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(54) **MODULATION/DEMODULATION OF A PILOT CARRIER, MEANS AND METHOD TO PERFORM THE MODULATION/ DEMODULATION**

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(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

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(58) **Field of Search** 370/203, 204, 370/206, 207, 208, 480, 484, 491, 515, 468, 210, 332, 474; 375/222, 357, 367, 377, 200, 285, 131; 455/10

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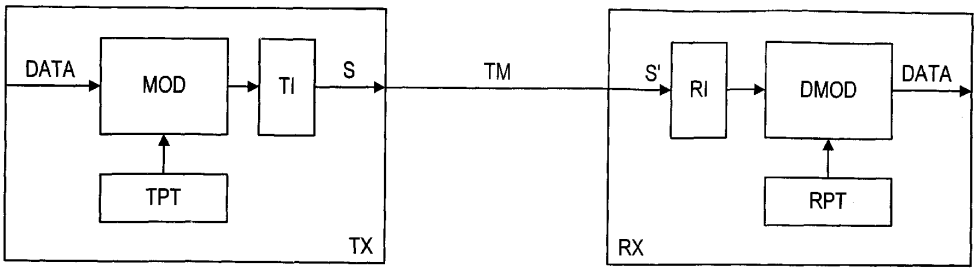
(57) **ABSTRACT**

For synchronisation purposes, a transmitter (TX) multiplexes a pilot carrier with carriers whereon data elements (DATA) are modulated, and transmits the pilot carrier together with the modulated carriers to a receiver (RX). The immunity of the pilot carrier from interference, such as radio amateur signals, is improved by modulating the pilot carrier with a non-constant signal, for instance a random signal, an alternating signal or even scrambled data elements (DATA), before transmission thereof. Since demodulation of the pilot carrier in the receiver (RX) and averaging successive demodulated pilot carriers reduces the effect of the interference induced on the non-constantly modulated pilot carrier, the degradation of the synchronisation between transmitter (TX) and receiver (RX) is reduced significantly.

12 Claims, 1 Drawing Sheet



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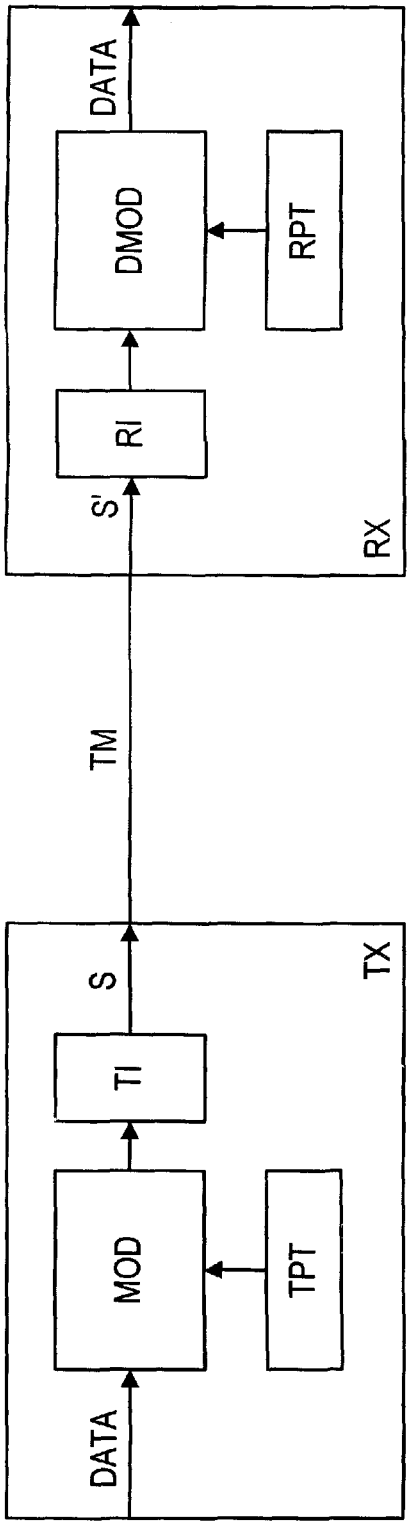

Fig. 1

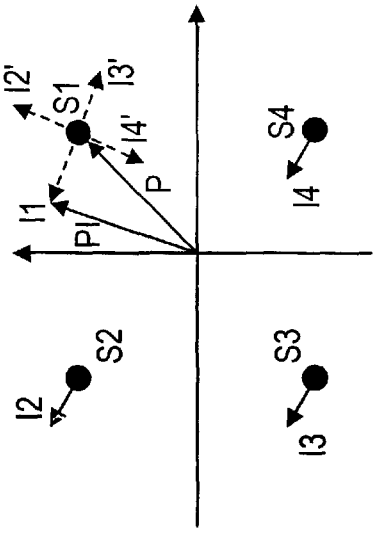

Fig. 2

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MODULATION/DEMODULATION OF A PILOT CARRIER, MEANS AND METHOD TO PERFORM THE MODULATION/ DEMODULATION

TECHNICAL FIELD

The present invention relates to a method for transmitting data elements from a transmitter to a receiver, wherein the data elements are modulated on at least one carrier; wherein a pilot carrier is used for synchronisation between the transmitter and the receiver which is multiplexed with the at least one carrier; and wherein the at least one carrier and the pilot carrier are transmitted over a transmission medium interconnecting the transmitter and the receiver.

It is also directed to a transmitter adapted to transmit data elements to a receiver via a transmission medium, the transmitter comprising modulation means to a first input of which the data elements are applied, the modulation means being adapted to modulate the data elements on at least one carrier, and to multiplex the at least one carrier with a pilot carrier used for synchronisation between the transmitter and the receiver; pilot information means, adapted to generate information to identify the pilot carrier, and to apply the information to a second input of the modulation means; and line interface means, coupled between an output of the modulation means and an input of the transmission medium and adapted to condition the at least one carrier and the pilot carrier to be transmitted over the transmission medium.

It is additionally directed to a receiver adapted to receive a signal transmitted thereto by a transmitter via a transmission medium, the receiver comprising: line interface means, coupled to an output of the transmission medium and adapted to condition the signal to be applied to components of the receiver; demodulating means, an input of which is coupled to an output of the line interface means, the demodulating means being adapted to demultiplex in the signal a pilot carrier from at least one carrier whereon data elements are modulated, and to demodulate the data elements from the at least one carrier; and pilot information means, adapted to generate information to identify the pilot carrier, and to apply the information to a second input of the demodulation means.

It is still further directed to a transmission system comprising a transmitter, a receiver and a transmission medium, coupled between an output of the transmitter and an input of the receiver, wherein the transmitter and receiver are of the above described type.

BACKGROUND OF THE INVENTION

Such a method for transmitting data elements, such a transmitter and receiver, and such a transmission system are already known in the art, e.g. from the specifications of the ANSI (*American National Standards Institute, Inc.*) Standard on ADSL, the approved version of which has the reference T1E1.413-1995 and title "*Network and Customer Installation Interfaces, Asymmetric Digital Subscriber Line* (*ADSL*) *Metallic Interface*". Therein, data elements are modulated on a set of carriers. In case of discrete multi tone (DMT) modulation, these carriers have equidistant frequencies. As is indicated in paragraphs 6.9.1.2 and 7.9.1.2 on pages 46 and 58 of the above cited standard, published in 1995, one of the carriers is reserved as a pilot carrier. This pilot carrier is used for synchronisation between transmitter and receiver and is modulated by a constant signal. In a vector plane, wherein the modulation constellation is represented by a collection of points, the pilot carrier is thus represented by a single point. On the transmission medium, e.g. on a telephone line interconnecting the ADSL transmitter and ADSL receiver in the known system, the pilot carrier thus represents a sine or cosine which does not change in phase, amplitude or frequency in time (in case a guard bond or cyclic prefix is added whose length does not contain an integer number of periods of the pilot tone, the pilot tone might be discontinuous at the edges of the DMT symbol).

A well-known source of narrowbanded or single frequency disturbances is a radio amateur or an AM radio station, which broadcasts radio signals at frequencies close to carrier frequencies. Forward error correction techniques, well-known in the art, can reduce the effect of such disturbances on data carried by the affected carriers. An alternative way to protect data against such interferers, proposed by Peter S. Chow et al. in the article "*A multicarrier E1-HDSL Transceiver System with Coded Modulation*" from the authors Peter S. Chow, Noafal Al-Dhahir, John M. Cioffi and John A. C. Bingham published in issue No. 3 May/June 1993 of the Journal of European Transactions on Telecommunications and Related Technologies (ETT), pages 257–266, is bitswapping: bit and energy allocations are updated so that the affected carriers carry less data bits then before. This technique requires an additional communication between transmitter and receiver.

Although data transmitted over the telephone line from the transmitter to the receiver may be protected by one of the above mentioned techniques, the presence of noise or an interferer, for instance a radio amateur signals with a frequency in the vicinity of the frequency of the pilot carrier, may still cause an offset between the received point representing the pilot carrier in the above defined vector plane and the expected point. If this offset in the vector plane is not sufficiently random, it biases the synchronisation mechanism, resulting in a performance degradation. This is e.g. the case if the instantaneous phase of the interferer is very slowly varying in time with respect to the duration of the DMT symbol or if this interferer is constant.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for transmitting data elements and related equipment of the known type, but wherein the immunity of the pilot carrier from interference is increased significantly, and consequently wherein the degradation of the synchronisation mechanism between transmitter and receiver is reduced.

According to the present invention, this object is achieved by a method for transmitting data elements from a transmitter to a receiver, wherein the data elements are modulated on at least one carrier; a pilot carrier used for synchronisation between the transmitter and the receiver is multiplexed with the at least one carrier; the at least one carrier and the pilot carrier are transmitted over a transmission medium interconnecting the transmitter and the receiver, characterized in that the pilot carrier is modulated with a non-constant signal before it is transmitted.

It is also achieved by a transmitter, adapted to transmit data elements to a receiver via a transmission medium, the transmitter comprising: modulation means to a first input of which the data elements are applied, the modulation means being adapted to modulate the data elements on at least one carrier, and to multiplex the at least one carrier with a pilot carrier used for synchronisation between the transmitter and the receiver; pilot information means, adapted to generate information to identify the pilot carrier, and to apply the information to a second input of the modulation means; and

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line interface means, coupled between an output of the modulation means and an input of the transmission medium, and adapted to condition the at least one carrier and the pilot carrier to be transmitted over the transmission medium, characterised in that the modulation means is further adapted to modulate the pilot carrier with a non-constant signal.

It is still further achieved by a receiver, adapted to receive a signal transmitted thereto by a transmitter via a transmission medium, the receiver comprising line interface means, coupled to an output of the transmission medium and adapted to condition the signal to be applied to components of the receiver; demodulating means, an input of which is coupled to an output of the line interface means, the demodulating means being adapted to demultiplex in the signal a pilot carrier from at least one carrier whereon data elements are modulated, and to demodulate the data elements from the at least one carrier; and pilot information means, adapted to generate information to identify the pilot carrier, and to apply the information to a second input of the demodulation means, characterised in that the demodulating means further is adapted to demodulate a non-constant signal from the pilot carrier and to use the demodulated pilot carrier for synchronisation.

It is still further achieved by a transmission system comprising a transmitter, a receiver and a transmission medium, coupled between an output of the transmitter and an input of the receiver, the transmitter comprising: modulation means to a first input of which data elements are applied, the modulation means being adapted to modulate the data elements on at least one carrier, and to multiplex the at least one carrier with a pilot carrier used for synchronisation between the transmitter and the receiver; pilot information means, adapted to generate information to identify the pilot carrier, and to apply the information to a second input of the modulation means; and line interface means, coupled between an output of the modulation means and an input of the transmission medium, and adapted to condition the at least one carrier and the pilot carrier to be transmitted over the transmission medium, and the receiver comprising: line interface means, coupled to an output of the transmission medium and adapted to condition a signal received therefrom to be applied to components of the receiver; demodulating means, an input of which is coupled to an output of the line interface means, the demodulating mean being adapted to demultiplex in the signal the pilot carrier from the at least one carrier, and to demodulate data elements from the at least one carrier; and pilot information means, adapted to generate information to identify the pilot carrier, and to apply the information to a second input of the demodulation means, characterised in that the modulation means is further adapted to modulate the pilot carrier with a non-constant signal; and the demodulating means is adapted to demodulate the non-constant signal from the pilot carrier and to use the demodulated pilot carrier for synchronisation.

In this way, by modulating the pilot carrier with a non-constant signal, the pilot carrier appears on the transmission medium as a sine or cosine with non-constant phase and/or amplitude. Demodulation of such a pilot carrier at the receiver's side, re-generates the unmodulated pilot carrier, i.e. a sine or cosine with non varying phase and/or amplitude from the transmitted modulated pilot carrier. For interference induced on the modulated pilot carrier, this demodulation has an averaging effect as will be explained in more detail later on in the description. The effect of an interferer on different states of the modulation constellation is thus averaged by demodulation. The final effect of an interferer after demodulation is far less than the effect of the interferer on one single state in the modulation constellation scheme as a result of which the transmission system according to the present invention has a significantly increased immunity for narrowband interferers, compared to the above described known system.

It is noted that the implementation of the synchronisation means can be simplified if the constellation points of the pilot carrier are well chosen, e.g. if all points have the same amplitude.

It is further to be noticed that the term "comprising" used in the claims, should not be interpreted as being limitative to the means listed thereafter. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

Similarly, it is to be noted that the term "coupled" also used in the claims, should not be interpreted as being limited to direct connections only. Thus, the scope of the expression "a device A coupled to a device B" should not be limited to devices or systems wherein an output of device A is directly connected to on input of device B. It means that there exists a path between an output of A and an input of B which may be a path including other devices or means.

A remark is also that, in view of the present invention, it is not important whether the frequency of the pilot carrier is a fixed one or not. The pilot carrier may change in frequency whenever the transmitter or receiver concludes that the pilot frequency is laying within a frequency bond with too much interference. The transmitter and receiver then have to negotiate a new pilot tone frequency More details about this technique are irrelevant in view of the present invention but it is stressed here that changing the frequency of the pilot tone and modulating the pilot tone with non-constant signals are two techniques which may be applied independently to improve interference immunity of the synchronisation between transmitter and receiver. These techniques may be used complementary or may be applied separately.

In a particular implementation of the present invention, the pilot carrier is modulated as a random or pseudo-random signal.

In this way, by modulating a randomised signal on the pilot carrier, the state of the pilot carrier in the constellation scheme will change randomly so that the demodulation will have a good averaging effect resulting in an increase of the interference immunity.

In another implementation of the present invention, the pilot carrier is modulated with a predefined sequence that ensures sufficient alternations of the states of the pilot carrier.

In this way, if the averaged effect of interference over all visited states in the constellation scheme is zero after demodulation, the best results will be obtained in terms of improvement of the interference immunity. Indeed, when each state has an equal probability and the constellation has a symmetry around zero, the effect of interference will be compensated for completely after demodulation. As an example, the constellation might contain only two points with the same amplitude but with opposite phases. Successive pilots would then have alternate phases.

It is remarked that the proposed technique con be used whether or not the predefined sequence is known at the receiver. If the sequence is unknown, the receiver has to demap the received pilot, i.e. it has to map the received point on a constellation point. The decision is then used to generate the unmodulated pilot.

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