence or absence of a procedure of fast Fourier transform (FFT). Thus, the total number of gates should not be less than the dimension of the FFT procedure.

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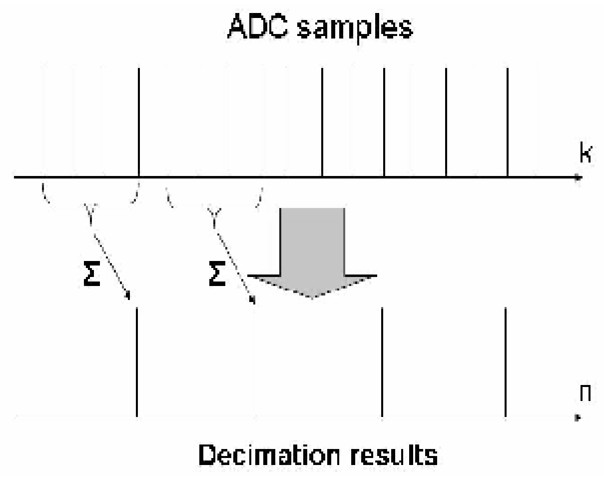

Fig. 2. Decimation process of ADC samples of digital video signals

As a basis for implementation of digital processing by the offered FOTS it is expedient to be guided by one of methods of formation of strobes.

1. Method for additional strobing of samples of analog-digital transformer that is in partial adding samples of analog-digital transformer (ADT) in fixed time intervals (strobes) that do not overlap, at that collection of signal samples within strobes is performed through weight processing. Formation of signal samples of strobes by results of collection of samples of ADT one performs with use or even and odd Hartley functions [6].

2. Method for additional strobing samples of analog-digital transformer is in partial adding samples of ADT in fixed time intervals (strobes) that do not overlap, at that collection of signal samples within strobes is performed through weight processing [7, 8].

3. Method for additional strobing digital readings of signals is in partial adding readings of ADT in fixed time intervals (strobes) that do not overlap. Formation of signal readings of strobes by results of collection of digital readings is preceded by preliminary digital I/Q demodulation of readings of ADT in mode of “sliding window”, this forms quadrature components of voltages of signal U(t), where t – the number of the reading of ADT. Following additional strobing of readings of voltages of signals obtained in such way one performs through collection weight processing. Operations of preceding digital I/Q demodulation of readings of ADT in the mode of “sliding window” and following partial adding of digital readings of voltages of signals in fixed time intervals (strobes) one performs at once in two quadrature channels with formation of massifs of digital readings [9].

4. Method for additional strobing of digital readings of signals is in partial adding readings of analog-to-digital converter (ADC) in fixed time intervals (strobes) that do not overlap. Operations of preliminary digital I/Q demodulation of readings of ADC in mode of “sliding window” and following partial adding of digital readings of voltages of signals in fixed time intervals (strobes) are performed at once in two quadrature channels with formation of massifs of digital readings [10].

In case of the frequency diversity of subchannels on value of width of the synthesized FFT filter, a N-OFDM-signal it will be transformed to OFDM.

At the same time, for the correct decoding of signals it is necessary to consider possible disbalance of the quadrature channels N-OFDM (OFDM).

One of candidate solutions of this task is offered in [11]. This method for correction of square unbalance with use of additional strobing of samples of analog-digital transformer is in fact that one of square subchannels is assigned to be standard, and the other one – as unbalanced, to each of square sub-channels one applies same control signal, with performing analog-digital transformation of control signal in each of square subchannels, one performs distribution of samples of ADT, then one switches off control signal and goes to processing of information signals.

However, in the initial look it can`t be applied as it does not consider the disbalance of polarization channels of real FOTS with PDM.

For elimination of this lack of operation the option of correction of receiving channels taking into account joint implementation of PDM and N-OFDM with decimation is offered.

The essence of this approach is to use a test signal which is input to an optical receiver, forming the samples of the gates (strobes) after the decimation, the evaluation of the amplitude and phase of the polarization nonidentity and further the correction information signals of channels of the optical system with PDM.

In the synthesis of the corresponding calculation procedure of the correction factors is the adoption of one of the polarization channels as a reference, while on another channel, which is regarded as distorted, a further correction of the amplitude and phase of the original signals. Evaluation of the amplitude and phase nonidentity is carried out by calculating the voltage samples are obtained through an analog-to-digital conversion of the control signal at the outputs of the polarization channels.

It is important to note that the sampling period of analog-to-digital converter (ADC) τ_{ADC} should be selected so as to provide a ratio of the following form:

$$f = \frac{4(2i+1)}{\tau_{ADC}}, \tag{1}$$

where f is the central frequency of the signal; i is the number of temporary sample, $i = 0, 1, 2, \ldots$

We assume that in the band reception signal dependence of the amplitude and phase nonidentity polarization channels of the frequency can be neglected. Such a restriction can be provided, for example, using of the N-OFDM signals [12], which occupies a smaller spectral bandwidth than the OFDM signals.

Take in the further calculations, that

$$f = \frac{5}{4\tau_{ADC}}. \tag{2}$$

Voltage values of the samples at the outputs of the ADC receiving polarization channels can be represented in the form:

$$U_H(i) = a\sin\left(2\pi f i\,\tau_{ADC} + \varphi\right), \qquad (3)$$

$$U_V(i) = (1+\delta a)a\sin(2\pi f i\,\tau_{ADC} + (\frac{\pi}{2} + \Delta\varphi) + \varphi), \qquad (4)$$

where $U_H(i)$, $U_V(i)$ are the time samples of the ADC output receiving channels horizontal and vertical polarizations, respectively; a, φ are the amplitude and the initial phase signal, respectively; δa is the absolute value of the non-identical amplitude signals of the polarization channels; Δj is the deviation of the phase difference of signals of different polarizations from 90^0.

An important step in the implementation of this approach is the supply to the ADC inputs of the polarization channels of the control signal with a frequency f_c, which corresponds to the expression (2). The amplitude and initial phase of the control signal denote, respectively, a_c and φ_c. We assume that the flow control signal is carried out simultaneously in the two polarization channels so that the signals at their inputs are equal in amplitude and phase. This can be done using the transmitter control signal, the two orthogonal polarizer, powered from a common source.

Choose as the reference channel with horizontal polarization, and we assume that it is free of interference cross-polarization. Then the output voltage of the *i*-th temporal ADC reference polarization channels when applying a control signal on the basis of (2) and (3) can be written in the form:

$$H(i) = p_H + a_c\cos(\pi\,\frac{5}{2}i + \varphi_c), \qquad (5)$$

where a_c, φ_c are the amplitude and the initial phase signal, respectively; f_c is the frequency of control signal; p_H is the possible value of constant component voltage in the channel.

In this case, as mentioned above, the voltage of the second polarization of the channel will be focused amplitude and phase non-identical coefficients of transmission of the polarization channels caused by cross-polarization interference cancellation (XPIC), which can be displayed in the form:

$$V(i) = p_V + a_c(1+\delta a)\sin(\pi\,\frac{5}{2}i + (\varphi_c - \Delta\varphi)), \qquad (6)$$

where p_V is the value of the possible constant component of the voltage in the unbalanced channel.

The next stage of implementation is the procedure of decimation ADC samples:

$$\begin{aligned} H1 &= U_H(0) - U_H(2) + U_H(4) - \ldots - U_H(N-2), \\ H2 &= U_H(1) - U_H(3) + U_H(5) - \ldots - U_H(N-1), \\ V1 &= U_V(0) - U_V(2) + U_V(4) - \ldots - U_V(N-2), \\ V2 &= U_V(1) - U_V(3) + U_V(5) - \ldots - U_V(N-1), \end{aligned} \qquad (7)$$

where N is the accumulation period, $H1$, $H2$, $V1$, $V2$ are the voltage corresponding to two adjacent time gates (strobes) the outputs of the two polarization channels.

It is seen that in this case, the corresponding processing is separation of discrete samples of the voltage on the basis of parity of numbers of arrivals. This is a separate accumulation of even and odd elements of arrays with inversion of the sign from one reference to another. As a result, specified the procedure of decimation, eliminates the constant offset of the signals, without taking into account the action of noise, get:

$$\begin{aligned} H1 &= \frac{N}{2}a_c\cos(\varphi_c), \\ H2 &= -\frac{N}{2}a_c\cos(\varphi_c), \\ V1 &= \frac{N}{2}a_c(1+\delta a)\sin(\varphi_c - \Delta\varphi), \\ V2 &= \frac{N}{2}a_c(1+\delta a)\cos(\varphi_c - \Delta\varphi). \end{aligned} \qquad (8)$$

In the absence of polarization nonidentity, that is $\delta a = 0$ and $\Delta\varphi = 0$, the values of $V1$ and $V2$ will have the form:

$$V1 = \frac{N}{2}a_c\sin(\varphi_c), \qquad (9)$$

$$V2 = \frac{N}{2}a_c\cos(\varphi_c). \qquad (10)$$

Taking into account the above calculations, for a pair of neighboring time samples $H1$ and $H2$ of the reference channel obtained in the result of the procedure of decimation, will be true the following expression:

$$H1^2 \quad H2^2 - \frac{N^2 a_c^2}{4}. \qquad (11)$$

Similarly, for the second polarization of the channel will take place the following expression:

$$V1^2 + V2^2 = \frac{N^2}{4}a_c^2(1+\delta a)^2. \qquad (12)$$

Substituting (11) into (12), it is easy to estimate the amplitude component of the polarization not identical, after the decimation of ADC samples:

$$\delta a = \sqrt{\frac{V1^2 + V2^2}{H1^2 + H2^2}} - 1. \qquad (13)$$

By simple mathematical transformations of (8) can be obtained:

$$V1 = (1+\delta a)\left(-H2 - H1\,\mathrm{tg}(\Delta\varphi)\right)\cos(\Delta\varphi),$$

$$V2 = (1+\delta a)\left(H1 - H2\,\mathrm{tg}(\Delta\varphi)\right)\cos(\Delta\varphi).$$

Dividing $V1$ by $V2$, will receive:

$$\frac{V1}{V2} = \frac{-H2 - H1\,\mathrm{tg}(\Delta\varphi)}{H1 - H2\,\mathrm{tg}(\Delta\varphi)} \text{ or}$$

$$\mathrm{tg}(\Delta\varphi) = \frac{V1H1 + V2H2}{V1H2 - V2H1}.$$

Thus, to evaluate the phase identical polarization channels have the formula:

$$\Delta\varphi = \mathrm{arctg}(\frac{V1H1 + V2H2}{V1H2 - V2H1}), \qquad (14)$$

that is appropriate when the condition is:

$$(V1H2 - V2H1) \neq 0.$$

For finding the correction algorithm will take as targets the production of such corrected values $V1_{cor}$ and $V2_{cor}$ responses of the distorted channel of a procedure for gating, which would correspond to the ideal values of (9) and (10), i.e. we assume that:

$$V1_{cor} = \frac{N}{2} a \sin(\varphi),$$

$$V2_{cor} = \frac{N}{2} a \cos(\varphi).$$

Imagine the response of $V1$ gate (8) of a distorted channel in the flattened record:

$$V1 = \frac{N}{2} a(1+\delta a)\sin(\varphi_c - \Delta\varphi) =$$

$$= (1+\delta a)\frac{N}{2} a\big((\sin(\varphi_c)\cos(\Delta\varphi) - \cos(\varphi_c)\sin(\Delta\varphi)\big) =$$

$$= (1+\delta a)V1_{cor}\cos(\Delta\varphi) - (1+\delta a)H1\sin(\Delta\varphi).$$

Here,

$$V1_{cor}(1+\delta a)\cos(\Delta\varphi) = V1 + (1+\delta a)H1\sin(\Delta\varphi).$$

Thus, the correction algorithm of the polarization imbalance can be written in the form:

$$V1_{cor} = H1 \cdot \mathrm{tg}(\Delta\varphi) + \frac{V1}{(1+\delta)\cos(\Delta\varphi)}. \qquad (15)$$

Similarly, we can prove that:

$$V2_{cor} = H2 \cdot \mathrm{tg}(\Delta\varphi) + \frac{V2}{(1+\delta a)\cos(\Delta\varphi)}. \qquad (16)$$

The proposed correction algorithm includes the following steps:

the input of the receiver of the harmonic test signal sequentially on some or all of the subcarrier;

analog-to-digital conversion of signals in each of the polarization channels;

decimation of ADC samples;

determination of the coefficients of the amplitude and phase of the polarization nonidentity and stored in a memory module with the FPGA.

Process of receiving of information signals is characterized in that after the procedure, additional gating of ADC samples of the correction of the feedback gates unbalanced polarization channel.

CONCLUSIONS

Thus, the proposed approach reduces the computational load on the digital segment of the FOTS with the scheme of multiplexing of N-OFDM-PDM due to the introduction of distributed digital signal processing with a low speed digitization on the basis of decimation. This provides a simplification of the equipment of formation of the polarization channels, reducing the nonlinear harmonics in the system and, as a consequence, creates prerequisites for increase of the order of polarization or quadrature amplitude modulation signals and the transmission rate information.

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